Aircraft Carrier Operations At Sea:

The Challenges of High Reliability Performance.

Final Report

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When organizations operate technologies that are beneficial, costly and hazardous, they are pressed to achieve failure free operations. This is an extraordinary situation, one deemed impossible in contemporary organization theoretic terms. This project examines one type of such organization - aircraft carrier operations at sea - that demonstra remarkable levels of operational reliability. The objective is to seek out the conditions that account for these very high levels of operational performance. This report includes the conceptual perspective defining and focusing the research problem, a discussion of methodological processes, and a review of preliminary findings. An appendix includes an annotated bibliography of project papers. Keywords:)

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This report was prepared under the Navy Manpower, Personnel, and Training R&D Program of the Office of Naval Research under Contract N00014-86-K-0312.

We wish to acknowledge the extraordinary welcome and cooperation of the officers and men of Carrier Group Three, USS Carl Vinson (CVN-70) and CVW-15, and USS Enterprise (CVN-65) and CVW-11 who have so ably oriented us to naval flight operations at sea. Without their interest and generosity this work would not have been possible. Of the many who participated, Capt. Thomas Mercer, Commanders Robert Williams, Robert Mantie, Rich Wolter and David Waggnor of Carl Vinson and Capt Robert Spane, Commanders Michael Samuels, George Root, Harry Hartsell, Tom White and A.J. Johnson of Enterprise were especially helpful.

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Part 1. Introduction and Overview.

When organizations operate technologies that are beneficial, costly and hazardous, they are pressed to take on goals of failure free operations. There is a class of organizations that have accepted such goals and nearly always achieve them. This is an extraordinary situation, deemed impossible in contemporary organization theoretic terms. The research summarized here is part of a project studying the organizational patterns associated with very high levels of operational reliability in three such organizations. One of them is aircraft carrier operations at sea.

Our work with the Navy began informally summer of 1984 with a meeting of representatives of Air Traffic Control, Federal Aviation Administration; Electric Operations, Pacific Gas and Electric Company. We met on-board USS Carl Vinson, hosted by her Commanding Officer, Captain Tom Mercer, to explore some of the means and problems associated with attempting to achieve very high levels of reliability in complicated technological operations. It was an extraordinary meeting. Organizational representatives discussed something of the changes and problems they encountered in seeking "failure free performance." They conveyed to each other and the academics there something of the complexity of the systems they led and the processes they felt accounted, in part, for the very high levels of operational performance they effect. To our surprise the hint of common patterns emerged. Excitement rose and plans for further exchanges were made.

Later, after a third meeting, Captain Mercer noted that, "It's not enough to just talk about this. You (academics) have to come see for yourselves." This began a series of informally arranged visits to USS Carl Vinson and then to three weeks on board in far east. The University of California, Berkeley, High Reliability Organization Project was off the ground. Subsequent work has been carried on in the other organizations as well. [See a brief Project summary in the Appendix.]

After protracted discussion, ONR support was begun, March, 1986. The major portion of resources were spent through Dec. 1986. Very modest sums of ONR funds remained. Contract extensions, at no cost to the government, were approved through March, 1988. This was to assist in completing the Navy portion outlined in the original proposal (including work with USS Enterprise) which was intended to cover 18 months of work. The necessary additional funds were provided by the NSF and the University of California, Berkeley. This report covers that portion of research and writing carried on in supported by the Office of Naval Research. Additional work, especially that based on field work aboard USS Enterprise is reported elsewhere. (See annotated project papers in appendix.)

The rest of the report is organized as follows: Part 2 is drawn from a conceptual paper defining and delimiting the research problem, Part 3 summarizes the project's several methodological processes, and Part 4 re-prints an article discussing the ONR stage findings that appeared in the Naval War College Review, Autumn, 1987. An appendix includes a summary of the overall three organization study and an annotated bibliography of project papers.

Part 2. Dimensions of the Research Problem.

This section outlines the character of the research problem, identifies the underlying theories that inform it, and discusses several major aspects that have guided our field work. The section is an abridgement of **High Reliability Organizations: The Research Challenge** (T.R. La Porte, K. Roberts, and G. I. Rochlin, 1987.) It is limited to the Navy portion of the study; comparative aspects have been deleted. *

Introduction:

Many advanced technologies greatly increase the prospects for material and social benefit. They also carry the potential for great biological, environmental, human, and social damage. Failures can be costly and hazardous. Both the prospects and the potential hazards increase as technologies of great power are deployed, increasing their capacity, organizational scale, and social complexity. To secure those benefits while controlling potential harm, industrial firms and governments -- as operators, promoters, and regulators -- impose conditions intended to make such failures rare. Nevertheless, for a number of such systems, the potential costs of operating failures rival the benefits they provide.

When technologies are rich enough in benefits to warrant development, yet must be operated reliably to avoid imposing unacceptable costs, the process is colored by efforts to proceed by trials without error, even at early stages of development, lest the next error be the last trial. If this is successful, and the technology becomes widespread, operating organizations are expected to continue nearly failure-free organizational performance -- the avoidance altogether of certain classes of incidents or accidents judged by overseers to result in absolutely unacceptable consequences.* In effect, such organizations attempt to operate so reliably that the risks of the hazard are radically reduced. Benefits, in effect, are conditioned

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*Examples abound: the extraordinary problems of operating nuclear power plants; public wariness of the industrialization of genetic engineering; demands that air traffic control be failure- free; insistence on accuracy in identifying dangerous drugs; alarm regarding the safety of bridges and dams and the use of pesticides in agriculture; and, less dramatically, concerns that the distribution of electricity, on one hand, and computer based financial and administrative data, on the other, be quickly and very accurately effected over very large geographical regions.

on nearly failure-free operations. And demonstrating that high hazard, low risk operations can be realized over long periods of time is often a requirement for public support, government funding and regulatory approval.**

Such a requirement is extraordinary. Achieving very high levels of reliable individual or group performance even for short periods is difficult at best. Attempting to sustain such operations in large scale organizations facing the contemporary pressures of increasing performance demands, and technological complexity, poses very substantial managerial and intellectual challenges.

Systematic understanding of the dynamics and structure of "high reliability" organizations that successfully match performance with demand is quite limited. Repairing this situation calls for improved understanding of the conditions and costs associated with very high operational reliability in organizations that, in pursuing their primary missions, have also accepted the goal of always avoiding certain classes of failures - and have almost always succeeded.***

** A note on terms: Hazard refers to the characteristic of a production technology such that if it fails significantly, the damage to life and property can be very considerable. Risk is taken in the engineering sense, i.e., the magnitude of harmful consequences multiplied by the probability of an event causing them. Error refers to mistakes or omission in procedure or operational decision that result in occurrences judged as undesirable and sometimes costly to remedy. Organizations continually experience errors, those that result in consequences that threaten their viability in part or whole, result in a "system failure". A high hazard/low risk system would be one in which a dangerous technology is operated in such a way as almost never to experience an operating failure of grievous consequence, i.e., to be nearly failure-free. (See W. W. Lowrance, Of Acceptable Risk: Science and the Determination of Safety (Los Altos, CA.: Wm. Kaufmann, Inc., 1976), ch. 2, and C. Hohenemser, R. W. Kates and P. Slovic, "The Nature of Technological Risk," Science, 220 (22 April, 1983), 378-384.

*** Organizational reliability is a condition in which the organization demonstrates continuously the capacity to provide expected levels and quantity of services, without off-setting failures of critical processes. In organizations that accept this challenge, four types of reliability are involved. Each has distinctive operating, training and managerial implications.

Six central questions are prompted by these phenomena and lay out their broader dimensions:

1. The Evolution of "High Reliability" Organizations. Organizations that exemplify successful highly reliable performance do not emerge full blown into this state. What were the processes and circumstances that resulted in public and organizational consensus about failure avoidance? What was the pattern of external pressures to attempt failure-free performance? Are there distinctive patterns and/or political conditions which facilitate this consensus and prompt the allocation of the necessary resources to attempt the reduction of operational failures altogether?

2. Structural Patterns and the Management of Interdependence. These organizations' central day-to-day challenge is continuously to operate complex, demanding technologies without major failures while maintaining the capacity for meeting intermittent periods of very high, peak production, e.g., peak traffic/power demand loads, or maximum air operations. What patterns of formal organization structure and rules have developed in response to these requirements under conditions of constrained resources? Complex technologies tend to increase the interdependencies within and among operating organizations. What are the patterns of interdependencies associated with units requiring reliability? What processes have emerged to coordinate and manage them in meeting the demands of reliability and potential peak pressures?

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i) Reliability of Aggregate Supply (of produce/raw materials): Assure continuous, unbroken flow of production input.

ii) Reliability of (Physical) Infrastructure: Seek perfection in operation/physical integrity of parts, pieces and networks.

iii) Reliability of Signals: Seek to perfect accuracy and timeliness of communication signals.

iv) Reliability of Human Response (Operational Reliability): Seek to perfect performance of human operators.

All high reliable systems exhibit reliabilities ii - iv. Some also satisfy supply reliability themselves; most depend on other organizations for the products used in operations.

3. <u>Decision Dynamics in High Demand/High Reliability Conditions</u>. Top management seeks to commit the organization to high levels of performance, while senior operating officials are committed to assuring superior reliability (and safety) in the face of often unexpected operating conditions. What decision making and communication dynamics evolve in the processes of day-to-day planning and operation when contingencies are expected but their specifics are unpredictable? How are the operational constraints inevitably imposed by formal structure dealt with, especially in confronting those activities from which unacceptable failures may arise?

4. <u>The "Organizational Culture" of High Reliability</u>. Formal structure and rules (SOP's), or informal operating rules, rarely provide guides for behavior sufficient to account for the technical and cooperative skills or motivations necessary for effective organizational performance. These "gaps" are filled variously in the development of an organization's culture. In "high reliability" organizations, the substance of this culture is likely to be crucial for effective operations. What group norms are evident within and between units requiring reliability concerning relations with and obligations to group members and to the organization as a whole? How are they created and maintained?

5. <u>New Technologies' Promise: More or Less Than Expected</u>. New, often computer-based, technologies are promoted in high reliability organizations as a solution to the problems of expected demand and scarce resources. Where are such technologies now being considered, and for what purposes? What experiences have organizations had to date in incorporating technologies possessing different operating properties into working groups? How have new technologies mixed with traditional, reliability trusted ones in day-to-day activities? How are organizational structure, culture and functions effected?

6. <u>The Design of Consequential Organizational Systems</u>. Improved answers to these questions are likely to shed considerable light on the conditions and costs associated with a social dependence on hazardous, consequential systems. What are the implications of these answers for the design and management of technical systems and organizational processes in the interests of moderating the costs and stress of "high reliability" operations? Is it possible to alter

technical design so that the social requirements of attaining high reliability will be less surprising or difficult to attain? Can technical systems be designed in such a way that regulatory agencies faced with the requirement to oversee "high reliability" activities may do so without encountering tasks of such difficulty that the regulation process itself is not called into question due to the inability (perhaps impossibility) of reasonable overseeing efforts?

Addressing these questions requires: a conceptual basis for defining the problem, including the theoretical requisites for high reliability operations; identifying the limitations of current literature in addressing them; and an explication of the central questions that should serve as a basis for intensive field observation, interviews and data collection in units requiring high reliability....

[The larger project includes three organizations: the Air Traffic Control System, Federal Aviation Administration; the Electric Operations and Power Generation Departments, Pacific Gas and Electric Company (managers of northern California's electric power distribution grid;) and - the organization of interest here - the U.S. Navy's Carrier Group 3, and U.S.S. Enterprise (CVN 65) and U.S.S. Carl Vinson (CVN 70,) its two nuclear aircraft carriers and their respective air wings, CVW-15 and 11. Each organization has a particularly rigorous organizational setting that should be taken into account in considering these questions.]

What the types of challenges do "high reliability" organizations confront? .... Each of these organizations is large, and routinely engaged in managing often very intense activities, in which time sensitive decisions and decisive actions are often crucial....

The Carrier Group involves up to ten ships, centered on an aircraft carrier manned by a crew of up to 3000, supporting an Air Wing of some 90 aircraft and another 2800 men. During phases of high readiness (daily operations from mid-morning to mid-might), the Air Department may handle up to some 200 sorties per day/night, involving some 300 cycles of aircraft preparation, positioning, launch, and arrested landings (often at about 55 sec. intervals). Over 600 aircraft movements across portions of the deck are likely with a "crunch rate," i.e., the number of times two aircraft "nick" each other," of about 1:7000 moves. At the same time, aircraft are re- fueled, serviced and ordinance loaded sometimes with engines still running. These periods of high performance run continuously for up four weeks time with short break for the duration of a 6-8 month deployment.

Another property of these organizations increases both the difficulty of studying them and the theoretical value of doing so: each is embedded in a widely dispersed network linking operating and coordinating units in a set of tightly-coupled, overlapping interdependent webs of direction, action and feedback. (The effects of failures propagate quickly and often widely.) These organizations do not experience errors uniformly, nor are they everywhere equally tightly coupled. Rather they vary in ways that allow theoretically interesting questions to be addressed: in the expected magnitude of failures' consequences, the degree the functional interdependence among units requiring reliability, and the "tightness" of their technological systems.[1]....

Failures on the aircraft carrier, are very critical. If any one of five activities fail significantly, the ship can be disabled by fire or explosions, many men killed, very valuable equipment lost irretrievably and in the nuclear areas a major ecological and human catastrophe. ....

The degrees of interdependence among functional units within these organizations [is also important.]2.... On the carrier there is intensive, often face-to-face, reciprocal interdependence among those carrying out air operations planning and missions. A third [property] is also instructive - the degree to which the operating technology impels, indeed, substitutes for coordination relationships.... [T]he units involved in air operations aboard an aircraft carrier are [not so] technologically tightly-coupled to each other. The technologies specific to individual functions, e.g., catapult, arresting gear, landing signal operations, and foul weather radar, are each as tightly coupled as for the ATC, but their necessary coordination is not "hardwired" at all. This depends almost wholly on often continuous, face-to-face/phone-to-phone contacts and negotiations among senior crewmen and officers.

Requisites for High Reliability Organizations

Strong challenges to public and/or corporate policies arise when on-going or proposed programs require large scale, knowledge intensive organizations, and the consequences of operational failures are very costly. Technological deployers and regulators strive: to improve policies in situations where trial and error learning is of diminished utility; to achieve nearly failure-free operations of large, complex public and industrial organizations; and to design effective regulatory units charged with overseeing such operations. In effect, operational reliability rivals short-term efficiency as a dominant organizational value. The higher the perceived hazard or costliness of failures, the more insistent the demands for operational reliability. Nearly failure-free operations are difficult to achieve in any setting. Within technically complex, large scale organizations, these challenges are especially severe. Meeting them, or understanding the limits of such efforts, requires more than skillful leadership and successful bureaucratic politics. Additional knowledge is necessary.

This requires a theoretical explication of the organizational requisites for and limitations of attaining nearly failure-free operations in large scale organizations; and an improved empirical understanding of the technical, organizational and political conditions --and their costs--that satisfy these requisites.[3] What are the theoretical properties and empirical conditions associated with successfully attaining what appears on its face to be a nearly impossible requirement?

Attaining nearly failure-free organizational operations, logically entails the satisfaction of at least five pairs of knowledge/behavioral conditions, each with measures to assure effective implementation.

1.K. **Unambiguous, nearly complete casual knowledge** concerning the necessary functioning of the technical and organizational system in order to assure expected outcomes, both in the earlier stages of development and certainly as the technology reaches operational maturity; and,

1.B. **Nearly error-free performance** from both personnel and machines, based on this knowledge, to ensure a level of performance that maintains the consistent operations of the system.

It is obviously not justified to assume that these two conditions can be met without preparing for unexpected deviations within the system. Therefore:

2.K. **Error regimes** specifying the small deviations from operational norms for both machines and operating personnel behavior that signal the potential onset of failure for each critical component, under actual operating conditions, rendered in quantitative terms;[1] and,

2.B. Detection vis-a-vis continuous error identification activities of people/units charged with alerting organizational leaders if critical components malfunction or human perfcrmance flags. Deviations must be spotted, failure avoided and the sources of error onset repaired or eliminated.[5]

But detecting the early on-set of potential failures does not eliminate their eventuality. Therefore,

3.K. Improved knowledge of the character of failures' consequences, especially the potential for the propagation of damage and dislocation through the system; and,

3B. "Error" (or failure) absorbing capabilities in groups organized both to contain damage within the organization, affecting only those closest to the breakdown,[6] and to provide "redundant channels" of operation to insure that the system will continue performing despite breakdown.[7]
With "failure consequence absorbers" in place, society might be assured of benign operations, particularly when failures are relatively limited and only moderately costly to remedy. But as the capacity of the technical/organizational enterprise to do both good and ill rises, so does the urgency of systematic attention to the effects upon the surrounding region of significant failures in the rare event they occur.

