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iMAST

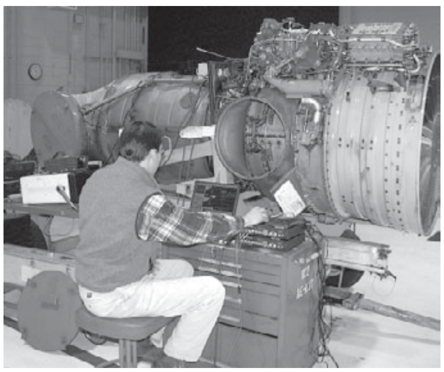
Institute for Manufacturing and Sustainment Technologies

A U.S. Navy Manufacturing Technology Center of Excellence

QUARTERLY

2001 No.3

Vibration Sensor Configuration Optimization for Marine Corps AV-8B Harrier Engine



ARL research engineer Jeff Banks analyzing data for the Pegasus engine.

Marine Corps AV-8B Harrier.

The Naval Air Systems Command recently identified an operational reliability challenge to the Institute for Manufacturing and Sustainment Technologies (iMAST), relative to the AV-8B Harrier. The iMAST program at Penn State University's Applied Research Laboratory was asked to address improved fault diagnostics and health management on its F402-RR-408A/B gas turbine engine via the Navy ManTech rapid response program.

An ineffective diagnosis of fault conditions can lead to decreased aircraft availability, unnecessary maintenance actions, and/or catastrophic loss of crew and aircraft. With this in mind, a collaborative effort was initiated between the NAVAIR program office, iMAST, and the Naval Aviation Depot at Marine Corps Air Station Cherry Point.

iMAST's Condition-Based Maintenance (CBM) expertise addressed condition monitoring issues through a Repair Technology (RepTech) rapid response (RR) project. The focus of this effort was to identify optimum vibration sensor positions, determine the number and type of sensors needed to monitor the engine, and provide signal processing and data analysis recommendations for effective engine health monitoring.

The proposed engine analysis effort defined the optimum sensor configuration for assessing the health condition of the Pegasus engine. Specific engine health monitoring aspects included shaft imbalance, shaft misalignment, and bearing condition. The ability to address these specific engine health concerns depended upon the availability of key data. The existence of shaft imbalance fault data coupled with the ability to gather engine test cell data facilitated iMAST's evaluation of the engine for shaft imbalance and misalignment. However, evaluating bearing fault detection methods for the engine was thought to be more difficult because of the lack of operational or seeded fault data. With the understanding that shaft imbalance and misalignment contribute directly to excessive bearing loading and wear, iMAST expected a large reduction in the number of bearing failure incidents as a result of having the capability to detect shaft imbalance and misalignment. Since this evaluation focuses primarily on shaft imbalance and misalignment issues, a more in-depth analysis is further recommended to address bearing condition monitoring for gas turbine engines. The immediate effort, however, was addressed as requested.

The sensor configuration optimization evaluation was conducted primarily by the use of spectrum analysis of the engine test cell data for the existing aircraft sensor positions and alternate sensor positions. The spectrum evaluation included HP and LP shaft narrowband analyses as well as 30–500 Hz broadband analyses. The alternative sensor positions were chosen by evaluating the engine

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Focus On Advanced Composites

Report Documentation Page

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IN THIS QUARTERLY

DIRECTOR'S CORNER

Paths to Implementation

This issue highlights two projects that were completed in a short period (months) for low levels of funding (less than $50K). These projects showcase the capabilities and flexibility of the Applied Research Laboratory, and demonstrate the benefit of the Navy's Center of Excellence approach. Within a short period of time, the problem was identified, researched, and addressed at a low cost. Only because ARL had the knowledge base and the experience with the technologies involved could a ready solution be achieved.

As this is being written, the fiscal year 2002 budget is being worked. Demands for funding are especially intense. As this situation is resolved, the impact will be promulgated as soon as possible. I appreciate the stress that this situation is causing and don't have a solution for it. I anticipate next year will be better.

