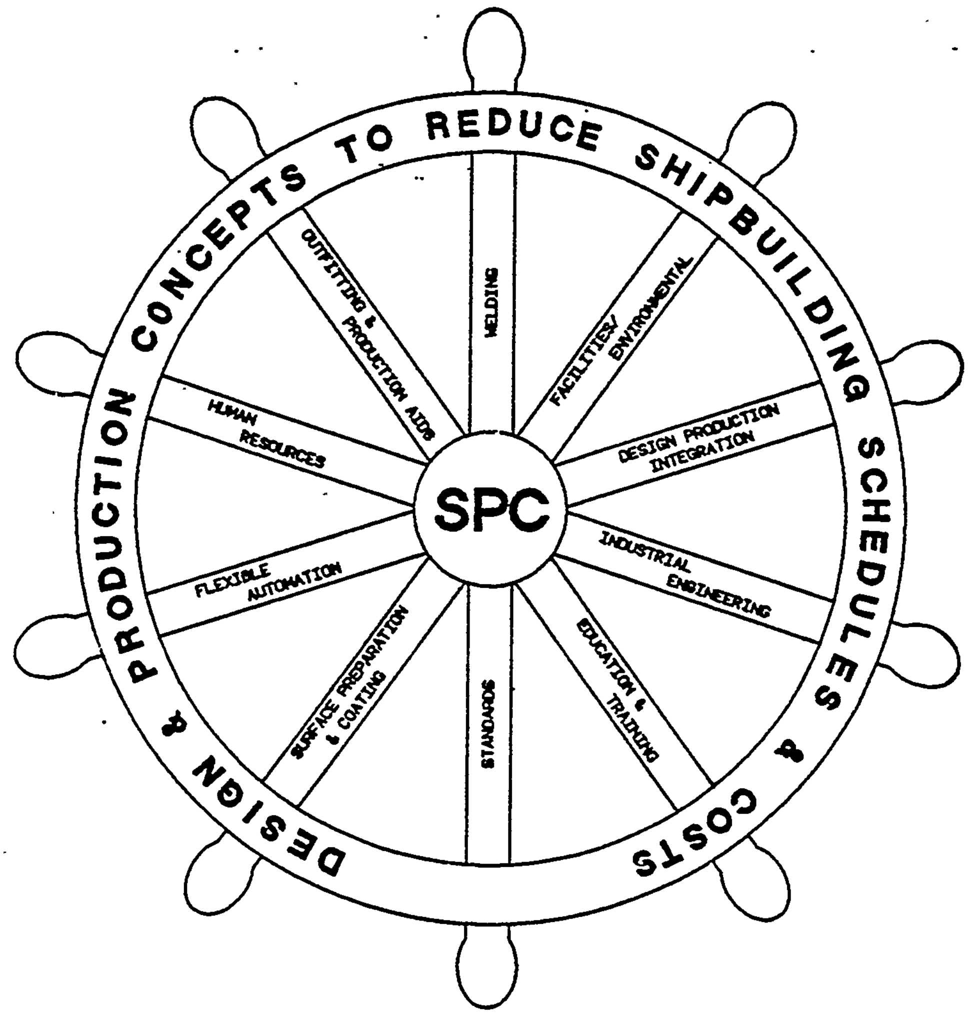
ONAL SHIPBUILDING RESEARCH PROGRAM
1986 SHIP PRODUCTION SYMPOSIUM



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THE ANNUAL REPORT OF THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

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1986 SHIP PRODUCTION SYMPOSIUM

THE ANNUAL REPORT OF THE NATIONAL SHIPBUILDING RESEARCH PROGRAM: PART 1

V. W. RINEHART, Maritime Administration

INTRODUCTION

Founded by shipborne immigrants from various seagoing nations, and blessed by deep rivers and natural harbors along their eastern coasts, the North American colonies early in their history developed a vigorous and successful shipbuilding industry. The ships produced in these shipyards not only supported a thriving trade among the colonies and between them and Europe, but also formed the backbone of the fledgling navy of the American Revolution. Since that time, U.S. shipyards have continued to serve both the commercial and-defense needs of the Nation.

By the beginning of this century, however, two factors had developed which had detrimental effects on the U.S. shipbuilding industry. The first was the continued westward expansion during the nineteenth century which decreased the relative role of shipping in the national economy as domestic resource development and trade increased. The second was the competition of foreign technology -- specifically, iron hulls and steam propulsion -- which gradually displaced the wooden-hulled sailing vessels at which U.S. yards excelled. The result was that by the beginning of World war I, U. S. shipyards were hard put to meet the demands of war shipping.

For the first time. in the Shipping Act of 1916, the Government found it necessary in the national interest to pass legislation "for the purpose of encouraging, developing, and creating a naval auxiliary and naval reserve and a merchant marine to meet the requirements of the commerce of the United States and its Territories and possessions and with foreign countries ... Subsequent legislation, namely, the Merchant Marine Acts of 1920, 1928, and especially the landmark Merchant Marine Act of 1936, greatly increased the role of the Federal Government in the maritime industries, including shipbuilding. Supported by this body of legislation and under wartime demands, U.S. shipyards produced ships at an amazing rate during World War II. By 1945, the United States possessed a Navy and Merchant Marine unequaled in world history.

By 1970, however, the maritime industries once more found themselves in a depressed state, and additional Legislation was deemed necessary to stimulate them. One of the specific. results of this legislation was the establishment of a greatly expanded research and development (R&D) program under the Maritime Administration (MARAD), which had emerged in 1950 as the Agency responsible for maritime policy. One of the new R&D programs begun in 1971 was the National Shipbuilding Research Program (NSRP).

GOALS OF THE NSRP

The initial goal of the NSRP was to respond to the direction given to the Secretary of Commerce in the Merchant Marine Act of 1970 to "collaborate with . . . shipbuilders in developing plans for the economic construction of vessels" [Section 212(c)]. To-provide industry management anti technical input, MARAD selected the newly . formed Ship Production Committee (SPC) of the Society of Naval Architects and Marine Engineers (SNAME). While the content and technical thrust of the NSRP has varied over its 15-year life, its basic goal has remained the same: to reduce production costs and to accelerate deliveries through improved shipbuilding methods.

In addition to responding to the Congressional mandate, the Government has additional reasons for wanting to improve shipyard efficiencies. Title V of the 1936 Act provided for payment of Construction Differential Subsidy (CDS) of up to 50 percent of the cost of constructing a new vessel in a G.S. yard. While the CDS program is now inactive, large sums were expended on this program each year for a number of years. As the administrator of the program, MARAD had an obvious interest in reducing construction costs, and hence CDS payments. Furthermore, reduced construction costs result in lower domestic shipping costs and contribute to the competitive position of U.S. shipping companies operating in the foreign trades -- hence, contributing to the viability of the U.S. merchant marine. Finally, in recent years, improvements introduced through the NSRP have resulted in enormous savings to the U.S. Navy's shipbuilding program.

Program Approach and Mechanisms

The approach of the NSRP and its basic mechanisms are well understood by its participants. However, because of their importance and because of recurring evidence that they are not understood throughout some elements of both government and industry, they are briefly summarized here. Shipbuilding in the United States is carried out by a number of independent private companies in competition with each other, and to some degree with the shipyards of other countries. while each company obviously has an interest in improving its products and reducing its costs, the fragmented nature of the industry and the severe variations in work load overtime have made it very difficult for even the largest shipyards to maintain formal R&D programs. furthermore, anti-trust laws have discouraged companies -- until recently -- from banding together inco-operative R&D programs. At the same time, however, shipyards in both Europe and the Far East have improved their construction technologies dramatically through cooperative and government-sponsored research programs.

The NSRP seeks to overcome these disadvantages to U.S. yards by establishing a framework for a cooperative, cost-shared program across a wide spectrum of shipbuilding activities. The Government (MARAD, and more recently Navy) provides broad guidance and direct funding of a number of technical projects each year. Projects are selected and monitored by 10 technical panels of the SNAME/SPC. These projects are performed on a cost-sharing basis through contracts with shipyards and, in one case, an academic institution. Results of all research projects are made available to all participants through panel meetings and formal reports.

The net results have been a substantial improvement in productivity of the entire U.S. shipbuilding industry at a fraction of the cost of subsidies or individual research programs. Projects selected through a competitive screening process in the panel structure tend to be both relevant and broadly applicable. Wide industry participation throughout the selection and execution process virtually guarantees implementation of results. Some additional benefits, not anticipated at the program's inception are discussed in a later section of this paper.

A more detailed description of the program structure and recent activities is given in an excellent paper by F. Baxter Barham, Jr., entitled "The SNAME Ship Production Committee - Overview," presented at the January 25, 1984, meeting of the Hampton Roads Section of SNAME, and reproduced in the SNAME Journal of Ship Production (February 1985, Vol. 1, No. 1).

Program Accomplishments

Since the beginning of the NSRP, well over 200 individual projects have been completed and another 100 are ongoing. Results of completed work have been disseminated to the entire shipbuilding industry through seminars such as this, written reports, books, and since early 1985, the Journal of Ship Production, the quarterly SNAME publication referred to earlier. Some of these projects, especially earlier ones have been oriented toward hardware and shipbuilding processes. Later projects have tended more toward planning and organizational techniques, with generous attention given to education and better use of the human resources in the industry.

Technical Accomplishments

A comprehensive review of NSRP technical accomplishments --- even a complete listing --- is beyond the scope of this brief paper. However, it is appropriate to list a few of them to impart some flavor of the direction and scope of the program. Those listed below are examples of the early emphasis on hardware/process subjects:

- Automatic machine for painting structural shapes (1975);
- Improved vertical butt welder (1976);
- Semi-automatic pipe handling and fabrication facility

Concurrently, other projects have sought to apply advanced scientific or engineering developments to ship manufacturing methods. Examples of such projects are:

- Shipbuilding alignment using lasers (1974);
- Photogrammetry in shipbuilding (1976);
- Plasma cutting and welding processes for shipbuilding (1976);

Approved electrical cable splicing procedure. (1979);

Evaluation of waterborne coatings (1981).

A special category of projects has focused on applications of computer-aided design and manufacttiring techniques. Research projects in this category include:

Licensing of the AUTOKON automated plate cutting system for use in U.S. yards (1976);

Shipyard planning and scheduling applications using the MOST system (computerized labor standards) (1982-1984);

Software tools for shipbuilding productivity (1984).

AS the program developed, and as knowledge grew of concepts developed in other industries and other countries to better utilize human resources, a series of exploratory projects was launched to determine the applicability of these concepts to the shipbuilding industry These areas inclcded: the development and utilization of robotics and flexible automation techniques; social technologies related to human resources, specifically worker participation/involvement; development of national marine industry standards; development of reports, texts and other learning materials to further education and training for all levels of shipyard employees.

However, one of the most significant areas of research and development to emerge has been the study and application of advanced manufacturing technologies to work organization using group technology principles. An impressive data base has been accumulated to help in the understanding and implementation of an integrated concept of design and production to permit zone-oriented ship construction. Projects in this area dealt with:

Outfit planning (1979):

Product work breakdown structure (1980);

Process analysis using accuracy control (1982);

Pipe-piece family manufacturing (1982);

Line heating (1982);

Integrated hull construction, outfitting, and painting (1983);

Design for zone outfitting (1983);

- **Product-oriented material management (1985);**
- **Design-for-production manual (1986).**

The results of these projects initiated in individual ship-yards have rapidly spread and are now used intensively in all major U.S. shipyards. Their use has been directly responsible for large cost savings and significant schedule acceleration in the naval construction program.

Non-technical Accomplishments

While solution of technical problems is an important element of progress, there are other areas of equal importance, as I was reminded on a recent trip to Philadelphia to attend a joint meeting of the SNAME SP-6 Panel and the ASTM F-25 committee on marine standards. I took the opportunity to visit the Franklin Institute, on the third floor of which I found an area dedicated to ship design and shipbuilding. One exhibit in particular caught my eye. It was a rather large-scale model of an open boat with a primitive steam engine installed. Beside the model was a placard, which read:

"FITCH (1743-1798)

"John Fitch lead an adventurous life. He was a clockmender, brass-founder, silversmith, gunsmith, and frontiersman. He was captured by Indians and published a map of the Northwest Territory.

"Then his life took a turn which made Fitch a significant figure in American history.

"I was so unfortunate in the month of April 1785, as to have an idea that a Carriage might be carried by the force of Steam along the Roads. I persued (sic) that Idea about one week, and gave it over as impracticable, or in other words turned my thoughts to Vessels, which appeared to me that it might be applied to advantage on the Water . . . it has been the most imprudent scheme that I ever engaged in.

"Fitch joined forces with Philadelphia clockmaker Henry Voight -- 'the first Mechanical Genius that I ever met in the whole course of my life' -- and formed a stock company in 1785. They began building a steamboat. Unable to buy an English steam engine, Fitch and Voight had to design one and build it themselves.

"Continuing mechanical troubles, unreliable financing, and the public resistance to steamboating resulted in Fitch's commercial failure. He died in Kentucky in 1798, a broken man."

The depth of Fitch's frustrations are revealed in this excerpt from his writings:

"I know of nothing so perplexing and vexatious to a man of feelings, as a turbulent Wife and Steam Boat building. I experienced the former and quit it in season. and had I been in my right senses, I should undoubtedly treated the latter in the same manner, but for one man to be teased with Both, he must be looked upon as the most unfortunate man of this world."

We may not agree with John Fitch in all respects. I am sure that his attitude toward marriage is not a typical one. Furthermore, if he had known the term "R&D," he would have included it as one of the nagging curses of mankind. But I am sure many of those in today's industry will agree that he was absolutely correct about the problems of "Steam Boat building."

The reasons cited for Fitch's commercial failure were "mechanical troubles, unreliable financing, and the public's resistance to steamboating." Today similar problems exist which I will refer to as technology, organization support, and markets. AS indicated earlier in this paper, great steps have been taken by the NSRP to assist U.S. shipyards in upgrading their technology. The other two issues are addressed briefly below.

Organizational Support

The past role for financial support of the U.S. maritime industries has been alluded to in an earlier section which discussed related Federal legislation. It is not the purpose of this paper to discuss national maritime policy nor the support mechanisms required to implement it. it is appropriate, however, to discuss some serendipitous organizational benefits of the NSRP.

The NSRP organizational structure as it evolved was designed to facilitate the implementation of the program and to maximize its benefits by: (1) supplementing the minimum staffing (l-3 persons) of the MARAD program office; (2) obtaining the active participation of the shipyards which would use the results; while at the same time, (3) avoiding the appearance of industrial collusion. The attitude of the industry before the beginning of the NSRP, and indeed during its early years, could be described in two terms -- mistrust and anti-trust. Shipyard personnel -- especially management -- found it difficult to understand that cooperation in solving technical problems could be both mutually beneficial and legal.

These-concerns were overcome largely ly by the patience and wisdom of two MARAD officials, Jim Higgins and Jack Garvey, and the first chairman of the Ship Production Committee, Ellsworth Peterson. By restricting early projects to basic common technologies such as welding, and by insisting that committee members workout organizational problems with minimum government involvement a set of strong, committed, and sometimes fiercely independent panels and program managers was forged.

The resulting organization has served the NSRP well. It has had two other benefits which, while not foreseen, are probably as important as the one originally sought. First, the organization provides a ready and active mechanism for technology transfer. "Hands-on" participation in the selection and management of research projects provides many opportunities for exchange of new technology, not only between participating shipyards, but from foreign shipyards and non-maritime industries into the U.S. shipyard industry.

The second unplanned benefitis the unifying effect of this organizational infrastructure. Results achieved in a cooperative manner have generated a feeling of common purpose and a sense of pride in the quality of the American shipbuilding industry that other industry ozganizations, specifically the Shipbuilders Council of America (SCA) and SNAME, had not achieved because of their different purposes. The NSRP organization forms a highly valuable link between the technical interests of individual SNAME members and the business interests of the corporate members of the SCA.

Markets

Now, what about markets, and how does the NSRP relate to that issue? Certainly, the Navy shipbuilding program benefited from the NSRP results. On the other hand, the Navy program provided an opportunity for application of research results that might otherwise not have been available. There is no doubt that new technology without market application is sterile.

However, there is also no doubt that without technological refurbishment, new markets are hard to come by, anti existing markets fade away. Certainly the benefits to the Navy of productivity improvement will affect their attitudes toward American yards, and if properly publicized, will not go unnoticed by U.S. commercial ship operators when they consider new buildings. Furthermore, the new attitudes toward R&D and American yard quality can have a positive effect on the thinking of shipyard management as they contemplate moving into new markets, say, industrial plant vessels. Finally, the attitudes of the yards will certainly be considered by those now in the process of developing new maritime policies.

In summary, markets, organizations, and technical improvements are all related and support each other. It will be a mistake to neglect further efforts to improve productivity even though markets may be temporarily depressed, or to allow the valuable infrastructure already established to crumble and disappear.

OUTLOOK TO THE FUTURE

As Charles Dickens wrote in the opening lines of A Tale of Two Cities? "It was the best of times, it was the worst of times." Certainly, there are aspects of the maritime industry that are not very bright at present, nor that look promising for the near future However, there are some very positive factors in the current shipbuilding business. From the standpoint of the NSRP, one of these is that great progress has been made in increasing shipbuilding productivity, thereby reducing costs and accelerating deliveries. Properly used, this record can be used to advantage in seeking new markets. The second factor is that a highly effective organization to promote transfer of existing technology and to encourage further productivity improvements is in place.

TWO areas invite further attention in the future. One is the market development area addressed previously. The second is the ship repair and refit market. Previous conventional wisdom had it that productivity improvements in new construction could only be realized by design stantiardization or by multiple orders. The repair and refit market was considered an even more difficult area for improvement. New concepts demonstrated under the NSRP and now widely in use in new construction make it clear that these concepts are also applicable to a large degree in the ship repair and refit market. AS the Navy construction program draws to a close, the other. market should be addressed much more seriously.

Finally, what will be the role of government in the future?

Present Administration policy is clear that research and development for improvement of industrial technology is the primary responsibility of the private sector. On the other hand, it is clear that both as a major customer (Navy) and as a. responsible agent (MARAD) for ensuring an adequate merchant marine "supplemented by efficient facilities for shipbuilding and repair" as required by national policy as set forth in the Merchant Marine Act of 1936 (as amended), the Government has an interest in the future quality of U.S. shipyards. While it is likely that future government involvement will be less direct than before, it seems unlikely that involvement will cease entirely.

ACKNOWLEDGEMENTS

I must admit that I take pride in reciting the accomplishments of this extraordinary program; however, let me quickly point out that the accomplishments are those of others. My sentiments parallel those of Sir Archibald Wavell who once published a book of his favorite poems entitled "Other Men's Flowers." To put his own contribution to the book in perspective, Wavell quoted the French philosopher Montaigne: "I have gathered a bouquet of othermen's flowers," he said, 'and only the thread that binds them is my own."

The accomplishments are those of the hundreds of men and women from industry, government, and academia who have devoted long hours of hard work to formulating and carrying out the National Shipbuilding Research Program. Special credit is due to those, both past and present, who have served as chairmen of the Ship Production Committee, chairmen or program managers of the various technical panels, and government program managers. The support of senior officials of the shipbuilding industry, the Government, and the Society of Naval Architects and Marine Engineers is also recognized and appreciated. If I have provided only a bit of thread to help bind the program together, I count it as one of my most worthwhile contributions.

1986 SHIP PRODUCTION SYMPOSIUM

THE ANNUAL REPORT OF THE NATIONAL SHIPBUILDING RESEARCH PROGRAM: PART 2

J. W. BRASHER, Ingalls Shipbuilding

ABSTRACT

The highly successful National Shipbuilding Research Program is creating a revolutionary change in how we build ships. In one and a half decades, the benefits of improvements shipbuilding management processes have resulted in significant cost reductions to customers -- both military and commercial.

The program, implemented by the Ship Production Committee and supported by most shipyards, design agents, and the Government, provides mutual transfer of technology, thus benfitting all -- even some who do not participate in the program. The use of product-oriented, modular construction techniques has been well set forth in monographs published by the National Shipbuilding Research Program in a tutorial and applicable format. Thus, the yards who have adopted the technology have a standard to which to work.

The cost of the program is shared by the Government and industry, at a payback factor of 25 times the cost. This was reported in the Effectiveness Report of 1985, which showed that the National Shipbuilding Research Program enjoyed the highest payback of all the projects of the Manufacturing Technology Program.

However well received the program has been by Government and industry, the current curtailment of Government funding is jeopardizing the program. It is the intent of the Ship Production Committee to maintain the work and the structure of the Ship Production Committee and its transfer of technology, even if at some level lower than currently realized.

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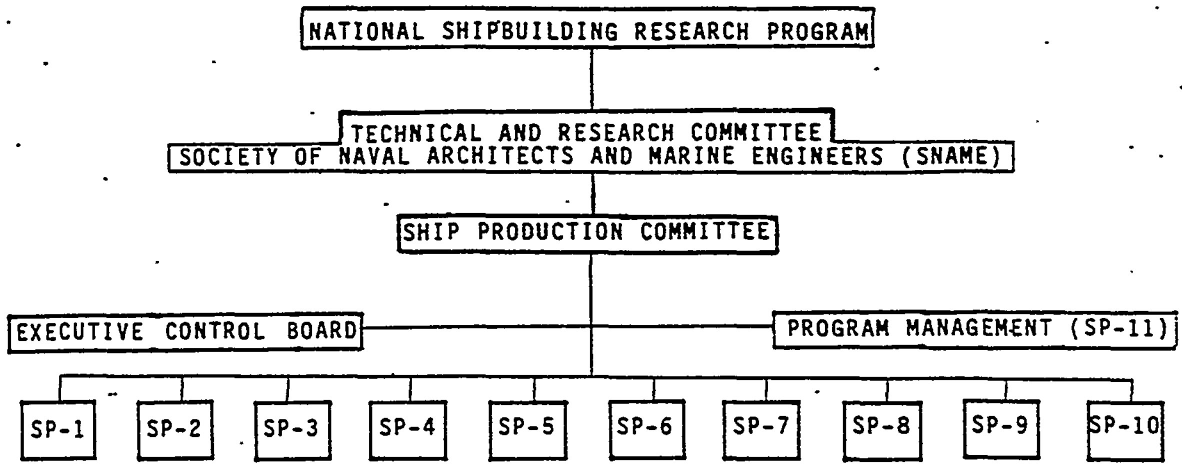
The National Shipbuilding Research Program is a successful program. has led the way on a national scale to an unprecedented level of cooperation among shipyards to achieve a better quality product at a 1ower cost. Other speakers will fill in the details, but the bottom line is substantial cost savings to the purchaser of ships. At this time, the principal ship buyer is the U.S. Navy; therefore, the savings are to the taxpayer.

The Ship Production Committee one of the committees within the oversight of the Society of Naval Architects and Marine Engineers (Figure 1). The committee membership represents diverse private sector groups (Appendix l), primarily shipyards, educational institutions and several government agencies. Most members are experts in their field.

The Committee was formed in 1970 to provide industry management and technical input to a government sponsored cooperative effort to develop more economical construction approaches to shipbuilding. This effort has become known as the National Shipbuilding Research Program (NSRP). Originally, this was a partnership of the Maritime Administration and the private sector. In 1982 the U. S. Navy joined the partnership, and the program has greatly benefitted by the participation of this "new" member.

Although the collective effort bears the name of a research program, in fact essentially all of the effort, and it is considerable, would more accurately be described as a program to apply engineering, management, and technical developments to shipbuilding or ship acquisition situations. Whichever words one chooses to use, it brings the shipbuilding know-how of the shipyards, the needs and requirements of the federal agencies and the technical expertise of the academic institutions into sharp focus. The contracted projects



FUNDING

MARITIME ADMINISTRATION
U. S. NAVY
INDUSTRY

SP-1 FACILITIES & ENVIRONMENTAL EFFECTS	**SP-2 OUTFITTING & PRODUCTION AIDS**
SP-3 SURFACE PREPARATION & COATINGS	**SP-4 DESIGN/PRODUCTION INTEGRATION**
SP-5 HUMAN RESOURCE INNOVATION	**SP-6 MARINE INDUSTRY STANDARDS**
SP-7 WELDING	**SP-8 INDUSTRIAL ENGINEERING**
SP-9 EDUCATION	**SP-10 FLEXIBLE AUTOMATION**

FIGURE 1. ORGANIZATION CHART FOR MANAGING AND FUNDING OF NSRP

approached by the Committee are managed by the ten research panels (Appendix 2), each concerned with some specific phase or area of the shipbuilding process. panel has volunteer chairman, about 30 volunteer members, and a funded Program Manager. It is the Program Manager's job to oversee, coordinate, and disseminate information on the various authorized projects under his cognizance. Appendices 3 and 4 list the top priority projects of the panels for Fiscal Year 1987 and the ongoing projects, respectively.

Financial participation by the program partners is clearly the facilitator that permits this program to work, and in particular, work at the level that it has since the Navy joined as a funding partner. But what was made the program successful has been the active participation of marine experts from both the private sector and the public sector, from large and small organizations across the Nation. This blend of talent and excellent communication facilitated by the Committee and its project has made it possible- Since projects are documented and reported as a matter of public record, all shipbuilders share in the benefits, even those yards who choose not to be represented on the Committee.

Implementation of more modern shipbuilding technology was initially and primarily in the production of commercial vessels. Most published empirical data have been commercial related. Without question, the construction of a large bulk carrier is relatively simple and cheap compared with a man-o-war. It is not necessary to go into great detail to establish this fact. One has only to consider the density of the outfitting elements and the difference in both quantity and types of distributive systems, such as pipe and electrical for Naval ships. Nevertheless, two important things happened, through this program we refer to as NSRP, to facilitate a technology transfer to military ship construction. One was that the gospel of modern ship-building technology, according to the SPC Panel Program Managers and others, was made available and public, and two, on the SPC and its panels there existed experts interested lowering ship construction cost to receive the message and take it back home. The absence of either of these factors would have greatly impeded our progress. Was the war over when the messenger took the word back home? Each. of you will remember that was when the war began. Application of the more modern management and construction technologies had to be assimilated by old line shipbuilders, and it had to be modified in many-cases to apply to warship construction. Implementation is a subject we shipbuilders approach with a Dr. Jekyll and Mr. Hyde personality. We are quick to point out and discuss those elements of modernization that have been picked up by the various yards. We never bring up all the other elements and all the other yards that have not adopted practices which have been documented as effective cost reducers. The fact is that it is a little embarrassing to us, because we take it as a program failure, and in a way, it is. It is not, however, quite as simple as a failure to communicate properly, nor a lack of desire to improve productivity. There are businesses with little or no business; others have a contract in hand, with little or no prospects for follow work; and still others are loaded with work, but struggling to make budgets and schedules. All are capital constrained.

Although al1 have different situations, the basic factor controlling major shipbuilding changes is still the same -- lacking protective financial incentives, "Who is going to cover my losses during a transition phase or if it doesn't work?" Mostly what has happened, therefore, has been an evolution, rather than a revolution. Although the rate at which we as an industry are moving can always be labeled as too little and too slow, I'm not sure that approach is all bad. There have been no fatalities to which skeptics can point as an excuse. Rather, the successes have built confidence and trust, both in the implementors and observers, and encouraged them to do more to take the next step, or perhaps to "eat the whole thing". It is also evident that more and more modernization technology is being applied in overhaul and ship alteration work on military ships in both private and public yards. This is a natural step to improve productivity in an enormous market.

I believe the environment is right to quicken the pace and, in fact, there is ample evidence of that taking place even today. The industry is doing better, much better, and those that survive will participate in a new day in American shipbuilding. That doesn't mean the U. S. industry can look forward in the foreseeable future to head-to-head competition. with the Far East. There are simply too many factors totally outside the control of the shipbuilder to achieve that state. To mention a couple is adequate to make a point:

1. The cost of material purchased in the United States.

2. Governmental requirements.

What we will see, however, is for a comparable ship, comparable manhours for vessel construction. Those are carefully chosen words, designed to carve out the ship acquisition cost element most directly in the control of the shipbuilder. Of the various participants controlling ship acquisition cost, the shipbuilding industry is, in fact, leading the way in real cast reduction efforts.

Much has been written encouraging the shipbuilder to diversify, to build anything and everything made of steel. Mostly, this comes from experts outside the shipbuilding industry. The industry has and does work that marketing strategy in the absence of or to supplement shipbuilding. Today, however, one finds that so much of that market has al so been shipped overseas, the vanishing industrial base is not adequate to support existing machine shops. There is much more supply than demand. The opportunities are simply not there. Taken to the other end of the spectrum, assuming the steel fabricator market improved and shipbuilding opportunities remained limited, this situation could lead to a simple "iron works" masquerading as a shipbuilder. That is actually happening at shipyard in Japan I recently visited. Effective February 1987, the shipyard will no longer build ships, but will be a large machine shop/iron works. What the United States shipyards want is to build ships.

What do the outside experts say about industry/government cooperation? The Committee on the Role of the Manufacturing Technology program in the Defense Industrial Base of the National Academy of Sciences, in an outstanding detailed report recently issued, stated:

1. Despite the significance of manufacturing technology, many in the government and private sector hold misconceptions that lead, in part, to the incorrect conclusion that satisfactory progress in such technology

will occur as a matter of course.

2. Evidence refuting these misconceptions can be found in companies from many industries that invest in advancing-their process technologies.

3. The Committee concludes that continuing DOD investment in manufacturing process development is essential that manufacturing technology is essential for maintaining a strong industrial base.

4. The Committee also found that industries and countries that actively process technology are generally competitively successful over time.

In the interim report of the Committee on Strategies to Improve R&D and its Implementation in the Marine Industries, the Marine Board of the National Research Council had this to say concerning the NSRP:

1. The R&D program of the Maritime Administration (MARAD) has contributed in several ways to improving or maintaining the competitiveness of the U.S. maritime industries.

2. Without government participation, the industry-based collaborative R&D institutions that are now in place (as a direct result of the activities of the MARAD R&D program) are not likely to continue.

3. Regardless of the direction of future activities, it is essential to maintain at least a minimum level of funding and program activity, if the U. S. government is to maintain its technical capability to understand and reap the benefits of technology developments in the world maritime industries. Furthermore, it is essential to continue to monitor technological developments around the world, and to make that information available to U. S. industry.

In a recent speech, Congressman Walter Jones, Chairman of the House Marine and Fisheries Committee, emphasized that "there is a need for a national maritime policy and that it must be devised jointly by the federal government and private sector”.

Other references supporting this program and this program objective are available to concerned individuals.

Reducing the cost of ship acquisition is a gigantic task in itself. Today the entire program is faced with challenges which must be mastered if our primary mission is to continue unabated. Even before the current budgetary convulsions were begun, the winds of change were blowing. As you have heard many times, this national program is a partnership of three government agencies, several academic institutions, and about fifty private companies working as one. The level of experience, education, and talent brought to bear on this problem from these diverse participants is nothing short of overwhelming. The additional challenge with which we are now faced is the Possibility of Government withdrawal from the program Can we do better? Can we meet the challenges? You bet!

What can we do? First, my recommendation is simply, “Don’t panic -- keep working”. Second, we must seek to ensure government - participation in the partnership at a sustaining and expanded level. A moment ago, I indicated that it would be my option to express the program bottom line -- cost reductions. As an example, one element of the program has documented savings of $183,000,000, based on a program investment of $7,200,000, and these savings are acknowledged as conservative. The projected cost savings through 1990, based on current ship construction data, are $675,000,000. By any measure, that is an acceptable return on investment.

Some have expressed an opinion that the NSRP is a private sector matter and have initiated withdrawal procedures. Lest anyone of the opinion that this program at this level will be continued solely by the private sector be misled, let me clearly and publicly state that, in my opinion, you are in error. I have long contended that the industry financial contribution to this program, which is substantial, is far overshadowed by the immense but undefined value of the pool of talent and experience blended together to meet this national challenge --increased productivity and lower cost of shipbuilding. The industry has other tasks for this talent, and we are already seeing some of it reassigned. Of course, this valuable asset is not all found in the private sector; the government agencies also contribute. Any reduced participation by the government will result in a corresponding decrease in the level of the program activity and financial damage to government agencies buying ships. In a fixed price environment and with no productivity development interest expressed by the government, I believe that it is not even open to debate.

That leads me to my next recommendation. This program is too good, there has been too much labor put into it by too many outstanding people, and it has been too successful to allow it to die. I propose that this program must continue, albeit at significantly reduced levels, should the principal beneficiary of these savings, the government, withdraw. Finally, there are some other concerns that have to be considered by this body if for no other reason than that they have been a matter of concern and debate by other reasonable men. These have to do with such issues as project selection criteria, implementation ratios, results measurement and consensus. Pragmatically, it would be easy to turn these questions or concerns aside with a quick reference to the savings mentioned earlier and a comment that the current process, whatever its faults, has generated a 25 to 1 return on investment with a projected 94 to 1 return on investment. That is, of course, not an acceptable answer. Whether or not government participation continues, these issues must be deliberated by the Committee.

There are other reasons why government withdrawal is unacceptable. I will cite only two, the industrial base and the defense-industrial base. In a recent publication, the comparison between a manufacturing economic base and a service economic base was crystallized in a few words. They are: Manufacturing produces wealth; services not only depend on the manufacturing base for their being, they are consumers of wealth. Now the entire shipbuilding industry is only a small part of the gross national product, but its importance to the industrial base and the defense-industrial base is far more significant than the naked statistic would imply.

In a recent situation at one shipyard, a particular type of pipe could not be obtained in the United States and was, therefore, ordered from an overseas supplier. The supplier had twice rescheduled the delivery date, without much or any concern that he was holding up production. When the foreign flag ship carrying the foreign made pipe docked in New Orleans, you can bet a truck was alongside with the motor running. This little example clearly says that for some products, the industrial base is not even there, not to mention a defense-industrial base or a surge capability.

Technological excellence cannot be sustained in the long term without a manufacturing capability on which it can feed. The technological excellence of today is, to some degree, living off the past, and its continued viability is in jeopardy as our manufacturing base continues to shrink. Consider the naval and air excellence demonstrated in a "for real" encounter in the Gulf of Sidra earlier this year. Such excellence was not born of a service economy. Neither technological excellence nor its companion, manufacturing technology, is an automatic product of a large manufacturing base, but neither will long exist without it. Maintenance of our standard of living, and perhaps our way of life, depends on our commitment to these entities or conditions. Of course, we are speaking of only one area of the defense-industrial base, and only a small part of the defense-industrial base; but as such elements are being incrementally abandoned, the total effect has been crippling. Thus, the questions facing our government partners in this endeavor should not be one of participation, but simply one of how and to what degree.

PARTICIPANTS IN THE SHIP PRODUCTION COMMITTEE, EXECUTIVE CONTROL BOARD, AND TECHNICAL PANELS

Advanced Marine Enterprises, Inc.
American Boat & Yacht Council, Inc.
American Bureau of Shipping
American Society for Testing & Materials
AMERON
ARINC Research
Avondale Shipyards, Inc.
Bath Iron Works
Bay Shipbuilding Corporation
Bechtel Group, Inc.
Bell Aerospace Textron
Bell Aerospace/Bell Halter
Bethlehem Steel Corporation
Casde Corporation
CDI Marine, Inc.
Certain-Teed Corporation
Charles Stark Draper Labs
Charleston Naval Shipyard
Cornell University
David Shipbuilding, LTD
David Taylor Naval Ship Research and Development Center
Designers and Planners, Inc.
Devoe Marine Coatings Company
EG&G Sealol
Eness R&D Corporation
Engineered Systems and Development Corporation
Equitable Shipyards, Inc.
ESCO Corporation
Exxon Shipping Company
FMC Corporation
Fraser's Boiler Service
General Dynamics, Inc.
Georgia Institute of Technology
Georgia Tech
Gibbs & Cox, Inc.
Grumman Aerospace
Grumman Data Systems Corporation
Hemple Marine Paints, Inc.
Hyde Products, Inc.
H. B. Maynard & Company, Inc.
INFAC
Ingalls Shipbuilding Division
Institute of Industrial Engineers
Insulation Resources
Jacksonville Shipyards, Inc.
Jeffboat, Inc.
J. J. Henry Company
J. J. McMullen Associates, Inc.
Kaiser Steel Corporation
Kuh & Associates
Lockheed Marine
Lockheed Shipbuilding & Construction Company
Long Beach Naval Shipyard
L. D. Chirillo Associates
Mare Island Naval Shipyard
Marinette Marine
Maritime Administration
Massachusetts Institute of Technology
McDermott Shipyards
Military Sealift Command
Mobot Corporation
Morrison Molded Fiber Glass Company
NACO
Nashville Bridge Company
National Steel & Shipbuilding Company
Naval Industrial Resources
Naval Sea Systems Command
Naval Ship Systems Engineering Station
Newport News Shipbuilding
Norfolk Naval Shipyard
Norfolk Shipbuilding Company
North Star Navigation Systems
Office of the Assistant Secretary of the Navy
ORI, Incorporated
Pearl Harbor Naval Shipyard
Pennsylvania Shipbuilding
Peterson Builders, Inc.
Philadelphia Naval Shipyard
Portsmouth Naval Shipyard
Puget Sound Naval Shipyard
RAM Corporation
Riley-Beaird Company
Robotics International of SME
Robotix Corporation
Rosenblatt & Sons
RPM, Incorporated
R. D. Jacobs & Associates
Science Applications, Inc.
Shipbuilder's Council of America
Shipbuilding Consultants, Inc.
Society of Naval Architects and Marine Engineers
Southwest Marine, Inc.
Stanley Associates, Inc.
St. John Shipbuilding & Drydock Company
St. Louis Ship
Tacoma Boatbuilding
Tampa Shipyards, Inc.
Tano Corporation
The Jonathan Corporation
Todd Pacific Shipyards Corporation
University of Delaware
University of Massachusetts at Amherst
University of Michigan
University of New Orleans
University of Washington
U. S. Coast Guard
Various Union Representatives
Virginia Polytechnic Institute & State University
Webb Institute of Naval Architecture
Wilkins Enterprises, Inc.

APPENDIX I

APPENDIX 2

THE SHIP PRODUCTION COMMITTEE TECHNICAL PANELS

FACILITIES & ENVIRONMENTAL EFFECTS
OUTFITTING & PRODUCTION AIDS
SURFACE PREPARATION & COATINGS
DESIGN/PRODUCTION INTEGRATION
HUMAN RESOURCES INNOVATION
MARINE INDUSTRY STANDARDS
WELDING
INDUSTRIAL ENGINEERING
EDUCATION
FLEXIBLE AUTOMATION
PROGRAM MANAGEMENT

APPENDIX 3

PRIORITY PROPOSED PROJECTS FOR FY 1987

6-01	Cost Effective Management Program for Smal1 and Medium Sized Shipyards
5-01	Determining Rework and Block Fits to Facilitate HuLL Erection
5-01	The Economics of Shipyard Painting, Phase III - Control System Development for Earlier Recognition of Cost Variances
5-01	Engineering Drawing Practices for Computer Produced Drawings
5-01	Human Resource Innovation and Safety
5-01	Accelerated Publication of National Standards
6-01	Manual of Welding Planning and Design Guidelines - Phase III
6-01	Shop Floor Control Systems for Shipbuilding Environment
6-01	SQC/AC Evaluation and Application
36-01	Design Production Integration for Robotic Ship Manufacture
36-01	Program Management

APPENDIX 4

SHIP" PRODUCTION COMMITTEE PROJECTS IN PROCESS

PANEL SP-1

1-83-5	Group Technology/Flow Application in Production Shops
1-83-6	Portable Flushing System for Ship Piping System Cleaning
1-SP-1	Sheet Metal Shop Analysis
1-84-1	Moving Personnel and Light Material Onto and About a Shipyard
1-84-2	Pipe Storage and Movement
1-84-3	Development and Implementation of an On-Line Material Control System
1-85-I	Comparison of U. S. and Foreign Cost for Shipbuilding Material and Components, Phase I
1-85-2	cost Effective Maintenance and Repair of Air Compressors
1-85-3	Evaluation of Smoke Extraction versus Ventilation
1-85-4	Staging System for Ships During New Construction and Repair

PANEL SP-2

2-83-1	Zone Oriented Scheduling
2-83-2	Indices for Monitorinq Manhours, Program and Productivity
2-84-1	U.S. Shipbuilding Accuracy - Phase I
2-84-2	Analytical Quality Circles
2-84-3	Safety and Health Management Program
2-85-1	U. S. Shipbuilding Accuracy - Phase II
2-85-2	Product Work Breakdown Structure for Overhauls
2-85-3	Precut Electric Cable Lengths

PANEL SP-3

7 9	Ship Design Considerations: Adaptation of Japanese Pre-Fabrication Priming
79	Reclamation of Mineral Abrasives
81	Work Planning for Shipyard SP&C Training
	Overcoating of Zinc Primers
82	Citric Acid Cleaning - Phase II - Waterborne Coatings
83	Economics of Shipyard Painting
83	Performance Testing of Marine Coatings
SP	Cathodic/Partial Coating Evaluation - op. III
SP	Design of Accelerated Test Equipment
SP	Economics of Shipyard Painting - Part II

PANEL SP-3 (continued)

84	Certification of Weld Through Primers
84	Effect of Contaminants
84	cost Effectiveness of F1ame Spray
84	Automated Painting of Smal1 Parts
85	Calcite-Type Coatings in Salt Water Ballistic Tanks
85	Top Side Components and Equipment Corrosion
85	Estimating SP&C Bids
85	Degree of Coating Cure Effect

PANEL SP-4

4-83-2	Group Technology: Parts Classification and Coding - Phase II
4-83-3	incorporating Modern Shipbuilding Technology Early. in the Ship Design Cycle
4-83-4	Computer Aided Process Planning - Phase I
4-84-1	Design for Production Manual - Phase III
4-84-2	Study of Required Content/ Format of Engineering Documentation for Productivity Enhancement
4-84-3	Information Flow Requirements for Design/Procurement Processes
4-84-4	Interface Impacts - System to Zone Transition
4-84-5	Develop System for Specification Driven Pipe Arrangement Drawings and Pipe Details
4-85-1	Investigation Design/ Planning organizations
4-85-2	Study Application of Advanced Measuring Techniques to Shipbuilding
4-85-3	Computer Aided Process Planning - Phase II
4-85-4	Interface Impacts - System to Zone Transition - Phase II
4-85-5	Workshop on Management of Advanced Technology in Shipbuilding

PANEL SP-5

84	Problem Solving Teams in Shipbuilding
84	organizational Innovation and Shipyard Safety
84	Cross-Crafting, Semi-Autonomous Work Groups
85	Problem Solving Teams in Shipbuilding - Phase II
85	Product-Oriented Workforce Organizational Correlates of Statistical Accuracy Control
85	Gainsharing in Shipbuilding/Ship Repair
85	Employee Involvement and Organizational Redesign in U. S. Shipbuilding

PANEL SP-5 (continued)

85	Technical Publication Translations

PANEL SP-6.

.6-83:2	Development of Standard Equipment Purchase Specifications
6-SP-2	HVAC Design Configurations
6-SP-3	Accelerated Standards Development
6-SP-4	ISO TC-8
6-SP-5	Diesel Engine
6-SP-6	Shaft Alignment
6-SP-7	Window Standards
6-SP-8	Portlights
6-SP-9	Hull Construction Standards Development Support
6-84-1	Cableway Standards for Surface Ships
6-84-2	Standard . Practice for the Selection and Application of Marine Deck Coatings
6-84-3	Navy Document Conversion Program (Todd/LA, BIW, CASDE)
6-85-1	Standards Development Support
6-85-2	Accelerated Publication of National Shipbuilding Standards - Other Subcommittees
6-85-3	Navy Document Conversion Program - Phase II
6-85-3	Navy Document Conversion Program - Phase II
6-85-4	Accelerated Publication of National Shipbuilding Standards - Phase II

PANEL SP-7

7-83-3	Tracking System for Automatic Welding - Phase 11
7-SP-1	Benefits of Low Hydrogen Welding
7-SP-8	Plastic Welding Models for Vis. Ref. Standards - Phase II
7-84-01	Design and Planning Manual
7-84-02	Robotic Arc Welding Tech. - Phase I
7-84-03	Automatic UT Inspection Review
7-84-04	Substitute Eddy Current Inspection for Hag. Part.
7-84-05	Evaluate Benefits of New HSLA Steel
7-84-06	Development of Fitting and Fairing Aids

PANEL SP-8

8-SP-1	Quality Defects Measurement and Control System
8-SP-2	Project Support for Task EC-21
8-SP-3	Applied Operations Research: Analytical Solutions to Complex Shipyard Scheduling Problems

PANEL SP-8 (continued)

8-SP-4	Computer-Assisted Methodology for the Determination of the Optimal Number and Location of Tool Sheds
8-84-1	Improved Planning and Shop Loading in Shipyard Production Shops
8-84-2	Shipyard Training Packages for Industrial Engineering Procedures - Phase I
8-84-4	Optimal Use of Industrial Engineering Techniques in Shipyards
8-84-5	Analysis of Current Manpower Estimating and Control Procedures
8-85-1	Shipyard Training Packages for Industrial Engineering Procedures - Phase II
8-85-2	Materials Handling and Facilities Layout Training Module
8-85-3	The Cost of Quality - A Quality Assurance Cost Measurement and Control System for Shipyards
8-85-4	Analysis of the Impact of Workload Variability on Shipyard Productivity

PANEL SP-9

8-84-3	Video Lecture Course on Basic Naval Architecture for Trade Schools
8-84-4	Improving Communication Skills of Shipyard Workers
8-84-7	Industry Indoctrination Program for New Professional Employees
8-84-8	Ship Production Textbook Publication
8-84-9	Condensation of the IHI/ Avondale Technology Transfer Reports
8-84-10	Engineering for Ship Production Textbook
8-85-1	Journal of Ship Production - Phase II
8-85-2	Microfiche Library Service - Phase II
8-85-3	Indoctrination of New Professional Employees - Phase II
8-85-4	Translation Services on Foreign Language Books, Reports, and Other Materials
8-85-5	Workshops on Management of Advanced Technology in Shipbuilding
8-85-6	Certificate in Manufacturing Engineering - Ship Production Specialist
8-85-7	Development of Improved Coordination of Community College Support for Shipyards
8-85-8	Cast Studies on Welding Design
8-85-9	Survey of Available Instruments for Evaluating Shipyard Trade Applicants

PANEL SP-9 (continued)

8-85-10	Purchase of Corrosion Engineering Modules. for Shipyard Use

PANEL SP-10

8-83-1	Manufacture, Inspection and Repair of Welding Cable Using Flexible Automation
8-84-1	Marking Plate Cut by CNC Burning Machines - Phase II
8-84-2	Plan for Implementing Flexible Automation - Phase II
8-85-1	Plan for Implementing Flexible Automation - Phase II
8-85-1	Families-of-Parts Robotic Welding Cell
8-85-2	Off-Line Programming of Welding Robots

PANEL SP-11

8-85-1	National Shipbuilding Research Program 1986 Ship Production Symposium

1986 SHIP PRODUCTION SYMPOSIUM

THE ANNUAL REPORT OF THE NATIONAL SHIPBUILDING RESEARCH PROGRAM: PART 3

W.L. CHRISTENSEN, Naval Industrial Resources Support Activity

ABSTRACT

This paper reviews the benefits of the National Shipbuilding Research Program (NSRP) to the shipbuilding industry, and more specifically. its benefits to the Navy and the shipbuilding and ship repair mobilization base. The paper also identifies significant additional benefits that the Navy can gain in the next few years if the NSRP can not only continue on its present course of solving productivity problems in building new ships. but also address additional targets of Opportuinty in solving productivity problems in the overhaul, repair and modernization of Navy ships. The labor part here appears to be an even larger budget item than the labor part of new ship construction.

INTRODUCTION

The NSRP provides a forum where experts from the entire shipbuilding industry can identify and transfer the best proven shipbuilding methods in the world and also develop new technologies.

The research and development activities under the NSRP have been very successful in reducing shipbuilding costs by reducing manhours. Two reasons for this success have been the high level of participation by shipbuilders in recent years and the free exchange of information between shipyards which the Maritime Administration (Marad) requires in its. NSRP contracts. The panels and program activities have grown in number. attendance and sophistication. The quality of these NSRP projects and their resulting benefits have also increased.

HISTORY OF INITIAL IMPLEMENTATION

The National Shipbuilding Research Program started in 1970 when the Merchant Marine Act of 1936 was amended to charge the Secretary of Commerce (now the Secretary of Transportation) to "collaborate with . . . . shipbuilders in developing plans for the economic construction of vessels." The key word is. 'collaborate. " This was not to be a typical government directed research program. to help industry. rather it was to be a government/ industry collaboration. MarAd took it one Stip further and established a program structure with the then recently formed Society of Naval Architects and Marine Engineers (SNAME) Ship Production Committee (SPC) which provided for full industry participation and responsibility for project identification. management and implementation. It was this innovative structure which provided the "magic" in the program.

In 1971, the NSRP started developing its program to identify and attack problems common to the industry. Progress was slow in the beginning because the industry participants did not trust the Government nor did they trust each other. It took awhile before they felt comfortable with each other. After the NSRP's industry participants learned that they could work together on facilities and equipment development projects. they started to investigate lore complex things such as management and shipyard organization.

In 1976, the NSRP started to uncover some of the best proven methods of shipbuilding anywhere in the world. The breakthrough began as a simple project by the outfitting and production aids panel of the SPC to investigate outfit planning techniques utilized by shipyards worldwide. It identified the Japanese methods as the most promising and followed by issuing contract to Ishikawajima-Harima Heavy Industries (IHI) CO.. Ltd. of Japan to describe these methods in detail. The resulting report demonstrated that the reasons for high productivity in Japan were not only what we often thought them to be i.e.. quality circles. superior work ethic. calisthenics, uniforms and the supposed cradle-to-grave employment security. They were also very systematic and analytical up front planning activities which led to an entirely different way of building ships. Well before the report was issued in 1979, it generated a lot of interest throughout the industry. However. most industry participants were still skeptical.

In 1977. 14MarAd contracted with Livingston Shipbuilding in Orange, Texas (the parent of Penn Ship in Pennsylvania) to implement outfit planning. The NSRP funded 50% of the effort with the provision that Levingston fund the remaining 50% and share the technology with the shipbuilding industry. Livingston brought shipbuilding experts from IHI into their shipyard, tried some of the Japanese methods and verified that outfit planning could work in an American shipyard with American workers. They also learned a significant lesson (not unique to. but emphasized by the Japanese) that most construction problems start in the design and Planning. stages. not in production. The technology was subsequently transferred to Penn Ship with personnel relocated due to closure of the Texas Shipyard.

But the shipbuilding industry remained skeptical: all, how many industries have remained unchanged for so many years? The shipbuilding/ship repair industry had become a mature. consecrative industry. A protected market existed due to the lack of cost reducing incentivized contracts and the existence of subsidies such as the Navy reserve for domestic shipbuilders. the construction differential subsidy (CDS). and the Jones Act (for American coastal ships). The U.S. shipyards were not competing with foreign shipyards; they only had to compete among themselves. Meanwhile. the rest of the world was advancing. The shrinkage in demand for American ships in the mid-70!s made the shipbuilding industry realize it had fallen behind the rest of the world. A technical survey performed under the sponsorship of MarAd and the NSRP in 1978 demonstrated to the U.S. yards how they compared technologically with the rest of the world.

In 1979, after obtaining a contract from the NSRP and gaining a commitment from their upper management. Avondale Shipyards agreed to split the costs" 50%-50% and to try the methods identified by the NSRP. When they completed their implementation. favorable results were reported almost immediately. These results caused other shipyards to hire IHI on their own .

At the same time. the NSRP began looking at shipbuilding as a system. This meant looking at such things as design/production integration (i.e.. design "married" to production). the creation of national standards. education and training, and human resource innovations. The program became a truly national effort to improve productivity with active participation by all major United States private shipyards.

In 1982. Bath Iron Works (BIW), having seen the improvements at Livingston and Avondale. also began implementing advanced shipbuilding methods. BIW hired IHI with its own funds to assist them..

Also. in 1982. eight more shipyards were significantly involved in the NSRP effort. including Puget Sound Naval Shipyard a public yard specializing in overhaul. modernization and repair work. The NSRP was now activ in both public private yards. Also, the Navy. seeing the potential benefit to its shipbuilding program. started participating in the NSRP by contributing two million dollars per year from its Manufacturing Technology (ManTech) Program. With this additional money. the NSRP could now fund a more comprehensive program. Technology development accelerated. Since the Navy had become the.. dominant customer to the shipbuilding industry. the advanced methods were now being applied to Navy ships.

In 1983. more shipyards began trying the advanced shipbuilding methods. Today, practically all private shipyards are participating, to some extent. in the NSRP.

DIFFICULTIES IN QUANTIFYING BENEFITS

There are many difficulties in quantifying the benefits of the NSRP to the Navy. the shipbuilding industry and the defense industrial base with a reasonable degree of accuracy.

One problem is that the magnitude of the data is extremely large. Many man-years have been spent analyzing data and regenerating this data and information in many summaries. theses. reports and publications. Some conflict. Many do not contain enough information. Some need clarification of sources. assumptions, definitions, terminology, time spans covered or conditions.

Standard definitions of words and phrases do not exist. One person's "cost" is another person's "price" and another person's 'bid.ʷ There are many different types of labor. There is direct and indirect labor. There is also labor included in "materials". One shipyard's "Cost" may include a different amount of overhead, profit or burden compared to another shipyard.

It is difficult to allocate costs and track progress. Open job orders attract charges like a magnet, including questionable ones. Closed job orders attract charges. which may require months to adjudicate. Progress is often driven by contractual terms. Drives to accelerate progress payments in the past led to hull compartments being assembled too early and too empty and too incomplete. PiPe pieces being left to rust in open fields for months. Schedules were not schedules . that controlled work Progress. but instead were a related sequence of events and a history. of slippages.

Proprietary interests-and contractual requirements of confidentiality make it difficult to quantify the benefits. Under cost type contracts. the Navy was contractually bound to guard cost and progress information. Also under fixed price type contracts a company will zealously guard its cost and performance data.

Domestic and worldwide economic. political and social conditions change continually. some of these factors lead. while others lag. If one were preparing a five year plan in 1982. where would he or she have placed the dots in figure 1 for the increases in the consumer price index for the years 1983 through 1987? Try predicting 1986 and 1987 today. It is difficult to filter the 'cause" from the "effect" How does one measure the value of "work ethic" or lack of "civil strife"?

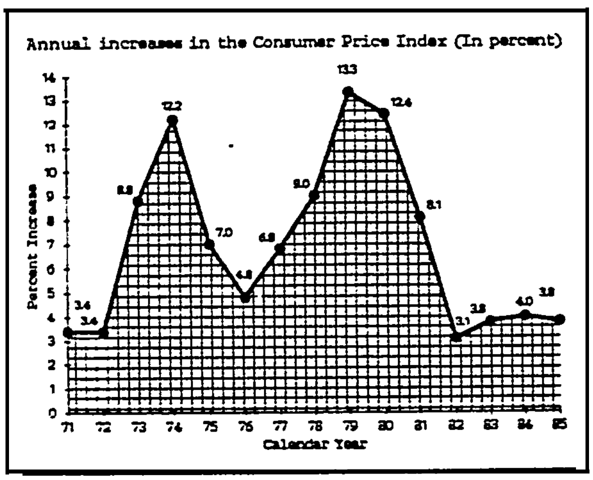


Fig. 1 Annual increases in the consumer price index.

Ships differ Some ships have had over 30,000 "Mod's" (modifications to contract). Equipment becomes unavailable or late and a substitution has to be made, or better equipment becomes available. It is difficult to make valid comparisons among shipyards in the same country. let alone between different countries.

MICROANALYSIS OF BENEFITS

The proprietary nature of cost data in the private sector precludes the type of discussion which would be desirable here. However. some information has been obtained from Puget Sound Naval Shipyard in Bremerton. Washington, the only public shipyard to substantially implement those NSRP initiatives applicable to repair work. Puget Sound documented the following four projects which resulted in schedule enhancements directly attributed to the NSRP:

a. CIWS and Electrical Shop Modifications -(CV 61).
b. Submarine Tank Repairs - (SSN 650 and 679).
c. Tomahawk Installations - (CGN 9, 39 and 41), and
d. Special Hull Treatment Program - (SSN 637 class)

Unfortunately, a cost tracking system to measure costs was not in place for the first three projects. The Special Hull Treatment project was tracked though and the cost savings were estimated to be 353 of the total estimated cost (not just 35% of the labor Part) and a schedule enhancement of about 45 days.

A cost tracking system is in development for the following projects being implemented in 1986:

a. Sonar Done " Modification - (SSN 637 class).
b. Transducer Modifications - (SSN 637 Class).
c. Ballasting Codification - (SSN 637 class).
d. Tank Repairs (SSN 637 class)
e. Electronics Packages (front end of SSN 637 class).
f. Main Sea Water Bay Overhaul and Repair - (SSN 637 class)
g. Rubber Booted GRP Dome Installation and Refurbishment - (SSN 637 class). and
h. Zinc Cathodic Protection (SSN 637 class).

MACROANALYSIS OF BENEFITS

Obtaining a global view of the benefits of the NSRP to the shipbuilding industry can be accomplished by investigating the information made public in official Navy publications, trade journals, masters and doctoral theses and interviews with experts possessing many years of experience.

The Department of the Navy's Report to the Congress for Fiscal Year 1987 cites large bid reductions for its shipbuilding and conversion, Navy (SCN) program for fiscal years 1983, 1984 and 1985, as shown in figure 2. Many factors have caused these bid reductions including increased competition (through incentivized contracts). technology development and implementation. profit margin shrinkage. market forces as market predictability and market Size. inflation.- facilities improvements, multiship procurement. improved management, organizational changes. improved education and training etc.

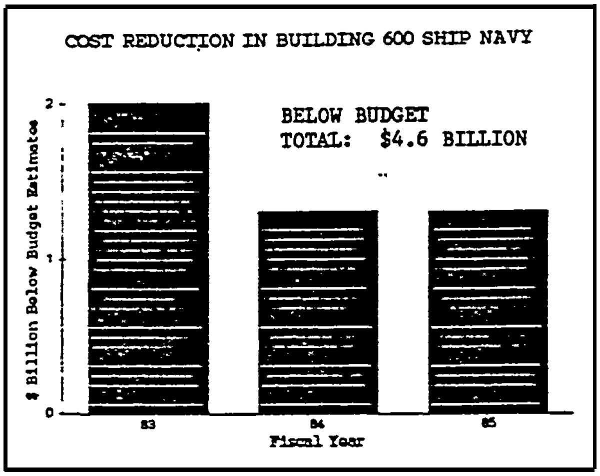


Fig. 2 Dramatic bid reductions in recent years are due to many factors.

Most of these factors were put into three major groups in order to Study their interaction with the NSRP'S efforts to improve productivity. An inflation index is not included since it would affect bids. but-not productivity.

Profit is impossible to assess publicly since profit figures for a private shipyard are combined with profit figures of other operations within a conglomerate. The other factors mentioned above are addressed as follows:

The Forces of Technology, Market and Competition are Applied to Productivity Problems

TABLE I

NSRP FUNDING SUMMARY - $M

FY	MARAD	NAVY	INDUSTRY
71	.7		.2
72	1.8		.6
73	5.3		.8
74	2.4		.8
75	2.3		.8
76	2.4		.8
77	2.7		.9
78	2.6		.9
79	2.6		.9
80	3.3		1.1
81	2.6		.9
82	2.2	2.3	2.2
83	2.0	2.2	2.0
84	2.1	2.2	2.1
85	2.0	2.2	2.0

Table I Shews the government funding history of the NSRP which was approximately $2 million per year for the first ten years and then greater than $4 million for the next three. Figure 3 shows the approximate number of projects started each year. There were approximately twenty projects per year in the 1970's. thirty projects in 1982 and 1983 and forty Projects in 1984 and 1985. In the the early 1970's these projects addressed "harc technology development such as facilities improvements. In the late 1970's the projects concentrated on "soft" technology development such as management. organization, education and - training.

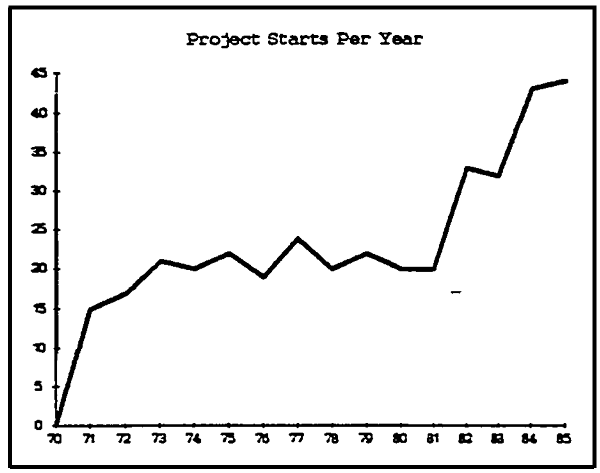


Fig. 3 The number of projects increased in the early 1980's.

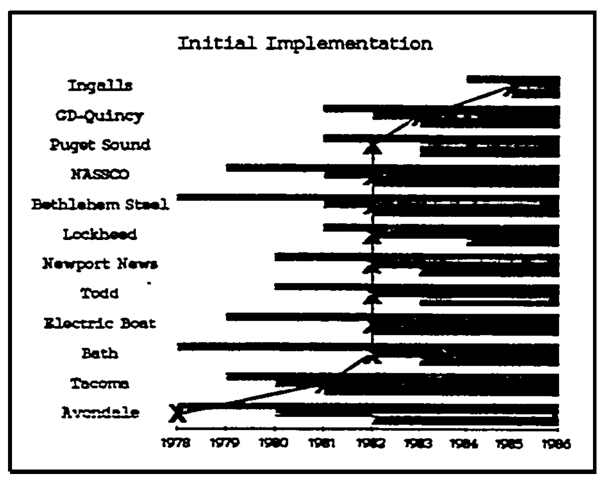


Fig. 4 History of initial implementation of Zone Outfitting at twelve shipyards. Shading indicates relative degree of NSRP end-product technology utilization. "X" is approximate time when shipyard recognized the benefits of zone oriented ship construction and started implementation.

Figure 4 Shews the approximate initial implementation date of zc oriented ship construction at twelve shipyards. Note the significant implementation rate in the early 1980's. Presently, almost all major private shipyards have recognized the benefits of zone oriented ship construction and have begun implementation.

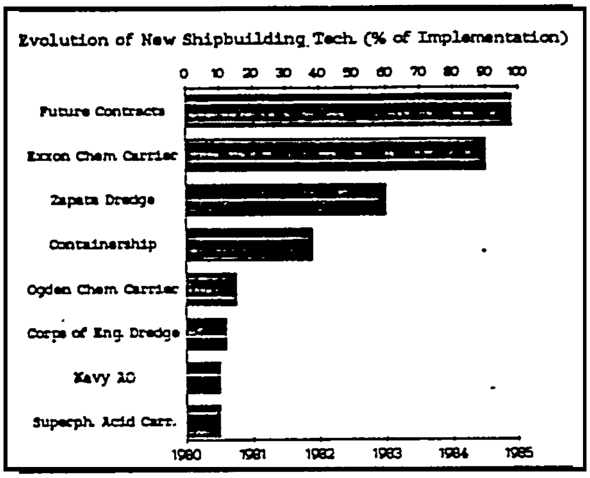


Fig. 5 Irnplmentation of the National Shipbuilding Research Program's zone oriented ship construction l t Avondale Shipyards. Inc. Accuracy control. production planning and design engineering for zone outfitting were implemented in 1981. Process lanes was implemented in 1983.

Figure 5 shows details of Avondale Industries implementation starts. Figure 6 shows the history of implementation starts at Bath Iron Works. Figure 7 shows an implementation plan for National Steel and Shipbuilding Company's (NASSCO) Shipyard. So. technology was applied to productivity pcoblems in the early 1980's.

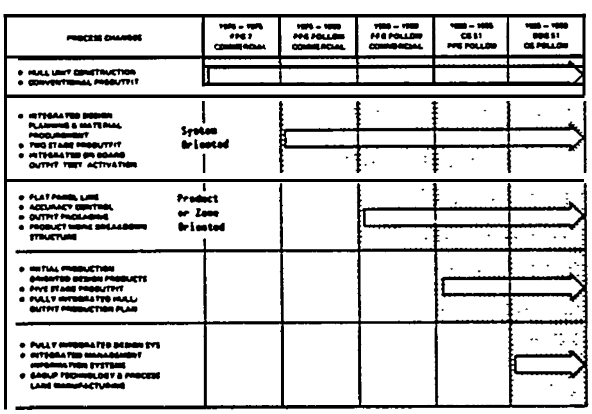


Fig. 6 Initial implementation of the advanced shipbuilding methods identified by the National Shipbuilding Research Program started in the early 1980's at Bath Iron Works.

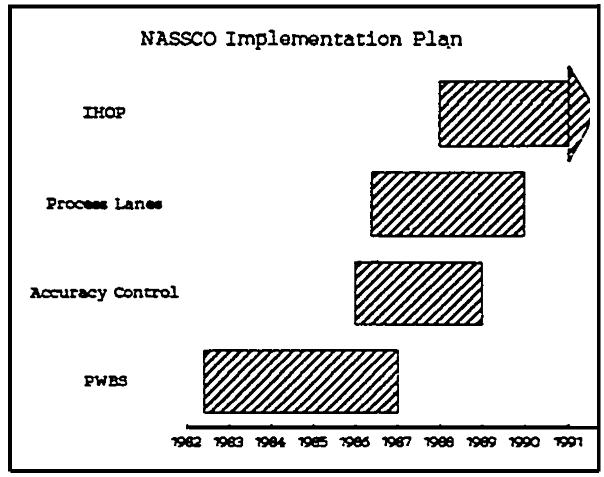
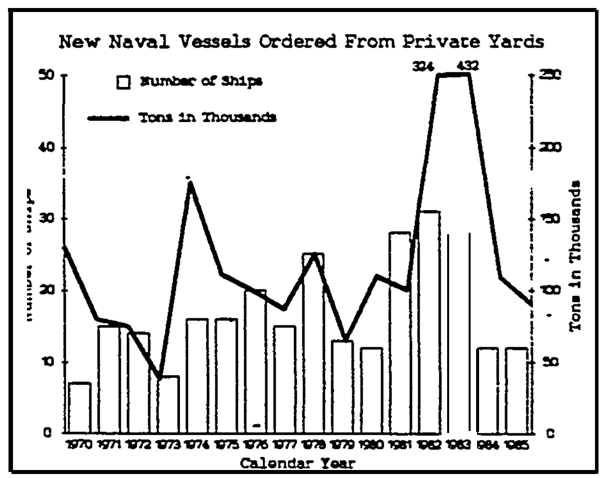


Fig. 7 NASSCO initially implemented the advanced shipbuilding methods identified by the National Shipbuilding Research-Program in 1982.



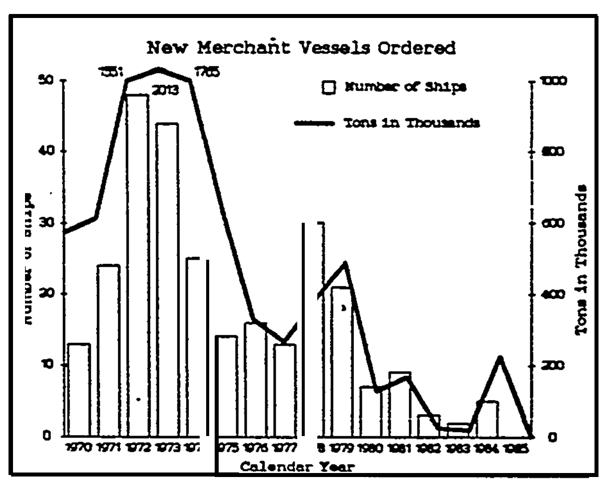


Fig. 8 The "600 Ship" Naval expans ion policy gave the shipbuilding industry market predictability and market quantity in the early 1980's.

Figure 8 shows commercial and Navy ship orders. The "600 ship" Naval expansion policy gave the depressed shipbuilding industry some market demand and predictability in the early 1980's, So market forces were applied to shipbuilding in the early 1980's.

Figure 9 shows that the pressure of competition was also being increasingly applied to Navy acquisitions in the early 1980's.

These three forces. shown in figure 10, were almost simultaneously being applied to the Navy's new ship purchases in the early 1980's. Figure 2 shows dramatic bid reductions following shortly afterward, Suggesting a cause and effect relationship.

The NSRP does not trigger investment. The NSRP is the vehicle to develop new technology and transfer existing technology from a massive technology base. It is important to note that without technology improvements. competition and market predictability and size will trigger investments, but they might be in the wrong areas. Lack of competition will lead to bid increases.

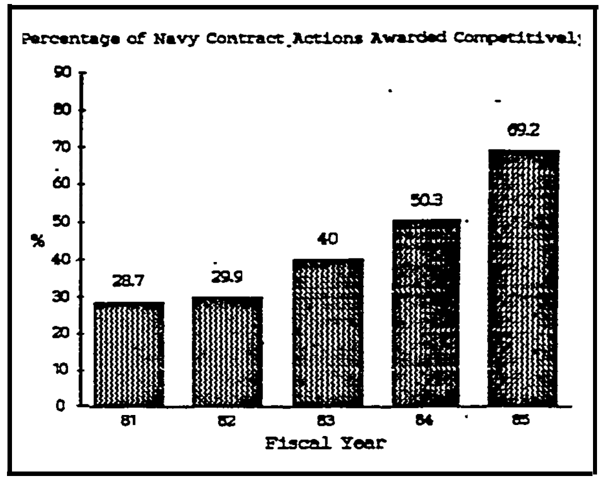


Fig. 9 The relentless pressure of competition had been applied to Navy contract actions in the early 1980's.

The lack of market predictability and market volume will lead to high risk gambling; i.e.. operating under conditions of business uncertainty caused by short-term. stop-and-go cycles. This gambling will cause sporadic bid reductions. buy-ins,

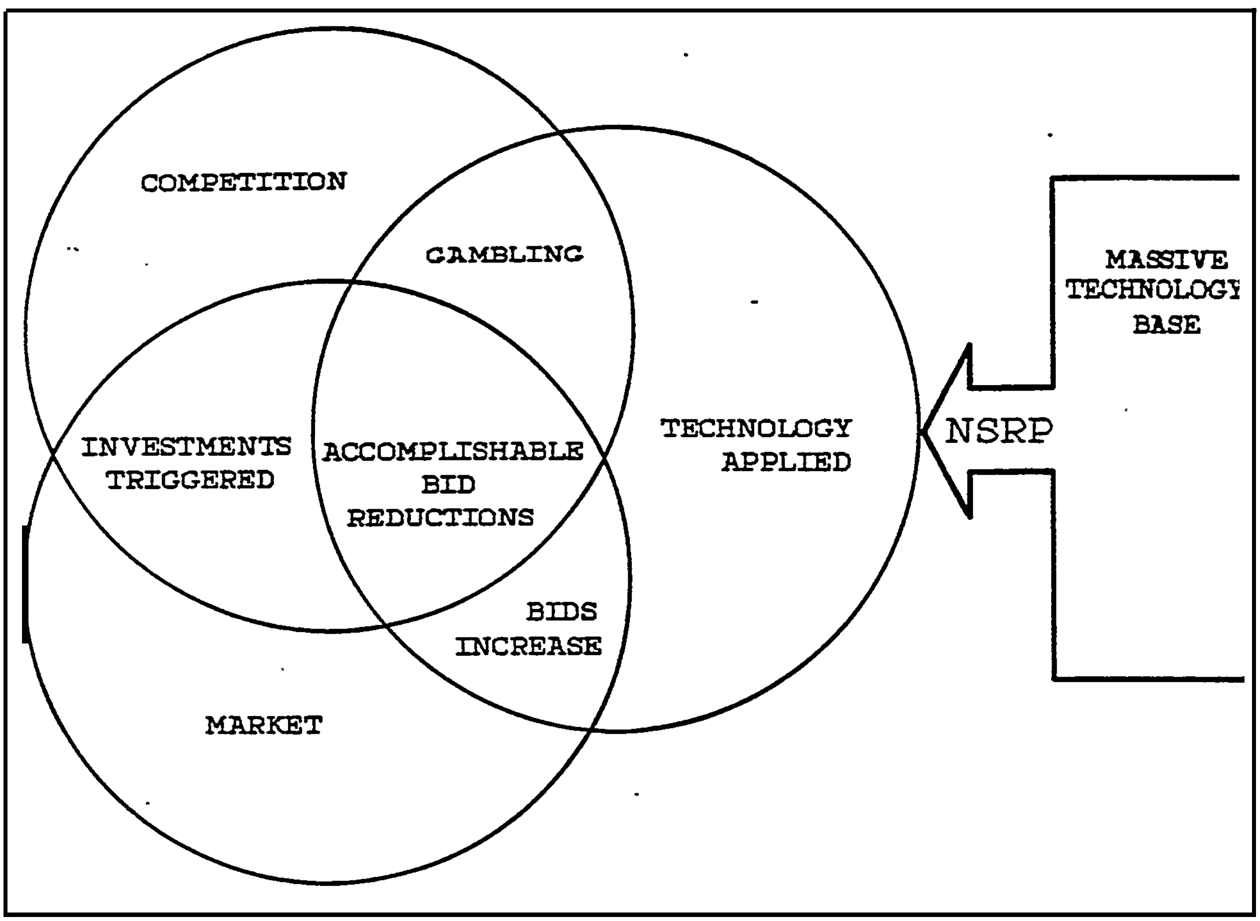


Fig. 10 Many factors affect the long term economic health of the Navy's Defense Industrial Base. Domestic & Worldwide economic. political and cultural factors also play a part. (Circles not to scale)

bankruptcies and perhaps the development of the wrong types of ships. When the three forces of competition. market (predictability and size) and technological improvements are applied. accomplishable bid reductions are possible.

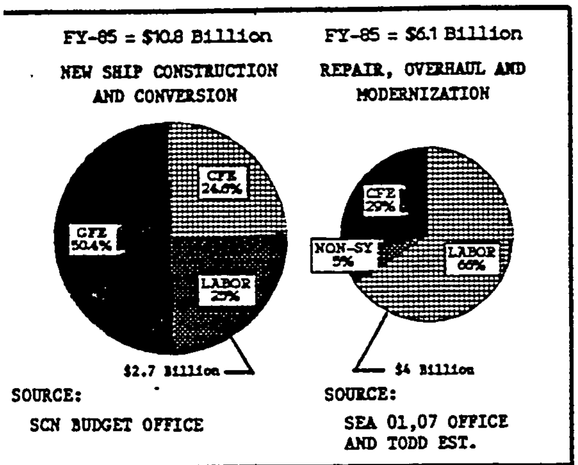


Fig. 11 The Navy's FY-85 program included almost seven billion dollars for direct and indirect labor in the public and private shipyards.

FUTURE ADDITIONAL BENEFITS

The Navy spends about $4 billion annually on labor to repair, overhaul. modernize. and maintain its ships in private and public yards, as shown in figure 11. Puget Sound Naval Shipyard has started to implement some of the NSRP developed methods applicable to ship repair. Pearl Harbor. Philadelphia. Portsmouth. Norfolk and Mare Island Naval Shipyards are looking for "targets of opportunity" to get started. There could be hundreds of millions of dollars of additional cost and bid reductions in the years ahead if we fully implement the applicable NSRP initiatives in all shipyards. Figure 12 is a proposed plan for the future implementation of the NSRP sponsored methods in a repair. overhaul and modernization yard. Note that with full. top-down management commitment and a market. it shows full implementation in approximately five yards.

Figure 13 shows that the modernization of ships is increasing. This will spread and increase their complexity. Modernization will also increase testing time and cost. Testing time is fast approaching

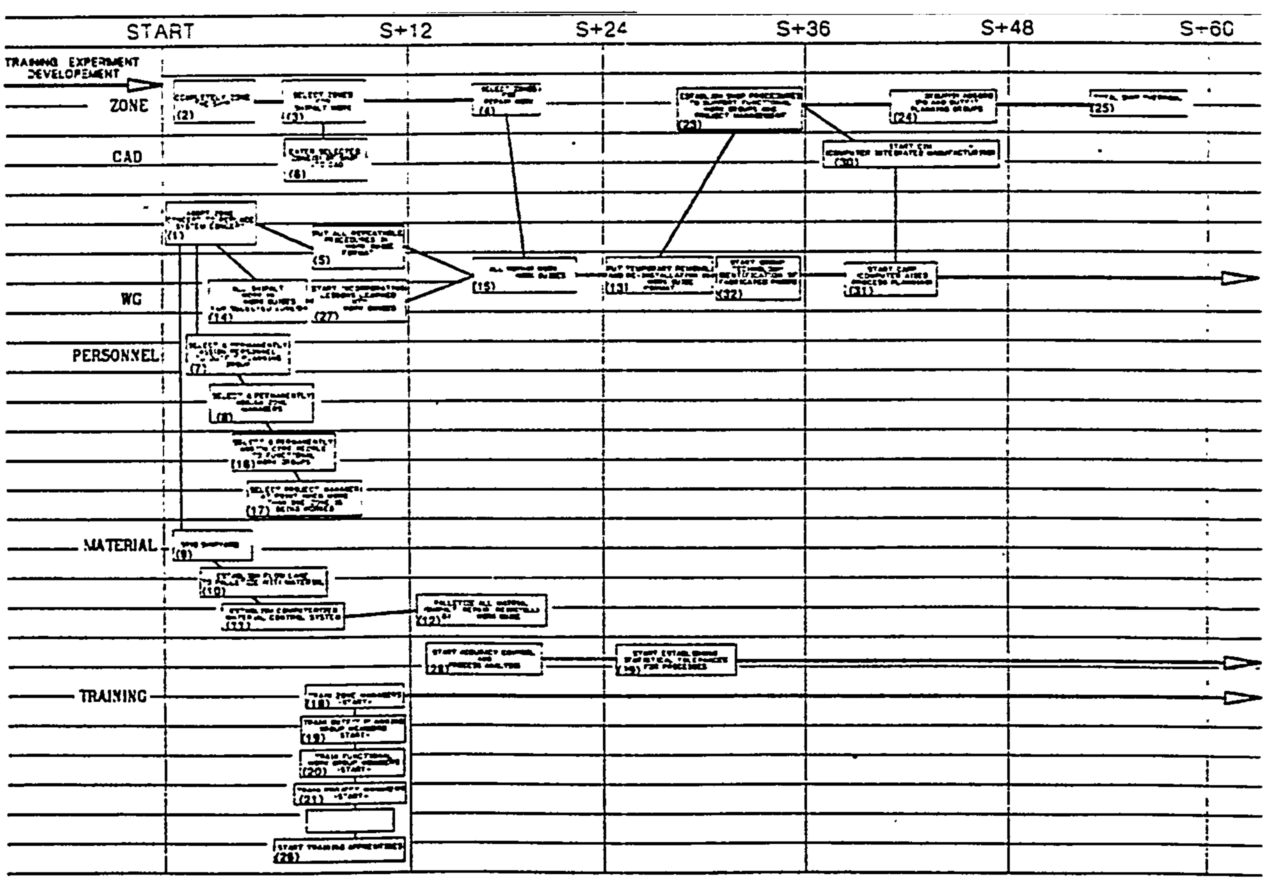


Fig. 12 Plan to implement advanced ship repair methods in a ship repair, overhaul and modernization yard. Note the four to six year time frame for a complete change.

production time for ships with large electronic suites such as missile carriers. Outfit planning has allowed phase one testing of control modules to be accomplished Prior to arrival for short availabilities. The increasing density of systems especially in submarines, has dramatically increased the need for improved process planning and control. The NSRP has given us the tools to do this. The NSRP has allowed shipyards to provide more complete instructions and better schedules through improved process planning. The NSRP gives the mechanic the tools. materials and instructions he needs. when he needs them. to do the job.

The NSRP procedures can save money in three ways. One is to continue on the present course of solving productivity problems in new ship construction as shown in figure 14. The second is to use some of the applicable NSRP initiatives in ship repair. overhaul and modernization. as shown in figure 15; the labor part here is larger than the labor part of the SCN budget as shown in figure 11. The third area for additional savings is to apply the applicable NSRP initiatives in some of the vendor community. also illustrated in figure 15.

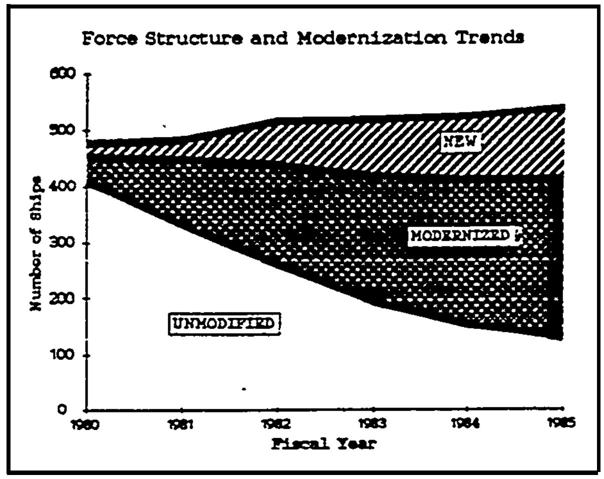


Fig. 13 Ships are becoming more complex. Modernization will spread and increase complexity. Testing time and cost will increase.

Note that implementing the NSRP initiatives allows the following seven targets of the Carlucci Initiatives to be addressed:

a. Implement increased competition (shipyards can cooperate, yet compete),

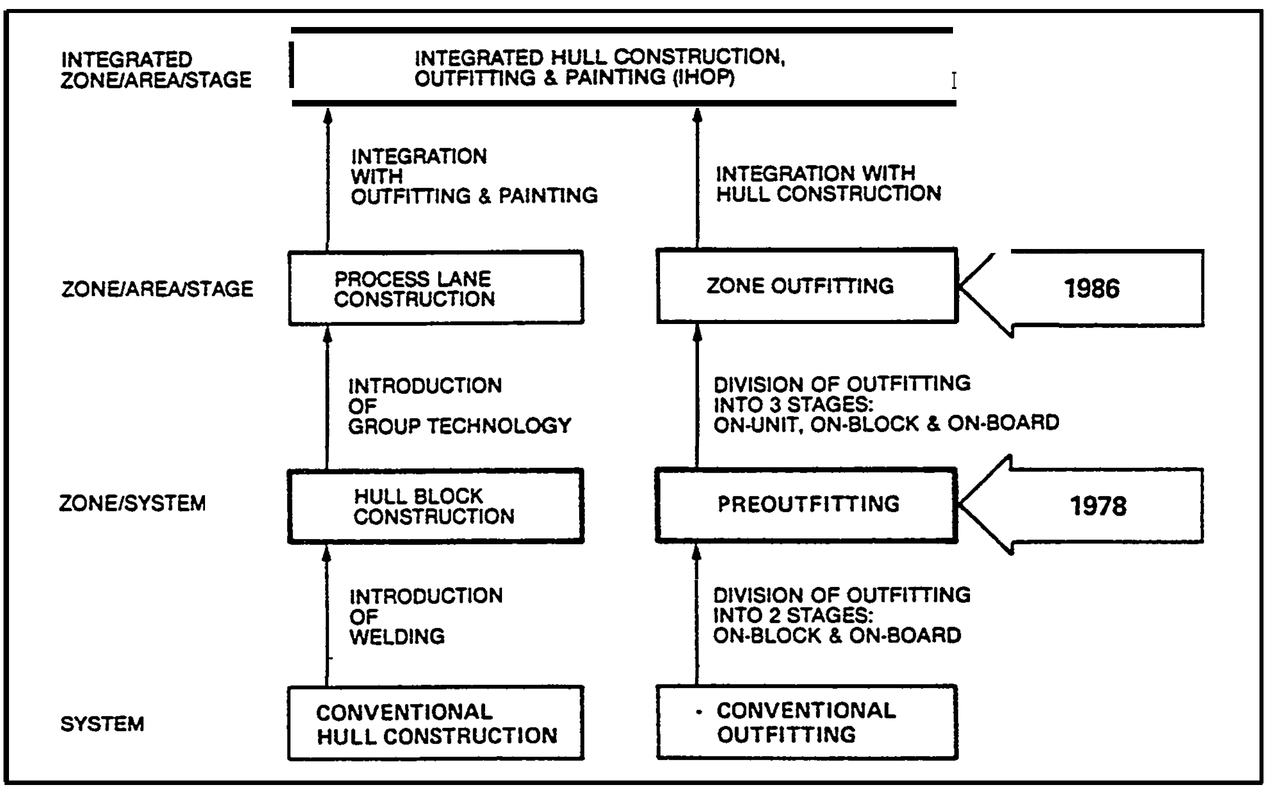


Fig. 14 History of basic improvements in shipbuilding methods. Note that "pre-outfitting" sounds like "old-hat" because "2-stage (pre-)outfitting" has been around for many years - but it was still "system oriented", not "product oriented". Note that additional benefits will result from additional technology development.

b. Implement economic production rates (using group technology).

c. Reduce time to procure (schedules can be compressed).

d. Reduce apparent cost growth (costs can be measured and controlled).

e. Improve reliability through specifications (panel SP-6 addresses this).

f. Improve schedule realism (progress can be measured and controlled).

g. Provide more appropriate design to cost goals (costs can be measured and controlled).

ADVANTAGES OF CONTINUING THE NSRP

There are several advantages in continuing the NSRP. Its structure is such that it keeps everyone's "eye-on-the-ball." Since the participants are spending some of their own money, unpromising projects are quickly discontinued and efforts are redirected.

Another advantage is that the NSRP not only finds the best proven methods in the world, but it also develops new technology. Since the working panels meet every three to four months, technology is transferred quickly. There is also widespread implementation since the technology is generic and can be customized for each shipyard's unique product mix and facility. It produces generic answers to common problems. The technology allows for alternative products to be manufactured, such as power and chemical plants and floating factories and prisons. NSRP's flexible manufacturing and group technology allow a shipyard to adapt to different types of ships or different products.

Other advantages of the NSRP are that costs and progress can now be measured and controlled and workload can now be levelled. It is projected that the NSRP initiatives can reduce shipyard labor by at least 30 percent. Thirty percent of the approximately seven billion dollars per year the Navy spends on labor to build, repair, overhaul, maintain and modernize its 600 ship navy is about two billion dollars per year. With approximately twenty new ship constructions awarded each year, each five percent reduction in bids means an average of one more ship can be built for the same amount of money, or the Navy can get the same number of ships, but save the cost of one ship.

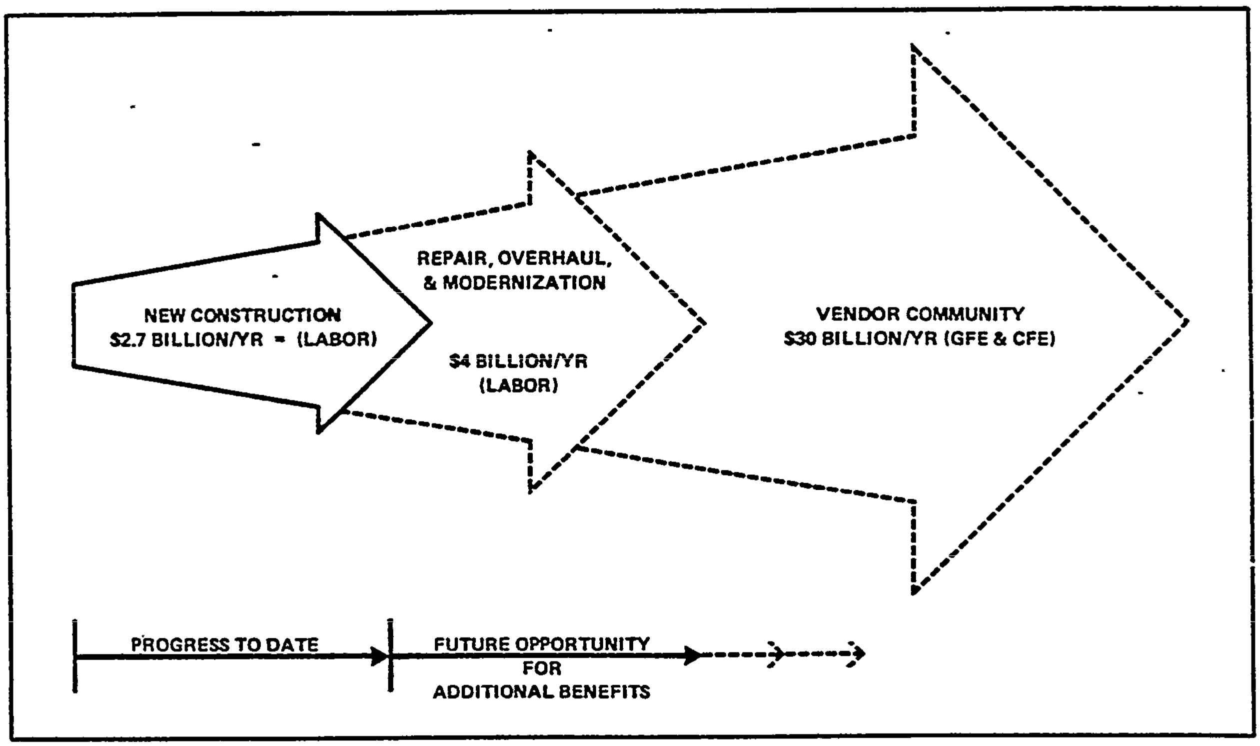


Fig. 15 Three areas for additional benefits are: 1) continue improving productivity in new ship construction, 2) improve productivity in ship repair, overhaul and modernization, and 3) apply the NSRP initiatives to the vendor community.

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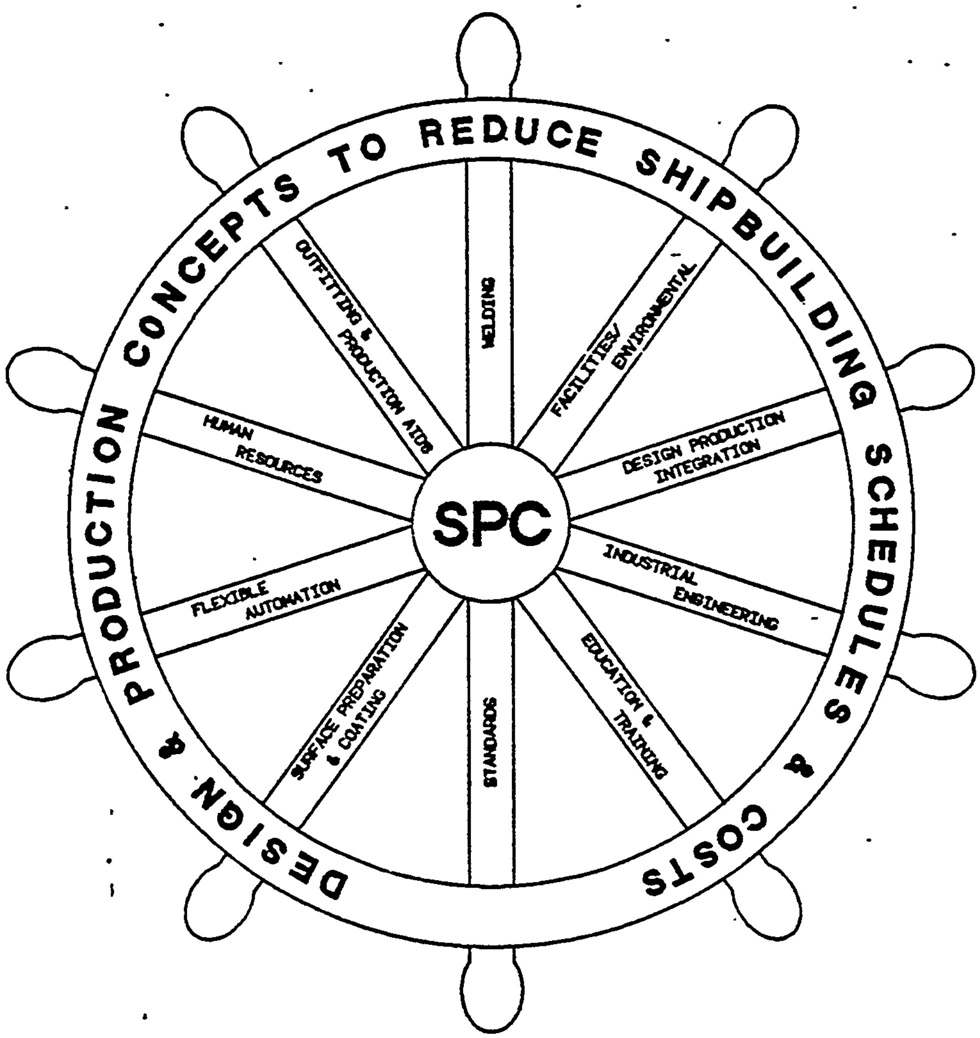

PAPER NO. 3

AN INTEGRATED PROCEDURE FOR HULL DESIGN AND PRODUCTION

BY: RENZO DI LUCA

SYMPOSIUM SPONSOR:
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AUGUST 27-29, 1986

1986 SHIP PRODUCTION SYMPOSIUM

AN INTEGRATED PROCEDURE FOR HULL DESIGN AND PRODUCTION

RENZO DI LUCA, Fincantieri, Trieste

ABSTRACT

The effective integration of hull design and production procedures is achieved by applying a comprehensive modeling technique that recognizes both the stages in the design process and also the structural component generation requirements. This paper describes an operational CAD/CAM system that is fully integrated from preliminary design through production. Some features discussed are ship-oriented model representations, common descriptive techniques, multi-user model access, and general graphic technology.

INTRODUCTION

Within the Fincantieri organization, the Computer Application Development department plays a prominent role in the development of practical CAD/CAM systems that support all aspects of ship production from design to construction. Important among these systems is SCAFO, a computer aided design and manufacturing software package for the development of steel structure from the original definition phase to the production of complex assemblies. This highly interactive system is subdivided into modules which deal with specific areas of application. Figure 1 shows the linkage of the following modules: FORMS, HYDRO, LINES, MODDEF, MOULD, PARGEN, SOLID, and GAIN.

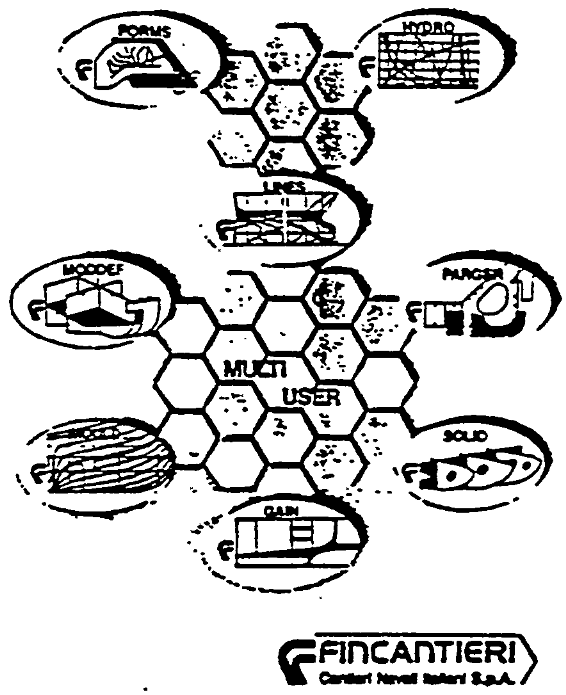


Figure 1 Component Modules of SCAFO

The FORMS module produces a preliminary definition of the hull form by either digitizing the appropriate body plan or by producing variations of ship characteristic data previously loaded into a library. The HYDRO module performs hydrostatic calculations for ships modeled in SCAFO. The HYDRO module contains the SIKOB package that produces naval architectural data in a conversational mode, and it is fully integrated with the structural model. LINES provides multipurpose hull form definition, transformation, and fairing. Refinements and completion of the hull form require no additional manual intervention. The MODDEF and DRACOM modules are used to produce the definition and illustration of the internal structure in terms of complete representations of surfaces, stiffening, seams, and structural parts. The definition and generation of the shell structure are provided by MOULD. This module encompasses all aspects of the shell from the design to the preparation and erection of shell blocks. PARGEN deals with the generation of parts and stiffeners for the internal structure. Each part is classified in accordance with model-oriented and production-oriented catalogs. The faired lines and structural components generated by LINES, MOULD, and PARGEN can be translated into a three-dimensional representation through the SOLID subsystem. The three-dimensional model can then be rotated to display different views. The GAIN module provides the shop documents and the nesting of plate parts.

MODEL REPRESENTATION

The Language

Throughout all of the modules, the SCAFO system is supported by a user-oriented functional command language which assists the user in a step-by-step manipulation of the model and evaluation of the results achieved. From large structural components to small collar plates, each entity is defined by a term derived from a ship-oriented frame of reference. Editing functions to alter the model are performed on-line, and the results are immediately-available.

Model Definition

A comprehensive representation of the steel structure is a fundamental requirement for **a** successful interactive approach to hull design. Throughout the SCAFO system the concept of topology is utilized to describe the interrelationships between the different structural components of the ship. This concept was first introduced by Fincantieri in 1976 with the TRALOS, TRADET, and DRAW systems.

A topologic description. of the structural interrelationship has proven to be the only method which provides a straightforward definition of the steel structure on the basis of limited input data. A design procedure that is based on this technique offers three distinct advantages: delimiting structural elements can be readily referenced, even before the delimiting structural elements are completely defined or generated; the data base can easily be edited or modified-to accommodate design developments; and various activities in the design cycle can be scheduled in a parallel manner, thereby permitting more design iterations and reducing the time required to produce a completed design.

The ship model is fully three-dimensional: however, for continuity purposes the user is always referenced to a preselected view. This provision of the system ensures the compatibility of connecting structures during the evolution of the design. An example of a three-dimensional structural model is shown by figure 2.

Scantlings

For a model representation to be meaningful, the model components must be described as three-dimensional objects in terms of plate thicknesses and stiffener scantlings. The stiffeners must be rigorously defined and located with respect to the direction of the

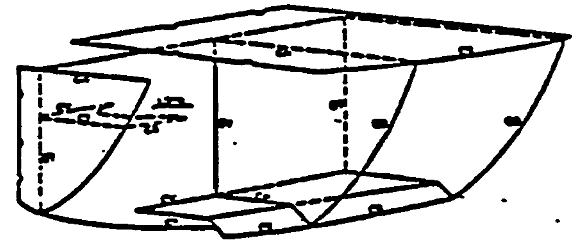


Figure 2 A Three-Dimensional Structural Model Developed from Topologic Descriptions

webs and flanges, or face plates, anc the relationship to the lofted or molded lines must be indicated. The systen incorporates the effect of the materi scantlings when the ship geometry is expanded and a definition of connectinc structure is established; also, the deformation of stiffeners, as required tc conform with sloped structure, is estab lished.

Working Station, Outputs, and Drawings

The majority of the working activities is conducted interactively at a graphic screen. All of the modules hav the feature of permitting either small details or large portions of the model to be represented on a graphic screer or a plotter. If a plotter is used, a post-processor is employed to transmit graphical data to various devices; the various modes of output available are illustrated by figure 3.

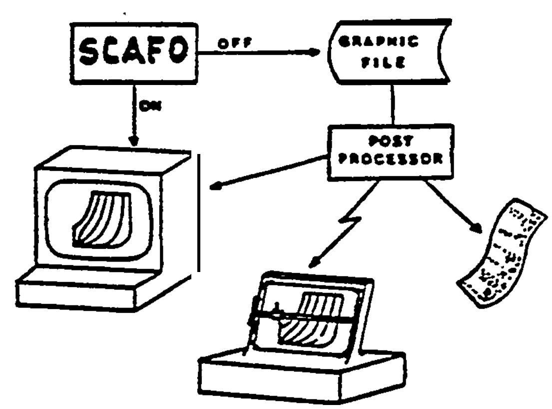


Figure 3 SCAFO Model Output Alternatives

The extent of the definition in th graphical output is dependent upon the level of model completion. At each pro gressive design phase, additional infor mation is incorporated into the model, and the graphical representation become more comprehensive. Initially the mode

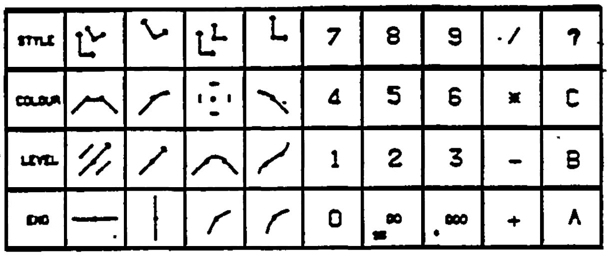


Figure 4 General Purpose Tablet for SCAFO Graphics

is loaded primarily by inputting data at the keyboard. As the model progresses, additional details are incorporated by using a special tablet that is designed to use graphic entities as model entities; additional details are thereby incorporated into both the drawings and the model. The multipurpose tablet, which is shown by figure 4, makes it possible for the user to define simple graphics and micrographics (symbols or complex graphics) that nave been loaded into a library.

SCAFO FILE CONFIGURATION

The standard version of the SCAFO system operates on a set of integrated files that have been configured to store and access model information without intervention or translation interfaces between design and production. Multiple access to the data base is essential; therefore, the various entities of the structure, as well as steel parts, are stored in different files. Each of these files contains specific information which is uses or manipulated for a particular application. Interferences among users is avoided because a single file is either dedicated to a particular function of the system or it contains information usable simultaneously by different users.

The data base is model-oriented and is subdivided by zone with particular emphasis placed upon applications for production purposes. A detailed analysis of all the information arranged in the structural model and the logical subdivision among the modules have led to the model arrangement as shown by figure 5.

The Header file contains general purpose information including the catalogs for transverse and longitudinal surfaces, pointers to zones, ship title, catalog of standards (stiffeners, hole cuts), midship section information, and the parallel body extension.

The Lines Fore and the Lines Aft files are oriented to the null form at the design stage. Information contained in the Lines Fore and Lines. Aft files

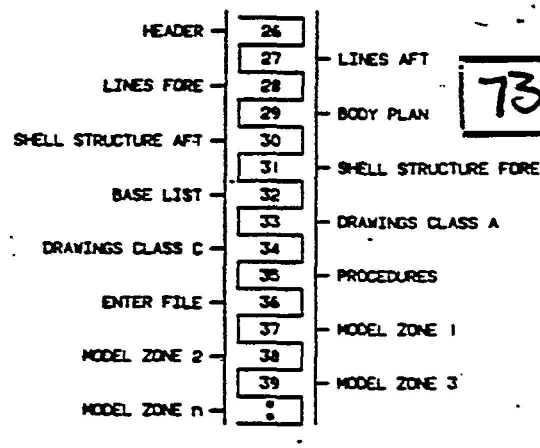


Figure 5 File Subdivision of the SCAFO Model

includes boundaries, spatial curves, design stations, water lines, buttock lines, general curves, and the derived curves catalog. This data is used to form the Body Plan as shown by figure 6. When the hull has a parallel body, two users can operate simultaneously in the separate zones; if there is no parallel body, the hull forms can be defined and faired as unique surfaces.

The curves derived from the design hull form are stored in the Body Plan file. This file also contains data for the frame lines and the butts of the shell blocks.

Shell structure information is contained in the Shell Structure Fore and Shell Structure Aft files and is derived from the Body Plan as indicated by figure 6. Data in these files define the seams and longitudinals, shell block subdivision and preparation, plates, webs, and a production catalog.

The Base List file, which has not yet been implemented as multiple access, will contain production information. This file will include information concerning the characteristics of structural parts and stiffeners, the product structure of subassemblies, material handling and processing requirements, and block erection procedures.

The Drawing Class A file contains data for structural drawings, drawings catalogs, views catalogs, and views descriptions.

Production drawing information is contained in the Drawings Class C file. Information concerning parts completion, panels, and the data structure of parts and stiffeners is in this file. The drawings are developed from the model and annotated with symbols, arrows, text, and additional sketches not related to the model.

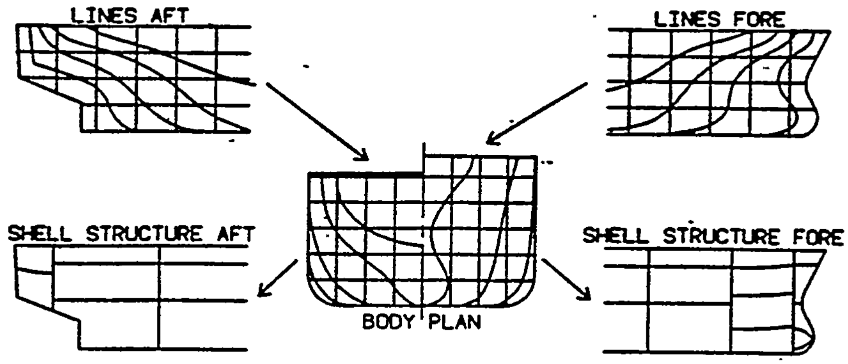


Figure 6 Relationship Between the Lines, Body Plan, and Shell Files

The Enter file allows access to the data base. The user is provided information concerning the configuration of the zone to ensure that the proper area is accessed.

The Procedures file allows the user to create macros and is a powerful system feature. Macros are predefined programs that are coded by using the language common to most of the modules and can include functions such as variable lists, do loops, and logic tests such as GO TO, THEN, and ELSE statements. There are three levels of macros: temporary, permanent to the zone, and permanent to the ship.

The Model Zone 1 through Model Zone n files contain a description of the structural model. The subdivision of the ship into zones is at the discretion of the user and is established before the internal surfaces are defined. A zone can be defined as a section such as a group of transverse surfaces, an area such as the double bottom, or a large structure such as the main deck. Only one user may access a zone at any one time; however, there can be as many users working on the model as there are zones used to describe the ship. The linking of zones is accomplished via the Header file. Interferences are limited to those few cases when dimensions are required to generate derived contours that cross zones. The subdivision of a ship into zones is shown in Figure 7.

Zone Approach

Effective ship construction procedures require that the production planning be oriented to modular zones. The zone approach is the best method to deal with production problems that relate to material handling because it is possible to palletize and route material along channels that support the zones. The requirement is more critical for outfitting, and a substantial reorientation and reorganization in the responsibilities of the engineering, planning, and construction trades may be required by the zone approach.

The SCAFO system is well suited for the zone concept, and the initial definition of the design model is based on the zone approach. The user is able to be fully cognizant of the entire ship model thereby making it possible to ensure the compatability of the development status of the structure with specific phases of design.

For large and complex applications the zone approach allows part of the model to be down-loaded to smaller stand-alone computers. Work can then be performed on the isolated part of the model, with the results later up-loaded to the host computer. The continuity and compatibility of the zones are confirmed at all model definition and modification stages.

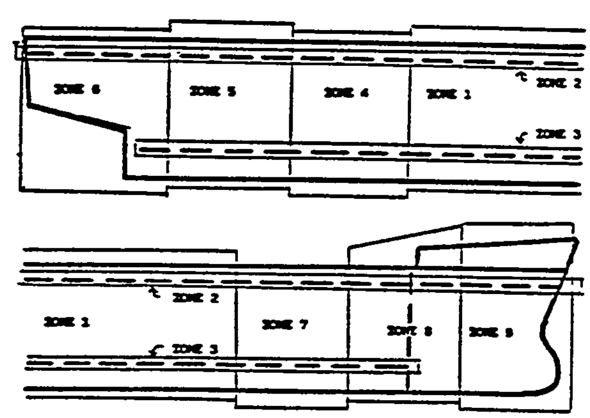


Figure 7 The Sudivision of the Model into Zones

INTEGRATION BETWEEN DESIGN AND PRODUCTION

The validity of a computerized modeling system is limited by the validity of the concepts on which the sytem is based. The most important aspect of the model definition is to ensure that the model rigrorously represents the ship and all of its components. ..Sin~e the design process has to be considered the first step of production, the model serves as the unique source of information for design purposes and naturally evolves into a comprehensive data base that can be used for production planning as well as the preparation of work instructions.

LINES Module

The definition of the hull form is a significant example of the integration between design and production. In the SCAFO system, the hull form is defined and modified with the LINES module. The output from this module not only supplies the traditional contours of build ing frames for production requirements at it also provides a modeled surface with other applications. This modeled surface provides hull form and deck data directly to the KYDRO model in order to perform hydrostatic calculations. The MODDEF, PARGEN, MOULD, and SOLID modules are provided transverse building-frames contours for their specific applications. LINES also provides derived lines or concours of the intersections of all solids penetrating the hull form in the three principal views. Seams, butts, anti spatial contours for the shell plates are delineated with a particular emphasis placed on the plates at the extreme stem and stern. The lines of intersection between the main longitudinal structure and the hull are included in the output. In addition to providing data that is used throughout the design and pro~uction of the ship, the LINES module also provides output data to drive the numerical-control milling machine which produces a scaled model of the ship for towing tank tests. Hundreds of water line sections are extracted from the computer data base to ensure the accuracy of the scaled model. Examples of the LINES module output are shown in figures 8, 9 and 10.

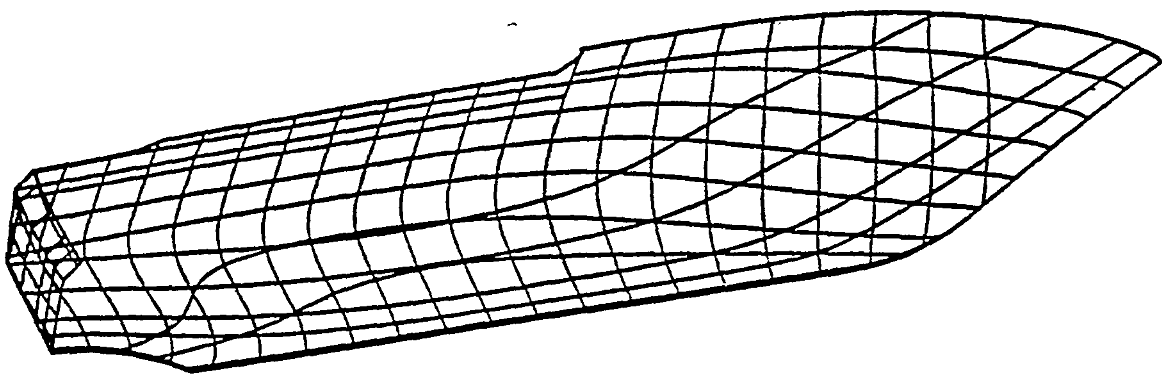


Figure 8 Body Plan of a Motor Yacht Produced by the LINES Module of SCAFO. The hull surface is defined by space curves, design stations, water lines, and buttocks. (Courtesy of: Cantieri Picchiotti-Viareggio, Italy).

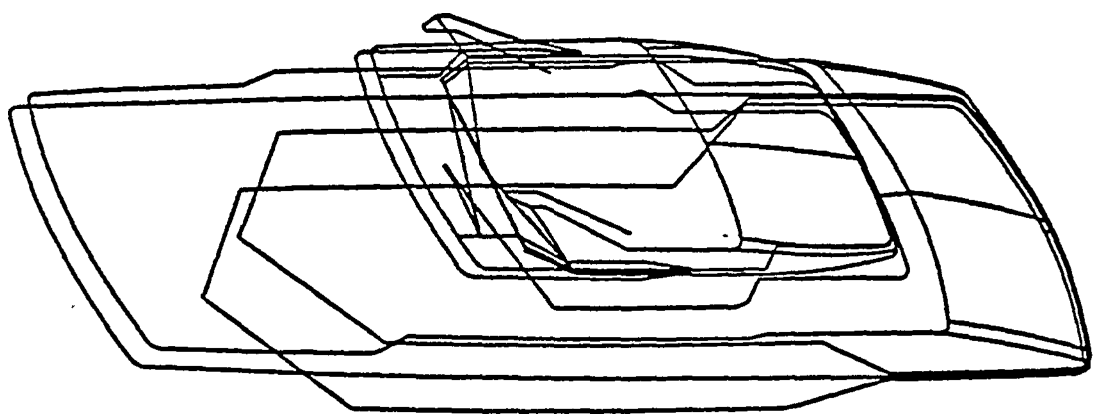


Figure 9 The Lines of the Upper Structure of a Motor Yacht are Defined as Independent Surfaces in the LINES Module.

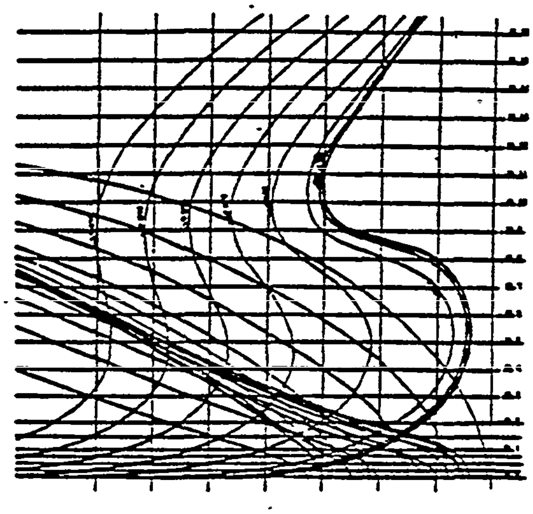


Figure 10 LINES Module Output Showing the Forebody Plan of a Merchant Ship

MODDEF Module

The MODDEF module is used to define the internal structure in terms of surfaces, stiffening, and connections as indicated by figure 11. This module can be used in either of two interactive modes of operation; the conversational mode, which is generally used during the preliminary stage; and the interactive graphics mode in which a special tablet is used to augment the graphical data that is loaded in the conversational mode. The interactive graphics mode allows the user to complete the structural drawing as stand-alone graphics or to augment the model with additional structural entities. The information provided by the MODDEF module is used to prepare structural drawings and shop drawings, to establish connection lines to the shell, to define derived contours required to fabricate parts and profiles, and to prepare material lists. An example of output from the MODDEF module is shown in figure 12.

MOULD Module

The MOULD module interactively deals with all aspects of the shell structure. Topology and the geometry of the model are used during operations performed with the LINES and MODDEF modules to establish a wire model of seams, longitudinals, and connections; this data is the start point for the MOULD module. The MOULD module is used to provide additional information about scantlings and plate thicknesses. Figure 13 shows that seams, butts, and transverse webs are derived from the hull form and generated by MOULD. MOULD synthetically defines the longitudinals and transverses, provides a one-hundred per cent expansion of the shell plates, draws the body and shell expansion plans, expands the longitudinals, and provides documents for shop operations and shell block erection. Figure 14 shows a typical shell assembly.

DRACOM Module

The continuing evolution of the interactive graphic operational mode of the SCAFO system has resulted in a

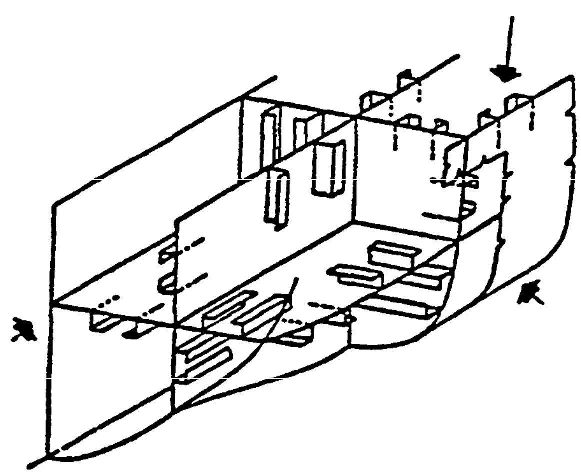


Figure 11 Typical Data Stored in the MODDEF Module

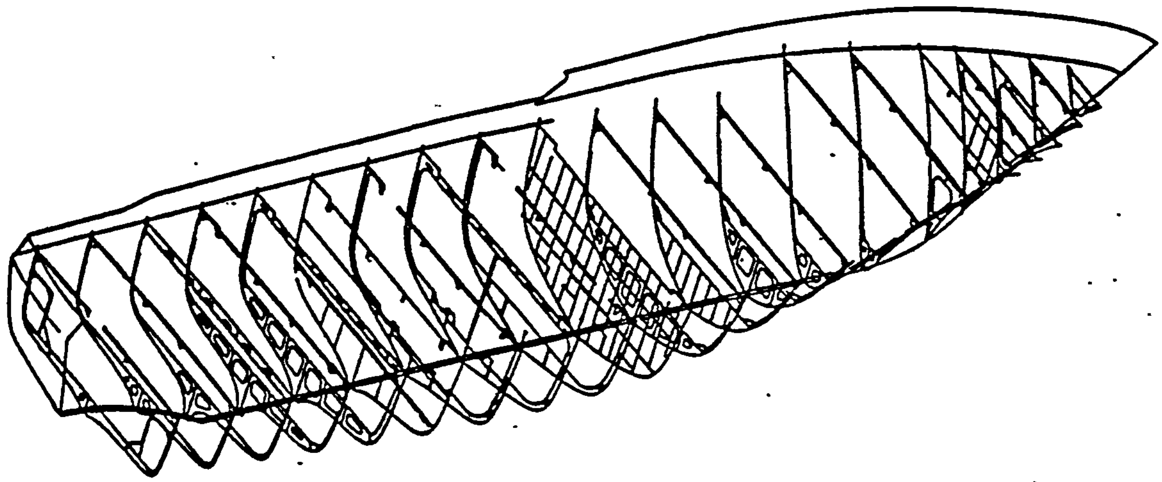


Figure 12 Drawing of Internal Ship Structure Produced by MODDEF Module of SCAFO. Structural drawings are prepared by deriving scantlings from the model.

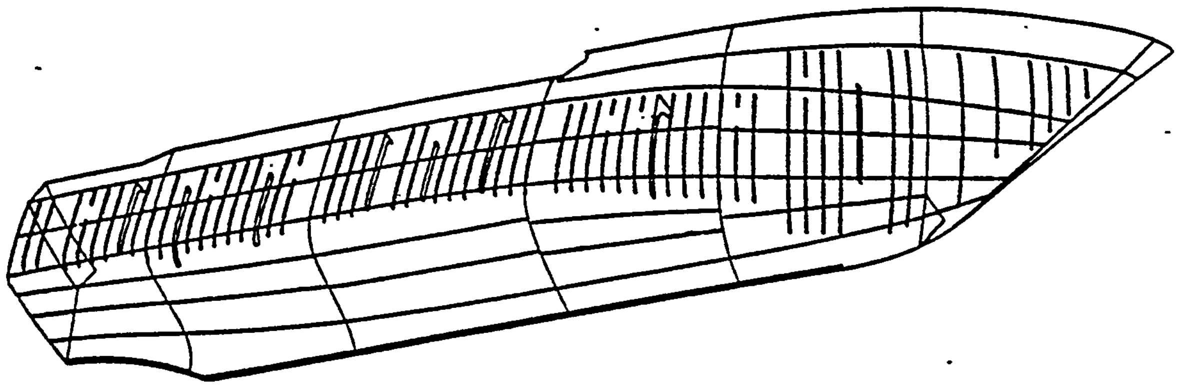


Figure 13 The MOULD module of SCAFO is used to derive the contour of seams and butts from the hull form. Shell structure such as transverse webs and plating are generated with the MOULD module.

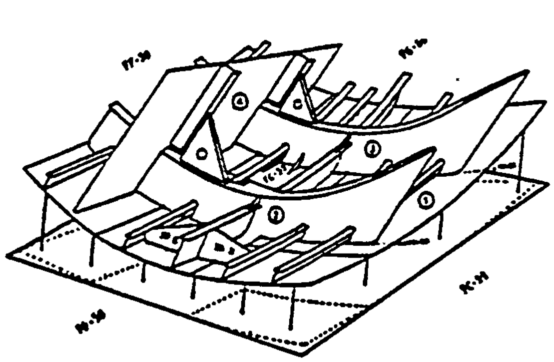


Figure 14 Shell Assembly Erected by Using Data Derived from the MOULD Module

recognized need for enhanced modern graphic technology. The LINES, MODDEF, and MOULD modules completely define the entire structural model during the design stage; however, the output from these modules is a set of nearly blank drawings with minimal text related to model entities and no annotations for production purposes. The drawings also contain few details concerning many of the structural elements, which are necessary to clarify drawing interpretation. The required graphic technology is necessarily fully interactive with respect to definition, modification, and verification and is required to be capable of being performed on-line using a keyboard, screen, and plotter.

The function of drawing completion can be carried out via a new module, DRACOM (DRAwing COMposition), which interrogates the model for the steel details loaded up to that particular phase of design. The graphics are linked with a table of contents which identifies the

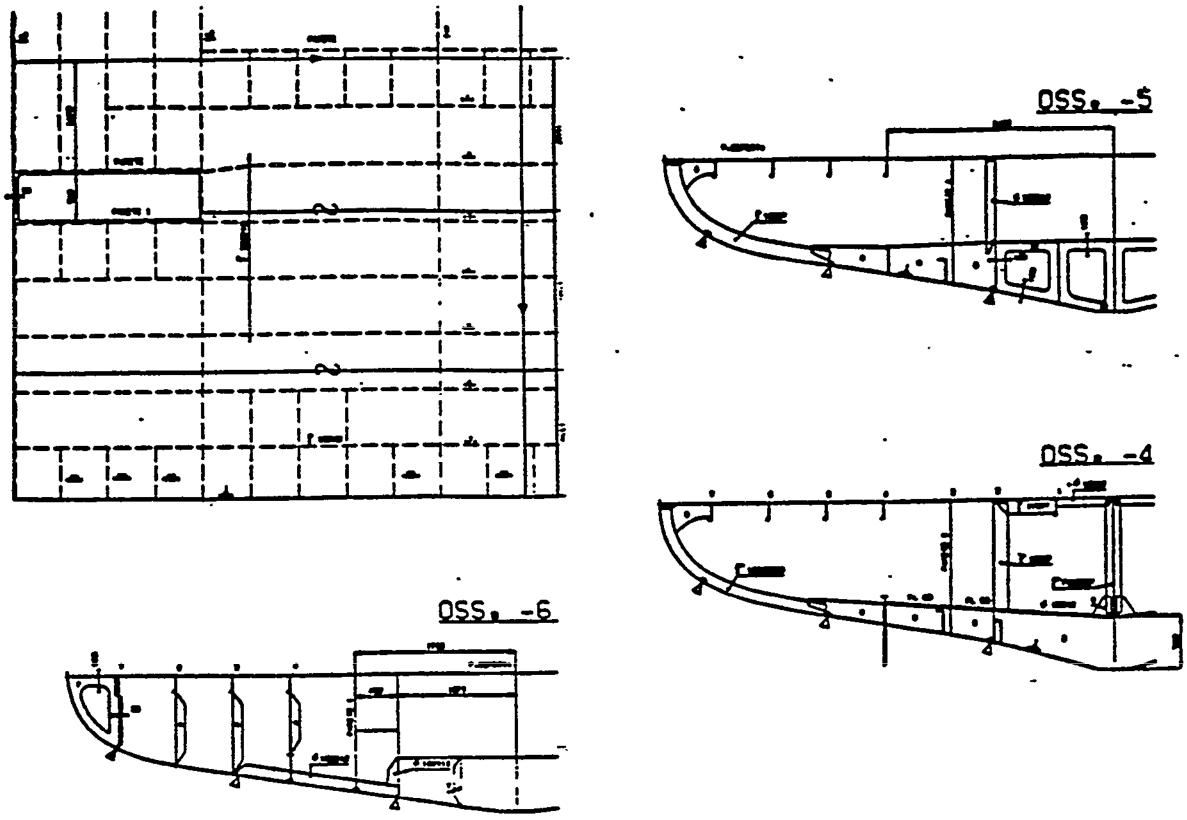


Figure 15 Plan View and Transverse Views on a Drawing Generated with DRACOM

drawing entities as contours, surfaces, holes, seams, stiffeners, or cutouts. The system can reference back to the model entities and label the entities with the correct text, such as surface name or scantling number.

DRACOM allows the user to add and manipulate additional text, symbols and arrows, contours, and minor graphic details. All of these operations are performed using a tablet as stand-alone information for pure graphics, or the information can be sent back to the model, as in the case of holes and contours. The graphics are assembled into a set of views of a predefined structure or group of structures. These views are then nested into a drawing format. If the model is modified, the views impacted can readily be regenerated from the model; however, after the views are regenerated, there are annotations which must be added and the user must either confirm or modify the annotations to ensure that the revised drawing is compatible with the model. Examples of drawings generated with DRACOM are shown in figure 15.

PARGEN Module

The preparation of fabrication documents for plate parts and stiffeners has customarily been a demanding and time-consuming process that has often impacted construction schedules due to the exhaustive amount of geometrical descriptive data required for each part and the short time period available for the preparation of this data. The introduction of part-coding programs in the relatively recent past has been beneficial; however, this development is not an entirely satisfactory solution to the problem. The computer modeling technique that has been introduced by SCAFO dramatically reduces the lead time for part generation such that this consideration is no longer a critical aspect of the preparation phase. SCAFO provides the data for parts and stiffeners as a by-product of the model through PARGEN, and their computer description requires only a limited topological reference to the model. Figures 16 and 17 show transverse and longitudinal parts generated from the model with the PARGEN module.

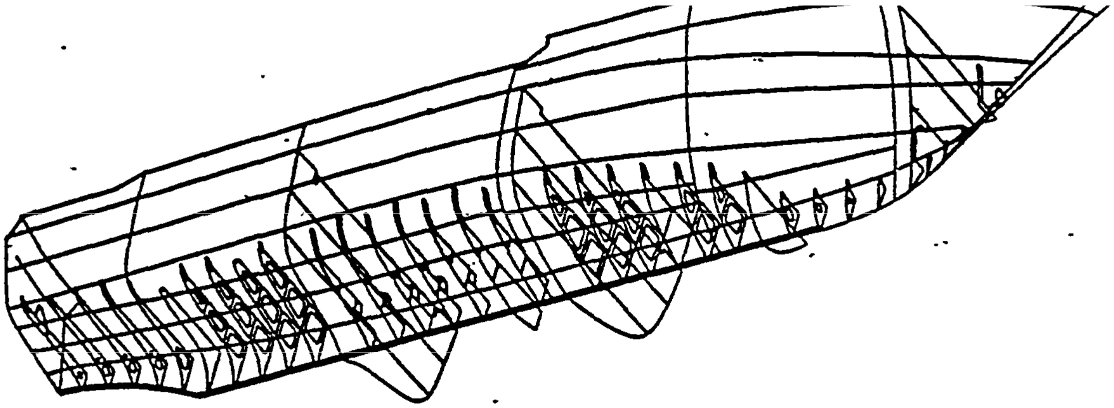


Figure 16 Transverse parts generated with PARGEN. Similar parts are generated by repetitive commands.

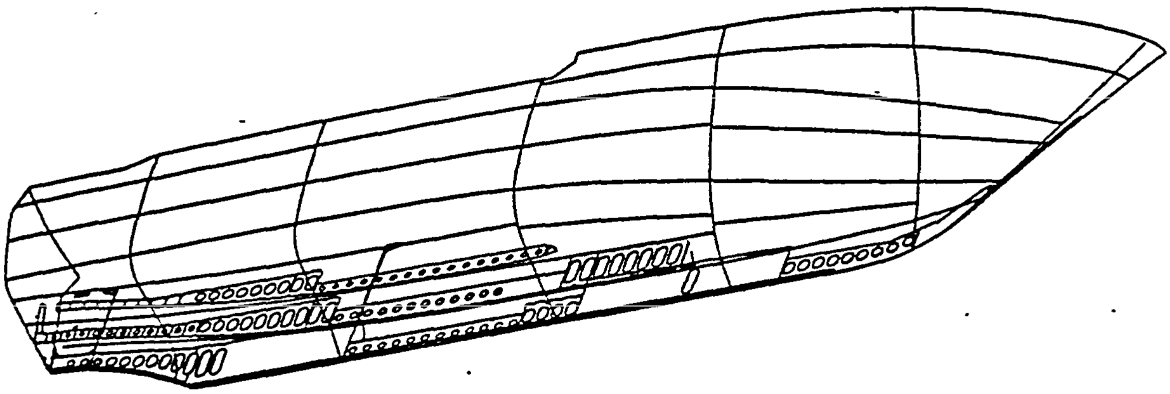


Figure 17 Parts located in various positions are generated with reference to a major view in PARGEN. Parts on skewed surfaces are expanded automatically.

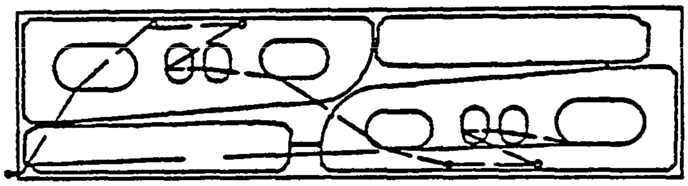


Figure 18 Nested Plate Generated with the GAIN Module

GAIN Module

The GAIN module of SCAFO has been operational since 1974 and represents a high level of graphic technology in part nesting operations. Parts can be linked on a computer representation of the steel plate, and refreshed graphics allow the parts to be moved as necessary to obtain an optimum nesting arrangement. A modification of parts in the model does not require a redefinition of the nested plate unless the modification increases the size of the parts and causes the parts to overlap. In addition, the user can perform limited modifications to the nested plates, such as the addition of extra material on the edge of parts. Figure 18 shows an example of a nested plate that was generated with the GAIN module.

