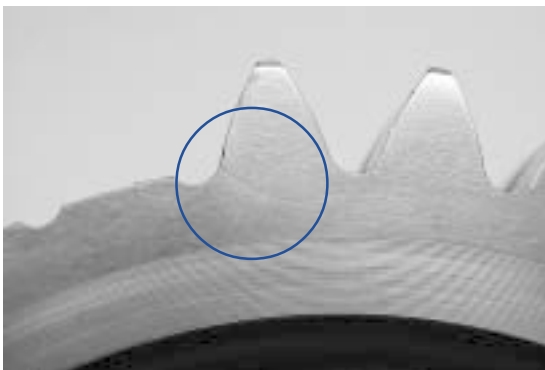




ARL Penn State 3.5-inch gear test rig.



ARL Penn State 4-square 6-inch test rig.



Example of gear-tooth material failure (crack propagation).

Rotorcraft Materials Coalition Program Update

ARL Penn State's rotorcraft materials coalition program continues to make progress in its effort to develop a comprehensive, precompetitive advanced-materials database for rotorcraft and turbine engine drive system components. The goal of the program, established by the Drivetrain Technology Center in late 1995, is to eliminate duplication of costly advanced materials research and development efforts conducted by individual industrial members within the rotorcraft industry. The program has successfully united members of the rotorcraft industry including ALLVAC (an Allegheny Teledyne Company), Arrow Gear Company, Bell Helicopter Textron, Boeing Mesa/Philadelphia, Boeing Precision Gear Incorporated, Carpenter Technology Corporation, Latrobe Steel Company, Rolls Royce Allison, Sikorsky Aircraft Corporation, and The Purdy Corporation.

During the past four years, heat treatment processing studies have been thoroughly conducted on selected steels to optimize initial processing steps and metallurgical features that reduce production time while maintaining repeatable processing reliability. Fatigue and scoring evaluations have also been conducted on high-precision test specimen gears. This includes single-tooth-bending fatigue testing, rotating-surface fatigue testing, and scoring-resistance testing. All test gears have been manufactured by the three sponsoring gear manufacturer coalition members (Boeing Precision Gear, Arrow Gear, and Purdy). ARL's Drivetrain Technology Center has conducted the testing on its state-of-the-art test rigs.

The following gear materials have been produced and supplied.

- Pyrowear 53 and 675 (Carpenter)
- CBS-600 (Latrobe)
- VASCO M+Ni, (ALLVAC)

The following single-tooth-bending fatigue test gears have been supplied.

- Pyrowear 53 (Purdy)
- VASCO M+Ni (Arrow)
- CBS-600 (Boeing Precision Gear)
- Pyrowear 675 (Boeing Precision Gear)

CONTINUED ON PAGE 7

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DIRECTOR'S CORNER

New Challenges

Our first newsletter of the millennium reflects an organization undergoing substantial change. Our previous director, Henry Watson, has retired from ARL to become the



director of the Clemson Institute for Advanced Materials and Manufacturing. We wish him well and will maintain a close relationship with him in his new position. A new iMAST director will be selected during the first half of calendar year 2000.

The research programs of the institute are continuing with increasing momentum. New initiatives in rhenium net shape fabrication, ultrashort-pulse (femtosecond) laser processing, and propulsor affordability have been established. In addition, Dr. Tim Eden is making excellent progress in development of a high-strength, high-temperature aluminum alternative to titanium for the Joint Strike Fighter engine stator vanes. Dr. Eden recently authored a feature article on this subject for *Industrial Heating* magazine.