No new starts have been identified for iMAST. However, I do believe funding will be available for new starts in FY03. Now is the time to start planning for those issues. I ask you to consider requirements that have strong program office needs and commitments—commitments such as cost share and a planned improvement to the system. As ManTech does not fund the certification often required to insert a technology into a weapon system, the program office must plan for this aspect, both in their budget and schedule. Careful coordination is necessary. Resources are too important to not be spent in the most efficient way possible.

In the coming months, James Mattern, our ManTech Coordinator, and I will be conducting an in-depth review of each project, both iMAST and RepTech. Participation by the Technical Assistant is a requirement. The goal will be to specify an implementation path and to finalize the project plan. I expect the review to last two to three hours. The better we identify the necessary steps to implementation, the better our chances of success!

Bob Cook

PENNSTATE iMAST

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MECHANICAL DRIVE TRANSMISSION TECHNOLOGIES

LASER PROCESSING TECHNOLOGIES

ADVANCED COMPOSITES MATERIALS TECHNOLOGIES

NAVY/MARINE CORPS REPAIR TECHNOLOGIES

MANUFACTURING SYSTEMS TECHNOLOGIES

Focus on Advanced Composites

Manufacture and Attachment of a Fragmentation Package for the Land Attack STANDARD Missile

by Kevin Koudela and Dan Metrey

The Land Attack STANDARD Missile (LASM) is one of the most reliable missiles in the U.S. Navy's inventory. A recent Navy ManTech rapid response effort was initiated through the iMAST's Advanced Composites Materials Technologies department at Penn State's Applied Research Laboratory. This task was initiated by the Missiles Warhead Branch at NSWC Dahlgren Division (NSWCDD). The effort was used to demonstrate a feasible manufacturing process to attach the fragmentation package to the outer surface of the warhead section shroud. A further objective of the program was to then demonstrate effectiveness of the fragmentation package via a Full-Scale Arena Test at NSWCDD. If successful, a new project would be initiated to further evaluate the fragmentation package for in-flight integrity and to help transition an optimized manufacture and attachment method to production.

Several manufacturing and technical issues had to be addressed within the effort. The fragmentation package had to be added to the shroud with as little weight increase as possible. The small fragments had to be securely attached. Furthermore, a negative interaction between larger fragments of the warhead shroud and the smaller fragmentation packages had to be avoided.

Introduction

LASM converts existing STANDARD Missile-2 Block II/III missiles by using a Global Positioning System/Inertial Navigation System (GPS/INS) guidance package and a modified Warhead Section. LASM's primary missions are (a) Naval Surface Fire Support (NSFS), (b) Self defense/Counterbattery and (c) Suppression of Enemy Air Defenses (SEAD). LASM's Secondary Mission is Interdiction.

The LASM Warhead Section consists of a MK 5 Fragmentation Shroud, a MK 125 Mod 2 Warhead, a MK 54 Safe and Arm Device, and a MK 73 Fuze Booster (Figure 1). The shroud is approximately 19 inches in length and is made of steel. The shroud is notched in a grid pattern to produced controlled fragmentation. The fragmentation package is attached to the shroud and consists of thousands of smaller fragments. The larger fragments produced by the shroud are mainly used to inflict damage to materiel targets while the smaller fragments from the fragmentation package are used to enhance the lethality against personnel targets.

Fragmentation Package Manufacture and Evaluation

Approach

The approach used to successfully develop and demonstrate a fragmentation package for the LASM is summarized below. The first step was to develop the fragmentation package processing