SOLID Module

SOLID, which is the most recently developed module of the SCAFO system, incorporates a high level of integration with the other system modules. The SOLID module can be used to represent most of the entities described or included in the LINES, MODDEF, MOULD, and PARGEN modules. The SOLID module has a hidden-line algorithm which suppresses the representation of structural parts that are blocked from view; this feature greatly simplifies the model representation and avoids the tedious and time-consuming chore of cleaning-up hidden lines by manual intervention.

Hardware

The entire configuration of the SCAFO system is operational on VAX computers which are a product of the Digital Equipment Corporation. At Fincantieri the system runs primarily on a Sperry mainframe, but some of the applications can also be run on the VAX. The DRACOM, GAIN, and SOLID modules can operate on a VAX computer only.

EMERGING DEVELOPMENTS

In order to fully comprehend the emerging developments within the Fincantieri organization, a familiarity with the company is required. Fincantieri-Cantieri Navali Italiani, S.p.A. is the major and most diverse shipbuilding, shiprepairing, and diesel engine manufacturing facility on the Mediterranean, and is one of the largest in Europe. A company of the IRI Group, Fincantieri has combined the skills and facilities of the oldest, most respected, and advanced Italian companies in these fields. The company consists of four divisions: Merchant Shipbuilding based in Trieste, Naval Shipbuilding based in Genoa, Shiprepairing based in Genoa, and Diesel Engine Manufacturing based in Trieste.

Within the Fincantieri organization the level of applied technology varies widely from one facility to the next. Modern technology has been introduced in some plants, whereas out-dated operational procedures continue to be used in others. Both obsolete and state-of-the-art machinery are in use, and there are dissimilar computer installations at the various plants and sites. These problem areas have been recognized, and programs are underway to modernize the design and production processes in use.

An INTERGRAPHS system, which is a CAD package designed to confirm the compatibility of structure and outfitting, was installed at the Naval Ship Division in March, 1986. Steel structure is stored via neutral file by extracting information from the SCAFO model. Three entities are transferred from SCAFO: space curves and lines, structural planes, and shaped structures. The data transferred is the minimum necessary to identify potential fouls with structure when designing and locating the outfitting components. A provision has also been made to conduct interference checks between components of the hull structure.

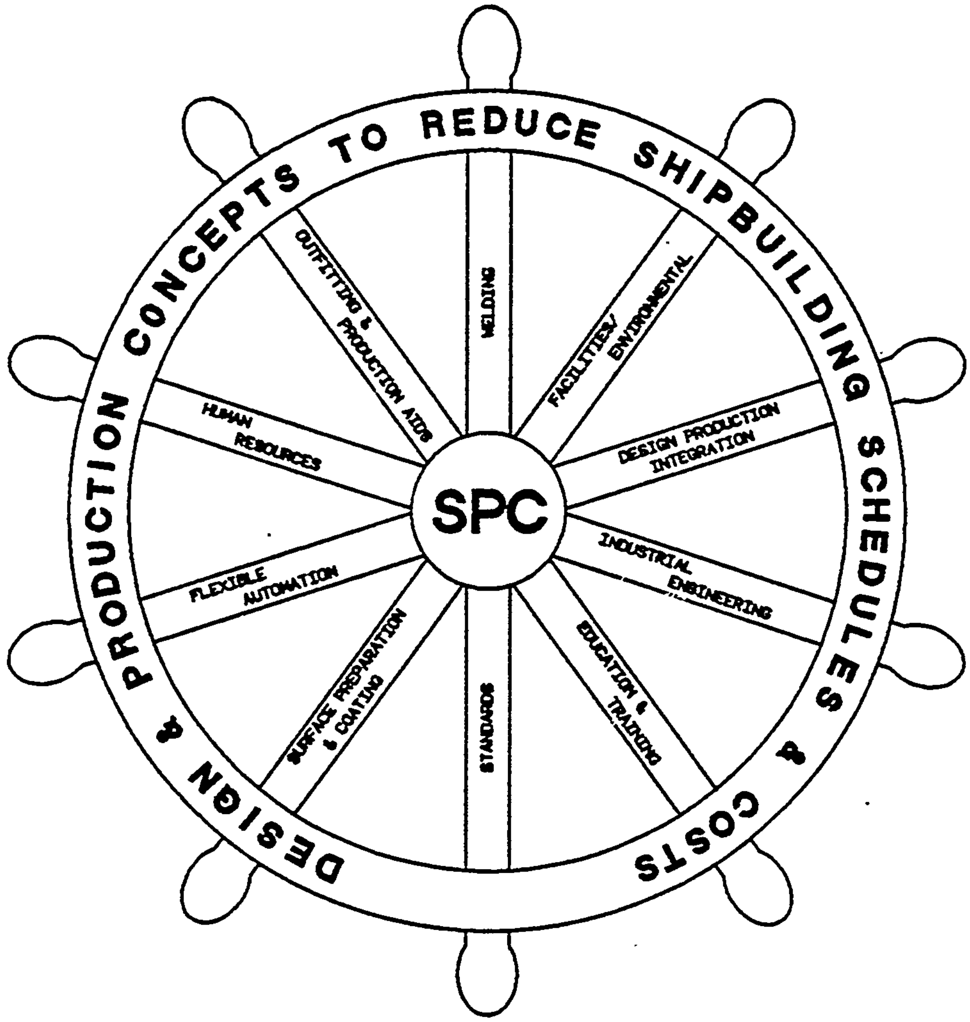
The installation of an automatic welding station is now under intensive study for subassemblies that have dimensions which warrant the application of this technology. From an economic point of view, the preparation of robotic programming to weld individual parts is not considered feasible because the steel structure varies so widely that an excessive amount of time would be required to develop the required input data. However, with the modeling techniques used within SCAFO, each piece is generated with respect to its spatial arrangement; therefore, the data structure and correlation among structural parts are potentially available from the SCAFO ship model. Using this approach the individual parts can be translated and rotated to form the required orientation and assembly sequence to be used during production. By using a data structure having the proper intelligence during the assembly operation, each part will have retrievable information about its stiffening and its solid representation within the assembly. A specific interface module will be developed to identify horizontal and vertical weld orientations and to identify interferences; the interface module will also program the robotic weld sequence for an entire assembly.

Throughout all the modules of the SCAFO system, the majority of input operations are conducted via a simple user-oriented functional language. However, this commonly used input technique, which is considered indispensable, can be provided with an appropriate interface which will make it possible for the commands to be given orally rather than through a keyboard. Fincantieri is presently analyzing the feasibility of a voice-control interface.

CONCLUSIONS

In summary, the practicability of effectively integrating the hull design and production operations has been demonstrated. The key to this effective integration is the application of a comprehensive modeling technique that can assimilate design and production-planning data, as it is developed during the evolutionary design phases, and later produce, with only minimal intervention, the production data required for fabrication and construction. Much progress has been made in this direction; however, many opportunities for further advancements remain.

)NAL SHIPBUILDING RESEARCH PROGRAM
1986 SHIP PRODUCTION SYMPOSIUM



PAPER NO. 4

DECENTRALIZATION - THE MANAGEMENT KEY TO EFFECTIVE ACCURACY CONTROL

BY: TAMARA S. UPHAM
W. MARK CRAWFORD

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AUGUST 27-29, 1986

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DECENTRALIZATION - THE 1986 SHIP P KEY TO EFFECTIVE ACCURACY CONTROL

TAMARA S. UPHAM AND W. MARK CRAWFORD, National Steel & Shipbuilding

ABSTRACT

This paper presents the organizational structure, methods, and results of National Steel and Shipbuilding Company's efforts to decentralize the responsibility of statistical accuracy control from a central Accuracy Control Department to hourly production workforce. It includes an accounting of the problems and successes encountered during implementation. The results are both quantitative and qualitative in form, including methods for measuring reductions in rework.

During this Study, workteams were established in the Hull Fabrication Shop. A three phase methodology was used to introduce the workteams to statistical methods for improving the dimensional accuracy of their products.

CONTENTS

INTRODUCTION

Scope of Problem

International competition and foreign labor rates have put most commercial shipbuilding contracts out of reach for U.S. shipbuilders. .This has created a fiercely competitive environment for U.S. Naval contracts. The recent commitment by the U.S. Government to award contracts to the lowest technically qualified bidder has put increased pressure on U.S. Shipyards reduce production costs as quickly and drastically as possible.

Many shipyards have seen major reductions in outfitting manhours due to downhand zone outfitting methods. an important step, but additional improvements must come from the budgets of the Hull Structure Departments. The commonly recognized methods of increasing steel productivity are;

1. Better designs for production and material cost.
2. Improved detail scheduling and material control.
3. Introduction of Yardwide dimensional accuracy control.

Prerequisites for each of these improvements are: standardized processes, product-oriented construction, and well defined manufacturing process lanes.

United States shipbuilders are recognizing that improved quality of interim products will result in increased productivity. At the recommendation of industry publications and outside consultants many U.S. shipyards have formed Accuracy Control Departments hoping to reduce rework and optimize production processes. As they implement accuracy control procedures they are finding that decentralization of responsibilities is most effective.

Background

Most U.S. shipyards have an Accuracy Control "Department, but there is little published information addressing the status of their functions. Most literature date addresses the factors necessary to initiate an accuracy control program.

The referenced articles on

accuracy control implementation in U.S. shipyards conclude that for an accuracy control program to succeed, the shipyard must have product-oriented construction and process lanes (l). There must be a strong commitment from upper management, willingness to invest enough time to build the necessary data base for establishing process capabilities and monitoring improvement (2)(3).

U.S. Shipbuilding is not the first to implement statistical accuracy control in a manufacturing organization. A literature search of progress made in foreign shipyards and in other U.S. manufacturing industries brought to light some successful approaches to implementing accuracy control.

Implementation In European~ Shipyards. The international economic climate for commercial shipbuilding in European yards is just as competitive as for U.S. yards. In some countries, the shipyards are owned by the state, and commercial work is more evenly divided. This has not prevented some of those shipyards from closing due to international competition.

In 1985, as part of a SNAME SP-5 Human Resource Innovation Panel project, a survey was made of the status of product-oriented workgroups in European yards (4). The purpose of the survey was to learn how European yards use the participation of smal1 workgroups to improve their work processes. Some factors these yards found necessary for change to occur were:

1. Strong directive from top management, i.e. "It will be done".
2. Job protection for supervisors who cooperate (with possible changes in job
3. Supervisor training in workteam management.
4. Leadership training for supervision.
5. Opportunity for groups to receive feedback and evaluate performance.
6. Suggestion program with monetary awards relative to the value of suggestion.

Similar observations were made by the Norwegian consulting of Bedriftsradgiving which participated in a Norwegian. Shipbuilding Research Project from 1976 to 1980. They noted that group activities must be tied to quantifiable objectives, and intended outcomes should be made clear. Also, strategies must be established to involve key players of an organization [5).

All shipyards participating in the Norwegian Shipbuilding Research Project agreed the potential for productivity increases depended on their ability to interface with and motivate people who perform the work. Advances in automated equipment or administrative control. systems did not significantly increase productivity (S).

Implementation In Japanese Shipyards. The shipyards of Ishikawajima-Harima Heavy Industries co. (IHI) have sought to develop an organization that promotes continual improvement and high productivity through worker participation at the small workgroup level. Their plan considers union representation and common work practices. The effectiveness of their organization also relies on a foundation of product-oriented design, material preparation, and planning (6).

The formal kick-off for the IHI continual improvement campaign was in 1969. Known as the 3Z or 3 ZEROES campaign: zero accidents, zero defects, and zero waste, it started with IHI top management issuing a formal policy to all shipyard employees, identifying areas that needed improvement in the following year. Areas such as safety, morale, productivity, and accuracy control were addressed. To date, a policy has been issued each year, feeding back the results of an analysis of each shipyard's major sources of costs, rework, and inefficiencies. To achieve the goals set forth in the annual policy, these steps are taken:

1. Quantitative annual targets for improvement are established by middle managers for each work process. These targets may be concerned with productivity, accuracy, and/or safety improvements. Guidelines for achieving the targets are also developed. Established work rates are an important management . tool for analyzing relative improvements made in process efficiency. Likewise, knowledge of current accuracy capabilities is required to monitor relative improvement.

2. Each Workstation or workteam is to achieve the annual targets established for them. Everyone in the company belongs to such a workteam and receives training in problem solving methods. This includes understanding statistical charts, graphs, and data collection methods.

3. Each workteam meets at the beginning of each shift, and also twice a month for one hour to discuss their plans and progress in reaching their target. Interim revised are evaluated and quarterly by the workteam members.

4. An employee suggestion system is considered an important factor in providing the workforce a method to have their ideas for improvement implemented. A portion of the manager's annual evaluation is based on the number of good suggestions that are implemented in their area. Thousands of suggestions are accepted and implemented year (approximately one per employee per month). Small monetary are given based on the quality of the suggestion.

5. Large meetings for giving recognition to workteams are held quarterly and annually. Specific workteams are publicly recognized for submitting large quantities or quality suggestions and also for achieving annual targets ahead of schedule.

The cost of training, recognition meetings, and suggestion review each month is high, but considered well spent by IHI. IHI feels this Feedback and Suggestion Program is the key to higher productivity and morale. Because good morale is considered an important motivational factor for worker participation in continual improvement of processes, more than ninety-nine percent of all employee suggestions are implemented, usually within one month (7].

As in European yards, direction is from the top down and implementation is from the bottom up. Analysis of data gathered during the year on work rates and rework enables management to set attainable targets for improvement:

At the IHI yard in Kure, a centralized Accuracy Control Depart- ment sets targets statistically as guidelines for improving accuracy of vital dimensions. Recommendations for achievement are included with these targets which are revised every six months. All Hull Department Management. must approve the accuracy control targets. The organization structure that has evolved over the past fifteen years to support this process of feedback and implementation is shown in Figure 1.

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Implementation in Other U.S. Industries

The distinction between the statistical quality control programs used in other industries, and the dimensional accuracy control addressed in this paper is minor. Dimensional accuracy control in shipbuilding is one application of statistical quality control methods. In shipbuilding the accuracy of vital dimensions on interim products is what needs to be kept in statistical control. In a design company it may be the number or type of drawing errors which need to be monitored with statistical control charts. In a purchasing department a statistical control program might be introduced to identify problem suppliers.

Many companies in other industries with successful statistical quality control programs used consultants for guidance in starting and maintaining their programs. The resulting education of management in the use of statistical control methods was a key factor in the success of these companies.

Two of the most noted consultants in this group are Dr. W. Edwards Deming and Dr. Joseph M. Juran. In the 1950's they formed the basis of the Japanese quality programs. In the late 1970's, due to Japanese competition, U.S. industry sought the help of these men [8).

Status At Onset of Project

Status of Process Lanes At Onset. At the onset of this project there were two established process lanes functioning in the yard for the construction of tanker midbody blocks. One process lane was for flat blocks and the other was for curved blocks. The lanes were

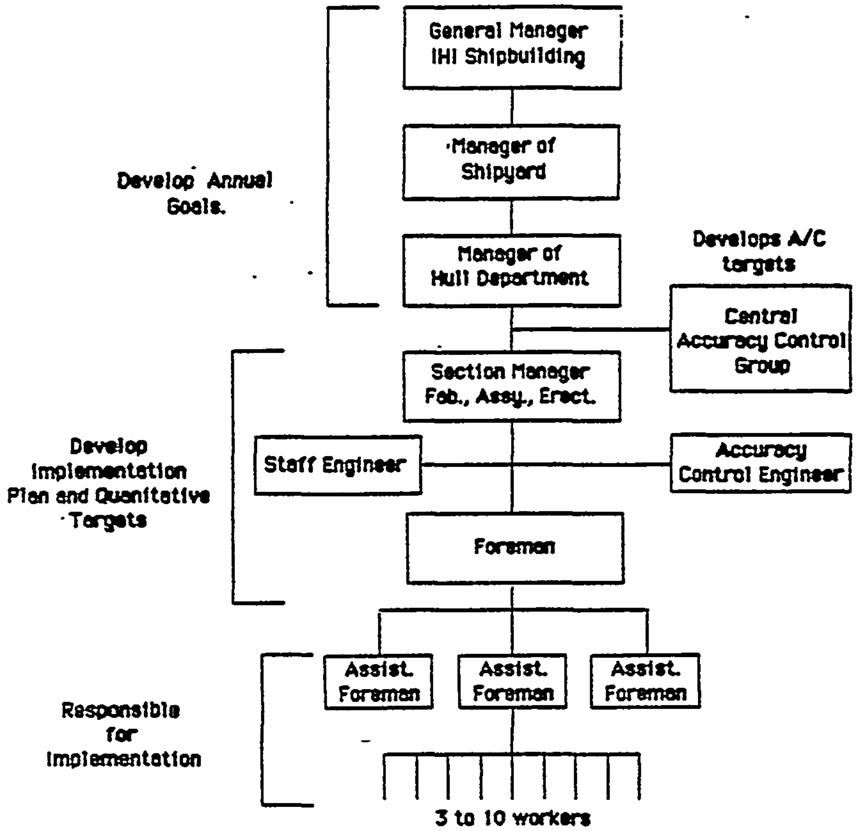

Fig. 1 IHI Organization for Improvement (Small Work Teams)

in place for sub-assembly and assembly. They stabilized the workforce at each workstation and optimized material flow for each block type. This contributed to the success of decentralizing Accuracy Control because workers had fewer checking procedures to learn and were more familiar with their work processes. Figure 2 illustrates the flat block process lane. Figure 3 shows a typical flat block.

<u>Status Of Accuracy Control At Onset</u>. The Accuracy Control Department at National Steel and Shipbuilding Company was formed in October, 1984 with the purpose of analyzing work processes and making recommendations for improvement. The focus was to reduce production manhours by shipping more dimensionally accurate products to follow-on stages of construction. It was realized early on that to achieve this goal yardwide, the production workforce had to become actively involved.

The Department was started with two full-time members. After ten months it was expanded to a total of seven including one person on third shift and two on second shift. Prior to the start of this study, progress had been made in training the hourly workforce to check vital dimensions, and workstations had been exposed to regular data collection over the previous ten months. This included some workstation members that had been taking their own daily data samples. This data was analyzed by the Accuracy Control (A/C) Department on a weekly basis.

Accuracy Control representatives periodically attended the short meetings held for each trade at the beginning of each shift. The A/C representatives answered questions, solicited feedback, and discussed the positive downstream effects of improved accuracy. Most importantly the analysis of data collected at that workstation was discussed.

Pre-planning activities by the A/C Department included the development of an Excess Material Plan to be used in the fabrication, assembly and erection of the midbody

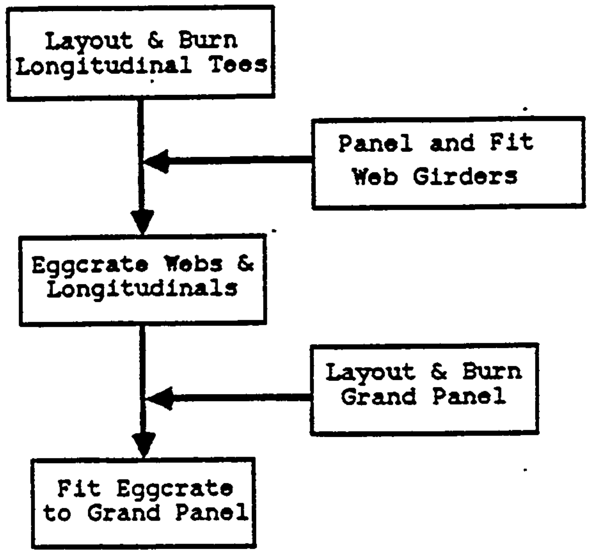

Fig. 2 Process Lane for Flat Midbody Blocks

blocks of two 209,000 DWT oil tankers. This plan called for material to be added for normal (in-process) variations, such as predicted weld shrinkage. All other variations were designed to be adjusted with one inch of excess material located on every third hull block. These "adjusting butts" allowed for maintenance of contractual length, breadth, and depth tolerances of the ships. The plan for building two-thirds of the midbody section "neat" differs from hull construction approaches, where one inch of excess was allowed on each hull block. This past method for usage of excess resulted in the expenditure of many extra manhours for trimming and fitting of parts and plates at erection.

To reduce manhours at erection, each stage of construction had to build its parts, sub-assemblies, and assemblies within specified tolerances, and perform in-process checking. A booklet containing sub-assembly vital points and checking procedures was issued to foremen and hourly employeees. Education meetings were held to explain the contents and use of this reference guide. The booklet addressed each process, such as webs, panels, and floors. Since the vital points were the same for each process, regardless of the size or shape, generic checksheets were developed. This eliminated the need for specific checksheets to be prepared ahead of time.

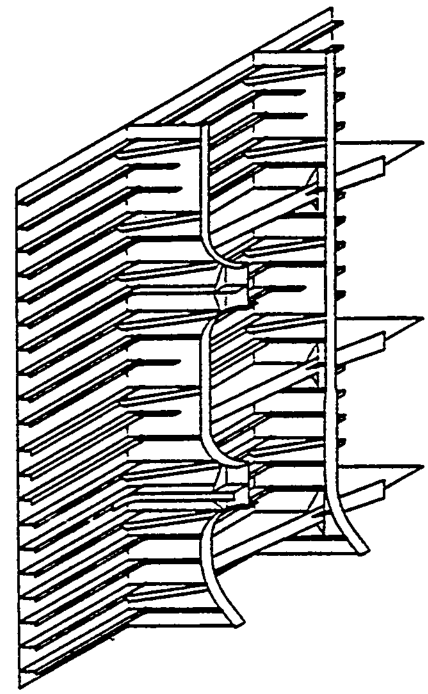

Fig. 3 Typical Flat Block (Side Shell)

METHODOLOGY USED FOR DECENTRALIZING

The methods used to decentralize accuracy control at NASSCO are similar to those already in use by other manufacturing industries. They have been modified as required to suit the fabrication and assembly processes used in a shipyard work environment.

In this study, the decentralization of statistical accuracy control responsibility had three phases of implementation:

Phase I. Determine maximum tolerances acceptable for erecting neat blocks without rework. Analyze standard assembly procedures for flat blocks types and develop standard checking procedures and tolerances.

Phase II. Introduce standard checking procedures and tolerances to the hourly workers at each stage of construction. Give the workteam feedback on analysis of data collected from their workstation, in the format of percentage out of tolerance charts.

Phase III. Introduce statistical control charts to the members of the workstation as a tool to refine the accuracy capability of their work process. Give training in how to plot daily random samples of data.

Phase I

An analysis of each process in the construction of flat blocks was the first phase. The data collection analysis in this initial Study was undertaken by the Accuracy Control Department. The steps used were:

1. Identify the recurring problems arriving at erection from earlier stages of construction.
2. Use problem solving methods to determine likely causes of rework.
3. Collect data on likely causes of rework.
4. Analyze data and recommend changes to process.
5. Make Production Supervision responsible for implementing changes with technical support provided by A/C Department.
6. A/C Department monitors for improvement.

From this preliminary analysis, procedures were developed for two types of checking:

IN-PROCESS CHECKING: Done each step in the process at the hourly worker as a self check. Data is not necessarily collected.

VITAL POINT/VITAL DIMENSION CHECKING: An overal1 check of a block or sub-assembly prior to welding. A designated person was made responsible for these checks, and for data collection.

Phase II

The next phase involved teaching the hourly workforce to correctly follow the checking procedures and continually try to imp rove the accuracy of their work processes. This was achieved as follows:

1. Introduce concept of workteam and accuracy control to area supervision.
2. Instruct workteam on tolerances and in-process checking procedures.
3. Data collection by A/C Department and presentation of data analysis to workteam.
4. Provide training in the understanding of statistical control charts to supervision and subsequently to workforce.
5. Post statistical control charts at the workstation, with A/C department plotting data.

Initial upper and lower statistical control limits were calculated from at least ten consecutive daily subgroups of data previously collected (five samples per subgroup). The initial target for the workteam was to stay in statistical control (within upper and lower control limits).

Phase III

Once the process was in statistical control, the workteam Could concentrate on eliminating common cause types of error from their work process. This is the continual refinement stage that will reduce the percent defective and at the same time bring the control limits of plus or minus three standard deviations within specified tolerance limits.

1. Workteam meets to discuss ways imp rove process and bring control limits within specified tolerance limits. Foreman and staff engineers participate and help facilitate worker recommendations for removing outside sources of error.
2. Provide training to supervision and workforce in how to actually plot the data.
3. Designate (ask for volunteer) member of the workteam to take daily random sample and plot data point. A/C department also continues to take daily random sample to verify that the workstation remains in control.
4. Workteam meets regularly with A/C representatives, supervisors, and staff

engineers to identify common causes of error from processes, including feeding back information on errors to early stages of construction.

5. Provide frequent recognition of accomplishments, both to workers and supervision.

IMPLEMENTATION AT THE MANAGEMENT LEVEL

Gaining Commitment of Upper Management

The top management of National Steel and Shipbuilding remained committed to the implementation of accuracy control yardwide. This was evidenced by their acceptance of the design to build without excess material on each hull block. This plan requires good accuracy throughout the midbody construction process since gaps resulting from short material WOUld result in an expensive problem at erection.

Company management showed an equal commitment to the development of its human resources. Al1 supervision was encouraged to use the first portion of each shift to hold meetings with the hourly employees reporting to them in order to advise them of work to be done, schedules to be followed, and any other information deemed useful to the employees. This meeting also provided time for the hourly employee to present ideas for improvement.

Training was also provided in statistical accuracy control methods to supervisors and hourly employees participating in this project.

Agreement on Supportive Organizational Structure

Production Department Organization. The organization under which this decentralizing effort developed was as follows: a Production Department managed by the Sr. Vice President for Operations with the Director of Hull Outfitting and the Director of Hull Structure reporting to him. For this project, accuracy control implementation took place only in the Hull Structure Department. The Director of Hull Structure is responsible for the Fabrication Shop, Assembly, and Erection. To facilitate these operations, there is an Assistant Superintendent for each area. There is also a Chief Welding Engineer in charge of Welding, Burning, and Chipping. He provides technical support and supplies personnel to both the Hull and Outfitting Departments.

Within each hull group (i.e. Fabrication, Assembly, Erection) are two staff engineers and a traditional General Foreman, Foreman, Leadman hierarchy.

Accuracy Control Organization. The Accuracy Control Department was formed approximately one year onset this Study as a Staff Department supporting the Director of Hull Structure. The Supervisor of Accuracy Control reported to the Director of Hull Structure. The Accuracy Control Department had two degreed Engineers (Accuracy Control Analysts) and four Technicians with hull design experience. These numbers remained stable throughout the majority of the study.

When the technicians joined the Department, they were trained to make vital point checks at subassembly and assembly workstations. Later, their responsibilities expanded to include teaching the foremen and hourly employees checking procedures. It was soon discovered that even though errors were being identified early, the necessary corrections were not being made before the product was shipped. Also, it was not possible for the four Technicians to thoroughly check all the blocks and sub-assemblies being built and conduct the necessary training. It became apparent that more manpower was required.

Instead of hiring more technicians, the plan to decentralize the responsibility of collecting data and plotting the data on histograms was accelerated. One highly skilled and motivated shipfitter was chosen from each of the main assembly workstations to be trained as Accuracy Control Field Checkers. These. field representatives still reported to their foremen, but their first responsibility was to perform vital point checks of the assemblies and to make any necessary corrections. The rest of their time was spent shipfitting. Figure 4 shows this organization for the Hull Structure Department.

Pronosed A/C Organization. It is anticipated that increased responsibility will be placed with the hourly Field Checker for supporting the accuracy controlneeds of his/her workstation. in-

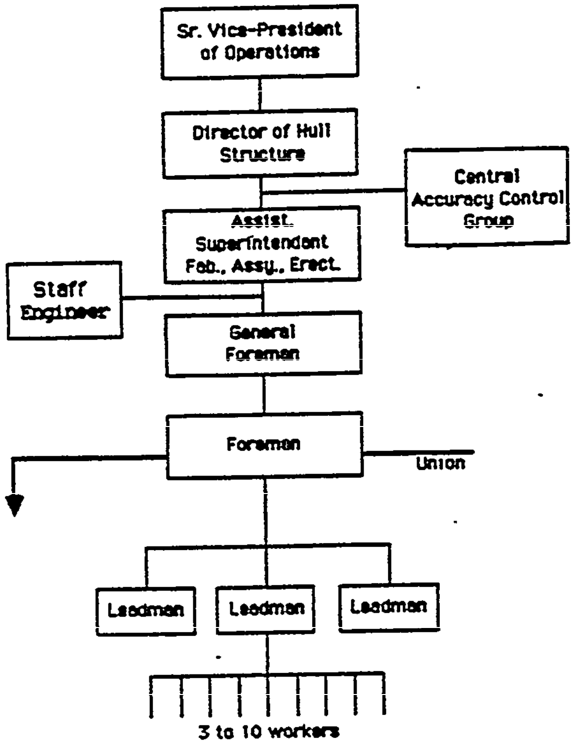

Fig. 4 Initial Organization of Hull Structure Dept.

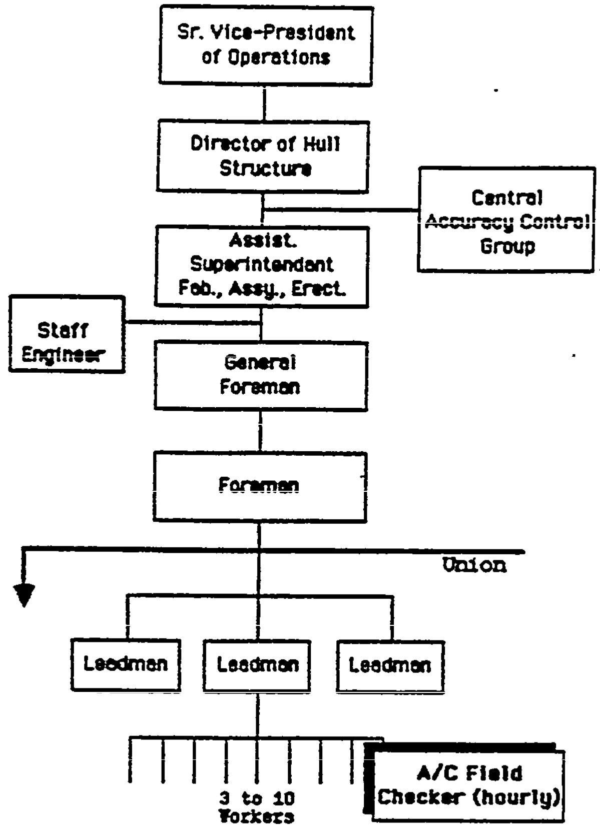

Fig. 5 Present Organization of Hull Structure Department

creased responsibilities of the Field Checker will include plotting the data they collect on histograms, percent defective charts, and statistical control charts. They will also be given the important task of feeding back the results of their data collection to the other members of their workstation during meetings at the start of the shift. In-process checking will remain the responsibility of each hourly employee.

In this proposed evolution, a small central Accuracy Control Department will still exist, but its function will evolve from one of data collection to one of coordination, training, preplanning for future contracts, and analysis of new processes. This group will also develop the vital points for each block type and standard formats for check sheets. Data from the accuracy control Field Checkers will be compiled and published by the Central Accuracy Control Group. Periodic progress reports will also come from this central group. Figure 5 illustrates the proposed supporting organization for decentralized accuracy control.

Education of Management And Direct Supervision

The education of management and direct supervision is one of the most important aspects of any new program. An accuracy control program is no exception.

Just prior to the start of this study, the Sr. Vice President for Operations and the Director of Hull met with all Hull Department Supervision on all three shifts. The Supervisors were asked for their commitment for implementing in-process checking procedures and hourly worker education about vital construction dimensions.

Soon after these meetings the previously discussed Vital Points Booklet was issued by the Accuracy Control Department. A series of meetings was held to distribute the booklets and to educate the supervisors about the vital points to check. Once the supervisors were trained, they were tasked with educating the workers.

In three months, training sessions on control charts were started. Supervisors and hourly workers were trained in the theory and maintenance of XBAR and R Charts. The hourly workers and foremen at the Fabrication workstation learned together how to plot data points on the control chart. At least one foreman seemed embarrassed that he did not understand, and expressed discouragement front of the hourly workers. To eliminate problem in later training sessions, the foremen were trained prior to the hourly workers.

Several times, it was necessary to re-explain to participants on all three shifts that as long as each shift stayed within their respective control limits, it did not matter how their data compared with the other shifts. These explanations helped, but they indicated that the understanding of control charts and control limits was not solid, and was easily forgotten without a periodic re-explanation.

Along with this classroom training, the supervision of Fabrication and Assembly viewed educational video tapes from the Audio Visual Material Available for Shipyard Training Library at the University of Michigan [9)

Just prior to the start of erection on the second tanker, a kickoff meeting was held with supervision assigned to this task. Training included building with the "neat system", fitting strategies to optimize accuracy, excess material plans, and other accuracy control information.

The education of management and supervision is an important process that must precede the training of hourly workers. This illustrated by the success of companies in other industries who have already implemented statistical quality control programs and followed this rule.

IMPLEMENTATION AT HOURLY EMPLOYEE LEVEL

Introduction Of Motivated Factors

Previously referenced literature recommended that a workable motivation factor would increase the interest of the hourly workforce for improving the accuracy of their products. It is a false assumption to believe that motivational factors alone will eliminate worker errors. Through training sessions and discussions it was determined which training methods increased or decreased worker interest in improving the dimensional accuracy of their work process. A summary of these positive and negative factors are Dresented in Table 1.

Table 1. Positive and Negative Motivational Factors

Positive	Negative
Pride in workmanship.	Saving the Company money.
Quality work won't be re-worked later.	Saving manhours.
Checking is part of the job.	Shorten contract duration
Work smarter not harder.	Accuracy is Japanese technology.
Accuracy at earlier work-stations Im-proves working conditions.	
Recognition of accomplishments	

An important motivational factor for inspiring improved performance was frequent recognition of good work. Several articles and photographs have appeared in company newspaper recognizing worker participation and accuracy accomplishments. The Sr. Vice President for Operations also made a personal appearance on all three shifts at the Fabrication workstation to recognize their dramatic improvement in accuracy. A certificate was presented to each shifts' work-team recognizing both workers and foremen.

In implementing accuracy control at the workforce level it was very important to gain the commitment and participation of the foremen. They responded positively to public recognition of good performance by their workstations. Whenever pictures were taken for the company newspaper it was made certain that the foremen were included.

Another way foremen and their supervisors were recognized was through the weekly report issued by the Accuracy Control Department. This report was an important tool that commented on progress at each stage of construction, and presented results of data collection. Whenever possible positive recognition of improvements was made.

One difference between this approach and others is that monetary awards were not introduced to recognize worker suggestions for improving the process.

Establishment of Workteams

A NASSCO workteam is defined as a group of people of one or more trade skills, working together with their supervision to improve their work process. The first workteams of this project were established in the steel Fabrication Shop. The marking and cutting of longitudinal beams to an accurate length was a process selected for several reasons:

1. Data gathering by A/C had been going on for ten months.
2. The process was simple and straightforward.
3. The accurate length of longitudinals was a vital dimension in erecting neat hull blocks.

The first step in establishing the fabrication workteam was to gain the support and understanding of the Assistant Superintendent and General Foremen. The following was requested of them at the onset:

1. Allow for training meetings of hourly workers up to one half hour every week.
2. Encourage self-checking and the following of checking procedures.
3. Work to eliminate causes of error outside the workers control.
4. As much as possible, do not move personnel around, instead, keep them working at one workstation.

The last item was the most difficult on which to reach agreement because management felt there was a strong benefit in keeping burners skilled by working in different areas. It eventfully was agreed that when a new worker was brought from a different workstation he/she would be trained right away in the specific checking procedures and tolerances. Most of the time the same people worked at the workstation. although as the workload shifted, they would be transferred as necessary.

The burning and layout trades were the two groups at the Fabrication workstation. Each group met separately with their foreman for a meeting at the beginning of each shift. This made the establishment of a multi-skilled workteam at morning meetings difficult since other burners and layout people from the rest of the Fabrication Shop also attended the meetings.

It was decided not to isolate the workteam into separate morning meetings because there was only one layout foreman and one burner foreman. The solution was to continue the morning meetings as is, but groups together (about 20 people per shift) when making a presentation about accuracy control. This way, all hourly burners and layout people were Up to speed on A/C implementation. This seemed to work well, and added the benefit of having people already trained if some movement of personnel occurred.

Selection of A/C Targets

It is generally accepted that arbitrary numerical targets set by management are not effective motivators for improvement, and can be very demoralizing to a workteam. Often the targets are unattainable because a large percentage of defects are caused by sources outside the control of the hourly worker (11).

Before setting targets it is first necessary to identify whether the causes of the errors are operator-controllable or management-controllable. Some examples of these two types of errors are:

Management-controllable (Common

- -Poorly maintained equipment
- -Inadequate facilities, poor lighting, unlevel work area
- -Ambiguous work instructions

Operator-Controllable (Assignable Causes):

- -Inadvertant or accidental errors, poor concentration
- -Errors due to lack of technique and training
- -Willful errors

The main use of a statistical control chart (XBAR and Range) is to identify the presence of operator-controllable or assignable causes of error. If a process is operating without any assignable causes of variation and only normal random variation is present, the process is said to be in statistical control or "in control". On an XBAR and Range Chart, if the average of the measurements of a sample are within the upper and lower control limits it can be assumed that the process is in control. Figure 6 shows an example of an XBAR and Range Chart used at the Fabrication workstation.

The upper and lower control limits represent plus and minus three standard deviations around a mean value for the process. These control limits will predict approximately ninety-nine percent of the averaged sample of data points as long as the process remains the same and no assignable causes of error are introduced. Control limits should be calculated after at least 50 individual measurements (e.g. 10 samples of 5 each) have been collected with no assignable causes of error appearing in the data (11).

An important point is that even though the process may be in statistical control, with no assignable causes of error, the percentage defective or percentage out of tolerance may be unacceptable to management. If this is the case, the process needs to be altered and sources of management-controllable (common cause) errors have to be sought out and eliminated. It is also possible that all assignable causes of variation were not removed from the process when the control limits were calculated.

With this basic overview of the use of statistical control charts it can be seen why placing all the responsibility of improving the percentage out of tolerance on the hourly employee will not produce the desired results.

In this study the foremen and hourly workers were asked to stay within the control limits day-to-day, and work together with management to identify sources of error outside the workers control. The target for each shift at the workstation was to refine their work process until the upper and lower control limits fell within the specified tolerance limits such as +/- 1/16 inch. Once this

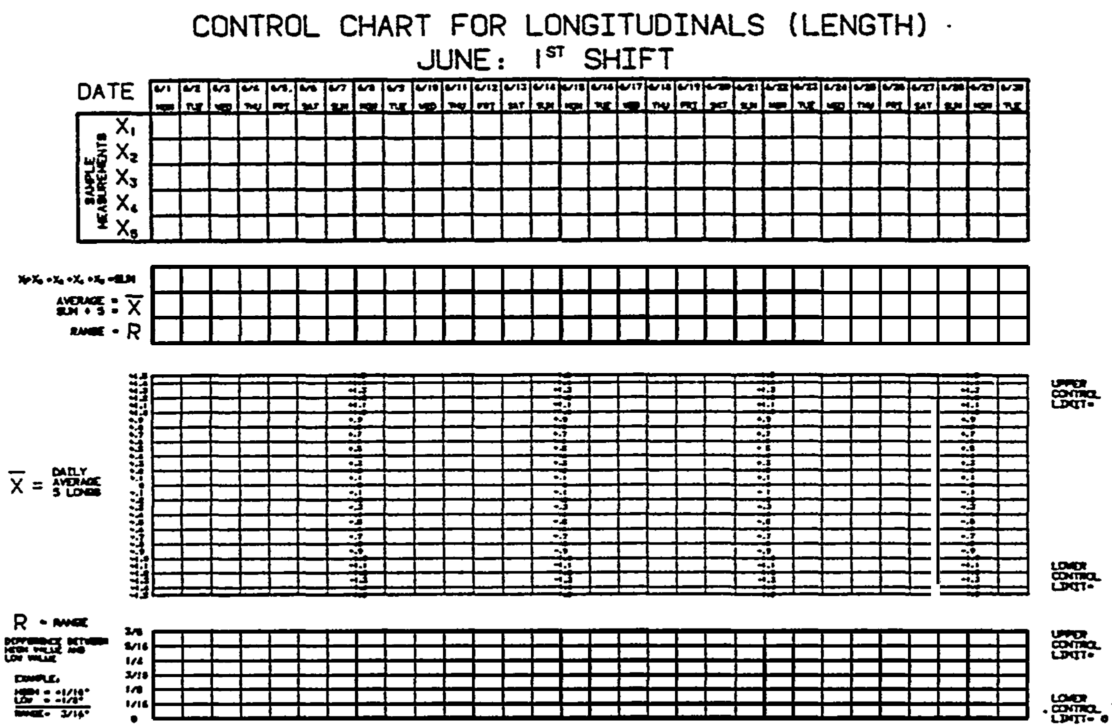

Fig. 6 Example of Control Chart used at Workstation

target was achieved, the small percent that fell out of tolerance would be considered acceptable, although refinement of the process to eliminate more sources of error would continue.

Education of Hourly Employees

Training the hourly employees in checking procedures and in the use of statistical charts was successfully accomplished. Training in checking procedures usually took place at the short meeting at the start of the shift. Written checking procedures were provided along with a graph of recent data describing the workstation's performance to the design dimensions. Many times the hourly employee did not know the standard tolerances for his/her work process. In general they took the data results very seriously, and improvements in accuracy were promptly seen in most cases. Follow-up at the worksite during the day assured that the information presented at the beginning of the shift was fully understood.

For the Fabrication workteam, this introduction to checking procedures and review of tolerances occured four months before the start of this study. During this period, data collected by A/C personnel was presented in the format of a percent out of tolerance chart. These graphs were made for each shift at the Fabrication workstation and discussed at the daily meetings.

Soon after the hourly workers had been trained in the checking methods, the percentage-out-of-tolerance longitudinal dropped sharply and then leveled off, but was still at an unacceptably high level. A statistical control chart analysis confirmed that two of the shifts were in control. The control limits were outside the specified tolerance limits though, which explained the unacceptable percentage out of tolerance. The next step was to encourage input from the hourly workers to identify errors that they did not control. At this time training was provided to the hourly workers and foremen in maintaining control charts on a daily basis. This training by the Accuracy Control Department took place in a training room away from the worksite. Although everyone received hands on experience in the classroom, at first only one person was made responsible for collecting and plotting the data at the worksite.

QUALITATIVE RESULTS: ATTITUDES OF THE PARTICIPANTS

Attitudes of Management

Top management remained committed to training the workforce in vital point and in-process checking throughout the project. Their commitment became apparent when, even as schedule pressures peaked, it was agreed to have one shipfitter at each Assembly work area trained in accuracy control methods. He was responsible for making vital point checks, collecting data, and making corrections as necessary.

Upper management was also an important part of the recognition program for special achievements accuracy improvement. Their participation in recognizing good performance confirmed to the employees company's commitment to accuracy.

Upper management expressed a growing interest in the improved communication the Accuracy Control program generated. They were especially interested in the weekly reports updating progress, which included summaries analyzed data.

Middle Management and Line Supervisible. Initial meetings were held with Assistant Superintendents, General Foremen, and Foremen to discuss basic goals of the decentralizing plan. There was no resistance to this plan but, as schedule pressures increased, these managers were more reluctant to have a skilled shipfitter taken away from his tools to collect data, or to take care of rework. This concern dissipated as the designated shipfitter soon became expert in not only the correct checking procedures, but also in assembly procedures. This made the foremen's job easier because the shipfitter could help instruct the other hourly employees.

Hourly Workforce/Union Response

During implementation, the following opinions were common among the hourly workforce:

1. Most workers were interested in knowing if their workstation was improving.

2. They felt increased pressure from foremen to be accurate.

3. Data collection by A/c personnel made them nervous.

4. For a new person to the workteam, there was anxiety in having to follow a precise checking procedure, and to perform within a tolerance.

Initally Union Representatives expressed concern about requiring the workers to put their initials on their work. The Union felt that this data might be used to reprimand or punish workers with high error rates. It was explained to union shop stewards the use of data to single out workers for punishment would not occur, since it would discourage teamwork at the workstation between workers and supervision.

It is interesting to note that statistical control chart data can actually defend the hourly worker if his/her workmanship is in statistical control, and yet the percentage out of tolerance is unacceptably high to management. This is true since, once a process is in control, errors still occurring are the result of management-controllable (common) causes.

Unexpected Problems or Evolutions

In teaching the employees how to plot their own data on control charts, the theory was taught first, and the mechanics of plotting the data points on the chart second. The theory of normal distribution and upper and lower control limits was not easily understood. This discouraged the participants and increased their apprehension toward learning how to plot the data on a control chart. Fortunately, they did learn the mechanics of how to plot the data, and at later meetings the theory was re-explained to this group. When teaching subsequent groups about control charts, less emphasis was put on teaching the meaning of upper and lower control limits, and more emphasis was put on how to plot XBAR and Range points.

QUANTITATIVE MEASURES AND RESULTS

Measures and Results

Rework is defined as unplanned work to correct inaccuracies, errors, or distortion. These errors can be in fabrication. fitting, engineering, or lofting. The collection of rework data is essential to an accuracy control program. Without this data and subsequent analysis, management cannot identify and correct problem areas.

In a series of ships, it is difficult to assign an improvement in productivity to any one cause. In addition to improved accuracy, savings could be attributed to an experience curve, components of which might be; improved shipwrighting methods, or design modifications. The question then arises, "How successful is the current accuracy control effort?".

At IHI Shipbuilding in Japan, rework is carefully documented, with each process assigned a rework rate.. Through collection of data on rework, an estimate of rework. costs can be calculated and compared for each ship, hull block, or year. Relative improvements made at Erection are measured by comparing percentages of rework in terms of burning or welding footage. Comparison of rework footage (and not a comparison of overall manhours), is the best measure of success for dimensional accuracy control at earlier stages of construction. This method of comparing rework footage was the one adopted by National Steel and Shipbuilding Company. Examples of the formulas used are shown below.

$$(1)\quad \%\ \text{REWORK (BURNING)} = \frac{\text{UNPLANNED BURNING (FEET)}}{\text{TOTAL FEET OF NEAT PLATE EDGE}}$$

$$(2)\quad \%\ \text{REWORK (WELDING} = \frac{\text{UNPLANNED WELDING (FEET)}}{\text{TOTAL FEET OF PLATE EDGE}}$$

When rework data is broken down by block type, equations (1) and (2), can indicate if further analysis of a process is necessary. Figure 7 shows an example of percentage rework data. Each data point represents the percentage of burning rework for a group of six successive longitudinal bulkhead blocks.

To gauge relative improvement at earlier stages of construction, percent out of tolerance charts were kept for each vital point.

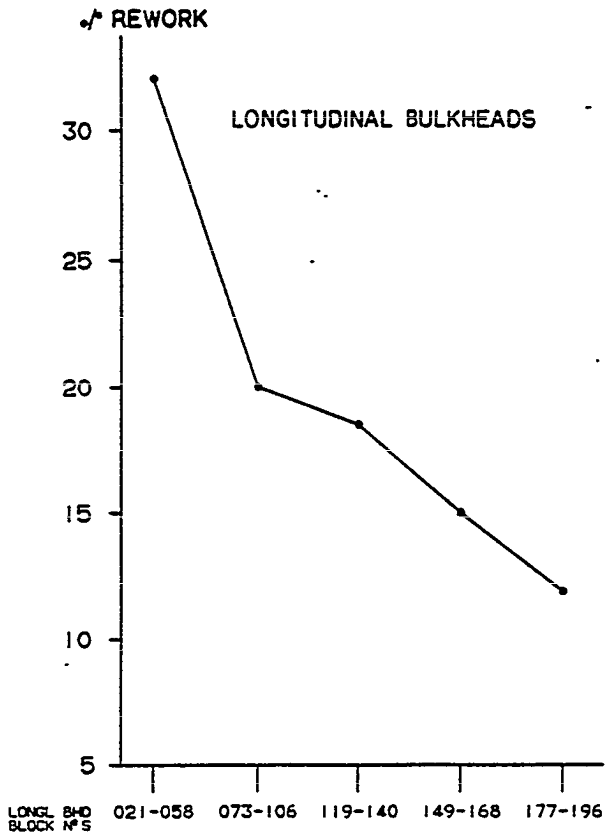

Fig. 7 Rework at Erection (Burning)

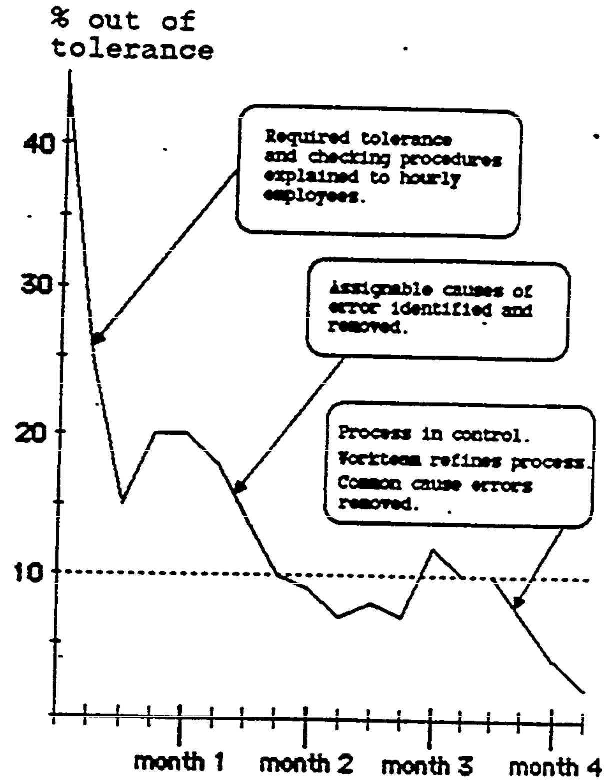

Fig. 8 3 Week Averages of Longitudinal Accuracy (Length)

At the Fabrication workstation a percentage out of tolerance chart documented the accuracy improvements. A distinct decrease in percentage out of tolerance occurred after each phase of the decentralizing methodology. Figure 8 shows the running three week averages of all the data collected at the Fabrication workstation during the first four consecutive months of implementation. All the data shown on this chart was collected by Accuracy Control personnel. This data can be used to determine the savings due to reduction of rework of longitudinal beams.

Methods of Data Collection

The rework data for this study was collected from all the stages of construction.

To reduce the variation in measuring caused by the use of different tape measures, the company supplied each layout person at the Fabrication workstation with the same brand tape measure. Similarly, the same brand of tape measures were provided for the fabrication area burners to check their work, and were also provided to each area in Assembly and Erection. These tape measures were regularly checked for accuracy against a new tape of the same brand.

Standard check sheets and written checking procedures were provided for vital point processes on all midbody blocks. All A/C personnel and Field Checkers were trained to use the same methods of checking. If a checking procedure was modified, each affected workstation would receive a revised procedure.

Check sheets were filled in by Accuracy Control Technicians or hourly Field Checkers. This checking took place in the Assembly area, before the block was released to Erection. The completed checksheets were forwarded to the Accuracy Control Department to be analyzed. Feedback of problems and trends were addressed through the appropriate production management channels, such as the weekly Accuracy Control Report, posted data, and meetings with workers.

At Erection, data was collected and rework was recorded on a shell expansion drawing. This information was then transferred to data sheets for later analysis. The data collected consisted of unplanned trimming, welding, and plate inserting. The Foremen, Planners, and Staff Engineers at Erection participated in this data collection. Accuracy Control then collected the data sheets for analysis and feedback to earlier stages of construction. The Hull Planners were, later given the responsibility collecting the data, and became the equivalent of a Field Checker at Erection.

Factors Affecting Rework At Erection

Many factors affect the amount of rework at Erection at any given time. Some of those factors include schedule pressure, worker experience level, fitting procedure. During the tanker contract the manpower level in the yard increased significantly. Most of this increase came in the form of trainees. These trainees had to be instructed on vital points, and fitting procedures. During this time the trainee to journeyman ratio approached fifty percent.

The shipwrighting strategy of the Erection Department also affects rework. This strategy evolved throughout the tanker contract. Early in the contract, emphasis was placed on erecting each block individually, and very accurately. Halfway through first hull, more emphasis was placed on erecting hull blocks as a group of neat blocks, correcting for any variation at an "excess" butt. This new strategy contributed to the decrease in rework at erection.

SUMMARY AND CONCLUSIONS

This paper has described the three phase methodology used by National Steel and Shipbuilding Company to decentralize the Statistical Accuracy Control responsibility to the hourly workforce. The methods included in-process and vital point checking procedures, data collection, and plotting data samples on statistical control charts and histograms.

The measure of success of this the reduction of rework in the erection of hull blocks in the midbody of two 209,000 DWT tankers. A method for calculating reduction of rework at erection was presented. The lowering of percentage out of tolerance of interim processes at earlier stages of construction was also considered a successful indicator of improved accuracy. A chart of actual data collected after each phase of implementation illustrated significant improvement in dimensional accuracy.

1. Process lanes and standard assembly procedures are prerequisites to decentralizing the statistical accuracy control responsibility to the ship production workforce level.
2. Visible commitment from upper management throughout the implementation of this accuracy control program was important to the success of decentralizing.
3. It was important to gain the support and understanding of supervision early in the program.
4. A large decrease in percentage defective occurred immediately after the hourly workers were taught the correct checking procedures and the desired tolerances.
5. A second and third large decrease in percentage defective occurred after assignable and common causes of error were removed.
6. Positive feedback. and recognition from upper management was important to the participating supervisors.
7. Quick response to hourly worker and foreman suggestions was helpful in building a team spirit for continual improvement.
8. Honest collection of data by hourly workers, was not a problem as long as the workstation was being monitored by Accuracy Control personnel.
9. First shift at the Fabrication workstation collected and plotted their own data. The other two shifts had their data collected and plotted by A/C personnel. There was no significant difference in the accuracy of the three shifts.
10. The hourly workers and their union did not make any protest to the added job responsibilities of collecting and plotting data on an XBAR and Range chart.

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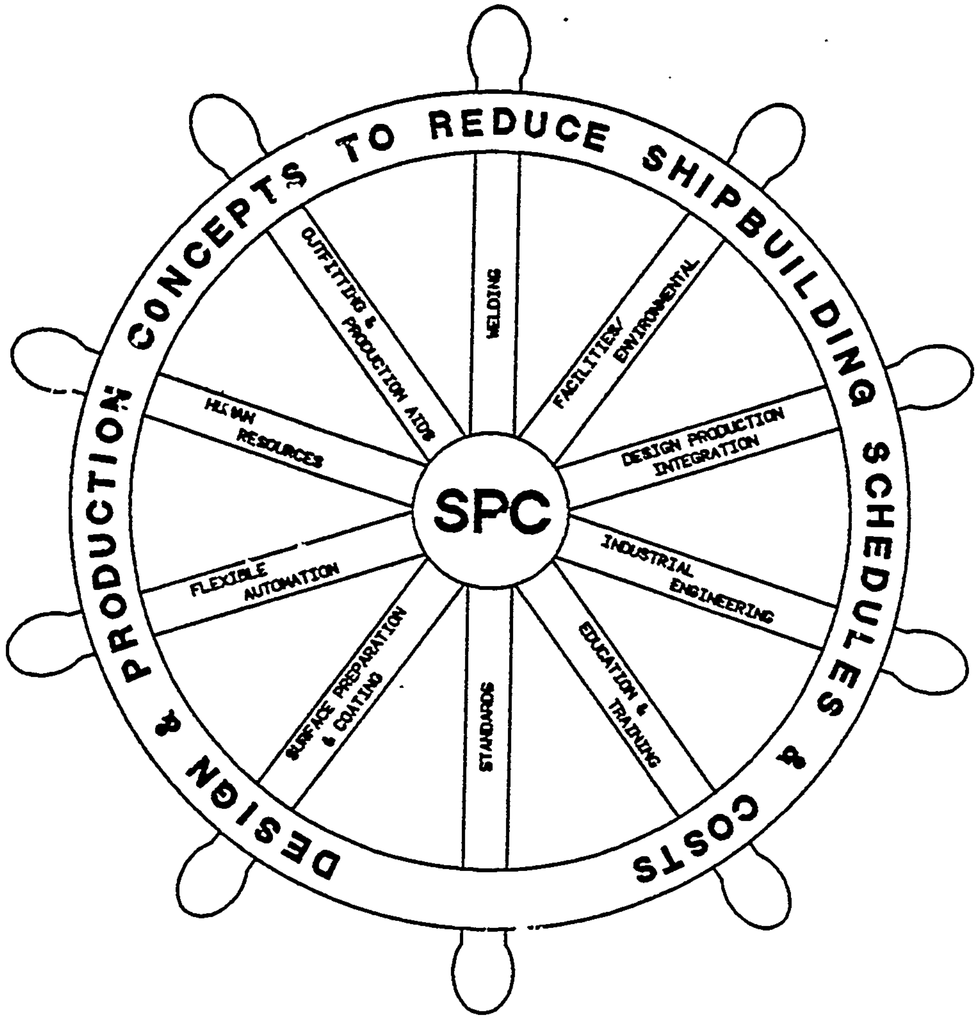

PAPER NO. 6

COMPARISON OF THE CONSTRUCTION PLANNING AND MANPOWER SCHEDULE FOR BUILDING THE PD214 GENERAL MOBILIZATION SHIP IN A U. S. SHIPYARD AND IN A JAPANESE SHIPYARD

BY: HOWARD McRAVEN BUNCH

SYMPOSIUM SPONSOR:
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AUGUST 27-29, 1986

COMPARISON OF THE CONSTRUCTION PLANNING AND MANPOWER SCHEDULE FOR BUILDING THE PD214 GENERAL MOBILIZATION SHIP IN A U. S. SHIPYARD AND IN A JAPANESE SHIPYARD

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The University of Michigan

ABSTRACT

The study compares the construction planning and manpower schcdnles for production of five PD214 general mobilization ships at Avondale Shipyard New Orleans, and at Kawasaki Shiyard, Kobe, Japan. As background for the comparison an examination was also of the facilities and eqipment in place at each at yard

The analysis indicated that Avondale has approximately 25 timcs more area than does KHI-Kobe. However, at Avondale the typical movement of material travels a ditionstance that is typically five times greater than at KHI-Kobe.

Kawasaki goes into the erection squence with smaller blocks than does Avondale. There were a total of 250 erection units specified by KHI; Avondale's count was ony 209 erection units.

Over-all KHI's delivery period for the ship was 60 weeks after contract signing: Avondale's construction schedule for the first ship is 140 weeks after contract. The differences are related to construction philosophy, lead time requirements for material and productivity..

The manloading for building the five ships is consistently greater in every phase of construction at Avondale than at Khobe. The overall difference is about 232 times (1374 thousand manhours at Avondale versus 594 thousand manhours at KHI-Kobc). The greatest difference by functional area was in planning, engineering, and mold loft where the combined total for the five ships was 1010 thousand manhours at Avondale (202 thousand per Ship) and 190 thousand manhours at KHI-Kobe (38 thousand per ship).

The over-all conclusion of the study is that the differences in productivity found in comparing the two yards are primarily traceable to the organization of work. Fixed facilities have little impact on the differences that exist

1.0 INTRODUCTION

1.1 Background

In 1978 the U. S. Maritime Administration (Marad) releascd preliminary plans, specifications, and design considerations for a general mobilization ship, commonly known as the PD214. The ship was designed for rapid construction in large quantities in event of a national emergency. The ship was also designed so that it could be configured for a wide variety of missions with a minimium of redesign

Marad decided to use one of the new designs as a mechanism for better understanding the ship production planning and construction methodologies employed overseas. Accordingly, in 1980 a contract was signed with Kawasaki Heavy Industries KI of Japan to provide detailed construction and manpower expenditure schedules for the construction of five of the PD214 ship Kawasaki uscd their Kobe yard as the basis for the planning estimates. [1][1]

The Kawasaki study indicated significant production manhour differences from what was projected by Marad as necessary to build the Ship in United States yards. This differences resulted in Marad deciding to support a second study similar to the Kawasaki report but based on a U.S. shipyard production system. In 1983 The University of Michigan Department of Naval Architecture and Marine Engineering, was given a contract [2] to develop the construction and manpower expenditure schedules for fiVe of the PD214 Ships at Avondale Shipyard New oOrleans. Avondale was selected as the shipyard for which the schedules and estimates Would be prepared for several reasons. Avondale was one of the first yards in the United States to commit itself to emplacing advanced production techniques, and has produced Ships utilizing these concepts (product-work-breakdown–structure and zone outfitting, for example):. Importantly, Avondale indicated a Willingness to partcipate in the projec and supported efforts of the study team in the collection and of sensitive information. Additionally, Avondale gave its approval to the consultant retention of a retired senior official of the company, Mr. Charles K. Starkenburg, formerly vice-president of production planning.

The base line ship for which both Studies was conducted was the PD214 general mobilization ship described in the 1978 Marad report [3], with the following options: multi-purpose design, jumbo Option with steam tubine, main propulsion plant cargo cranes, and a slewing stern ramp. Separatc production schedulcs and manpower allocations were preparcd for the following variations to the base desigm (1) medium speed diesel plant **(2) slow-speed diesel plant, and (3) 30-ton booms and kingposts**

The Avondale study was structured to be as much like the Kawasaki study as possible. The study assumptions were the same. However, there were instances where it was not possible to have complete identity. One instance was time. The Kawasaki Study WaS prepared on practices in place at the Kobe yard in 1980, with a contract signing on January 1, 1980. The Avondale study, on the other hand,was based on practices in place in 1983,with a contract signing on January 1,1983.

Some might argue that the three-year difference in when the Ships Were to be built would invalidate the Comparisons. The two major factors compared were constructions schedules and manhours consumed Neither of these factors arc subject to the time distortions of inflation (or deflation) in the same way as the purchasing power of a monetary unit For the two primary factors

[1] Numbers in brackets esignate reference at end of manuscript

that were considered, time would only impact changes in productivity. And the tbree-year productivity improvement for Kawasaki was considered relatively minor when compared with the gross productivity differences between the two yards even without the time adjustment.

The production plans and schedules were prepared on the basis of the following assumptions:

a. the construction contract was signed on the final day of the business negotiations;

b. the engineeeing working drawings for the ship were complete and available to the shipyard at signing of the contract;

c. five ships of the PD214 (Jumbo) clss were ordered in the contract: all were identical;

d. the total shipyard facility was shipyard facility avai/able to construct the five ships, and no existing contracts or follow-on work would impact the PD214 SChedules;

e. purchase orders for equipment, materials, and supplies would be issued subsquent receipt of the contract;

f. the five ships would be consecutively constructed in each shipyrd's main facility.

This paper is the summary of the results of at a third study[4]to evaluate the earlier works, and to make meaningful comparisons. The project was supported by the U.S. Maritime Administration under its university research program. The support of Marad is gratefully acknowledged. Likewise, the patience and understanding of the contract technical monitor, Mr. Fred Seibold, is also gratefully acknowledged.

Figure 1.1 shows the inboard profile view and the main deck of the PD214 (Jumbo) ship. Table 1.1 is a list of the appropiate laws and classifications that would apply to construction of the PD214. The complete description of the ship, with options is contained in Reference [3].

Table 1.1

LIST OF APPROPRIATE.LAWS AND CLASIFICATIONS THAT WOULD APPLY TO CONSTRUCTION OF THE PD214

- –ABS Classification Rules + AIE+E+AMS
- –U.S. Coast Guard, including International Rules of the Road
- –USPHS Publication #393 (Sanitation) and PB161019 (Ratprooing)
- ---SOLAS Convention 1974
- –USCG Panama Canal and Suez Canal Tonnage Certificates
- –Panama Canal Company Regulation
- –Suez Canal Company Regulation
- –IEEE #45
- –Federal Communication commission
- –ABS Cargo Gear Requirements
- –USDL Safety and Health Regulation for Longshoring

Source References [1] [2]

1.3 Study Structure

The study was divided into the three phases. First there was a detailed comparison of yards' facilities. Then there was a comparison of construction methods, and the factors that affect any differences. Finally, there was a comparison of time and manhour budgets for each of the production activities. A final section draws general concULsions from the study comparisons.

2. FACILITYS COMPARISON

2.1 Land and Buildings

Table 21 presents the square footage tallies for the different facilities for the two yards. Avondale has nearly 319 thousand square feet for prefabrication and fabrication operations; KHI has about 84 thousand feet dedicated for service.Avondale's availabilty is 3.8 time that utilized KHL

For the assembly operations Avondale again utilizes significantly more Space than does KHL As Table 21 shows, ASTs sub-assembly operations comprise 113 thousand square feet while KHI's sub-assembly activities require only 68 thousand to square feet. This is a difference of 1.7 times in favor of Avondale.

Thefinal assembly operations have 441 thousand square feet of space; KHI utilizes only 140 thousand square feet Avondale dedicates over three times as much to this production activity as does KHL

The erection space use is 422 thousand square feet at ASI and only 230 thousand square feet at KHI. There is a ratio difference of 1.8:1.

Overall, Avondale production facilities encompass about 1,294 thousand square feet and KHI facilities cover 522 thousand square feet. The difference is significant in that KHTs space use is only 40 percent of Avondale's.

In Table 22 there is shown the weather protection afforded each yard's production facilities.The information reveals KHI has cover protection of some type at every construction area; only the storage is in the open. Avondale has less extensive cover structure. Interestingly, the weather protection is provided at the yard with the more moderate of weather conditions; KHI has less rain than does ML and the average temperature is more comfortable at Kobe than in New Orleans.

Table 23 details the distances material must travel as it passes through the production process. In developing this table the analysts utilized the production lane classification system followed by Avondale. Depending upon the type of block being manufacture the travel distance is 6 to 15 times greater at Avondale than at KHI-Kobe. The greatest difference, interestingly, is for the high-volume units (flat block,or category #1) where KHI-Kobe has a movement distance of 420 to 480 feet and ASI has a typical movement distance of 7040 feet.

Tables 2.1, and 2.3 show, convincingly, the compactness and protection of the IC131-Kobe facilities, especially when compared with a typical American Shipyard.

2.2 Shipyard Equipment

The comparisons of the shipyard equipment are shown in Tables 2.4 and 23. The first, Table 2.4, describes the crane equipment available at each yard. As seen, each yard has a variety of crane types. At Avondale, the predominant type is the bridge crane, whereas the overhead crane dominates at KHI-Kobe. The whirley crane is the type found in the largest numbers at both yards.

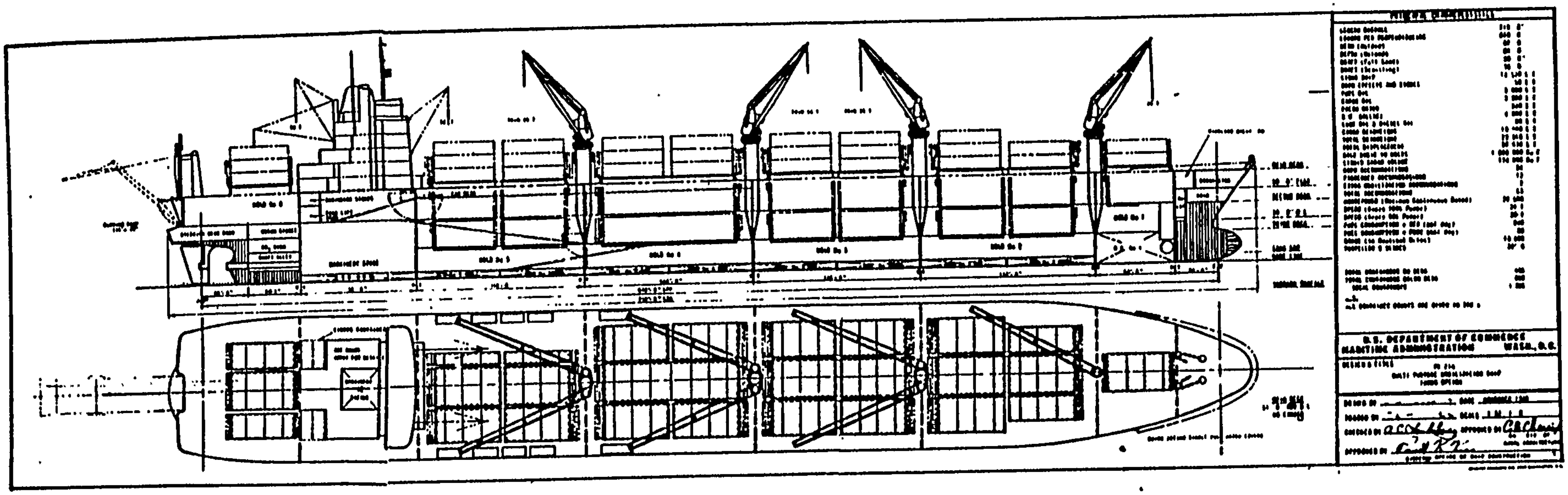


Figure 1.1 INBOARD PROFILE AND MAIN DECK VIEWS FOR PD214 GENERAL MOBILIZATION SHIP

TABLE 2.1
DESCRIPTION OF PRODUCTION FACILITIES AT TWO SHIPYARDS

ASI Area/Shop	ASI Square Feet	KHI Area/Shop	KHI Square Feet
	—FABRICATION—		
Plate shop	178,000	Shop #2P	42,910
T-beam shop	27,700	Shop #3P	23,000
Platen 23	32,500	Shop #4P	17,600
Platen 24	32,500		
Platen 16	48,100		
Sub-Total	318,800		83,510
	—SUB-ASSEMBLY—		
Platen 8	6,750	Shop #2P	18,390
Platen 9	8,000	Shop #3P	23,000
Area 307	14,400	Shop #4P	26,400
Platen 17	51,350		
Platen 20	32,200		
Sub-Total	112,700		67,790
	—ASSEMBLY—		
Platen 8	20,250	Shop #10K	11,800
Platen 9	24,000	Shop #1B Mid	23,700
Area 307	43,200	Shop #3B Mid	17,200
Platen 10	50,600	Shop #3B Fore	8,600
Platen 13	48,400	Shop #3B Aft	17,200
Platen 14	48,100	Yard Fore	14,000
Platen 19	33,800	Yard Aft	23,700
Platen 20	104,800	Shop #5K	11,800
Platen 25	38,000	Shop #5B	11,800
Platen 26	30,000		
Sub-Total	441,150		139,800
	—ERECTION—		
Upper yard	421,800	Berth #4	140,800
		Berth #7	89,600
Sub-Total	421,800		230,400
SHIPYARD TOTALS	1,294,450		521,500

Source: References [1] [2]

TABLE 2.2
WEATHER PROTECTION OF PRODUCTION FACILITIES AT TWO SHIPYARDS

ASI Area/Shop	ASI Status	KHI Area/Shop	KHI Status
	—FABRICATION STAGE—		
Plate Shop	Covered	Shops #2P, 3P, 4P	Covered
T-Beam Shop	Covered	Steel Yard	Open
Blacksmith Shop	Covered	Shop #5P	Open
Sheetmetal Shop	Covered	Shop #6P	Open
Steel Yard	Open		
	—SUB-ASSEMBLY AND ASSEMBLY STAGE—		
Platens 8, 9, 10, 11, 13, 14, 16, 17, 19, 20, 23, 24, 25, 26 and Area 307	All Open	Shop #5B	Sliding Covers
		Shop #1B	Sliding Covers
		Shop #3B	Sliding Covers
		Shop #5K	Sliding Covers
Platen 19	Partially Covered	Assy Yard	Sliding Covers
		Shop #10K	Covered
	—ERECTION STAGE—		
All Facilities	Open	All Facilities	Open
	—OTHER FACILITIES		
Pipe Shop	Covered	Pipe Shop	Covered
Support Services	Covered	Support Services	Covered
Paint and Blast	Covered	Paint and Blast	Covered
Warehouses	Covered	Warehouses	Covered

Source: References [1] [2]

TABLE 2.3
TRAVEL DISTANCE IN FEET FOR PRODUCTION BLOCKS
AT TWO SHIPYARDS

Production Unit Classification (ASI definition)	ASI	KHI
Flat Panel Units (Category #1) Mid Parts Double Bottoms Side Shell Longitudinal BHDS	7040	420-1120
Curved Shell Units (Category #2) Aft & Fore Parts Side Shells	2880	430
Superstructure Units (Category #3) Decks Flats Bulkheads Houses, etc	2840	650-740
Fore Peak and Aft Peak Units (Category #4) Large and Heavy 3-Dimensional Units	2880	430
Engine Room Interbottoms (Category #5) Large and Heavy Intricate Units	4580	420-1120
Special Units (Category #6) Skegs Rudders Bulbous Shapes Stern Castings	3060	420-1120

Source: Calculated

TABLE 2.4
CRANE INVENTORY OF ASI AND KHI-KOBE
(Number)

Crane Type (using ASI def.)	ASI # based on capacity >50 tons	ASI # based on capacity ≤50 tons	KHI # based on capacity ≥50 tons	KHI # based on capacity ≤50 tons
Bridge Cranes	31	4	—	—
Overhead Cranes	13	3	27	3
Peg Leg Cranes	8	—	1	—
Whirley Cranes	—	12	6	8
Locomotive Cranes	4	1	—	—
Mobile Cranes	—	2	—	—
Magnetic Cranes	3	—	—	—
Hoists	—	—	14	—
Hoisting Cranes	—	—	8	—

Source: References [1] and [2]

TABLE 2.5
SUMMARY LIST OF PRODUCTION EQUIPMENT
AT
TWO SHIPYARDS

Equipment	ASI #	ASI Maximum Capacity	KHI #	KHI Maximum Capacity
1. Burning Machines				
--N.C.	4	3-axis by 2-axis 36"bed by 12" thick	1	plate 3600mm by .2
--Triple bevel flame planer	2	12" wide by 12" thick	--	
--Deflange burning	1	8" wide	--	
--Optical line burning	1	8" wide	--	
Flame Planer	3	55' by 22' table	1	2800mm wide
Parallel cutting machine	--		1	2200mm by 1200mm
2. Marking Machines				
EPM	--		1	10X magnification
3. Shears	7	1.4" be 14'	--	
4. Presses	10	120ton	--	
5. Forming Equipment				
--Bending rolls	11	4-1/2" by 39"	1	11.5 M by 30mm
--Press brakes	13	3/4" steel, 2000T	9	1000T hydraulic
--Forming Presses	2	5000tons	--	
--Frame Bender	1	700 tons	2	300 tons

Source: References [1] [2]

Table 2.5 describes the other types of equipment found at the yards. On balance both yards seem to have about the same maximum capacity in their equipment. There are some types of equipment found at one yard, however, that is missing at the other. Most notable is the electro-plate marking (EPM) equipment found at KHI-Kobe, but which is absent from the ASI equipment list. This difference is a national difference; all yards in Japan use the EPM process in the fabrication marking; no yards in the United States have the process.

By contrast, ASI has plasma burning equipment, and KHI-Kobe has none. Again, this difference is almost a national difference. Most U.S. yards use the equipment, while most Japanese yards do not.

On balance, there is no significant difference in the equipment capacities in the two yards. Both yards have sufficient equipment, both in size and in number, to be approximately equal in production output. There are some isolated differences that impact production philosophy. The most notable example is the crane capacity found at the erection docks. Avondale has whirley cranes whirley cranes with 160-ton lift capacities on their upper building ways. KHI-Kobe, has jib cranes with only 120-ton limits on their building ways. This difference in lift capacity is reflected in the number of required erection lifts.

A final difference is the consistency of the levels of capacity at each production level. KHI-Kobe appears to have more of a consistency of capacity at each of the areas than does ASI. As one Japanese manager explained, "we go to great lengths to fine-tune our equipment capacities, and to make sure that all stages are in 'harmony'".[5]

3. COMPARISON OF CONSTRUCTION METHOD

3.1 Unit Block Breakdown

There are differences in the location of the unit between the two yards. At the KHI-Kobe yardthe maximun size is 46 feet in length by 36 feet in breadth. The mid-ship is divided as follows :

A) Double bottom units include three rows :
   1) Center line double bottom units.
   2) Starboard outboard double bottom units.
   3) Port outboard double bottom units.
B) Wing Tank Units :
   1)Port/Starboard wing tank units innerbottom to second de
   2) Port/Starboard wing tank units from secor main deck.
C)Longitudinal/Transverse Girders.

There were a total of 240 hull blocks specified by the planners with 108 being "single" block units, and 132 "double" block units. (A single block unit is one with only of plating. The side shell with attached webs would be a block unit. A double block is one with two sets of platin double-bottom unit with the bottom shell and inner-bottom would be a double unit. It requires about 1.5 times the worl to manufacture a double unit as compared with a single

In addition to the 240 hull units, there are 10 super st units, adding up to a total of 250 hull units for the ship.

All the blocks are grouped into categories based upc similarity of block shape. The assembly work for each block is then scheduled in relation to the erection sch

AVOUdale planners would have specified a block division as follow

A) Double bottom units:
   1) Center line double bottom_
   2) Port/Starboad double bottom units.
B) Wing Tanks
   1) Port/starboard tank between inner bottom
   2) Port/Starboard wing tanks between second and
C) Longitudinal/Transverse Girders.

Total number of blocks, including superstructure, was 209. In general, the largest blocks are 48 feet in length by 42 feet in breadth. All the blocks are grouped into categories based upon the Similarity fo block shape. The assembly work for each block group is then scheduled in relation to the erection schedule.

3.2 Methods of construction on Building Ways

At KHI-Kobe each assembled hull unit is erected on assembly berth using a jib crane installed at both Sides of the berth. The starting block for erection sequence is the engine room double bottom block for the reason of maintaining the shaft center sighting schedule and considering the amount of work involved in the engine room. The remaining bottom blocks are then erected in regular Sequence fore and aft Of the engine room. when all the blocks are erected fore and aft of engine room, the bow is first erected upward prior to all other block mountings, followed by erecting the remaining blocks inregular sequence to make the hull form. The shaft center sighting is carried out one (1) month before launching, because it takes about one month to load and install the main engine and to fit the propeller and rudder.

All Upper deck block and deck house blocks Up to boat deck levelare erected and welded b y the time of the shaft center sighting to maintain the tolerances. The blocks around the hatches are finished as quickly as possible due to the early start of outfitting work. To increase the erection speed the side shell and adjacent decks are together into one block and then erected on berth.

The main advantage of this type of Construction is the short duration required to accomplish hull erection (three months). There are other reasons, though. relieve storage pressure accuracy control and facilitates outfitting in the forepeak ares.

To relieve storage pressure, the yard stack the blocks (about 30 percent of the total number of blocks are built before keel is layed). Since the easiest block to store are the double bottom units, the yard stores the double bottoms by stackingMng units utilizing the minimum of storage space.

KHI-Kobe engineers maintain that accuracy control is also improved by laying the double bottoms as quickly as possible. Accuracy is improved because the double bottoms contain the key centerline dimension, and also are part of the length dimension. With the double bottoms in place and surveyed, any deviations or errors in other block coming to the erection site are quickly identified and corrected.

At Avondale each assembled hull unit is erected on the building ways using whirley cranes. The starting block is the engine room double bottom unit From the engine room several double bottom units are erected. Then the lower and hold units are erected on top of the double bottoms. The remaining bottom blocks are then erected in regular sequence fore and aft of the engine room followed by the hold, internal members, stern, fore and deck units to make the hull form.

Shaft center sighting is carried out during the second month after keel when the stem unit is erected This facilitates the early start of the work necessary to install main engine and propulsion shafting system. At the same time, early shaft sighting requires necessary precautions to be taken to avoid hull distortion when stem deck iand super structure units are erected amd fully welded. All units are erected individually except for the super structure in which case more than one unit can be assembled together and the complete unit is erected a grand assembly.

Avondale's type of construction is designed to erect hulls of more than one ship at a time. Avondale feels comfortable in handling construction of more ships at a time on one building area Inspite ofhaving storage area, ASI does not store many units before laying keel Only 12 percent of the total number of blocks are built before keel is layed.

ASI prefers to hold the ship on the building ways after the completion of the erection schedule and finish as much work as possible, which would otherwise be done after (early) launching alongside quays.

Since ASI works simultaneously on more than one ship, there is a need to move hulls during the construction stage from one location to another. The building ways are designed to handle such Situations.

Even though both yards utilize the process lane construction concepts, there arc differences in the category descriptions. KHI-Kobe divides the ship into 13 categories, plus the superstructure, shown in Figure 3.1. Avondalc has six construction categories Figure 3.2 presents the ASI divisions. Examination of the two figures shows that ASI makes their divisions more consistently with the classic group technology concepts; KHI however, has a strong geographical orientation in their division definitions.

Figure 3.3 compares the status of erection between the two yards at identical times keel.The differences in erection sequences for the two yards are evident . Likewise,KHTs faster erection speed becomes evident

3.3 Subcontracting

The activities that are subcontracted at KHI-Kobe include scaffold erection,tack-weld assembly, welding, piping and sheet metal outfitting, painting, accommodations carpentary and joinery, and insulation work Avondale, on the other hand rarely subcontracts its labor activities. At KHI-Kobe about 60 percent of its painting manhours are subcontracting labor. However, there is a long-term trend downward for this percentage because of the increasing use of robotics. KHI-Kobe also subcontracts a significant portion of its pipe outfitting typically, about 30) percent would be placed outside the shipyard.

Regardless of where the work is done -interally, or through SUb-COntractor~-KHI-KObe includes the Subcontractingcosts in its own manpower estimates. This reflects the close working relationships that exist between the yard and its sub-contravtors.

3.3 Material Purchasing

At Avondale purchased material is acquired in group lots, but allocated against unit and zone areas. The maerial is received and stored by overall material family groupings by groupings by job and purchase order number. Using the unit and zone pre-outfitting lists as reference, the material is pallcretized at the warehouse in accordance with croft type. The material control section calls up a given pallet for work release within two to four weeks of the scheduled work date. By controlling the release of the material to the work site, it is possible to monitor the progress of a specified work systcm.

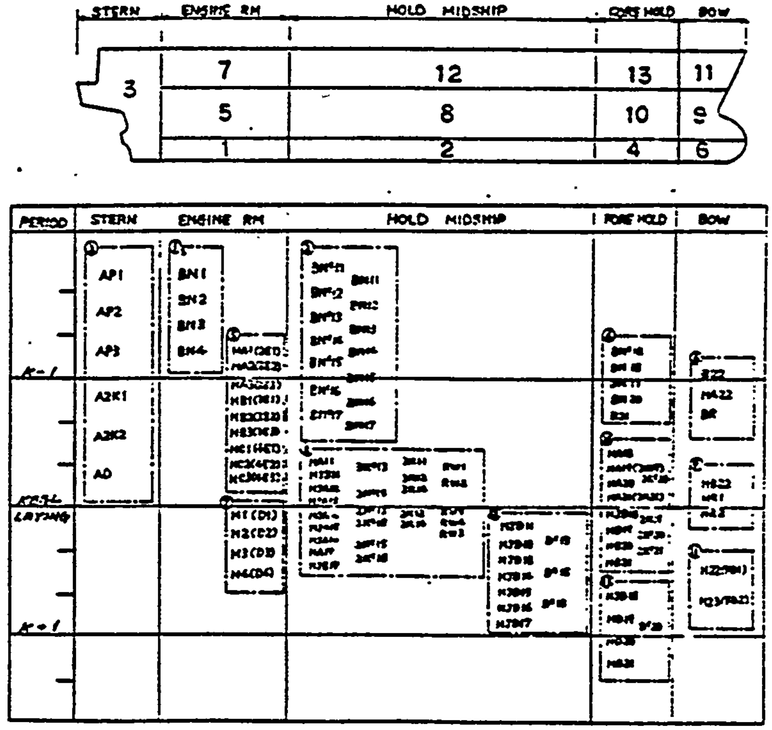


Figure 3.1 SHIP'S HULL CONSTRUCTION CATEGORIES FOR KAWASAKI-KOBE YARD

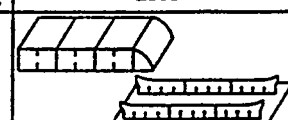
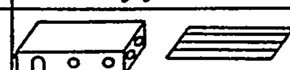
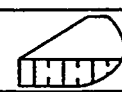
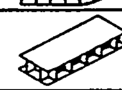
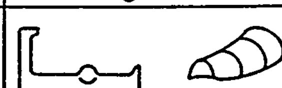
CATEGORY	UNIT NAME	PLATEN SUPPLYING FABRICATED PARTS	SHAPE	ASSEMBLY PLATEN
No. 1 FLAT PANEL UNIT	MID PART DOUBLE BOTTOM SIDE SHELL LONG BHDS	23 24		20
No. 2 CURVED SHELL UNITS	AFT & FORE PART SIDE SHELLS	16		17
No. 3 SUPERSTRUCTURE UNITS	DECKS FLATS BULKHEADS HOUSES ETC.	16		8 9 11
No. 4 FORE PEAK AFT PEAK	LARGE AND VERY HEAVY 3 DIMENSION UNITS	16		10 13 307
No. 5 ENGINE ROOM INNER BOTTOMS	LARGE AND HEAVY INTRICATE UNITS	16		14 307
No. 6 SPECIAL UNITS SKEGS RUDDERS ETC.	BULBOUS SHAPES STERN CASTINGS	18		19

Figure 3.2 SHIP'S HULL CONSTRUCTION CATEGORIES FOR AVONDALE SHIPYARD

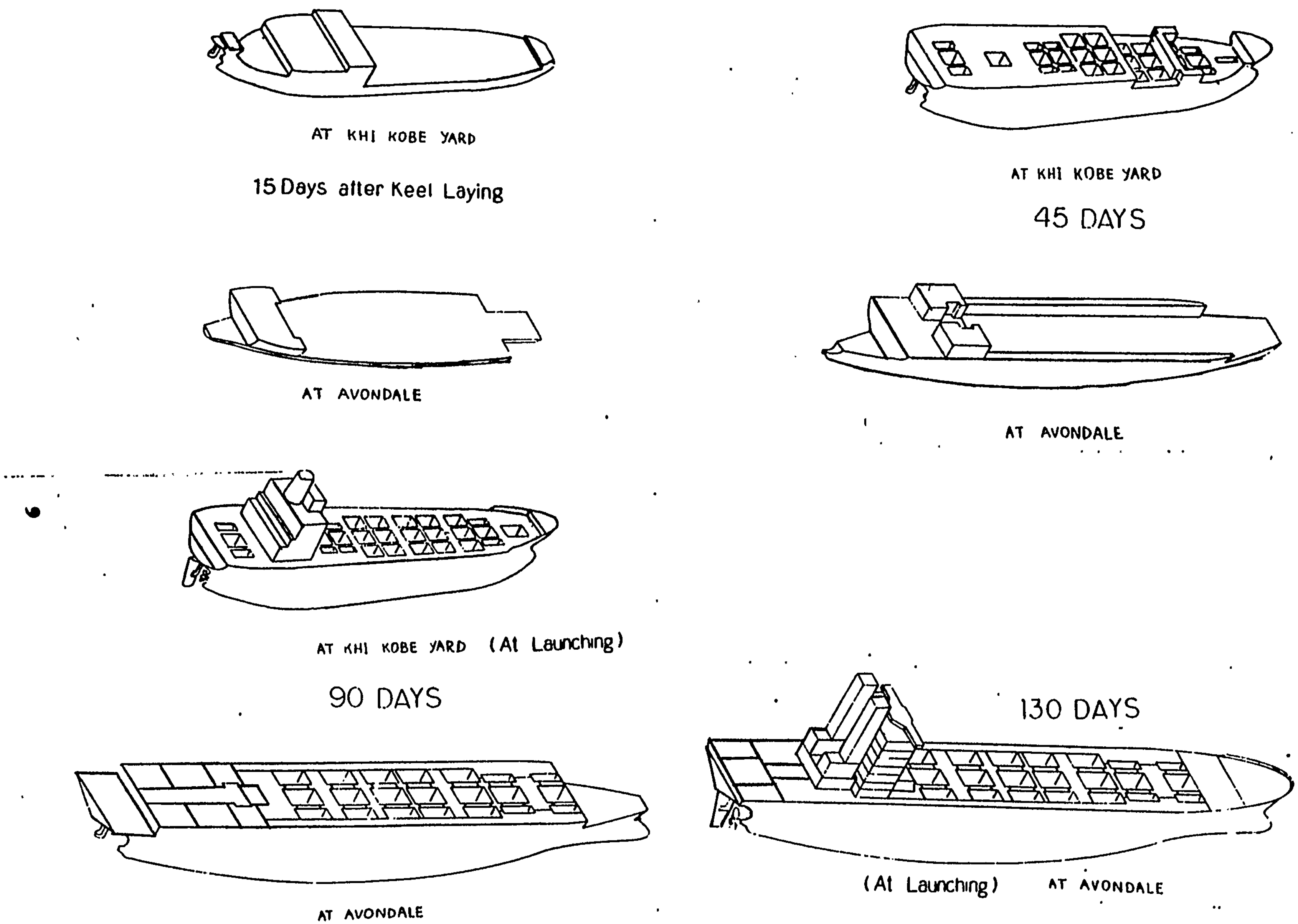


Figure 3.3 HULL ERECTION STATUS OF PD214 AT SPECIFIC POINTS IN TIME AFTER KEEL LAYING FOR AVONDALE AND FOR KHI-KOBE

Avondale requires much greater time than does Kawasaki to procure major material and equipment. This means ASI has longer lag between contract signing and the start of construction. The longer lag delays the delivery of a ship. The major milestone of laying keel (dates) depend largely on the lead time requirements of key equipment. Both yards, ASI and KHI, based their keel laying date for the PD214 on the procurement of the boiler. Lead times are determined from the date of issue of purchase order and the time of delivery of equipment in the yard. In case of Avondale, the lead time for the boiler is 14 months. Whereas, in the case of Kawasaki, the lead time for the boiler is only eight months.

Other lead times for the major items at each of the shipyards are shown in Table 3.1, shown below.

TABLE 3.1

LEAD TIME IN MONTHS FOR OUTFIT MATERIAL

EQUIPMENT	ASI	KHI
A/C Unit	13	4
Deck Cranes	15	6
Deck Machinery	14	9
Hatch Covers	14-	6
Steel Plates	8	2
Main Valves	12	4
Rudder	9	8
Slewing Ramp	13	7
Stern Casting	9	6
Auxiliary Machinery	12	9
Main Boiler	14	8
Bridge Console	15	8
Control Console	15	8
Electric Generator	8	8
Main Condenser	15	7
Main Reduction Gear	14	10
Main Turbines	14	10
Propeller	15	5
Propeller Shaft	6	5
Steering Gear	12	10

Source: Reference [1] [2]

Comparing the two yards, it is obvious that the lead time requirements of Avondale are much greater than Kawasaki's requirements. Figure 3.4 shows, graphically, the major milestone schedules for delivery of the first ship for the two shipyards whith the presently existing lead time requirements. Also, illustrated is a modified milestone schedule for Avondale if it were to have the same lead time support from its vendors as does KHI-Kobe. The improvement in ASI's delivery schedules would be 22 weeks (16 perecnet) if the company had the same vendor delivery support as does KHI.

Table 3.2 is a comparison of the duration times for the major production activity sectors--fabrication, assembly, and erection--between the two shipyards. As seen, there is a n consistent difference between the two; Avondale's span activity is 2.4 to 2.6 times that of KHI-Kobe. With sector,though, as there is considerable variation. In the fal area, for example, the time from start-to-finish of the engi material is about 3.5 times that of KHI-Kobe (17 weeks weeks). Fabrication of material for the hold units, th nearly the same for the two yards: 16 weeks for Avondal 13 weeks for KHI-Kobe. Similar differences exis assembly activities and in the erection activities.

On balance it appears that for the more complicated are bow, engine room, stern--Avondale requires mor proportionally, than does KHI-Kobe. This is consiste KHI's approach of concentrating on the fabricating, assen and erecting one or two units at once; whereas, Avc philosophy is to work on 3 or 4 units at a time, and to sp work over a longer period

4.0 COMPARISONS OF PRODUCTIVITY

In comparing the man-loading estimates for the two shi there was first the requirement that the line-item group consistent. Hull work at Avondale, for example, only i that production work and supervision related to actu construction. It does not include moldloft, working dr cranes, production planning and engineering, or the misce services needed by the hull craft workers. Conversely, a above items are considered part of the hull work at KH differences in categories required that adjustments be mac figures contained in the two basic studies.

In addition to the internal rearrangement of man-hou were two instances where additional hours had to be adde estimates that were presented in the basic KHI study. approximately 50 thousand manhours for costs of basic modifications had to be added to the KHI estimates. personnel assummed that there would be no need for an design modifications from the contract drawings; Avondale other hand, followed the assumption that all contract drawin be corrected and changed before production drawing prep can proceed. The adjustment makes the classification com the adjustment estimate was supplied by KHI during p interview.)

The second major adjustment was in the area of insulat KHI all of this work is done by subcontractor. The KH allowed for material used by the subcontractor, but did not subcontractor's labor.

Table 4.1 shows the comparison for the five ships a adjustments, and the categories are approximately the same. first ship's budget at Avondale was estimated at 1.834 man-hours. The budget at KHI-Kobe was 710 th man-hours, or 39 percent of the Avondale estimate. Bec the heavier front-end loading by Avondale to cover the engi man-hours, the differences narrowed between the two y subsequent ships. The budget for the fifth ship in the seri set at 1.235 million man-hours, and 537 thousand man-h KHI-Kobe. The latter estimate is 44 percent of the Av budget.

Avondale's improvement for the follow-on ships was than KHI-Kobe's in absolute values, the same was true basis of percentage improvement. As Table 4.2 shows, KH projected that the second ship would have a total ma expenditure of about 85 percent of the first ship; the estir the same ship at Avondale was about 71 percent of the fi

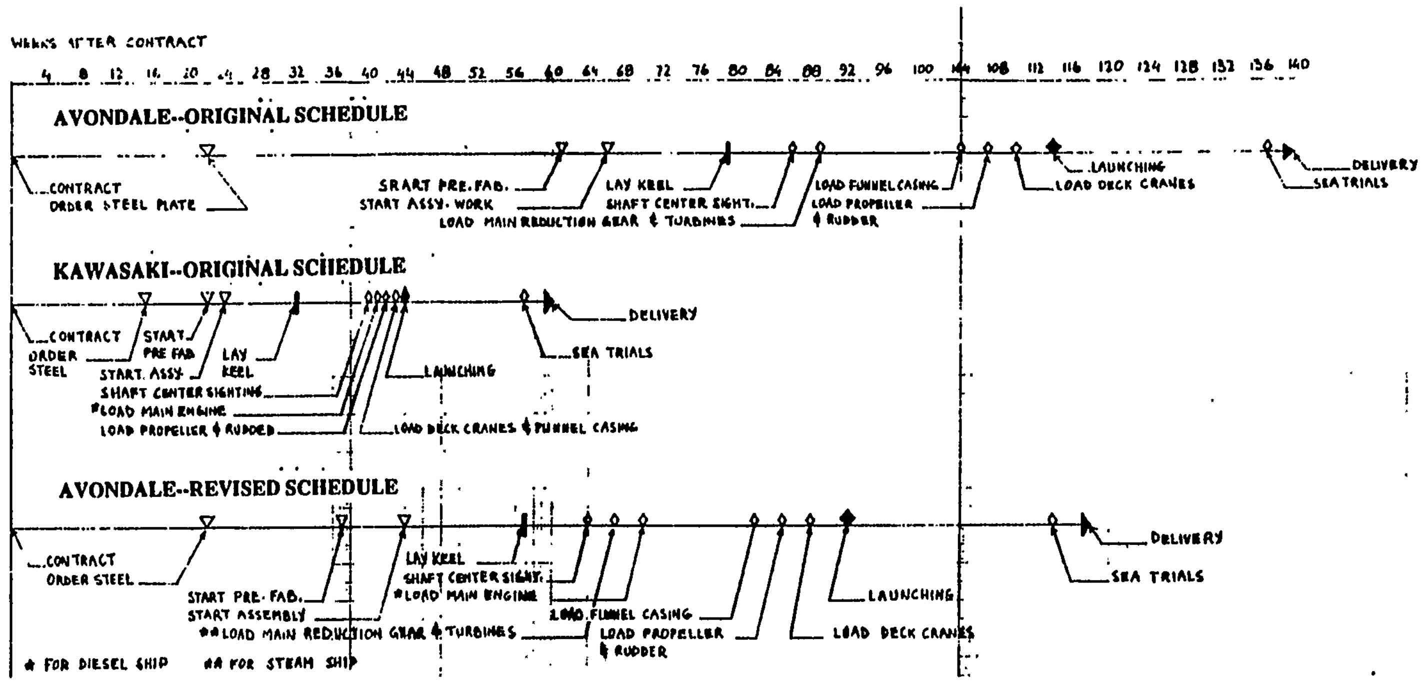


Figure 3.4 MAJOR MILESTONE SCHEDULES FOR FIRST SHIP

TABLE 3.2. COMPARISON OF PRODUCTION ACTIVITY DURATIONS BY SHIP'S SECTION

	----PRODUCTION ACTIVITY (Weeks Duration)----								
	--Fabrication--			---Assembly---			----Erection----		
SHIPS AREA	ASI	KHI	Ratio	ASI	KHI	Ratio	ASI	KHI	Ratio
Engine Room	15	5	3.5	18	5	3.6	12	5	2.4
Holds	16	13	1.2	17	13	1.3	11	8.5	1.3
Fore Holds	21	6.5	3.2	24	6.5	3.7	16	8	2
Stern	18	6.5	2.8	22	7	3.1	17	3.5	4.9
Bow	18	6.5	2.8	20	7	2.9	15	3	5
--Average--	18	7.5	2.4	20.2	7.7	2.6	14.2	5.6	2.5

Source: Reference[1][2]

However, when only production manhours is considered, percentage reduction is the same for both yards; the second ship budget was 96 percent of the lead ship costs. In fact, the comparative production manhours improvements were essentially the same for all of the ships in the series,with the percentage difference never being greater than one percent for any specific ship.

There is major improvement for both yards from the first to the second ship when only the engineering, planning, and mold loft activities are considered. Avondale, for example, needs only 18 percent of the man loading on the second ship as necessary for the first. KHI-Kobe's improvement, though not as dramatic, was nevertheless significant: 31 percent of the first ship effort is all that is required for the second ship. Improvements continue throughout the series; however, the rate of improvement was better at KHI-Kobe than at ASI.

Avondale has a slightly better improvement curve for its hull activities, as a total, than does KHI-Kobe. The budget for the second ship is 76 percent of that required for the first at Avondale; the improvement was 82 percent at KHI-Kobe. The same relative difference occurred for the rest of the series.

Avondale's comparative improvement was also better in the outfitting area. Its budget for the second ship was 66 percent of the first; KHI-Kobe's budget was 87 percent of the first. Again, the same relative difference occurred through the series.

Tables 4.3 and 4.4present budget comparisons by major production classifications for the two shipyards for the first ship, the fifth ship, and the average for all five ships. Table 4.3 shows the budgets broken into hull and outfitting activities, but further sub-divided into production activities and into design-planning-mold loft activities. Several conclusions can be made from this table. The first is that there is little change in total production budget relationships between the two yards from the first through the fifth ship: KHI-Kobe requires only 47-48 percent of the manpower necessary at Avondale to build the first ship, or the fifth ship, or all of the ships. But Avondale does better, comparatively, in the outfitting production activities. In this activity, KHI's productiion man hour needs goes up to 51 percent of Avondale"s.

As seen in Table 4.4 several isolated areas in outfitting show Avondale's productivity very close to KHI-Kobe. The major category of piping-fabrication-assembly shows that ASI has the same manloading requirements for all five ships as does KHI-Kobe. This area was for the entire study, Avondale's brightest point, and showed the contribution that the automated pipe shop has made to its overall productivity. The inference can be made that ASI is competitive with any yard in the world, or close to it, in this activity.

The better comparative position of Avondale in outfitt offset by its poorer comparative position in hull pro activities. In this area, KHI-Kobe's production requiremer only 43 percent of Avondale's on the first ship; the dif remained essentially the same throughout the five-ship serie

Without a doubt, KHI''s strongest comparative perfo was in the area of design, engineering, planning, and mo Here, KHI's budget for the first ship was 122 thousand compared with Avondale's projected budget of 601 th hours. While the absolute difference is reduced(on a p basis) as the series is built, there continues to be maj budget differences, and significant relative difference completion of the contract, the total resource requiren Avondale is over one million hours, for an average of 202 t hours for each of the five ships. The comparable fig KHI-Kobe is a total need of 190 thousand hours, or 38 th hours per ship for each of the five ships.

5.0 CONCLUSION OF THE STUDY

The first conclusion of the study is that there are productivity differences between an advanced U.S. shipbuil a typical Japanese shipbuilder. The overall difference is over 2:1 in favor of the Japanese yard, with a wide spread o side of this overall comparative relationship for the functional areas. There are instances where the American approximately competitive; the most important activity wa fabrication and assembly of piping for outfitting. The U.S poorest comparative performance is in the categ design-engineering-planning-mold loft. The difference is to the fact that the Japanese yards have developed conc standardization and modularization that permit a large portio design and engineering activities to be essentially the retr the documentation from files. The standardization is forward into the production areas where the facili specifically designed to deal with standardized production n

While there are some differences in the production fac the Japanese shipyard and the U.S. shipyard, these differe not the major causes for the wide productivity spread. In U.S. yard, in several instances, had more advanced pro facilities; the automated pipe shop is one example. example is the extent of integration of CAD/CAM i production environment; Avondale was further advance area than was KHI-Kobe. KHI-Kobe still utilizes optical

	---FIRST SHIP--		---SECOND SHIP--		---THIRD SHIP--		---FOURTH SHIP-		---FIFTH SHIP---		--5SHIP AVG--	
	ASI	KHI	ASI	KHI	ASI	KHI	ASI	KHI	ASI	KHI	ASI	KHI
HULL ACTIVITIES												
Cut and Fabrication	107	34	103	33	101	32	100	31	99	31	102	32
Sub assy and Assy	135	95	130	92	127	89	126	87	126	86	129	90
Erection	219	96	211	93	207	90	205	88	204	87	209	91
Production Engineering	48	13	5	5	5	3	4	2	4	0	13	5
Mold Loft	54	32	52	12	51	6	51	4	50	1	52	11
Cranes	56	16	55	15	54	15	53	15	53	15	54	15
Miscellaneous	44	2	43	2	42	2	41	2	41	2	42	2
SubTotal	663	288	599	252	587	237	580	229	577	222	601	246
Design Engineering	148	23	15	5	14	1	13	0	13	0	41	6
TOTAL HULL ACTIVITIES	811	311	614	256	601	238	593	230	590	223	642	251
OUTFITTING ACTIVITIES												
Piping, Fabrication, and Assembly	125	116	115	112	110	109	108	107	106	106	113	110
Machinery Fab and Assy	49	35	48	34	47	33	47	32	47	32	48	33
Electrical Fab and Assy	60	31	56	30	54	29	53	29	52	28	55	29
Sheet Metal Fab and Assy	64	23	62	22	61	22	60	21	60	21	62	22
Insulation	29	24	28	23	27	23	27	22	27	22	28	23
Painting	107	44	103	42	102	41	101	40	100	40	102	42
Fitting and Outfitting	143	56	139	54	136	53	135	52	134	51	137	53
Testing	32	2	31	2	29	2	28	2	28	2	30	2
Cranes for Outfitting	14	1	14	1	13	1	13	0	13	1	13	1
Services and Unallocated	50	13	49	13	48	12	47	12	47	12	48	12
Outfitting Production Engineering	86	26	8	10	8	5	8	3	8	1	24	9
Subtotal	758	371	653	343	635	329	627	320	622	315	660	336
Design Engineering	265	28	26	6	25	1	23	0	23	0	72	7
TOTAL OUTFITTING ACTIVITIES	1023	399	679	348	660	330	650	320	645	315	732	343
TOTAL MANHOURS	1834	710	1293	605	1261	569	1243	550	1235	537	1374	594

TABLE 4.1 KHI/ASI 5 SHIP COMPARISON (IN THOUSANDS OF MANHOURS)

Production Category	1ST	2ND	3RD	4TH	5TH
	----ship of series (%of first ship manhours)----				
Engineering, Planning, and Mold Loft					
ASI	1	0.18	0.17	0.16	0.16
KHI	1	0.31	0.13	0.07	0.02
All Production Activities					
ASI	1	0.96	0.94	0.93	0.92
KHI	1	0.96	0.94	0.92	0.91
Total Hull Activities (Incl. Eng)					
ASI	1	0.76	0.74	0.73	0.73
KHI	1	0.82	0.77	0.74	0.72
Total Outfitting Activities (Incl. Eng)					
ASI	1	0.66	0.65	0.64	0.63
KHI	1	0.87	0.83	0.8	0.79
TOTAL MANHOURS					
ASI	1	0.71	0.69	0.68	0.67
KHI	1	0.85	0.8	0.77	0.76

TABLE 4.2 EXPERIENCE CURVE ANALYSIS FOR FOLLOW SHIP. (Percent of 1st ship's manhours)

	-----FIRST SHIP-----			-----5SHIP AVERAGE-----			-----FIFTH SHIP-----		
	ASI	KHI	RATIO KHI/ASI	ASI	KHI	RATIO KHI/ASI	ASI	KHI	RATIO KHI/ASI
TOTAL PRODUCTION ACTIVITIES, ONLY	1233	588	0.48	1172	556	0.47	1137	535	0.47
DESIGN, PLANNING, AND MOLD LOFT	601	122	0.20	202	38	0.19	98	2	0.02
HULL PRODUCTION ACTIVITIES, ONLY	561	243	0.43	536	229	0.43	523	222	0.42
HULL DESIGN, PLANNING, AND MOLD LOFT	250	68	0.27	106	22	0.21	67	1	0.01
OUTFITTING PRODUCTION ACTIVITIES ONLY	672	345	0.51	636	327	0.51	614	314	0.51
OUTFIT DESIGN, PLANNING, AND MOLD LOFT	351	54	0.15	96	16	0.17	31	1	0.03

TABLE 4.3 KHI/ASI PRODUCTION COMPARISON FOR THE FIRST, FIFTH, AND AVERAGE OF FIVE SHIPS (IN THOUSANDS MANHOURS)

	-----FIRST SHIP-----			-----5SHIP AVERAGE-----			-----FIFTH SHIP-----		
	ASI	KHI	RATIO KHI/ASI	ASI	KHI	RATIO KHI/ASI	ASI	KHI	RATIO KHI/ASI
HULL ACTIVITIES									
Cut and Fabrication	107	34	0.32	102	32	0.31	99	31	0.31
Sub assy and Assy	135	95	0.70	129	90	0.70	126	86	0.68
Erection	219	96	0.44	209	91	0.44	204	87	0.43
Production Engineering	48	13	0.27	13	5	0.38	4	0	#DIV/0!
Mold Loft	54	32	0.59	52	11	0.21	50	1	0.02
Cranes	56	16	0.29	54	15	0.28	53	15	0.28
Miscellaneous	44	2	0.05	42	2	0.05	41	2	0.05
SubTotal	663	288	0.43	601	246	0.41	577	222	0.38
Design Engineering	148	23	0.16	41	6	0.15	13	0	#DIV/0!
TOTAL HULL ACTIVITIES	811	311	0.38	642	251	0.39	590	223	0.38
OUTFITTING ACTIVITIES									
Piping, Fabrication, and Assembly	125	116	0.93	113	110	0.97	106	106	1.00
Machinery Fab and Assy	49	35	0.71	48	33	0.69	47	32	0.68
Electrical Fab and Assy	60	31	0.52	55	29	0.53	52	28	0.54
Sheet Metal Fab and Assy	64	23	0.36	62	22	0.35	60	21	0.35
Insulation	29	24	0.83	28	23	0.82	27	22	0.81
Painting	107	44	0.41	102	42	0.41	100	40	0.40
Fitting and Outfitting	143	56	0.39	137	53	0.39	134	51	0.38
Testing	32	2	0.06	30	2	0.07	28	2	0.07
Cranes for Outfitting	14	1	0.07	13	1	0.08	13	1	0.08
Services and Unallocated	50	13	0.26	48	12	0.25	47	12	0.26
Outfitting Production Engineering	86	26	0.30	24	9	0.38	8	1	0.13
Subtotal	758	371	0.49	660	336	0.51	622	315	0.51
Design Engineering	265	28	0.11	72	7	0.10	23	0	#DIV/0!
TOTAL OUTFITTING ACTIVITIES	1023	399	0.39	732	343	0.47	645	315	0.49
TOTAL MANHOURS	1834	710	0.39	1374	594	0.43	1235	537	0.43

TABLE 4.4 KHI/ASI PRODUCTION COMPARISON FOR THE FIRST, FIFTH, AND AVERAGE OF FIVE SHIPS (IN THOUSANDS MANHOURS)

and cutting processes; Avondale, on the other hand, is nearly totally committed to numerical-controlled marking and cutting.

KHI-Kobe has a better organized flow of material, and has long utilized the process lane concepts of construction. Avondale has only recently implemented process lane construction, and was, at the time of the study, continuing to switch over to the concepts. It is expected that some of the productivity differences described in this study will be significantly reduced as the process lane construction program is completed and the process is stablized.

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[2] "Construction Planning and Manpower Schedules for Single Screw, Multipurpose Mobilization Ship, PD214, in Cooperation with Avondale Shipyards, Inc., New Orleans" performed by Department of Naval Architecture and Marine Engineering, University of Michigan, Ann Arbor., U. S. Department of Commerce, Washington, D. C., February, 1985. 156 pages.

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#7

NAL SHIPBUILDING RESEARCH PROGRAM
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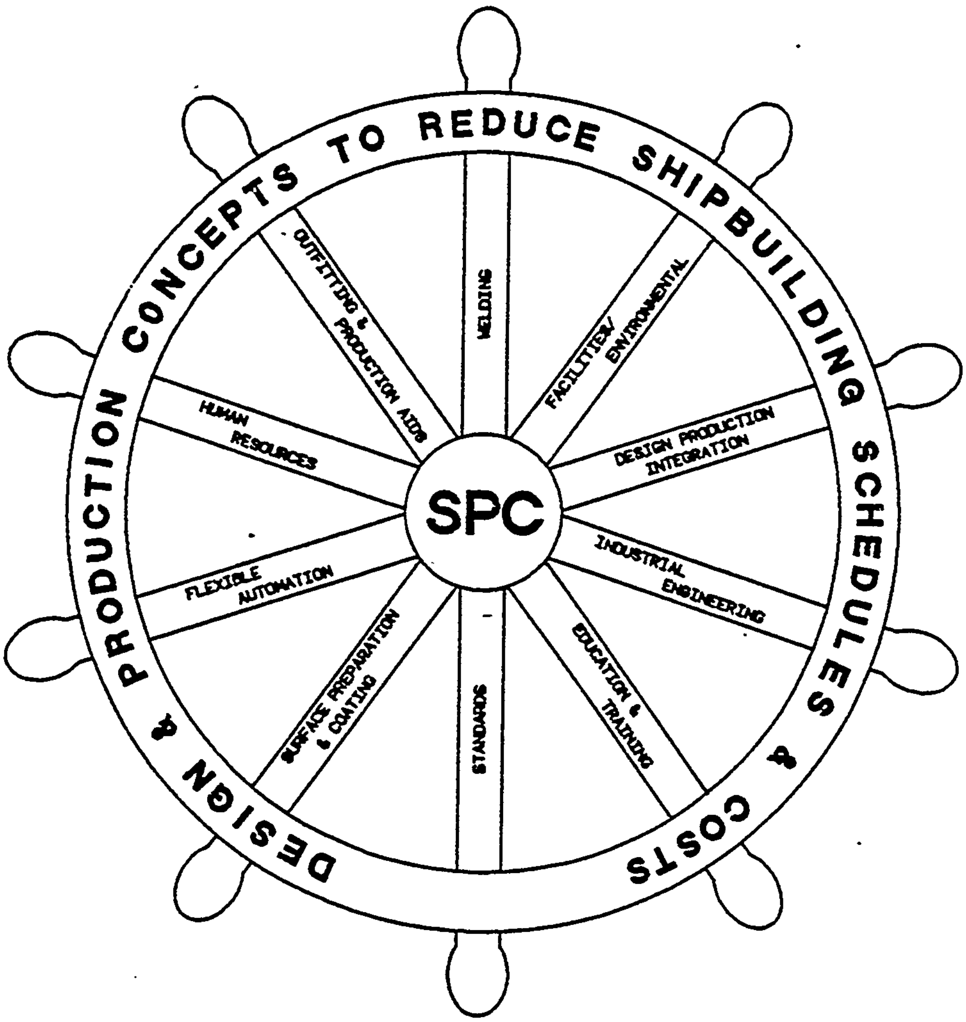

PAPER NO. 7

THE STREAMLINING OF NAVY PROCUREMENT SPECIFICATIONS

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AUGUST 27-29, 1986

1986 SHIP PRODUCTION SYMPOSIUM

73869

THE STREAMLINING OF NAVY PROCUREMENT SPECIFICATIONS

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INTRODUCTION

The Department of Defense has instigated a number of initiatives to reduce the time, risk, and costs associated with developing, producing and maintaining weapon systems. These initiatives are not stand alone policies, but have definite interrelationships that need to be addressed and developed into a cohesive policy. This paper provides a brief discussion of some of these initiatives and how they have been implemented in various shipbuilding programs. We, the authors, hope that some of our forecasts for future acquisition techniques will stimulate discussion and lead to the development of the cohesive acquisition policy that the Navy requires.

BACKGROUND

Streamlining. A very current, stylish word, although the public would not necessarily associate it with Government acquisition. Streamlining is one of several major Government initiatives to cut the cost and lead time of weapon system acquisitions. As a by-product it will also lead to increased accountability for both Government and industry. Department of Defense Directive 5000.43 of 15 January 1986 is the latest and highest level document requiring the application of streamlining in DOD acquisitions. This directive amplified the policies set forth in both Deputy Secretary of Defense Taft's Memo of 3 June 1985 and Assistant Secretary of the Navy (Shipbuilding and Logistics) Mr. Everett Pyatt's Memo of 8 August 1985. Streamlining includes any action that can be taken that will reduce the cost and time to develop, test, and field a weapon system. Initial efforts were aimed at streamlining solicitations and contract requirements, but now are being extended into technical specifications and other requirements documents. Implementing streamlining may not be that difficult since many of the mechanisms required are already in place within the Navy.

Concurrent with the efforts to decrease acquisition cost and time came the media reports of overpriced spare parts, overly detailed specifications and the notorious three foot specification pyramid to make an ashtray. To counteract these problems, other initiatives within the Government procurement hierarchy have been developed. BOSS was initiated to identify the true source for some parts to eliminate the costly stocking of third party spares. This program will result in calling a 3/8 inch fastener/remover/installer, Brand X part number 38SRBW, a Craftsman 3/8 inch box wrench. The cost savings in stocking, ordering and procuring cost effective quantities are in the millions.

The Specification Improvement Program has been instituted within the Naval Sea Systems Command (NAVSEA) to ensure that the procurement documents used for acquisition are technically correct and compatible with today's rapidly changing technology. This is an enormous undertaking as NAVSEA has responsibility for preparing approximately 8500 different documents. Concurrent with keeping the documents technically correct, NAVSEA must ensure that the cost of the administrative and contractual requirements of the specifications and drawings are not in excess of the benefits derived.

NAVSEA has also exhibited strong support for using commercial standards for procuring non-combat related equipments and materials. NAVSEA is an active supporter of the ASTM F-25 Shipbuilding Standards Committee as evidenced by NAVSEANOTE 4121 of 31 Oct. 1985 which has directed the use of applicable commercial specs and standards and encouraged NAVSEA engineers to participate in technical and administrative committees. Office of Management and Budget Circular A-119 made it national policy for federal agencies to cooperate with voluntary industry standards writing bodies in developing industry standards that can be used in the federal procurement process. Using industry standards in lieu of federal procurement specifications also lessens the document maintenance burden on the Government.

The Specification Elimination and Reduction (SPEAR) project is another initiative in the Naval Supply Systems Command (NAVSUP). This project has taken a different approach towards identifying excessive specification requirements. NAVSUP personnel are reviewing the price of spare parts for items that appear to be excessively costly. They are then reviewing the procurement documents to determine what technical requirements are responsible for the high cost of the spare part. Some reviews have determined that there was not necessarily a hard Government requirement for the cost and complexity of the part, but rather either a slightly overzealous contractor or Government technician invoking requirements to make it better rather than just good enough.

The programs q mentioned so far have dealt with the acquisition of equipment and spare parts. But how is the Navy dealing with streamlining for bigger items, such as ships? Streamlining ship acquisitions involves many of the same requirements as streamlining any other acquisition: the involvement of competent concerned production contractors on the team with Government personnel who are capable of assuming reasonable business risks in the procurement cycle.

As George Santayana once wrote, "Those who cannot remember the past are condemned to repeat it." The Navy has taken a number of different approaches to obtain shipbuilder involvement during the preliminary and contract design phases of ship acquisition recent years. All of these efforts have provided valuable lessons and useful feedback for the next ship acquisition project to use that procurement approach. Streamlining, in a manner that is both effective and palatable to engineering community, is an evolutionary procedure.

The Mine Sweeper/Hunter (MSH) is a design developed competitively by industry based on high-level Navy performance requirements. The program used many streamlining techniques before they were officially required. The technical package for this design evolved over a period of time frog the 6overnment-imposed top-level requirements to more conventional contract design packages developed by the competing prime contractors. During development process, standard Navy technical documents such as the General Specification were provided for use as baseline documents, but the prime Contractors were given direction to tailor their respective packages to suit their design parameters and solutions. Similar approaches, using a Circular of Requirements (COR) to define requirements and have competing shipyards develop contract packages, are being used for the acquisition of commercial type ships such as the T-AVB and the T-AGS. One limitation in the process is the qualitY of baseline or framework documentation available to aid the shipyards in developing the contract design package. The MARAD developed Standard Specifications for Merchant Ship Construction are outdated and not compatible with what the largest customer (the U.S. Navy) expects. The Navy's General Specification is heavily biased toward the construction of surface combatants and it is difficult for a shipyard oriented towards commercial ship acquisition packages to be able to determine exactly where and how far they can deviate from the specified requirements. The T=AKR program first used this type of approach except the Navy performed an integration effort of all the shipyard design proposals to obtain a consolidated design package. This package was the one for the final competitive acquisition among all participating shipbuilders.

One problem that emerged from this effort was the fact that the Navy had not really and design criteria shipbuilding standards criteria were normal practice and which were absolute nondeviation requirements. HAVSEA has initiated the development of Ship Design Standards to define the nondeviation standards and the rationale behind them so that they can be tailored in special cases for unique problems encountered. We anticipate that any future contractor-developed or contractor-aided procurement packages have to address these standards as a part of design development.

The DDG 51 design effort employed a different technique involving shipbuilders in the contract design package development process. This was basically the Ship System Design Support (SSDS) contract used previously on program such as LSD 41 and MCM 1. Prospective shipbuilders were given contracts to provide design support and provide technical comments during the Navy controlled design effort. The shipyard personnel performed special studies, reviewed and commented on the specifications and drawings and participated in integrating the technical package. NAVSEA received the benefits of early shipyard inputs on producibility and detail design concerns that enabled the package to be n edified to- eliminate nonproductive and overly restrictive and costly requirements.

The Board of Inspection and Survey (INSURV) was also included in the design review team. The LHD 1 program was the first ship acquisition program to involve INSURV during the contract design phase. This enabled INSURV to hjghlight some of their concerns during the design process and avoid some post-construction modifications correct identified deficiencies. These efforts all helped to produce a better, sore accurate contract design package for these ships and to eliminate some of the changes that would have occurred later.

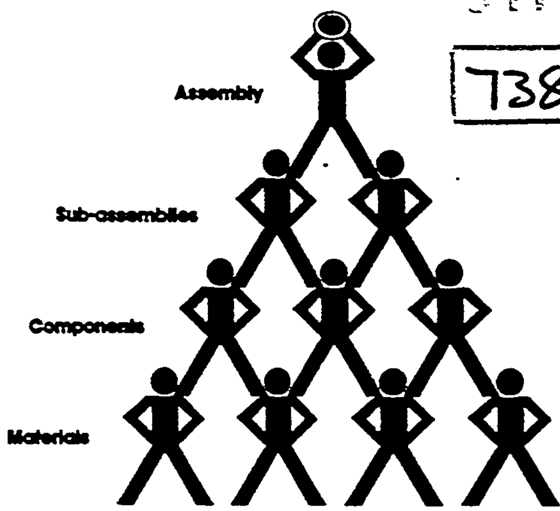
The DDG 51 program included some innovations in both streamlining and standardization. The requirements to support the BOSS program and Functional Group Coding of equipment were both invoked for the first time in a new ship design. use computer-aided drawings, in the contract design package as well as for later contractor deliverables, was accelerated. Contract drawings were annotated to identify the strict nondeviation areas and also other areas where minor rearrangements could be made without the costly and time-consuming processing of Engineering Change Proposals (ECPS). These techniques will be incorporated into future contract design packages.

A third approach, which was used on the LHD 1 - SECNAV's designated pilot program for streamlining ship acquisition - is to use a shipyard as the contract design agent. This obviously has some contractual difficulties if the shipyard has not already been selected as the building yard. In the case of the LHD, since it was a modified repeat of the LHA and maximum commonality was desired by the Program Office, selecting the proposed lead shipyard as the design agent was not a contractual problem. There were difficulties, however, in coordinating shipyard design activities with the desires of the NAVSEA technical codes and resolving the independent technical inputs into an integrated package. This approach does have significant possibilities for modified repeat designs where a shipyard has indepth experience with the ship type. Shipyards are being used as design agents in the SSN 21 design, although they are nominally competing against each other in the early phases. The Navy has assumed responsibility for total integration of the technical package as in the T-AKR program.

Streamlining procedures are evolving in an environment that also has a number of restrictive covenants. These restrictions are limiting some of the directions in which streamlining can progress. Government contracts are vehicles for social, environmental, and economic change as well as the purchase of products. Small business provisions, disadvantaged business clauses, minority employment, Buy American acts, environmental restrictions, and the myriad other clauses in the Federal Acquisition Regulations create a massive paperwork reporting network even before the product is under production. The Government has the responsibility for effecting social change and needs to set a positive example in its contracts to support these desired changes; however, significant cost savings might be found if the reporting and paperwork burdens associated with these programs could be reduced.

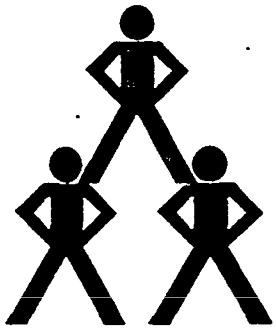
Competition is another major contracting initiative in the Navy and it is a two-edged sword. Clearly, competition and the free enterprise system are fundamental to our economic system. Some approaches to streamlining and standardization tend to rely on long-term association with a single contractor. Competition requirements provide a real challenge in using this type of arrangement as the solution to some acquisition difficulties. Again, just as in the social changes encouraged by Government contracting, there are strong financial and strategic reasons why the nation should not put all of its production in the hands of just one organization. The stated goal of the Navy's Competition Advocate is to "obtain the best value for the dollars invested."

The requirement to ensure fair and equitable competition while ensuring product quality has led to the development of the massive base of specifications, standards and drawings used to procure products. This documentation base is enormous, and like any large collection of data, it needs a selective purge to eliminate the obsolete and redundant items. The frequent discussions in the media and elsewhere as to the number of specifications that are invoked for any product, if the specification pyramid, Figure 1, is followed to its lowest tier, overlook a number of points.



Specification Pyramid
FIGURE 1

The production of a complex product involves many subassemblies and materials, each produced by different sources. The different tiers of the specification pyramid are frequently invoked on different levels of suppliers. Figure 2 displays how the specification pyramid is frequently viewed by the various activities that produce products used in a higher level assembly. While contractually the prime contractor is responsible for the entire product the reality is that the requirements are passed down to the actual producer. It is this foundation of available parts, subcomponents and materials that allows a contractor to assemble his complex products with confidence at a reasonable cost. One of the concerns expressed by engineers with regard to streamlining is that the elimination of the specification foundation of lower tier documentation will degrade product performance to an unacceptable level in an attempt to lower acquisition costs.



Each individual is primarily concerned with those who directly support him.

FIGURE 2

The DOD directive on streamlining specifically allows the full tiers of specifications to be invoked on production contracts. DOD Directive 5000.43 states the following about production contracts and commercial items:

"(5) For production contracts, those specifications, standards, and related documents to the tiers identified as the baseline for production shall be contractually applicable for procurement and reprocurement purposes. Acquisition streamlining shall continue throughout the production phase with emphasis on ensuring that only essential requirements are carried forward into follow-on production contracts.

(6) When there is a decision to use items developed, such as standard parts and off-the-shelf items, all of the applicable specifications and standards that define the product baseline for those items shall be contract requirements, irrespective of acquisition phase."

The advent of streamlining will not eliminate various levels of specifications that are needed to control the production of a product. The number of specifications invoked during the product development process will be reduced, especially ones relating to management requirements.

Streamlining will provide additional impetus for keeping the specification base current. Concurrent with keeping the specification base accurate, there will be increased emphasis on defining product performance, not on how to obtain that performance. Specification requirements will be more closely reviewed to ensure that the performance requirements are the minimum necessary. The earmarks of a good specification, especially one that is streamlined, will be to:

SAY WHAT YOU WANT
SAY IT CLEARLY
SAY IT ONCE

These guidelines can only be met by a performance-based specification. The only weakness of a performance based specification is its inability to enforce individual component and subcomponent standardization. The competitive environment that drives the acquisition process does create standardization once production begins.

Ships last a long time, 30 to 40 years for the hull and some of the more prosaic distributive systems. The cost to maintain the ship for that time period exceeds acquisition cost by a significant margin. This is where the complex logistics tail enters the picture. Navy ships operate in a self-repair mode; a significant amount of maintenance and repair is done by the ship's force with onboard spare parts and equipment. Marine supply houses and commercial repair facilities are not required for most routine equipment overhaul and maintenance. The number of spare parts, special tools, test equipment and components that must be stocked to support the fleet, and the distribution system to deliver those parts where and when they are needed is staggering.

Reductions in the number of spare parts that must be stocked and distributed are obviously beneficial. This has led to the number of standardization-related projects initiated within the Navy. Standardization can be handled at many levels. Interface standardization is one level; an item may be bolt- or plug-compatible. The item will connect right up and deliver the same performance. This is the level to which most Government specifications, streamlined or not, will produce standardization. For replaceable items like circuit boards, filters, small valves and other similar items, this is an acceptable level of standardization. It is not feasible, however, to carry or install a spare diesel generator onboard a ship.

To further complicate the problem, every manufacturer has his own stocking and coding system for the components he used to assemble a product. This not only applies to complicated weapons systems, but to any other product as well. Many manufacturers use the same basic parts, but how does the end user know it? The BOSS program requires the manufacturer to identify the original production source so the same individual component can be stocked for use in many applications, reducing cost and complexity of the stock system.

As we stated earlier, Navy ships are intended to be relatively independent of shore support for equipment and component repairs. This also includes the "friendly neighborhood equipment technical representative". Navy personnel, as they change ships and departments, are exposed to dozens of different equipments for which they are responsible for maintenance and operation. Since they seldom will have a career with one model of manufacturer's equipment, more detailed technical data and instructions are needed for the equipment to be properly maintained. This creates significant expense with regard to the acquisition and maintenance of the technical data to maintain the equipment. Increased standardization, which limits the variety of equipment and models of equipment in the fleet, creates a significant payback in the technical data trail that supports the equipment.

Component standardization basically comes from one of two methods: buy all the parts from one manufacturer, forever, or have anybody capable of building the item build from the same detailed design and drawings. Instant standardization is achieved, yet product innovation doesn't have a place in the process. Competition, streamlining, innovation and standardization all need to be addressed in the life cycle of a weapons system; the big question is who does what, and when.

FUTURE DIRECTIONS

The major question to be addressed is the influence of these various procurement-related initiatives on future acquisition packages. Based on our experience and observations, we have some opinions as to the courses that these acquisition packages may take.

Traditional Navy contract design packages already incorporate many of the streamlining initiatives now being invoked. While there is room for improvement, by and large, the NAVSEA contract design package is among the most tailored of any Navy acquisition. This has been more of an evolutionary rather than revolutionary change.

A Navy contract design package does not just invoke the Top Level Requirements, the General Specifications and associated reference documents and wish the contractor good luck. A year or more is spent in tailoring the basic design requirements of the General Specification into specific performance requirements for the ship the Navy needs. This performance definition goes down to the system, subsystem, and component level which accounts for the volume of a ship specification.

The reference documents in a ship specification are also frequently tailored. Examples of this are the reliability and maintainability standards, MIL-STD-785 and MIL-STD-470. A few years ago the entire reference document was invoked, whereas now only specific tasks in the standard are required. Other references are tailored in the ship specification to bring component or system requirements up-to-date or to suit different applications. There is also an increased use of commercial standards and the acceptance of contractor management software products that meet basic Navy requirements.

Occasionally, to bring a reference document up-to-date in the ship specification, pages of line-in, line-out changes to a standard reference are required. This is difficult for Navy engineers to review and for contractors to interpret. A frequently used solution in recent designs is the Project Peculiar Document (PPD). PPDs frequently are complete updates of standard references issued as project unique documents. This is easier for both the Navy and the contractor to use and is tailored exactly for the required application.

