CRAY CHANNELS

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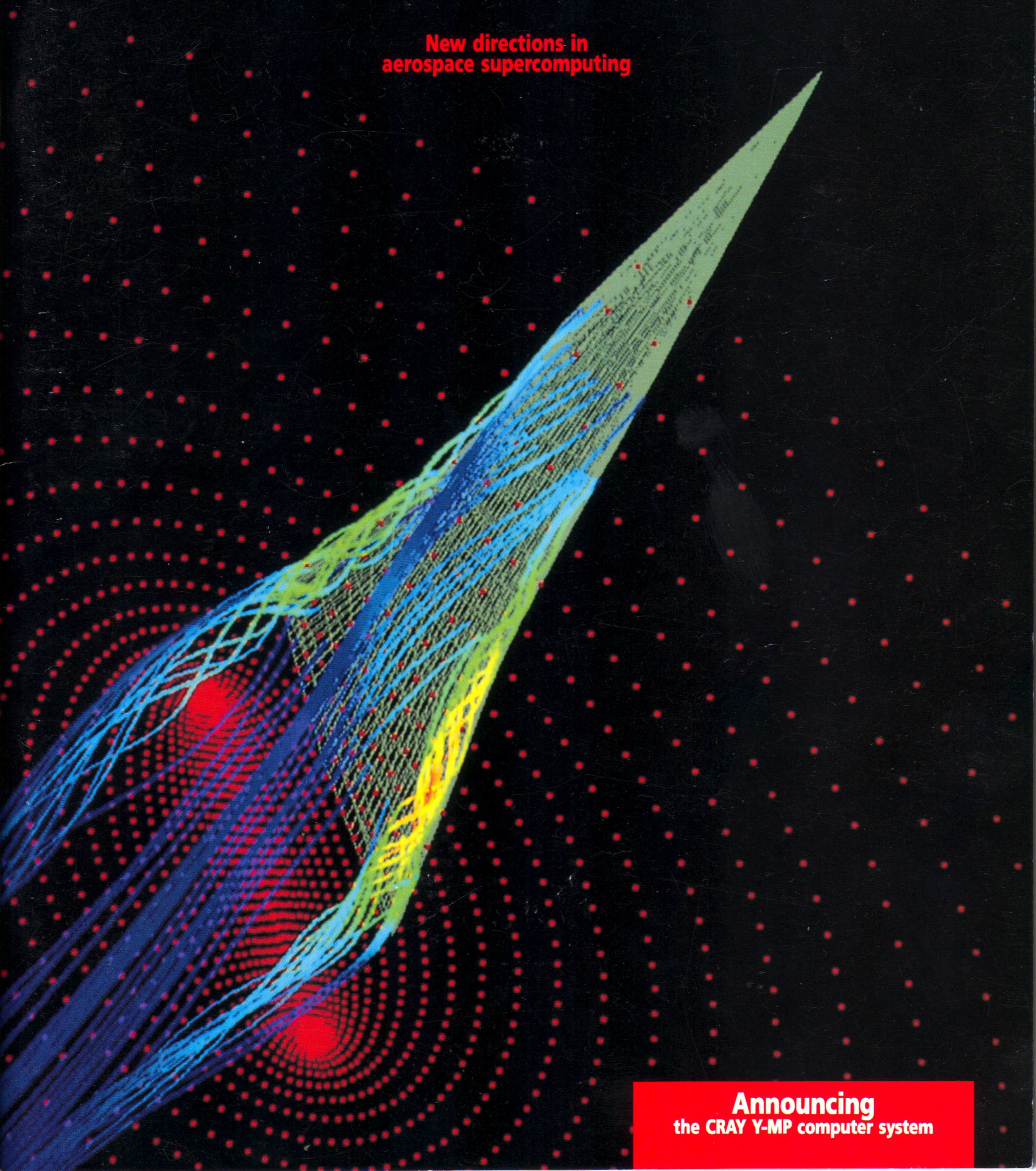
New directions in aerospace supercomputing



Announcing
the CRAY Y-MP computer system

CRAY CHANNELS

In this issue

Since the first Cray computer landed on the aerospace scene in 1980, aerospace design has soared into new frontiers. Eight years later, supercomputers are standard tools of the trade for computational fluid dynamics (CFD) and structural analysis, allowing designers to create more complex and accurate aerospace models. Today, designers are applying Cray power to other disciplines of aerospace engineering such as electronic current analysis, electromagnetics, signal and image processing, and hydraulic systems analysis. To improve and refine designs, engineers are exploiting computational power by linking numerical optimization codes to analysis codes.

This issue of CRAY CHANNELS presents a variety of traditional and emerging aerospace technologies. NASA Marshall Space Flight Center engineers address efforts to redesign the Space Shuttle propulsion elements. We also look at rotorcraft CFD applications and approaches for solving complex structural optimization problems. Besides illustrating an array of aerospace applications, we introduce the CRAY Y-MP computer system, the most powerful supercomputer to date. Our regular departments feature five Cray Research software releases and application software for aerospace design. Also included are some unique user success stories, such as modeling bone formation and analyzing characteristics of the stock market with Cray systems.

Clearly, the power of supercomputers is vital to the aerospace community. This issue of CRAY CHANNELS presents both a sampling of our user experiences and the perspectives of Cray Research staff people who are dedicated to the aerospace industry. It provides insight not only for the aerospace industry, but for many engineering disciplines in the larger supercomputing community. Finally, in this issue we inaugurate a new design, the first major graphics change in years. We hope you enjoy our new look.

Features

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Departments

CRAY CHANNELS is a quarterly publication of Cray Research, Inc. intended for users of Cray computer systems and others interested in the company and its products. Please mail subscription requests, feature story ideas, and news items to CRAY CHANNELS at Cray Research, Inc., 608 Second Avenue South, Minneapolis, MN 55402.

Volume 10, Number 1

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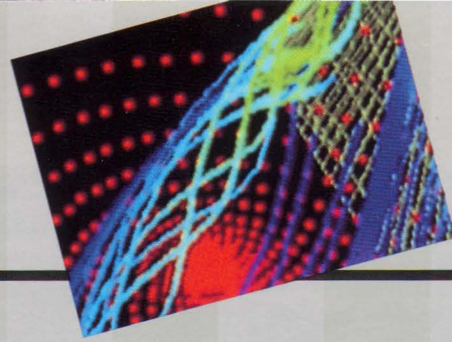
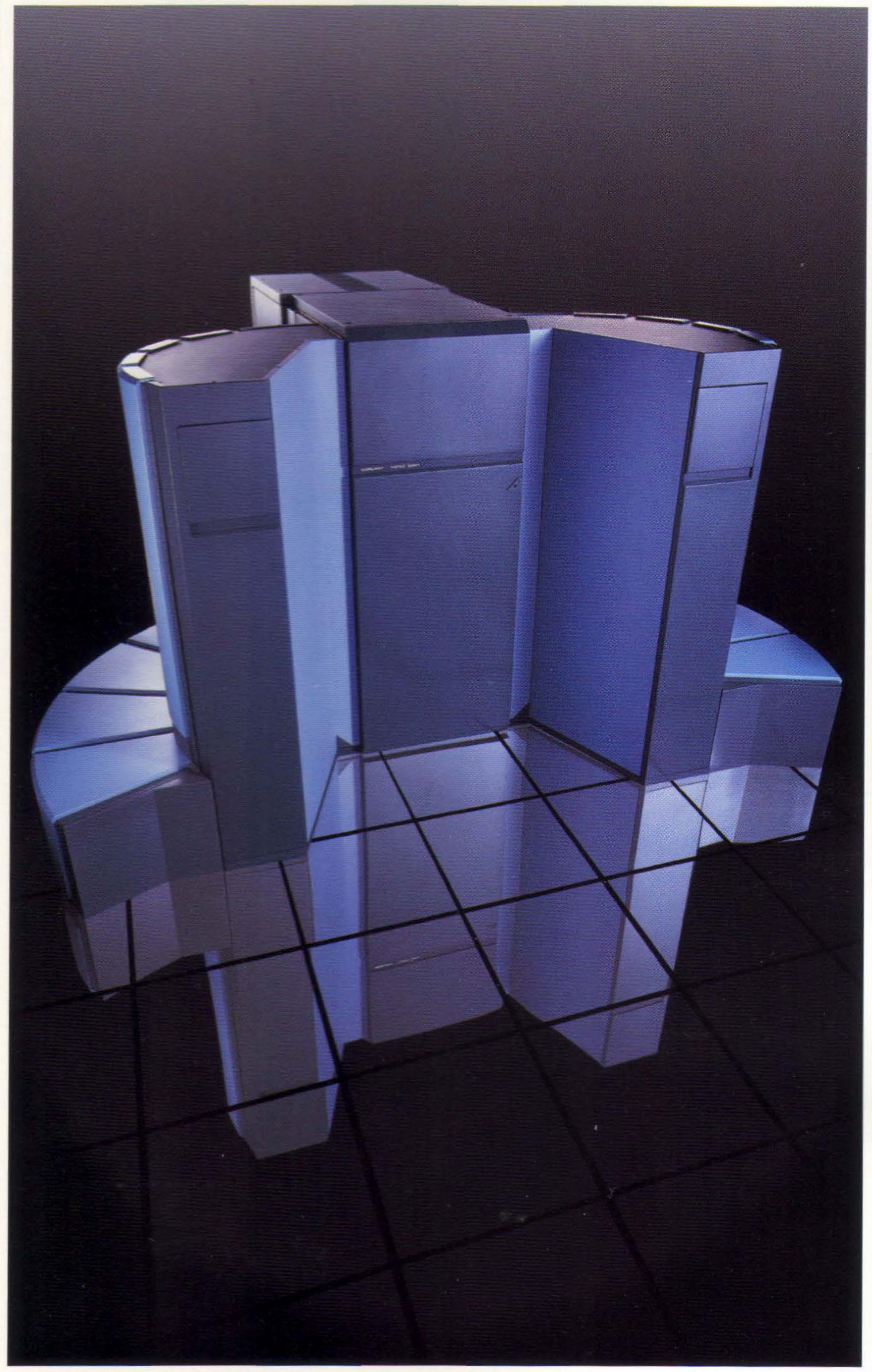
On the cover is a model for the National Aerospaceplane. The image shows spatial particle traces calculated over the plane's surface for a flight speed of Mach 0.8 and an angle of attack of 8°. The Euler solution was calculated in 1000 CPU seconds using the BOD57 program on a CRAY X-MP/416 computer system. The model geometry was provided by McDonnell Aircraft Company.



Introducing the CRAY Y-MP computer system



The CRAY Y-MP computer system is the most powerful general-purpose computer system available, encompassing the latest in computer design and technology innovation from Cray Research. The CRAY Y-MP/832 system dramatically extends the CRAY X-MP series of computer systems to new levels of throughput with twice the number of central processing units (CPUs) and twice the memory as in the largest CRAY X-MP system. The CRAY Y-MP system also accommodates all UNICOS and Fortran software developed for CRAY X-MP systems, thereby protecting user software investments.

The CRAY Y-MP/832 computer system offers 32 million words of fast ECL central memory. This large memory contributes to the system's unprecedented performance. The CRAY Y-MP/832 computer system comes standard with a 128-million-word SSD solid-state storage device, and can be configured with a single Input/Output Subsystem (IOS), which comes standard, or with two IOS units for expanded I/O capacity. A larger SSD with 256 or 512 million words of storage is optional.

The CRAY Y-MP computer system continues the tradition of balanced performance established by the CRAY X-MP series of computer systems. It retains all of the important features of the CRAY X-MP series, including gather/scatter and compressed index vector instructions, flexible hardware chaining, and dedicated registers for interprocessor communication and control. But the CRAY Y-MP system surpasses the capabilities of the CRAY X-MP series with greater power than ever before through technology and design breakthroughs.

System highlights

Hardware

- Eight central processing units
- 32 million words of directly addressable central memory
- 128-million-word SSD standard
- 6-nsec clock cycle
- Powerful I/O with optional second IOS
- CRAY X-MP compatible instruction capability

Software

- UNICOS or COS operating system; the UNICOS system is based on the AT&T UNIX System V operating system, with enhancements for large-scale scientific computing environments
- COS operating system with the UNICOS system as a guest operating system
- Compatability with CRAY X-MP and CRAY-2 UNICOS software products
- Vectorizing Fortran, C, and ISO Level 1 Pascal compilers
- Software for versatile network connectivity
- Optimized Fortran mathematical and I/O subroutine libraries
- Optimized scientific subroutine libraries
- The Cray macro assembler, CAL2
- A rich assortment of public domain and third party applications software

Each CPU in the system consists of a single module. Two of the system's 2500-macrocell array logic chips contain the processing power of an entire module in a CRAY-1/S system.

Hardware

Seen from above, the CRAY Y-MP system is Y-shaped, with the mainframe forming the middle stem, and the IOS and SSD each forming one shorter arm of the Y. The mainframe houses the CPU and memory modules, power supplies, power distribution units, and coolant hoses, and occupies 19.2 square feet (1.78 square meters) of floor space. The IOS and SSD each comprise four vertical columns arranged in a 90° arc and occupy 15 square feet (1.4 square meters) of floor space. An optional second IOS can be placed up to 9.5 feet (2.9 meters) from the mainframe cabinet.

A single module in the CRAY Y-MP system contains a complete central processing unit, along with logic for memory conflict resolution, I/O channels, and semaphore registers. Users can assign each of the CRAY Y-MP/832 system's eight CPUs to a separate job, or harness any number of CPUs to operate concurrently on the same job. This multitasking option can reduce dramatically the time needed to solve the largest, most complex problems, opening new avenues of research and discovery to engineers and scientists.

Each of the 32 memory modules in the CRAY Y-MP system contains one million 64-bit words of bipolar, random-access memory. Central memory is arranged in 256 banks to minimize memory contention. The memory features single-bit error correction/double-bit error detection (SECDED) logic. The interleaved multiport design, coupled with the short memory cycle time, provides high-performance memory organization with sufficient bandwidth to support high-speed parallel CPU and I/O operations. Each CRAY Y-MP CPU has four parallel memory ports connected to central memory: two for vector and scalar fetches, one for result store, and one for independent bidirectional I/O operations. The memory also features built-in conflict resolution hardware to minimize delays and maintain the integrity of simultaneous memory bank conflicts.

The input/output capabilities of the standard IOS complement the CRAY Y-MP CPUs and enable fast and efficient data access and processing. One IOS comes standard with CRAY Y-MP systems, and a second can be connected to accommodate greater I/O needs. The CRAY Y-MP/832 system allows users up to 48 disk streams — more than that allowed by any other Cray Research product. The architecture of the IOS, with its parallel data paths and direct access to main memory, results in a very high I/O bandwidth with a minimum of interference to computation. The IOS is an integral part of the CRAY Y-MP design and acts as a data distribution point for the mainframe.

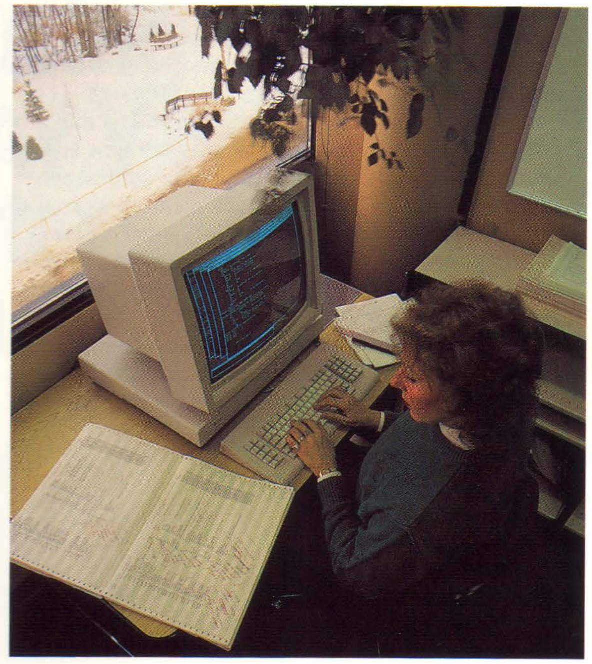
The I/O processors in each IOS have access to buffer memory, a solid-state secondary storage space. The CRAY Y-MP/832 system comes with a four-million-word (32-million-byte) dynamic MOS buffer memory; an additional four million words may be added. Buffer memory provides extremely efficient transfers of data to and from peripheral devices. It also can be used to store user data sets, thus contributing to faster and more efficient data access by the CPUs.

Additional data storage capacity is provided by the Cray SSD solid-state storage device, a fast random-access device suitable for use with CRAY Y-MP computer systems. System performance is significantly enhanced by the SSD's exceptionally high transfer rates and short data access times. Transfer rates of 100 to 1000 Mbytes/sec per channel and access times of under 25 microseconds can be achieved between an SSD and a CRAY Y-MP system. The 128-million-word SSD that comes standard with the CRAY Y-MP/832 system also can be connected to a Cray IOS. This connection enables data to be transferred directly between the SSD and IOS without passing through central memory.

"The CRAY Y-MP system incorporates architectural features and technologies that put it in a class by itself," says Les Davis, Cray Research's executive vice president, development and manufacturing. "For example, two of the 2500-macrocell array chips used for the system's logic contain the processing power of an entire module in a CRAY-1/S system. This logic technology contributes to the system's reliability by reducing the number of modules, solder units, and interconnect wires needed. This system is an outstanding, reliable performer."

Disk support

Disk storage capacity for the CRAY Y-MP system is provided by the DS-40 disk subsystem, Cray Research's latest and largest capacity disk subsystem. The DS-40 disk subsystem includes four DD-40 disk storage units. The 5200-Mbyte (5.2 Gbyte) capacity of each DD-40 disk storage unit is more than four times the capacity of Cray Research's previous disk units. The high storage capacity is enhanced by "hardware striping," a technique that spreads user data across four disk spindles in the DS-40 disk subsystem. The DS-40 disk subsystem provides a sustained transfer rate of 9.6 Mbytes/sec at the user job level and a maximum burst rate of 20 Mbytes/sec. A fully configured CRAY Y-MP/832 system, with two model D I/O Subsystems, will support up to 12 DS-40 disk subsystems, providing a maximum disk storage capacity of 249.6 Gbytes. Also available for use with CRAY Y-MP systems is Cray Research's DD-49 disk drive, which offers a storage capacity of 1.2 Gbytes and a sustained transfer rate of 9.6 Mbytes/sec at the user job level.



The CRAY Y-MP/832 system comes with a complete package of system software, including the UNICOS operating system, two vectorizing Fortran compilers, library routines, and utilities.

Software

CRAY Y-MP system software includes the proprietary Cray operating system UNICOS, as well as two vectorizing Fortran compilers and an extensive set of Fortran, multitasking, and scientific library routines and program- and file-management utilities.

Cray Research's CFT77 Fortran compiler complies fully with ANSI standard 3.9-1978 (Fortran 77). Features under development for CFT77 include the ability to automatically recognize and partition parallel constructs. Cray Research plans to include this automatic partitioning feature by the time the first CRAY Y-MP system is shipped to a customer site, scheduled for the third quarter of 1988.

Features under development for CFT77 include the ability to automatically recognize and partition parallel constructs.

Cray Research also offers scalar optimizing and vectorizing C and ISO level 1 Pascal compilers, the Cray CAL assembler, and parallel-processing tools featuring source code maintenance, debugging, editing, dynamic and static analysis, and conversion aids. In addition, hundreds of application programs are available for CRAY Y-MP systems to solve problems in aerospace and automotive engineering, chemical and physical research, petroleum exploration and recovery, electronic design, and other areas of scientific research and engineering.

The CRAY Y-MP system accommodates all UNICOS and Fortran software developed for CRAY X-MP computer systems, thereby protecting user software investments. Cray Research's COS operating system also is available, allowing COS programs developed for use on CRAY X-MP systems to use up to four processors and 16 million words of memory on a CRAY Y-MP system. The Guest Operating System (GOS) feature of the COS operating system allows users to run COS and UNICOS concurrently on a CRAY Y-MP system. The GOS feature provides downward compatibility with CRAY X-MP systems for running production codes under COS. It also is a valuable tool for migrating from COS to UNICOS on a CRAY Y-MP computer system.

"Release 4.0 of the UNICOS operating system will provide complete support for the CRAY Y-MP system and will be available for the first customer shipment in the third quarter of 1988," says Bob Ewald, vice president, software development. "We want our customers to be able to put CRAY Y-MP systems into full production as soon as they are installed."

Connectivity

Cray Research provides versatile connectivity for CRAY Y-MP systems, enabling the systems to be integrated into networks that comprise a variety of other vendors' computer systems. Cray Research network interfaces provide point-to-point communication at the I/O channel level to computers and workstations from Control Data Corporation (CDC), Data General, Digital Equipment Corporation (DEC), Honeywell Bull, International Business Machines Corporation (IBM), and Unisys Corporation. In addition, multiple front-end systems can be configured with CRAY Y-MP systems by using channel adapters such as Network Systems Corporation's HYPERchannel, Computer Network Technology's LANlord, and similar network adapters. DEC offers a VAX Supercomputer Gateway that provides a high-performance direct connection between the DEC VAXcluster environment and CRAY Y-MP systems. The Cray Research fiber optic link allows a Cray network interface (FEI) to be separated from a CRAY Y-MP system by a distance of up to 1 kilometer (about .6 miles).

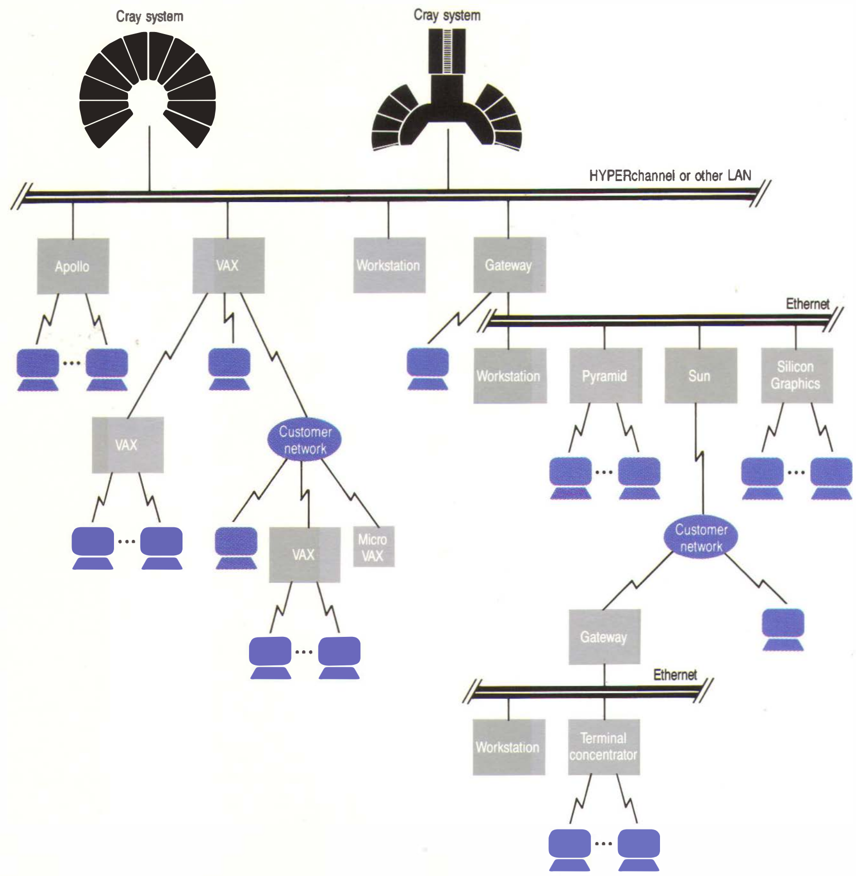
Cray Research's new FEI-3 network interface, used in conjunction with an Apollo, IRIS, Motorola, or Sun intelligent workstation, provides a link between an Ethernet local area network or other VME device and any CRAY Y-MP, CRAY X-MP, or CRAY-2 system, or any CRAY-1 system configured with an IOS. The FEI-3 also provides connections for remote Cray stations and for graphics output from a Cray system to a frame buffer in a host system. Cray Research network interfaces compensate for differences in channel widths, word size, logic levels, and control protocols between other manufacturers' computer systems and Cray computer systems.

Also available from Cray Research is the HSX-1, a special high-speed external communication channel that provides full-duplex point-to-point communications (up to 100 Mbytes/sec) with very fast devices over distances of up to 70 feet (22 meters).

Support and maintenance

Prior to installation and throughout a system's lifetime, hardware engineering and system software support are provided on-site and by technical centers throughout the company. Cray Research also provides comprehensive user documentation for hardware and software products. Technical software training is offered to customers on-site and at Cray regional and corporate training facilities.