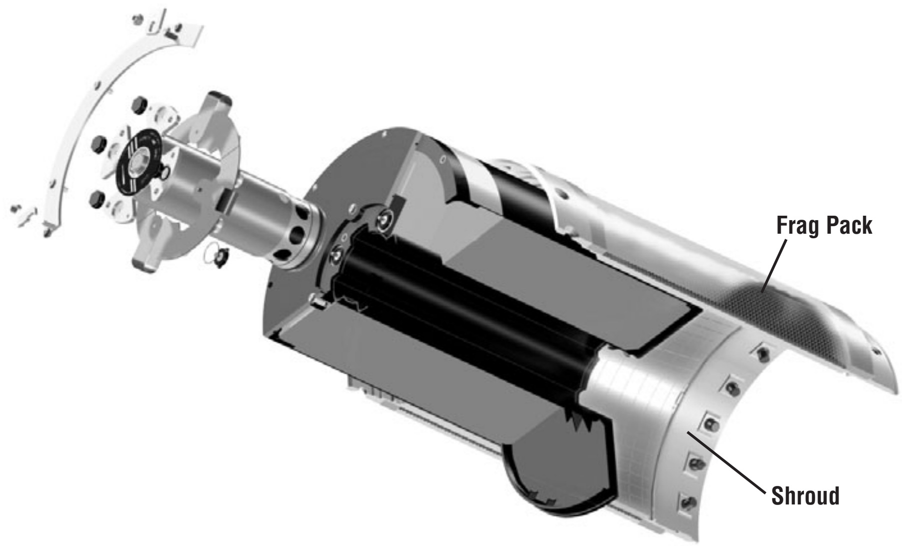


Figure 1. LASM Warhead Section

PROFILE

Kevin Koudela is head of the Advance Composites Materials Division at ARL Penn State. In his role as a Research Associate he conducts research in design, analysis, fabrication, and testing of fiber-reinforced composites. Dr. Koudela's area of expertise includes fracture mechanics, life prediction, structural and acoustics analysis, and mechanics of composite materials.

Prior to his arrival at Penn State, Dr. Koudela was employed by Loral Defense Systems (1984–1990) where he was responsible for performing explosive and penetration analyses using large scale finite element and finite difference algorithms, and also developing design and analysis algorithms for composite structures.

Dr. Koudela earned his B.S. and M.S. degrees from the University of Akron in mechanical engineering. He completed his Ph.D. in engineering science and mechanics at Penn State. You may reach Dr. Koudela at (814) 863-4351 or by e-mail at <klk121@psu.edu>.

technique. Candidate materials were identified to encapsulate the fragments. Fabrication trials were then conducted to optimize the encapsulation process. A Fragment Interaction Test at NSWCDD was performed to evaluate the interaction between the larger shroud fragments and the smaller fragmentation package fragments. Upon successful completion of the fabrication trials and Fragment Interaction testing, a full-scale fragmentation package fabrication and attachment methodology was demonstrated. The completed warhead shroud, with fragmentation package, was then evaluated via detonation in a Full-Scale Arena Test at NSWCDD. Details of each step of the fragmentation package development process are provided in the following sections.

Adhesive Foam Trials

Due to the warhead weight restrictions and fragment detonation velocity requirements, the small fragments in the fragmentation package had to be contained in a lightweight material. Low density foam adhesive was evaluated as a candidate encapsulation material. Because the LASM is in the air for relatively long flights, the foam adhesive must survive high temperatures. Therefore, a high-temperature foam adhesive was selected for encapsulation trials and a small trial mold was fabricated. The trials indicated that the sheets of foam adhesive, when applied over an ideally packed arrangement of fragments and heated (to both activate and cure the foam), would penetrate around the fragments without separating them out of plane and completely fill the mold (Figure 2). It was also determined that a film adhesive applied to the top layer of foam would yield a smooth outside finish for the part.

Fragment Interaction Test

After the trials had been successfully completed, a test was required to determine the interaction between the fragments produced by the shroud and the small fragments encapsulated in the foam. In late 2000, ARL Penn State fabricated an 8-inch square fragmentation mat (fragmat). The fragmat consists of a layer of steel cubes covered with smaller fragments encapsulated in the foam. This assembly was used to simulate the fragments from the shroud and from the fragmentation package. COMP B explosive was mounted to the fragmat and detonated at NSWCDD. Flash X-ray photographs were taken of the explosion. Various personnel protection devices [i.e. U.S. Personnel Armor System Ground Troops (PASGT) systems and Kevlar helmets] were positioned near the explosion to evaluate fragment penetration. The result indicated that no negative interaction was present as the selected small fragments survived the explosive launch and were capable of inflicting significant damage to the personnel protection devices (Figures 3 and 4).