Drawings, both contract and contract guidance, are the next largest portion of the contract design package after the shipbuilding specification. Over the years, many of the drawings have been incorporating greater amounts of detail and are exerting more control over detail design than is warranted or desired. Steps are being taken, starting with the DDG 51 design, to ensure that only those requirements that need to be tightly controlled are being controlled. General notes are being added to the General Arrangement drawings, and some space arrangement drawings, to define the shipbuilder's latitude in making changes without processing ECPs. Items such as door locations, noncritical equipment locations, and placements of lockers and other small structures may be adjusted within the framework of specification requirements without an ECP being processed. This should help streamline the detail design process and stop the processing of "fact of life" contract changes.

Contract guidance drawings are contractual "no-win" documents for the Government. The features illustrated are not contractually enforceable, but if they are incorrect they may be the basis for change orders or claims. We have discussed the situation of contract guidance drawings with a number of different shipbuilders over the years. They are virtually unanimous in the opinion that contract guidance drawings are vital tools in preparing a bid, and are all but useless after contract award for configuration on design purposes. We would not be surprised to see them deleted from the contract package at contract award and not used again unless a bid package for a second source is being issued. The Navy has been heading in this direction by repeatedly modifying the definition of guidance drawings in the shipbuilding specification to emphasize their noncontractual status, and the fact that the shipbuilder can freely deviate from them within the framework of specification and contract drawing requirements. Contract guidance drawings are also useless in a contractor-developed design once the source selection process is completed.

The current practice for procuring ships to commercial standards is a greater barrier to streamlining than strict Navy designs. The current baseline document for developing commercial ship specification packages, the Standard Specifications for Merchant Ship Construction, is out-of-date contractually, technically, and organizationally. Many of the references contained in the document are totally outdated and unsuitable for procurement. The work boundaries, since they are not based on the more common Ship Work Breakdown Structure (SWBS), place requirements in different specification sections which many people are not familiar with. Since the MARAD spec is not being maintained, it is useless as a mechanism for invoking the National Shipbuilding Standards being developed under the auspices of the ASTM F-25 committee.

The concept of streamlining requires that the basic acquisition document invoke the necessary minimum requirements in the baseline document. A commercially- oriented ship specification does not do this. Many requirements are invoked by reference to the regulatory bodies, the American Bureau of Shipping (ABS), the Coast Guard, Public Health Service and so on. The Code of Federal Regulations (CFR) is not always the easiest place to locate technical requirements and frequently the requirements are not expressed in performance based terms.

In support of streamlining, competition and standardization, we need a SWBS based replacement document for the MARAD specification. It should be administered by a "neutral" party with concern for both military and commercial designs. Contractor developed technical designs should undergo a technical review and "normalization" prior to cost competition. If the designs were all updated to a position where the Navy would not have any technical difficulties in accepting any competing design, a number of benefits will accrue. Pricing for the final acceptable design would take place in a competitive atmosphere, thus improving the cost to the Government. The contractor benefits from knowing exactly what he priced out. Once the contract is awarded against that specification and drawing package, the detail design and construction phase can be promptly initiated without a time and cost consuming ECP process to obtain a technical design that satisfies the Navy. There are some obvious dangers in this approach. The Navy Program Manager must ensure that only the minimum number of technical changes are made to the contractor's package to meet minimum Navy standards. A second danger might be the protection of the competitive integrity of the competing designs. One shipbuilder's innovative approach should not be invoked on, or passed to, the competition. The use of small, separate "tiger teams" to evaluate each design from a technical standpoint would eliminate many of the cross-fertilization risks. The Program Manager and Ship Design Manager and their direct staffs would be the only persons privy to all of the technical packages.

The circulation of draft solicitations will become a normal part of weapon system acquisition. Prime contractors will have the same opportunity to comment on the contract provisions as they have had to comment on the specifications and drawings included in the technical package. Contracts covering more than one design phase, i.e., preliminary, contract, and detail design and construction may need a number of checkpoints to allow risk assessment. This will place a burden on the Government to ensure that the time frames for assessing progress and future direction at these checkpoints is held to a bare shipbuilding. ABS and the Coast Guard should ensure that this National Shipbuilding Specification incorporates their requirements and possibly supersede the use of the CFR for establishing Federal shipbuilding standards for commercial ships. The existence of a valid, current National Shipbuilding Specification would invoke greater discipline on the configuration of commercial shipbuilding packages and provide a central location for commercial ship construction requirements. Its existence as a living document could be a valuable tool for both increasing competition and facilitating the identification of all requirements being invoked in a ship acquisition. It would also make it easier for the Navy to marry commercial requirements and Navy General Specification requirements where they can be combined; for example, in auxiliary ships.

The Navy will continue to use total contractor designs for acquiring new technology ships and for civilian-manned ships. These contract design packages may be based on either contractor or Navy developed preliminary and feasibility designs. The final package that becomes the technical part of the contract will be very similar in configuration to the standard Navy contract design package and will have varying degrees of Navy assistance in its development. The Ship Design Standards being promulgated by NAVSEA will ensure that high-priority technical requirements are invoked in the technical package from the beginning. The National Shipbuilding Specification would provide a solid framework for contractors developing a commercially-based ship design. Also some portions of the package such as drawing policies, logistics support and other management-type requirements should only be handed to the contractors on a "do it this way" basis. There is no percentage in expanding design cost and effort on something that must be compatible with existing Navy practices.

A change is needed in the source selection process for contractor minimum to control costs. This concept is compatible with the streamlining initiatives to run acquisitions like a business and to share risks between the Government and the contractor.

Technical data - the mass of paper and other software deliverables that accompany an acquisition - is a high-cost item. Any effort to streamline a contract package must address the volume of data delivered in conjunction with hardware. Streamlining initiatives are running into a conflicting initiative to ensure that NAVSEA has the technical information necessary to maintain ship, systems and equipments over their life cycles. The DDG 51 program was one of the first to initiate an increase in delivered technical data for NAVSEA specifically for life cycle maintenance purpose, including supporting the expanded planning yard concept. A significant portion of the extra data is related to new equipment and ship systems. The data will not have to be reprocured for follow ships or for other ship classes using the same equipment, thus flattening the bulge of delivered data in future programs.

To balance out this increase in technical data, there needs to be more flexibility in delivery, format and schedule requirements. Most data for life cycle maintenance is not time critical for delivery. Drawings and other data are already designated for delivery on shipbuilder-developed schedules to coincide with detail design and construction requirements. A majority of shipbuilding Contract Data Requirements Lists (CDRLs) for follow ships are annotated to indicate which data elements are required to be submitted, and then only under specific circumstances. Data which is unchanged from a previous procurement may be waived or satisfied by certification of identicality and not resubmitted. Program plans, test procedures, and other management-related procedures are being developed and implemented on a class rather than individual-hull basis.

The contract includes the CDRL. The CDRL obtains program management oriented data as well as data for technical support. Streamlining initiatives are emphasizing a greater acceptance of contractor formats and schedules for preparing and submitting management oriented data.

We believe that if more information on the cost of technical data were provided down to the functional engineer level, it might then be easier to filter the data requested to the minimum required. The functional engineer needs to have cost information available to enable him to work with the Program Office on tradeoffs. It may be necessary to identify a couple of acquisition programs as target programs in order to develop a working database for deliverable costs. There would be an initial cost penalty to have the contractor provide individual pricing information for each data product submitted and unit costs for copies, but the future benefits should provide significant return on the investment.

Equipment procurement, whether directly by the Government or via prime system contractors, is also going to be influenced by the streamlining initiatives. Recent shipbuilding procurements have seen an increasing amount of class standard equipment. Once the lead shipbuilder selects a vendor who satisfies the procurement specification, he obtains options for follow-on procurements which may be exercised by either the lead or follow shipbuilders. This insures intraclass standardization for this equipment. Interclass standardization should come from contractual incentives to select equipment that has already been approved for full production by the Navy or standard commercial products that satisfy the performance requirements.

The Navy needs a coordinated approach to obtain equipment in its pool of Approved for Full Production equipment that incorporates streamlining, competition and standardization. We have a suggestion for such an approach. The initial competitive procurement should be based on a performance specification, streamlined as applicable. If possible, the military specification should be compatible with commercial specifications or standards for the same product. For example, valve outside dimensions and bolt patterns should be compatible, or the same size of window should be required so that in an emergency a commercial product can be substituted.

For complex or innovative equipment, hardware prototypes should be part of the competition. This would allow comparative testing and evaluation of hardware, not paper solutions to the performance requirements. This will require an increase in up-front funding for development and testing which has been hard to find for the more prosaic Hull, Mechanical and Electrical (HN&E) equipment. A condition for winning the competition would be the delivery at the end of the first year's production of a set of Level III drawings with full rights in data to be used for future competitive procurement. As add compensation for the possible 10ss in competitive advantage, the first company would be guaranteed a decreasing percentage of procurements over the next two years. The equipment developed and procured in this manner would also be specified by referencing the original performance procurement specification in shipbuilding packages.

This would coordinate many of the current stand alone procurement initiatives - streamlining, competition, commercial specifications and standardization - into a cohesive acquisition policy.

SUMMARY

The Navy is complying with the streamlining initiatives set forth by the Department of Defense. Different techniques have been employed, and will continue to be employed, to implement streamlining within the framework of various acquisition programs. Streamlining will continue to evolve within the existing acquisition guidelines and under the influence of competition and standardization requirements.

The Navy needs to accelerate the upgrade of its specification base and to continue to coordinate with industry standards writing bodies. Resources need to be applied for the development and evaluation of additional families of standard HM&E equipment. Finally, the nation, as well as the Navy, needs a standard specification framework for commercial shipbuilding requirements that can ensure safety, improve standardization and increase productivity.

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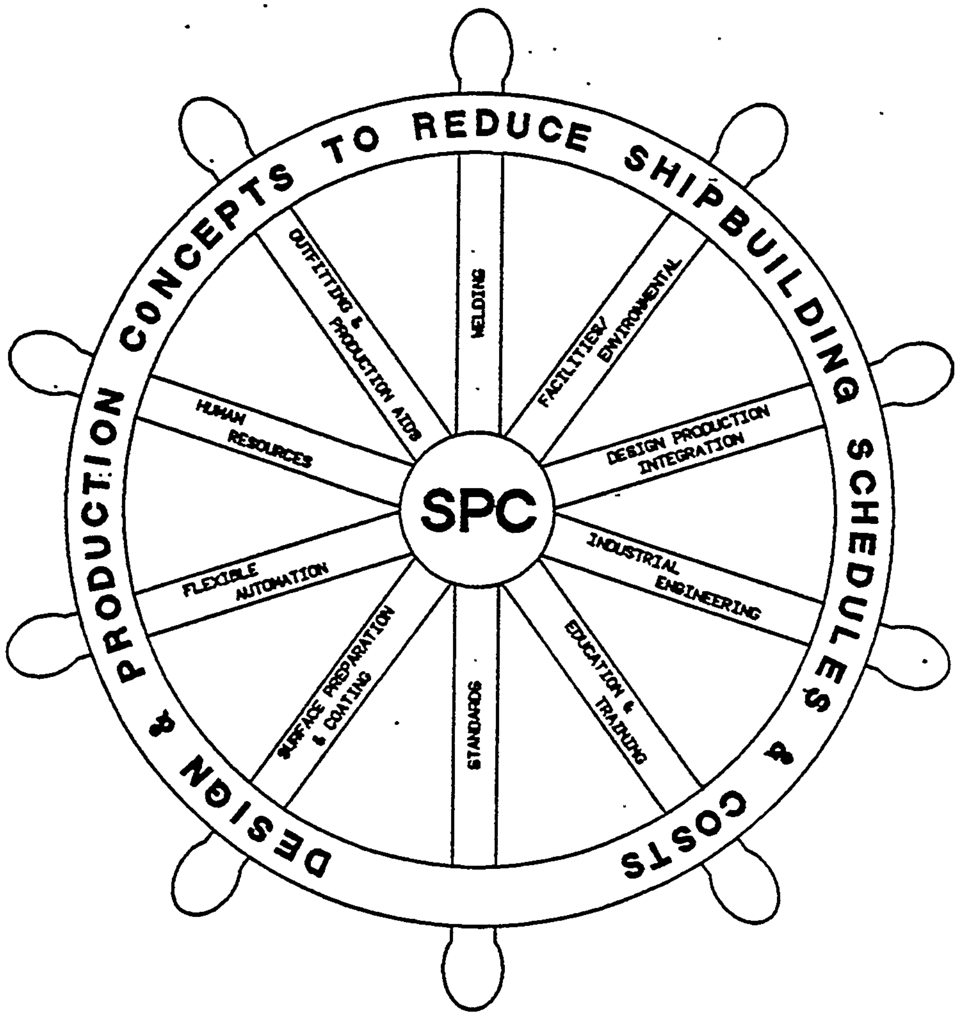

PAPER NO. 8

LASER LINE HEATING

BY: KEVIN SCULLY

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LASER LINE HEATING

KlVN SCULLY, DTNSRDC

ABSTRACT

Many shipyards now employ line-heating processes to form metal by controlled heating and cooling. The benefits of line-heat forming include improved accuracy and productivity. The current line-heating method utilizes an oxyacetylene torch as the heat input. A new forming technique that uses a high-power laser as the heat source is being researched. The feasibility of forming q mild- and high-strength steels with a laser heat input is reviewed. The primary incentives for using a laser are: the capability to accurately control the forming process, the capability to minimize the material degradation, the capability to form high-strength steels, and the increased compatibility with other advanced manufacturing systems. In summary, by manipulating the laser power, laser beam diameter, and plate travel speed, one may form metal plates to a predetermined shape in a repeatable manner.

INTRODUCTION

The use of lasers on the manufacturing floor to perform material fabrication tasks such as: drilling, cutting, scribing, brazing, soldering,and heat treating is expanding at an ever-increasing rate. From its inception the laser has been advocated as a highly versatile tool for a broad range of materials processing applications. However, it is only within the last several years that laser systems have been available with sufficient power output to perform tasks such as industrial welding and forming.

Some of the typical benefits associated with the implementation of laser systems are: high productivity, elimination of the need for other high-quality tools, a reduction in the number of manufacturing operations, reduced energy requirements, and consistent high-quality performance. An example of high-quality laser cutting on quench-and-tempered steels was demonstrated at United Technologies Research Center, East Hartford, CT. Laser cutting produced a heat-affected zone (HAZ) of only 5 mils, as compared with a -1/8 inch HAZ with plasma-arc cutting. In addition. the laser cut width is only 30 roils and laser cutting can be performed at higher speeds. However, a major drawback to laser fabrication systems is the high capital outlay for the laser.

It is important that manufacturing companies recognize the potential of laser systems and analyze them as any other material fabrication system to perform joining, cutting, heat treating and forming operations. The laser is not the answer to everything; but, used properly, lasers are valuable new machine tools in a class of the same importance as a mill or a grinding machine (1).

LASER FORMING OBJECTIVE

The objective of the Laser Line Heating (LLH) research and development program is to study the feasibility and producibility of forming steel plates with a laser as the heat source, for naval ship construction. The driving force behind this project is the capability to form high-strength steels, such as HY-80, with a minimal material degradation and the capability to accurately control the forming process.

Currently, the navy specifies that high-strength steels, quench and tempered, may only be formed by cold working. The limitations of cold working are discussed in more detail in a following section of this paper. The other plate forming process, oxyacetylene line heating, is not permitted due to the resulting material degradation. The Navy has approved oxy-flame straightening of HY-80 (3/8 inch maximum thickness); but, flame straightening is permitted only on a limited basis where toughness is not an important design consideration; i.e.,flame straightening is not permitted on bilge, stringer, and shear-strake plating, nor is it permitted on the vertical keel within the 3/5 midship length (2).

The need to accurately control the forming-of plates is well documented in the National Shipbuilding Research Program report entitled, "Line Heating", reference 3. The most significant shipbuilding problem commonly encountered " is the difficulty in joining blocks during hull erection due to inaccuracies such as in the overall block dimensions and the misalignment of structural members. During block assembly, traditionalists provide extra material, i.e., margins and defer certain welding such as at the ends of longitudinal to the shell. Their subsequent marking and trimming when erecting the hull is, therefore, rework. The resulting cost for safely performing the deferred welding at the building site, is at least three times more than the cost for the same welding during block assembly. (3)

In an attempt to alleviate the aforementioned rework costs, a new forming fabrication technique is being researched: laser line heating. Line heating is a process of forming plates by controlled heating and cooling. Utilized in conjunction with group technology and accuracy control, line heating is a means for converting much of the rework and deferred work, which traditionalists perform at the building site into safer, easier, and more efficient work tasks, which results in reduced costs.

This project is sponsored by the Navy Manufacturing Technology (ManTech) Program. The ManTech Program was established in 1977 to provide a mechanism to transition advanced equipment and processes from research to the factory floor. The goals of this program are, generally, to increase supplier productivity thereby reducing navy costs, and, more specifically to:

1. Reduce the cost and delivery time of navy systems;
2. Reduce dependency on strategic and critical material in navy systems;
3. Improve the quality of fleet hardware; and,
4. Improve the navy's technology - base.

FORMING OVERVIEW

Forming takes place in a metal any time it is subjected to stresses that are greater than the yield point or when the deformation stress moves from the elastic to the plastic range.

Forming operations are generally classified as cold or hot. Cold working is usually associated with those operations done at room temperature. The properties of a material, such as yield strength, strain-hardening rate, and ductility are all very much temperature-dependent. With increasing temperature, it is generally true that the yield strength and rate of strain hardening will progressively decline and ductility-will increase. Hence, a hot-formed material will exhibit a high ductility (ability to greatly deform before cracking) and less energy input will be required to form the plate. Conversely, a cold-formed material will exhibit high strength (the corresponding strain-hardening that occurs may be relieved by annealing) and will typically require less subsequent machining or finishing operations. (4)

All methods-of material forming are based upon a combination of plastic and elastic behavior. In addition, it is a well-known phenomenon that any metal-forming process will impose residual. stresses (locked-in stresses) in the metal (5). Residual stresses are generated by nonuniform plastic deformation (4), and the degree of induced residual stresses will vary from one forming process to the next. It is these locked-in residual stresses that contribute to distortion problems in operations subsequent to the hull plate-forming operation. For example, when longitudinal and transverse stiffeners are welded to hull plates, the plate deforms as shown in figure 1. The two major factors

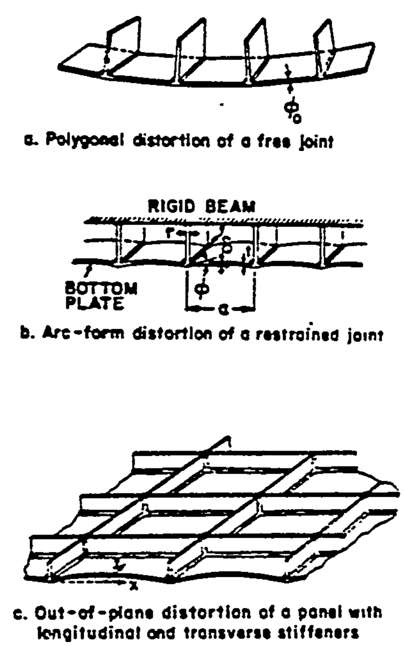


Figure 1. Distortions produced by angular changes at fillet welds (6)

contributing to distortions of welded structure are:

1. The welding process heat input causes.distortion in the fabricated structure; and

2. Upon welding some of the built-in residual stresses, which were created during the forming process, are released and the metal deforms.

There is no process that completely eliminates weld distortion, but weld distortion can be minimized, for example, by preheating the plate or restraining the plate. (6). It has been shown that weldments produced using narrow-gap welding, electron-beam welding, and laser welding all exhibit less distortion than weldments produced using arc-welding. Hence, by minimizing the total weld heat input, the plate deformation can be minimized. (6)

It is hypothesized that by accurately controlling the laser heat input during the forming process and by minimizing the HAZ, one may minimize the locked-in residual stresses. Hence, the structural distortion, which would result from the subsequent operation of welding stiffeners to the hull plating, is further minimized. This in turn will reduce block assembly rework, which is very time consuming and expensive.

The methods currently used for forming ship steel plates may be classified according to the mechanisms used to bend the plates. They are:

1. Mechanical forming; and
2. Thermomechanical forming.

In the mechanical forming of a steel plate, the steel plate, which is initially flat and at room temperature, is formed into a desired shape by producing plastic deformations in appropriate amounts and distributions. One of the most common methods of producing the necessary plastic deformation is to press the plate to a die of the proper shape. Another method is to feed the plate through a set of rollers (cold rolling) to produce the desired shape.

When thermomechanically forming a plate, plastic deformation is produced by the thermal stresses generated during the heating and subsequent cooling of the plate. The thermomechanical process involved. in plate bending is based upon the principle of heating one side of a plate while the other side is kept cool. The temperature gradient in. the material causes the metal to deform in the negative direction (opposite to final desired shape). During this transient State, the expanded metal is constrained by the surrounding cooler metal and compressive stresses result. When the heat is removed, the plate cools and the metal contracts. The plate will then deform in the reverse direction than when it was heated, and the plate will assume an equilibrium position which has a positive curvature. (7)

The ideal thermomechanical forming system would consist of a large heating pad (i.e. maintained at 1050°F). that could be pressed onto one side of the steel plate, while the other side of the plate would be maintained at room temperature (angular distortion is a function of temperature differential between the plate top and bottom). In addition, the ideal deformation process would produce shrinkage in one direction (longitudinal) with no dimensional change in the transverse direction. Of course, economic and processing constraints prohibit this forming method.

The line-heating process, which is currently being used in a few shipyards to form hull plates, utilizes an oxy-acetylene torch or a set of torches as the heat source, and is commonly referred to as oxy-line heating.

LIMITATIONS OF CURRENT FORMING TECHNIQUES

Mechanical forming is the most suitable for repeatedly foming thin sheets into the same shape in a large volume. A good example of such an application is the forming of automobile bodies. However, two aspects of the shipbuilding situation are quite different when compared with the automotive industry; namely:

1. The plates are thick, which requires a press of large capacity; and,

2. The plates must be formed into a variety of shapes in relatively small batches.

To cope with the shipbuilding situation, a set of straight rollers, instead of dies in predetermined shapes, is frequently used. This makes it extremely difficult and sometimes impossible to form plates with more than one degree of curvature. Also, it is not possible to form regions within about two inches of the plate edge. The biggest problem with cold-rolling is that significant residual stresses are imbedded in the metal. Consequently, when stiffeners are welded to the plate, the plate becomes deformed, resulting” in much rework at the erection site. This redundant and unsafe erection site rework includes tasks such as an extensive realignment of butts, seams, and internal structural members with dogs, clips, wedges, hydraulic jacks, etc.; the cutting free, realigning, and rewelding of previously assembled parts; gas-cutting for the adjustment of erection joints: the removal of dogs, clips, yokes and lugs; and the restoration of surface finishes.

In comparison with mechanical pressing, thermomechanical forming, using an oxyacetylene torch, is more versatile and less expensive. Steel plates can also be formed with complex curvature, and the resulting residual stresses are minimal. However, line heating with an oxyacetylene torch has some inherent drawbacks, as listed below:

1. Thermomechanical forming is an art which requires many years of experience because complex mechanisms are involved. During heating, the plate deforms in one direction, and then it deforms in the opposite direction upon subsequent cooling. In order to form a plate into an exact desired shape, one must know how the plate should be heated. One must also have a means to control the heating and cooling processes. To master this skill through experience, many years of on-the-job training are often required:

2. The torch - flame is diffuse, which results in a degradation of material properties, consequently, high-strength steels are not permitted to be formed by this method;

3. The shortage of skilled workers entails some serious implications. According to Professor Koichi Masubuchi (MIT), even a skilled worker makes many mistakes during the flame-heating operation, e.g. heating spots too long which causes surface melting;

4. A precise heat input and bending is difficult to reproduce; and,

5. The heating must be followed by water quenching.

Another forming method is the forging process. Some shipyards utilize the hot forging (furnacing) process to fabricate plates having double and complex curvature. Forging is the working of metal into a desired shape by hammering or pressing. It is the oldest of the metalworking arts, having an origin dating with the primitive blacksmiths of biblical times. But, even today, highly skilled blacksmiths are required for forging ship hull plates. Some other furnacing limitations are: the plate size is limited by the size of the furnace; furnacing is a time-consuming process; and furnacing is costly. These plus other reasons have caused shipyards to investigate and develop other methods for fabricating plates having a compound curvature.

THE LASER LINE HEAT FORMING SYSTEM

Laser forming is a thermomechanical method which uses a laser instead of an oxyacetylene torch as the heat source. The basic metal forming mechanisms for the laser method are essentially the same as the current forming technique using oxyacetylene torch. However, there are a few subtle differences which suggest that the laser is a more effective source of heat input. Some of these anticipated benefits are:

1. The laser forming technique is reproducible and precise;

2. A laser system, with a focused beam and controllable travel speed, is ideally suited for automation;

3. A laser line-heating fabrication system is capable of forming double or complex curvature plates;

4. The heat-affected zone of the plating is minimized; and

5. The plate deformation is optimally controlled with a minimum material degradation.

The components of a laser heat-line forming system is envisioned to consist of: a 9 kw laser, a two-axis NC table, a laser interferometer (for feedback control of plate distortion), a computer controller, a process parameter algorithm (the material type and thickness and desired shape are input and the controller computes the required laser power, beam diameter, travel speed, and travel path), and a material handling system (optional). A schematic diagram of a proposed laser heat-line forming system is shown by figure 2.

LASER FORMING EXPERIMENTS

Experiment Objectives

As mentioned earlier, the goal of the LLH project is to determine the feasibility of forming steel plates in a production environment, with a laser as the heat source, for naval ship construction. In order to prove the feasibility of the laser forming process a series of experiments was performed to analyze the following parameters:

1. Real-time changes of temperatures and strains;

2. Angular distortions obtained on low-carbon and HY-80 steel plates

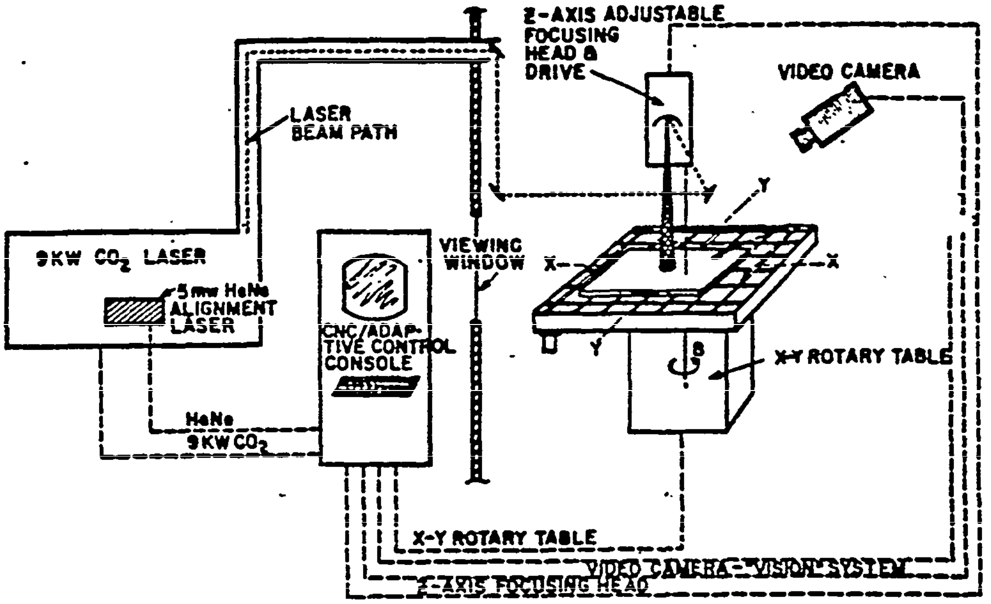


Figure 2. Proposed Laser Forming System (---control and Feedback loops).

subjected to single- and multi-pass heating;

3. Effects of laser heating parameters and plate thicknesses on angular distortions (effects of primary factors);

4. Effects of heating locations, boundary constraints, and cooling methods on angular distortion (effects of secondary factors); and

5. Forming of complex shapes.

The following is a summary of the laser forming experimental results performed by MIT at the Naval Research Laboratory. The laser used was a 15 kw, continuous top-hat beam, CO_2 laser with a 10.6 micron wavelength (8). A copy of the Phase I final report may be obtained by contacting the Ship Technology Division of the David Taylor Naval Ship Research and Development Center.

Changes of Temperature and Strain

The temperature changes in mild steel during laser heating are shown in figure 3. Plate #2 was heated at 12.7 kw and plate #1 was heated at 7 kw hence, the maximum temperature reached on plate #2 was higher than that on plate #1. The travel speed for both plates was 12 ipm.

A plot of the strain changes that occurred in a mild-steel plate heated at 12.7 kw with a travel speed of 12 ipm is shown in figure 4. The strain gages were mounted on the bottom surface of the plate. When the top surface was heated by the laser beam, very high compressive strains were produced on the bottom surface. After the laser heat passed, the high compressive strains transformed to tensile strains and then stabilized. Though this result was anticipated, the plot demonstrates that strain changes during laser heating and cooling are indeed complex.

Angular Distortions

The amount of angular distortion as a function of the number of laser passes is plotted in figure 5. As shown in the figure, there is a linear relationship between the number of passes and angular distortion. Hence, this implies that a linear algorithm is sufficient to predict deflections for a given plate thickness and heat input.

Effects of Primary Factors

The primary factors in forming plates are laser power (P), plate travel speed (v), and plate thickness (t). The parameters P/v and $P/(t\sqrt{v})$ are used to analyze plate distortion since similar parameters have been used to analyze the effects of process variables on angular changes caused by welding and flame heating. Figure 6 shows the relationship between heat input, P, and the final angular distortion θ_f (after the specimen cooled to room temperature). For a given thickness, the amount of angular distortion increases with an increase in heat input (heat input = P/v, KJ/in.). The graph also implies

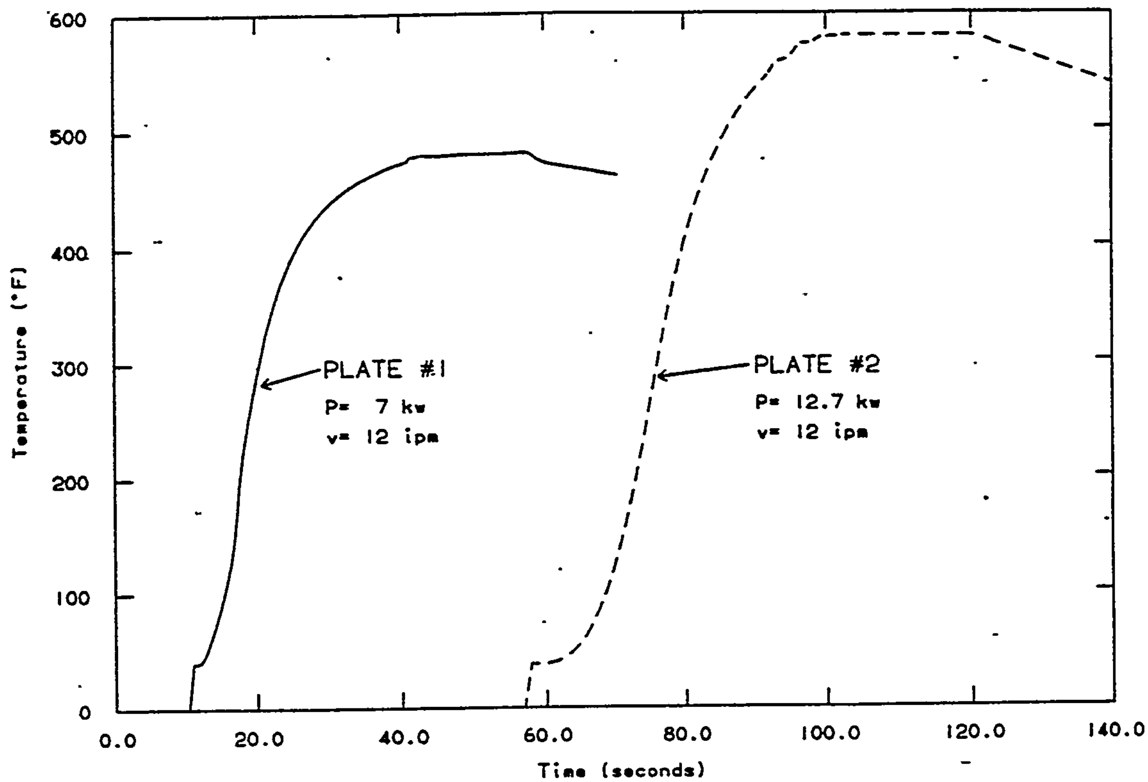


Figure 3. Plate temperature change during laser heating.

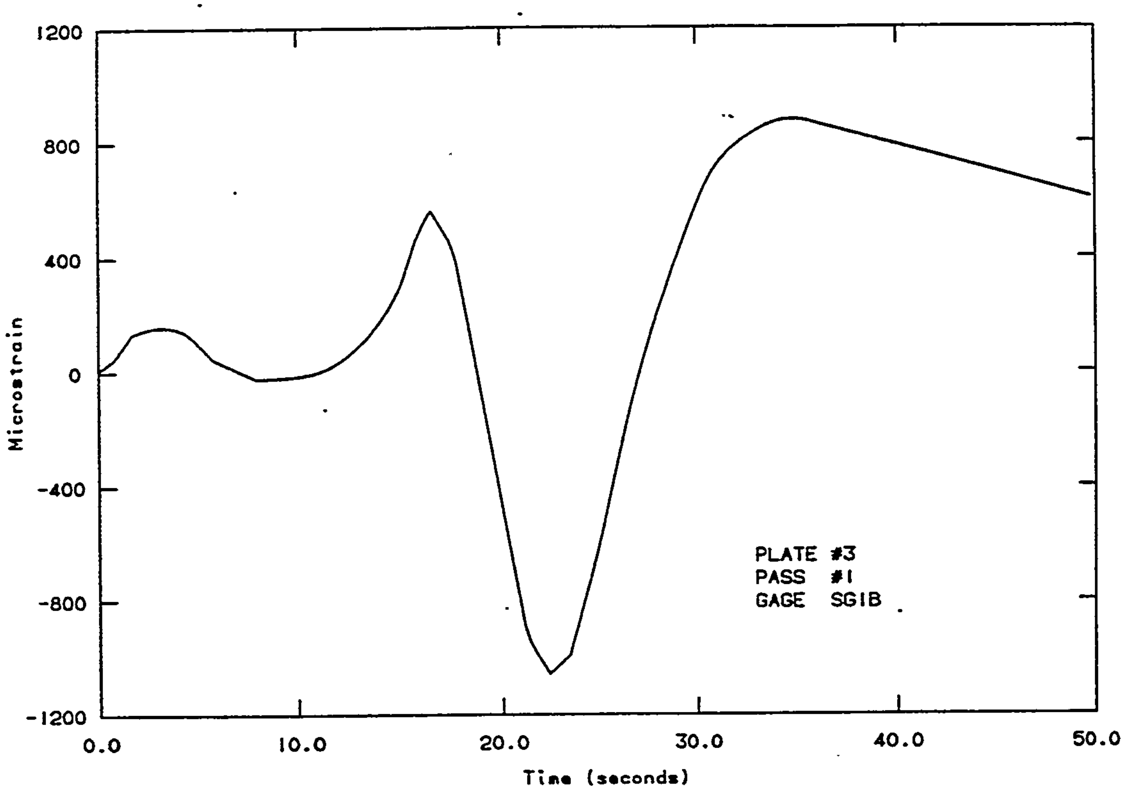


Figure 4. Strain changes during laser heating of mild steel.

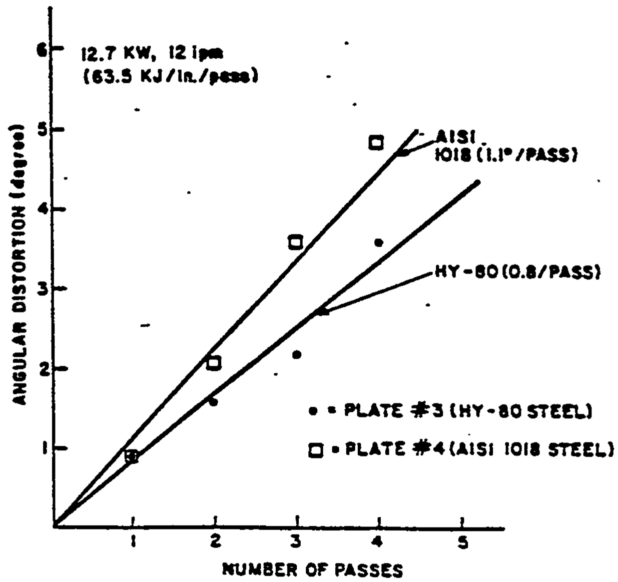


Figure 5. The relationship of angular distortion and the number of laser passes for mild steel and HY-80 steel.

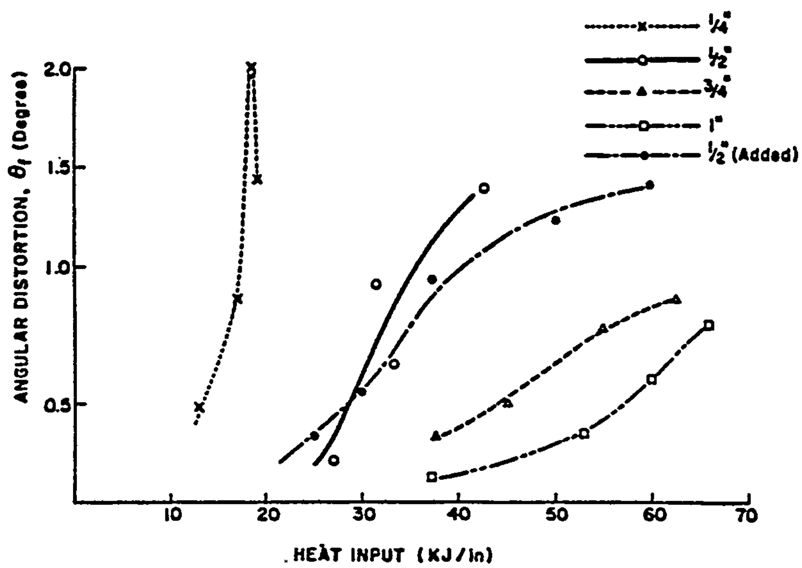


Figure 6. The relationship of heat input and angular distortion for mild steel.

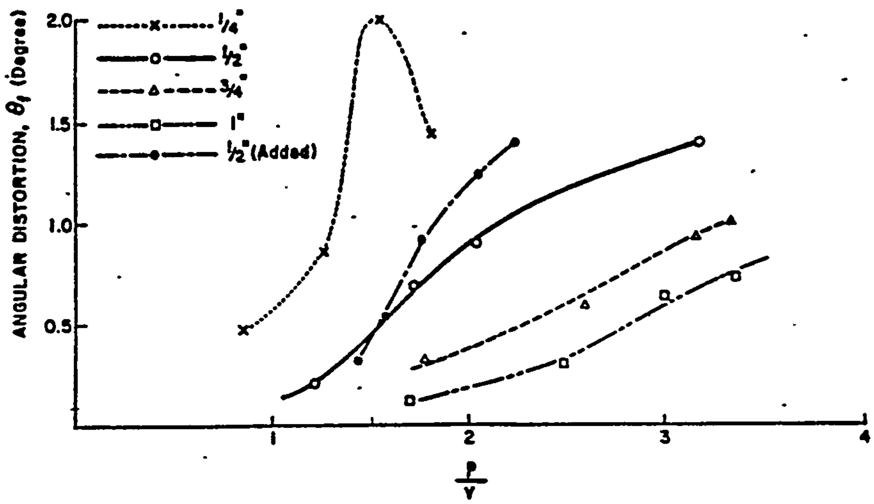


Figure 7. The relationship of P/v and angular distortion for mild steel.

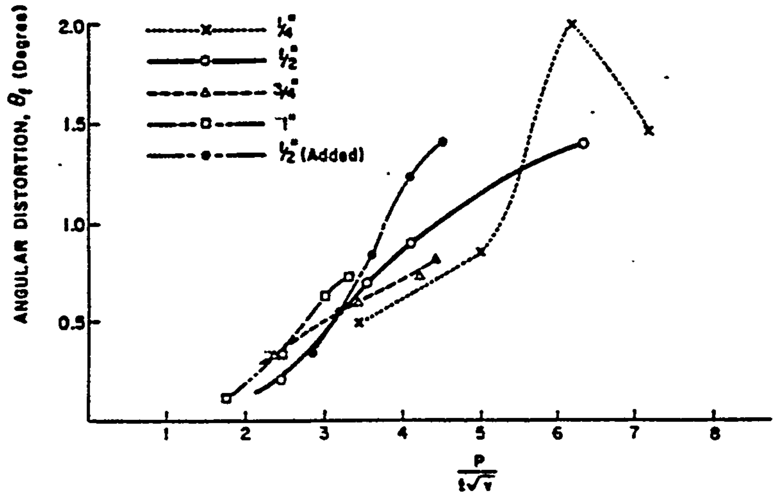


Figure 8. The relationship between $P/(t\sqrt{v})$ and angular distortion for mild steel.

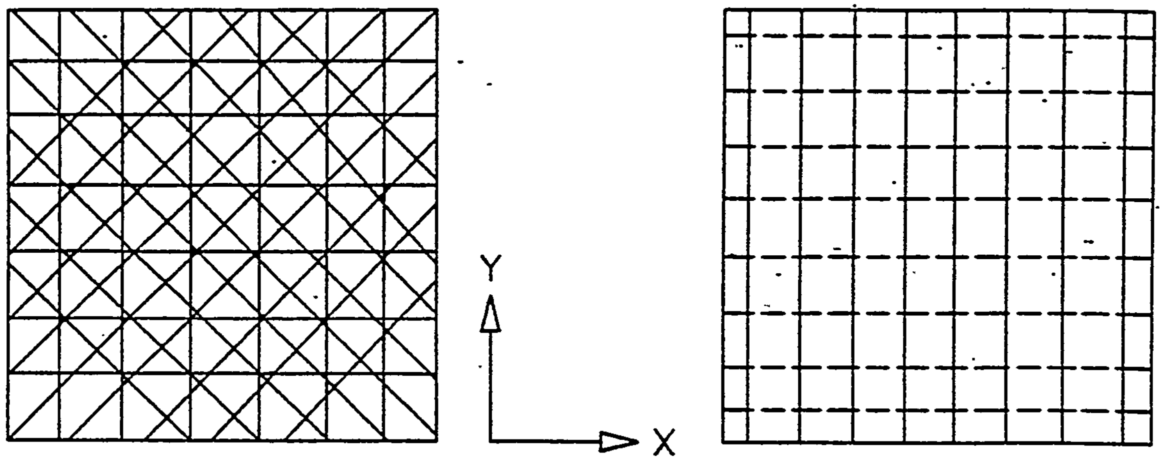
that there is an optimum heat input for each plate thickness. For example, for a 1/4 inch mild-steel plate the optimum heat input is approximately 19 KJ/in.

Figure 7 is a plot of the relationship between angular distortion and the parameter P/v for mild steel plates.

A plot of $P/(t\sqrt{v})$ versus angular distortion for mild-steel plates is shown in figure 8. As may be seen from figure 8, when a plot of $P/(t\sqrt{V})$ versus θ_f is constructed, the data will gather in a narrow band. This suggests the following:

1. The basic mechanisms by which process parameters and plate thickness affect the amount of distortion are similar in laser heating, flame heating, and arc welding.

2. The parameter $P/(t\sqrt{v})$ may be used effectively for estimating the amount of angular distortion of a plate. For example, if one would like to estimate the amount of angular distortion when a 3/8 inch thick plate is heated, the data in figure 8 should be useful. Similarly, given a required angular distortion and knowing the plate thickness one may vary the laser power and plate travel speed to obtain the necessary distortion.



a. Heating Pattern for Dish shape

b. Heating Pattern for Saddle shape

Figure 9. Heating patterns to form plates having a complex curvature. Solid lines represent a topside laser pass and a dashed line represents a laser pass on the bottom side of the plate.

Effects of Secondary Factors

The effect of having no boundary constraints is that there will be a decreased distortion near the plate edge. The effect is minimum except for 1.6 inches from the plate edge. This is approximately the diameter of the laser beam. This effect may be attributed to two effects:

1. Heat flow. When the heating line is very close to an edge, the heat flow pattern is altered by the presence of the edge. Areas near the edge are heated to temperatures higher than those in areas away from the edge resulting in a smaller temperature differential hence, causing less distortion near the edge.

2. Plate restraint. When the heating line is close to an edge, the restraint or the bending rigidity of the plate becomes nonsymmetric resulting in less distortion.

One method of increasing distortion when heating near a free edge is to clamp the edge to a fixture.

Angular distortion is produced by temperature differences between the irradiated top surface and the cool bottom surface. Therefore, the bending process should become more efficient by developing a means for increasing the temperature differential. The results of the experiments performed to determine the optimum cooling method is shown by table 1. In general, the pleasantly surprising results summarized in table 1 show that the cooling method has no effect on angular distortion when laser forming. Hence, natural air convection (Method #5) was used during all subsequent experiments.

Forming of Complex Shapes

An important advantage of the laser line-heating process over the conventional bending process is the ability to form complex shapes from a flat steel plate in a controlled and accurate manner. To prove the capabilities of laser forming, experiments were conducted to form a series of "generic" complex shapes that might be found in the construction of navy frigates, destroyers, cruisers, and commercial tankers. A ship's hull requires many complex curvatures, especially towards the bow, around the sonar dome and bulb, and in way of the stern, especially the propeller and transom areas. By utilizing different heating-pattern methods, it was demonstrated that: sine, dish, saddle, cone, and screw shapes could be produced.

The heating patterns used to form the more complex dish and saddle shapes are shown by figure 9.

MATERIAL DEGRADATION ANALYSIS

A complete analysis and discussion of the material degradation of laser-formed plates are included in the Phase I final report, reference 8. As noted in reference 8, a series of tests was performed to determine the effect of

Table 1. Effects of cooling method on angular distortion

	Cooling Method	Angular 'Distortion
#1	Water bath, natural convection, with steel support underneath HAZ	.1.16
#2	Water bath, natural convection, no steel support underneath HAz	1.08
#3	Dry ice, entire plate rested on a block of dry ice	1.11
#4	Forced air convection, plate suspended by clamp on one edge	1.13
*5	Natural air Convection, plate rested on an aluminum table	1.28

laser line heating on material properties for HY-80. The material testing methods employed were: a Charpy V-notch (CVN) test to determine toughness; a microhardness test to determine tensile strength; and a microscopic examination to determine the crystal structure and characterize fracture surfaces.

The effect of heat input on the CVN results of HY-80 showed that as the heat input increases, the ductile-to-brittle transition temperature and the upper shelf energy decreases. Also, an increasing hardening effect was observed as the heat input was increased.

For multi-pass heating, the fracture toughness of the HAZ was as good as that of the base metal. Single-pass heating with high heat input (54KJ/in.) caused some degradation in fracture toughness of HY-80 steel.

Multi-pass heating with low heat input per pass (18KJ/in.) and single pass with intermediate heat input (33KJ/in.),showed a beneficial effect of hardening while the fracture toughness was maintained.

Temper embrittlement due to laser line heating of HY-80 steel was not observed.

3ENEFITS OF LASER LINE HEATING

The investigations which have been conducted have clearly shown that the laser line-heating method provides a number of advantages when compared with conventional forming techniques (cold-rolling and oxy-line heating). Some of these advantages are as follows:

1. The focused heat source of the laser minimizes the heat-affected zone of the plate to small areas near the surface (approx. .15t), which is very effective for forming plates;

2. Water quenching is not required; air cooling is adequate;

3. Material degradation is minimized;

4. The entire process (laser power, density, and travel speed) is easily and accurately controlled;

5. Since the laser forming technique can be completely automated, consistent results can be obtained. It is possible to develap a manufacturing cell equipped with sensors and control devices so that plates can be formed into exact predetermined forms ;

6. The capability to form plates with compound curvature is provided;

7. The capability to form high-strength steels is provided;

8. The process of forming plates becomes a science, not an art;

9.- Rework is reduced during subsequent operations, especially during the block assembly stage; and,

io. Enhanced safety.

An indirect benefit of LLH is the design flexibility. At the 1986 American Society of Naval Engineers Conference (ASNE Day) Vice Admiral Metcalf, Deputy Chief of Naval Operations, presented the keynote address. One of his main points was the need for-more innovative hull designs to increase ship speed, to save fuel, and to reduce radar signatures. A laser line heat forming system would allow design engineers a greater flexibility in hull design to attain the aforementioned goals.

A preliminary economic analysis of a conceptual laser line-heating system indicates that there may be a low return-on-investment and a long payback period (approximately six years). The main drawback is the high cost of the laser, For example, a 9 kw laser costs approximately $750,000. But, one should consider that lasers of high-power are relatively recent entries to the market place and their price will eventually decline,. and also that as other laser applications (e.g., welding and cutting) are implemented on the manufacturing floor, one may reduce laser costs through economies of scale. Newport News Shipbuilding is already using a laser for the cutting and drilling of metal plates in the thickness range of 1/16 to 3/8 inch.

FUTURE WORK

The work summarized in this paper is mainly the results obtained from Pnase I reseach. The objectives of Phase II of the research-program are:

1. To develop control strategies and algorithms to automatically form steel plates;

2. To develop a method of automatically measuring plate distortion for real-time feedback of plate deformation data;

3. To determine the optimum heat input;

4. To generate additional plate-forming data; and,

5. To perform an economic analysis of all plate-forming techniques.

The end goal of Phase II will be to host a demonstration of a laser line-heating system automatically forming a hull plate to a predetermined shape. Phase II is scheduled to be completed by December 31, 1986.

CONCLUSIONS

Overall Comment

Laser line heating is a very effective method of forming steel plates, especially plates in the thickness range of l/4 to l/2 inch. The major advantage of laser forming over the current flame-heating method is its accuracy and controllability. A plate can be formed to an exact shape in a repeatable manner. The process is fast, efficient, and requires little or no skill by the worker. The manner in which a plate deforms can be predicted by knowing. how the plate is to be heated.

The material degradation effects were minimal on laser-formed mild-steel plates. High-strength steel plates maintained conformity to Military Specification MIL-S-16216J after multi-pass low-heat line heating (e.g., three passes at 18 KJ/in.); however, material degradations were observed on high-strength steel plates that were subjected to a single pass of high-heat input laser line heating (e.g., 54 KJ/in.).

In general, lasers will not eliminate the need to roll plates due to the cost effectiveness of rolling. For example, the Japanese use rolls to perform the bulk of forming, then line heat to accurately form to the final desired shape.

Effect of Plate Thickness

For a given value of laser heat input, the amount of distortion increases as the plate thickness decreases. In other words, it is easier to bend a thinner plate than a thicker plate - Angular distortions in the amounts of 2 and 1.5 degrees can be achieved on plates 1/4 and 1/2 inch thick, respectively, by laser line-heating in a single pass. But for plates 3/4 to 1 inch thick, the amount of angular distortion obtained is decreased to approximately 0.8 degree for single-pass laser line-heating.

Thickness and Heat Input Limits

On the basis of the information obtained thus far, the maximum plate thickness for laser line heating is 1 inch, and the maximum laser heat input is approximately 65 KJ/in. The use of a higher heat input may not be practical because of the following adverse effects:

1. The intense heat caused by laser irradiation may result in the metal surface being damaged by melting; and,

2. Material degradation may become significant.

Effects of Primary Factors

The primary factors that affect the amount of angular distortion inelude the plate thickness, laser power, and plate travel speed. The heat input is expressed as 60 * 0.9 * P/v (0.9 represents a 10% optical loss in the laser system). The more significant results that were obtained from the experiments relative to the primary factors are summarized below:

1. For a given plate thickness, the amount of angular distortion increases with an increase in heat input. However, there appears to exist an optimum heat input that produces the maximum amount of angular distortion for each thickness. A further increase in heat input causes a reduction in angular distortion. Results obtained on l/4" thick plates indicate that the" maximum distortion of approximately 2.0 degrees can be achieved at the optimum heat input of approximately 19 KJ/in. For 1.2" thick plates, the optimum heat input appears to be in the range of 60-65 KJ/in., with a maximum angular distortion of approximately 0.8 degree per pass.

2. The plots between $:\sqrt{v})$ and angular distortion display that the data gathers in a narrow band for various combinations of t, P, and v. Hence, the parameter **$P/(t\sqrt{v})$ can be effectively** utilized as a primary algorithmic process parameter to estimate plate distortion.

Effects of Secondary Factors

The secondary factors that affect plate distortion include boundary constraints, cooling method, and heating locations. The results obtained concerning the secondary factors are:

1. When heating close to the plate edge, the amount of distortion decreases. This effect can be reduced by clamping the plate to a fixture,

2. A series of experiments has shown that the optimum cooling method is to place the plate on a bar of aluminum or copper and use natural air convection (assuming the facility is well ventilated); and,

3. By employing different heating patterns, it is possible to form a variety of complex shapes (e.g., dishes, saddles, and cones).

ACKNOWLEGEMENTS

The author would like to thank Professor Koichi Masubuchi and his graduate students for their quality research on this project and their patience for answering my many questions (Kbichi - I promise not to call after midnight again). I would also like to thank Clyde Brown, United Technologies Research Center, for his educated and valuable input.

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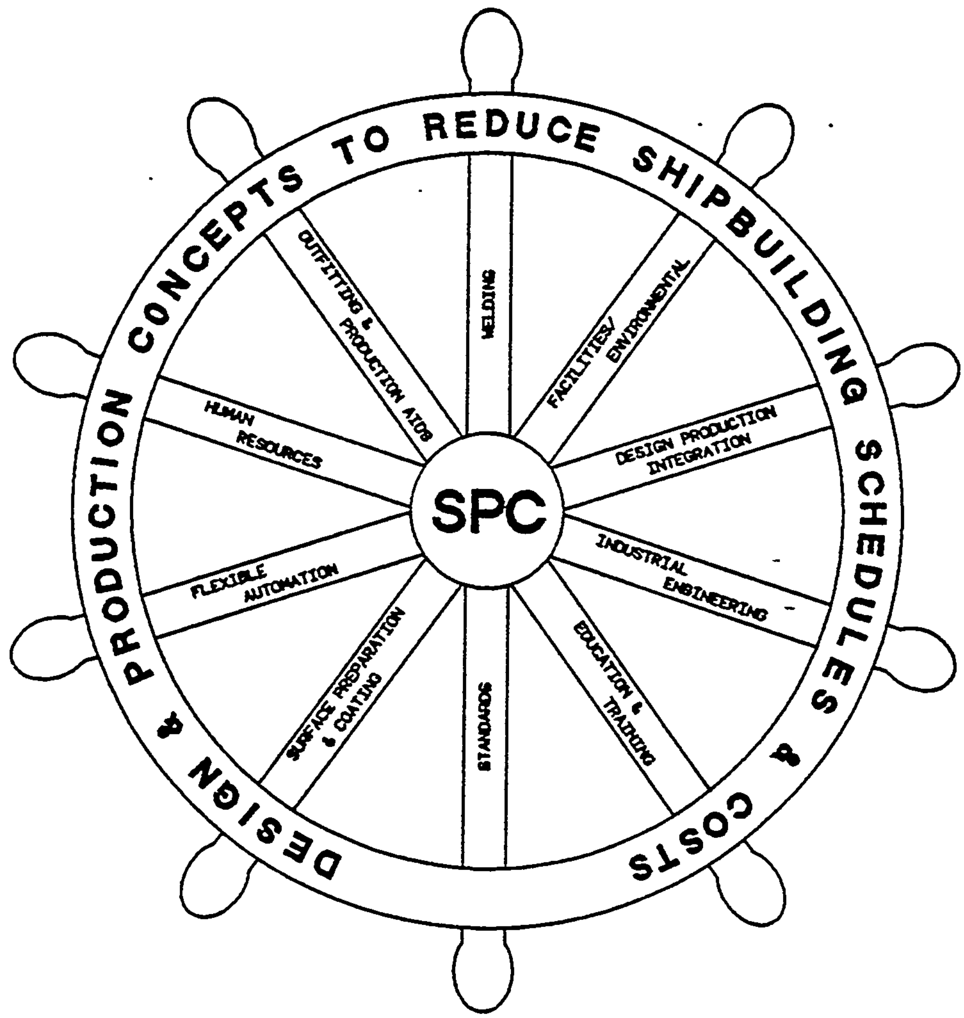

PAPER NO. 9

PLANNING FOR SHIPYARD SURFACE PREPARATION AND COATING

BY: J. A. CANTOR
R. F. ENDERT

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1986 SHIP PRODUCTION SYMPOSIUM

PLANNING FOR SHIPYARD SURFACE PREPARATION AND COATING

J. A. CANTOR AND R. F. ENDERT, DDL Omni Engineering

ABSTRACT

The surface preparation and coating (SP&C) functions occur late in the ship completion cycle and can be impacted by all previous schedule derangements. Therefore, acknowledging the complexities involved, the work content of the SP&C. activities were analyzed to plan, organize, and schedule work for effective production. This paper presents the results achieved and describes the self-contained instructional material available for use by SP&C planners and supervisors.

BACKGROUND

The surface preparation and coating (SP&C) functions in the shipbuilding and repair industry have historically been the last things to receive attention on the ship's construction completion list. As a result, SP&C fabrication, assembly, erection and outfitting processes often become subject to cumulative delays, omissions and changes. These shipbuilding activities become difficult to manage. Given the advent of hull block construction and zone outfitting in the United States shipbuilding industry, SP&C can be more effectively integrated into the total ship construction planning process. The Japanese shipbuilding industry has been a leader in this area. Shipbuilding, as a multifaceted industry requires the coordination of many trades to effect the desired outcomes. Peart, et.al. [1] describes painting as an integral part of that operation, and discusses the Zone Painting Method as a new concept in ship construction which is based on the Product Work Breakdown Structure. Peart describes Zone Painting Method in terms of proper planning and scheduling in coordination with hull construction and outfitting.

NEED

As work organization in terms of planning, scheduling and managing systems differ from shipyard to shipyard in the United States, a planning model, generic in nature and adaptable to individual organizational considerations is needed. Recent studies conducted by both the U.S. Maritime Administration and the U.S. shipbuilding industry confirm the labor intensiveness of the industry, relative to the international shipbuilding market (Peart & Soltz [2], Peart and Kurose [3], Jonson s Chirillo [4], Chirillo & Okayama [5]).

Productivity improvement through a reduction of man-hours and more work performed in segments rather than on-board is needed in order to improve the competitive position of U.S. shipyards. One such means to improve productivity is through improved shipbuilding techniques such as work packages associated with the hull block construction method, zone outfitting and painting, and through improved managerial efficiencies gained via information transfer and training. The National Shipbuilding Research Program recognizes this need and has sponsored a project to develop a package for training in surface preparation and coating work planning and scheduling.

OBJECTIVES

The objectives of this project were twofold:

1. To develop a surface preparation and coating (SP&C) work planning model which can be used to systematically plan, organize, and schedule work in a diverse U.S. shipbuilding community to achieve effective production.
2. To develop a self-contained course of instruction, generic in nature.

MODEL ASSUMPTIONS

The primary focus of this model is to provide those personnel involved in near-term planning, scheduling, and supervising of the surface preparation and coating operations with the necessary structure and framework for efficiently carrying out their job functions. The model is not designed to solve higher-level management, organizational planning, or scheduling difficulties that impinge on SP&C schedules but to assist the SP&C planners and supervisors in ensuring that they consider all aspects of their work that can affect efficient production. The model assumes that the users of this model are technically qualified in those aspects of surface preparation and coating for which they are responsible. The focus of the SP&C work planning is on new ship construction.

DEFINITIONS

Surface Preparation and Coating (sp&c): The surface preparation of all materials on the ship and their coating for preservation, appearance, and other functions (e.g., anti-fouling).

Near-Term Planning: Generally, the lowest level of planning and scheduling (2-week schedule) or to the first level of craft supervision (Foreman).

SP&C Work Planning: The means of performing the necessary steps to prepare for and accomplish SP&C tasks, including:

1. Determining where, when, and who will perform the work (planning and scheduling).
2. Acquisition of the required materials and equipment to perform the work.
3. Scheduling SP&C craftsmen to perform the work.
4. Integrating SP&C Craft work with work planned for other crafts.

Assembly: First level of construction outfitting - a preassembly of components for a system, an assembly of deck, shell and frames.

Slock: A group of assemblies Joined together to form an integral section of the vessel (bow, -stern, deck house, engine room). Blocks are joined together to form the complete vessel.

Zone: An identifiable space or group of spaces of the assembled vessel; it is used to establish boundaries for work and control purposes.

Planners: Individuals whose primary job function is to plan work accomplishment through equipment, processes, or manpower applications.

Schedulers: Individuals whose primary job function is to schedule work accomplishment through the various. planned processes in the most efficient manner.

SP&C Supervisors: Craft foreman and higher supervisors who are responsible for planning and scheduling SP&C work.

SP&C Operations: Craft performance of surface preparation and coating work tasks, e.g., blasking, cleaning, painting, etc.

METHODOLOGY

The study team responsible for this project consisted of two SP&C professionals with significant direct supervisory and management experience in work planning and execution in the SP&C area. They were teamed with two instructional systems designers experienced in instructional design and development. The approach taken by the team involved on-site surveys and reviews of several east and west coast shipyards to gain a familiarity with the general SP&C work planning practices. This information together with extensive reviews of technical documentation in and related to SP&C work functions, planning and materials and general ship construction documentation formed the basis for an initial drafting of the planning model.

Information gathering was conducted both at representative shipyards around the country in conjunction with SP&C work crews, supervisors and managers, and in "think tank" sessions involving the study team and consultants. Final testing of the model was carried out via a series of pilot convenings to use the instructional materials under actual teaching conditions with SP&C supervisors and managers. Feedback obtained as a result of these convenings was then reviewed and integrated, as applicable, into the final model. The project deliverables included the Technical Manual -- a discussion and description of the SP&C work planning model and its application within a ship construction organization, and an Instructor Guide containing a complete curriculum for a course in SP&C work planning for supervisors with supporting instructional materials. The curriculum materials consist of an Instructor Guide, Trainee Guide, sample class exercises, and transparencies. The materials are designed to be used either in classroom or self-study formats. The curriculum materials desescribed at the close of the paper can be obtained from either Avondale Shipyards or the U.S. Maritime Administration. This paper will describe the process for work planning for Surface Preparation and Coating.

THE PROBLEM

Several major problem areas in surface preparation and coating are inherent in the nature and complexity of ship construction and repair. First and foremost has been the pressure to complete surface preparation and painting just before delivery. Access, lighting, ventilation, staging and safety are frquently less than optimum. A lack of precision exists in preparing machinery, equipment, piping and modules for on-board installation, thus, surfaces often require re-preparation and repainting. The most completely controllable preparation and painting processes occur within a shop where there are installed blasting and coating rooms with adequate ventilation, dehumidification end drying facilities. The day-to-day problems normally associated with in-shop SP&C are non-availability of materials and schedule slippages.

Blasting, associated with surface preparation and coating within the yard and off-ship, presents the normal problems of wind direction and force, temperature and humidity, and closure/protection of any nearby equipment that could conceivably be damaged by blasting or coating. Reacting to these problems can cause frequent schedule changes.

SP&C on the ship presents the most varied situations and the largest number of problems. On-board SP&C can be roughly catalogued into underwater bottom, tank, compartments/superstructure and bilge situations. Each situation has somewhat different problems that must be considered and dealt with by the painting foreman, planners, and schedulers.

Given underwater bottom and appurtenances, various factors must be considered. These are: the type of blasting, the degree of white metal desired, shot removal, staging or man-lift equipment, vendor sen-ices, weather conditions, and the placing of preparation and painting materials in drydock on a not-to-interfere basis. Additionally, details such as heavy smoke exhaust from poorly maintained man-lift equipment, which deposits a film on the bottom, prior to painting must be dealt with by the painting planner, scheduler and supervisor.

Tanks present additional problems. Gas- free testing and authentication, humidity and ventilation control, shot removal, staging within the tank, proper grounding and safety watches must be considered and scheduled. The cumulative effects of these factors complicate the supervisor's job in advance of and during the surface preparation and coating process.

Compartments and superstructures present the normal types of preparation, weather, temperature/humidity problems. In addition, the interference problem caused by both planned and unplanned work by other trades makes scheduling difficult for the painting supervisor.

Bilges, in-place machinery, and equipment preparation and coating present a myriad of problems that cover all aspects of the safety, staging, temperature/humidity, and interferences. No two jobs are alike and all require close attention, flexibility, and patience on the part of the SP&C supervisor. For example, if the SP&C involves working on nuclear-powered ships for construction and/or repair, then the number of scheduling constraints may be significantly increased.

The computer, sophisticated Gantt charts, and aspects of PERT and CPM are all devices that, when used properly, will assist the painting supervisor/foreman in accomplishing his difficult job of maintaining productivity with his man/material resources. It would appear, however, that sophisticated scheduling must be coupled with a realization that major improvement in SP&C efficiency cannot be accomplished by the blasters and painters in isolation from other trades. The SP&C tasks must be considered in each step of the total ship construction/overhaul process.

There are a number of factors that differ from shipyard to shipyard and from project to project. Because of the variety and diversity of these factors it is not possible to set forth stringent rules, methods or considerations that the SP&C planner/scheduler can apply directly to one's particular situation. Rather, one must apply them within the context of the home shipyard and specific project.

Some of the major factors that cause each yard to be quite different are as follows:

- The degree to which block/-zone/ module pre-construction, preoutfitting and pre-SP&C (before on-ship erection) is in use affects all planning and scheduling.

- The method of organization, titles and distribution of responsibility and authority among the design, engineering, planning, procurement and production departments can differ significantly from yard to yard.

- Methods and systems for work accomplishment can vary significantly because of size of the project and whether it is new construction, major overhaul or repair.

- Different projects/jobs can have varying time/cost constraints which affect planning and scheduling.

- The actual facilities and equipment for SP&C operations will vary from yard to yard (e.g., a large modern blast house vs. none or an antiquated facility) .

- The geographical location of the shipyard has considerable effect on planning and scheduling because of weather, water access,. and physical restrictions.

- Variations from state to state and among local municipalities with respect to environmental rules and regulations can change methods, schedules and procedures from yard to yard.

- The degree to which outside vendor services are used to accomplish SP&C operations affects scheduling flexibility and control.

- The differences in customer specifications, inspections and certifications directly affect methods, planning and scheduling.

A typical shipyard organization follows as a means of illustrating this concept.

Thedetailed SP&C plans and schedules with respect to what, where and when tasks are completed in the total process are a function of the overall system in the shipyard.

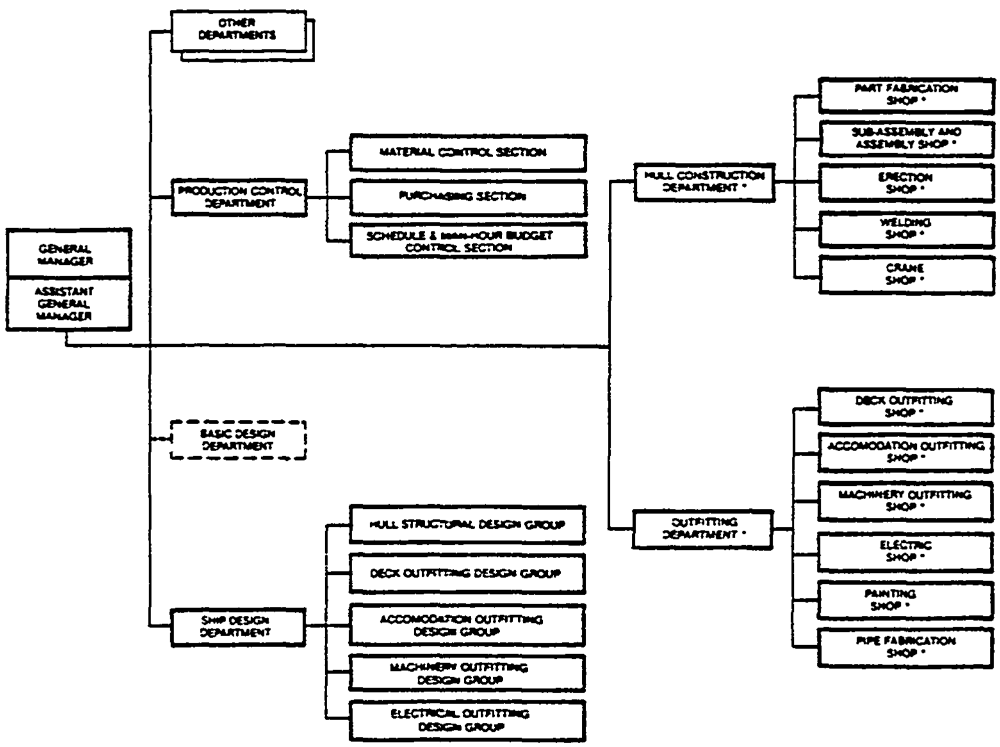

Figure 1. Typical Shipyard Organization.

Since both the type and magnitude of pre-construction, fabricating, outfitting and SP&C work prior to erection and/or installation on the ship can vary significantly both from yard to yard and project to project, it is not possible to specify in detail systems/procedures/plans that would work for all shipyards.

Within the context of this model it is intended that the following basic requirements or subsystems would be discussed from the viewpoint Of the most practical and productive means of improving overall SP&C short-term scheduling.

- An SP&C feedback data system from on-the-job production to engineers, planners, designers and proposal writers that provides up-to- date time/manpower standards by type job, location, special conditions, and recommendations for alternative methods/equipment, etc.
- Method(s) to ensure that SP&C department experts contribute to proposals, paint schedules (specification by project/ship), work flow plans and conferences that integrate trade requirements by space/location on the ship.
- A system whereby, once the near-term schedule is fixed, the responsibility for pre-positioning equipment and prep and coating materials and ensuring that the production employee is properly dressed-out is clearly defined so that the shift supervisor can start actual work immediately.
- A material classification and standard SP&C flow pattern through the yard for each classification so all engineers, planners, schedulers will be aware of the intended location and type of prep or coat for each type of material (piece, part, subassembly, module, non-structural component).

WORK PLANNING FACTORS

The following discussion presents the details of thirteen planninq factors which should be considered in the total process of establishing the most efficient SP&C work plan. This discussion does not categorize the factors into near, middle or long term. The near-term SP&C supervisor and work planner is somewhat at the mercy of how well others in the yard plan for and consider, the many aspects leading to "limited rework" on ship. However, the near-term SP&C planner/scheduler can cause improvements by considering all of these and contributing his opinions, suggestions and recommendations. This model uses the term "planning factors" (for the planner/scheduler/supervisor) in its broadest sense.

The planning factors, including the variables considered for each factor, have been identified as follows:

These factors provide a structure from which to address the multifaceted problems of SP&C work planning. The groupings are designed to assist planners/schedulers and supervisors concerned with near-term work accomplishments of the ship repair/construction process. The information provided in the detailed matrix, a sample cited herein, provides information from the research to be used to develop the model.

SHIPBUILDING PLANNING PHASES

This structure provides a means of addressing the multifaceted problems of SP&C work planning. The work planning factors are designed to assist planners/schedulers and supervisors concerned with near-term SP&C work planning for ship construction or repair. The matrix provides information from the research which was used to develop the training manual. The work planning factors are presented in the model within the context of five shipbuilding planning phases:

- Pre-Construction Planning and Operations
- Assembly-Level Operations
- Design Planning
- Block-Level Operations
- Zone-Level Operations

PHYSICAL DESCRIPTION SIZE OPENINGS SHAPE MATERIAL TYPE WEIGHT. CONDITION
LOCATION OFF-YARD IN-SHOP IN-YARD OFF-SHIP EXTERNAL ON-SHOP-INTERIOR
SUPPORT HANDLING VENTILLATION UTILITY SERVICES STAGING CHEMIST TEMPORARY PROTECTION CLEANUP SAFETY ENGINEER VENDORS
SPECIFICATIONS SOURCES THICKNESS TYPE OF COATING DRY/CURE INSPECTION APPLICATION METHOD SURFACE PREPARATION NUMBER OF COATS
TIME/MANPOWER MANPOWER PLANNING LABOR SKILLS LEVEL ALLOTTED TIME SCHEDULE ESTIMATED TIME TO COMPLETE AVAILABLE MANPOWER SCHEDULE VS TIME ESTIMATE SPACE RESTRICTIONS
MINIMIZING REWORK WHEN TO APPLY PRIMER WHEN TO APPLY INTERMEDIATE WHEN TO APPLY FINAL
MATERIAL EXAMPLES OF MATERIALS SAFETY
INSPECTION SPECIFICATION REQUIREMENTS INTERNAL REQUIREMENTS FOREMAN'S LEVEL
SCHEDULES CONTRACT SCHEDULES MASTER SCHEDULE MAIN EVENTS SCHEDULE SHOP MANUFACTURING SCHEDULE MODULE BLAST/COAT SCHEDULE HULL ERECTION SCHEDULE LAUNCHING SCHEDULE DOCKING SCHEDULE OUTFITTING SCHEDULE
EQUIPMENT TYPE OF SP&C SUPPORT OPERATIONS (i.e. FORK LIFT) TYPE OF CLEANING EQUIPMENT TYPE OF COATING EQUIPMENT
HANDLING AND STORAGE WHAT/WHY/WHO WHAT IS TO BE HANDLED WHY IS IT TO BE HANDLED WHO IS TO HANDLE IT ROUTING AND SCHEDULING STORAGE
DISRUPTION/INTERFERENCE GENERATED BY SP&C BLAST OPERATIONS COATING OPERATIONS CURING OPERATIONS
SAFETY WHAT AND WHO SP&C HAZARDS

Figure 2. Surface Preparation & Coating Work Planning Factor Considerations

Practical applications of SP&C work planning which apply generally to each of these shipbuilding planning phases are as follows:

a. Prepare and paint as early as possible in the ship construction process.

The design planning phase will involve allowing for surf ace preparation and coating of pieces before assembly to the extent possible. It will also allow for predetermination of the best and earliest points for SP&C on each assembly - whether at the preconstruction stage or at either the assembly, block or zone levels.

b. Do as much as possible under SP&C controlled conditions.

SP&C operations are best carried through under controlled conditions whether on-board or in a paint house. This is true in any of the phases. Blasting operations will be accomplished under safer and more efficient circumstances in a controlled environment.

c. Use blast and paint houses when possible.

Blast and paint houses are controlled by the SP&C Craft personnel. Therefore, planning for using these facilities whenever possible in each of the phases will prove to be the most efficient means for SP&C operations.

PHYSICAL DESCRIPTION (of the item to receive SP&C)			
SIZE	Sq. Ft. Area/Cu. Ft. Area/Quantity Pieces Affects - Handling, transportation - Quantity of labor and material - Schedules and work location	Size data comes from SP&C Spec. Drawings, groups, shop mfg. orders or similar instructions included in work packages. Needs to be considered early in the planning process.	For off-ship SP&C work - put primer coat on small pieces/plates/beams/brackets/foundations/pipe hangers/nuts/bolts/washers doors/hatches, etc.
SHAPE AND APPURTENANCES	Affects - Handling, positioning - Ventilation, Staging, lighting, access	Impacts decision on how and where SP&C is best accomplished and SP&C efficiency	- put intermediate coat(s) on intermediate size PCS subassemblies, modules, etc.
WEIGHT	Affects - Handlings (liftings) movings	Important to off-ship work (N.A. to on ship work.)	- put final coats on large pre-erection assemblies and aux. items such as masts/king posts/smokestacks/elevators
OPENINGS	Affects - Ventilation, lighting accessibility/protection/staging/number workers/cleanup/curing	Generally more opening preferred except "In-yard" requires more protection, to blank the excess openings	
TYPE MATERIAL	Whether Mild, HY-80 Steel, S.T.S. Aluminum Stainless Steel, other Affects - Selection of SP&C extent of protection type of blast media	Determines the types of SP&C process and length of time to perform it.	- put primer on as soon as structural erection is complete in area
CURRENT MATERIAL CONDITION	New steel, w/wo millscale, Rusty old paint, Toxic/non-toxic, Grease, Oil, Special contaminations	Impacts type cleaning Impacts type personnel protection Impacts cleanup and disposition of residuals Impacts degree of disruption to	- put final coats on per compartment completion schedule * NOTE - All plate to be blasted and coated 3/4 mil with pre-erection primer

Figure 3. Physical Description Work Planning Factor Characteristics

d. Apply preconstruction primer as an extension of other fabrication processes.

To the extent possible in the early stages of planning and construction, the applications of primer **as a** part of most fabrication processes will expedite the completion of SP&C functions. This will require close planning cooperation between SP&C planners and the other crafts. This might also require establishing SP&C functions within other craft houses.

e. Paint final coats only after all other work is done in order to minimize rework.

Proper SP&C coordination and work planning will provide for little or no rework through withholding of final coat applications until all other work is completed. This will involve close coordination with other trades' work planning.

f. Minimize hand work when possible.

Hand work is expensive and time-consuming. Therefore, hand work should be limited to areas and applications which are absolutely essential.

g. It may be cheaper to move the paint than the item to he painted (cost trade off).

Careful consideration should always be given to bringing the SP&C processes to the work site whenever significant rigging or handling activity becomes necessary in order to move the objects to be prepared. Planning attention should be given to the cost benefits derived by moving the SP&C activity to the work site versus moving materials to the SP&C shop.

Inspect <u>before</u> you paint as well as after painting.

Inspection should be done to ascertain conditions of materials which might indicate need for fabrication rework prior to SP&C. This will reduce SP&C rework later. Post-SP&C inspection is also necessary to reduce the need for return visits.

i. Plan the blaster's and painter's work in relationship to other crafts which are involved in the construction process.

Blasting and painting are two craft tasks which require controlled conditions. As such, they will interfere with (and be interfered with by) other craft operations. Therefore, SP&C planning and coordination with other crafts is essential.

The following benefits can be derived through application of these work planning factors to ship construction using the hull block construction approach.

Reduced blasting and painting time through more efficient coordination with other trades and more efficient planning of the SP&C tasks.

- Minimizing of onboard work, therefore better use of SP&C houses and more preconstruction SP&C work - earlier SP&C applications.
- Simplification of SP&C plan- ning and scheduling through coordination with other craft planners.
- Avoidance of interference between trades through early planning of SP&C activity.
- Greater efficiency achieved in handling equipment and material through reduced transportation of these items for SP&C work.
- Improved safety through more controlled operations and less intercraft interference.
- Improved working environment as a result of these improved efficiencies and controls.
- Improved productivity - as a result of the time saved, more manpower can be detailed to other important jobs.

Improved quality - as a result of these savings, more effort can be devoted to a better product.

Minimized rework equals greater profits.

APPLICATIONS

The design planning phase (pre-award) will involve the planning, budgeting and scheduling necessary to prepare competitive bids for new ship construction and alteration - repair projects. The ultimate aim is the optimum design for such work within yard constraints. Each of the SP&C work planning factors is considered with respect to the pre-award design planning phase process. An example of this process,is presented below:

Factor #1: Physical Description

a. In Yard. For materials fabricated in the yard, SP&C design planning inputs will consider the type of materials, (their composition and purpose), the construction stages, and the size, shape, weight, openings and appurtenances at each construction stage, and the client's SP&C specifications.

b. SP&C planning considers ways to put primer coat on small pieces, plates, beams, brackets, foundations, pipe handlers - nuts, bolts, washers - doors, hatches, etc. for off-ship SP&C work.

PRECONSTRUCTION

The preconstruction planning and operations phase is concerned with the planning, budgeting and scheduling in conjunction with a new project awarded to the yard. The objective of this planning phase is to effectively execute the job well within the proposed project values to maximize profit.

Preconstruction Planning includes:

a. Planning material processes

b. Issuing purchase orders and contracts

c. Planning material receipts, processing and storage

d. Developing detailed work schedules

e. Developing shop load plans

f. Writing work packages

g. Taking the design plan and converting it to a work plan

h. Determining module sizes

i. Developing work process flow paths

Preconstaction Operations include:

a. Material preservation upon receipt

b. Raw material processing

c. Material cutting, shaping, bending

d. Subassembly manufacture

The SP&C Work planning factors will influence preconstruction planning and operations in the following manner:

a. Influencing the preconstruction planning process and operations to make SP&C work that follows the most efficient as it is translated into:

   o Detailed work schedules

   ° Material and equipment requirements consistent with the bid specifications

   o The cost of operations based upon the bid price

b. Once the design plan has been translated to detailed work packages and fixed schedules, the SP&C planner has very little influence over his efficiency, or destiny on the project. His work is now driven by what others produce for him to paint.

c. The most effective operations will be built from this process, integrating the SP&C planner into the detailed yard planning process with other craft planners.

An example of the Physical Description SP&C Work Planning Factor application is illustrated below for preconstruction planning and operation.

Factor #1. Physical Description

a. Plan work packages and schedules for:

   o Size of items for in-shop SP&C

   o Minimizing in-yard open work on items with many openings

   o Minimizing number of item appurtenances

   o Minimizing degree of SP&C difficulty

ASSEMBLY

SP&C work factor "planning for each of the assembly; block - and zone-level construction operations proceeds as follows. For assembly-level operations, there will be a transition of work from SP&C-controlled shops and spaces to the open yard. Small assemblies will be put together as subassemblies with some work still done in the shop. Subassemblies are put into sub-block level configurations. All of this work will now require increased coordination between work crews and the various trades. Planners must schedule near term against. . .

Other trades' deadlines

Availability of personnel mix

Availability of materials

Availability of support resources

There also exist more chances for obstacles to meeting the desired goal; i.e., weather, etc.

BLOCK-LEVEL CONSTRUCTION

Work planning factor planning for block level oprations involves characteristics different from assembly-level operations. There is increased work carried on in the open yard in spaces controlled by other trades. Work is done on assemblies foundationed on blocks and on erected hull structures.

Near-term planning and scheduling is done in work packages generated from production control. There are increased safety requirements, increased materials and handling requirements and increased appurtenances and access openings to be considered. Planning for support requirements such as lighting, ventilation, etc. must be accomplished. All in all, the complexity of operations will be felt by all departments. This increased interaction will affect near-term planning in terms of:

deadlines

- Availability of personnel mix
- Availability of materials
- Availability of support resources
- Weather

The goal of SP&C planners and schedulers is to complete as much SP&C work in as close to finished condition (and in accordance with specifications and construction stage constraints) as possible.

The SP&C efficiencies to be realized include opportunities, despite increased complexity, to:

- spot opportunities that arise from other trades' misscheduling holdups.
- Use coordination lines that are shorter because one interacts with fewer trades' supervisors and personnel.
- Implement closer supervision.

ZONE-LEVEL OPERATIONS

The last of the construction levels, zone-level operations, involves the movement of work onboard the erected ship. In this regard, work must be performed with the ship in water, with an open deck environment, and involving spaces controlled by other than SP&C trade personnel on both internal and external SP&C tasks. This means that the need for temporary services such as water, heat and elevators will increase.

Near-term planning and scheduling is based again on work packages originating in Production Control. Considerations must-be made for the increased need for temporary services, the need for several intermediate coats and remaining final coats of paint on all involved services, increased equipment-and-materials-handling requirements, preparation and cleaning and increased appurtenances and restricted access to spaces and surfaces.

The zone-level construction stage involves the greatest complexity of all of the steps for all trades. Maximum disruption and interference from other trades can be anticipated. Therefore, planners usually schedule near-term work through plan-of-the-day meetings to consider:

- Other trades' deadlines/-rework
- Availability of personnel mix
- Availability of materials
- Availability 05 support resources
- Weather

Therefore the zone-level construction phase requires maximum coordination, as well as SP&C contingent plans, and increased supervision requirements to effect the planned work as well as integration of shift work.

TRAINING MATERIALS

The training materials designed for the SP&C Work Planning course provide the framework of the training to be presented to SP&C supervisors, planners and schedulers. The details include:

A. The course objectives and topic objectives.

B. Course outline for instructional purposes.

C. Training aids (viewgraphs, charts, handouts, etc.).

The shipyard organization presenting the course will be able to use the manual both for student self-instruction or for classroom or workshop type of instruction in groups. The overall goal of the course is to develop surface preparation and coating supervision abilities to systematically plan, organize and schedule work on a weekly and daily basis to achieve effective production.

Because SP&C work planning is so integral with all of the other ship construction processes, there are several ways to approach the training effort. These strategies for SP&C training are:

- Train the supervisor to apply the applicable planning factors on any type of job he may encounter. This training approach would be very broad. It is based upon the supervisor not being able to influence his near-term schedules.

- **Train the SP&C supervisor to use the planning factors he can control to work a given 2- week schedule. This minimizes his interac**tion with other SP&C planners and focuses directly on work planning (manpower, equipment, materials, and processes) that he can regulate on a day-to-day basis.

- Train the SP&C supervisor to understand the Planning factors and how to use them in interaction with the Planning and scheduling process of the shipyard. This approach recognizes that his work planning is as efficient as his near-term schedules (developed by others) will allow him to be. The emphasis now would be on the SP&C supervisor working with planners and schedulers to develop the most effective schedules for him to execute.

- Train the planners and schedulers in understanding the planning factors to be applied in developing near-term SP&C schedules. This training would focus on better planning for SP&C work through greater understanding by those outside the paint departments of the effects of their decisions on SP&C work efficiency.

The course of instruction designed for the delivery of the SP&C Work planning Model consists of a two-day rigorously structured lecture/discussion session with several planned group exercises. The lecture/discussion provides the structure and elements of the SP&C Work planning Model. The exercises provide an opportunity for the workshop participants to apply the newly acquired skills and knowledge within the context of their individual shipyard organizational structures.

The course materials consist of the Technical Manual, which details the model including detailed work planning factors; the Instructor Guide, which provides lecture points and references to the prepared viewgraphs, exercises and technical references; the Student Guide (formatted to accompany the Instructor Guide), which provides the trainee with a framework for following the instructor through the course. Within any of the preceding approaches there are determinations to be made on the ways in which to logically organize the material.

SUMMARY

As part of a continuing effort to improve shipyard efficiency, the Ship Production Committee, SP-023-1, Surface Preparation has sponsored this project, entitled Work Planning for Shipyard Surface Preparation and Coating, under the auspices of the National Shipbuilding Research Program. and through Avondale Shipyards. The model described is based-upon recent industry developments in Zone Painting and Product Work Breakdown Structure, which have led to an emphasis on the cost savings that accrue when detailed planning and scheduling are done well in advance of the actual work. The processes of surface preparation and coating are being emphasized because they represent an increasingly significant part of the cost of new ship construction and overhaul, and because historically the proper planning,scheduling and prioritization - of processes have been neglected. The model provides a basis for work planning based on thirteen identified and described work planning factors. The model defines work planning in terms of design planning, near-term planning and three levels of hull block construction. The model is then presented to planners, schedulers and managers in a two-day action-oriented workshop.

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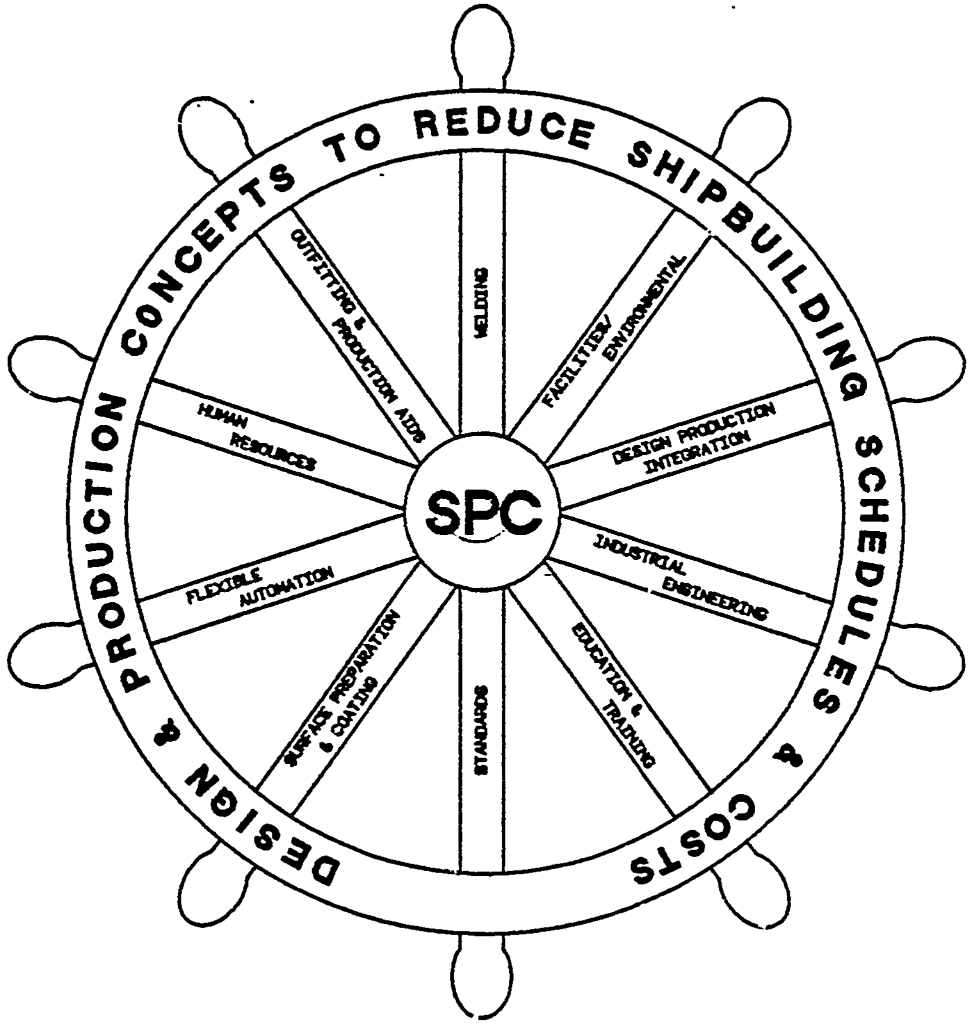

PAPER NO. 11

ADAPTION OF JAPANESE PREFABRICATION PRIMING PROCEDURE TO U. S. SHIPBUILDING METHODOLOGY

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ADAPTION OF JAPANESE PREFABRICATION PRIMING PROCEDURE TO U. S. SHIPBUILDING METHODOLOGY

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ABSTRACT

Current U.S. shipbuilding practices require that the preconstruction primer be "Near-White Blast Cleaned", followed by the application of a new zinc primer, and the remainder of the coating system. In Japan, the original primer is minimally cleaned (power Tool) with the primer not removed. Instead, it becomes a component of the final protective coating. This paper describes a comprehensive test program conducted to evaluate the two practices and presents the results obtained.

The U.S. and Japanese Marine shipbuilding coating practices currently involve the application of a preconstruction primer to blast cleaned steel prior to fabrication. After fabrication, the Japanese incorporate this primer into the protective coating system after minimal cleaning (Steel Structures Painting Council SSPC-SP3, "Power Tool Cleaning"). In contrast, the U.S. removes this primer by blast cleaning in accordance with Steel Structures Painting Council SSPC-SP10, "Near-White Blast Cleaning" followed by the application of a new inorganic zinc primer and the remainder of the coating system.

The National Shipbuilding Research Program discussed in this paper was designed to compare the U.S. and Japanese methodologies when used with six different coating systems: coal tar epoxy, polyamide epoxy, inorganic zinc, chlorinate rubber, vinyl, and bleached tar. Products from two Japanese suppliers and two U.S. suppliers were used. The Japanese materials were applied following the Japanese methodology only (incorporating the preconstruction primer into the final system) while the U.S. materials were applied following both methodologies.

The test exposures used to evaluate performance included:

Six-month 150°F Salt water immersion (three month grading reported).

Cycled pressurized immersion at 80 psi head pressure.

Alternating UV/heat/immersion cycling KTA Envirotest).

Salt fog exposure (2000 hours).

18-month ocean-front field exposure at Ocean City Research Laboratory.

This paper discusses the preparation of the test coupons and the general results of short-term accelerated weathering testing complete to date. Final testing will not be completed until 1987.

COATING SYSTEMS

Thirty-two (32) coating systems were used:

Preconstruction Zinc/Coal Tar Epoxy (Japanese Methodology)

Manufacturer J-A (Japanese)
Manufacturer J-B (Japanese)
Manufacturer U-A (U.S.)
Manufacturer U-B (U.S.)

Preconstruction Zinc/SP10/Inorganic Zinc/Coal Tar Epoxy (U.S. Methodology)

Manufacturer U-A (U.S.)
Manufacturer U-B (U.S.)

Preconstruction Zinc/Polyamide Epoxy (Japanese Methodology)

Manufacturer J-A (Japanese)
Manufacturer J-B (Japanese)
Manufacturer U-A (U.S.)
Manufacturer U-B (U.S.)

Preconstruction Zinc/SP10/Inorganic Zinc/Polyamide Epoxy (U.S. Methodology)

Manufacturer U-A (U.S.)
Manufacturer U-B (U.S.)

Preconstruction Zinc/Inorganic Zinc (Japanese Methodology)

Manufacturer J-A (Japanese)
Manufacturer J-B (Japanese)
Manufacturer U-A (U.S.)
Manufacturer U-B (U.S.)

Preconstruction Zinc/SP10/Inorganic Zinc (U.S. Methodology)

Manufacturer U-A (U.S.)
Manufacturer U-B (U.S.)

Preconstruction Zinc/Chlorinated Rubber (Japanese Methodology)

Manufacturer J-A (Japanese)
Manufacturer J-B (Japanese)
Manufacturer U-A (U.S.)
Manufacturer U-B (U.S.)

Preconstruction Zinc/SP10/Inorganic Zinc/Chlorinated Rubber (U.S. Methodology)

Manufacturer U-A (U.S.)
Manufacturer U-B (U.S.)

Preconstruction Zinc/Vinyl (Japanese Methodology)

Manufacturer J-A (Japanese)
Manufacturer J-B (Japanese)
Manufacturer U-A (U.S.)

Preconstruction Zinc/SP10/Inorganic Zinc/Vinyl (U.S. Methodology)

Manufacturer U-A (U.S.)

Preconstruction Zinc/Bleached Tar (Japanese Methodology)

Manufacturer J-A (Japanese)
Manufacturer J-B (Japanese)
Manufacturer U-B (U.S.)

Preconstruction Zinc/SP10/Inorganic Zinc/Bleached Tar (U.S. Methodology)

Manufacturer U-B (U.S.)

PREPARATION OF TEST COUPONS

Test coupons for the program were fabricated to simulate the procedures used in the shipbuilding industry. Mill scale bearing carbon steel test plates l/4" x 14" x 34" in size were blast cleaned using #24 aluminum oxide to a degree of cleaning-in accordance with Steel Structures Painting Council SSPC-SP10, "Near-White Blast Cleaning". A 2.0 to 2.5 mil surface profile was obtained.

Weldable preconstruction shop primers from each of the four coating suppliers were applied by automatic spray to both sides of the test plates at a film thickness from 0.5 to 0.7 mil. Approximately eleven (11) plates were coated with each primer.

Conventional (air) spray was used, consisting of a DaVilbiss Type AGB automatic spray gun fitted with a pressurized pot and individual pot and atomization pressure controls. An EX tip and needle assembly and a No. 704 air cap were used for the application of the preconstruction primers. The spray gun and pressure pot are mounted on the arm of an automatic sprayer which operates on an electric/hydraulic principle controlling both the traverse rate of the spray gun and the gallons per minute (gpm) flow rate of the materials. The automatic sprayer provides consistent control of the film thicknesses required for this type of application.

The primers were allowed to cure for approximately one to two weeks, then the large 14" x 34" test Plates were cut into 6" x 10" test coupons using an acetylene torch. The panels were flame cut rather than sawed in order to simulate shipbuilding cutting (burning) procedures, so that the effect of heat on the preconstruction primers might be evaluated. After cutting, a weld bead approximately 6" in length was deposited onto the front side of each test panel to simulate shipbuilding welding practices, and to create a heat effected zone on the backside.

The preconstruction primers were subsequently weathered by placing the coupons outdoors in a northern climate (Pittsburgh, Pennsylvania) for a four to six week period during April, May, and June, 1985. The natural weathering was assisted by a daily tap water wash and a weekly 0.5% sea salt water wash.

After the outdoor exposure, the zinc primers exhibited white zinc salts and the weld bead and edges of the coupons contained medium to tightly adherent red rust. The appearance was felt to be representative of preconstruction zinc primers after fabrication.

The panels were thoroughly rinsed with fresh tap water prior to further surface preparation. The four sets of panels representing the Japanese methodology (two Japanese and two U.S. suppliers) were power tool cleaned using a No. 16 mesh disc-type sanding wheel. The, cleaning removed the zinc oxides and loose rust, but allowed approximately 90% of the preconstruction primer to remain in place. The weld bead and edges were prepared using a rotary cup wheel, and cleaned to "Bright Metal". After Cleaning, those panels designated for immersion tests were "stripe-coated" at and around the weld bead, and along edges using a brush-applied organic zinc-rich supplied by the respective coating manufacturers.

The remaining sets of coupons from the two U.S. suppliers (representing the U.S. methodology) were blast cleaned in accordance with Steel Structures Painting Council SSPC-SP10, "Near-White Blast Cleaning". This resulted in complete removal of the preconstruction primers. An inorganic zinc-rich coating was applied.

The finish coats were applied to all six panel series at the same time. After sufficient cure of the topcoat materials, the test panels were subjected to the accelerated weathering environments and field exposure.

TEST EXPOSURES

Duplicate test panels of each coating system were exposed to the weathering tests described below.

Salt Fog

Salt fog testing was performed in accordance with ASTM B 117 "Standard Method of Salt Spray (Fog) Testing". A total of 2000 hours of exposure were used.

Salt Water Immersion at 150°F

The test panels were totally immersed in a 3% solution of synthetic **sea salt water heated to 150°F ± 5°F.** In addition, an aerating tube was included in the chamber. The test design is six months. Three months have been completed at the time of the writing of this paper.

80 psi Head Pressure Cycling

A pressurized/depressurized immersion test was comprised of three cycles conforming to the following schedule:

14 days of 3% synthetic sea salt water immersion at 80 psi.

3 days drying at atmospheric pressure.

The test panels were graded after the first, second, and third cycles. The results after the third and final cycle are reported.

KTA Envirotest

The Envirotest automatically cycles panels in immersion (3% simulated sea salt water) and drying under heat/ultraviolet lamps at a temperature of 130°F. The cycle consists of approximately one hour immersion followed by one hour of drying on a 24 hour per day-seven day per week basis. The test was designed for a total of two months exposure. Because of the limited capacity of the test apparatus, the panels were exposed in three sets. The results of two sets are reported; the exposure of the remaining set is underway.

Field Exposure

The systems are being exposed to 18 months of ocean-front exposure at Ocean City Research Laboratory, Ocean City, New Jersey. Four months of exposure have been completed with no significant failures observed.

TEST PANEL GRADINGS

Each of the grading areas (plane surfaces front and back, weld, heat effected zone, edges, and scribe) was graded individually for corrosion, blistering (ASTM D 714 "Evaluating Degree of Blistering of Paints"), cracking, delamination or other defects. The raw data at each of the grading areas was then converted into a 0-4 rating scale in order to arrive at a single performance number, to facilitate a system-to-system comparison. The results are shown on the attached tables:

Table I - 2000 Hours Salt Fog (Final Grading) Test Results - Blistering/Corrosion

Table II - **Sea Water Immersion** at 150°F (Three Month Grading) Test Results - Blistering/Corrosion

Table III - 80 psi Head Pressurize Cycling (Final Grading) Test Results - Blistering/Corrosion

Table IV - KTA Envirotest (Final Grading for One-Half of Systems) Test Results - Blistering/Corrosion

The basis for the 0-4 rating scale is shown below:

Front and Back Plane Surfaces

Blister Rating:

Blister Size/Frequency*

Rating	3.5	3.0	2.5	2.0
	8F	8M	8MD	8D
Blisters	6F	6M	6MD	6D
	4F	4M	4MD	4D
	2F	2M	2MD	2D

* Per ASTM D 714.

ASTM Rust Grades:

Rust Grade 9	Rating - 3.5
Rust Grade 8	Rating - 3.0
Rust Grade 6-7	Rating - 2.5

Weld Area and Heat Effected Zone

Ratings follow the blister tables shown above for front and back plane surfaces. In addition, a rating of 1.0 was subtracted from each when corrosion was present.

Edges

Rating 4.0 - No corrosion.
Rating 3.0 - Light rusting.
Rating 2.5 - Light rusting with slight blistering.
Rating 2.0 - Heavy rusting.
Rating 1.0 - Heavy rusting plus a few blisters.
Rating 0.5 - Heavy rust plus many blisters.

Scribe

Rating 4.0 - No defects.
Rating 3.0 - Light rust or few blisters.
Rating 2.5 - Light rust with blisters.
Rating 2.0 - Heavy rust.
Rating 1.5 - Heavy rust with blisters (4F, 6F, 8F).
Rating 1.0 - Heavy rust with blisters (2F).
Rating 0.5 - Heavy rust with many blisters (2M, 4M).

Weighted Average

It is acknowledged that scribes, welds, and edges will be more prone to failure than plane areas. In order to account for this difference, the ratings for the front and back sides of the panels were given a weight of 2X while the ratings for the irregularities were given a weight of 1X when the total rating numbers were compiled.

The cumulative ratings are shown on Tables V through IX as discussed under "Results".

Results

The results for the salt fog, sea water immersion, and 80 psi pressurized/depressurized cycle have been tabulated. The results of the KTA Envirotest have not since only one-half of the test panels have completed the exposure. The tables attached showing the test results are as follows:

Table V - System Ratings - Salt Fog (2000 Hours)

Table VI - System Ratings - Sea Water Immersion at 150 F

Table VII - System Ratings - 80 psi Pressurized/ repressurized Cycle

Table VIII - System Ratings - Average of Three Exposures Combined (Salt Fog, Sea Water Immersion, 80 psi Cycle)

Table IX - Average System Performance Per Generic Type

CONCLUSIONS

The following conclusions can be drawn from the data compiled to date:

A. There are often significant differences in the performance of given generic coating types even though the exposure environments are the same. That is, all manufacturer's epoxies (for example) do not perform the same.

B. Salt Fog Exposure - The best and most consistent performers among the manufacturers were the inorganic zinc (used as a finish coat) and coal tar epoxy finish coat. The poorer performers are the chlorinated rubber and vinyl finish coats.

C. Sea Water Immersion at 150°F - After three of the six-months of exposure, the scatter of the data between manufacturers in each generic type is so wide, that it is difficult to generalize as to which generic types are the best and worst performers. Given this concern, it appears as if the inorganic zinc (used as a finish coat) and the coal tar epoxy will again be the front runners with the chlorinated rubber tending toward the worst.

D. 80 psi Pressurized/Depressurized Cycle - When averaging all manufacturer's products together, the best perfomers are again-the inorganic zinc (used as a finish coat) and coal tar epoxy. The spread in data is too wide to generalize on the worst performers.

E. Envirotest - Conclusions are not being drawn on the Envirotest since only on-half of the manufacturer's systems have been exposed.

F. Combined Exposure Data - Japanese Methodology - The results for all of the coating manufacturer's products have been averaged together for the salt fog, 150 F sea water immersion, and 80 psi cycles combined. The data is presented in Table IX, and can be summarized as follows:

Japanese Methodology (Best Performers to Worst)

1. Coal Tar Epoxy
   Inorganic Zinc

2. Bleached Tar

3. Vinyl

4. Polyamide Epoxy
   Chlorinated Rubber

When following the Japanese methodology, the average performance of the Japanese products was equivalent to, or better than, the average performance of the U.S. products for all of the coating types with the exception of the polyamide epoxy.

G. Combined Exposure Data - U.S. methodology Vs. Japanese Methodology - The data is again shown in Table IX. Briefly, the average results of the U.S. methodology (blast cleaning removal of preconstruction primer followed by the application of an inorganic zinc and the finish system) surpassed the average results of the Japanese methodology (whether U.S. or Japanese manufacture) for the coal tar epoxy, polyamide epoxy, inorganic zinc, and bleached tar. Thus, at this point in the study, the U.S. methodology appears to provide better performance for those generic coating Systems. In contrast, the U.S. methodology appears to provide lesser performance than the Japanese (again for both Japanese and U.S manufactured coatings) for the chlorinated rubber and vinyl systems.

TABLE 1
2000 HOURS SALT FOG (FINAL GRADING)
TEST RESULTS - BLISTERING/CORROSION

	Meth.	Front Result	R	Back Result	R	Heat Effect Zone Result	R	Weld Result	R	Edge Result	R	Scribe Result	R
PRECON ZN/COAL TAR EPOXY	Jap.												
Japanese Mfg. A		None	4	None	4	None	4	None	4	Heavy rust	2	Heavy rust	2.5
Japanese Mfg. B		Sm patch B's	3.5	None	4	None	4	None	4	Heavy rust	2	4-#6; Lt. rust	2.5
U. S. Mfg. A		None	4	None	4	None	4	None	4	Heavy rust	2	Heavy rust	2
U. S. Mfg. B		None	4	None	4	None	4	None	4	Heavy rust	2	Heavy rust	2
PRE ZN/SP10/IOZ/COAL TR EP	U.S.												
U. S. Mfg. A		None	4	None	4	None	4	None	4	Heavy rust	2	Heavy rust	2
U. S. Mfg. B		None	4	None	4	None	4	None	4	Heavy rust	2	Heavy rust	2
PRECON ZN/POLYAMIDE EPOXY	Jap.												
Japanese Mfg. A		Sm patch B's	3.5	None	4	None	4	None	4	Heavy rust	2	2-#6; Hvy rst	1.5
Japanese Mfg. B		None	4	1/4"-3/4" B's	2	None	4	None	4	2F-2MD	0.5	2-#2; Hvy rust	1.5
U. S. Mfg. A		None	4	None	4	None	4	None	4	Heavy rust	2	Heavy rust	2
U. S. Mfg. B		6M	2.5	None	4	4M	2.5	None	4	2M-4M; Hvy rst	0.5	Heavy rust	2
PRE ZN/SP10/IOZ/POLY EPOX	U.S.												
U. S. Mfg. A		None	4	8M	3	None	4	None	4	Heavy rust	2	1/4-3/4; Hvy rst	1
U. S. Mfg. B		None	4	None	4	None	4	None	4	Heavy rust	2	Heavy rust; 4F	1.5
PRECON ZN/IOZ	Jap.												
Japanese Mfg. A		None	4	None	4	None	4	None	4	Heavy rust	2	None	4
Japanese Mfg. B		None	4	None	4	None	4	None	4	Heavy rust	2	Lt. rust	3
U. S. Mfg. A		None	4	None	4	None	4	None	4	Heavy rust	2	None	4
U. S. Mfg. B		None	4	None	4	None	4	Lt. rust	3.5	Heavy rust	2	Lt. rust	3
PRECON ZN/SP10/IOZ	U.S.												
U. S. Mfg. A		None	4	None	4	None	4	None	4	Heavy rust	2	None	4
U. S. Mfg. B		None	4	None	4	None	4	None	4	Heavy rust	2	None	4

Notes: (1) Jap. Meth. - indicates primer incorporated into the protective coating system after minimal cleaning.
(2) U. S. Meth. - indicates primer removed by blast cleaning followed by the application of a new inorganic zinc primer and the remainder of the coating system.
(3) R - indicates the rating scale from 0 to 4.
(4) Number/Letter - indicates blister size/frequency designation per ASTM D 714.

TABLE I (Con't.)
2000 HOURS SALT FOG (FINAL GRADING)
TEST RESULTS - BLISTER/CORROSION (Con't)

	Meth.	Front Result	R	Back Result	R	Heat Effect Zone Result	R	Weld Result	R	Edge Result	R	Scribe Result	R
PRECON ZN/CHLOR. RUBBER	Jap.												
Japanese Mfg. A		None	4	None	4	None	4	None	4	Heavy rust	2	Heavy rust	2
Japanese Mfg. B		None	4	8M (cluster)	3.5	None	4	8MD to 8D	2	Heavy rust	2	Heavy rust	2
U. S. Mfg. A		None	4	4F	3	8M	3	4MD	2	4MD; Hvy rust	0.5	Heavy rust	2
U. S. Mfg. B		4F with PPR	2.5	None	4	6F	3	4F	3	Heavy rust	2	Heavy rust	2
PRE ZN/SP10/IOZ/CHL RUB	U.S.												
U. S. Mfg. A		None	4	None	4	None	4	None	4	Heavy rust	2	Heavy rust	2
U. S. Mfg. B		2M to >2MD	0.5	2F to 2M bot.	2.5	None	4	None	4	Heavy rust	2	None	4
PRECON ZN/VINYL	Jap.												
Japanese Mfg. A		None	4	None	4	None	4	6F-6M; rust	1.5	Heavy rust	2	Heavy rust	2
Japanese Mfg. B		None	4	None	4	None	4	4F to 4M	2.5	2MD; Hvy rust	0.5	4M-2M; Hvy rst	0.5
U. S. Mfg. A		None	4	None	4	8M	3	6M-8MD; rust	1.5	6F; Heavy rust	1	Heavy rust	2
PRECON ZN/SP10/IOZ/VINYL	U.S.												
U. S. Mfg. A		None	4	None	4	3/4"-1" B's	0.5	None	4	Lrg B's;Hvy rst	0.5	Heavy rust	2
PRECON ZN/BLEACHED TAR	Jap.												
Japanese Mfg. A		None	4	None	4	None	4	None	4	Heavy rust	2	Heavy rust	2
Japanese Mfg. B		None	4	None	4	8F to 8M	3	None	4	Heavy rust	2	Heavy rust; 2F	1.0
U. S. Mfg. B		None	4	None	4	9D	2	None	4	Heavy rust	2	Heavy rust; 6F	1.5
PRE ZN/SP10/IOZ/BLCH TAR	U.S.												
U. S. Mfg. B		None	4	None	4	None	4	None	4	Heavy rust	2	Heavy rust; 4F	1.5

Notes: (1) Jap. Meth. - indicates primer incorporated into the protective coating system after minimal cleaning.
(2) U. S. Meth. - indicates primer removed by blast cleaning followed by the application of a new inorganic zinc primer and the remainder of the coating system.
(3) R - indicates the rating scale from 0 to 4.
(4) Number/Letter - indicates blister size/frequency designation per ASTM D 714.

TABLE II
SALT WATER IMMERSION AT 150°F (THREE MONTH GRADING)
TEST RESULTS - BLISTERING/CORROSION

	Meth.	Front Result	R	Back Result	R	Heat Effect Zone Result	R	Weld Result	R	Edge Result	R	Scribe Result	R
PRECON ZN/COAL TAR EPOXY	Jap.												
Japanese Mfg. A		2F to 4MD	2	2F to 4M	2.5	None	4	None	4	Lt. rust	3	None	4
Japanese Mfg. B		4M to 6M	2.5	None	4	None	4	None	4	Lt. rust	3	None	4
U. S. Mfg. A		None	4	None	4	None	4	None	4	Lt. rust	3	None	4
U. S. Mfg. B		4D to 2MD	1	6M to 6MD	2	2F	2.5	None	4	Lt. rust	3	None	4
PRE ZN/SP10/IOZ/COAL TR EP	U.S.												
U. S. Mfg. A		None	4	None	4	1/4" B	3.5	None	4	Lt. rust	3	None	4
U. S. Mfg. B		2F	2.5	2F	2.5	None	4	None	4	Lt. rust	3	None	4
PRECON ZN/POLYAMIDE EPOXY	Jap.												
Japanese Mfg. A		6MD	2	6F to 6M	2.5	None	4	None	4	Lt. rust	3	Lt. rust	3
Japanese Mfg. B		Lrg B's; Delam	0	Lrg B's; Delam	0	None	4	None	4	Lt. rust	3	Lt. rust	3
U. S. Mfg. A		6MD	2	6M	2.5	None	4	None	4	Lt. rust	3	Lt. rust	3
U. S. Mfg. B		2F to 4MD	2	4M to 6MD	2	2M	2	None	4	Lt. rust	3	None	4
PRE ZN/SP10/IOZ/POLY EPOX	U.S.												
U. S. Mfg. A		2F	2.5	2F	2.5	None	4	None	4	Lt. rust	3	Lt. rust	3
U. S. Mfg. B		Sev. 3/4" B's	2.5	None	4	None	4	None	4	.5-1"B; Lt rst	2.5	None	4
PRECON ZN/IOZ	Jap.												
Japanese Mfg. A		None	4	None	4	None	4	6F	3	Lt. rust	3	None	4
Japanese Mfg. B		None	4	8D	2	2D, cracked	1	3MD-2D (sides)	1	Lt. rust	3	None	4
U. S. Mfg. A		None	4	None	4	None	4	None	4	Lt. rust	3	None	4
U. S. Mfg. B		4D	1	4D	1	None	4	None	4	Lt. rust	3	None	4
PRECON ZN/SP10/IOZ	U.S.												
U. S. Mfg. A		None	4	None	4	None	4	None	4	Lt. rust	3	None	4
U. S. Mfg. B		None	4	None	4	None	4	None	4	Lt. rust	3	None	4

Notes:
(1) Jap. Meth. - indicates primer incorporated into the protective coating system after minimal cleaning.
(2) U. S. Meth. - indicates primer removed by blast cleaning followed by the application of a new inorganic zinc primer and the remainder of the coating system.
(3) R - indicates the rating scale from 0 to 4.
(4) Number/Letter - indicates blister size/frequency designation per ASTM D 714.

TABLE II (Con't.)
SALT WATER IMMERSION AT 150°F (THREE MONTH GRADING)
TEST RESULTS - BLISTERING/CORROSION (Con't)

	Meth.	Front Result	R	Back Result	R	Heat Effect Zone Result	R	Weld Result	R	Edge Result	R	Scribe Result	R
PRECON ZN/CHLOR. RUBBER	Jap.												
Japanese Mfg. A		8M to 8D	2	6M	2.5	2D	1	4D	1	Lt. rust	3	None	4
Japanese Mfg. B		8M to 8MD	2.5	8MD	2.5	None	4	None	4	Lt. rust	3	None	4
U. S. Mfg. A		4D	1	4D	1	None	4	None	4	Lt. rust	3	None	4
U. S. Mfg. B		4M to 6MD	2	6MD	2	None	4	8D	2	Lt. rust	3	None	4
PRE ZN/SP10/IOZ/CHL RUB	U.S.												
U. S. Mfg. A		4M to 4D	1	4MD to 4D	1	None	4	None	4	Lt. rust	3	None	4
U. S. Mfg. B		2D; 1"-2" B's	0.5	2D; 1"-2" B's	0.5	None	4	None	4	Lt. rust	3	None	4
PRECON ZN/VINYL	Jap.												
Japanese Mfg. A		8M	3	8M	3	4F to 4M	2.5	None	4	Lt. rust	3	None	4
Japanese Mfg. B		4F to 8M	3	8M	3	None	4	None	4	Lt. rust	3	8D	2
U. S. Mfg. A		8F	3.5	8F to 8M bot.	3	8F to 8M	3	None	4	Lt. rust	3	None	4
PRECON ZN/SP10/IOZ/VINYL	U.S.												
U. S. Mfg. A		2MD	1	2M	2	None	4	None	4	Lt. rust	3	None	4
PRECON ZN/BLEACHED TAR	Jap.												
Japanese Mfg. A		8M	3	6F to 8F	3	None	4	None	4	Lt. rust	3	Lt. rust	3
Japanese Mfg. B		2F(crack);6M-4M	2	None	4	None	4	None	4	Lt. rust	3	None	4
U. S. Mfg. B		4D	1	4D	1	None	4	8F	3.5	Lt. rust	3	None	4
PRE ZN/SP10/IOZ/BLCH TAR	U.S.												
U. S. Mfg. B		3F	2.5	3F	2.5	None	4	None	4	Lt. rust	3	None	4

Notes: (1) Jap. Meth. - indicates primer incorporated into the protective coating system after minimal cleaning.
(2) U. S. Meth. - indicates primer removed by blast cleaning followed by the application of a new inorganic zinc primer and the remainder of the coating system.
(3) R - indicates the rating scale from 0 to 4.
(4) Number/Letter - indicates blister size/frequency designation per ASTM D 714.

TABLE III
80 PSI HEAD PRESSURE CYCLING (FINAL GRADING)
TEST RESULTS - BLISTERING/CORROSION

	Meth.	Front Result	R	Back Result	R	Heat Effect Zone Result	R	Weld Result	R	Edge Result	R	Scribe Result	R
PRECON ZN/COAL TAR EPOXY	Jap.												
Japanese Mfg. A		None	4	None	4	None	4	8F	3.5	Lt. rust	3	6F	3
Japanese Mfg. B		None	4	None	4	None	4	None	4	Lt. rust	3	None	4
U. S. Mfg. A		None	4	None	4	None	4	None	4	Lt. rust	3	None	4
U. S. Mfg. B		None	4	None	4	None	4	None	4	Lt. rust	3	6F to 4M	2.5
PRE ZN/SP10/IOZ/COAL TR EP	U.S.												
U. S. Mfg. A		None	4	None	4	None	4	None	4	Lt. rust	3	6F	3
U. S. Mfg. B		None	4	None	4	None	4	None	4	Lt. rust	3	None	4
PRECON ZN/POLYAMIDE EPOXY	Jap.												
Japanese Mfg. A		None	4	None	4	None	4	None	4	Lt. rust	3	None	4
Japanese Mfg. B		None	4	None	4	None	4	None	4	Lt. rust	3	6F	3
U. S. Mfg. A		None	4	None	4	None	4	None	4	8M; Lt. rust	2.5	None	4
U. S. Mfg. B		4F to 4M	2.5	6F to 6M	2.5	None	4	None	4	Lt. rust	3	None	4
PRE ZN/SP10/IOZ/POLY EPOX	U.S.												
U. S. Mfg. A		4F and 8M	3.0	9MD	2.5	None	4	None	4	Lt. rust	3	None	4
U. S. Mfg. B		None	4	None	4	None	4	None	4	Lt. rust	3	None	4
PRECON ZN/IOZ	Jap.												
Japanese Mfg. A		None	4	None	4	None	4	None	4	Lt. rust	3	None	4
Japanese Mfg. B		None	4	None	4	None	4	None	4	Lt. rust	3	None	4
U. S. Mfg. A		None	4	None	4	None	4	None	4	Lt. rust	3	None	4
U. S. Mfg. B		4M to 6MD	2.0	4M to 6M	2.5	None	4	None	4	Lt. rust	3	None	4
PRECON ZN/SP10/IOZ	U.S.												
U. S. Mfg. A		None	4	None	4	None	4	None	4	Lt. rust	3	None	4
U. S. Mfg. B		None	4	None	4	None	4	None	4	Lt. rust	3	None	4

Notes:
(1) Jap. Meth. - indicates primer incorporated into the protective coating system after minimal cleaning.
(2) U. S. Meth. - indicates primer removed by blast cleaning followed by the application of a new inorganic zinc primer and the remainder of the coating system.
(3) R - indicates the rating scale from 0 to 4.
(4) Number/Letter - indicates blister size/frequency designation per ASTM D 714.

TABLE III (Con't.)
80 PSI HEAD PRESSURE CYCLING (FINAL GRADING)
TEST RESULTS - BLISTERING/CORROSION

	Meth.	Front Result	R	Back Result	R	Heat Effect Zone Result	R	Weld Result	R	Edge Result	R	Scribe Result	R
PRECON ZN/CHLOR. RUBBER	Jap.												
Japanese Mfg. A		None	4	None	4	None	4	None	4	Lt. rust	3	None	4
Japanese Mfg. B		None	4	9F	3.5	None	4	None	4	Lt. rust	3	9F	3.5
U. S. Mfg. A		None	4	None	4	None	4	None	4	Lt. rust	3	None	4
U. S. Mfg. B		None	4	4F	3	None	4	None	4	Lt. rust	3	2F	2.5
PRE ZN/SP10/IOZ/CHL RUB	U.S.												
U. S. Mfg. A		None	4	None	4	None	4	None	4	4F; Lt. rust	2.5	9F	3.5
U. S. Mfg. B		2MD & Larger	0.5	2MD	1	None	4	None	4	Lt. rust	3	None	4
PRECON ZN/VINYL	Jap.												
Japanese Mfg. A		4M	2.5	None	4	None	4	6F	3	Lt. rust	3	None	4
Japanese Mfg. B		None	4	None	4	6F to 6M	2.5	None	4	Lt. rust	3	8F	3.5
U. S. Mfg. A		6M	2.5	None	4	6M to 8M	2.5	8D	2	Lt. rust	3	None	4
PRECON ZN/SP10/IOZ/VINYL	U.S.												
U. S. Mfg. A		None	4	4F	3	None	4	None	4	Lt. rust	3	8F	3.5
PRECON ZN/BLEACHED TAR	Jap.												
Japanese Mfg. A		None	4	None	4	None	4	None	4	Lt. rust	3	6F	3
Japanese Mfg. B		None	4	None	4	8MD	2.5	None	4	Lt. rust	3	8F to 9M	3
U. S. Mfg. B		None	4	4F	3	8M	3	None	4	Lt. rust	3	4M to 6M	2.5
PRE ZN/SP10/IOZ/BLCH TAR	U.S.												
U. S. Mfg. B		None	4	None	4	None	4	None	4	Lt. rust	3	None	4

Notes: (1) Jap. Meth. - indicates primer incorporated into the protective coating system after minimal cleaning.
(2) U. S. Meth. - indicates primer removed by blast cleaning followed by the application of a new inorganic zinc primer and the remainder of the coating system.
(3) R - indicates the rating scale from 0 to 4.
(4) Number/Letter - indicates blister size/frequency designation per ASTM D 714.

TABLE IV
KTA ENVIROTEST (FINAL GRADING FOR ONE-HALF OF SYSTEMS)
TEST RESULTS - BLISTERING/CORROSION

	Meth.	Front Result	R	Back Result	R	Heat Effect Zone Result	R	Weld Result	R	Edge Result	R	Scribe Result	R
PRECON ZN/COAL TAR EPOXY	Jap.												
Japanese Mfg. A													
Japanese Mfg. B													
U. S. Mfg. A		None	4	None	4	6F to 8F	3	None	4	Lt. rust	3	4F	3
U. S. Mfg. B		None	4	None	4	None	4	None	4	Lt. rust	3	None	4
PRE ZN/SP10/IOZ/COAL TR EP	U.S.												
U. S. Mfg. A		None	4	None	4	None	4	None	4	Lt. rust	3	None	4
U. S. Mfg. B		None	4	None	4	None	4	None	4	Lt. rust	3	None	4
PRECON ZN/POLYAMIDE EPOXY	Jap.												
Japanese Mfg. A													
Japanese Mfg. B													
U. S. Mfg. A		None	4	None	4	None	4	None	4	Lt. rust	3	None	4
U. S. Mfg. B		Rust (8-9)	3	None	4	None	4	None	4	Lt. rust	3	6F	3
PRE ZN/SP10/IOZ/POLY EPOX	U.S.												
U. S. Mfg. A		9F	3.5	9F	3.5	None	4	None	4	Lt. rust	3	None	4
U. S. Mfg. B		Rust (9)	3.5	None	4	None	4	None	4	Lt. rust	3	6F	3
PRECON ZN/IOZ	Jap.												
Japanese Mfg. A													
Japanese Mfg. B													
U. S. Mfg. A		None	4	None	4	None	4	None	4	Lt. rust	3	None	4
U. S. Mfg. B		None	4	None	4	6M to 8M	2.5	None	4	Lt. rust	3	None	4
PRECON ZN/SP10/IOZ	U.S.												
U. S. Mfg. A		None	4	None	4	None	4	None	4	Lt. rust	3	None	4
U. S. Mfg. B		Rust (6-7)	2.5	None	4	None	4	None	4	Lt. rust	3	None	4

Notes: (1) Jap. Meth. - indicates primer incorporated into the protective coating system after minimal cleaning.
(2) U. S. Meth. - indicates primer removed by blast cleaning followed by the application of a new inorganic zinc primer and the remainder of the coating system.
(3) R - indicates the rating scale from 0 to 4.
(4) Number/Letter - indicates blister size/frequency designation per ASTM D 714.

TABLE IV (Con't.)
EXPOSURE - KTA ENVIROTEST (FINAL GRADING FOR ONE-HALF OF SYSTEMS)
TEST RESULTS - BLISTERING/CORROSION

	Meth.	Front Result	R	Back Result	R	Heat Effect Zone Result	R	Weld Result	R	Edge Result	R	Scribe Result	R
PRECON ZN/CHLOR. RUBBER	Jap.												
Japanese Mfg. A													
Japanese Mfg. B													
U. S. Mfg. A		None	4	None	4	None	4	None	4	Lt. rust	3	None	4
U. S. Mfg. B		None	4	4F	3	None	4	None	4	Lt. rust	3	4F to 6F	3
PRE ZN/SP10/IOZ/CHL RUB	U.S.												
U. S. Mfg. A		None	4	None	4	None	4	None	4	Lt. rust	3	None	4
U. S. Mfg. B		4M	2.5	4F to 4M	2.5	None	4	None	4	Lt. rust	3	None	4
PRECON ZN/VINYL	Jap.												
Japanese Mfg. A													
Japanese Mfg. B													
U. S. Mfg. A		None	4	None	4	None	4	None	4	Lt. rust	3	None	4
PRECON ZN/SP10/IOZ/VINYL	U.S.												
U. S. Mfg. A		None	4	None	4	None	4	None	4	Lt. rust	3	None	4
PRECON ZN/BLEACHED TAR	Jap.												
Japanese Mfg. A													
Japanese Mfg. B													
U. S. Mfg. B		None	4	None	4	None	4	None	4	Lt. rust	3	6F to 8F	3
PRE ZN/SP10/IOZ/BLCH TAR	U.S.												
U. S. Mfg. B		Rust (7-9)	2.5	None	4	None	4	None	4	Lt. rust	3	None	4

Notes: (1) Jap. Meth. - indicates primer incorporated into the protective coating system after minimal cleaning.
(2) U. S. Meth. - indicates primer removed by blast cleaning followed by the application of a new inorganic zinc primer and the remainder of the coating system.
(3) R - indicates the rating scale from 0 to 4.
(4) Number/Letter - indicates blister size/frequency designation per ASTM D 714.

TABLE V
SYSTEM RATING - SALT FOG (2000 HOURS)

Rating	Coal Tar	Polyamide	IOZ	Chlor. Rubber	Vinyl	Bleach Tar
31						
30.5						
30			J-A U-A U-B(U) U-A(U)			
29.5						
29			J-B			
28.5	J-A		U-B			
28	U-A U-B U-A(U) U-B(U)	U-A		J-A U-A(U)		J-A
27.5	J-B	U-B(U)				U-B(U)
27						
26.5		J-A				
26						J-B
25.5					J-A	U-B
25		U-A(U)		J-B		
24.5						
24						
23.5					J-B U-A	
23				U-B	U-A(U)	
22.5						
22		J-B U-B				
21.5				U-A		
21						
20.5						
20				U-B(U)		
19.5						
19						
18.5						
18						
17.5						
17						

KEY
J-A - Japanese Manufacturer A (Japanese Methodology)
J-B - Japanese Manufacturer B (Japanese Methodology)
U-A - U.S. Manufacturer A (Japanese Methodology)
U-B - U.S. Manufacturer B (Japanese Methodology)
U-A(U) - U.S. Manufacturer A (U.S. Methodology)
U-B(U) - U.S. Manufacturer B (U.S. Methodology)

TABLE VI

SYSTEM RATING - SEA WATER IMMERSION AT 150°F

Rating	Coal Tar	Polyamide	IOZ	Chlor. Rubber	Vinyl	Bleach Tar
31	U-A		U-A U-B(U) U-A(U)			
30.5	U-A(U)					
30			J-A			
29.5						
29						
28.5						
28	J-B					
27.5		U-B(U)				
27					U-A	J-B
26.5						
26						J-A
25.5					J-A	
25	U-B(U)			J-B	J-B	U-B(U)
24.5						
24	J-A	U-A(U)				
23.5						
23		J-A U-A				
22.5						
22						
21.5						
21		U-B	J-B	U-B	U-A(U)	
20.5						
20						
19.5						
19			U-B	U-A U-A(U)		
18.5						U-B
18				J-A		
17.5						
17				U-B(U)		

KEY
- J-A - Japanese Manufacturer A (Japanese Methodology)
- J-B - Japanese Manufacturer B (Japanese Methodology)
- U-A - U.S. Manufacturer A (Japanese Methodology)
- U-B - U.S. Manufacturer B (Japanese Methodology)
- U-A(U) - U.S. Manufacturer A (U.S. Methodology)
- U-B(U) - U.S. Manufacturer B (U.S. Methodology)

TABLE VII

SYSTEM RATING - 80 PSI PRESSURIZED/DEPRESSURIZED CYCLE

Rating	Coal Tar	Polyamide	IOZ	Chlor. Rubber	Vinyl	Bleach Tar
31	J-B U-A U-B(U)	J-A U-B(U)	J-A J-B U-A U-A(U) U-B(U)	J-A U-A		U-B(U)
30.5		U-A				
30	U-A(U)	J-B		U-A(U)		J-A
29.5	J-A U-B			J-B		
29					J-B	
28.5					U-A(U)	J-B
28						
27.5				U-B		
27					J-A	
26.5						U-B
26		U-A(U)				
25.5						
25		U-B				
24.5					U-A	
24			U-B			
23.5						
23						
22.5						
22						
21.5						
21						
20.5						
20						
19.5						
19						
18.5						
18				U-B(U)		
17.5						
17						

KEY
J-A - Japanese Manufacturer A (Japanese Methodology)
J-B - Japanese Manufacturer B (Japanese Methodology)
U-A - U.S. Manufacturer A (Japanese Methodology)
U-B - U.S. Manufacturer B (Japanese Methodology)
U-A(U) - U.S. Manufacturer A (U.S. Methodology)
U-B(U) - U.S. Manufacturer B (U.S. Methodology)

TABLE VIII
SYSTEM RATING - AVERAGE OF THREE EXPOSURES COMBINED
(SALT FOG, SEA WATER IMMERSION, 80 PSI CYCLE)

Rating	Coal Tar	Polyamide	IOZ	Chlor. Rubber	Vinyl	Bleach Tar
31						
30.5			J-A U-A U-A(U) U-B(U)			
30	U-A					
29.5	U-A(U)					
29	J-B	U-B(U)				
28.5						
28	U-B(U)					J-A U-B(U)
27.5	J-A					
27		J-A U-A	J-B			J-B
26.5				J-B		
26	U-B				J-A J-B	
25.5				J-A U-A(U)		
25		U-A(U)			U-A	
24.5						
24			U-B	U-A U-B	U-A(U)	
23.5						U-A
23		U-B				
22.5						
22		J-B				
21.5						
21						
20.5						
20						
19.5						
19						
18.5				U-B(U)		
18						
17.5						
17						

KEY
J-A - Japanese Manufacturer A (Japanese Methodology)
J-B - Japanese Manufacturer B (Japanese Methodology)
U-A - U.S. Manufacturer A (Japanese Methodology)
U-B - U.S. Manufacturer B (Japanese Methodology)
U-A(U) - U.S. Manufacturer A (U.S. Methodology)
U-B(U) - U.S. Manufacturer B (U.S. Methodology)

TABLE IX

AVERAGE SYSTEM PERFORMANCE PER GENERIC TYPE

Rating	Coal Tar	Polyamide	IOZ	Chlor. Rubber	Vinyl	Bleach Tar
31						
30.5			U(U)			
30						
29.5						
29	U(U)		J(J)			
28.5						
28	J(J) U(J)					U(U)*
27.5						J(J)
27		U(U)	U(J)			
26.5						
26				J(J)	J(J)	
25.5						
25		U(J)			U(J)*	
24.5		J(J)				
24				U(J)	U(U)*	
23.5						
23						U(J)*
22.5						
22				U(U)		

* Based on one manufacturer.