In this issue, our feature article has been written by Mr. Al Lemanski who presents the pericyclic variable-speed rotor drive transmission (PVT). ARL and many of our industry partners view the PVT as the next-generation successor to current planetary and bull gear main transmissions. The emphasis of this newsletter, as you will note, is on technology advances in design and materials technology for rotorcraft drivetrains. These advances have the potential to substantially reduce cost while increasing reliability and power density in main drive transmissions. This effort has been and remains a major iMAST thrust dictated, by the cost and reliability drivers implicit in the flight-critical, highly stressed drive transmissions of advanced rotorcraft. The PVT technology thrust is augmented by work being conducted in the rotorcraft materials coalition program. The combination of advanced design concepts, materials, and materials processing options (becoming available through this work) will have a major positive impact on the affordability and reliability of future advanced rotorcraft. This work is addressing the unique requirements that our military platforms need to achieve in order to advance the state of the art.

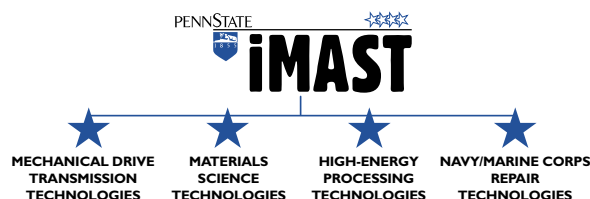
This has been a busy and challenging first calendar year quarter. Our staff has traveled to various functions and will continue to do so. Additionally, the handoff of iMAST responsibilities following Mr. Watson's retirement has been a smooth transition. The FY00 program has been developed and is now being executed with several new starts, as mentioned above. The new project planning process has been implemented for all ongoing and new FY01 iMAST projects. All told, it's been exciting.

If you have questions or comments regarding iMAST activities or the material presented in this newsletter, please contact me or any of my staff for further information. We welcome your feedback.

Paul Kurtz

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Focus on Mechanical Drive Transmission Technologies

The PVT Alternative

by Alphonse J. Lemanski

The need for an advanced, high-efficiency variable rotor speed main transmission system that features split-torque, split-path, reduced-parts, and



ARL Penn State PVT prototype.

pure rolling contact power transfer via kinematic/kinetic pericyclic technology is being addressed by the Applied Research Laboratory at Penn State. Current planetary and bull gear main transmission drives are fixed-ratio systems that preclude changing rotor speed. The basic architecture of planetary and bull gear main transmission drives tend to preclude achievement of a major increase in power-to-weight ratio and reduced cost due to the number of high-precision, high-cost, high-weight components and the accompanying reliability challenges they bring.

The pericyclic variable rotor speed drive transmission (PVT) has a higher probability to achieve the power density, reliability, and cost goals identified for the Joint Transport Rotorcraft (JTR) and other system upgrades.

The Department of Defense aviation science and technology road map and JTR technology road map define platform technology thrusts for air vehicle subsystems projected through FY 2012. The drive system technology

thrusts, for application to the JTR and to a number of system upgrades such as the AH-64 Apache, H-60 Sea/Blackhawks, CH-47D Chinook, OH-58D, RAH-66 Comanche, and V-22 Osprey, include the following:

Advanced Rotorcraft Transmission II (ART II) Program

- Integrate ART I components into subsystem demonstrations
 - Split torque
 - Split path
 - Single planetary
- Design, fabricate, and test subsystem modules.

Rotorcraft Drive System for the 21st Century (RDS-21) Program

- Integrate components into complete drive system of modules/subsystems.
- Demonstrate synergistic effects and benefits of:
 - Advanced lubes and lube system
 - Noise suppression
 - Lightweight flexible housing
 - Reduced stages and parts
 - High-load gears and bearings

The Army Aviation

Research Development Engineering Center rotorcraft drive technology road map (Figure 1 below) identifies additional project thrusts as follows:

- Ausform finishing of gears (ONR/ARL Penn State)
- Advanced gear steels (industry/Penn State)
- Ultrasafe gear design (NRTC/RITA, Boeing/Penn State)
- Case surface treatment gears (NRTC/RITA, Boeing/Penn State)