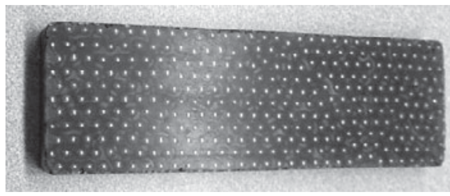


Figure 2. Encapsulation trial sample demonstrating complete encapsulation of fragments without separation.

Full-Scale Fragmentation Package Manufacture and Evaluation

120° Section Manufacture

The final deliverable for the rapid response project was to manufacture a full-scale fragmentation package mounted on an actual warhead shroud. The completed warhead shroud had to be delivered quickly to meet the tight evaluation window. To mitigate the risk of losing valuable time and limited materials by attempting to fabricate the fragmentation package on the shroud in a single operation, the fragmentation package was processed in three separate 120° sections and then secondarily bonded to the warhead shroud. Using this method, the shroud would completely satisfy the requirements for the proof of concept arena test and valuable information would be gained from the manufacturing process which could be used to optimize and improve the process in the future.

A mold was fabricated for the production of the 120° sections.

Figure 4. Results from Fragment Interaction Test demonstrating significant damage to personnel protection device.

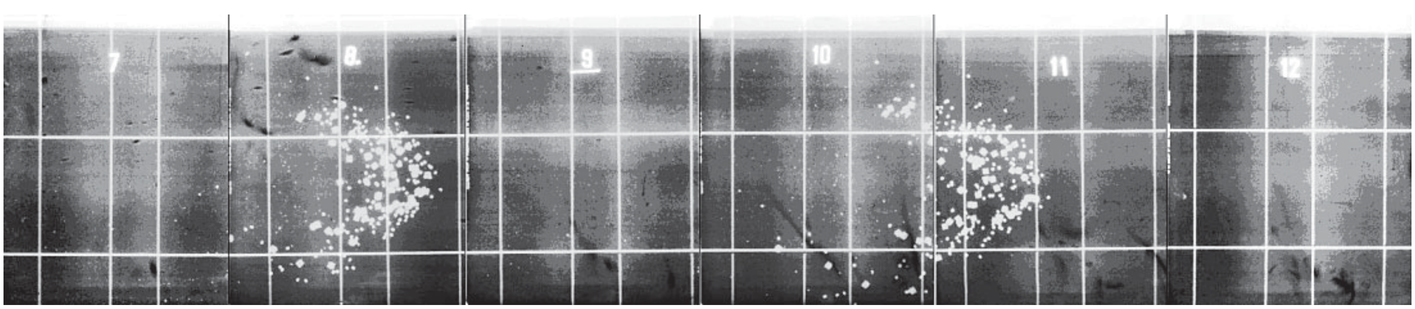


Figure 3. Flash X-ray from Fragment Interaction Test demonstrating no negative interaction between larger shroud fragments and the fragments of the fragmentation package.

Uncured film adhesive was placed on the bottom of the mold. The fragments were then stacked over the adhesive by hand in the ideally packed arrangement with the help of a fragment application tool. The tool allowed for the rapid pouring of the fragments into place. After a few rows of the fragments had been placed, the fragments and underlying adhesive would be heated and the fragments pressed into place. This procedure was repeated until the inner diameter of the section was completely filled with fragments (Figure 5a). After fragment placement was completed, sheets of foam adhesive were applied (Figure 5b). A final layer of film adhesive was used to cover the outside foam layer to obtain a smooth finish (Figure 5c). The top of the mold was bolted in place and the mold placed into an oven for foam activation and cure. The completed section (Figure 6) was removed and the procedure was repeated for each remaining section.