It is obvious that many organizations in modern society, may have failures of such severity that their consequences cannot be contained internally. There are also two requisites for sensing the onset of and responding to failures that spill outside of the organization parallel to those just listed for internal operations.

4.K. Credible, exact knowledge of the effects of the technical operations upon the biological, environmental and social world, necessary to establish a firm basis for judging the full range of benefits and costs of these operations; and,

4.B. A continuous monitoring capability so that the distribution of external effects may be detected as the technology spreads and "ages." This requires the institutionalization of expert groups holding the skills necessary to identify the changes in areas proximate to and caused by malfunctions of the technical system.

For systems seen as potentially the cause of great harm, it is unlikely that the public will be assured that continuous failure-free performance will be forthcoming due to efforts of the operators alone. Therefore, the final requisites:

5.K. Unambiguous "system error" specification regimes cast in terms of those conditions the public is seeking to enhance or avoid; and

5.B. Highly effective, continuously ready organizations alert to the commission of "system errors" and prepared to take immediate steps to contain their consequences.

The logical knowledge requisites listed above have the ring of an engineering view of the situation, i.e., specifying the information necessary for "closing the system," then applying more technical solutions to areas of uncertainty. The implicit "sociologic" is that human groups will be able to operate the technical systems at the level of reliability necessary to deliver their benefits. When each knowledge requisite is paired with its behavioral mate, the magnitude of the demand becomes more apparent.

The requisites for seeking perfection in organizational performance would be very stringent for any technical or organizational system. They are particularly rigorous for organizations that have increased rapidly in size and internal complexity, and which face considerable public anxiety about the consequences of failures.

A growing number of organizations confront these conditions. Some of them continue to achieve an enviable record of reliable performance. Now many are facing additional changes - in technical design, organizational scale and internal operations - that will substantially increase the challenge. Yet the organizational and institutional means and social relations necessary to realize these requisites are scantily understood.

Limitations of Current Literature.

Organization theoretic and management literatures are silent regarding such extraordinary requirements.[8] They are literatures based almost exclusively on experience with organizations, mainly in the private sector: 1) that are "loosely coupled" within and with their environments, (hence, the effects of operational failure rarely propagate much beyond the unit causing it;)[9] 2) whose internal dynamics appear increasingly characterized by coalition formation and "political behavior," where organizational goals and strategies are likely to be contested and where compromise, as well as more traditional analytical methods, play a major role in decision- taking;[10] 3) whose decision processes can be characterized as "incremental," trial and error, and sometimes as "organized anarchies," where groups with problem solutions seek those with problems to solve;[11] and 4) where failures of task technologies, though perhaps costly to replace, do not threaten the organization's existence or capacity to provide service.

Such organizations are, in a sense, "failure tolerant;" decision- making and policy improvements can be confidently based on incremental, trial and error procedures, where the value of the lessons learned from making an error is greater than its cost. And importantly, there is at least the tacit expectation that if some actually fail badly - and dissolve - that the goods and services they provided would be furnished by competitors.

If organizational reliability is cast in terms of improvement in individual performance, some guidance can be derived from the literature. Increases in reliability of performance follows from: high levels of formalization with explicit and specific definitions of rules and roles; cybernetic controls that provide feedback loops that convey timely information on performance values to performers and to their supervisors; "stable sub-assemblies", i.e., units capable of retaining their form and performing their functions without constant attention from superior units; strong organizational culture with shared cognitive and normative beliefs and common commitments to goals and ways of working; great attention to personnel selection and training; and the greater the technical and environmental uncertainties that more flexible the work system and organizational buffers.[12] These properties and relationships are posed with an implicit perspective of performance that is middling and needs improving somewhat rather than for situations in which failure free performance is stressed.

The Conceptual Challenge of High Reliability Organizations.

The organizations that interest us fall into an unusual category: they provide important public services which include operating for periods of very high peak demands; failures of their task/production technology can be catastrophic; trial and error learning in some areas seems a risky business; and the costs of major failures appear potentially much greater than the lessons learned from them. In organizations with these characteristics, what structural and behavioral patterns have evolved that are associated with extraordinarily high levels of reliable performance and enable them to realize the demanding requisites of "nearly failure-free" management?

In addressing this question, we assume that the character of the physical technologies serves strongly to shape a) the particular organizational forms, behaviors and effort (in resources and information) necessary to operate them, b) the character of the coordination and control dynamics, particularly in the face of expected but specifically unpredictable heavy demands on operators, and c) the public and organizational insistence that failures be avoided altogether. This suggests that organizations are composed of a technical core, a managerial level that coordinates activities among technical units and between them and an institutional level concerned mainly with anticipating, absorbing, and potentially shaping the demands thrust upon the organization by elements in its environment.[13] And we view high reliability organizations as open, rational systems with considerable reenforcement to behave like closed rational ones. At the work group level, we draw on conceptions of the dynamics of socio-technical systems, the rule making and following nature of organizational behavior, organizational culture, and "negotiated order."[14]

High reliability organizations, then, can be characterized roughly as composed of three overlapping communities: operators, manager/coordinators, and senior executives together attempting to maintain conditions enabling 1) hazardous operations to be carried on continually at high levels of capacity, 2) safely with 3) the capability to adjust flexibly to peaked demands and surprises from their external (institutional) environments. Thus, their main operating problems are twofold: to manage complex, demanding technologies making sure to avoid major failures which could cripple, perhaps destroy, the organization; and, at the same time, to maintain the capacity for meeting intermittent, somewhat unpredictable, periods of very high peak production, e.g., ... maximum air operations. A pervasive operating tension emanates from the pressures from top management to commit the organization to high levels of performance, and senior operating officials' insistence on investing in systems and processes which enhance reliability (and safety) in the face of unexpected operating conditions. Each community shares much the same goals, but their emphases are likely to differ as a function of their "proximity" to the technical operations per se and the scope and irreversibility of failures' consequences. ...

In returning to the central questions posed at the outset of this Section, the challenge is to discover the effects on the familiar patterns of complex, technical organizations occasioned by the perception that significant failure in day-to-day operations could have potentially catastrophic consequences. Four of the six sets of questions (sets 2-5) outlined above are taken up. They require attention before the evolutionary or design questions can be addressed confidently.

Structural Patterns and the Management of Interdependence.

What patterns of formal structure and rules have developed in response to the requirements of very reliable performance? This question would be reasonably straightforward for the usual, failure-tolerant organization. There is agreement on both the goals and means, the core technologies are well known. This is the classical situation for bureaucratic, hierarchical structure and formal processes.[15] But these expectations tacitly assume that errors in the production processes are not likely to be large; trial and error learning can be the order of the day.

In high reliability organizations, reliability-oriented allocation of responsibilities and control processes compete with production-oriented ones.**** What divisions of responsibility and distributions of formal authority emerge? To what degree is command responsibility vested mainly "at the center" as contrasted to its distribution on the basis of critical function? Do leaders of the units requiring reliability, or seeking to assure it in other units, take places formally in the "dominate coalition" of the organization, as expected by the contingency theorists?[16] What are the formal relations between the technically skilled, reliability-oriented groups and leaders, usually in higher status positions, charged with coordination and strategic direction?

> HY 1.1: As the severity of potential failure increases: the more likely the units directly involved will have formal representatives in "ruling coalition;" the most likely centralized authority structures will be

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**** We have not emphasized pressures due to demands for operating efficiency, a problem for most modern organizations. Until recently, high reliability organizations have operated with only a moderate concern for short-term efficiency. Their social function has been so important that effectiveness and reliability, even at substantial cost, that cost cutting measures have taken a backseat. The internal dynamics prompted by continued resource constraints is an important topic for subsequent research.

moderated by formal and informal delegation of critical oversight to the units directly involved; and the more likely the implementation of harsh penalties for those formally responsible for the organization and the directly involved units. [P:1.B, 2.B]*****

Complex operating technologies tend to increase the interdependencies within and among operating organizations.[17] In high reliability organizations, parallel, often redundant, sets of complex communication and control technologies are also evident.[18] Interdependencies of control overlay those of production. Each type exerts varied demands for watchfulness and interaction on operators and managers. What are the patterns of interdependencies associated with units requiring reliability, and what processes have emerged to coordinate and manage them in meeting the dual demands of reliability and peak loads?

HY 1.2: As the operating technologies become more functionally interdependent: the more fully formal and informal mechanisms of communication and coordination develop and overlay those of production; the more dense the channels of horizontal communication and the more frequent collegial authority processes; and the more likely the development of formal norms of intervention in the production process from members having functional knowledge regardless of their organizational status. [P:2.B, 3.B]

An aircraft carrier and its air wing, for example, are each highly interdependent operating units. For effective operations, they must somehow mesh during periods of maximum readiness, yet they are independent units during the times when the ship is in home port. They must manage a kind of organizational "quick connect and disconnect" - rapidly integrating some 2800 men and support machines for 90 aircraft into an ongoing ship of 3000, then disconnect again for training "on the beach," without incurring damage to either group. And, during "at-sea" periods, reliable operations require activities that assure rapid adjustment to changes in tactical missions, aircraft status and sea conditions, and assure accuracy of communications and safety information during the critical launch and recovery (landing) periods. ...

Such organizations' formal structure is designed to facilitate hierarchical direction and coordination; each has

***** Bracketed numbers, e.g., [P: 1.B], the indicates the reliability requisite noted above to which the hypothesis is related.

developed formal structures of reliability assuring units and processes, as well. Due to the demands imposed by sophisticated technologies, it is likely that there will be patterns of "horizontal, collegial" relationships of varying intensity and formal intent among interdependent, high reliability units. These patterns of cross-cutting authority relationships can be described and compared, in part, examining the degree to which they are formally or informally designed and operated.[19]

Decision Making in High Demand/High Reliability Conditions.

Research on decision-making in large organizations has been rooted in some notion of technical rationality, the attempt to optimize some value, within the limits of human cognitive capabilities and perceptual biases.[20] Studies of the reactions of decision-makers to contingencies, where attaining optimality is problematic due to analytic complexity and uncertainty, reveal decision-makers as "satisfiers."[21] Incremental, trial and error learning is the predominate, and recommended, behavior; strong dependence on comprehensive planning is criticized as a strategy leading to failures more grievous than the errors resulting from pragmatic trials. Both these descriptions, and coping behaviors observed, involve accepting the consequences of error and suboptimization and decisions of only moderate quality - the "best one can do."[22] Demands for reliability, the irreversibility of processes, the high cost of system failure, and the difficulty of decisions that achieve failure-free results, pose analytical and descriptive problems that strongly challenge the traditional literature. Much of it has only marginal relevance to the operation of high reliability organizations.

When failures are fatal, knowledge of the system and its behavior is valued: the more complete the better. Comprehensive analysis is sought even if completeness is impossible. What are the processes through which the technologies are exhaustively learned and that learning shared, corrected and expanded? What decision making and communication dynamics characterize the processes of day-to-day planning and operation when failures are very costly, maximum performance may be required, and contingencies are expected but their specifics are unpredictable? How are the constraints inevitably imposed by formal structure overcome, especially in confronting those activities from which unacceptable failures may arise?[23]

HY 2.1: As the severity of potential failure increases: the more insistence on complete formalization of decision rules related to technical apparatus; the greater the pressure from hierarchies on subordinates for assurances of maximum performance without failure, and the greater the expressed need from managerial subordinates for discretion in doing their work. [P:1.K, 1.B, 2.B]

As conditions became critical, communication and decision making patterns are expected to cross formal channels.[24] If they do, the extent of such informal relations, and the degree of negotiations (almost continuous in the Navy case) between and across formal status levels should be chartered. Similarly, the structure of information redundancy for purposes of maintaining independent sources and for accuracy checks should be outlined.[25]

HY 2.2: Within a system of highly specific rules of technical operations and reporting relationships, as the degree of uncertainty about external demands increases: the more likely conflict will occur concerning the degree to which such rules or reporting relationships are inappropriately applied; the more likely the sense of ambiguity and fear expressed by responsible subordinates; and more likely responsible subordinates will act informally to compensate for what they perceive to be inappropriate or dangerous rules, procedures or directives from higher authority. [P:2.B, 3.B]

In observations with the carrier, our team followed the conflicts that cascaded from the Carrier Group Commander, an Admiral, through the ship's Captain, and his Operation Officer and spread out to involve the Air Boss (tower), the Aircraft (Deck) Handling Officer, the Operations Officers of the Air Wing, and three Squadrons when an order came at 8pm for a 4am mission the next day. It was to carry out a mission no one but the Admiral and his staff believed was worth the disruption of prior plans and was expected to greatly increase the risk to pilots. Pressures mounted through the chain of command, increasing the stress on the operating units. This was especially felt by the aircraft handler, who believed attempting the mission as desired would put his people at even greater risk than usual. Several sharp encounters sessions occurred revealing a pattern negotiation and interaction quite different from the apparent chain of command. The Admiral prevailed, finally, after a series of compromises were struck.

Tracking the networks of interdependence that characterize these organizations provide clear research opportunities. They also drive up the necessary research effort. Decisions and actions within these networks often trigger interactions that spread quickly through different units usually dispersed across the system. The most interesting evolutions - the patterns of reactions to the potential onset of crises - happen with astonishing speed. To capture the dynamics requires the presence of a well trained and experienced team coordinating their observations simultaneously from different "locations."

The "Organizational Culture" of High Reliability.

These organizations present operators with substantial challenges and very demanding circumstances. Successes and failures are consequential. Individuals' involvement is seen as efficacious, if risks are met and overcome; foolhardy, if skills are wanting and working conditions risky. Full knowledge of the processes and high motivation to carry them out are requisites for reliability. But formal structure and rules (SOP's), or informal operating rules, rarely provide sufficient guides for behavior to account for all the technical and cooperative skills or motivations necessary for effective performance. These "gaps" are filled variously in the development of an organization's culture.[26]

In "high reliability" organizations, the substance of this culture is likely to be crucial for effective operation. What group norms are evident within and between units requiring reliability concerning relations with and obligations to group members and to the organization as a whole? This question is perhaps the most difficult and most important of the several research areas. When one observes the operators in these organizations for any length of time, one wonders why they would subject themselves to the rigors and hazards inherent in these jobs and processes. Why they do, the norms they come accept about their behavior, and the conditions which sustain them are important, and unknown.

> HY 3.1: As the severity of potential failure increases: the more likely formal and informal (on-the-job) training will intensify, and include pressures for new members to accept attitudes that legitimate self-sacrificing behavior and a sense of personal responsibility for the welfare of the whole working group. [P:1:B, 2.B, 3.B]

Top technical operators and upper-middle level managers struggle to develop and maintain norms among their workers that facilitate both ability for limited periods of maximum performance and long term, highly reliable performance. Due to the different operational demands of various sub-organizations, we expect variations among the sub-groups. Successful "high reliability" organizations have somehow been able to stimulate high commitment and intense effort from operators. Our initial work suggests that members of high reliability groups develop a sense of trust in group members and take on an obligation of collective responsibility for each other.

> HY 3.2: As tensions between the requirements for stable technical operations and flexible responses to unexpected peaked demands and surprise increase (due in part to perceived increases in the magnitude of failures' consequences,): organizational norms of submission to rules AND to ignore them intensify; and informal norms develop that specify what situations warrant challenges to authority and moderate the application of sanctions in formal evaluation/inspection processes. [P:2.B, 3.B]

The Promise of New Technologies.

High reliability organizations are the objects of efforts to introduce new technologies, often computer-based. These are promoted as a solution to the joint demands of increased performance, maintenance of safety and reliability, and competition for scarce resources. Faced with the prospect of budget reductions, or nearly constant budget levels, many high reliability organizations are nevertheless pressured by management to increase operational capacity and efficiency. Yet, the social environment remains as intolerant of major failures as before, holding the organization to an absolute standard that effectively requires an increase in safety levels per unit operation.

Under such circumstances, it is perhaps not surprising that the use of computer-assisted decision technologies in a variety of forms has been the subject of intense discussion in each of the organizations we are studying. ...[T]he development of the U.S.S. Carl Vinson involved a variety of on-board experimental computer systems designed to aid and augment planning as well as operational functions.[27]

Operators generally welcome the idea of beneficial change. Many high reliability organizations are highly technical, and in the past they have themselves initiated a good deal of innovation. Yet, they remain wary of the new computer-aided technologies, particularly those that are intended supplement or supplant the human operator in any dimension rather than simply augmenting or facilitating the flow and integration of information.