Cray Research recognizes the need for high system reliability while maintaining a high level of system performance. The use of higher-density integrated circuits and an overall higher level of component integration help ensure that CRAY Y-MP system reliability meets or exceeds the reliability of previous Cray systems. Components used in CRAY Y-MP systems undergo strict inspection and checkout prior to use. All fully assembled CRAY Y-MP systems undergo rigorous operational and reliability tests prior to shipment. Cray Research's service philosophy includes replacing system elements on-site, minimizing system downtime and providing the highest system reliability.



Sample multiple-vendor TCP/IP configuration.

"The CRAY Y-MP system is significant for many reasons," says John Rollwagen, chairman and CEO of Cray Research. "It represents yet another Cray Research product setting a new performance standard; it gives users a chance to really sink their teeth into multiprocessing; and it reaffirms Cray Research's position as the world's top supplier of supercomputers. No other general-purpose system offers the performance levels available from the CRAY Y-MP system."

The CRAY Y-MP computer system reflects Cray Research's commitment to provide researchers around the world with the most advanced possible computing solutions. Increasingly high levels of multiprocessing, abundant I/O capability, and very large, fast-access memory make CRAY Y-MP computer systems the tool of choice for leading-edge research and industrial production computing. The balanced capabilities, reliable hardware and software, and comprehensive customer support that Cray Research provides ensure that CRAY Y-MP system users will derive the most revealing, precise, and profitable results.

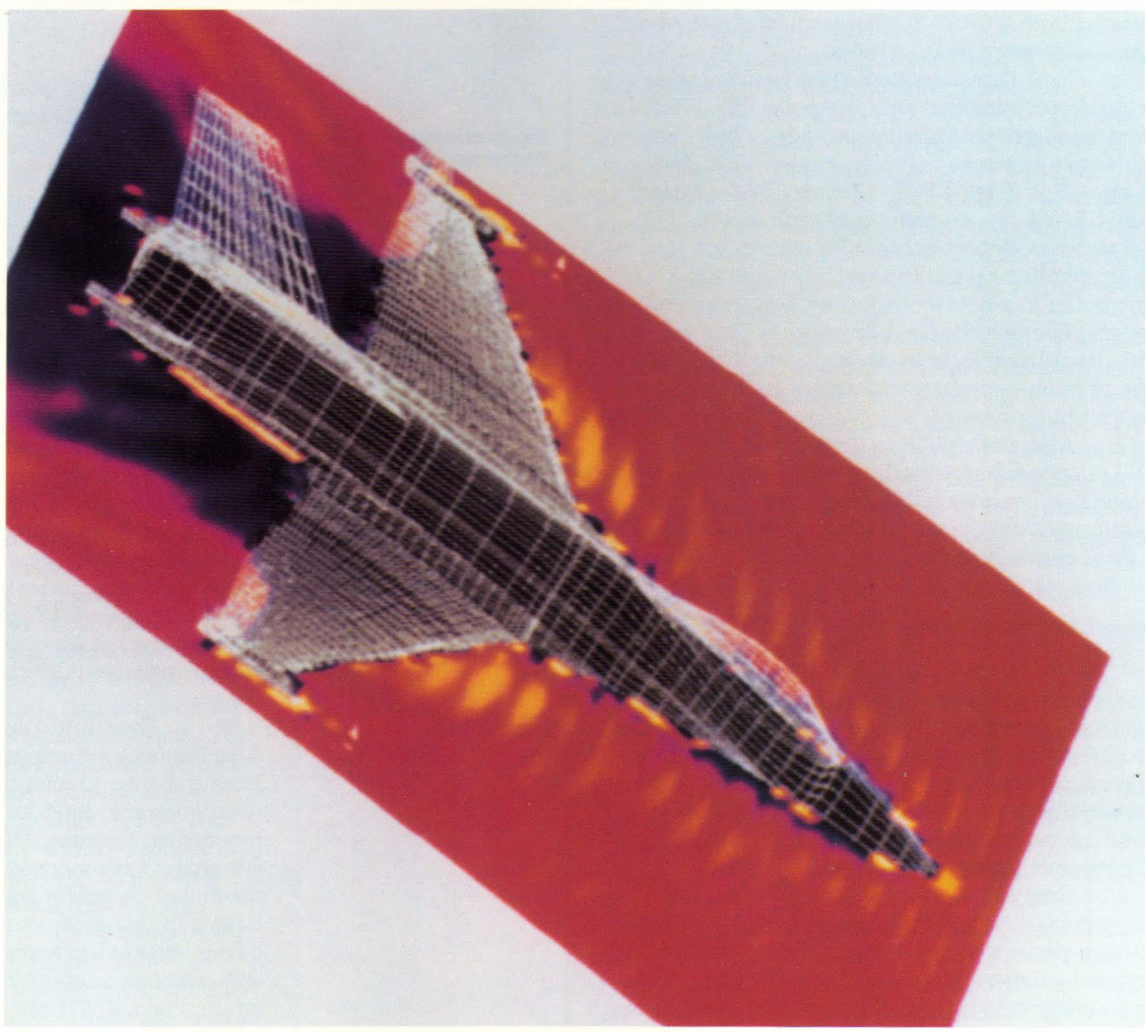
SUPERCOMPUTING SOLUTIONS IN AEROSPACE DESIGN

Loren Lemmerman, Cray Research, Inc.

When Cray Research first sold a Cray computer system to an aerospace customer in 1980, it launched a new era in aerospace design. At that time, aerospace scientists had a limited view of supercomputing, and envisioned Cray systems only as tools that would allow them to move one step closer to the goal of calculating air flows around complex aerospace designs.

Because of the power provided by Cray systems, aerodynamic technology has accelerated faster than imagined. Over the past eight years, the accuracy of aerodynamic models has improved to the extent that, as a design tool, computational fluid dynamics (CFD) is now equal in importance to any of the industry's other experimental design tools. Supercomputing has become an invaluable cost-cutting and time-saving technology for most aerospace companies.

A second technology, structural analysis, also has become a more exact science thanks to supercomputers. The power to analyze large structures has developed rapidly in the past ten years. Using common application programs such as MSC/NASTRAN, models of staggering complexity (100,000 degrees of freedom) are executed routinely. These complex models provide insight to structural responses that cannot be obtained reasonably by experimental means. The most dramatic demonstration of this capability



Electromagnetic field surrounding an F-16 fighter. Image courtesy of Boeing Computer Services.

is the recently developed ability to perform plastic structural analysis, in effect "crashing" a structure to determine its failure modes.

Today, the aerospace industry represents one of the larger communities of Cray system users. Cray computer systems solve large-scale design and engineering problems for aerospace engineers and researchers in government laboratories in the United States, Japan, and Europe and in commercial aerospace companies in the United States and Europe. This vision of using computational physics as a replacement for physical experiments has broadened into many disciplines. Cray computers are used routinely for electronic current analysis, electromagnetics, signal processing, image processing, hydraulic systems analysis, and other applications. Analysis codes frequently are linked with a numerical optimizer executive to derive new designs from proven analysis techniques. Cray computers are not simply used to perform old tasks faster, but to enable designers and engineers to uncover completely new approaches to problem solving.

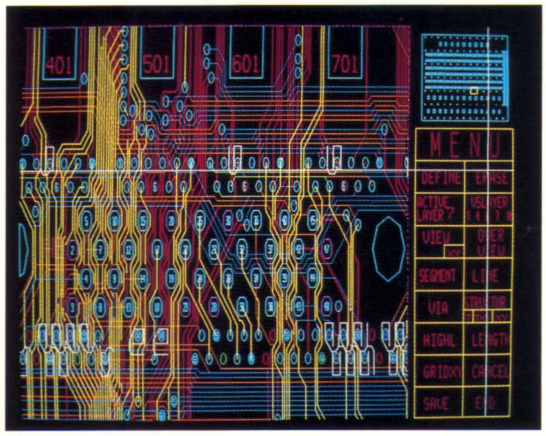
Because many industries, including aerospace, face design and engineering problems beyond the capabilities of today's computer systems, Cray Research continues to develop new products offering higher performance and greater throughput. The company's newest product offering, the CRAY Y-MP/832 computer system, with eight processors, a 32-million-word memory, and enhanced input/output capability, significantly extends the problem-solving range of computational modeling. The CRAY Y-MP system will increase productivity, improve price/performance, and allow users to solve even more complex engineering models. Cray Research is involved in many other development projects, including

- ☐ Ada
- ☐ Artificial intelligence
- ☐ Database management systems
- ☐ Real-time operating systems
- ☐ Secure systems enhancements
- ☐ Simulation languages and tools

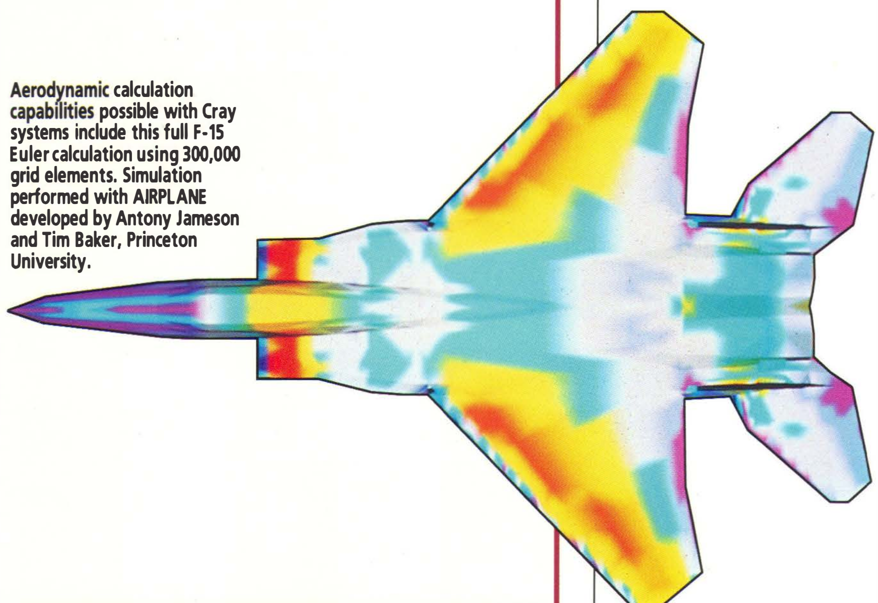
The range of problems that can be addressed with computational tools is as vast as the imagination. In this issue of CRAY CHANNELS, we explore many facets of the industry to provide a balanced picture of Cray system capabilities in a mix of traditional and emerging aerospace technologies. More than anything else, we offer this issue as a challenge to you, our users, to find new and innovative ways to apply Cray products.

About the author

Loren Lemmerman is director of aerospace marketing at Cray Research. Before he joined Cray Research in 1985, he held several leadership positions at Lockheed-Georgia Company, including manager of the System Engineering Department. He also has worked at LTV Aerospace Corporation and Rosemount, Inc. Lemmerman earned his B.S. and M.S. degrees in aerospace engineering from the University of Minnesota in 1965 and 1967, respectively. He earned his Ph.D. degree from the University of Texas at Arlington in 1976.



Full chip circuit simulation on Cray computer systems dramatically reduces design time for complex analog circuits. In the past, a 10,000-gate bipolar analog chip took an average of four iterations and approximately three years to design. Today, a chip of this complexity can be designed correctly in the first iteration, within 15 months.



Aerodynamic calculation capabilities possible with Cray systems include this full F-15 Euler calculation using 300,000 grid elements. Simulation performed with AIRPLANE developed by Antony Jameson and Tim Baker, Princeton University.

Structural analysis and image generation reach challenging dimensions in this F-16 stress calculation with 65,000 elements and 28,000 nodes. Image supplied by K.A. Hunten, General Dynamics.

This wing optimization performed with the FLO-22 analysis code is not feasible without Cray system power.

Supercomputing and the redesign of Space Shuttle propulsion elements

Paul McConnaughey, Henry Lee, and Carleton Moore
NASA George C. Marshall Space Flight Center, Huntsville, Alabama

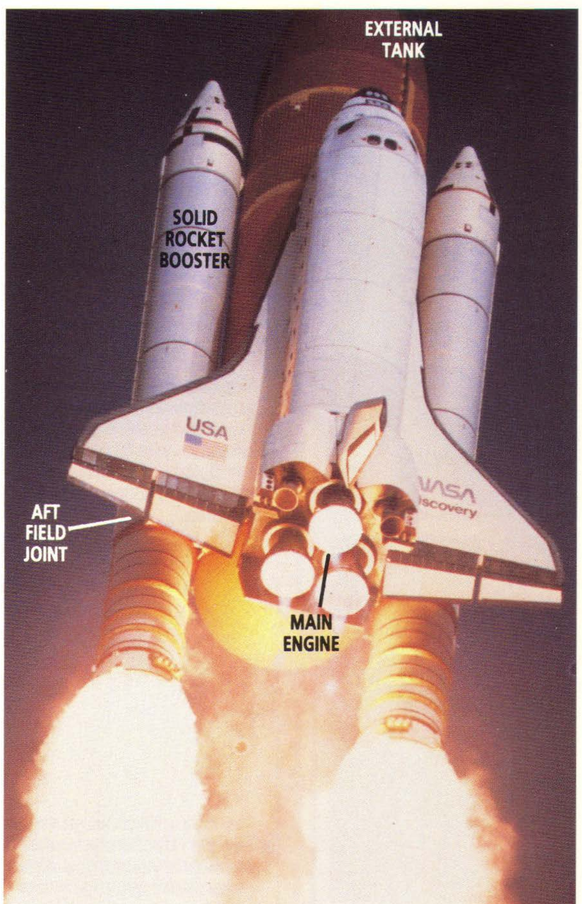


Figure 1. Space Shuttle showing components targeted for computational study and redesign.

NASA engineers have expended considerable effort to redesign and recertify Space Shuttle propulsion elements as a result of the Space Shuttle Challenger accident that occurred during flight 51-L. The CRAY X-MP/44 computer system at NASA Marshall Space Flight Center has been used extensively in the redesign effort to define environmental data and design margins. The redesign effort has ranged from analysis of failure modes to detailed evaluation of several alternative designs for rocket hardware. The types of analyses performed include the definition of aerodynamic and thermal environments, stress and dynamic analyses, system response analysis, and the definition of structural margins.

Hardware design in the shuttle program is certified through a process in which analysis and testing synergistically prove that a given design is acceptable. In the case of component redesigns as a result of 51-L, failure modes were investigated for the old designs using computational fluid dynamics and structural analysis. The detailed understanding gained from analysis of these failure modes and associated physical phenomena led to appropriate redesigns, which currently are being certified by additional analysis and testing. Most of these analyses were performed on the CRAY X-MP system at the Marshall Space Flight Center to obtain accurate results in a timely manner. Since the Cray system's installation in October 1985, approximately 60 percent of its use at the Marshall Space Flight Center has supported shuttle redesign efforts.

Several shuttle components have been analyzed in this effort, including the solid rocket booster aft field joint, nozzle-to-case joint, aft skirt, bore flow, and joint heaters. Analysis and testing of the Space Shuttle main engine has focused on evaluation of the high-pressure fuel turbopump turbine blades and high-pressure oxidizer turbopump bearing durability and margin issues. All structural models for the external tank have been reassessed as well. A subset of the computational results pertaining to the solid rocket booster field joint and Space Shuttle main engine high-pressure fuel turbopump turbine blades are presented here.

Analysis of the solid rocket booster field joint

The solid rocket booster field joint is a tang-and-clevis joint that connects cylindrical segments of the solid rocket motor (Figures 1 and 2). The old design included two O-rings and zinc chromate putty between adjacent insulation surfaces to prevent hot exhaust gases from passing through the joint. The new design incorporates a "capture" feature that minimizes movement of the joint under stress and an additional O-ring that acts as a barrier to hot motor gases. The insulation is redesigned as an unvented J-seal that forms a thin bond line at the motor assembly. Analysis of these joint designs has emphasized joint movement and displacement during pressurization of the motor, stresses in the joint, O-ring dynamics, and thermal and flow conditions in the joint.

The SPAR and ANSYS software packages were used to perform finite element analyses of the old and new field joint designs. Figure 3 shows joint displacement and stresses throughout the 0.6-second solid rocket booster ignition transient that occurred during flight 51-L. The small displacement (rotation) in the 51-L joint that developed during ignition is due primarily to pressure inside the booster. This pressure (950 psi) caused the motor casing to expand radially and axially. The joint, which is stiffer than the casing, rotates as the casing walls deform, opening the joint seals. The maximum opening in the old aft joint design as a result of this mechanism is 0.038 inches. Stack-up tolerances and case loading of the 51-L joint added at most 0.020 inches to the dynamic seal gap that occurred as a result of pressure and loads.[1]

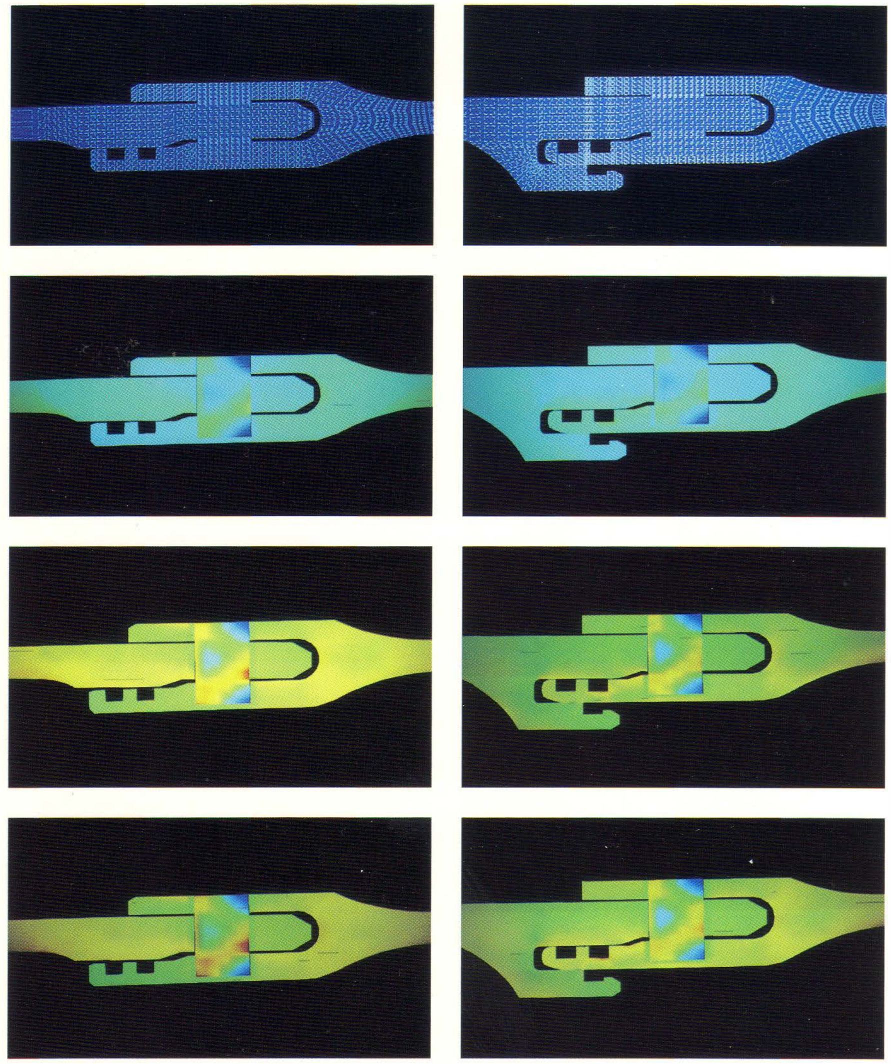


Figure 3. Aft field joint displacement and stress during solid rocket booster ignition transient. Red indicates higher stress; blue indicates lower stress. The left column shows analysis of the old joint at, from top to bottom, 0.0, 0.2, 0.4, and 0.6 seconds after ignition. The right column shows analysis of the redesigned joint during the same time span. Graphics by W.M. Remus (Morton Thiokol).

The maximum seal opening for the redesigned field joint is 0.009 inches. The redesigned joint also has the third O-ring at the capture feature location, which is subjected to a closing compressive force during the ignition pressure transient. The interference fit of the capture feature is designed to eliminate the effects of case out-of-roundness and stack-up tolerances.

Analysis of the 51-L joint showed that the stresses were low and of no significance in the failure. The mating and fracture mechanics analysis of the old joint showed that the loads and the resulting stresses during mating of the center segment to the aft segment were low, resulting in no damage to the joint during assembly. The redesigned joint has even lower operational stresses and is designed for safe assembly stresses. The solid rocket motor lateral bending and shell modes were found to have a negligible effect on seal gap opening. This analysis used the finite element code EAL (a commercial version of the public domain code SPAR). EAL was also used to investigate the effect on seal clearances of a 3-Hz structural dynamic oscillation during liftoff. The effect was found to change clearances by ±0.002 inches.

O-ring dynamic response was investigated using the SPAR code.[2] Although linear elastic theory predicts that the seal would snap back very fast from

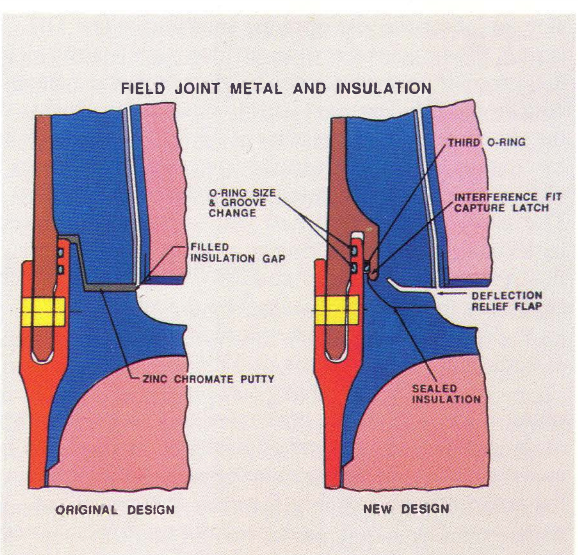
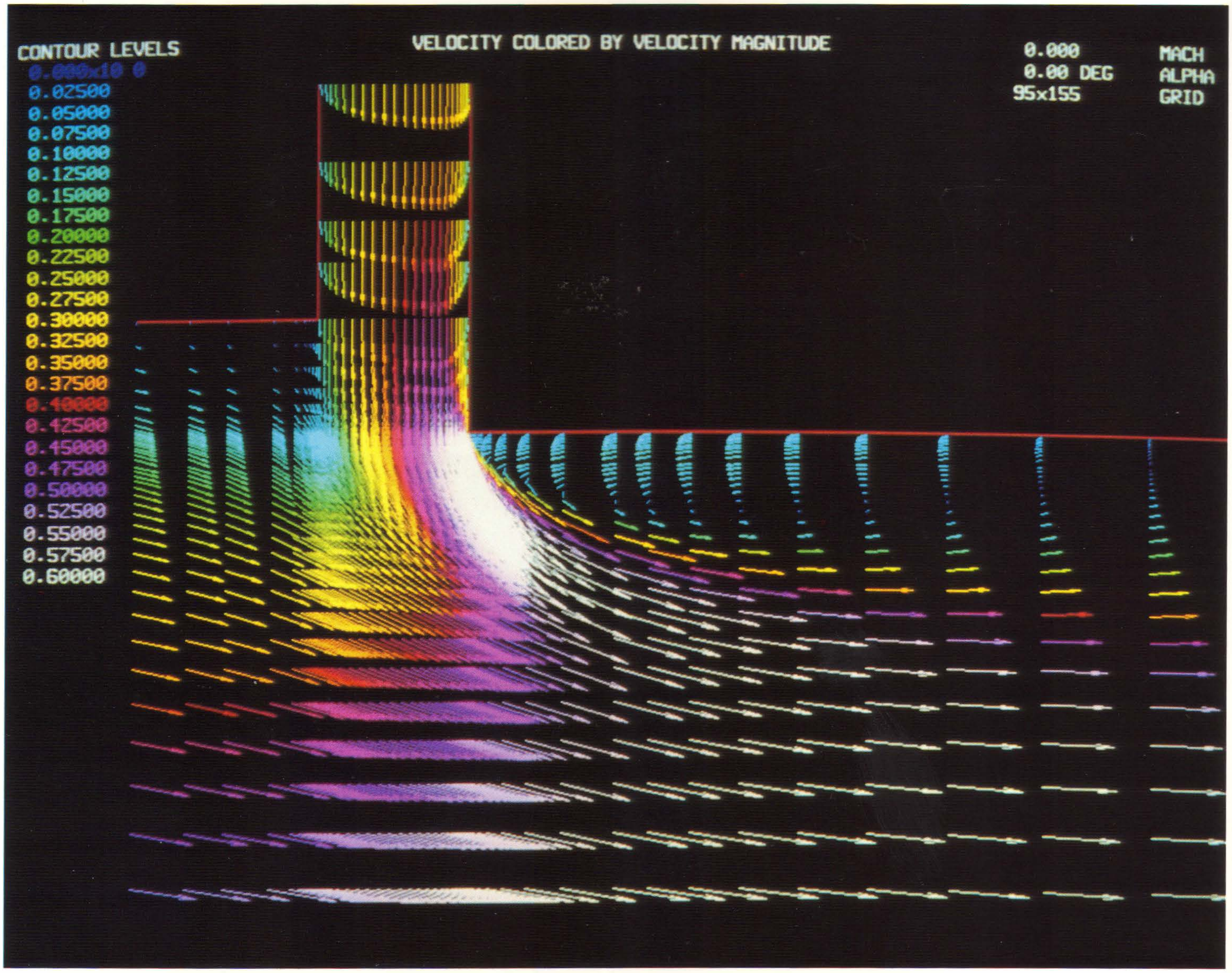


Figure 2. Old (left) and new (right) aft field joint designs.