Section Attachment

An epoxy-based adhesive was applied to the shroud and all three sections were clamped into place. ARL Penn State's McClean Anderson W60 4-axis filament winding machine was used to wrap two

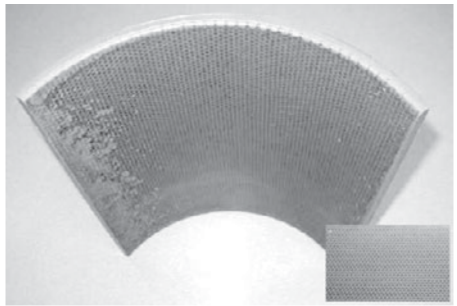


Figure 6. Completed 120° fragmentation package section, with close-up of encapsulated fragments (inset).

thin (~ 0.010 in.) glass epoxy layers over the sections. The epoxy-impregnated glass fiber was placed over the sections under significant tension to hold the sections in place as the clamps were removed. Upon completion of the filament winding, the completed shroud was placed in an oven under constant rotation to cure the filament wound composite layer.

Full-Scale Arena Test

The prototype shroud (Figure 7) was evaluated in a Full-Scale Arena Test at NSWCDD. The main objective of the test was to determine the performance of the fragmentation package. The fragments from the fragmentation package once again met or exceeded expectations (Figure 8). The fragments remained intact at launch and showed good penetration capability. More than 90% of the protected personnel targets (mannequins wearing U.S. PASGT systems) were penetrated by multiple fragments. In addition, the fragmentation package also caused significant damage to materiel targets.

Future Efforts

A continued effort, funded by NSWCDD, is currently underway at ARL Penn State. In this effort, ARL Penn State would address improved manufacturing techniques for attaching the fragmentation package to the warhead shroud. Complete (360°) fragmentation packages have been attached to warhead shrouds, negating the need for the production and attachment of three separate sections. Further streamlining of the manufacturing process is planned.

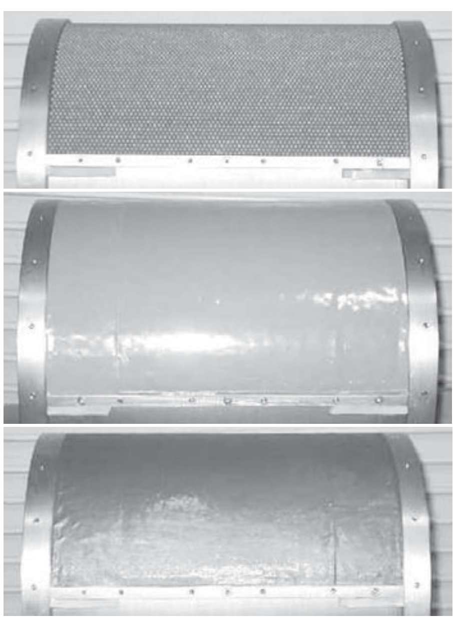


Figure 5. Fabrication of 120° fragmentation package section: (a) after fragment placement, (b) after foam sheet placement, and (c) after placement of top film adhesive layer.

Figure 7. Completed full-scale warhead shroud with attached fragmentation package (after final painting).

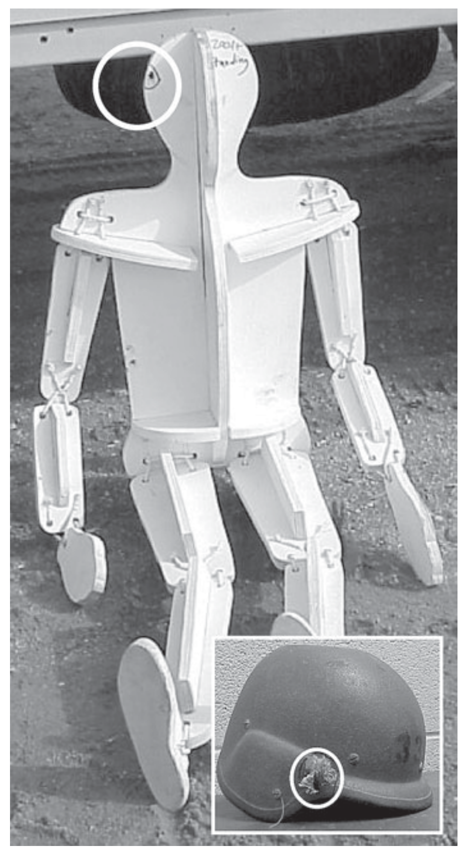


Figure 8. Results from Full Arena Test demonstrating damage to a standing personnel target, 200 feet from warhead detonation, by fragments from fragmentation package.