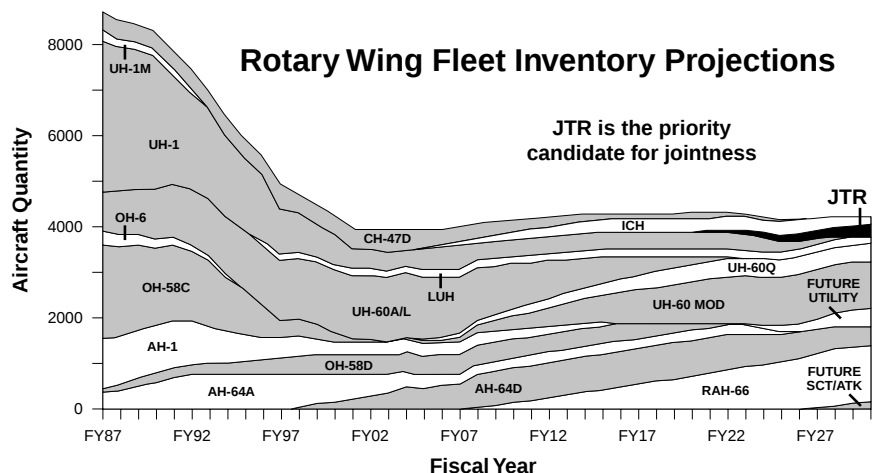


Figure 1. Rotorcraft drive technology roadmap.



PROFILE

Al Lemanski is a senior research engineer and associate director of the Drivetrain Technology Center at ARL Penn State. Mr. Lemanski received a B.S. degree in mechanical engineering from the University of Hartford and completed advanced management training at the Hartford Graduate Center. He established, and is the director of, the ARL Penn State Rotorcraft Materials Coalition, a precompetitive alliance of ten industries that include three rotorcraft, one turbine engine, three specialty steel, and three transmission/component manufacturing companies. The materials research and development work includes process optimization, test specimens manufacturing, quality evaluation, fatigue testing and scoring resistance evaluation, and materials characterization. Mr. Lemanski can be reached at (814) 863-4481 or by e-mail at: <ajl3@psu.edu>.

- Face gear development (DARPA/Boeing)

It is obvious from the preceding air vehicle drive system technology thrusts that a serious effort is intended—and needed—to develop advanced drive system technologies that will meet the requirement goals for reduced weight, reduced noise, improved reliability, and increased power density (power-to-weight ratio)—all within affordable cost target ranges.

Architecture

The basic architecture of current planetary and bull-gear-type main rotor transmission drives are fixed ratio systems that preclude their capability to facilitate air vehicle multi-role performance via customized rotor speeds. Also, the current conventional type gear drives tend to preclude achievement of major increases in power to weight ratio and reduced costs due to the typical large number of high-precision, high-cost, and low power-to-weight-ratio components with their attendant reliability issues and formidable cost and power density challenges. However, there is an alternative: the PVT.

Concept and Applications

The pericyclic variable rotor speed drive transmission architecture permits the incorporation of cost-effective advanced technology design features and very reliable and efficient hardware components that can maximize increased power density and low cost in



MV-22 Osprey in forward flight mode.

production. Due to its pericyclic-kinematic/kinetic features, many more components share the transmitted load under pure rolling contact than is possible by main rotor gear type drives. Therefore, it is believed that the PVT system architecture can be the most cost-effective and reliable technology for the Rotorcraft Drive System for the 21st Century Program and its application to the JTR and drive system upgrades for the V-22, AH-64, H-60, CH-47D, OH-58D, RAH-66, and SH-53s.