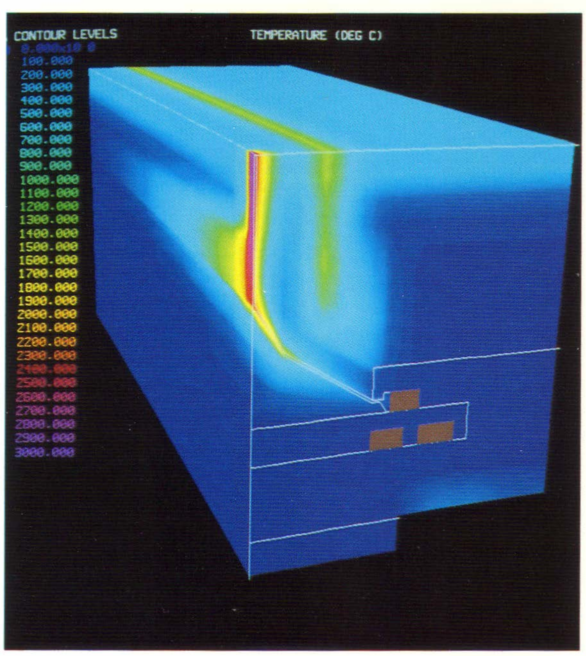


Figure 4. Velocity vectors near the aft field joint slot exit. Computation by J. S. Sabnis (Scientific Research Associates), graphics by D. Goode.

Figure 5. Temperature field predicted in aft field joint for J-seal debond (defect) scenario. Computation by D. Doran, graphics by D. Goode.

the compressed state at normal temperatures, the extreme temperature dependency of the O-ring material made response from a highly compressed state too slow to follow the gap opening transient at the 51-L launch. The material response slows significantly as the temperature approaches its glass transition temperature of 10°F. The new joint is designed such that the elastic response capability of the Viton seal material can maintain constant contact (within a safety factor of 2) with the joint throughout the ignition transient. The safety of the redesigned joint is further increased by locating the third O-ring at a closing position on the capture feature. Safety and low-temperature launch capability have been enhanced by the addition of joint electrical heaters that will maintain the O-rings at a minimum temperature of 75°F.

Analyses involving computational fluid dynamics (CFD) also were performed to support redesign of the solid rocket booster aft field joint, including analyses of the circumferential pressure gradient at the seal entrance, which influences the flow of hot gases near the O-ring. Such pressure gradients can be induced in the motor by a canting of the solid rocket booster nozzle or by other geometric asymmetries within the motor. Other geometric factors include propellant slumping and inhibitor irregularities (inhibitors control the amount of burning on some propellant surfaces). In one failure scenario, a section of inhibitor was assumed to break off at motor ignition. Analysis of this three-dimensional bore flow problem was completed using the Navier-Stokes code MINT with 721,525 grid points and boundary layer resolution. A failure of this type would likely cause a circumferential pressure gradient of 1 psi at the aft field joint. Figure 4 shows the calculated flow in the aft field joint slot.

Boundary conditions were developed by considering all factors contributing to the circumferential pressure gradient and were then input to an analysis of flow near the capture O-ring. Defects and failures were simulated because the joint is designed not to contain a flow under nominal conditions. Modeled defects included debonding of the J-seal at various stations around the motor, thus allowing hot (5540°F) propellant gas to reach the capture O-ring. This unsteady three-dimensional analysis used the PHOENICS code with 20,088 grid points to predict flow in the joint coupled with heat conduction in adjacent insulation, O-rings, and steel casing. Each analysis assumed 50°F as the initial temperature, and simulated the complete two-minute firing of a motor (including ignition transient). Six different cases were analyzed, and each calculation took approximately 11 hours on the CRAY X-MP system at Marshall Space Flight Center.

Figure 5 shows the predicted thermal environment 120 seconds after ignition for the 15° debond separation and the 1 psi circumferential pressure gradient case. All predicted temperatures near the O-ring were significantly less than temperatures required for O-ring ablation and erosion. Predicted gas impingement velocities in the O-ring region were very low (less than 0.05 ft/sec). It should be noted that for all cases considered, the analyses predicted that no O-ring erosion would occur, even for severe off-design conditions and several debond (defect) scenarios. The exception to this occurred in one case where flow parameters in the model were taken to five times greater than the worst-case conditions.

In summary, analysis of the redesigned solid rocket booster field joint shows minimal joint displacement during pressurization, low stresses, and resistance to O-ring erosion for a range of failure and defect scenarios. Recent full-scale firings of test motors support these conclusions, but further testing is needed before flight certification.

Turbine blade analysis

The Space Shuttle main engine high-pressure fuel turbopump turbine is a two-stage reaction turbine powered with hydrogen-rich steam generated by a fuel preburner that produces a gas temperature near 1540°F and pressure of 5500 psi. This turbine powers the high-pressure liquid hydrogen (LH_2) fuel pump. At full power, the turbine produces nearly 74,000 horsepower while rotating at 36,595 revolutions per minute. With 63 blades on the first-stage rotor and 59 on the second stage rotor, each blade produces

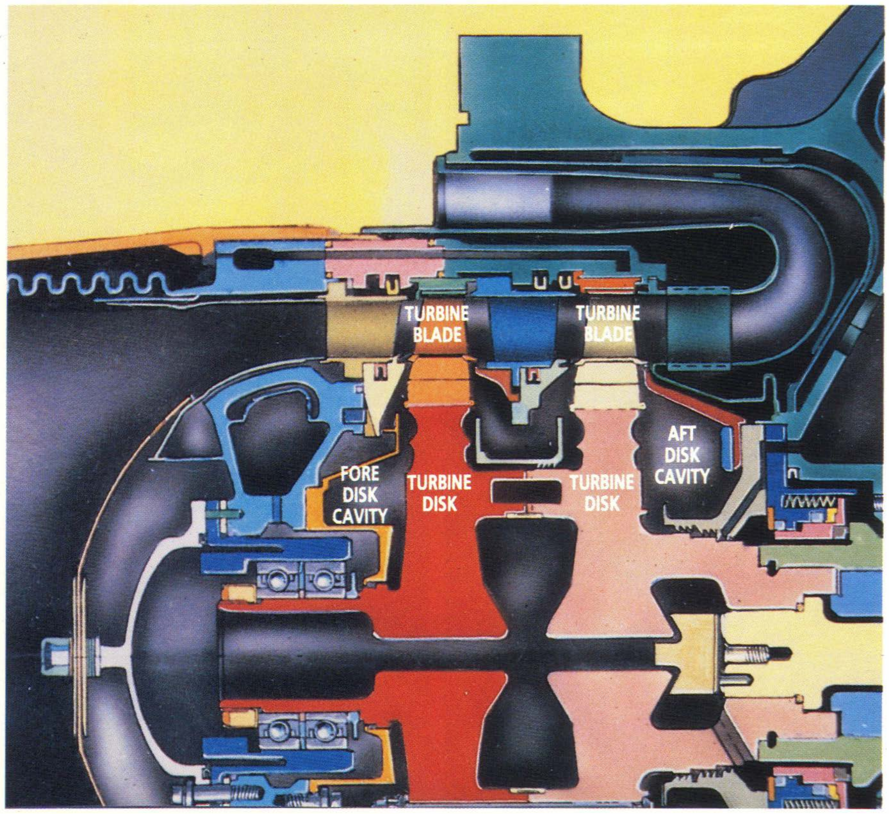


Figure 6. Cutaway of turbine end of Space Shuttle main engine high-pressure fuel turbopump.

approximately 600 horsepower. Components of the hot gas bath of the Space Shuttle main engine high-pressure fuel turbopump can be seen in Figure 6.

Historically, the turbine blades have experienced several types of cracks at many locations. Because of the severity of the environment, these cracking phenomena result from high cycle fatigue, low cycle fatigue, and hydrogen environment embrittlement. Most of the cracks were self-arresting and some were minimized or eliminated by design changes. However, in the past few years, critical transverse hydrogen-assisted low cycle fatigue cracks have appeared on the second-stage downstream face of the region connecting the blade to the rotor (known as the fir tree).

Although these particular crack types occur infrequently, a few have grown to fairly large depths, increasing with every engine test. Continued crack growth in this load-carrying area has caused a great deal of concern regarding the safe operating life of the blades.

To address this problem, Marshall Space Flight Center initiated the integrated task of defining aerodynamic and thermal environments using CFD and finite element analysis. These environments were then included in large three-dimensional finite element models of the second-stage Space Shuttle main engine high-pressure fuel turbopump turbine blade and rotor. The primary goal of this effort was to develop and apply analytical tools of sufficient accuracy to predict the state of strain existing in the fir tree using the three main load components of rotation (36,595 rpm), airfoil pressure (generating 126,000 in-lb torque), and thermal gradients.

Pressure on the turbine blade airfoils was defined using the inviscid quasi-three-dimensional-plus-boundary-layer code MTSBL.[3] This analysis resulted in blade pressures that, when integrated over the airfoil surface, predicted engine torque within 0.07 percent. Midspan airfoil pressures for the first stage of the high-pressure fuel turbopump from the MTSBL code also were compared to those predicted by the unsteady rotor-stator code ROTOR-1.[4] This two-dimensional CFD analysis used 25,484 grid points to predict the time-dependent flow environment of the rotor blades as they pass through the stator wakes. Velocity and temperature profiles resulting from the rotor-stator analysis are shown in Figure 7. The airfoil midspan loads predicted by MTSBL agree with the time-averaged results of ROTOR-1.

Figure 8 shows flow in the high-pressure fuel turbopump fore disk cavity. This analysis used the MINT code and 21,600 grid points for an axisymmetric analysis of the rotating cavity. Results indicate that the hot gas flow ingestion at the turbine first-stage platform seals results in high thermal gradients at the first-stage blade shank, whereas analysis of the aft disk cavity shows that high thermal gradients exist at the downstream face of the second-stage fir tree.

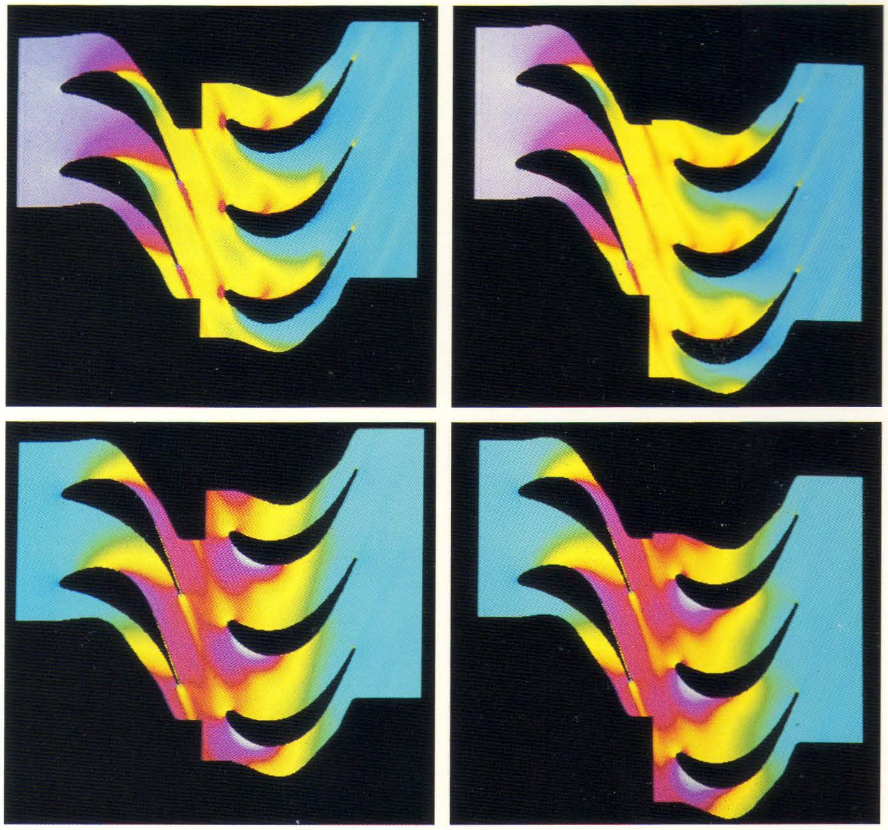


Figure 7 (above). Unsteady velocity and temperature fields predicted for Space Shuttle main engine high-pressure fuel turbopump first stage blades: temperature (upper left and right) at times 1 and 2; velocity (lower left and right) at times 1 and 2. White indicates higher velocity and temperature; blue indicates lower. Computation by H. McConnaughey, graphics by D. Goode.

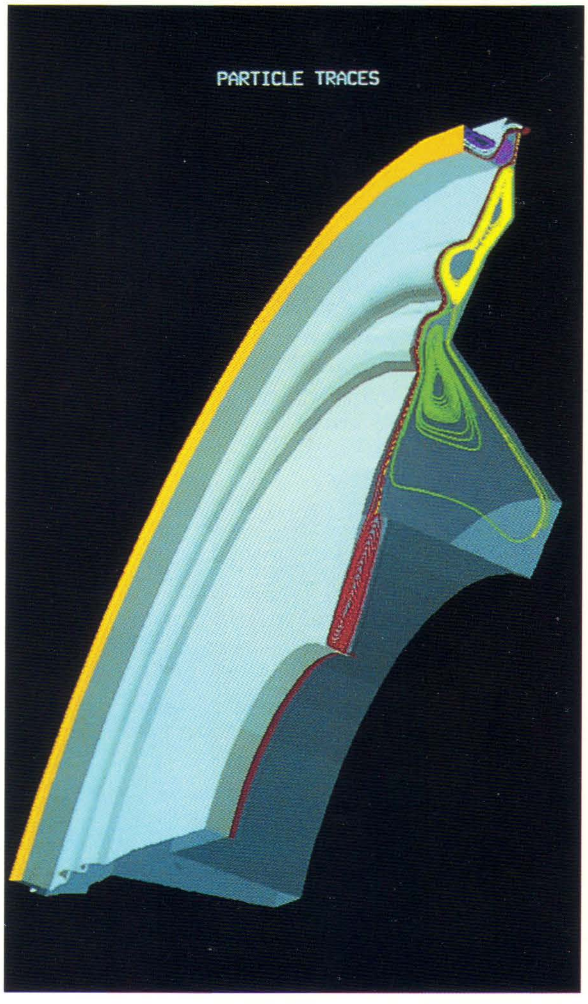


Figure 8 (left). Particle traces of flow in the front disk cavity of the Space Shuttle main engine high-pressure fuel turbopump. Computations by E. Stewart, graphics by D. Goode.

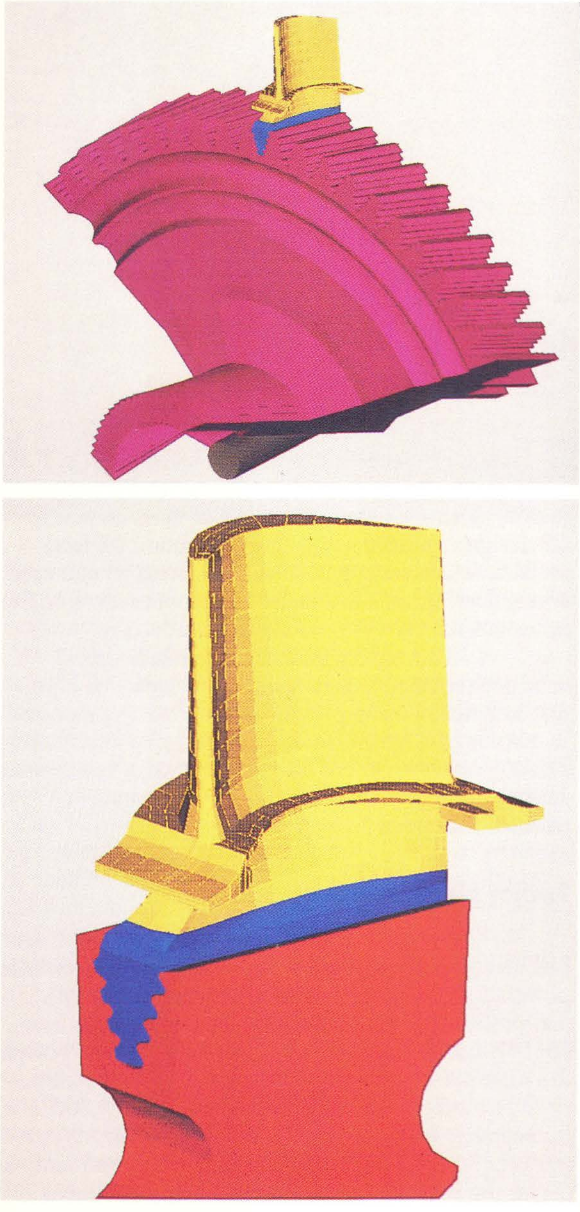


Figure 9 (right). (Top) The finite element model of a Space Shuttle main engine turbine blade attached to the symmetrically displayed disk. (Bottom) A closeup of the second-stage turbine blade showing the downstream face of the fir tree. Computation and graphics by H. Lee.

Stress analysis of the second-stage blades used the above results for blade loads and finite element results for the thermal environment.[5] The structural models were developed on a CAD/CAM system and then translated into the ANSYS structural program. The solution phase was performed on the CRAY X-MP/44 system and took five hours of CPU time. The second-stage blade model consisted of 14,476 three-dimensional isoparametric elements, while the associated rotor contained 9770 such elements. These two structural representations were connected in the fir tree region with 744 bilinear gap elements (Figure 9).

Results of the stress analysis indicated that the highest strain levels indeed were occurring on the downstream face of the fir tree (Figure 10). The analysis also confirmed that the surface train on this face was controlled largely by a steep thermal gradient normal to the surface. This gradient is caused by hot turbine gases mixing with LH_2 coolant in the fir tree region. The predicted state of stress across the face has been found to be above the level needed to produce hydrogen-assisted low cycle fatigue cracking. Thus, an analytical basis for understanding the crack occurrences seen on actual hardware has been developed.

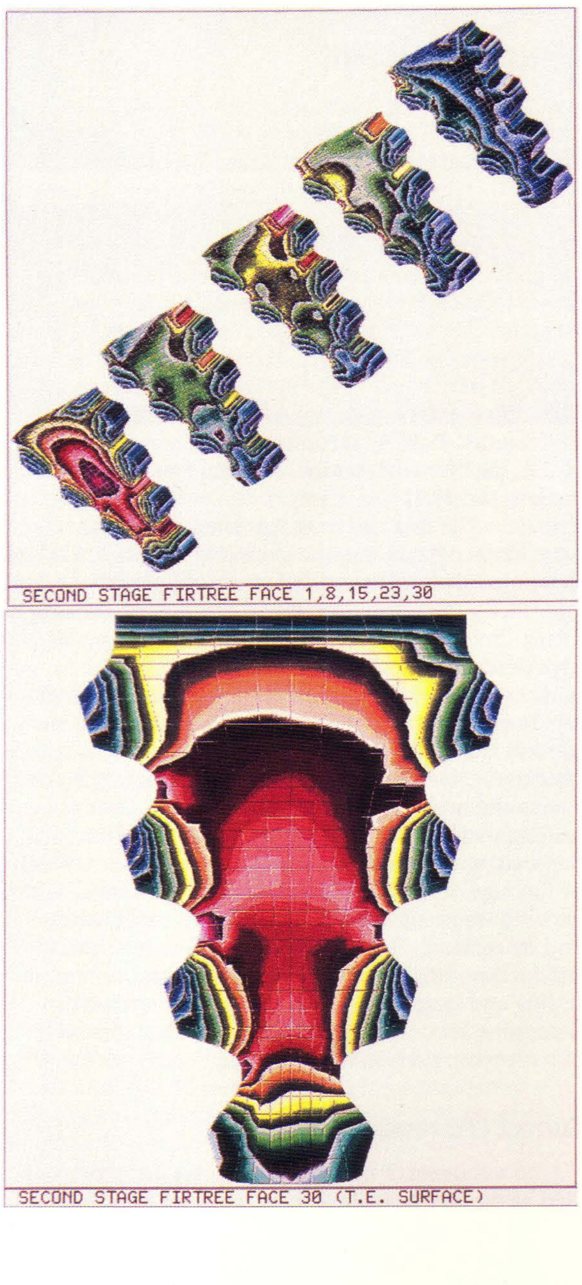


Figure 10. (Top) Principal strain magnitude for several slices through the fir tree region from the upstream face (upper right) to the downstream face (lower left). (Bottom) A closeup of strain contours on the downstream face. Computations and graphics by H. Lee.

Understanding the parameters that initiate these flaws and cause them to grow has been critical in providing an engineering basis for design changes. Modifications presently in place include stress relieving and shot peening of blades, providing more generous radii on fir tree corners, changing fit-up to improve load sharing, and reducing the acceptable material microporosity. Analysis indicates that a positive margin against fir tree downstream face cracking now exists.

Engine ground tests of the Space Shuttle main engine turbine hardware confirm that the implemented design changes minimize low cycle fatigue cracks on the turbine second stage. The analytical effort described here and the testing accomplished to date are establishing confidence in the durability of the modified turbine blades.

Summary

Significant analytical effort has been expended to support the redesign efforts of the Space Shuttle propulsion system. Much of this analysis used the CRAY X-MP/44 computer system at the Marshall Space Flight Center, which has allowed for the development of larger and more complex models than those used previously. To be effective, each analysis must be not only timely and accurate, but also integrated with testing so that it influences hardware design and management decisions. Continued computational efforts of this type and further testing should restore the shuttle to a safe flight status.

Acknowledgments

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CFD opportunities in rotorcraft aerodynamics

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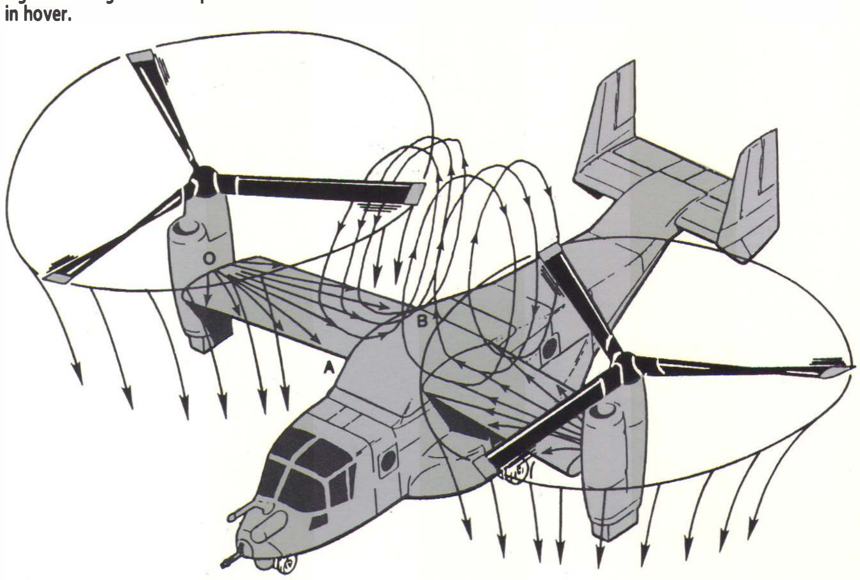
The aerodynamic flow field around rotorcraft vehicles is a complex phenomenon. Figure 1, which shows flow patterns around a hovering tiltrotor vehicle, illustrates this complexity. A flow field such as that illustrated is highly three-dimensional, unsteady, and nonlinear. To predict the performance characteristics of rotorcraft vehicles accurately, aerodynamic models must account for phenomena such as flow separation, transonic compressibility effects, complex vortical wakes, and interactions between components. Traditional prediction methods rely on various assumptions to simplify this complex modeling problem. These assumptions can result in high development costs when performance or handling problems that were not predicted during the aerodynamic design studies appear during flight testing.