Figure 9. Results from Full Arena Test demonstrating high volume of fragment impact on armored target.

The manufacturing process will then be transitioned to a shroud manufacturer for production.

Acknowledgement

The authors wish to express appreciation for support of this effort by the Institute for Manufacturing and Sustainment Technologies (iMAST), a U.S. Navy Center of Excellence sponsored under contract by the U.S. Navy Manufacturing Technology Program, Office of Naval Research. Any opinions, findings, conclusions and recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the U.S. Navy. We would like to also acknowledge the support and guidance offered by the Missile Warheads Branch, NSWC Dahlgren, who provided materials, information, and other invaluable assistance. In particular, we would like to recognize Mr. Nguyen Nguyen for his technical support. From Penn State's Applied Research Laboratory, we would like to thank the following two colleages: Mr. Jim Sabo, who provided material application expertise, and Mr. Steve Struble, who designed and machined the fragmentation application tool which saved significant time in the manufacturing process.

For additional information on this project, the following contacts apply: ARL Penn State, Mr. Robert Cook, iMAST Director, (814) 863-3880; NSWCDD, Mr. Nguyen Nguyen (540) 653-2101 or Mr. Scott Such (540) 653-4363.

COVER STORY CONTINUED FROM PAGE 1

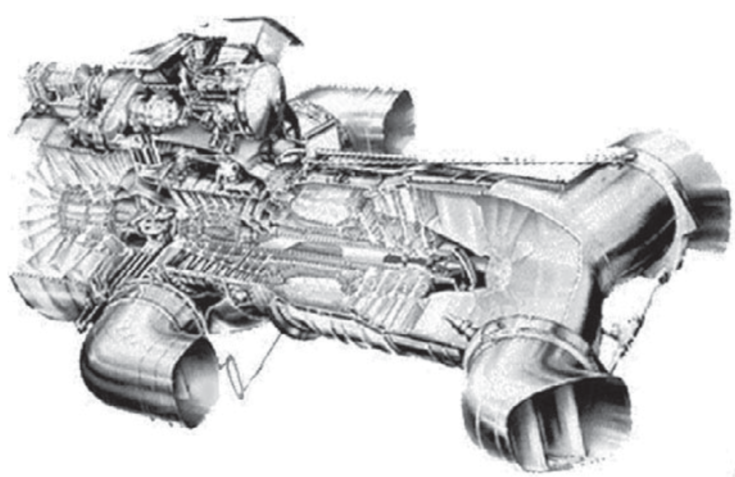
schematic drawings, analyzing the engine seeded fault test data, and performing static engine vibration transmissibility tests.

The project was successfully completed within the prescribed six-month period. Ms. Rebecca Ahne, an engineer within NAVAIR 4.4.2 (Propulsion & Power Fuel Systems, Controls, & Diagnostics) had the following comments to offer relative to the project effort: "ARL was able to gather data at the depot rework facility at Cherry Point from an available engine. From this data (and analytical data gathered from other engines), iMAST was able to provide recommendations for the ideal vibration monitoring configuration. They identified the minimum number of sensors needed to 'see' the engine's vibe characteristics and the best placement for these sensors (not only where on the engine, but also the orientation). iMAST endorsed one of the current monitoring positions, but recommended moving another one. They were able to recommend use of an accelerometer instead of the currently-employed velocity transducer."