Features

The following unique advanced technology features constitute the PVT architecture:

1. Customized rotor speeds to facilitate multi-role air vehicle performance capability
2. Up to 50 percent (two quadrants) load sharing by the rolling element torque transfer members, thereby resulting in a major power-density increase not possible with gear-type main rotor transmission designs
3. Very-high-torque transmitting efficiency commensurate with high-precision rolling element bearings
4. Large speed reduction ratios in one stage (over 20:1) maintaining very high efficiency
5. Split-torque and split-path designs permitting a very low number of parts as compared to gear-type drive designs
6. Inherent dynamic component balance resulting in noise suppression and quiet operation
7. All pure rolling contact torque transfer members eliminating generation of transmission error (vibration/noise) inherent in gear teeth meshing during torque transfer
8. Extensive (several hours) oil-off operation possible with the use of robust tribological material for a number of rolling element torque transfer members to permit controlled film transfer to all mating load transfer surfaces
9. Permits the effective use of composite, hybrid, and tribological materials for

the dynamic components and housing support structure; and

10. Facilitates the use of embedded diagnostic sensors for condition-based diagnostics.



PVT rotor and stator.



PVT rotor and stator with pericyclic member.

Figure 2 (adjacent page) is a generic representation of a split torque/path variable speed PVT configured as a main rotor transmission for rotorcraft application. A typical set of spiral bevel gears (1) are shown as the input torque/RPM members to the PVT split torque/path pericyclic retaining ring assembly (2) that is journaled to the upper housing structure (3). The retaining ring assembly (2) embodies two opposing identical pericyclic units (4-5) that are journaled at a calculated design coning angle to permit conversion of input shaft rotation to pericyclic (oscillatory type) kinetic motion that facilitates customized variable rotor speeds for multi-role rotorcraft performance capability not possible with state-of-the-art fixed-ratio main rotor transmissions.

The pericyclic units are designed somewhat like rolling element

bearings. The design embodies an outer ring (6) and an inner ring (7) that support two sets of equally spaced and radially positioned rollers, journaled on radially positioned pin-like spoke members (8). The outer set of rollers (9) on the two pericyclic units (4-5) are designed to permit simultaneous and continuous rolling contact engagement with the face cam-like teeth of the output rotor member (11) while both pericyclic units are traversing a mathematically higher-order spherical path of action during

torque transfer to the output shaft (12). The inner set of rollers (10) on the two pericyclic units (4-5) are designed to permit simultaneous and continuous rolling contact engagement with the face cam-like teeth of the journaled reaction member (13) and the fixed reaction member (14) respectively. Permitting controlled rotation of the reaction member (13) via an actuator/controller will result in changing the effective angular relationship between the pericyclic lower unit assembly (4) and



U.S. Army RAH-66 Comanche.

the output rotor member (11). This relationship will result in a discrete output rotor shaft speed (and ratio) change under operating load.

Summary

The PVT is a promising alternative to gear-type main transmission systems. It holds great promise in providing advanced technology features to benefit twenty-first-century rotorcraft drive system upgrades as well as the future Joint Transport Rotorcraft (JTR). As previously mentioned, these upgrades and the JTR have all been identified on DoD technology road maps. Unique PVT basic architecture features such as its pericyclic kinematic/kinetic design will permit more load-transmitting components to simultaneously share the transmitted torque under pure rolling contact, thereby facilitating a major improvement in power density not previously possible with gear-type transmission systems. Additionally, the pericyclic design feature permits customized rotor speeds not possible or practical with gear-type transmission systems. The overall basic PVT architecture can permit extensive oil-off operation (several hours) using tribological film transfer among its pure rolling torque transfer members. Gear-type systems require auxiliary oil supply reservoirs resulting in a weight penalty and lower reliability.

The PVT is the first serious innovative, high-efficiency, variable-power transmission system to come along as an alternative to conventional gear-type transmission systems.

