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Institute for Manufacturing and Sustainment Technologies

A U.S. Navy Manufacturing Technology Center of Excellence

QUARTERLY

2001 No.1

Laser Center Director, Dr. Rich Martukanitz (left) discusses cladding processes with BGen William Catto. Mr. Bob Cook, director iMAST (third from left) and Mr. John Allison (far right), of the Marine Corps Warfighting Laboratory, look on.

FOCUS ON LASER PROCESSING

Vice Chief of Naval Research Visits iMAST

Brigadier General William Catto, USMC, Vice Chief of Naval Research (VCNR), recently visited iMAST as part of a capabilities overview relative to on-going project efforts within the Navy ManTech Center of Excellence program located at ARL Penn State.

Brigadier General Catto provides expertise in Marine Corps affairs to the Chief of Naval Research, RAdm Jay Cohen, USN. On 5 June 2000, Brigadier General Catto assumed his duties as VCNR, in addition to his responsibilities as Commanding General (CG) of the Marine Corps Warfighting Lab at Quantico, Virginia.

In his capacity as CG of the Warfighting Lab, General Catto is tasked by the Commandant of the Marine Corps to improve Naval expeditionary capabilities across the spectrum of conflict for current and future operating forces. To do this, the Warfighting Lab works closely with the Marine Corps' Warfighting Development and Integration Division, Training and Education Command, Marine Corps Systems Command, and Marine Corps Forces Atlantic and Pacific. Additionally, the lab conducts wargames and experimentations to evaluate new tactics, techniques and technologies. Results obtained from the various experimentation are forwarded to the Combat Development System with recommendations for action. The Warfighting Lab also conducts wargames and experimentation as directed by not only the Commandant of the Marine Corps, but also the Commanding General of the Marine Corps Combat Development Center.

Brigadier General Catto is a 1973 graduate of Bethel College. He holds a masters degree from Webster University. Commissioned a second lieutenant after completing Officer's Candidate School, he was designated a Naval Aviator in December of 1974 and served throughout the Fleet Marine Force as a CH-46 pilot as well as air and operations officer with the 7th Marine Regiment.

Following studies at the Marine Corps Command and Staff College, General Catto was assigned to Headquarters, U.S. Marine Corps, Washington, D.C., where he worked in the Manpower directorate as the Rotary Wing Major's Assignments Officer, and later as the Administrative Assistant to the Deputy Assistant Chief of Staff for Aviation.

Returning to the fleet, General Catto served as CO of Marine Medium Helicopter Squadron 163. Further assignments included a tour at the RAND Corp. in Santa Monica, California as a Marine Corps Fellow. In July 1995, he was ordered to duty in Washington, D.C. where he was assigned to the Office of the Secretary of Defense; Programs, Analysis, and Evaluations; Weapons Systems Cost Analysis Division. In this capacity he served as an operations and support cost analyst working on the Milestone Reviews of the C-17, F-22, V-22, and H-1 4BN/4BW remanufacture program. In May of 1998, Brigadier General Catto was assigned Commanding Officer of Marine Aviation Weapons and Tactics Squadron One at MCAS Yuma, Arizona.

General Catto served in this capacity until selection to the grade of Brigadier General and his subsequent current assignment.

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IN THIS QUARTERLY

DIRECTOR'S CORNER

Director's Intent

As planning for next fiscal year gets underway, please let me share a few thoughts with you that I've passed on to my project leaders. The system commands have been collecting issues for review and prioritization. Looking ahead, I project iMAST will be able to start two to three new projects in FY-02. This is in addition to several REPTECH projects. My goal is to have new starts each year in order to allow for some of the latest developments to be applied to requirements from the fleet. Teaming and close communication by the program office, system commands, and Centers of Excellence must take place in order to focus on the best solutions for the Navy and Marine Corps.

The Navy is facing an aging fleet of ships, vehicles and aircraft. Total ownership costs have been highlighted as a major decision factor in the acquisition of new systems or the upgrade of existing equipment. There are numerous opportunities to apply innovative processes to reduce the cost of acquiring, operating, and maintaining the fleet. Our responsibility is to inform the Navy of groundbreaking opportunities, and how they may be applied to an existing system.