Computational fluid dynamics (CFD) methods are being developed to predict more accurately the performance characteristics of rotorcraft. These methods are directed toward designing improved rotor blades and tip shapes for rotary wing applications. A few new CFD methods that are of interest to Bell Helicopter Textron, Inc., (BHTI) are discussed here.

Because these methods generate more detailed evaluations than do standard design methods, their use requires much larger and faster computer systems. In June of 1987, BHTI acquired a dedicated phone link to the computing resources at the NASA Ames Research Center. As part of a joint effort between NASA and BHTI, we are executing and evaluating CFD codes on the center's CRAY X-MP/48 computer system.

Figure 1. Wing rotor flow pattern in hover.



History of CFD at BHTI

During the past 15 years, CFD methods have been used increasingly to perform vehicle design and performance prediction tasks for rotorcraft. The first CFD codes to make significant impact on the design of new rotorcraft at BHTI were two-dimensional airfoil analysis codes. Initially, these codes were potential codes to which boundary layer techniques were linked. Although they were quite simple by today's standards, these codes had significant impact on the design process. Airfoil sections designed with these methods performed better in rotorcraft applications than did standard National Advisory Committee for Aeronautics (NACA) sections. (NACA was replaced by NASA, the National Aeronautics and Space Administration, in 1958.)

The first three-dimensional codes used were surface-panel methods, which have been used to determine the air-load distributions on complex configurations such as a tilt rotors during maneuvers. Three-dimensional potential transonic blade codes produced in the 1970s were modifications of the wing codes developed for the transport aircraft industry. These codes model single blades and have been used to aid in the design of new tip shapes and to predict the acoustic response of the advancing blade. Free wake models can determine the tip vortex and trailing vorticity sheet locations and their effect on the loading distribution on the rotor disk when wing or fuselage influences are ignored. All of these CFD capabilities provide relatively sophisticated analysis and design tools for individual components used in production today. However, extensive wind tunnel testing and large-scale rotor testing are required to determine accurately the maximum lifting capability of a tilt rotor, such as that illustrated in Figure 1.

Current CFD research

Figures 2 through 4 show results generated at the NASA Ames Research Center for applica-

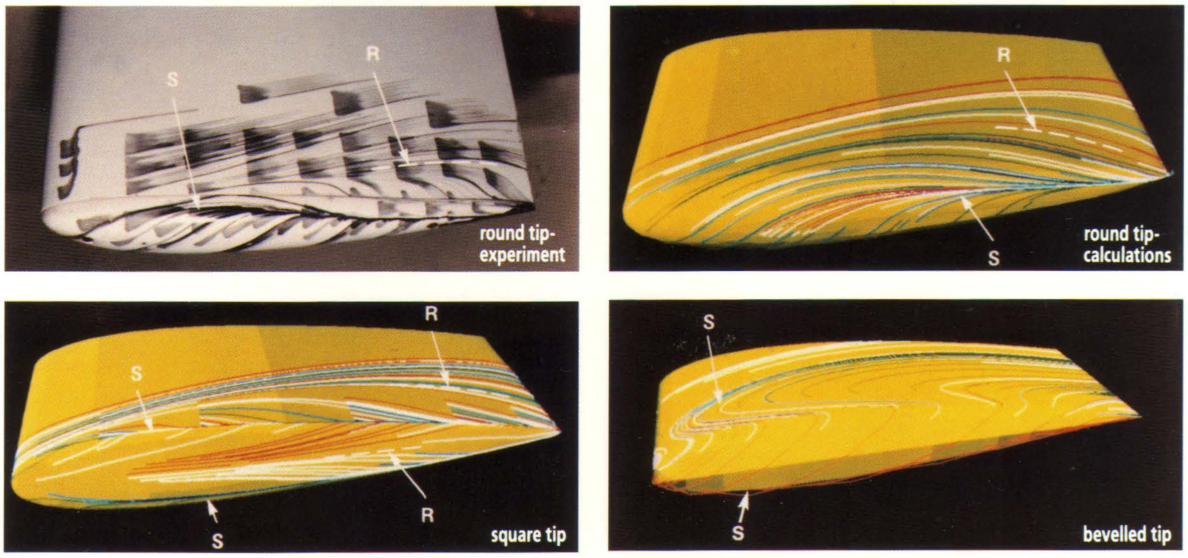


Figure 2. Surface oil flow in tip region for unswept rectangular wing. S indicates flow separation; R indicates flow reattachment.

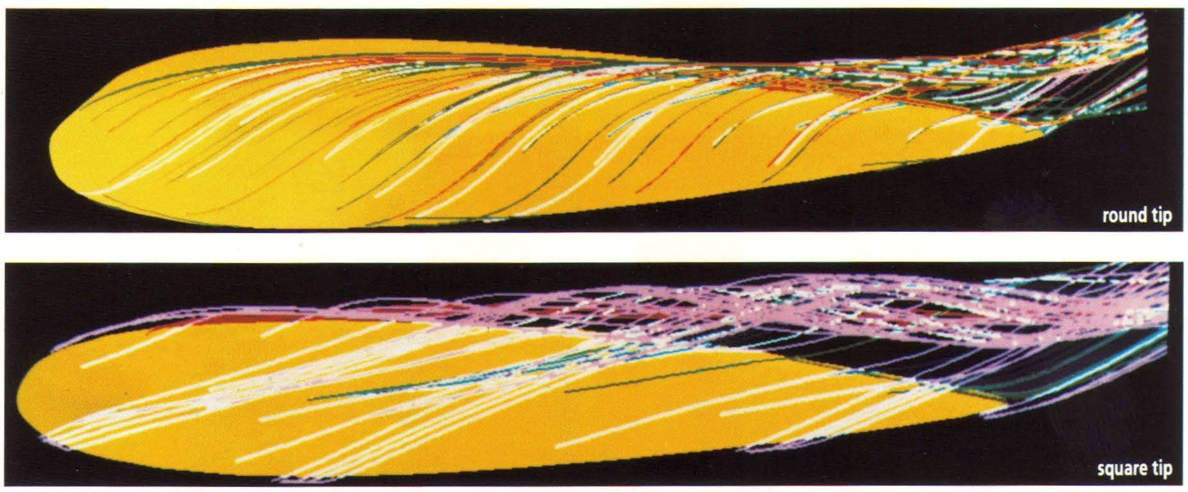


Figure 3. Tip vortex formation for a rectangular wing.

tion to rotorcraft problems. Because the radially increasing blade speed generates highly concentrated bound circulation over the outer portion of the blade, one of the more important issues in the design of new tip shapes for rotor blades is the influence of the surface contour on the tip vortex roll-up structure.

G.R. Srinivasan and his associates at the Ames facility are working to predict this influence computationally. Using an unsteady thin-layer Navier-Stokes method, they are evaluating in detail the flow field in the region near the tip. This method is written in rotor coordinates and solved using a flux-split, approximately factored, implicit, numerical algorithm to calculate the quasi-steady flow field of a hovering rotor blade.[1]

Figure 2 shows experimental oil flow and calculated Navier-Stokes solutions for a rectangular wing with three different tip shapes. This figure shows that the particle trace calculations agree qualitatively with experimental oil flow results for a wing section with a rounded tip. Calculations for square tips and beveled tips produce significantly different tip region flow characteristics and generate different tip vortex roll-up flow fields as shown in Figure 3. In addition, the effect of blade rotation on the tip vortex roll-up must be considered. Results

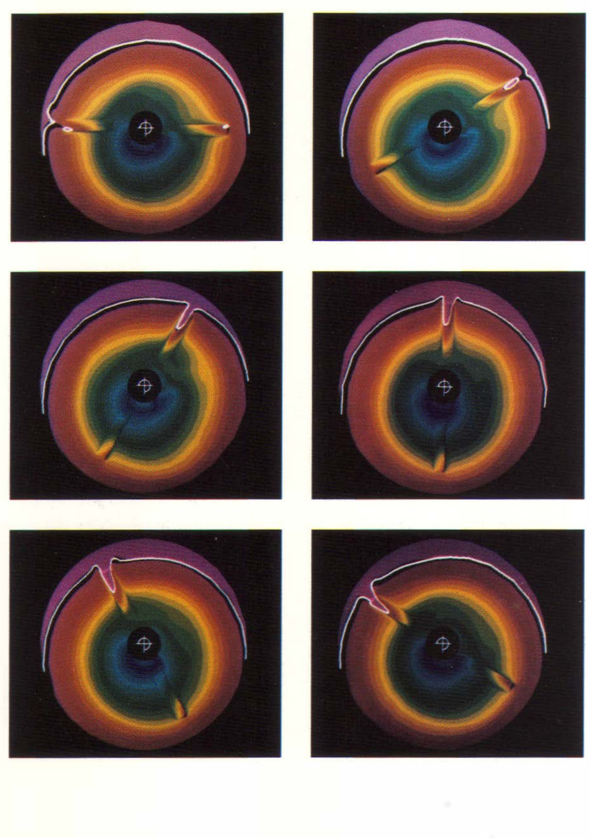


Figure 4. Mach contours at various azimuth angles for a forward flight two-blade rotor.

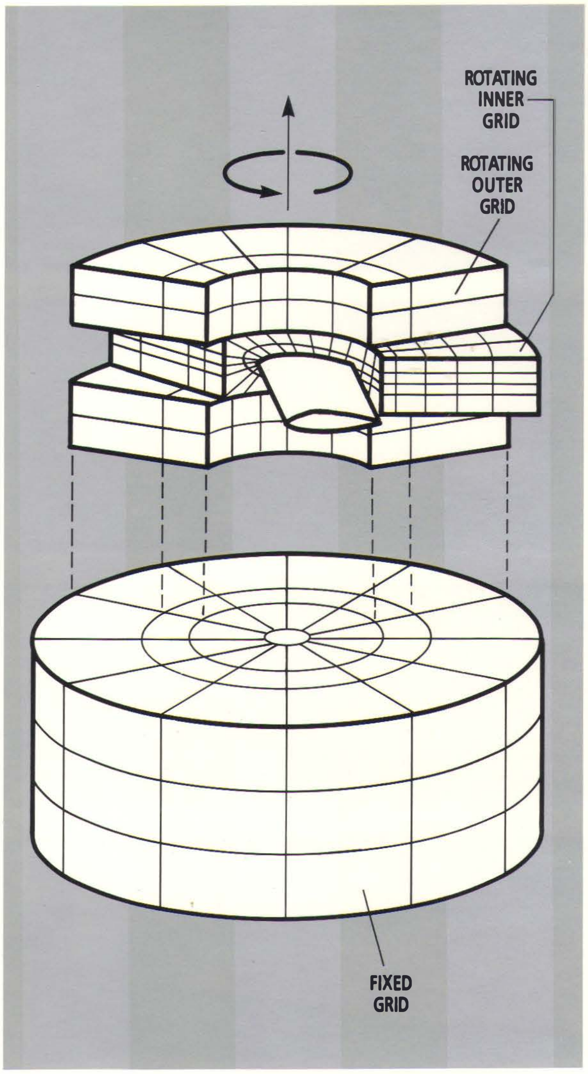


Figure 5. Cylindrical grid topology for rotor-fuselage interaction.

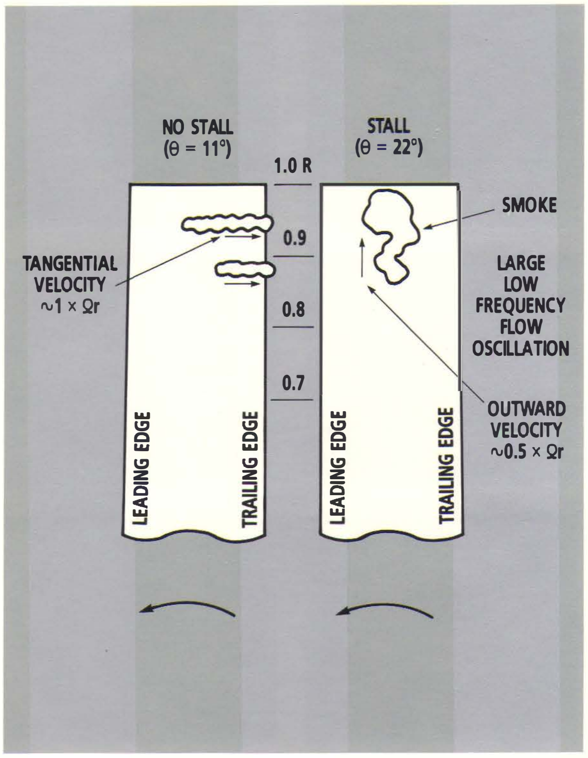


Figure 6. Model rotor tests indicate an outflow of the wake behind a stalled rotorblade, which may increase power needs.

indicate that the tip vortex does not roll up into a tight core as quickly when the blade is rotating.

Researchers at the Ames facility also are applying to rotorcraft problems a patched-grid technology in which the grid boundaries are moving with respect to one another. C. L. Chen and his associates currently are modeling a multiblade rotor using a finite-volume, partially flux-vector split Euler code with a cylindrical grid topology.[2] Mach contours in the flow field about a two-bladed rotor in helicopter mode advance ratio of 0.2 are shown in Figure 4. The approach being taken allows the method to be expanded to include a fixed grid in which the fuselage can be modeled as depicted in Figure 5.

Full Navier-Stokes efforts

BHTI is working with N. L. Sankar at the Georgia Institute of Technology and R. Vermeland of Cray Research to evaluate a hybrid time-marching technique for the numerical solution of the three-dimensional unsteady Navier-Stokes equations.[3] This study is intended to determine the method's usefulness in calculating the flow field in the region of retreating blade stall on a helicopter rotor in a maneuver. This flight condition was chosen so that the controversial issues of centrifugal pumping, three-dimensional dynamic stall, and forcing function distributions during stall could be evaluated. A stalled wake outflow due to centrifugal force on a rotating blade is depicted in Figure 6. The amount of power associated with this centrifugal pumping flow is to be computed by the three-dimensional Navier-Stokes code.

We are using the full Navier-Stokes equations rather than the thin-layer Navier-Stokes equations because we are interested in the three-dimensional unsteady solution with massive separation. The transport of momentum and energy through turbulence is modeled through the eddy viscosity concept. The two-layer Baldwin-Lomax model is used even though it is not considered reliable in massively separated flows. These equations were solved in a body-fitted coordinate system. The system was obtained by constructing a sheared parabolic coordinate system around the rotor and clustering the body-conforming grid lines at each span station such that the first grid line parallel to the rotor surface was at a user-specified distance from the surface. The blade geometry that was analyzed represents a typical helicopter with a swept tip as is shown in Figure 7.

To date, calculations have been performed in the azimuth angle range from 255° to 270° for the generic rotor blade using the Georgia Institute of Technology three-dimensional Navier-Stokes solver with a 121-by-19-by-45 grid. As a result, 100 points define the airfoil contour at a given radial station having 51 nodes on the upper surface, 51 nodes on the lower surface, and a common leading-edge node. Fourteen radial station nodes exist on the rotor surface with a radial spacing that clusters these nodes about the rotor blade tip. The first grid line in the direction normal to the blade, within the boundary layer, is set off from the surface by 0.11 percent of the local chord.

The Navier-Stokes calculations were performed on a single processor of a CRAY X-MP computer system at Cray Research's computer center in Mendota Heights, Minnesota. The computer time required to advance the calculations by one time step was 3.21 seconds for the 121-by-19-by-45 grid. Roughly 1000 time steps were needed to obtain a quasi-steady solution at 255° azimuth. After establishing this starting condition, about 160 time steps were needed to advance the unsteady Navier-Stokes calculation by 1° azimuth. Initial results are shown below.

Future directions

These examples illustrate the current state of the art. Today we can perform detailed evaluations of simplified configurations, although we cannot model in detail the complex flow situations that exist on complete rotorcraft vehicles as depicted in Figure 1. Acquiring this capability will require improved algorithms and expanded computing capability. As these requirements are developed, new opportunities will appear for advancing rotorcraft technology.

About the author

Jim Narramore is a principal engineer in the aeromechanics methodology group at Bell Helicopter Textron. Narramore received his B.S. degree in aerospace engineering in 1972 and his M.S. degree in engineering in 1973 from the University of Texas at Austin. He joined Bell Helicopter Textron in 1979 and has worked on the application of CFD methods and information systems technology to problems of aerodynamic design, evaluation, and performance.

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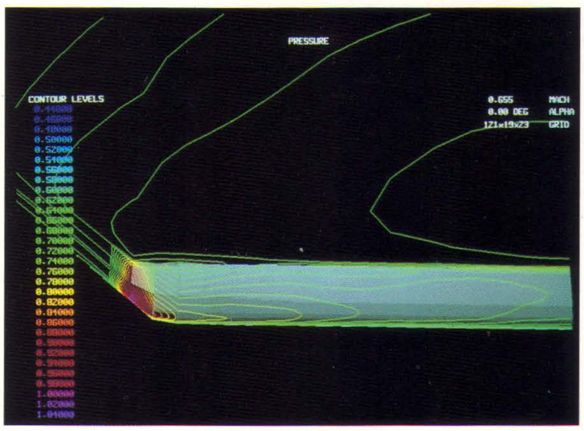


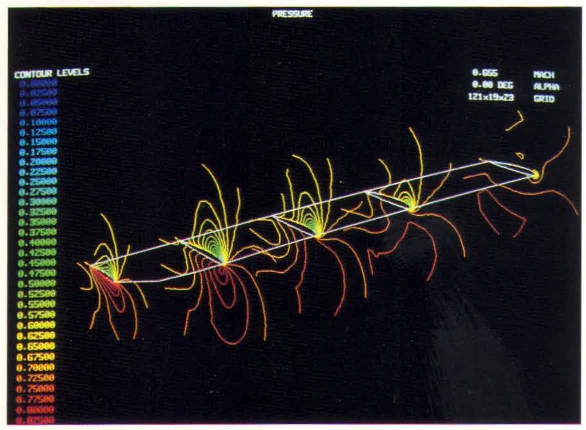


Figure 7. Blade surface evaluated with GIT2DNS program, showing blade planform upper surface and pressure contours.

Figure 8. Blade pressure contours computed with GIT2DNS program.

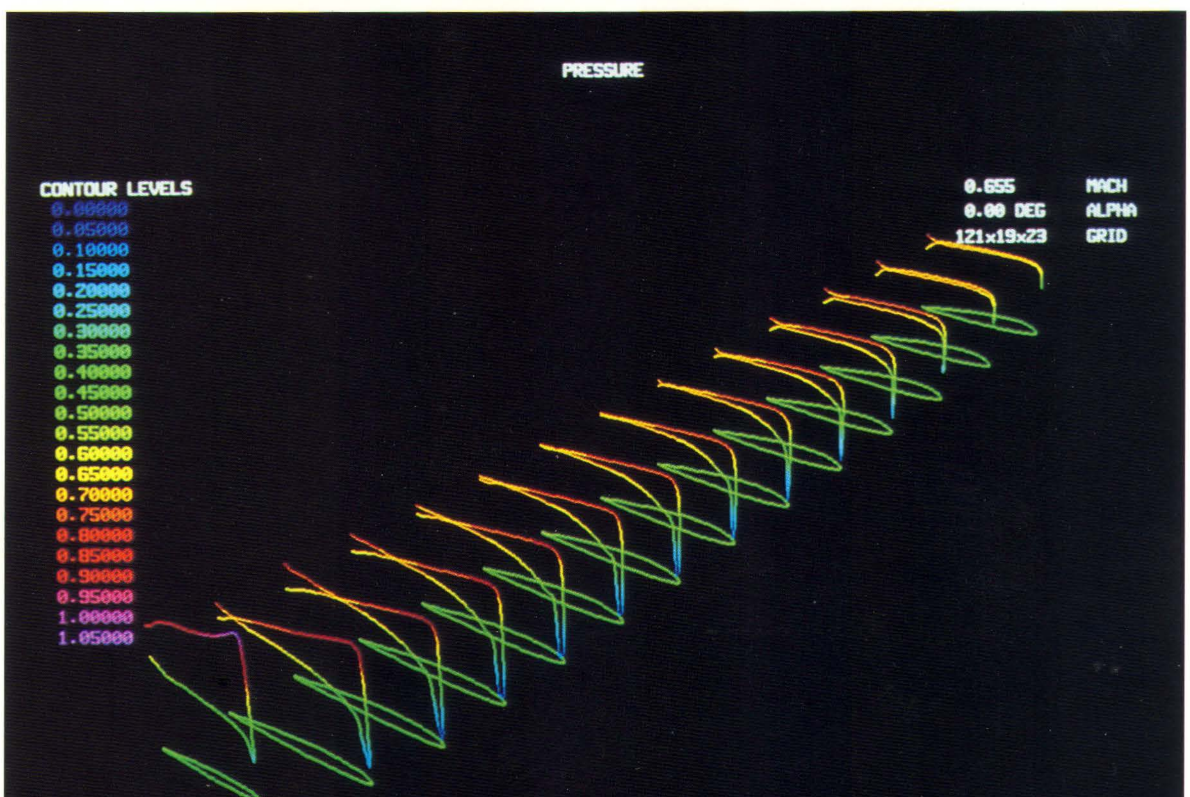


Figure 9. Blade surface pressures computed with GIT2DNS program.

Future directions for aerospace systems

Karen Allen, Cray Research, Inc.

As the complexity of aerospace technology grows, so does the demand for Cray computer systems. Cray supercomputers are finding a new niche in the aerospace field as integrated elements of operational aerospace systems. This rapidly growing area promises to open exciting aerospace applications.

Cray systems were introduced to the aerospace community as research and development tools for engineers. In this environment, large batch applications are submitted and executed, and then results are returned to the engineer. As computational techniques matured and problems became increasingly complicated, engineers began to interact with the analyses as they were being run. Freedom to experiment with previously static analyses encouraged innovative, creative engineering solutions to complex problems, based on the power and flexibility of supercomputers.

Although these applications will continue to evolve, the supercomputer is emerging as an integrated element in operational aerospace systems that require immense computational resources. Cray supercomputers are participating in these new aerospace systems in two significant ways — by being linked directly in real time to other real-world, operational equipment, and by functioning as very large computational engines, providing integrated simulation capabilities across multiple, otherwise independent, simulations.

The supercomputer is emerging as an integrated element in operational aerospace systems.

Real-time programs

Cray systems are ideally suited to support the objectives of several major aerospace programs through direct, real-time linkage to the external world. In next-generation satellite ground telemetry processing, as is planned for NASA's Space Station program, data will arrive at peak rates of 300 to 600 Mbytes/sec, with sustained rates of 100 to 200 Mbytes/sec, on a 24-hour duty cycle. Current satellite telemetry processing systems can handle data at rates of at most 5 to 10 Mbytes/sec due to a lack of processing and I/O capability. Programs such as these are ideal for applying the traditional Cray system strengths of large I/O bandwidth, high processing power, and extensive connectivity. Using a Cray high-speed external channel coupled to a special telemetry interface, data can be fed into a Cray system's memory, sorted, and placed on disks for data reduction and analysis at rates required for next-generation satellite telemetry systems.

Cray supercomputers are also a natural choice for primary computational support for next-generation, real-time flight simulation applications. Although powerful computers have been linked to flight simulator equipment for years, the complexity of simulations has grown to the extent that only supercomputers have the computational power required to support today's simulations. Several simulations demand one- to two-millisecond processing. Because Cray systems can apply up to eight processors to simulations, depending on the code, tasks can be completed within one microsecond of wall-clock time while applying three to four milliseconds of processing time.

Many radar systems, such as those at Kwajalein Missile Range or the Ballistic Missile Early Warning System, are primary candidates for supercomputer capabilities. These radar systems must receive data in real time from multiple sources, cross-correlate data within a limited time, and transmit resulting decision-support information to range safety officers or military commanders. The increasing complexity of the processing algorithms and stringent processing time requirements have driven the computational requirements into the supercomputer range. A natural solution to such problems is a Cray supercomputer accepting and analyzing multiple data input streams.

A more comprehensive example of an aerospace system that will use Cray systems in a new way is the National Test Bed (NTB) element of the Strategic Defense Initiative (SDI) program. The NTB will be used to test complex physical systems that are not physically testable, to gather data directly from physical prototypes of new devices, and to provide decision support for the management of multiple complex systems in several geographic locations. The NTB program can use Cray systems to provide direct linkage to external resources in real time, and to supply computational support for large integrated simulations to help manage multiple interacting resources.