1. Spiral bevel gear members-input torque and speed
2. Split torque/path pericyclic retaining ring assembly
3. Upper transmission housing
4. Pericyclic lower unit assembly
5. Pericyclic upper unit assembly
6. Outer ring of pericyclic unit assembly
7. Inner ring of pericyclic unit assembly
8. Pericyclic unit assembly pins
9. Outer pericyclic unit rollers
10. Inner pericyclic unit rollers
11. Output rotor member
12. Output shaft
13. Journaled reaction member
14. Fixed reaction member

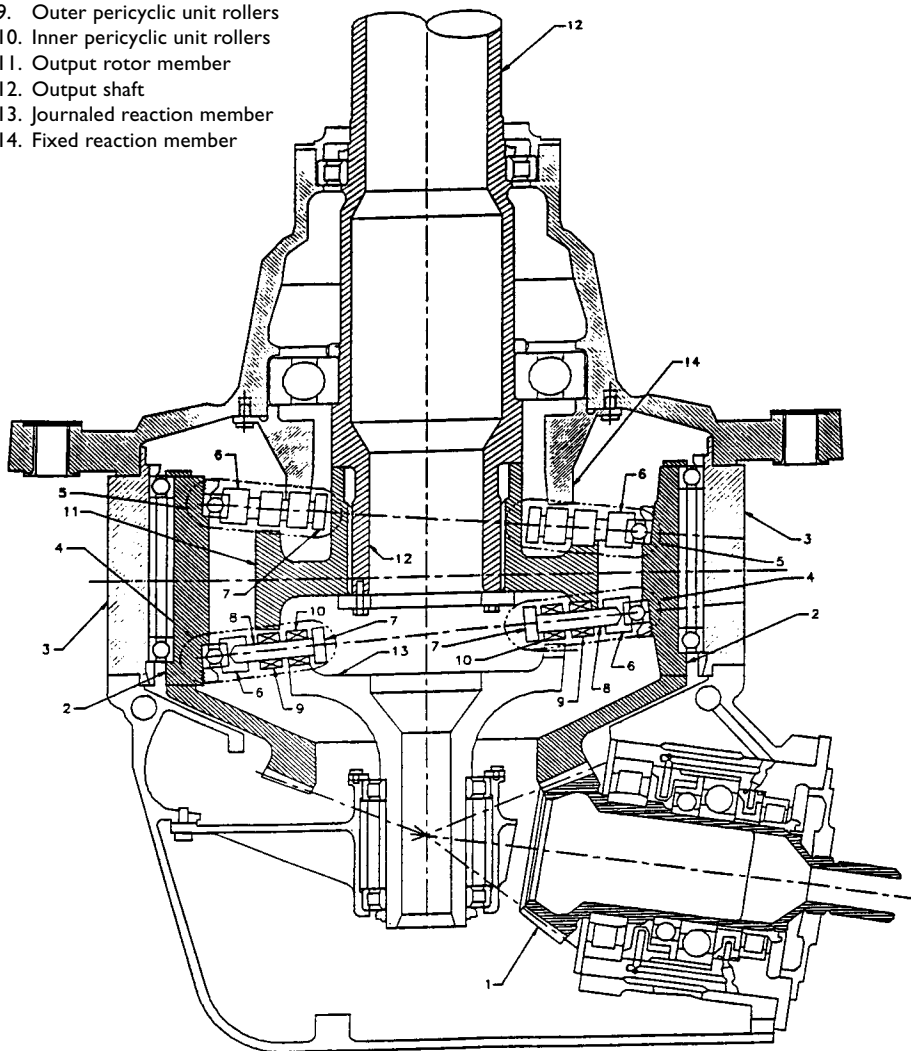


Figure 2. PVT configuration.



Former iMAST director Henry Watson discusses ManTech program efforts with exhibit visitor at DMC '99.



Mr. John Thomas (second from right) of The Gleason Corporation visits the Drivetrain Center's metrology laboratory.



iMAST Participates in DMC '99

Members of iMAST recently participated in the annual Defense Manufacturing Conference, held in Miami, Florida. Once again, leaders from government, industry, and academia assembled to exchange perspectives and information relative to manufacturing technology and industrial modernization. This year's theme, "Manufacturing into the New Millennium," set the forum for discussions concerning the future of defense manufacturing and sustainment for both military and commercial products. Next year's annual conference is scheduled to be held in Tampa, Florida, from 26-30 November 2000.