Manufacturing Technology (ManTech) is the bridge between science and technology and acquisition. It is our goal to mature technology to the point where an acquisition program can accept the risk of a new process. Ideally, a project should be structured to achieve milestones throughout its life, allowing for a comprehensive review that allows for continued effort, redirection, or even cancellation. Communication with technical assistants is vital to ensure the project is on track towards meeting the fleet requirements. I recognize that fleet requirements may change, so projects must be flexible enough to redirect efforts to maximize the benefits.

Let me say something once again about implementation. Without it, there is no return on investment, which is the principal metric on which ManTech projects are graded. A project may meet its performance goals, but if it fails to transition to the fleet, we have failed in some form. While some benefits may be derived from a project that doesn't complete the transition, we need to have successes to ensure continued funding. We can improve our chances for success by frequently communicating with all the parties involved.

One of iMAST's ManTech successes has been LASCOR. This newsletter contains an article on the process. Platforms have been installed on two naval vessels, saving weight and improving stability. LASCOR can provide the necessary strength and rigidity with a low weight penalty. Other applications such as blast protectors, and sound dampening structures are possible, although not investigated. And last, but not least, aerospace applications abound. Our feature article addresses another potential application in the weight-conscious aerospace domain.

Bob Cook

PENNSTATE iMAST

MATERIALS PROCESSING TECHNOLOGIES | MECHANICAL DRIVE TRANSMISSION TECHNOLOGIES | LASER PROCESSING TECHNOLOGIES | ADVANCED COMPOSITES MATERIALS TECHNOLOGIES | NAVY/MARINE CORPS REPAIR TECHNOLOGIES

Focus on Laser Processing

Lightweight Laser-Welded Stiffened Structures

by Edward W. Reutzel and Kevin L. Koudela

The rotorcraft industry has a need for lightweight, stiffened flooring to support increasing payloads. The Applied Research Laboratory at The Pennsylvania State University has many years of experience in developing and producing stiffened structures (such as laser-welded corrugated core – LASCOR) that exhibit stiffness and strength comparable to conventional steel plate, but at a greatly reduced weight. Through structural modeling, the configurations and materials used in these structures can be customized to provide application-specific properties. Recent work has demonstrated the feasibility of LASCOR-like structures in shoring up the decking of the V-22 to support new vehicular payloads. Preliminary models and manufacturing concerns will be presented.

Introduction

The decking of the V-22 was designed with very specific loads in mind. As missions evolve, it will become important to support the increased payloads associated with new vehicles. The original proposed solution calls for the introduction of a reinforcing aluminum plate to shore up the decking by more evenly distributing the new vehicle loads. However, lighter weight, stiffer structures are also desired. With this is mind, sandwich structures were considered as an alternative decking solution.

Sandwich panels are commonly used in the world of composites for improved stiffness in lightweight structures. However, advances in laser welding in the past decade have led to the development of laser welded metallic sandwich panels as a low-cost, lightweight alternative to standard composite sandwich structures. A section of a laser-welded corrugated panel is shown in Figure 1.

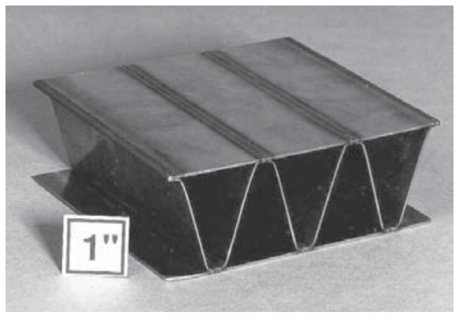

Figure 1. LASCOR panel.

Although manufacturability and applicability of LASCOR and other laser-welded sandwich panels in certain Naval applications have been demonstrated,[1,2,3] this technology has not been fully investigated for aerospace applications. The analyses and results presented herein demonstrate the feasibility of using laser-welded stiffened structure for aerospace applications.

Background

Lasers offer several benefits over conventional joining methods for producing this type of metallic sandwich structure. Conventional arc welding involves significant heat input, often leading to significant distortion and a large heat-affected zone (HAZ) with degraded material properties. Additionally, arc welding is not well suited to produce the stake welds required to join two thin sheets when processing from one side.