Linking Cray systems directly to the external world in real time requires system software that can manage the supercomputer resources according to demands from external equipment. When multiple codes within the computer all demand service within small, separate, and uncorrelated time windows, with some requiring all the processors for that very short time, sophisticated reserve management algorithms must be developed.

Integrated simulation programs

Although supercomputers have revolutionized the aerospace industry with the ability to simulate and test increasingly complex systems, a new dimension of computational simulation is emerging that will challenge the supercomputer industry. To date, most of the phenomena and processes that constitute an aerospace system have been independent enough to be analyzed separately and cross-correlated only at a system level.

However, with systems such as the National Aerospace Plane, the interactions between fluid flow, chemicals, and structures are as important as their independent effects. Simulations of these phenomena must be integrated and linked to other simulation applications in an extended, interactive scenario.

The defense simulation requirements of NTB illustrate the computational complexity of integrated simulation environments. Although the U.S. Department of Defense uses hundreds of independent simulation codes to simulate aerospace defense systems, none can analyze the interactions of these systems with the accuracy required to develop the integrated defense capabilities needed by SDI. Developing and running these next-generation integrated defense simulation codes will require a supercomputer complex larger than any in existence today.

DETEC: a new approach

The DETEC project was initiated three years ago by Los Alamos National Laboratory to help solve this integrated simulation problem. The laboratory is applying over 35 years of experience to complex physics and process-control modeling problems associated with the design and operation of advanced defense systems such as those constituting the NTB. The project, called DETEC (for Defensive Technology Evaluation Code), has resulted in a completely new application of computational simulation technologies to the design and development of complex aerospace and defense systems.

Four significant aspects define the DETEC concept: a full fidelity representation of the real world, a nondeterministic representation of the discrete objects in that real world, interaction of these discrete objects, and management of actions based on the perceived world versus the real world. Representation of the real world within DETEC allows it to handle multiple physical processes, physical phenomena, and object-state vectors at variable resolutions and scales. DETEC handles the nondeterministic attributes of the discrete objects in the real world using an approach based on information theory, and provides a multifidelity engagement model that controls discrete object interactions. The concept of perceived worlds allows DETEC to account for the information errors, inaccuracies, and incomplete data that characterize complex defense system scenarios.

Figure 1 illustrates the three major functional groupings that constitute DETEC: system functions, real-world functions called "Mother Nature," and "engagement" functions. The system functions provide the traditional capabilities, such as user interface, simulation management, and output control. All

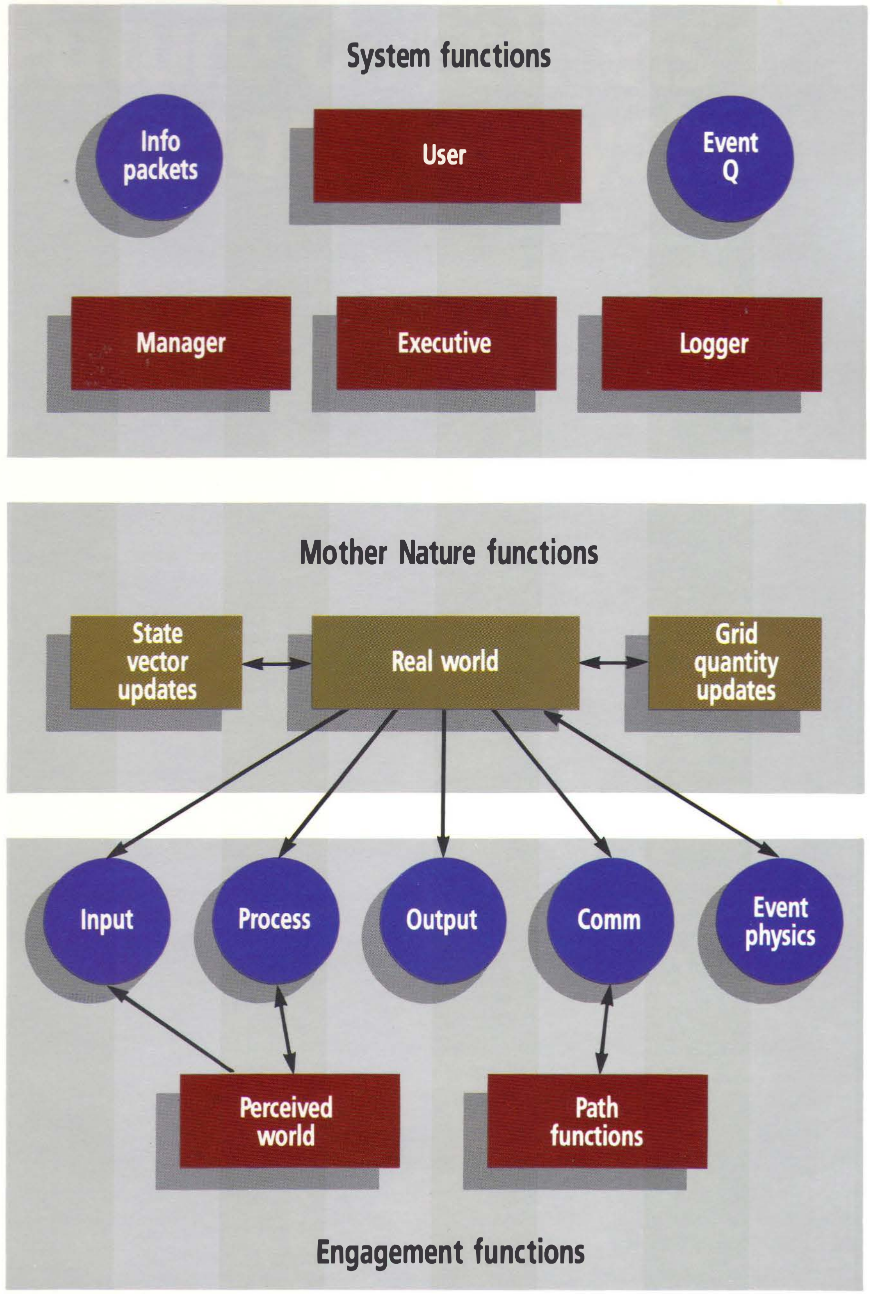
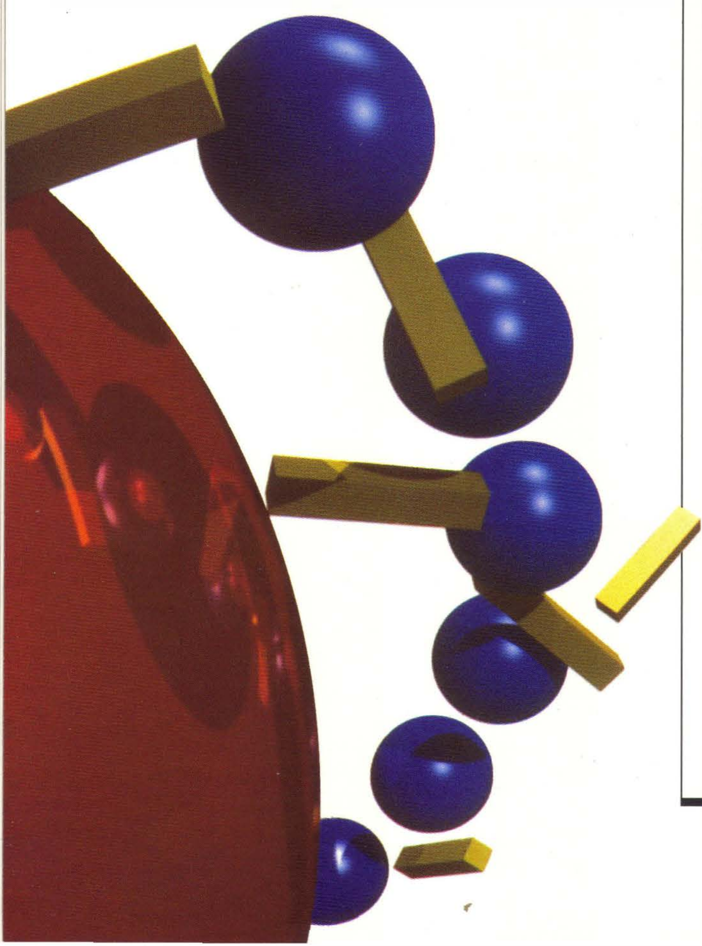


Figure 1. DETEC functional groupings.



the actions and interactions occurring within DETEC are defined by the Mother Nature functions. These functions describe the environment in which discrete objects operate. At any instant, the physical processes and states existing within Mother Nature define a closed system capable of being projected in time along a deterministic path.

The engagement functions link the deterministic elements of Mother Nature with the nondeterministic attributes of the discrete objects, using the input-process-output model of information theory. The engagements are generic, rather that explicit, and account for extended and unintended consequences of the actions of discrete objects.

The DETEC approach to integrated simulation will allow multiple, interacting, physical phenomena to coexist; allow multiple, distributed, dissimilar processes to interact; and allow these physical and system processes to build upon each other. DETEC is targeted for very large-scale, general-purpose computers to ensure its capabilities are not limited by the performance or architectural limitations of host computing systems. DETEC presently runs at Los Alamos on CRAY X-MP systems with SSD solid-state storage under the CTSS operating system. The code is interactive to support efficient development, and is intended to execute in real time to support man-in-the-loop experiments and hardware validations. DETEC is an excellent example of future integrated simulation codes that require the power of supercomputer systems.

Integrating structural and thermal analysis

In the engineering design area, an application called FANTASTIC (Failure Analysis Nonlinear Thermal and Structural Integrated Code) is being developed by Failure Analysis Associates, Inc. of Palo Alto, California, under contract to NASA Marshall Space Flight Center (MSFC). FANTASTIC provides an example of the integration of thermal and structural analysis. Although motivated by the need for more accurate analysis of hot rocket motor nozzles, FANTASTIC provides a general thermostructural analysis capability. The program contains finite element thermal and structural analyzers that may be used in an integrated thermostructural analysis, or used separately for stand-alone thermal or structural analysis. The code is being installed on a CRAY X-MP system at NASA MSFC.

Figure 2 provides a schematic of the FANTASTIC program architecture. It consists of the Interactive Analysis and Control (IAC) analysis management system, two databases, and five processing modules. The IAC provides a user interface for data entry and queries, and controls the analysis flow between modules. The IAC was developed by Boeing Aerospace Company for NASA Goddard Space Flight Center, and is used without modification.

The FANTASTIC database provides a structure for all files associated with the code, including finite element models, materials data, and analysis results. The pre- and postprocessing database is provided to organize pre- and postprocessing files. It is separate from the FANTASTIC database because its file structure is often proprietary. The pre- and postprocessor module is a pre- and postprocessing program (PPP) for finite element analysis programs, such as Intergraph or PATRAN. It is not a part of FANTASTIC, but is shown because of its importance in finite element analysis. The PPP translator program provides a translator between the PPP database and the FANTASTIC database. The translator provides the flexibility to allow PPP to be used with a specific finite element code.

The FACT, FAHT, and FAST modules provide thermal and structural analysis. FACT is a thermochemical analyzer that performs gas flow field analysis, boundary layer analysis, and surface thermochemistry analysis. FAHT is a heat transfer and mass diffusion analyzer that performs heat transfer analysis and mass diffusion analysis by the finite element method. FAST analyzes structures with the finite element method.

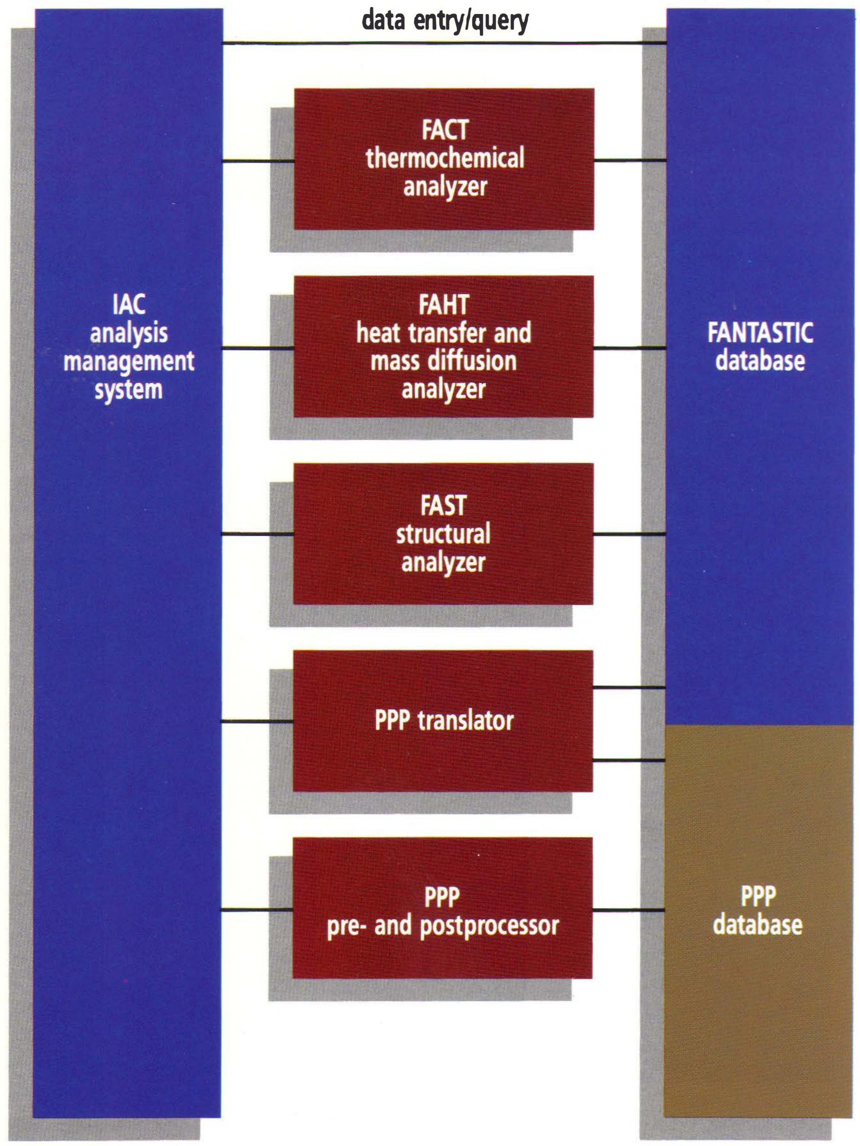


Figure 2. FANTASTIC program architecture.

Growing needs

Both DETEC and FANTASTIC demonstrate the emergence of integrated simulation and engineering design capabilities that will impose immense computational loads — even upon supercomputers — as needs grow for greater fidelity and extended capabilities. In addition, real-time operational environments such as the National Test Bed represent the opening of new application areas in the aerospace industry.

About the author

Karen Allen is an aerospace system engineer with Cray Research's aerospace industry marketing department in Sunnyvale, California. Her primary areas of expertise are in government requirements analysis, aerospace system design, and real-time systems. Allen joined Cray Research in early 1987 after working for Control Data Corporation for 16 years. She received a B.S. degree in mathematics from Stanford University in 1964.

Fighter canopy optimization at General Dynamics

J. Carl McConnell, General Dynamics Structures Technology Department, Fort Worth, Texas

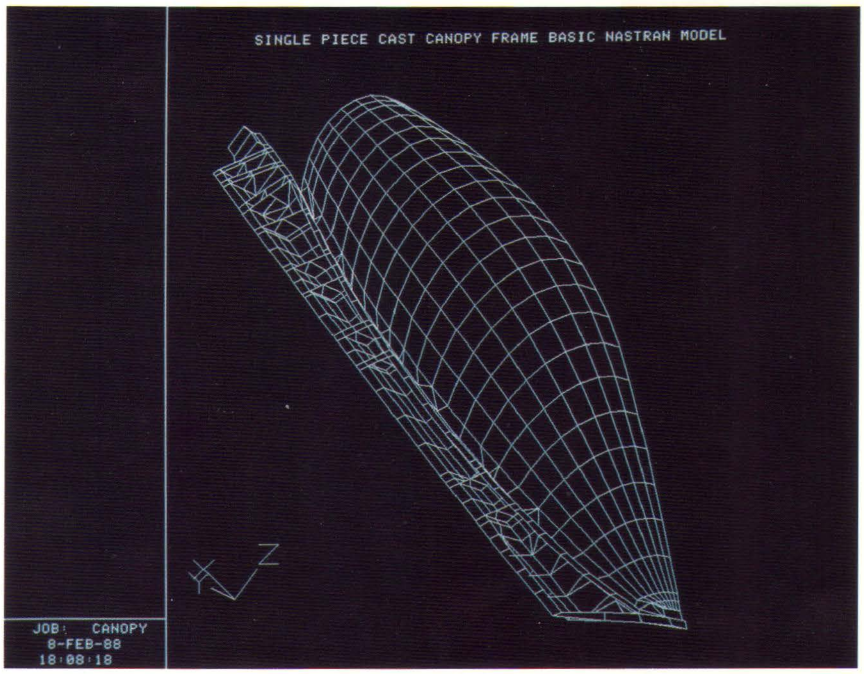


Figure 1. NASTRAN model of F-16 canopy. Access covers are removed to show the internal stiffeners.

Single-piece cast canopy frame ADS/NASOPT example

Design variables:	88 design variables representing gage thickness for various parts of the canopy frame.	
Constraints:	Gauge thickness: 0.080 < T < 0.500 in	
	Stress: casting, Von-Mises stress ≤ 26,250 psi	
	transparency, Von-Mises stress ≤ 2000 psi	
	covers, bow hoop, principal stress −40,000 ≤ stress ≤ 50,000 psi	
	tension rod, axial stress ≤ 75,000 psi	
Materials:	Frame cast: A357	Young's modulus = 10.4 E6 psi Poisson ratio = 0.33 density = 0.097 lb/in³
	External covers, bow hoop: 2024	Young's modulus = 10.7 E6 psi Poisson ratio = 0.33 density = 0.101 lb/in³
	Transparency: polycarbonate	Young's modulus = .35 E6 psi Poisson ratio = 0.37 density = 0.0429 lb/in³
	Pivot fitting, tension tie: steel	Young's modulus = 29 E6 psi Poisson ratio = 0.33 density = 0.283 lb/in³

Table 1. Behavioral constraints and material properties of model components.

The automated execution of complex structural engineering design requires iterative analysis and is a computationally intensive task made possible only through the use of supercomputers.[1] Manually iterated analysis and resizing is the alternative to automated structural design techniques. Manual techniques are practiced widely in industry, but require specially prepared and developed routines to perform data recovery and resizing. The resizing routines rarely are standardized and lack the ability truly to optimize because they do not take into account all engineering factors, such as aerodynamics, flight performance, and mission requirements.

General Dynamics Fort Worth Division engineers are performing extremely complex structural design problems with a CRAY X-MP/28 system. Automated engineering design is accomplished with the ADS (Automated Design Synthesis) subroutine in conjunction with MSC/NASTRAN via the ADS/NASOPT routine supported by Warren Gibson at CSA Engineering, Inc. ADS is an optimization code developed by Garret Vanderplaats of Engineering Design Optimization, Inc. ADS/NASOPT prepares an approximate design model by screening NASTRAN analysis results and the information obtained from NASTRAN design sensitivity analyses. The approximate model is presented to the ADS subroutine for optimizing, and the results are updated automatically into the design and analysis models.

Optimizing the F-16 canopy

A design study of a single-piece cast canopy frame for the F-16 fighter plane gave General Dynamics engineers and designers some insight into the capabilities of the ADS/NASOPT routine for structural optimization. A modern fighter canopy is constructed primarily of a polycarbonate transparency mounted in an aluminum frame. The frames are very labor-intensive products made from various castings, extrusions, and plate and sheet stock.

Figure 1 shows a basic NASTRAN model of the canopy with access covers removed to reveal the internal stiffeners in the canopy frame. The finite element model comprises 1140 grid points, 588 elements, and two load cases. The model has one plane of symmetry at the center line, and the applied loads are symmetric.

To represent various components of the canopy model, 88 design variables were assigned. Table 1 lists the model components, their behavioral

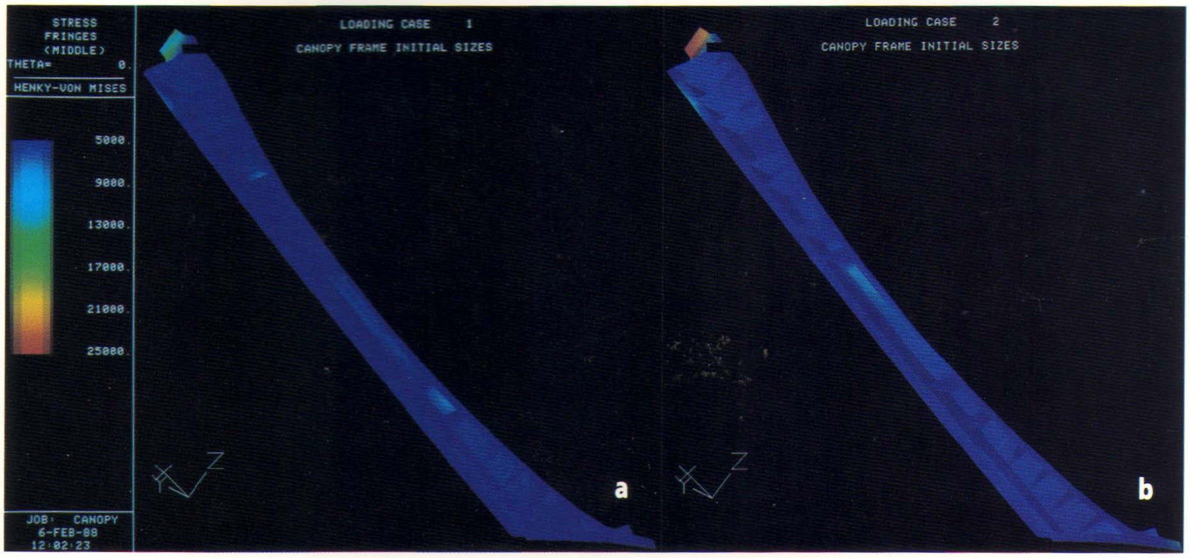


Figure 2. Stress distribution in the canopy frame for the design load condition for the initial design. The transparency has been omitted for clarity; (a) cabin pressure, (b) ejection condition.

Figure 3. Stress distribution for the final design; (a) cabin pressure, (b) ejection condition.

constraints, and the material properties. The design objective was to create a minimum weight structure with an additional behavioral constraint — that the first modal frequency reside in a range close to that of the current production model.

Linking design variables

The 84 design variables describing the canopy frame were given initial gauge sizes of 0.200 inch, and permitted to vary from a minimum thickness of 0.080 inches to a maximum of 0.500 inches. Design variables representing the access covers, pivot fittings, bow hoop, tension tie rod, and transparency were given properties based on the current production canopy because these items were to be carried over, unchanged from the canopy assembly as it now exists.

However, by defining these "fixed" components as design variables, behavioral constraints (in this case stress constraints) could be imposed on these components, causing the casting to be optimized not only for its internal stresses, but for stresses in components attached to the cast canopy frame. In particular, design variables were linked to ensure that the optimization sequence sized the canopy frame so that stresses in the polycarbonate transparency and access covers did not exceed current hardware limits (Figures 2 and 3).

One iteration comprises a static analysis, a modal analysis, static and frequency sensitivity analyses, and the creation and solution of an approximate model by ADS optimization software. Two separate paths were followed toward optimum design. The first path involved using the ADS optimization scheme for four iterations. One fully stressed design, FSD (stress-ratio) step, started off the second path, which required two additional iterations before converging. Each path resulted in a different final weight within the number of iterations pursued, which shows that an optimum design may not be unique. Each full iteration required approximately 60 seconds on the CRAY X-MP computer system; the FSD step required 38 seconds. The total design study required four minutes following the

This result just happens to satisfy one additional requirement — that a new design for a canopy frame should not alter the weight and balance of the production aircraft to any appreciable degree.

first path, and three and one-half minutes following the second path. Figure 4 shows the design iteration history.

A design success

The final design weight of the cast frame canopy structure compares extremely well to the current built-up frame assembly weight. This result just happens to satisfy one additional requirement — that a new design for a canopy frame should not alter the weight and balance of the production aircraft to any appreciable degree. This particular study was beneficial not only in giving the design team an acceptable preliminary starting point for their detail design work, but also in demonstrating the enormous potential for optimization provided by the CRAY X-MP system.