Gleason Visits DTC

The Gleason Corporation recently visited ARL's Drivetrain Technology Center to evaluate non-contact gear measurement efforts at ARL Penn State.

Gleason is one of the world's most comprehensive resources for gear manufacturing technology. It has broad expertise in all phases of gear production. For more than 130 years, the company's efforts have focused on serving the precision gear industry by optimizing both bevel and cylindrical (spur and helical) gear-making processes.

The product lines of The Gleason Works (Gleason-Pfauter, Gleason-Pfauter-Hurth Cutting Tools, and Gleason-Hurth) encompass the full spectrum of gear machining, finishing, and testing operations. This includes advanced CNC machines and tooling and software for cutting, grinding, lapping and inspection of bevel gears, and for hobbing (dry or wet), shaping, shaving, honing, grinding, chamfering/deburring, and inspection of cylindrical gears.

For more information on the Drivetrain Center's noncontact gear measurement effort, contact Dr. Karl Reichard at (814) 863-7681 or by e-mail at <kmr5@psu.edu>.

New iMAST REPTECH Program Manager

Mr. Sean Krieger has recently taken over the helm of the Repair Technology (REPTech) Program effort at Penn State's Applied Research Laboratory. Mr. Krieger previously served in the Program Executive Office for the Virginia Class Submarine Program logistics office at the Naval Sea Systems Command. Prior Department of the Navy assignments include service as fleet representative on the Maintenance and Logistics staff for the Commander, Submarine Force Pacific Fleet (COMSUBPAC) and a 10-year assignment at the Naval Undersea Warfare Center Division Maintenance & Repair Depot at Keyport, Washington.

A native of Seabeck, Washington, Mr. Krieger holds a B.S. degree in Industrial Engineering from California Polytechnic University, and an M.S. degree in management engineering from the University of Massachusetts. Mr. Krieger can be reached at (814) 863-8096, or by e-mail at: <slk22@psu.edu>.



Eden Featured in Industrial Heating Magazine

Tim Eden, Ph.D., a research associate at ARL Penn State, recently had a feature article published in the January issue of *Industrial Heating*, the international journal of thermal technology. Dr. Eden's article discusses aluminum alloys produced by the process of spray metal forming. Dr. Eden is head of the Materials Science Division's Metals and Ceramics Processing department. He can be reached at (814) 865-5880 or by e-mail at: <tje1@psu.edu>.



Research assistant Ken Meinert discusses new robotic laser capabilities with Captain Violette.



Commander NUWCD Keyport Visits iMAST

Captain Thomas Violette, USN, the commander of the Naval Undersea Warfare Center Division at Keyport, Washington recently visited ARL to receive a capabilities briefing on the Navy ManTech Program effort at ARL Penn State. iMAST has been working with the Weapons Department at Keyport to develop hardware specifications, laser repair, and laser paint-stripping procedures for the repair of aluminum torpedo shells and other internal components.

New Navy Program Manager

Mr. James Mattern has been designated as iMAST's new program manager for the Navy ManTech Program effort ongoing at ARL Penn State. Mr. Mattern succeeds Mr. Ted Hicks, who served as program manager until his recent assignment change.

Mr. Mattern will provide financial and programmatic oversight to iMAST, as directed by the Office of Naval Research. A summa cum laude graduate in mechanical engineering from the University of Maryland, Mr. Mattern has extensive engineering experience in both surface ship and aviation systems platforms. Additionally, he is well trained and versed in manufacturing and production processes, engineering economics, program and project management, government contracting, software analysis and design, design of experiments, statistics, and artificial intelligence. Prior to his current assignment, Mr. Mattern was assigned to the Naval Sea Systems Command. We are pleased to have Mr. Mattern as part of the ARL Penn State-Navy ManTech team.