Selecting a variety of high reliability organizations with a variety of circumstances in design, plan, and implementation of new technologies enable us to ask a variety of questions about their effects. To what degree is a trend towards automating or replacing operators' judgments being considered? How and where is it being tried or implemented? How are operators reacting, and how much input do they have to the process of innovation? What are their expectations of problems as well as benefits, and on what experience is this based?

> HY 4.1: As the severity of potential failure increases: so does resistance to the replacement of a traditional technology or technique by an advanced technology unless, in the long term operation of the technology, greater reliability can be demonstrated in situations which are perceive to be associated with the early onset of operational failures. [P:1.B, 2.B]

This is another area where the interaction between the researchers and operators produces far more than either could achieve separately. Operators often have no language to describe their concerns. These are often based on perceived aspects of organizational design and complexity that contribute critically to safety, yet have never been formally described or analyzed. The research team has the language, but only through the closest continual interaction with operators in real-time conditions can the empirics of each situation be discerned.

Of particular interest are cases where new technologies are mixed with traditional ones of proven reliability in actual day-to-day activities.[28] Experience shows that technologies said to offer increased flexibility often impose instead new constraints to facilitate their operation. Technologies designed to reduce operator workload can instead increase demand for throughput, so that operator loads increase once again, while the margin for recovery if the new technology should fail goes down.[29] For ordinary, failure-tolerant systems these are treated as "side-effects". For the systems the interest us, they are crucial. What other surprises might lie in store for future new technologies? To what extent are operators aware of and sensitive to the potential for surprise? What actions, if any, can they or the organization take to exert some control?

> HY 4B: The greater the supporting infrastructure and relative increase in required operational knowledge

required to operate a technical innovation, the more likely its implementation will require substantial workgroup and organizational re-structuring, and, if implemented, the more likely the degradation of high reliability activities. (The time to recovery of initial reliable performance is indeterminant.) [P:1.K, 1.B, 2.K., 2.B, 3.K, 3.B]

Concluding Comments

Generalizing on the basis of both theoretic reflection and a limited amount of empirical observation, "high reliability organizations" that pose the most interesting intellectual and operational/policy challenges have the following characteristics: [Organizations demonstrating very high levels of operational reliability are likely to have the following characteristics:]

-- They have a strong, reasonably concrete sense of their primary missions, operational goals and the technical means necessary to accomplish them.

-- All operate quite powerful, knowledge intensive technologies with very few significant operational failures. These technical systems are well known; their mechanisms and processes can be nearly completely specified.

--Their major production units, e.g., power station, ATC center, or naval vessel, are quite complex and linked together, often in large, tightly coupled operating networks, e.g., power grid, national system, or task force, that strongly effects levels of internal operating strains and the capacity to adjust to surprise.

-- They manage activities for which external or internal consequences of failure are perceived to be great. The rare operational failure gravely threatens the organization's capacity to operate, to deliver crucial services, and/or threatens the lives of its members or those of the community at large.

-- Recently, such organizations have seen their workloads increase while their resources bases have been in relative decline; as a result, an additional level of sustained stress has been added to the amount of stress operators are expected to absorb in highly responsible time-urgent jobs, calling for maintaining absolute performance levels, in the face of increasing magnitude and complexity of the tasks.

-- Computers and other technical systems are used, often extensively, but primarily as sources of information and data -- inputs to human judgment. And recently such organizations have been pressed to turn to new computer technologies in the hope of increasing their operational capacity without directly altering organizational size or structure.

Somewhat more speculatively:

-- Organizational structures, authority relationships, and decision- making dynamics appear to have evolved in common patterns: there is clear separation of operations from system maintenance, substantial delegation of operating authority to subordinate units, and redundant information sources to inform decision-making.

-- Despite the diversity of their tasks, operators in each system have similar working environments, share similar responsibilities, expectations, objectives, and goals, and show similar manifestations of the stress of their jobs.

-- Their operating "cultures" are strongly failure averse. Internal dynamics and structures are predominantly influenced by consistent efforts to eliminate certain types of events, accidents or failures altogether.

ENDNOTES

1. We use "tightness" or "tight-coupling" in the same sense as, C. Perrow, **Normal Accidents: Living with High-risk Technology**, New York: Basic Books, 1984., ch. 3. This term is used to characterize the physical structural properties of the technologies operated by the organizations he studied that experienced "normal accidents," i.e., those that could/should be expected given the complexity and tightness of these technical systems. See also K.E. Weick, "Educational Organizations Loosely Coupled Systems," **Admin. Science Quarterly**, 21 (March, 1976), 1-19;

2. J.D. Thompson, **Organizations in Action**, New York: McGraw- Hill, 1967, and the discussion in W.R. Scott, **Organizations: Rational, Natural and Open Systems**, 2d ed. Englewood Cliffs, N.J.: Prentice-Hall, 1986, especially chs. 9 and 10.

3. For work that provides a conceptual pre-requisite - a view of technology that forges a tighter integration with concepts of organizational dynamics and institutional change, see T.R. La Porte, "Technology As Social Organization: Implications for Policy Analysis," Studies in Public Organization, Institute of Governmental Studies, University of California, Berkeley, Jan. 1984.

4. M. Landau, "On the Concept of Self-Correcting Organization," **Public Administration Review**, 33 (Nov./Dec., 1973), 533-539.

5. D. Metlay, **Error Correction in Bureaucracy**, (Diss. University of California, Berkeley, 1978), Chs. 1 and 9. See the revision and extension, **Tempting Fate**, forthcoming, esp. ch. 1 and 9.

6. Cf. Perrow, **op. cit.**, for his distinctions concerning different categories of the "victims" of breakdowns, i.e., those harmed as a consequence of major accidents

7. M. Landau, "Redundancy, Rationality and the Problem of Duplication and Overlap," **Public Administration Review**, 39 (Nov./Dec., 1969), 346-358.

8. Landau's work on redundancy, ibid., comes closest, although he considers the question of reliable outcomes in systems in which major internal

failures will not cripple them. Studies of "**reliability" per se** are typically production oriented, focussing on the technical processes that increase the reliability of products or components within complex machines. Very little has been done on whole-system reliability, even in the electric power industry where most reliability work concerns the estimation of power demand so that enough "reserve margin" in producing capacity will be available to meet all consumer needs. ...

9. Weick, op.cit. and J. Meyer and B. Rowan, "Institutionalized Organizations: Formal Structure as Myth and Ceremony," **American Journal of Sociology**, 83 (Sept., 1977), 261-82.

10. S.B. Bacharach and E.J. Lawler, **Power and Politics in Organizations**, San Francisco: Jossey-Bass, 1980; J. Pfeffer, **Power in Organizations**, Boston Pitnam, 1981; and D. Yates, **The Politics of Management**, San Francisco Jossey-Bass, 1985.

11. C.E. Lindbloom, **The Intelligence of Democracy**, New York: Free Press, 1965; and "Still Muddling, Not Yet Through," **Public Admin. Review**, 39 Nov./Dec.), 517-526; R.M. Cyert and J.G. March. **A Behavioral Theory of the Firm**, Englewood Cliffs, N.J. Prentice-Hall, 1963; M.D. Cohen, J.G. March and J.P. Olsen, "A Garbage Can Model of Organizational Choice," **Admin. Science Quarterly**, 17 (March, 1972), 1- 25; and J.G. March and J.P. Olsen, eds. **Ambiguity and Choice in Organizations**, Bergen, Norway: Universutetsforlaget, 1976.

12. W.R. Scott, Report to the High Reliability Organization Project, (Stanford University, Aug. 1987.)

13. Thompson, **Organizations in Action**, op. cit.

14. Scott, **Organizations: Natural...**, op.cit.; and T. E. Burns, **The Shaping of Social Organization: Social Rules, Systems Theory with Applications.** London: Sage Publications, 1987.

15. J.D. Thompson and A. Tuden, "Strategies, Structures, and Processes of Organizational Decision," in **Comparative Studies in Organization**, J.D.Thompson, et al, eds. Univ. of Pittsburgh, 1959; and J.D. Thompson, **Organizations ...**, **op.cit.**

16. J.D. Thompson, op.cit.; P.R. Lawrence and J.W. Lorsch, **Organization and Environment: Managing Differentiation and Integration**, Boston: Graduate School of Business Administration, Harvard Univ., 1967; and J. Galbraith, **Designing Complex Organizations**, Reading, Mass: Addison-Wesley, 1973.

17. See especially, W.R. Scott, op.cit., chs. 9 and 10 for a good summary of a disparate literature addressing this question.

18. See A.W. Lerner, "There Is More Than One Way To Be Redundant: A Comparison of Alternatives for the Design and Use of Redundancy in Organizations," **Administration and Society**, 18 (Nov., 1986), 334-359.

19. ... This work draws from developments in social and communication network research. See H.E. Aldrich and D.A. Whetten, "Organization-Sets, Action-Sets, and Networks: Making the Most of Simplicity," in P. Nystrom and W. Starbuck, eds., **Handbook of Organizational Design**, Vol.1. New York: Oxford Univ. Press, 1981; J. A. Barnes, **Social Networks**, Reading, Mass: Addison-Wesley, 1972; R.S. Burt, "Models of Network Structure," **Annual Rev. of Sociology**, 1988, 6,79-141, and J.R. Lincoln, "Intra-(and Inter-) Organizational Networks," S. B. Bacharach, ed., **Research in the Sociology of Organization**, vol.1.' Greenwich, CT: JAI Press, 1982, 1-38; and N. Tichy, M.L. Tushman and C. Fombron, "Social Network Analysis for Organizations," **Academy of Management Review**, 4 (Oct.,1979), 507-519.

20. H. Simon, **Administrative Behavior**, 2nd ed. New York: MacMillian, 1957.

21. H. Simon, op.cit.; J.G. March and H. Simon, **Organizations**, New York: John Wiley, 1958. See also J. Steinbrunner, **Cybernetic Theory of Decision-Making**, Princeton, N.J.: Princeton Univ., Press, 1978.

22. Lindbloom, op.cit.

23. H. Wilensky, **Organizational Intelligence**, New York: Basic Books, 1967

24. C.A. O'Reilly and K.H. Roberts, "Task Group Structure, Communication and Effectiveness in Three Organizations," **Journal of Applied Psychology**, 62

(1977), 676-681; and R. Blair, K.H. Roberts, and P. McKechnie, "Vertical and Network Communication in Organization: The present and the Future," in P. Thompkins and R. McPhee, eds., Organization Communication: Traditional Themes and New Directions, Beverly Hills, CA: Sage, in press.

25. ... See K.H. Roberts and C.A. O'Reilly, "Organizations as Communication Structures: An Empirical Approach," Human Communication Research, 4 (Oct.,1978), 283-293.

26. L. Smircich, "Concepts of Culture and Organizational Analysis," Admin. Science Quarterly, 28 (Sept., 1983), 339-358, and "Is the Concept of Culture a Paradigm for Understanding Organizations and Ourselves?" in P.J. Frost, et al, eds., Organizational Culture, Beverly Hills, CA.: Sage, 1985; M.R. Lous, "Organizations as Culture- bearing Milieux," in L.. Pondy, et al eds., Organizational Symbolism, Greenwich, CT: JAI Press, 1983; and J.P. Spradley, Culture and Cognition: Rules, Maps and Plans, San Francisco: Chandler, 1972.

27. USS Carl Vinson was, for a time, a virtual testbed for new computer systems and applications, some of which are discussed in detail in G.I. Rochlin, "Command and Control" and other papers in the forthcoming volume from the Conference on Strategic Computing, U.C. Santa Cruz, March 1985. The now-defunct ZOG system is repeatedly cited in popular texts on artificial intelligence as Feigenbaum and McCorduck's The Fifth Generation, New York: Signet, 1983, as one of the successes of expert systems.

28. See R.W. Bailey, Human Performance Engineering, Englewood Cliffs, NJ: Prentice-Hall, 1982, for an discussion of the effects of parallel rather than sequential modes of introduction.

29. See, for example, W.M. Hoffman and J.M. Moore, eds., Ethics and the Management of Computer Technology, Cambridge MA: Oelgeschlager, Gunn & Hain, 1982. Traditional analyses are dominated by worker-oriented issues such as "de-skilling", job displacement, and occupational morale, and, in some cases, on the resulting impact on the firm. Since the organization in question is almost always failure-tolerant and profit-oriented, more widespread social effects and impacts are rarely taken into consideration.

Part 3. Methodological Considerations.

The high reliability organizations in this project are extraordinarily complex, tightly coupled systems. They operate technical systems that require continual attention lest they malfunction and result in grievous consequences. They prompt public concern, sometimes media watchfulness, and occasionally fears for the national security. And there are no earlier studies of these types of organizations, no study guidelines nor tested data collection instruments. These conditions suggest both considerable potential for advance and substantial pressures on researchers both in sorting out the research problem and in carrying out in-depth research.

The modern aircraft carrier battle group (BG) extreme expression of this combination. There is no prior work on the internal dynamics of carriers engaged in flight operations at sea; none on the relations between elements on the ship or within the Group. Due to the sensitive nature of BG operations, the highly classified status of some the weapon systems, and the demanding nature of the nuclear propulsion plants, there is a deep seated reserve about allowing non- Navy people on board for extended periods of time. Finally, the intensive nature of organizational interactions, particularly during fully developed flight operation, present phenomena that overwhelm the naive observer with "buzzing confusion." This is a situation in which the researcher could become "part of the problem" if hazardous conditions arise. Yet these times are likely to be the most instructive in revealing the patterns of relations that enable such organizations to respond effectively to the onset of potential failures.

The methodological challenge, then, is at least two fold: initially, to gain access and the trust of organizational members, and then, to employ data collecting regimes appropriate to the stage of theoretical development and the constraints of the operating situation.

Access and establishing legitimacy within the organization is addressed is an early project paper, "Research in Nearly Failure Free, High Reliability Organizations:...' [1] It outlines some of the condition that researchers should meet in order to do such research and discusses something of the project teams perspective regarding our relationship with ship and air wing members. Suffice, here, to say that a central methodological premise is that operators/managers in complex technological systems have a deep intuitive sense of what they are doing, though they may be unable to describe precisely how they do it, and are sometimes unaware of the relational activities they carry out. Researchers are skilled in description, but naive about how these organizations are run. The result is a research strategy in which the researchers and operator/managers work together to clarify hypotheses about how nearly failure free operations are carried out. The rest of this section reviews the means used to collect data.

Within the conceptual perspective on the requisites for high reliability organizations outlined above, three main substantive themes framed our data collecting requirements: patterns of organizational structure and interdependence, decision-making dynamics andauthority relations, and profiles of organizational culture. The fourth substantive area - the affects of technological change - drew from aspects of each of these.

Organizational Structure and Interdependence. Three sources of research information were important. Documents were reviewed for the formal picture, to furnish evidence of performance levels, and as a basis for discovering what is learned informally. Most necessary were intensive, on-site observation and interviews with people occupying important coordinating (and reliability related) roles (see decision-making questions.) A self-administered survey instruments was also used with the first ship and air wing in describing the perceived patterns of dependence and interdependence. Operational difficulties and the discovery of an instrument problem limited us that case.

Decision-making dynamics and authority relations. The most intensive part of the field research, our primary research tools were interviews and observations. Operations that must be failure free are identified. After a period of familiarization with them and the overall functions of the organization, questions were developed to uncover decision strategies used in these operations. These interview were supplemented by self-administered questionnaires that invite respondents to indicate those to whom communications are sent and from whom they are received.[2] Initially, typifications of routine decisions under normal operations were made along with the network of people within the unit and across the organization that are likely to be involved. At the same time, circumstances which prompt high levels of stress were outlined.

On-site, at sea observations of operators/managers were carried out during portions of four increasingly complex operational phases of ship and air wing training. These were focussed on various critical functions to verify the expected relationships and unexpected surprising ones. With additional resources from University of California, Berkeley, and the National Science Foundation made it possible to spent considerable time on each ship. This enabled the team to be present when operational conditions brought on the stress of incipient failure. This revealed the underlying operational norms and patterns of authority in a ways often muted in normal tempo operations.

In all, the research team spend approximately thirty (30) working person weeks at sea with the two ships and air wings and numerous in- port and air station visits and interviewing periods. Over 150 interviews were conducted with 100 different ships's company and air wing personnel during and after working hours on each ship. Some 20 shore based support and command personnel were interviewed as well.