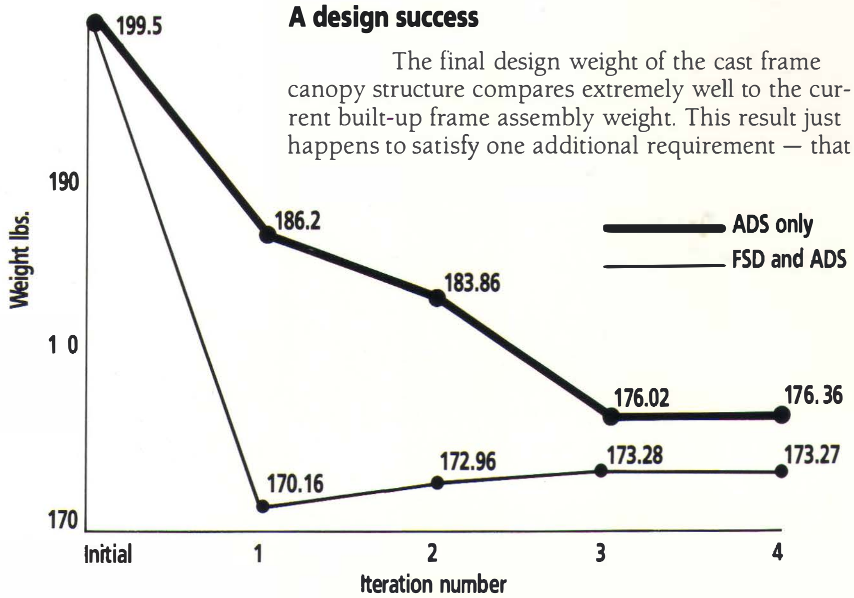


Figure 4. Design iteration history.

Acknowledgments

This article is adapted from the author's master's thesis. The canopy model described here was adapted from a model developed by Norman Lindsey at General Dynamics, Fort Worth Division.

About the author

J. Carl McConnell has worked as a stress analyst in the structures group at General Dynamics Fort Worth Division since 1982. He earned his B.S. degree in mechanical engineering from Pennsylvania State University and is currently completing his M.S. degree at the University of Texas, Arlington.

Reference

1. Vanderplaats, G. N., "Computational Requirements and Trends in Design Optimization," *CRAY CHANNELS*, Vol. 8, No. 4, 1987, pp. 16-21.

Testing canopy strength

Simulation of a bird strike on an F-16 canopy at 500 knots (575 miles per hour).

Before a new F-16 canopy designed at General Dynamics is certified, it must be tested to withstand the impact of a bird strike at 350 knots (approximately 403 miles per hour). Otherwise, a bird strike could cause a canopy to fail, injuring or killing the pilot. To test canopy strength, birds are fired at the canopy from a long steel pipe 75 feet away while high-speed cameras record the event.

By using its CRAY X-MP/24 system to simulate a bird strike on an F-16 canopy, General Dynamics engineers have reduced the amount of physical testing needed. "Physical tests are very expensive; one test would pay for all model development analysis so far," says engineering specialist Keith Hunten, who designed software for pre- and postprocessing analysis.

Computationally simulating a bird strike is an extremely complex process that combines many different nonlinear problems, says Hunten. "The problem takes into consideration the contact problem, the deformation behavior of the bird during the period of time it is in contact sliding along the canopy, and the mechanics of the nonlinear material and large deformations encountered during the strike." To simulate the bird, the mechanics of the bird strike, and its deformation, a special subroutine was written.

Analysis is performed with the ABAQUS code. Results from a series of time steps are then translated into sequential load cases. "Many hidden surface contour plots are made," says Hunten, "but the light-source shaded color fringe images of strain and deflection data produced by our GD-Display graphics package are most useful." With GD-Display, Hunten and colleagues created a movie to present the data. "Since the problem is very time-dependent, animation of the analysis provides even greater insight into the physics of the problem," says Hunten. A capability to interpolate between the time steps (each stored in a separate load case in the database) was incorporated into GD-Display to perform this animation. Each time step is treated as a key frame, with several frames linearly interpolated between the time steps to provide smooth motion.

Engineer Norman Lindsey, who designed and performed the analysis, explains that the complexity of this problem requires the memory of a Cray system with SSD solid-state storage device. "This is a very difficult problem to debug. No other computer could debug this model and solve the problem in a reasonable amount of time," he says. "This allows timely consideration of alternative designs."

CORPORATE REGISTER

Customers join Cray Research's worldwide market

In December Cray Research announced its first Spanish customer — **Construcciones Aeronauticas, S.A.** (CASA) — an aerospace agency located in Madrid. CASA ordered a CRAY-1/S computer system. The agency will use the Cray system for computational fluid dynamics, aeronautical optimization, structural analysis, and basic research. To support Spain's supercomputer needs, Cray Research has opened a subsidiary office in Madrid. Sales manager Eugenio Pardo will direct the new office.

Technology Applications, Inc., acting as prime contractor for the United States **Naval Underwater Systems Center** (NUSC), ordered a CRAY X-MP/28 computer system with SSD solid-state storage device. The system was installed at the NUSC labratory in Newport, Rhode Island in the fourth quarter of 1987, and will also provide service to the NUSC laboratory in New London, Connecticut. The center will use the machine for scientific and engineering applications including structural analysis, computational fluid dynamics, signal processing, simulation and modeling, combat systems engineering, and environmental analysis. Cray Research announced the order in December.

Also in December, Cray Research announced that French tire manufacturer **Michelin** ordered a CRAY X-MP/14se computer system. The system was scheduled for installation in the first quarter of 1988 at Ladoux Research and Test Center in Clermont-Ferrand, France. Michelin is the first tire manufacturer to order a Cray computer system. The company will use the Cray system for tire research and development.

In January Cray Research announced that **Bayerische Motoren Werke AG** (BMW) ordered a CRAY X-MP/28 computer system with SSD solid-state storage device. The system, which is the tenth Cray system in the automotive industry, is scheduled for installation in the second quarter of 1988 at BMW's engineering center in Munich, West Germany. It will be used for structural analysis, crash analysis, and computational fluid dynamics.

Marathon Oil Company, a subsidiary of USX Corporation, has ordered a CRAY X-MP/14se computer system. The system, which is the first Cray supercomputer for Marathon Oil, will be installed in the second quarter of 1988 at the company's Exploration and Production Technology Center in Littleton, Colorado. The company will use the system for general petroleum research, including seismic analysis and reservoir modeling. Cray Research announced the order in January.

In February Cray Research announced that **Exxon Research and Engineering** of Clinton, New Jersey, has ordered a CRAY X-MP/14se computer system. Exxon R&E plans to use the computer system for applications including computational chemistry, computational fluid dynamics, process engineering, simulation and modeling, and algorithm development. The system will be installed at a new supercomputer center managed by Exxon R&E in Clinton Township.

In February Cray Research announced that the **Commissariat à l'Energie Atomique** (CEA) had ordered a CRAY X-MP/28 computer system and a CRAY X-MP/14se computer system. Both systems will be used for scientific research and development to supplement existing Cray systems used by CEA. The CRAY X-MP/14se computer system was installed in the first quarter of 1988 at CEA's computer facility in Cadarache, France, and the CRAY X-MP/28 computer system will be installed in the third quarter of 1988 at CEA's facility in Saclay, France.

Cray Research announces marketing promotions

In December Cray Research announced three significant promotions in the company's marketing organization, including the election of two new officers.

Neil Davenport has been elected a vice president of Cray Research. Davenport joined the company in 1981 as managing director of Cray Research (UK) Ltd. Prior to joining the company, Davenport served for 11 years in marketing and sales with ICL, a British computer manufacturer.

Cray Research has elected Edward Masi vice president, marketing. Masi has been with Cray Research since 1980, serving as general manager of the company's U.S. Eastern Region. Prior to joining Cray Research, Masi worked for 11 years with International Business Machines Corporation (IBM). He received a bachelor of science degree in mechanical engineering from Tufts University in 1969.

Charles Breckenridge has been named to replace Masi as general manager of the company's Eastern Region. Breckenridge joined Cray Research in 1980, and has served as an account manager and regional marketing manager in the company's U.S. Western Region. Prior to joining Cray Research, Breckenridge operated his own electronic business equipment company. He received a bachelor of science degree in electrical engineering from the University of Minnesota in 1956.

CFT77 release 2.0 offers performance improvements

Release 2.0 of CFT77, a vectorizing, scalar optimizing, and multitasking Fortran compiler for all Cray computer systems, is now available. CFT77 is an extended implementation of the ANSI X3.9-1978 (Fortran 77) standard.

Previous releases of CFT77 incorporated all features of the ANSI Fortran 77 standard, many features well-established as Fortran extensions, and features expected to appear in the next ANSI Fortran standard. Release 2.0 adds new features including

- ☐ Vectorization of more loops
- ☐ Faster compiling (performs approximately 8 percent faster than previous release on CRAY X-MP systems and 20 percent faster on CRAY-2 systems)
- ☐ Improved dependency analysis for vectorization
- ☐ Source INCLUDE facility
- ☐ LOOPMARK facility
- ☐ SHORTLOOP directive
- ☐ Tabs
- ☐ New directives to control bottom loading
- ☐ Generation of new traceback format, which allows use of UNICOS-shared code feature
- ☐ Alternative error-listing file for COS

Release 2.0 of CFT77 also incorporates CRAY-2 system performance improvements. These include improved generated code, less local memory usage by subprograms, and options to limit local memory use. Also, TASK COMMON storage for multitasking is now implemented for all Cray systems.

With CFT77, a Fortran program that compiles and runs on one Cray system will compile and run on all Cray systems. CFT77 runs on CRAY-2, CRAY X-MP, and CRAY Y-MP computer systems under the UNICOS operating system. The compiler runs on CRAY-1 and CRAY X-MP computer systems under the COS operating system.

CFT77 contains several external functions that provide access to system and user library routines. Products and tools available include

- ☐ Extensive scientific library
- ☐ Symbolic debugging package
- ☐ Segment loader
- ☐ Hardware performance monitor for CRAY X-MP and CRAY Y-MP systems
- ☐ Flow-tracing and program-analysis tools
- ☐ Links to non-Fortran routines
- ☐ System I/O routines

For additional information about obtaining release 2.0 of CFT77, contact the nearest Cray Research sales office.

Cray Research announces NOS/VE Link software

Cray Research now offers version 1.0 of NOS/VE Link software, a modular communication product that links Control Data Corporation's CYBER 180 computer systems (except model 930) with Cray computer systems running under the Cray operating systems COS or UNICOS. This new product offers full station functionality, including batch job submission, file transfer, interactive access, and status and control facilities.

Items required to operate NOS/VE Link software include

- ☐ COS 1.15 BF3 or later, or UNICOS 2.0 or later
- ☐ NOS/VE 1.2.3 level 688AC
- ☐ Cray Network Interface (FEI) or NSC HYPERchannel connection

Release 1.0 of NOS/VE Link software provides features including

- ☐ Batch job submission from NOS/VE to the Cray input queue; the Cray system's job output is returned to the NOS/VE output queue or to a NOS/VE permanent file
- ☐ Data set transfer to and from the Cray computer system in response to the execution of the Cray ACQUIRE, DISPOSE, and FETCH statements within Cray jobs
- ☐ Status display of Cray jobs and the Cray computer system; Cray jobs are controlled by using the drop, kill, rerun, or switch functions
- ☐ Cray interactive job execution from a NOS/VE terminal
- ☐ Cray master operator functions
- ☐ System fine-tuning or problem resolution using the trace and debugging facilities
- ☐ Accounting for resources used by the station or station users
- ☐ Support interaction between NOS/VE and NOS (or NOS/VE) in dual-state mode

The Cray environment is a NOS/VE command utility that provides the user interface to the Cray computer system. Features supported in the Cray environment include job submission, Cray system status and job status display, interactive access, and access to an on-line reference manual.

During execution on a Cray system, the job can access or create files on the CDC front-end system by using the Cray ACQUIRE, DISPOSE, and FETCH data transfer statements. These statements provide a TEXT parameter that lets users uniquely identify the NOS/VE file to be staged.

Users can specify station commands that display status information and manipulate jobs as they pass between NOS/VE and Cray systems. Status commands let users display information about the status of both the Cray system and specific Cray jobs at the NOS/VE terminal. Job manipulation commands let users select, drop, kill, or rerun Cray jobs.

The operator environment is a NOS/VE command utility that provides operators and administrators interface to the Cray computer system. All user station commands that are available in the Cray environment are also available in the operator environment.

Multiple copies of the operator environment can be active simultaneously. The environment can be brought up from an interactive terminal, from a batch job, or from the NOS/VE console. Features supported in the NOS/VE operator environment include

- ☐ Cray operator functions
- ☐ Station activation and termination
- ☐ Station configuration
- ☐ Trace facilities and basic diagnostics functions
- ☐ User station commands

For additional information about using NOS/VE Link with Cray computer systems, contact the nearest Cray Research sales office.

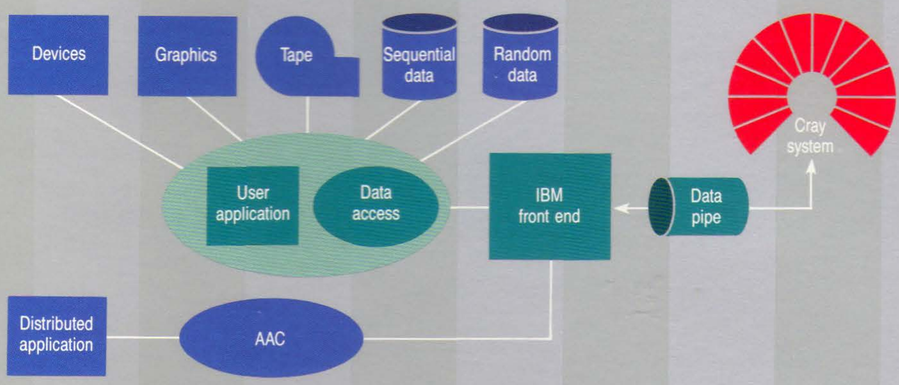
Improved C compiler boosts CRAY-2 system performance

Cray Research has released the first automatic vectorizing C compiler for CRAY-2 computer systems. Release 2.1 of the Cray C compiler allows CRAY-2 system users to take greater advantage of the increasing number of applications programs written in the C programming language.

Release 2.1 of the Cray C compiler, based on the portable C compiler from AT&T, executes on all CRAY-2 systems. It translates C language statements into assembler instructions that effectively use the CRAY-2 system.

New features that enhance performance in release 2.1 of the C compiler include

- ☐ Automatic vectorization of many FOR loops encountered in a C program
- ☐ Common subexpression elimination, a compile-time option that enhances the performance of generated code and allows users to specify optimization levels
- ☐ The choice of either faster computation through 46-bit integer arithmetic, or extended precision through 64-bit integer arithmetic (Integers are now stored in 64-bit words; short integers continue to be implemented in 32-bit words)
- ☐ Flexnames, a feature that allows variable names of up to 244 characters in upper- and lowercase
- ☐ Intrinsics, a command-line option that invokes intrinsic functions, allow-



Superlink/MVS organization.

ing inline function code to be generated in lieu of the expensive overhead of a jump to a function
☐ Command line -F option, which enables flowtrace processing

This latest release of the Cray C compiler operates on CRAY-2 systems under Cray Research's UNICOS operating system. The C programming language offers a large standard library of functions, and C programs can call both the Cray Assembly Language (CAL) assembler and Fortran routines to maximize performance.

The C preprocessor, *cpp*, is included as part of the C compiler. The preprocessor allows macro substitution, conditional compilation, and the inclusion of named files in the compilation process.

SUPERLINK/MVS 2.0 provides enhanced communication link

Cray Research now offers SUPERLINK/MVS 2.0, a high-performance software link between the Cray operating system, COS, and the IBM operating system, MVS. SUPERLINK/MVS, which is used with the Cray MVS station, provides fast sequential and random access to MVS data sets from COS jobs. It also provides application-to-application communication (AAC) for distributed processing.

SUPERLINK/MVS runs on CRAY X-MP computer systems under COS 1.16 or later, and runs on CRAY-1 computer systems configured with a Cray I/O Subsystem (IOS). It links to IBM/370 or compatible mainframes running the MVS/XA operating system.

With SUPERLINK/MVS, a COS user job has sequential or random access to an MVS front-end resident data set as if it were local. This enables a Cray Fortran user to access IBM/MVS data at the record level in both sequential and random mode, which allows
☐ Local access to MVS data without data set staging
☐ Access to random datasets on MVS
☐ Access to datasets that are too large for Cray system storage
☐ Improved throughput over the Cray MVS station

SUPERLINK/MVS 2.0 also offers application-to-application communication (AAC), a symmetric, operating system-independent facility for distributed applications processing over a full-duplex path. With AAC, applications residing on different systems can exchange information, allowing the applications to be distributed.

For more information about using SUPERLINK/MVS, contact the nearest Cray Research sales office.

Cray Research releases improved migration tools

To help users migrate from COS to UNICOS, Cray Research now offers release 2.0 of the migration tools package. Supplementing these tools are Cray Research's migration support team and the COS Guest Operating System (GOS) feature.

This release of the migration tools package includes a premigration site analysis tool, a new version of the COS file-format converter, application coversion aids, a menu system, and a sample accounting interface. The package consists of software tools on tape, and a binder with migration notes and documentation describing the tools.

Tools retained from release 1.0 consist of
☐ Premigration site analysis tool (COSJCL), which collects statistics on site use of COS
☐ CAL translator, which converts a CAL version 1 source file into a CAL version 2 source file for CRAY-2 systems
☐ JCL converter tools (*cjprnt*, *cjcl*, *cjproc*, and *cjplib*), which aid in the conversion of COS JCL to UNICOS shell script

New software tools consist of
☐ A menu system, including a JCL-equivalents menu that helps new or infrequent UNICOS users perform basic tasks
☐ A COS file-format converter, *cosrd*, that modifies the format of COS files to conform to UNICOS format (replaces the *ctou* and *ptoa* PDSDUMP file conversion tools from release 1.0)
☐ $DMYLIB library of entry points for UNICOS routines, which identifies a COS application's use of any COS library routines that will be unavailable when the program is ported to UNICOS
☐ The *libmig* migration library, which provides the functions of the COS GETPARAM routine
☐ An accounting interface that can be customized to allow accounting information output under UNICOS to conform to the format generated by a front-end accounting summary program

Migration note topics retained from release 1.0 consist of
☐ UNICOS philosophy
☐ Introduction to migration notes
☐ Premigration site analysis tool
☐ CAL migration
☐ JCL conversion utilities
☐ Comparison of Cray Fortran environments in COS and UNICOS
☐ System analyst's guide to GOS
☐ Comparison of batch processing in COS and UNICOS
☐ System-action request equivalents
☐ JCL equivalents
☐ GOS installation

Release 2.0 migration notes include
☐ Application conversion tools
☐ Formatting UNICOS accounting information
☐ UNICOS menu system guide
☐ COS file-format conversion tool, which replaces the PSDDUMP format file conversion tools *ctou* and *ptoa*
☐ Application conversion techniques

Training for migrating from COS to UNICOS also is available. Contact the nearest Cray Research sales office for additional information.

Helicopter aerodynamic analysis with VSAERO and USAERO

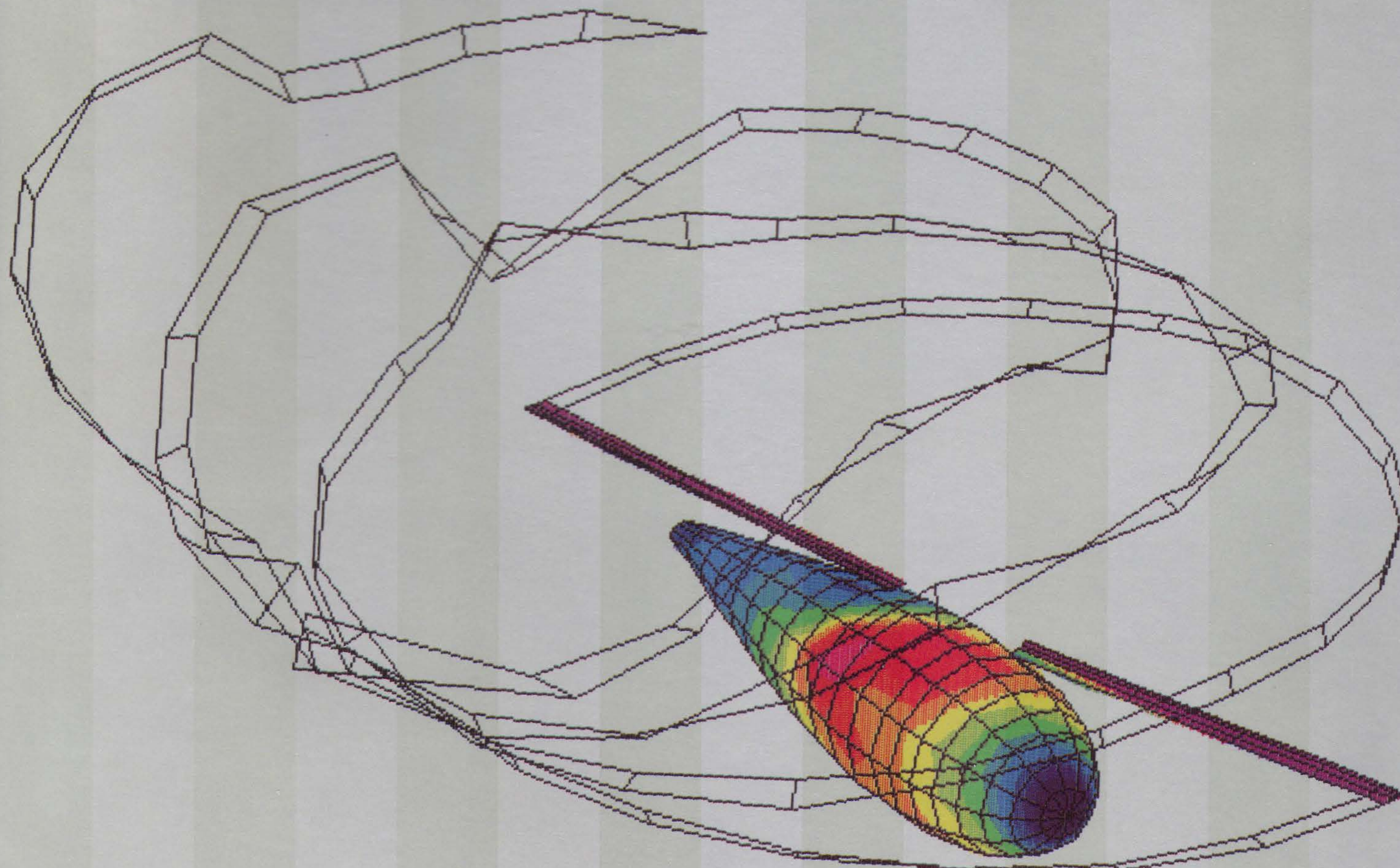
Aerodynamic helicopter designs must take into account the real-world forces met in aircraft operation, such as separated flow, vortex interference, power plant inlet and exhaust effects, and even internal flow.

VSAERO software, which runs on all Cray computer systems under COS and UNICOS operating systems, enables helicopter designers to calculate the performance of a coupled rotor and fuselage configuration. VSAERO achieves coupling through a blade-element model of the rotor, providing the radial and azimuthal loading on a panel model of the disk, the area described by the rotating blades. With this approach, designers can calculate rotor-body and body-rotor effects. VSAERO, which stands for Vortex Separation Aerodynamics, is a second-generation, low-order panel method developed by Analytical Methods, Inc.

As models grow in detail, the computer processing required to solve them increases at a rate somewhat higher than the square of the number of panels. The standard version of VSAERO models up to 3000 panels and operates on a wide range of computers. An expanded version of VSAERO, which requires the use of a Cray system, models up to 10,000 panels. This version will handle problems such as the new 80-by-120 wind tunnel at NASA Ames Research Center, and will allow users from automotive, aerospace, and other industries to create more detailed models.

A typical VSAERO project is the tilt-rotor aircraft being developed by Bell Helicopter Textron, Inc. and Boeing Helicopter Company. The performance of this aircraft, which can operate in both helicopter and fixed-wing modes, is influenced strongly by the interaction of rotor downwash and the wing.

VSAERO performs steady-state analysis; that is, it assumes a vehicle is in uniform motion. In most cases, a time-averaged flow is adequate, but in the helicopter problem, this is not the case. In some situations, knowledge of the un-



Contours of surface wing pressure on NASA Ames 40-by-80 rotor test module, with a two-bladed H-34 rotor at 0.15 advance ratio.

steady behavior is essential. To provide this knowledge, a new program, USAERO, has been developed that uses the same basic flow model as VSAERO.