U(U) - U.S. Products (U.S. Methodology)
U(J) - U.S. Products (Japanese Methodology)
J(J) - Japanese Products (Japanese Methodology)

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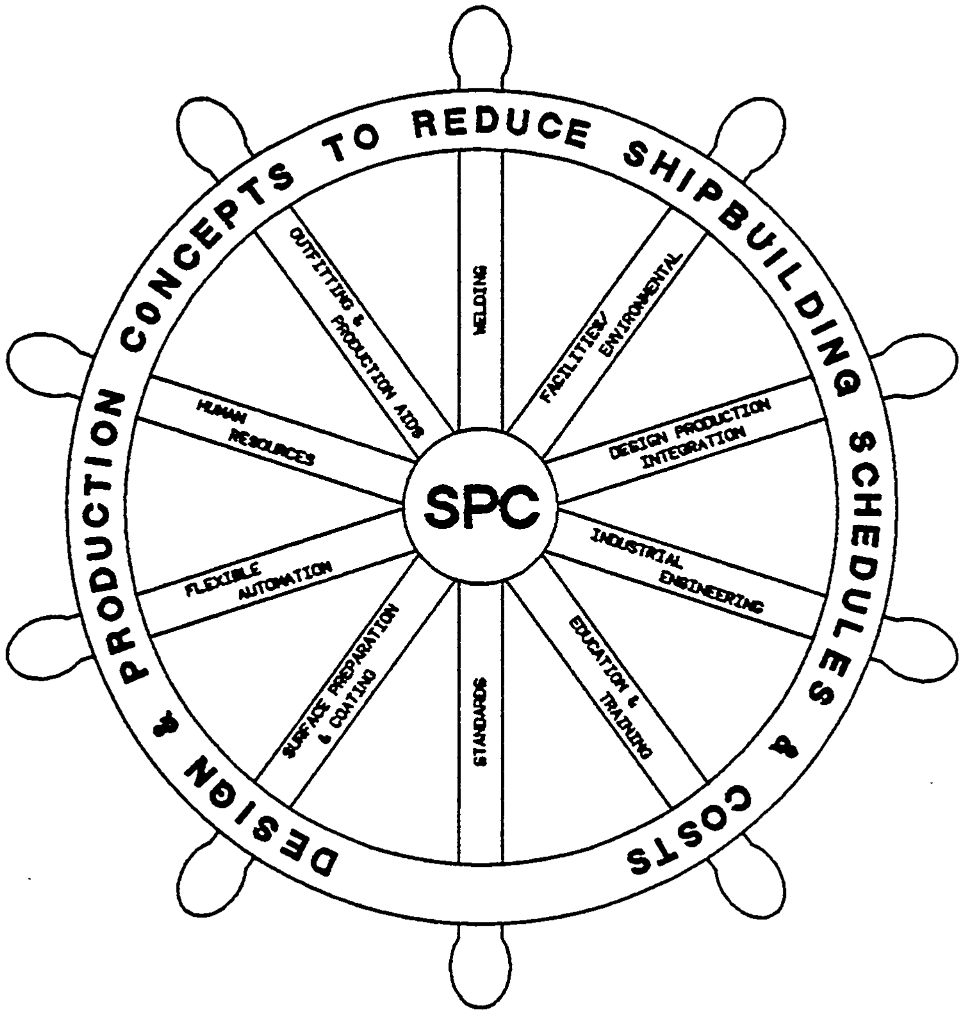

PAPER NO. 12

THE BENEFITS OF A MODIFIED-CHEMISTRY, HIGH-STRENGTH, LOW-ALLOY STEEL

BY: JOHN C. WEST

SYMPOSIUM SPONSOR:
SNAME SHIP PRODUCTION COMMITTEE

SYMPOSIUM HOST:
SNAME HAMPTON ROADS SECTION

AUGUST 27-29, 1986

1986 SHIP PRODUCTION SYMPOSIUM

THE BENEFITS OF A MODIFIED-CHEMISTRY, HIGH-STRENGTH, LOW-ALLOY STEEL

JOHN C. WEST, Bethlehem Steel Corporation

ABSTRACT

Steels with 50 ksi and up yield points usually acquire their strength from some fern of heat treatment. Most of these steels, 1-1/2 in. thick and up, must be welded using sustained preheat and controlled interpass temperatures, plus controlled welding heat input of approximately 50 to 60 kilo joules per inch. These two items can add as much as SO percent to the cost of submerged-arc welding and increases of up to 30 percent are common for manual welding when compared with lover-strength steele previously used.

In our pursuit of reduced costs, we found that a quenched and precipitation hardened steel, ASTM A71O Grade A Class 3, had a high degree of weldability. Also it could be welded without sustained preheat and almost unlimited heat input. Therefore, we have welded, as outlined previously, and extensively tested this material in the thicknesses from 2-1/4 in. through 6 in. The following results were obtained: 80 ksi yield point through 3 in., 75 ksi yield point through 5 in., and 70 ksi yield point through 6 in.

In addition, a steel with a modified A71O chemistry has been obtained and work is proceeding towards the following goals: 100 ksi yield point through 3 in. thick, 90 ksi yield point through 5 in., and 85 ksi yield point through 6 in.

Although this steel costs more than the usual quenched and tempered plates at these strength levels, cost reductions of 40 to 75 percent in welding labor costs are probable. In addition, sizeable material savings would be realized when these items are used in place of HY-80 and HY-1OO.

INTRODUCTION

In 1982 two events occurred, almost simultaneously.

In the first event, the goal of NAVSEA's material fabrication improvement (MFI) program plan for FY 1983 - FY 1990 was established. Its aim was to "reduce shipbuilding costs through improvement of welding processes, materials, technologies, procedures, and techniques; while simultaneously improving quality."

NAVSEA bad found that over 11% of the construction man-hours needed to build a ship were devoted to structural welding, which was dominated by the manual process. Sustained preheat and interpass temperature controls needed when welding HY-80 and HY-1OO cost approximately $1,500,000 for a fair sized vessel and larger units can cost up to $15,000,000 as outlined by author R. R. Irving in his "A Cost Effective Replacement for HY-80?" in the May 16, 1986 issue of Iron Age (l).

In the second event, we at Beaumont were deeply involved in worldwide offshore drilling and exploration for oil and gas. Our purpose was to design, build, and continue to improve in our production of top-quality, economical drilling rigs.

Bethlehem-Beaumont has, over the years, designed 84 jack-ups, 8 semi-submersibles, 4 drill ships, 1 tender, and 1 submersible, which have been built at Beaumont; Singapore; Sparrows Point; Durban, South Africa; and in the People's Republic of China.

TECHNICAL DEVELOPMENT

The jack-up rigs are classified bv rated water depth -- 150 ft., 80 ft., 175 ft., 200 ft., 250 ft., etc. The model (Figure 1) has three legs or columns, which are pierced with holes when unit is built, to permit entry of the jacking and fixed pins. Surrounding each column is an area of the platform known as the jack house. This is where lifting and lowering of the mat is controlled.

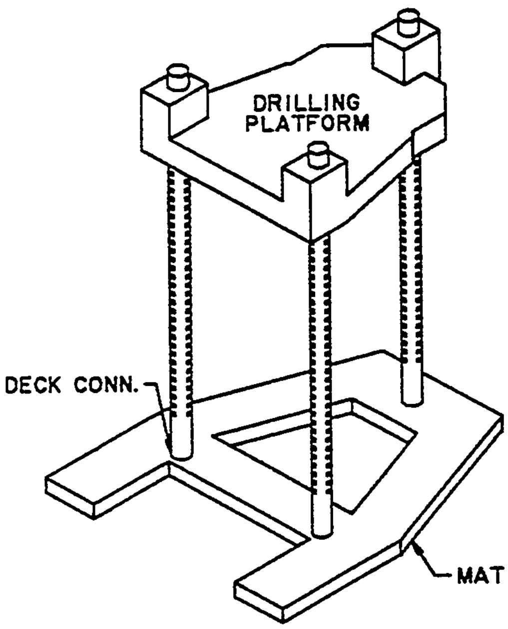

FIG. #I
250' W. D.
JACK UP

The mat, resting on the sea floor, is penetrated by the three columns. This treat deck to column connection is shown on the attached "old design." The section view shows the ABS EH36 column (2-1/2 in.) and ABS EE36 wrapper plate (1-3/4 in.) tied to it with an upper and lower 2-1/2-in. by 3-in. fillet weld made by sub-arc in the fabricating shop. Note the gap between the wrapper plate and column between the fillet welds, this allows the plate to move, or "flex." The drawing call-outs are for 100 percent ultrasonic test inspection. The weld at the deck is made with E8018C-3 electrodes and ground to a 7/8-in. radius on the building ways.

Initially, the wrapper plate was used for easier assembly of this vital joint. It could be installed as a coaming on the deck and columns passed through it and tied in by the two fillet welds.

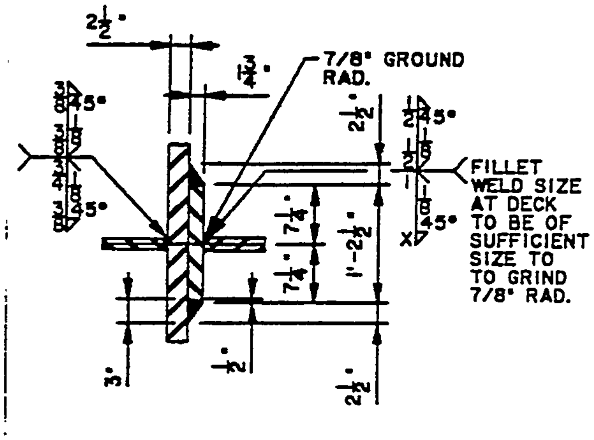

FIG. 2
"OLD" DESIGN
MAT CONNECTION

Later on this was changed as previously outlined.

The original joint was designed to flex or "breathe" as the loads were transmitted between the column and the deck. The wrapper plate did its job, but as such became a sacrificial member of the rig. It would crack through behind the upper part of the deck to wrapper plate weld. Then it had to be replaced, under difficult conditions, in remote parts of the world, such as Angola, Brazil, Egypt, Gabon, and Southeast Asia. On many occasions, due to local limitations, workers had to be imported from the United States or Western Europe.

The vast costs incurred to our customers, plus the drop in their "day rate" while laid up for repairs, plus ABS insistence, led us to work toward a new design for this joint.

THE NEW DESIGN

The attached sketch of the new design, which evolved at Beaumont, led to a search for a steel 5-1/2 in. thick with a 65 ksi yield point and a high toughness level.

Discussions between Armco and Bethlehem personnel led to the selection of their "NI-COP" for this application.

"NI-COP" was made to ASTM A710 for general applications and ASTM

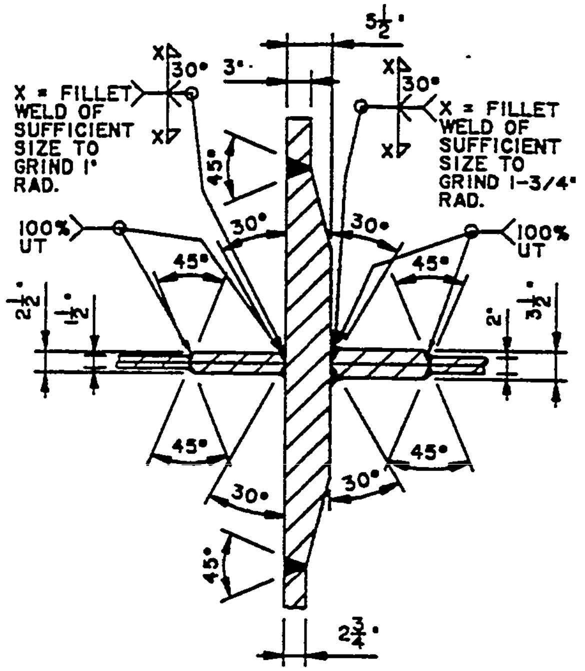

FIG. 3
"NEW" DESIGN MAT CONNECTION

A736 for pressure vessel use. A/36 was chosen for our application because of its stricter testing requirements. At that time, Armco had not produced anything thicker than 3-1/4 in. and were not sure that 5-1/2 in. could be produced, rolled, and welded to attain a 65 ksi yield point.

After consultation with various metallurgical engineers, it was decided to purchase the 2-3/4-in., and 5-1/2-in. material in the quenched condition only. We would roll the 2-3/4-in. and 3-in. at Beaumont and subcontract rolling the 5-1/2-in. to Wyatt Industries in Houston. Wyatt's rolling preheat of the 5-1/2-in. plate, because of job limitations, was limited to 500 degrees Fahrenheit. We would weld up the subassembly, including the diaphragm, a 15-in. section of deck plate, and the lover portion of the column tube. We would then precipitation harden the subassembly in our furnace. The section view of the attached new design shows this in detail.

This we did with the three column to mat 45-ton stub subassemblies for the first rig being welded and heat treated by March 8, 1982. Succeeding subassemblies were also done in this fashion at a later date. No one had ever done this in the past.

Average yield points attained were 83.2 ksi for 2-3/4 in., // .1 ksi for 3 in., and 70.7 ksi for 5-1/2 in. These are recorded on *our* ABS approved Welding Procedures 335 and 336 dated April 12, 1982. V-notch values were excellent and there was *no* adverse HAZ degradation.

You are, perhaps, familiar with this material as it is also known as HSLA-80 and being used on U.S. Navy ships. The July 1985 issue of Welding Journal contains an excellent article, "An Improved High Yield Strength Steel for Shipbuilding" (2) authored by L. G. Kvidahl of Ingalls Shipbuilding. In the article, test results are extensively detailed; and when compared with HY-80, a better product for less money results.

THE NEW CHEMISTRY

These findings were then fed back to Armco to assist them in their product development work. *On* March 28, 1983, we were advised that Armco had developed a modified chemistry for A71O that could attain a guaranteed minimun yield point of 100 ksi through 2 in.; and that the standard chemistry could now be sold at an 80 yield point minimum through 1-1/4 in. We were informed that Armco was planning to sell this to the U.S. Navy in place of HY-80. Verbal quotes at that time were 58 cents/lb. for the standard chemistry and 63 cents/lb. for the modified.

In late September or early October of 1983, it was learned that Armco would close its Houston works and that the above products would be no more. At that time we received. some of Armco's development data and documents that further endorsed the belief that this product really had the potential to replace HY-1OO.

REQUEST FOR MARAD STUDY FUNDS

The preceding events led us to propose to the SP-7 Welding Panel of SNAME on November 10, 1983, the study "Evaluate the Benefits of Higher-Strength HSLA Steels." On February 13, 1984, we were advised that SP-7 had approved the study and a formal contract for $95,000 for the first year funds would be forth coming from MARAD.

Work commenced in August, 1984, to accomplish the following goals, without using sustained preheat and limited heat input.

Phase	Goal & Plate Thickness	Scheduled cost	Time
1	80 ksi Y.P. thru 3"	$ 95,000	1 yr.
2	75 ksi Y.P. thru 5" 70 ksi Y.P. thru 6"	$ 75,000	9 mos.
3	100 ksi Y.P. thru 3"	$ 70,000	6 mos.
4A	90 ksi Y.P. thru 5" 85 ksi Y.P. thru 6"	$100,000	1 yr.
4B	Publish results	$ 50,000	9 mos.
TOTALS		$390,000	4 yrs.

ACCOMPLISHMENTS

In May, 1986, we met our goals and completed Phases 1 and 2 within our budget.

The welding processes used were manual, gas metal-arc with pulse, and submerged arc (single, dual arc, and narrow gap). Heat inputs varied from SO KJ/in. to 200 KJ/in. Some plates were welded in the quenched only condition, and precipitation hardened after welding, others vice versa. Test results obtained In 3-in. material show a minimun yield of 84.7 ksi welded at 200 KS/in. with dual are *to* 94.7 ksi welded at 7S KJ/in. with the same process. Charpy V-notch values were well above the American Bureau of Shipping values for EQS6 plates.

Figure 4 shows our test results of Phases 1 and 2. Note that we list results for welding before and after precipitation hardening. Beaumont has done this in production runs as we have a 17 ft. x 17 ft. x 85 ft. car bottom furnace. We do not recommend this practice for overall general use. The soak times and temperatures plus cooling rates are exacting and

PHASE I RESULTS
ALL CHARPY "V"S ARE TRANSVERSE

THICKNESS	PROCESS	KJ/IN INPUT	Y.P. KSI	T.S. KSI	% E	% RA	CHARPYS AT -80°F W	F	1 M/M	3 M/M	5 M/M
PRECIPITATION HARDEN AT 1050°F FOR 165 MIN. AFTER WELDING											
2-3/4	DC & AC SAW	208	87.2	107	22	63	9	8	30	41	22
2-3/4	"	175	89.2	108	22	58	11	10	64	27	20
P/H AT 1050°F FOR 165 MIN. AFTER WELDING, CHARPYS AT -40°F											
2-3/4	DC & AC SAW	150	91.1	107	26	67	31	51	53	48	43
2-3/4	"	125	87.9	107	24	66	28	46	52	48	43
2-3/4	"	100	93.2	107	26	67	43	58	77	38	32
2-3/4	DC ONLY	75	94.3	106	26	68	29	15	46	33	29
P/H AT 1050°F FOR 165 MIN. AFTER WELDING, CHARPYS AT -40°F											
2-1/4	DC & AC	135	93.2	108	26	69	23	98	63	103	103
2-1/4	VERT-STICK	65	89.6	100	26	72	26	173	136	151	117
P/H AT 1050°F FOR 165 MIN. AFTER WELDING, CHARPYS AT -40°F											
2-3/4	DC & AC SAW	100	97.6	109	24	67	76	54	50	80	103
2-3/4	"	150	88	108	24	69	78	109	74	64	102
3	"	200	84.7	106	23	67	40	94	88	95	56
3	DC ONLY	75	94.7	106	24	67	74	86	52	72	91
3	DC & AC	125	89.7	107	24	63	86	96	76	64	94
3	DC N.G.	75	93.4	106	25	66	61	68	112	73	67
2-3/4	VERT. MIG.	95	88.7	102	23	58	79	110	109	93	69

PHASE II RESULTS
ALL CHARPY "V"S ARE TRANSVERSE

P/H AT 1100°F FOR 135 MINS. PRIOR TO WELDING

THICK NESS	PROCESS	KJ/IN INPUT	Y.P. KSI	T.S. KSI	CHARPYS AT -40°F W	1 M/M	5 M/M
4	DC & AC SAW	192	84	99	30	86	94
4	VERT. MIG.	55	87	100	84	83	82
4-1/2	SAW - NG	73	78.1	90	71	139	134
4-1/2	VERT - STICK	55	79.6	90	33	112	117
4-1/2	VERT. MIG.	73	76.5	88	59	160	129
5	DC & AC SAW	140	78.4	86	37	132	131
5	SAW - NG	75	79.4	90	87	135	172
6	DC & AC SAW	130	80.9	95	64	77	59
6	SAW - NG	75	84.6	92.7	51	71	89

FIG. 4
PHASE I & II
RESULTS

critical. Undivided attention, accuracy, and constant monitoring are required to be successful. There is no room for error. These items may be too costly or difficult to attain in a production environment.

In general, it is best to order plate, with the desired properties, (yield point, percent reduction of area, V-notch, and temperature) in its final precipitation hardened condition from the mill.

FUTURE PLANS

In May, 1986, we were advised that there would not be anymore MARAD funds available. We have revised our estimate to perform Phase 3 from $70,000 to $51,000 of SP-7 funds available from cancelled or completed projects with a December completion. Our goal will be to prove that A710 modified chemistry plate with a minimum 100 ksi yield point through 3 in. thick can be successfully welded without sustained preheat and no heat input limitations.

We have the material on hand through 5-3/4 in. thick, it took almost one-year's time to procure same.

We were unable to find a U.S. producer willing to make anything less than 100 tons of modified chemistry 100 ksi yield point material, therefore, a foreign producer filled the gap. The 22 tons were delivered in two lots, one costing 52 cents/lb. and the other at 58 cents/lb.

Comparison of Modified Chemistry Plate:

	A710 Grade A Class 3	A710 Grade A Modified
C	.07	.07
Mn	.40 - .70	1.20 - 1.70
P	.025	.025
S	.025	.025
Si	.40	.40
Ni	.70 - 1.00	.70 - 1.00
Cr	.60 - .90	.10 - .50
Mo	.15 - .25	.20 - .50
Cu	1.00 - 1.30	1.00 - 1.35
Cb	.02	.02
Al	N/A	.015 - .065
B	N/A	T

Mechanical properties for material over 2 in. are:

TS min.	75 ksi	125 ksi
YP min.	65 ksi	100 ksi
% E min.	20	20
% RA "Z"	N/A	25
"V" ft./lbs. °F "L"	50 @ -80°	
"V" ft./lbs. ABS - FQ70 @ -76°F MODU 1985 Table B.2		30 L 20 T

Completion of Phases 4A and 4B is dependent on additional funds becoming available to do so. It is strongly believed that this work needs to be done. The potential savings that can be realized are enormous. Beaumont is unable to carry on without MARAD support. We can supply 100 ksi yield point plate in 3-3/4 in., 4-1/4 in., 4-3/4 in., 5-1/4 in., and 5-3/4 in. thickness to whomever MARAD selects to finish the job.

BENEFITS AND POTENTIAL SAVINGS

1. The savings outlined- in Hay 16, 1986 issue of Iron Age (1) are factual. Specification and use of A710 or its modification will make them a reality.

2. Increased weld metal "in place" per man-hour. Possible doubling of the "in place" metal with sub-arc. As much as 50 percent more for out-of-position manual welding.

3. Decreased schedule time and shorter delivery times.

4. Decreased welding wire costs.

5. Less welding repairs.

When A710 or its modification replaces a lover strength material, the following savings will accrue, as a reduction in material thickness will be realized.

6. The use of lighter material decreases the deadweight of the unit, thereby increasing its payload or reducing the power requirements to propel it.

7. Lighter material increases the length or width of plates ordered from the mill. This in turn reduces the number of hurts or seams required In the unit's design. Therefore, welding requirements are further reduced.

8. Thinner higher-strength plates of greater surface area to construct a unit will reduce plate handling times at the site. Incoming freight bills will decrease as less tonnage is delivered by the carrier.

in addition *to* the above, less time and effort will be expended by architects and designers in producing the most *economical* product.

REFERENCES

Magazine Articles:

1. R. R. Irving, "A Cost-Effective Replacement for for HY-80?" Iron Age, Hay 16, 1986.

2. L. G. Kvidahl "An Improved High Yield Strength *Steel* for Shipbuilding," Welding Journal, July, 1985.

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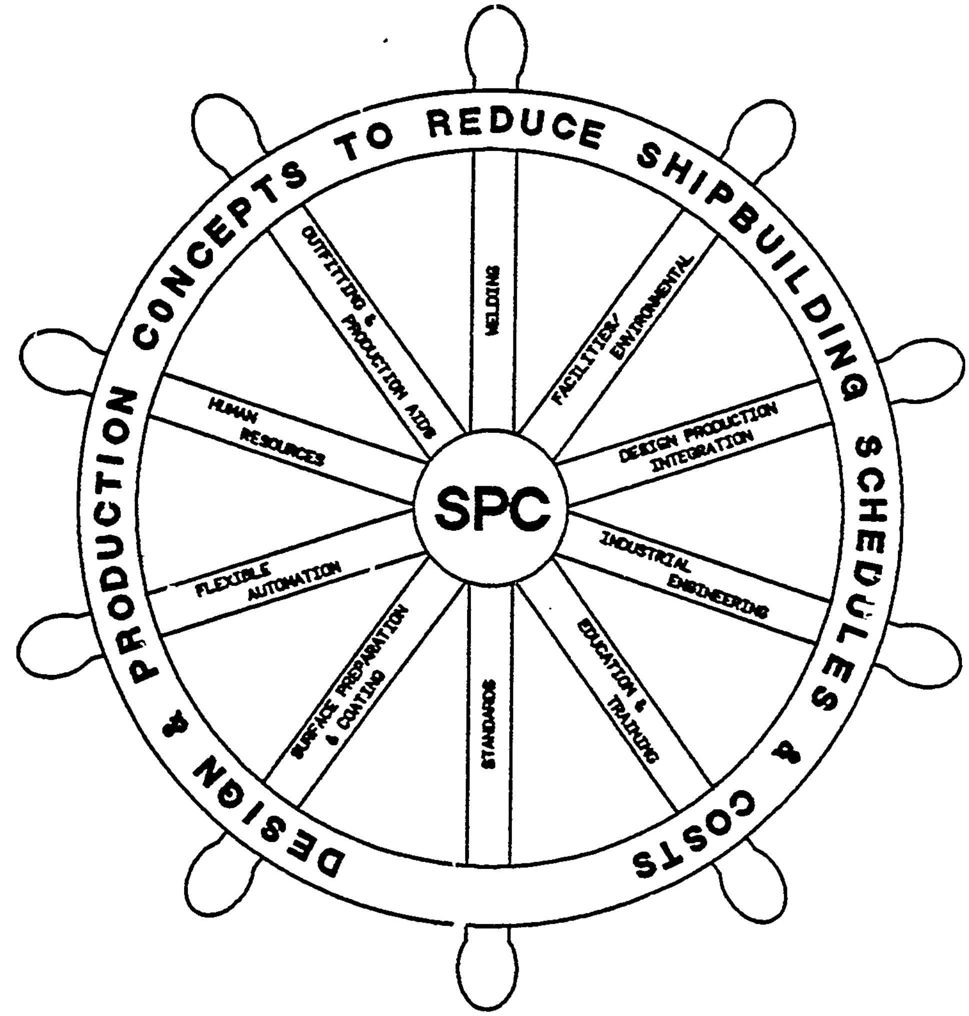


PAPER NO. 13

REDUCED FILLET WELD SIZES FOR NAVAL SHIPS

BY: ED GAINES

SYMPOSIUM SPONSOR:
SNAME SHIP PRODUCTION COMMITTEE

SYMPOSIUM HOST:
SNAME HAMPTON ROADS SECTION

AUGUST 27-29, 1986

1986 SHIP PRODUCTION SYMPOSIUM

REDUCED FILLET WELD SIZES FOR NAVAL SHIPS

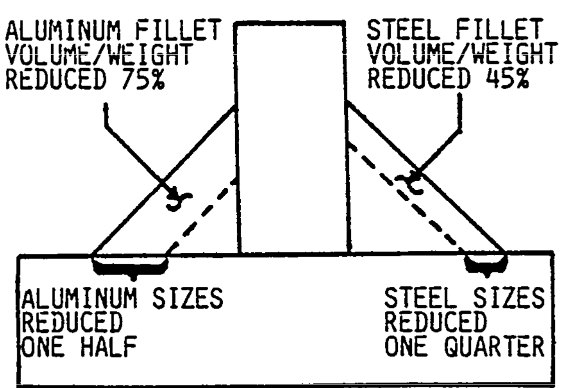
ED GAINES, Ingalls Shipbuilding

ABSTRACT

Recently, Ingalls Shipbuilding Division of Litton updated its fillet weld design practices for naval ship construction. This task was part of a continuing effort to improve accuracy control by decreasing weld caused distortion. Recent material properties and a more rigorous engineering analysis were used to reduce the required fillet sizes by about 25 percent for steel and about 50 percent for aluminum. The analysis method was developed for the Navy at Newport News Shipbuilding during the 1970's. Intermittent weld tables were developed and, where utilized, proved to be a very cost effective distortion control measure. Reducing the amount of weld reduces distortion and economically improves accuracy control. Fabrications costs were significantly reduced.

This paper reviews the methods and properties used to develop and implement the new weld tables. The benefits to distortion control and construction costs are also discussed.

FIGURE 1: EFFECT OF CHANGES ON FILLET WELD SIZE



NOTE: NOMINAL REDUCTIONS DO NOT APPLY TO WELDS NEAR OR BELOW MINIMUM PRODUCIBLE SIZE

NOMENCLATURE

WELDING TERMINOLOGY IS IN GENERAL ACCORDANCE WITH AMERICAN WELDING SOCIETY AND APPLICABLE MILITARY STANDARDS. NEVERTHELESS, A DEFINITION OF ALL SYMBOLS USED WOULD STILL BE APPROPRIATE. SPECIAL TERMS ARE AS FOLLOWS:

CONTINUOUS MEMBER- The member which continues through the tee joint. See figure 1.

INTERCOSTAL MEMBER- The member which ends at the tee joint. See figure 1.

C- Center to center spacing of intermittent welds

E- Weld joint efficiency; weld strength as a percentage of the strength of the controlling (generally intercostal) member.

K- Controlling value for weld size ratio, S/T, from equations 1 through 6.

L- Length of intermittent fillet, exclusive of crater.

S- size of fillet leg

SQRT- Square root (argument)

SUC- Ultimate Shear strength of the Continuous member.

SUI- Ultimate Shear strength of the Intercostal member.

SWL- Shear strength of the Weld, Longitudinal direction.

SWT- Shear strength of the Weld, Transverse direction.

T- Thickness, intercostal member unless otherwise noted.

TUC- Ultimate Tensile strength of the Continuous member.

TUI- Ultimate Tensile strength of the Intercostal member.

ALTERNATE FILLET SIZING

Alternate fillet sizing refers to an alternate NAVSEA approved method of calculating the required fillet size for a given joint efficiency. The method was developed and proposed by Charles Jordan and Bob Krumpen of Newport News Shipbuilding and Drydock Co. (references (1) - (3)) during the 1970's and 80's. Reference (1) reported that the Navy has drafted a change proposal to incorporate the alternate method into reference (4). In the meantime, NAVSEA has authorized incorporation of the alternate method into new and existing surface ship construction and repair contracts. Significant distortion and cost reduction resulted when the alternate method was incorporated into the CG and LHD class designs.

DERIVATION OF METHOD

A very complete and well written description of the method is in reference (1). What follows is a summary of references (1) through (3). There are six failure modes to be considered. The first three concern longitudinal shear failure and the last three concern transverse shear failure. Each failure mode is described by a corresponding equation that determines the fillet size necessary to provide a weld with strength equal to the weaker joint member for the given load condition. A correctly sized 100% efficient weld will satisfy all six equations and provide 100% of the strength of the weaker member.

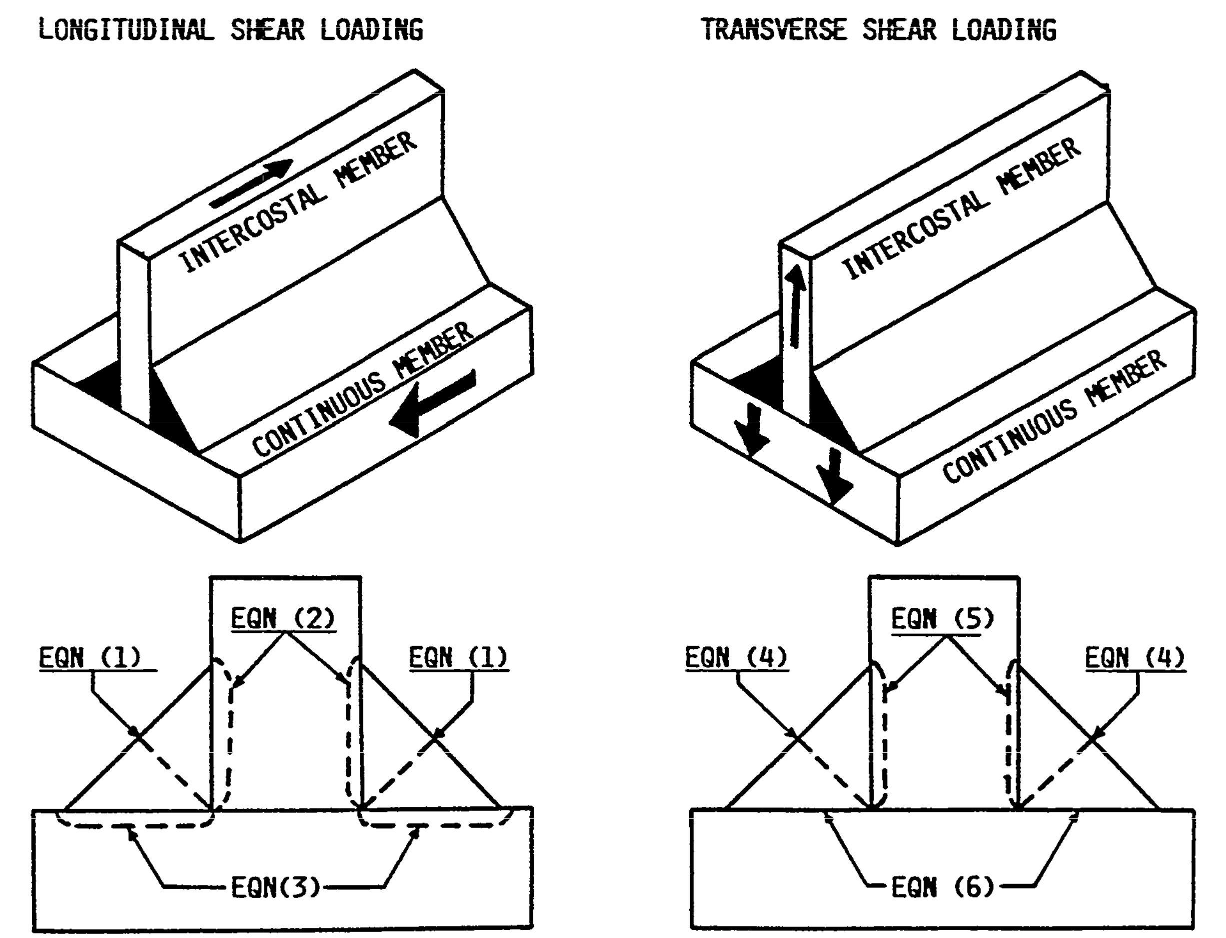
For longitudinal shear loading, consider failure through the weld throat, ignoring bead reinforcing or penetration and assuming a 45 degree fracture. This reduces to:

(S/T) = (SUI / SWL) / SQRT(2) (1)

For longitudinal shear loading, consider failure at the heat affected zone boundaries. The boundary typically has a longer length in cross section than the weld leg size. An approximation of 1.1 times the weld size has been approved by NAVSEA. For failure at the intercostal member boundary, this reduces to:

(S/T) = 1/2.2 = 0.455 (2)

FIGURE 2: MEMBER ORIENTATION AND FAILURE MODES



For longltudinal shear loading, consider failure at the continuous member boundary. Because the strengths of the members may be different, and it is necessary to develop the intercostal member strength, this reduces to:

(S/T) = 0.455* (SUI / SUC) (3)

For transverse shear loading, consider failure through the weld throat. Both theory and experiment predict a failure angle of 60 degrees. However, the angle of fracture is conservatively assumed to occur at a 45 degree angle, and penetration and reinforcement are again ignores. This reduces to:

(S/T) = (TUI / SWT) / SQRT(2) (4)

For transverse shear loading, consider failure at the heat affected zone boundary of the intercostal member. For the intercostal boundary. a length of 1.1 times the weld size has been approved by NAVSEA. This reduces to:

(S/T) = 0.455* (TUI / SUI) (5)

For the continuous member heat affected zone boundary, the increased length is not used, and a conservative assumption of boundary length equal to weld leg size is used. This reduces to:

(S/T) = 0.5* (TUI / TUC) (6)

When the intercostal member is weaker, the standard weld Sizing equation from reference (4) can be rewritten for comparison to the alternate method as follows:

(S/T) = (TUI / SWL) / SQRT(2) (7)

When the continuous member is weaker, the standard weld sizing equation from reference (4) can be rewritten for comparison to the alternate method as follows:

(S/T) = (TUC / SWL) / SQRT(2) (8)

When the intercostal member is much stronger than the continuous member equation 8 may yield a smaller required size, thereby controlling design. In the new weld table, (see table 2) the lower portion is based upon this condition. he ratio of intercostal to continuous member thicknesses where the transition occurs is stated at the top of each section of the table.

SELECTION OF MATERIAL PROPERTIES

It can be seen from the previous discussion that the alternate fillet sizing method requires material properties not previously required to satisfy the stangard method. The standarad method from reference (4) (equations 7 and 8) required tensile 73875 strengths of the Continuous and intercostal ease materials, and the longitudinal shear strength of the weld material. The alternate method (equations 1 through 6) requires. in addition to the above mentioned properties, the ultimate shear strengths of the continuous and intercostal base materials. and the transverse shear strength of the weld Material. Based upon material testing Programs and a pplication of weld and metallurgical theory. NAVSEA has approved the use of some ratios to approximate the additional material properties required by the alternate method".

First, the ultimate shear strengths of the base materials are related to their ultimate tensile strengths. For steels, NAVSEA has approved the conservative assumption that the ultimate shear strength is 75% of the tensile strength. For aluminum, NAVSEA has approved the assumption that the ultimate shear strengths is 60% of the tensile strength. This results in the followlng equations:

SUI=TUI l (0.75 for steel) (9a)
(0.60 for aluminum) (9b)

SUC=TUC l (0.75 for steel) (10a)
(0,60 for aluminum) (lOb)

The strength of HSLA80 (a modified A-710

applications) is not listed in reference (4), but NAVSEA has a proved the use of HY-80 tenSile Strength to determine weld properties. This simplifies.table design and app ears to be conse~rvatlve based upon the lower permissible design stress for HSLA80.

Second. the transverse shear stren9th of the weld is related to its longitudinal shear strength. For steels, NAVEA has approved a ratio of 1.44. For alumlnum. the approved ratio is 1.58. This results in the following equations:

SWT=SWL l (1.44 for steel) (11a)
(1.58 for aluminum) (llb)

There are some significant improvements in weld properties that have been approved by NAVSEA based upon test programs reported in references(3) an (5): These references document increase of 10 and 30 % for weld shear strengths of 5356 and 5556[wires, respectivelY. References 1(1) through (6) show some of the beneficial property changes which can De can be icqorporated into individual shipyard weld tables. A list of the pertinent weld properties currently in use at Ingalls Shipbuilding and their sources are shown in table 1, NAVSEA has approved these values.

IMPLEMENTATION

The alternate fillet sizing method was implemented at Ingails in several pnases. The first pnase involved aeveloptlient of the properties and weld tables, In the second phase. the tables sowere presented to the Navy and approvals appllcable to exlstlng contracts were obtalned. The thra pnase involved Cnanglng the construction arawings. In tne process. wela cost studies were made oy industrial engineers to assess the cost impact of the changes.

The previous sections described the methodand material properties used to develop the weld tables. The tables were develop~ea using a microcomputer and electronic spreadsheet program. A Sample page from the iflnlshed weld table is snown in table 2. The format differs from reference (1) which shows the requires fillet for a given late size. The format used at Ingalls displays the maximuml allowable member thicKness for a given weld size. This results in the minimum weld size for rolled and extruded shapes whose thicknesses lie between the standard plate sizes. The lower section of the weld table covers Joints where equation 7 or 8 controls the weld size.

The third phase was the actual modificatlon of the existing construction drawings. It was intended tnat the Implementation be the most cost eftective possible. To this end, lndustrial engineering studies were made to recommend areas of application and to assess the impact on costs, Effort was concentrate on changing welds with the greatest Impact upon cost, thereby maximizing the return on engineering investment, The greatest impact occurs with conversion from complete penetration welds to fillet welds. There are Significant savings where Multi-pass fillets (typically3/8 inch and over) can be reduced to single pass welds. There was no significant effort made to reduce welds be below the minimum producible weias. The minimurn manual (semi-automatic) production weld generally is about 3/16 Inch for steel and 1/4 inch for aluminum.

Another economical change during alternate fillet size implementation concerned the maximum fillet size. Previous tables limited the maximum fillet to 1/2 inch, beyond which cotnplete penetration welds are indicated on the drawings, The weld tapleS were extended to cover larger sizes. and the drawings changed to reflect this. In many cases, it is more cost effective to use a large multi-pass fillet, rather than a complete penetration weld. weld standards always permit the substitution of an equal or higher efficiency joint design. Therefore. production has the option of substituting a complete penetration weld for any indicated fillet where other constraints control.

TABLE 1

WELD LONGITUDINAL SHEAR STRENGTH (KSI)

FILLER METAL	NAVSHIP 0900 -000-1000	MIL-STD 1628	APPROVED AT ISD
[illegible]	[illegible]	[illegible]	[illegible]
10018	71	N/A	78
11018	75.3	87	87
100S-1	N/A	83	83
5356	18.4	20	22; ref 5
5556	19.2	20	26; ref 3

COMPARISON

The alternate method always reduces the minimum required weld size when compared to the standard method, equation 7, Comparing the current weld tables to the previous ones snows a size reduction of 20 - 25 percent for steel and about 45-50 percent for aluminum.

TABLE 2: SAMPLE WELD TABLE

COMPONENT	MATERIAL TYPE	KSI WELD LONG'L SHEAR STRENGTH	KSI WELD TRANSV SHEAR STRENGTH	KSI BASE METAL ULT TENSILE STRENGTH	KSI BASE METAL ULT SHEAR STRENGTH
FILLER ALLOY	70XX	59.0	84.96		
INTERCOSTAL MEMBER 'I'	HS			75.00	56.25
CONTINUOUS MEMBER 'C'	HS			75.00	56.25

USE THIS TABLE IF THE THICKNESSES OF I/C < 1.33

SIZE OF FILLET WELD EACH SIDE	UPPER LIMIT OF PLATING THICKNESS IN INCHES 50%	60%	75%	100%
1/8	0.371	0.309	0.247	0.185
3/16	0.556	0.464	0.371	0.278
1/4	0.742	0.618	0.494	0.371
5/16	0.927	0.773	0.618	0.464
3/8	1.113	0.927	0.742	0.556
7/16	1.298	1.082	0.865	0.649
1/2	1.483	1.236	0.989	0.742
9/16	1.669	1.391	1.113	0.834
5/8	1.854	1.545	1.236	0.927

USE THIS TABLE IF THE THICKNESSES OF I/C ≥ 1.33

SIZE OF FILLET WELD EACH SIDE	UPPER LIMIT OF PLATING THICKNESS IN INCHES 50%	60%	75%	100%
1/8	0.278	0.232	0.185	0.139
3/16	0.417	0.348	0.278	0.209
1/4	0.556	0.464	0.371	0.278
5/16	0.695	0.579	0.464	0.348
3/8	0.834	0.695	0.556	0.417
7/16	0.973	0.811	0.649	0.487
1/2	1.113	0.927	0.742	0.556
9/16	1.252	1.043	0.834	0.626
5/8	1.391	1.159	0.927	0.695

NOTE: I = INTERCOSTAL MEMBER THICKNESS
C = CONTINUOUS MEMBER THICKNESS

The reduction in aluminum sizes is greater because the aluminum material and weld properties were updated during the implementation of the alternate method. It should be remembered that weld volume is proportional to the **square of the Weld Size. Therefore.** volume related variables (cost, distortion, etc.) are reduced about 40 percent for steel and about 70 percent for aluminum.

INTERMITTENT WELDING

Intermittent welding is a widely used commercial design with excellent cost effectiveness, particularly with manual welds. However. it has Only rarely been uses for Naval combatant fabrication at Ingalls. The existing designs of the LHD and CG class ships under construction at Ingalls did not use any intermittent Weld designs for hull structure. There were a few instances were intermittent weld designs were used for miscellaneous items such as coamings supporting joiner bulkheaas and false deck structure. Intermittent welding was first implemented for steel structure on LHD. **Later, weld tables for** otner applications were developed based upon the alternate fillet sizing method. out these have not yet deen implemented.

SIZING OF INTERMITTENT WELDS

There are two standards applicable to sizing lntermittent welds. The first is the American Bureau of Shipping Rules. reference (8). This standard is applicable to steel structure on the LHD. but not to CG class ships. As this standard is simple and well known. sizing using this standard won't be discussed here, other than for comparison purposes. The second standard is a collection of sizing requirements from various sources invoked by the ship construction contracts currentlY in effect at Ingalls.

Basically, the Navy method starts with the minimum required continuous fillet. then increases the intermittent fillet size Inproportion to the ratio of unwelded to welded length. This requirement is from section 11.3.3.2 of reference (7) (same as reference (6)). **When the alternate fillet Sizes were implemented, the requirements** for lntermittent welding sizes were impacted. Intermittent weld tables were developed to reflect alternate fillet sizes and applicable Navy requirements as outlined below.

First, the increase of leg size proportional to welded length ratio. as outlined above, is put into an equation as

$$(S/T) >= (E / K) * (C / L) \qquad (12)$$

This requirement will be uses to find the minimum length, so it is rewritten as:

$$L >= C * (E / K) * (T / S) \qquad (12a)$$

The intermittent weld cannot provide any overall increase in shear load capacity beyond what the intercostal member wi1l support at the weld. That is, a 100 percent efficient weld means the weld strength equals the member strength. Wled sizes, larger than this simply mean that member strength controls, rather than weld strength. and that additional weld material does not provide additional strength. Thus. weld designs with single fillet 1egs oversized for the thickness of the intercostal member (stiffener web, typically) will be prevented if the staggered intermittent weld were less than twice the leg size of a 100 percent efficient double continuous fillet. This requirement from section 11,3.3.2 of reference (7) is satisfied when

$$(S/T) <= 2 / K \qquad (13)$$

Equation 13 is valid for staggered intermittent welding when the fillet length is less than half the spacing. This is satisfied when

$$(L) <= C / 2 \qquad (14)$$

TABLE 3: SAMPLE INTERMITTENT WELD TABLE

ALLOWABLE INTERMITTENT WELDS PER
MIL-STD-1689 AND MIL-STD-22,
TABLE GIVES FILLET SIZE-LENGTH-SPACING
WITH EQUIVALENT CONTINUOUS DOUBLE FILLET
IN PARENTHESES

INTERCOSTAL MATERIAL =5456 AL
CONTINUOUS MATERIAL =5556 AL
FILLER MATERIAL
MATERIAL CONSTANT=K = 1.291

I'COSTAL MEMBER	JOINT EFFICIENCIES 50%	60%
0.188	1/4-2 3/4-9 (1/8)	1/4-3-8 (1/8)
0.219	5/16-2 3/4-10	5/16-3-9
0.225	5/16-3-10	5/16-3 1/2-10
0.250	3/8-3-11	3/8-3 3/4-12
0.258	3/8-3-11	3/8-4-12
0.277	3/8-3 1/2-12	3/8-4 1/4-12 (3/16)
0.3125	3/8-4-12	3/8-4-10 (3/16)
0.325	5/16-5-12 (3/16)	3/8-5-12 (3/16)
0.349	3/8-4 1/2-12 (3/16)	3/8-4-9 (3/16)
0.391	3/8-5-12 (3/16)	3/8-6-12 (3/16)

The requirements from figure 22 of reference (9) are reflected in equations 15 through 20 below.

$8 * S <= L$ (15)

1.5 inches $<= L$ (16)

$L <= 24 * T$ (17)

$L <=$ 6 inches (18)

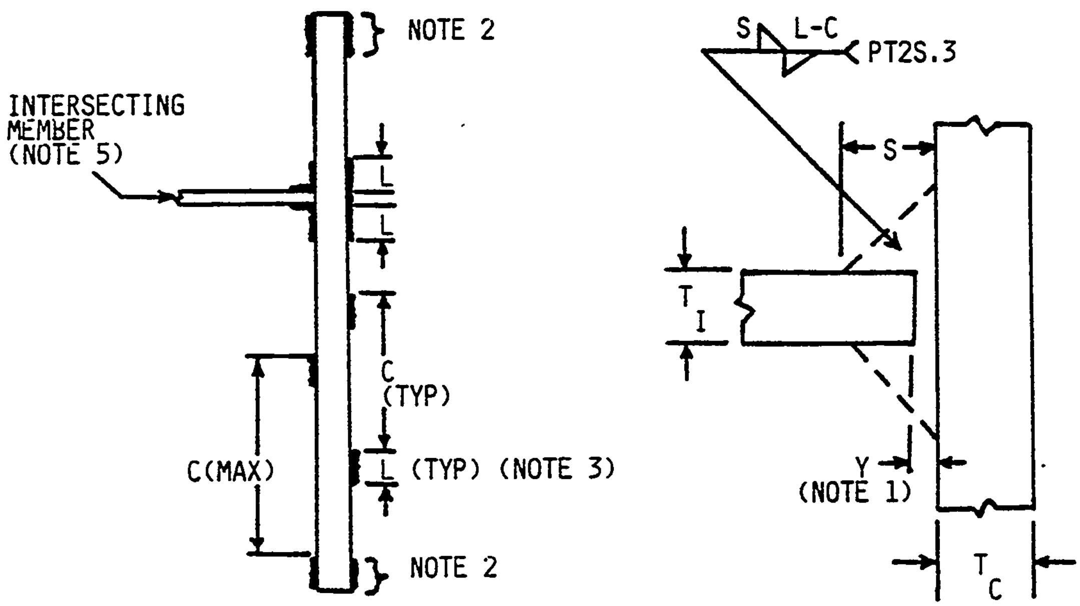
$C <= 48 * T$ (19)

$C <=$ 12 inches (20)

Equations 12a through 20 describe the boundaries of acceptable solutions for staggered intermittent weld sizes. A microcomputer and electronic spreadsheet program were used to interactively derive the intermittent weld tables.

By convention, only integer spacing is used because it simplifies layout of welds. Integer fillet lengths are preferred, but not necessary. The use of weld marking tools, adjustable as to length and spacing make these restrictions less important. The most cost effective intermittent welding generally results when the spacing and

FIGURE 3: INTERMITTENT WELD STANDARD DETAIL, PT 2S.3



NOTES:

1. Where "Y" is greater than 1/16 inch as a nominal condition, "S" shall be increased by an amount equal to the excess of the opening above 1/16 inch.

2. All intermittent fillet welded joints shall have continuous welds on both sides of the joint at each fixed end for one eighth the length of the member. Members with sniped ends shall have end welds on both sides, equal in length to the intermittent weld (see note 6). The length and spacing of increments specified shall be laid off between the continuous end welds.

3. The specific length of the fillet shall be the length of the weld at full size. Craters and tapered ends shall not be included when measuring dimension "L".

4. Fillet size(s) shall be determined in accordance with the requirements of the applicable fabrication documents and weld sizing tables.

5. There is to be a pair of matched intermittent welds on each side of an intersecting member (see note 6).

6. Matched, chained, and end weld sizes need not exceed the size required for 100% efficient continuous fillet welds.

single pass fillet sizes are the largest. A single pass fillet weld is desired for economic reasons. Production single pass fillet welds in steel can be made up to about 3/8 inch using the flux core process and up to 5/16 inch using shielded metal arc. In aluminum, production single pass fillets can be made up to about 3/8 inch. Where feasible, the preferred fillet size reflects these limits. The tables may include larger sizes, but cost trade-off studies show that single pass continuous welding is preferred to multipass intermittent welding.

Construction of the tables proceeds as follows:

A. Select the material thickness and weld efficiency.
B. Determine the maximum spacing from equations 19 and 20.
C. Determine the maximum fillet size from equation 13.
D. Select a target fillet size between 3/16 inch and item C. If the nominal target size is greater than item C, the exact value from item C is used in the calculations.
E. Find the minimum fillet length from equations 12a, 15 and 16.
F. The minimum length from item E must be less than the maximums from equation 14, 17 and 18.

A sample of an intermittent table is shown in table 3.

IMPLEMENTATION

Actual implementation of intermittent welding to Navy standards has not occurred at Ingalls, pending further study and development. There are some additional criteria from references (7) through (9) that must be considered in production welding. At Ingalls, these restrictions have been incorporated in the standard joint detail notes, shown in figure 3.

COMPARISON

There are noticable differences between ABS and Navy intermittent welding requirements. Most obvious is that the Navy frequently requires more weld for a similar member than does ABS. Second, Navy allowable intermittent weld spacing is smaller for thin members, but increases to 12 inches. ABS allowable spacing starts at 12 inches for thin members and decreases for thick members. Navy requires more double continuous end welding for fixed members than does ABS. The ABS weld requirements do not differentiate between various strength steels and weld materials, but the Navy requirements are adjustable for strength.

As an example of the differences in the amount of welding required, compare the welds required for a miscellaneous bulkhead steel stiffener. On the LHD, a member for such an application would be a 4x4x5# I-T with a web thickness of 0.17 inches. ABS rules require a 3/16 - 2 1/8 - 12 inch weld size. If this were to be done to Navy requirements, the weld would be at least 3/16 - 2 1/2 - 8. The volume of weld material for this non-structural bulkhead stiffener is 76 percent greater by Navy standards, not counting any additional end welding.

As yet, the ABS Rules for Building and Classing Aluminum Vessels do not reflect ABS recommended practices used for comparison in this report. These recommendations have been in use along the Gulf Coast for 8 - 10 years to design aluminum vessels under 200 feet. Typically, these commercial aluminum vessels experience heavy pounding due to their high speeds, large deck cargo loads, and generally severe load patterns. Aluminum intermittent welding to ABS recommendations has proven to yield a satisfactory service life for these vessels.

For comparison of ABS to Navy weld requirements, consider an aluminum stiffener on the internal structural bulkhead in the superstructure. For LHD, a member for such an application would be 6x3.0# T with a 0.219 inch web thickness. A comparable weld in accordance with ABS recommendations would be a 3/16 - 2 1/2 - 8 inch weld size, while Navy requires a 5/16 - 3 - 9. The volume of weld material for this non-structural bulkhead stiffener is 78 percent greater by Navy standards, not counting additional end welding.

The variation of spacing requirements with thickness can plainly be seen when comparing the Navy and ABS tables. When the intermittent welds are loaded in longitudinal shear, there is a tendency for the web to buckle at the end of the fillets or in the spacing between fillets. Buckling in general is related to the unsupported length and the thickness. For thinner members, which are more susceptible to buckling, a limit on the unsupported (unwelded) length makes engineering sense.

End welding requirements are another significant difference between ABS and Navy intermittent weld requirements. ABS requires a pair of matched (chained) intermittent welds at the ends of non-tight bulkhead stiffeners, and continuous welds for one tenth the length of water and oil tight bulkhead stiffeners. Navy requires continuous end welds for one eighth the ends of fixed ended members (typically water and oil tight bulkhead stiffeners).

DISTORTION IMPACT

Weld caused distortion is a common problem when welding stiffeners and framing to thinner plates. There are several good references, such as (10) and (11), concerning weld caused distortion. Simply put? angular distortion of the platingOue to Stiffener welding increases as the weld heat Increases aria as the plate thickness decreases,

Continuous fillet weld heat is related to the weld volume, and, to a large extent. the travel speed. A high travel speed significantly decreases the distortion, although weld quality **factors** limit top speed. Alternate fillet sizing decreases distortion primarily because the smaller fillet sizes permit nigher travel speeds, Higher travel speeds also benefit labor costs for manual and semi-automatic processes, and improve machinery utilization for automatic weld **processes.** When distortion decreases. shipfitting is easier, and less flame straigntening effort is necessary per elate panel. However, these benefits do not occur when the weld size is already near the minimum producible,

Intermittent welding is the most cost effective available distortion control method. Where. intermittent welding has **been** used; the angular distortion of the plate at the stiffener has been virtually eliminated, This was found to be true even for thin bulkhead plating (3/16 inch steel). When the end welds are made after the plating periphery has been fully welded out, even the distortion due to the continuous end welds was **found to be Significantly reduced or eliminated,**

WELD COST IMPACT

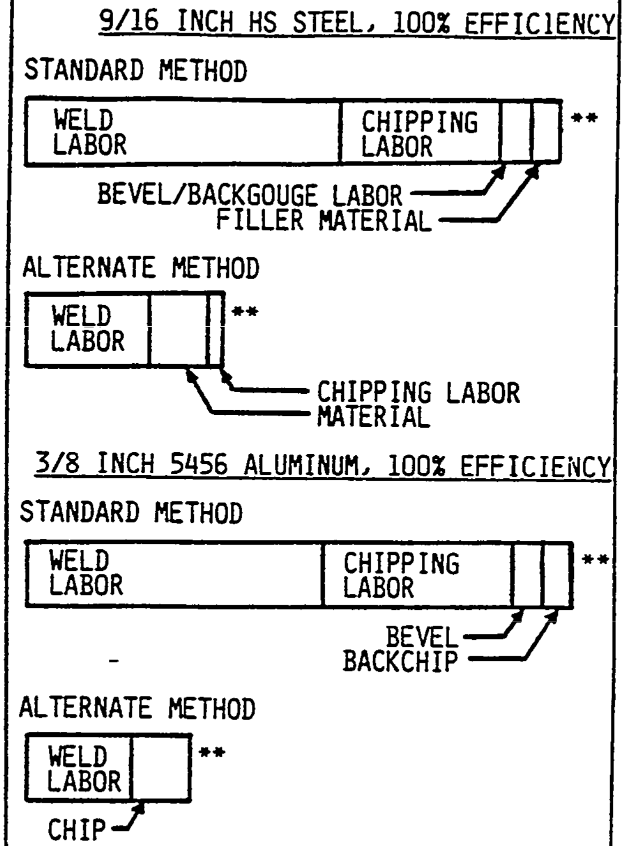
The weld design changes made at Ingalls initially were part of an effort to reduce weld caused distortion, However, a very beneficial side effect of the distortlon reduction is a significant cost reduction. Savings estimates for intermittent welding by Navy StandardS have not been campleted. Weld savings are passed onto the Navy by reduced old estimates. and benefit the shipyard by increased competitiveness.

ALTERNATE METHOD COST IMPACT

Implementation of the alternate fillet sizing method impacts cost both dilrectly and indirectly. The savings directly **related to the weld size** lnclude labor (weld. chip. bevel. gouge and supervision), material (filler, flux and shielding gas), and electricity. Indirectly, the alternate fillet sizing method **reduces distortion related costs. long terml capitol investment** for weld machines, and the size requirements for interrlmittent welding.

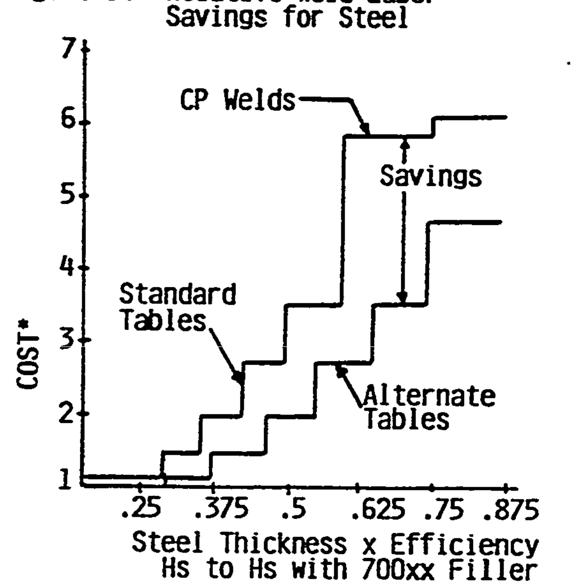
As a rough-approximation, direct costs are related to the volume of the Weld, which varies as the square of the weld size. The weld size is directly

FIGURE 4: RELATIVE COST COMPARISON OF BEVELLED WELD TO CORRESPONDING ALTERNATE FILLET WELD

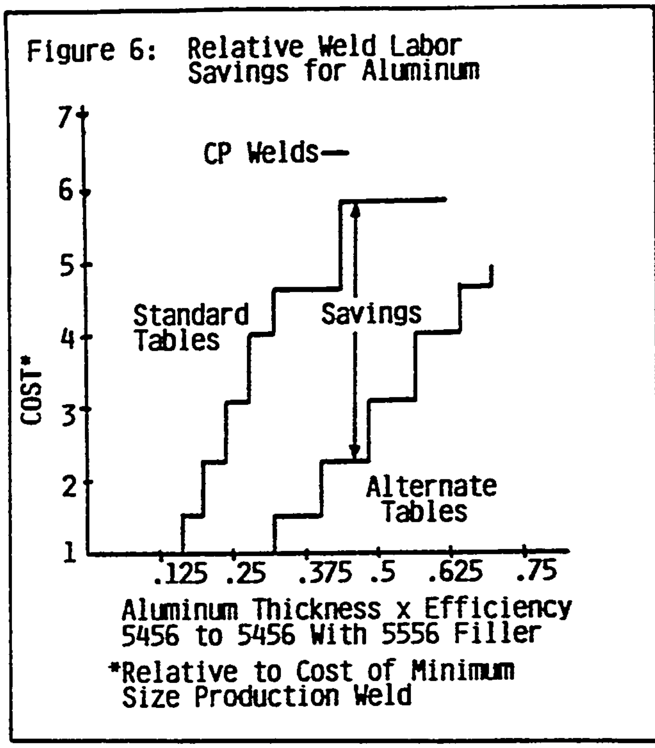


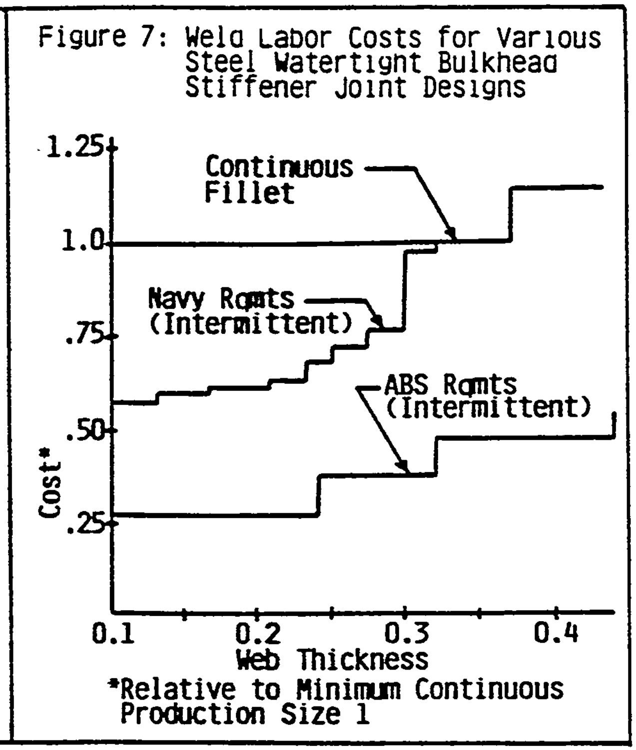
** INDERECT COSTS ARE GENERALLY EXPRESSED AS A PERCENTAGE OF DIRECT COSTS, THEREBY INCREASING THE DISPARITY SHOWN ABOVE.

Figure 5: Relative Weld Labor Savings for Steel



*Relative to Cost of Minimum Size Production Weld





proportional (albeit stepwise) to the material thickness and to the required joint efficiency. The proportions of the various types of direct costs involves In some representative weld assigns can be seen in the bar charts in figure 4. Figures 5 and 6 show the variation of relative total cost with respect to materlal thickness. The effect of weld joint efficiency on costs is simply to shrink or expand the horizontal scale while holding the cost curve in place.

The actual costs are not smoth curves because weld sizes are step functions. and because there are several discontinuous jumps. The first of these Jumps occurs when welds must be made with multiple passes. because chip costs are more clasely related to feet of weld to be cleaned rather than weld size. The second. even larger jump occurs when complete penetratlon joints are encountered. This occurs because two new types of labor (bevel, and backgouge or backchip), again related to feet of Weld, not weld size. are required.

INTERMITTENT WELDING COST IMPACT

Intermittent welding is generally more cost effective than continuous weldS where thin members are involved. The labor cost difference is particularly large for thinner members, and becomes less significant as the members become thicker, see figure 7. This is because the intermittent size rapidly reaches the point where multi-pass Intermittent welas are necessary, causing the smaller continuous fillets become more attractive. There is an additional cost invalved in laying out the intermittent welds. This increased cost was offset by the virtual elimination of weld caused distortian. Intermittent welding is a very cost effective distortion prevention measure. Intermittent welding is very cost effective for joints in lighterscantlings, as shown in figure 7, and it is the lighter scantlings that are more susceptible to weld CaUSed distortion. Reduction of distortion through the use of smaller continuous fillets primarily benefits shipfitting costs. The eliminatian of distortion through the use of intermittent welding not only cuts costs far shipfitting labor. but also eliminates straightening casts and attendant paint rework. As an additional benefit, outfitting does not have to be scheduled to occur after the straightening operatian, permitting more flexible planning.

CONCLUSION

Weld caused distortion due to fillet welds has been significantly reduced or eliminated through recent weld design changes, The alternate, NAVSEA approved. fillet sizing provides significant reductions in the required fillet sizes, as well as reducing the size requirements for intermittent welding . The improvement in accuracy cantrol and the reduction is weld costs nave resulted in tangible savings, whicn are passed on to the Navy in the form of reduced construction prices.

ACKNOWLEDGMENT

I wish to express my appreciation to Charles Jordan and Bob Krumpen of Newport News Shipbuilding and Drydock Co. As a taxpayer, I commend their willingness to share their research with other shipyards.

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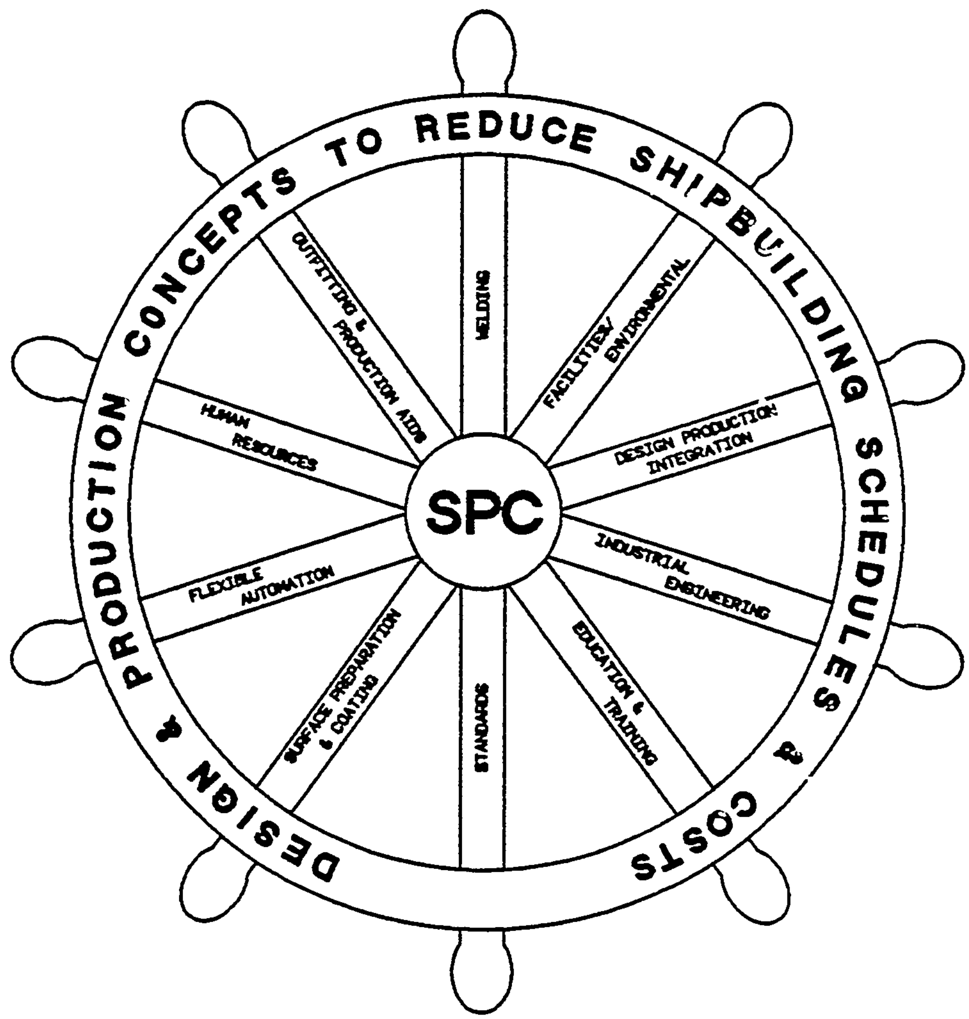

PAPER NO. 14

INVESTIGATION OF TUBULAR ELECTRODES DESIGNED FOR SUBMERGED ARC WELDING APPLICATIONS

BY: R. A. WHANNELL
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AUGUST 27-29, 1986

1986 SHIP PRODUCTION SYMPOSIUM

INVESTIGATION OF TUBULAR ELECTRODES DESIGNED FOR SUBMERGED ARC WELDING APPLICATIONS

R. A. WHANNELL AND B. H. HALVERSON, Bay Shipbuilding

ABSTRACT

The Submerged Arc Welding Process has long been an important tool for joining thick steel plate in all areas of steel fabrication. Recent electrode manufacturing techniques introduced flux cored electrodes designed for Submerged Arc Welding Applications. This paper deals with the results of an investigation designed to study the relative operating characteristics of flux core submerged arc welding electrodes and to compare these results against solid submerged arc welding electrode performance.

Base metals selected for this investigation were those used in shipbuilding **for** hull envelopes or corrosion resistant tankage applications. Weld test data was recorded using the solid electrode results as 100% of normal Submerged Arc Welding performance. Using the same welding parameters as those used **for** solid electrodes, weld tests were conducted using the flux core electrodes. We were able to conclude that the flux cored electrodes offered several economic improvements as well as improved mechanical properties on some types of steel.

Applications And Economies Of Submerged Arc Process [1][1]

With proper selection of equipment, Submerged Arc is widely applicable to the welding requirements of industry. It can be used with all types of joints, and permits welding a full range of carbon and **low-alloy** steels, from 16-gage sheet to the thickest plate. It is also applicable to some high-alloy, heat-treated, and stainless steels, and is a favored **process** for rebuilding and hardsurfacing. my degree of mechanization can be used from the hand-held semi-automatic gun to boom or track-carried and fixture-held multiple welding heads.

The high quality of Submerged Arc welds, the high deposition rates, the deep penetration, the adaptability of the process to full mechanization, and the comfort characteristics (no glare, sparks, spatter, smoke, or excessive heat radiation) make it a preferred **process in** steel fabrication. It is used extensively in ship and barge building, railroad car building, pipe manufacture, and in fabricating structural beams, girders, and columns where long welds are required. Automatic Submerged Arc installations are also key features of the welding areas of plants turning out mass-produced assemblies joined with repetitive short welds.

The high deposition rates attained with Submerged Arc are chiefly responsible for the economies achieved with the process. The cost reductions, when changing from the manual Shielded **Metal Arc Process** to Submerged Arc are frequently dramatic. Thus, a hand-held **submerged arc gun with** mechanized travel may reduce welding costs more than 50%; with fully automatic multiarc equipment, it is not unusual for the costs to be but 10% of those attained with stick-electrode welding.

Factors other than deposition rates enter into the lowering of welding costs. Continuous electrode feed from coils, ranging in weight from 60 to 1,000 pounds, contributes to a high operating factor. Where the deep penetration characteristics of the process permit the elimination or reduction of joint preparation, expense is lessened. **After** the weld has been run, cleaning costs are minimized because of the elimination of spatter by the protective flux.

When Submerged Arc equipment is operated properly, the weld beads are smooth and uniform, so that grinding or machining is rarely required. Since the rapid heat input of the process minimizes distortion, the costs for straightening finished assemblies are reduced, especially if a carefully planned welding sequence has been followed. Submerged Arc Welding, in fact, often allows the premachining of parts, further adding to fabrication cost savings.

A limitation of Submerged Arc Welding is that imposed by the force of gravity. In most instances, the joint must be positioned flat or horizontal to hold the granular flux. To **deal with this problem, weldment positioners are used to turn assemblies to**

[1] Numbers in brackets indicate references at the end of paper.

present joints flat or horizontal - or the assemblies may be turned or rotated by a crane. Substantial capital investments in positioning and fixturing equipment in order to use Submerged Arc Welding to the fullest extent and thus gain full advantage of the deposition rate, have proved their worth in numerous industries. Special fixturing and tooling have been developed for the retention of flux and molten metal in some applications, so that 'three o'clock" welding is possible.

1986 SHIP PRODUCTION SYMPOSIUM - EXPLANATION OF ABSTRACT

The intent of this investigation was to verify manufacturer's claims of improvements in physical properties and operating economies by the use of the new generation cored wire electrodes. A solid wire electrode, which has been the industry standard, was chosen for each of the four materials investigated, and its test results were used as a control sample baseline for comparison purposes. All test welds were run under identical conditions of welding parameters, travel, voltage, stick out and amperage. The welding equipment was located in a large fabrication shop representative of the actual conditions these electrodes are used in 90% of shipyard applications. The resulting data collected reflects actual production job site results rather than laboratory generated results, which manufacturers normally report in advertising brochures. Data was obtained at two settings, a lower setting which would represent root pass welding and fillet weld applications, and a higher setting which would reflect fill pass production applications.

A standard welding procedure was followed for all materials tested. It specified the use of a groove weld into a backing bar. This eliminated any error in collecting data that would occur if back gouging was utilized. It also eliminated one more variable which could enter into mechanical or spectrographic data.

The operating characteristics of each electrode during testing was documented by an obsemer as well as by soliciting comments from the welding operator. The comments were recorded and reviewed at the end of each weld test. Some comments were of an opinion nature which could not be supported by physical evidence, others were based on the physical evidence present, (i.e. sound of tie arc, bead appearance, etc.) at the time the procedure was being run. Only the comments which were supported by some form of physical evidence were reported in the conclusion section of this report.

Although several manufacturer's products were used in this investigation, they were given a designation by material type and procedure used. The welding operators and testing laboratory personnel did not know the manufacturers involved. In this manner, it was possible to eliminate any preconceived bias toward a trade name of a particular manufacturer's product.

Strict control was exercised in the identification of individual materials and filler metals. Upon receipt, the plate material was inspected to confirm that it matched the material certification received from the mill, then it was plasma burned into test coupons. Each coupon was immediately stamped to reflect its identity and mill certification. The electrode was also given a two letter identification code. In this respect, each procedure test plate was given a discrete code which would identify it during the sectioning and testing operations. Each step of the process required that the individual pieces be remarked with the procedure code to maintain traceability.

The mechanical tests selected to evaluate the weld metals were based on standard industry requirements. Tensile and bend tests were specified to check . the strength and ductility of the weld deposits. Hardness surveys were performed to get a general indication of properties from the weld center line across the heat affected zone and out into the base metal. Spectrographic checks were also made to look for segregation of elements in the weld which could result from inconsistence in the manufacture of the tubular wire. Charpy impact tests were specified to check the properties of the weld, H.A.Z. and base metal at low temperature. Impact values are a good indicator of a structure's reliability to resist catastrophic fractures at low temperatures. Higher impact values was one of the claims which was common to all of the tubular wire manufacturer's literature. It was also one of the areas which most interested the industrial users and military concerns alike.

Submerged Arc Welding Equipment

The power source used in this program was a DC-1500 ampere three phase rectifier type, set in the Constant Voltage Control Mode. This power source has input line voltage compensation which will maintain constant secondary output up to a 10% line fluctuation value. It is also equipped with a SCR-type control circuit which provides precise control of voltage and amperage setting as well as having excellent starting characteristics needed for Submerged Arc Welding.

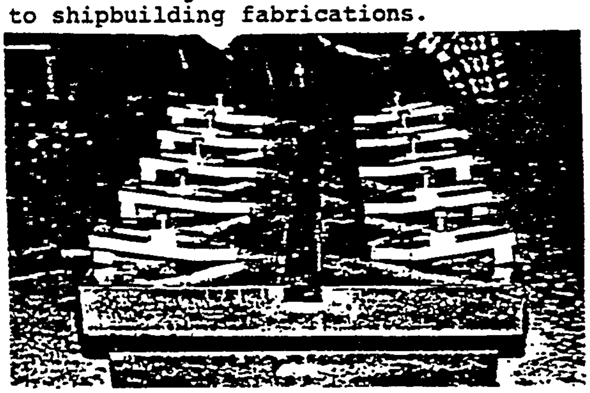
Control was provided by a Lincoln NA-3 solid state wire feeder-head equipped with an optional start control board, and full metering capabilities for Voltage, Amperage and Wire Feed Speed in inches per minute. The control head was set for reverse polarity operation (electrode +) in the constant voltage mode. The head was coupled to a wire feed motor and gear box to which a mechanical wire straightener and torch were attached. The torch used a tang contact system which provides positive electrical contact at the nozzle of the assembly.

All meters were calibrated at the start of the program and were checked at 90 day intervals. The wire feed speed meter was also verified on each pass by the use of a hand held digital wire feed speed meter.

Only one correction was made during the length of the program. This was to the amperage meter to correct a 20 to 25 amp error on April 25, 1985. There were only three procedures run subsequent to this date; HY-8-AC1, HY-8-AC-HHI-1 and HY-0-AC-1. Because the program was dependent on all electrodes operating at the exact same amperage, there may be a maximum 4 to 5 percent difference due to meter drift between the start and finish of this program.

Weld Tooling

The hold down fixture used in this program was fabricated from a piece of 3" x 24" x 42" ABS Grade A plate steel. A 1" x 2" slot was milled in the fixture to allow a relief for the backing bars on procedure test plates. Ten 3/4" High Strength Bolts with dogs were used to clamp the plate in place and prevent rotational distortion. Three 3/4" x 8" x 24" strong backs were welded to the underside of the fixture to provide a high level of restraint to simulate job site conditions common to shipbuilding fabrications.



Hold down fixture used to simulate the restraint levels typical of shipbuilding applications.

The side beam carriage was a Pandjiris Model VSC-40-12 mounted on a Pandjiris Model PBT-15/144 side beam. The travel mechanism was a Pandjiris tachometer control type which is solid state controlled to regulate travel speeds precisely regardless of differing resistance on the carriage guide rollers or cable rack.

The voltage and wire feed speed settings were frequently double checked using a Lincoln Voltage Indicator, No. M-12421, and Lincoln Wire Feed Speed Meter, No. M-13367.

The scale used for all weight measurements on test plates and wire spools was a Detecto Model 4570. It has a 130 lb. capacity accurate within 1/2 oz.

Preheat and Interpass temperatures were verified by a Pacific Transducer Corporation surface thermometer, Model PTC-313F.

Weld Joint Design

The joint design used in this program was a 45° groove weld with a backing bar of identical material as the base metal being welded. Fit-up tolerances are depicted in fig. 1. This particular design was selected to accommodate the mechanical tests that were to be cut from the test assembly, particularly the longitudinal all weld metal tensile specimen which requires a large cross section of weld to ensure a valid test. The actual weld metal required to fill the joint was 2.54 pounds per foot.

JOINT FIT UP TOLERANCES

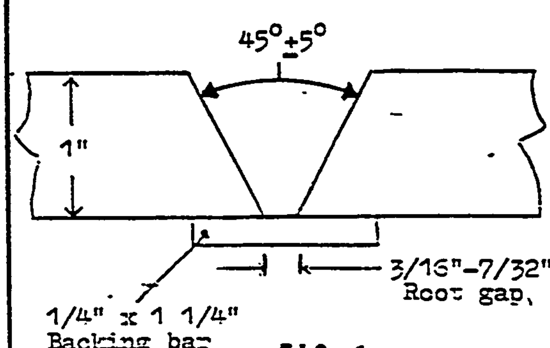
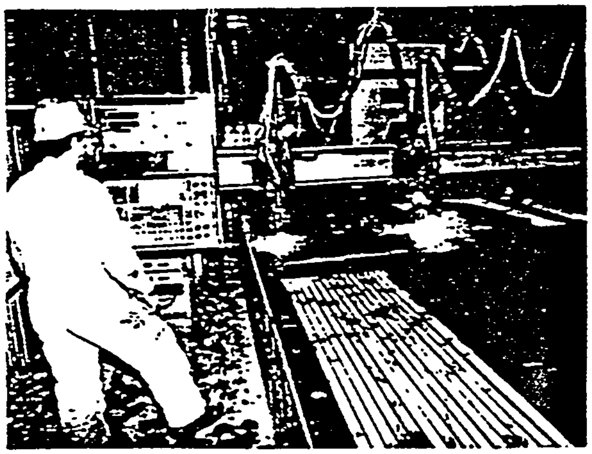


FIG. 1

Preparation Of Test Plate Material



Test material being prepared on NC Plasma Burning Machine.

All weld test materials used in this program were prepared by Plasma Arc Cutting on a water table. It is normal for this process to create a thin zone of high hardness along the cut edge of the plate. This is due to the rapid speed of the process and the water coolant which combine to give this zone a quench effect. It is a very pronounced effect in the higher strength steels because they are chemically formulated to respond to thermal processing. This thermal induced zone of hardness is not due to pick up of carbon *or* other elements during cutting. It is strictly a quenching of the immediate microstructure to a depth of .020″ to .030″ maximum as determined in our efforts to measure this zone. This zone should not have an effect on mechanical properties of the finished weld. The reasons for this is that the bevel surfaces of the weld joint were lightly ground to remove surface oxides or cutting dross. Secondly, the welding operation was producing an average of .080″ penetration into the base metal which would completely melt this zone thus canceling any effect of the prior thermal quenching effect from cutting.

Base Materials Welded

The specific steels selected for this program cover the shipbuilding industry as a whole, both commercial and military. They were selected to reflect the current technological level in steels on the higher end of the spectrum in tensile strength and impact resistance or corrosion resistance requirements.

American Bureau of Shipping Steel EH-36 was selected to represent typical steels used in commercial construction applications where higher strength or impact resistance is required.

A 316L Stainless Steel was selected to represent applications where corrosion resistance is a primary concern.

TWO grades of steel were selected to represent military applications: HY-80 and HY-1OO conforming to NIL-S-16216 J.

Selection Of Test Electrodes

Submerged Arc Welding Electrodes for this program were selected on the basis of vendor literature and verbal recommendations of formulations engineers on specific wire-flux combinations. To get a direct and accurate assessment of each electrode, a neutral flux was required. The use of a neutral flux would eliminate the variance that could be introduced by iron powder or alloy additions in the flux aggregate.

The terms used in this presentation are directed at the individual who has a basic knowledge of welding terminology. To set the record totally correct we will reference the American Welding Society and its publication AWS A 3.0 WELDING TERMS AND DEFINITIONS [2].

Where solid wire is used in this report, it is synonymous with the AWS definition of bare electrode. BARE ELECTRODE - a filler metal electrode consisting of a single metal or alloy that has been produced into a wire, strip, or bar form and that has had no coating or covering applied to it other than that which was incidental to its manufacture or preservation.

- Where flux cored wire is used in this report, it is intended to fit the definition of metal cored electrode as defined below. The electrode tested in the EH-6-FC designation was actually a true flux cored electrode which could be used for Submerged Arc applications also. Both definitions are included below - notice that the difference is in the amount of stabilizing or fluxing ingredients allowed to be used. FLUX CORED ELECTRODE - A composite filler metal electrode consisting of a metal tube or other hollow configuration containing ingredients to provide such functions as shielding atmosphere, deoxidation, arc stabilization and slag formation. Alloying materials may be included in the core. External shielding may or may not be used. NBTAL CORED ELECTRODE ˉ A composite filler metal electrode consisting of a metal tube or other hollow configuration containing alloying ingredients. Minor amounts of ingredients providing such fuctions as arc stabilization and fluxing of oxides may be included. External shielding gas may or may not be used.

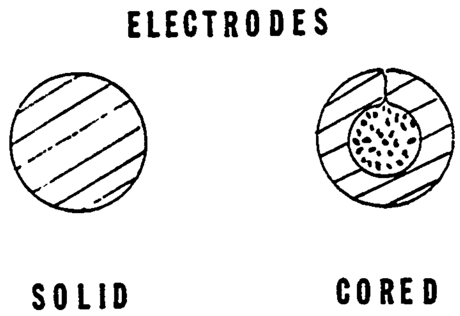


FIG. 2

For the purpose of comparison, a solid electrode was selected for each material category; its results were used as a baseline for this program. The solid electrodes were purchased from a single well-established vendor in the industry. The exact electrode/flux combinations recommended in this vendor's literature were used. It should be noted here that this particular vendor has since developed a new flux which produces higher impact values than the flux used in this program.

The flux cored electrodes selected were specifically recommended for this application in the vendor's literature. The electrode/flux combination listed by the vendor was strictly adhered to. Where a choice of fluxes was recommended, the flux which produced the highest impact values was selected. This information was provided by vendors on the basis of research that they themselves had performed. It should be pointed out, at this point, that even though all the fluxes are "neutral", they each exhibit markedly different mechanical properties with wire/flux combinations different from those recommended in the vendors' literature. The difference results from the flux's contribution to control manganese and carbon contents within acceptable levels. Even minor variances in amounts of these two elements have a great influence on mechanical properties. If the flux allows a very low manganese level (below 0.7% as defined by one vendor), the weld may be prone to "hot cracks", or "center line cracking", as it is commonly referred to in production terms. If it allows a higher than normal pick up of carbon, it can also have a detrimental effect on mechanical properties, or even produce a tendency for cold cracking to occur if it is too high a carbon content. For this reason it is highly stressed to the end user that a procedure test be conducted to confirm that the results desired are, in fact, being produced by the wire/flux combination used at the welding parameters required for the specific application.

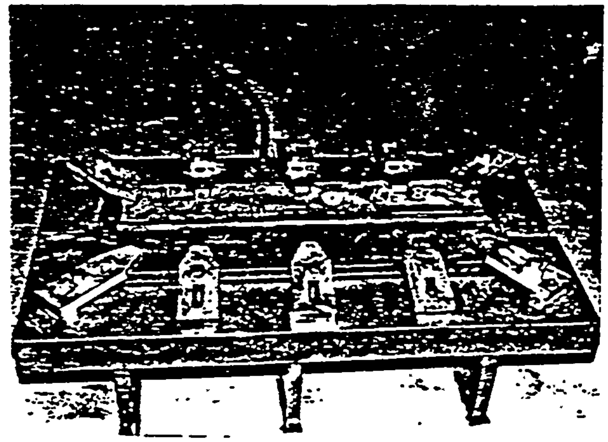
The vendors' literature for flux cored electrodes all claimed improvements in deposition ranging from five percent up to twenty-five percent over the solid wire. They also claimed marked improvements in impact properties at low temperatures. This was due to "cleaner" weld deposits from the flux cored electrode arc physics. It was claimed that the flux cored electrodes had a more stable arc with less agitation of the molten puddle, therefore, less opportunity for contaminants to be drawn into the weld.

Standard Procedure for Welding And Recording Data

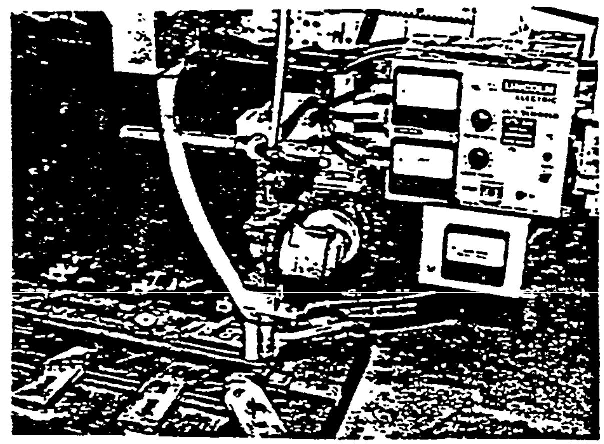
The following is a detailed description *of* the methods used to control the welding and data collection for all electrodes tested in this program. After the plates were ground on the bevel surfaces to be welded, they were tacked together in the joint design previously specified in this report. At this point, the plate assembly was weighed on the Detecto Model 4570 scale to record its "base" weight. The plate was then bolted into the welding fixture and dogged down to simulate the high restraint encountered in most applications in the shipbuilding industry. Next, the spool assembly and electrode roll were mounted and weighed together as a unit. The wire spool assembly was then installed on the welding carriage and the electrode was inched down and aligned in the joint. All electrode clippings were retained during the welding procedure for inclusion with the wire spool assembly weight. In this manner accurate arc efficiency and deposition data could be obtained without the chance of the wasted electrode affecting the results of one test more than another, because more or less wire was discarded as clippings. The assembly was then preheated as specified with the oxy-fuel process. Temperature verification was made throughout the welding operation with a surface temperature thermometer, P.T.C. #313F, with a 0° to 500°F. range. The welding was then commenced at the root pass settings specified in the procedure specification. For each of the four root passes the welding parameters were monitored and recorded from the calibrated meters. A stopwatch was used to keep a record of actual arc time. On each pass the electrical stick out was set using a one inch high sheet metal template to insure accuracy of all data. Even though all meters were calibrated, they were frequently double checked through the use of a hand held wire feed speed meter and a voltage and amperage meter which were also calibrated. In this respect, the stationary equipment mounted in the welding head could be checked for drift or mechanical problems which would occur during or between separate procedure tests, thus destroying the accuracy of the comparison in deposition and other data collected. After pass number four the assembly was allowed to cool to ambient temperature and then was removed from the fixture and reweighed. The wire spool assembly and clippings were also dismounted and weighed at this point. The plate was then reinstalled in the fixture and nreheated in preparation for the remainder of the welding to be completed at the higher parameters specified to simulate production fill pass welding operations. Again, strict control and monitoring of all welding parameters was maintained in accordance with the specified procedure settings and interpass temperatures. During the welding operation the operator was encouraged to record his observations and opinions on the wire/flux combination in use. After the welding was complete, the plate was allowed to cool to ambient temperature before removal from the welding restraint fixture. At this time it was stamped with the procedure designation and wire/flux combination used. Its final weight was recorded as well as the final weight of the electrode spool assembly and clippings. Efficiency and deposition data were then computed on the basis of the original weights, the weights of the electrode used and the plate weight gain after the four root passes, and the electrode and plate weight at the completion of fill pass welding.

The completed plates were then sent to the Machine Shop for removal of the backing bar by milling. This process was used to prevent any heat effects that may enter into the picture if a thermal process were used in the removal operation.

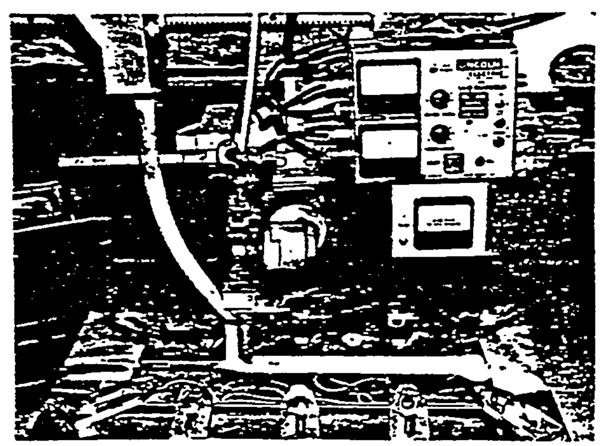
After the milling operation the plates were released for radiographic testing evaluation to a 2 - 2t sensitivity level. Upon satisfactory completion, the test assemblies were sent to the physical test facility for further processing to the appropriate spec. or code for the base material used.



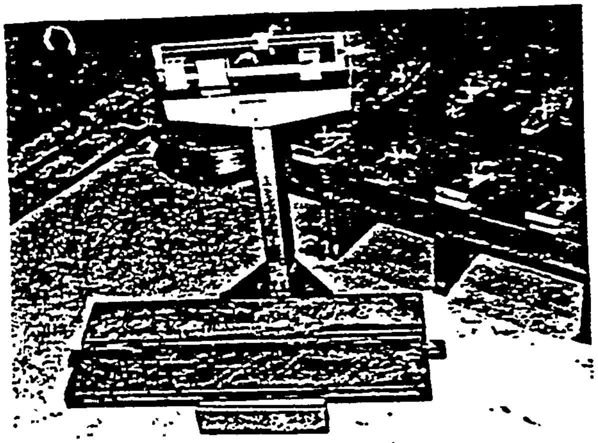
Test assembly installed in fixture.



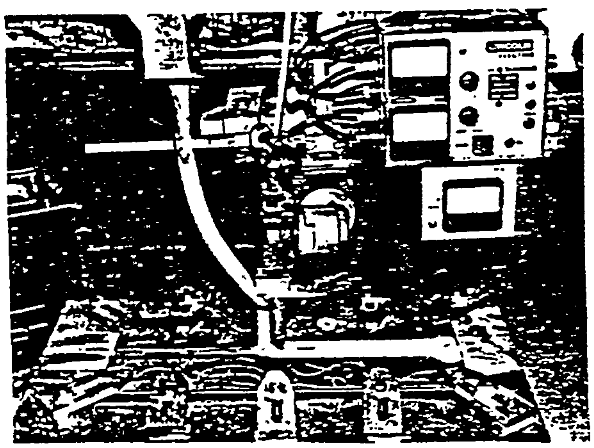
Electrical stick out was set at 1" on all weld passes.



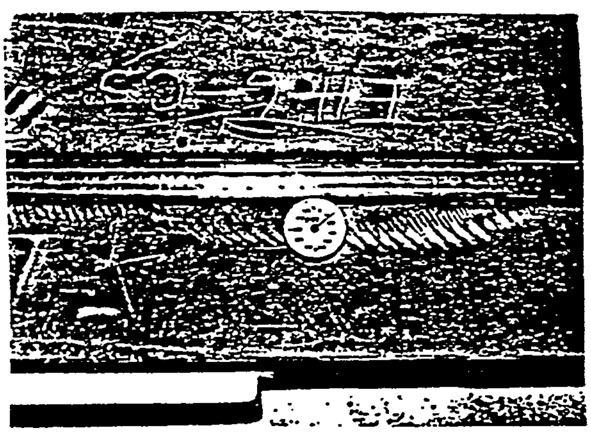
Welding in progress - voltage, amperage and wire feed speed meters indicating actual arc conditions which are obscured by the flux shielding.



Detecto scale measuring the root pass deposition data.



After the root pass data was collected the assembly was reinstalled in the fixture and preheated for the final welding operation.



Typical appearance of completed welds. PTC surface thermometer indicating ambient conditions (70°F.).

Weld Testing

The finished procedure plates were visually inspected for deficiencies before they were released for testing. After the backing bars were milled off they were radiographically tested using either IR 192 or a 300KV x-ray tube.

The first and second procedure plates run with 316L Solid Wire were rejected for cracking in the center of the weld. This cracking was eliminated on the third procedure plate by reducing the parameter settings to 30 volts and 350 amps at 12 I.P.M. It should be noted that satisfactory plates were produced by the cored 316L Wire at higher parameter settings.

All other procedure plates were satisfactory by radiographic testing.

Mechanical test specimens were then removed from the plates in the order depicted in Fig. 1. All removal was accomplished using a band saw to eliminate heat input effects associated with thermal cutting processes.

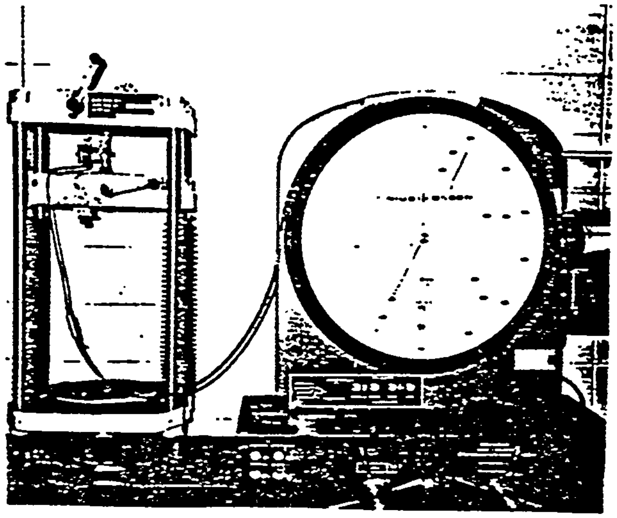
Mechanical tests on EB-36 and 316L Stainless were prepared and tested in accordance with the ABS RULES FOR BUILDING AND CLASSING STEEL VESSELS 1984. Specifications used for testing HY-80 and EY-100 was MIL-STD-418C.

Charpy tests were run with a variation in that 5 samples were tested at each location. To eliminate scatter, the highest and lowest values were not included in the average ft. lbs. reported in this repoft.

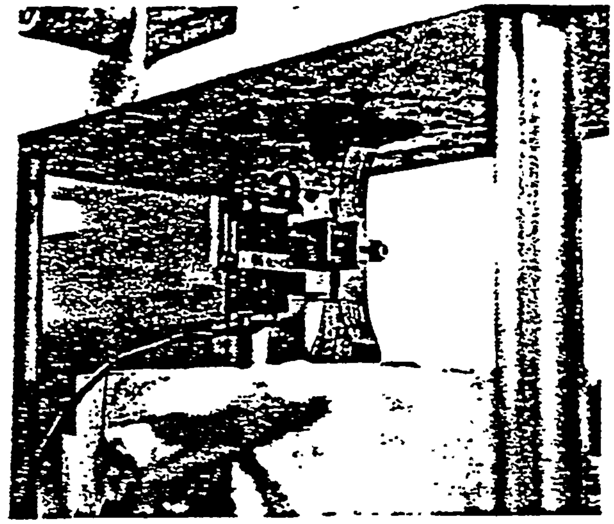
Mechanical Test Results

A. TENSILE AND BEND TESTS

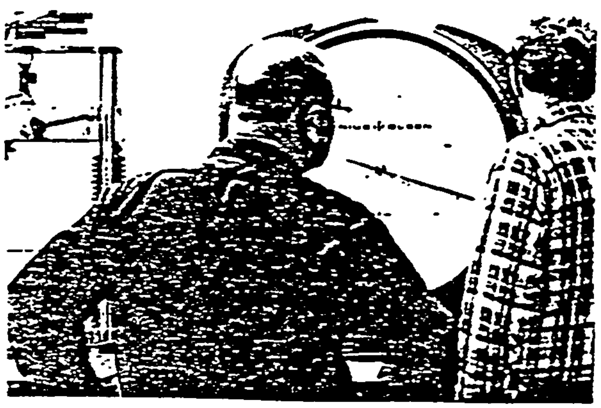
All of the wire/flux combinations tested met the minimum specified mechanical properties for longitudinal all weld metal tensile tests. The majority of them met the transverse tensile and side bend test requirements. The BY-80-AC and HY-100-AC wire/flux combinations both failed these tests indicating that the deposits had differing directional properties. The vendor was contacted on the results and went to a reformulation of the electrode. This reformulation process took a cycle time of eight weeks. The reformulation of the NY-80 and BY-100 electrode *were* then welded and successfully retested under the wire/flux designations EY-80-AC1 and EY-100-AC1. The reformulation process had also confirmed the vendors' claims in the sales literature that these cored electrodes could be quickly and economically tailored to specific job or customer requirements, unlike the solid wire counterpart which has its chemistry determined from the steel mill.



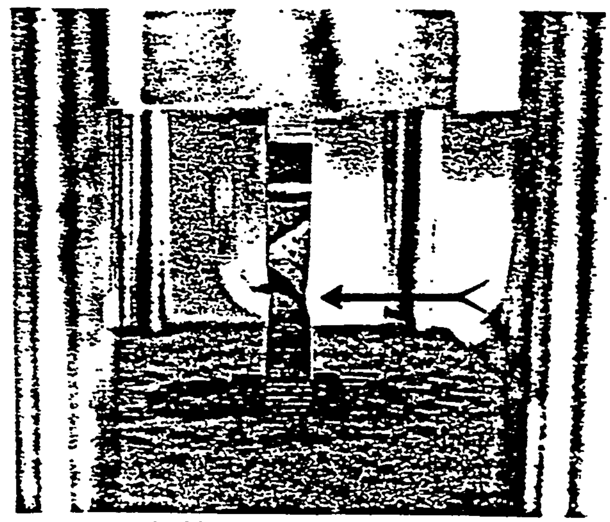
Tinius Olsen Tester with extensometer attached to tensile test specimen in cross head.



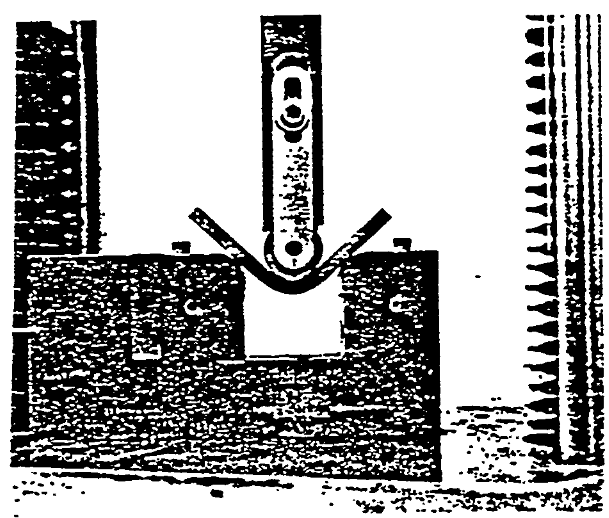
Close up view of extensometer and tensile test specimen in jaws of cross head.



Lab technicians checking stress-strain data to determine the yield strength value has been reached; extensometer was then removed prior to reaching ultimate tensile strength value.



Arrow indicates necking in base metal prior to final fracture of the tensile specimen.



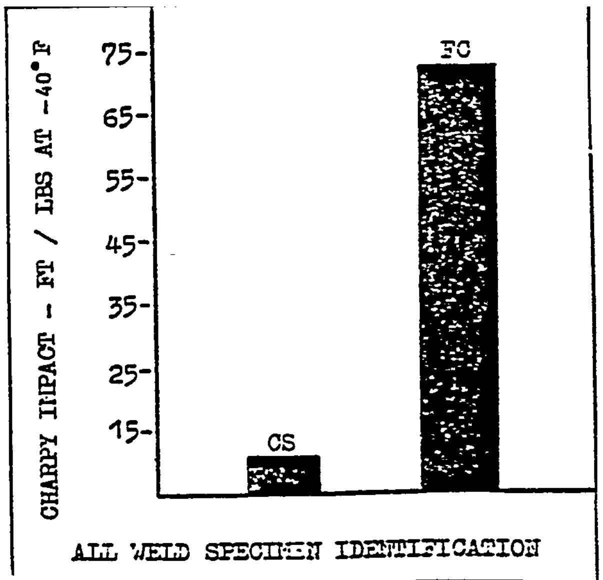
180 degree side bend test in progress.

B. CHARPY IMPACT TESTS

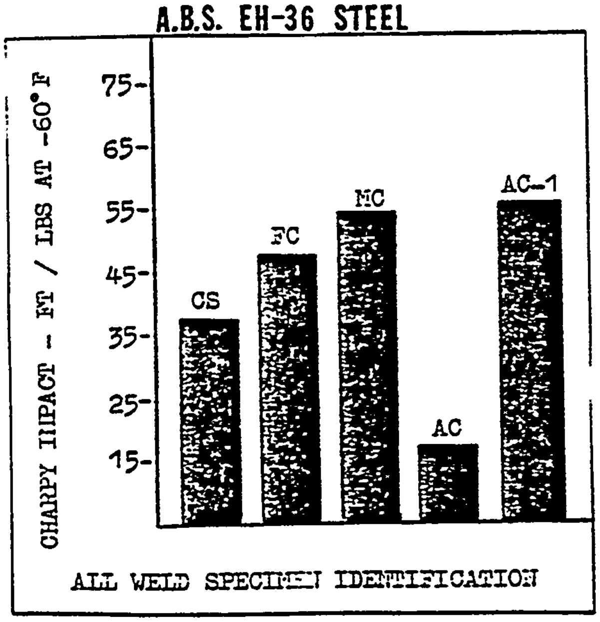
The carbon steels underwent Charpy tests to determine weld, heat affected zone, and base metal properties at the specified temperatures set forth in the respective standards.

The ABS EH-36 procedures were tested at the -40°F. temperature spelled out for manual and semi-automatic welds. It should have been tested at the -22°F. temperature specified for automatic procedures. The results obtained at the lower temperate still provide a valid comparison but are markedly lower than they would have been at the -22°F. temperature.

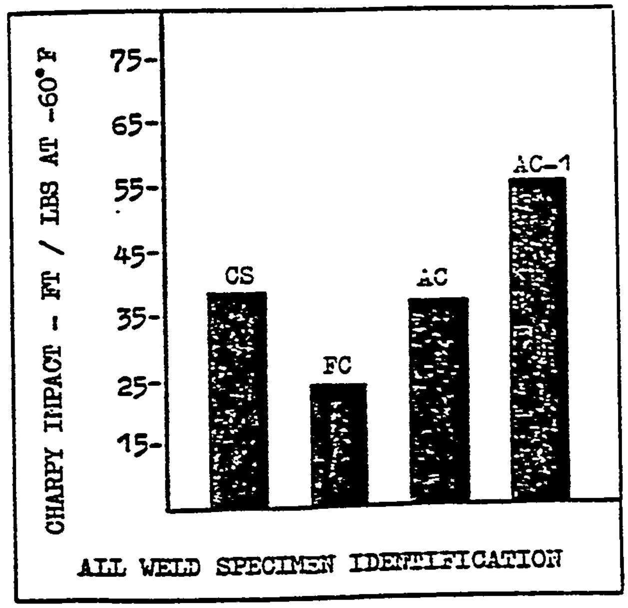
These three charts will be used to compare test data from the electrdes in each material category.



A.B.S. EH-36 STEEL

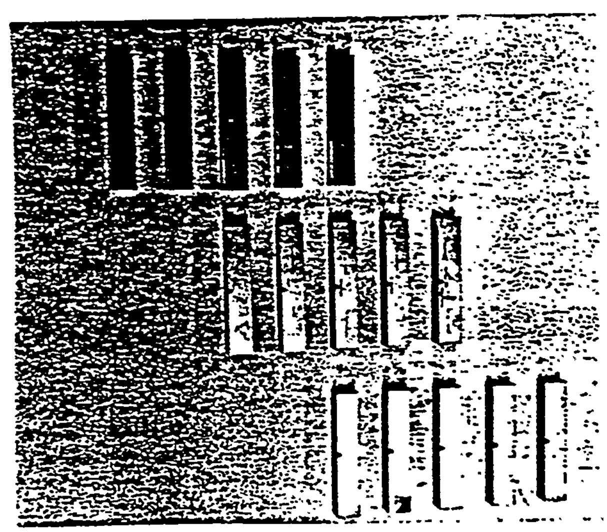


HY-80 STEEL

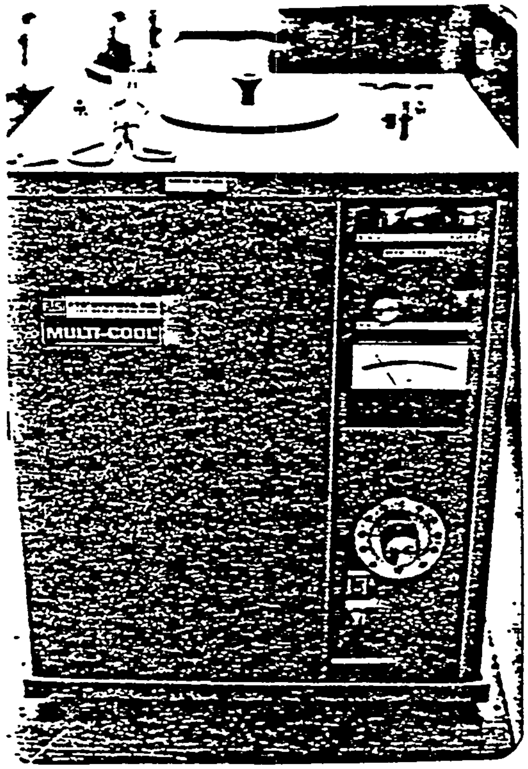


HY-100 STEEL

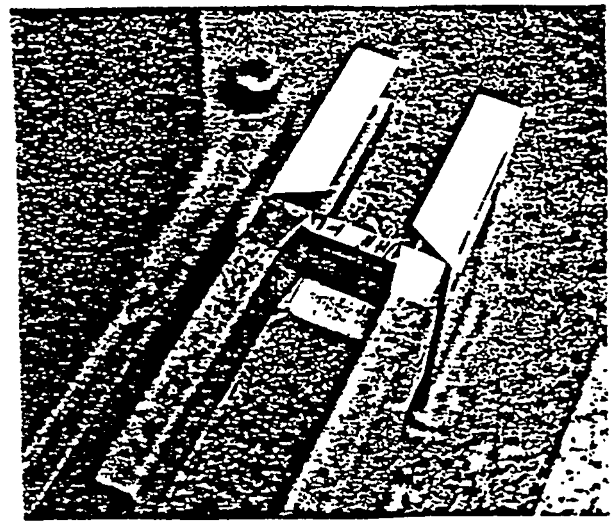
The results have been presented in bar chart form for easy comparison. The results of the three materials tested indicate gains in impact strength when compared to the solid wire control samples (CS on chart). Notice the large gain in the reformulated ACl wire/flux combination over its original AC formula.



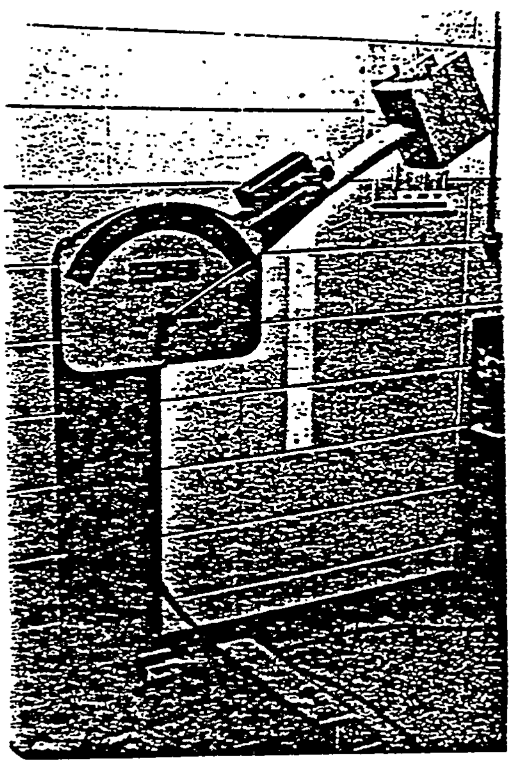
charpy test bars after notching, 5 base, 5 E.A.Z. and 5 all weld specimen.



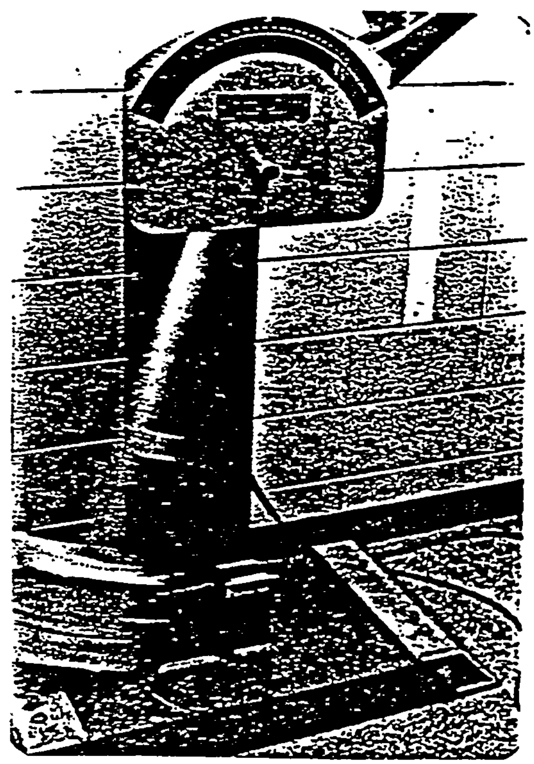
Charpy test bars being
cooled to -60°F. for
HY-100 - CS procedure.



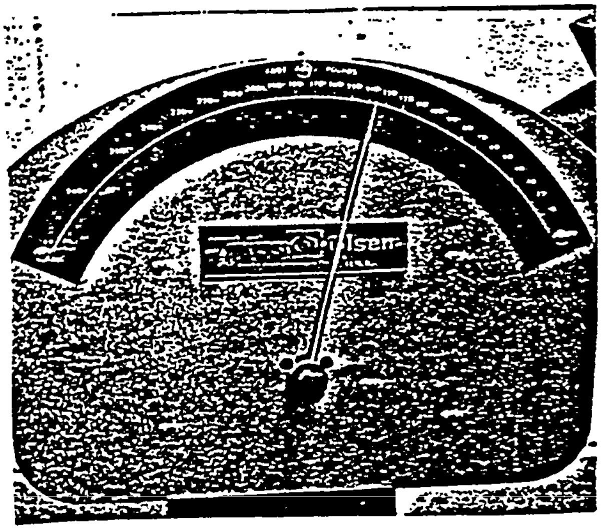
Notched bar in place prior
to pendulum drop.



Charpy tester after free swing
drop to check if the arrow
indicates 0 ft. lbs.



Charpy test in progress.



This 137 Ft. Lb. reading was for a base metal test bar.

Physical Test Results

Spectrographic testing was used to compare chemical compositions between the solid and flux cored electrodes. It also was used to search for any large chemical segregations which were a concern of some panel members when using flux cored electrodes. There were only minor differences in deposited metal chemistry.

The weld metal was also checked for inclusion size and amount. It was fold that the flux cored **wires were** marginally cleaner than the solid wires, but not to a degree that would be a substantial consideration when evaluating weld quality. Both types of electrodes would meet or exceed the quality levels of ship hull envelope inspection codes for radiography or ultrasonic testing methods.

CONCLUSIONS

The following is a comparison of operating characteristics between solid electrodes and the new family of flux core - metal core electrodes designed for Submerged Arc Welding.

The flux core type electrodes investigated in this project demonstrated several areas of improvement related to ease of operation. Flux core electrod types were easier to cut to renew the electrode and prior to starting a weld. This was particularly true in regard to the higher strength electrodes. The high strength solid electrodes are a problem to cut using bolt cutters, and if proper care is not used in this operation, the electrode may be dislodged from the contact tine inside the submerged arc welding head. When the above condition exists, an attempt to restart the arc results in no contact, thus no arc start, or accidental contact inside of the head, destroying the time. Destruction of the contact tine usually results in an erratic short arc initiation and the introduction of foreign material from the tine being introduced into the weld puddle, thus causing a serious weld defect. Failure of the arc to initiate on contact with the work piece can also result in misalignment of the electrode in relation to the desired arc path, thus resulting in poor weld bead placement. This can be particularly damaging to weld quality in multipass welds of long duration.

Another improvement noted in using the flux core electrode is arc initiation. Arc initiation is exceptionally smooth and consistent; during the life of this project the flux core type electrode far out-performed the solid electrodes in this respect. On multipass welds on heavy steel plate this ease of starting is extremely impotiant. Again, weld bead placement, due to the nature of the process, is obscured from the operator's view until the solidified flux can be removed from the weld deposit. If the arc initiation is poor or causes the welding head to be pushed off the joint, the operator will not be able to correct this misalignment until he has deposited 12″ to 18″ of weld. Poor **arc** starting is responsible for many Submerged Arc Welding defects that can be extremely costly to repair.

The flux core type electrodes, because of their design, are much easier to straighten prior to entry into the weld pool. The cast and helix of solid spooled sub arc electrode influences the amount of pressure required to straighten the electrode prior to welding. The cast and helix of solid sub arc **wires** does change significantly between the top layers on a spool and the bottom layers. This change, particularly on higher strength solid electrodes, will cause the electrode to change the location of the weld pool. This change can be significant in width in relation to the weld bead placement. The obvious advantage of the flux core type electrodes is the relative ease of straightening due to the lower columnar strength of the electrode sheath. In this investigation we found **that** repeatable control of the electrode location, in maintaining alignment on straight multipass welds, was excellent with the flux core type electrodes.

In regard to horizontal fillet welding with the flux core electrodes, our investigation showed better arc initiation and a more uniform fillet bead shape. The fillet welds were produced using a "Lincoln Electric Co." Hand Held Submerged Arc Welding Package. The fillet weld crossectional etched samples proved that the solid sub arc electrodes produce a much deeper penetration at the root of the weld faying surfaces. The flux core electrodes do not have the deep penetrating capability of the solid electrodes; however, both types produce satisfactory root penetration. The fillet weld break tests indicated that the flux core electrodes produce fillet welds that exhibit less porosity in the root of the weld than the solid electrodes. Producing fillet welds over till scale or primed plate (weld through primers) indicated that the flux core electrodes and the solid electrodes will not tolerate excessive mill scale or uncontrolled amounts of primer on the faying surfaces to be joined. Weld through primers cannot exceed a combined thickness of over 2 roils on faying surfaces without serious porosity developing in the root of the weld and also porosity that is visible on the surface of the fillet welds. till scale is not as devastating to weld quality in fillet welds as compared to excessive weld through primers when millage of the primer's thickness is not scrupulously controlled.

GENERAL CONCLUSIONS

The flux core type electrodes exhibited a marked improvement to reduce the tendency to undercut the upper leg of horizontal fillet welds compared to the solid wire electrodes at identical settings. The depth to width ratio which governs internal centerline cracking tendencies is clearly more favorable to the flux cored electrodes. This was extremely evident in the case of the 316L test plates welded with solid wire at 380 and 400 amperes. These two preliminary panels exhibited centerline cracks in several of the passes. At the same amperages, the cored wire electrodes produced results which were radiographically acceptable. The 316L panels which were mechanically tested were run at 350 amperes. Although the cored wire panels that were run at 380 and 400 amperes were not mechanically tested, there is no reason to believe that mechanical test results would not have been satisfactory. This width to depth consideration was also visible in the single pass fillet welds which were evaluated in this program. Even though the results of the fillet weld tests were satisfactory and no centerline cracks were found, it would seem logical, based on the groove weld results, to conclude that the cored wires may be less susceptible to centerline cracks because of their inherent bead shape. Fig. 4 and Fig. 5 illustrate this point.

Figures 4 and 5 are used to show the depth to width differences between solid and cored electrodes.

SOLID WIRE

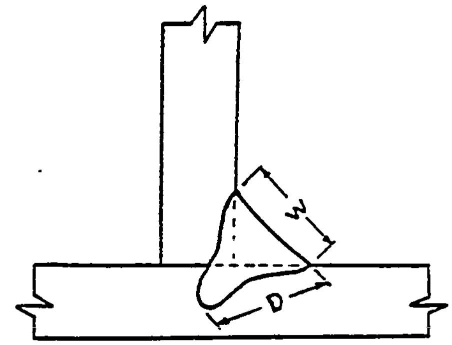


FIG. 4

CORED WIRE

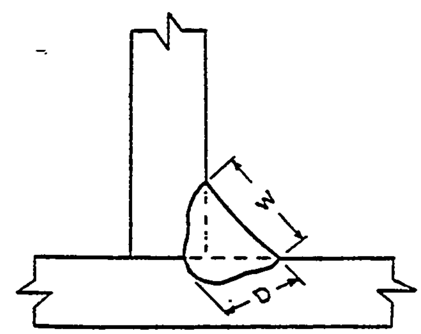


FIG. 5

Economic Impact Comparison

The following comparison is made to illustrate the dramatic bottom line improvement that could be obtained by the use of flux cored submerged arc welding electrodes. Since the change in electrode does not significantly change the use of the process or equipment as it relates to cost, the comparison below presents a condensed study of the cost factors that do significantly change the bottom line costs. Where other factors do change, the writer feels that they also favor the flux cored electrodes. For example, the electrical cost reduction due to the higher deposition rates that would reduce the arc time required. It should be noted that the comparison below is for the HY-100 material, using the CS and AC1 designation results.

Cost To Deposit 1,000 Lbs. of Weld Metal

Material Cost:
Solid Wire
1,000 lbs X $2.2S\lb. = $2,250
Flux Cored
1,000 lbs X $1.12/lb. = $1,120

Labor Cost:
(50% Operator Factor Level)
1,000 lbs x (Deposition Rate x Operator Factor) = Labor Hours
Labor Hours x $25/hr rate = labor cost

Solid Wire
1,000 lbs X (13.15 lbs/hr X 50%) = 152 hours.
152 hrs. x $25/hr = $3,800

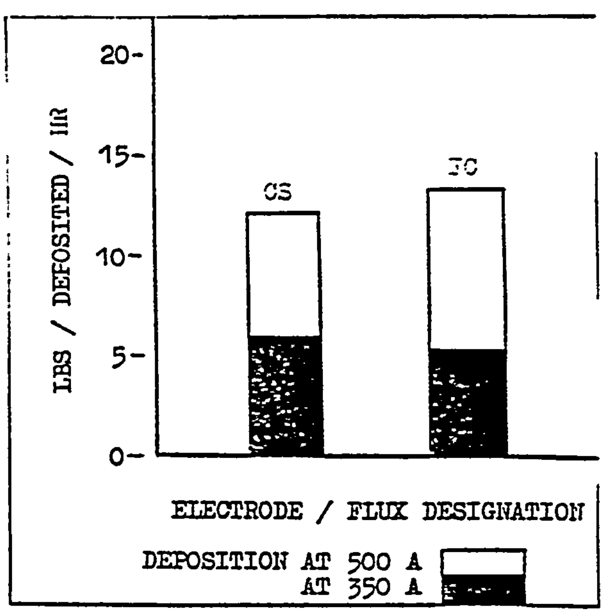
Flux Cored
1,000 lbs. X (19.46 lbs/hr x 50%) = 102.7 hours
102.7 hrs. x $25/hr = $2,567.50

	Solid	Flux-Cored
Material Cost	$2,250.00	$1,120.00
Labor Cost	$3,800.00	$2,567.50
Total Cost	$6,050.00	$3,687.50

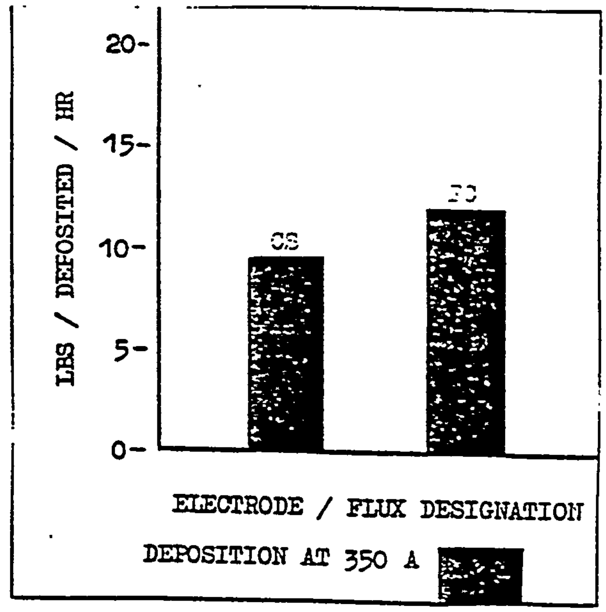
The result: For 1,000 lbs. of weld a $2,362 savings, or a 39% bottom line improvement.

NOTE: Using the average deposition rate of the HY-100 electrodes (16.42 lbs/hr) a savings of $1,907 or an improvement of 31% would result.

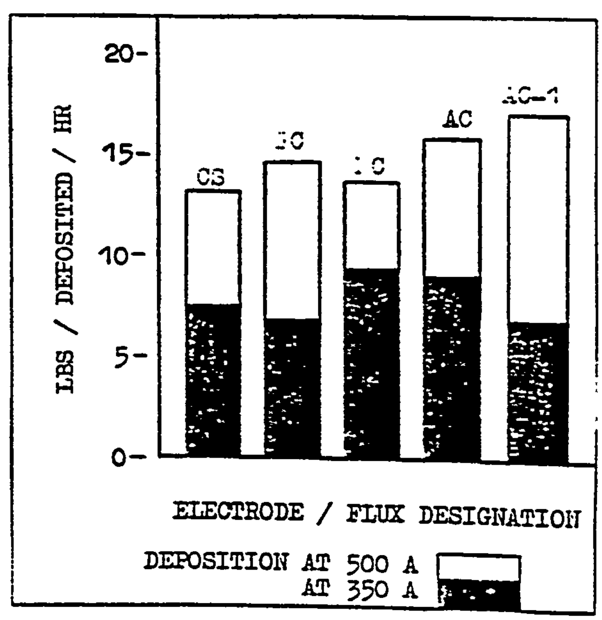
The next four charts will be used to illustrate the deposition capabilities of the electrodes.



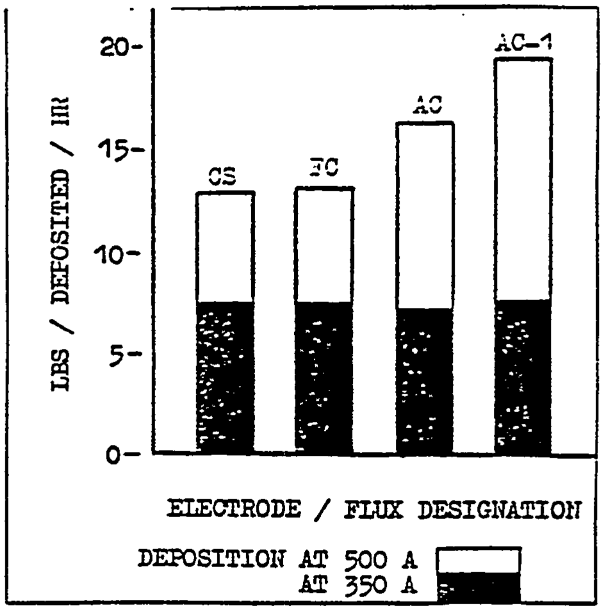
A.B.S. AH-36 STEEL



316 L STAINLESS



HY-80 STEEL



HY-100 STEEL

SUMMARY

One of the most significant results noted when comparing solid vs. flux core type electrodes is the improved deposition rates of the flux core electrodes as measured at the same amperage and voltage. In the lower amperage range, used for root passes against the backing bar (350 amps), the overall average of the deposition improvement was 3.5% of all samples tested. At the manufacturer's recommended welding amperage (500 amps), the average improvement in deposition rates was 19% of all samples tested. We feel that this is a significant improvement that demonstrates an economic advantage in favor of the flux core type electrodes.

Electrode cost comparison for the high strength type electrodes is also a very significant factor that impacts operating costs. Flux core - metal core fabricated electrodes for HY-80 and HY-100 Submerged Arc Welding applications are as much as 50% lower in price per lb. than the solid electrodes designed for the same applications. In some cases, fabricated electrodes are designed for Gas Shielded Flux Core Welding as well as Submerged Arc Welding applications. This latter item is, in itself, important by allowing a manufacturer to reduce electrode inventories.

In conclusion, we feel that this investigation has produced conclusive data that fabricated electrodes have several advantages in operating characteristics that improve weld quality and at the same time, reduce costs. There is one area, however, that must be addressed in this final conclusion. A point to consider is the difference in the penetrating capabilities of the two electrode types. If a weld joint design requires a deep penetrating arc, the solid electrode has a definite advantage over the fabricated electrodes. The type of joint design that requires a deep penetrating arc is a square butt joint, without edge preparation, welded from two sides. For this type weld joint design we recommend the solid electrodes be used. For all other Submerged Arc Welding, we recommend strong consideration be given to the use of fabricated electrodes.

ACKNOWLEDGMENTS

This program was initiated by the members of the SP-7 Welding Panel of the Ship Production Committee of the Society of Naval Architects and Marine Engineers. It was financed largely by government funds through a cost sharing contract between the United States Maritime Administration, The United States Navy, Newport News Shipbuilding and Dry Dock Company and Bay Shipbuilding Corporation.