Organizational Culture. An important research task was to discover the profiles of an organization's cultures of reliability and what sustains them. Survey of elements of ship's company and five air wing squadrons were administered tool the Organizational Culture Inventory. This instrument of 120 items (compressed into 12 scales) seeks the degree various attitudes are important in order to "fit into one's work group." It treats culture as: "[A] set of cognitions shared by members of a social unit... which are acquired through social learning and socialization processes exposing individuals to a variety of culture-bearing elements. These cognitions are acquired through social learning and socialization processes exposing individuals to a variety of culture-bearing elements.... In organizations, [these] patterns of activities and interactions members observe and carry out (e.g., decision making, communicating) constitute major elements of the organization's structure, making structure itself an important culture-bearing mechanism in organizations."[3]

Survey of those units in which high reliability is essential were sampled (from 50 to 80 percent of their members) at a time when each ship and air wing was in a peak state of readiness. Total returns neared 95 percent of the 1750 questionnaires administered. Preliminary analyses have been completed on the data from USS Carl Vinson (CVN-70) and Air Wing 15.

Endnotes. Section 3.

1. K.H. Roberts and D. M Rousseau, "Research in Nearly Failure Free, High Reliability Organizations: Having the Bubble,"

2. See K.H. Roberts and C.A. O'Reilly, "Organizations as Communication Structures: An Empirical Approach," Human Communication Research, 4 (Oct.,1978), 283-293.

3. R. A. Cooke and D. M. Rousseau, "The Organizational Culture Inventory: A Quantitative Assessment of Culture," Working Paper, School of Business Administration, Northwestern University, 1984. One of the few scales of its kind, the instrument is in the final stages of psychometric development. It has been used in over fifty organizations, including some Air Traffic Control Centers, Federal Express, and numerous "failure tolerant" organizations.

The Self-Designing High-Reliability Organization: Aircraft Carrier Flight Operations at Sea

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"A modern ship of war is one of the most complicated machines in existence. It is filled with machinery of various sorts from one end to the other. The finished ship, ready for service is of great cost and enormous value to the government. It is worth nothing unless efficiently handled, cared for, and kept in readiness for immediate service."

Annual Report of the Secretary of the Navy, 1899

"The job of this ship is to shoot the airplanes off the pointy end and catch them back on the blunt end. The rest is detail."

Carrier CO

"So you want to understand an aircraft carrier? Well, just imagine that it's a busy day, and you shrink San Francisco Airport to only one short runway and one ramp and gate. Make planes take off and land at the same time, at half the present time interval, rock the runway from side to side, and require that everyone who leaves in the morning returns that same day. Make sure the equipment is so close to the edge of the envelope that it's fragile. Then turn off the radar to avoid detection, impose strict controls on radios, fuel the aircraft in place with their engines running, put an enemy in the air, and scatter live bombs and rockets around. Now wet the whole thing down with salt water and oil, and man it with 20-year old's, half of whom have never seen an airplane close-up. Oh, and by the way, try not to kill anyone."

Senior Officer, Air Division

"How does it work? On paper, it can't, and it don't. So you try it. After a while, you figure out how to do it right and keep doing it that way. Then we just get out there and train tha guys to make it work. The ones that get it we make PO's. The rest just slog through their time."

Flight Deck Chief

"See that kid? He's only 19 and my best driver. Every day he picks up 40 million dollar, 40,000 lb. airplanes with an underpowered, under-tractioned tractor and pushes them into places you'd swear they never fit. He'd be a great parking lot attendant back home. 'Course he'd have to get a driver's license first."

Hangar Deck Chief

"If you take all the parts of an F-14 and multiply them by their failure probability, there is no chance you'd ever get one up. We do it with mirrors."

Maintenance Chief

"Here I'm responsible for the lives of my gang. In civilian life, I'm the kind of guy you wouldn't like to meet on a dark street."

Deck Petty Officer

"The flight deck terrifies me. I never feel safe until I'm buckled in and the canopy's down."

Attack Pilot

"As soon as you learn 90% of your job, it's time to move on. That's the Navy Way."

Junior Officer

"A hundred things I have no control over could go wrong and wreck my career ... but wherever I go from here, I'll never have a better job than this. ... This is the best job in the world."

Carrier CO

Recent studies of large, formal organizations that perform complex, inherently hazardous, and highly technical tasks under conditions of tight coupling and severe time pressure have generally concluded that most will fail spectacularly at some point, with attendant human and social costs of great severity.[1] The notion that accidents in these systems are "normal", that is, to be expected given the conditions and risks of operation, appears to be as well grounded in experience as in theory.[2] Yet, there are a small group of organizations in American society that appear to succeed under similar circumstances, performing daily a number of highly complex technical tasks for which they cannot afford to "fail." We are currently studying three unusually salient examples whose devotion to a zero rate of error is almost matched by their performance -- utility grid management (Pacific Gas & Electric Company), air traffic control, and flight operations aboard U.S. Navy aircraft carriers.

Of all activities studied by our research group, flight operations at sea is the closest to the "edge of the envelope" -- operating under the most extreme conditions in the least stable environment, and with the greatest tension between preserving safety and reliability and attaining maximum operational efficiency.[3] Both electrical utilities and air traffic control emphasize the importance of long training, careful selection, task and team stability, and cumulative experience. Yet, the Navy demonstrably performs very well with a young and largely inexperienced crew, with a "management" staff of officers that turns over half its complement each year, and in a working environment that must rebuild itself from scratch approximately every 18 months. Such performance strongly challenges our theoretical understanding of the Navy as an organization, its training and operational processes, and the problem of high-reliability organizations generally.

It will come as no surprise to this audience that the Navy has certain traditional ways of doing things that transcend specifics of missions, ships, or technology. Much of what we have to report interprets that which is "known" to Naval carrier personnel, yet seldom articulated or analyzed.[4] We have been struck by the degree to which a set of highly unusual formal and informal rules and relationships are "taken for granted", implicitly and almost unconsciously incorporated into the organizational structure of the operational Navy.

Only those who have been privileged to participate in high-tempo flight operations aboard a modern aircraft carrier at sea can appreciate the complexity, strain, and inherent hazard that underlie seemingly routine day-to-day operations. That naval personnel come to take the situation as more or less routine is yet another example of how adaptable people are to even the most difficult and stressful of circumstances.

Although we have now spent considerable time aboard several aircraft carriers in-port and at sea, our team of non-Navy academics retains a certain distance that allows us to recognize and report on the astonishing and unique organizational structure and performance of carrier flight operations.[5] We do not presume that our limited exposure to a few aspects of operations has given us a comprehensive overview. Nevertheless, we have already been able to identify a set of causal factors that we believe are of central importance to understanding how such organizations operate.

In an era of constant budgetary pressure, the Navy shares with other organizations the need to defend those factors most critical to maintaining performance without at the same time sacrificing either operational reliability or safety. Following many conversations with Naval personnel of all ranks, we are convinced that the rules and procedures that make up those factors are reasonably well-known internally, but are written down only in part, and generally not expressed in a form that can be readily conveyed outside the confines of the Navy.

The purpose of this note is to report some of our more relevant findings and observations to the Navy community that has been such a gracious host, to describe air operations through the eyes of informed, yet detached observers, and to use our preliminary findings to reflect upon why carriers work as well as they do.

Self-Design and Self-Replication

Aircraft carrier flight operations as we know them today are as much a product of their history and continuity of operation as of their design. The complexity of operations aboard a large, modern carrier flying the latest aircraft is so great that no one, on or off the ship, can know the content and sequence of every task needed to make sure the aircraft fly safely, reliably, and on schedule. As with many organizations of similar size and complexity, tasks are broken down internally into smaller and more homogeneous units as well as task-oriented work groups.[6] In the case of the Navy, the decomposition rules are often ad-hoc and circumstantial: some tasks are organized by technical function (Navigation, Weapons), some by unit (Squadron), some by activity (Handler, Tower), and some by mission (Combat, Strike). Men may belong to and be evaluated by one unit (e.g., one of the squadrons), yet be assigned to another (e.g., aircraft maintenance).

In order to keep this network alive and coordinated, it must be kept connected and integrated horizontally (e.g., across squadrons), vertically (from maintenance and fuel up through operations), and across command structures (Battle Group - Ship - AirWing). As in all large organizations, the responsible officer or chief has to know what to do in each case, how to get it done, who to report to and why, and how to coordinate with all units upon which he depends or who depend upon him. This is complicated in the Navy case by the requirement for many personnel, particularly the more senior officers, to interact on a regular basis with those from several separate organizational hierarchies. Each has several different roles to play depending upon which of the structures is in effect at any given time.[7]

Furthermore, these organizational structures also shift in time to adapt to varying circumstances. The evolution of the separate units (e.g., ships, air wing, command structures), and their integration during work-up into a fully-coordinated operational team, for example, has few counterparts in civilian organizations.[8] And there is no civilian counterpart to the requirement to adapt to rapid shifts in role and authority during deployment in response to changing tactical circumstances.

No armchair designer, even one with extensive carrier service, could sit down and lay out all the relationships and interdependencies, let alone the criticality and time sequence of all the individual tasks. Both tasks and coordination have evolved through the incremental accumulation of experience to the point where there probably is no single person in the Navy who is familiar with them all.[9] Rather than going back to the Langley, consider, for the moment, the year 1946, when the fleet retained the best and newest of its remaining carriers, and had machines and crews finely tuned for the use of propeller driven, gasoline fueled, Mach 0.5 aircraft on a straight deck.

Over the next few years, the straight flight deck was to be replaced with the angle deck, requiring a complete re-learning of the procedures for launch and recovery, and for "spotting" aircraft on and below the deck. The introduction of jet aircraft required another set of new procedures for launch, recovery, and spotting, and for maintenance, safety, handling, engine storage and support, aircraft servicing, and fueling. The introduction of the Fresnel lens landing system and air traffic control radar put the approach and landing under centralized, positive on-board control. And, as the years went by, the launch/approach speed, weight, capability and complexity of the aircraft increased steadily, as did the capability and complexity of electronics of all kinds. There were no books on the integration of this new "hardware" into existing routines, and no other place to practice it but at sea; it was all learned on the job. Moreover, little of the process was written down, so that the ship in operation is the only reliable "manual".

For a variety of reasons, no two aircraft carriers, even of the same class, are quite alike. Even if nominally the same, as are the recent Nimitz class ships, each differs slightly in equipment, and develops a unique personality during its shake-down and first work-up and deployment.[10] While it is true that each ship is made up of the same range of more or less standardized tasks at the micro-level, the question of how to do the job right involves an understanding of structure in which the job is embedded, and that is neither standardized across ships nor, in fact, written down systematically and formally anywhere. If they left the yards physically different, even such apparently simple matters as spotting aircraft properly on the deck has to be learned through a process of trial and error.[11]

What is more, even the same formal assignment will vary according to time and place. Carriers differ; missions differ; requirements differ from Atlantic to Pacific, and from fleet to fleet; ships have different histories and traditions, and different equipment; COs and Admirals retain the discretion to run their ships and groups in different ways and to emphasize different aspects. Increased standardization of carriers, aircraft loadings, missions, tasks, and organizational structure would be difficult to obtain, and perhaps not wise.[12] There is a great deal to learn in the Navy, and much of it is only available on the spot.

Shore-based school training for officers and crew provides only basic instruction.[13] It includes a great deal about what needs to be done and the formal rules for doing it, but this only provides generalized guidelines and a standardized framework to smooth the transition to the real job of performing the same tasks on board as part of a complex system. NATOPS and other written guidelines represent the book of historical errors -- they provide boundaries to prevent certain actions known to have adverse outcomes, but little guidance as to how to promote optimal ones.

Operations manuals are full of detail of specific tasks at the micro-level, but rarely discuss integration into the whole. There are other written rules or procedures, from training manuals through SOPs, that describe and standardize the process of integration. None of them explain how to make the whole system operate smoothly, let alone at the level of performance that we have observed.[14] It is in the real-world environment of work-ups and deployment, through the continual training and re-training of officers and crew, that the information needed for safe and efficient operation is developed, transmitted, and maintained. Without that continuity, and without sufficient operational time at sea, both effectiveness and safety would suffer.

Moreover, the organization is not stable over time. Every 40 months or so there is an almost 100% turnover of the crew, and all of the officers will have rotated through and gone on to other duty. Yet, the ship remains functional at a high level. The Navy itself is of course the underlying structural determinant. Uniforms, rank, rules and regulations, codes of conduct, and specialized languages provide a world of extensive codification of objects, events, situations, and appropriate conduct;

members who deviate too far from the norm become "foreigners" within their own culture, and soon find themselves outside the group figuratively, if not literally.[15]

Behavioral and cultural norms, SOPs, and regulations are necessary, but they are far from sufficient to preserve operational structure and the character of the service. We have noted three mechanisms that act to maintain and transmit operational factors in the face of rapid turnover. First, and in some ways most important, is the pool of senior chiefs, many of whom have long service in their specialty, and circulate around similar ships in the fleet.[16] Second, many of the officers and some of the crew will have at some time served on other carriers, albeit in other jobs, and bring to the ship some of the shared experience of the entire force. Third, the process of continual rotation and replacement, even while on deployment, maintains a continuity that is broken only during a major refit. These mechanisms are realized by a continuous process of on-board training and re-training that makes the ship one huge and continuous school for its own officers and men.

When operational continuity is broken or non-existent, the effects are observable and dramatic. One of us has had the opportunity to observe a new Nimitz class aircraft carrier as she emerged from the yard, and has remarked at how many things had to be learned before she could even begin to commence serious air operations.[17] Even for an older and more experienced ship coming out of an ordinary refit, the work-up towards deployment is a long and arduous process. Many operational weeks are spent just qualifying the deck for taking and handling individual aircraft, and many more at gradually increasing densities to perfect aircraft handling as well as the coordination needed for tight launch and recovery sequences. With safety and reliability as fixed boundary conditions, every moment of precious operational time before deployment is devoted to improving capability and efficiency.

The importance of adequate work-up time, if flight operations are to be conducted safely at present levels of technical and operational complexity at the tempo required for demonstrating effectiveness, can not be over-emphasized. During our research, we followed one carrier through a work-up shortened by "only" two weeks for reasons of economy. As a result, the ship was forced to complete its training during the middle of a difficult and demanding mid-ocean exercise, with resulting enormous and visible strain on all hands. Although she succeeded, and although referees were willing to adapt evaluation procedures a bit to compensate, risks to ship's personnel, to the equipment, and to the Navy were visibly higher. Moreover, officers and crew were openly unhappy with their own performance, with an attendant and continuing impact on morale.[18]

The Paradox of High Turnover

Because of the high turnover rate, a U.S. aircraft carrier will begin its workup with a large percentage of new hands in the crew, and with a high proportion of officers new to the ship. The U.S. Navy's historical tradition of training generalist officers (which distinguishes it from all other military services) assures that many of them will also be new to their specific jobs. Furthermore, tours of duty are not coordinated with ship sailing schedules, so that the continual replacement of experienced with green personnel, in critical as well as routine jobs, continues even during periods of actual deployment.

Continual rotation creates the potential for confusion and uncertainty even in relatively standardized military organizations. Lewis Sorley has characterized the effects of constant turnover in other military systems as "turbulence", and identified it as prime source of loss of unit cohesion.[19] A student of Army institutional practices has remarked that the constant introduction of new soldiers into a unit just reaching the level of competence to perform in an integrated manner can result in poor evaluations, restarting the training cycle and keeping individuals perpetually frustrated at their "poor" job performance.[20]

Negative effects in the Navy case are similar. It takes time and effort to turn a collection of men, even men with the common training and common background of a tightly-knit peacetime military service, into a smoothly functioning operations and management team. SOPs and other formal rules help, but the organization must learn to function with minimal dependence upon team stability and personal factors. Even an officer with special aptitude or proficiency at a specific task may never perform it at sea again.[21] Cumulative learning and improvement are also made slow and difficult, and individual innovations and gains are often lost to the system before they can be consolidated.[22]

Yet, we regard this practice to contribute greatly to the effectiveness of Naval organizations. There are two general reasons for this paradox. First, the efforts that must be made to ease the resulting strain on the organization seem to have positive effects that go beyond the direct problem they address. And, second, officers must develop authority and command respect from those senior enlisted specialists upon whom they depend, and from whom they must learn the specifics of task performance.