"These recommendations were presented to representatives of the AV-8B Program Office, the Engine Monitoring System Lead Engineer, the F402 Engine Systems Engineer, and Rolls Royce. The report has been passed to Rolls Royce's F402 engineering group, where all of the recommendations will be implemented into a 'whole engine stress model' and analyzed. If that assessment is successful, the recommendations will then be used in full engine test and then expanded to fleet activities (potentially including the Royal Air Force and Royal Navy of the United Kingdom, the Italian Navy, and the Spanish Navy, in addition to our U.S. Marine Corps fleet—all of whom operate the AV-8 Harrier)."

"Bottom line: iMAST performed a great service by conducting the study very quickly and accurately. The information gained from the study is actively being used to revise and improve the AV-8B's engine vibration monitoring capability, which is critical to avoiding catastrophic engine failures. We consider the project a great success. Future postings on the Rolls Royce review and any future testing will be forwarded."

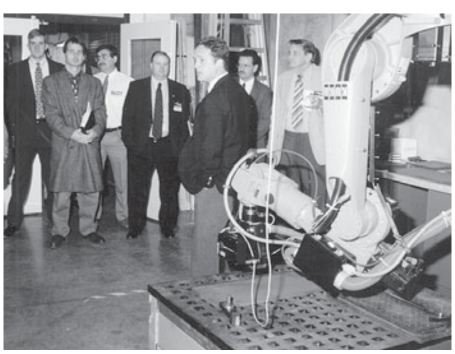
For more information about this project, contact iMAST's project leader, Jeff Banks at (814) 863-3859, or Robert Cook, iMAST Director, at (814) 863-3880. For questions pertaining to the Repair Technology Program, contact Sean Krieger at (814) 863-0896.



AV-8B F402-RR-408 Pegasus Engine

iMAST director, Bob Cook discusses center activities with Naval R&D Industry Conference exhibit booth visitor.

Dr. Ray Hettche, Director, ARL Penn State, discusses Navy ManTech projects with Congressman John Murtha at ARMTech 2001



Mr. Ted Reutzel discusses specifics of laser plate forming interaction which is about to be demonstrated using ARL's advanced Nd:YAG laser robotics system.

Second Annual Naval-Industry R&D Partnership Conference Concludes

iMAST recently participated in the second annual Office of Naval Research Navy-Industry Research and Development Partnership conference designed to promote dialogue between government, industry, academia, and the U.S. Navy. Established to leverage corporate research and development efforts for the Department of the Navy, a series of interactive breakout sessions provided forums to seriously discuss the challenges facing the defense industrial base. Held in Washington, D.C., a progressive agenda included discussion area topics such as: attracting commercial partners, creating incentives, enhancing technology insertion, and meeting Navy program managers and suppliers. Next year's conference will be held in Washington, D.C. again at a date to be announced.

iMAST Participates in ARMTech 2001

Members of iMAST recently participated in the annual Armstrong County Technology Showcase in Kittanning, Pa. Participation at these events is considered an important part of the Navy ManTech implementation process. As with any technology, the ability to transfer and implement depends on finding appropriate industry partners. Events like the Armstrong County (western Pennsylvania) Technology Showcase provide an opportunity for government, academia and industry to meet in order to identify and exchange new ideas for technological innovation. This, in turn, provides a vehicle which can enhance the production and performance of DoD-related products at an affordable cost to the U.S. taxpayer.