Processing with the laser permits high aspect ratio stake welds with precisely controlled, low heat input. Figure 2 shows a cross section of a CO_2 laser stake weld joining a face sheet to the corrugation. This unique ability to perform stake welds enables the laser to weld the face sheet to the corrugation for production of sandwich panels.

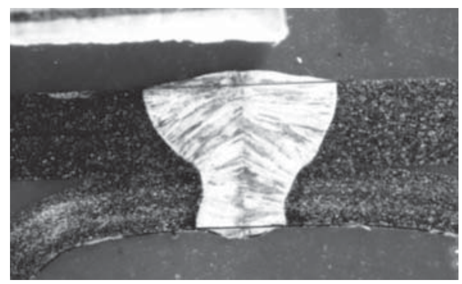

Figure 2. Cross section of a laser stake weld.

Several examples of successful implementations of this technology have emerged in recent years. Metallic sandwich panels fabricated in this manner have been installed on the antenna platform of the USS *Mt Whitney* (see Figure 3). Meyer Werft, a German shipbuilding company, is manufacturing

PROFILE

Ted Reutzel is an engineer in the Laser Processing Division at ARL Penn State. He has more than four years experience in welding modeling, sensing, and control, and three years experience in laser processing of a variety of materials. During his past three years at Penn State he has been involved primarily in technical management, sensing and control of laser processes, and laser-based coating removal technology.

Mr. Reutzel received a B.S. degree in mechanical engineering (with honors and high distinction) from The Pennsylvania State University. He holds an M.S. degree in mechanical engineering from the Georgia Institute of Technology. In addition to his full-time job responsibilities, Mr. Reutzel is engaged in coursework in pursuit of a Ph.D. in mechanical engineering at Penn State. Prior to joining ARL, Mr. Reutzel was employed with Lockheed Martin Idaho Technologies and GE Fanuc Automation. Mr. Reutzel can be reached at (814) 863-9891 or by e-mail at: <ewr101@psu.edu>.

a similar laser-welded sandwich structure.[2] A laser built by Prima Industrie SpA, in Turin, Italy, has recently been employed to produce a temperature controlled fermentation tank utilizing similar design concepts[4] (in this case, welding of corrugation onto a cylindrical vessel).

Figure 3. Antenna platform of the USS *Mt. Whitney* constructed using LASCOR panels.

Despite these successes, the technology has failed to find a foothold in the aerospace industry. The requirement to reinforce the floor of the V-22 to support loads larger than those specified in the original design may provide an excellent opportunity to demonstrate laser-welded sandwich structure as a stiff, lightweight, alternative construction.

Reinforcing Requirements and Assumptions

The following vehicle specifications were used to develop loading requirements for the V-22 decking:

Heavy Vehicle Specifications:

- 3863 kg (8,500 lbs)
- Two axles with a 60/40 weight distribution
- Tire contact area equal to 0.42 m^2 (65 in^2)
- Tire footprint size equal to 279 mm × 150 mm (11" × 5.9") (Assumed)
- Wheel base equal to 3.3 m (130")
- 4.5 G maximum flight maneuver with pitch accelerations
- Ultimate loading factor equal to 1.50

The maximum bending moment and shear force were calculated assuming that the sandwich panel is a simply supported beam with a 1.07 m (42") span (panel spans the critical gap between Station 463 and Station 505 of the V-22 decking). A graphical representation of the loaded panel is displayed in Figure 4.

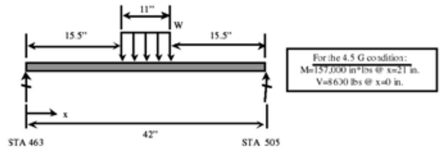

Figure 4. Loading specification.