FY-99 iMAST Annual Report Available On-Line

The fiscal year 1999 iMAST annual report is now available on the iMAST Web site. You can reach our site at: < www.arl.psu.edu/areas/imast/imast.html >. The Web site document can be downloaded and printed via a .pdf file. A limited number of hard copies are also still available (on a first-call, first-served basis) by contacting the iMAST administrator at (814) 865-8207.

COVER STORY CONTINUED FROM PAGE 1

The following rotating surface fatigue test gears have been supplied or are in process:

- Pyrowear 53 (Purdy)
- VASCO M+Ni (Arrow)
- CBS-600 (Boeing Precision Gear)
- Pyrowear 675 (Boeing Precision Gear)

Single-tooth-bending fatigue tests conducted, to date, by the Drivetrain Center:

- Pyrowear 53 (baseline)- 31 tests
- CBS-600- 24 tests
- VASCO M+Ni- 25 tests
- Pyrowear 675-process optimization ongoing

Rotating surface fatigue tests conducted, to date, by DTC:

- Pyrowear 53 (baseline)- 19 tests (conducted initially by NASA)
- CBS-600- test gears in manufacturing process
- VASCO M+Ni- testing in progress
- Pyrowear 675- process optimization ongoing

Data obtained from the noted testing will be entered into a comprehensive database for use by coalition designers to determine the material that is most effective for specific applications. Results will be available only to the sponsors. Future work will entail testing the materials noted above, as well as new materials, at elevated temperatures. For more information on the coalition, contact Mr. Al Lemanski at (814) 863-4481 or by e-mail at: <ajl3@psu.edu>.



ARL Penn State single-tooth-bending fatigue test rig.

CALENDAR OF EVENTS

13–16 Mar	NDIA Logistics Conference & Exhibit	Kansas City, MO
27–30 Mar	U.S. Army Ground Vehicle Survivability Symposium	Monterey, CA
4–5 Apr	M ² AB Advisory Meeting	State College, PA
18–20 Apr	Navy League Expo	Washington, D.C.
25–26 Apr	Spring ARLAB	State College, PA
2–4 May	American Helicopter Society Forum 56 ★★★★★ <i>visit the iMAST booth</i>	Virginia Beach, VA
9–11 May	National Aerospace Systems and Technology Conference ★★★★★ <i>visit the iMAST booth</i>	St. Louis, MO
9–11 May	NDIA Science and Engineering Technology Conference	John Hopkins APL, MD
15–18 May	Aging Aircraft 2000	Dayton, OH
16–18 May	SAE Aerospace Manufacturing Technology Conference	Fort Worth, TX
17–19 May	JDMTP Sustainment Working Group	State College, PA
23–26 May	NCMS Technical Conference and Expo	Orlando, FL
22–25 Aug	2000 Ship Production Symposium	Williamsburg, VA
19–21 Sep	Modern Day Marine Expo ★★★★★ <i>visit the iMAST booth</i>	Quantico, VA
16–18 Oct	AUSA Expo	Washington, D.C.
29 Oct–1 Nov	AHS Powered Lift Conference	Arlington, VA
30 Oct–2 Nov	4th Annual NDIA DoD Maintenance Conference	Columbia, SC
26–30 Nov	Defense Manufacturing Conference 2000 ★★★★★ <i>visit the iMAST booth</i>	Tampa, FL
28–30 Jan 2001	NDIA Tactical Wheeled Vehicles Conference	Monterey, CA
3–5 Apr	AW&ST Maintenance, Overhaul and Repair Conference	Dallas, TX

Quotable

“In the final analysis, government and industry must work together to do what is best for U.S. national security. Neither can afford to adhere to the management styles of the past. Rather, we must work together in the same spirit that served our nation throughout the long, tumultuous 20th century. The global economic realities of the new century demand nothing less.”

— John Hamre, Deputy Secretary of Defense.

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