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2. Welding Terms and Definitions - A.N.S.I./A.W.S. A 3.0-85, An American" National Standard.

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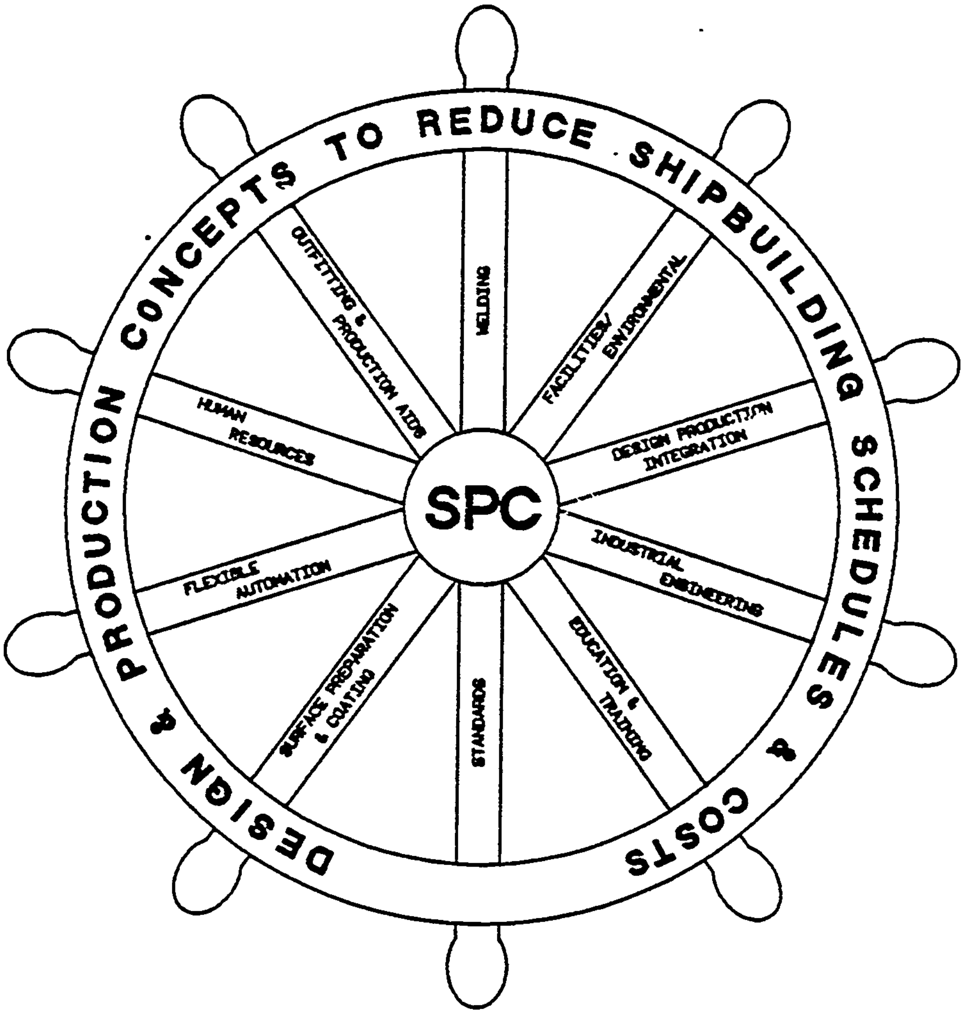

PAPER NO. 15

ENGINEERING FOR SHIP PRODUCTION

BY: THOMAS LAMB

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AUGUST 27-29, 1986

1986 SHIP PRODUCTION SYMPOSIUM

ENGINEERING FOR SHIP PRODUCTION

THOMAS LAMB Bell Aerospace Textron

ABSTRACT

Engineering for Ship Production is tne use of production-oriented techniques to transmit and communicate design and engineering data to various users in a shipyard.

The changeover from a traditional craft-organized shipyard to one of dcvanced technology has obviously had d tremendous effect on all shipyard departments. It should have had its second greatest impact on the engineer-?ing department. However, many engineering departments did not rise to this challenge and, therefore, lost what might have been a lead position for directing and controlling change.

Production performance depends largely on the quality, quantity, and suitability of technical information supplied by engineering. By organizing for integrated engineering and preparing design and engineering for zone construction, engineering can step forward and take its proper place and play an essential role in the renaissance of C.S. shipbuilding. Using examples, this paper describes how this can be done.

INTRODUCTION

Engineering for Ship Production is tne use of production-oriented techniaues to transmit and communicate design and engineering data to various users in a shipyard. There has been increasing interest in this matter during tne last few years as witnessed by discussions on the format and content of engineering drawings, Instead of focusing on engineering drawings discussion snould center on what technical information is required to procure and construct the ship, and what is the *best way* to prepare and transmit this information.

The -format of engineering information, including the content of drawings, has developed over many years. Changes and improvements have occurred very slowly, and in some shipyards and design offices, not at all. Traditionally, shipyards were craft-organized and only required the minimum number of drawings for which accuracy was not essential. The loft prepared the templates and made everyday decisions on structural details. The pipefitters worked from diagrammatics and developed their own pipe templates from the ship being built. This system was also true for the other shipyard crafts.

The changeover from a traditional craft-organized shipyard to one of advanced technology has obviously had a tremendous effect shipyard departments. It should have had its second greatest impact on the engineering department. *However,* many engineering departments did not rise to this challenge and, therefore, lost what might have been a lead position for directing and controlling change. Engineering simply ignored the needed changes and left them to be incorporated into the shipbuilding process after their work was completed in the traditional manner. Shipyards responded to this problem by getting the necessary production information from other sources, usually new groups that may have been called industrial or production engineering or perhaps from an existing planning group. Some shipyards even accepted the fact that engineering information was inadequate for production and left it to production workers to perform as best they could. This situation often resulted in the same work being done many times before it was reluctantly accepted by the inspectors. It is not surprising that the attitude found in many shipyards throughout the world is that engineering is a necessary evil and that ships are built despite engineering.

Production performance depends largely on the quality, quantity, and suitability of technical information supplied by engineering. By organizing for integrated engineering and preparing design and engineering for zone construction, engineering can step forward and take its proper place and play an essential role in the renaissance of U.S. shipbuilding. This paper discusses how this can be done, but first considers what is production-compatible engineering (integrated engineering) by comparing it to traditional engineering.

TRADITIONAL ENGINEERING

Usually all the visual information used by a shipyard production department today is not prepared solely by the engineering department. Most shipyards still have various preparation phases divided in a way developed and used 30 to 40 years ago. At that time, the following division of labor made sense because of the methods used:

1. Engineering
   - Design and working drawings
2. Loft
   - Full-size fairing of lines
   - Layout of structural parts
   - Template construction
3. Pipefitters
   - Pipe templates and sketches
4. Sheet Metal Workers
   - Layouts, developments, and templates
5. Shipwrights
   - Full-scale layout on ship.

However, U.S. shipyards have been improving their production processes for years, and their information needs have changed during that time. Some shipyards utilize structural module construction, preoutfitting, advance outfitting and, more recently, zone construction. To perform these tasks from traditional engineering is not impossible, but it requires additional planning and even design and engineering has to be prepared after traditional engineering is complete. This system obviously involves additional man-hours and does not assist the move to shorter performance time.

In many shipyards, the preparation of structural drawings has really not advanced much from the days of the iron ship. Only within the last two decades have a few U.S. shipyards prepared their structural drawings as block or module drawings (showing each erection module of the ship on individual drawings) even though they had actually been constructing ships that way for 20 years. Yer most U.S. shipyards and the design agents that support them still prepare structural drawings as item drawings, such as tank top, shell plating or expansion, decks, bulkheads, frames, etc.

The preparation of hull outfit; machinery; piping; heating, ventilation, and air conditioning (HVAC); and electrical drawings has developed over time with progress in the respective technologies. However, these drawings are also currently prepared on a system basis and to differing levels of detail.

In many shipyard engineering departments, the installation of hull outfit systems and equipment is conveniently considered a craft akin to cabinetmaking. With this in mind, engineering gives very little data to the production department in the belief it is better left to the master craftsmen. Other shipyards get around the need of having the engineering department involved by subcontracting joiner work to companies specializing in this field. In reality, there is no logical reason to give joiner work any less engineering effort than is given to hull structure or piping, especially since outfit can be just as large a consumer of both engineering and production man-hours as structure or piping.

The machinery drawings are used by the shipbuilder as a definition of equipment arrangement so that ocher engineering disciplines can prepare their detail design, such as foundations, piping, floor plates, grating, etc.

Piping drawings are for individual systems for the complete ship. They may or may nor show pipe breaks, hangers, and some production-added information. The same is true for HVAC and electrical, except that electrical drawings are sometimes little more than pictorial concepts with no locating dimensions for equipment.

Usually interference control in traditional engineering is provided by space composites, although engineering models are also used extensively for this purpose. A major problem with this approach is that the electrical crafts go ahead and complete their “hot work” before many of the other detailed systems and composites are completed. The work is performed in the easiest location without checking it or even feeding it back to engineering to locate it in the composites. Apparent production work progress is achieved early in the project, and everyone is happy until the interference problems start and extensive rework is required.

Traditional engineering usually includes the bills of material on the drawings or as a sheet of a multisheet drawing. It also makes use of large drawings, often up to 12 feet in length. Figure 1 graphically portrays the problem this system creates on the ship compared to the smaller sheets of the proposed Engineering for Ship Production. Since each drawing is for the total ship, but is required each time part of it is used in each module or zone, the drawing must be printed and issued many times, resulting in wasted paper and duplicated effort. Also when reissued because of a revision, planning and production must spend time to deteraine how many modules or zones are impacted by the revision.

Traditional engineering is perpetuated by the U.S. Navy "General Specifications for U.S. Navy Ships" (GEN SPECS), DOD-D-1OOO, and DOD-STD-100. These documents require preparation of drawings, including format, concents, referencing, etc, that are not compatible with the engineering needs For today's best shipbuilding methods.

Traditional engineering drawings contain little production-required information such as module weights, module breaks, system breaks, lifting pad locations, bolting torque, pipe hanger locations, system testing, tolerances, and quality requirements.

Some shipyards attempt to provide some of this information on traditional engineering drawings by having prints of the drawings marked up with production data by the planning/production control groups for incorporation into the original drawings before formal issue. Others provide the required production information on unique additional docunencs to the traditional engineering drawings.

The practice of referencing instead of including the information on the drawing, other drawings, ship specification, standard specifications, and other data is a serious problem to production. To expect production workers or even their supervisors to have access and knowledge of the references is impractical. Because of this situation, items are often ignored and the work is not "done to spec". Engineering must provide production information in a clear and complete manner. This means that engineering must interpret the specifications, use applicable standards, and give all the necessary information. In traditional design where it will still be necessary to list references for data control, this practice must be changed to using references as a way to record that the drawing has been prepared in accordance with the references, and not that production should do its work in accordance with the references.

Traditional engineering is not suitable for high productivity, shorebuild cycle shipbuilding, and therefore, has no place in today's struggle to maintain some semblance of competitishipbuilding.

a) Problem

b) Solution - booklet work station/zone information

Fig. 1 Large drawing handling problem

PRODUCTION-COMPATIBLE ENGINEERING

The first break from the traditional systems drawings occurred when some shipyards introduced structural module drawings. The next stage was the use of subassembly, assembly, and module-sequenced drawings, but these were initially prepared in addition to the structural module drawings. Next, pipe sketches or drawings for pipe assemblies were prepared by engineering, first manually and later by computer-aided design. Currently computer-aided designjcomputer-aided manufacturing is being used to provide production information for both pipe and sheet metal products. Today the goal for-optimum data transmittal is to have an engineering information package for each work station (including zones on board the ship). This is not only for structure, but for all other material and equipment. A work station drawing shows all the work that occurs at one location, either shop or ship zone. It can be one sheet showing the completed product at the end of all work at a given work station with written sequence instructions, or it can be a booklet of drawings showing the sequenced buildup for the product from its received status to its completed status for the work station.

The MarAd/SNAME Ship Production Committee Japanese Technology Transfer efforts have resulted in a generally accepted work breakdown structure for design and engineering (l). The proposed integrated engineering approach follows this generally accepted structure, except that basic design also includes functional design, and the term product engineering covers transitional design and work instruction design. The proposed approach suggests chat the design/engineering process can be conveniently divided into basic design and product engineering. Figure 2 shows the meaning of the different terms as well as the flow of the design and engineering information.

Both basic design and product engineering are further subdivided into concept, preliminary, contract and functional design, and transitional design and work station/zone information respectively. In basic design, all phases except functional design must be completed before the award of a contract. Functional design is the phase where the contract design is expanded to encompass all design calculations, drawings, and decisions.

Product engineering covers all tasks required to prepare the technical information to be transmitted to production and ocher shipyard groups to assist and direct the construction of the ship.

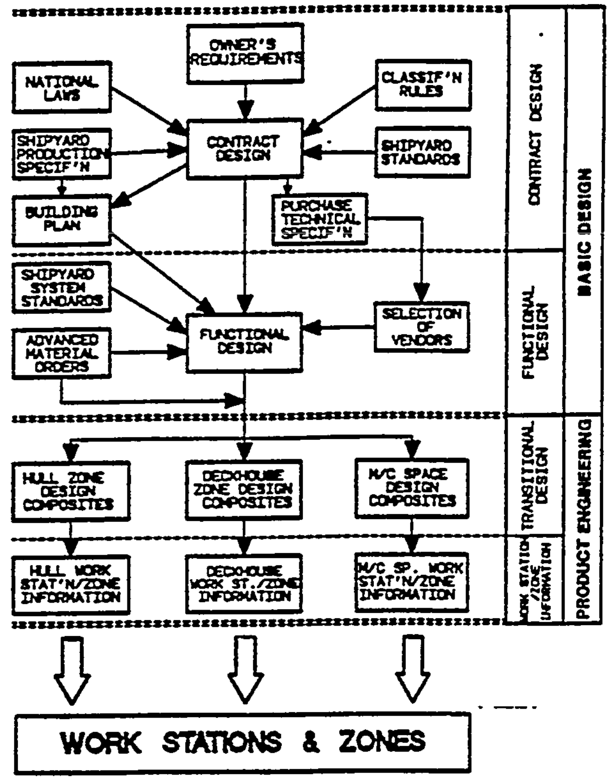


Fig. 2 Flow of design and engineering information

It is divided into two phases. The first, transitional design, is the task of integrating all design information into complete zone design arrangements and to complete the ordering/assigning of all materials. The second, work station/zone information preparation, is the task of providing all drawings, sketches, parts lists, process instructions, and production aids (such as NIC tape for plate burning/marking and pipe fabrication) required by production and other service departments to constmct the ship.

Throughout basic design, the tasks are accomplished on a system basis, whereas throughout product engineering, the tasks are accomplished on a zone basis for transitional design and a work station/zone basis for work station/zone information.

This process of design and engineering is integrated with construction planning and is in constant participation and communication with the production department. This integration can be seen in Figure 3, which shows the process flow during contract and functional design. Figure 4 shows the process flow during transitional design and work stationlzone information preparation. It should be noted that all plan-

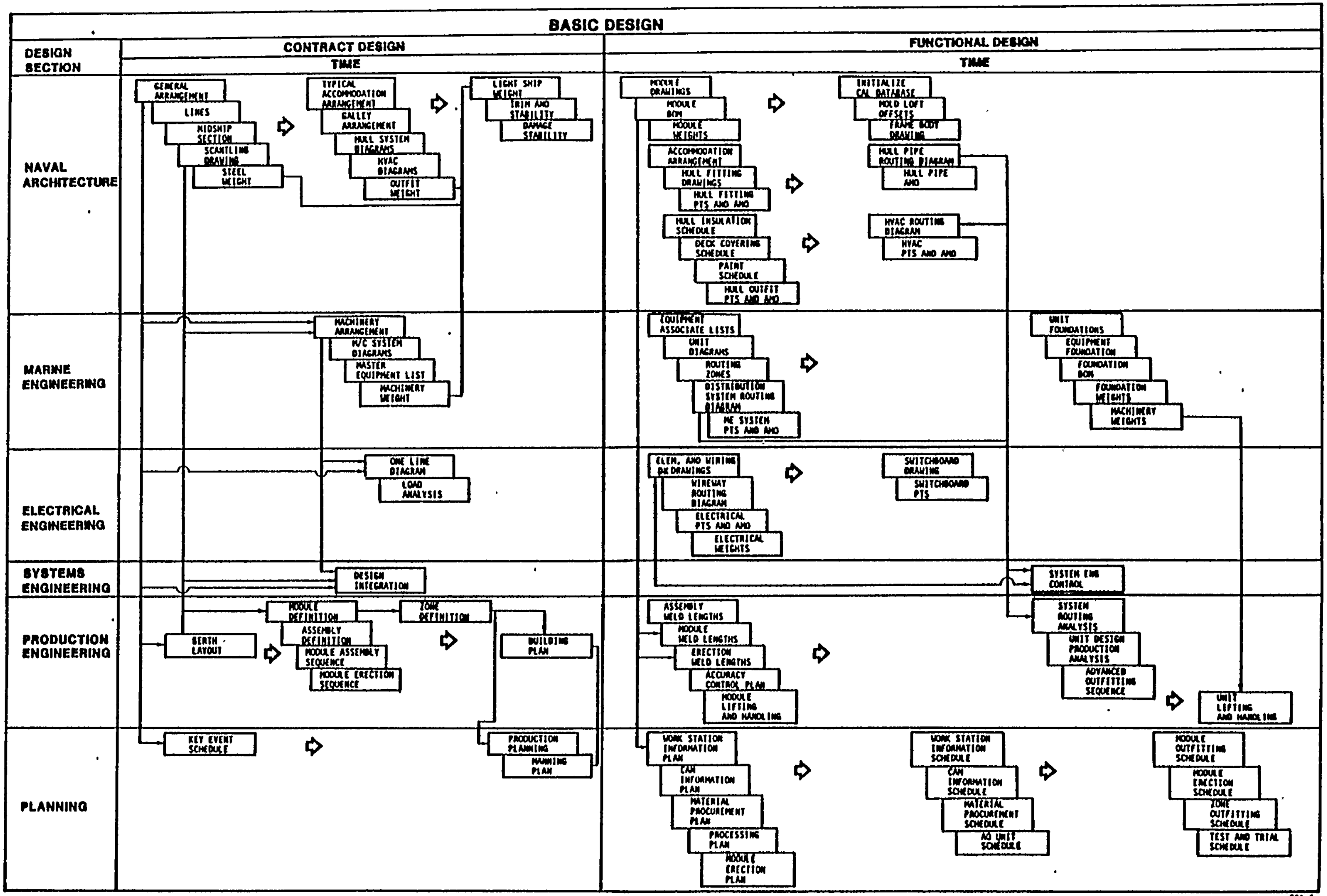


Fig. 3 Basic design flow

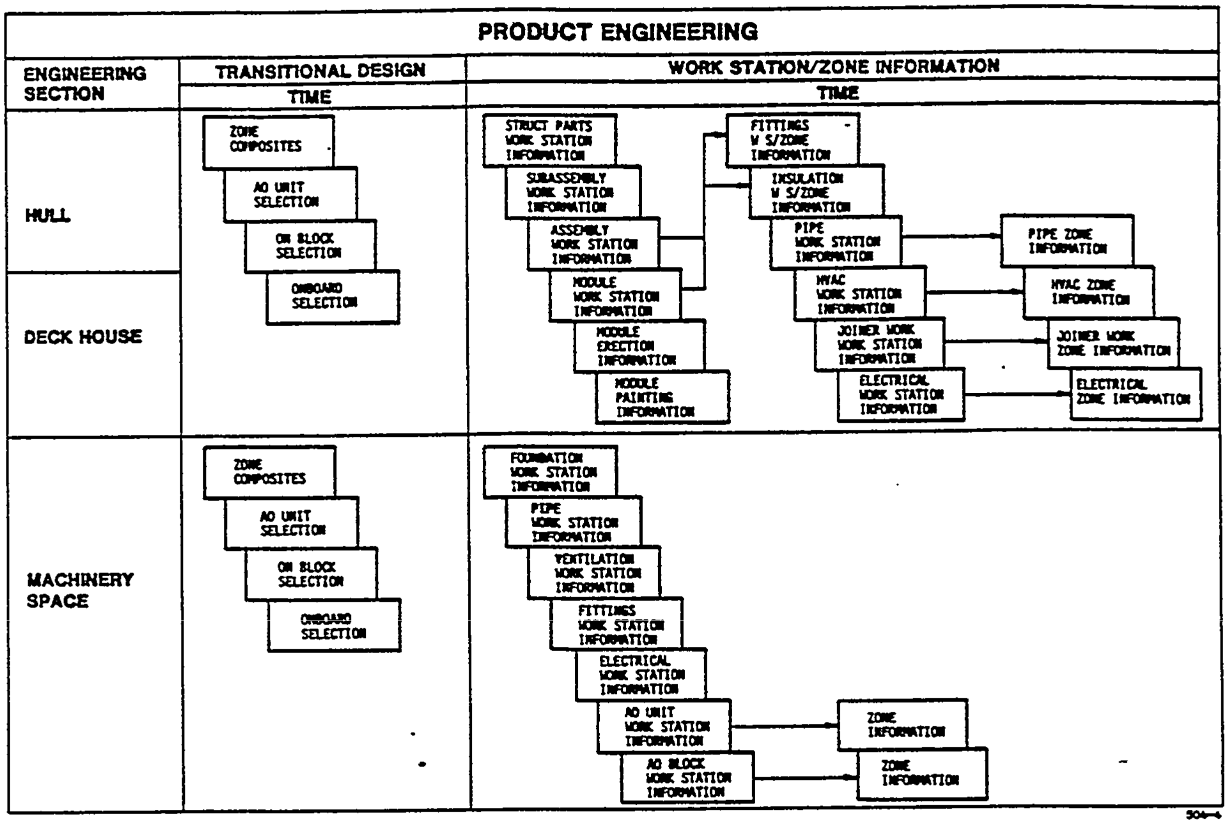


Fig. 4 Product engineering flow

ning is completed during contract and functional design and in the proposed approach this includes advanced outfitting planning.

Zone constaction, including advanced outfitting installation, requires engineering for the outfitting and machinery to be available at the same time as the structure. In fact, tne installation of piping, ventilation ducting, ladders, mooring fittings, equipment foundations, and wireway supports should be accomplished on flat panels and/or three-dimensional modules, along with items of equipment such as auxiliary and deck machinery.

The shipyard production specification and building plan are essential to the proposed engineering approach. Reference (2) is a good description of the development of a building plan. The approach is also based on the use of zone construction. It is further beneficial if all manufactured and purchased material to construct the ship is categorized within a standard classification system (product definition). If the production methods to be used (product processes) are defined, work stations can be decided. All this information will be contained in the shipyard production specifications to be used by engineers and planners when preparing the contract design and the building plan. The product definition can be based on a group technology classification and coding system such as the one described in reference (3), or it can be a simple listing of major products as shown in Table I. The product processes will be based on a process analysis for each product and the available work stations.

The proposed methods of preparing engineering data can actually reduce the hours for structural engineering, but will increase all the ocher areas by up to 30 percent, except for piping engineering, which can increase up to 50 percent depending on the extent of the traditional engineering it replaces. The use of computer-aided design can reduce the structural and piping engineering.

However, the overall increase in engineering man-hours to accomplish the proposed work should be less than 20 percent for a commercial vessel. In return for this additional effort by engineering, production man-hours-should be reduced by 20 to 30 percent. It is easy to see that this is a worthwhile tradeoff. Table II gives an overview comparison between traditional and production-compatible engineering.

Table I Typical Production Definitions

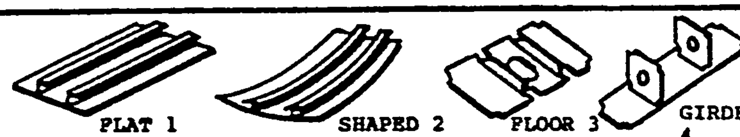
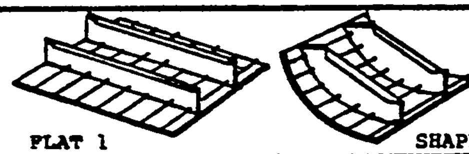
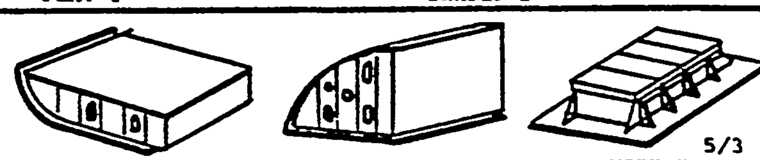
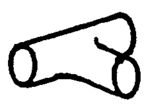
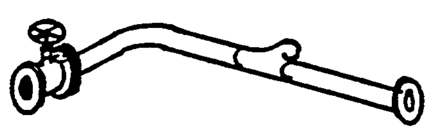
PRODUCT DEFINITION		
CODE	NAME	EXAMPLES
PL 1	PLATE PART	 FLAT 1, SHAPED 2, FLAT NOTCHED 3
S 1	SECTION PART	 STRAIGHT 1, SHAPED 2
SA 1	SUB-ASSEMBLY	 FLAT 1, SHAPED 2, FLOOR 3, GIRDER 4
A 1	ASSEMBLY	 FLAT 1, SHAPED 2
M 1	MODULE	 DOUBLE BOTTOM 1, WING TANK 2, 5/3 DECK WITH HATCH
P 1	PIPE	 STRAIGHT P 11, BENT P 12
PT 1	PIPE TEE	
PV 1	PIPE VALVE	
PF 1	PIPE FLANGE	
PA 1	PIPE ASSEMBLY	

Table II
Comparison of Traditional and Zone Engineering

TRADITIONAL	ZONE	BENEFIT
Structural drawings prepared on item basis from bow to stern, eg, °Shell drawing °Deck drawing °Bulkhead drawing °Tank top drawing °Framing drawing	Structural drawings prepared on a construction sequence basis for subassemblies, assemblies, and modules, eg, °Web frame subassembly °Transverse bulkhead assembly °Double bottom module °Wing tank module	1. With traditional approach, construction cannot be started until a number of item drawings are complete. For example, one module required 13 drawings to be completed before module could be lofted. With zone approach, construction can commence when the first module drawing is complete. 2. With traditional approach, it is necessary for someone (production planning) to prepare module parts lists and sequence assembly sketches. With zone approach, production can use engineering-prepared drawings directly, thus saving additional effort and time.
Machinery arrangements laid out for individual equipment and piping installation.	Machinery arrangements laid out for on-unit advanced outfitting packages and piping and grating package assemblies.	On-unit advanced outfitting has been demonstrated to be the greatest productivity improver. Also allows work to be performed on unit and the ship to be completed earlier.
System diagrammatics prepared for design use only in preparation of A&D drawings with no particular accuracy in equipment location or pipe routing.	System diagrammatics prepared accurately as possible, including scheming for pipe routing with other systems and showing all information required for material procurement and planning.	1. By integrating all system diagrammatics in a given space, the grouping for piping of various systems can be considered. 2. Also, knowing that the diagrammatics are more accurate allows material to be ordered with greater confidence which reduces the need for margins. 3. More complete diagrammatics are acceptable for complete owner and classification approval, ie, it is not necessary to send A&D drawings for approval.
A&D system drawings prepared for complete ship or areas of ship without regard to module breakdown or on-unit advance outfitting. Usually prepared as independent drawings for each system, thus making integration and grouping of piping and supports together for installation difficult, if not impossible.	System working drawings consist of final instructions to the production worker, such as spool sheets, installation sketches, and material lists suitable for direct incorporation in work packages.	1. Elimination of traditional A&D system drawings. 2. Earlier availability of construction information for piping. 3. Prepared on a zone basis, earlier installation of piping. 4. Eliminates current additional step which can introduce human error and can mushroom due to unexpected interferences and/or rework.
Engineering drawings, data, etc, that are unsuitable for direct issue to production, must be further processed by production planning.	Engineering prepares all production-required drawings and data, such as structural subassembly, assembly, and module sequencing sketches; pipe spool sketches; advanced outfitting drawings and lists.	1. Elimination of some engineering effort resulting in time savings. 2. Cost savings due to eliminated effort. 3. Increase in mutual engineering/production knowledge and cooperation. 4. More problems solved on paper rather than on hardware.
No input for advanced outfitting.	Prepares advanced outfitting drawings and parts lists.	1. Engineering designs ship to facilitate advanced outfitting. 2. Forces material definition to support advanced outfitting. 3. Results in a more integrated ship.
Lofting is prepared from and therefore after detailed structural drawing is completed.	Lofting is an integrated part of structural development. Usual detailed drawings eliminated.	1. Shortened time from contract award to cutting steel. 2. Increased productivity of combined engineering and lofting.
Independent planning and scheduling keyed to a master event schedule.	Integrated planning and scheduling for engineering, material procurement, and production for individual work packages.	1. Compatibility of all detailed schedules. 2. Effect of change on one department automatically apparent to other departments. 3. Schedule items identifiable to simplest production package.

Suggestions on how engineering can best be provided to the production department will be presented for each of the individual groups within the engineering department, even though it is obvious that standardization of data preparation is the ultimate goal. With this in mind, it is surprising how many different drawing scales are used by different groups in the engineering department. There is really no need for more than two scales for each project. This is more significant when computer-aided drawings are utilized as the basis for, or start of, all other drawings. It also assists interference control if all drawings are to the same scale.

BASIC DESIGN

General

Basic design covers all design from conceptual to at least contract design. It is proposed that it should also cover Functional design. In that way, after the award of a contract, all design to define systems and required material would be part of basic design. This would keep the responsibility of contract design work-within the same group.

The development of experience and skills could then be easily integrated into future contract designs. However, the main reason to include functional design in basic design is the concept that when functional design is completed, and the work tasks move on to product engineering, all design calculations, vendor selection, and system design (including system sizing, routing, and grouping) will be compleced. Also, all planning would be developed parallel with basic design.

In basic design, the division of the task can follow the traditional breakdown into naval architecture, marine engineering, and electrical engineering. Some shipyards may also have designated system engineering and production engineering functions. This division is not being recommended, but is discussed and shown in Figure 3 to identify necessary functions. Naval architecture, marine engineering, and electrical engineering responsibilities should be integrated and handled as normal necessary tasks. Some of the tasks shown under production engineering may be handled by planning rather than the basic design group.

Design for Ship Production must be applied during basic design. As seen in Figure 3, the structural breakdown definition as well as zone and advanced outfitting "on unit", "on block", and “on board” definitions must be decided during this phase. The building plan, finalized for its initial issue at the end of the contract design phase, will be continuously developed parallel to the preparation of functional design.

The concept and preliminary design process is well known and documented elsewhere (4, 5, 6, 7, 8). Therefore, no further discussion will be given. However, it is emphasized that Design for Ship Production should be incorporated into these phases of design.

Contract design and the various disciplines of functional design, as well as the impact of regulator and classification rules and owners requirements, will be described in the context of proposed Engineering for Ship Production.

Contract Desire

The 1930 Maritime Bill required that shipowners requesting government financial assistance to construct new vessels had to submit preliminary data for the intended vessels and trade route. If MarAd approved the preliminary request, the shipowner had to submit a contract design package consisting of drawings and specifications to MarAd for review and approval. MarAd then sent the package to interested shipbuilders who in turn submitted their bids to MarAd.

Understandably, shipbuilders were unwilling to spend time preparing contract designs because there was no guarantee they would be the lowest bidder when the design was sent out for bid. Thus, contract designs were mostly prepared by marine consultants. Although this system has produced many fine and successful ship types, it has a number of significant disadvantages, which can be understood by reviewing the list of documents required by MarAd. Many of the drawings define basic construction and installation details which the shipbuilder must follow. When this is done, it is difficult to take full advantage of any particular shipyard’s production facilities and methods since it is not known at the time which shipyard will be the successful bidder. If the shipyard has developed standard details to suit its facilities, then prior to bid, it must either request to use its own standards or else add extra cost to deal with a nonstandard vessel. Of course, the shipyard could bid based on its standard, and then hope the shipowner will accept the standards if it is the successful lowest bidder. As an attempt to relieve this problem, consultants list certain plans as contract guidance plans in the contract specifications. If a drawing is for guidance only, then it is not really required, and it would be more economical to eliminate it. In most cases, a special requirement can be adequately covered by a description or a simple sketch in the contract specifications.

The 1970 Maritime Bill introduced the negotiated contract. This development permitted shipowners and shipbuilders to combine efforts to design and construct the most economical vessel the shipyard could build to meet the shipowner's requirements. This approach had some early successes, but mainly for bulk carriers and oil tankers. A number of shipyards without in-house design capabilities started to build up this capability. Unfortunately, the Arab oil embargo eliminated the U.S. tanker boom, and the general work recession has reduced the growth of world trade. Therefore, the demand for new vessel construction in the U.S. has fallen far short of the expectations of the early 1970's. The economic fact of no work and no need for in-house designers stopped shipyard design group growth, and most new designs are again being prepared by consultants.

Parallel to this commercial ship development, the U.S. Navy up until recently had its own in-house design staff who prepared contract designs for all naval ships. Initially, this changed to having marine consultants prepare the contract designs for a Savy design program group, and then to shipbuilder-prepared contract designs based on a Navy-prepared Technical Requirements Document. In the latter case, the shipbuilder usually used marine consultants to prepare or at least assist them to prepare the contract design.

One way to achieve a minimum cost U.S. snipbuilding industry is to reduce tae number and detail of contract design plans prepared by a consultant for an owner or the U.S. Navy. A contract lines plan should only be provided if the model tank tests have been run as pare of the contract design. If the model tank tests are to be run by the shipbuilder, or if the shipbuilder is contractually responsible for the trial speed, only a preliminary plan need be prepared showing body plan and bow and stern profiles (9).

In the past, many commercial contract designs were submitted to the classification societies and regulatory bodies for approval before they were released to the shipyards for bidding. While some shipyards may like the apparent insurance of knowing that contract documents are approved by such organizations, this is only necessary for novel design concepts and not for normal modern ships. By eliminating this step, the contract design package could be in the hands of the shipbuilder at least two months earlier. If these two months were given to the shipbuilder as additional time to prepare the bid. a better bid could be submitted, thus ensuring the most competitive prices. It would also give the successful low-bid shipyard the responsibility of getting the design details approved as early as possible by its regional approval office. This is so important because often when consultants get approval of contract plans, they are approved in New York or Washington DC. The shipyard developing the plans proceeds assuming everything is in order, until it is quickly brougnt back to reality when the regional office disapproves details based on headquarter's approved contract design.

If the contract design is prepared by the shipbuilder, the basic planning for design of the machinery space should be performed. When locating the propulsion machinery, the space needed for units, pipe/system corridors; and working space should be taken into account as shown in Figure 5. This is where the use of standards, such as standard machinery space arrangements, system units, system corridors, etc. pays off. This approach also enables a quick check on space requirements before the design has progressed too far. The module definition should also be prepared either for an in-house contract design or as a bid preparation document for an owner-prepared contract design.

<u>Classification and Regulatory Organization Requirement</u> .

For commercial ships, the drawings that must be sent to the classification society and the regulatory bdoy to obtain their approval and certificates for the vessel are listed in the rules and regulations of those organizations. It is unusual to prepare drawings exactly matching the lists, but the intent is all that need be followed.

The normal practice of submitting the shipyard's proposed drawing list to various organizations for approval achieves.a useful end result, but often results in organizations requesting drawings they really do not need. In the past, many drawings were really shop detail and duplicated information shown on other general drawings. Every attempt should be made to keep shop detail and instructions out of the drawing list and therefore the approval cycle. For example, some shipyards prepare work station drawings for each structural assembly in addition to the complete structural module drawings. The structural module drawings are approved, but the shipyard still sends the assembly work station drawings for approval, which is completely unnecessary. The American Bureau of Shipping (ABS) has indicated it would rather not receive the assembly drawings. However,

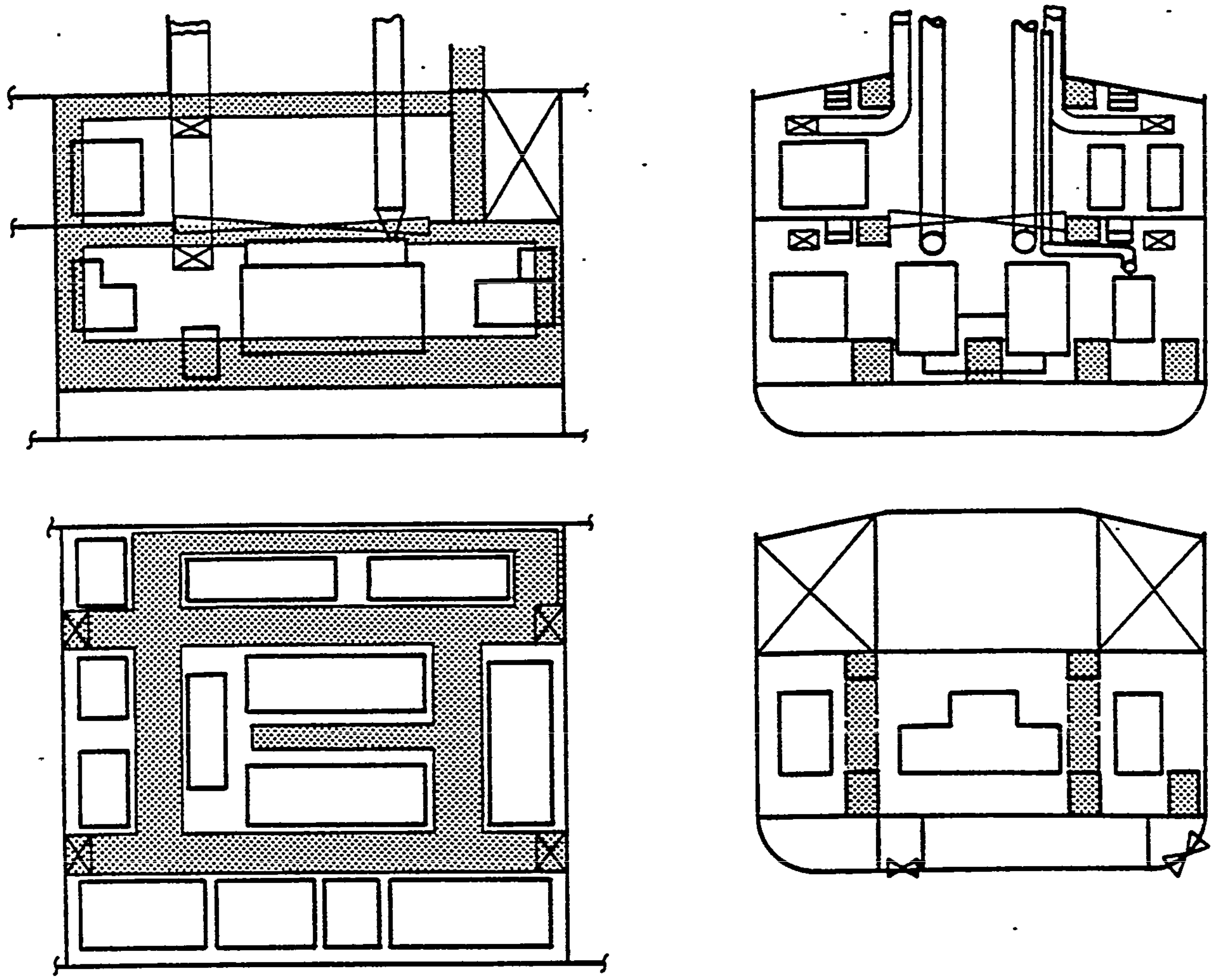


Fig. 5 Space allocation

if a drawing is submitted, it must be reviewed and approved by the ABS. The concept of approving a detail only once should be the guide on when a drawing should be submitted to external organizations for approval or record and what is simply more detailed shop instructions of the same data and should be kept in-house. In the proposed approach, this is conveniently accomplished by only submitting functional design data. It is an obvious requirement that work station instructions should be given to the resident owner and other inspectors to assist them in their work.

In this country, the U.S. Coast Guard accepts hull drawings after they nave been approved by ABS. The ABS also approves machinery drawings for the Coast Guard. This procedure is beneficial to all concerned and compliments the above suggestions.

Many preparers of engineering data leave necessary information off design drawings and diagrammatic, knowing that detailed drawings will be submitted later. However, it is better to provide all the information required for approval on the drawings and diagrammatic, even though it requires more detail and greater accuracy. Complete diagrammatic with piping shown in the correct location and all materials and equipment specified should be provided. Both the U.S. Coast Guard and ABS have agreed to accept complete and accurate piping diagrammatic as full submittal for most piping systems. It is not necessary to prepare a piping arrangement and detail plan for classification and regulatory body approval. Again, the proposed approach is that the functional design group completes all design and provides information as desired by the classification and regulatory bodies.

Owner Engineering Requirements

The commercial shipowner has a need for the following types of engineering information:

1. The same drawings as required by classification and regulatory organizations. The shipowner needs them as a record of approval from the various organizations and as a means of checking to see that the vessel the shipbuilder plans to build is the one under contract. This verification is accomplished by approving drawings prior to construction and using them to inspect the work under construction. These drawings will also be a final record kept on board as information that may be needed by the ship's crew.

2. Selected shipbuilder constaction drawings chat may be required by the owner to repair, convert, andl/or upgrade the ship throughout its life.

3. Special drawings and data not used by the shipbuilder but necessary for the ship operator, such as:

   - Capacity plan
   - Firefighting arrangements
   - Trim and stability booklet
   - Damage stability booklet
   - Safety plan (fire and - lifesaving)
   - Tank sounding tables
   - Ship operating manual.

Although some shipyard product engineering data could be useful to a ship repairer in the event of damage to snip structure or systems, it is not essential. and therefore would not be provided as a normal part of the data package to the shipowner. However, the owner could be advised to obtain from one shipyard any data such as structural material lists, NIC tapes, or piping shop sketches in the event they are needed for future repairs or upgrading the ship.

The shipowner also requires data lists, equipment manuals, and any other special instructional data necessary to enable safe and proper operation of the snip.

The engineering requirements for the U.S. Navy are different in a number of respects from those of the commercial shipowner. These requirements are clearly defined in the "General Specifications for Ships of the U.S. Navy" and various Department of Defense standards. These requirements are unique due to follow-on shipbuilder, integrated logistics support,. reliability and maintenance, standardization, and many other aspects of naval ships. Since these detailed requirements are based on past practice, it is not surprising they are incompatible with the proposed Engineering for Ship Production approach. Therefore, it is necessary for the shipbuilder to present in detail how the "intent" of U.S. Navy requirements will be met in the bid proposal, while allowing the proposed approach to be used and thus achieving benefits to both the shipbuilder and the U.S. Navy.

Structural Functional Desire

In most shipyards today, no production worker or even supervisor is involved in all stages of processing the hull structure from raw material to erection on the berth. Therefore, the practice of preparing a very detailed structural drawing indicating all the information needed for lofting, cutting, processing, subassembling, module construction, and erection is not an efficient method. Past practices coupled with the still-used method of preparing construction structural drawings as complete item drawings (such as deck plan, bulkhead plan, etc) results in a system that can only lead to confusion when any structural subassembly or module construction is attempted. Instead, functional design structural drawings should be prepared for each module. Steel ordering takeoffs should also be prepared on a modular basis. This is basic, but very important. A typical structural module drawing is shown in Figure 6. Such drawings show all the structure and details necessary to prepare product engineering for the module, Standard structural detail and ship welding booklets could be used by product engineering to prepare the module work station information and by loftsmen to loft the structural parts.

The following example is one obvious indicator of how this approach simplifies understanding the job to be done compared to traditional engineering. To construct a typical module, 13 structural drawings were needed, whereas obviously only one structural module drawing would have been required.

Another advantage of using module drawings compared to complete item structural drawings is the simplification of the part numbering system. For example, consider a complete deck structural drawing. If the part number-

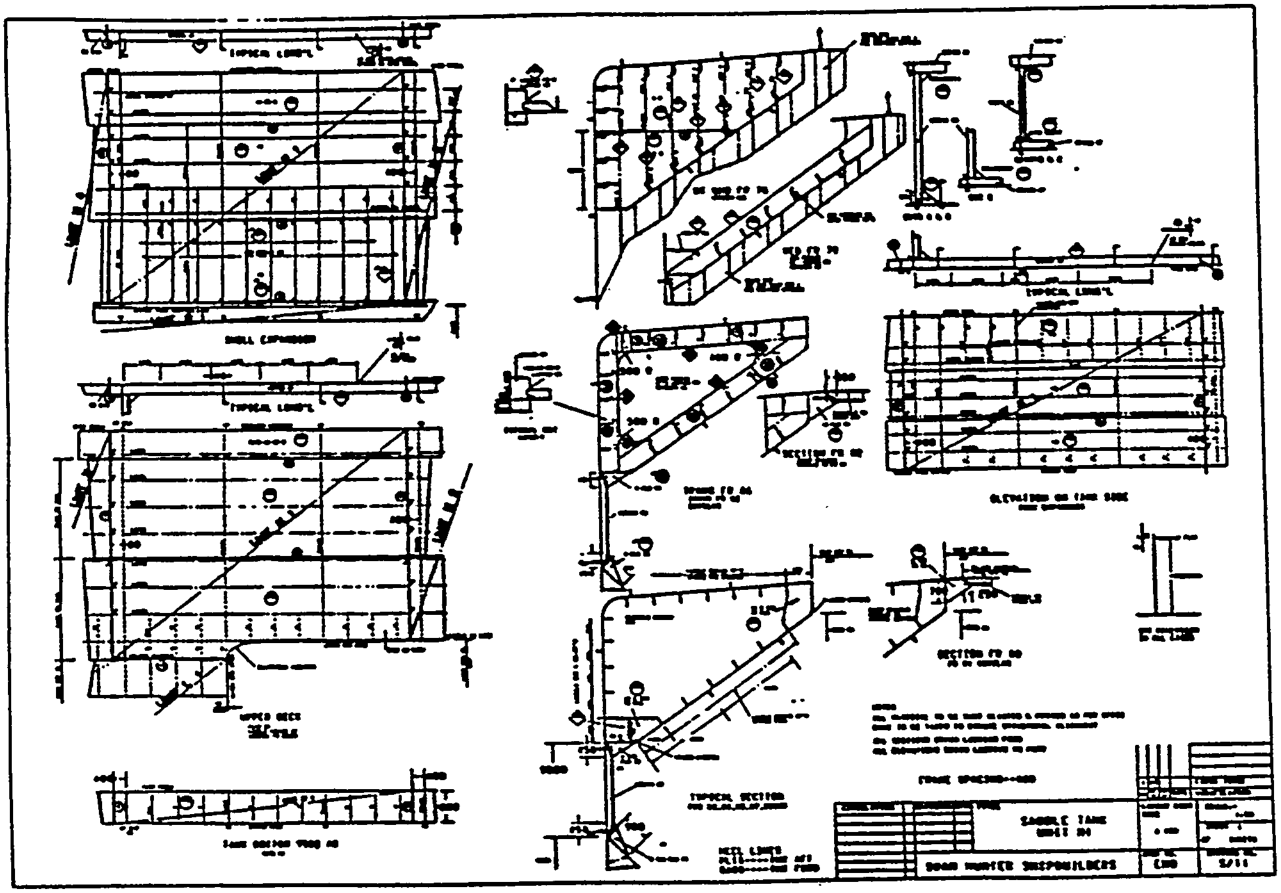


Fig. 6 Structural module drawing

ing system consists of the drawing number and a sequential number, considerable effort must be used to group the parts in special subassembly, assembly, and module lists to help the computer-aided lofting programmer to nest parts needed for a given product and the material handlers to find the material and deliver it to the work station building the product. On the other hand, if structural drawings are prepared for each module, the part numbering can be unique to a given module, assemblies, and the subassemblies. That is, the part number will be the module/assembly/subassembly numbers and a sequential number for each. The above-mentioned problems simply disappear with this approach. Also, sequential numbers are smaller since they start with one for each module/assembly/subassembly. This obviously helps marking the individual parts, especially if they are

The engineering information prepared for the modular approach must be complete and accurate compared to traditional practice. Before, the designer could leave some details to be resolved by the loft. Now this is no longer acceptable.

The usual practice of preparing the lofting from the structural drawings should be changed. Most shipyards today utilize computer-aided lofting (CAL). The initialization of the CAL data base should be commenced as soon as possible. This includes CAL fairing of the lines, interior and shell traces, butts and seams, etc. As a minimum, the CAL system can then be used to provide the basic structural module drawing backgrounds. Many shipyards are using computer-aided design (CAD) systems which are linked with the CAL system. In that case, the drawing data base and the CAL data base are ideally one and the same or at least developed parallel and from each other. The lofting is then effectively developed along with the design, and is turned over to product engineering for retrieval of computer-aided manufacturing (CAM) data to process structural parts. Such an approach results in significant reduction in engineering/lofting man-hours due to the logical and hierarchical development of the detailed parts. This can be contrasted with the lofting-after-engineering approach, where even with module structural drawings, the CAL programmers are inclined co program each drawing separately. This, in turn, requires additional part programming and checking as well as extra effort to check that interfacing parts shown on different drawings are compatible. Another advantage of using a single-data-base CAD and CAL system is that the drawings will show details of the structure as they will be actually cut and processed. This obviously assists in interference avoidance and control, especially if all penetrations are programmed into the data base and cut by the NIC burning machine.

Hull Outfit Functional Design

Hull outfit functional design consists of developing all the details for the outfit design and completing the definition of all outfit material. Again the use of standards reduces the effort. Also, ship standard details should be completed for issue to the product engineering section. A very large pare of hull outfit functional design consists of preparing purchase technical specifications for the required equipment and advanced material ordering. If the contract design for the ship is not prepared by the shipyard, considerable effort will be required to prepare accommodation layouts .

Marine Engineering Functional Design

Engineering for Ship Production places more responsibility and output demands on the marine engineering functional design than does traditional engineering because all design calculations as well as system diagrmmatics must be completed in this phase. The locacion of the machinery, units, system corridors, and working space will have been prepared for the contract design. In developing the functional design, contract design marine engineering is effectively checked. Any standards selected in the contract design phase are considered in greater detail and the design capacity confirmed. The system diagrammatic must be prepared showing distribution in the assigned system corridors and must be sized and show required flow information.

To accomplish this task, a distributive system routing diagrammatic for the machinery space should be developed as shown in Figure 7. The pipe, electrical, and HVAC systems must be located within their distribution corridors, and corridor sectional cuts are very helpful for control. The master routing diagrammatic would become the basis for the transitional design phase zone design arrangements. All machinery purchase technical specifications would be prepared during this phase. As the system diagrammatic are completed. advance ordering of pipe, valves, fittings, sheet metal for vent duct, etc, should be performed. Vendor selection and vendor plan approval should also be . compleced.

Electrical Engineering Functional Design

Again, all design calculations and distribution wiring diagrammatic (elementary and isometric or block drawings) should be completed during the functional design phase. The wiring diagrammatic should be routed in assigned wireway corridors with the cable size and type shown. If standard machinery units, accommodation units, etc, are used, the wiring diagrammatic should simply consist of distribution design to the standard units. The distribution design should take into account the modular breakdown, zone definition, and extent of advanced outfitting before erecting and joining modules. For example, Figure 8 shows two possible ways to arrange electrical system distribution. For passenger ships, warships, and multideck cargo ships, vertical distribution within each module is best for production and from the damage control aspect. For a bulk carrier or tanker. there is no choice, and horizontal distribution is-used. Again, all purchase technical specifications and advanced material ordering should be prepared.

System and Production Engineering

It is preferable to integrate both systems engineering and production engineering into the three basic design disciplines than to-have separate specialist groups. However, for this to occur, it is necessary to know what the functions entail.

Systems engineering is an organized approach to the interaction between the parts of a system (such as a unit, a machinery space, a deckhouse, or a complete ship.) It is based on two concepts, namely:

1. The interconnections, the compatibility, the effect of one upon the other, the objectives of the whole system, the relationship of the system to the users, and the economic feasibility must receive even more attention than the parts, if the complete system is to be more successful.

2. The ever-increasing degree of specialization requires a formal integration of the specialist parts to ensure that the overall objective solution is the best and most economical.

The tools of system engineering consist of systems theory, systems

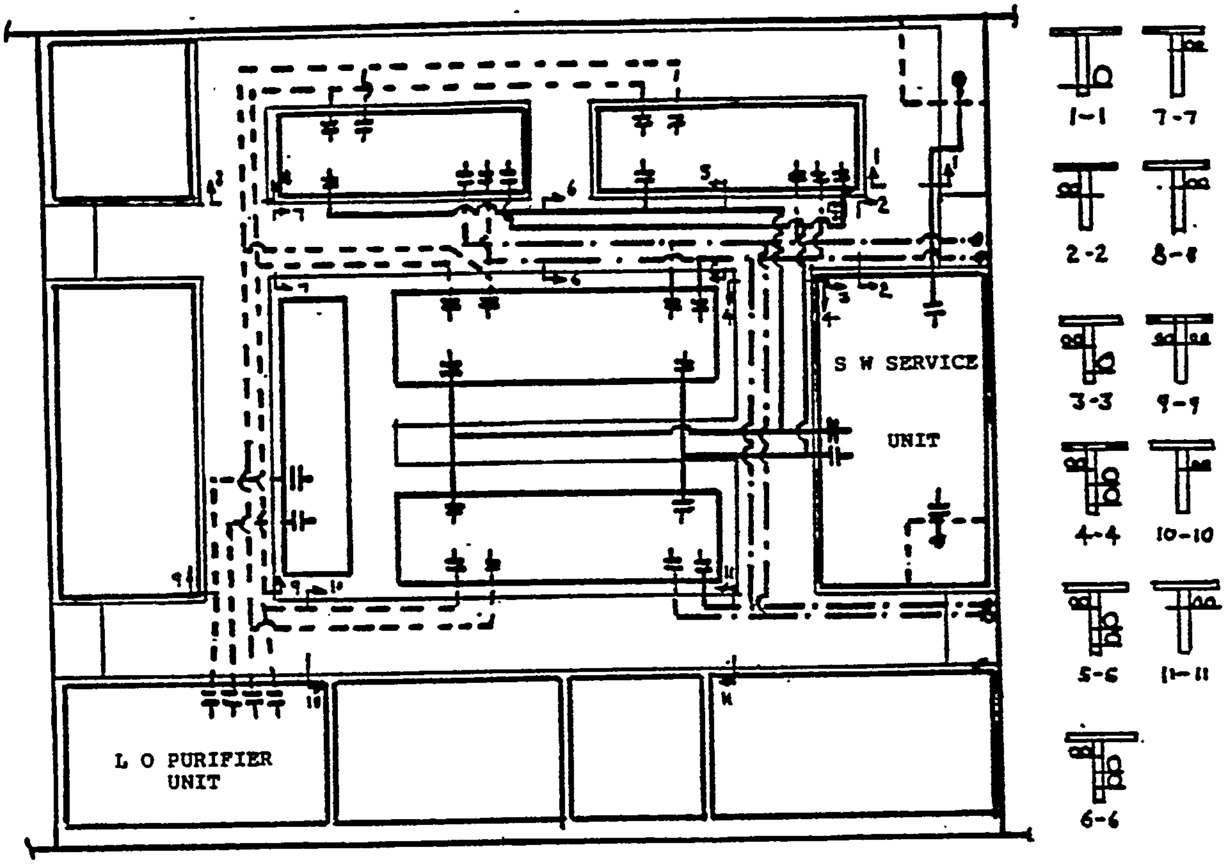


Fig. 7 Distributive system routing diagrammatic

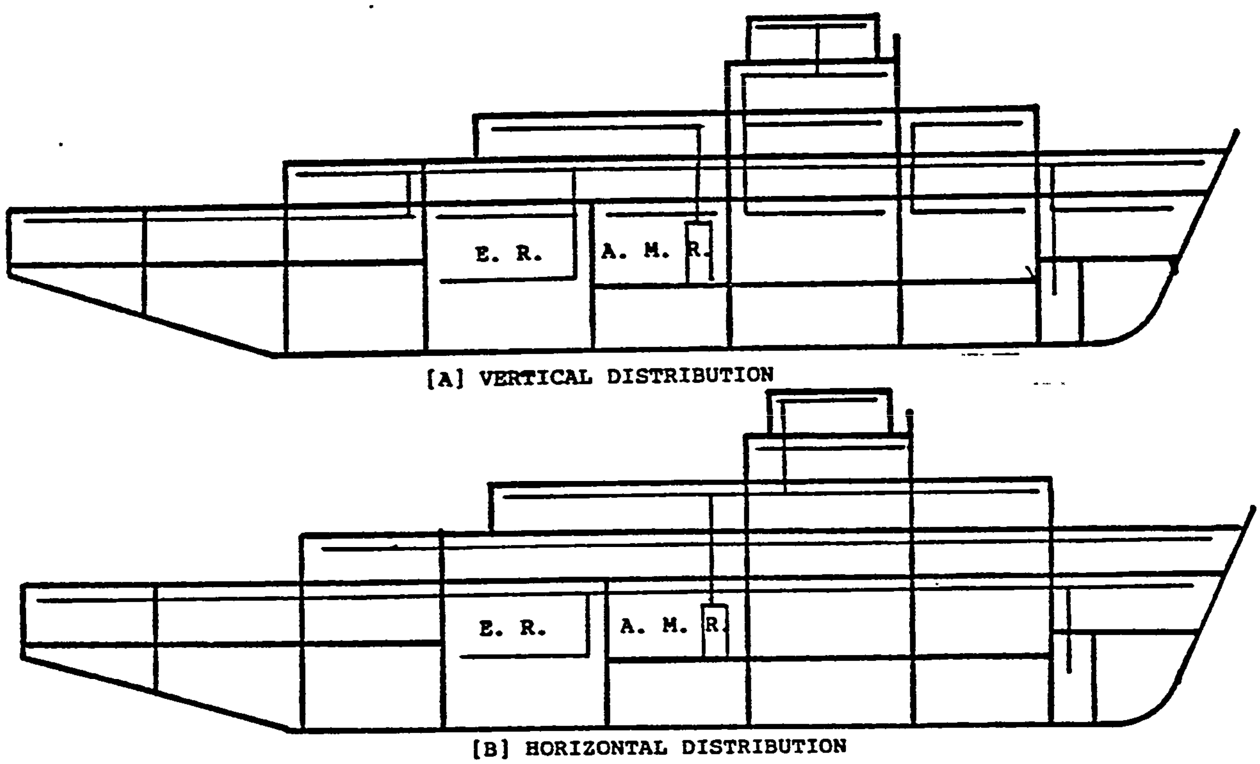


Fig. 8 Electrical system distribution

analysis, computer processing aids, operations research, decision concepts, and statistical decision theory.

Therefore, design engineers must become familiar with these tools so that the integration of systems engineering with traditional shipbuilding engineering can be effectively accomplished. The role systems engineering plays in Engineering for Ship Production is to ensure that the various ship systems are well-integrated and offer the best possible design and construction cost.

Production engineering and industrial engineering are synonymous. They can be defined as the task of determining the best methods for performing the various manufacturing processes within a given facility, taking into account its limitations and operational goals. The functions of production engineering are:

- Product definition
- Process analysis
- Process planning
- Value engineering
- Work and method study
- Machine and tool requirements
- Process information and instruction requirements
- Link between engineering and production departments.

For further discussion on the application of production engineering to shipbuilding, a number of technical papers are recommended (10, 11, 12, and 13). The production engineering function can be shared in part, between engineering and planning. However, industrial engineering tasks, such as work measurement and method study, require specialist training and experience.

In performing the production engineering function, decisions should be made on module definition, zone definition, assembly and construction approach, and advanced outfitting approach.

These decisions should be made before the functional design is begun. This is important because the application of production engineering during contract design makes possible the lowest cost design. If production engineering is applied after the completion of contract design, it will probably result in design changes to achieve low cost, but will have wasted time and design effort (cost). Production engineering decisions should become part of the building" plan as shown in Figure 9, which is based on a figure from reference (13).

Fig. 9 Integration of production engineering and contract design

An effective production engineering tool is the product/stage chart shown in Figure 10, which is based on a similar chart developed by A&P Appledore. From such charts, the sequencing of the various products that go into a module, zone, or onto a unit can be better understood and planned.

The module definition could be based on a structural product breakdown structure such as the one shown in Figure 11. The zone definition can be similarly based on a zone breakdown structure as shown in Figure 12. Both breakdown structures are integrated in Figure 13.

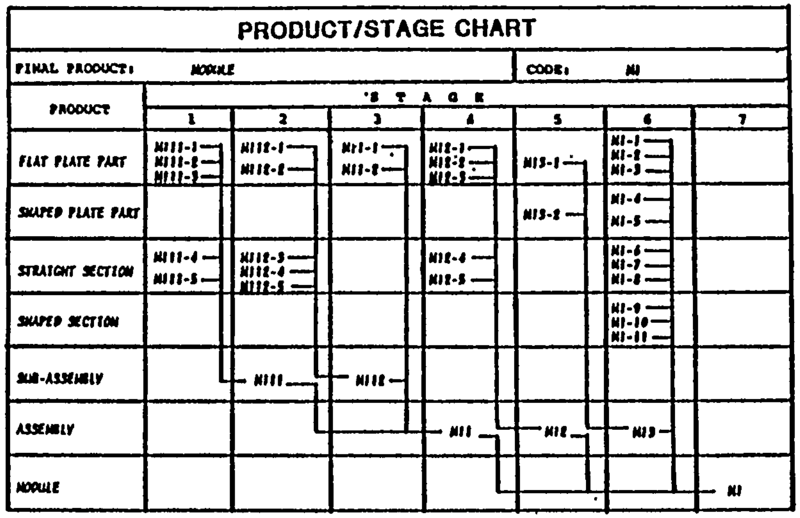


Fig. 10 Product/stage chart for structural module

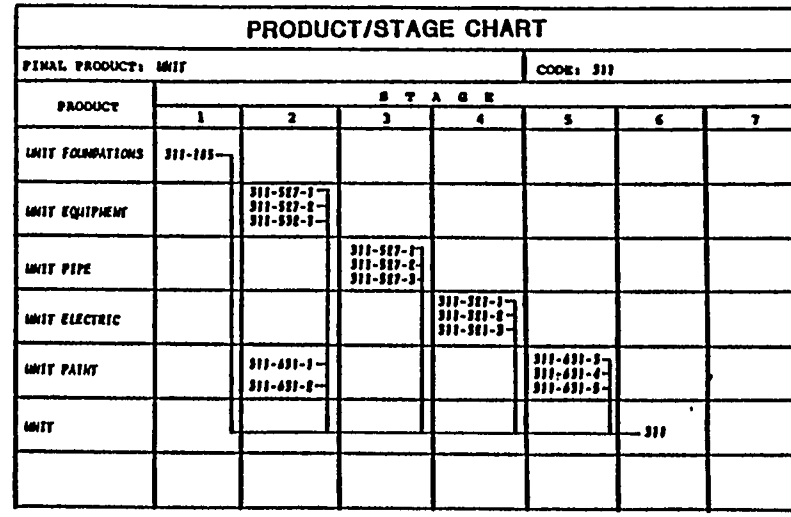


Fig. 10 (Cont) Product/stage chart for machinery unit

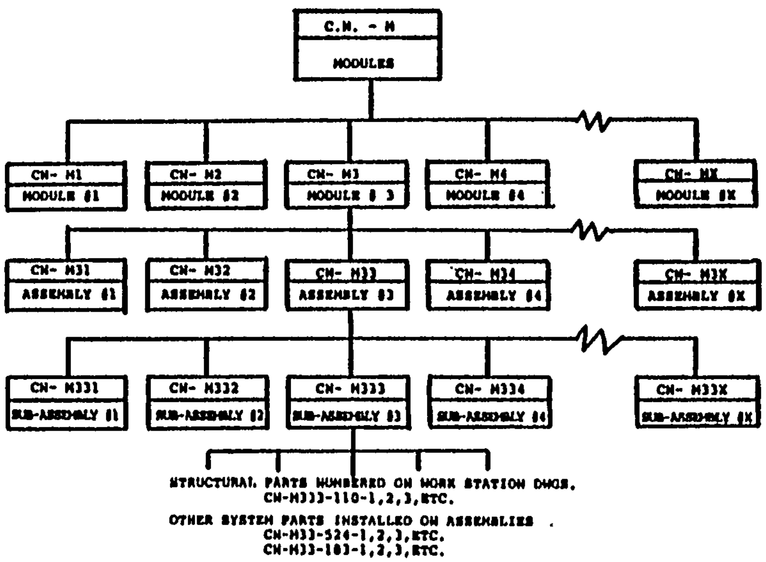


Fig. 11 Structural module breakdown

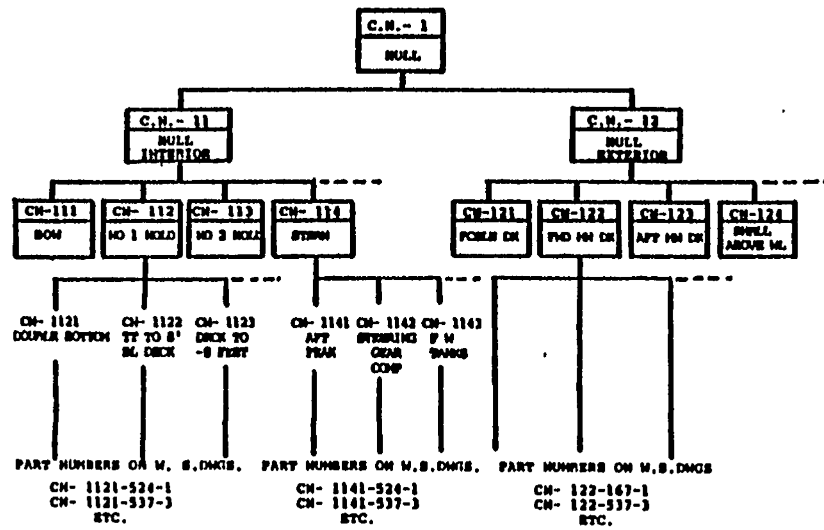


Fig. 12 Hull zone breakdown

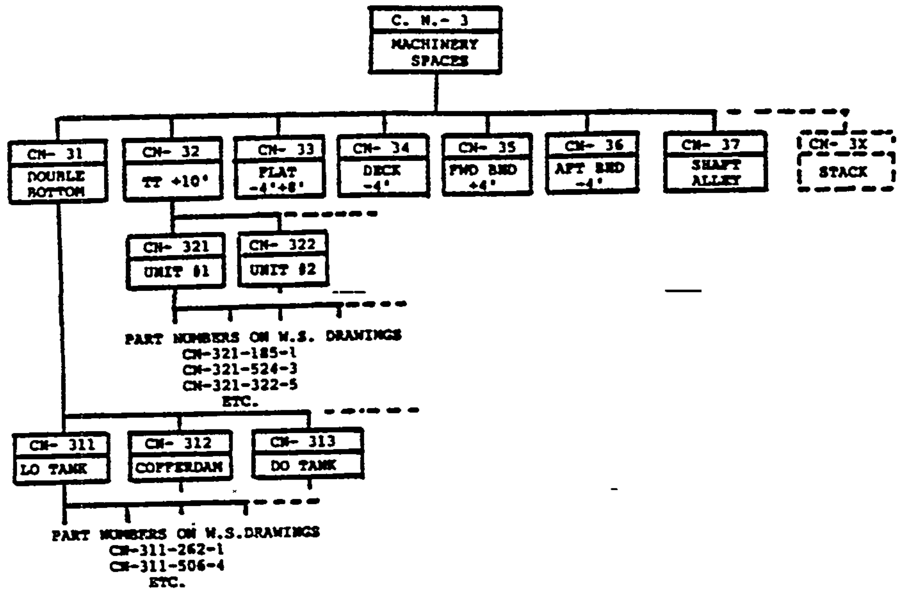


Fig. 12 (Cont) Machinery spaces zone breakdown

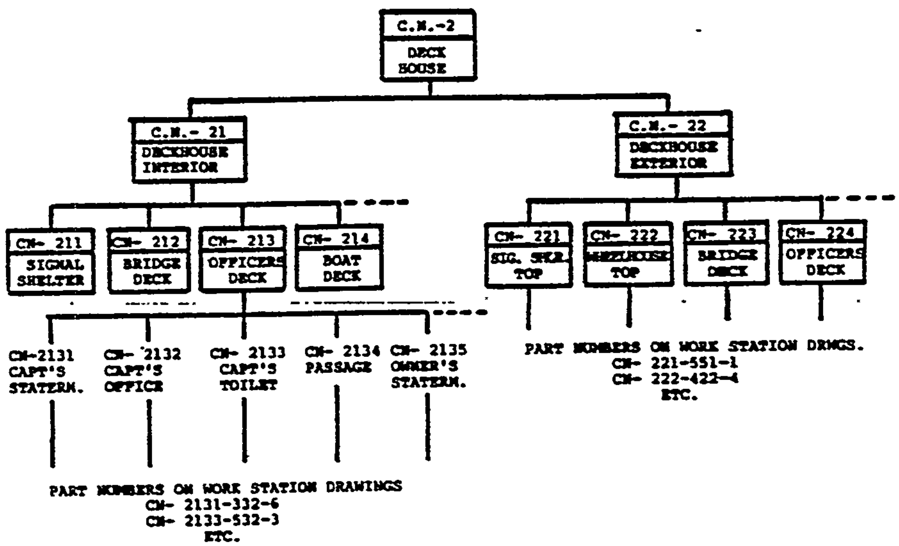


Fig. 12 (Cont) Deckhouse zone breakdown

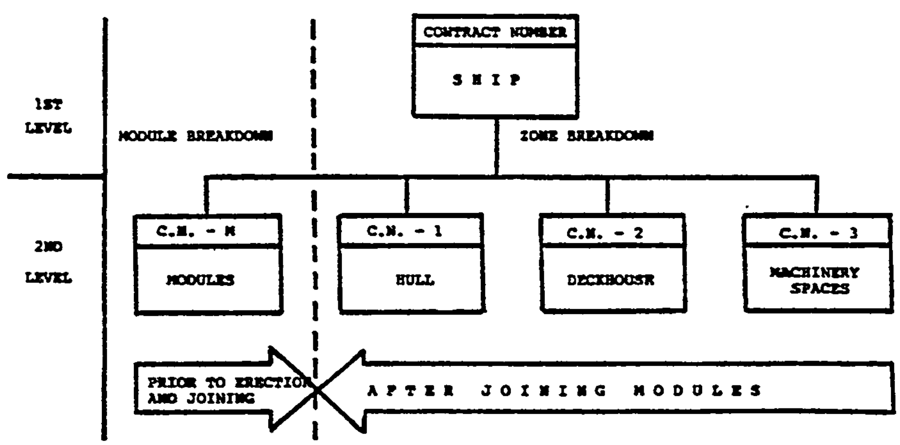


Fig. 13 Ship breakdown structure

Transitional Design

The transitional design can be likened to building a prototype, except that it is constructed on paper. If CAD is used, the prototype is effectively modeled in the computer. important cask in transitional design is the selection of the zon/subzone breakdown for the design effort. As a guide, a subzone could be a compartment surrounded on all sides by major structural divisions, such as deck/flat/tank top, transverse bulkheads, side shell, longitudinal bulkheads, etc.

Zone design arrangements are similar to the traditional composites. However, they are prepared from distribution system routing diagrammatic developed during functional design. The traditional composites are prepared from completed system arrangement and detail drawings. Traditional composites are drawn as an interference checking tool and, for this purpose, are slices through the compartment, showing only the items in the immediate layer below. Zone design arrangements show all the visible items seen from the viewing plane. All products should be included no matter how small. The traditional composite practice of excluding pipe below l-lj2-inch diameter is no longer acceptable. When the zone design arrangements are prepared manually, the backgrounds can be provided by the CAL system. Manually prepared zone design arrangements could be drawn with single line pipe representation. However, ic is preferred to show double line, including insulation where appropriate.

Once the zone design arrangement is completed, the products are identified as follows: unit, pipe assembly, vent assembly, wireway, foundation, and floor plate group.

The required zone/unit material quantity is also developed at this time. Typical forms used for this purpose are shown in Table III. By accumulating the material quantities as zone design arrangements are prepared and deducting the material from advance material orders, effective material ordering control is possible. A list of all the products in a zone/subzone provides an accurate compartment checkoff list.

Obviously, during the preparation of zone design arrangements, all systems are developed for interference avoidance and checked for interference as the work progresses.

It should be obvious that the use of CAD for this design phase has many advantages. Three-dimensional solid modeling CAD systems enable a true prototype to be modeled and all working, maintenance, and access requirements to be checked prior to any construction.

Work Station/Zone Information

Many successful shipyards claim that their success is based on better work organization. This is accomplished through better planning and better instructions/information and work packages. The work package concept is the division of a total task into many work packages for small tasks. A USUAL guide is that a work package should be as follows.

Table III Zone/Unit Material Lists

ZONE DESIGN ARRANGEMENT		ZONE NUMBER: 31	
PRODUCT: FIRE PUMP UNIT		PRODUCT NUMBER: 312	
		QUANTITY	
CODE	DESCRIPTION	NUMBER	MEASURE
1453066627	Foundation	1	
	Floor	1	
	Rail	1	
	Ladder	3	
5200661004	Fire Pump 1	1	
5200661004	Fire Pump 2	1	
5280661003	Duplex Filter	2	
5228661407	Pipe Assembly 1	1	
5228661407	Pipe Assembly 2	1	
5228661407	Pipe Assembly 3	1	
5228661407	Pipe Assembly 4	1	
5228641404	Pipe Assembly 5	1	

ZONE DESIGN ARRANGEMENT		ZONE NUMBER: 31	
PRODUCT: PIPE ASSEMBLY 1		PRODUCT NUMBER: 31-527-1	
		QUANTITY	
CODE	DESCRIPTION	NUMBER	MEASURE
5220461471	Pipe, 6-Inch	1	10 Feet
5220461482	Pipe, 4-Inch	1	20 Feet
5220441494	Pipe, 1-1/2-Inch	4	80 Feet
5230661463	90 Elbow, 6-Inch	2	-
5240000001	6-Inch Hanger Type I	5	-
5240000002	4-Inch Hanger Type I	7	-
5240000003	1-1/2-Inch Hanger Type I	6	-
5211100042	Gate Valve, 6-Inch	2	-
5221100032	Globe Valve, 4-Inch	4	-
5221100021	Globe Valve, 1-1/2-Inch	3	-

1. Two-week duration maximum

2. Two-hundred hours of work maximum

3. Work for a maximum of three workers

4. Include only (but all) the information required by workers to complete the work package tasks, including drawings, parts lists, and work instructions

5. Include production aids such as N/C tapes, templates, and marking tapes.

The first three items are difficult to adhere to for certain shipbuilding tasks on the berth but are achievable for most shop work.

Engineering can effectively participance in preparing some of this information and, in doing so, eliminate a lot of current duplication of effort. Planning will select the tasks to meet the first three requirements. Engineering can prepare the information covered in the last two.

For this approach, it is proposed that separate work station information be prepared for each work package. Work station information should be prepared on the following basis:

1. Information should only show that necessary for a given work station.

2. Information should consist of sketches and parts list.

3. Complete information for the tasks must be given. No referencing allowable.

4. Separate work packages should be prepared for each craft (trade). Sketches and parts lists should not mix work that must be done by different crafts.

5. Sketches should be prepared to show work exactly as workers will see it. For equipment, piping, or other products that will be installed on an assembly when it is upside down, the sketch should be drawn that way rather than for the final attitude plan view.

6. A reference system should be used, and all dimensions should be from the reference system planes.

7. Information should be prepared so it can be issued on 8-112- by 11-inch sheets.

Structural Work Station Information

Today most shipyards use CAL to prepare the lofting and to develop the necessary production aids for construction of the ship structure. This system eliminates the need for manual measuring and layout of plates. Therefore, the drawings used for subassembly, assembly, and module construction need not contain any dimensions other than check and quality assurance control dimensions. What is needed is a way to provide required information that is completely compatible with the way in which it will be used in various stages of construction of the structural hull and deckhouse.

This can be effectively and efficiently accomplished by using the following data packages:

1. For burning plate. Nest tape sketches and NIC tapes.

2. For cuttiny shapes. Process sheets, marking tapes, and sketches.

3. For processing plate or shapes (ie, bending, flanging, drilllng). Process sheets and templates.

4. For subassembly construction. Subassembly drawing and parts list.

5. For assembly construction. Assembly drawing and parts list.

6. For module construction. Subassembly, assembly, and parts list, module assembly sketch, and welding sequence.

7. For module erection. Hull module plan, excess stock plan, rolling and lifting sketches, and welding sequence.

The advantage of structural work station information is that only the data necessary for the work being performed at a particular stage is given. There is no need to search through a number of large plans to get the necessary data. An advantage of module assembly sketches is that they enable the designer to consider access requirements for both people and machines at various construction stages. The advantage of sequence sketches is they actually show how to build the subassembly, assembly, or module. This is of great assistance to engineering, planning, production workers, and their supervisors. The preparation of sequential construction sketches requires a closer relationship with planning and production than usual. In order to correctly design a ship structure, it is necessary to know how it will be built. However, for sequential sketches, it is essential to work with planning and production to decide in considerable detail how the structure will all go together. Holes, notches, clips, and other means to facilitate the use of available manual alignment and fairing tools (such as hydraulic pullers and fairing rams) could be designed into the structure and shown by engineering on the subassembly, assembly, and module construction sketches.

Actually, this extra effort is valuable because once it is done it aids everyone involved in getting the structure constructed. Without the added effort, either planning has to prepare instructions to accomplish the same end result or it is left to the supemisor and men on the job to plan the construction sequence. With such an arrangement, the shipfitters may construct the module in a different way to that envisioned by the designer. Sometimes the parts cannot go together and modification on the job is necessary. It is better to get all the people responsible for engineering, planning, and building the structure to decide these matters at an early stage of the project and to include them in the building plan.

A typical work station information package (process sheet) for structural shapes is shown in Figure 14. It shows the finished part for a floor stiffener and gives material total quantity required to cut all the parts listed. "The package also shows the parts are of different lengths. Delivery instructions for unused material and finished parts can be included on such a drawing. Accuracy control data can also be included.

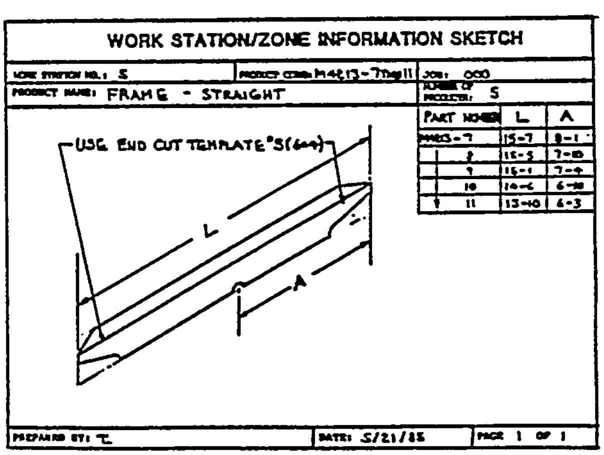


Fig. 14 Structural section process sheet

The CAL NIC plate cutting drawing with attached instruction sheet (shown in Figure 15) is typical of a place part work station information package.

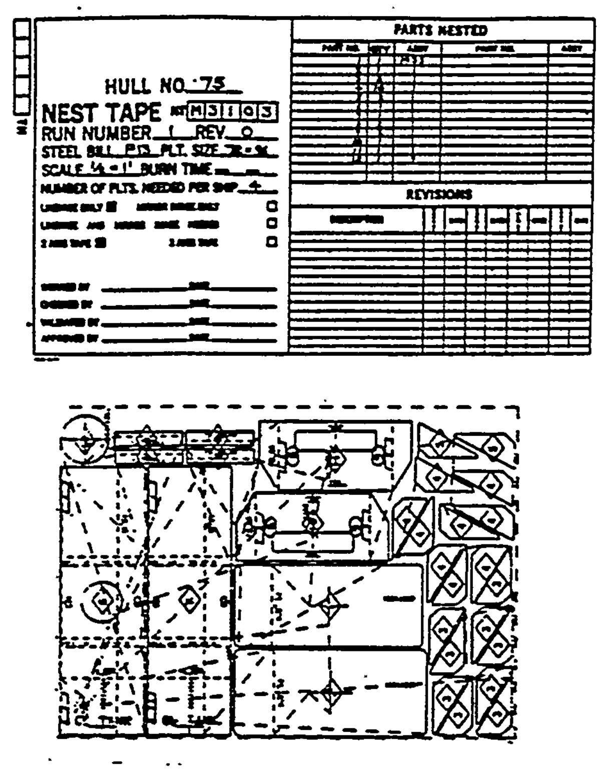


Fig. 15 Structural plate process sheet

Figures 16, 17, and 18 show the work station information packages for typical subassembly, assembly, and module, respectively. Note that for the assembly and module, the parts lists are separate from the drawings. The parts list should be sequenced in the wav the product is to be constructed. Again, the product/phase chart can be used to develop the sequencing. Figure 19 shows a typical parts list.

The work station information for joining the modules could include alignment, fitting, dimension control, accuracy control, and welding data. Figure 20 shows a typical welding work station information sheet.

It is important to remember that all the information required by the workers to perform a work package should be included in the package. The worker should not have to obtain or look at any other drawing, work package, standard, etc, to complete the task.

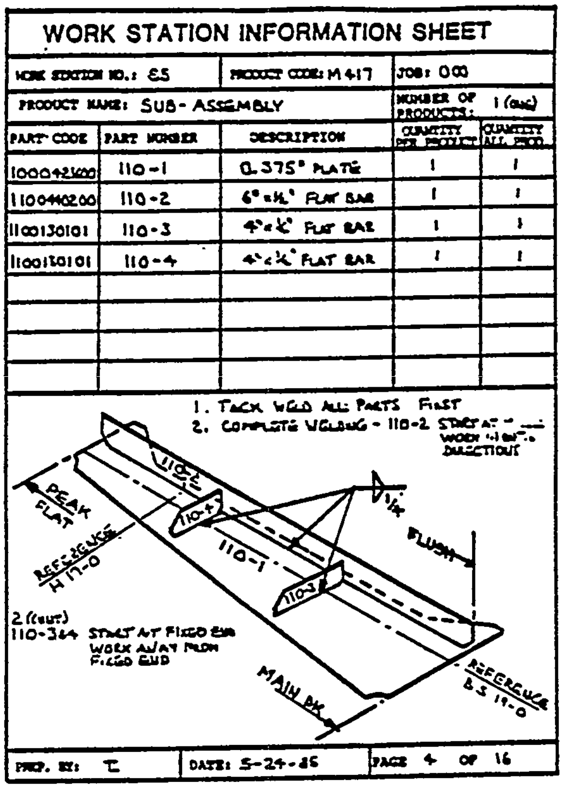


Fig. 16 . Structural subassembly work station information

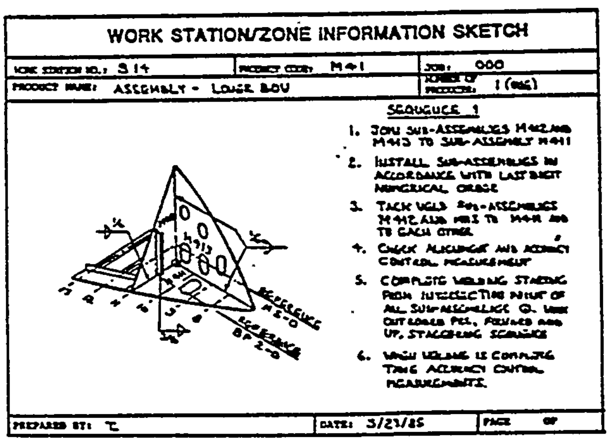


Fig. 17 Structural assembly work station information

Outfit Work Station/Zone Information

The work stacion/zone information will be provided for shops, assemblies, modules, and zones. The product/stage chart is helpful in deciding the work packages. Work station information for shops for both processing and assembly will be required for hull fittings, pipe, sheet metal, foundation structure, joiner, paint, and electrical work. It is suggested that zone be used instead of the term work station for all onboard installation work package information. For example, work station installation information could be prepared for all on-block advanced outfitting work. Zone instruction information could also be prepared for the same type of product installation for all onboard advanced and remaining normal outfitting. .

The work station/zone information prepared for the machinery spaces will be considerably simplified compared to the traditional engineering approach This is mainly due to the logical break-down of the total machinery space design and engineering, and the provision of work station/zone information packages in place of traditional working draw-ings. The machinery arrangement becomes a series of major pieces of machinery, units, and connecting system corridor/ floor plate units. However, the quan tity of information provided to produ tion is vastly increased in scope c pared to traditional engineering, pl all systems are given equal depth o consideration and are shown to the detail.

Work station information for sho for both processing and assembly wi required for foundation structure, pi sheet metal, paint. and electrical w Work station information will also b required for machinery installation, etc, for units.

One area where electrical produc engineering can save significant el trical production man-hours is in id tifying cables on each wireway, iden fying cables starting and ending in each compartment, providing required length of cable for each run, and length of cable in each space where it starts or ends.

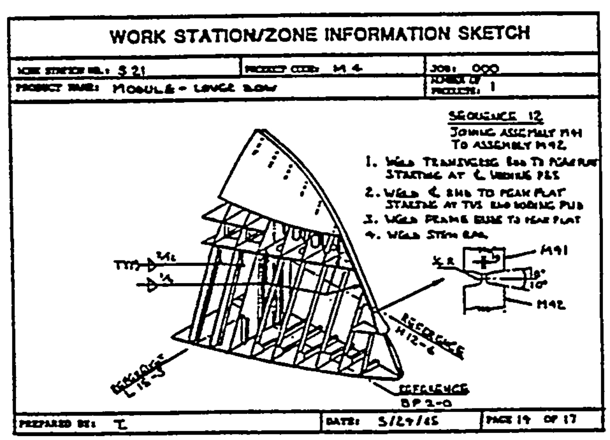


Fig. 18 Structural module work sta-tion information

WORK STATION PARTS LIST				
WORK STATION NO. S 14		PRODUCT CODE: M41	JOB: 000	
PRODUCT NAME: ASSEMBLY - LOWER BOW			NUMBER OF PRODUCTS: 1 (ONE)	
PART CODE	PART NUMBER	DESCRIPTION	QUANTITY PER PROD.	QUANTITY ALL PROD.
SEQUENCE 1				
	M411	SUB-ASSEMBLY	1	1
	M412	SUB-ASSEMBLY	1	1
	M413	SUB-ASSEMBLY	1	1
SEQUENCE 2				
	M414	SUB-ASSEMBLY	1	1
	M415	SUB-ASSEMBLY	1	1
	M416	SUB-ASSEMBLY	1	1
	M417	SUB-ASSEMBLY	1	1
	M418	SUB-ASSEMBLY	1	1
	M419	SUB-ASSEMBLY	1	1
SEQUENCE 3				
	M41-1	PART	1	1
	M41-2	PART	1	1
	M41-3	PART	1	1
	M41-4	PART	1	1
SEQUENCE 4				
	M41-A	ASSEMBLY (MINOR)	1	1
SEQUENCE 5				
	M41-5	PART	1	1
	M41-6	PART	1	1
PREP. BY:	DATE:		PAGE	OF

Fig. 19 Structural assembly work station parts list

WORK STATION INFORMATION SHEET					
MODULE JOINING WELDING					
MODULE M4 TO M3				JOB: 000	
SEQUENCE	ITEM	TYPE OF WELD	SIZE	WELDING PROCESS	REMARKS
1	℄ BHD TO TRS BHD	DOUBLE CONT FILLET	1/4	MANUAL	START AT MIDDLE WORK BOTH WAYS
2	PLAT TO TRS BHD	DOUBLE CONT FILLET	1/4	MANUAL	START AT ℄ WORK [illegible]
3	FLAT KEEL TO [illegible]	CONTINUOUS BUTT		MANUAL	START AT ℄ WORK P&S
4	STRINGER TO STRINGER	CONTINUOUS BUTT		MANUAL	START AT SHELL
5	MAIN DECK GIRDER TO GIRDER	CONTINUOUS BUTT		MANUAL	
6	MAIN DECK TO MAIN DECK	CONTINUOUS BUTT		MANUAL / SUB ARC	[illegible] TOPSIDE
7	SHELL TO SHELL	CONTINUOUS BUTT		MANUAL	OUTSIDE FIRST THEN [illegible]

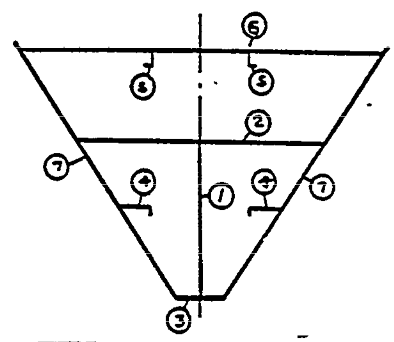


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Fig. 20 Module joining welding work station information

Electrical fixtures in accommodation spaces should be located on the joiner work zone information sketches. All distribution panels, controllers, junction boxes, and other electrical equipment must be shown and located on installation sketches. The support connections to the structure should be included in the structural assembly and/or module work station sketches.

Figures 21 through 28 are typical work station/zone instruction sketches and lists for outfit.

MATERIAL REQUIREMENTS

Figure 29 summarizes the material definition approach for Engineering for Ship Production. It shows how the major equipment is defined by purchase technical specification during concract design. The majority of raw material is defined by advance material order per system during functional design. During transitional design, all material remaining to be defined is identified. Also, through the product/stage chart approach, the preparation of the zone/unit lists is started. The sorting function, shown in Figure 29 under work station/zone information, corresponds to the product/stage chart approach to work station parts list preparation.

A major requirement to ensure success of any material definition system is a detailed preparation and issue schedule compatible with the material ordering and material receipt requirements to construct the ship to plain. This integration of schedules must be a dynamic system, changing as circumstances change. It is not a once-prepared schedule that is followed even when it makes no sense.

CAD/CAM AND ENGINEERING FOR SHIP PRODUCTION

The major difference between manual and CAD design and engineering is that all manual approaches are based on producing drawings at various stages in order to record and transmit design decisions. The correct CAD approach is based on constructing a computer prototype from which data can be extracted at any stage in whatever format desired.

With manual design, it does not matter if the drawings at the completion of one stage are usable in the next. Usually the parts of the previous stage drawings are redrawn as needed for the continual development of engineering. In CAD, this same approach could be and sadly is still used. However, using CAD correctly and building a common data

WORK STATION INFORMATION SHEET

WORK STATION NO.: 62 | PRODUCT CODE: 321-527-21 | JOB: 000

PRODUCT NAME: PIPE ASSEMBLY | NUMBER OF PRODUCTS: 1

PART CODE	PART NUMBER	DESCRIPTION	QUANTITY PER PRODUCT	QUANTITY ALL PROD.
5120071473	321-527-21-1	8-PIPE SCH 80 ASTM A53	1	1
5135071431	321-527-21-2	8-TEE SCH 80 ANSI B16.1	1	1
5130071491	321-527-21-3	8-90° ELB SCH 80 ANSI B16.1	1	1
51520714	321-527-21-4	8-FLANGE 150# WELD NECK	2	2
5139071410	321-527-21-5	8-WELDING CAP SCH 80	1	1
51520614	321-527-21-6	4-FLANGE 150# WELD NECK	6	6

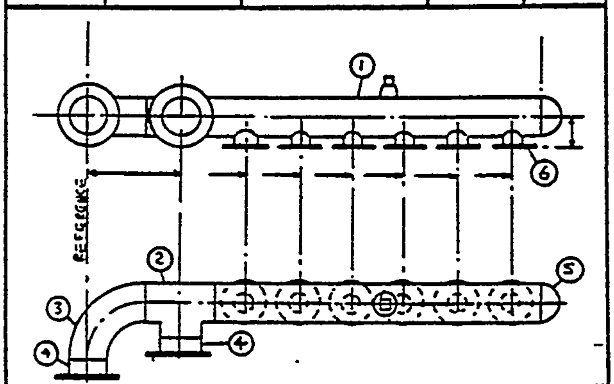

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Fig. 21 Pipe assembly work station information

WORK STATION INFORMATION SHEET

WORK STATION NO.: 15 | PRODUCT CODE: OM16 | JOB: 000

PRODUCT NAME: OUTFITTED ASSEMBLY - ELECTRIC | NUMBER OF PRODUCTS: 1

PART CODE	PART NUMBER	DESCRIPTION	QUANTITY PER PRODUCT	QUANTITY ALL PROD.
36104310	304-1	CABLE RACK	1	1
36104310	304-2	CABLE RACK	2	2
36104610	304-3	CABLE RACK	1	1
3714	332-1	LIGHT FIXTURE WITH FOUNDATION	12	12

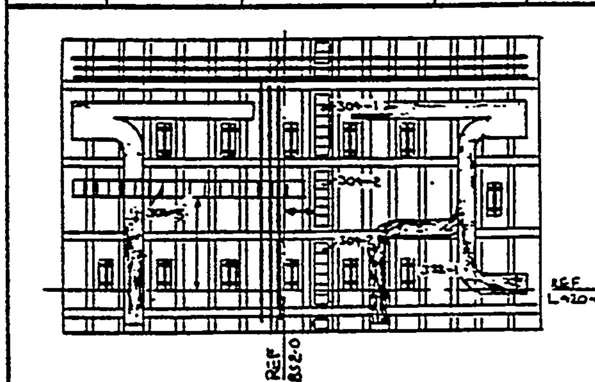

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Fig. 22 "On block" advanced outfitting installation work station information for electrical

WORK STATION/ZONE INFORMATION SKETCH

WORK STATION NO.: 54 | PRODUCT CODE: OM 12 | JOB: 000

PRODUCT NAME: OUTFITTED ASSEMBLY - PAINTED | NUMBER OF PRODUCTS: 1 (OMC)

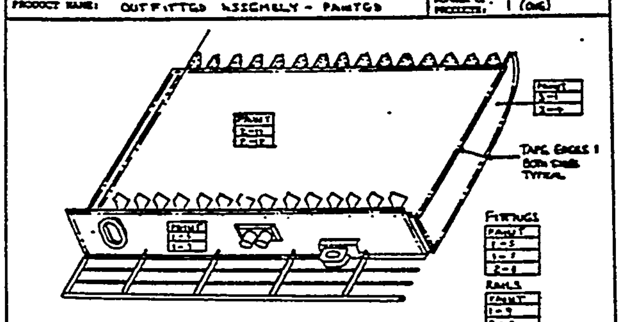

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Fig. 23 Painting work station information

WORK STATION/ZONE INFORMATION SKETCH

WORK STATION NO.: ZONE 32 | PRODUCT CODE: 321 | JOB: 000

PRODUCT NAME: INSTALLED UNIT - "ON BOARD" | NUMBER OF PRODUCTS: 1 (OMC)

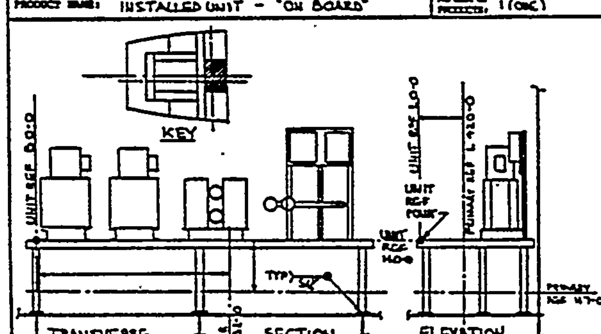

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Fig. 24 "On board" advanced outfitting unit installation work station information

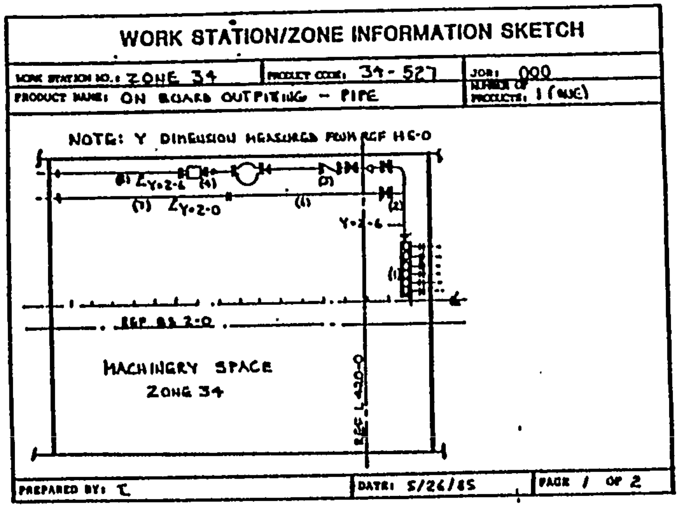

Fig. 25 Pipe assembly installation work station information (parts list)

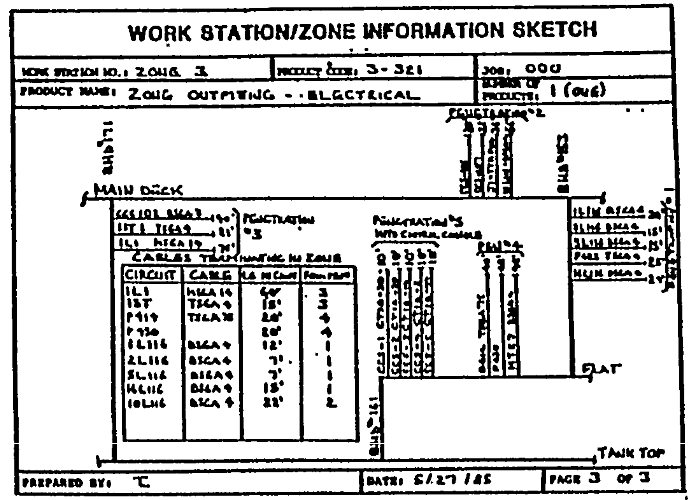

Fig. 26 Zone information, electrical equipment location

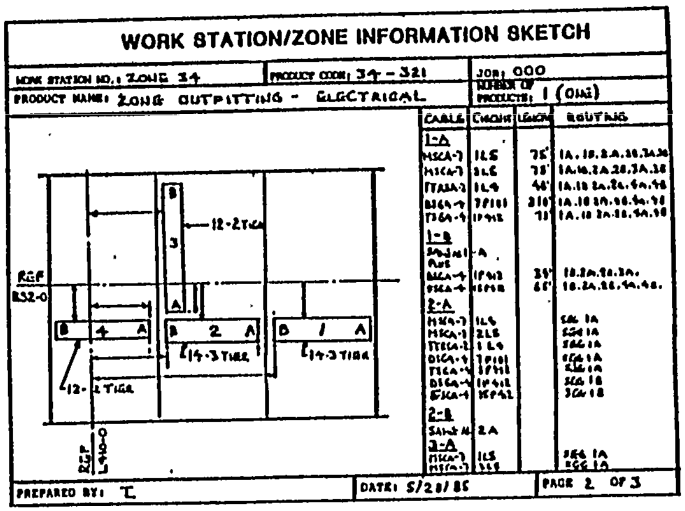

Fig. 27 Zone information, wireway and cable routing/lengths

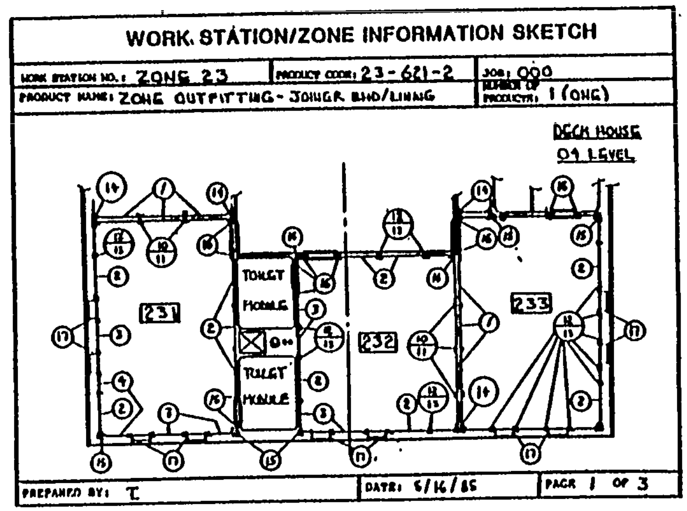

Fig. 28 Deckhouse zone information for joiner lining and bulkheads

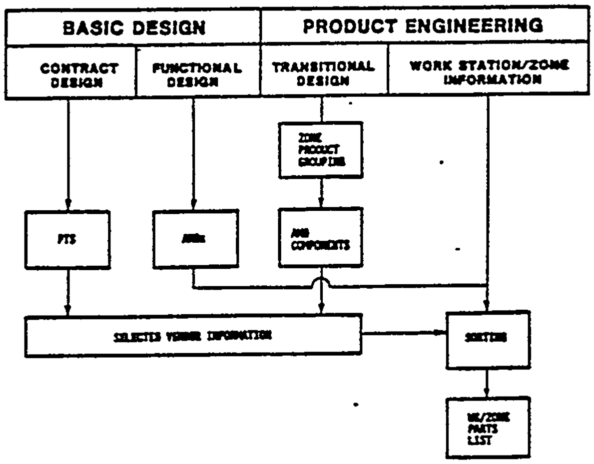

Fig. 29 Material definition phases

base from concept, or at least contract design through work instruction information, requires that each stage be prepared so that it forms the logical inundation for the next stage. This approach leads to the concept of an expanding data base as shown in Figure 30. This requires each designer to develop his work as a full-sized prototype in accordance with design to that stage and in correct location to all other spaces, structure, outfit, etc. for the ship. A designer cannot develop the details in isolation and then have someone else check to see if it fits, a current practice in traditional manual engineering.

Another major difference is that with manual design and engineering, the use of functional drafting and systems drafting approaches makes economic good sense. Since the objective of CAD is to model the complete ship and since the duplication of details is so simple, functional drafting and/or systems drafting concepts need not be used.

The final format of the work scation/zone information is limited to drawings, skecthes, and lists in manual engineering. In CAD engineering, the options are many.

Although the CAD/CAM systems specifically developed for shipbuilding are usable in a number of ways, they were probably developed with a specific sequence of tasks in mind. Therefore, it is important that shipyard techniques, planning, scheduling, and material control desires and the engineering approach be at least conceptually developed when deciding which CAD/CAM system to use. The use of computers for ship design and engineering is a natural catalyst for Engineering for Ship Production since they force the user to document his approach and to develop a logical sequence and formalization for the methods used. While CAD and CAD/CAM could be used to duplicate the traditional manual method and produce data in exactly the same traditional format and content, it would not achieve all the possible benefits. On the other hand, if CAD/CAM is utilized to prepare the information for the proposed Engineering for Ship Production, it would enhance the approach. The approach for Engineering for Ship Production and typical time frame is given in Table IV. It uses the normal shipbuilding language, such as lofting, structure, machinery, outfit, etc. However, it is perhaps of more benefit to consider them all interim products of the final product (the ship) as also shown in Table IV. The Engineering for Ship Production logic fits well with current computer system capability, but must be communicated to system developers for future development. Otherwise, it is possible that new developments will not perform the desired tasks in the best way for a shipyard.

Computers force the users to logically think out what they want co do and how they should do it before they start. Program flow diagrams, structured programming, etc. lead the user through the operation steps. In addition, since computer processing unit (CPU) use time is usually expensive, programmers have developed a basic need to efficiently develop the required data and to eliminate unnecessary steps and duplication of information.

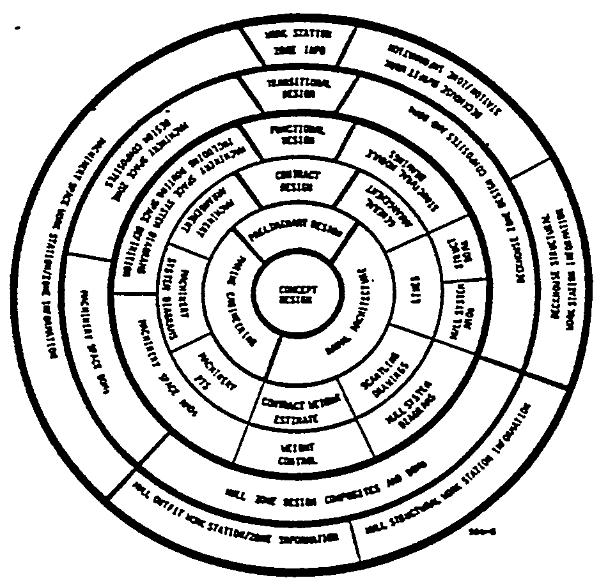

Fig. 30 Expanding ship design data base

These goals are an exact match-up with the goals of Engineering for Ship Production. As already noted, the biggest hurdle to overcome is the tendency to use computers to provide the same information currently available. Instead computers could be used to develop data such as a full-size procotype of the design from which necessary information to procure, fabricate, construct, and test the ship can be extracted and presented in the most effective way.

TECHNICAL SUPPORT

In addition to functions and tasks described, engineering must provide the usual technical support for launching, inclining, tests and trials, ship configuration control, liaison, etc. Engineering for Ship Production requires further additional tasks. The output from these tasks should be incorporated into the work station/zone information, wnere possible. These tasks include the following:

1. Use group technology to classify and code products for production control to:

   • Determine number of parts

   • Determine number of unique parts

   ž Select appropriate processing plan.

2. Determine joint weld length. This should be divided into weld type, size, and attitude.

3. Perform alternative design detail analysis.

4. Provide moving, turning and lifting analysis, and sketches for modules.

5. Provide access and staging sketches.

6. Provide blocking and temporary support sketches for assemblies, modules, and ship.

7. Include production, planning, scheduling, and material handling data/instructions in the work station/zone information as it is prepared by engineering.

There are many other items performed by the craftsman or supervisor in the traditional shipyard which need to be performed prior to work package issue in the modern shipyard. in-many-cases, these items can be effectively and efficiently performed by the engineering department.

CONCLUSION

If engineering is considered just another interim product in the shipbuilding cycle, a natural result is the analysis of the product process. This paper has proposed a particular process, which is considered in step with the current U.S. shipbuilding move to improve productivity and shorten build cycles through zone design and construction. Some shipyards are currently using similar engineering approaches and more will eventually follow. It is hoped that this paper will provide a forum for other engineers to discuss their approaches, ideas, and concerns about this critical matter.

ACKNOWLEDMENTS

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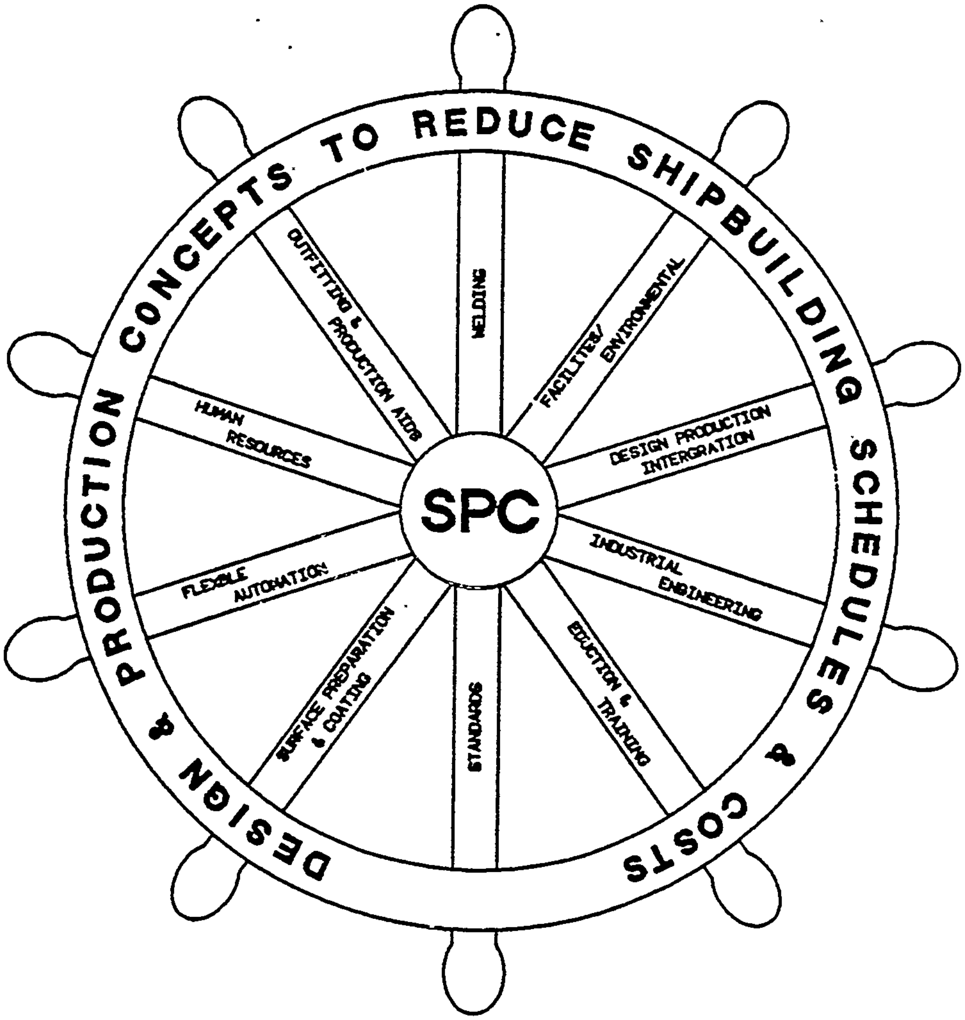


PAPER NO. 17

AUTOMATIC SUBMERGED ARC WELDING WITH METAL POWDER ADDITIONS TO INCREASE PRODUCTIVITY AND MAINTAIN QUALITY

BY: PHILLIP D. THOMAS

SYMPOSIUM SPONSOR:
SNAME SHIP PRODUCTION COMMITTEE

SYMPOSIUM HOST:
SNAME HAMPTON ROADS SECTION

AUGUST 27-29, 1986

1986 SHIP PRODUCTION SYMPOSIUM

AUTOMATIC SUBMERGED ARC WELDING WITH METAL POWDER ADDITIONS TO INCREASE PRODUCTIVITY AND MAINTAIN QUALITY

Phillip D. Thomas, Newport News Shipbuilding

ABSTRACT

This paper presents the results of a SNAME SP-7 Welding Panel research and development project recently completed by Newport New Shipbuilding. It was directed toward the evaluation testing, and qualification of automatic submerged arc welding (SAW-AU) with metal powder additions for shipyard use. It is concluded that using controlled metal powder additions with SAW-AU is indeed a production concept that can reduce shipbuilding costs. This is possible through increased deposition rates and (possibly) reduced consumables costs while, at the same time, maintaining or improving quality.

INTRODUCTION

The purpose of this report is to present the results of a research and development project which was initiated by the members of the SP-7 Welding Panel of the Ship Production Committee of the Society of Naval Architects and Marine Engineers (SNAME) and financed largely by the U. S. Maritime Administration, the U. S. Navy and Newport News Shipbuilding. The purpose of the project was to develop techniques, test, and qualify the use of Automatic Submerged Arc Welding (sAx-AU) with metal powder atiditions to join either carbon steel/ high tensile steel (CS/HTS) or high yield quenched and tempered steel (HY-80) plate for shipyard use.

BACKGROUND

Automatic Submerged Arc Welding (SAW-AU) has a long and proven track record in the shipbuilding industry. This "under powder" or "smothered" arc process was developed by the National Tube Company and patented by Robinoff in 1930. The patent was later sold to Linde Air Products Company who renamed the process "Unionmelt" welding. SAW-AU was used extensively during the defense buildup in the late 1930's and early 1940's in both shipyards and ordnance factories. It is a high deposition welding process that remains stable at amperages four or more times greater than the familiar manually performed Shielded Metal Arc Welding. The American Welding Society (AWS), in AWS A3.0 "Welding Terms and Definitions" defines submerged arc welding as:

> An arc welding process that produces coalescence of metals by heating them with an arc or arcs between a bare metal electrode or electrodes and the workplaces. The arc and molten metal are shielded by a blanket of granular fusible material on the workplaces. Pressure is not used, and filler metal is obtained from the electrode and sometimes from a supplemental source (welding rod, flux, or metal granules).

SAW-AU does not require burdensome welding snieltis, earmuffs, or constant operator torch manipulation like manual or semi-automatic welding processes. The physical size of the equipment usually does not allow "tight quarters" welding nor much out-of-position work. It is ideally suited for long, thick section welding in the flat or horizontal position with reduced double-bevel joint angles as low as 45°, one sided joint angles as low as 20°, and square butts on thin materials. This combination of high deposition, operator appeal, and suitability for large weldments makes SAW-AU a very effective process and an attractive first choice for shipyard weldments.

To increase the deposition rate[2] of conventional single-wire SAW-AU,

The opinions expressed in this paper, and the conclusions drawn, are those of the author and do not necessarily reflect the views or policies of Newport News Shipbuilding.

2 Measured in pounds per hour (lbs/hr)

most efforts have centered around increasing the total heat input, either through the use of multiple electrodes or higher currents/lower travel speeds. The *use* of multiple electroties/highheat input usually requires special joint de*signs* with large root faces and larger included angles, as well as more restrictive fitting tolerances. These efforts give higher deposition rates with resultant lower mechanical properties. The lower mechanical properties are related to the microstructure in the heat affected base material immediately adjacent to the weld fusion line (see Figure 1). The area between the weld fusion line and the point where the base metal is unchanged is known as the heat affected zone (HAZ). The base material in the HAZ is heated to different levels, with near-molten temperatures at the fusion line. As the weld is cooling, the HAZ is also cooling, with the metal near the fusion line cooling more slowly. The overall width of the HAZ is directly related to the total cooling rate. A slower cooling rate allows the grains to grow (or, for HY-80, to change structure) and therefore the base metal grain structure adjacent to the fusion line will be coarse (or of an undesirable form). These coarse grains reduce ductility and toughness below acceptable levels.

The addition of controlled-chemistry metal powder just ahead of the SAW-AU flux (see Figure 2) can also be used as a method to increase deposition rates. Using a special system (see Figure 3), metal powder of compatible chemistry is metered into the joint at a specific rate. As the welding arc passes over, the powder melts and becomes part of the weld puddle, producing higher deposition rates without the use of additional electrical energy (i.e., a lower total heat input). This method provides a finer HAZ grain structure, a narrower HAZ, and higher mechanical properties. It does not require special joint designs or stringent fitup tolerances, and the reduced number and large size of the beads will help reduce distortion. The use of metal powder additions can result in reduced consumables cost. The disadvantage of metal powder addition is that, unlike conventional SAW-AG, weldinq can only be performed in the flat position.

[3] Measured in kilojoules per inch (KJ/in) using the formula:

$$\text{Heat input} = \frac{\text{arc volts} \times \text{amps} \times 60}{\text{travel speed}}$$

TASK

The primary objective of this project was to develop and qualify procedures for both--carbon steel/HTS and HY-80 that meet military specifications (MIL-STD-248C) using SAW-AU with metal powder additions. The main function of the project was to determine working parameters, optimum powder-to-wire ratios, usable joint designs, and the criticality of bead placement through nondestructive and destructive tests. Other areas of study were to include: (1) storage and handling problems, (2) effect on productivity and quality, (3) consumables cost, (4) best powder addition equipment, and (5) the effect on distortion.

EQUIPMENT

After investigating, only one commercially available-metal powder dispensing system was found. Users of metal powder additions either used no metering system at all, or used the Tapco system. Throughout the project, the Tapco metal powder dispensing system was used with either a permanent side-beam SAW-AU installation or a portable track mounted SAW-AU carriage (the two most commonly used methods in shipbuilding). Figure 4 shows the operator working with the side-beam equipment, and Figure 5 shows how the powder hopper, metal meter and powder tube were adapted. Specific equipment used during the majority of this project is listed below:

- Linde CM100 Side Beam Welding Station
- Lincoln Idealarc DC1500 Power supply
- Lincoln NA-3S Controller
- Tapco Metal Powder Dispensing system
- Electric Strip Heaters (For HY-80 Only)
- Temperature Indicating Crayons (For HY-8o Only)
- Steel Wool (For Arc Initiation)
- Lincoln Digital Wire Feed Speed Indicator

The same safety precautions used for normal SAW-AU operations were followed when adding metal powder.

METHOD AND RESULTS

Calculations on typical one-sided and double-beveled joint volumes and consumables cost for HY80 were performed and are provided in Appendix A. The consumables costs reflect typical welding electrode, metal powder, and flux costs and contain projections based *on large-scale* purchases of the metal powder.

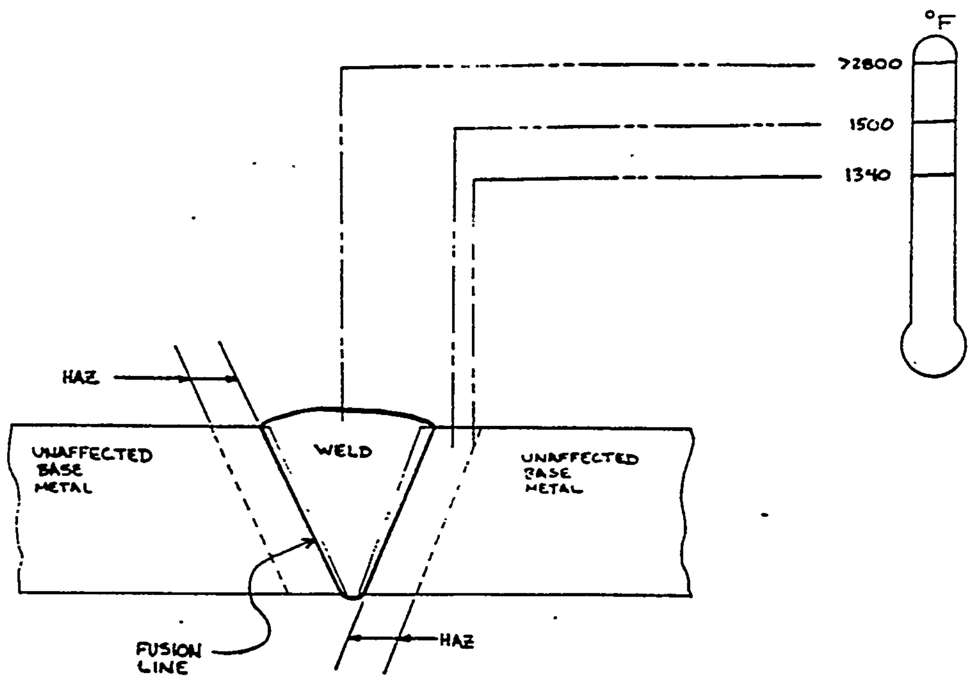


Figure 1
Peak Temperatures Across the Weld Zone

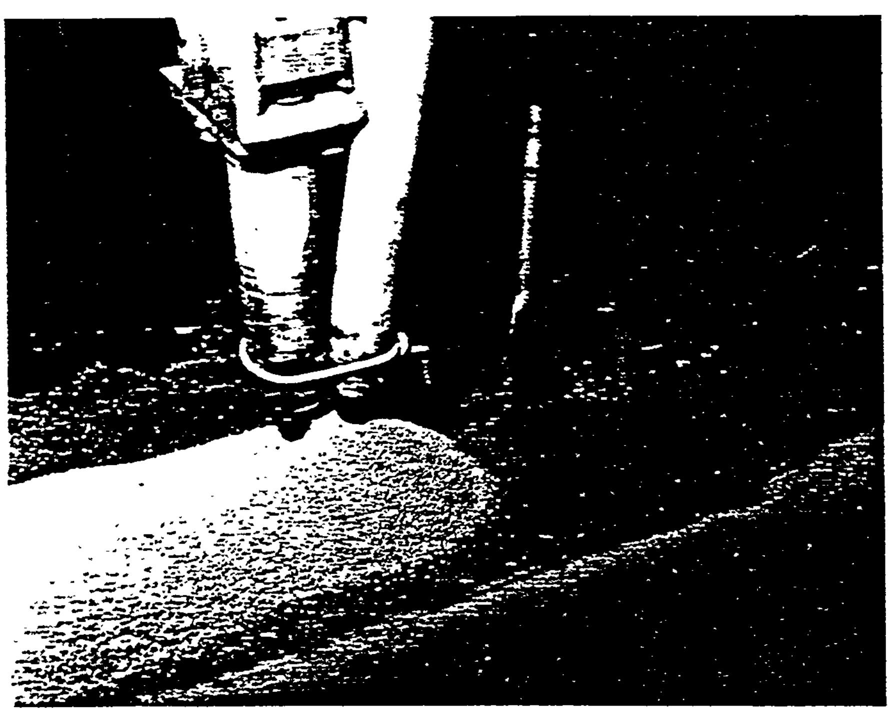


Figure 2
Metal Powder Additions to SAW-AU

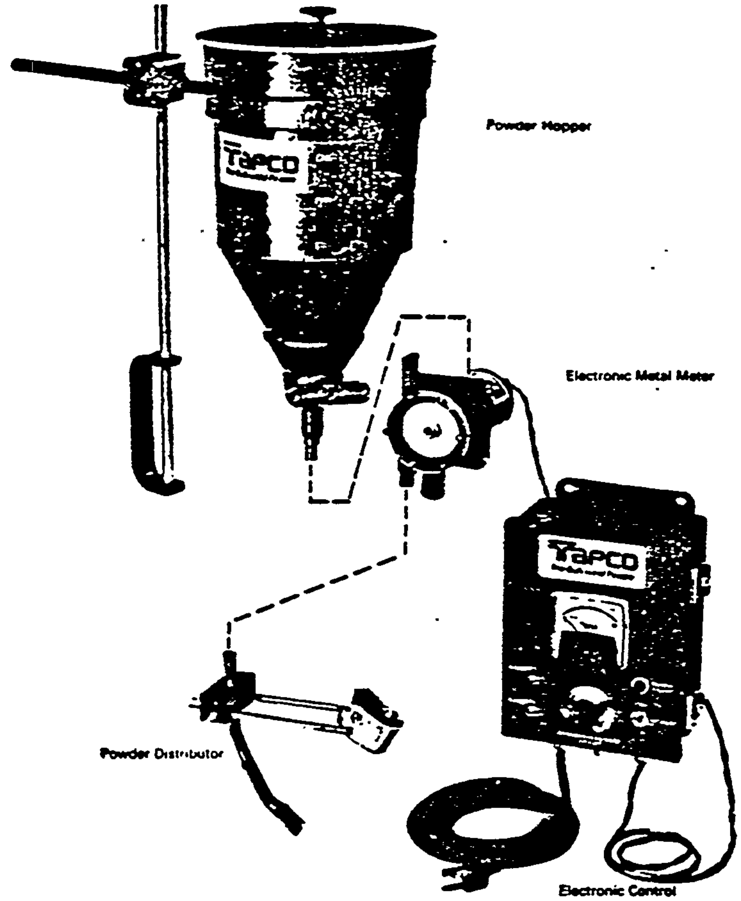


Figure 3
Metal Powder Dispensing System

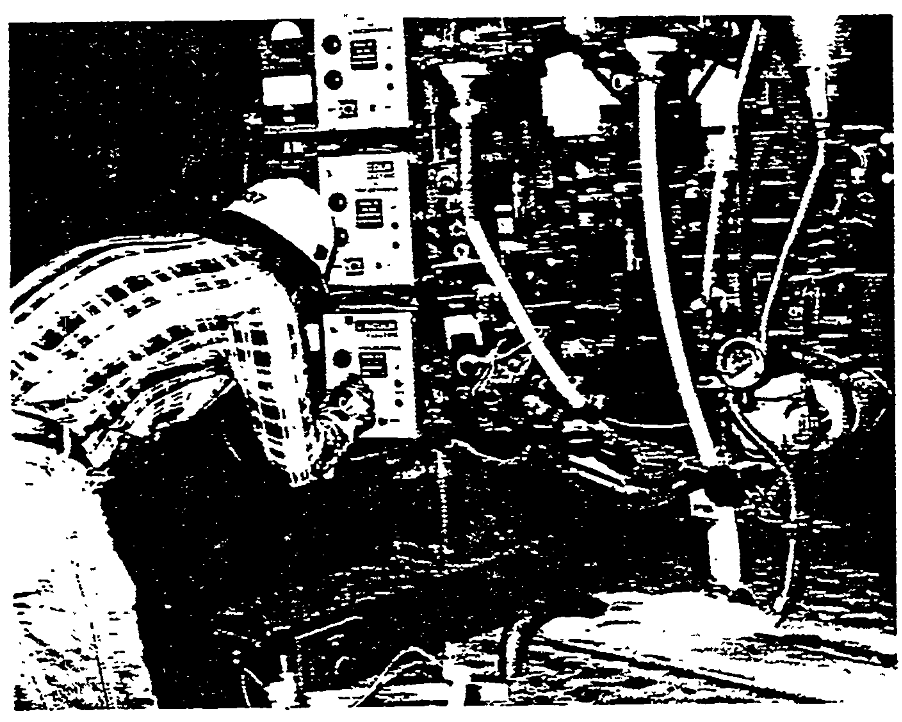


Figure 4
Technician Operating Side-Beam SAW-AU with Metal Powder Additions

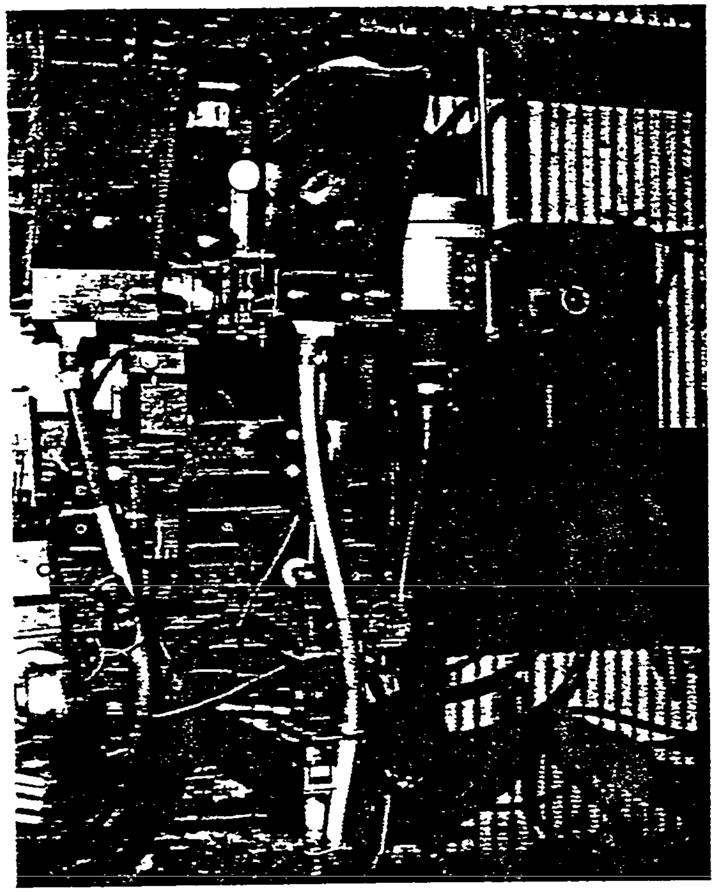


Figure 5
Adaptation of Powder Hopper, Metal Meter, and Powder Tube to the Side Bean Carriage

All of the joints in this project were prepared by oxypropane cutting and grinding run-on/run-off tabs were installed and the joints tacked together. One-sided joints were tacked on the side opposite the joint to a 3/8" minimum thickness backing strap. Double-bevel and fillet joints were joined only by the run-on/run-off tabs, with *no* tacks in the joint. NO addititional restraint other than the run-on/run-off tabs and four hold-down "dogs" were used in order to simulate large "plate blanket" weldments. This method also allowed a qualitative comparison of the distortion caused by the metal powder additions versus conventional SAW-AU. In some cases, double-bevel joints used 314 backing tape SJ8073 to avoid burn-through during root pass welding. All three joint designs are shown in Figure 6.

Base materials were Carbon Steel (CS) of MIL-S-22698, High Tensile Steel (HTS) of XIL-S-24113, and High Yield Quenched and Tempered Steel (HY-80) of MIL-S-16216. For the purposes of MIL-STD-248C procedure qualification, carbon steel anti STS are classed under *one* general category (S-1 of Table 1, MIL-STD-248C) and qualify each other. All welding was performed with direct current, reverse polarity in the flat (1G and lF) position. For carbon steel/ETS joints, welding was performed using 5/32" diameter MIL-A1 electrode of KIL-E-18193B (Linde 80) and MIL-F2 flux of MIL-F-18251C (Lincoln 780). For HY-80 joints, welding was performer with 1/8" diameter MIL-1OOS-1 electrode of MIL-E-23765C (Lincoln LA-1OO, Linde 95) and MIL-100S-1F flux of MIL-E-23765C (Oerlikon OP121TT, Lincoln 880M). HY-90 joints were welded using 150°F minimum and 300°F maximum preheat and interpass controls. MIL-100S-1F flux was heated to 250°F minimum prior to use and remained warm to the touch while welding. Three different heat inputs were used for HY-80 welds - 55, 85 and 110 KJ/in. Parameter levels across the applicable range were used for carbon steel welds.