The final geometric and weight goals for the V-22 decking:

- 6.1 m long × 0.46 m wide × 50 mm thick (20' × 1.5' × 2")
- < 136 kg (300 lbs.) total mass

The proposed solution is a solid aluminum plate. It was calculated that a 305 mm (12") wide solid aluminum plate of 276 MPa (40 ksi) yield strength will require a thickness of 36 mm (1.4") and a 6.1 m (20') length will weigh 180 kg (395 lbs.).

$$\sigma_y = \frac{My}{I} = \frac{M\left(\frac{t}{2}\right)}{\left(\frac{bt^3}{12}\right)} \Rightarrow t = \sqrt{\frac{6M}{\sigma_y b}} = \sqrt{\frac{6(157{,}000)}{40{,}000(12)}} = 36\text{mm } (1.40")$$

In order for new sandwich paneling to be considered a viable alternative to this option, it had to meet or exceed these specs.

Results

The results of the analysis are summarized below. The method of calculation, verification procedures and three possible configurations are discussed.

Method of Design and Analysis

The panels under consideration have a shape that can be defined with the parameters shown in Figure 5.

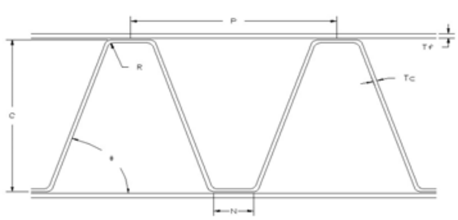

Figure 5. Schematic of a LASCOR panel.

Each of the parameters can be varied to change the shape of the sandwich panel corrugation. The moment of inertia and first moment of area can be calculated for various corrugation shapes and used in simple beam calculations to estimate panel strength. Hence, the parameters can be optimized to produce desired strength characteristics.

The maximum bending stress for a given panel design was determined by calculating the center of gravity, first moment of area and moment of inertia, and applying standard beam/span calculations. These methods were verified with real data, and then varied by hand to determine a suitable corrugation design. Computer optimization was not performed. The calculation of total weight was based solely on cross-sectional area, and does not include edge pieces or connection hardware.

It should be noted that the calculations performed in this preliminary investigation do not completely verify a given design, as they do not consider compressive and buckling instabilities, lateral bending and twisting, local changes in strength associated with the fusion and heat affected zones, and other non-linearities that would require evaluation in final design. Other researchers have documented the importance of buckling in failure, and have taken a more detailed analytical approach in its consideration.[2,3,5]

Verification

In order to verify the accuracy of the design methodology, calculations were compared to loading tests conducted on real LASCOR panels produced by ARL Penn State. The experimental set-up employed for testing is shown in Figure 6.

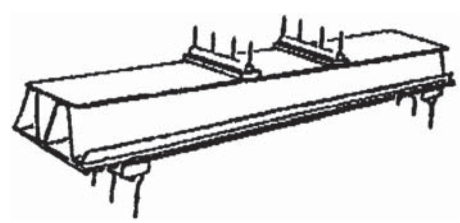

Figure 6. Schematic of load test.

The test was conducted on 34-inch beam span with a 229 mm (9") load span on LASCOR beam with specifications listed in Table 1 (note that design parameters correspond to Figure 5).

Material	316L SS
Corrugation Angle, θ	74°
Corrugation Height, C	51mm (2.0")
Landing Width, N	9.88mm (0.389")
Face Sheet Thickness, T_f	1.52mm (0.060")
Corrugation Thickness, T_c	0.97mm (0.038")
Bend Radius, R	1.37mm (0.054")
Pitch, P	50mm (1.98")

Table 1. Corrugation parameters used in maximum load verification.

The average maximum load obtained prior to yielding as measured over three load tests was 34.8 kN (7,840 lbf). The maximum load calculated using the aforementioned methodology was 37.1 kN (8,348 lbf). These results show less than 10% discrepancy between calculated and actual data, which is well within the standard range of acceptable results and indicates a viable preliminary design.

Possible Corrugation Configurations

Three possible configurations that meet the design specifications were determined using a manual parameter search. It is believed that each of these configurations is realizable from a manufacturing perspective. The specifications of the panels are listed in Table 2. Note that the calculated weight does not include edge pieces and connection hardware.