The Navy's training cycle is perforce dictated by the schedule of its ships, not its personnel. Because of high social costs of long tours of sea duty, the Navy has long had to deal with such continual turnover, and attempts as best it can to mitigate the negative effects. Most important is the institutionalization of continual, cyclic training as part of organizational and individual expectations. This is designed to bring new people up to speed with the current phase of the cycle, thus stabilizing the environment just before and during deployment at the cost of pushing the turbulence down into individual units. Although the deployment cycle clearly distinguishes periods of "training" from those of "operations", it is a measure of competence and emphasis, not of procedural substance, that applies primarily to the ship as a unit, not its men as individuals.

The result is a relatively open system, which exploits the process of training and re-training as a means for socialization and acculturation. At any given moment, all but the most junior of the officers and crew are acting as teacher as well as trainee. A typical Lt. Commander, for instance, simultaneously tries to master his present job, train his juniors, and learn about the next job he is likely to hold. If he has just come aboard, he is also engaged in trying to master or transfer all the cumulated knowledge about the specifics of task, ship, and personnel in a time rarely exceeding a few weeks.[23] In addition to these informal officer-officer and officer-crew interactions, officers and crew alike are also likely to be engaged in one or more courses of formal study to master new skills in the interest of career advancement or rating.

As a result, the ship appears to us as one gigantic school, not in the sense of rote learning, but in the positive sense of a genuine search for acquisition and improvement of skills. One of the great enemies of high reliability is the usual "civilian" combination of stability, routinization, and lack of challenge and variety, which predispose an organization to relax vigilance and sink into a dangerous complacency that can lead to carelessness and error.[24] The shipboard environment on a carrier is never that stable. Traditional ways of doing things are both accepted and constantly challenged. Young officers rotate in with new ideas and approaches; old chiefs remain aboard to argue for tradition and experience. The resulting dynamic can be the source of additional confusion and uncertainty at times, but at its best leads to a constant scrutiny and re-scrutiny of every detail, even for SOPs.

In general, the Navy has managed to turn the rapid turnover to advantage through a number of mechanisms that have evolved by trial-and-error for the purpose of insulating against personnel changes. SOPs and procedures, for example, are often unusually robust, which in turn contributes another increment to reliability. The continual movement of people rapidly diffuses organizational and technical innovation as well as "lessons learned", often in the form of "sea-stories", throughout the organization. Technical innovation is eagerly sought where it will clearly increase both reliability and effectiveness, yet resisted when suggested purely for its own sake. Operators reading sophisticated radar systems log data with grease pencils; indicators for the cables to arrest multi-million dollar aircraft are set and checked mechanically, by hand. Things tend to be done in proven ways, and changed only when some unit has demonstrated and documented an improvement in the field. The problem for the analyst, and for the Navy, is the separation of functional conservatism from pure tradition.

Authority Overlays

We also have noted with great amazement the adaptability and flexibility of what is, after all, a military organization in the day-to-day performance of its tasks. On paper, the ship is formally organized in a steep hierarchy by rank, with clear chains of command and means to enforce authority far beyond that of any civilian organization. We supposed it to be run by the book, with a constant series of formal orders, salutes, and yes-sirs. Often it is. But flight operations are not conducted that way.

Flight operations and planning are usually conducted as if the organization were relatively "flat" and collegial. This contributes greatly to the ability to seek the proper, immediate balance between the drive for safety and reliability and that for combat effectiveness. Events on the flight deck, for example, can happen too quickly to allow for appeals through a chain of command to a formal authority. Even the lowest rating on the deck has not only the authority, but the obligation to suspend flight operations immediately, and without first clearing it with superiors, under the proper circumstances. Although his judgement may later be reviewed or even criticized, he will not be penalized for being wrong, and will often be publicly congratulated if he is right.[25]

Coordination of planning for the next day's air operations requires a series of involved tradeoffs between mission requirements and the demands of training, flight time, maintenance, ordnance, and aircraft handling. It is largely done by a process of ongoing and continuing argument and negotiation among personnel from many units, in person and via phone, which tend to be resolved by direct order only when the rare impasse develops that requires an appeal to higher authority. In each negotiation, most officers play a dual role, resisting excessive demands from others that would compromise the safety or future performance of their units, while maximizing demands on others for operational and logistic support.

This does not mean that formal rank and hierarchy are unimportant. In fact, they are the lubricant that makes the informal processes work. Unlike the situation in most civilian organizations, relative ranking in the hierarchy is largely stable, and shaped by regular expectations and formal rules and procedures. Although fitness reports and promotion review boards are not free of abuses or paradoxes, the shipboard situation tends to promote cooperative behavior, which tends to minimize the negative effects of jealousy and direct competition.[26] Although officers of the same rank are competitively rated, each stands to benefit if joint output is maximized and suffer if the unit is not performing well. Thus, we rarely observe such strategies as the hoarding of information, or the deliberate undermining of the ability of others to perform their jobs, that characterize so many civilian organizations, particularly in the public sector.

Redundancy

Operational redundancy -- the ability to provide for the execution of a task if the primary unit fails or falters -- is a necessity for high-reliability organizations managing activities sufficiently dangerous to cause serious consequences in the case of operational failures.[27] In classic organization theory, redundancy is provided by some combination of duplication [two units performing the same function] and overlap[two units with functional areas in common]. Its enemies are mechanistic management models that seek to eliminate these valuable modes in the name of "efficiency".[28] For a carrier at sea, several kinds of redundancy are necessary even for normal peacetime operations, each of which creates its own kinds of stress.

A primary form is technical redundancy, involving operations-critical units or components on board -- computers, radar antennas, etc. In any fighting ship, as much redundancy is built is as in practicable. This kind of redundancy is traditional, and well understood. Another form is supply redundancy. The ship must carry as many aircraft and spares as possible to keep its power projection and defensive capability at an effective level in the face of maintenance requirements, and possible operational or combat losses. Were deck and parts loading reduced, many of the dangers and tensions involved in scheduling and moving aircraft would be considerably lessened. Here is a clear case of a tradeoff between operational and safety reliability that must be made much closer to the edge of the envelope than would be the case than for other kinds of organizations. Indeed, for a combat organization, the tradeoff point is generally taken as a measure of overall competence.[29]

Most interesting to our research is a third form, decision/management redundancy, which encompasses a number of organizational strategies to ensure that critical decisions are timely and correct. This has two primary aspects: (a) internal cross-checks on decisions, even at the micro level; and, (b) fail-safe redundancy in case one management unit should fail or be put out of operation. It is in this area that the rather unique Navy way of doing things is the most interesting theoretically as well as practically.

As an example of (a), almost everyone involved in bringing the aircraft on board is part of a constant loop of conversation and verification, taking place over several different channels at once. At first, little of this chatter seems coherent, let alone substantive, to the outside observer. With experience, one discovers that seasoned personnel do not "listen" so much as they monitor for deviations, reacting almost instantaneously to anything that does not fit their expectations of the correct routine. This constant flow of information about each safety-critical activity, monitored by many different listeners on several different communications nets, is designed specifically to assure that any critical element that is out of place will be discovered or noticed by someone before it causes problems.

Setting the arresting gear, for example, requires that each incoming aircraft be identified (for speed and weight), and each of four independent arresting gear engines set correctly.[30] At any given time, as many as a dozen people in different parts of the ship may be monitoring the net, and the settings are repeated in two different places (Pri-Fly and LSC). During a trip aboard *Enterprise* in April of 1987, she took her 250,000th arrested landing, representing about 1,000,000 individual settings.[31] Because of the redundancies built in, and the cross-familiarity of personnel with each other's jobs, there had not been a <u>single</u> recorded instance of a reportable error in setting that resulted in the loss of an aircraft.[32]

Fail-safe redundancy, (b), is achieved in a number of ways. Duplication and overlap, the most familiar modes of error-detection, are used to some extent -- for example, in checking mission weapons loading. Nevertheless, there are limits to how they can be provided. Space and billets are tight at sea, even on a nuclear-powered carrier, and, unlike land-based organizations, the sea-going Navy cannot simply add extra departments and ratings. Shipboard constraints and demands require a considerable amount of redundancy at relatively small cost in personnel. In addition to the classic "enlightened waste" approach of tolerance for considerable duplication and overlap, other, more efficient strategies that use existing units with other primary tasks as back-ups are required, such as "stressing the survivor" and mobilizing organizational "reserves".[33]

Stressing the survivor strategies require that each of the units normally operate below capacity, so that if one fails or is unavailable, its tasks can be shifted to others without severely overloading them. Redundancy on the bridge is a good example.[34] Mobilizing reserves entails the creation of a "shadow" unit able to pick up the task if necessary. It is relatively efficient in terms of both space and personnel, but places higher demands on the training and capability of individuals. What the Navy effects through the combination of generalist officers, high job mobility, constant negotiation, and perpetual training, is a mix that leans heavily on reserve mobilization with some elements of survivor stressing. Most of the officers, and a fair proportion of senior enlisted men, are familiar with several tasks other than the ones they normally perform, and could do them in an emergency.

The Combat Decision Center (CDC, or just "Combat"), for example, is the center for fighting the ship.[35] Crucial decisions are thereby placed nominally in the hands of relatively junior officers in a single, comparatively vulnerable location. In this case we have noted several of the mechanisms described above. There is a considerable amount of senior oversight, even in calm periods. A number of people are "just watching", keeping track of each other's jobs or monitoring the situation from other locations. There is no one place on the ship that duplicates the organizational function of combat, yet each of the tasks has a back-up somewhere -- some on the carrier, some distributed among other elements of the Battle Group.[36]

In an "ordinary" organization, these parameters would likely be characterized in negative terms. Back-up systems differ in pattern and structure from primary ones. Those with task responsibility are constantly under the critical eye of others. Authority and responsibilities are distributed in different patterns, and may shift in contingencies. In naval circumstances where reliability is paramount, these are seen as positive and cooperative, for it is the task that is of primary importance.

Thus, those elements of Navy "culture" that have the greatest potential for creating confusion and uncertainty turn out to be major contributors to organizational reliability and robustness under strain. We believe this to be an example of adaptive organizational evolution to circumstance, for it responds very well to the functional necessities of modern operations. In the days of great, compact flotillas, loss of navigational or deck or gun capability by one ship could be compensated for by shifting or sharing with another. There is only one carrier in a Battle Group, and only a handful of other ships, spread over many hundreds of square miles. Each, and most particularly the carrier, must internalize its own processes and modalities for redundancy.

Some Preliminary Conclusions

Even though our research is far from complete, particularly with regard to comparisons with other organizations, several interesting observations and lessons have already been recorded.

First, the remarkable degree of personal and organizational flexibility we have observed is essential for performing operational tasks that continue to increase in complexity as technology advances. "Ordinary" organization theory would characterize aircraft carrier operations as confusing and inefficient, especially for an organization with a strong and steep formal management hierarchy (i.e., any "quasi-military" organization). However, the resulting redundancy and flexibility are in fact remarkably efficient in terms of making the best use of space-limited personnel.

Second, an effective fighting carrier is not a passive weapon that can be kept on a shelf until it is needed. She is a living unit, possessed of dynamic processes of self-replication and self-reconstruction that can only be nurtured by retaining experienced personnel, particularly among the chiefs, and by giving her sufficient operational time at sea. This implies a certain minimum budgetary cost for maintaining a first-line carrier force at the levels of operational capability and safety demanded of the U.S. Navy.

The potential risk of attempting to operate at present levels under increasing budgetary constraints arises because the Navy is a "can-do" organization, visibly reluctant to say "we're not ready" until the situation is far into the red zone.[37] In time of war, the tradeoff point between safety and effectiveness moves, and certain risks must be taken to get units deployed where and when they are needed. In peacetime, the potential costs of deploying units that are less than fully trained are not so easily tolerated. If reductions in at-sea and flying time are to be taken out of work-ups to preserve operational time on deployment, training and evaluation procedures will have to be adapted to reduce stress -- perhaps by overlapping final readiness evaluations into the beginning of the deployment period.

Third, as long-term students of organizations, we are astounded at how little of the existing literature is applicable to the study of ships at sea. Consider, for example. the way in which the several units that make up a Battle Group (carrier, air wing, supply ships, escorts) are in a continual process of formation and re-formation. Imagine any other organization performing effectively when it is periodically separated from and then rejoins the unit that performs its central technical function.[38] More importantly, most of the existing literature was developed for failure-tolerant, civilian, organizations with definite and measurable outputs. The complementary body on public organizations assumes not only a tolerance for failure, but at best an ambiguous definition of what measures failure (or, for that matter, of success).

Fourth, we have been encouraged to reflect on the new large Soviet nuclear carrier now being fitted out in the Black Sea.[39] The Soviet Navy is completely without experience or tradition in large carrier operations. Their internal structure is more rigid and more formal than ours, and with far less on-the-job training, especially for enlisted personnel.[40] It will be very interesting to watch their work-up time, deck loading, and casualty rates. Of course, it is not clear that they will be trying to emulate U.S. carrier operations rather than the rather different style and objectives of the British or French.[41] In either case, we estimate a minimum of several work-ups (each taking perhaps 2-3 years) before they begin to approach the deck loads and sortie rates of comparable Western carriers, and, unless they are remarkably lucky, the loss of not a few lives in the learning process.[42]

1. See, for example, Charles Perrow, Normal Accidents (New York: Basic Books, 1984).

2. Examples that have attracted recent attention include Bhopal, Seveso, Three Mile Island, and Chernobyl. All four meet Perrow's criteria for coupling, response time, and complexity. The essence of a "normal" accident is that the potentiality inheres in the design of the system, and, despite attempts to fix "blame", is not primarily the result of individual misbehavior, malfeasance, or negligence.

3. By comparison, civil air traffic controllers deliberately stay far away from the edge. Such fixed rules as maintaining five mile intervals are designed to err broadly in the direction of safety. Moreover, the turnover rate for controllers is relatively low (barring extraordinary events such as the recent strike), and even equipment changes are few and far between.

4. From this point we refer to carrier personnel as "men", since as yet the Navy does not allow women to serve aboard combat vessels.

5. We have followed both the U.S.S. <u>Carl Vinson</u> (CVN-70) and the U.S.S. <u>Enterprise</u> (CVN-65), under a total of four different Captains, through their training and work-up from Alameda and San Diego and across the Pacific into the South China Sea. In addition, one of us (Roberts) has been able

to observe the initial sea trials of the U.S.S. Theodore Roosevelt (CVN-71).

6. In formal organization terms, we refer to this as "decomposability". The basic notion was introduced by Herbert A. Simon in "The Architecture of Complexity", Proceedings of the American Philosophical Society, 106 (December 1962), 467-482; (reprinted in Herbert A. Simon, The Sciences of the Artificial (Cambridge MA: The MIT Press, 1981).

7. During our interviews, one senior officer on Flag staff suggested that the several different functional and hierarchical modes of organization might be viewed as a set of "overlays" that are superimposed upon the formal organization at different times depending upon the task or circumstance at hand. Many of the officers must shift roles many times during the course of a single active day of flight operations.

8. The few examples that come to mind are large construction projects, e.g., nuclear power plants, the Alaskan pipeline, etc. However, these usually have considerable oversight from a separate firm whose sole task is to coordinate and schedule the work properly.

9. This point was brought home sharply by the effort to bring up the ZOG computer system on the USS Carl Vinson, which would have required that almost complete knowledge about all details of ship operations be known and entered if the system were to function as originally intended. In retrospect, this can be seen as a near-impossible requirement without the mounting of a considerable special effort to collect and organize the data.

10. Furthermore, a strong Captain is capable of altering both the character of a ship and the way it operates, if he so chooses.

11. Given the size of modern jet aircraft and the number carried at full load, the matter of spotting is far from trivial. Inefficient spotting can greatly reduce the ability to move aircraft about quickly. Incorrect spotting can lead to serious interference with operations, or even to a "locked" deck, in which it becomes impossible to move aircraft at all. In a trial using the deck model in Flight Deck Control, one of us managed to lock the deck so thoroughly that an aircraft would have had to be pushed over the side to free it.

12. Some non-functional variations are being reduced. For example, all LSO platforms will soon be located at the same level and position relative to the arresting gear wires. However, it is nearly impossible to upgrade all of the ships at once when new equipment in introduced, so each is at a different stage of modification and upgrade at any given point in time.

13. To some extent this situation is improving. Landing System Officers (LSO), for example, now have a simulator to work with. Although this is no substitute for experience when "eyeball" judgement is concerned, it helps.