USAERO (for unsteady aerodynamics) operates in a time-stepping mode, solving for the body aerodynamics at a given time, then solving for the next time step, moving the body and its wake as appropriate. USAERO applications include the calculation of aircraft in dynamic flight, such as in response to a gust, or in the unsteady motion of some store released from an aircraft. USAERO also is being used to examine the unsteady motion of a helicopter rotor relative to the fuselage.

For the first time, designers can examine the full spectrum of unsteady loads encountered by a helicopter rotor blade as it rotates in the presence of the fuselage. The accompanying figure is taken from a calculation of a rotor in forward flight at about 70 knots, as the rotor blade passes over the front fuselage of a body. The picture is scaled to represent a simple wind tunnel test module.

For clarity, the figure shows only the outermost element of the distorting helical wake sheets laid by the rotor blades. This illustrates the distortion of the wake sheets as they drift back over the body. The color contours show variations in surface pressure, with blue representing higher pressure, and red indicating lower pressure. The contours show how fluctuating local pressures can generate unsteady loads on the body. The rotor, passing through the highly nonuniform flow field created both by its own wake and by body interference, also suffers a fluctuating load as indicated by the unsteady leading-edge history on one of its blades. The dynamic loads on the body and rotor add up to become a fluctuating force that creates undesirable vibration.

USAERO's target is to provide insight into these vibration problems, which eventually will lead to smoother, quieter helicopters. The payoff for reduced vibration, lower stress, and the resulting increased component lift, will be a more comfortable ride and lower life-cycle costs.

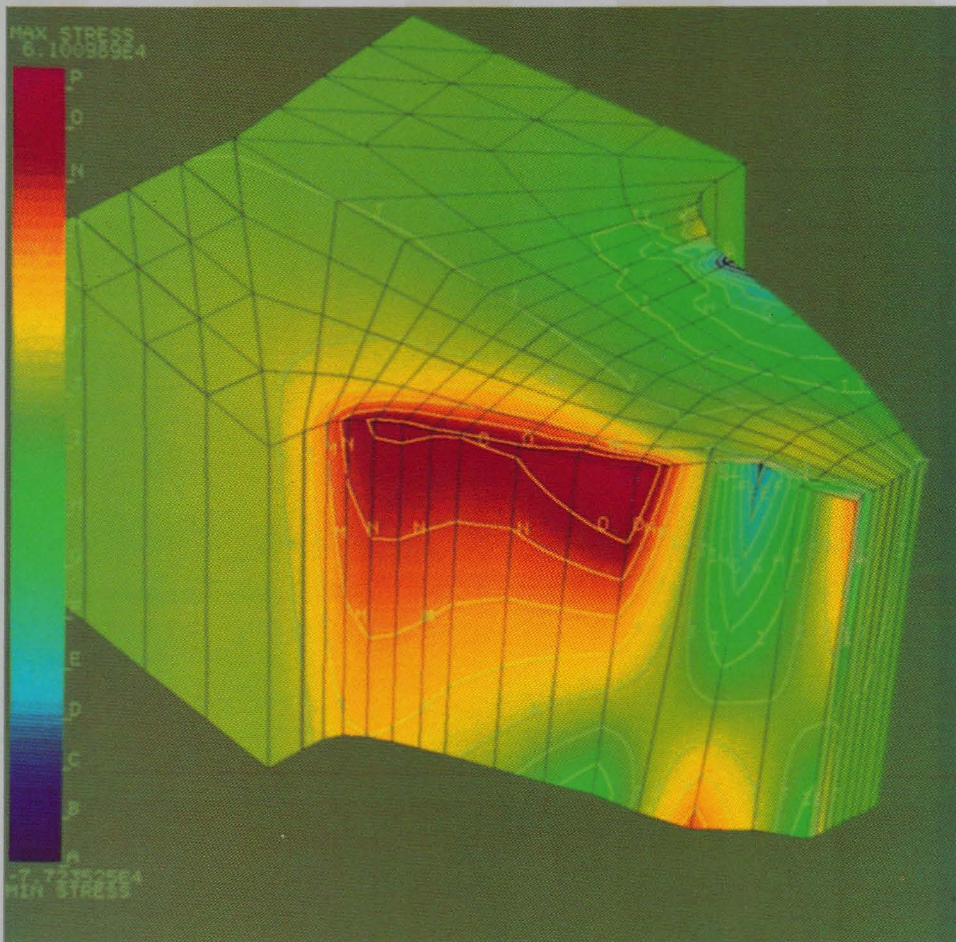
For more information about using VSAERO and USAERO with Cray computer systems, contact David Clark, Analytical Methods, Inc. P.O. Box 3786, Bellvue, WA 98009; telephone (206) 643-9090.

MSC/NASTRAN update includes new features

MSC/NASTRAN solves a wide variety of engineering analysis problems using the finite element method. The program has been applied to problems involving static and dynamic structural analysis, material and geometric nonlinearity, heat transfer, aeroelasticity, acoustics, and electromagnetics. The program, which is a product of the MacNeal-Schwendler Corporation, runs on CRAY-1, CRAY X-MP, and CRAY Y-MP systems under the UNICOS and COS operating systems. It is currently being ported to run on CRAY-2 systems.

MSC/NASTRAN features sparse matrix routines, multilevel supplements, cyclic symmetry, generalized dynamic reduction, and component mode synthesis. Version 66 will feature major enhancements, including a new executive system that provides improved data management, restart, and analysis. The new executive system provides users with the foundation needed to implement an Engineering Analysis Data Base Management Utility System (EADMUS).

This capacity allows programs such as MSC/NASTRAN and user-developed code



Stresses on a gear tooth as simulated by MSC/NASTRAN.

to store and retrieve information directly to and from a common database, and to provide direct interaction between the various software packages. These improvements enable users to apply MSC/NASTRAN to a broader set of engineering problems. The new executive system will feature enhancements including

- ☐ MSC/NASTRAN Definition Language (NDDL), which is the key feature in the description of the database, and handles the distribution of data between machine types by providing the scheme necessary for representing the data block structure
- ☐ Enhanced Direct Matrix Abstraction Program (DMAP), a new DMAP language that allows for structuring solution sequences into task-oriented areas of engineering analysis
- ☐ Automatic restart, based on the dependencies of data blocks, data items within data blocks, and parameters as they relate to changes in bulk data

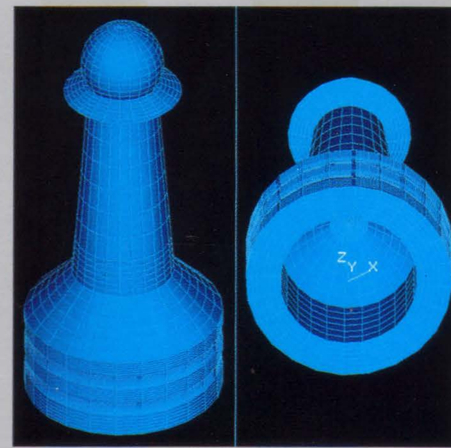
For more information about using MSC/NASTRAN with Cray computer systems, contact Karen Ruppert at The MacNeal-Schwendler Corporation, 815 Colorado Boulevard, Los Angeles, CA, 90041; telephone: (213) 259-3830.

ANSYS revision increases power, flexibility

ANSYS® Revision 4.3 is the latest version of the ANSYS finite element analysis program developed by Swanson Analysis Systems, Inc. The program runs on CRAY X-MP and CRAY Y-MP systems under the UNICOS and COS operating systems.

This revision contains more than 250 enhancements, including new analysis capabilities, more advanced solid modeling features, improved design optimization functions, enhancements to existing analysis abilities, and refinements to the solution process.

New analysis features available with version 4.3 include fluid dynamics and acoustics. Because many of these new features are computationally intensive, they are well suited for use with Cray systems. New fluid flow capabilities allow for coupled heat-transfer/fluid-flow analysis of fluid movement resulting from buoyancy effects, and may be used to determine fluid flow



Automated meshing routines of the ANSYS code reduce the time needed to create finite element models with irregular geometries found in objects such as this chess piece.

patterns in applications involving the low laminar flow velocities typical of free convection. New acoustics capabilities allow users to analyze the propagation of sound waves created by structural vibrations in a fluid medium. An ANSYS acoustics analysis can predict the dynamic response of a structure submerged in a fluid medium.

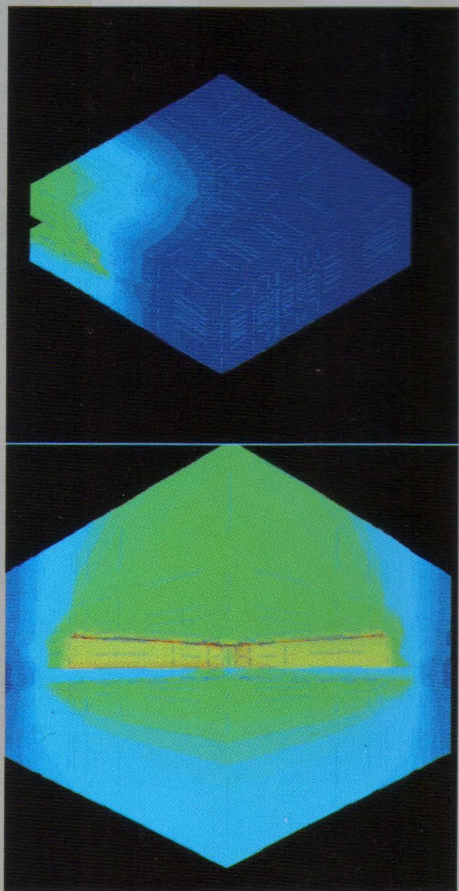
The program's solid modeling features include

- ☐ An option to connect key points or define model entities with a graphic pointing device
- ☐ Ability to apply boundary conditions directly to the solid model, then transfer them to the finite element model
- ☐ Two safety features added to prevent the creation of an invalid solid model
- ☐ Reduced time required for tetrahedral meshing
- ☐ Ability to define triangle-meshed areas and tetrahedron-meshed volumes with up to 200 edges or surfaces, respectively

Revision 4.3 features strengthened design optimization, as well as enhanced analysis capabilities. Most analysis enhancements have been brought about through the addition of elements including

- ☐ New two- and three-dimensional hyperelastic solid elements
- ☐ A new isoparametric composite shell element, designed to analyze composite materials with up to 100 uniform or 50 tapered layers
- ☐ A two-dimensional/axisymmetric multifield element for magnetics analysis
- ☐ A three-dimensional joint element for large deflection analysis for flexible kinematic studies

Also, the solution phase of the ANSYS code has been upgraded in three major ways — with the addition of the mode



Simulation of a printed circuit board from ANSYS.

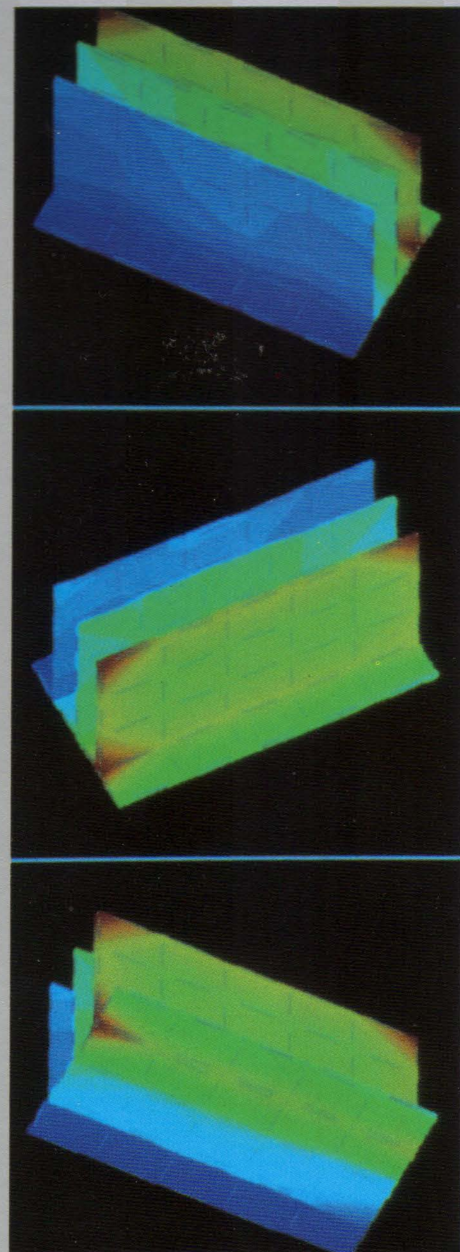
superposition method, the Newton-Raphson incremental solver, and the Newmark integration technique.

For more information about using ANSYS software on Cray systems, call Jim Finkel, Swanson Analysis Systems, Johnson Road, P.O. Box 65, Houston, PA, 15342; telephone: (412) 746-3304.

CACI ports SIMSCRIPT II.5 to Cray systems

SIMSCRIPT II.5® simulation programming language is now available from CACI Products Company to run on CRAY-2 computer systems under the UNICOS operating system. SIMSCRIPT compilers from CACI Products Company have been used to create discrete event simulation models for industries such as defense, aerospace, communications, energy, transportation, distribution, and manufacturing.

Although primarily a discrete event simulation language, SIMSCRIPT II.5 has features to model processes that change continuously with simulated time. This helps users to construct systems that are described in terms of differential equations with superimposed discrete events. The combined capabilities allow users to define models in which dependent variables may



ANSYS simulation of automated radiation view factor computations of printed circuit boards mounted in a simulated satellite.

change discretely, continuously, or continuously with discrete jumps superimposed.

SIMSCRIPT II.5 has been used to formulate and design simulations of communication systems, oil distribution systems, and detailed manufacturing models used to design factory production lines and construction projects. It can simulate efficient patient care and staff use at large health care institutions. SIMSCRIPT has been used in military applications including war gaming, logistics, and C^3I (control, command, communications, and intelligence).

SIMSCRIPT II.5 includes features for ease in all steps of model development, including

- ☐ A powerful "world view" — consisting of entities, attributes, and sets — that provides a natural conceptual framework for design so that real objects can be related to the model. Entities have arbitrarily assigned distinguishing attributes. They are created dynamically and destroyed as they represent the flow of objects through a system. FILE and REMOVE commands allow them to be grouped into appropriate sets.
- ☐ Modern, free-form language that contains structured programming constructs and all built-in facilities needed for model development. Model components can be programmed to clearly reflect the organization and logic of a modeled system.
- ☐ A built-in package of program testing facilities. Tools are included to detect errors in complex computer programs.
- ☐ Program structure that allows models to evolve easily and naturally from simple to detailed formulations as more information becomes available. Many modifications, such as choices of set disciplines and performance measurements, are simply specified in the program preamble in a nonprocedural manner.
- ☐ English-like language that allows for modular implementation. Because each model component is readable and self-contained, the model listing can be understood by the end user who may not be familiar with programming.

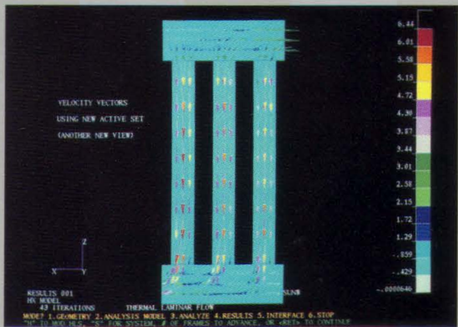
CACI is porting the SIMSCRIPT II.5 compiler to the CRAY X-MP and CRAY Y-MP computer systems running under the UNICOS operating system. Delivery is scheduled for May 1988.

For more information about using SIMSCRIPT II.5 with Cray computer systems, contact Hal Duncan, CACI Products Company, 3344 North Torrey Pines Court, La Jolla, CA, 92037; telephone: (619) 457-9681.

Compuflo introduces FLOTRAN CFD software

FLOTRAN is a finite element-based general purpose software package with a full range of capabilities for two- and three-dimensional fluid flow and heat transfer problems. The code, which was released last year by Compuflo, Inc., runs on all Cray computer systems under the UNICOS operating system.

FLOTRAN was developed with formulations, solution strategies, and data structures to allow users to realize increased accuracy and inherent flexibility in finite element methods without losing computational



A cut through the center plane of a three-dimensional heat exchanger display of velocity vectors. This represents some of the display options that can be mastered by a FLOTRAN user familiar with commercial pre- and postprocessors such as PATRAN.

efficiency. Complex problems with 5000 nodes and three dimensions can be analyzed in a few minutes on Cray computer systems. This work can be accomplished by engineers who are not necessarily fluid experts. FLOTRAN software features finite element flexibility for modeling complex geometries, ease of integration into the computer-aided engineering workplace, and ease of use. Solution features include

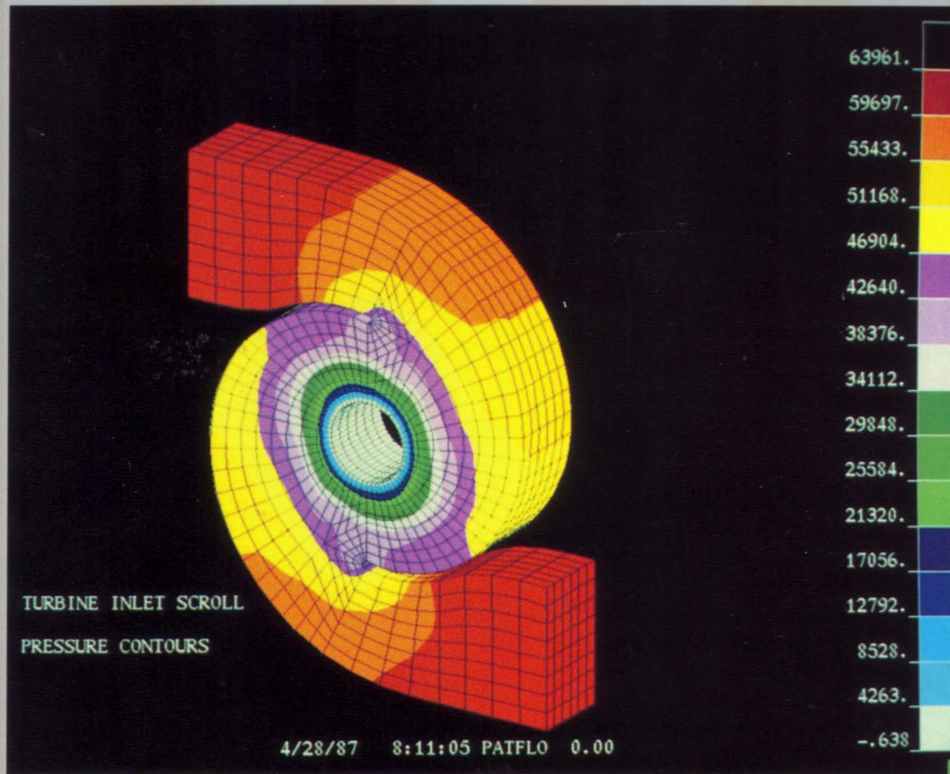
- ☐ Steady-state solution algorithm
- ☐ Minimal storage requirements
- ☐ Equal order approximation for velocity and pressure
- ☐ Minimal execution time requirements
- ☐ Monotone streamline upwind approximation for advection terms

FLOTRAN's analysis capabilities include

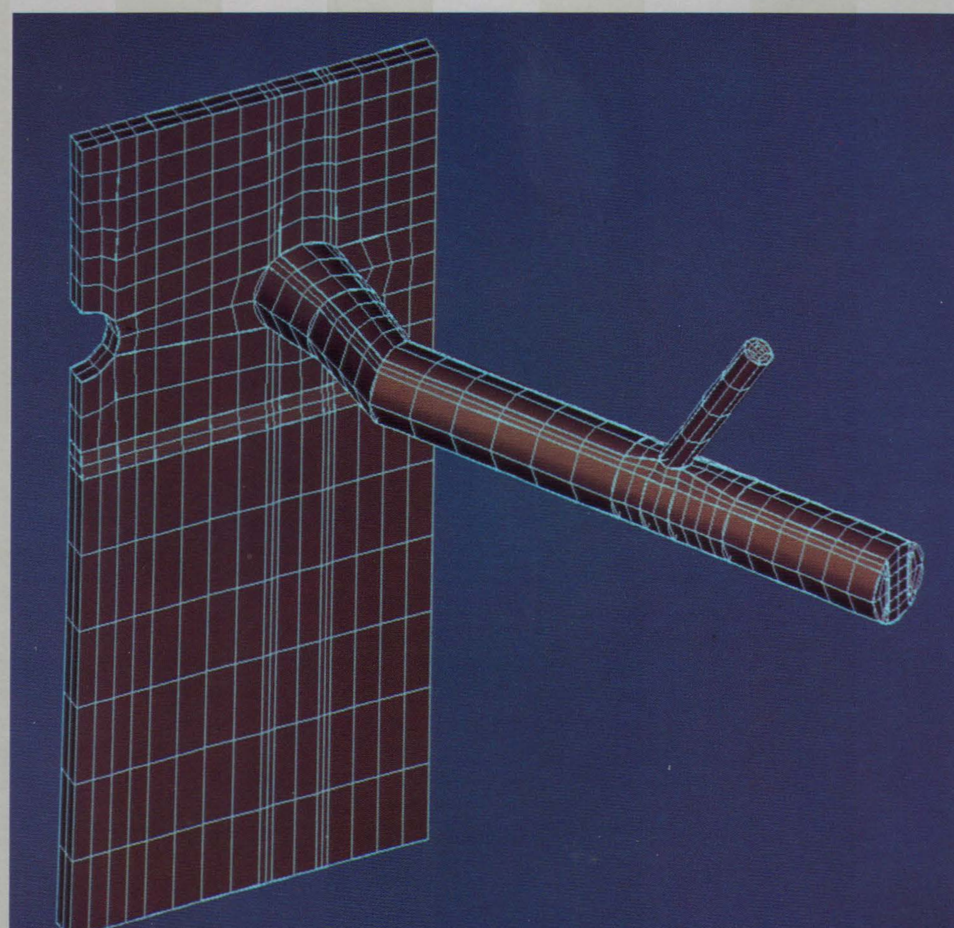
- ☐ Forced, natural, and mixed convection
- ☐ Turbulent flow and/or heat transfer
- ☐ Two- or three-dimensional analysis
- ☐ Laminar viscous flow and/or heat transfer
- ☐ Boundary conditions such as prescribed nodal values, turbulent wall flux, prescribed heat flux, adiabatic, symmetry, and pressure-driven flow

FLOTRAN is tightly coupled with PDA Engineering's pre- and postprocessing software, PATRAN Plus. The FLOTRAN/PATRAN combination reduces the time required to perform overall analysis — from setup to evaluation of results, and allows users to perform element generation interactively with ease. Also, structural and flow analysis can share the same surface model, saving time and money. The pressure field calculated by FLOTRAN can be included directly as input for the structural analysis.

For more information about using FLOTRAN with Cray computer systems, contact Gregory Menke, Compuflo, Inc., P.O. Box 4851, 2250 Old Ivy Road, Charlottesville, VA, 22905; telephone: (804) 977-3569.



Pressure distribution for turbine inlet scroll performed by FLOTRAN.



Pressurized thermal shock problem modeled by FLOTRAN.