Material	Al	Al	316L
Corrugation Angle, θ	75°	75°	75°
Corrugation Height, C	43.2mm (1.7")	43.2mm (1.7")	12.7mm (1.3")
Landing Width, N	11.4mm (0.45")	15.2mm (0.60")	12.7mm (0.50")
Face Thickness, T_f	3.8mm (0.150")	3.8mm (0.150")	2.3mm (0.090")
Corrugation Thickness, T_c	3.2mm (0.125")	3.2mm (0.125")	2.3mm (0.090")
Pitch, P	49.3mm (1.94")	56.9mm (2.24")	45.5mm (1.79")
Total Panel Thickness	50.8mm (2.00")	50.8mm (2.00")	37.6mm (1.48")
Panel Width	305mm (12")	305mm (12")	305mm (12")
Max. Allowable Stress	275.8 MPa (40 ksi)	275.8 MPa (40 ksi)	586.1 MPa (85.0 ksi)
Calculated Max. Stress	275.6 MPa (40.0 ksi)	274.7 Mpa (39.8 ksi)	566.9 MPa (82.2 ksi)
Calculated Weight	70.9 kg (156 lb)	68.6 kg (151 lb)	128.2 kg (282 lb)

Table 2. Specifications of potential corrugation configurations.

It should be noted that these designs are conservative in that they incorporate a 1.5 factor of safety and they do not consider additional support provided by the existing composite flooring. Also, the designs would likely improve if a formalized optimization algorithm were applied to the problem during the parameter search.

Corrosion Considerations

The above designs call for either aluminum or stainless steel materials, both of which are strongly corrosion resistant. It is important to note that in certain stainless steel alloys, laser welding can sensitize the material, which will degrade its corrosion resistance. This is caused by chromium precipitating into complex chromium carbides in the grain boundaries. Low-carbon steels, such as 304L and 316L, and stabilized stainless steels, such as 321 and 347, tend to reduce the incidence of sensitization.[6]

Corrosion resistance is assured because the composite floor of the V-22 has a large electrical resistance, which will mitigate any potential galvanic corrosion. Although ARL Penn State has been successful in producing LASCOR from both aluminum and 316L stainless steel, aluminum is often more difficult to laser weld, due to its strong reflectance and high thermal conductivity.

Corrosion of laser welded sandwich panels has been investigated by other researchers. Their studies indicate that laser welding closes internal voids providing excellent corrosion protection, which can be augmented by filling the voids with an appropriate material.[2]

Estimate of Manufacturing Costs

Several assumptions must be made in calculating a reasonable cost estimate for production of laser-welded stiffened structures. In past work at ARL Penn State, the majority of corrugated panel has been produced with press brake forming or die stamping. These panels typically have ten corrugations. It is believed that costs can be cut by roll forming each corrugation (or sets of two to three corrugations) and laser welding them at the time of production. It is not proven whether proper fixturing will permit production welding of roll-formed corrugation. If proper fixturing permits successful welding of roll-formed corrugations, the following cost estimates may be considered reasonable.

Non-Recurring Costs

Non-Recurring costs would likely include tool and die costs for the new corrugation design shape. One roll-forming company in New York state reports non-recurring costs of $8–$15,000 and 8–12 weeks to manufacture a new die set and begin production. If existing dies meet design specifications, costs may be reduced.

Other non-recurring costs would include design and manufacture of the fixturing required for the laser welding process. To date, completely effective fixturing has not been realized. Effective fixturing is estimated to cost approximately $15,000. The fixturing would be designed to be reusable for a variety of corrugation sizes and specifications.

Recurring Costs

Recurring costs would include material and weld assist gas costs. The same roll forming company mentioned above estimated $5.25 per linear meter ($1.60 per linear foot) of 11-gauge 304L stainless steel for a 152 mm (6") wide corrugation (in quantities of greater than 365 linear meters (1,200')—enough to provide reinforcement for approximately 10 aircraft). Shielding gas cost would likely be negligible.

Labor and laser costs were estimated from prior work performed at ARL Penn State. LASCOR panels 1.2 m × 2.4 m × 76 mm (4' × 8' × 3") required 50 labor hours and 20 laser hours to produce. Based on this information, it is estimated that ARL Penn State could produce one panel of size 0.3 m × 6.1 m × 51 mm (1' × 20' × 2") every two days, and would require 6 hours of laser time per panel. A manufacturing facility geared toward production and with appropriate fixturing could likely increase this rate to 1–2 panels per day. Using a labor rate of $40/hr. and a laser rate of $75/hr., this would result in a combined labor and laser cost of approximately $275–$550 per panel. These estimates do not include material costs, edge pieces, connecting hardware, or non-recurring costs.