14. As one Senior Chief remarked to us: "You have to know it, but it rarely helps when you really need it."

15. Roger Evered, "The Language of Organizations: The Case of the Navy", in Louis R. Pondy, Peter J. Frost, Gareth Morgan, and Thomas C. Dandridge, eds., Organizational Symbolism (Greenwich CT: JAI Press, 1983), 125-144.

16. A very few stay on one ship for many years, but such "plank owners" are rare in the modern Navy.

17. For example, the first crew was unable to spot the deck effectively; Flight Deck Control was laid out with the deck model at right angles to the deck (interfering with spatial visualization) and obstructing the Aircraft Handling Officer's direct view of the deck out of his only window.

18. The recent grounding of USS Enterprise on Bishop Rock off San Diego may be at least partially due to her being in a difficult exercise combining elements of what were usually two exercises. See Karlene H. Roberts, "Bishop Rock Dead Ahead: The Grounding of U.S.S. Enterprise", submitted to Naval Institute Proceedings. The effect on ship's morale was very visible.

19. Lewis Sorley, "Prevailing Criteria: A Critique", in Sam C. Sarkesian, ed., Combat Effectiveness (Beverly Hills: Sage Publications, 1980), 57-93.

20. L.R. Giguet, "Coordinating Army Personnel Agencies Using Living Systems Theory: An Example," U.S. Army TRADOC, 1979, as quoted by Sorley at p. 76-77.

21. The term "proficiency" is used in the special sense of Hubert L. Dreyfus and Stuart E. Dreyfus, Mind Over Machine (New York: Free Press, 1986), who classify five steps of skill acquisition: novice; advanced beginner; competence; proficiency; expertise. For most officers mastery of a specific assignment means at most the acquisition of

proficiency -- the ability to identify situations and act upon them without having to systematically think through the procedural steps involved. The most advanced stage, expertise, involves moving past "problem-solving" to "intuition" in decision-making. Examples of relevance here include the flying skills of experienced pilots and the specific expertise of senior chiefs -- in each case representing many years of continuous practice of a small range of specific skills.

22. We have observed several mechanisms used by the Navy to prevent such loss, including incentives for reporting successful innovation and formal procedures for their dissemination. The most general mechanism, however, is the informal dissemination of information by the movement of personnel, and through those responsible for refresher and other forms of at-sea training. A most remarkable combination of trainers and active personnel is the recently formed association of Air Bos'n's, which holds annual meetings at which information is exchanged and formal papers are presented.

23. Officers near the end of their tours, with new assignments in hand, are often also trying to learn as much as they can about their future tasks and responsibilities.

24. K. Weick, "The Role of Interpretation in High Reliability Systems", California Management Review, 39, 1987, 112-127.

25. Roberts (op.cit.) observes that similar rules would operate to similar advantage on the Navigation Bridge, which of necessity operates under more formal and traditional rules.

26. Even when fitness report ratings are based solely on merit, they are necessarily subjective to some degree. It is inherently difficult to compare ratings taken on different ships, in different peer groups, by different superiors, even in the best of circumstance. But the general opinion among those we have interviewed is that direct abuses of the system are relatively rare. As with all hierarchical organizations, politics will begin to enter as one moves to higher rank, but is thought to be a minor factor below the level of Captain.

27. We note that the kinds of redundancy required to assure continued effectiveness in combat -- e.g., in situations where physical damage to ship or command chains is anticipated -- are qualitatively different from redundancy directed primarily to assuring the performance of safety-critical tasks. Elements of the former, however, are often major contributors to the latter.

28. Martin Landau, "Redundancy, Rationality and the Problem of Duplication and Overlap," Public Administration Review, 23 (Nov/Dec 1973), 316-351.

29. In this context, we note that the tempo and character of U.S. carrier operations are so qualitatively different from those of other navies -- including the French, British, and prospective Russian -- that the envelope itself can only be measured by our own expectations and capabilities.

30. The engines are in different compartments, and set by hand by separate operating teams, so that collective failures in setting can only occur at the command level, i.e., in the Tower, where a number of other independent measures for cross-checking and redundancy are in place.

31. During heavy flight operations, there may be anywhere from 600 to 1000 settings of the engines during a single day. A typical deployment will have 8,000 to 10,000 arrested landings ("traps"), involving 30,000 to 40,000 settings over a six to eight month period.

32. Although the probabilities are low, the possibility does exist. A minor error may simply result in too much runout, cable damage, or some damage to the aircraft. But an engine set for too heavy a weight can pull a tail hook out, leading to aircraft loss; setting for too low an aircraft weight can result in its "trickling" over the end of the angle deck and into the sea. Experienced Air Bos'ns and Chiefs estimate that perhaps six or seven such serious errors have occurred throughout the entire U.S. fleet over the past twenty years. Our estimate for the rate of uncorrected wrong settings with serious consequences is therefore about one in a million -- roughly comparable to the probability of a mid-air collision in a domestic commercial airline flight. Setting errors that are corrected are "non-reportable" incidents, and therefore not documented. We also note that on the USS Carl Vinson, a much newer ship with a still unbroken memory, no reportable incident of any kind could be recalled in the first 70,000 traps since its commissioning.

33. Allan W. Lerner, "There Is More Than One Way To Be Redundant", Administration & Society, 18, No. 3 (November 1986), 334-359.

34. This was brought home to us during a General Quarters drill, in which the bridge took simulated casualties.

35. During the period of observation, CDC was also the center for fighting the Battle Group, a task that will increasingly be supervised by the new Tactical Flag Command Centers (TFCC) as they are installed. Depending upon the physical arrangement of the ship, the CDC area contains the Combat Information Center (CIC), anti-air warfare control consoles, and perhaps air operations and ship air traffic control (CATCC); other warfare modules, such as those for anti-submarine or anti-surface warfare, may also be included or in physically adjacent spaces.

36. For example, control of fighter aircraft can be done from the carrier, from an E-2, or from one of several other ships in the group.

37. Evered, op. cit., lists qualities of "responsiveness to authority", "being ready", "can do", and "not fazed by sudden contingencies" as among the more 'obvious' character traits of Naval officer culture. These are transmitted by training programs, ceremonies, and historical models. The latter is particularly important for the 'can do' aspect of culture.

38. Not only are the ship and its air wing parted, but the Wing itself is split into component squadrons, which train under different functional commands.

39. No definite name for this 1000+', angle-deck, 65-70,000 ton nuclear-powered carrier has been ascertained at this time.

40. Bruce W. Watson and Susan M. Watson, The Soviet Navy: Strengths and Liabilities (Boulder: Westview, 1986).

41. Although it is currently believed that arresting gear and catapults will be fitted, and the deck mock-up at Saki airfield in the Crimea is so equipped, ski-ramps for a total loading of 60-70 STOL aircraft appear more likely in the short term, with possible future retrofit of catapults into pre-existing deck slots at some future date. See, for example, Normal Polmar, Guide to the Soviet Navy, 4th Edition (Annapolis: Naval Institute Press, 1986), 164-165.

42. As a group, we doubt they will be able to approach the operating conditions and efficiency of U.S. carriers in this century, if at all, even if they master the associated naval and aircraft technologies.

Appendix
Project Summary and Annotated Bibliography of Project Papers

1. Project Summary

HIGH RELIABILITY ORGANIZATION PROJECT

University of California
Berkeley, California
Project Overview - May 1988

Faculty Group:

Geoffrey Gosling, Transportation Engineering
Air Traffic Control; Computer Applications
Todd R. La Porte, Political Science - Co-chair
Organization Processes; Response to Complex Technologies
Karlene H. Roberts, Business Administration - Co-chair Organizational Behavior; Decision and Group Processes
Gene I. Rochlin, Energy and Resources
Technology and Organizations; Energy and Regulation

Corresponding Member:

Charles Perrow, Department of Sociology, Yale University - Organization Theory and Risk Management
Denise M. Rousseau, School of Business Administration Northwestern University - Organizational Behavior and Methodology.
W. Richard Scott, Department of Sociology, Stanford University - Organization Theory
Karl Weick, School of Business Administration University of Texas; Austin, Texas
Social Psychology and Organizational Behavior

Student Participants

Paula Consolini, Political Science
Ted Lascher, Political Science
Jennifer Halprin, School of Business Administration
Suzanne Stout, School of Business Administration, Stanford University

Prepared by Todd R. La Porte

Institute of Governmental Studies

The project began, summer,1984, within a small group of Berkeley faculty [1 and Note 1] who were meeting regularly to discuss an organizational problem of increasing salience - the performance of a growing class of organizations in both the public and private sectors charged with tasks for which the societal and organizational costs of "errors" or "failures" are extremely high. [2] Few organizations perform such tasks well, yet our society increasingly demands that significant errors be avoided in organizations performing a host of critical tasks, e.g., toxic waste disposal or nuclear power plant operation.[2]

A series of workshops brought together senior operating officials from three "high reliability" organizations located nearby: the FAA's Oakland Enroute Air Traffic Control Center, PG&E's Electric Operations Division, the senior officers of the nuclear powered aircraft carrier, U.S.S. Carl Vinson. A strikingly similar set of problems - and solutions - emerged from these discussions. None of these organizations had been studied systematically. Each was quite interested in further study and opened itself to us. Fortuitously, we had had substantial experience with each one in earlier and somewhat unrelated projects. We eagerly took up the opportunity to study a small group of organizations whose performance not only meets, but exceeds criteria and expectations based on other experiences.[3]

Each of these organizations perform very complex and demanding tasks under considerable time pressure, and do so with a near-zero error rate and an almost total absence of

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1 **Current Berkeley Faculty Group:** Geoffrey Gosling, Transportation Engineering - Air Traffic Control, Computer Applications; Todd R. La Porte, Political Science - Organization Processes, Response to Complex Technologies; Karlene H. Roberts, Business Administration Organizational Behavior, Decision and Group Processes; Gene I. Rochlin, Energy and Resources - Technology and Organizations, Energy and Regulation. **Corresponding Faculty:** Karl Weick, School of Business Administration, University of Texas, Austin, Social Psychology and Organizational Behavior; Denise M. Rousseau, Business Administration, Northwestern University - Organizational Behavior and Methodology; W. Richard Scott, Stanford University - Organization Theory; and Charles Perrow, Yale University - Organization Theory.

2 Regrettably, NASA's space shuttle launch management must be placed in the category of organizations that "failed" under the joint stress of demands for very high reliability and operational continuity.

catastrophic failure. Based on our work thus far, it is evident that they have a number of similar characteristics:

--Each organization has a strong, reasonably concrete sense of its primary missions, operational goals and the technical means necessary to accomplish them.

-- All operate quite powerful, knowledge intensive technologies with very few significant operational failures. These technical systems are well known; their mechanisms and processes can be nearly completely specified.

--Their production units, e.g., power station, ATC center, or naval vessel, are quite complex and linked together into large operating networks, e.g., power grid, national system, or task force, that strongly effects levels of internal operating strains and the capacity to adjust to surprise.

-- They manage activities for which external or internal consequences of failure are perceived to be great. The rare operational failure gravely threatens the organization's capacity to operate, to deliver crucial services, and/or threatens the lives of its members or those of the community at large. As a result, "errors" such as near-misses between aircraft, partial blackouts, or damaged or diverted military aircraft are almost as difficult to tolerate as actual system failures, e.g., mid-air collisions, extensive system shut downs, or loss of aircraft or lives.

--There is a high degree of agreement in the society regarding the events, accidents or failures to be avoided (and within the organization on the indications of the on-set of such failures.)

-- Each organization has accepted the signal importance of reliable, safe operations as a major goal and there appears to be an ethic of personal responsibility for the safe operation of the whole. There is an operating "culture" that is strongly failure averse. Internal dynamics and structures are predominantly influenced by the requirement to avoid certain types of events, accidents or failures. However formal the organization, the informal operating structure shares responsibility for maintaining safety in a largely non- hireråchical way.

-- Despite the diversity of their tasks, operators in each system have similar working environments, share similar responsibilities, expectations, objectives, and goals, and show similar manifestations of the stress of their jobs.

-- In each case, it is the judgment, experience, and trained intuition of seasoned operators that is most responsible for maintaining systems reliability and safety. The historical learning process has been one of trial and error, but in an unusual sense. Open acknowledgement of and acceptance of responsibility for past error is rewarded in the interest of prompting future improvement.

-- Organizational structures, authority relationships, and decision- making dynamics appear to have evolved in common patterns: there is clear separation of operating from system maintenance, substantial delegation of operating authority to subordinate units, and redundant information sources to inform decision-making.

-- Each of these organizations has seen its workload increase while its resources base has been in relative decline in recent years: air traffic has increased in a system still recovering from the controller's strike of a few years ago; utility grid management is becoming much more complex as large numbers of relatively small independent electricity producers come on line; naval aircraft have become faster, heavier, and more complex and deck load density has increased.

-- Due to increased relative demand, an additional level of sustained stress has been added to the amount of stress operators are expected to absorb in highly responsible time-urgent jobs, calling for maintaining absolute performance levels, in the face of increasing magnitude and complexity of the tasks.

-- Computers and other technical systems are used, often extensively, but primarily as sources of information and data -- inputs to human judgment. Recently, in the face of increasing demand, each organization has been pressed to turn to new computer technologies in the hope of increasing its operational capacity without directly altering organizational size or structure.

-- Finally, the organizations, by virtue of their high reliability, have been nearly invisible to the public. The more failure-free their operation, the less opportunity for "outsiders" to learn about them. It appears likely that policy makers and interested consumer groups are systematically under-informed about the organizations' actual requirements and dynamics.

Two implications of this pattern of conditions follow: unexpected, subtle and unpredictable consequences are likely to result from the introduction of powerful and demanding new technical systems into organizations as large and complex as these; and criticisms and proposals for change are likely to underestimate or misunderstand their consequences for organizational operations.

The research group has undertaking observations in each of these organizations to answer questions about how they manage to attain such high levels of reliable performance while maintaining the capacity for sustained peak performance, and how they redesign themselves in the face of contingencies not considered by their original designers. It is already apparent that existing management and organizational theory must be modified, indeed extended, to address design, management, training and related issues. When these modifications are made and tested, they can be used to derive policies to help insure that, as an increasing numbers of complex systems are developed, they are not accompanied by a raise the likelihood of catastrophic error.

Each of these studies, briefly described below, has a different technical focus and unqiue set of operational and instrumental conditions. Each is directed to a specific set of immediate concerns identified by the particular organization. Our common objective is to gain a deeper understanding of the conditions and costs to the organizations and their personnel of those activities and stresses associated with maintaining such high levels of reliable performance. This is enabling us to identify a larger set of specific operational issues and alert us to the problems of at least maintaining or increasing the operational reliability of a variety of very complex systems.

Finally, an important aspect of this work has been a series of workshops involving senior operating officers from each organization. To date eight day-long meeting have been held, first, on site in each organization to brief the group on the reliability aspects of its operations, then to examine cross-cutting and comparative issues, e.g., the function and surprises in training activities, problems of formal and informal control system management during the onset of operational stress, and variations of working group cultures within high reliability organizations. Recent workshops have centered on provisional findings from our work thus far.

Below is a brief description of our work with each organization. (Modest support for this work has come from a number of sources indicated for each study area along with those of the team that assume initial responsibility. In June, we received a grant from the National Science Foundation to continue this work.)

1. U.S. Air Traffic Control. (La Porte and Gosling)

[UCB, Inst. of Transport. Studies]

Study of the evolution of ATC was begun in 1980, examining the technical, organizational and institutional conditions which had resulted in a stunning level of operational reliability. Intensive examination of technical and organizational changes were conducted through reviews of documents and extensive interviewing at FAA headquarters in Washington, D.C., and at Washington and later Oakland Air Route Traffic Control Centers. The PATCO strike so disrupted the FAA that the study was "put on hold" for nearly two years after the strike, and was resumed when the organization's equilibrium was regained. Subsequent work in Washington and at Oakland Center has been done to explore 1) the longer lasting effects of the strike, and 2) the potential for surprise and personnel difficulties that could accompany the introduction of the newest technical proposals for automation of air control functions.

In fall 1985, further study in Washington and in several ATC centers was begun (by La Porte) to further the work begun in 1980. Other work has proceeded independently (by Gosling) on aspects of the use of "artificial intelligence" for various ATC functions. Both Gosling and La Porte have familiarized themselves with the operation of European Air Traffic Control during visits to ERUOCONTROL facilities near Paris and Brussels, by La Porte in June, 1986, and both La Porte and Gosling in September 1987 with visits to EUROCONTROL facilities near Paris, Brussels, and the operational center at Maastricht, Netherlands. Three week were spend at the FAA facilities in Washington, D.C., and Leesburg, VA, April 1988, to up-date the teams information on changes in policies and operations during the past three years anticipating moderately intensive in-site observations at Oakland Center, this summer.