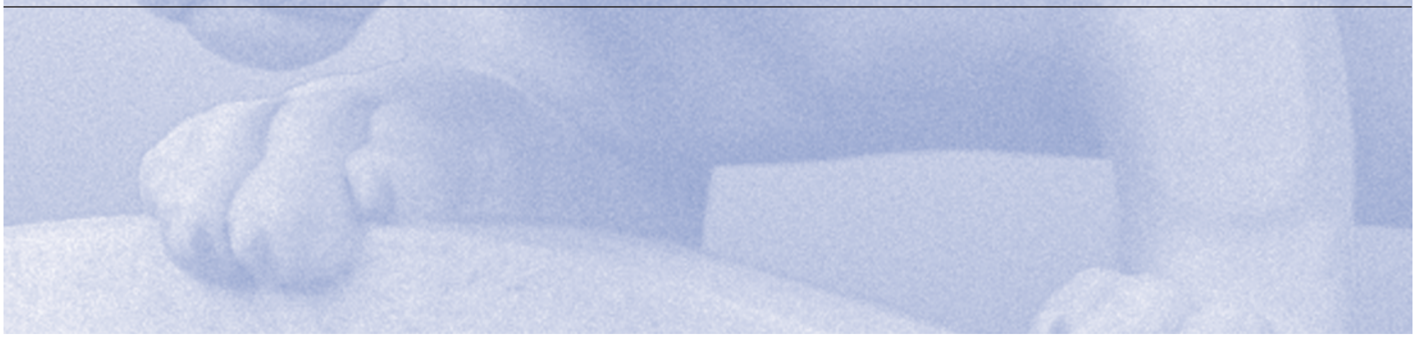
Laser-Assisted Ship Hull Plate Forming Demo Conducted

iMAST recently conducted a Navy ManTech mid-project demo to illustrate the success of the design concept for a production system using ARL Penn State/iMAST prototype hardware and software. The demo highlighted the integration of a robotic laser processing system, sensor, data acquisition hardware, and analysis software (Matlab). This integration was achieved using specially developed LabView interface and control software. Prior work at ARL Penn State has shown significant potential for the laser assisted forming (LASFORM) process, which uses laser radiation to form relatively complex plate shapes without the necessity of ancillary tooling. Using the LASFORM process to obtain controlled deformation of thick plates to form complex curvatures, required for ship hull fabrication, promises many benefits. These include improved worker safety as well as high manufacturing repeatability and accuracy, which will ultimately decrease downstream costs through improved fit-up.

Although laser-assisted forming has been investigated since the early 1980s, it has been slow to gain industry acceptance due to the difficulty in predictive path planning. Many factors contribute to the complexity of path planning, including the presence of unknown residual stresses and preferential grain orientations in the material. Computational complexity of the inverse solution of finite element analysis codes also presents further challenges. ARL Penn State has been on the vanguard for addressing these issues. For more information about this project effort, contact Mr. Ted Reutzel at (814) 863-9891 or by e-mail <ewr101@psu.edu>.

CALENDAR OF EVENTS

26–29 Nov.	Defense Manufacturing Conference 2001	★★★★★ *visit the iMAST booth*	Las Vegas, NV
11–12 Dec.	Materials and Manufacturing Advisory Board Meeting		State College, PA
26–28 Mar. 2002	Navy League Sea-Air-Space Expo		Washington, D.C.
3–4 April	Tech Trends 2002		Baltimore, MD
May TBA	Materials and Manufacturing Advisory Board meeting		State College, PA
May TBA	Johnstown Showcase for Commerce	★★★★★ *visit the iMAST booth*	Johnstown, PA
11–13 June	AHS Forum 58	★★★★★ *visit the iMAST booth*	Montreal, Canada
Aug TBA	3rd Annual ONR Naval-Industry R&D Conference	★★★★★ *visit the iMAST booth*	Washington, DC
17-19 Sept.	Marine Military Expo	★★★★★ *visit the iMAST booth*	Quantico, VA
Sept. TBA	NDIA Tracked Vehicle Conference		Ft. Knox, KY
Oct. TBA	AUSA Expo		Washington, DC
Oct .TBA	Materials and Manufacturing Advisory Board Meeting		State College, PA
Nov. TBA	NDIA Expeditionary Conference		Panama City, FL
Nov. TBA	DMC 2002 Defense Manufacturing Conference 2002	★★★★★ *visit the iMAST booth*	TBA



Quotable

"We owe the Sailors and Marines who may go into harm's way every edge technology can provide. Technology will never be a substitute for courage and human toughness in conflict, but it can increase the likelihood that the tough and the courageous will be successful."

—Admiral William A. Owen, USN
Vice Chairman, JCS

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