Recommendations

Several topics must be explored before laser-welded stiffened structures are chosen for this or other tasks. First, an optimization of design parameters must be performed to identify the optimum corrugation dimensional specifications. Second, the design must be subjected to a more rigorous design analysis, including buckling, twisting, and other nonlinear effects. Preliminary experiments should be performed to develop the processing parameters and to optimize the manufacturing technique. Fixturing for production and edge piece design should be investigated. For this application, surface treatments to produce a non-skid surface should be investigated. Finally, a more detailed cost estimate must be performed.

Conclusions

The preliminary simply supported beam calculations conducted in this program indicate that laser-welded stiffened structures may be a viable option for reinforcing decking on the V-22 to support new vehicular payloads. The limited manual design optimization has produced panel specifications that are calculated to provide strength comparable to a solid aluminum plate at significantly reduced weight. Corrosion has been considered, and is not believed to be of concern. Preliminary cost estimates have been presented.

Acknowledgments

The authors would like to thank Bill Rhoads, Jake Sames, Terri Marsico, and Paul Denney for laying the groundwork necessary for this work to be realized. We would also like to acknowledge support provided by the U.S. Navy Manufacturing Technology Program. The opinions, findings, conclusions, or recommendations expressed in this article, however, do not necessarily reflect the views of the U.S. Navy or Marine Corps.

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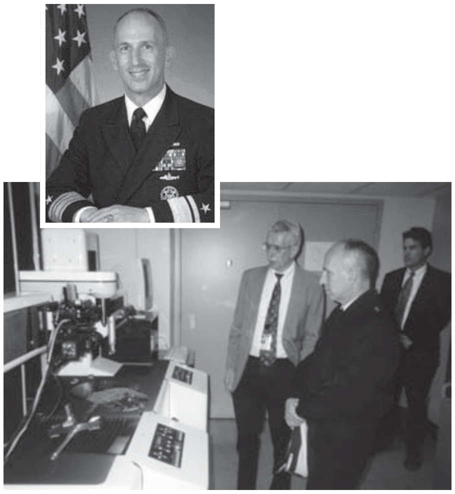
V-22 Osprey.

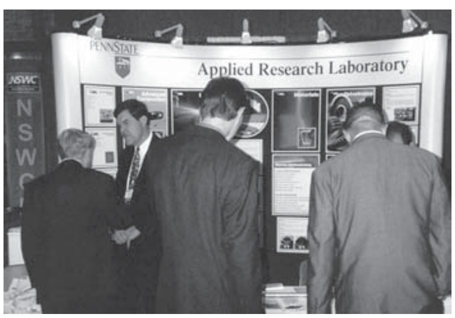


Dr. William Mark, senior scientist and head of the Drivetrain Technology Center's metrology and performance prediction division, briefs Admiral Fages on equipment that support ARL's Navy Metrology Laboratory facility.

N-77 Visits iMAST

Rear Admiral Malcolm I. Fages, Director, Submarine Warfare Division (N-77) recently visited iMAST as part of a capabilities overview of Penn State's Applied Research Laboratory. As director of N-77, Admiral Fages is the warfare requirements and resource sponsor for the Integrated Undersea Surveillance System as well as submarines. N-77 is organized under the Deputy Chief of Naval Operations (Warfare Requirements and Programs), which is located at the Pentagon. During tours throughout the laboratory, Admiral Fages was able to visit ARL's Navy Metrology Laboratory. ARL Penn State provides the Navy and the Marine Corps a neutral or "honest broker" testing site for verifying measurement accuracies related to gear specifications. This capability is fundamental and basic for the advancement of mechanical drive transmission manufacturing science and technology. The laboratory provides the Navy with an on-call 48-hour resident resource for addressing gear metrology technical issues related to naval weapon systems platforms. For more information, contact Dr. Mark at (814) 865-3922 or by e-mail at <wdm6@psu.edu>.