Arrangements have been made to conduct on-site observations and interviewing at ATC enroute and terminal control facilities, especially in periods of operational stress.

2. The Electric Operations Department, Pacific Gas and Electric Company. (La Porte, Rochlin) [UC Energy Research Group; PG&E]

Studies began in 1981-82 as part of a study on the effects of dispersed energy supply on organizational change. To our surprise, we discovered that the management of the electrical power distribution grid had many similarities to what we had found in the FAA. In 1984, we resumed systematic contacts with PG&E, with several briefings on their operations and periodic discussions of the challenges they face in the next decade.

In summer 1985, we continued charting the evolution of the grid management function and operating organizational structures, decision- making dynamics, the demands of increased conservation and load management efforts, and the changes associated with new automated information control technologies may have within PG&E as they continue to be the pivotal actor in the Western States power grid. This general phase included the beginning of systematic study of the past decade's development of the Electric Operations Department and an examination of routine and emergency switching decision-making and performance.

Two more detailed studies were initiated in winter, 1986: the first examined the organizational effects of managing the growing number of widely dispersed, independently owned electric power producers. The second studied the political dynamics arising from a series of persistent major outages in a large Central Valley community, and the utility's response to the difficult technical and operational problems involved is nearly completed. This paper will be submitted for publication soon. Workshops were devoted to each project.

Arrangements are being made; 1) to develop an organizational history of PG&E's leadership and operational involvement in establishing the California Power Pool, the association of utilities increasing tied together in power transfers that greatly improves regional performance, and 2) to conduct on-site observations of several switching centers, especially in periods of operational stress.

3. Nuclear Aircraft Carriers. (Roberts, La Porte, Rochlin) [UCB, Inst. of Govt. Studies, Sch. of Bus. Ad.; Office of Naval Research, U.S. Navy]

Over two years ago, initial acquaintance with these very complex, tightly-packed organizations was began at pier-side locally with U.S.S. Carl Vinson and continued at-sea during an intensive period of her deployment. After intensive briefings on the ship's operation, two of us boarded her for 17 days underway off Japan, December, 1984, to observe her management and technical teams. During flight operations at-sea, field data were collected from our observations and the results of interviews with her senior officers, about how various of her department are managed, how crucial decisions are made, and how her departments are interlinked to carry out the overall functions of a modern aircraft carrier. These data and subsequent at-sea experience provide foundation for understanding of the conditions which have resulting in the Carl Vinson's very good record, and the potential changes in operations that should or should not be seriously considered (including the mounting of additional computerized decision making aids.)

During Summer, 1985, in addition to continued study of Carl Vinson, we extended our work to include: a) a parallel study of U.S.S. Enterprise, the second nuclear carrier in Carrier Group Three (CARGRU 3); and b) the effects of a new computer based information system designed to aid decision-making in the command of CARGRU 3, with particular attention to the effects on staff planning and subsequent relationship to reliable carrier air operations, and the CARGRU coordination of the battle group underway. This presented the opportunity for a comparison of two carriers, in the same command, but with quite different histories - the Enterprise, a long established ship, first of her class and the much newer Vinson. We are observing the process each goes through during her readiness "workup," i.e., the evolution from early preparations to full readiness for deployment in the Pacific. There is also the opportunity to examine the interaction of new technologies with established operations on the performance of the ships

Research on Carl Vinson has been conducted periodically during the ship's "work-up" to a full state of readiness after undergoing overhaul and repair routinely carried out after each major deployment. The team boarded the ship for five at-sea periods, from mid-winter through mid-Sept.,1986. Data collected include observations of the ship's navigation, air and combat coordination operations, and survey data on organizational culture, and communication from both elements of the ship's Air, Operations and Engineering Departments and five squadrons and command staff of the Air Wing. The last at-sea period was at a time of "practiced readiness," just before starting battle patrol in the Indian Ocean, when operations are intense and involve tightly interdependent decision-making dynamics.

A similar study began with U.S.S. Enterprise in February, 1987, after she completed "overhaul and repair." The final field segment of three weeks of on-board observation was completed in Jan. Survey data was collected from five squadrons and several ship's departments. The team observed operating dynamics during four separate at-sea periods. In addition, several visits have been made to headquarters, Navy Air Force Pacific, San Diego, to gathering information on the quantity and character of shore based support to ship board high reliability activities.

NOTES

1. The three senor researchers have the following relevant research and experience. T.R. La Porte: research and advisory experience on issues of radioactive waste and nuclear power plant operation; studies of California electric power system, and the national and European air traffic control systems, and for a decade was sponsored by the U.S. Marine Corps as a user of air traffic control and, for a short time, aircraft carrier services. **Karlene Roberts**: research on communication and organization in the first Naval Squadron to receive the F-14 aircraft; advisory and legal experience on personnel matter in complex organization involving hazards to employees. Gene Rochlin: research on radioactive waste management and other aspects of nuclear technology and safety; nuclear, fossil fueled, and alternative energy systems, including distributional effects and grid management; other advanced technological systems including military technologies, nuclear weapons and control systems.

2. See, for example: Todd R. La Porte, "The Design and Management of Nearly Error-Free Organizational Control Systems," in D. Sills, C. Wolf, and V. Shelanski, eds. **The Accident at Three-Mile Island: Human Dimensions** (Boulder, CO.: Westview Press, 1982); --, "Managing Nuclear Wastes," **Society/Transactions**, July/August, 1984; "Nuclear Wastes: Increasing Scale and Sociopolitical Impacts,: **Science**, 191 (7 July 1978), 22-29. For a good description of the problems organizations face with low-probability, high consequence events, see. C. Perrow, **Normal Accidents**, (New York: Basic Books, 1984.)

3. A striking example is air traffic control, where serious errors can threaten lives or completely disrupt commercial air traffic. See T.R. La Porte, "The Search for Nearly Error-Free Management: Lessons from Air Traffic Control for the Future of Nuclear Energy," for Colloquium Series, Woodrow Wilson International Center for Scholars, Smithsonian Institution, Nov. 1980.

2. HIGH RELIABILITY ORGANIZATION PROJECT PAPERS

1. T.R. La Porte, "High Reliability Organization Project Summary," rev. 7, May 1988
The latest in a series of short overview summaries of the UC Berkeley Project.

2. T.R. La Porte, "High Reliability Organizations: The Research Challenge." March 1987
The conceptual paper that outlines the theoretical problem, the conceptual orientation and particular definitions informing the High Reliability Organization Project, including the requisites of high reliability organizational dynamics.

Papers Drawn from Carrier and Navy Work.

3. K.H. Roberts and R. Boettger, D.W. Scott, and S.B. Sloane, "USS Carl Vinson: An Evaluative History." 1985.
The early development of USS Carl Vinson is discussed. Attention is focused on the ship's early use of an artificial intelligence system and its demise. The environment of the ship is described along with problems that developed and the way they were addressed is discussed. Finally, differences between the first and second commanding officers of the ship are highlighted. Used by US Navy for development of new ships and ship's emerging from Ship's Life Extension Program (SLEP.)

4. J.L. Eccles, Interdependence in a Highly Complex Organization." MBA Thesis, June 1986
A study of on-board interactions between the Carrier Air Group and its host carrier, including the various kinds of interdependence that characterize the relationship of ship's company to her air wing aboard USS Enterprise are the focus of this paper. A new kind of interdependence (flexible reciprocal interdependence) is defined.

5. G.I. Rochlin, "Technology Specification and Operator 'Power' in Large Organizations: The Special Case of Naval Aircraft Carrier Flight Operations'", July 1986.
This paper discusses the unusual degree of authority over technical specification that is possessed by the naval carrier community, analyzing the degree to which this represents a recognition of the special requirements of high hazard operations.

6. G.I. Rochlin, "'High Reliability' Organizations and Technical Change: Some Ethical Problems and Dilemmas,"

IEEE Technology and Society Magazine, Sept. 1986.
Discusses the distribution of responsibilities in 'high- reliability organizations, including aircraft carriers at sea, with special attention given to the ethical dimensions and assumptions of moral responsibility for operational safety and reliability.

7. G.I. Rochlin, T.R. LaPorte, K.H. Roberts, "The Self-Designing High Reliability Organization: Aircraft Carrier Flight Operations At Sea." **Naval War College Review**, Autumn 1987, 76-90.
Aircraft carrier flight operations at sea are beset with a number of paradoxes if analyzed in terms used to describe "conventional" organizations. This paper explores organizational self-design as a response to operational demands and the ways in which the Navy makes the best use of factors such as high turnover and structural ambiguity, which are normally treated as negative, counter-productive factors in analyzing organizational performance.

8. G.I. Rochlin, "High-Tech, Low-Tech, and No-Tech Complexity: Technology and Organization in U.S. Naval Flight Operations at Sea."
Paper presented to Section on Military Studies, International Studies Association, Atlanta, GA, Sept. 1987.
This paper analyzes the peculiar mix of "high" and "low" technologies used in aircraft carrier flight operations, discussing the balance chosen between the need for very advanced technologies to meet external threats and the desire for simple, more robust new where the need for operational reliability is paramount.

9. K. H. Roberts, "Some Characteristics of High Reliability Organizations". Submitted to **Organizational Sciences**. Jan. 1988.
This paper identifies some characteristics of high reliability organizations that are similar to or different from those characteristics of high risk organizations identified by Perrow (1984) and Shrivastava (1987) of their analysis of major organizational catastrophes. The paper shows how high reliability organizations mediate against some of the dysfunctional characteristics of high risk organizations. Examples are drawn from USS Carl Vinson, USS Enterprise, USS Theodore Roosevelt and an Air Force phased array early warning system.

10. T.R. La Porte, "Operational Design for CVNs\CVWs in Battle Group Configuration: Feedback from the Field,"

February, 1988.
Drawn from the final three weeks of at sea observations, this paper discusses three situations that might call for modest changes in the relations of a CVN/CVW team to upper level units. Each change responds to the same underlying condition, increase interdependence and complexity among battle group and ship board elements.

11. K.H. Roberts, J. Halpern, S. Stout. "Organizational and Cognitive Factors Influencing Decision Making in a High Reliability Organization." Submitted to **Academy of Management Journal**. July 1988
Individual decision making propensities, such as the tendency toward miserliness, the impact of accountability, and the effects of commitment on a decision makers behavior, are examined in the context of organizational constraints on decision making (such as the existence of SOPs and restriction in amount of information flow). The operation of these propensities and constraints are illustrated with two decision making scenarios drawn from two aircraft carriers.

12. K.H. Roberts and G. Gargano, "Redundancy and Interdependence in a High Reliability Organization." Submitted to **Academy of Management Review**. Aug. 1988.
This paper extends on the previously mentioned interdependence paper by examining components of a theory of interdependence and discussing the relationship of interdependence, complexity, and system stability.

13. K.H. Roberts, D M. Rousseau and T.R. LaPorte, "The Culture of High Reliability Organizations." working paper, Aug. 1988.
Using a sample of approximately five hundred respondents from USS Carl Vinson, this paper discusses the culture of high reliability organizations along the twelve scales of Cooke and Rousseau's (1986) organization culture inventory. It also examines the relationship of culture, communication, and commitment in this organization.

14. T.R. La Porte and P. Consolini, "High Reliability Organizations: Challenges to Organization Theory," paper presented at the American Political Science Association meeting, Washington, D.C., Sept., 1988.
Drawing from work on two high reliability organizations - air traffic control and aircraft carrier operations at sea - this paper outlines phenomena that challenge the adequacy of contemporary organization theory to provide explanation. Of particular interest is the

emphasis on extreme error avoidance - a theoretically impossible condition - and the resulting patterns of decision-making and mix of authority relations and operating modes.

15. G.I. Rochlin, "Organizational Structure and Operational Effectiveness in Complex Military Organizations: Naval Flight Operations as a Case Study," paper presented at the American Political Science Association meeting, Washington, D.C., Sept., 1988.
During a typical flying day, the various command and operational units aboard a U.S. aircraft carrier may reorganize the lines of authority and negotiation several times, adapting in each case to the demands of the moment and the task at hand. Operational history and high demand are shown to be determining in the maintenance of this fluidity structure in nominally formal and hierarchical organization.

16. K.H. Roberts, "Bishop Rock Dead Ahead: The Grounding of the U.S.S. Enterprise," **Naval Institute Proceedings**, (in press).
In November, 1985, USS Enterprise grounded on Bishop Rock shoal in the Navy's Southern California Operations Area. This paper discusses the antecedents to that grounding.

17. K.H. Roberts and G. Gargano, "Managing a High Reliability Organization: A Case for Interdependence." In M.A. Von Glinow and S. Mohrmon, (Eds.), **Managing Complexity in High Technology Industries: Systems and People.** New York: Oxford University Press, 1988.
This paper defines five types of interdependence that can occur in high reliability organizations. It then presents a number of tensions that the organizational literature predicts about interdependence and related issues in high risk organizations. These paradoxes are illustrated through observational and questionnaire data collected aboard USS Enterprise and USS Carl Vinson.

18. K. H. Roberts and S. Sloane, "An Aggregation Problem and Organizational Effectiveness," in B. Schneider and D. Schoornman, eds., **Facilitating** Work Effectiveness. Lexington, MA: Lexington Press, 1988.
This paper briefly reviews the major aggregation issues in organization research. It then focusses on the linkage problem as an aggregation issue. The simultaneous presence of three kinds of linkages (function, communication, and authority) are illustrated by observations made aboard USS Carl Vinson.

19. K.H. Roberts and D.M. Rousseau, "Research in Nearly Failure-Free, High Reliability Systems: 'Having the Bubble'," **IEEE Transactions**, (in press)
The methodological challenges and problems of doing research in high reliability organizations are described. The paper begins with a description of the distinctiveness of high reliability organizations; then discusses issues of entre, problem identification, studying systems and events, data gathering and interpretation.

20. K.H. Roberts, "An Evaluative Review of Perrow's **Normal Accidents.**" **Academy of Management Review**, forthcoming 1989.
This review focusses on the influence of Perrow's book influence on Robert's research on "high reliability organizations" via her response to a number of issues raised in the book.

<u>Papers dealing with other High Reliability Organizations.</u>

21. T.R. La Porte, "The Search of Nearly Error-Free Management: Lessons from U.S. Air Traffic Control for the Future of Nuclear Energy," Colloquium Series, Woodrow Wilson International Center for Scholars, Smithsonian Institution, Washington, D.C., Nov. 1980. Rev. 1984.
This paper outlines the requisites for what we now call "high reliability organizations", and shows how the FAA's Air Traffic Control operations meets them. Comparisons are made to the U.S. nuclear power industry.

22. T.R. La Porte, "On the Design and Management of Nearly Error-Free Organizational Control Systems", in D. Sills, C. Wolf and V. Shelanski, eds., The Accident and **Three Mile Island: The Human Dimensions.** Westview Press, Boulder, CO., 1982
Part of the Social Science Research Council's response to the Three Mile Island Disaster, the paper discusses the requisites for what we then called "nearly error-free" management in the context of the nuclear fuel cycle.

23. T.R. La Porte, "Technology-As-Social-Organization: Implications for Policy Analysis," Working Paper 84-1, Studies in Public Organization, Institute of Governmental Studies, University of California, Berkeley, Jan. 1984.
This paper extends the conception of technology to

include various organizational properties necessary to express technologies in large scale form. Properties that prompt the demand for high levels of operational reliability are included.

24. T.R. La Porte and T. Lascher, "Cold Turkeys and Task Forces: Pursuing High (Electric Power) Reliability in California's Central Valley," July 1987.
This is a case study of a district in which above average outages had been experienced for several years, the reasons why this was the case, and the remarkable response of the utility when the problem was finally pin-pointed. The case highlights several properties of large networked technical systems.

25. T.R. La Porte, "The United States Air Traffic System: Increasing Reliability in the Midst of Rapid Growth," in T. Hughes, and R. Mayntz, eds., The Development of Large Technical Systems (New York: Martinus Vijhoff, 1988.)
This paper traces the evolution of U.S. Air Traffic Control from 1936-1980 and outlines a number of important properties of high reliability, large networked technical systems.