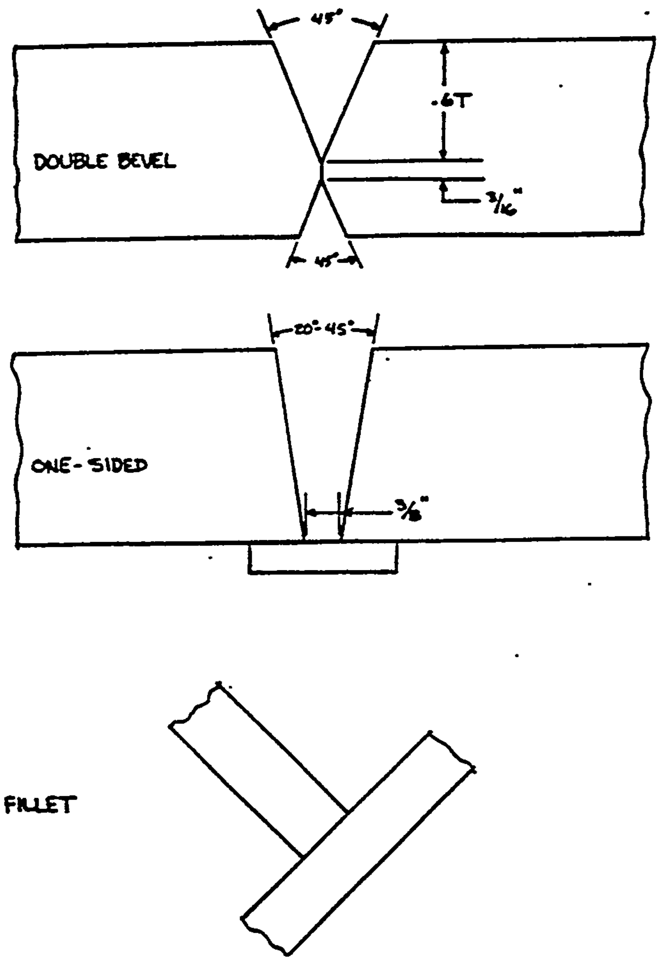


Figure 6
Joint Designs Used for Evaluation

The three metal powders used during the project were Oerlikon's EL-12, M-13K, and M-2. When powder was added to a weld joint, it was metered at a specific rate, i.e. a certain powder-to-wire ratio. Several different powder-to-wire ratios ranging from .50:1 to 1.5:1 were tried.[4] See Table 1 for a listing of chemical specifications for the base and filler metals used during this project.

For many of the joints, an actual deposition rate was found by weighing the weldment (in pounds) at various stages and recording the arc time (in minutes). Double-bevel joints were weighed just prior to welding (W_1) and after the first side was complete (W_2), after backgouging (W_3) and after completion (W_4). This method eliminates much of the inconsistency associated with backgouging. One-sided joints were weighed after fitup (W_1) and after completion (W_4). The deposition rates were calculated using these formulas:

Double-bevel:

$$\frac{(W_2 - W_1) + (W_4 - W_3)}{\text{arc time in mins}} \times 60 = \text{Dep Rate in lbs/hr}$$

Single-bevel:

$$\frac{(W_4 - W_1)}{\text{arc time in mins}} \times 60 = \text{Dep Rate in lbs/hr}$$

4 For a description of the method used to determine the correct dial settings for a given ratio, see the SP-7 final report.

TABLE 1

FILLER METAL/BASE MATERIAL CHEMICAL ANALYSES: CARBON STEEL/HTS

	C	Mn	Si	P	S	Cr	Ni	Mo	Cu
Oerlikon M13K Metal Powder (typical)	0.07 to 0.19	0.90 to 1.40	0.45 to 0.70	0.03 max	0.035 max				0.30 max
Oerlikon EL-12 Metal Powder (typical)	0.07 to 0.15	0.35 to 0.60	0.05 max	0.03 max	0.035 max				0.30 max
MIL-A1 of MIL-E-18193	0.07 to 0.14	0.35 to 0.55	0.03 max	0.03 max	0.035 max				0.30 max
Carbon Steel of MIL-S-22698	0.18 max	0.90 to 1.60	0.10 to 0.50	0.04 max	0.04 max	0.25 max	0.40 max	0.08 max	0.35 max
High Tensile Steel of MIL-S-24113	0.20 max	0.90 to 1.35	0.15 to 0.45	0.035 max	0.040 max	0.25 max	0.25 max	0.08 max	0.35 max

FILLER METAL/BASE MATERIAL CHEMICAL ANALYSES: HY-80

	C	Mn	Si	P	S	Cr	Ni	Mo	Cu
Oerlikon M2 Metal Powder (actual analysis)	0.08	1.53	0.40	.01	.01	0.25	1.75	0.40	0.20
MIL-100S-1 of MIL-E-23765	0.08 max	1.25 to 1.80	0.20 to 0.55	0.01 max	0.01 max	0.30 max	1.40 to 2.10	0.25 to 0.55	0.30 max
HY-80 of MIL-S-16216	0.12 to 0.18	0.10 to 0.40	0.15 to 0.35	0.025 max	0.025 max	1.00 to 1.80	2.00 to 3.25	0.20 to 0.60	0.25 max

Table 2 gives a list of joint variables and actual deposition rates, and was used in determining the optimum powder-to-wire ratio.

Nondestructive testing (NDT) included magnetic particle testing of backgouged surfaces and final weld faces and radiography (RT) of completed welds. In some cases ultrasonic testing (UT) of completed welds was performed for information. All NDT was performed as outlined in MIL-STD-271D in order to satisfy the procedure qualification requirements in MIL-STD-248C. The NDT results are reported in Table 3 along with the acceptance criteria for each test.

Mechanical testing included combinations of side bends, transverse tensiles, all weld metal tensiles, Charpy-V-notch impacts (both weld metal and across the HAZ), and dynamic tear impacts. Mechanical testing was done in accordance with MIL-STD-248C procedure qualification requirements. Test results from the side bends, transverse tensiles, and all weld metal tensiles are shown in Table 4. Results from the impact tests are reported in Table 5 and include test temperatures, individual values and averaged values. HY-80 joints M729-38, -40 and -41 were explosion tested as specified in MIL-STD-2149, with successful results. The qualitative distortion comparison revealed that the use of metal powder additions to SAW-AU caused distortion less than or equal to other conventionally welded SAW-AU joints.

DISCUSSION

The initial use of metal powder additions resulted in increased consumables costs, due to small-scale purchase of metal powder, as shown in Appendix A. Assuming that the cost of metal powder is reduced to nearly the same level as the electrode (based on large-scale purchases of metal powder), the cost of consumables is lower for metal powder additions than for conventional SAW-AU. This is due to the reduced amounts of wire and flux needed to complete the weld. Specifically, the consumables cost of a 2" thick double-bevel HY-80 joint could be $0.72 per foot less than conventional SAW-AU, and

TABLE 2

LIST OF JOINT VARIATIONS AND DEPOSITION RATES

JOINT NO.	BASE MATERIAL	HEAT INPUT (KJ/IN)	POWDER-TO-WIRE RATIO	JOINT DESIGN	ACTUAL DEPOSITION LBS/HR
M729-1	HTS	62.2	1.00:1	45° B1V.3	31
M729-2	HTS	48.0	.50:1	45° B1V.3	18
M729-3	HTS	67.2	1.00:1	45° B1V.3	60
M729-4	HTS	58.8	1.00:1	45° B1V.3	37
M729-5	HTS	48.0	No Powder	45° B1V.3	14
M729-9	HTS	61.2	1.00:1	45° B2V.3	21
M729-10	HTS	51.2	1.00:1	45° B2V.3	22
M729-11	HTS	51.2	.50:1	45° B1V.3	14
M729-12	HTS	61.7	.50:1	45° B1V.3	34
M729-13	HTS	64.0	.50:1	45° B1V.3	40
M729-16	HY-80	49.5	1.00:1	45° B2V.3	N/R
M729-17	HY-80	53.4	1.25:1	45° B2V.3	N/R
M729-18	HY-80	85.0	1.00:1	45° B2V.3	N/R
M729-19	HY-80	53.4	1.00:1	45° B2V.3	22
M729-20	HY-80	53.4	1.25:1	45° B2V.3	36
M729-21	HY-80	53.4	1.50:1	45° B2V.3	25
M729-24	HY-80	85.0	1.25:1	45° B2V.3	27
M729-26	HY-80	85.0	.75:1	45° B2V.3	21
M729-27	HY-80	53.4	1.25:1	45° B2V.3	N/R
M729-28	HY-100	53.4	1.25:1	45° B2V.3	N/R
M729-29	HY-80	53.4	1.25:1	45° B2V.3	N/R
M729-31	HY-80	106.4	.50:1	45° B2V.3	27
M729-32	HY-80	106.4	.75:1	45° B2V.3	31
M729-33	HY-80	106.4	1.00:1	45° B2V.3	29
M729-36	HY-80	106.4	.50:1	45° B2V.3	26
M729-37	HY-80	85.0	1.00:1	45° B2V.3	23
M729-38	HY-80	85.0	1.25:1	45° B2V.3	N/R
M729-40	HY-80	85.0	1.25:1	45° B2V.3	N/R
M729-41	HY-80	85.0	1.25:1	45° B2V.3	N/R
M729-45	HY-80	85.0	1.25:1	45° B2V.3	N/R
M729-47	HY-80	53.4	1.25:1	20° B1V.3	27
M729-48	HY-80	53.4	1.25:1	PT2S.2	N/R
M729-49	HY-80	51.0	1.25:1	PT2S.2	N/R
M729-51	HY-80	53.4	1.25:1	PT2S.2	N/R
M729-52	HY-80	85.0	1.25:1	PT2S.2	N/R
M729-53	HY-80	53.4	1.25:1	20° B1V.3	N/R
M729-54	HY-80	85.0	.75:1	20° B1V.3	N/R
M729-55	HY-80	106.4	.50:1	45° B2V.3	N/R
M729-56	HY-80	83.6-85.0	1.25:1	45° B2V.3	N/R
M729-64	CS	62.3	1.25.1	45° B2V.3	22
M729-66	CS	64.8	1.25:1	45° B2V.3	27
M729-67	CS	76.8-96.0	1.25:1	45° B2V.3	27
M729-68	CS	64.8	1.25:1	45° B2V.3	26
M729-69	CS	76.8	1.25:1	45° B2V.3	29
M729-70	CS	64.8	No Powder	45° B2V.3	18
M729-72	CS	76.8-96.0	No Powder	45° B2V.3	18
M729-73	HY-80	55.0	No Powder	45° B2V.3	23
M729-74	HY-80	85.0	No Powder	45° B2V.3	20

TABLE 3

NONDESTRUCTIVE TEST RESULTS

Definitions:

MT - Magnetic Particle Inspection, tested to MIL-STD-271, accepted to NAVSHIPS 0900-003-8000 Class 1

RT - Radiographic Inspection, tested to MIL-STD-271, accepted to NAVSHIPS 0900-003-9000 Class 1

UT - Ultrasonic Inspection, tested to MIL-STD-271, accepted to NAVSHIPS 0900-006-3010 Class 1

JOINT NO.	MT BACKGOUGED SURFACE	MT FINAL WELD SURFACES	RT COMPLETED WELD	UT COMPLETED WELD
M729-1	N/A	N/A	SAT	--
M729-2	N/A	N/A	SAT	--
M729-3	N/A	N/A	SAT	--
M729-4	N/A	N/A	SAT	--
M729-5	N/A	N/A	SAT	--
M729-6	N/A	N/A	SAT	--
M729-7	N/A	N/A	SAT	--
M729-8	N/A	N/A	SAT	--
M729-9	SAT	N/A	SAT	--
M729-10	SAT	N/A	SAT	--
M729-11	N/A	N/A	SAT	--
M729-12	N/A	N/A	SAT	--
M729-13	N/A	N/A	UNSAT-Slag	--
M729-16	SAT	SAT	SAT	--
M729-17	SAT	SAT	SAT	--
M729-18	SAT	SAT	UNSAT-Slag	--
M729-19	SAT	SAT	SAT	SAT
M729-20	SAT	SAT	SAT	UNSAT
M729-21	SAT	SAT	SAT	UNSAT
M729-22	SAT	SAT	SAT	--
M729-24	SAT	SAT	UNSAT-Slag	--
M729-26	SAT	SAT	SAT	--
M729-27	SAT	SAT	SAT	--
M729-28	SAT	SAT	SAT	--
M729-29	SAT	SAT	SAT	--
M729-31	SAT	SAT	SAT	--
M729-32	SAT	SAT	SAT	--
M729-33	SAT	SAT	SAT	--
M729-36	SAT	SAT	SAT	--
M729-37	SAT	SAT	SAT	SAT
M729-38	SAT	SAT	SAT	SAT
M729-40	SAT	SAT	SAT	SAT
M729-41	SAT	SAT	SAT	SAT
M729-47	N/A	SAT	SAT	SAT
M729-53	N/A	SAT	SAT	--
M729-54	N/A	SAT	SAT	--
M729-55	SAT	SAT	SAT	--
M729-56	SAT	SAT	UNSAT-Slag	UNSAT
M729-57	SAT	SAT	UNSAT-Slag	UNSAT
M729-59	SAT	SAT	SAT	--
M729-60	SAT	SAT	UNSAT-Slag	--
M729-61	SAT	N/A	--	--
M729-62	SAT	SAT	--	--
M729-64	SAT	SAT	SAT	UNSAT
M729-66	SAT	SAT	UNSAT-LOP	UNSAT-4" LOP
M729-67	SAT	SAT	SAT	--
M729-68	SAT	SAT	SAT	--
M729-69	SAT	SAT	SAT	--
M729-70	SAT	SAT	SAT	UNSAT-7" LOF
M729-72	SAT	SAT	UNSAT-8" LOF	--

TABLE 4

MECHANICAL TEST RESULTS

JOINT NO. M729-	SIDE BENDS[1,3] SAT/UNSAT	ALL-WELD METAL TENSILE: YIELD STRENGTH[2] KSI	ALL-WELD METAL TENSILE: TENSILE STRENGTH[2] KSI	ALL-WELD METAL TENSILE: % ELONG[2] PERCENT	ALL-WELD METAL TENSILE: % REDUCTION IN AREA[2] PERCENT	TRANSVERSE REDUCED SECTION TENSILE[2] KSI	BASE MAT'L
8	--	80.2	89.0	23.5	59.9	79.1	HTS
16	--	101.3	110.4	22.3	63.8	109.3	HY-80
17		99.5	110.6	22.0	64.1	109.7	HY-80
19	SAT	--	--	--	--	107.3	HY-80
20	SAT	--	--	--	--	107.7	HY-80
21	SAT	--	--	--	--	108.0	HY-80
22	UNSAT	92.2	105.0	22.8	66.8	102.7	HY-80
24	SAT	89.8	103.7	24.5	68.8	104.9	HY-80
26	SAT	91.0	105.7	21.5	57.5	103.9	HY-80
27	SAT	90.7	104.2	22.0	61.7	103.4	HY-80
28	SAT	92.6	102.9	23.0	67.6	111.3	HY-100
29	SAT	95.5	107.7	19.5	50.6	113.2	HY-80
31	UNSAT	94.8	116.0	18.5	48.2	108.3	HY-80
32	UNSAT	99.3	116.7	18.5	42.7	109.7	HY-80
33	UNSAT	88.5	113.3	19.5	51.9	110.9	HY-80
36	UNSAT	98.8	114.7	20.0	51.6	112.4	HY-80
37	SAT	97.2	113.7	24.3	58.5	113.9	HY-80
38	SAT	--	--	--	--	--	HY-80
40	SAT	88.8	106.1	22.3	64.0	--	HY-80
53	SAT	101.6	113.2	20.5	65.0	110.1	HY-80
54	SAT	87.7	103.8	24.0	66.9	107.6	HY-80
60	SAT	91.7	106.6	20.5	55.4	--	HY-80
64	SAT	--	--	--	--	71.7	CS
66	SAT	75.9	85.9	25.0	63.2	78.3	CS
67	SAT	71.3	82.9	26.5	63.3	69.2	CS
68	SAT	76.9	85.7	24.5	61.6	67.8	CS
69	SAT	73.0	83.0	25.0	63.9	68.1	CS
70	SAT	78.0	86.6	24.3	65.5	69.9	CS
72	--	71.9	83.3	24.0	57.6	71.1	CS

Requirements:

		Yield Strength	Tensile Strength	% Elong	% Reduction in Area	Transverse Reduced Section Tensile
CS/HTS	Weld Metal [3]	N/R	N/R	N/R	N/R	N/R
	Base Metal [3]	34 min	N/R	21	N/R	58-71
HY-80	Weld Metal [3]	82 min	N/R	16	N/R	N/R
	Base Metal [3]	80-99.5	N/R	20	N/R	99.5 min

NOTES:

[1] All side bends used a 1-1/2" mandrel, three specimens.

[2] Average of two specimens.

[3] No open fissures or cracks greater than 1/8".

TABLE 5

IMPACT TEST RESULTS

JOINT NO.	CVN TEST TEMP.	CVN IMPACT ENERGY	AVG. CVN ENERGY [1]	CVN LOCATION	DT TEST TEMP.	DT ENERGY	BASE MAT'L.
M729-	°F	FT-LBS	FT-LBS		°F	FT-LBS	
8	-20	15.8,24.1,13.8	17.9	WM			HTS
	0	17.7,37.8,14.0	23.2	WM			
	20	32.3,36.8,27.8	32.3	WM			
	40	33.7,65.6,29.7	43.0	WM			
	60	62.3,59.0,31.6	51.0	WM			
16	-60	57.8,59.0,48.2,45.2,59.7	55.0	WM			HY-80
	0	88.7,76.4,80.3,82.2,86.6	83.0	WM			
17	-60	56.7,66.2,72.0,64.5,72.1	67.6	WM			HY-80
	0	83.0,81.6,90.6,81.5,87.7	84.1	WM			
19	-60	52.7,82.0,49.1,66.9,58.5	59.4	WM			HY-80
20	-60	61.7,75.6,73.5,49.1,78.9	70.3	WM			HY-80
21	-60	73.9,61.4,40.4,47.6,50.9	53.3	WM			HY-80
22	-60	57.2,58.0,58.4,56.8,73.2	57.8	WM			HY-80
24	-60	96.9,91.5,87.8,47.4,56.2	78.5	WM			HY-80
26	-60	51.4,61.5,59.3,52.9,48.7	54.5	WM			HY-80
27	-60	61.2,74.0,67.2,64.9,71.9	68.0	WM			HY-80
	0	95.1,77.8,81.5,93.3,96.0	90.0	WM			
	20	87.5,93.7,89.7,104.8,88.3	90.6	WM			
28	-60	71.9,68.7,74.8,68.9,60.0	69.8	WM			HY-100
29	-60	70.0,62.3,79.1,56.6,65.0	65.8	WM			HY-80
	-40	71.5,76.5,58.3,80.1,69.8	72.6	WM			
	-20	85.7,68.2,89.4,71.1,90.8	82.1	WM			
	0	72.2,90.9,80.2,88.6,74.9	81.2	WM			
	20	93.8,88.5,95.9,84.8,94.5	92.3	WM			
31	-60	49.1,35.4,29.5,53.9,33.6	39.4	WM			HY-80
	0	68.5,66.4,69.6,57.4,86.3	68.2	WM			
32	-60	45.1,23.6,53.3,39.3,50.7	45.0	WM			HY-80
	0	56.7,66.6,54.5,76.7,66.8	63.4	WM			
33	-60	20.5,18.2,45.8,45.4,39.8	35.2	WM			
36	-60	51.1,46.9,42.1,61.6,64.9	53.2	WM			HY-80
	0	73.0,72.9,69.8,90.3,88.7	78.2	WM			
37	-60	29.1,54.3,32.0,37.2,25.3	32.8	WM	-20	272.4,420.0	HY-80
	0	70.9,68.4,69.8,63.6,60.7	67.3	WM	30	661.0,730.3	
	-60	33.9,30.4,36.7,24.5,40.9	33.7	WM			
	0	66.1,71.0,69.9,58.0,70.0	68.7	WM			
40	-60	49.5,28.5,46.2,35.6,46.8	42.5	WM	-20	272.8,301.9	HY-80
	0	49.0,66.6,48.6,76.9,52.4	56.0	WM	30	723.7,508.4	
	-60	46.5,48.4,45.2,53.5,42.9	46.7	FL			
	-60	64.3,43.8,49.1,46.7,49.2	48.3	+1 mm			
	-60	36.0,38.9,49.1,34.4,41.0	38.6	+3 mm			
	-60	40.4,35.3,42.2,38.2,40.2	39.6	+5 mm			
45	-60	47.7,45.3,50.8,57.8,40.1	47.9	Top WM			HY-80

TABLE 5 (continued)

JOINT NO. H729-	CVN TEST TEMP °F	CVN IMPACT ENERGY FT-LBS	AVG. CVN ENERGY [1] FT-LBS	CVN LOCATION	DT TEST TEMP. °F	DT ENERGY FT-LBS	BASE MAT'L.
45	-60	47.7,45.3,50.8,57.8,40.1	47.9	Top WM			HY-80
	0	68.3,85.9,89.1,91.4,69.6	81.5	Top WM			
	-60	40.3,35.8,40.0,39.3,30.9	38.4	Bot WM			
	0	60.2,69.6,60.5,65.5,58.9	62.1	Bot WM			
53	-60	33.5,79.8,135.4,67.6,126.6	91.3	WM			HY-80
	0	97.1,135.6,93:7,133.4,97.1	109.2	WM			
54	-60	49.5,54.9,44.9,54.1,41.4	49.5	WM			HY-80
	0	82.0,60.2,79.3,62.9,79.1	73.8	WM			
59	-60	39.7,48.9,35.6,36.8,39.4	38.6	WM	-20	429.0,312.9	HY-80
	0	82.8,53.7,76.7,58.9,64.1	66.6	WM	30	714.2,599.1	
60	-60	69.3,46.2,76.5,50.1,71.2	63.5	WM			HY-80
	0	64.5,85.0,69.8,93.8,66.1	73.6	WM			
64	30	22.7,30.9,37.7,31.1,29.2"	30.4	WM			Cs
	0	16.7,11.7,15.7,22.2812.6	15.0	WM			
66	30	62.1,64.6,55.8,54.3,49.1	57.4	WM			Cs
	- 0	53.5,26.9,46.5,17.9,37.3	36.9	WM			
67	30	50.2,39.4,38.6,34.8,37.2	3a.5	WM			Cs
	0	25.9,40.8,23.8,37.9,57.6	34.9	WM			
68	30	30.0,69.6,36.2,23.1,31.7	32.6	WM			Cs
	0	15.7,15.6,18.8,20.5,41.5	18.3	WM			
	-20	12.9,13.2,23.0,16.1,17.1	15.5	WM			
69	30	47.3,58.2,42.7,47.2,49.3	48.0	WM			Cs
	9	46.5,33.3,18.4,22.9,30.1	28.8	WM			
	-20	23.2,12.6,11.3,12.8,17.9	14.4	WM			
70	30	55.2,45.9,56.4,33.8,38.8	46.6	WM			Cs
	0	24.8,18.4,30.7,34.2,18.0	24.6	WM			
72	30	34.0,66.2,32.7,34.7,45.7	38.1	WN			Cs
	0	17.0,32.1,20.5,38.6,41.4	30.4	WM			

Requirements:

CS / HTS	-20°		For information Only			
HY-80	-60°		35	WM	-20°	300[2]
	0°		60	WM	30°	450[3]

NOTE:

[1] Average CVN values are determined from five specimens by disregarding the high and low values and averaging the three middle values.

[2] One specimen may be 50 ft lbs low.

[3] One specimen may be 25 ft lbs low.

the consumables cost for a 2″ thick one-sided HY-80 joint could be $1.31 per foot less than welding without metal powder. Storage. and handling of the metal powder required no special controls for either temperature or humidity. Between shifts, the metal powder remained in the powder hopper, and when not in use, it was kept in a closed plastic bag.

For. purposes of clarity, the remainder of this discussion will be divided into three sections: (1) Carbon Steel/HTS Welds, (2) HY-80 Welds, and (3) Metal powder Dispensing and related problems.

1. Carbon Steel/HTS Welds

During this part of the project, 16 joints were welded using either a 45 one-sided or 45 double-bevel joint. Heat inputs ranged from 48-96 KJ/in to cover the 400-800 amp range associated with the 5/32″ diameter electrode. Powder-to-wire ratios ranging from .50:1 to 1:1 were used with M-13K metal powder during the initial work (M729-1 through -13). It was later determined that a 1.25:1 powder-to-wire ratio provided the optimum combination of deposition rate, mechanical properties, and minimum loss of unfused metal powder (based on HY-80 work). The remainder of the carbon steel/HTS joints (14729-64 through -72) used either a 1.25:1 powder-to-wire ratio or no powder for comparison.

The initial carbon steel/HTS joints were destructively tested and the results reviewed while the HY-80 part of the project was king welded. Joint M729-8 had higher strength levels than expected (see Table 4), and further investigation revealed that the low-manganese 5L-12 powder would be better suited to the low-manganese MIL-Al electrode than the high-manganese M-13K metal powder. Joints M729-68 and -69 used EL-12 powder, and these joints had strength levels more closely matched to the base material requirements.

Figures 7 and 8 show macrophotographs comparing joints M729-68 (600 amps with 1.25:1 EL-12) and M729-70 (600 amps with no powder). Using metal powder additions at 600 amps, the number of beads needed to complete the 2″ thick joint was reduced from 31 to 22, and the deposition rate was increased from 18 lbs/hr to 26 lbs/hr; a 44%increase. Figures 9 and 10 show macrophotographs comparing joints M729-69 (800 amps with 1.25:1 EL-12) and M729-72 (800 amps with no powder). Using metal powder additions at 800 amps, the number of beads needed to complete the 2″ thick joint was reduced from 22 to 18, and the deposition rate was increased from 18 to 29 lbs/hr; a 61% increase.

Both joints M729-68 and -69 could be used to satisfy the procedure qualification requirements of MIL-sTD-248C. Nondestructive and destructive testing was perfomed as outlined in MIL-STD-248C with acceptable results. Both joints together will qualify EL-12 metal powder aditions of 1.25:1 or less for the entire range of 400-900 amps on carbon steel/HTS welds from 3/16″ to 4″ thick. This process can be used on double-bevel, one sided, and fillet joint designs in the flat position.

2. HY-80 Welds

During this part of the project, 31 joints were welded using three different joint designs: 45 double bevel joints, 20 one-sided joints and flat fillets. Initially, heat input levels of 55, 85, and 110KJ/in were used to determine the optimum powder-to-wire ratio and heat input for double-bevel joints. Joints M729-16, -17, -19, -20, and -21 were at 55 KJ/in using powder-to-wire ratios ranging from 1:1 to 1.5:1. Table 5 shows that the impact strength was highest at 1.25:1. Also, the amount of unfused metal powder (seen along the edges of the solidified slag) was nearly the same as 1:1 but considerably less than the amount left atl.5:1. Therefore, the 1.25.1 powder-to-wire ratio was chosen as optimum for 55 KJ/in heat input. Joints M729-18, -24 and -26 were welded at 85 KJ/in using powder-to-wire ratios ranging from .75:1 to 1.25:1. Again the 1.25:1 ratio provided the highest impact strength and an acceptable amount of unfused metal powder. Joints M729-31,-32, -33 and -36 were welded at approximately 110 KJ/in using powder-to-wire ratios ranging from .50:1 to 1:1. Table 4 shows that all of these joints failed side bend testing. Based on that information, the 110 KJ/in welding was not pursued any further.

Since the mechanical and impact results for 55 anti 85 KJ/in both met the requirements, and the 85 KG/in heat input gave higher

Figure 7
Microphotograph of M729-68
(600 amps with 1.25:1 Metal Powder Additions)

Figure 8
Microphotograph of M729-70
(600 amps with No Metal Powder Additions)

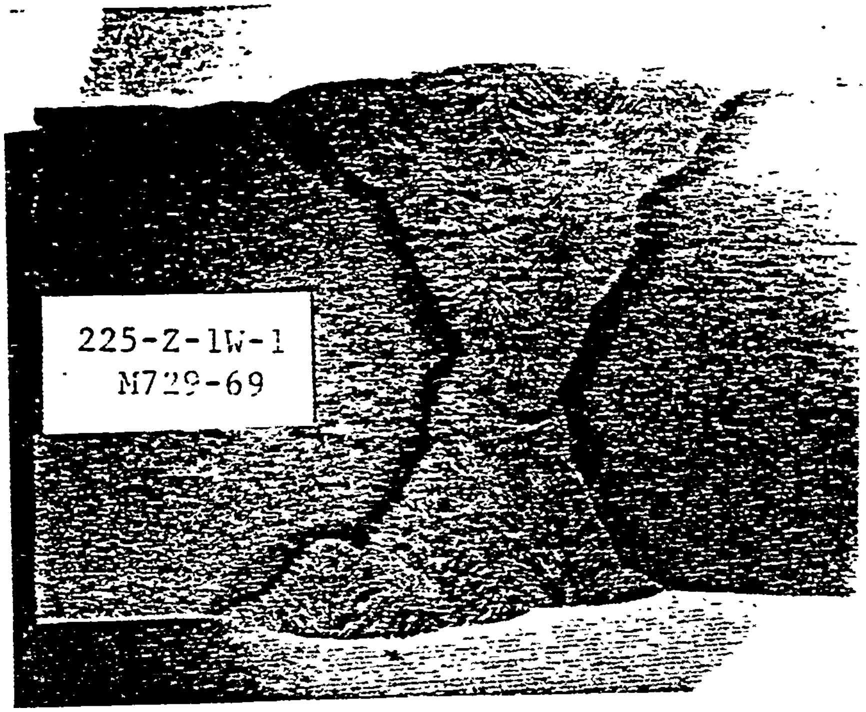


Figure 9
Microphotograph of M729-69
(800 amps with 1.25:1 Metal Powder Additions)

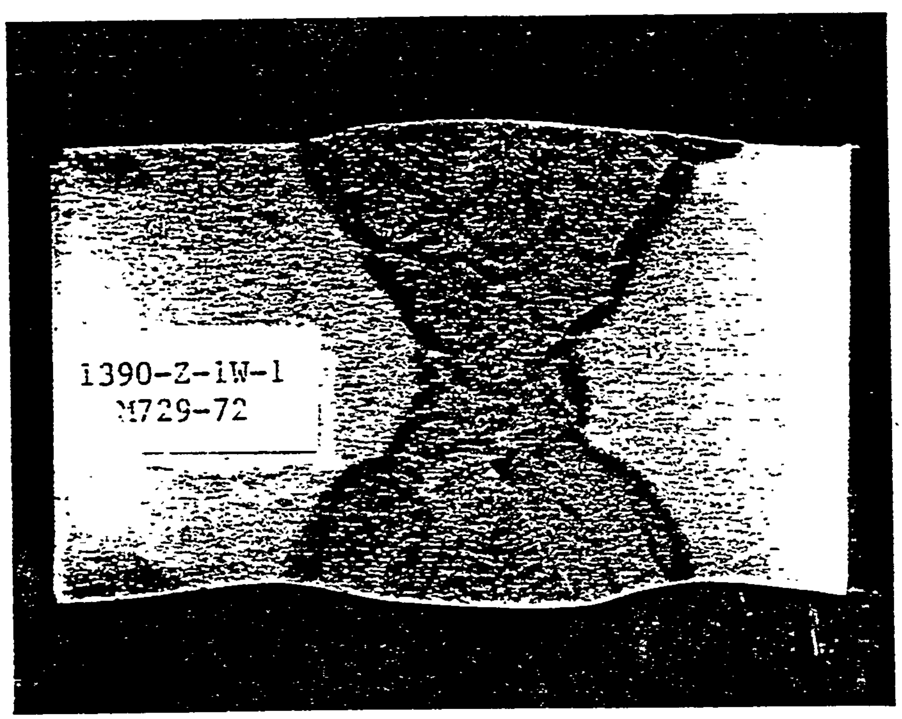


Figure 10
Microphotograph of M729-72
(800 amps with No Metal Powder Additions)

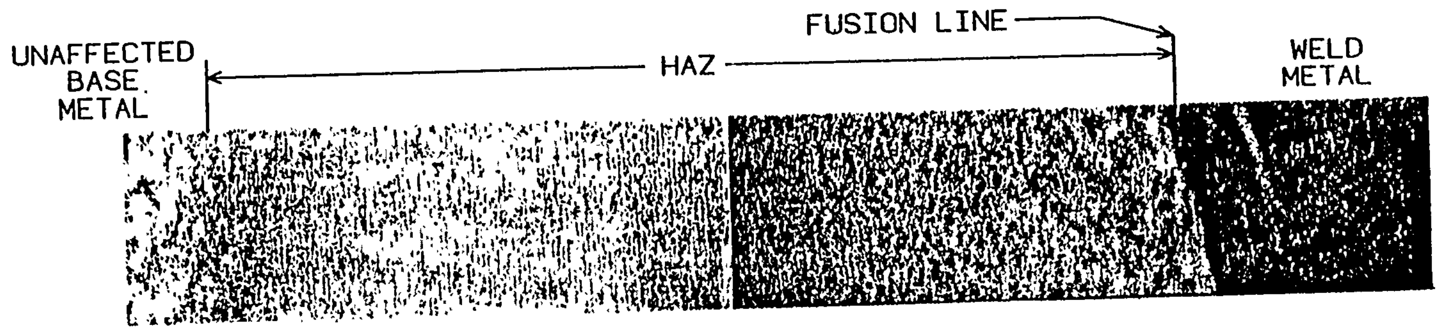
deposition rates, the Optimum combination for 45 double-bevel joints was selected to be 85 KJ/in using a 1.25:1 powder-to-wire ratio. Figure 11 shows microphotographs of a conventional SAW-AU weld at 85 KJ/in and a SAW-AU with powder additions weld at 85 KJ/in. Notice that the weld with powder additions had a narrower HAZ and finer grain structure near the fusion line, as expected. Using 1.25:1 metal powder additions at 85 KJ/in, the number of beads necessary to complete the 2" thick joint was reduced from 39 to 20, and the deposition rate was increased from 20 to 27 lbs/hr; a 35% increase (compare H729-24 and -74) Using 1.25:1 metal powder additions at 55 KJ/in, the number of beads necessary to complete the 2" thick joint was reduced from 31 to 14, and the deposition rate. was increased from 23 to 36 lbs/hr; a 36% increase (compare joints M729 -2o and -73).

During the welding of the early HY-80 joints, two specific problems were encountered. First, the solidified flux was nearly impossible to remove from the root pass when metal powder was used in the root. Second, the use of metal powder for the reinforcement passes caused the height of the crown to exceed the specification limits, and grinding was required to reduce the crown to an acceptable level. Figure 12 shows a comparison of average weld metal CVN values for joints reinforced with and without powder. Discontinuing the metal powder for the reinforcement reduced the impact values. After experimentation, it was found that using lower heat input without powder for root passes would allow easy slag removal, and discontinuing the powder for the reinforcement would eliminate the unnecessary grinding. Although both of these steps will reduce the total deposition rate slightly, and not using powder for reinforcement will slightly reduce impact strength, the reduction is more than offset by reduced labor costs for the additional grinding/chipping, particularly on long joints associated with SAW-AU. These two steps then became part of the standard weld procedure.

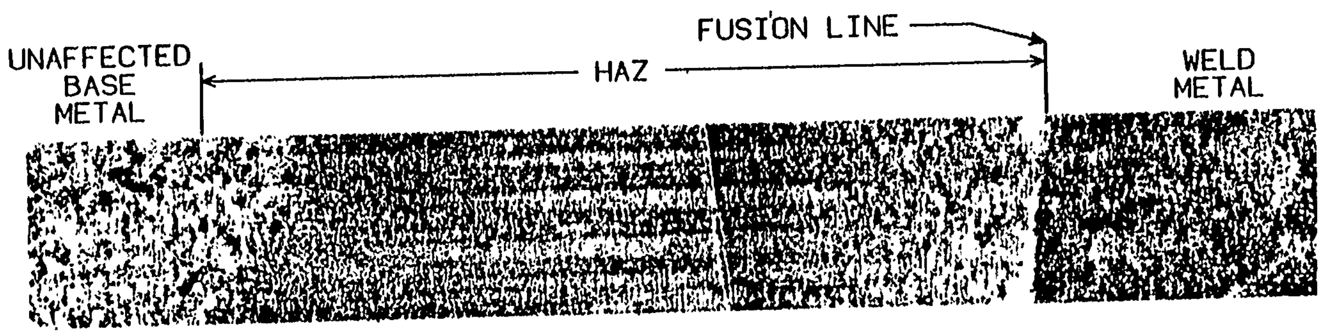
At this point, joints M729-38, -40, and -41 were fabricated using 85 KJ/in and 1.25:1 powder-to-wire to provide six 30" x 30" test specimens for explosion testing. H729-40 also had a prolongation that was destructively tested prior to shipping the plates for explosion testing. All mechanical properties of the prolongation except for CVN impact strength at 0°7 met the MIL-STD-248C requirements. (See Tables 4 and 5). The Charpy V-notch tests conducted at 0°F and one dynamic tear (DT) test at -20 F were below specification although one low DT is allowed for MIL-STD-248C qualification. Discussion with NAVSEA suggested that the explosion tests be conducted since only one DT was low, and since all Of the weld metal/HAZ CVN'S at -60 were satisfactory. The explosion testing was conducted by Mare Island Naval Shipyard at the Army Ammunition Plant in Hawthorne, Nevada. This testing consisted of two parts: (1) Explosion Crackstarter testing and (2) Explosion Bulge testing, which together provide a harsh test of the entire weld zone. The crackstarter tests use artificially created "notch" in both the transverse anti longitudinal directions that are explosively loaded twice to see if the weld deposit is capable of keeping the crack from propagating either through the slate thickness, or into the hold-down area. See Figure 13 for a photo of a tested explosion crack starter assembly. (Notice the two hardsurfacing beads deposited on the SAW-AU reinforcement which are used for causing the "notch"). The bulge test uses explosive loading through successive shots to try and achieve 16% minimum reduction in thickness without allowing crack propagation either through the plate thickness, or into the hold-down area. See Figures 14 and 15 for photos of a tested explosion bulge assembly.

After the explosion testing was successfully completed, work centered around the two other joint designs that could be encountered. The first was a fillet. Joints M729-48 and -49 were used to establish parameters for an 85 KZ/in flat fillet. Joint M729-50 was tried in the horizontal position and proves that since the metal powder falls on the bottom place, SAW-AU with metal powder addiitions cannot be used for an equal-legged horizontal fillet. Joint M729-51 was welded with 1.25:1 powder-to-wire at 55 KJ/in in the flat fillet position and is shown in Figure 16. Joint M4729-52 was welded with 1.25:1 powder-to-wire at 85 KJ/in in the flat fillet position anti is shown in Figure 17.

Joints M14729-42, -43, and -46 were used to establish root pass



85 KJ/IN WITHOUT METAL POWDER



85 KJ/IN WITH METAL POWDER

FIGURE 11
MICROPHOTOGRAPHS ACROSS HY-80 HEAT AFFECTED ZONES;
METAL POWDER ADDITIONS VS. NO METAL POWDER ADDITIONS
(EQUAL MAGNIFICATION, APPROX. 50X)

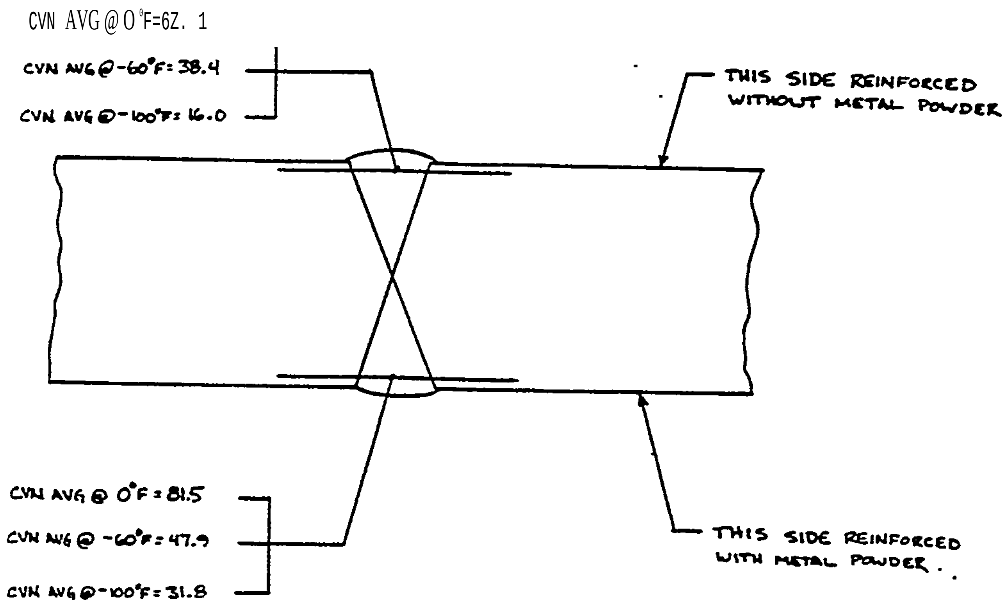


Figure 12
Average Weld Metal CVN's (in ft lbs) for HY-80;
Metal Powder Reinforcement vs. No Metal Powder Reinforcement

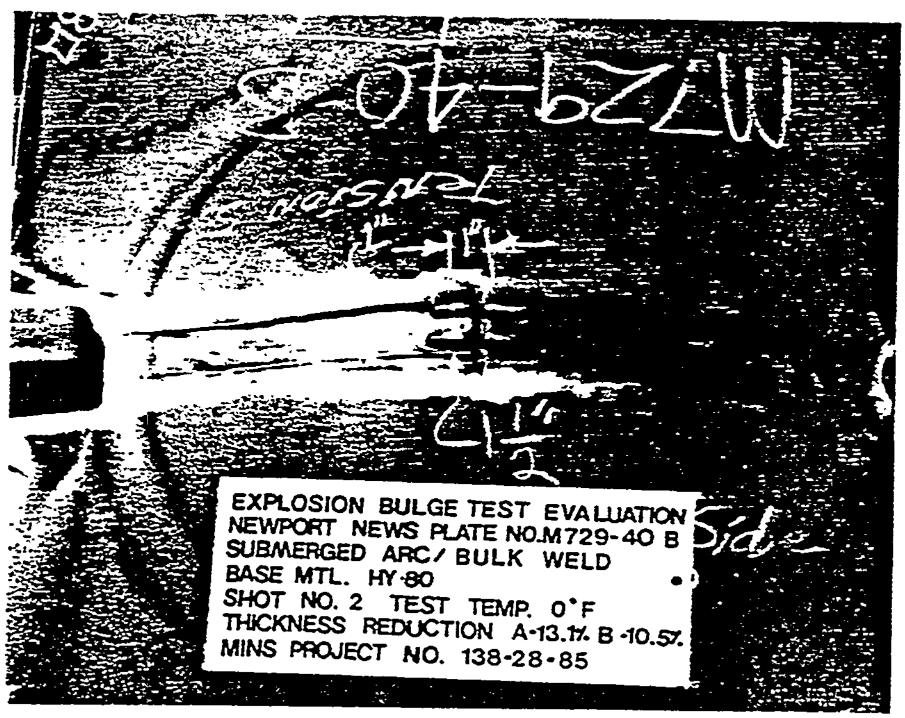


Figure 13
Completely Tested Transverse Crackstarter Assembly

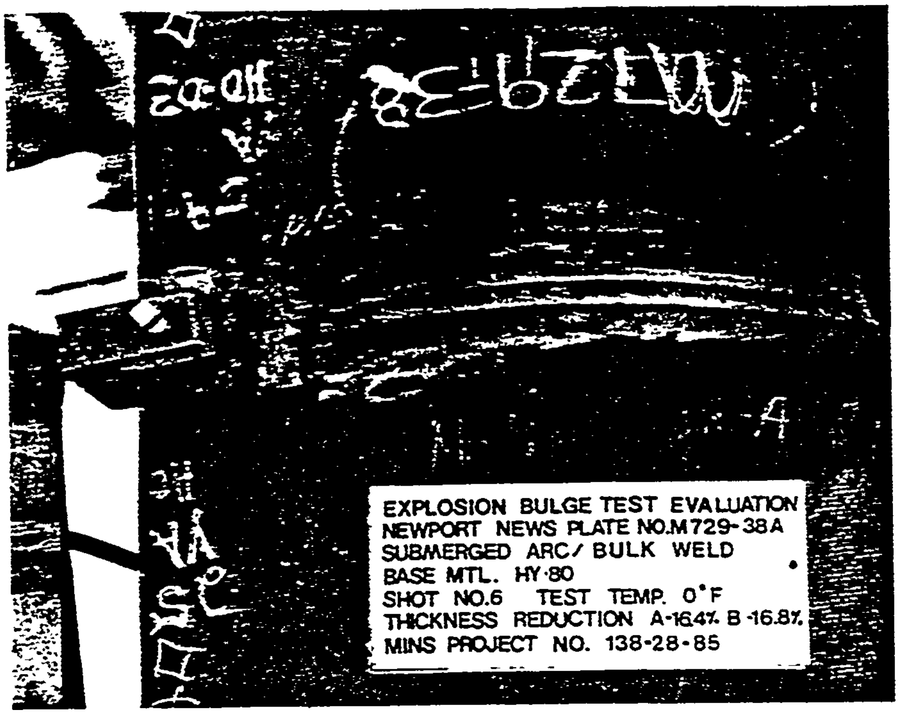


Figure 14
Completely Tested Explosion Bulge Assembly - Front View

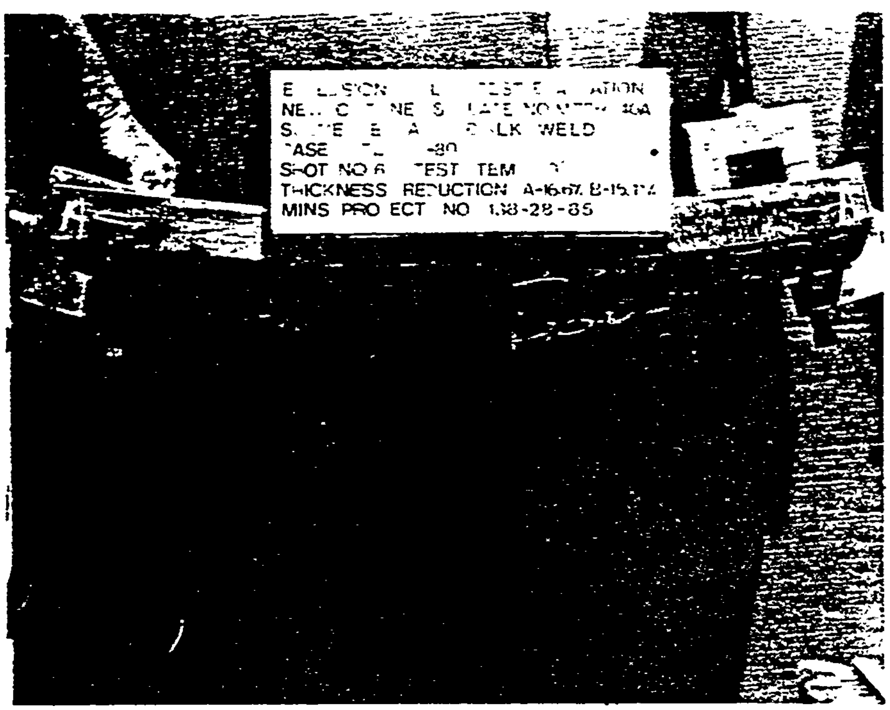


Figure 15
Completely Tested Explosion Bulge Assembly - Side View

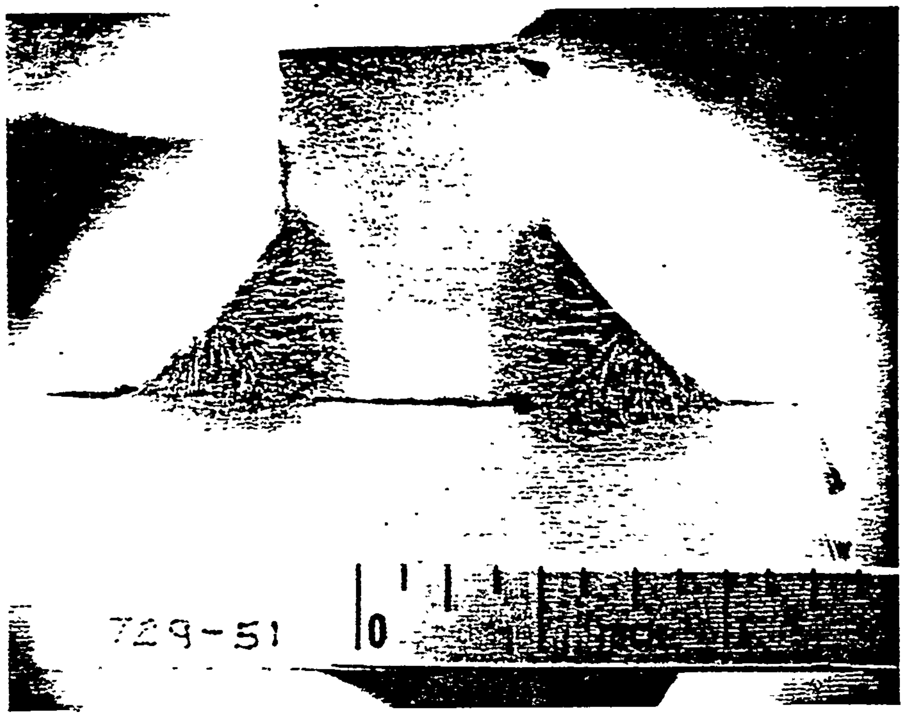


Figure 16
Microphotograph of M729-51

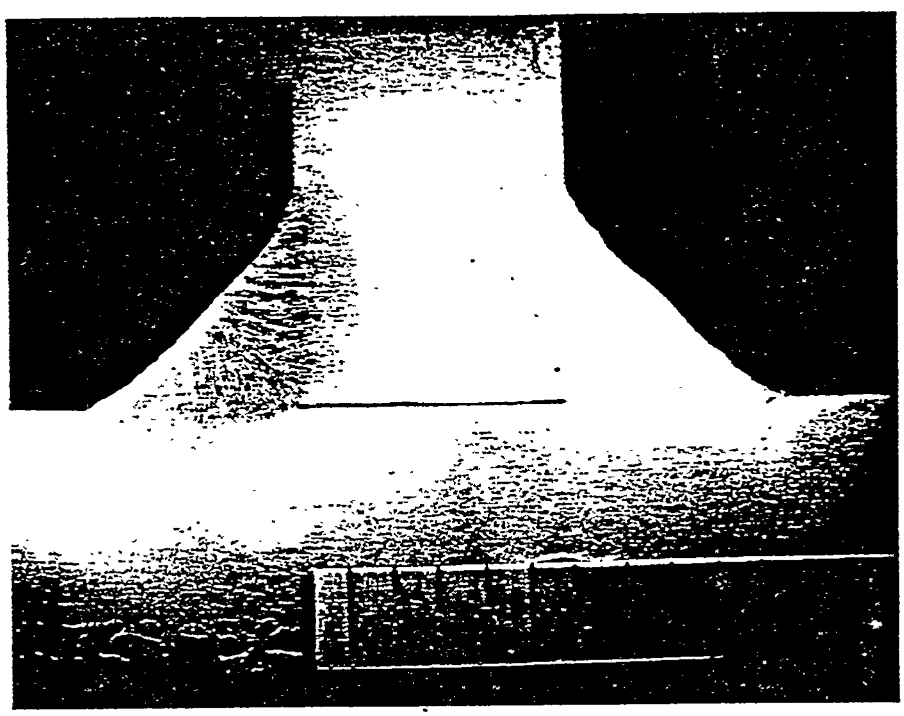


Figure 17
Microphotograph of M729-52

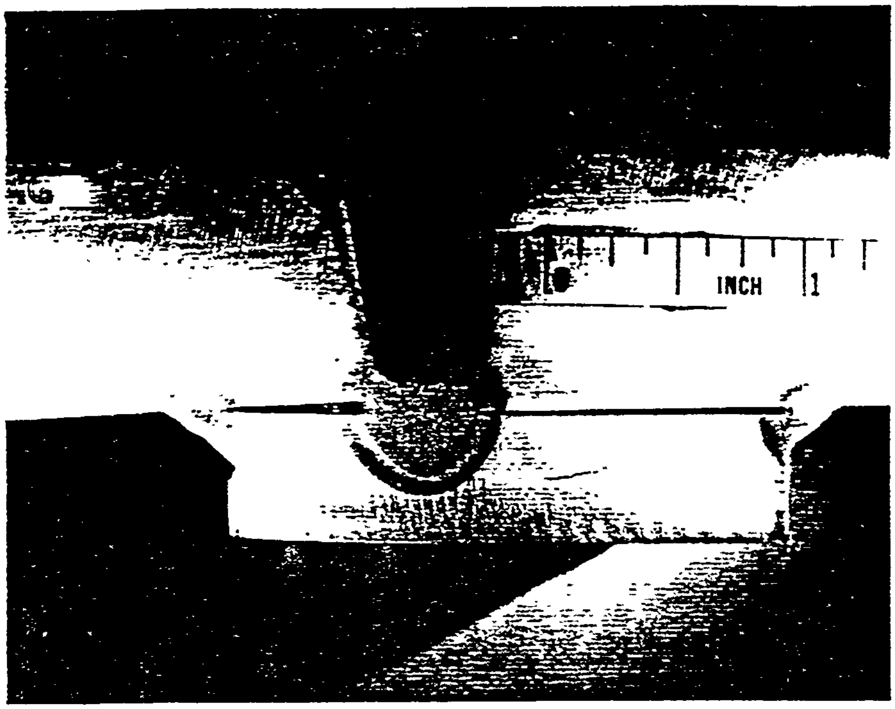


Figure 18
Microphotograph of M729-46 Root Pass

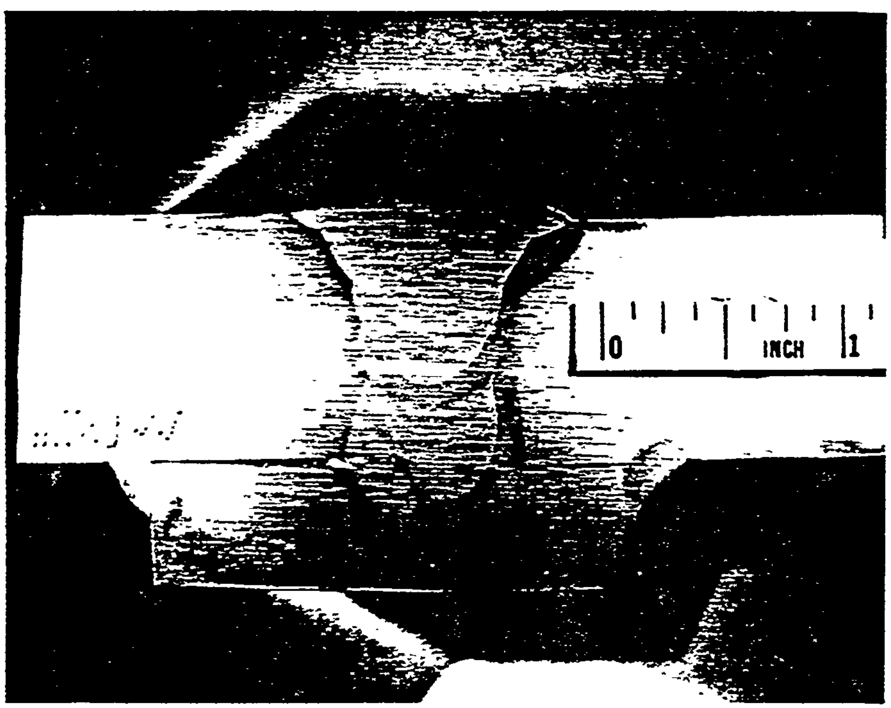


Figure 19
Microphotograph of M729-47

parameters (without metal powder) for 20 one-sided, backing strap joints. Acceptable parameters for the root (425 A, 34 V, 15 1PM) were used to produce the weld pass shown in Figure 18. M729-53 was welded with 1.25:1 powder-to-wire at 55 KJ/in and is shown in Figure 19. 14729-54 was successfully welded using .75:l powder-to-wire at 85 KJ/in.

As outlined in MIL-STD 248C. joint M729-40 will qualify the use of SAW-AU with M-2 metal powder additions (ratios 1.25:1 and lower) up to 85 KJ/in to join HY-80 from 3/16″ to 4″ thick. Transverse tensiles of that joint were not tested; however, based on the remainder of the data and successful explosion testing of the same joint, it is considered complete data.

3. Metal Powder Additions and Related. Problems

During the course of this project, there were no mechanical difficulties with the metal powder dispensing system. It was easily adapted to either the portable track-mounted SAW-AU carriage or the permanent side-beam SAW-AU carriage. The only major obstacle was determining the correct dial setting for a particular powder-to-wire ratio. The method used in this project was acceptable, however, it was found that changing or adjusting the dial potentiometer required recalculating the graphs and tables. The need for graphs, tables, and calculations to determine the correct dial setting for a particular powder-to-wire ratio/ powder type causes several concerns:

a. Each powder dispensing meter would require calibration and/or a separate set of graphs and tables.

b. The welder would have to determine the dial setting - this is difficult to do without a calculator. During this project, the technician was suplied with the correct dial setting in his instructions from the engineer.

c. Without a limiter on the maximum dial setting, it is possible that the welder could deposit excessive amounts of metal powder and drastically increase chances of discontinuities such as lack of fusion (LOF) or trapped slag.

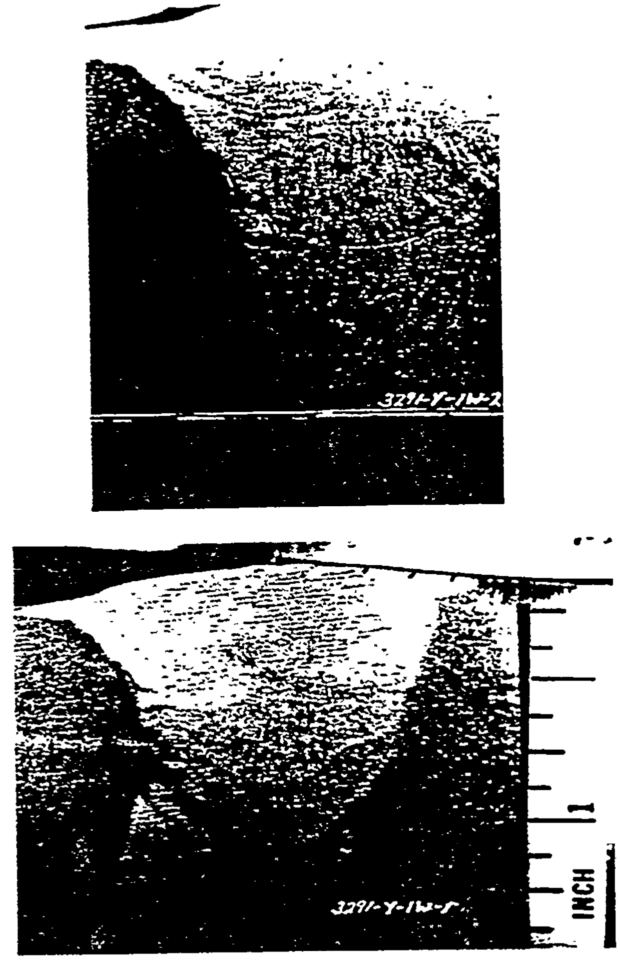


Figure 20
Mecrophotographs of Trapped
Slag Discontinuity

The use of metal powder, which increases the size of the weld deposit and tends to cool the puddle, can multiply the frequency of trapped slag or LOF. Figure 20 is a graphic example of the most often occurring discontinuity associated with both conventional SAW-AU, and SAW-AU with metal powder additions. The two major causes for this most common discontinuity are improper bead placement and/or excessive travel speed. During the course of the project, it was discovered that slower travel speeds helped assure complete consumption of the metal powder into the weld puddle, thus reducing the tendency to trap slag/powder. While admittedly being a problem for both techniqes (SAW-AU and SAW-AU with metal powder additions) the Prob-lem is-not so large as to defeat the practicality of the process. To test this, a new technician who had never before welded SAW-AU was started on joint M729-61. The next. three joints provided enough practice for him to become proficient with bead placement such that with the exception of a 4" discontinuity near the run-on tab, joints M729-64 through,-70 were all RT acceptable.

CONCLUSIONS

1. The use of controlled metal powder additions to SAW-AU will increase deposition rates, up to 60%, over conventional SAW-AU. The reduced number of larger beads will help reduce distortion. 45 minimum double-bevel, 20 minimum one-sided, and flat fillet joint designs can be used.

2. The use of SAW-AU with metal powder additions at higher heat inputs (up to 85 KJ/in on HY-80) will provide acceptable mechanical properties, and will reduce the width of the heat afected zone, as well as producing a finer HAZ grain size.

3. Procedure qualification of metal powder additions to SAW-AU for carbon steel materials (as outlined in MIL-sTD-248C) is possible using the data presented in this report. Oerlikon's EL-12 powder should be used with the MIL-A1 electrode.

4. Procedure qualification of metal powder additions to SAW-AU for HY-80 materials (as outlined in MIL-STD-248) is possible using the data presented in this report. Oerlikon's M-2 powder should be used with the MIL-lOOS-l electrode.

RECOMMENDATIONS

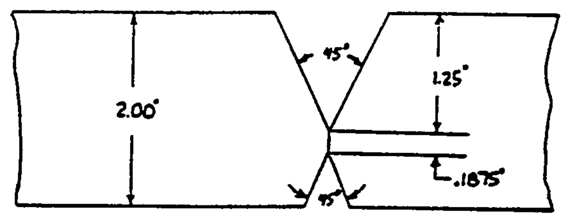
1. Purther work at the 110 KJ/in heat input level on HY-80 should be pursued. The RT quality was acceptable, and an increase in deposition rate was realized; however, the side bend failures were reason enough to stop work at that level due to time limitations.

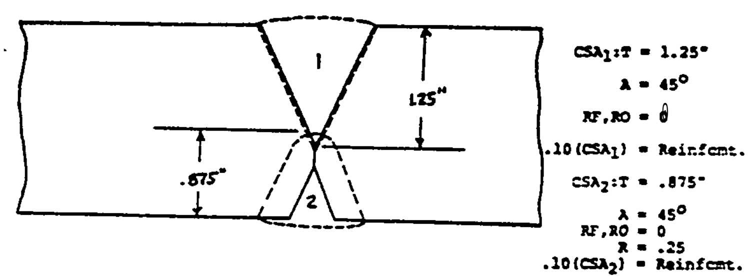
2. Some way of controlling the powder-to-wire ratio without the use of graphs and tables should be explored. Perhaps a microprocessor control that senses wire feed speed could be utilized. Then the operator would simply enter the desired powder-to-wire ratio and the microprocessor would determine (and possibly even set) the correct dial setting.

APPENDIX A
JOINT VOLUME CALCULATIONS AND CONSUMABLES COST ESTIMATES FOR HY-80

Objective:

The objective of this appendix is to establish joint volumes and consumables costs for two different joint designs using conventional SAW-AU, and compare those costs to the costs of consumables for the same two joint designs welded using SAW-AU with metal powder additions. Projections of consumables costs based on large scale purchases of metal powder are also presented.





To determine cross sectional area ($CSA_{B2V.3}$)

$$CSA_{B2V.3} = CSA_1 + CSA_2 + .10(CSA_1) + .10(CSA_2)$$

$$= \left[(T-RF)^2 \tan \frac{A}{2} + RO \times T\right] + \left[(T-R-RF)^2 \tan \frac{A}{2} + 2R(T-R-RF) + \frac{1}{2}\pi R^2 + RO \times T\right] + .10(CSA_1) + .10(CSA_2)$$ (from Cary, "Modern Welding Technology")

$$= \left[(1.25)^2 \tan 22.5^\circ + 0\right] + \left[(.875-.25)^2 \tan 22.5^\circ + .5(.875-.25) + \frac{1}{2}\pi(.25)^2 + 0\right] + .10(CSA_1) + .10(CSA_2)$$

$$= .65in^2 + .57in^2 + .065in^2 + .057in^2$$

$$= 1.34\ in^2$$

To determine weight of weld metal per linear foot - B2V.3

1.34 in^2 x .283 lbs/in^3 x 12 in. = 4.55 Ibs per foot

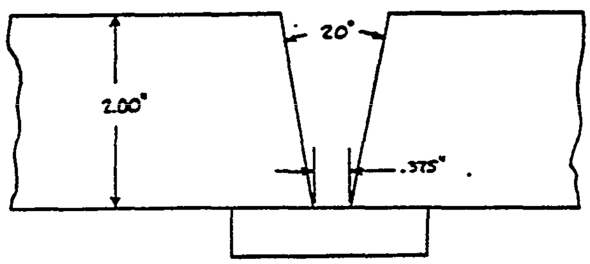
Cost of 1/8″ MIL-1OOS-1 Electrode	=	$1.08 per pound
Cost of MIL-1OOS-1F Flux	=	.32 per pound
Cost of M-2 Metal Powder	=	$2.00 per pound

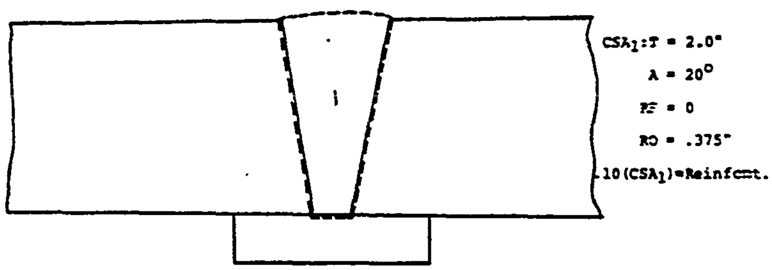
Current consumables cost of welding one foot with 1/8″ filler wire and no powder for B2V.3:

4.55 lbs of MIL-100S-1 = $4.91
4.55 lbs of MIL-100S-1F = 1.46

Current consumables cost of welding one foot with 1/8″ filler wire and M-2 metal powder @ 1:1 for B2V.3:

2.28 lbs of MIL-100S-l	= S2.46
2.28 lbs of MIL-100S-lF	= .73
2.28 1bs of M-2	= 4.56
	$7.75





To determine cross sectional area ($CSA_{B1V.3}$)

$CSA_{B1V.3} = CSA_1 + .10(CSA_1)$

$= \left[(T-RF)^2 \tan \frac{A}{2} + RO \times T\right] + .10(CSA_1)$ (from Cary, "Modern Welding Technology")

$= \left[(2-0)^2 \tan 10^\circ + .375 \times 2\right] + .10(CSA_1)$

$= 2.16 \text{ in}^2 + .22 \text{ in}^2$

$= 2.38 \text{ in}^2$

To determine weight of weld metal per linear foot - BlV.3:

$2.32 \text{ in}^2 \times .283 \text{ lbs/in}^3 \times 12 \text{ in} = 8.10$ lbs per foot

Cost of 1/8″ ;4IL-100S-1 Electrode	= S1.08 per pound
Cost of MIL-100S-1F Flux	= S0.32 per pound
Cost of M-2 powder	= S2.00 per pound

Current consumables cost of welding one foot with 1/8″ filler wire and no powder for BlV.3:

8.10 lbs of MIL-100S-1	= $ 8.75
8.10 lbs of MIL-100S-1F	= 2.60
	$11.35

Current consumables cost of welding one foot with 1/8″ filler wire and M-2 metal powder @ 1:1 for BlV.3:

4.05 lbs of MIL-100S-1	= $ 4.37
4.05 lbs of MIL-100S-1F	= 1.30
4.05 lbs of M-2	= 8.10
	$13.77

Assuming the cost of M-2 is reduced to 1.08 per pound: (the same as 1/8″ MIL-100S-1)

Cost of 1/8″ MIL-100S-1 Electrode	=S1.08 per pound
Cost of MIL-100S-1F FlUX	= $0.32 per pound
Cost of M-2 Metal Powder	= $1.08 per pound

Projected consumables cost of welding one foot with 1/8″ filler wire and no powder for B2V.3 (from page 1):

= S6.37

Projected consumables cost of welding one foot with 1/8″ filler wire and M-2 metal powder @ 1:1 for B2v:3:

2.28 lbs of MIL-100S-1	= $2.46
2.28 lbs of MIL-100S-1F	= .73
2.28 lbs of M-2	= 2.46
	$5.65

Savings: $0.72 per foot

Projected consumables cost of welding one foot with 1/8″ filler wire and no powder for BlV.3 (from page 2):

= $11.35

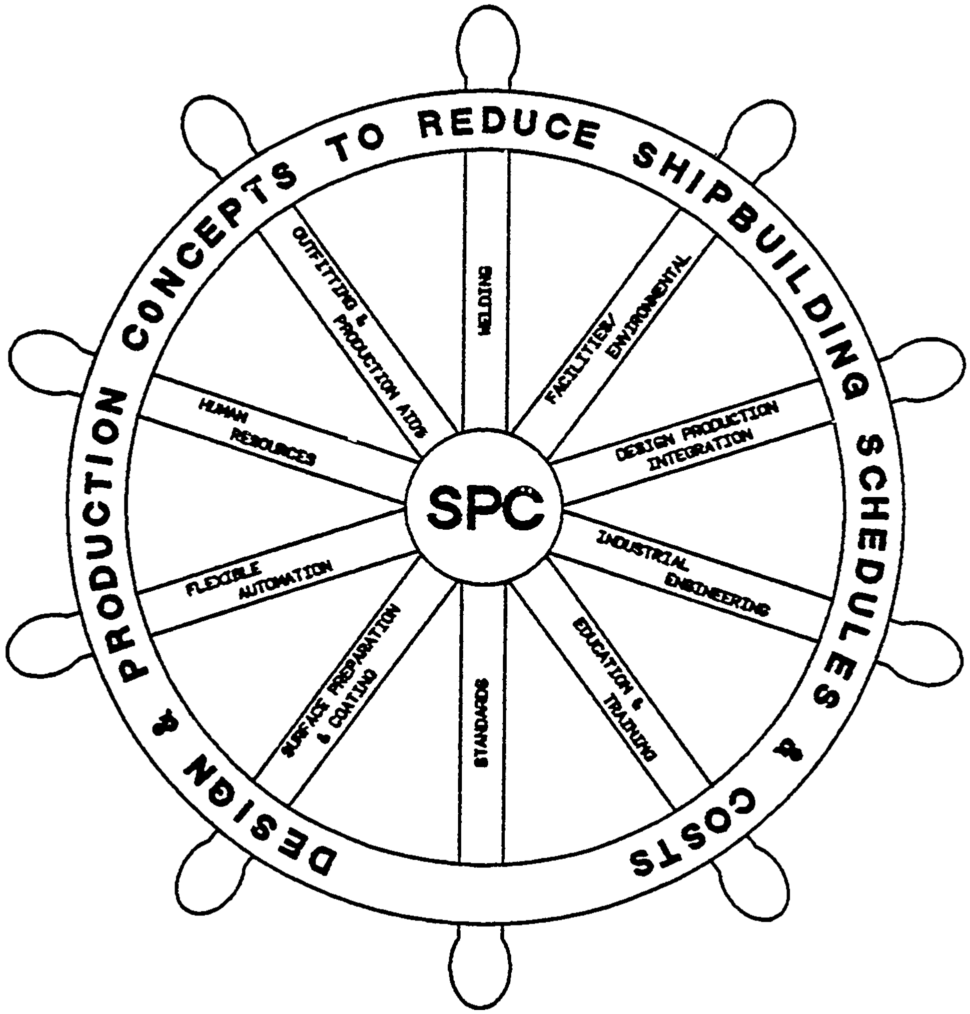
Projected consumables cost of welding one foot with 1/8″ filler wire and M-2 metal powder @ 1:1 for BlV.3:

4.05 lbs of MIL-100S-1	= $ 4.37
4.05 lbs of MIL-100S-1F	= 1.30
4.05 lbs of M-2	= 4.37
	$10.04

Savings: $1.31 per foot

ONAL SHIPBUILDING RESEARCH PROGRAM

1986 SHIP PRODCTION SYMPOSIUM



PAPER NO. 18

GENERATIVE PROCESS PLANNING BY EXPERT SYSTEMS

BY: F. A. LOGAN

SYMPOSIUM SPONSOR:
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SYMPOSIUM HOST:
SNAME HAMPTON ROADS SECTION

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GENERATIVE PROCESS PLANNING BY EXPERT SYSTEMS

FRANK A.LOGAN Associates

ABSTRACT

This paper examines the attributes of expert systems and their application to the Process Planning function in manufacturing industry. It will trace the evolutionary stages from low level interactive computer aided process planning through to complex rule based automated Process Planning (APP) driven by a Part Recognition Code (PRC) derived from a Computer Aided Drafting (CAD) system.

It will outline the requirements for the Knowledge transfer by the existing human experts into their own expert knowledge base. It will also review, based on the author's experience in implementing such systems, towards progress to Logic Generators and the extension of APP to embrace Generative Design. It will conclude that Computer Aided Manufacture (CIM) will only become a reality as Manufacturing Engineers commit their manufacturing knowledge to an expert system.

INTRODUCTION

The title of this paper raises a number of questions, quite apart from the technical aspect of process planning. What is meant by generative or expert ? Are there any common definitions ? Or does confusion reign ? So, first let us examine these words.

Generative

A dictionary definition is 'having the power to produce[1]. In CAPP terminology it has come to mean the ability to create a process plan from first principles, as opposed to the 'variant' approach of having 'similar to' variations of a process plan.

My definition of a generative system, applied to process planning, would be, one that has the power to produce a process plan by selecting from, and performing calculations on database items, using decision rules, and outputting the results in the formats required by recipient systems. This definition allows flexibility in that 'the power to produce' does not have to be absolute. It can evolve through increasing levels of sophistication.

Expert

Useful dictionary definitions are: 'having the facility of performance' , or 'taught by practice'. These imply that there are rules of performance for an activity and that human beings learn these rules by experience or practice of the activity.

Rules of manufacture can be both general or specific; for example, the basic principles of - say - welding, are universal. Their application will, however, be very specific to the nature, quantity and quality of the particular welding operation. we already have expert systems in manufacture - they are the manufacturing engineers, superintendents, foremen and operatives - this could also include design and detail engineers, who apply their rules in their every day operations.

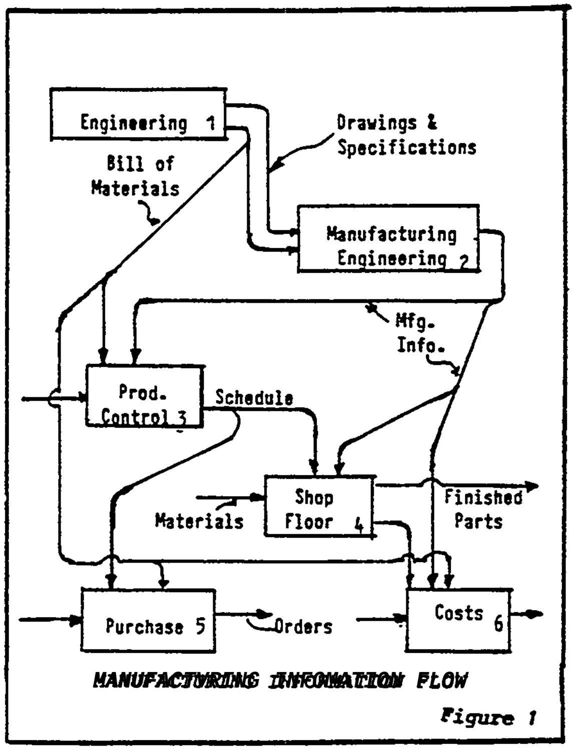
PROCESS PLANNING

This paper sets out the author's experience in implementing LOCAM, a generative expert system, and highlights the concepts on which it is based. It has evolved, over the years, from the interaction of manufacturing engineers and computer specialists to a stage where it is only dependent upon the manufacturing skills of users to define decision logic, database elements and output formats for their particular application. It has the power to produce process plans based on the combined experience and practice of the company.

Traditional Information Flow

Manufacturing organizations (indeed all organizations) exist on information flow, both by printed, written and Spoken words. Sales orders pass to work orders, drawings and specifications from engineering to manufacture, irate customers write and telephone pursuing late deliveries. The list is endless. Information crosses and re-crosses departmental boundaries.

One thing is common in this seemingly endless flow. The received information is processed by the recipient, be it human or machine, then reformatted (repackaged) for onward transmission to the next recipient. To formalize and Structure this flow, forms are designed to format the elements of information being passed, and color coded to aid distribution. Figure 1 is a schema of a typical Manufacturing Information flow between Engineering and the production of Finished parts.



MANUFACTURING INFORMATION FLOW

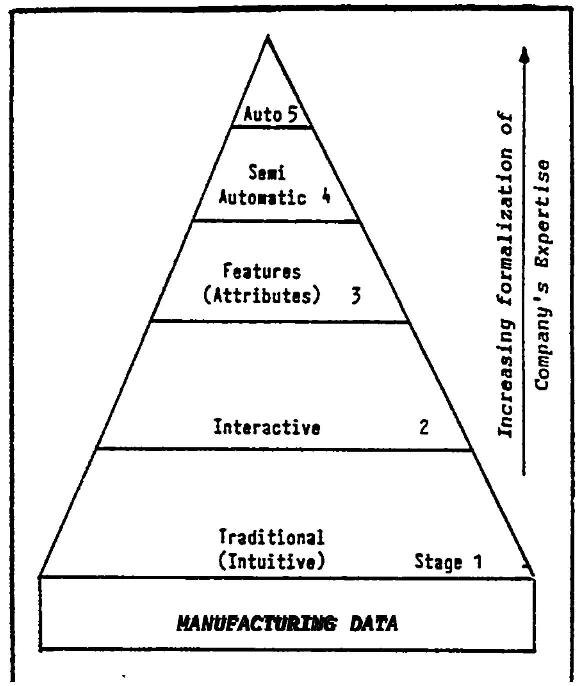
Figure 1

Processing depends on humans using their knowledae (expertise), however limited in range, to decode this information and carry out calculations and decision making of various complexity. At this level they use a range of tools, calculators, look-up tables, telephone (to enquire status of allied information and validity of suspect or missing information), even computer programs, to name but a few. The following encapsulates our experience in assisting manufacturing engineers to implement CAPP.

The Stages

Effective process planning is seen to be a vital requirement of a Manufacturings philosophy (l). Traditionally, time technicians have viewed drawings and specifications, searching for key data. They use this key information to trigger decision processing through their personally acquired manufacturing logic, and access their knowledge base to define the process plan; then move down through further levels of knowledge to retrieve more operational oriented data such as machine capacities, tooling, speeds, feeds, etc. See Fiqure 3, Process Planners decode the drawing.

At the highest level this process seems intuitive, in fact they use their minds as inference machines (a term now used in Artifical Intelligence - AI) to step through the decision and action possibilities. As they proceed to refine the process plan -down into the operational level, the degree of seemingly intuitive decision making becomes less pronounced, and is replaced by data look-up. calculations and formatting of data for onward transmission.



STAGES OF DEVELOPMENT

Figure 2

Lessons from this Experience

The first, and maybe the hardest, lesson to have been learned in implementing generative expert CAPP systems was that the users already had the knowledge and the data and they must be involved as implementation. Imposition does not work. Without their dedicated commitment, knowledge will not be transferred.

Secondly, in moving on from this traditional stage, the specification of an expert system has evolved. This can be summarized as:

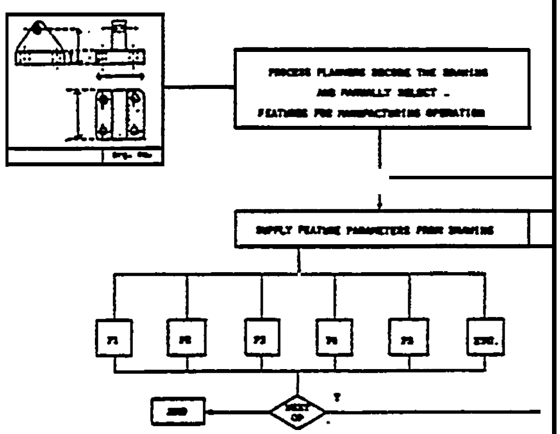
The core module needs to be a logic processor capable of accepting inputs in a variety of modes, for example:

Interactive through user defined question and keywords (Stage 2, Figure 2).

Attribute driven Features, i.e., a means of pre-packaging (with variability) a re-occuring sequence of events (Stage 3)

Code of gross properties by family group to call Decision/Action Tables which selects and recalls Features. In process planning terms this is equivalent to the routing. Supplementary questions are required to satisfy the more detailed planning requirements, for example, unique dimensions (Stage 4 Semi Automatic Process Planning):

part Recognition Codes that contains both the gross properties and all unique dimensional note information for fully automatic process planning, including the generation of the numerical control tape image. (Stage 51.



PROCESS PLANNERS DSCODE THE DRAWING

Figure 3

Utility modules to create and maintain large and powerful data sets which are accessed by the logic module. These data sets are organised in a variety of formats within each of the following groups:

The first represents data sets which contain no variability, i.e. they are used, if called, without modification, for example, user defined:

- Standard Time/Cost Elements
- Questions
- Keywords
- Speed and Feed data
- Tooling
- Help Files

The second represents data sets, which contain variability, i.e. internal logic. These data sets are called by the logic modules, which also sets the required variability parameters. These data sets may themselves call the first group of sets.

The third and most powerful group creates and maintains Decision/ Action Tables. These are driven either from an externally created code, or from a code generated internally from a series of user-defined questions. These Tables can also automatically generate Flowcharts for visual display.

In addition to the above expert system 7388

mundane utilities are required for Menus, Format Generators, Code and Classification and File Management.

Above all, the expert system skeleton must be common for all users; it is only the logic and data which changes for each different area of application.

Evolution of an Expert System

This progression from the characteristics of human intervention at the low level system through to those of the fully automated system are illustrated in Figure 4. This approach has allowed process planners from many backgrounds and age groups to build and maintain the system without direct MIS type assistance. It should be emphasised that it is a building block approach i.e. capturing and consolidating the logic appropriate to each stage.

The blocks, see Fiqure 4 Evolution of a Expert Database, are:

Constant Data Sets. This is standard data with no variability other than frequency. It is normally transferred direct from written records to magnetic storage through appropriate data set utility, and is common across all stages.

Variable Logic Data Sets. These, organised by micro activity groups, Select reaquired Constant Data Sets depending upon parameter values passed" at run time. The groupings and the variability logic is usually well understood by process planners; it simulates their manual selection techniques. They are common across all stages.

Attribute Logic. These higher level data sets, common over Stages 3 to 5, are usually organized by macro (Feature) activity groupings. They contain internal logic and can call any of the lower data sets. A characteristic of these sets is that they consolidate, by their grouping, much of the keyword input used at Stage 2. A group of questions, unique to the grouping, generates calls to lower data sets and passes appropriate parameter values. Again these logic requirements are not difficult; they are in common daily use in traditional process planning.

Decision/Action Tables. A prerequisite is firstly to have achieved the previous stage, and secondly, to have identified a broad family group to which the Features (Attributes) can be linked.

These Tables: from which a Manufac- turing Code (2) can be derived are currently constructed using an interactive program. The resulting tables are displayed in Flowchart format. Changes to logic are achieved by editing the tables and a new flowchart drawn. This process is now being updated and is described later in this paper under the "Logic Generator" heading.

At this level, process planning/meods engineers are capturing the intuitive processing by which they select work stations operations. knowledge already exists and is used every time a process plan is created or a part made. In a manual system where the planner makes an error, the superintendent, foreman or operative corrects the mistake. The comfort of a human backstop does not exist in an automated system, therefore al I who can contribute knowledge should be involved.

Logic Driver: The initial segment 'A' in Figure 4, is constant across all stages, but whereas at Stage 2, the user interacts by question and keyword, this interaction is progressively diminished as added expertise allows the system to answer the questions or provide the keywords and associated parameters. By Stage 5 all interaction is eliminated and process pIanning is automatic, as a key system in a CIM environment, (3).

Stages	2	3	4	5
input Fully Automatic Semi Automatic Interactive	*	•	•	•
C Part **Definition Code** **B Mnufacturing Code** **A Logic Modules**	A	A	B A	C B A
D Decision Tables A Action Tables M Macine Tables			0 A M	D A M
E Atiribute (Features) (variable)	-	E	E	E
V Variable Logic **Data** (Macros. **Paragraphs)**	v	v	v	v
S Standard Datasets (Bon variable)	S	S	s	s

EVOLUTIONARY CYCLE FROM INTERACTIVE TO FULLY AUTOMATIC

Figure 4

SYSTEM OVERVIEW

To provide a background against which to understand the interaction of data, logic and outputs, the following overview and the accompanying flowchart, Figure Generative Process Planning, describe' the relationships.

Modular Construction

LOCAM is a generative, expert based, process planning system which can progress through levels of sophistication to be fully automatic, including NC part programming, driven by a Part Description Code generated by a CAD system, organized around six major modules. These are:

- Manufacturing Engineering Database
- Layout Generator
- Interactive Logic Driver
- Automatic Logic Driver
- Macro Processor
- Systems Output

Manufacturing Engineering-Database

Computer Aided Process Planning (CAPP), like traditional process planning, Manufacturing and Industrial Engineering data. Indeed, it may need to be even more structured, as unlike humans, computers cannot guesstimate. The database structure is organized around utilities for the creation and maintenance of:

- Text
- Macro and Pattern
- Tables
- Driver Data Sets
- APP Decision Trees

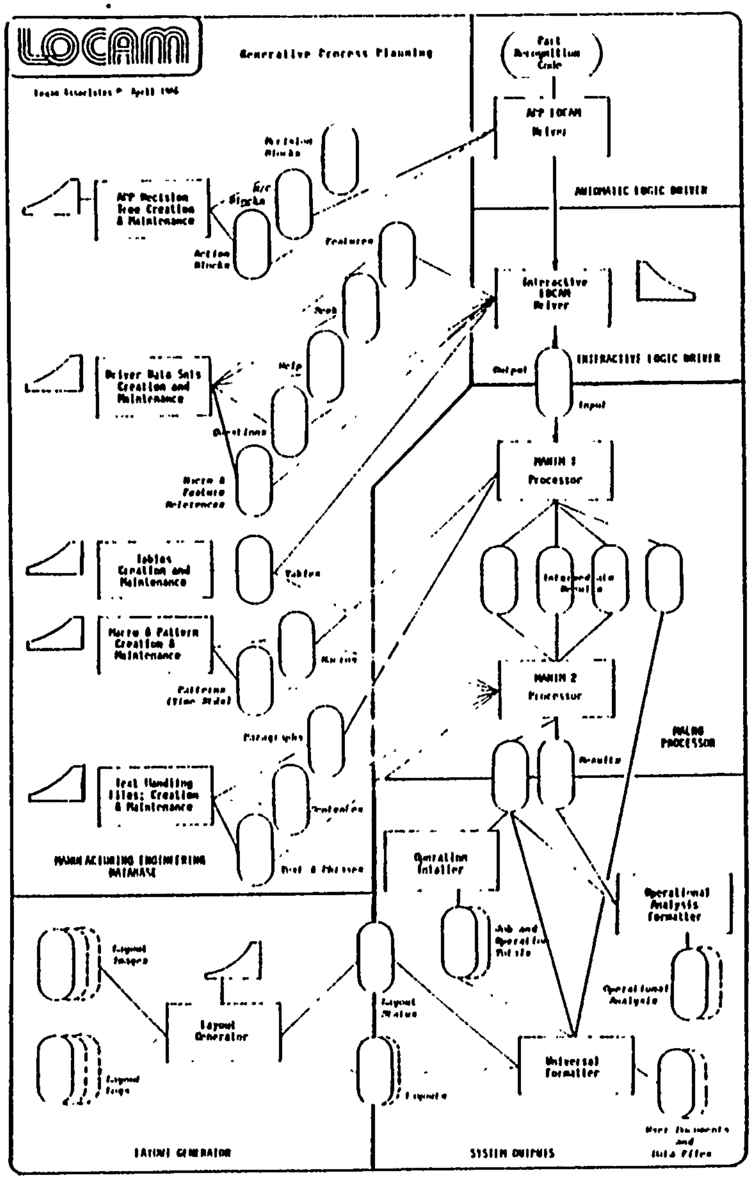
The first three are accessed by the Macro Processor, whilst generating process planning information. Tables are also used by the Interactive Logic Driver together with the Driver Data Sets. The APP Decision Tree utility is only used by the APP Logic Driver.

Variability within items in the database is controlled by:

$ dummy arguments,
eg. $1 S12 etc., where the numeric value signifies the position in the argument list

Expressions evaluated at runtime eg. * $4 or * ($1+1*$4)
where a returned value of zero or less will supress any action on the command line

LOCAM SYSTEM FLOWCHARTS



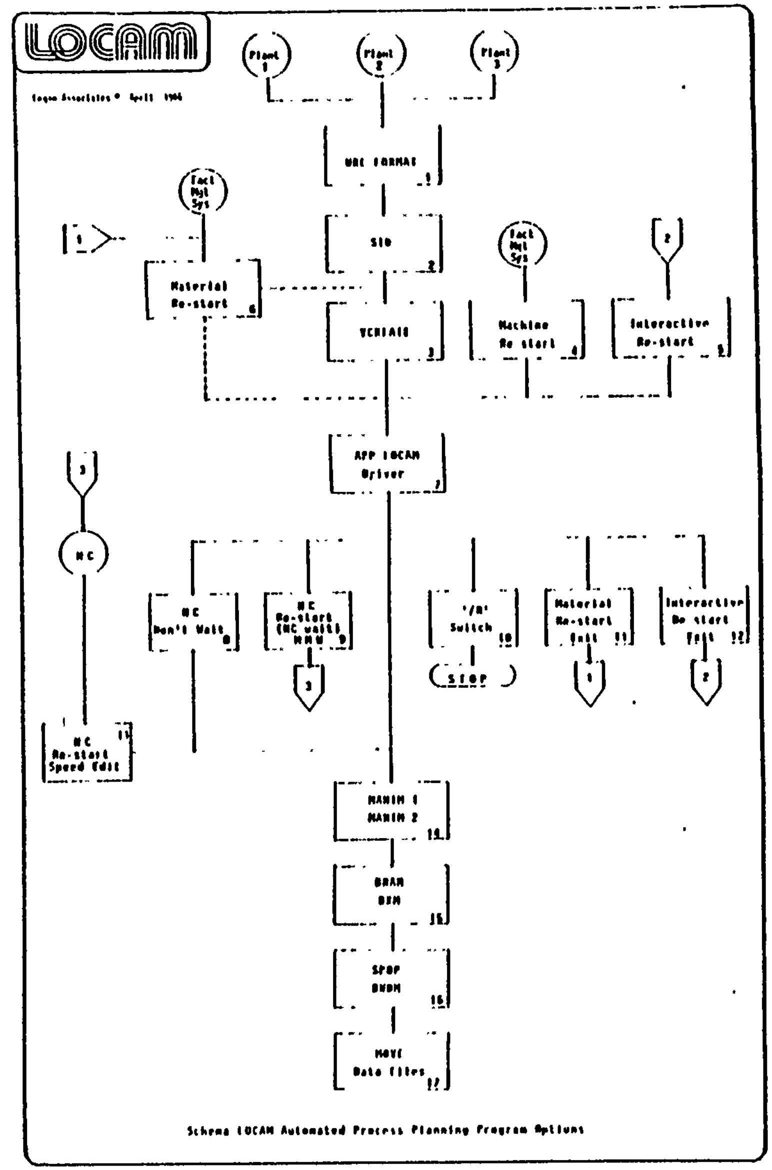


Figure 5

Text. This section of the database consits of:

Paragraphs with variability, that is, alphanumeric data can be Passed in as arguments. Paragraphs can also Call Sentences, Phrases and Text. See Figure 6a Paragraphs.

Sentences can also contain variable arguments and can call Phrases, and Text. See Figure 6b.

Phrases and Text have no variability and are used in an 'as is' condition. See Figure 6C

The ability to combine these datasets and then, from the logic module, generate the required arguments, enables very complex text output to be generated.

Macros and Patterns: Whereas the Text utilities only generate character output, the objective of these data sets is to generate process planning text and time standards. They have, in their own right, a powerful text generation capability, however, for detailed manufacturing instructions a combination of both Macros and Paragraphs may be required.

Patterns. These are the equivalent of traditional time standards and consist of a description and a time and can usualy be taken direct from company standards. See Figure 7a.

Macros. These mimic the well established Industrial Engineering technique of grouping standard data under a work station heading; say, Light Drilling. To establish a time, a Process planner would traditionally select the items he required. Macros, through the use of dummy arguments ($ variables) perform a similar, but automatic selection. However, they also use the same technique to include such functions as, the automat-it look-up of tables generating text using nested Paragraphs

To summarise, these user definable Macros carry out the detailed operation planning (methods engineering) function of process planning. They select, and organise output data - say - for machining, feeds, speeds, number of cuts, manual and machine times, as well as text. Similarly, they will output the type of information required for all other types of work, such as assembly, fabrication, welding. See Figure 7b.

```
Para 12 Fit Shias.
PT: fit shims, Item # $3. cheek Brg.
    clearance # $1. $1 $2 and re-fit
    Shim. Enter details in log.
$1: Clearence tolerance from drg.
$2: Sentence 6, 7 or 12
$3: Item # from Bill of Materials
```

PARAGRAPH **Figure 6a**

```
Sent 12  Bolt up Bearing cap
PT: $PH $1 & bolt up using bolts $2
$1: Phrase # 56 78 or 109
```

sentence Figure **6b**

```
Phrase 56  : Locate gasket
```

PHRASE **Figure 6c**

```
LISTIMG OF UMACR-P, PRODUCED BY UMACR ON 5 JUN 86

   Macro   1602.
   1>T:Tap blind manipulations
   2>TAs 1920 S1 $2
   3> TAB 1920 $3 $2 * S4
s 1:  v250 sot from material group
s 2:  v251 set from cap sizer
s 3:  v252 set from Material group •alder
s 4:  v253 set from frequency

   macro   1603.
   l> T: Tap blind holes manipulations drill Clearance
   2>PATT 1197  •S1 •S2
s 1:  v254 set from tap size •and tapping depth
s 2:  v253 set from frequency

   Macro   1604.
   l> T:Drill Manipulations, drill to layout
   2>PATT S1
   3>PATT s2 •s3
   4>PATT 1214 * S4 •s3
   5>PATT 1227 * S5
   6>PATT 1215 •S6
   7>PATT 1216 •S6 •S3
   8>PATT 1219 * S7
   9 >PATT 1220 •S7 * s3
  10>PATT 1223 •S8
  ll>PATT 1224 •$8 * S3
s 1:  v250 set from drill size
s 2:  V251 set from drill size
s 3:  V252 set from frequency
S 6:  V253 set if drill depth exceeds 4*dia
s 5:  V254 set for blind hole from IOC
S 6:  V255 set from drill dia and flute length
s 7:  v256 set from drill dia and flute length
      v257 set from drill dia and flute length
```

MACRO Figure 7b

```
4:OBTAIN ONE TOOL GAUGE FROM STORE               :  6.000 : : 208:STOP SPINOLE
5:OBTAIN EACH ADDITIONAL TOOL OR GAUGE           :  0.500 : : 211: ADVANCE TABLE
6: PREPARE TOOLS : M/C FOR SET-UP. CLEAN ETC.    :  4,000 : : 212:COOLAN
7: FIT-R EMOVE  S/C  CHUCK OR FACE  PLATE        ;  10.000  :
```

PATTERN **Figure 7a**

Tables. These parallel the traditional tables already used by Process planners. Essentially a value can be extracted by a X (column) and Y (row) co-ordinate. When called from a Macro, **$ variables can be substituted for table, column, and row numbers. Tables** values can also act as pointers to other items in the database. See Figure 8.

Driver Data Sets. These data sets consist of information that is used by both the Interactive and Automatic Logic Drivers.

Questions. A process planner takes key data from a drawing (i.e. he asks himself the relevant questions)- arly, LOCAM asks the same questions to drive its in-built expertise. These are stored in the Questions dataset.

At Stage 2 these questions are asked interactively, however, as the system evolves through to Stage 5, more of the questions will be answered by the system, as it decodes the Features (Stage 3), Manufacturing Code (Stage 4), until at Stage 5, all the questions that drive logic must-be answered from the Part Definition Code (POC). See Figure 9.

Seek. The basic function of this dataset is to check the validity of input, such as Material Specs., work Station Codes, Keywords and then return additional information to the system to direct the decision making logic. The Driver will not allow the program to advance until there is a match between the input and the valid answer to the question.

Help. If there is a mismatch on input, a list of the possible answers at that logic stage can be automatically displayed. Alternatively, the user may request help before answering a question.

Features. These are a method of describing a group of activities within which there is an overall theme, but where considerable variability can occur. Like Macros, Paragraphs and Sentences, they also use $ variables to reflect this variability. both to substitute values or alphanumeric strings or to inhibit Feature logic commands where an expression evaluates to zero or less. See Figure 10.

Macro and Feature References. These cross reference the location of data to be substituted for $variables.

APP Decision Tree Tables. Tree-Tables are used to decode the Manufacturing Code element of the Part Description Code (POC) or to set constants. The validity of interaction between the various blocks within Tables and looping limits are checked out by a Validation Program. The interaction can also be automatically flowcharted from the Tables, for visual representation. They are only used by the APP Driver, and consist of:

Decision Tables. These evaluate elements of the Manufacturing Code and branch on a True or False result. A branch may be another Decision. Action or M/C Block within the Tables.

Table 211 : REC M/C DATA -MTL GRP1 - VERT MILLS :

		(1) OP CODE	(2) MACREF	(3) SPEED(R)	(4) SPEED(F)	(5) FEED(R)	(6) FEED(F)
(1)	FORM (ARB-HSS)	118.0000	250.1230	0.0000	24.0000	0.0000	0
(2)	FACE MILL(CARB)(R&F)	101.0200	256.1290	53.3500	68.5900	0.1770	
(3)	FACE MILL(CARB)(R)	102.0200	243.1160	53.3500	0.0000	0.1770	
(4)	FACE MILL(CARB)F	103.0200	244.1170	0.0000	68.5900	0.0000	
(5)	SLT/MILL(SIDE&FACE)R	108.0000	245.1180	24.0000	0.0000	0.0610	
(6)	STRADDLE MILL	110.0000	247.1200	0.0000	24.0000	0.00	
(7)	SLITTING SAW	114.0000	248.1210	0.0000	24.0000		
(8)	SLOT DRILL(R)	104.0000	254.1270	18.0000			
(9)	SLOT DRILL(F)	105.0000	255.1280				
(10)	END MILL(R)	106.0100	241.1				
(11)	END MILL(F)	107.0100					
(12)	WOODRUFF OR T CUTTER	115.000					
(13)	CENTRE						
(14)	DRILL						
(15)	REAM						

TABLES *Figure 8*

N
) Number of pins to locate gear. N
(42) Pin diameter. (in inches) N
(43) Weight of gear and shaft 2nd reduction.(in lbs) N
(44) Number of electrical clips to wire bearings. N
(45) Number-of bearings. N
(46) Bearing diameter. (in inches) N
(47) Number of retainers per bearing. N
(48) Number of straps per bearing. N
(49) Cap diameter. (in inches) N
(50) N

QUESTIONS *Figure 9*

```
Feature file 10   -10- NC mach cplt/p blt

3.84 Last Modified 2.25.85 Number of Quest

What is the length under the head?          (Lol)
What is the length of the head?             (L02)
What is the head diameter?                  (D0l)
What is the thread diameter?                (D03)
What is the body diameter?                  (D02)
What is the raw stock diameter?             (M02R)
What is the thread angle?                   (A06)
What is the width of the choler?            (L09)
What is the thread length?                  (Llo)
   Front of blt to str body dia?            (x99)
Bo dy/u'cut rad?                            (R05)
SEND
FS:TO ($1+$2+0.5)
   0.250
T2IR $6 ($3+0.25) ($1+$2+0.25)
T2IR ($3+0.25) ($4+0.0625) $1
   CLS ($4+0.0625)$8 $7 Lc 'End'
T2R ($4+0.0625) $5 ($1-$9) * ($5+0.01-$4)
T2F $3 $2 LC'Head'
T2F $4 $9
   $4 $9 8TPI
F2S $3 $5 0.06 LC'wshr fc & ucut rad'
T4R $4 $5 ($1-$9) $11 LC'tr ucut' * ($4-$5)
CO $6 0
SEND
```

FEATURES *Figure 10*

Action Tables. These select operation details such as:

- Any legal LOCAM Command
- Setting of numeric or alphanumeric values
- User definable commands

On completion of the Action, the sequence can be directed to either another Action, Decision or M/C Block within the Tables.

M/C Block. These select operation details such as:

- Manual, NC No Wait, NC Wait
- Automatic or Interactive Planning
- If Automatic and NC - Program Name
- Work Station
- Next Block
- Alternate Block

See Figure 11 for examples of the interaction between the various Tree Tables.

Label	Digit Anlzd	Elmnt Id	Cond Value	Satisfactory Typ	Satisfactory Number	Non-Satisfac Typ	Non-Satisfac Number
[illegible]	02	[illegible]		[illegible]	00050	D	00020
[illegible]	01			M	[illegible]	D	00030
[illegible]	01	3		D	[illegible]35	D	00040
[illegible]	[illegible]	[illegible]		[illegible]	00055	M	[illegible]
[illegible]	[illegible]	1		[illegible]	[illegible]075	M	[illegible]
[illegible]	01	[illegible]		M	[illegible]	D	[illegible]
[illegible]	01	1		M	[illegible]100	D	[illegible]
[illegible]	01	[illegible]		[illegible]	[illegible]	M	[illegible]
[illegible]	[illegible]	[illegible]		[illegible]	[illegible]65	D	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	M	[illegible]	M	[illegible]070
[illegible]	[illegible]	[illegible]	8	M	00120	M	[illegible]110

Decision BlOCK Table

Example of *Decoding PDC for Routing Where* code - 22A.

Starting at decision 10, path *branches to D(ecision) 5O because 3rd* character of Code is true (= A).

At D5O, path *branches* to *M(acbine Block)* 80 *because 1st* character is True.

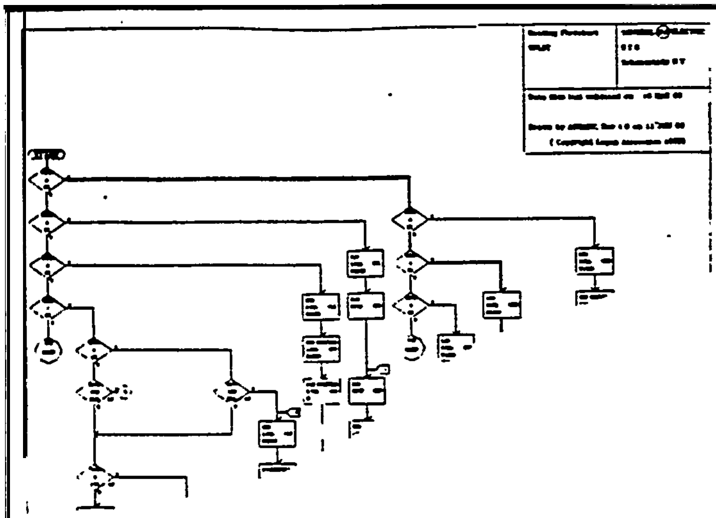
M80 selects Feature and *completes process planning, then branches to M90 for nest operation.*

File: SPLST.MB

Label	Nc codes	Bch	Auto/ Intor	Program Name	Op Cde	Work Stations 1	2	3	4	5	Next Block Typ	Next Block Number	Altnt Block Typ	Altnt Block Number	Lbr Rte	No. Opers	M/c Cost	Misc	Pa Cc
00010	0	0	A		SBH	G36A					M	00015		00000	D14	1	50	N	
00015	2	1	A		2SS	D33A					M	00999		00000	D17	1	100	A	
00020	0	0	A			NOTT					M	00030		00000	D17	1	100	?	
00030	0	0	A		MCH	NOTT					M	00999		00000	D17	1	4	[illegible]	
00040	2	1	A	DBSPLL4	2SS	G32A	G33A	G35A			M	00045	M	00045	D17	1	4	A	
00045	2	1	A	DESPLL6	2SS	G30A					M	00999		00000	D17	1	4	B	
00050	0	0	A		MSF	C32A					M	00060		00000	D15		1000		
00055	0	0	A		SAW	G36A					M	00040		00000	D14	1	50	N	
00060	2	1	A	DBSPLL5	2SS	G32A	G33A	G35A			M	00999		00000	D17	1	4		
00065	0	0	A		SAW	G36A					D	00090		00000	D14	1	50	N	
00070	2	0	A	DBSPLL3	2SS	G32A	G33A	G35A			M	00075	M	00075	D17	1	4	A	
00075	2	1	A	DBSPLL5	2SS	G30A					M	00999		00000	D17	1	4	B	
00080	0	0	A		SBH	G36A					M	00090		00000	D14	1	50		
00090	2	1	A	DBSPLL2	2SS	G32A	G33A	G35A			M	00999		00000	D17	1	4		
00100	0	0	A		SBH	G36A					D	00090		00000	D14	1	50		
00110	2	1	A	DBSPLL1	2SS	G32A	G33A	G35A			M	00999		00000	D17	1	4		
00120	2	1	A	DESPLL7	2SS	G32A	G33A	G35A			M	00130		00000	D17		100		
00130	2	1	A	DESPLL1	2SS	G32A	G33A	G35A			M	00999		00000	D17	1	4		
00140	0	0	A		SBH	G36A					M	00150		00000	D14	1	50		
00150	2	1	I	DESPLL5	2SS	G32A	G33A	G35A			M	00150		00000	D17	1	100		
00160	2	0	I		SFX	D33A					M	00999		00000	D17	1	4		
00888	0	0	I			MANP						00000		00000					
00899	0	0	I		STP	STOP						00000		00000	D17	1		^	
00999	0	0	I			SHIP						00000		00000					

Machine Block Table

Figure 11a



Example of Automatic Flowchart from previous Decision/MC Block Tables

Figure 11b

Example of Decision and Action Blocks where A(actions) are setting values, e.g.

A15 sets WS(Work Station) = 450
FN(Formula No.) = 68

On completion path branches back to D20.

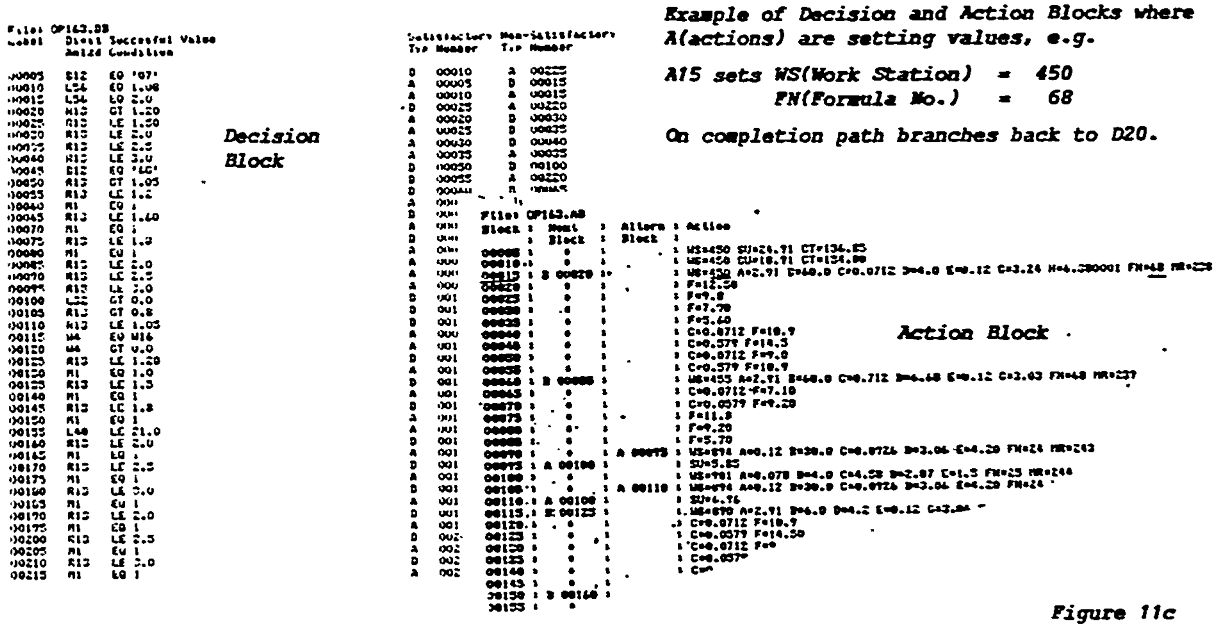
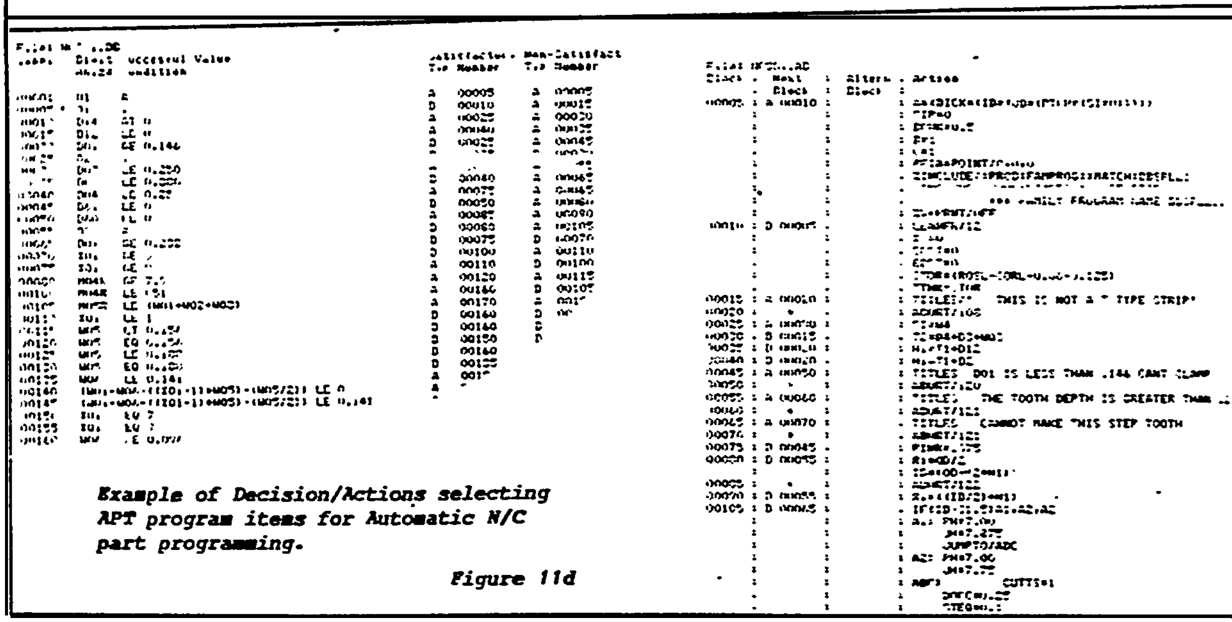


Figure 11c



Example of Decision/Actions selecting APT program items for Automatic N/C part programming.

Figure 11d

File: OP018.DB

Label	Digit Anlzd	Succesful Value Condition	Satisfactory Typ	Satisfactory Number	Non-Satisfa Typ	Non-Satisfa Number
00005	B21$	EQ 0	D	00009	A	00005
00009	N5	EQ 'B51'	D	00013	D	00010
00010	N5	EQ 'B22' 'B23' 'B24' 'B25' 'B35' 'B57' ' B36' 'B41' 'B42' 'B43' 'B44' 'B60'	D	00012	D	00011
00011	N5	EQ 'B45' 'B46' 'B47' 'B48' 'B49' 'B50' ' B52' 'B53' 'B54' 'B55' 'B61' 'B62'	D	00012	A	00005
00012	KEY	EQ 2	A	00455	A	00010
00013	WS	EQ 356	A	00610	D	00012
00015	L40	LT 8	D	00020	D	00110
00020	N5	EQ 'B22'	D	00021	D	00025
00021	M1	EQ 1				
00025	N5	EQ 'B23'				
00026	M1	EQ 1				
00030	N5	EQ 'B25'				
00031	M1	EQ 1				
00035	N5	EQ 'B47'				
00036	M1	EQ 1				
00040	N5	EQ 'B49'				
00041	M1	EQ 1				
00045	N5	EQ 'B50'				
00046	M1	EQ 1				
00050	N5	EQ 'B51'				
00051	M1	EQ 1				
00055	N5	EQ 'B53'				
00056	M1	EQ 1				
00060	N5	EQ 'B62'				
00061	M1	EQ 1				
00065	N5	EQ 'B64'				
00066	M1	EQ 1				
00070	N5	EQ 'B65' 'B70'				
00071	M1	EQ 1				
00075	N5	EQ 'B66' 'B63' 'B7'				
00076	M'	EQ 1				
00080	N	EQ '[illegible]				

File: OP018.AB

Block	Next Block	Altern Block	Action
00005	*		MR=0
00010	D 00015		WS=704 MR=26 SU=3.51 B=0.75 C=1.667 D=2.92 FN=6.
00015	*	A 00016	A=3.208
00016	*		WS=701 MR=25 A=3.208 F=0.8
00020	*	A 00021	A=3.208 G=10
00021	*		WS=701 MR=25 A=3.208 F=0.8 G=10
00025	*	A 00026	A=2.859
00026	*		WS=701 MR=25 A=2.859 F=0.8
00030	*	A 00031	A=2.859 G=10
00031	*		WS=701 MR=25 A=2.859 F=0.8 G=10
00035	*	A 00036	A=2.795
00036	*		WS=701 MR=25 A=2.795 F=0.8
00040	*	A 00041	A=2.795 G=10
00041	*		WS=701 MR=25 A=2.795 F=0.8 G=10
00045	*	A 00046	A=3.044
00046	*		WS=701 MR=25 A=3.044 F=0.7
00050	*	A 00051	A=3.044 G=10
00051	*		WS=701 MR=25 A=3.044 F=0.8 G=10
00055	*	A 00056	A=2.117
00056	*		WS=701 MR=25 A=2.117 F=0.8
00060	*	A 00061	A=2.117 G=10
00061	*		WS=701 MR=25 A=2.117
00065	*	A 00066	A=2.902
00066	*		WS=701 MR=25 A=
00070	*	A 00071	A=2.902 G=10
00071	*		WS=701 M[illegible]
00075	*	A 00076	A=5
00076	*		
00080	*	A [illegible]	

```
      SUBROUTINE OP018
      DIMENSION VAR(400)
    5 IF(R21$.EQ.0)GOTO 9
10005 MR=0
      GOTO 10000
    9 IF(N5.EQ.'B51')GOTO 13
      GOTO 10
   10 IF(N5.EQ.'B22'.OR.
     +    N5.EQ.'B23'.OR.
     +    N5.EQ.'B24'.OR.
     +    N5.EQ.'B25'.OR.
     +    N5.EQ.'B35'.OR.
     +    N5.EQ.'B57'.OR.
     +    N5.EQ.'B36'.OR.
     +    N5.EQ.'B41'.OR.
     +    N5.EQ.'B42'.OR.
     +    N5.EQ.'B43'.OR.
     +    N5.EQ.'B44'.OR.
     +    N5.EQ.'B60')GOTO 12
      GOTO 11
   11 IF(N5.EQ.'B45'.OR.
     +    N5.EQ.'B46'.OR.
     +    N5.EQ.'B47'.OR.
     +    N5.EQ.'B48'.OR.
     +    N5.EQ.'B49'.OR.
     +    N5.EQ.'B50'.OR.
     +    N5.EQ.'B52'.OR.
     +    N5.EQ.'B53'.OR.
     +    N5.EQ.'B54'.OR.
     +    N5.EQ.'B55'.OR.
     +    N5.EQ.'B61'.OR.
     +    N5.EQ.'B62')GOTO 12
      GOTO 10005
   12 IF(KEY.EQ.2)THEN
            WS=704
            MR=26
            SU=3.8
            B=0.75
            C=1.667
            D=2.92
            FN=6
            F=0.8
            G=6.5
            GOTO 330
      ENDIF
10010 WS=704
      MR=26
      SU=3.51
      B=0.75
      C=1.667
      D=2.92
      EN=6
      F=1
      G=6.5
      GOTO 15
   13 IF(WS.EQ.356)THEN
            WS=356
            SU=4.09
            A=5.149
            B=2.0
            C=1.1286
            E=1.667
```

```
            FN=35
            MR=24
            GOTO 10000
      ENDIF
      GOTO 12
   15 IF(L40.LT.8)GOTO 20
      GOTO 110
   20 IF(N5.EQ.'B22')GOTO 21
      GOTO 25
   21 IF(M1.EQ.1)THEN
            A=3.208
            GOTO 10000
      ENDIF
10020 A=3.208
      G=10
      GOTO 10000
   25 IF(N5.EQ.'B23')GOTO 26
      GOTO 30
   26 IF(M1.EQ.1)THEN
            A=2.859
            GOTO 10000
      ENDIF
10030 A=2.859
      G=10
      GOTO 10000
   30 IF(N5.EQ.'B25')GOTO 31
      GOTO 35
   31 IF(M1.EQ.1)THEN
            A=2.795
            GOTO 10000
      ENDIF
10040 A=2.795
      G=10
      GOTO 10000
   35 IF(N5.EQ.'B47')GOTO 36
      GOTO 40
   36 IF(M1.EQ.1)THEN
            A=3.044
            GOTO 10000
      ENDIF
10050 A=3.044
      G=10
      GOTO 10000
   40 IF(N5.EQ.'B49')GOTO 41
      GOTO 45
   41 IF(M1.EQ.1)THEN
            A=2.117
            GOTO 10000
      ENDIF
10060 A=2.117
      G=10
      GOTO 10000
   45 IF(N5.EQ.'B50')GOTO 46
      GOTO 50
   46 IF(M1.EQ.1)THEN
            A=2.902
            GOTO 10000
      ENDIF
10070 A=2.902
      G=10
      GOTO 10000
   50 IF(N5.EQ.'B51')GOTO 51
```

Example of Decision/Action Tables automatically generating Fortran77 program code.

Figure 11e

EXAMPLES OF DECISION TREE TABLES

Figures 11a - 11e

Layout **Generator.** **This** module allows users to define output formats for both documents and data files. Up to ten different formats can be output per part number being process planned.

Layout Images. **This** module allows the user to define the layout by Sections, such as Job, operation and continuation Header, Page End and Detail Line, etc.. for each document or data file. See Figure 12.

Layout Logs. The interactive Logs program asks questions as to the placing of data within the various sections of the Image. When completed it places a composite of the Image and Log in Layouts and is accesssed by the system Output module at runtime. See Figure 13.

```
+---------------------+------------------------------------------
! Date:               !'
!                     !                              BUDD  DIE
! Process Eng:        !                              -- Revisio
!                     !
+---------------------+-------------------------+----------------
!                     !                         !
!                     !                         !
!         .           !                         !
+--------,----------. +---------,----------  --+--------,--------
! Customer            :
! Model               :
! Part/Assy. Name     :
+----------------------------------------------------------------
! Metal Spec.         :
!
! Coating             :
+-------------+-------+----------------------------------
!  EC or DC   !  Date  !                          C H A
+-------------+--------+----------------------------
^ job header
' operation header
!             !        !                  Revisi
+-------------+--------+--------------------
^ page tail
- job totals
^ operation totals
+------------------------------------
!
!
!
!
+------------------------------
' continuation header
!             !        !
+-------------+--------+---
- end of report
!             !        !
' fill-up line
!             !
^ detail seperator
!             !
- detail line
```

LAYOUT IMAGE

Figure 12

```
 2) Is the layout:                                              %
 3)                (1) for a printed document                   &
 4)                (2) for a data file                          N 1
55) Is this a standard layout                                   A Y
61) Length of output record in characters                       N 121
34) Is the document a :                                         &
35)                 (1) P: directed                             &
36)                 (2) T: directed                             &
37)    .            (3) KTP directed                            &
21)                 (4) M: directed                             &
22)                 (5) S: directed                             &
23)  Option number :                                            N 1
30) TOTALLING FORMAT OPTIONS                                    &
31) JOB & OP TOTALS                                             &
58) Is time to be in :  (1) minutes                             &
59)                     (2) hours and minutes                   &
60)                     (3) decimal hours (3 dec.pl.)           N 1
17) Number of decimal places for time                           N 2
32) SET-UP TOTALS                                               &
58) Is time to be in :  (1) minutes                             &
59)                     (2) hours and minutes                   &
60)                     (3) decimal hours (3 dec.pl.)           N 1
17) Number of decimal places for time                           N 2
 6) JOB HEADER                                                  &
12)    Enter item's identity (0 to end. -999for list)           N 997
13) Line number within the section where item will be           N 2
14) Start character number on line                              N 8
12)   " Enter item's identity (0 "              -999for list)   N 999
13) Line numb-                                              be  N 3
14) -
```

LAYOUT LOG

Figure 13

Interactive Logic Driver

LOCAM Driver. Users create Logic Drivers by defining their logic using LOCAM user library routines. When linked with the LOCAM System, these libraries create Driver Programs. At this interactive level the program will require answers to user questions and/or Keywords with associated parameter values. See Figure 14.

The input is stored in the input database and can be recalled and edited to reflect Engineering and/or Manufacturing changes. Updates and subsequent re-processing can be controlled by the Revision History sub-system.

During the Interactive session a file, transparent to the user, is created, containing calls to the Manufacturing Engineering Database. At the end of the session he is asked to specify from a menu, the output documents and/or datafiles he wishes to produce, and also to specify immediate or defered batch processing options.

Macro Processor.

This module picks up the file created at the interactive session (one for each part number planned) and uses this to generate times, text and other information required for outputs, such as, Manufacturing and Processing instructions, Tooling Lists, Routing Data, etc. This is a two stage process all carried out in batch, and the results for each part number are written to temporary files.

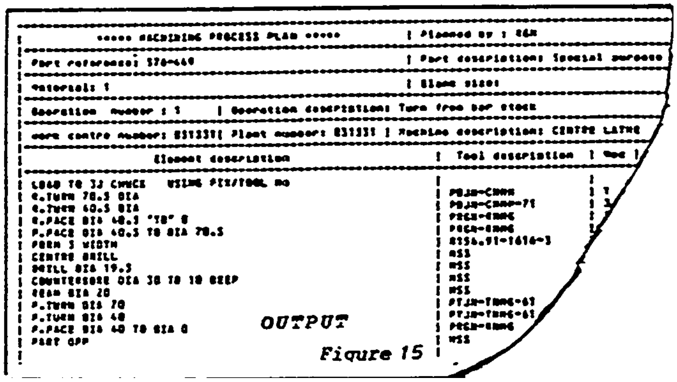
System Outputs.

This module organises the information supplied by the Macro processor, using the formats created by the Layout Generator. The previously specified documents or data files are then created. Output can be transmitted directly to other systems. See Figure 15.

```
  2) PLANed by                                                  N RGM
  3) DESCription                                                N Spec
  4) BSIZ(Batch Size)                                           N 100
  5) WNUM (Works Number)                                        N 1
 43) Start Weight (Kilos)                                       N 18
 41) Material code or group number ($HELP for list)             S 1
  6) OPNO (Operation Number)                                    N 1
  7) OPDE (Operation Description)                               N
 42) Machine code ($HELP for list)
 44) Default Gauging Rate
 45) No.of pieces per cycle
  9) GALW (Global Allowance)
 10) SALW (Set-Up Allowance)
 13) Enter Machining Details
)L/SJ
)RTR 75 70.5 105 TN'PDJN-CNMM' LC'Rgh.Turn'
)RTR 70.5 40.5 41 TN'PDJN-CNMM-71' LC'Rgh.'
)RFA 40.5 0 .9 TN'PRGN-RNMG' LC'Rgh.Fac
)FFA 40.5 70.5 TN'PRGN-RNMG' LC'Fin '
)FPG 40.5 3.5 5 5 TN'R156.91-1616-
)CDRL 8 TN'HSS' LC'Center Drill'
)DRL 19.5 110 TN'HSS' LC'Drill'
)CBR 30 10 TN'HSS' LC'Count-
)REAM 20 105 TN'HSS' LC'R-
)FTR 70 104 TN'PTJN-TNM'
)FTR 40 40 TN'PTJN-T'
)FFA 40 0 TN'PRGN-
)PD 70 20 TN'
)SEND
```

INPUT

Figure 14



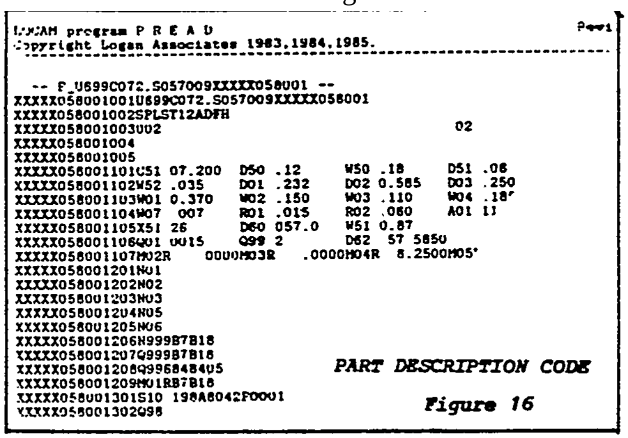
```
***** MACHINING PROCESS PLAN *****          | Planned by : RGH
Part reference: 576-660                     | Part description: Special purpose
Material: 1                                 | Blank size:
Operation number : 1    | Operation description: Turn from bar stock
Work centre number: 831331| Plant number: 831331 | Machine description: CENTRE LATHE
               Element description              | Tool description | ...
LOAD TO 3J CHUCK   USING FIX/TOOL NO            |
R.TURN 70.5 DIA                                 | PDJN-CNMM
R.TURN 60.5 DIA                                 | PDJN-CNMP-71
R.FACE DIA 60.5 "TO" 0                          | PRGN-ENMG
F.FACE DIA 60.5 TO DIA 70.5                     | PRGN-ENMG
FORM 3 WIDTH                                    | 8156.91-1616-3
CENTRE DRILL                                    | HSS
DRILL DIA 19.5                                  | HSS
COUNTERBORE DIA 38 TO 10 DEEP                   | HSS
REAM DIA 20                                     | HSS
F.TURN DIA 70                                   | PTJN-TNMG-61
F.TURN DIA 60                                   | PTJN-TNMG-61
F.FACE DIA 60 TO DIA 0                          | PRGN-ENMG
PART OFF                                        | HSS
```

OUTPUT

Figure 15

Automatic Logic Drivers (APP)

At its highest level, LOCAM has the potential to be driven by a Part Description Code which contains a Manufacturing Code, which is decoded through the Decision Tree, Action and M/C Tables. If no dimensional or note information has been provided in the PRC, then Features will ask questions interactively, i.e., the system will operate in Semi Automatic Mode. However, where drawings have been parameterized, the full dimensional note data is included in the PRC. The system will then operate in a fullY automatic mode. See Figure 16.



```
LOCAM program P R E A D                                                Page1
Copyright Logan Associates 1983,1984,1985.
-------------------------------------------------------------------------------

  -- F_U699C072.S057009XXXXX058001 --
XXXXX058001001U699C072.S057009XXXXX058001
XXXXX058001002SPLST12ADFH
XXXXX058001003U02                                  02
XXXXX058001004
XXXXX058001005
XXXXX058001101C51 07.200  D50 .12     W50 .18     D51 .06
XXXXX058001102W52 .035    D01 .232    D02 0.585   D03 .250
XXXXX058001103W01 0.370   W02 .150    W03 .110    W04 .18
XXXXX058001104W07  007    R01 .015    R02 .060    A01 11
XXXXX058001105X51 26      D60 057.0   W51 0.87
XXXXX058001106Q01 0015    Q99 2       D62  57 5850
XXXXX058001107M02R    0000M03R   .0000M04R  8.2500M05
XXXXX058001201N01
XXXXX058001202N02
XXXXX058001203N03
XXXXX058001204N05
XXXXX058001205N06
XXXXX058001206N999B7B18
XXXXX058001207Q999B7B18
XXXXX058001208Q9968484U5
XXXXX058001209M01RB7B18
XXXXX058001301S10 198A8042F0001
XXXXX058001302Q98
```

PART DESCRIPTION CODE

Figure 16

In both the above cases, the APP Driver generates answers to those questions that would normally be asked by the Interactive Driver. This enables the Interactive Driver to be run in a backgroud mode, with no human intervention, taking its answers from the APP generated file. Processing then continues in the background mode to generate documentation and data files. This can include automatic NC Library routines which LOCAM organizes through Features into unique NC programs. See Figure 17.

Automated Process Planning Options

The flowchart, Figure 5b, illustrates in graphic format a number of the major options available to the LOCAM user during and at the end of an automated process planning run.

URE Format, Box 1. This option supports the automatic re-formatting of Part Recognition Codes, generated by individual plants - or sections within one plant - to a common format, prior to automatic process PlanninG. It was provided to-meet the idiosyncrasies of applications at different locations without demanding absolute standardization of the PRC elements as applied to a common family group.

S10, *Box* 2. The executive program accepts the requirements for process planning file' containing Part Description Codes together with production requirements, such as- quantitY, due date and priority, from Business Systems. The executive is activated by a wake-up message passed by the Message Matching Utility (MMU). This MMU is used to pass information from one computer to another. The message also passes user parameters for requirements 'filename' and the number of jobs (partnumbers) to be grouped in a batch. when this task is complete the program continues to poll, at specified intervals, for the arrival of the next message.