Tech Trends 2001



iMAST Director Bob Cook discusses project specifics with a visitor to ARL's display booth at Tech Trends 2001.

iMAST, as part of an ARL Penn State contingent, recently particpated in Tech Trends 2001. The Tech Trends conference series is a forum for interested parties within the Mid-Atlantic states who want to learn about federal research and development programs in such diverse areas as electronics and computers, medical and pharmaceutical research, aeronautics, space, national defense, security, energy and environmental technologies. The conference is intended to provide opportunities for researchers and executives to engage in dialog with representatives from government research and development agencies, as well as major R&D corporations. This year's theme "Profiting Through Technology Partnerships" was hosted in Atlantic City, New Jersey. Under the organizational leadership of NDIA, the congressional delegations of Pennsylvania, New Jersey, Delaware, and Maryland, as well as the New Jersey Commission on Science & Technology, presented two days of valuable conference agenda that included numerous breakout sessions. Dr. Ray Hettche, Director of Penn State's Applied Research Laboratory, and Dr. Tom Donnellan, ARL Associate Director for Materials and Manufacturing, served as panelists. Corporate co-sponsors included Boeing, Northrup Grumman, American Competitiveness Institute, SAIC, and Lockheed Martin. Keynote speakers featured Marine Corps Commandant, General James Jones, Daniel Goldin (Administrator, NASA) and Dr. Jane Alexander (Acting Director, DARPA). Next year's Tech Trends conference is scheduled to be held at the Baltimore Convention Center 3-4 April 2002. For more information about Tech Trends 2002 contact the NDIA at <www.ndia.org>.

NAVY MANTECH
manufacturing technology program

Leveraging Enhances ManTech's Impact

Did you know Navy ManTech is actively leveraging funding and related efforts from other federal and private sources? The objective is to assure ManTech only funds those things which are defense-essential and beyond the normal risk of industry. The DoC and DoD acquisition programs have committed millions of dollars for ManTech programs. In addition, the DoC and DoE, and NSF have also contributed significantly each year in related work in electromechanical design and manufacturing. Individual DoD laboratories and the National Laboratories also provide crucial feed technologies into the ManTech Program's technology base. Most ManTech efforts build directly on private sector products, practices, processes, and lessons-learned, and are the result of many years and many dollars of investment by private industry. ManTech is a force multiplier. Contact us to see how you can become a partner for success.

CALENDAR OF EVENTS

9–11 May	American Helicopter Society Forum 57	★★★★★ *visit the iMAST booth*	Washington, DC
15–17 May	NASTC 2001		Dayton, OH
23–24 May	Materials and Manufacturing Advisory Board Meeting		State College, PA
12–13 June	AeroMat 2001		Long Beach, CA
12–15 June	2001 Ship Production Symposium & Expo	★★★★★ *visit the iMAST booth*	Ypsilanti MI
18–29 June	Penn State–USMC Integrated Logistics Course		University Park, PA
20–24 Aug	Penn State Rotary Wing Technology Short Course		University Park, PA
TBA	Second Annual ONR Naval–Industry R&D Conference	★★★★★ *visit the iMAST booth*	Washington, DC
5–6 Sep	Shipbuilding Technologies 2001		Biloxi, MS
10–13 Sep	NDIA Joint Undersea Warfare Technology Conference		Groton, CT
18–20 Sep	Marine Corps League Expo	★★★★★ *visit the iMAST booth*	Quantico, VA
24–26 Sep	NDIA Combat Vehicles Conference		Panama City, FL
TBA	AUSA Expo		Washington, DC
29 Oct–1 Nov	5th Annual DoD Maintenance Symposium		Kansas City, MO
29 Oct–1 Nov	NDIA Expeditionary Warfare Conference		Panama City, FL
26–29 Nov	Defense Manufacturing Conference	★★★★★ *visit the iMAST booth*	Las Vegas, NV
3–4 April 2002	Tech Trends 2002		Baltimore, MD

Quotable

"The Department of Defense has been unable to procure advanced weapons systems that can lower the cost and increase the performance of the Armed Forces. The need to swiftly introduce new weapons systems is paramount."

—Donald Rumsfeld, Secretary of Defense

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