HIGH RELIABILITY ORGANIZATION PROJECT

University of California
Berkeley, California

Project Overview - February 1988

Faculty Group:

Geoffrey Gosling, Transportation Engineering
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Institute of Governmental Studies

The project began, summer,1984, within a small group of Berkeley faculty [* and Note 1] who were meeting regularly to discuss an organizational problem of increasing salience - the performance of a growing class of organizations in both the public and private sectors charged with tasks for which the societal and organizational costs of "errors" or "failures" are extremely high.[2] Few organizations perform such tasks well, yet our society increasingly demands that significant errors be avoided in organizations performing a host of critical tasks, e.g., toxic waste disposal or nuclear power plant operation.[**]

A series of workshops brought together senior operating officials from three "high reliabilty" organizations located nearby: the FAA's Oakland Enroute Air Traffic Control Center, PG&E's Electric Operations Division, the senior officers of the nuclear powered aircraft carrier, U.S.S. Carl Vinson. A strikingly similar set of problems - and solutions - emerged from these discussions. None of these organizations had been studied systematically. Each was quite interested in further study and opened itself to us. Fortuitously, we had had substantial experience with each one in earlier and somewhat unrelated projects. We eagerly took up the opportunity to study a small group of organizations whose performance not only meets, but exceeds criteria and expectations based on other experiences.[3]

Each of these organizations perform very complex and demanding tasks under considerable time pressure, and do so with a near-zero error rate and an almost total absence of catastrophic failure. Based on our work thus far, it is evident that they have a number of similar characteristics:

--Each organization has a strong, reasonably concrete sense of its primary missions, operational goals and the technical means necessary to accomplish them.

-- All operate quite powerful, knowledge intensive technologies with very few significant operational failures. These technical systems are well known; their mechanisms and processes can be nearly completely specified.

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** Regrettably, NASA's space shuttle launch management must be placed in the category of organizations that "failed" under the joint stress of demands for very high reliability and operational continuity.

--Their production units, e.g., power station, ATC center, or naval vessel, are quite complex and linked together into large operating networks, e.g., power grid, national system, or task force, that strongly effects levels of internal operating strains and the capacity to adjust to surprise.

-- They manage activities for which external or internal consequences of failure are perceived to be great. The rare operational failure gravely threatens the organization's capacity to operate, to deliver crucial services, and/or threatens the lives of its members or those of the community at large. As a result, "errors" such as near-misses between aircraft, partial blackouts, or damaged or diverted military aircraft are almost as difficult to tolerate as actual system failures, e.g., mid-air collisions, extensive system shut downs, or loss of aircraft or lives.

--There is a high degree of agreement in the society regarding the events, accidents or failures to be avoided (and within the organization on the indications of the on-set of such failures.)

-- Each organization has accepted the signal importance of reliable, safe operations as a major goal and there appears to be an ethic of personal responsibility for the safe operation of the whole. There is an operating "culture" that is strongly failure averse. Internal dynamics and structures are predominantly influenced by the requirement to avoid certain types of events, accidents or failures. However formal the organization, the informal operating structure shares responsibility for maintaining safety in a largely non-hirerachical way.

-- Despite the diversity of their tasks, operators in each system have similar working environments, share similar responsibilities, expectations, objectives, and goals, and show similar manifestations of the stress of their jobs.

-- In each case, it is the judgment, experience, and trained intuition of seasoned operators that is most responsible for maintaining systems reliability and safety. The historical learning process has been one of trial and error, but in an unusual sense. Open acknowledgement of and acceptance of responsiblity for past error is rewarded in the interest of prompting future improvement.

-- Organizational structures, authority relationships, and decision-making dynamics appear to have evolved in common patterns: there is clear separation of operating from system maintanence, substantial delegation of operating authority to subordinate units, and redundant information sources to inform decision-making.

-- Each of these organizations has seen its workload increase while its resources base has been in relative decline in recent years: air traffic has increased in a system still recovering from the controller's strike of a few years ago; utility grid management is becoming much more complex as large numbers of relatively small independent electricity producers come on line; naval aircraft have become faster, heavier, and more complex and deck load density has increased.

-- Due to increased relative demand, an additional level of sustained stress has been added to the amount of stress operators are expected to absorb in highly responsible time-urgent jobs, calling for maintaining absolute performance levels, in the face of increasing magnitude and complexity of the tasks.

-- Computers and other technical systems are used, often extensively, but primarily as sources of information and data -- inputs to human judgment. Recently, in the face of increasing demand, each organization has been pressed to turn to new computer technologies in the hope of increasing its operational capa-city without directly altering organizational size or structure.

-- Finally, the organizations, by virtue of their high reliability, have been nearly invisible to the public. The more failure-free their operation, the less opportunity for "outsiders" to learn about them. It appears likely that policy makers and interested consumer groups are systematically under-informed about the organizations' actual requirements and dynamics.

Two implications of this pattern of conditions follow: unexpected, subtle and unpredictable consequences are likely to result from the introduction of powerful and demanding new technical systems into organizations as large and complex as these; and criticisms and proposals for change are likely to underestimate or misunderstand their consequences for organizational operations.

The research group has undertaking observations in each of these organizations to answer questions about how they manage to attain such high levels of reliable performance while maintaining the capacity for sustained peak performance, and how they redesign themselves in the face of contingencies not considered by their original designers. It is already apparent that existing management and organizational theory must be modified, indeed extended, to address design, management, training and related issues. When these modifications are made and tested, they can be used to derive policies to help insure that, as an increasing numbers of complex systems are developed, they are not accompanied by a raise the likelihood of catastrophic error.

Each of these studies, briefly described below, has a different technical focus and unqiue set of operational and instrumental conditions. Each is directed to a specific set of immediate concerns identified by the particular organization. Our common objective is to gain a deeper understanding of the conditions and costs to the organizations and their personnel of those activities and stresses associated with maintaining such high levels of reliable performance. This is enabling us to identify a larger set of specific operational issues and alert us to the problems of at least maintaining or increasing the operational reliability of a variety of very complex systems.

Finally, an important aspect of this work has been a series of workshops involving senior operating officers from each organization. To date eight day-long meeting have been held, first, on site in each organization to brief the group on the reliability aspects of its operations, then to examine cross-cutting and comparative issues, e.g., the function and surprises in training activites, problems of formal and informal control system management during the onset of operational stress, and variations of working group cultures within high reliability organizations. Recent workshops have centered on provisional findings from our work thus far.

Below is a brief description of our work with each organization. (Modest support for this work has come from a number of sources indicated for each study area along with those of the team that assume initial responsibility. In June, we received a grant from the National Science Foundation to continue this work.)

1. U.S. Air Traffic Control. (La Porte and Gosling) [UCB, Institute of Transportation Studies]

Study of the evolution of ATC was begun in 1980, examining the technical, organizational and institutional conditions which had resulted in a stunning level of operational reliability. Intensive examination of technical and organizational changes were conducted through reviews of documents and extensive interviewing at FAA headquarters in Washington, D.C., and at Washington and later Oakland Air Route Traffic Control Centers. The PATCO strike so disrupted the FAA that the study was "put on hold" for nearly two years after the strike, and was resumed when the organization's equilibrium was regained. Subsequent work in Washington and at Oakland Center has been done to explore 1) the longer lasting effects of the strike, and 2) the potential for surprise and personnel difficulties that could accompany the introduction of the newest technical proposals for automation of air control functions.

In fall 1985, further study in Washington and in several ATC centers was begun (by La Porte) to further the work begun in 1980. Other work has proceeded independently (by Gosling) on aspects of the use of "artificial intelligence" for various ATC functions. Both Gosling and La Porte have familiarized themselves with the operation of European Air Traffic Control during visits to ERUOCONTROL facilities near Paris and Brussels, by La Porte in June, 1986, and both La Porte and Gosling in September 1987 with visits to EUROCONTROL facilities near Paris, Brussels, and the operational center at Maastricht, Netherlands. La Porte plans a two week visit to the FAA facilities in Washington, D.C., spring 1988.

Arrangements have been made to conduct on-site observations and interviewing at ATC enroute and terminal control facilities, especially in periods of operational stress.

2. The Electric Operations Department, Pacific Gas and Electric Company. (La Porte, Rochlin) [UC Energy Research Group; PG&E]

Studies began in 1981-82 as part of a study on the effects of dispersed energy supply on organizational change. To our surprise, we discovered that the management of the electical power distribution grid had many similarities to what we had found in the FAA. In 1984, we resumed systematic contacts with PG&E, with several briefings on their operations and periodic discussions of the challenges they face in the next decade.

In summer 1985, we continued charting the evolution of the grid management function and operating organizational structures, decision- making dynamics, the demands of increased conservation and load management efforts, and the changes associated with new automated information control technologies may have within PG&E as they continue to be the pivotal actor in the Western States power grid. This general phase included the beginning of systematic study of the past decade's development of the Electric Operations Department and an examination of routine and emergency switching decision-making and performance.

Two more detailed studies were initiated in winter, 1986: the first examined the organizational effects of managing the growing number of widely dispersed, independently owned electric power producers. The second studied the political dynamics arising from a series of persistant major outages in a large Central Valley community, and the utility's response to the difficult technical and operational problems involved is nearly completed. This paper will be submitted for publication soon. Workshops were devoted to each project.

Arrangements are being made; 1) to develop an organizational history of PG&E's leadership and operational involvement in establishing the California Power Pool, the association of utilities increasing tied together in power transfers that greatly improves regional performance, and 2) to conduct on-site observations of several switching centers, especially in periods of operational stress.

3. Nuclear Aircraft Carriers. (Roberts, La Porte, Rochlin) [UCB, Inst. of Govt. Studies, Sch. of Bus. Ad.; Office of Naval Research, U.S. Navy]

Over two years ago, initial acquaintance with these very complex, tightly-packed organizations was began at pier-side locally with U.S.S. Carl Vinson and continued at-sea during an intensive period of her deployment. After intensive briefings on the ship's operation, two of us boarded her for 17 days underway off Japan, December, 1984, to observe her management and technical teams. During flight operations at-sea, field data were collected from our observations and the results of interviews with her senior officers, about how various of her department are managed, how crucial decisions are made, and how her departments are interlinked to carry out the overall functions of a modern aircraft carrier. These data and subsequent at-sea experience provide foundation for understanding of the conditions which have resulting in the Carl Vinson's very good record, and the potential changes in operations that should or should not be seriously considered (including the mounting of additional computerized decision making aids.)

During Summer, 1985, in addition to continued study of Carl Vinson, we extended our work to include: a) a parallel study of U.S.S. Enterprise, the second nuclear carrier in Carrier Group Three (CARGRU 3); and b) the effects of a new computer based information system designed to aid decision-making in the command of CARGRU 3, with particular attention to the effects on staff planning and subsequent relationship to reliable carrier air operations, and the CARGRU coordination of the battle group underway. This presented the opportunity for a comparison of two carriers, in the same command, but with quite different histories - the Enterprise, a long established ship, first of her class and the much newer Vinson. We are observing the process each goes through during her readiness "workup," i.e., the evolution from early preperations to full readiness for deployment in the Pacific. There is also the opportunity to examine the interaction of new technologies with established operations on the performance of the ships

Research on Carl Vinson has been conducted periodically during the ship's "work-up" to a full state of readiness after undergoing overhaul and repair routinely carried out after each major deployment. The team boarded the ship for five at-sea periods, from mid-winter through mid-Sept.,1986. Data collected include observations of the ship's navigation, air and combat coordination operations, and survey data on organizational culture, and communication from both elements of the ship's Air, Operations and Engineering Departments and five squadrons and command staff of the Air Wing. The last at-sea period was at a time of "practiced readiness," just before starting battle patrol in the Indian Ocean, when operations are intense and involve tightly interdependent decision-making dynamics.

A similar study began with U.S.S. Enterprise in Februray, 1987, after she completed "overhaul and repair." The final field segment of three wecks of on-board observation was completed in Jan. Survey data was collected from five squadrons and several ship's departments. The team observed operating dynamics during four separate at-sea periods. In addition, several visit have been made to headquarters, Navy Air Force Pacific, San Diego, to gathering information on the quantity and character of shore based support to ship board high reliability activities.

NOTES

1. The three senor researchers have the following relevant research and experience. T.R. La Porte: research and advisory experience on issues of radioactive waste and nuclear power plant operation; studies of California electric power system, and the national and European air traffic control systems, and for a decade was sponsored by the U.S. Marine Corps as a user of air traffic control and, for a short time, aircraft carrier services. **Karlene Roberts**: research on communication and organization in the first Naval Squadron to receive the F-14 aircraft; advisory and legal experience on personnel matter in complex organization involving hazards to employees. **Gene Rochlin**: research on radioactive waste management and other aspects of nuclear technology and safety; nuclear, fossil fueled, and alternative energy systems, including distributional effects and grid management; other advanced technological systems including military technologies, nuclear weapons and control systems.

2. See, for example: Todd R. La Porte, "The Design and Management of Nearly Error-Free Organizational Control Systems," in D. Sills, C. Wolf, and V. Shelanski, eds. **The Accident at Three-Mile Island: Human Dimensions** (Boulder, CO.: Westview Press, 1982); --, "Managing Nuclear Wastes," **Society/Transactions**, July/August, 1984; "Nuclear Wastes: Increasing Scale and Sociopolitical Impacts,: **Science**, 191 (7 July 1978), 22-29. For a good description of the problems organizations face with low-probability, high consequence events, see. C. Ferrow, **Normal Accidents**, (New York: Basic Books, 1984.)

3. A striking example is air traffic control, where serious errors can threaten lives or completely disrupt commerical air traffic. See T.R. La Porte, "The Search for Nearly Error-Free Management: Lessons from Air Traffic Control for the Future of Nuclear Energy," for Colloquim Series, Woodrow Wilson International Center for Scholars, Smithsonian Institution, Nov. 1980.

High Reliaiblity Organization Papers

Listed below are the several papers and notres derived from this project thus far.

1. T. R. La Porte, "High Reliability Organization Project Summary," rev. 6; July, 1987

2. T. R. La Porte, "High Reliability Organizations: The Dimensions of the Research Challenge." March 1987

Papers Centrally on the Carrier work...

3. K. H. Roberts and D. M. Rousseau, "Research in Nearly Failure-Free, High Reliability Systems: 'Having the Bubble'," (submitted to Academy of Management Review)

4. G. I. Rochlin, T.R. LaPorte, K. H. Roberts, "The Self-Designing High Reliability Organization: Aircraft Carrier Flight Operations At Sea." Naval War College Review, Autumn 1988.

5. K. H. Roberts, "Bishop Rock Dead Ahead: The Grounding of the U.S.S. Enterprise," Jan. 1987 (forthcoming, Naval Institute Proceedings)

6. K. H. Roberts and S. Sloane, "An Evaluative History of U.S.S. Carl Vinson." March 1986.

Other papers drawning on the Navy work.

7. K. H. Roberts and S. Sloane, "An Aggregation Problem and Organizational Effectiveness," in B. Scheider and D. Schoornman, eds., Facilitating Work Effectiveness. Lexington Press, 1987.

8. K. H. Roberts and S. Sloane, "Decision-Making in Conditions of Complexity and Tight Coupling," Feb. 1986 (submitted to Management Science Review)

9. G. I. Rochlin, "'High Reliability' Organizations and Technical Change: Some Ethical Problems and Dilemmas," IEEE Technology and Society Magazine, Sept. 1986.

10. G. Rochlin, "Technology Specification and Operator 'Power' in Large Organizations: The Special Case of Naval Aircraft Carrier Flight Operations'", July 1986.

11. K. Weick, "The Role of Interpretation in High Reliability Systems." California Management Review, 1987

12. J. L. Eccles, Interdependence in a Highly Complex Organization, MBA Thesis, June 1986 (Study of on-board interactions between the Carrier Air Group and its host carrier.)

Papers dealing with High Reliability Organizations more generally.

13. T. R. La Porte and T. Lascher, "Cold Turkeys and Task Forces: Pursuing High (Electric Power) Reliability in California's Central Valley," July 1987.

14. T. R. La Porte, "Technology-As-Social-Organization: Implications for Policy Analysis," Working Paper 84-1, Studies in Public Organization, Institute of Governmental Studies, University of California, Berkeley, Jan. 1984.

15. T. R. La Porte, "On the Design and Management of Nearly Error-Free Organizational Control Systems", in D. Sills, C. Wolf and V. Shelanski, eds., **The Accident and Three Mile Island: The Human Dimensions.** Westview Press, Boulder, CO., 1982

16. T. R. La Porte, "The Search of Nearly Error-Free Management: Lessons from U.S. Air Traffic Control for the Future of Nuclear Energy," Collcquium Series, Woodrow Wilson International Center for Scholars, Smithsonian Institution, Washington, D.C., Nov. 1980. Rev. 1984.

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