VCREATE, *Box* 3. This process is firstly initiated by a_batch job organized by S10. Its principle function is to organise the dimensional and note information. including material specifications, of the Part Recognition Code into storage arrays. The program has optional start points for Material Re-starts, see Boxes 6 and 11.

APP LOCAM Driver Program, Box 7. The application area for the particular process is selected through a Driver Cross Reference table. Using the Family Group name, contained in the third element of the PRC, it selects the application area which contains the appropriate data and logic. The driver program processes manufacturing through Decision Action and M/C Block Tables and creates an internal file for subsequent manipulation by the Macro Processor suite, Box 14.

Additionally, it provides switching capabilities for intermediate processing on parallel systems. Also, it can suspend processing pending the resolution of any information mismatch. Currently these options are:

NC Don't Wait	Box 8
NC Re-start	9
/R	10
Material Re-start	11
Interactive Re-start "	12

NC Don't Wait, Box 8. If this option is selected (set in M/C Block Tables) a request is passed via the MMU for automatic or interactive part programming. However, LOCAM processing is not suspended, times are calculated by LOCAM, any tape time generated by the part program is discarded.

NC Wait Times, Box 9. In this case the message is Dassed, as in Box 8 above. However, in this instance a request for a tape time from the part program is initiated. Internal pointers are set so that returning times via the MMU can be matched to the correct operation. These times are automatically inserted into the process plan (see BOX 13). LOCAM continues to process operations.

/R. Switch, Box 10. This switch option runs processing up to and including a list of operations selected. It does not produce detailed operation planning. This switch option is being extended so that, for example /E will produce an estimate but will not generate NC tape information. Tape times will be generated on an 'NC Don't Wait' basis.

Material Re-start, Exit Box 11. One of the first activities in the LOCAM Driver is to automatically evaluate the raw stock requirements for a part. These requirements together with tolerances e.g. alternative specification or permissible raw stock oversize, are passed to the Material Inventory systems.

If the requirements are matched, LOCAM is allowed to proceed with the next process planning activity. However. if the requirements are not satisfied a message is written, with relevant details, to a Material Restart log file. The job is aborted.

From the Log file, a process planner can take action to ensure that the requirement can be satisfied, and/or restart the job in the batch queue. Depending on the circumstances this restart option (Box 6) Entry 1 can either run VCREATE or go straight into the LOCAM Driver.

Interactive Re-start Exit, Box 12 This exit is triggered by an automatic request for intervention by a process planner, or alternatively by a Part Recognition Code mis-match. A message is Written, with details, to the Interactive Restart log file and the jab processing suspended. The process planner can restart the job, carrying out interactive planning for the operation, before restarting the job to run automatically, (see Box 5) Entry 2.

Output Processing, Box 14 to 16. The options (common with LOCAM Interactive Process Planning) are:

Ten (maximum) document or data files per part processed.

Image for each file user definable.

Contents of each file user definable.

Ability to switch any file, on and off during processing run.

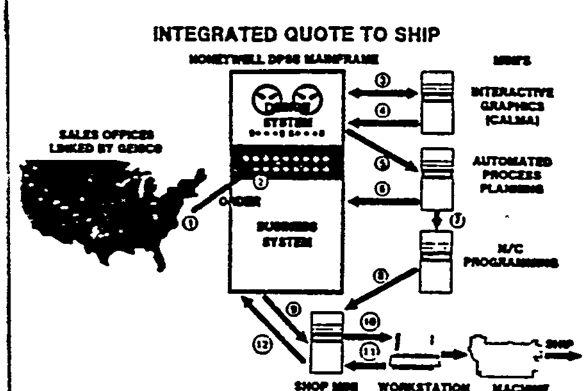
Immediate or Deferred processing switches.

Hove Data Files, BOX 17. When part processing is complete, the MMU, through appropriate communication software, will distribute document and data files to the various parallel systems, such as Production Scheduling, Factory Management, Shop Floor Control, etc.

Factory Management System. The responslblllty of a process planner is to create a process plan for the most economic method of manufacture. At the time of planning he is often unable to forecast future loads at any work station.

However, in the real world, the requested facilities or material may not be available when required. To overcome this, LOCAM is able to accept from scheduling systems the resource constraints and the part numbers involved.

These would be entered, via BOX 6 or Box 4, and be automatically re-planned. In the case of a machine re-start, alternative processes and/or work stations will be selected and a new process plan, with any NC tape images, will be created.



Acknowledgements to:
GE Steam Turbines
see Bibliography, Note 3

Figure 17

-

LOGIC GENERATOR

From our experience in using Decision Tree Tables to capture and flowchart complex manufacturing Logic, we have now developed a prototype Logic Generator. This is being implemented in co-operation with a major LOCAM user with a very advanced CIM system.

The objective is to provide the experts with powerful tools so that they can define a structured logic model and automatically generate Decision/Action Trees, Flowcharts, and where necessary, computer programs.

Traditionally, computer solutions have been undertaken by Management Information System type organizations. To do this they have attempted to understand the end users needs and then convert these needs into computer systems. Most users and some MIS departments have become dissolusioned by this approach. They *are* aware of practically unsurmountable communications problems that this creates. This is especially true with complex technical systems such as are involved in generative design and process planning.

It is the intention that the logic generator shall marry the needs of the user (his expertise) with pre-packaged computer expertise. It is recognized that the generator will evolve, like computer aided process planning, through successive levels.

The present developments are based on aligning the techniques of structured modeling, based on IDEF (ICAM Definition Language (5)) and the Decision, Action Tree Table capability.

System Structure

The system consists of five major modules, and these are:

- IDEF Generator
- Logic Box Generator
- Decision Tree Tables
- Command Blocks
- Program/Code Generator

IDEF Generator. This allows the user to interactively build a structured model of the activities. Figure 18. Currently, it uses IDEF O, and later versions will include IDEF 1 and 2. There are powerful facilities to create, edit and generate IDEF flowcharts.

The objective of the IDEF generator is to provide the user with a tool with which he can progressively define increasing levels of complexity of activities and their relationship. The IDEF model will drive a flowcharting capability, as a vital communication media between the user experts involved.

```
*****************************************
Logic Decision, Action, and Command Blocks
*****************************************

Enter Group Code  (? for Help)>  ?

Options

          $ED    - Edit input file
          $REV   - Revue input file
          $CHART - Print chart
          $....  - ... etc          !all options yet to be defined

Enter Group Code  (? for Help)>  BK
Enter Title of Main Activity  >  Outline: Engineering to finished Buc
Logic Node Type(? for Help)   >  ?

Options

          IDEF   - Activity Diagram
          LB     - Logic Block
          DAB    - Decision/Action Block
          CB     - Command Block
          MBDB   - Machining/Decision Block  !existing program

Logic Node Type(? for Help)   >  IDEF

*** Logic for Level BK0 ***
Title for Box 1      >  Bucket Engineering
Title for Box 2      >  Bucket Mfg. Eng.
Title for Box 3      >  Bucket Manufacture
Title for Box 4      >  $

***    Box 1 Details     ***
Input       >  Bucket Specification
Input       >  $    !$options to look at database, help files ...etc

Control     >  $    !$options to look at database, help files ...etc

Output      >  PRC
Output      >  $    !$options to look at database, help files ...etc

Mechanism   >  $    !$options to look at database, help files ...etc

    Inputs Controls Outputs Mechanisms are:

             I $1 Bucket Specification
             O $2 PRC

***    Box 2 Details     ***
Input      >  $2
Input      >  $

Control    >  $

Output     >  Process Planning
Output     >  $
```

LOGIC GENERATOR

Figure 18

Loaic Box Generator. With this module the internal activities of any IDEF Box can be logically defined. This uses a variant of existing Decision Tree Tables and can also output Command Blocks. These Blocks contain any LOCAM command or computer language macros. See Figure 19.

Also see Figure 8 for examples of current Decision and Action Tree Table usage.

This logic box approach overcomes a major obstacle to the usefulness of IDEF in that the user will be able to describe the internal logic of an IDEF activity box by using Decision Tree facilities. These Tables can already generate flowcharts and have powerful edit and enquiry facilities so that logic changes be easily introduced. These changes will also be logged using the LOCAM Revison History modules.

```
Enter Logic Node Number        > BK02231
Enter Description              > Bar/Shroud Bucket Selec
Logic Node Type(? for Help)    > DB

*** Logic for Level BK02231 ***

    Inputs Controls Outputs Mechanisms are:

                 I $2    PRC
                 C $10.3 Final Bucket Selection Paramete
                 O $11   Bucket Type
                 I $16   Bar/Shroud

Input            > $2
Input            > $

Control          > $10.3/S
Control $10.3.1 > N5
Control $10.3.2 > Z5
Control $10.3.3 > L3
Control $10.3.4 > R21
Control $10.3.5 > Z4
Control $10.3.6 > Z14
Control $10.3.7 > $
Control          > $

Output           > $11
Output           > $

Mechanism        > $

*** Create Decision-Block Logic ***

D  5 >Z14 EQ 1        A  5    D 10
D 10 >N5  EQ 65 68 70 71 78 80 403          D 15    *
D 15 >Z5  EQ 1        D 20    *
D 20 >L3  GE 0.8      D 25    *
D 25 >R21 GE 0.187    A 10    D 30
D 30 >Z4  EQ 1        A 15    A 20

If D 15 not positive what now > D 30
If D 20 not positive what now > D 30

*** Create Action Block Logic ***

A  5 >01
A 10 >ZM
A 15 >03
A 20 >ZB

Enter Option      > 3
```

LOGIC BOX GENERATOR

Figure 19

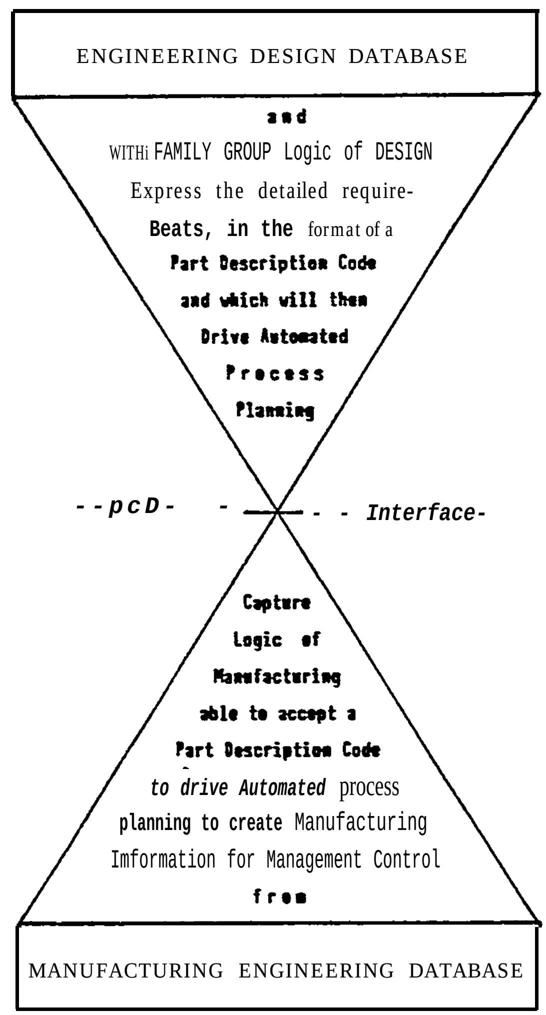
Decision Tree Tables. These are an enhanced version of the present Tables and are called from within the Logic Generator. They are used by the Program/ Code Generator to create a runtime program.

Command Blocks. These will be referenced by the Logic Box and Decision Tree Tables to recall LOCAM commands and computer language macros. The commands and macros will be expanded and handed on to the Program/Code Generator.

Program/Code Generator. In the prototype, now under test, Decision Tree Tables can run in an interpretive or compiled mode. In the latter mode they generate program code, currently Fortran 77, but this will be extended to cover the main high level languages.

GENERATIVE DESIGN

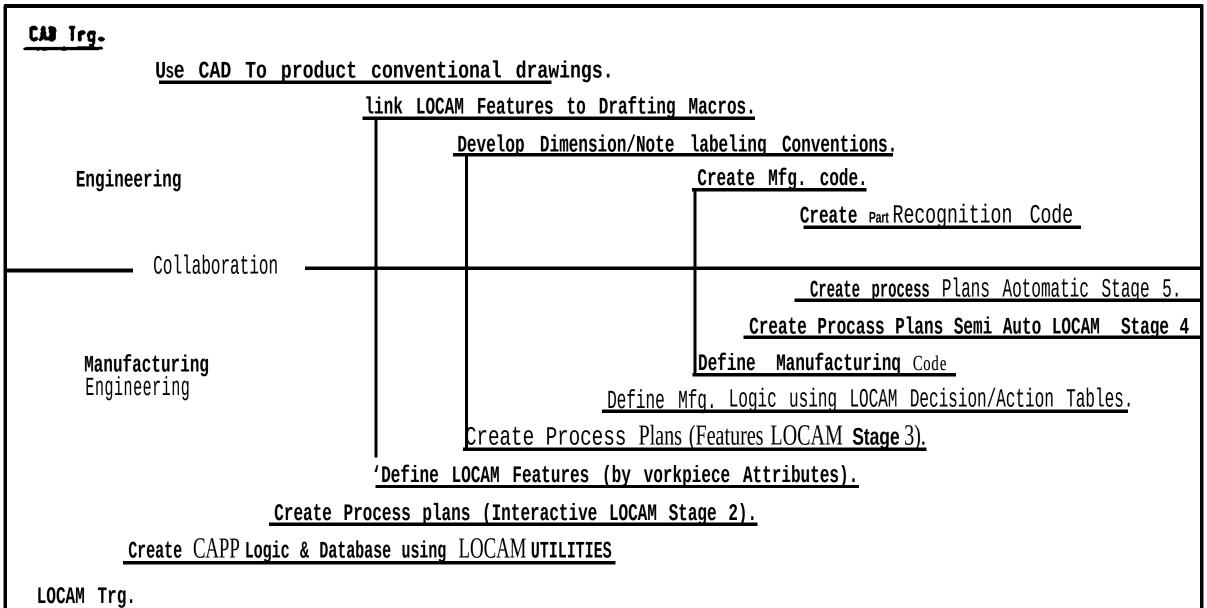
The requirement for Engineering to be able to generate a Part Definition Code (PDC) for Automatic process planning, is the key to Computer Integrated Manufacture (CIM). It will require that Engineering and Manufacturing collaborate as the PDC evolves, See Figure 20 The collaborative Steps to Automated Process Planning, on the following Page.



GENERATIVE *DESIGN TO* GENERATIVE *PROCSSS PLANNING THE=* KEY TO *TOTAL CIM*

Figure 21

Engineering will need to use Generative Design that will ensure that the application of Engineering Standards are also conditioned by Manufacturing requirements. Figure 21 above is a schema of this approach.



COLLABORATIVE STEPS TO AUTOMATIC *PROCESS PLANNING* *Figure 20*

CONCLUSION

Although these latest developments have only recently started, the extention of the concepts of logic capture and generation are having a dramatic impact on the ability of ordinary humans to describe and capture their intuitive experience. They are being provided with the tools to build expert manufacturing systems. Once the knowledge base is in place, that is, the computer has acquired experience, there is a possibility that the structured Part Recognition Code can be replaced with more random descriptions. If so, an Artificial Intelligence system will have evolved.

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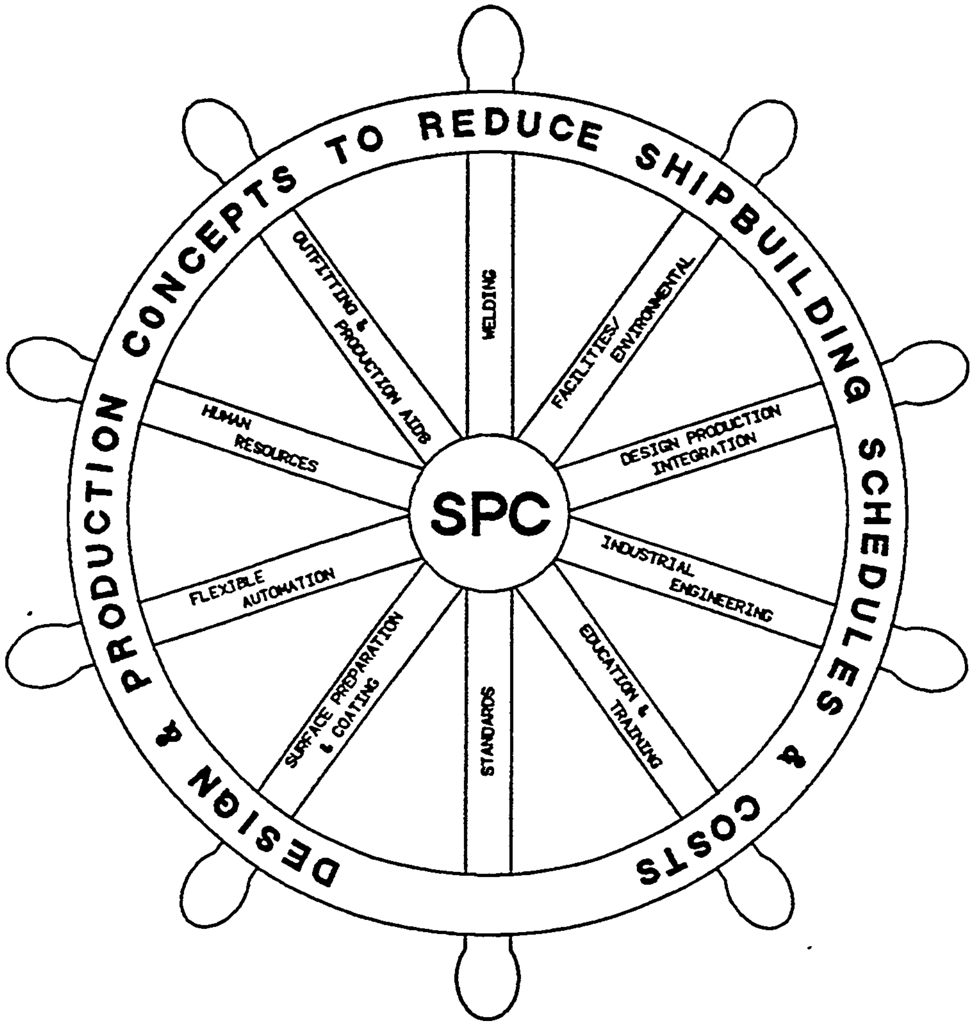
NATIONAL SHIPBUILDING RESEARCH PROGRAM

1986 SHIP PRODUCTION SYMPOSIUM



PAPER NO. 19

THE ESTABLISHMENT OF SHIPBUILDING CONSTRUCTION TOLERANCES

BY: J. D. BUTLER
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AUGUST 27-29, 1986

1986 SHIP PRODUCTION SYMPOSIUM

THE ESTABLISMENT OF SHIPBUILDING CONSTRUCTION TOLERANCES

J. D. BUTLER AND WARREN, Newport News Shipbuilding

ABSTRACT

Predictable and economically achievable construction tolerances are a prerequisite for the establishment of effective shipbuilding procedures, as unproductive rework and on-the-job fit-ups are the alternative. This paper reviews the factors to be considered in the development of tolerances and suggests the use of variation merging equations and variation simulation as techniques that can be used to formulate a practical system of tolerances.

INTRODUCTION

The adoption of modular construction methods for shipbuilding can impact the way designers develop and specify tolerances during the design phase. Historically, design tolerances have been developed on the basis of functional system requirements and the knowledge that the ship would be built in a system-oriented fashion. With this construction technique the ship is built in a linear manner where each piece is installed "to fit" existing conditions, relative to final design tolernaces. Using modular construction methods, the ship is assembled by module or zone, with system components being built and installed in various units in a simultaneous, parallel, and independent manner. Compared to system-oriented techniques, this results in units that are typically much larger and contain more structure and distributive system connection points. For modular construction methods to be effective, units must be joined with all connections being made within tolerance. The application of design tolerances during the initial installation of items in modules (as is typical for system-oriented methods) will not guarantee a successful fit when modules are joined because of the added variation that can occur during the joining process. It is therefore desirable, during the design phase, to analyze the normal variations that occur during the processes of modular construction to determine the potential for out-of-tolerance situations.

To establish tolerances that are appropriate for modular construction methods, the designer can develop both the design and the manufacturing sequence as part of the design process. This will ensure that proper consideration is given to the process variations inherent in modular construction methods. Once the sequence has been developed, the designer can identify individual process variations and compare their overall effect with the required design tolerances. If this comparison indicates that the expected manufacturing variations are greater than the design tolerances, then the designer can take action to bring the tolerances and manufacturing variations together by either:

- Changing the design,
- imposing interim manufacturing tolerances,
- changing the design tolerances, or
- improving the accuracy or consistency of the manufacturing processes.

One approach that the design engineer can use to analyze the variations having an impact upon the design is based on statistical principles and applies the techniques of variation merging equations and variation simulation to the analysis problem. With variation merging equations, the mean and variance for the interim production processes are geometrically added to provide an estimate for the mean and standard deviation of the entire manufacturing process. When the mean and standard deviation of the production processes are unknown, or if any of the processes can not be represented as an independent random variable, then variation simulation can be used to generate a solution based on a series of randomly generated values within a specific range.

This paper will concentrate on tolerance determination, evaluation, and identification with discussions on the use of tolerance budgets, reference lines, self-contained systems, design fouls, and individual component design. An introduction to the development of variation merging equations and variation simulation is presented as a foundation for these discussions.

VARIATION MERGING EQUATIONS AND VARIATION SIMULATION

Variation merging equations and variation simulation can be used to predict the probability of out-of-tolerance conditions of an assembly for a given set of tolerances and assembly sequence. The use of variation merging equations was introduced to the shipbuilding industry in references such as (1) and (2), primarily as a technique for analyzing assembly sequences and determining the amounts of excess material required to minimize rework. These references only consider linear combinations of independent random variables involving ship structure, which is adequate for a large number of shipbuilding applications. The more general development of variation merging equations however, can be applied to more complicated geometric situations involving both independent and dependent random variables for either ship structure, outfitting or combined structure and outfitting assemblies. Variation simulation is a technique that applies variation merging equations with either estimated variations and distributions for each variable or, with distributions generated ramdom number generator to the analysis. In cases with dependent random variables, variation simulation may be the only practical way to reach a solution.

Variation merging equations predict the probability of an out-of-tolerance condition by approximating the distribution of potential variations of the complete process. Reference (1) demonstrates that the variation of many shipbuilding processes reasonably approximate a normal distribution. A normal distribution can be determined from the mean (x) and standard deviation(s) of the process if they are known. With variation merging equations, the mean of the complete process is obtained by geometrically adding the means for all of the interim processes that lead to the complete process. The standard deviation is determined by summing the variances (the variance is the standard deviation squared) of the same interim processes. For the discussions that follow in the remainder of this paper, all process variations will be considered to be represented by normal distributions.

The concept of merged equations is most simply demonstrated by considering the joining of two flat plate parts as shown in figure 1. Each plate has a mean length and standard deviation associated with its manufacturing process. For this example, the mean will be considered to be the design length of the plate. Both parts were manufactured with the same process and therefore have the same standard deviation. Using a standard deviation of 0.02 will mean that 99.9%(3S) of similarly manufactured plate parts will be within +1/16″ of the mean dimension as indicated in figure 1. The overall length of the joined part is the length of Part A plus the length of Part B. The mean length of the of joined plate is found by adding the mean lengths of parts A and B:

$$\bar{x}_{AB} = \bar{x}_A + \bar{x}_B = 96'' + 120'' = 216''.$$

Similarly, the standard deviation of the joined plate, S_{AB}, is found by summing the variances of the individual parts:

$$s_{AB}^2 = S_A^2 + S_B^2 = (.02)^2 + (.02)^2 = 0.0008, \quad \text{and}$$

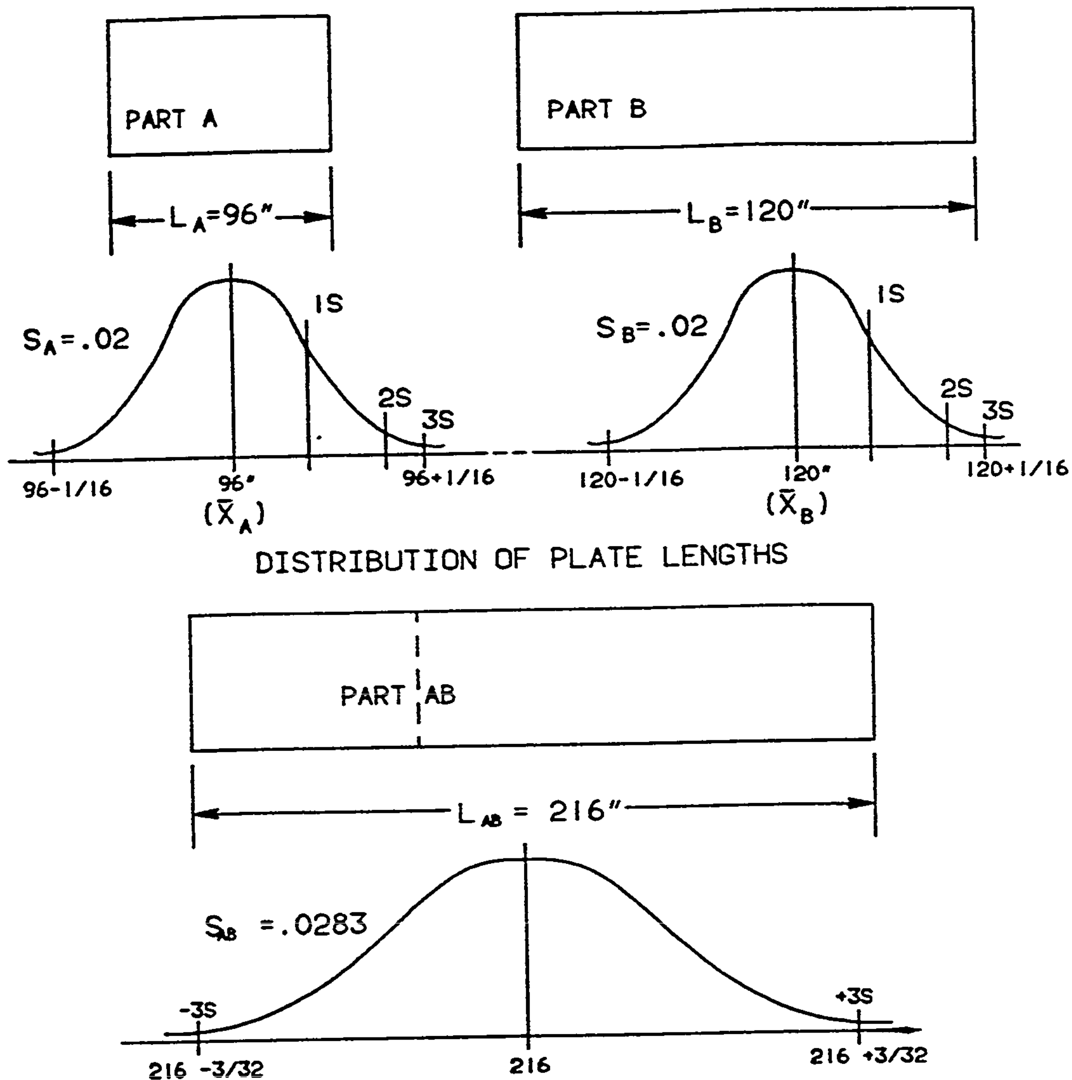
taking the square root resulting in:

$$s_{AB} = 0.0283.$$

Considering this process to be represented by a normal distribution, 99.9% of all similarly joined plate parts will be their design lengTh +3/32″. This is an extremely simplified example and does not consider the effects of shrinkage across the weld, flatness, squareness, and so on. This type of analysis is useful at the manufacturing level for determining the amount of extra material to be added (or subtracted) from the design dimension of plate parts so that at the completion of the panel assembly the required length is attained with the least number of assemblies ***requiring*** rework.

Figure 2 illustrates another merged equation example. The object of this example analysis is to predict the distance between continuous stiffeners such that intercostal stiffeners can be cut to fit with a minimum number of intercostal stiffeners requiring rework. For this example, the mean and standard deviation of the distance between a stiffener and a reference line must **be** known. The mean distance will be taken as the design location and the standard deviation to be 0.04. This means that 99.9% of the stiffeners will be within +1/8 of the design location. The distance between the stiffeners can be geometrically expressed as D=A-B (ignoring the thickness of the stiffener web). The mean distance between sttiffeners ***is*** similarly expressed as $\bar{x}_D = \bar{x}_A - \bar{x}_B$. **The standard deviation of the distance between bars is found by** summing the variances of the two stiffener locations:

$$s_D^2 = S_A^2 + S_B^2.$$



DISTRIBUTION OF JOINED PARTS AB

GEOMETRIC EQUATION: $L_{AB} = L_A + L_B$

MEAN OF AB: $\bar{X}_{AB} = \bar{X}_A + \bar{X}_B$

$= 96" + 120" = 216"$

VARIANCE OF AB: $S^2_{AB} = S^2_A + S^2_B$

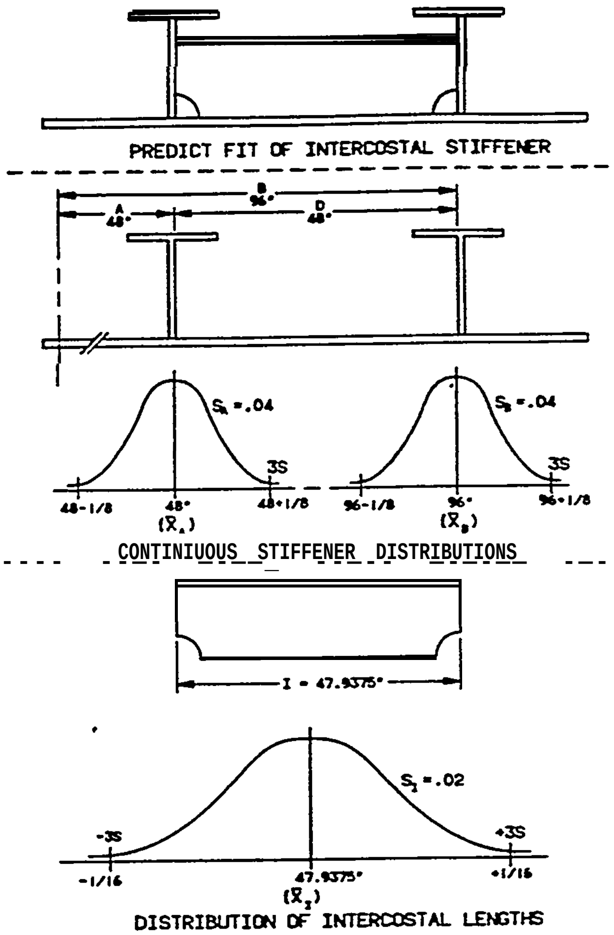
$= .02^2 + .02^2 = .0008$

STANDARD DEVIATION: $S_{AB} = \sqrt{0.0008} = 0.0283$

VARIATION MERGING EQUATIONS AND DISTRIBUTIONS FOR JOINING TWO FLAT PLATE PARTS

FIGURE 1

This produces a distribution that indicates that 99.9% of time the stiffeners will be within ±3/16″ of their design location.



STIFFENED PANEL ASSEMBLY: NORMAL DISTRIBUTIONS FOR CONTINUOUS STIFFENER LOCATIONS AND INTERCOSTAL STIFFENER LENGTH :

FIGURE 2

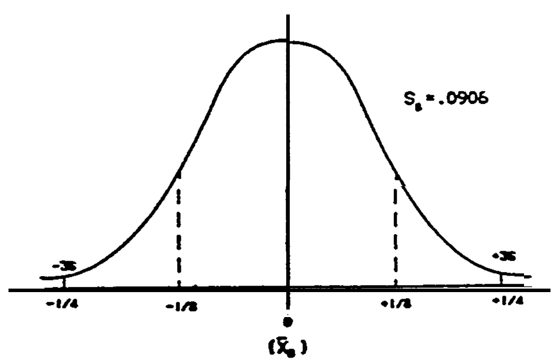
This fact by itself is of little value for the problem at hand. The variation of the intercostal length and the allowable root opening at the ends of the intercostal must also be considered in order to determine the potential for rework in fitting the intercostal.

Figure 3 illustrates the intercostal with the gap lumped at one end to simplify the example. In reality this gap would be split between both ends. The gap, g, is the variable that will indicate the need for rework and can be geometrically expressed as g=B-A-I. If g is negative then the intercostal and the continuous stiffener overlap and the intercostal must be reworked by trimming one or both ends to make it fit. If the gap is greater than the maximum allowable root gap then rework must be done by adding material to the end of the intercostal.

Using the values in figure 3, the mean gap is found to be 0.0625” and the standard deviation is found to be 0.06. Under a normal distribution, 15% of bars will be reworked by trimming and less than 1% by adding material. These rework figures can be manipulated by adjusting the manufactured length of the intercostal. For example, shortening the length of the bars shifts the entire distribution curve to the right. Such a shift results in a larger area under the distribution curve in the ‘no rework″ zone, which would appear beneficial. However, to determine the best length to cut the intercostal, the costs of each type of rework must be considered and the most cost-effective proportion of rework/no rework found. Such as analysis would necessitate a more indepth study than is required for the purpose of this paper.

This type of analysis can be applied to both design and manufacturing situations for a variety of purposes. It can be used for comparing assembly sequences, determining excess material requirements, and determining design tolerances that are acceptable for manufacturing.

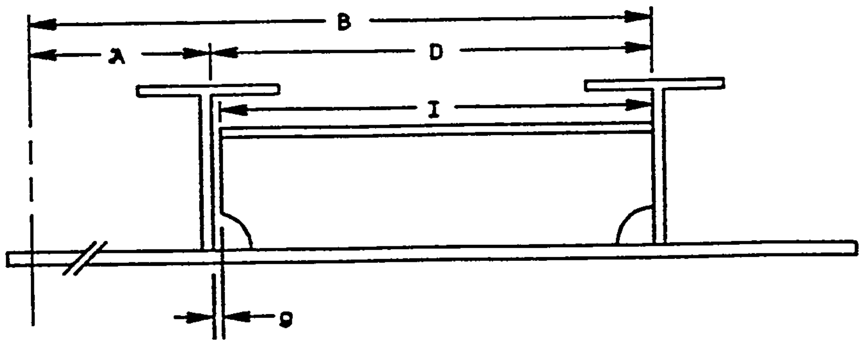
The analysis can also be applied to more than the structural applications presented as examples in both this paper and references (1) and (2). Figure 4 illustrates a situation where two double-bottom units will be built, outfitted separately, and then joined. For design and planning purposes, there would be great value in knowing the potential mismatch between the heat exchanger flange and the pump flange, also considering the manufacturing variation of the pipe itself. The merged equations for this problem are presented in figure 4 and the resulting distribution is shown in figure 5.



DISTRIBUTION OF PIPE/HEAT EXCHANGER MISMATCH ;

FIGURE 5

There are numerous questions that can be asked about this problem many of which will be discussed in the later sections. These merged equations will be used to evaluate proposed changes.



GEOMETRIC EQUATION: $g = D - I = B - A - I$

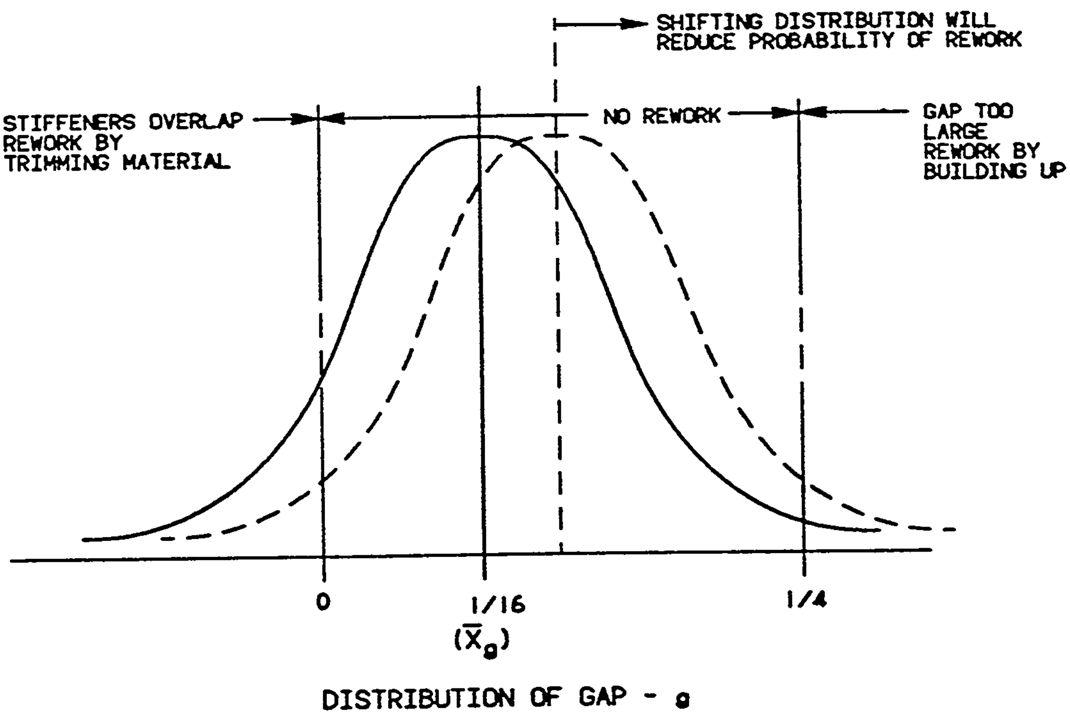
MEAN OF g: $\bar{X}_g = \bar{X}_B - \bar{X}_A - \bar{X}_I$

$= 96'' - 48'' - 47.9375'' = .0625''$

VARIANCE OF g: $S_g^2 = S_B^2 + S_A^2 + S_I^2$

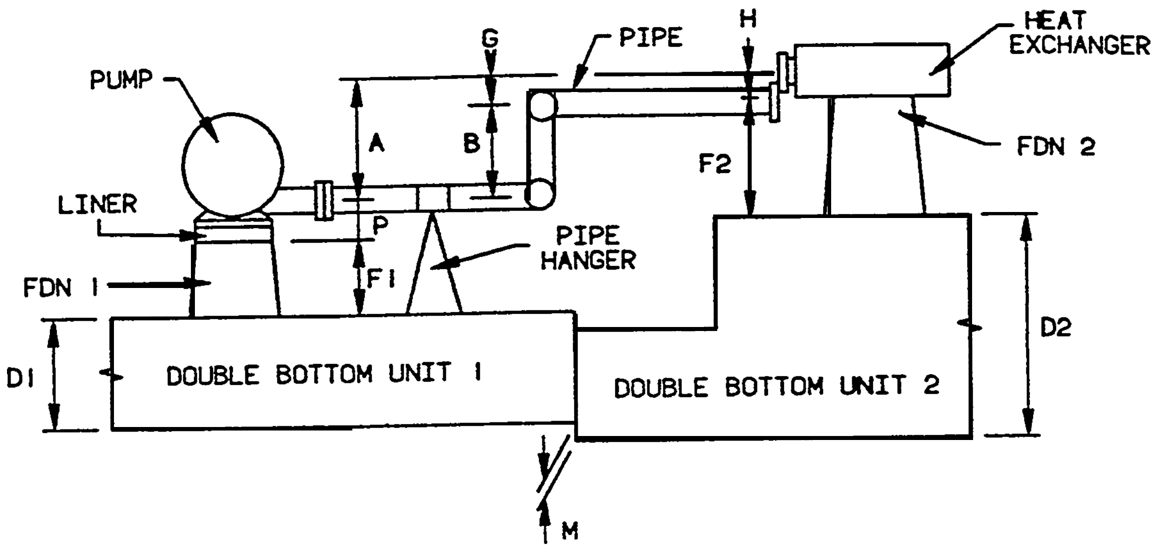
$= .04^2 + .04^2 + .02^2 = .0036$

STANDARD DEVIATION: $S_g = \sqrt{.0036} = .06$



VARIATION MERGING EQUATION FOR INTERCOSTAL STIFFENER FIT-UP AND PROBABILITY OF REWORK

FIGURE 3



ELEVATION VIEW

DETERMINE-POTENTIAL MISMATCH BETWEEN PIPE AND HEAT EXCHANGER.

ASSEMBLY SEQUENCE

BUILD D.B. UNIT I
BUILD & INSTALL FDN. I
INSTALL PUMP

BUILD D.B. UNIT 2
BUILD & INSTALL FDN. 2
INSTALL HEAT EXCHANGER

JOIN DB I & DB 2
INSTALL PIPE

GEOMETRIC EQUATIONS: $G = A - B$

$M + D1 + F1 + P + A = D2 + F2 + H$

THEREFORE: $G = D2 + F2 + H - M - D1 - I - P - B$

MEAN OF $= \bar{X}_{D2} + \bar{X}_{F2} + \bar{X}_{H} - X_{M} - X_{D1} - X_{F1} - X_{P} - X_{B}$

$= 96 + 48 + 12 - 0 - 48 - 36 - 18 - 54 = 0$

VARIANCE OF $S_G^2 = S_{D2}^2 + S_{F2}^2 + S_H^2 + S_M^2 + S_{D1}^2 + S_{F1}^2 + S_P^2 + S_B^2$

$= .04^2 + .02^2 + .01^2 + .02^2 + .04^2 + .02^2 + .01^2 + .06^2$

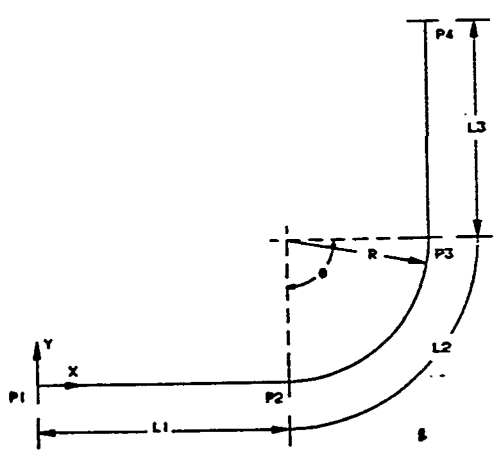
$= .0082$

STANDARD DEVIATION: $S_G = .0906$

VARIATION MERGING EQUATION FOR PIPE/HEAT EXCHANGER MISMATCH
DURING JOINING OF DOUBLE BOTTOM TANK ASSEMBLIES

FIGURE 4

The Procedure for developing merged equations by adding terms in a linear manner is simple and valid if all of the variables are random, independent, and have approximately normal distributions. There are many situations, however, when the variables can not be added in a linear fashion nor are all of the variables necessarily independent. For example, the analysis in figure 4 ignores the effects of flatness and levelness of the tank top and the foundation in determining the location and orientation of the pump flange. All together there are six degrees of freedom that must be considered to accurately describe the location and orientation of the pump flange. The determination of these six degrees of freedom involves more than linear combinations of variables, many of which are coupled or dependent on one another. A slightly simplier example can be used to demonstrate the same problem. Consider the problem of manufacturing a pipe with one bend and determining the location of one end of the pipe relative to the other end of the pipe. The mathematical equation for expressing the relative end point locations is given in figure 6. This expression is more complicated than the linear combinations of variables and in some manufacturing scenarios the radius of the bend and the bend angle could be considered dependent on the length of the straight sections of pipe. The prevalent method of applying merged equations is not valid in this case, therefore the theory must be expanded.



GEOMAETRIC EQUATIONS

P4X - LI + RISING + L3.COSE

P4Y = R(I-Cose) + L3.SING

MANUFACTURED PIPE SEGMENT WITH ONE BEND. EQUATION FOR LOCATING RELATIVE END POINTS

FIGURE 6

Reference (3) presents a solution that can be applied to the more general case of approximating the mean and standard deviation of a complete process. Mathematically, the problem can be stated as approximating a function

$$Y = f(X_1, X_2, \ldots, X_n)$$

where X. is a random variable. For the pipe bending problem in figure 6, $P4_x$ is a function of L_1,R,e and L_3. In other words

$$Y=P4_x=f(L_1,R,\theta,L_3)=L_1+R\sin\theta+L_3\cos\theta$$

where L ,R,ø, and L_3 are random **variables. The approximation is based** on a first-order Taylor series expan sion of Y about the point $x_1, x_2, \ldots, X_n$. This can be represented as

$$Y=f(x1,x2, \ldots xn)+$$

$$\sum_{i=1}^{n}\left[\frac{\partial f}{\partial x_i}(\bar{x}_1,\bar{x}_2,\ldots,\bar{x}_n)\right](X_i-\bar{x}_i).$$

This is exactly of the form

$$Y=a_0+\sum_{i=1} a_i(X_i-\bar{x}_i)$$

where

$$a_0=f(\bar{x}_1,\bar{x}_2,\ldots,\bar{x}_n)$$

and

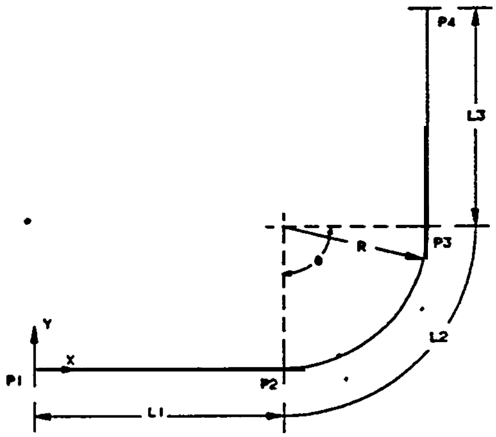
$$a_i=\frac{\partial f}{\partial x_i}(\bar{x}_1,\bar{x}_2,\ldots,\bar{x}_n).$$

Thus $\bar{x}_Y = a_0$ **and**

$$S_Y^2 = \sum_{i=1}^{n} a_i^2 S_{X_i}^2 + \sum_{\substack{j=1\\ i\neq j}}^{n}\sum_{i=1}^{n} a_i a_j S_{ij}.$$

If the X_i's are independent then the covarianc e, S_{ij} becomes zero and the entire double summation term drops out. Reference (3) states that the Taylor series approxtimation is good if Y is not too far from linear within the region that is within one standard deviation of the mean.

Figure 7 demonstrates the use of these equations for the pipe illustrated in figure 6, given all of the variables are independent. Developing the equation for the entire pipe in figure 4 would get quite complicated, involving several potential angles of rotation at each bend. Additionally, there is a twisting rotation that must be considered if the pipe were to have bolt holes on the flanges of the Pip[e] that must align with holes on the pump or heat exchanger. As an aside, problems this intricate would be well suited for the capabilities of a computer.



GEOMETRIC EQUATIONS:

$$P4X = L1 + R \cdot SIN\theta + L3 \cdot COS\theta$$

$$P4Y = R(1-COS\theta) + L3 \cdot SIN\theta$$

MEANS:

$$\bar{X}_{P4X} = \bar{X}_{L1} + \bar{X}_R SIN\bar{X}_\theta + \bar{X}_{L3} COS\bar{X}_\theta$$

$$\bar{X}_{P4Y} = \bar{X}_R(1-COS\bar{X}_\theta) + \bar{X}_{L3} SIN\bar{X}_\theta$$

VARIANCES:

$$S^2_{P4X} = S^2_{L1} + S^2_R SIN\bar{X}_\theta + S^2_\theta[\bar{X}_R COS\bar{X}_\theta - \bar{X}_{L3} SIN\bar{X}_\theta] + S^2_{L3} COS\bar{X}_\theta$$

$$S^2_{P4Y} = S^2_R(1-COS\bar{X}_\theta) + S^2_\theta[-\bar{X}_R SIN\bar{X}_\theta + \bar{X}_{L3} COS\bar{X}_\theta] + S^2_{L3} SIN\bar{X}_\theta$$

VARIATION MERGING EQUATION FOR MANUFACTURED PIPE SEGMENT USING INDEPENDENT VARIABLES

FIGURE 7

In figure 7, all of the varibles were considered to be independent. However, as mentioned above, there are some manufacturing sequences that would make the angle, θ, and the radius of the bend, R, dependent on the length of the straight sections of the pipe. In this case, the covariance between the dependent variables must be known. The covariance between dependent varibles is often difficult to determine and is well suited for solution by variation simulation.

Variation simulation is a technique that applies the variation merging equations using either estimated distributions or distributions generated using random number techniques such as the Monte Carlo technique. The simulation methods using randomly generated distributions can be used to solve the problems with dependent variables. The simulation would select a value for the first variable and calculate results based on a randomly generated distribution of the second variable. This process is reversed and then repeated as necessary to determine the covariance between the dependent variables. The remainder of the problem is then solved.

variation merging equations can be useful for a variety of reasons, as stated above. The use of merged variation equations during design to establish tolerances will be dealt with in more detail in the following sections. However, there are some prerequisites to using merged variation equations effectively. First, an assembly sequence must be determined. Secondly, distributions for each of the variables must be known or reasonably estimable. The lack of concrete statistical data on a process does not need to deter the engineer from using merged variation equations. Distributions for many variables can be estimated or randomly generated based on common sense and discussions with the manufacturing trades. Approximate results based on such estimated distributions can be used with confidence for comparative purposes during design and planning stages. However, analytical results based on these approximations can only be used with caution until the distributions are verified.

TOLERANCES

Tolerances can be assigned during the design phase to ensure that the functional requirements of a particular design are met while still providing the shipbuilder with allowances for variation. The adoption of modular construction methods requires different ways of developing and identifying design tolerances due to the increased number of critical connection points. Techniques such as tolerance budgets and reference line systems are suggested as ways to control tolerances and affect the way tolerances are identified. The evaluation of design tolerances for manufacturing with modular construction is discussed in sections on self-contained systems, design fouls, and individual component design. These concepts can have the most impact if they are studied and incorporated during the design stage.

Tolerance Identification

Design tolerances are imposed to ensure that the system performs as required by the specifications. Manufacturing tolerances are interim limits imposed to ensure that the variations of the manufacturing processes do not exceed the design tolerances. Considerable confusion can be avoided if a tolerance is specifically identified as either a manufacturing tolerance or a design tolerance. There are several reasons for this. It may occasionally be acceptable to violate manufacturing tolerances, they are established as guidelines in the first place, whereas design tolerances usually can not be violated without careful study. Also, there may be a need to re-engineer or re-plan the project. Having tolerances properly documented can make this job easier because there is no dispute over what is really required by design. Likewise it is important to identify the need for the tolerance, or what it is really relative to. For example is it important that a piece of equipment be 10 feet +1/8 inch off centerline or is it really only important that two pieces of connecting *equipment* be aligned within 1/8 inch of each other and they both fit into the same general area which is approximately 10 feet off centerline. The distinction needs to be made clear. It is often required and beneficial to use local reference lines to locate items during modular construction. However it is also important to idsntify what the overall tolerances are and when they apply. Other reasons for properly identifying tolerances will become apparent in following sections.

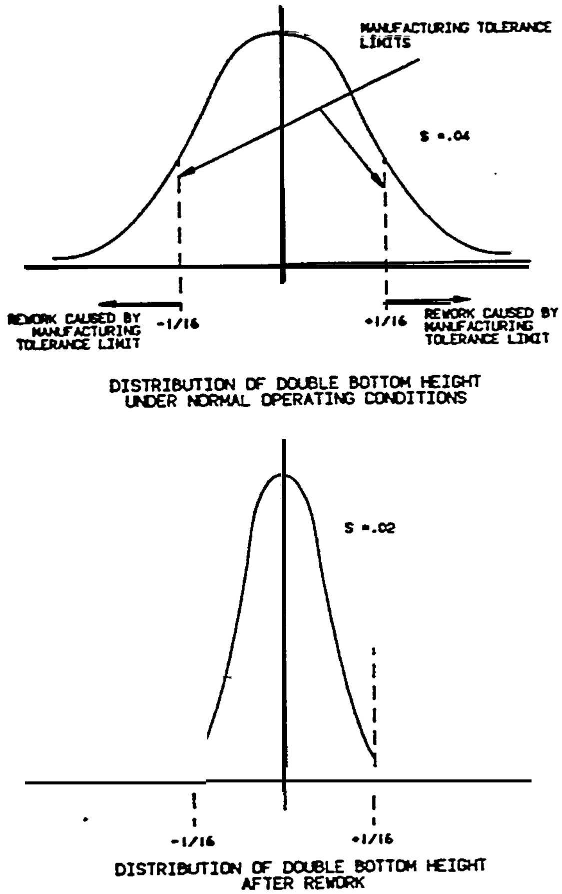
Tolerance Budgets (Controlled Tolerance Stack-up)

Tolerance stack-up occurs when independently manufactured components of a system and any associated support structure are brought together at the different levels of the construction process. Each component is built with some amount of allowable variation from the design *dimensions.* As the pieces are brought together, these variations can rapidly add up to the point where rework(must be preformed to correct an out-of-tolerance condition or to make mating components of a system fit. To control tolerance stack-up, manufacturing tolerance budgets can be established to limit the amount of variation that may occur at each stage of the construction process. The manufacturing tolerance budgets at each of the independent interim product levels are typically more restrictive than the final design tolerances that may apply to each of the individual components.

Tolerance stack-up is less of a problem with system-oriented shipbuilding methods due to fewer dissimilar interim products as compared to modular construction methods. System-oriented shipbuilding is based on constructing the ship in a manner such that all structure is built first, requiring mating structure to meet mating structure. Afterwards, each of the outfitting systems is installed on an individual basis around the *existing* structure *on a "to* fit work" basis. The various system components can be templated against structure and mating system components prior to manufacture. This practice of building to existing items reduces the tolerance stack problem and allows the utilization of final design tolerances from the outset. During modular construction interim products consist of both structure and outfitting systems. These interim products must *come* together with the structure and all systems fitting. The luxury of installing systems "to fit" is gone. To ensure that interim products match and are within design tolerance, the variations of all components must be predictable and controlled. The ideal design/manufacturing scenario would be to have the sum of the component variations stack up to less than the final design tolerance so that under normal operating conditions additional tolerances are not required. In the event that this is *not* the case, tolerance budgets should be considered.

Manufacturing tolerance budgets can be determined by the designer and the shipbuilder through careful planning of the assembly sequence considering the expected variations of the specific manufacturing tasks including, if required, the best time for rework. Merged equations/variation simulation can be used to analyze the assembly sequence and determine reasonable tolerance budgets.

For example, suppose there is a +1/8 inch design tolerance on the gap, g, calculated in figures 4 and 5.There is a 17% probability that this tolerance will be exceeded, potentially forcing rework of some type to correct the misalignment. For this particular problem, the most obvious solution would be to adjust the height of the liner to obtain the appropriate fit. This solution will be discussed in more detail in a later section. However, in situations where adjustments are not available through such means as *liners,* it may be desirable to establish a set of manufacturing tolerances. Examining the merged equation of the variances, it can be seen that the accuracy of the tank top height and the pipe contribute the most to the overall distribution. The largest effect on the overall distribution can be made by applying manufacturing tolerances on these interim products. The potential for rework and the relative cost of rework on each of these interim products should be compared to find the most cost effective solution. Consider the case of the tank top height. The distribution of the double bottom units under normal operations is given in figure 8.



DISTRIBUTION OF VARIATION IN DOUBLE BOTTOM TANK HEIGHT BEFORE AND AFTER REWORK TO SATISFY TOLERANCE LIMITS

FIGURE 8

By imposing manufacturing tolerance limits of +1/16 inch it can be seen that 12% or the units would require rework. After rework, a new distribution results that can be used to calculate a new gap distribution. The cost of imposing manufacturing tolerances on the double bottom units can be compared to the cost of imposing manufacturing tolerance limits on other processes, such as the bending of the pipe, to achieve the most cost effective solution. The analysis may prove a design to be very expensive to build. However, if this type of analysis is performed during the design stage, it may be possible to modify the design to more adequately suit producibility.

Reference Line Systems

The ***use*** of a predetermined set of reference lines can reduce tolerance stack-ug problems and provide a datum for identifying design and manufacturing tolerances. A reference line can be used throughout the manufacturing process as a common datum for all dimensions. Interim products may also be aligned by matching corresponding reference lines. The selection of the reference lines, thair use, and implementation throughout the manufacturing process requires careful planning. The use of reference lines can impact the assembly sequence, achievable tolerances, and datum points for dimensioning on design drawings, and should therefore be considered during the design stage.

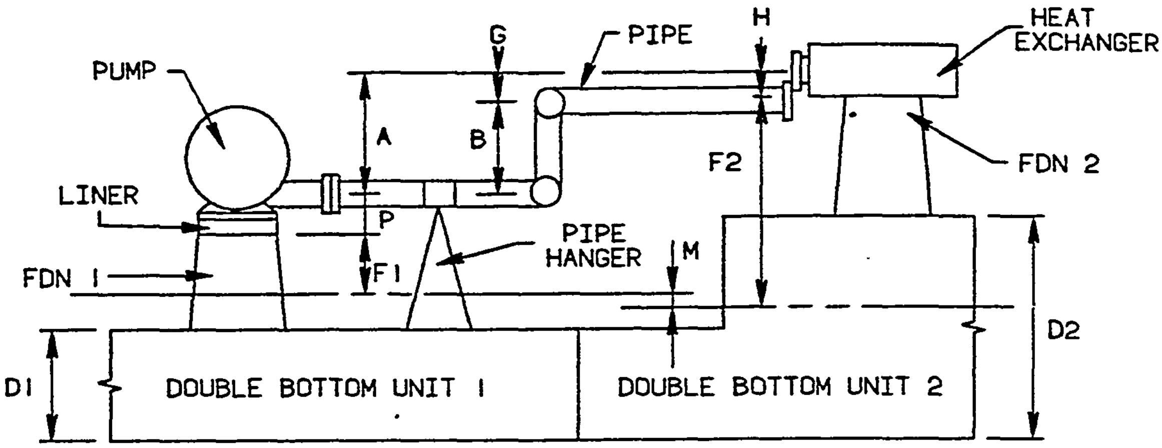
The criteria for selecting reference lines can include the following:

- accessibility at the desired manufacturing stage
- continuity across zones
  independence from flexible itens
- accessibility to external alignment
  ease and accuracy of marking and maintaining

If the reference line system can be identified early ***in*** the design stage it can be used consistently throughout the detail design for dimensioning and locating all components of the ship. Identifying all of the lines involved in a reference line system may not be practical early in the design stage because all of the interim products are not identified and the accessibility of certain lines can not be evaluated until the design is nearly complete. However, it should be possible to identify several primary lines for initial use.

The benefits of reference lines to reduce tolerance stack-up can be illustrated by comparing merged equations of an assembly sequence with and without the use of reference lines. Reference lines effectively eliminate terms from the equation. This is similiar to eliminating one step in the entire process. As an example compare the merged equations in figure 4 with those developed in figure 9. The equations in figure 9 show the interim products being assembled relative to a reference line and have one less term that can contribute to the overall process distribution.

The concept of reference lines is significantly different between system-oriented and modular construction techniques. With system-oriented methods the structure is built to meet structural tolerances. When the major structure has been completed, "ship" lines are established for outfitting that best fit the existing structure and still maintain structural tolerances. During modular construction outfitting is done before final "ship" lines can be established. Modular construction reference lines are therefore more subject to change than system-oriented reference lines so their use requires careful planning to



ELEVATION VIEW

DETERMINE POTENTIAL MISMATCH BETWEEN PIPE AND HEAT EXCHANGER.
(USING REFERENCE LINES)

ASSEMBLY SEQUENCE

BUILD D.B. UNIT
BUILD & INSTALL FDN.
RELAT INE
INSTALL

BUILD D.B. UNIT 2
BUILD & INSTALL FDN. 2
RELATIVE TO REF. LINE
INSTALL HEAT EXCHANGER

JOIN DB I & DB 2 BY MATCHING REF. LINES
INSTALL PIPE

GEOMETRIC EQUATIONS: $G = A - B$
$M+F1+p+A=f2+H$

THEREFORE: $G=F2+H-M-FI-P-B$

$= 84+12-o-24-18-54=o$

$= .02^2+.012+.022+.022+.012+.06^2$

$= .0050$

STANDARD DEVIATION: S_G**=.0707**

VARIATION MERGING EOUATION FOR PIPE/HEAT EXCHANGER MISMATCH DURING **JOINING**
Of DOUBLE BOTTOM TANK ASSMEBLES USING REFERENCE LINES

FIGURE 9

include possible adjustments without effect on completed items. The poten- tial for reference line mismatch and movement can be included in the merged equation analysis to determine the impact of line adjustments. Knowing the expected variation between the sub-assembly reference lines and the new assembly lines, and any items built to the original sub-assembly reference lines, allows the designer and the ship- builder to determine at what levels of construction certain items can be join- ed or outfitted and meet the overall design requirements.

In some situations there is no need to make reference line adjustments because the items referenced to the lines are complete or the items are local and the mismatch of reference lines is of no consequence. The local nature of these tolerances needs to be well documented to avoid confusion if lines are adjusted.

It can be seen that the implemen- tation of reference lines can be just as important as the selection of the lines. The specification of the ref- erence lines is useless unless detailed instructions are given on how the ref- erence lines are to be used at each stage of construction for each com- ponent of the ship. Development of an implementation plan for reference lines and their use is necessary as early in the design process as possible so that it is available for design and produci- bility studies. Such a plan may be developed using a hierarchical system of reference lines. ***At*** the pre- assembly and assembly stages, available waterlines, buttocks or frames would be used for the fitting of local structure, foundations, and outfitting items. When assemblies come together, one or more primary waterlines or buttocks would take precedence for the joining of the assemblies. As higher order assemblies continue to come together, this process of using primary lines would continue until the assembly reaches the block (or module) stage. At the block stage, three primary or master lines, one each for horizontal, vertical, and longitud- inal dimensions, would be used for the alignment of adjacent blocks. At the block or module level of construction it may be beneficial to lay off a new grid of reference lines relative to the master lines for the convenient instal- lation of remaining outfitting items. However, once the block level of con- struction is reached the reference lines would never be reestablished. The centerline for that block would be treated as the ship centerline. For systems that cross several module or zone boundaries and have continuous alignment requirements across those boundaries, it may be better to estab- lish system lines after the blocks are joined that are independent of the individual block reference lines. This will allow independent system specific lines to be modified for final align- ment purposes without affecting the inspected location of other previously installed and unrelated equipment. It ***is*** important that this distinction between system and ship lines be made during the design stage to eliminate confusion during construction.

Self Contained Systems

Reducing the number of independ- ently assembled system components or confining outfitting systems to one structural interim product is another effective way of reducing tolerance stack-up. By identifying construction zones during the design process, outfitting and structural systems can be designed to lie fully within these zones and be structurally self- supporting as an interim product. Good coordination between structural and outfitting product boundaries will greatly improve the success of this concept. This may involve design iterations to resolve purely produc- tivity considerations. If the ship is being designed for a multiship class, the extra design iterations can be cost justified from both time and dollar aspects.

Tolerance Stack-up and Design Fouls

A further consequence of the stack- up problem can be a design foul. Most designs are developed and tolerances assigned based on performance criteria for that one system. Design fouls are usually checked based on the design locations. Consideration can be made for the potential foul resulting from any tolerance stack-up occurring during assembly. The merged equations devel- oped for the planned assembly sequence can be used to predict potential foul problems and evaluate potential solu- tions. The resolution to a foul prob- lem might be a design change if the probability of a foul is high, a change in the assembly sequence to avoid or reduce the probability of the foul, or the establishment of a new manufac- turing tolerance to avoid the foul.

Component Designs Based on Merged Equation Results

In the development of a design, situations routinely exist where the design of an individual component can benefit from the results provided by merged equations. For example in figure 4, the amount of latitude that must be provided by the liner under the pump can be calculated. If the founda- tion and liner can be designed to handle the range of probale misalign- ment between the pump and the heat ex-

changer, including the expected variation of the bent pipe, then substantial rework can possibly be eliminated at all stages of construction. Additionally, tolerance budgets could be reduced, further reducing construction costs.

The same process can be applied to the foundation location on the tank top. If the foundation and the location of the associated backing structure under the tank top can be designed to handle the expected variation in the foundation /backing structure misalignment, then less rework will result. Another potential solution for this problem would be a two part foundation. One part is built with the tank top and the second part is attached *to* the pump. This permits the tank top portion of the foundation to be completed with the confidence that the foundation will not be relocated later to suit the alignment of the pump, and allows-all hotwork, blasting and coating to be completed on the unit sooner, or with less rework. In this situation, the design would be required to compensate for the expected variation between the joining of the *two* foundation parts.

CONCLUSION

The use of modular construction techniques in shipbuilding requires that more control be maintained over all phases of the ship construction process. The application of modular construction techniques has increased the complexity of the shipbuilding process because of the continual use of larger, more complete structural and outfitting assemblies to build the ship. As a result, a higher, more complete degree of control is required throughout the production process. This control can be achieved through the imposition of interim and design tolerances established on the basis of both design requirements (functionality) and the variations caused by the construction process. To establish such tolerances, variation merging equations and variation simulation can be employed during the design development phase of construction, in a manner similar to their *use* in analyzing the effects of variation on the construction process.

In this paper, the impact of modular construction techniques on design tolerances has been examined. Because Of the use of large, fairly complete assemblies to build the ship, design tolerances can accumulate, or stack-up, to result in an out-of-tolerance situation, relative to the final design requirements. To minimize this problem, several approaches can be taken, such as the use of tolerance budgets, reference line systems or self-contained systems. However, the most effective means of establishing realistic tolerances is the use of variation merging equations and variation simulation techniques to model the production process. With these techniques, the design engineer can predict the effects of variation on the design and thereby establish the best system of tolerances to both effectively control production and satisfy the design requirements.

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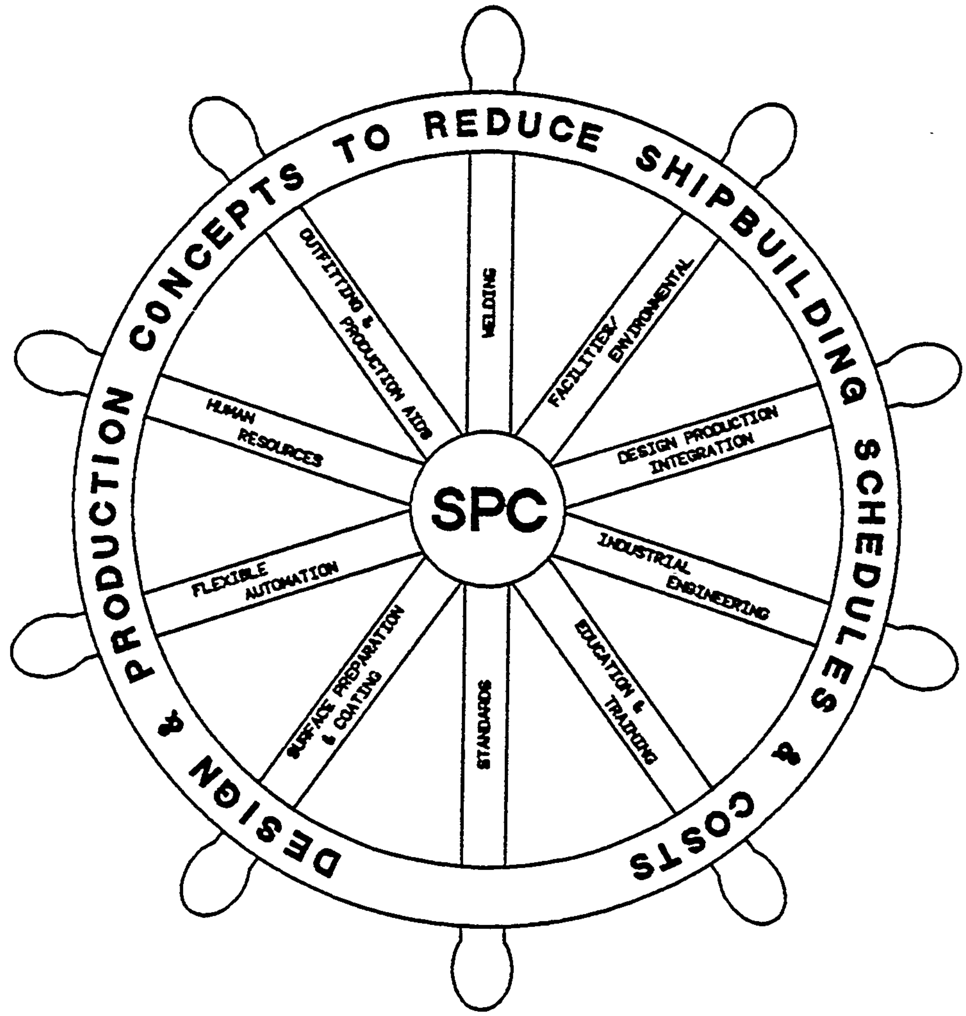
NNS- 3802000

ONAL SHIPBUILDING RESEARCH PROGRAM
1986 SHIP PRODUCTION SYMPOSIUM



PAPER NO. 20

THERMAL SPRAYING IN THE UNITED STATES NAVY

BY: STEPHEN VITTORI

SYMPOSIUM SPONSOR:
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AUGUST 27-29, 1986

1986 SHIP PRODUCTION SYMPOSIUM

THERMAL SPRAYING IN THE UNITED STATES NAVY

STEPHEN VTTOR, Puget Sound Naval Shipyard

Thermal spraying emerged as a recognized repair process in the Navy in the mid-1970s. Much of the Navy's early production work was done at Puget Sound Naval Shipyard (PSNS). Test and evaluation programs are in progress with funding, technical assistance and guidance from Naval Sea Systems Command (NAVSEA) and David Taylor Naval Ship Research and Development Center (DTNSRDC).

The three biggest test and evaluation programs to date are:

1) Wire flame spaying aluminum onto about 600 shipboard valves and related components in 1977.

2) Thermal sprayed metal and ceramic coatings on 25-30 shipbcard machinery components in 1980.

3) Thermal sprayed coatings on main feed pump and turbine shafts and a forced draft blower turbine shaft at a land-based naval training facility in 1984. Coated areas include journals, labyrinth seals, packing sleeves and babbitt bearings.

The need for thermal spray repair is evident during ship overhauls, when critical time and cost schedules must be met. The applications listed are under evaluation in the test programs to establish confidence in thermal spraying. New candidates for this repair process are continually being identified within shipyards. With detailed written standards now in place at the NAVSEA level *to* ensure production reliability and quality control, increasing use of thermal spray in the Navy is expected.

PHILOSOPHY OF THE TEST PROGRAMS

Each test and evaluation program had progressively more ambitious goals. Flame sprayed aluminum for corrosion control presented the lowest risk. Before thermal spraying was used, valves "failed" as often as every six months, and were "fixed" by continual repainting. The benefits of applying aluminum were cosmetic, as rusting did not normally affect the operation of the valves or piping. This program entailed essentially no risk, as failure of the sprayed coatings would merely result in the valves deteriorating to the same condition as they would have been in if not thermal sprayed. The thrust for introducing thermal sprayed aluminum for corrosion control was the vast reduction of manhours spent in frequent repainting. Figures 1 and 2 show valves at the start and finish of the overhaul.

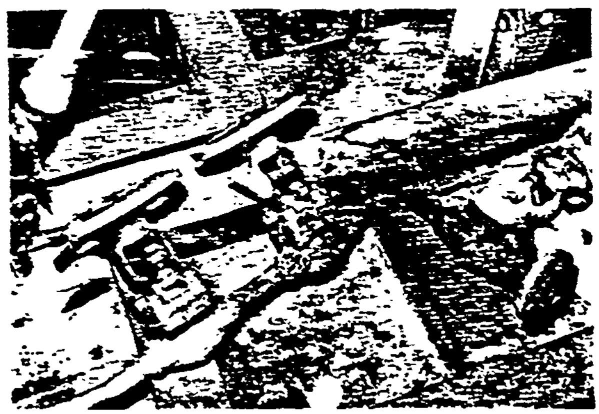


Fig. 1 Typical condition of valves and piping at beginning of overhaul

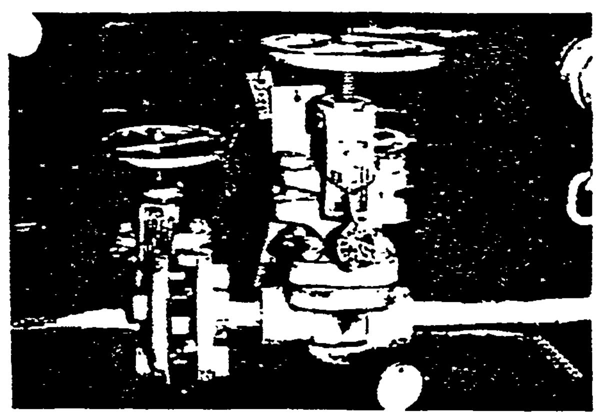


Fig. 2 Installed aluminum-sprayed valve and piping at end of overhaul

The shipboard machinery program addressed low-risk machinery parts. The parts that were repaired by thermal spraying were unusable, due perhaps to dimensional wear below acceptable tolerances, or pitting that permitted fluid leakage past packing. Coating failures in these applications could have made the components work inefficiently. No part was chosen, though, without first considering the potential results of a catastrophic coating failure. If serious consequences were possible, the part was rejected as a candidate for spraying in this test program.

A typical application was the ceramic coating of a collection, holding and transfer tank pump rotor. The loss *or* impairment of one of these pumps would not endanger the ship or mission, yet the service was quite severe, so this was a good *test* location. One critical part, a main feed pump shaft, was sprayed, but only in static fit areas such as under impellers. With no relative motion between the shaft and mating part, the chance of coating failure in service was remote. Figure 3 shows a damaged winch drum shaft seal. This seal was repaired with a ceramic coating, Figure 4. The goal of this program was *to* elevate thermal spraying from a fix of last resort to a fix of first resort, since it often presented a desirable alternative to plating, welding or replacement.

With the foundation laid by the shipboard machinery component program, the land-based test program was undertaken *to* prove the value of thermal spraying on high-risk components, with emphasis on reliability and technical adequacy. Failure of a main feed pump turbine shaft journal, for example, could be catastrophic. This test program was designed to show that properly applied coatings will meet demanding service requirements. Confidence in the eventual success of this program was boosted by valuable service data from private industry on thermal spray coating of high-risk components.

The parts worked in the shipboard programs needed to be completed and installed within the normal overhaul schedule. The land-based program was also tied to a tight schedule, since the facility was shut down for a restricted period for its maintenance. However, this program was more oriented toward test and evaluation. There was a concerted effort to include coatings service-proven in industry, and as many processes as practical to meet the capabilities of the ordinary repair facility equipped for and competent at thermal spraying. Figures 5, 6 and 7 show the main feed pump shaft, main feed pump turbine shaft and forced draft blower turbine shaft, respectively.

SELECTION OF COMPONENTS AND COATINGS

A look into the organizational structure illustrates how thermal spraying decisions were made. Within Puget Sound Naval Shipyard, a committee was put together with members from engineering divisions (welding engineering, design engineering, metallurgy), production shops (welders, machinists) and planning and estimating offices. The diverse backgrounds of the membership assured that all aspects of a job were looked into. On a wider scope, such organizations as Naval Sea Systems Command and David Taylor Naval Ship Research and Development Center helped direct and approved thermal spraying of the equipment.

There was much work done before a single part was sprayed. Detailed programs had to be established in such areas as quality assurance, component selection, process and coating selection, qualification testing and mockup testing.

The first step was the appraisal of service application and program goals. This gave focus and direction

Fig. 5 Winch drum shaft seal area at beginning of overhaul

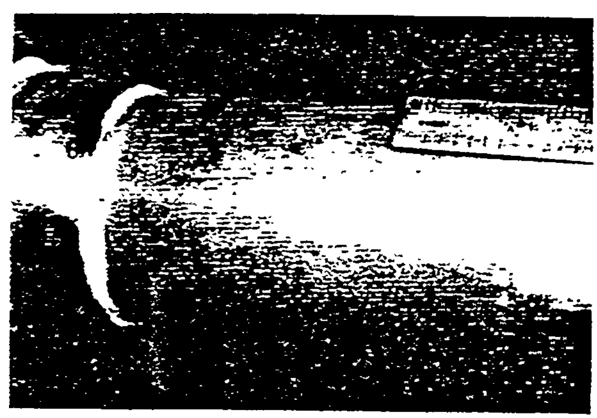


Fig. 4 Plasma-sprayed alumina-titania coating on area shown in fig. 3

to plans for mappingout the necessary tests.

Primarily valves were picked for evaluation of aluminum coatings. suc-cessful applications with the wire flame spray process had been widely reported in technical literature as an effective corrosion control tool. The Navy picked this over other effective, well-documented solutions (e.g., arc spraying, zinc coatings).

The shipboard machinery component candidates included booster pump shafts, packing sleeves, air compressor cylinders, electric motor rotors and valve stems. Theses were all approved by NAVSEA as meeting low-risk criteria. When passible, the parts chosen for

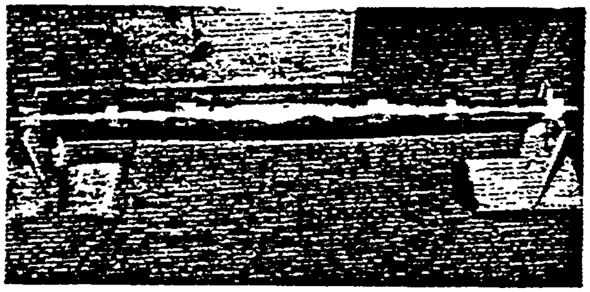


Fig. 5 Main feed pump shaft before spraying

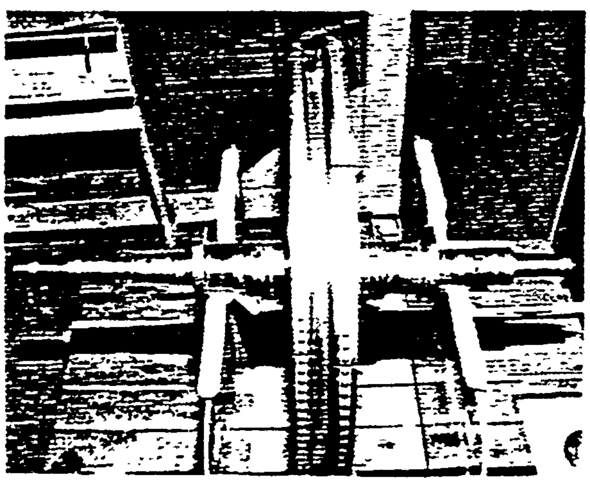


Fig. 6 Main feed pump turbine shaft before spraying

Fig. 7 Forced draft blower turbine shaft before spraying

spraying were one of a pair, to allow performance comparisons with identical unsprayed items. Processes evaluated: to apply the desired coatings were plasma, arc, wire flame and powder flame, all of which were available to PSNS. The plasma and arc spray processes were used for all but one application. Their higher temperature heat sources and rapid particle velocities gave the strongest bonds and densest coatings. For example, ceramic powders are more efficiently melted and propelled by the plasma than by an oxy-fuel flame, and metallic wires achieve higher bond strength when arc sprayed than when flame sprayed. A requirement for an extremely dense, wear and corrosion resistant metallic coating was fulfilled by fusing a powder flame sprayed nickel-chromium-boron-silicon coating. Here, oxyacetylene torches created metallurgical bonding of the coating to the mild steel substrate where, without fusing, mechanical bonding is normal.

The goal in choosing coatings was to develop a procedure selection chart that, for any given application, would guide the reader to one or two procedures. Achievement of this goal required a review of available spray materials, technical literature, shipyard experience and test results. To relate the chart to applications, categories were established for substrate (carbon and low alloy steels; stainless steels; nickel-copper; copper-nickel; bronze), service (restore dimensions; prevent wear, corrosion and erosion; seal against air or fluid leakage) and operating medium (fresh water; salt water; steam; air; oil). Other considerations included similarity of thermal expansion coefficients. The intent was to keep the number of coatings and procedures to a minimum to ensure operator familiarity.

Shafting and associated parts for three components were sprayed for the land-based machinery component program-a main feed pump, main feed pump turbine, and forced draft blower turb ine. These all commonly need repair, are expensive to replace, and have unacceptably long lead times for replacement or remanufacture.

The process and coating selection approaches were similar to those for the shipboard program. In the meantime, relevant shipyard experience had grown and increased contact with private industry had broadened the Navy's knowledge. Static fits, packing seals, bearing journals, labyrinth seals and babbitt bearings were all nominated for spraying. The effort to include a broad range of coatings and processes thought to be technically sound presented a different approach to that used on the shipboard program. Instead of limiting the scope and relying heavily on accumulated experience, PSNS was faced with the need for extra qualification and training.

QUALITY ASSURANCE

Commitment to a strong quality assurance program boosted confidence in the product. Each mechanic was thoroughly grounded in the principles and techniques for obtaining good coatings. Additional support was provided by welding engineering personnel. In addition *to* monitoring testing and production, they kept an accurate daily log to use when writing the engineering reports delivered at the end of each project.

Qualification testing was one critical quality assurance function, and was done for both procedures and operators before production. Quality assurance functions carried out during production included analysis of consumables, hardware control, visual inspection and documentation.

Before the machinery projects started, each sprayer had completed many hours of in-shop instruction and training in thermal spraying, including the use of equipment, surface preparation, handling of parts and coating inspection. All that was needed was to qualify (i.e., complete specified tests) and document the sprayers' credentials for each project.

For the aluminum spray project, operator training was conducted on the job after oral indoctrination by shop supervision and by welding engineering. Each operator had to spray five tensile bond strength coupons and one small plate of sheet metal for bending. Results were evaluated for tensile bond strength and coating adhesion under stress.

Tensile bond strength and bend tests were also used in procedure development and qualification. For aluminum spraying, equipment and wire manufactured by the same company were used. Using their recommended spray parameters, test results were judged satisfactory.

On the shipboard machinery program, the Navy chose procedures that were previously qualified at PSNS. That is, tensile bond strengths, bend results, and measured microstructural oxide and porosity contents were obtained and judged satisfactory by the welding engineering division. The fuse coated bars were repaired at a shop with extensive experience using this process. This was judged quicker, more cost-effective and more reliable than having PSNS embark on a crash program of development, training and qualification.

For the land-based machinery program, the Navy researched literature and sought industry's opinions and experience to select coatings not sprayed before at PSNS, so new procedures had to be developed. The new procedures were qualified using the coating manufacturers' parameters when available, and with equipment already in use at PSNS.

There were several material analysis tests run for each project. These checked 1) grit size, uniformity and angularity, 2) dew point and oil content of compressed air for blasting and spraying, 3) wire chemistry, and 4) uniformity of powder particle size, shape and color.

Visual inspection steps during flame spraying of aluminum assured 1) removal of grease and oil from the substrate before blasting, 2) surface cleanliness and roughness standards were complied with, 3) uniform as sprayed coating appearance and 4) the required thickness was applied.

On the shipboard machinery program, there were visual inspections made after undercutting (for proper diameters and angles) and during and after spraying. Temperature was measured with a contact pyrometer whenever this was a critical element of the procedure.

The land-based facility shafts were magnetic particle inspected upon receipt. They were visually inspected with the unaided eye and at 10x magnification after undercutting, after threading (if done) and blasting, during and after spraying, and after grinding or machining.

Parts were marked to assure traceability. This was especially important for shipboard components. The aluminum-sprayed valves were numbered with round-bottomed die stamps, each number corresponding to a quality assurance form.

Each shipboard machinery part was engraved with its job control record number. On the outside of the component (e.g., a valve body containing a sprayed stem, or a pump casing containing a sprayed shaft) a red metal tag was attached, identifying the sprayed part and its job control record number, and instructions to follow if a change in the condition of the sprayed part was observed.

Traceability was easier in the land-based test, since only three components contained sprayed parts. Each sprayed part was engraved with its job control record number. Copies of all job control records were included in the machinery engineering reports.

Two different documentation/ quality assurance forms were used. The wire Spray process Operation Sheet was filled out for each aluminum sprayed valve, documenting the times when blasting, spraying and sealing were completed. The Thermal Spray Job Control Records filled out for each machinery part documented base metal, ship system, operating medium, reason for spraying, undercut dimensions, signoffs for-production sprayers and machinists, engineering approval signatures, and installation location.

TESTING

The need for pre-production testing was greater for more sophisticated (i.e., high-risk) projects. There were no pre-production tests, other than for operator qualification, for the flame sprayed aluminum project. Salt spray testing, hardness testing, and packing seal service simulation testing were performed before production spraying in the shipboard machinery program. The most elaborate of these was the packing seal test, where candidate ceramic coatings were sprayed onto test shafts. These shafts were cycled in a specially-built machine with two packing areas exposed to fresh water, hot water and saturated steam. Simultaneous wearing of sprayed and unsprayed shaft packing areas showed better leakage prevention with the ceramic coatings.

A broad battery of tests was run before production spraying of the land-based components. Each new and existing procedure was qualified on ASTM A470, Class 8 substrate coupons. All tests, whether qualitative or quantitative, were evaluated to either prove that a coating met certain minimum requirements, or establish a competitive ranking to aid in coating selection.

Procedure qualification tests for tensile bond strength, oxide content and porosity content were quantitative. Bend tests were qualitative. Figure 8 shows a typical lab report of qualification data.

No coatings were rejected based on tensile bond strength, oxide or porosity content values. Instead, the numbers obtained in qualification tests will be considered after in-service coating evaluation to help establish realistic, reasonable limits that assure an adequate coating. Of coatings

SUBJECT: METAL SPRAY REPORT — CODE 134.6

TO: 2133 — JOB ORDER 9133-040410-000 — REPORT NO. M- 827-83

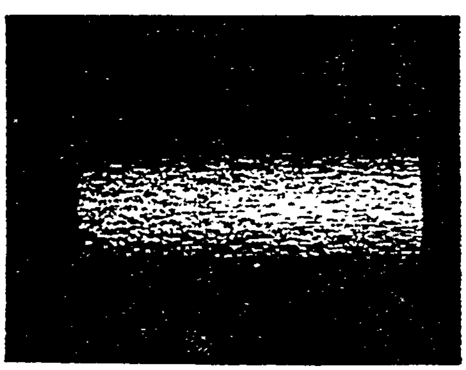
PURPOSE OF TEST
PROCEDURE QUALIFICATION:ARC SPRAYED MIL-1005-1 ON ASTM A470 — SPECIMEN NO. 382

TENSILE TEST RESULTS

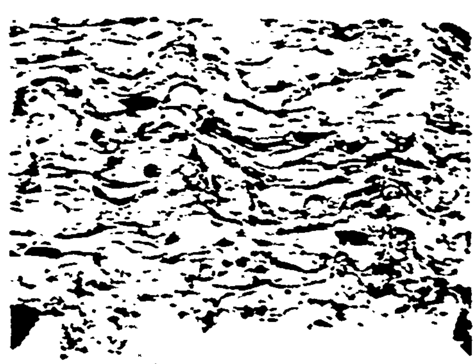
SAMPLE NO.	BOND STRENGTH(PSI)
1	4624.
2	4726.
3	4866.
4	4357.
5	3975.
6	4446.

AVERAGE 4499.PSI
STANDARD DEVIATION 316.PSI
FAILURE REGION:65% IN MIL-1005-1, 35% AT INTERFACE

3. BEND SAMPLES
BEND ANGLE 180DEGREES
BEND RADIUS 1/2 INCH



4. MICRO EXAMINATION — 5 Hardness: 95 HRB
MAGNIFICATION 100X
OXIDE PERCENT 16.1% POROSITY PERCENT 2.2%



OPERATOR: [signature] — REVIEWER: [signature] 2-16-84
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Fig. 8 Typical lab report of **qualification test data**

currently in service, tensile bond strengths range mostly from 4,200 psi to 7,200 psi; oxide content from 10% to 23% (oxide content was not measured for ceramics); and porositY contents from less than 2% to nearly 8%. One exception was the babbitt coating over a nickel-chromium-iron bond coat, which had a bond strength of 2,300 psi. All bend samples showed good adhesion, with no flaking or gross cracking that expcsed the substrate.

Machining tests were semi-quantitative, in that samples were evaluated visually (qualitative) and surface finish was measured with a profilometer (quantitative). Metallic coatings were tooled and ground, all samples at like parameters. Ceramic coatings were all ground at the same parameters. Coating surface was important. In subsequent production, one coating was removed from a shaft journaldue to small pits.

Labyrinth steam seal mockups were prepared. They were made from pieces of carbon steel round stock, three inches in diameter and six inches long. Four candidate coatings were tested. Each mockup was undercut and threaded the same as the main feed pump turbine shaft would be, and then sprayed with a l/8-inch thick per side coating. A groove pattern identical to the steam seals was machined into each coating using carbide tools. Quality of tooling (e.g., with respect to chatter, and visual appearance) was recorded.

Once the mockups were finished, a rough but informative test was performed on each. Technical and shop personnel observed as an engineer used a hammer and chisel to destroy each coating bond at the bond line. Enough difference was apparent in the amount of bond damage at equivalent striking forces to rate the coatings. Close examination of one coating revealed fine cracks, causing its rejection. Two of the other ***three*** ceatings were rated acceptable. The coating judged best also had the highest tensile bond strength results of the four coatings. As it turned out, this coating failed in three of four areas on the shaft, but not due to bond failure; fine cracks were discovered after cooldown. The coating rated second best in the chisel test (third highest tensile bond strength) was then sprayed in these three seals, and all were good.

Tribology tests were quite exhaustive because of the recognition that babbitt spraying on bearings is a big-payoff application. The primary goal was to obtain sliding wear comparisons between proposed journal coatings and babbitt-lined bearings, examining poured (cast], wire flame sprayed and arc sprayed babbitt.

The prepared babbitt samples were small cylinders, each with a raised annular ring as the wearing surface. The counterface samples were flat-faced cylinders sprayed with proposed journal coatings. The testing simulated close surface contact under hydrodynamic lubrication, when a rotating shaft stops and starts. This represented a condition of maximun wear on the babbitt surface. A high-load, low-speed reciprocating sliding tribometer was used.

The lab report presented hardnesses of the three babbitts. The hardest was the flame sprayed babbitt, which ***also*** wore slightly less in the test against uncoated counterface samples than either poured or arc sprayed babbitt. Equal evaluation conditions of sliding velocity, load, nominal contact pressure, ***total*** sliding distance and lubricant type were used. wear determination was based on weight loss.

The data was examined in two ways. Arc and wire flame sprayed babbitt performed about equally well to each other and to poured babbitt against the various counterface samples. Of proposed journal coatings on the counterface samples, high carbon steel and low alloy steel coatings caused greater babbitt wear than either the mild steel control sample, or other nickel-base and iron-base coatings. The test results influenced journal coating selection, and gave confidence in installing thermal sprayed babbitt bearings.

Two types of corrosion tests were run. Salt spray tests evaluated proposed pump shaft packing sleeve coatings, and condensed steam exposure tests evaluated proposed labyrinth steam seal coatings.

PRODUCTION

Logistics at the worksite was critical for the production sequence to follow the prepared written procedures closely. Ideally, all operations should have taken place in the same work area. This would have guaranteed most efficient part tracking, and minimun time between preparation and spraying, to assure the highest quality coatings.

After solvent cleaning; all components in the aluminum spray program were delivered to a section of the shep set aside for masking, blasting, spraying and sealing. The production process for machinery components included an additional step for finishing the coatings (i.e., grinding, machining). This differed from the aluminum coatings which were placed in service in the as-sprayed surface condition. The PSNS machine shop had a booth used solely for thermal spraying, which was located near the lathe and grinder sections. Thus, parts were prepared, sprayed and finished in adjacent areas. Grit blasting and spraying were done in the spray booth. This assured a quick transition between grit blasting and spraying, and between spraying the bond and finish coats. Arc and plasma Spray units. each mounted on wheels, were easily maneuvered into position for procedures using an arc sprayed bond coat and plasma sprayed finish coat.

Only a minimum number of sprayers and machinists were used, to assure that experienced personnel were doing the work. For the test program, QA/ engineering personnel were on-site to monitor production and collect data to write accurate engineering summaries of the work.

Some production details were noteworthy, particularly the thought behind some of the Procedural decisions. Quality assurance steps during aluminum spray production included logging of the valves by the shop and collection of grit samples for sieve analysis. Companion sheet samples were sprayed, bent and evaluated. Masking was applied to protect threads, and to keep aluminum off the end preps so as not to interfere with subsequent welding and inspection. After blasting, parts were handled with clean gloves or rags, and temporarily stored in polyethylene bags to keep them clean. Preheat was applied by torch and measured with a contact pyrometer.

After spraying, coating thickness was measured and recorded. Slight imperfections were correctable. If the coating was too thin in spots. additional aluminum could be sprayed as long as the surface was not contaminated. Any small areas gouged or damaged during transit were brushed with additional sealer.

The procedures selected for the shipboard machinery program used either the plasma spray, arc spray or fuse coat process. The choice was often dictated by the coating composition needed. For example, similar metal buildup of bronze and nickel-copper surfaces was best met by PSNS with arc sprayed coatings using spooled bare welding electrode. Material upgrade with ceramic powders was achieved with the plasma spray process.

Each part that was sprayed needed repair. Undercutting cylindrical parts removed defects such as pits and ensured sufficient buildup allowance for good coating integrity. Masking was adapted to the configuration of the part; tape, sheet metal, carbon rods and wound copper wire were all used at one time or another. Blasting grit cleanliness was so crucial that only new (unrecycled) grit was used. Seal coats were brushed on before and after finishing, to infiltrate pores and help block the service environment from the substrate.

The land-based machinery program was an effort in high-production spraying. Whenever possible, two or more areas on each shaft were sprayed simultaneously. Examples of the differences among the various areas on each shaft were the coating types, coating thicknesses, interference and surface configuration (e.g., keyways, labyrinth seals). Finished journal coatings were 0.020-inch thick, compared to over 0.100-inch per side on labyrinth seal coatings. Figure 9 shows two labyrinth seals and a bearing journal on the main feed pump turbine shaft before spraying, after undercutting and threading. Figure 10, photographed in the balancing machine, shows the finished journal and labyrinth seal coatings. Most coatings were plasma sprayed, although arc sprayed and wire flame sprayed coatings were included. Shaft diameters ranged from about two inches to four and a half inches.

The standard surface preparation was undercutting and abrasive blasting.

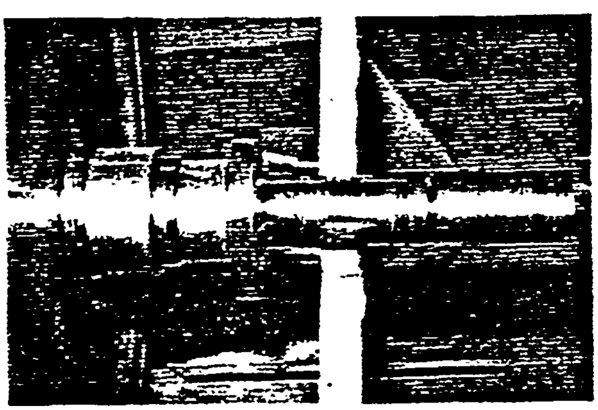

Fig. 9 From left to right are two labyrinth seals (undercut and threaded) and a bearing journal (undercut) for the main feed pump turbine, along with a QA companion sample

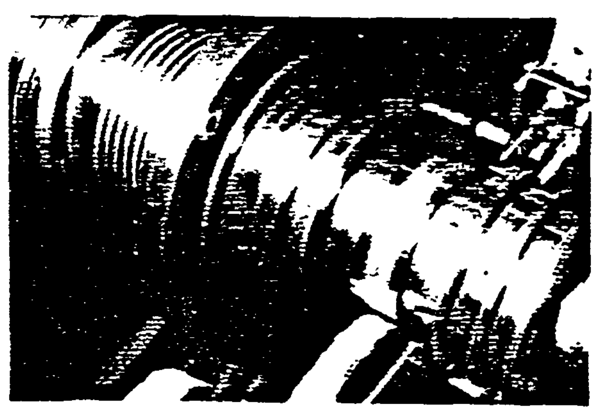

Fig. 10 The finish ground main feed pump turbine shaft coating is seen on either side of a brass ring used for balancing. The grooves machined into the ground labyrinth seal coating are seen at left

The substrate was threaded before depositing the heavy labyrinth seal coatings, to increase the bond surface area and minimize stresses detrimental to bonding. PSHS anticipated potential bonding and cracking problems in the labyrinth seals, and refined the coating decision by spraying and evaluating the mockups. Even so, the job was not successful on the first shot. one bond failure occurred under an austenitic stainless steel coating that was arc sprayed to the required thickness in fifteen minutes. The suspected failure cause was the drastic cooling rate. Some nickel-base plasma coated labyrinth seal areas had fine cracks, but still bonded well. These cracks were revealed by liquid penetrant inspection. This is normally not a reliable inspection method for sprayed coatings due to their porous nature, but in this case was effective. The coatings that ultimately passed inspection were plasma sprayed at a slow buildup rate on a thoroughly preheated shaft to assure even, slow cooling.

Part of the solution to the cooling problem was with the method of masking the adjacent integral bucket wheel. The first masking technique used aluminum sheet metal shields to block overspray from striking the wheel. However, there was an air gap between the shield and the wheel, preventing a thorough soak. When the successful coatings were sprayed, the wheel was completely taped, assuring both satisfactory masking and soaking.

Type 420 (martensitic) stainless steel is a common sprayed coating due to its good bonding, wear resistance and buildup capabilities. Its availability in wire and powder allowed it to be sprayed by wire flame, arc and plasma spraying.

This project proved the value of experience. As PSNS tried to include as many worthwhile coatings as possible, we found ourselves spraying with procedures for which we were qualified, but with which we had little production experience. Several coatings new *to* PSNS were rejected for cracks, rough appearance or inconsistent buildup.

The final production step before shipment was the balancing of each shaft. Balancing on sprayed coatings was not recommended, especially in loaded areas (e.g., bearing journals). All three shafts had sprayed-bearing journals. For the main feed pump turbine, brass rings were shrunk onto the journals for balancing and subsequently removed; the forced draft blower turbine shaft was balanced on wrought metal next to the journals; and the main feed pump shaft was balanced on coated areas outside the journals.

Figure 11 shows a babbitt bearing from the forced draft blower turbine, before spraying. Production spraying of babbitt initially pursued the simplest setup. This meant setting each half-shell upright on the work table and manually spraying the inner diameter. This produced slight warpage, though, and created the danger that areas of bond coat or substrate could be exposed during machining of the babbitt. The coating was stripped and the shells were re-prepared. Distortion was eliminated by bolting the **half-shells together, rotating them in** and spraying with a mounted traversing gun.

CONCLUSION

The aluminum sprayed valves were inspected at six month intervals for a five year period by DTNSRDC. Direct observation verified that the aluminum coated valves required minimal maintenance and showed no sign of corrosion beneath the coatings. Follow-up inspections revealed that unsprayed valves were often repainted two to three times ***a year.*** It was learned that one valve with a chip in its aluminum coating was repaired by wire brushing and applying heat-resistant aluminum paint. Subsequent repair was not necessary, attesting to the galvanic protection offered by thermal sprayed aluminum.

The machinery programs are ***still*** undergoing their in-service phases. Examination of sprayed parts requires that equipment be opened to permit access.

The winter of 1986 is the next scheduled overhaul of the machinery component test ship. To the Navy's knowledge, almost all of the parts are still in operation. One rotor shaft reportedly had a ceramic coating fail in a seal area. Evidence indicates that the shaft was reworked during a port call. One keyway was found to extend into the seal area - this keyway had terminated outside the sprayed area during the PSNS overhaul. By the end of this year, the Navy will have the data to show the overall success rate of thermal spray repair for this ship.

Fig. 11 Babbitt bearing from forced draft blower turbine, before spraying

The land-based components have been logging extensive running time over the past two years. An inspection after one year showed all coatings were still sound. Facility personnel reported normal equipment operation.

Thermal spray has earned its place among the Navy's accepted repair methods. When final results are in from all three of the test programs, even greater use of thermal spray on naval ship components is expected.

ACKNOWLEDGEMENTS

The accomplishments reported were performed over a period of years that saw a change in the cast of key characters. Appreciation is extended to the various Shipyard Commanders of Puget Sound Naval Shipyard, as well as Naval Sea Systems Command, David Taylor Naval Ship Research and Development Center, Naval Surface Fleet Pacific, Great Lakes Naval Training Center, and crews of USS Standley and USS Albert David for their valuable assistance in completing these programs. The author is grateful for the invaluable assistance of the Puget Sound Naval Shipyard Photographic Laboratory.

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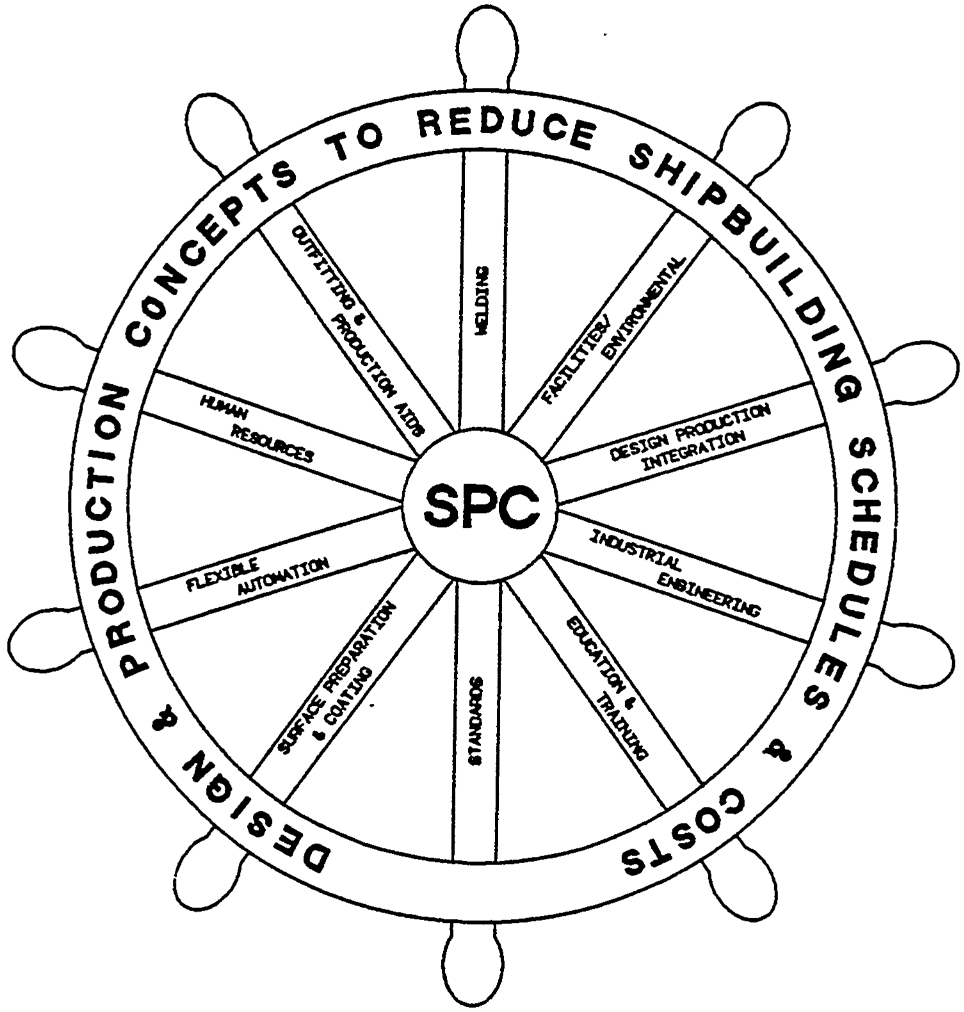

PAPER NO. 21

THE DEVELOPMENT OF AN INITIAL GRAPHICS EXCHANGE SPECIFICATION (IGES) CAPABILITY

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AUGUST 27-29, 1986

1986 SHIP PRODUCTION SYMPOSIUM

THE DEVELOPMENT OF AN INITIAL GRAPHICS EXCHANGE SPECIFICATION (IGES) CAPABILITY

D. J. WOOLEY AND M. L. MANIX, Newport News Shipbuilding

ABSTRACT

Industry has long recognized the importance of computerized data exchange. The concept of a neutral ex change format is the key to an efficient and maintainable data exchange capability due to the number of dissimilar CAD/CAM systems in use today. The capability to exchange computerized design data provides the opportunity to eliminate many redundant activities such as recreating computer data from computer generated paper drawings. The resulting improved communication of design data between contractors, subcontractors, customers, and operation and maintenance activities can reduce costs and upgrade fleet operations.

This paper will focus on the need for, and the methods used, to develop a workable computerized data exchange capability. Topics of discussion include the merits of electronic data exchange, the limitations of direct translators, and the benefits of a neutral data format. A project will be presented that addresses various aspects of digital data exchange within the shipbuilding industry. Emphasis will be placed on two working groups that address the digital exchange of design drawings and product model data using the Initial Graphics Exchange Specification (IGZS).

INTRODUCTION

The widespread use of Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) technology within the shipbuilding industry offers the opportunity to exchange computer-based information bitween customers, designers, builders, suppliers, and repair yards. Such an exchange would eliminate many redundant activities and reduce the number of errors caused by misinterpretation of drawings that represent a physical object. Customer conceptual or preliminary designs, created on a CAD system, could be transferred to the designer's CAD system. Vendors could supply CAD models of their products to be directly loaded into the designer's CAD system. Designers could then supply a CAD model to the shipbuilder from which fabrication and construction data can be extracted. Finally, the ship could be delivered with a complete "as built" computer model to be used and updated by logistic organizations and repair yards throughout the life of the ship. Each of the above exchanges would eliminate the reinterpretation and reloading of data from paper drawings into the receiving sites computer system. The resulting cost savings and schedule reductions would be dramatic.

Every stage of a ship's life cycle is becoming more computerized as computer system capabilities are rapidly increasing while computer system costs are rapidly decreasing. With todays systems' capabilities, most of the scenario discussed above is feasible and dependent only upon the development of an efficient and reliable digital exchange of CAD/CAM data. Such an exchange capability is inherent if the same CAD/CW. system with the same software release is used the same way at each site. In reality, however, very few sites have the same system with the same software release and even fewer use the same system the same way. For example, the attributes used by one shipyard to describe a stiffener within CADAM would probably not be the same attributes chosen by any other yard using CADAM.

Today, the only way to communicate a complete description of a shig design is through drawings. Some parts of the design can be exchanged in model form, but not a complete product model. The digital exchange of drawings does not produce the dramatic savings that a product model exchange would, but a digital drawing exchange would allow the recipient to more easily modify the design and load it into another CAD/CAN system.

NEUTRAL EXCHANGE F0RMAT

The diqital exchange of data between dissimilar systems can be accom-

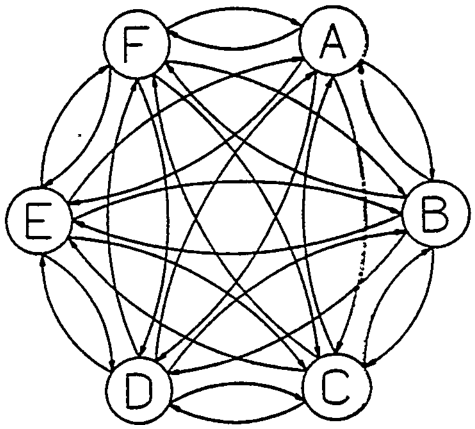


Figure 1 Translators Required for Direct Transfer with Six Systems

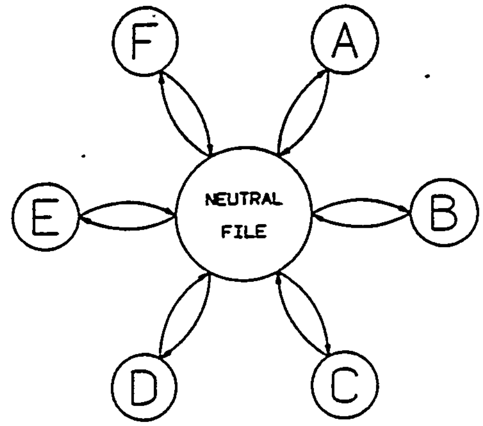


Figure 2 Translators Required for Neutral Format Transfer With Six Systems

plished through either direct or neutral format translation software. Direct translators convert the internal format of one system to the internal format of another. This type of exchange can usually be made substantially complete because it is specific to the two systems involved. The disadvantage of the direct translator method is illustrated in figure 1. In an environment which requires six systems to exchange data, thirty direct translators would have to be created and maintained. When one of these systems changes, ten of the trans lators ***need to*** be updated and retested. Currently there are over fifty different CAD/CAM systems on the market and typically, these systems are changed several times a year. This all equates to a massive programing effort just to maintain a status quo.

The concept of a neutral format, that each system can translate to greatly simplifies the problem. Figure 2 illustrates that only two neutral-format translators are needed for each system. If any system changes, only those ***two*** neutral-format translators directly related to that system need to be updated and tested. Rather than having thirty translators to maintain, there are only twelve. Additionally, if another system is added to the circuit, only two translators need to be Eeveloped rather than twelve. Therefore, in an industry such as shipbuilding, where many different CAD/CAM systems contribute to a final product, the use of a neutral format is essential.

The most widely used neutral data format today is the InitiaL Graphics Exchange Specification (IGES). IGES was conceived in the course of a co-operative effort between the joint NASA/industry project Integrated Programs for Aerospace-Vehicle Design (IPAD), and the Air Force Integrated Computer-Aided Manufacturing (ICAM) program. IGES development began in 1979 Under the sponsorship of the National Bureau of Standards with the first version released in early 1980. IGES was adopted by the American National Standards Institute as AVSI standard Y14.26M in 1981. Development of IGES has continued at a steady pace with the release of IGES version 3.0 in April 1986.

Acceptance of IGES as an ANSI standard alone was not enough to make the data exchange process workable. IGES translation software was often immature and inconsistent between different CAD/CAM systems. Vendors of CAD/CAM systems seemed to consider the development of IGES translators a low-priority item since this activity seldom generated much, if any, revenue. Fortunately, this attitude has changed due to industry giants such as General Motors and government sgencies like the Naval Sea Systems Command (NAVSEA) making IGES compliance a condition of CAD/CAM system procurement. For example, the Navy CAD/CAN Program Technical Specification, which specifies the technical requirements for future Navy CAD/CAN system acquisitions, specifies IGES compliance and states that any offer that takes exception to this requirement will be rejected without discussion. It is through contract requirements like this, as well as through projects similar to the one discussed below, that the IGES data exchange process has progressed to a workable exchange mechanism.

DIGITAL DATA EXCHANGE PROJECT

Newport News Shipbuilding (NNS) is participating with NAVSEA and General Dynamics Electric Boat Division (EB), in a joint project to develop digital data exchange capabilities, for SEAWOLF, the next class of fast attack submarines. Newport News proposed the project in early 1985 based on the recognition of the necessity for an efficient digital data exchange between different systems and the immaturity of existing IGES translators. NAVSEA aggressively organized and funded the project to take advantage of the potential cost savings and schedule reductions possible with digital exchange of CAD/CAD data.

The project consists of a guidance committee and four working groups, each responsible for a specific aspect of data exchange. The guidance committee is made up of representatives from Newport News, Electric Boat, and NAVSEA Codes PMS394 and SEA507. Each working group is made up of representatives from Newport News, NAVSEA, and Electric Boat. The organization of the project and the areas of responsibility of the four working groups are *shown in* figure 3.

Working Group A

The objective assigned to Working Group A is to develop an efficient exchange capability for word-processing data by the fourth quarter of 1986. The group investigated system compatibilities at each site, neutral formats, and direct translators. The Working Group determined that the use of the WANG Office Information System (OIS) at each site was the best solution. The basis of this decision was the availability of WANG OIS at Newport News, NAVSEA, and Electric Boat, the low reliability of existing direct translators, and the lack of translators for the neutral fomats available. As expected, the exchange of data between identical systems is reliable and efficient.

Working Group B

Working Group B is assigned the objective of developing an exchange capability for structured text, such as drawing indexes, bills of material, anti material catalogs. Working Group B has developed a data dictionary to define the format for structured text exchange between Newport News, NAVSEA, and Electric Boat. Working Group B also developed a procedure that establishes data controls and exchange techniques that will ensure an efficient processible data exchange.

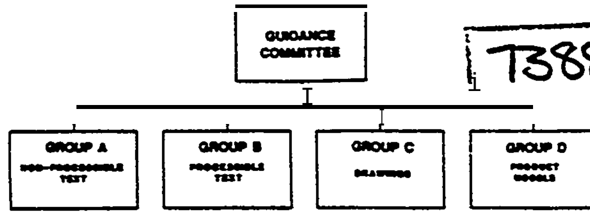


Figure 3 SEAWOLF Digital Data Exchange Project Organization

Working Group C

The purpose of Working Group C is to develop a digital drawing exchange capability for the SEAWOLF class between NAVSEA, Newport News, and Electric Boat. The computer systems being used for digital drawings in the design of the SEAWOLF are CADAN at Newport News and Computer Vision at NAVSEA and Electric Boat.

Working Group C first met in June of 1985 and began by testing the *existing* IGES translators developed by Computervision and IBM. Larse drawings were exchanged to facilitate the testing of numerous entity types and combinations at one time. These exchanges were frequently followed by small test cases that focused on specific problems. These small test cases were much easier to analyze than the larger IGES files. The working group elected to use drawings prepared by Newport News and Electric Boat as test data because previous experience with IGES indicated that the way a CAD system is used by the originator of an IGES file can dramatically affect the fidelity of the exchange. Standard IGES test cases available from the National Bureau of Standards do not reflect the CADAM operational procedures used at Newport News, nor the Computervision procedures being used at Electric Boat.

Figure 4 illustrates the necessity of using actual drawings as test data. As an example, Electric Boat uses layered subflgures when preparing diagrams. This allows the Computervision *user* to select an appropriate layer of a symbol depending on the geometry to be shown in the diagram. However, IGES currently has no provisions for layered subfigures. Therefore, if an attempt is made to translate layered subfigures, all of the layers of the subfigure will be superimposed upon each other. When single layer subfigures are used by the Computervision operator, the exchange to CADAM is correct. The prohibition of the use of layered subfigures is not a satisfactory solution as this feature

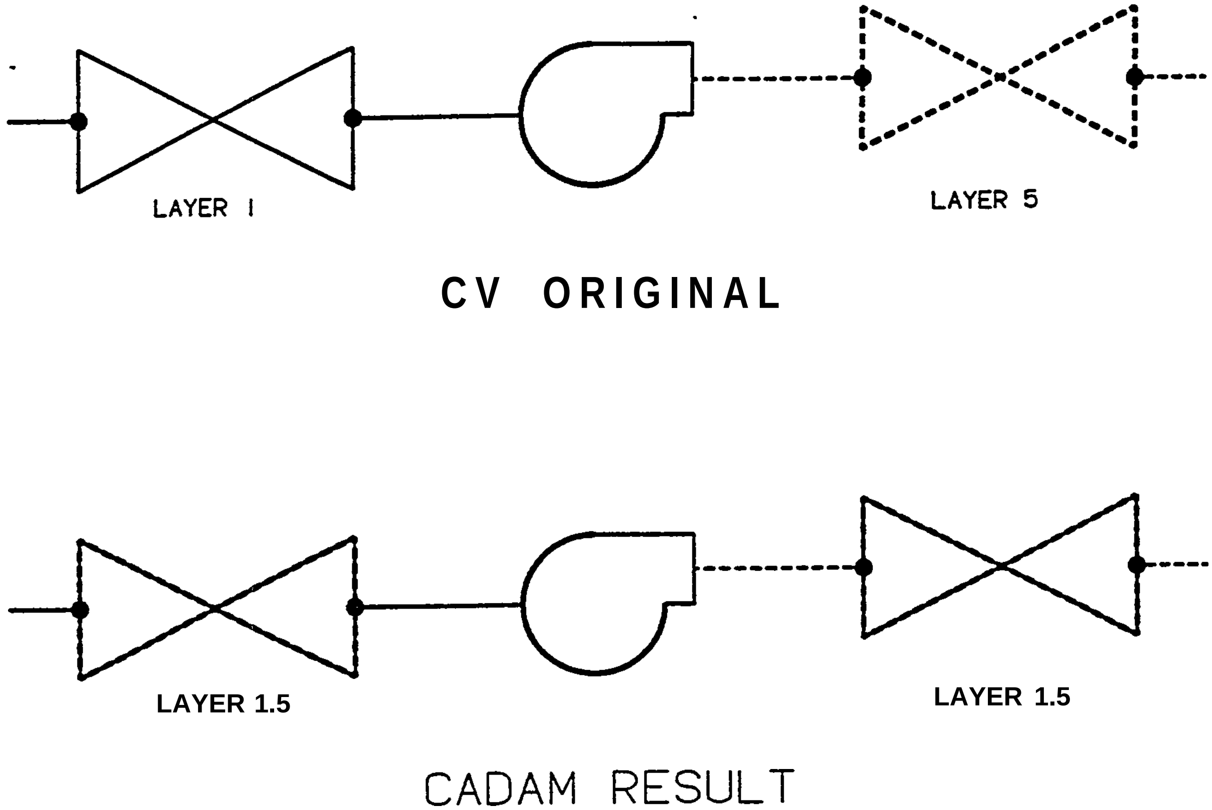


Figure 4 Problem Encountered when Translating Layered Subfigures

is a strength of the Computervision software; therefore, it may be necessary to develop preprocessor software that will reduce layered subfigures to multiple, single layer subfigures. This problem is currently under study by the IGES development committee.

The numerous problems encountered by Working Group C can be divided into four categories. They are:

- o Translator Problems
- o System Differences
- o IGES Specification
- o User Errors

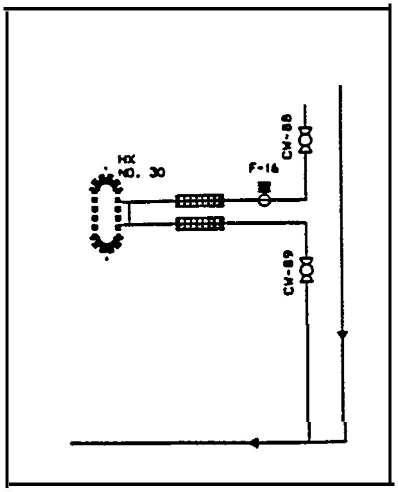
The majority of the problems encountered have been in the first two categories.

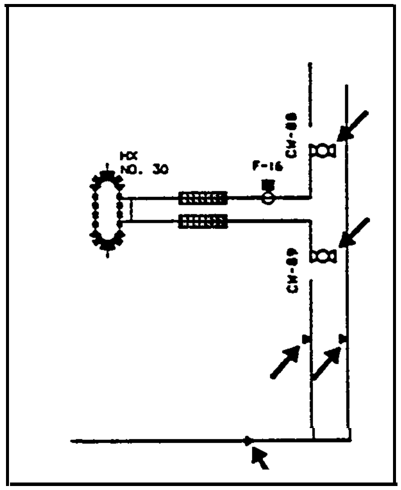
Translator Problems are caused by errors in the translation software or incomplete and incompatable levels of IGES implementation. Neither the IBM (CADAM) *nor* the Computervision translator has implemented all provisions in the IGES 2.0 specification, and features that are supported by one translator are not always supported by the other.

An error discovered in one of the translators is illustrated in figure 5. The symbols, pointed out by bold arrows, in the translated result are not oriented correctly. The original IGES file, which contained this error, included over 7,000 lines and was, therefore, impractical to work with.

A small test case, figure 6, was therefore developed to analyze this specific problem. The resulting IGES file showed that the sending system translator was not formatting the transformation matrix correctly for subfigures. The translator developer was notified and a fix was promptly provided. Working Group C has tested a Pre-release version of the corrected translator and found the problem to be resolved.

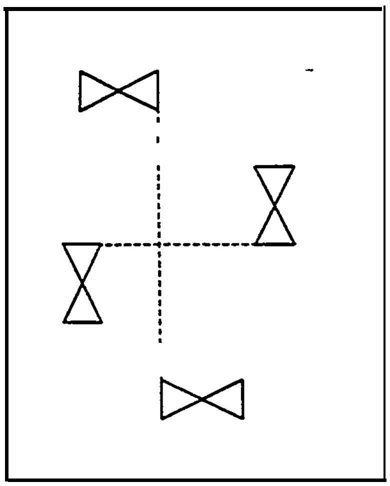
The problems in the category entitled System Differences are a result of the different design philosophies of the CADAM and Computervision systems. For example, methods used by CADAM and Computervision to segregate and organize data are dramatically different. In one system clipping planes are used to limit the extent of a three-dimensional model seen in any view, whereas, the other system does not use *clipping* planes. Consequently, when an original drawing that uses clipping planes is translated

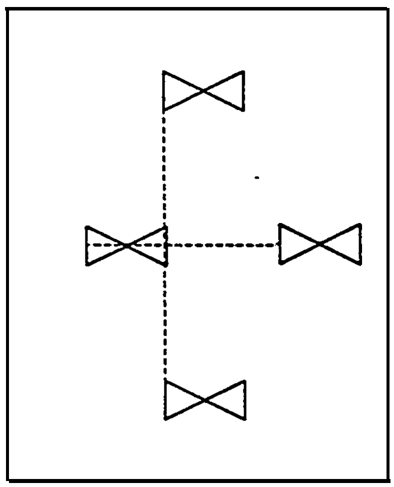




ORIGINAL. RESULT

Figure 5 Portion of a Large Drawing Showing the Subfigure Orientation Problem





ORIGINAL RESULT

Figure 6 Small Test Case to Analyze Subfigure Orientation Problem

and transmitted to the other system, the entire three-dimensional model appears in all views as illustrated in figure 7. This problem has been identified to the system supplier and is under study at this time.

The IGZS Specification has proven to be a usable exchange format, however, there are some ambiguities that have been interpreted differently by the translator developers. For example, IGES does not require subfigure names to be unique across IGES files. CADAM Details, which translate to IGES subfigures, are named with sequential numbers that are unique only to the drawing that contains the detail. Therefore, the first detail of a CADAM drawing always results ***in an*** IGES subfigure with the same name. Compctervision figures are functionally the same as CADAM details, but their names are unique to the computer file system, not just to a drawing. Therefore, the ComputerVision translator is designed to not reprocess an IGSS subfigure if it finds a figure with the same name already on the file system.

Figure 8 shoks the result of the two different interpretations of the IGES specification. The CADAM.I gene-

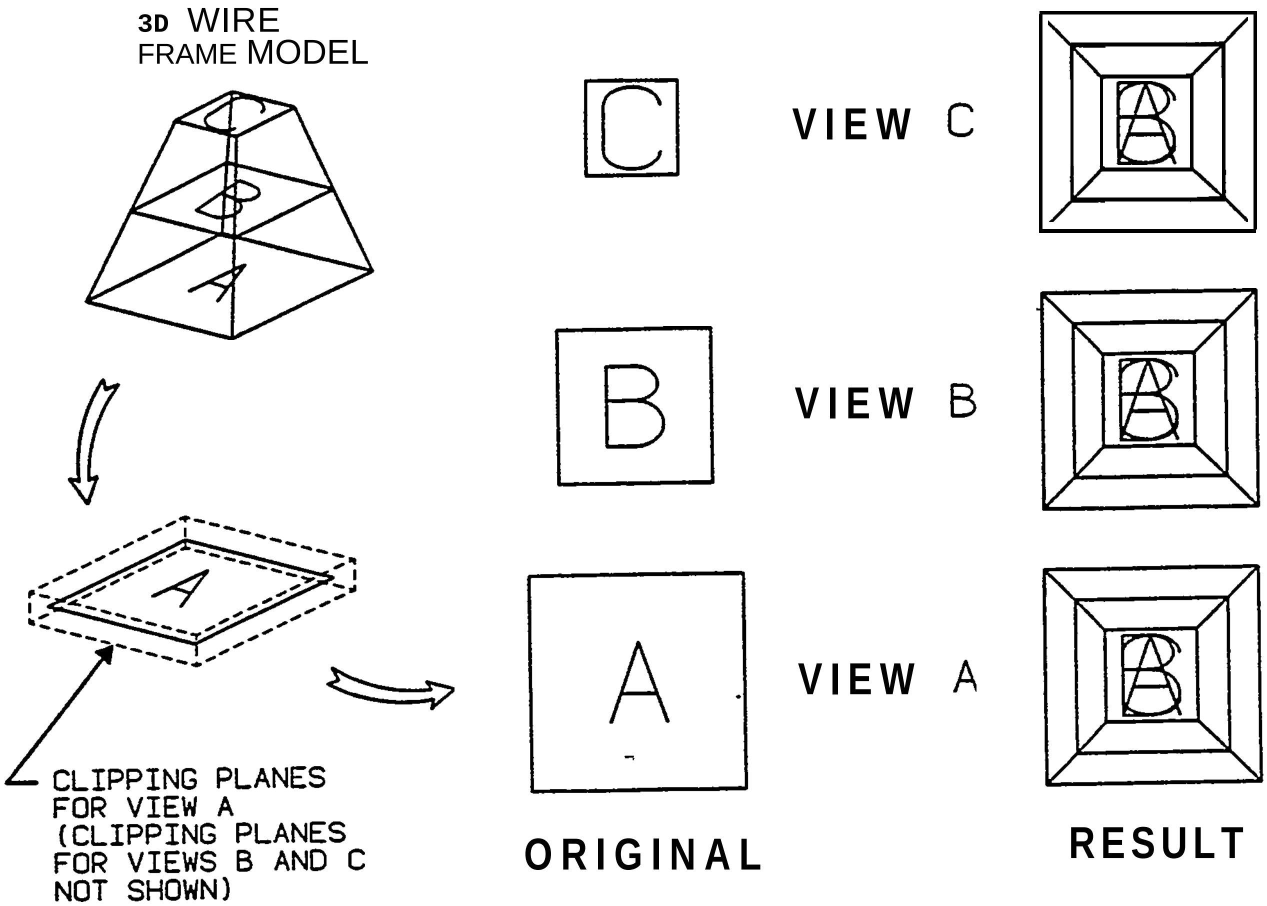
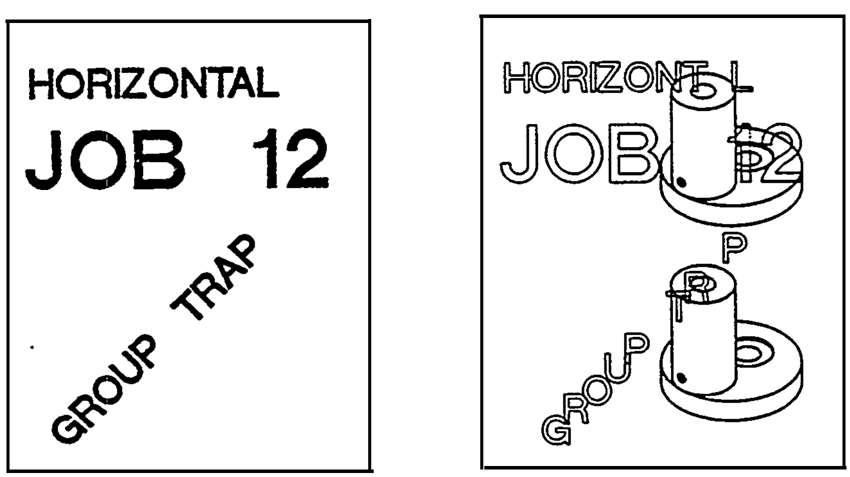


Figure 7 Clipping Plane Zxchange Problem



CADAM ORIGINAL

CV RESULT

Figure 8 Illustration of Subfigure Naming Problem

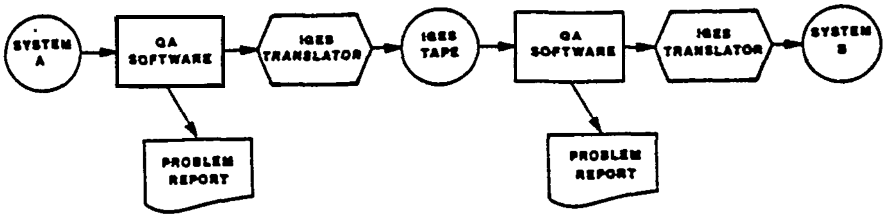


Figure 9 Flow Chart of the Quality Assurance Procedure

rated subfigure for the symbol "A" was not processed because a figure already existed on the Computervision *system* with the same name. The subfigure from a previous exchange shows up in its place. At the reguest of Working Group C, IBM has implemented a new naming convention in their translator that gives CADAM Details unique IGES subfigure names. A pre-release version of the translator containing this enhancement has been tested by Working Group C and has resolved the problem.

The last problem category, User Errors, contains problems caused by users not following the prescribed procedures; for example, incorrect tape format or an incorrect tape label. These errors have not been a major problem during the testing; but, in a large volume production exchange, *user errors could* be significant.

The need for an exchange Frocedure became evident very early in Group C's testing. Therefore, Working Group C has developed a procedure to govern the digital drawing exchange for SEAWOLF. The procedure is designed to eliminate confusion by requiring clear documentation of the exchange format and content. For example, the procedure requires the sender to specify the organization of the data. This is essential for the receiving site to efficiently translate the IGES file into a useful CADAM or Computervision drawing. The procedure also prescribes some limitations that serve to improve the translation. For example, the existence of no-show or blanked data in a drawing is prohibited by the procedure. *This serves* to reduce model sizes and clean-up time at the receiving site.