USER NEWS

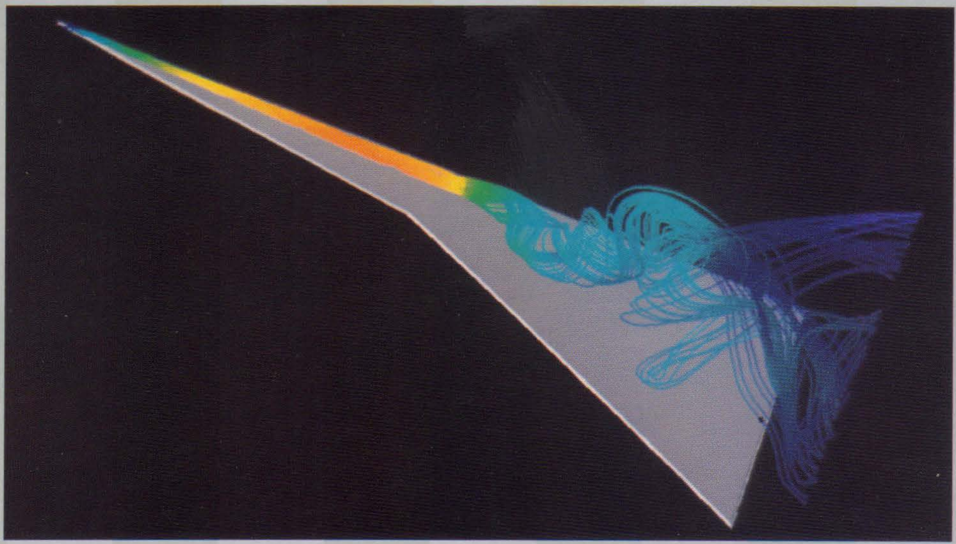
NASA CRAY-2 model tracks vortex breakdown

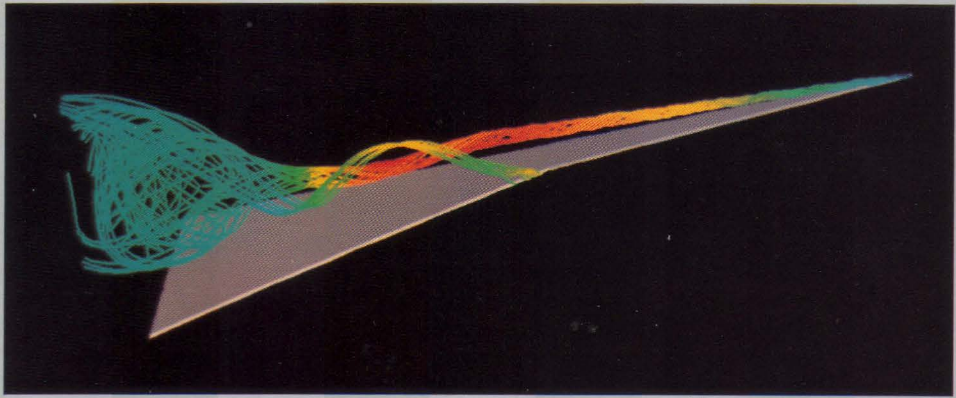
Vortex breakdown is a complex phenomenon that can cause high performance aircraft to lose lift and become difficult to control. Using the CRAY-2 system at NASA Ames Research Center, research fellow Kozo Fujii has developed a model describing the dynamics of vortex breakdown. Understanding and controlling vortices may lead to greater airplane maneuverability and safety.

"This research eventually will allow us to understand the aerodynamics of vortices associated with high angles of attack," says Terry Holst, chief of NASA's applied computational fluids branch. Fujii's work is one element in a larger venture — the High Angle Attack Research Vehicle (HARV) project. "Our ultimate aim is to compute the flow around an F-18 aircraft at 30- to 40-degrees angle of attack," says Holst.

The vortex model is the most in-depth analysis of vortex breakdown to date, according to Holst. The simulation is the first to predict spiral and bubble breakdown, two of the more common types of vortex breakdown over aircraft wings. The model tracks vortex breakdown on strake delta wings, such as those found on F-16 and F-18 aircraft.

Above an aircraft's upper wing surfaces, vortices of swirling low-pressure air produce increased lift for fighter-type aircraft. When an aircraft's nose is pitched at a high angle, these vortices can burst,





Spiral breakdown (top), and bubble breakdown (bottom), illustrated by three-dimensional particle paths on a double-delta configuration at Mach 0.3 at high angles of attack. Colors vary according to pressure. Graphics by Pieter Buning and Kojo Fujii, NASA Ames Research Center.

causing the loss of aerodynamic lift. Once this breakdown occurs, air flow may become asymmetric, which can cause loss of aircraft control, and send a plane into a roll.

Simulating the flow inside a vortex breakdown is a complex computational problem, but it is nearly impossible to study experimentally because the phenomenon is unsteady, changing rapidly over short periods of time. Because breakdown occurs in the flow field above the wing surface, many experimental probes interact with the vortex flow field, distorting the measurements. Computational methods permit studying breakdown without disturbing the flow field. They allow the study of many aircraft configurations and parameters such as Mach number and the aircraft's pitch angle to flight path. "The complexity of this project required a computer with extensive storage capacity," explains Holst. "The CRAY-2 system's memory was an enabling feature of this research," he says.

To illustrate this complexity, the NASA model calculates the flow field at 850,000 grid points with the LANS3D computer code. The model, which is based on the Navier-Stokes equations, is three-dimensional, time accurate, and highly detailed, requiring 25 hours to run on a CRAY-2 system. To enhance the understanding of the computed flow fields, Fujii extensively used two dynamical graphics packages developed at NASA Ames: the Remote Interactive Processing and Graphics Animation System packages.

So far, the simulation has provided several clues to explain vortex breakdown. Fujii has found that under particular conditions spiral breakdown occurs only when the vortex breakdown interacts with the viscous layer on the surface of the wing, suggesting this interaction causes the breakdown. To confirm this finding, Fujii would like to see the test performed experimentally.

Next, Fujii is working to improve model accuracy. Though the model is valuable for analytical purposes, it requires more resolution for design use. Fujii believes the key to achieving higher resolution results lies in employing a zonal method, which increases the number of grid points in selected areas, without requiring additional computer time. Using this technique, Fujii plans to extend the model to complex geometries that would include the fuselage as well as wing surfaces.

Cray system looks down Wall Street

In the aftermath of Wall Street's October crash, analysts, investors, and market observers are looking for explanations. Two professors at Carnegie Mellon University (CMU) in Pittsburgh, Pennsylvania, are using a CRAY X-MP system to define the underlying dimensions of the New York Stock Exchange (NYSE) — fundamental information that may pave the way for an understanding of the market disaster.

By enumerating priced factors governing the stock market, CMU professors Keith Poole and Scott Richard would unravel a controversy that has long stumped financial economists. "It is ground-breaking research. We are establishing facts that could not be established without the use of a Cray system," says Poole, professor of political economics and chairman of the doctoral program at CMU's business school.

Richard, vice president for mortgage securities research at investment firm Goldman, Sachs and Company, is a finance professor on leave of absence from CMU's graduate school of industrial administration. He and Poole are close colleagues with complementary skills. "It seemed like a good combination," says Richard. "He had the background in managing data, and I had an economic and financial background, so we got together."

Determining the number of priced factors underlying the values of NYSE stocks "is a real hairy data problem," according to Poole. The team analyzes daily returns of 5000 securities observed from 1962 onward to map the systematic structure underlying market activity. This forms a 5000-by-6000 matrix — 5000 securities by 6000 days. "The controversy is over the number of dimensions in this stable structure," says Poole.

Adds Richard, "That's where the Cray system comes in. It's an appropriate match for this research because we have to hold lots of data in core memory, then calculate eigenvalues with a statistical procedure." They constructed a subsample of this matrix: a smaller 6000-by-2000 matrix with rows containing day-to-day information, and the columns representing firms. Then they transposed the 6000-by-2000 matrix. Poole explains, "To transpose a data set of that size you have to put it in the SSD solid-state storage device and read it about 30 times. I read it once, pick up the first 200 days, then write it off the disk and rewind the data set to pick up days 201 through 400 — until I get through 6000 days.

"The advantage of having the data transposed is that you can read through the data one row at a time and do cumulative addition. After one read of the data set you have a covariance matrix," Poole says. He adds that if the data is read in its natural form with the rows as firms, that data must be read and held in memory, wasting valuable memory space. "To do matrices of that size we need a Cray system," he adds. "It's like having a microscope 10 times the power of an old one; it's extraordinary."

Poole and Richard are approaching the project in two main steps: first they are determining the eigenvalue structure of the data, then they will do a Monte Carlo analysis to determine what the eigenvalue structure would look like under varied assumptions about the random process that generates the day-to-day values of stocks. "There is no known distribution theory for these statistics, so we will contruct one with the Monte Carlo simulation," explains Richard. Poole adds, "Depending on what assumptions we make, we should get a different kind of structure."

Preliminary results show that as the number of securities is increased, only one eigenvalue appears very large compared to the others. "That would suggest only one priced factor exists; everything else could be diversified away if you create large enough portfolios," says Richard, stressing that this is a preliminary hypothesis.

"We're a little skeptical," Richard adds. "Other researchers have found four or five priced factors in the stock market, and at least three or four in the bond market." The team is now checking its results with Monte Carlo simulations. "We're trying to see whether this is a statistical aberration. We want to see if we have enough data to conclude this one large eigenvalue is the only large one, or whether the other ones are big enough to represent a priced factor as well," he says.

After analyzing their results with a Monte Carlo method, the next step will be to identify the factors. "We will convert the mathematical construct called the factor into economic constructs such as the market portfolio, or a portfolio correlated with interest rates or the trade deficit." From there, the team's path of research depends on their findings. Both would like to use results to look into the recent stock market crash. "I'm trying to get my finance and economics colleagues interested in building a model of that," says Poole. "If you can identify the underlying structure of the market, you've said a lot."

Cray system aids implant development

Richard T. Hart makes no bones about his research — not yet, anyway. The Tulane University associate professor is using a Cray system to analyze and predict bone structure and growth, and eventually to design improved implants.

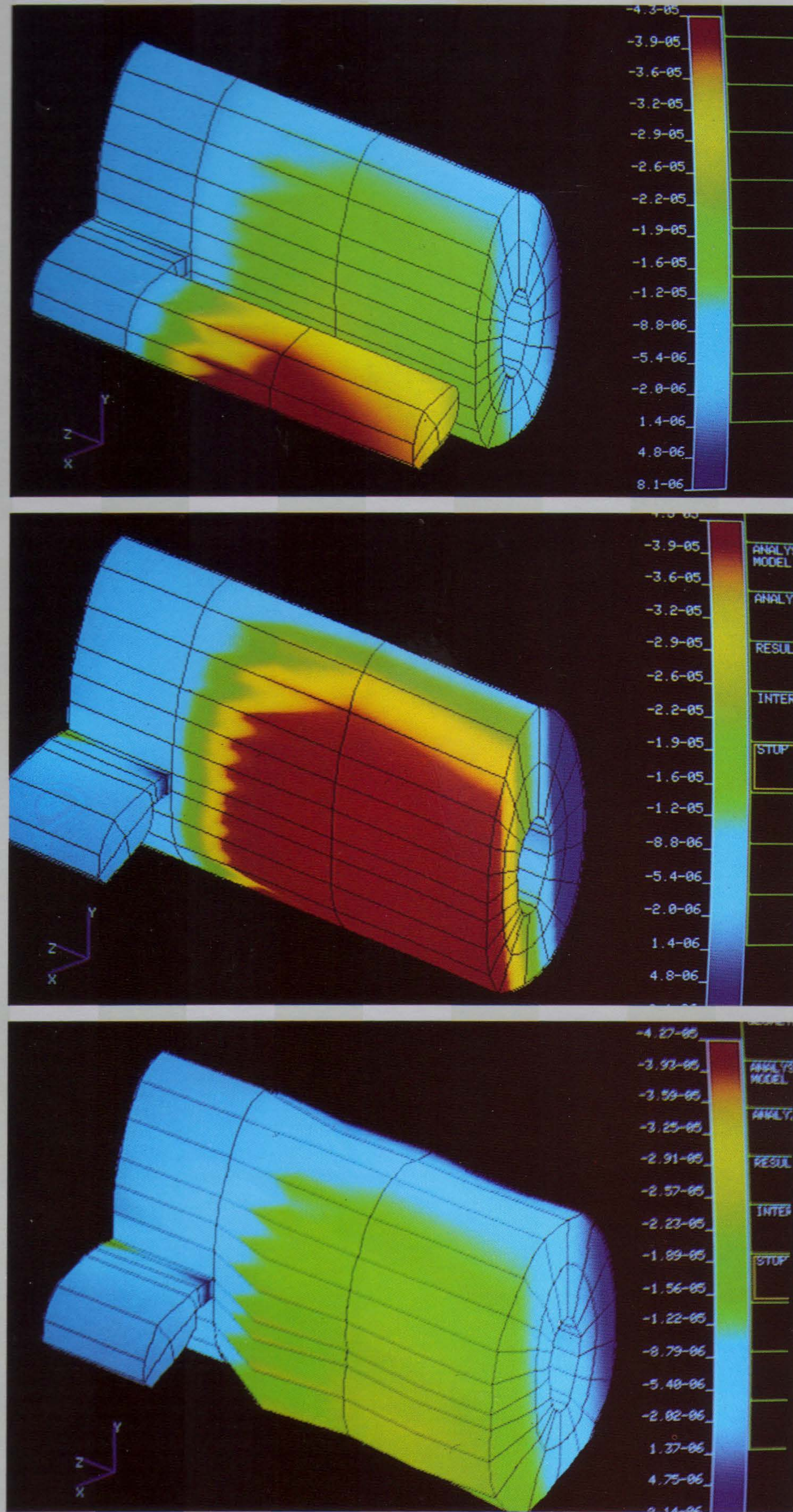
Hart, who has a Ph.D. degree in mechanical and aerospace engineering from Case Western Reserve University, specializes in biomechanics, a subfield of biomedical engineering. He uses mechanical engineering techniques to look at biological problems involving bones and other tissues. "The fascinating thing about bones as engineering structures is that over time they can change in size, shape, and material properties in response to the loads to which they are subjected," he says.

And just as airplanes, autos, and bridges can benefit from computational design, so can bones, according to Hart. "It's exciting to think we can predict something computationally that previously required animal experiments. Hopefully, we can cut the number of animal experiments and create a valuable tool for implant design.

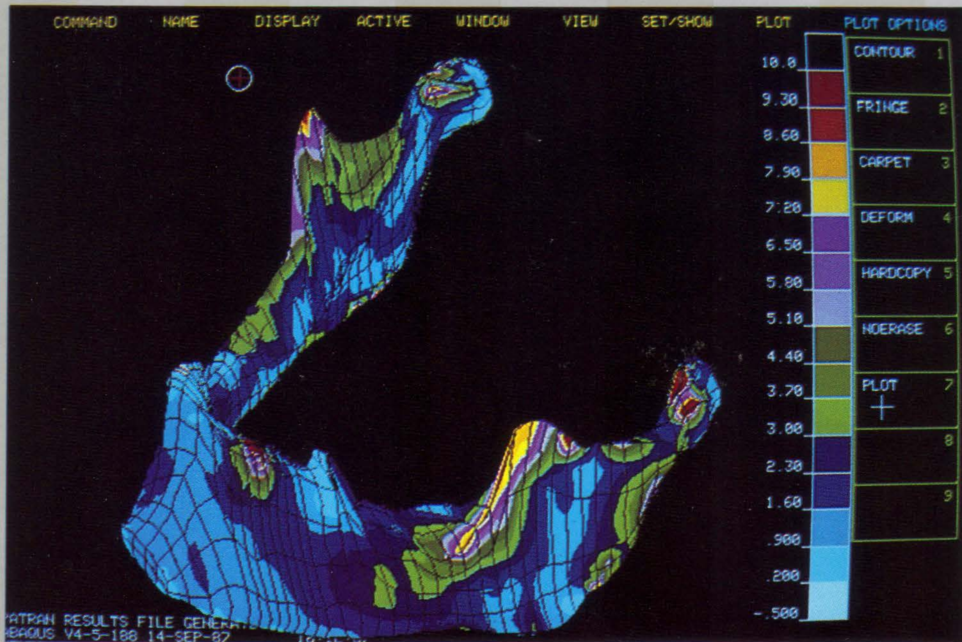
"In implants, the response of bones is sometimes detrimental, especially when a bone grows away from the implant due to new strain and stress fields. This causes an implant to become loose," he says, adding that this research also could be applied to induce bone growth. "We're looking at a device for children who have large sections of bone removed due to cancerous tumors. We are attempting to induce mechanical strains to close this gap by filling it with new bone."

Implants currently are developed on a trial-and-error basis. Prostheses are surgically implanted in 100 patients and tracked over a period of five to ten years. Unsuccessful designs are modified, but cause discomfort to patients. Says Hart, "The exciting possibility is that we could bypass some of that and come up with a design on the computer before it is put into people."

To provide a cornerstone for this research, Hart is comparing computer models with actual bone remodeling that has been performed experimentally on sheep forelimbs. "The purpose of the original experiment was to see how a sheep's radius would remodel if it alone was left to support the sheep's weight following the removal of the ulna, the smaller of the two bones in the forelimb," says Hart. To computationally describe this experiment, Hart has developed a vectorized Fortran code, RFEM 3-D, to



Computational analysis of an experiment performed on a sheep forelimb. By studying the changes in bone accompanied by changes in customary loading, researchers hope to predict effects of bone remodeling. The top image is a simulation of an intact sheep forelimb. Loads are distributed between two bones, the radius and ulna. The middle image shows the calculated strain distribution following the removal of the ulna. The bottom image is a computational description of the new bone geometry after one year. Strain distribution in this modeled bone is very similar to strain distribution in the intact limb.



Strain distribution of a jaw modeled with the ABAQUS code.

model bone stresses, strains, and displacements.

"What makes this thing so computationally intensive is that after I solve the initial problem, the bone is allowed to change its size. Then I do the analysis on the new structure and keep stepping in time — so this problem with 20,000 degrees of freedom might be performed about 400 times," he explains. The results of the computer analysis closely matched experimental observations. Also, the strain distribution on the remodeled bone was remarkably similar to the strain distribution in the intact limb.

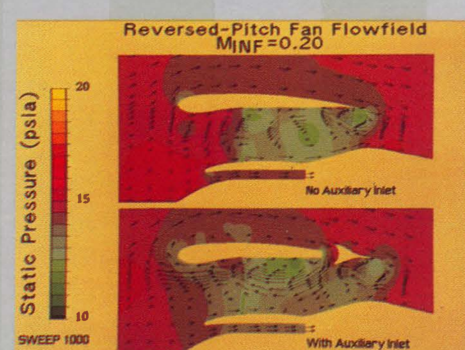
Hart, who has used 25 of 80 allotted hours at the Pittsburgh Supercomputing Center, says using a CRAY X-MP/48 system for this endeavor has been necessary because of great storage and speed requirements. "What took 11 days on the MicroVAX took 26 minutes on the Cray system," he says. "Using a Cray system really opened up the scale of problems we can look at, allowing us to do research we could not have attempted before. In addition, I'm able to look ahead to the next step without worrying about the computing capability."

Eventually, Hart hopes to computationally predict bone remodeling in experimental animals and humans to study bone changes accompanied by changes in customary loading, such as the effects of jogging, total knee or hip replacement, or even the relation of weightlessness to bone shrinkage experienced by astronauts and cosmonauts. "I'd like to put together a model of a knee joint and test a number of designs for a knee prosthesis," he says. "Knees are important because they are the second most replaced joint in the body, after the hip. They are a much more complicated joint and have a relatively high failure rate."

He is working with graduate student Nisra Thongpreda to develop a model of a jaw bone based on serial sections taken from a medical imaging scanner. He also plans to apply the same techniques to soft tissue mechanics to look at wound healing and the formation of skin, scars, and muscle. "Numerous problems in the biomechanical area can benefit from supercomputers," says Hart.

CFD at Boeing: a design case study

For every design that gets off the ground, there are many ideas that never fly. And therein lies the beauty of computational fluid dynamics — it encourages designers to take risks, to test unconventional ideas. CFD lets engineers bypass some expensive wind tunnel testing and the cost of many prototypes needed to test their ideas.



Computed flow fields in two engine configurations during thrust reversal. Forward flow is significantly improved by the addition of an auxilary inlet in the fan cowl (bottom).

"Analyzing ideas on a Cray system lets us look at a number of designs, and helps us get information to guide our choices," says Wayne Jones, an engineer at Boeing Commercial Airplane Company. Boeing recently opened a CFD lab in Bellevue, Washington, where engineers are using Cray computer systems to design airplanes.

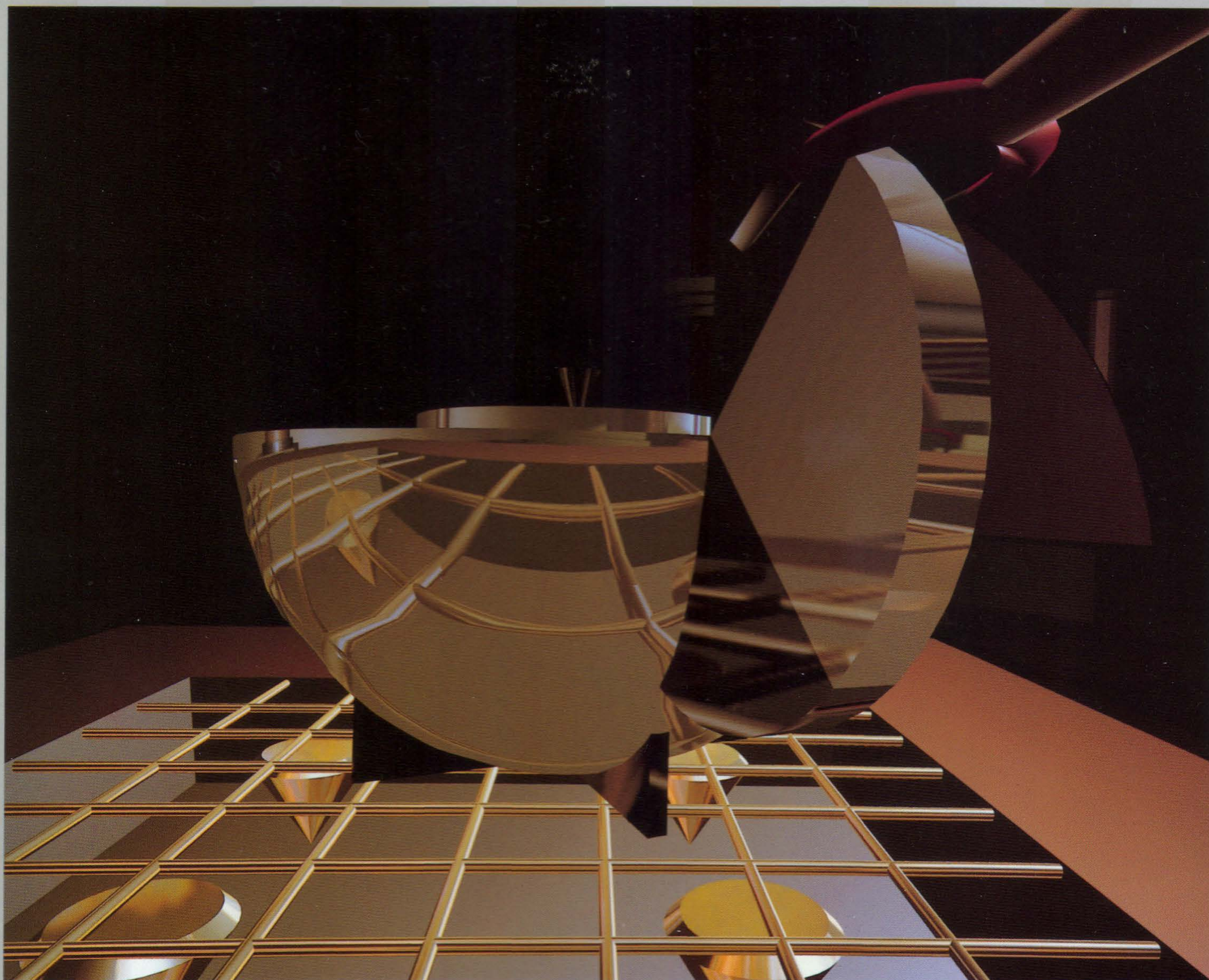
A novel concept in engine design that was tested with Boeing's CRAY X-MP system may not reach the skies in the near future, but illustrates the power of using CFD in a design environment. Engineers investigated changing the pitch of an engine's fan blades to reverse its thrust. This idea was unique because most thrust reversers are designed with doors to block fan flow and divert the exhaust air in the upstream direction. The upstream flow provides reverse thrust an aircraft needs for braking.

Using the conventional blockage method in this particular turbofan engine installation was not desirable because of the weight it would add, according to Jeffrey Brown, senior specialist engineer. Engineers decided to take a different approach — instead of following tradition, they decided to see if changing the fan blade pitch during landings would do the job. "One concern in trying this new approach was how well the nozzle would perform when acting as an inlet," says Brown.

Instead of constructing various designs of this reverse fan engine and examining their effectiveness with wind tunnel tests, Boeing engineers compared designs using CFD on a CRAY X-MP system. The physical simulation was modeled as an axisymmetric flow and was analyzed by modifying an existing Boeing code for solving the Navier-Stokes equations. Engineers created a movie from analysis results to better evaluate the dynamics of flow. "A picture of the flow field at each time step was saved and animated on an IRIS workstation to provide a realistic representation of the time-varying flow," says Jones.

After evaluating many designs, Boeing designers focused on a configuration using an opening in the fan cowl that could provide the reverse thrust required for landing. The research has been tabled temporarily for nontechnical reasons, but shows the importance of CFD as a design tool. "The analyses gave us good qualitative information," says Jones. "Though it didn't provide the final answer, we did confirm that certain designs wouldn't work and that others had potential."

GALLERY



"Teapot" by Shelley Lake was the first place winner in the 1987 Truevision-Raster Tech Image contest. A CRAY X-MP system computed the lighting effects, reflectivity, and color for the 5120-by-3072 image in approximately 10 minutes.

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