The Working Group C exchange procedure also provides a quality assurance procedure that is designed to monitor the exchange to identify new problems, and to report known problems as they are detected. Figure 9 is a simple flow chart of the quality assurance process. software will have to be developed for both Computervision and CADAM that will review a drawing before and after translation. This software will notify the sender of problem items that must be corrected, and also notify the receiver of items that may cause problems.

During the Working Group C testing, sample drawings from each design discipline were exchanged. No new problems have been discovered for some time The problems that have been found have been identified to the responsible translator supplier. Priorities have been established and encouragement applied to the supliers to obtain resolutions. Fixes will be tested and implemented as they become available.

Working Group D

Working Group D was assigned the objective of developing a capability to digitally exchange product models between Newport News, Electric Boat anti NAVSEA, specifically for SEAWOLF. A product model is a complete description of a product, and for SEAWOLF, the product model would be a complete description of the entire ship. As may be expected, this is a massive undrtaking, and the exchange of a true product model in a neutral format is still a concept and not a reality. The Product Data Exchange Specification (PDES) is currently under development by the IGES committee. PDES is aesigned to exchange product model data but will not be ready in time to assist the initial SEAWOLF design efforts.

However, IGES can be used to exchange some of the product model data if agreement between exchanging parties can be reached on a representation within IGES. For example, a straight stiffener can be represented wikhin IGES as a line in space with properties attached that describe its cross section, orientation, and end cuts. Both sites could. develop software to interpret these properties and buid a three-dimensional model of the stiffener as a solid, wire frame, or toe trace with properties as desired.

With this in mind, Group D set out to develop an IGES representation of a product model. The first obstacle encountered was the establishment of

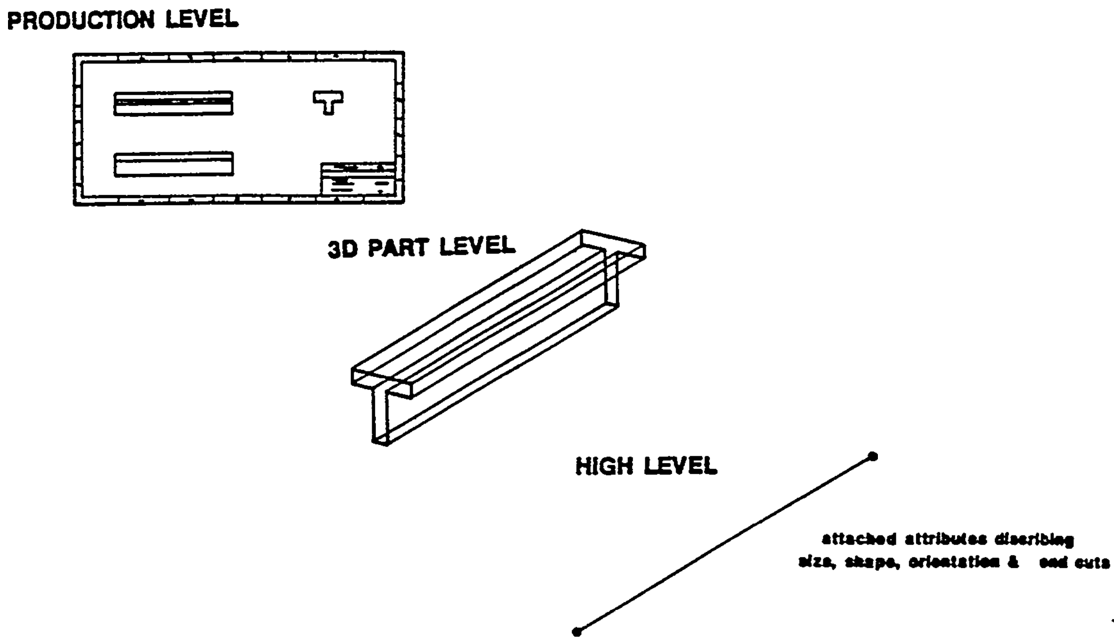


Figure 10 Three Data Levels

the portion of the product model that would be most valuable as design agent furnished data and would be available from either design yard. The group chose to begin with flat plate, straight stiffener, and piping parts.

The next obstacle encountered by Working Group D was to determine the level of data to exchange. Figure 10 illustrates the three levels of data exchange that were investigated. The production level is the final data needed to fabricate and construct the ship. This level includes items such as nested plates, stiffener cutting sketches, and pipe bending instructions. Although probably the easiest to exchange, the transfer of data at this level of detail does not provide adequate flexibility to the follow yard and the responsibility for errors would be difficult to determine.

The three-dimensional part level ***is*** defined as a three-dirensional wireframe representation of each part. This level was chosen for structure because it provides the necessary flexibility to the follow yard and is tractable with the CAD practices at both shipyards and within the schedule and resource limitations of working Group D.

The high level is closer to a true product model representation. It consists of a minimum of geometry with properties attached that completely describe the part. This level was chosen for piping representations for data exchange between the in-house distributive CAD/CM. systems at Newport News anti Electric Boat.

The conventions developed by Working Group D, however, are not supported by the IGES translators for all CAD/CAM systems. For example, the definition of inner and ***outer*** contours for a flat plate part uses the IGES Composite Curve entity (Type 102) to indicate the sequence of the contour by pointing to its constituent entities. The IBM IGES processor for the CADAM system at Newport News Shipbuilding, however, does not create a Composite Curve. Therefore, software was Eeveloped to interpret ***user*** defined properties that identify the contiours on CADAM, and to add the appropriate Composite Curve to the IGES file for each contour. The modification of an IGES file to reflect user spectric requirements is termed IGES flavoring.

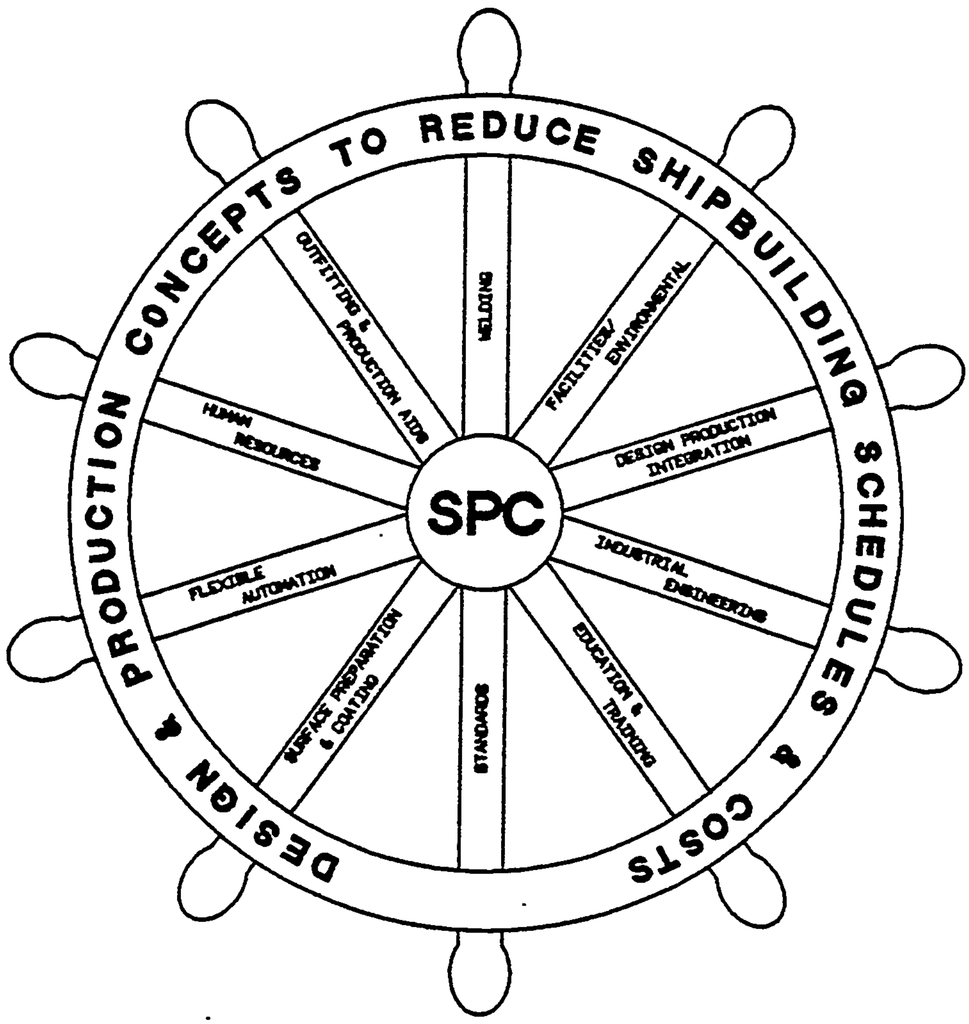
IGES flavoring may be used for many different purposes as long as the requirement is **clear** and the software can be developed on the sending and receiving systems in a cost-effectiive manner. Since CAD/CAM vendors must develop translators that support general IGES files, IGES flavoring can be used between two distinct systems to increase the percentage of entities translated correctly. Often it may be as simple as modifying existing entities or sometimes as complex as the interpretation of properties to determine the addition of new entities or deletion of others. IGES flavoring can help the IGES exchange process become effective in areas where it would otherwise be inadequate, even though it seems to contradict the purpose of a neutral format.

Working Group D is finalizing the IGES representations that have been developed to date. Software will have to be developed, tested and implemented at all sites that handle these IGES representations. Representations of other part types will also have to be developed. Data exchange management issues are being discussed and are in the formulative stages.

SUMMARY

The IGES exchange is a maturing capability that can produce far-reaching savings in schedules and costs. The varying levels of IGES implementation and the different design philosophies of existing graphics systems, combined with IGES specification ambiguities, mandate that extensive testing and evaluation be conducted and an exchange procedure developed before IGES can be used as a reliable and ef-ficient exchange format between any two systems. Therefore, the successful implementation of a production IGES exchange requires the commitment and cooperation of both those developing and using the systems. The development of a complete and comprehensive electronic data exchange can only be achieved through aggressive industry support.

NAL SHIPBUILDING RESEARCH PROGRAM
1986 SHIP PRODUCTION SYMPOSIUM



PAPER NO. 22

THE AUTOMATIC CUTTING, MARKING, AND PROCESSING OF STRUCTURAL SECTIONS

BY: GUNTER C. WILKENS
JOHN M. KALOGERAKIS

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AUGUST 27-29, 1986

1986 SHIP PRODUCTION SYMPOSIUM

THE AUTOMATIC CUTTING, MARKING, AND PROCESSING OF STRUCTURAL SECTIONS

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ABSTRACT

Structural sections used in the off-shore and shipbuilding industries require a wide range of cut-outs, end-cut configurations and edge preparations. Such shapes are currently sketched, layed-off and cut with manual and/or semi automatic methods.

This paper describes the development of a high-throughput automated (C.N.C.) shape cutting line that incorporates all of the activities from the planning stage through to the finished workpiece.

For the more complex shapes, a flexible automation (robotic) cutting system is described that includes an off-line programing capability. Two practical application examples are also detailed.

It is concluded that section preparation is now an area that can be automated, with robotics being a feasible and flexible solution.

INTRODUCTION

Steel entering the shipyard stockyard is of two basic types - plates and sections. The automation of plate processing was Successfully addressed many years ago. Today, shipyards are expected to have automated N.C. burning facilities for the cutting of flat plates. Further then that, data for the N.C. burning machines can now be generated at the design stage and downloaded directly. Technology has advanced from manual feeding of paper punch tapes to a direct CAD-CAM link. However, plates have been mainly treated as flat Objects. That assisted greatly the N.C. function, as torches etc. had to move basically in 2-D.

Sections on the other hand, are 3-D objects (e.g. of I, L, T, H etc. shapes) and although the cutting to length can be achieved by sawing in 2-D, most sections require a wide range of cut-outs, end-out configurations and edge preparations. Control of the torch head is much more complicated.

However, today N.C. technology has reached a level of sophistication that allows us to address the subject of automating the processing of sections.

Sections are currently processed in lengthy, cumbersome series of manual operations. Some shipyards have sketches manually prepared by the drafting department and the layout is achieved manually by using both standard tools and templets. The actual cut-outs and edge preparations are performed mostly by manually held oxy-fuel torches. Consequently, the accuracy and quality of cut reflects the methods used.

Two different systems (a C.N.C.) and a robotic one) have recently been designed (1) and built by Oxytechnik Systems Engineering in W. Germany, to the specific requests and guidance of certain shipyards (2,4) to meet the market's current and future demands.

SECTION PREPARATION

Structural sections-used in shipbuilding require a large variety of end-cut configurations, edge preparation for welding, and a wide range of cut-outs. Selection of some typical cut-outs is shown in Figure 1. while in Figure 2 certain edge preparations are illustrated (3).

There are many different types of structural sections. These include:- offset bulbs, joists, universal colums, angle bars, fabricatiangle bars, channels etc. They usually come in legnths, varying from 6 to 17 metres long. It is in the section preparation bay that these bars are cut to a variety of smeller lengths, and then manually marked and burned with the appropriate cut outs and edge Preparations. Following this, they are transported downstream to the production process, for welding onto panels etc.

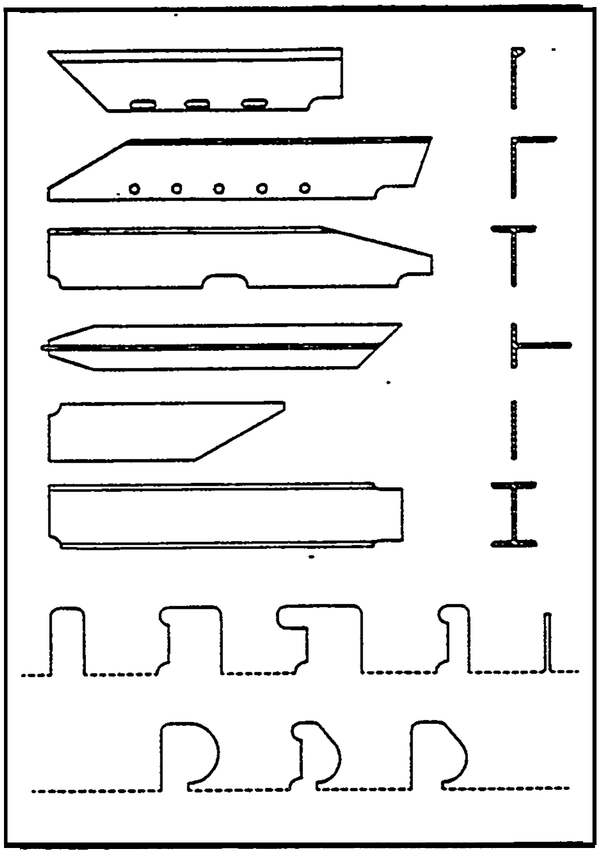


FIGURE 1
An Amalgamation of some typical cut-outs on Sections.

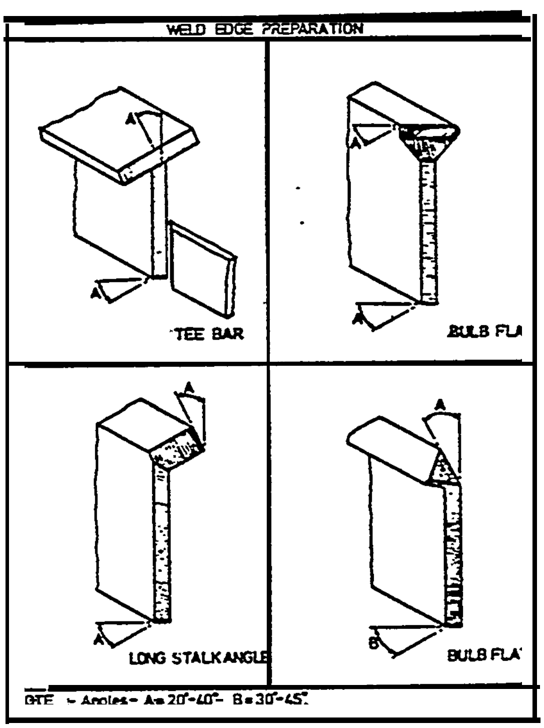


FIGURE 2
Typical Edge Preparation on Sections.

C.N.C. CUTTING LINE

A system has been designed by Oxytechnik following a request from Avondale Shipyards Inc. in accordance with shipbuilding standards end requirements. The system eliminated manual operations of drafting and cutting, and includes alphanumeric labelling and marking of bending lines on structural sections.

The total C.N.C. cutting line came into operation early in 1986. The installation of the advanced transporting system was finished recently and first test runs of the computer controlled cutting end labelling equipment have proven quite satisfactory. Not yet furnished is O.S.E. software designed as a stand-alone system. It includes a material management and shop scheduling system which will enable the line to be controlled easily.. A connection with the main frame for the direct link of the CAD/CAM generated data, is considered as a second step.

Layout and Equipment

The total is comprised of a number of transport and processing stations.

Loading of Structural Shapes on Conveying Pellets. Structural shapes are loaded on movesble pellets and conveyed on rails to all processing stations. Loading is done by crane. Accurate positioning on the pallets is realised by a length stop and specially supports. The system has the advantage of precise location of the workpieces in all stations and does not require any repositioning.

Labelling of Wirkpieces is according to A.S.I. codes, in alphanumerical characters and includes the ability to mark bending lines, etc. See figure 3. An ink spraying system is used to label each workpiece prior to cutting at predetermined locations. The quantity of characters is practically sufficient for all known cases. The ink is waterproof and mechanically resistant. The commercial labelling system was redesigned also to spray bending lines on structurals to be bent end markings for different purposes. The marking head is mounted on a semi portal and is operated in forward and reverse high speed mode.

cutting different configurations in flats tees, angles, i-beams etc. The *cutting* equipment is-capable of cutting *a* wide range of different configurations required for building ships, offshore platforms, etc.

In total 6 torches can be used or simultaneously in 2 groups of 2, 4 torches each. Therefore a two-track and a four-track cutting machine is provided depending on the beam sizes, see figures 3 and 4.

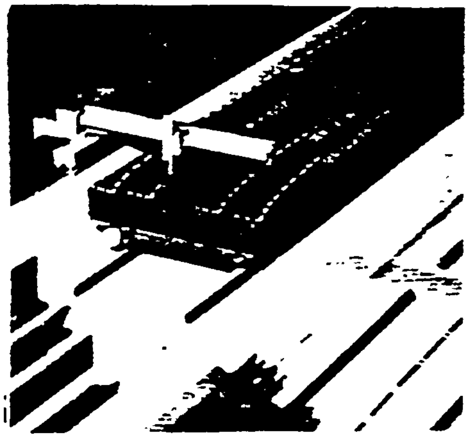


FIGURE 3 Marking of Bending Lines

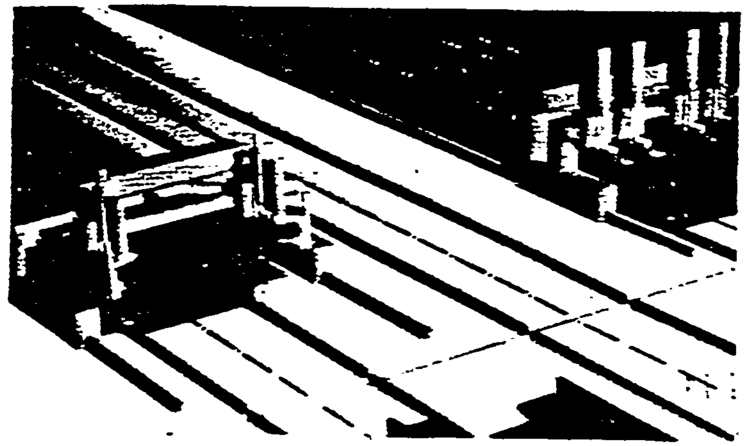


FIGURE 4 Two and Four Track Models of the Cutting Machines

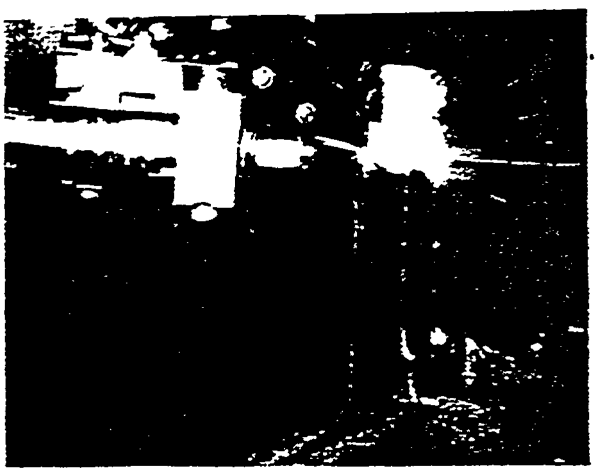


FIGURE 5 Close-up of a Practical Application of a predefined macro.

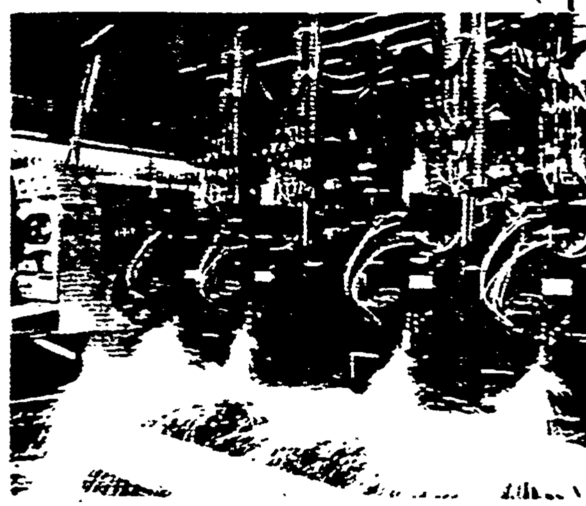


FIGURE 6 The actual four track cutting machine in operation.

Finding of the start position is by a searching process which is actuated from a programed torch location depending on the beam size.

Unloading of cut pieces is by crane. All stations are Connected by rails which are arranged in 3 parallel strings. Circulation is enabled by cross conveying of the pallets which return automatically to the starting position when mechanized scrap removal and reloading is done. Both cutting machines are designed to cut structurals in duplicate and mirror-image.

C.N.C. Control

In order to ensure easy operating of the total line a stand-along computerized system was created. It supplies the operator at esch station with all necessary information via screen and controls the cutting machine directly.

An essential part of the cutting machine control is based on predefined macros describing each configuration to be cut. See Figure 5.

The macros are stored in a data base and can be recalled by a code number on request.

A variable macro corresponds to a shape which is used for different section sizes and is adapted automatically to the required dimenaion.

The operation of the line is extremely simplified when all macros are programmed.

Material Menagement and Shop Scheduling

A shop management system takes care that the shop load is in line with the capacity of each station and bottle necks are avoided. Beside the routing of the material through the shop the management system includes a scheduling program which is based on the due date of workpieces. The computer then will indicate on which date the order must be given to the shop in order to meet the required delivery date.

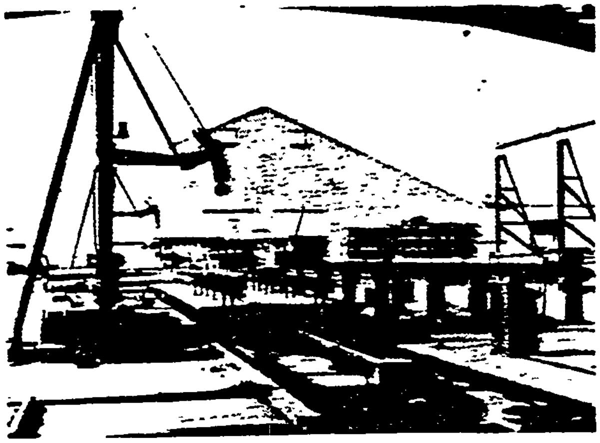


FIGURE 7

The actual cutting line of Avondale. (Loading /unloading/discrapping area).

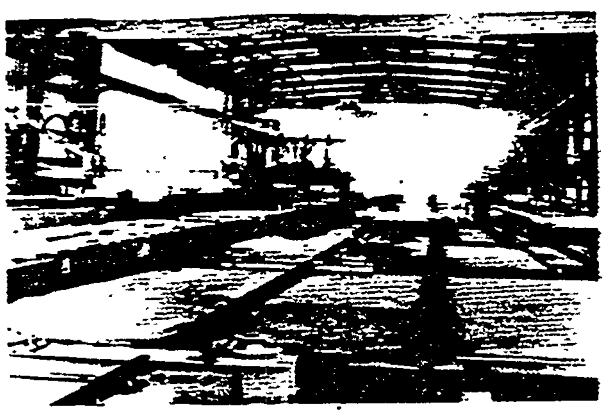


FIGURE 8

Front: cross - tranfer mechanism for moving pallets from tack 1 to tracks 2 and 3.
Left: Harking & labelling machine
Middle: Cutting machine with 4 cutting heads.
Right: " " " 2 " "

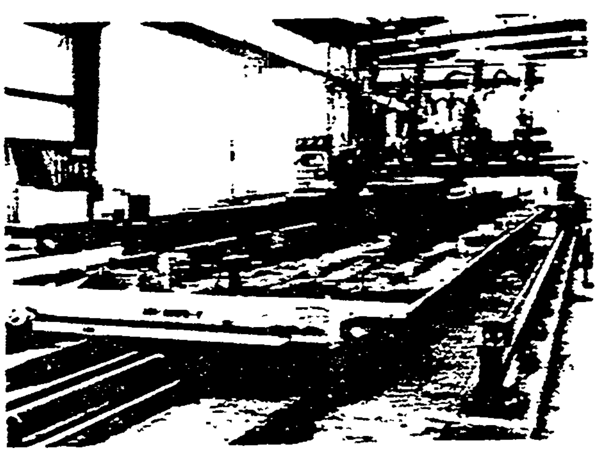


FIGURE 9

The fitting machine with the 4 cutting heads.

The production sequence is determined after utilizing a nesting program. The calculation distributes the required cut lengths to the stock lengths so that remnants are nininized. By this a maximum efficiency of the material is achieved.

A direct connection of the stand-alone system to the main frame will be provided as a second step.

Figures 7, 8, 9 illustrate the C.N.C. cutting line as installed at Avondale Shipyards.

ROBOTIC BEAM PROCESSING LINE

To start cutting at any edge of a section, requires precise positioning of the cutting torch. Due to the tolerances involved, positioning has to be done visually or automatically by using sensors. Both procedures are time consuming and reduce the duty cycle of the expensive flame cutting machines.

When VLCC'S were fabricated, multiline systems for simultaneous cutting of two or more, equal or mirror image cuts were several lines simultaneously for smaller ships nowadays, is not possible due to the lack of identical components. It even seems to be doubtful that searching for equal or mirror image bars over all ship sections will guarantee economic utilisation. After all, such a procedure would create additional organisation sod storage problems.

The Robotic Beam Processing Line, was specifically designed to overcome the limitations of traditional beam cutting machines. It also includes alphanumerical labelling and marking of bending and other lines on the workpieces.

At the heart of the system is an electric robot. It cannot only cope with the complications of the cut configurations required, but since the cutting torch is positioned within seconds, just one processing line was found sufficient in most cases.

The line is designed se a stand alone system. The control of the labelling, marking and cutting system uses information from a separate data storage or from the main frame. The cutting information is available in macros which describe all single cuts of each cutting configuration and cover the whole scope of the production programme possibilities.

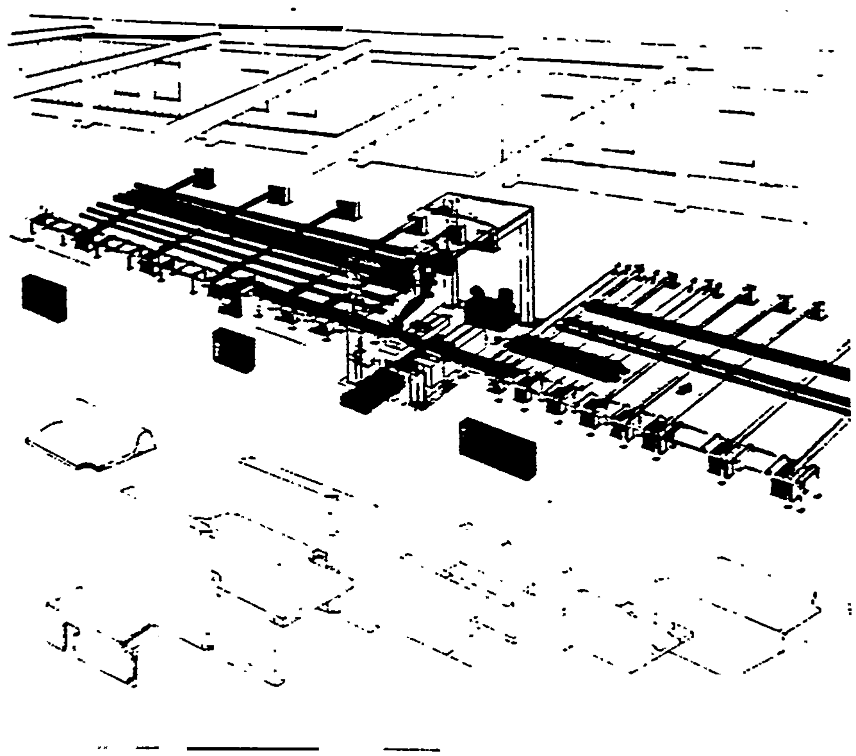


FIGURE 10 Artists impression of the total Robotic Beam Processing Line with six typical examples of workpieces in the fore ground

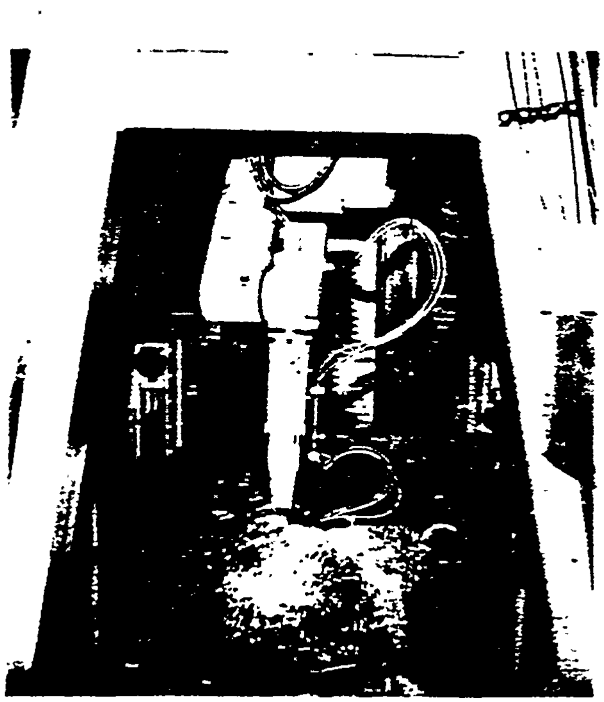


FIGURE 11
The actual gantry with the Manutec robot, cutting an I beam.

Automatic labelling and marking, mechnied section handling and robot cutting need only one operator.

SPSCIAL FETURES OF THE ROBOTIC B.P.L.

Automatic feeding and positioning of structural sections and automatic storing of cut pieces on a buffer table.

Automatic cuttting of nearly all types of shapes and sections, including welding edge preparation.

Precise cutting independent of workpiece tolerances, by newly designed process. (Pat. Penal).

Maximum efficiency of the cutting robot by extremely short positioning times and elimination of edge searching cycles.

Flexible processing by avoiding multibeam cutting. No batching or identical and mirror image Parts necessary. All intermediate storage of workplaces is eliminated.

- Elimination of sensors.

- Simple programming by using variable macros containing All Information for the scope of different cutting configurations. No “teach-in” programming.

  Automated length nesting of workplaces to get minimum remnants.

  Automatic lsbelling of workplaces and marking of bending lines.

  Possibility to connect the system to a main frame or a CAD system.

  Esey control of all equipment by only one operator.

  Cutting procedure in one area only, no wear of workpiece supports, optimal scrap and slag removal, with easy fume extraction.

  Optimal materisL flow within the production line without intermediate storage, or the need for cranes.

  Possibility to extend the line to shotblaseting, paintsprayting, sawing, straightening, bending, deflanging, splitting etc.

General Technical Description

The robotic BPL ahown in figures 10 to 16 is designed for a maximum profile height of approx. 600 mm and a of 100 mm. However, the robotic EPL can be designed to accommodate any specified dimensions.

As shown in figures 10 end 12, the line consists basically of certain transporting equipment, cutting equipment, the control system (including computer hardware and software) and labelling and marking equipment.

The gross transfer conveyor (item 1.1 in figure 12) is used for trsnsporting all type of framework section in stock lengths, to the positioning and length measuring device of the cutting equipment. An axial discharging the finished components.

For discharging small parts, a cross transfer conveyor is provided (item 1.3). The main cross transfer conveyor (item 1.4) serves for transporting and for the intermediate storage of all types of sections over 1.5 m length.

For remnants and small parts, two separate containers are provided on a carriage (item 1.5). They can essily be removed from the processing line and emptied.

The electric and hydraulic equipment of the transporting (item 1.6) and of the cutting line (item 2.4) consists of a switchboard cabinet and a hydraulic cabinet arranged beside the lines with the necessary operating and control elements. For the menuaL control of the transporting equipment, a separate control desk is arranged near the operator’s working area. The manual control is only used for setting-up and atepwise operation.

The cutting equipment consists of an axial feeding conveyor with a length measuring device (item 2.1) with free rollers end numericaL control, the positioning and clamping station (item 2.2) amd the portal with the overhead mounted cutting robot (item 2.3). The robot used is the Manutex R3 with gee cutting epuipment (all fuel gases can be used, preferably oxy-acetylene). See table 1.

In connetion with a computerised control system (item 3) the robot is able to cut nearly all shapes. Technical limits are given only by the cutting technology itself e.g. diameter of the torch, sequence of cuts etc.

Each cutting configuration at the end of a beam or elsewhere is stored in a data base and can be recalled as macro by a code number on request. A "vsriable macro" corresponds to a cutting shape which is used for different section sizes and is adapted automatically to the required dimensions.

The whole system can operate es a stsnd-alone system or can be linked via special interfaced to an existing main frame and CAD system.

A separate computer is programmed by all marking, labelling end cutting information and guarantees a minimum of access time. Automated nesting is integrated ensuring a minimum of remnants for a certain work load.

The cutting equipment is DNC e.g. the following production data will be transferred to the cutting equipment directly without interrupting the manufacturing process:

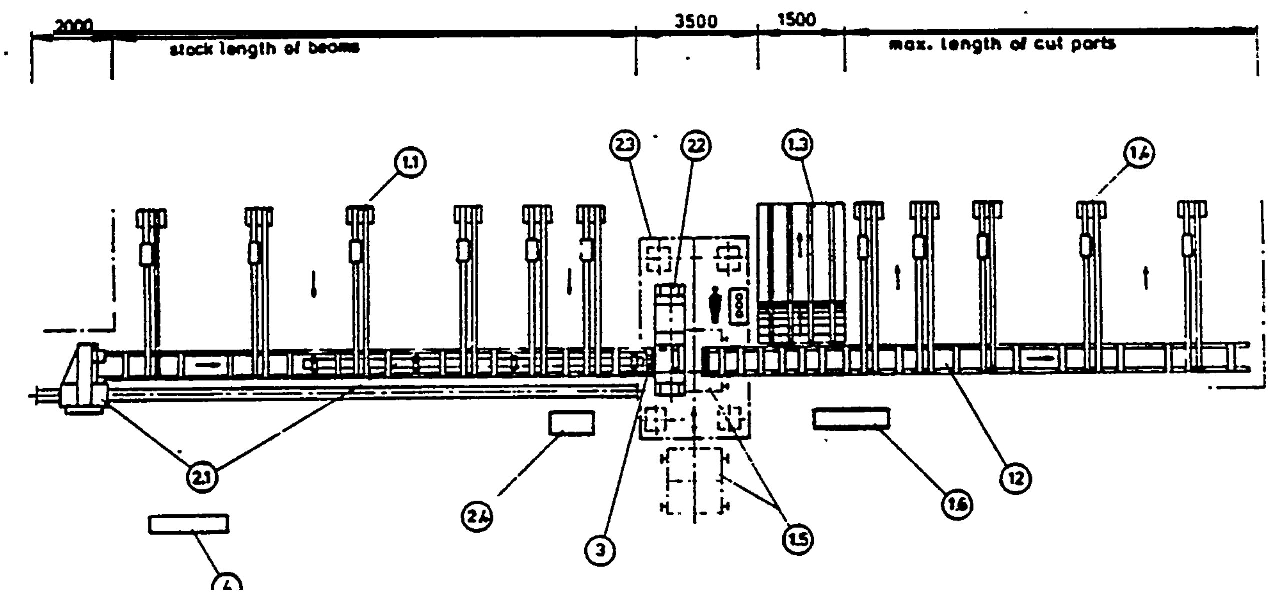
1. Identication characters for labelling.

2. Location data for bending lines and marks.

3. Codes for macros (according to the type and quantity of all cuts of a workpiece).

4. Distances between the macros.

The robot used is of standard design. With the OXYTECHNIK software and stand alone computer system, the robot is capable of cutting any end shape required immediately. Time consuming data-input end data-transfer between robot control and computer is avoided.



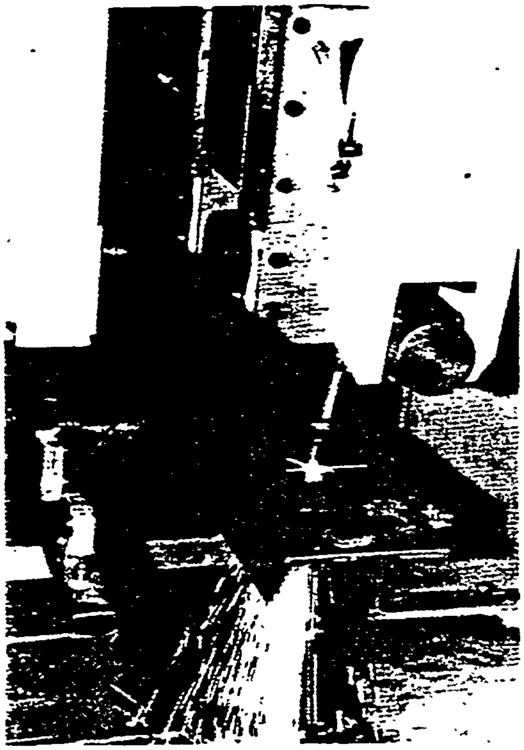
Item 1 Transporting Equipment
- 1.1. Cross Transfer Conveyor
- 1.2. Axial Discharging Conveyor
- 1.3. Cross Transfer Conveyor for Short Parts
- 1.4. Cross Transfer Conveyor
- 1.5. Container for Remnants and Small Parts
- 1.6. Electric and Hydraulic Equipment

Item 2 Cutting Equipment
- 2.1. Axial Feeding Conveyor with Length Measuring device
- 2.2. Guiding Station (Positioning and clamping)
- 2.3. Portal with Cutting Robot
- 2.4. Electric and Hydraulic Equipment

Item 3 Control System including Computer and Software

item 4 Labelling and Marking Equipment

FIGURE 12
description of the Robotic Beam Processing Line



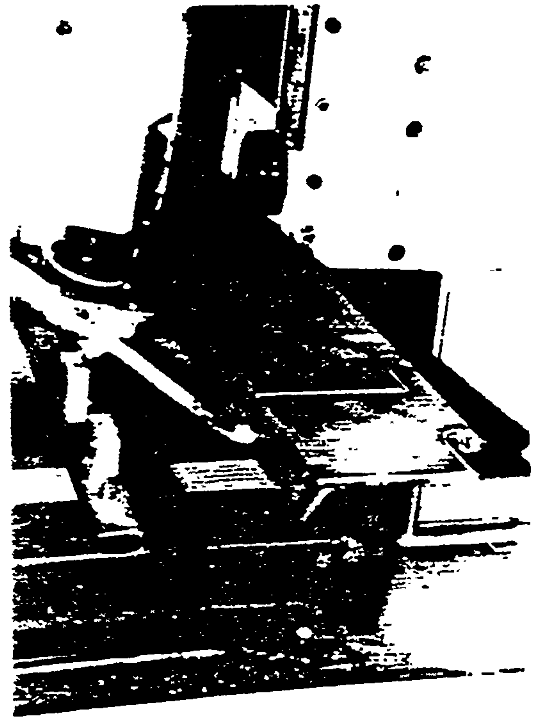


FIGURE 13 & FIGURE 14
Close Ups of the Robot Cutting an Angle Bar.

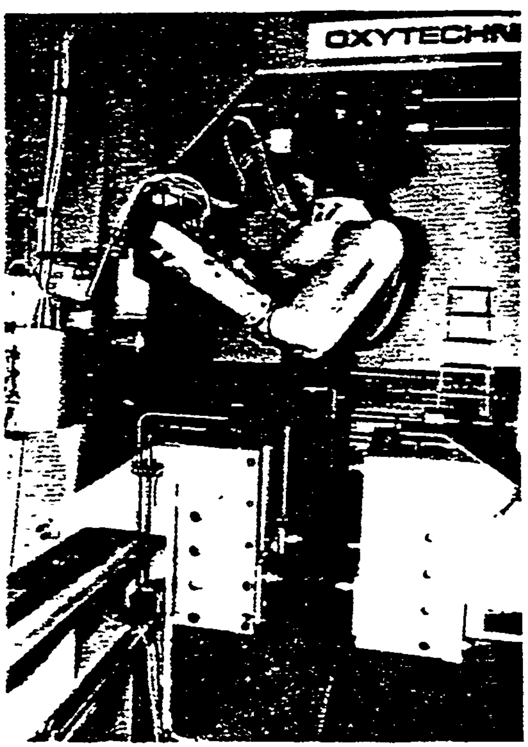


FIGURE 15
The robot at its "home" position, which is also the automatic ignition point.

FIGURE 16

The hydraulic clamp/feeder of the bars, which is also the length measuring device.

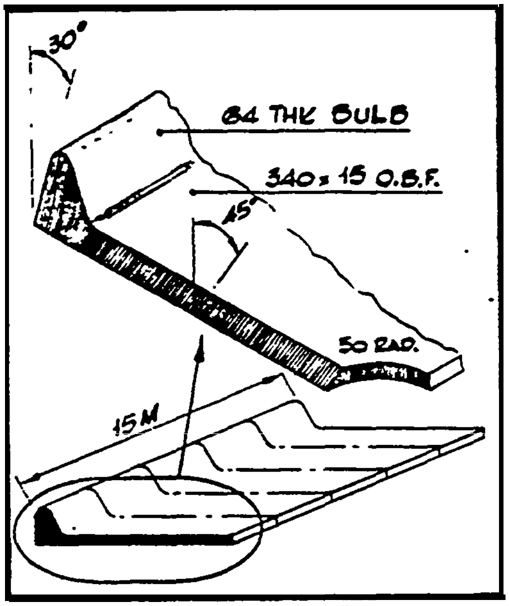


FIGURE 17
Offset Bulb Example

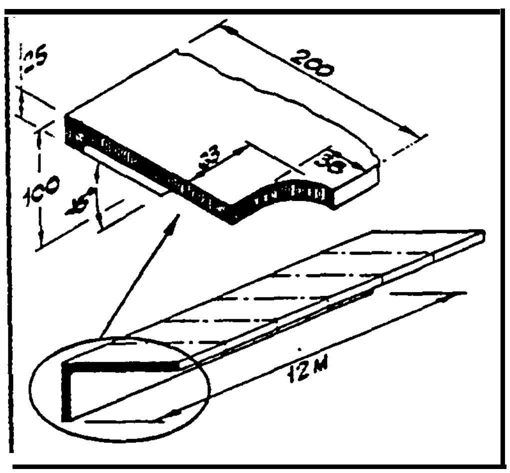


FIGURE 18
Angle Bar Example

Gas: / (mm) Thickness	Acetylene	Propane	Natural gas	MAPP
10	600	630	630	650
25	410	460	460	490
40	340	400	400	400
60	320	340	340	340
100	250	270	270	270

TABLE 1 - Cutting speeds (mm/min) for four different fuel gases.

The sequence of data transferred corresponds to the production sequence and is originated by a previous automatic nesting process.

The operator controls the prdouction sequence via a screen. An optional offer can be made to display and/or print out the actual cutting shape.

The labelling and marking equipment (item 4) use a spraying operation. The labelling speed corresponds to the transporting speed. Waterproof mechanically resistant marking fluid is jetted onto the surface. The system includs equipment for producing identification labels on the workpieces (labelling) and marks for different purposes. Narking may be also necessary to create bending lines or define any positions for further procesees.

64 alphanumerical digits can be stored and recalled as required. Both marking and labelling can be applied automatically.

Two practical Examples

Figure 17 illustrates a typical offset bulb example. Five single parts can be bevelled and processed at both ends within approximately 11.5 minutes. This time includes the handling and positioning of the total atrucural shape of 15 m length.

Figure 18 illustrates a typical angle bar example. Six single parts with shaped cuts at both ends can be processed within 14 minutes. This time includes the handling and positioning of the total structural shape of 12 m length.

Line Capacity

The capacity of the line may be calculated on the basis of some major influences such as:

- thickness of material
- total cut length
- quantity of single cuts
- quantity of beam positioning
- surface condition of the workpiece
- one, two or three shift operation

The following average values are valid for a calculation of the capacity:

- cutting speed : 400 mm/min
- preheating time per cut : 8 sec
- beam loading and positioning (first cut) 45 sec
- beam moving to next position : 5 sec

Baaed on the above examples and for a single shift operation, en approximate number of 40,000 components per year could be manufactured.

ECONOMIC CONSIDERATIONS (3)

The use of robots on the shop floor offers numerous benefits, some of which can easily be quantified such as : direct labour savings, reduced manufacturing times, and increased productivity (higher production rates). However many benefits can be very difficult to quantify, for-example:

- quality improvement
  increased safety of employees end quality of working life
- better consistency of finished parts
  increased flexibility when compared to conventional machines
- reduced inventory requirements
  increased ability to face the future skilled lebour shortage
  increased material savings with reduced scrap end rework
  increased technological development of employees
- enhanced company image
  increased ability to plain and schedule work with the provision of accurate manufacturing tines
- ability to communicate with other manufacturing machines for the provision *of* computer based integrated systems.

All such benefits ultimately increase the company's viability. However, it is very difficult to quantify them using traditional methods, which have been proved inadequate for new technology as these methods are geared-to a "quick return on the money." Companies must atop looking for the quick return on their investments and start planning for long-term viability.

There are many methods of evaluating expenditure. However, all capital appraisal techniques in exisatance are subject to a company screening process to see if the proposals are financially acceptable or not. There are tremendous variations in these screening processes. It is important to realise that management's choice of what it considers to be the most appropriate approach can restrict or even distort expenditure programmes.

Although no method is particularly suited to evaluating advaoced manufacturing technologies such as robotics, an attempt has been made to evaluate, using conventional methods and available data, the use of the two advanced manufacturing systems described on this paper, for S.H.S. use.

On the basis of a 48 week year, and a 39 hour week, the first system yields a payback period of 1.88 years, and the second 2.01 years. (5).

FUTURE TRENDS

In the future it is expected that all necessary data will be generated via the yards CAD/CAM system, and downloaded automatically to the shop floor equipment.

Computer applications in ship production technology are heading towards an integrated situation. (Computer Integrated Manufacutring) (3). Technology has attained such a level of innovation. that it is reasonable for shipbuilders to expect assistance in raising productivity and improving the quality of the working life.

There is still considerable scope for developing technology even further, but that must only happen se a specific response to identified problems.

CONCLUSIONS

Two advanced manufacturing systems have been described that automate the cumbersome section preparation areas of shipyards and offshore construction companies. The first system is particularly suited to high-throughput requirements, while the second is more appropriate to more complex shapes of sections. the use of a robot as a cutting machine in the second system ensures a highly flexible and capable situation.

Section preparation is undoubtedly an area that can now be automated in the light of the technological achievements of the computer and associated industries.

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Figures end Photos by:-

Swan Hunter Shipbuilders
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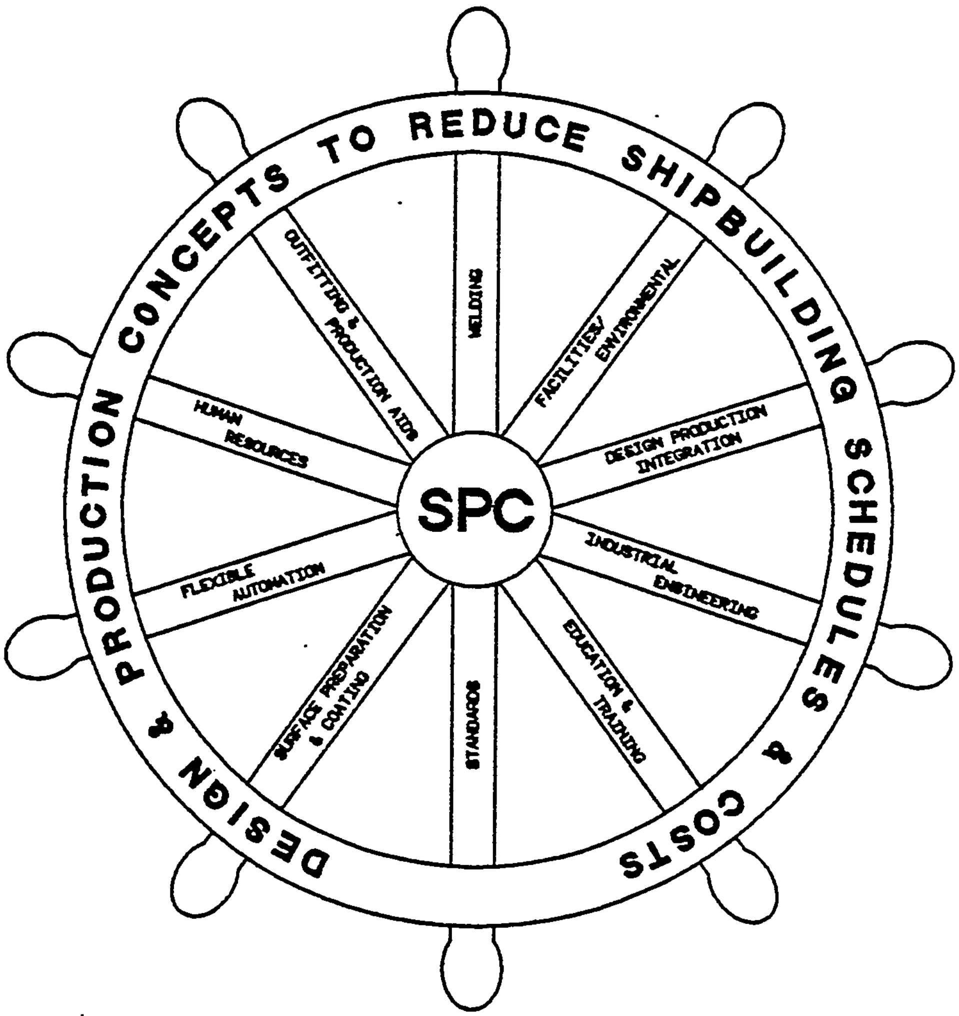

PAPER NO. 23

THE REPRODUCTION OF THE GODSPEED

BY: DUNCAN STEWART
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THE REPRODUCTION OF THE GODSPEED

DUNCAN STEWART AND WILLIAM BOZE, Newport News Shipbuilding

ABSTRACT

The authors, and designers, of the reproduction of the 17th century GODSPEED present the criteria used to design, build, launch, and sea trial the 1984 reproduction. Foul weather notwithstanding, the reproduced GODSPEED reinacted the Atlantic Crossing in 1985 and *is* now home-based at Jamestown, Virginia.

INTRODUCTION

She is a noble little ship of some 40 tons burden. She was launched in tandem with the smaller DISCOVERY on May 12, 1984 amidst the tall *trees along* the serene banks of the James River. "I'm thankful they're upright and stable", stated Joe Holzbach, launch master for the occasion. The latest wooden reproductions of GODSPEED and DISCOVERY were launched at Jamestown Festival Park in a "most fitting" ceremony attended by Governor Charles S. Robb and members of the General Assembly. In the ceremony the Governor's daughters Lucinda and Catherine Robb christened the GODSPEED with a flagon of mixed wine end *water.*

The 365th anniversary of the first legislative assembly in the New World was observed directly after the launching ceremony.

The new ships replace the two reproductions Built in 1957 and will assume a more prominent role than their rarely sailed" predecessors.

BRIEF HISTORY OF THE VOYAGE AND SHIPS

England was held in the colonizing fever until the early years of the 17th century. History records that on April 10, 1606, James I granted the charter to the London company that was destined to become the first permanent English Settlement in the New World. The London company was assigned territory between the 34th and 38th degrees, north latitude, Cape Fear to the Potomac, embracing the coast lines of Virginia.a and North Carolina. The SUSAN CONSTANT, 100 tons burden, the GODSPEED, 40 tons burden, and the DISCOVERY 20 tons burden were chartered and made ready for the voyage . . . A small company of 104 colonists was assembled . . . and under the command of Captain Christopher Newport plans were made for the trip. Captain Newport commended SUSAN CONSTANT, Captain Bartholomew Gosnold was put in charge of the GODSPEED, and Captain John Ratcliffe commanded DISCOVERY. Newport's Commission dated December 10, 1606 gave him "sole charge and command of captains, soldiers, marines and other persons that shall go in any of the said ships and pinace in the said voyage from the date hereof until such time as they shall fortune to land upon the said coast of Virginia". "The six and twentieth day of April, about foure o'clocke in the morning, we described the land of Virginia. The same day we entered into the Bay of Chesupio directly without let or hindrance."

History of the original GODSPEED contains little information as to what the vessel actually looked like or how it was constructed. Actual dimensional data that would represent size and meaning to the hull form and rig is nonexistent. Recorded tonnage figures were reflective of the ships carrying capacity of a Bordeaux wine cask indicative of the trade between England and France. The tun held approximately 252 gallons. Considering the awkward shape of the cask, the geometry of the ships hull in the hold region, and wasted space, a tun was considered to occupy 40 cubic feet instead of 33 cubic feet [1]. The tun became a standard unit with a fixed weight of 2240 lbs. Tons (burden) can be roughly equated to modern net - tonnage, tons and tonnage to the modern gross tonnage. The only indication of the vessel's size was the burden tonnage and proportions as to length on deck, length of keel, and beam. The 3:2:1 ratio [1] had been preferred during the early 1500's as the proportions of such a hull form would accommodate maximum cargo stowage. It is interesting to note that a Change towards more weatherly proportions was both appreciated and accepted during the latter 16th century in order to improve performance. The cargo carrying capacity of the round hull was preferred, but the need for improved handling qualities brought about by the heavy gun batteries located below decks changed the architecture of these vessels. Carvel flush planking construction replaced the earlier clinker hull construction method by the last quarter of the sixteenth century. This technique was brought about by the need to-strengthen the ship's hull in support of heavg weight concentrations coupled with the ship's motion in seaways. It is reasonable to assume that GODSPEED, circa 1586, and a merchantmen of the same period were influenced in design and construction by the master Elizabethan Shipwright Matthew Baker. An English Galleon of this period of 200 tons burden reveals dimensions of: keel 60 ft., beam 24 ft., and a depth of hold of 12 ft. The Ship's underwaterlines reflect Baker's refinement of a highly maneuverable Elizabethan warship and the scaled down version resembles the official painting of the Jamestown ship GODSPEED. An English Merchantman of the early seventeenth century reflects the general design characteristics of the period [8].

The late W. A. Baker, designer of the MAYFLOWER II, a 20th century reproduction, is considered to be the leading authority in the design and construction of period ships. Also the late Robert G. C. Fee, designer of ***the*** 1957 Jamestown fleet, established a research base for naval historians as his tireless work resulted in the construction of the first full scale reproductions.

It is interesting to note that Bill **Baker** made the following assessment of the 1957 Jamestown fleet in a discussion of Bob Fees' SNAME manuscript [21].

o SUSAN CONSTANT 14% too large

o GODSPEED 30% too small

o DISCOVERY 33% too small

Comparing the proportions of the aforementioned English Galleon **[1] it** is conceivable that the original GODSPEED could have been of the following proportions:

KEEL	BEAM	DEPTH OF HOLD	GALLEON
60.0'	24.0'	12'	Original
37.5'	15.0'	7.5'	GODSPEED (1957 Repro.)

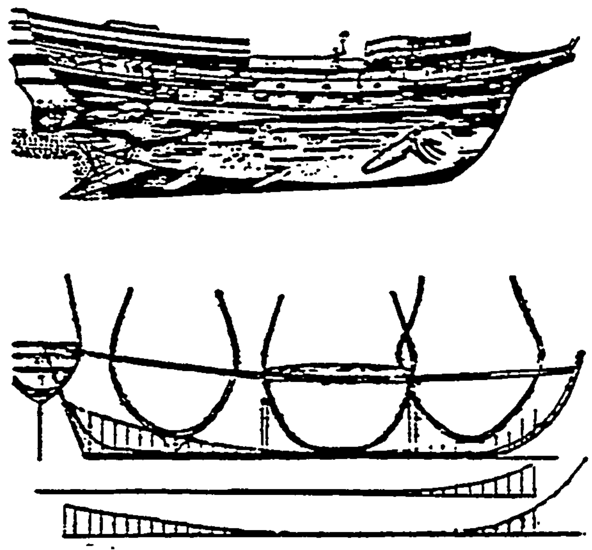


Figure 1 **- Matthew Baker's Illustration of Ideal Hull Form**

Figure [1] reveals the under waterlines and sections of an English galleon of C1586. Matthew Baker, the Elizabethan shipwright, clearly shows the image of a fish on the construction profile to demonstrate to a layman the ideal shape for a hull below the waterline. Even though ***the*** drawings are of a period warship taken from Fragments of Ancient Shipwrightry [1], it is widely accepted that a merchantman of this period followed the same general characteristics. The British Admiralty Library has a copy of "A Treatise on Naval Architecture" [1] printed in 1625 and lists the ships of the Elizabethan and James I period. Table I is shown to illustrate recorded sizes of selective period ships to comparable modern reproductions.

The authors/designers of the 1984 reproduction of GODSPEED will, in no way, attempt ***to*** "set the record straight" as to what the proper dimensions for the ship should be, since the dimensions of the original ships are unknown. Mr. Baker and Mr. Fee gave much of their time and energies in researching period ship history and both are considered by the authors to be noted authorities.

Methods used to calculate a period vessel's size is a subject of

	RATIO	ENGLISH GALLEON CIRCA 1586	RATIO	ELIZABETHAN WAR SHIP	RATIO	MAYFLOWER REPRO.	RATIO	ELIZABETH II REPRO.	RATIO	LA GRANDE HERMINE REPRO. CIRCA 1545	RATIO	SUSAN CONSTANT REPRO.	RATIO	GODSPEED REPRO. 1957
KEEL LENGTH	5	60.0 FT	4.6	60.0 FT	5.08	61.0 F	4.78	39.5 FT SCALED FROM SAIL PLAN	4.46	53.62 FT (APPROX.)	5.7	53.5 FT	5.5	33.5 FT
BEAM	2	24.0 FT	2	26.0 FT	2.08	25.0 FT	2	16.66 FT	2.08	25.0 FT	2.4	22.83 FT	2.18	14.3 FT
DEPTH (HOLD)	1	12.0 FT	1	13.0 FT	1	12.0 FT	1	8.25 FT	1	12.0 FT	1	9.33 FT	1	5.83 FT
TONS BURDEN RECORDED		200		202 (19 GUNS)		183		50		100 TO 120 242 TODAYS RATING		100		40
TONS BURDEN FORMULA KxBxD/100		172.8		202.0		183		55		160		114.0		27.9
TONS BURDEN VARIANCE TO RULE		(-13.6%)		0		0		(10%)		(+33%)		(+14%)		(-30%)

NOTE: - RATIO OF LENGTH OF KEEL, BEAM AND DEPTH OF HOLD ARE SHOWN FOR EACH SHIP IN THE STUDY.
- RECORDED TONS BURDEN DATA IS SHOWN TO ILLUSTRATE SIZE COMPARISON OF PERIOD SHIPS AND A FRAME OF REFERENCE FOR PRESENT AND FUTURE REPRODUCTIONS.

Table 1 - Size Comparisons of 16th Century Vessels and Reproductions

considerable dispute. Recorded tonnage and proportions of Elizabethan ships should be used as a guide only. Samuel Pepys, Clerk of the Acts of the Navy Board and later Secretary of the British Admiralty is credited with providing information of period ships considered to be authentic in research circles. Due to the fact that he was a collector and that many of the documents of his time were published, insight as to ship architecture of the period is available. The Pepysian Library of Magdalene College, Cambridge contains many of Mr. Pepys' collection of documents and models of the period.

Mr. W. A. Baker was consistent in applying a 5:2:1 ratio for length of keel, beam, and depth of hold on his design of period ship reproductions. Ships of the period generally followed these hull proportions and are evident in the reconstruction of ELIZABETH II and MARYLAND DOVE.

Design Criteria for the 1984 GODSPEED Reproduction

In designing the 1984 reproduction of GODSPEED the designers focused on the following considerations:

- The ship's appearance would be similar to the 1957 reproduction and in keeping with the official painting of the Jamestown fleet by Commander Griffith Baily Coale - (the same general requirement as the 1957 vessel), Figure [2].

- The vessel would be of a waterline length of about 45 feet. Proportions as to length,

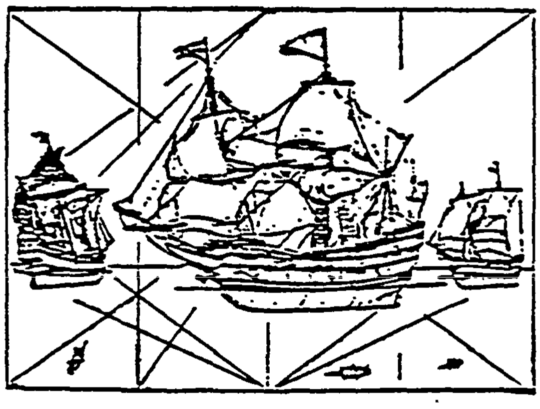


Figure 2 - Commander Coale's Preliminary Study of the "Jamestown Ships"

beam, and depth of hold would generally follow those of the Elizabethan ships, however good balance of hull and rig, stability and performance, would be the governing facts as ocean travel was envisioned.

- The sectional area curve would be the most significant factor in effecting the hull form of least resistance closely followed by the forebody load waterline shape.
- GODSPEED's waterline entrance, though fuller than a modern vessel, would be refined significantly so as to mitigate the "bluff", or full shape characteristic, of period vessels.
- The underbody lines aft, as developed from the sectional area curve, would be clean with moderate convex qarter beam buttock shapes effecting "sweet and easy" hull lines flowing to the transom.
- Since significant resistance can be experienced from a transom that is submerged, the design would limit this condition as much as possible.
- The waterplane area necessary to attain adequate stability would govern.
- The draft of the vessel would allow for navigation in local waters and be of sufficient depth to meet the requirement of ocean voyages.
- The ship would achieve the level of weatherly sailing that one could expect of a square rigger in addition *to* down wind performance, characteristic of square riggers.
- The new design would incorporate reasonable keel drag necessary to effect directional stability. Even though period ships reveal little or no keel drag, every consideration would be given *to* lateral plane and sail area centers with respect to balance.
- The rig would be considerably greater than the 1957 reproduction, since the "power to carry sail" of the earlier GODSPEED reproduction was much greater than the rig she
- The ship would have no auxiliary **power** and would depend upon tow assist as required.

THE DESIGN CHARACTERISTICS OF THE NEW SAILING VESSEL GODSPEED'S HULL FORM

The midship section is generally characteristic of a period merchant vessel, Figure [3]. It has no "flat of bottom" as a heavy "man of war" nor does it reflect "tight" bilges and **concave** upper works. The bilges are slack and the tumble home top sides were formed by simply connecting a straight line from the upper turn of the bilge tangent *to* the cap rail. Care was taken to insure that the upper Lines maintained the desired weather deck area and the volume requirements within the hold capacity. As a basis for developing the lines drawing the waterline length was set at 46' - 0", **maximum beam** 14' - 5", fairbody depth of hull *to* weather deck 10' - 1 1/2", and a depth of hold at 6' - 5 1/2". " A light ship mean draft of 6' - 0" and a mean full load draft of 6' - 6" was selected by the designers in order that bay passage with its many shoals, in addition to ocean passage, would be possible. The harbor at Jamestown Festival Park also required that draft be held to a minimum.

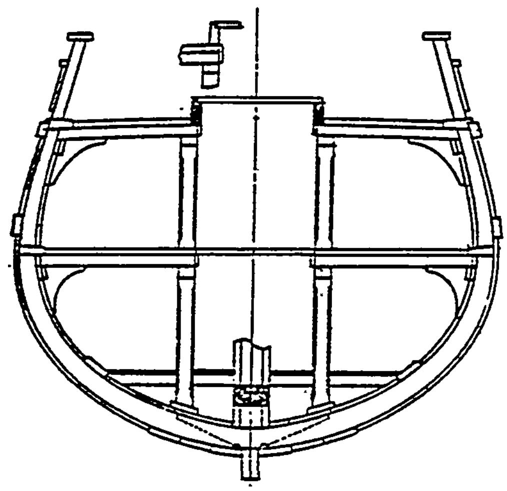


Figure 3 -Mdship **Section**

Developing the lines drawing for a 10 station vessel resulted in many iterations of reshaping the underbody design ordinates to attain the desired sectional area curve while maintaining the full shaped forward waterlines characteristic of a period ship design, Figure [4]. An initi al planimeter check of the lines indicated a light ship displacement of 42 tons and a

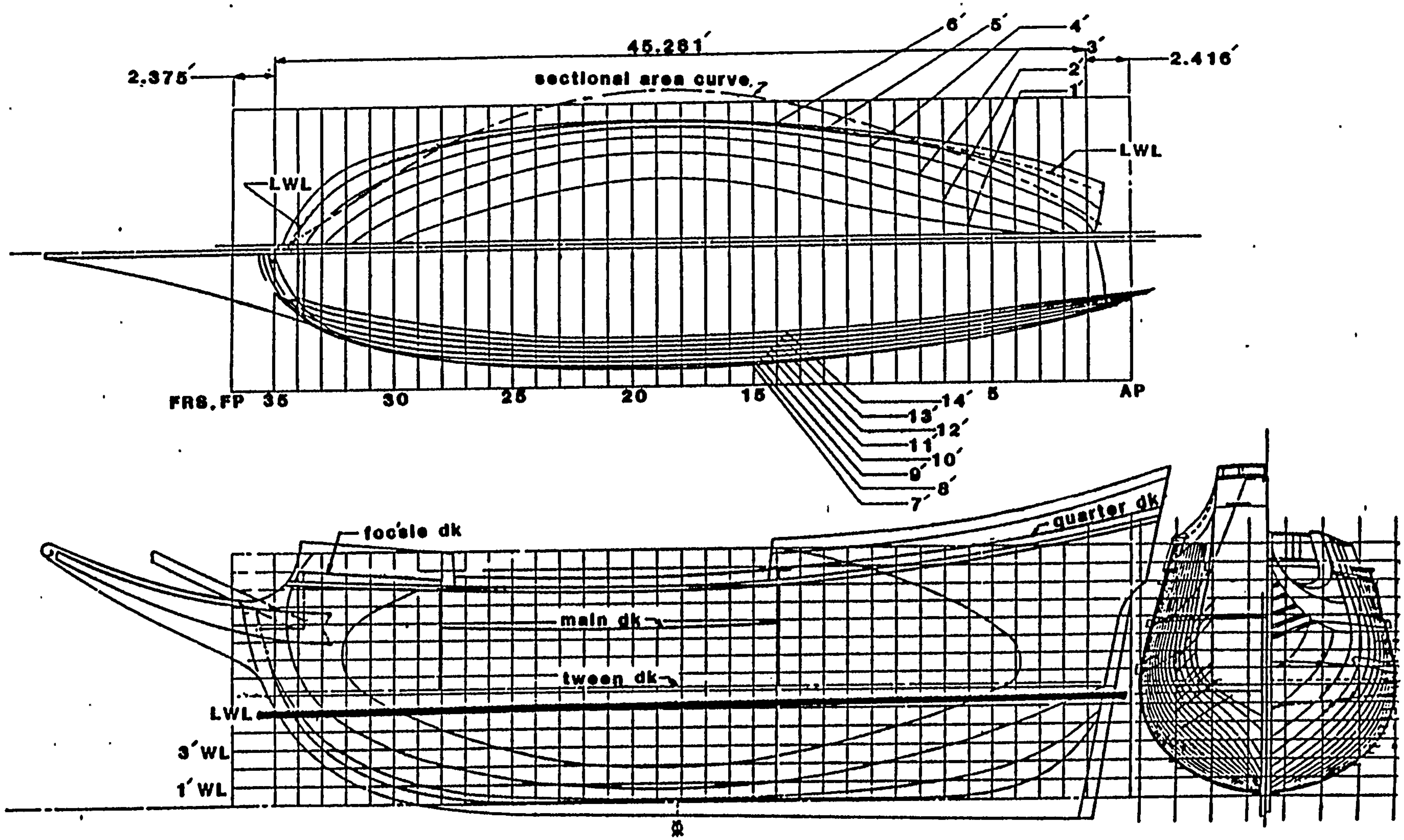


Figure 4 - Lines Plan

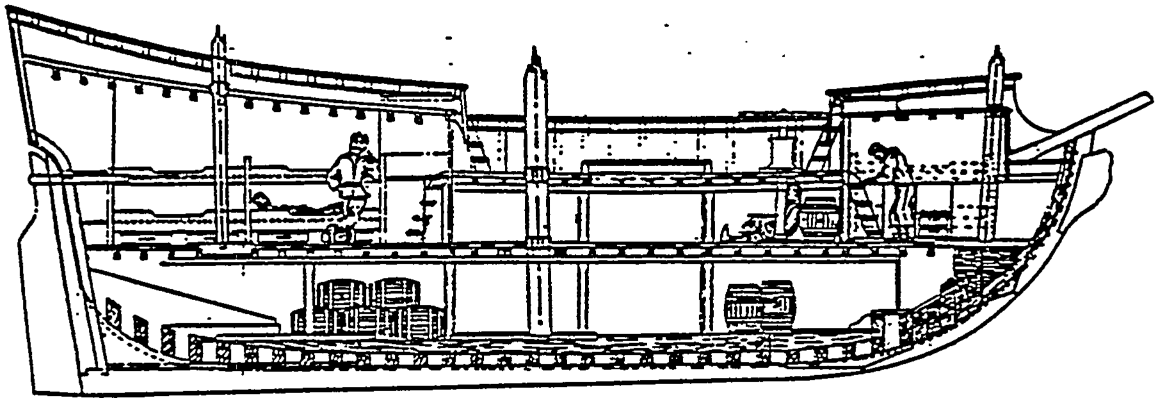


Figure 5 - Illustrate- Froftie

full load displacement of 48 tons at the stated drafts. Estimated weight of the light ship Lncluding spaces, rigging and outfitting items resulted in a weight of 27 tons. Preliminary hydrostatic calculations proved the vessel would perform favorably, providing that proper balance and loading of vessel to the design waterline are maintained.

Designers and builders of period ship reproductions are often criticized for not using mechanical methods in the creation of hull lines. "Arcs of circles" was an accepted method of the period, and lines for modem reproductions could follow the same methods. Shipwrights prior to the advent of lofting *or "laying* down of ship lines" on the mold loft floor had only mechanical methods as a process tor defining the hull form. Master templates constricted by arcs of circles were erected at the building site *at* predetermined locations and included the stem, keellkeelson and transom assemblies. Fairing battens were affixed to the master templates ending at the ships extremities. As in the case of lofting the lines, many iterations of adjusting these templates were required in order to bring about a fair surface. It is reasonable to assume that the original "Arcs of circles" master templates were transformed into faired lines of less severity than shown on the early drawings and are similar *to* today's lofted lines.

CONSTRUCTION

Jamestownflorktown Foundation under the direction of Les Sweeney elected to select a local boatwright, Carl Pederson, to build GODSPEED. Prior to actual construction, the task of selecting proper boat building lumber was the primary consideration. GODSPEED 's hull is primarily constructed of heart long leaf yellow pine, since longevity with little maintenance was a primary consideration. After the building material was selected the process started officially on May 14, 1982. The keel *was* authenticated by Virginia's first lady, Lynda Robb. GODSPEED's keel length is thirty six feet molded, nine inches sided at six inches, and contains a two inch worm shoe of white oak . The keelson rests atop the buttocks and is thru bolted to the frames and keel. The frame timbers

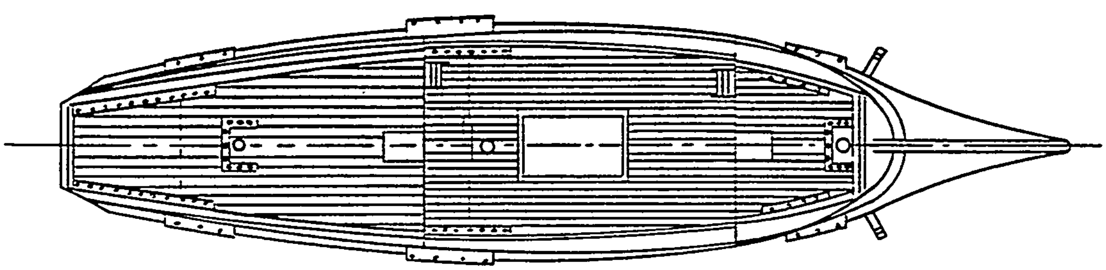


Figure 6 - Deck Arrangement

are of excellent grade heart pine, joined and bolted and sawn from patterna lifted from the Mold Loft body plan and beveled to suit the hull form. Molded dimensions are seven and one half inches at the heel with a taper to four inches at the cap rail. Transverse frame spacing is sixteen inches. The stem is constructed of black locust and the planking is long leaf yellow pine of one and five-eight inch thickness. The hood ends, both forward and aft, at locations of severe curvature are fabricated from select white oak and steamed prior to installation. Even though broad strakes for planking are shown adjacent to the garboard strake on the midship section drawing, they were eliminated during actual construction as the hull strength far exceeds the requirement of a vessel of this size, when considering the imposed loads. See Figure [5] for construction and illustrative profile. See Figure [61 for deck arrangements.

The locationa of the construction trames were scribed atop the keel and the contours templated from the hull term matrix or ribbands. Hull construction of wooden vessels, after templating timbers from the actual work site, is much the same today as it was during period times. Modern technology in the development of power tools is obtiously the vehicle for reducing labor hours during the construction process.

Nodern reproductions of period ships constructed in the manner of Elizabethan shipwrights, even with the use of power tools, would greatly inflate construction costs and the results as to authenticity would essentially be the same. Lofting of building frames and a master construction plan yield reduced labor and material costs and a predictable building duration.

During the latter half of the 17th century shipbuilding had become a science and ships could, theoretically, be constructed in advance as larger sturdier ships wert built.

A bilge stringer of heart yellow pine is attached to the frame futtocks inner contour and Is designed as a longitudinal strength member throughout the length of the vessel. Approximately fourteen tons of lead ballast is located atop the ceiling adjacent to the keelson and is distributed over the lower ceiling at two-thirds of the vessel's length. A dunnage deck rests atop the ballast. It is portable, secures the ballast, and provides a storage area for heavy items. Juniper ceiling is installed in the 'tween deck, great cabin, and forecastle regions. Tween deck beams of white oak are Iocated.adjacent *to* each tranaverse frame and are molded five and one half inches and aided at four inches. The beams rest on an oak clamp, five inches molded and three inches aided. Oak hanging knees are located at high stress areas beneath the deck beams and are secured and bolted to both the beam and side frame. The tween deck extenda the entire length of the vessel and the planks are two inch douglas fir. This deck provides the cabin sole for the great cabin aft and the forecastle area. Waterways of three inches by nine inches of heart yellow pine form the sheer boundary.

The main deck framing convention is similar to the tween deck and the beams are molded and aided at four inches. The planks are two and one half inch douglaa fir and the rather large water waya of four inches by nine inches provide the watertightness required for the weather deck. This deck extends from the forward bulkhead at frame twenty eight to the after bulkhead at frame fourteen. The vessel is additionally supported at high stress areas by stanchion set one foot ten inches off the center line port and starboard" and are fashioned from six inch by six inch heart pine or white oak timbers. The timbers are located at the main and *tween* deck hatch ends under tween deck at bulkhead fourteen and frame nine. The hatch openings for both the main and tween deck are approximately forty inches by four inches white oak and the grating is select marine *teak. The tween* deck hatch coaming is two Inches by seven inches white oak and the teak grating is set flush with the top of the tween deck planking.

The quarter deck is the uppermost deck aft, forms the deck over the great cabin, and serves as the helmsman station. The deck extends from the forward bulkhead of the great cabin to the extended transom aft. The deck beams are four inches sided, six inches molded, and are located on sixteen inch centers. The beams rest on a clamp, port and starboard, align with the side framing, and are secured in the same manner as the main deck beams.

The forecastle deck extends from **the after bulkhead of the forward** cabin to the forward weather bulkhead, just forward of the fore mast. The deck beams are three inches sided, two inches molded, and are located on sixteen inch centers. The beam connection to the side framing is, beam seated atop clamp, "and notched in way o-f clamp. The hanging knee convention forms the gusset as is the case with all of the decks at the beam end hull connections.

The bulwarks of the main deck-are approximately three feet high and are fitted with four gun ports to accommodate four breech loaders. The bulwark cap rail is seven inches by two inches white oak. Vales are located on the hull at the main deck sheer line and a lower vale above tween deck, port and starboard. The wales have a molded depth of six to seven inches and are sided three inches. The material is white oak.

The long head or stem extension is notched into the stem approximately seven feet above the bottom planking rabbit line and extends forward of the stem approximately eleven feet. The timber is heart long leaf yellow pine and is three feet at the head tapering to nine inches at the forward *extremity.* It is sided at six-inches and attached to the upper stem. It supports the grating for the "overboard" head and contains flat oval slots through which the bow sprit gammoning can be attached.

The rudder weighing four hundred pounds is slightly oversize *to* period standards and is deep and rather shallow. The effective **area is seventeen** feet square and constructed of white oak. Details of the rudder are shown on Figure [7] as developed from the construction profile.

The vessel is fitted with a capstan located on the main deck forward of the main deck hatch. Hawsers are led through port and starboard hawse pipes located on the ships prow. They pass through the foc'sle *to* the hand operated capstan. In addition to weighing anchor this hauling device was designed for loading cargo in the main hold from blocks affLxed to the main yard or lending the mechanical advantage necessary *to* haul running rigging in heavy weather. Figure (5) shows the construction profile and the meager accommodations afforded early 17th century seamen and passengers. Shown in figure [6] is the deck arrangement and a sectional view of the rig.

ACCOMMODATIONS

The height in the tween deck region between the top of tween deck and the underside of main deck beam is three feet five inches. This height represents an increase of nine inches over the earlier reproduction of GODSPEED. Tween deck was set at the

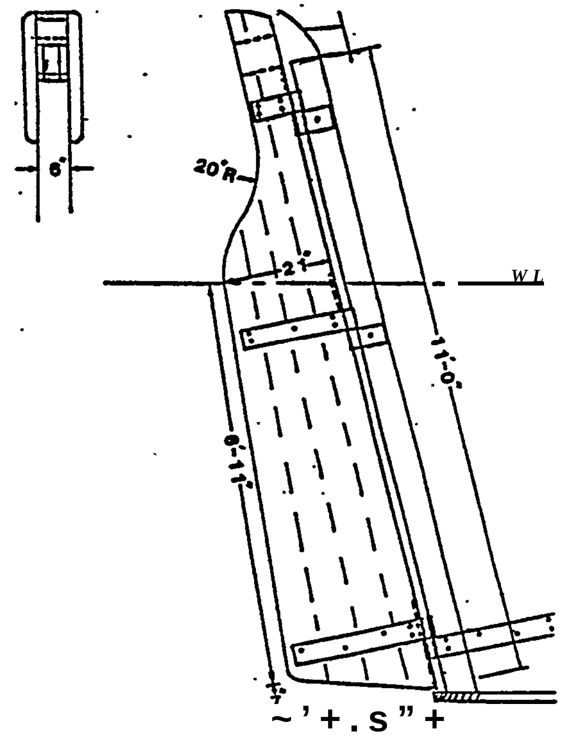


Figure 7 - Ruddder Details

10WeSt pOSSible height above the top of the keelson, four feet seven inches. The location is at the maximum beam of the hull. The possibility of installing pipe berths in this region for crew berthing was envisioned by the designer. Straw ticking was used in this region for transporting the colonist to Jamestown. With the able assistance of Les Sweeney, berthing was expertly designed to make habitability as comfortable as posstble considering a vessel of forty-six feet waterline length. Eight berths (four doubles) in the great cabin and a single berth in the foc'sle region would accommodate the crew. The foc'sle region was selected as the galley for an extended sea voyage and berthing accommodations for the cook were located in the same area. Galleys of larger period ships were located in the vicinity of amidship. The smaller GODSPEED would have required a deck house extension of. either the great cabin or the forecastle in order to attain the required head room in the tween deck area. Down wind performers, characteristic of square riggers, would best serve the crew in exhausting galley odors in the direction of the vessels heading. Hence GODSPEED's forward location of the galley seems most appropriate.

The steering arrangement is a vertical lever called the whipstaff and is used for controlling the rudder. This is a deviation from the period ship arrangement where the whipstaff passed through a fulcrum and attached to a rather long below deck tiller. This was altered *to* effect better rudder response. A series of blocks strategically arranged in the aft cabin allow cables to be connected and tensioned to a short tiller such that.a smooth motion is realized. This system is easily adaptable to a ship's wheel should the need arise. However the ease with which the whipstaff system operates should eliminate the need for a wheel.

THE SAIL PLAN AND RIG

The Elizabethan galleon introduced in 1581 had no beakhead, the fore-castle was located abaft the stem, and the castles were much lower than the Hawkins ships prior *to this* time (1). This was a logical evolution brought about by the need to reduce windage that had hampered windward sailing for many years. The reduction of the upper works also resulted in improved stability. It is interesting to note that the painting of the Jamestown fleet by Commander Coale reflect the characteristics of such a vessel. The square rig has three masts, no top gallants, no mizzen lateen top sail, and the sails are cut to set much "flatter" than the earlier full cut sails. GODSPEED carries a fore course, main course, main *top* sail course, a mizzen, and a sprit sail, see Figure [81.Th e sprit sail was added to improve performance as balance of hull and rig could be effected with different sail combi-nations.

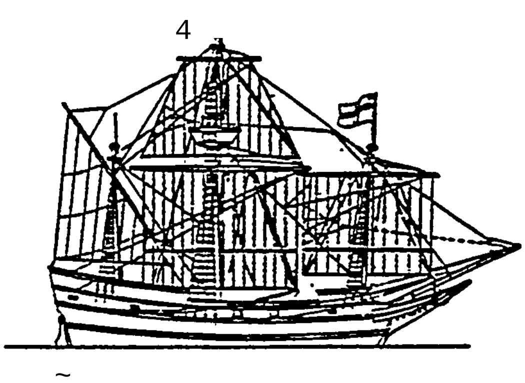


Figure 8 - Sail Plan (Spritsail Not Shown)

he location of the main mast is slightly abaft amidship and *in* alignment with the L.C.G. of the hull. The mast is well before the middle of the keel as the overhang of the keel is far greater forward than aft. The mast is stepped on the keelson.

The mizzen mast is located about 3/5 of the distance from the main mast to the taff rail in keeping with a period Commonwealth rule. The mast is stepped on *tween* deck.

The fore mast is set well forward and close to the stem head or about two thirds of the distance from the keel to the stem head. The mast is stepped on tween deck.

Published works of W. A. Baker and Dr. R. C. Anderson were of significant value to the designers in establishing GODSPEED's sparring and sail arrange-ments.

The "rake" of the masts and the "'steeve" of the bow sprit are largely a matter of judgment with respect to the *trim* of the ship. GODSPEED is trimmed by the stern and the foremast is raked slightly forward. Main mast and mizzen are raked aft approximately one in twenty.

GODSPEED's bow sprit rises at an angle of 25 degrees and is 24.5 feet in length. The PRINCE GEORGE of 1723 has a much steeper angle of 36 degrees. It is said that bow sprits became steeper during the later periods.

The lengths of the masts depend upon the measurement of the main mast and on small ships of the period the *main* masts were found to be as much as three times the beam. GODSPEED's main mast length was set at 38.5 feet or approximately 2.7 times the beam. In applying a three times the beam rule (3 X 14.41), GODSPEED's main mast length would have been 43.2 feet. In the opinion of the designers, a mast of this height when combined with a seventeen to twenty foot main top mast, would be better suited for a larger vessel of say ten foot draft, a waterline length of fifty feet, and a beam of approximately sixteen feet. The mainmast of a small third rate Dutchman of the period is recorded at 2.65 times the beam and most probably would have Seen an acceptable length for the English Vessel GODSPEED.

The foremast length of 30.42 feet or approximately 4/5 of the main mast is in keeping with recorded propor-tions and the mizzen mast is lightly shorter than the fore mast at

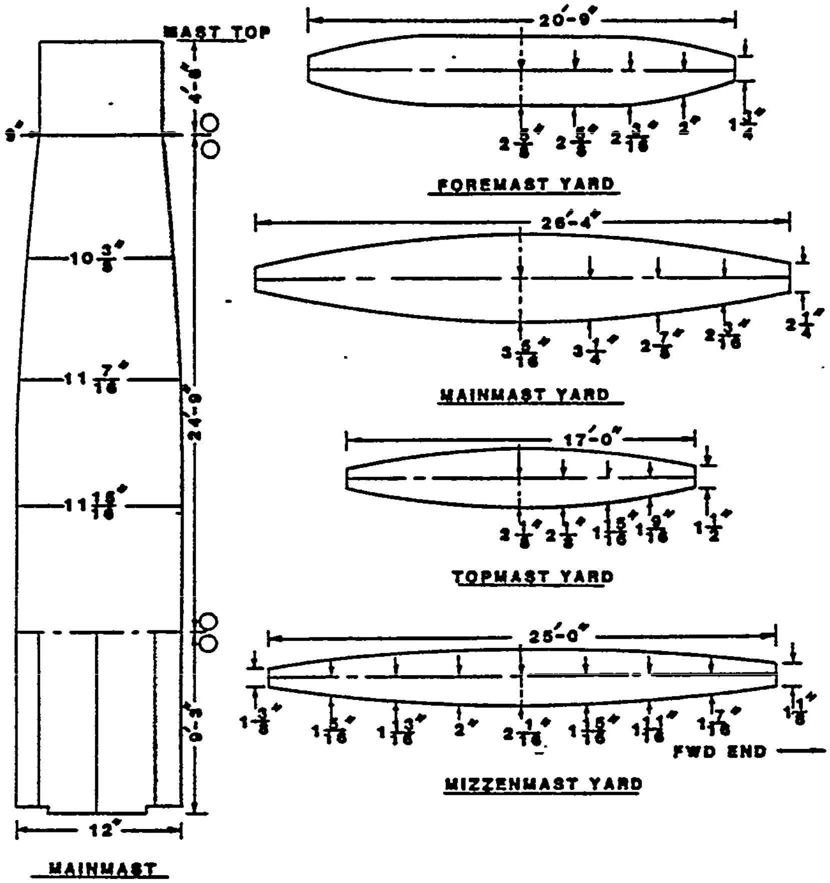


Figure 9 - Mainmast and Spars

MAIN PARTICULARS
1984 REPRODUCTION GODSPEED

LENGTH OVERALL	68' - 0"
LENGTH WATERLINE	46' - 0"
LENGTH KEEL	36' - 0"
BEAM (INSIDE PLANKING)	14' - 1 1/2"
DEPTH OF HOLD	5' - 11"
WIDTH OVER YARDS	26' - 0"
FORMAST (ABOVE BASELINE)	37' - 6"
MAIN MAST (ABOVE BASELINE)	42' - 0"
MIZZENMAST (ABOVE BASELINE)	37' - 6"
DRAFT FORWARD (FULL LOAD)	6' - 0 1/2"
DRAFT AFT (FULL LOAD)	6' - 10"

SAIL AREAS/MAIN SPARS

GODSPEED	AREAS	MAST BASE	THK RULE	LENGTH
FORE COURSE	285.0 SQ. FT.	9"	8 7/8"	30' - 5"
MAIN COURSE	412.2 SQ. FT.	12"	11 1/4"	38' - 6"
MAIN TOP SAIL	246.2 SQ. FT.	5"	5"	17' - 0"
MIZZEN (3/5 MAIN)	197.0 SQ. FT.	7 1/2"	7 3/16"	30' - 0"
SPRIT SAIL	143.0 SQ. FT.			

DISCOVERY	AREAS	BASE	RULE	LENGTH
MAIN SAIL	383.0 SQ. FT.	10"	9 5/8"	38' - 6"
FORE SAIL	294.0 SQ. FT.	8 1/2"	8 1/2"	34' - 0"

- GODSPEED - SPAR THICKNESS 7/8" PER YARD OF LENGTH. (RULE INTERPRETATION)
- C1595 - LARGE SHIPS - MAST THICKNESS ABOUT 1" PER YARD OF LENGTH.
  - SMALL SHIPS - MAST THICKNESS ABOUT 3/4" PER YARD OF LENGTH.
- RECORDED ACTUALS FOR SHIPS OF VARIOUS "TONS BURDEN" ARE UNKNOWN.

Table II

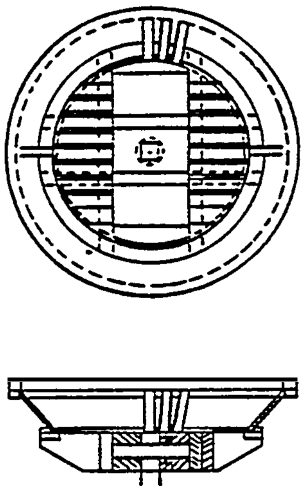


Figure 10 - Original Mainmast Top

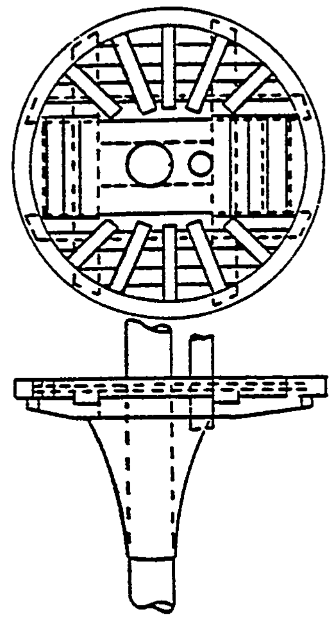


Figure 11 - -design Mainmast Top

30 feet. The main top mast is 17 feet in length.

Spar thicknesses for small ships of the period were approximately three fourth inch per yard of length. See Figure (19) and Table II for the details of masts and yards.

Mast heads rules of the period . were generally accepted by the designers as truly representing a merchantman of the late 16th century. GODSPEED's mast head length, tresletrees, caps and top are in accordance with these rules - (8]. Note that the main top as depicted by Commander Coale in his 1957 painting of the Jamestown ships illustrated GODSPEED's top, known by some naval historians as a "fighting top." The designers of GODSPEED created such a top and saw ***to*** its construction and installation, as shown on Figure
Prior to the Atlantic crossing of 1985, a new top was designed, installed and is representative of a platform configuration, Figure **[Ill-** Actually this design is widely accepted as that of a period merchantman. The primary consideration for the prevoyage top modification was the safety of the vessel as weight and windage were dramatically reduced.

Ray Brown, considered ***to*** be one of the best sailors in the Hampton Roads **area** and skipper of the earlier version of GODSPEED, was of great assistance in finalizing GODSPEED's rig . It was agreed that the new rig would be at least 50% larger than the 1957 reproduction and that the addition of a "Sprit Sail" would play a significant role in increasing performance.

November 22, 1983

GODSPEED

Rig Specifications

Standing/running rigging to be of excellent nautical grade Italian hemp (prestretched)

Fore Mast Rig

Fore Shrouds	3/4" dia.	
Pendants	5/8" dia.	
Tackle (yard) blocks P/S belayed to centerline pin rack.	5/8" dia.	double
Fore Stays layed)	3/4" dia.	(cable
Lanyards	5/8" dia.	
Lifts and Braces	1/2" dia.	
Pendants	1/2" dia.	
Ratlines	3/8" dia.	

Main Mast Rig

Shrouds 3/4″ dia.
Jeers -(yard) 3/4″ dia. (double block) P/S belayed to rail aft of main mast at deck
Lifts 5/8″ dia.
Braces 5/8″ dia.
Pendants 7/8″ dia.
Lanyards 5/8″ dia.
Ratlines 3/8″ dia.

Main Top Mast Rig

Shrouds 5/8″ dia.
Spring Stay 3/4″ dia.
Tackle (yard) 1/2″ dia. single block P/S belayed to centerline pin rack at deck.
Lifts 1/2″ dia.
Braces 1/2" dia.
Pendants 1/2″ dia.
Lanyards 5/8" dia.
Back Stay 3/4″ dia. (falls to quarter deck at centerline)
Ratlines 3/8″ dia.

Mizzen (Lateen Rig)

Shrouds 3/4″ dia.
Bridle (Mizzen Lift) 1/2″ dia.
Tackle (Yard) double blocks 5/8″ dia. Belayed to quarter deck pin rail abaft mast.
Lanyards 5/8″ dia.
Ratlines 3/8″ dia.

Sails (Running Rigging)

All rope to be three strand right hand layed of hemp. Marline to be of equal first grade quality hemp.

Rigging features, i.e. whipping of rope ends, serings, seizings, lashings, etc. will be in keeping with period sail making techniques. All work to be done by hand.

Main Sail.

Dimensions are obtained from sail plan. Earings (P and S) 3/8′″ dia. Eye splice to head cringle. Fasten *to* yard arm cleat clear of pendants.

Robands - - use braided line - pass through grommets under head rope of sail and tie around yard arm - recommend two robends per standard vertical layed cloth.

Sheets (P and S) 3/4″ dia. Standing part fastened *to eye* bolt in wale aft. Reeve through single block of clew to single block of wale. Block located about 2′ forward of - standing part to lead block on caprail. Belay to pin on bulwark.

Tacks (P and S) 3/4″ dia. Wall and crown knot at clew - reeve inboard through opening between bulwark and caprai1 and belay *to* rail pin or kevel on bulwark.

Clew Garnets (P and S) 1/2″ dia. Seize single block to yard about 1/3 of distance from parrel to end of yard arm. Standing part made fast (timber hitch) to yard just outboard of block. Reeve through clew block to yard block to deck. Belay on pin rail under shrouds.

Bunt lines (P, S, and centerline) 1/1″ dia. Standing part fastened to cringle on foot of sail or bonnet with bowline knot. Reeve to bull’s eye secured to yard arm top to single block secured to stay. Belay to pin rail at mast.

Bowlines and bridles (not shown on sail plan) six leg s, three bull’s eyes - secure to cringles on foot of sail (bowline knot) falls shall be 5/8″ dia. and lead forward to single block on head. Belay on forcastle pin rail.

Fore Sail

Dimensions to be obtained from sail plan. Earings and robands same as main sail. Sheets (P and S) and of 5/8″ dia. Standing part secured with throat and round seizing to ring bolt set in wale forward of main channel. Reeve through single block on clew to single block attached to bulwark stanchion. Belay to kevel on cap rail.

Tacks (P and S) 5/8″ dia. Wall and crown knot at clew. Reeve through fairlead on underside of billet head. Lead through head to forecastle. Belay on bulwark.

Clew garnets same as mainsail clew garnet block. Tack and sheet block secured in eye of bolt rope and lashed so as to be removable when bonnet is taken down for reefing.

Buntlines (P, S and Centerline) 1/2″ dia. Standing part fastened with bowline knot to cringle on foot of sail or bonnet. Reeve rope through bull’s eye secured to yard arm to single block attached to fore stay - belay to pin rack.

Bowlines/Bridles (P and S) 1/2″ dia. Secure to cringles on leech of sail with bow line knots. Bridle to consist of six legs and three bull’s eyes’ (alternate three legs and two bull’s eyes). Falls are 5/8″ dia. and lead forward to a single block spliced to outer end of bow sprit. Belay on forecastle.

Main Top Sail

Earings (P and S) S/16" dia. Eye splice to head cringles. Make turns from cringle outside of pendants at yard cleat and four or five !turnsga~~s around yard hitch end. - same as mainsail.

Sheets (P and S) 5/8" dia. Secure to eye of bolt rope at clew (walI-and-crown knot). Reeve through single block at lower yard arm to single block secured to lower yard near tie. Belay to cleat on mast.

Clew lines 1/2" dia. Seize single block arm outboard of tie. Standing part hitched to yard arm outboard of block. Reeve through clew block to yard arm block and belay on pin rail under shrouds.

Leechlines (P and S) 1/2" dia. Standing part secured with bowline knot to cringle on leech of sail. Reeve up forward side of sail to single block secured to tie on yard. Belay to pin rail under shrouds.

Bowlines/Bridles (P and S) 3/8" dia. Fasten to cringles with bowline knots, three legs and two bull's eyes'. Falls 1/2" dia. lead forward through block spliced to top mast stay. 5/8" dia. to double block fastened to foremast below trestle three. Belay on rail under shrouds.

MIZZEN

Sail dimensions as shown on sail plan.

Earings - same as main top sail.

Robands - fit about 12" apart.

Sheet 5/8" dia. standing part hitched *to* block of quarter deck caprail (taffrail) reeve through clew block to cap rail block. **Belay** to cleat on transom.

Tack 5/8" dia. Standing **part** secured to eye of bonnet bolt rope (wall and crown knot) hitch to eye bolt on deck.

Brails (P and S) 3/8" dia.Fasten ends with bowline knot to cringles on sail falls 3/8" dia. reeve through bulls eye on yard and belay on quarter deck.

Specifications of the sprit sail spars and rigging requirements

Head 15' - 6" foot 15' - 6" hoist abt 4' - 0". Material: 11.2 oz. dacron or duradon as required. Earings: (P andS) 1/4" dia. eye splice to head cringle. At least three turns from cringle outside pendants at yard arm cleat and several turns aroumd yard. Robands: Braided line - p ass through grommets under head bolt rope of sail and tie around yard - fit two per standard cloth tidth or more if cloth exceeds standard.

Sheets (P and S) Pendant (about 6') secure to 1/2" dia. eye of bolt rope at clew (wall and crown knot).

Falls: Standing part affixed to tricing line suspended from shroud, passed forward through pendant block, back through bulls eye at extreme end of tricing line, through double block above bulwark cap and belay to pin rail on cap.

Bunt Line 3/8" dia.: Centerline only 3/8'' dia. standing part secured with bowline to cringle on foot of sail. Lead up forward side of sail through bull's eye secured to top of yard arm. Pass through block near fore **stay** and belay on forecastle pin rail.

It should be noted that substitutions to the rigging material was made to best simulate hemp and manila as to authenticity while significantly increasing the factor of safety. Breaking strains of the three strand wire core standing rigging is 1500#. The running rigging is of equal quality and resembles nautical grade manila in quality.

Sails are of a synthetic, Duradon.

The material is similar in appearance to flax and is 14 ounce double weight.

SHIPS CHARACtERISTICS

GENERAL

An important consideration in the design of the GODSPEED was stability. The vessel must have an adequate metacentric height (GM) *to* comfortably and safely sail in normal weather conditions. However, stability criteria of sailing ships of the period is non-existent. Period ships were based upon the experience of the Naval Architects, and unfortunately this experience was not well documented.

Several methods for determining the adequacy of stability such as the Dellenbaugh Angle Method *are* used by yacht designers today. Another method, called the Wind Pressure Coefficient Method, compares the righting moments with the heeling moments of a vessel at 20 degrees heel in a beam wind, **[18]. In** addition the Federal Registrar cgntains intact stability requirements for mono hull sailing vessels on exposed waters, (19) . In order to analyze the stability of the GODSPEED using the aforementioned methods, the hydrostatic characteristics and righting arms had to first be determined.

The hydrostatic characteristics for the GODSPEED were calculated by using NavSea's "Ship Hull Characteristic Program (SHCP)". Scaled offsets from the lines plan were entered into the program to describe the hulls form. Normally, for steel vessels, the displacement calculated is that of the molded form. However, due to the thickness of the shell, the offsets entered were to the outside of the planking so as to calculate the displacement of the main hull. SHCP was also used to determine the statical stability of the vessel at various heeling angles. Figure [12] shows the righting arm curve for the GODSPEED in the light ship condition. This analysis considered the forecastle and poop deck to be watertight.

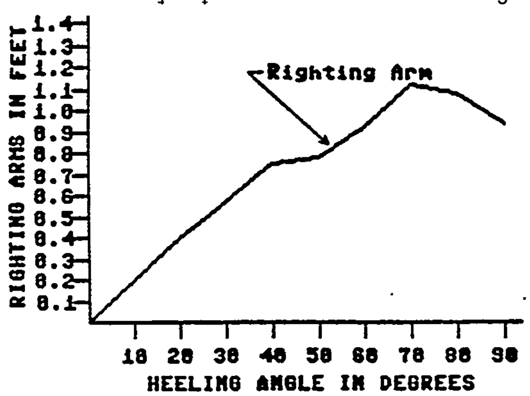


Figure 12 -RI ghting Arm **curvc-**

Stabilit Analvsis

The GODSPEED's projected sail areas were calculated for two separate conditions. The first condition was for all the sails trimmed fore and aft. The second evaluated all the sails trimmed at 45 degrees excluding the mizzen which remained at a-fore and aft trim. Table III shows the sail areas for both conditions and their respective cetroids measured above one-half the GODSPEED's lightship draft. It should be noted that this analysis did not include the spritsail which was backfitted after delivery of the vessel.

CONDITION I - SAIL AREAS - TRIMMED FORE AND AFT

SAIL	AREA (SQ.FT.)	VERTICAL LEVER (FT) ABOVE 1/2 DRAFT
Foresail	285	22.75
Mainsail	410	22.50
Top Mainsail	235	39.50
Mizzen	187	24.75

Total Area ll17 At a leverof26.S2

CONDITION II - SAIL AREAS - SAILS TRIMMED AT 45 DEGREES (EXCEPT MIZZEN)

SAIL	AREA (SQ.FT.)	VERTICAL LEVER (FT) ABOVE 1/2 DRAFT
Foresail	202	22.75
Mainsail	290	
Top	1 6 6	39.50
Mizzen	187	

Total Sail Area 845 at a Lever of 26.40

Table 111

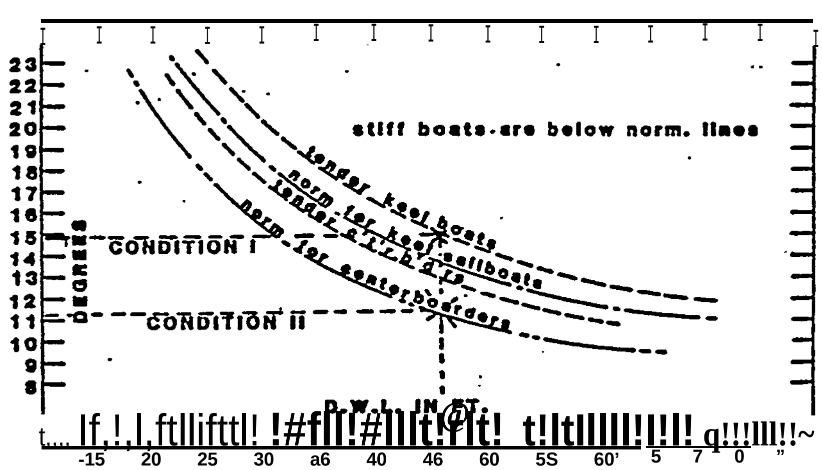


Figure 13 - Angle of Heel by **Dellenbaugh Coefficient Method**

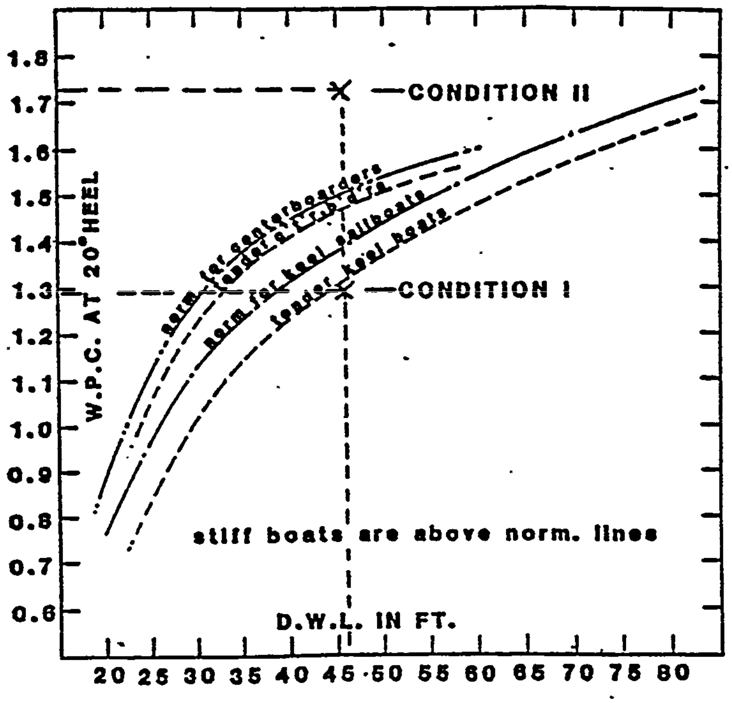


Figure 14 - Wind Ressure Coefficient at 20 Degrees Heel "

The Dellenbaugh and Wind Pressure Coefficient Methods were applied to the GODSPEED's lightship condition (worst case); and as can be seen in Figures [13) and [14) both methods arrived at similar conclusions. Condition I (sails trimmed fore and aft) indicated the vessel to be tender in a beam wind. However, when examined with sails in condition II, it can be concluded that the vessel would perform in a stiff manner.

Since the GODSPEED would have sails trimmed at a 45 degree angle in a beam reach, the analysis in condition II were determined to be an acceptable evaluation of the vessels stability. Hovever, the adequacy of these methods to square riggers of this type is unknown. The graphs compiled for these methods are based on historical data of actual sailing vessels which were not necessarily square rigged. Thus the ballasting of the GODSPEED did not fully rely upon these methods alone.

CFR-46 Section 171.055 of the U.S. Coast Guard Regulations requires **sailing** vesseLs *to* have positive righting arms from zero to 90 degrees heel for service on exposed waters. In' addition, each vessel must be designed to have stability numerals greater thatX = 1.5, Y = 1.7 and Z = 1.9 long toms/sq.ft. for three specified conditions. The first condition determines the stability numeral X at which the heel **angle** of the vessel caused by a beam wind equals the angle at which deck immersion first occurs. Stabiliv numerals Y and Z are determined when the area under the righting arm curve equals the area under the assumed heeling arm curve between the angles of zero and the down flooding or knockdown single respectively.

Figures [15), [16], end-[17)--show the fighting and heeling arm curves for these three conditions.

Table IV shows the calculated stability numerals of the GODSPEED in the lightship condition with sails in either condition I or II. As can be seen, only the stability numerals X and Z in sail condition 11 satisfy the requirements of the CFR. The dynamic balance *to* the downflooding angle did not exceed the required 1.7
LT/sq ft as a result of the momentary 4
loss of waterplane area between 40 and 60 degrees.

Although the U. S. Coast Guard regulations specify sails to be trimmed fore and aft, GODSPEED under sail would not have sails trimmed greater than 45 degrees.. In addition to prevent seas from flooding through the cargo hatch, the GODSPEED was fitted with a portable cargo hatch cover.

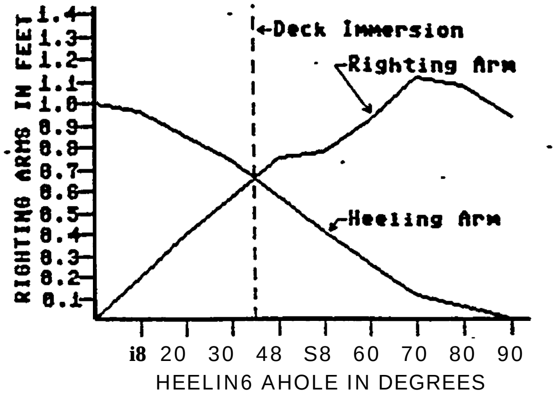


Figure 15 - Stability Criterin X, Dock I-raion

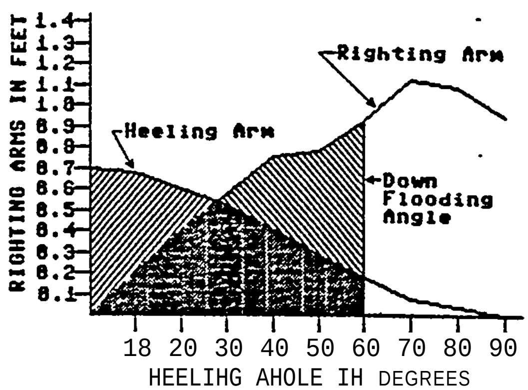


Figure 16 - Stability Criterin.Y, Down Fooldlng Angle

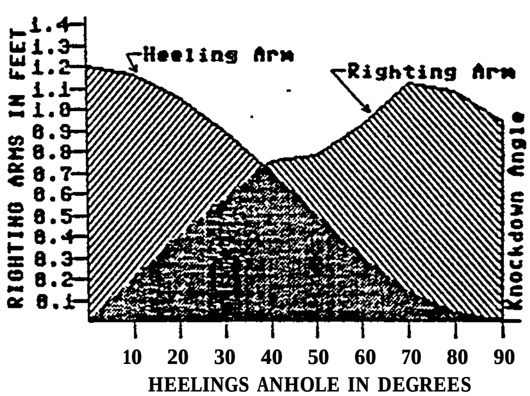


Figure 17 - Stability Criterin Z, Knockdown Angle

SUMMARY OF STABILITY NUMERALS

STABILITY NUHERAL (LT/FT 2)	CONDITION x	n
x - StatIc Balancq= at Deck Imrsion	1.29	1.e6 -
Y - Dynmic Balance to Down fooding	0.91	1.17
Z - Dynamic Balance to 90 Degrees	1.55	2.00

Table IV

As calculated from the stabilitv numerals, the largest beam wind the vessel can encounter with sails in condition II is 32.61 knots. In winds approaching this velocity, it is current practice on the GODSPEED *to* shorten sails.

WATERTIGHT SUBDIVISION

The GODSPEED was originally designed with watertight transverse bulkheads up to tween deck at frames 28 and 14. This would provide the vessel with a one compartment survivability after damage. Water-tight bulkheads do not exist on GODSPEED as the owner and captain decided that accessibility, on a planned extended sea voyage, would be greatly inhibited. A watertight hatch cover was fitted to the coaming of the main hatch and fastened below decks to effectively seal the hatch during heavy weather. Companionway doors at the forecastle and great cabin were made watertight and latches were placed on the inside.

Future plans, in the opinion of the designers, should include bulk-heads for watertightness, at least a collision bulkhead as required by U.S. Coast Guard Regulations.

LAUNCH

The launch of the GODSPEED was unusual relative to a standard end launching. Both ships, the GODSPEED and the DISCOVERY, were built on the same inclined shipway, one behind the other. The shipway, which was simply a constriction platform on rollers, . would descend along a rail with both ships at a controlled rate of speed, Figure (18): The DISCOVERY, located outboard, would enter the water first . and once afloat, would be hauled pierside to allow the GODSPEED *to continue* her descent.

One of the first steps in any end launching is to estimate the weight and centers of gravity of the ship at the time of launch. This, intum, would be used to determine the ballast required for trim and stability. During construction, it was considered advantageous to weigh the main hull so that an accurate reference point could be established. This was accomplished by the design and construction of a cradle which would ultimately serve three functions:

1. Lift and lower the vessel onto load cells

2. Provide transverse support for the ship at launch and

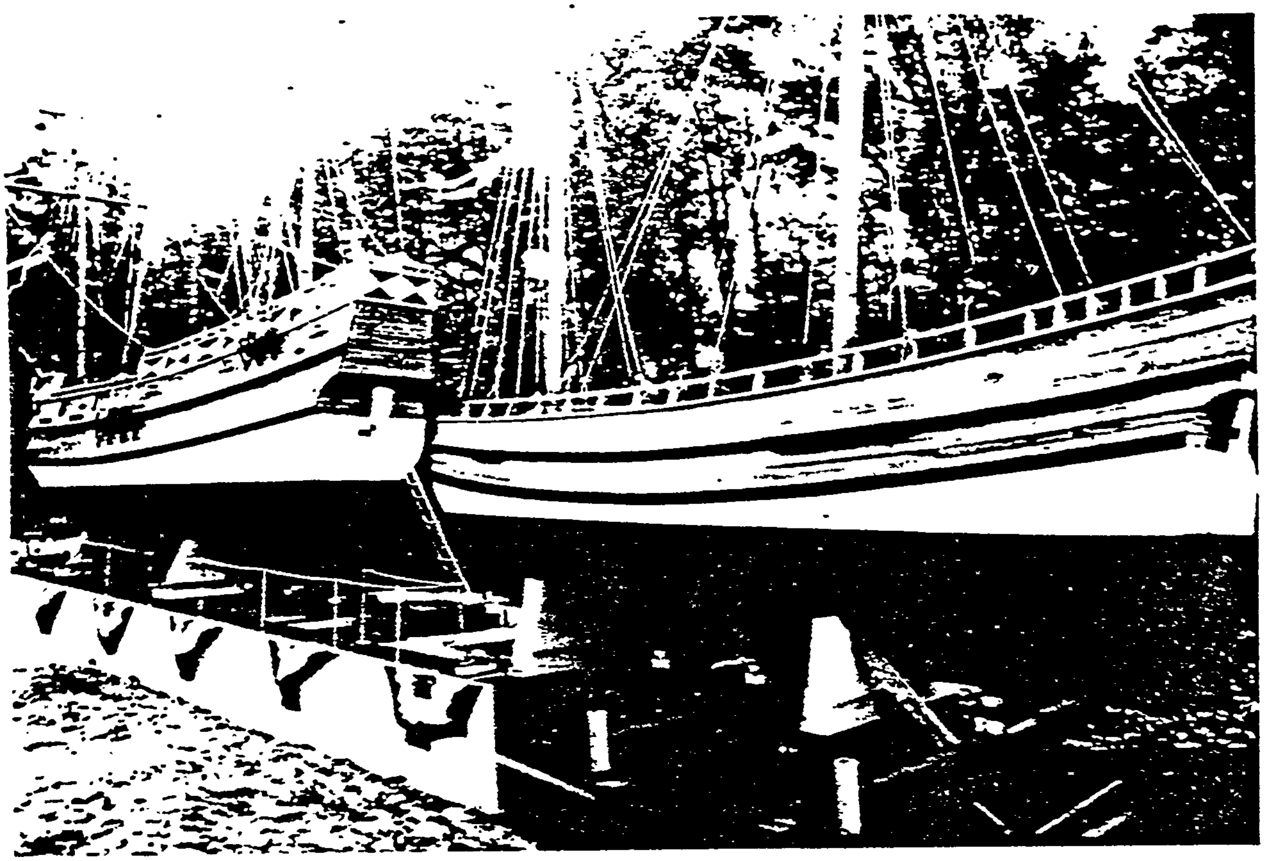


Figure 18 - Construction shipway

3. Act as a forepoppet for the vessel to pivot about.

Readings from the loads "cells were translated into a total weight and longitudinal center and modified to include an estimate of the outfitting to be completed by launch. hydrostatics characteristics and the launch weight of the vessel established, it was then possible to determine the *amount* and location of ballast required for trim and stability. At first, prior to having any information on the incline of the shipway, it was decided to ballast the vessel so that she would not pivot at launch. Hovever, this was later determined to be undesirable due to the unsightly trim afloat. Since the GODSPEED was expected to receive a high degree of publicity, she was ballasted to float off at her design

The most difficult determination was in the amount of ballast required for adequate stability. Prior to the stability analysis mentioned earlier, the following comparison of ballast to displacement ratios of existing reproductions was examined:

Mayflouer Repro	GODSPEED Repro 1957	DISCOVERY Repro 1957
37% *	592*	58% *

* Ballast in % of displacement.

The percentage of ballast for the 1957 reproductions were deemed excessive. The addition of several tons of ballast did not significantly improve the stability of these vessels. In addition, over-ballasting of the 1984 GODSPEED would greatly hamper her performance at sea. It was therefore decided that 12 long tons of ballast would be loaded prior to launch with an additional 2 long tons added when pierside. ThiS would result in a predicted metacentric height of 18 inches and a 33 percent ballast to displacement ratio. Prior to launch, there was grave criticism and some doubt as to the stability of the GODSPEED. *Its* huge crows nest (later reduced after delivery) gave an eerie feeling to onlookers. To justify the-ship's stability in the minds of those responsible, the ship was examined in the following manner. The vertical center of gravity of the vessel without ballast was assumed *to* **be** at main deck. The ballast when applied to this overly conservative assumption would still yield a positive metacentric height of 5 1/2 inches. Thus, it was concluded, and as discussed earlier, that the vessel would have adequate stability.

Another concern in the launch of *the* GODSPEED was the depth of water . that would be available at launch. As was previously mentioned the GODSPEED (the larger vessel) was built on the inboard end of the *Construction* Platform. The predicted water depth required to float off the cradle for the GODSPEED was one foot greater than that for the DISCOVERY. Ideally, the ships should have been constructed in reverse order with the DISCOVERY at the head of the shipway rather than the GODSPEED.

Soundings were taken to determine the amount of water above the ends of the track. With a predicted high water at launch of 22 feet and the estimated drafts of the ship afloat, it was concluded that the GODSPEED would float off safely after approximately 138 feet of travel resulting in a 5 foot draft margin.

INCLINE EXPERIMENT

After launch and upon completion of some finistig work, the GODSPEED was towed to Newport News Shipbuilding for outfitting.

On October 2, 1984, an incline experiment was conducted to determine the displacement and both longitudinal and vertical centers of gravity. The incline was performed pierside with the vessel simply moored and approximately 99 percent complete (she lacked sails, batteries and some miscellaneous items). The vessel's trim was kept near its design trim so as not to adversely change its hydrostatic characteristics. Care was taken to have all the spars in the raised position and secured to prevent movement.

It was estimated that a weight of approximately 720 pounds would be required *to* heel the vessel one degree. An arrangement whereby the weights could be rolled across the deck rather than lifted and settled down was desired. Thus, it was determined that the simplest method would be to use people-as the inclining weight. A grid pattern was laid out on the deck to maintain order and to eliminate personnel required to measure the distance the weight moved, Figure [19].

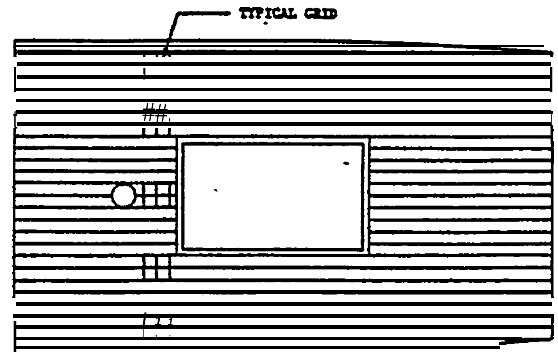


Figure 19- Grid Pattern - Main Deck

Prior to the ship being launched, draft marks were applied forward, admidship, and aft. The draft marks which are 3 inches in height were punched into the hull rather than painted so as not *to* be highly visible thus taking away from the appearance of the vessel. The drafts during the incline experiment were read using a draft tube which provides increased accuracy by eliminating the effect of wave action.

At *first* it was intended to use two micrometers and one pendulum *to* measure the tangent of the angle. However, the micrometers which are highly sensitive, were useless due to the slight rolling motion of the ship . Therefore, two pendulum arrangements were constructed, one in the hold and the other in the aft cabin to provide the longest pendulum length. Winds ranging between 5 and 10 MPH prevented pendulums from being mounted on the masts.

The displacement and centers of gravity from the incline experiment were adjusted to reflect the lightship and full load conditions. The incline experiment report revealed the GM of the vessel *to* be 14 inches in the lightship condition as opposed to the 18 inches predicted.

SALLYING TEST

A Sallying Test, performed at

Saint Katherines Dock, London, resulted in a period of roll of 4
Using the emperical formula:

$$T = \frac{C \times B}{\sqrt{GM}}$$

Where C = Constant
B = Maximum Beam
GM = Hetecentric Height

and solving for C, the GODSPEED would have a constant of 0.30.

. SEA TRIAL

The sea trial for the GODSPEED was conducted on October 25, 1984. The objective of the trial was to examine the balance of the vessel and the angles of heel when under sail.

Data was recorded for several sail configurations with the GODSPEED at different attitudes relative to the wind. Figure [20] shows the results of this data presented by righting and heeling moments. No formal tests were performed to establish any maneuvering characteristics.

Unfortunately, this limited amount of information is insufficient to make any assessments. Hopefully, in the years to come, similar data till be recorded and converted into informative performance -characteristics of the GODSPEED.

Traditionally, square-riggers do not sail well to windward, GODSPEED being no exception. The yards can be braced around by slacking the parrels, lowering the yards, using tweakers and other techniques only to find that excessive leeway is created.

The effect of a combination of broadside - on shipment of heavy green seas, large angle rolling, and wind acting in unison, can create critical conditions of which the designers are most aware. Good seamanship should prevent this from happening.

CONCLUSIONS AND RECOMMENDATIONS

Considering the historical knowledge available today of ships of the late 16th century, the designers of GODSPEED desired to reproduce a vessel that would represent a period merchantmen of forty tons burden in every minute detail. The designers were not commissioned by the state to perform such a task. Originally the task with the Jamestown/Yorktown 'Foundation was to develop hull lines similar to the 1957 reproductions of GODSPEED and DISCOVERY. Drawings of the first reproductions of GODSPEED and DISCOVERY were provided to the designers. Though they represented many hours of research, major modifications to the hull and rig for the new designs were deemed prudent-by the designers in order to improve authenticity and performance.

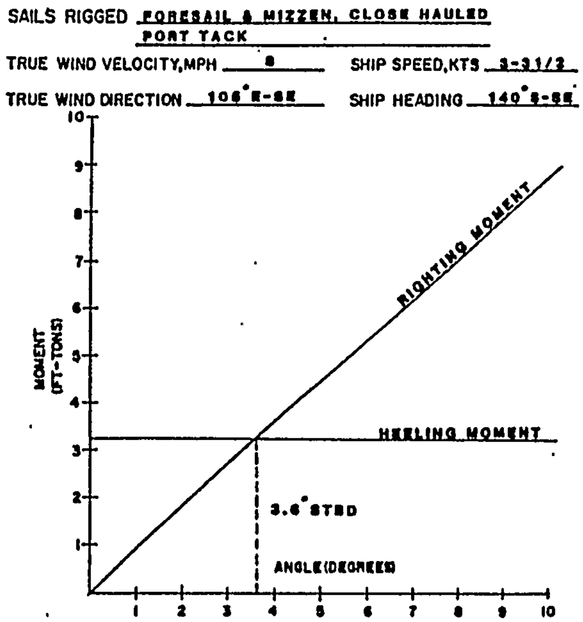
Details of the hull form and rig kindled the designers desire to further research available data as to the size of these ships. The tonnage formulas are only of general help as an approximation.- During the period, ships measurements actually were in terms of how many wine "tuns" the vessel could carry. In most cases that was probably rounded out to an even number, particularly if estimated. For the purposes of the Jamestown fleet, ships were undoubtedly selected on what would best serve to transport the colonists.

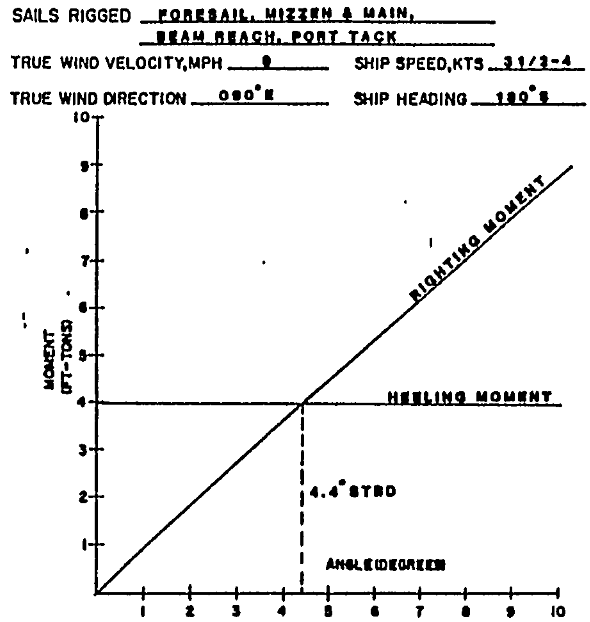
A complete redevelopment of the midship section and lines would have resulted in a dramatic departure from those depicted in the official painting of the Jamestown ships by Commander Coale. Being mindful of the guidelines given at the outset, a quest for a deeper understanding of period ship design prevailed. As a result of this research, modifications of hull and rig became a realization in the design of GODSPEED and DISCOVERY .

New insight into the understanding of period ships design and construction is becoming available. The raising of "MARY ROSE", flag ship of Henry VIII from the Solent will protide marine historians, archaeologists, and naval architects with technical information that has remained dormant for more than four hundred years. Duncan Stewart, as a guest of the Commander and Chief of "HMS Victory", had the pleasure of touring the Victory and viewing the hulk ofthe "Mary Rose". Both Vessels are housed at Portsmouth Harbor, England and are currently undergoing major modifications and preservation.

Designers of future period ship reproductions, endowed with a quest for knowledge, will have a greater research base as the past continues to unfold.

The information on GODSPEED contained herein is certainly not all inclusive. The designers hope that continued research on the part of many scholars will result from the works of the great designers of our period and from those of us who have a deep and abiding love for our rich heritage.





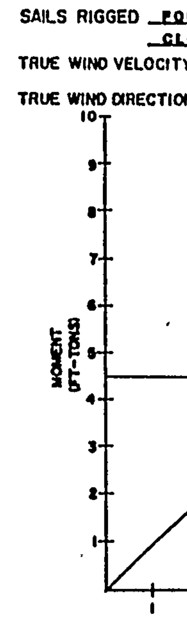
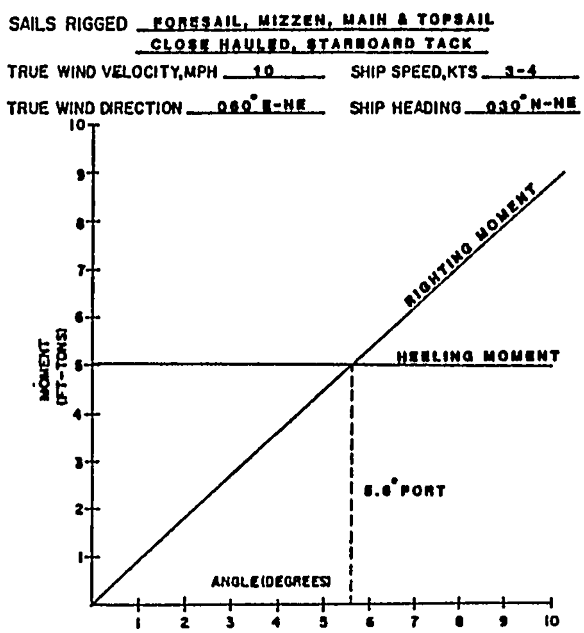
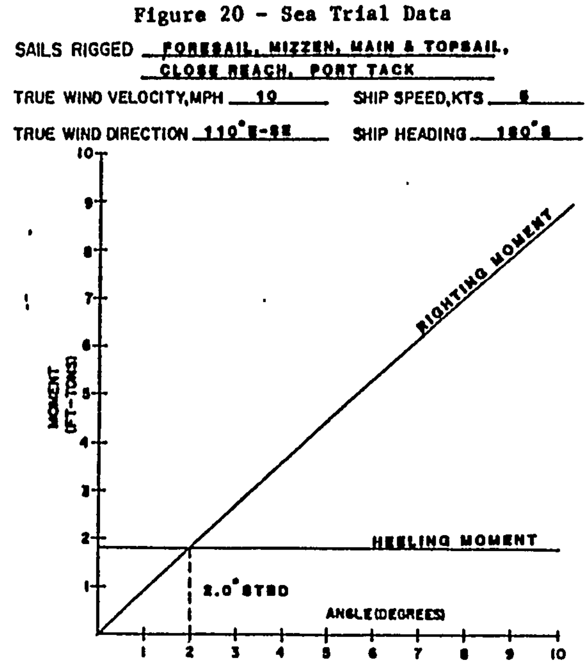
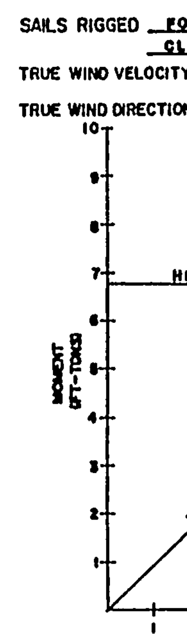


Figure 20 - Sea Trial Data







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