The Elmer A. Sperry Award 1996

FOR ADVANCING THE ART OF TRANSPORTATION

The Elmer A. Sperry Award

The Elmer A. Sperry Award shall be given in recognition of a distinguished engineering contribution which, through application, proved in actual service, has advanced the art of transportation whether by land, sea or air.

In the words of Edmondo Quattrocchi, sculptor of the Elmer A. Sperry Medal:

"This Sperry medal symbolizes the struggle of man's mind against the forces of nature. The horse represents the primitive state of uncontrolled power. This, as suggested by the clouds and celestial fragments, is essentially the same in all the elements. The Gyroscope, superimposed on these, represents the bringing of this power under control for man's purposes."

Presentation of

The Elmer A. Sperry Award for 1996

to

THOMAS G. BUTLER (IN MEMORIAM)
AND
RICHARD H. MACNEAL

for the development and mechanization of NASA Structural Analysis (NASTRAN) for widespread utilization as a working tool for finite element computation

by
The Board of Award under the sponsorship of:

The American Society of Mechanical Engineers
Institute of Electrical and Electronics Engineers
Society of Automotive Engineers
Society of Naval Architects and Marine Engineers
American Institute of Aeronautics and Astronautics
American Society of Civil Engineers

at the
1997 American Institute of Aeronautics and Astronautics
Global Air and Space Conference
May 8, 1997 - Crystal City, VA

Thomas G. Butler

(IN MEMORIAM)

Tom Butler was a scientist at the NASA Goddard Space Flight Center when he conceived the project for NASA to take a leading role in creating a large structural analysis computer program. Tom's vision and early initiative blossomed into a major program under his management, occupying him for over six years at NASA, as NASTRAN was ultimately deployed into widespread use throughout the industry.

Tom served as a naval surface line officer during World War II in both Atlantic and Pacific theaters, and was discharged with the rank of Lieutenant Commander in 1946. He then joined the Allis Chalmers Company in Milwaukee, working in the Pump and Motor-Generator departments while also pursuing graduate studies at the University of Wisconsin.

In 1956, he moved to the Martin Company in Baltimore to work on the Vanguard rocket, while also continuing his graduate studies in mechanical engineering at The John Hopkins University. At Martin, Tom was introduced to the emerging concept of finite element analysis (FEA) and soon became an expert in its application in structural analysis. He brought this knowledge to NASA Goddard in 1963 and there worked to incorporate FEA in a general software program.

Tom Butler left NASA in 1971 approximately a year after the structural analysis committee responsible for NASTRAN was disbanded, and went into a private consulting practice, Butler Analyses. There he worked with NASA to convert NASTRAN to mini-computers, taught applications to government and industry groups, and did structural analysis for satellite and space shuttle components.

One of Tom's greatest interests was music. He played string bass for many years in The Johns Hopkins Symphony Orchestra. Later, he also played with the Gettysburg Symphony and for locally produced musicals. His hobbies also included gardening and bird watching.

On November 19, 1993, Tom Butler passed away in Towson, Maryland. He is survived by his wife Margaret and their three children and four grandchildren. A few weeks before his death, NASA presented Tom with its highest honor, the Distinguished Public Service Award. The inscription on the medal and certificate reads:

For outstanding leadership in the development of the NASTRAN program which has furthered national undertakings, increased the competitiveness of U.S. industry, and advanced the practice of engineering.

THOMAS G. BUTLER

Richard H. MacNeal

After Dick MacNeal received his Ph.D. in Electrical Engineering from the California Institute of Technology in 1949, he continued working with analog computers in solving structural mechanics problems in the same CalTech Analysis Laboratory where he had undertaken his thesis work. A portion of the work of the lab was taken into a commercial venture, Computer Engineering Associates, which ultimately acquired its own computer and began doing contract work for the aerospace industry. The small, highly concentrated and energetic research firm such as CEA was to become the template of Dick's lifelong activity in numerous projects developing computer applications that could be transferred to industry for practical problem-solving. In 1963 Dick co-founded the MacNeal-Schwendler Corporation (MSC) and began to acquire and expand his small firm's expertise concurrent with the emergence of faster and more powerful digital computers and applications.

In 1966 MSC was awarded a contract by NASA to develop a general purpose structural analysis program, and Dick delivered the first operational software version (dubbed NASTRAN, for NASA Structural analysis) to NASA centers in 1969. In the years that followed, Dick MacNeal continued his close association with NASTRAN through a series of contracts with NASA involving program maintenance and the codification of new features and capabilities.

In 1982, more than fifteen years after MSC's original involvement with NASTRAN, Dick MacNeal and his colleagues procured the rights to market their subsequent versions of NASTRAN to industry as a revolutionary problem solver for a multitude of applications ranging from acoustics to heat transfer.

Dick is married with three sons and seven grandchildren. The MacNeals celebrated their 50th wedding anniversary last year.

Dick served as Chairman of the MacNeal-Schwendler Corporation, a company he co-founded in 1963, until his retirement in January of this year. Among his outside interests, Dick actively participates as a member of the Board of Governors of the Idyllwild Arts Foundation, which sponsors the development and training of gifted young artists from all over the world.

Dick MacNeal was elected to the National Academy of Engineering in 1996, the citation accompanying his elevation to that prestigious body reading, in part:

For his pioneering contributions to large-scale, general purpose finite element analysis and his development of the NASTRAN program.

RICHARD H. MACNEAL

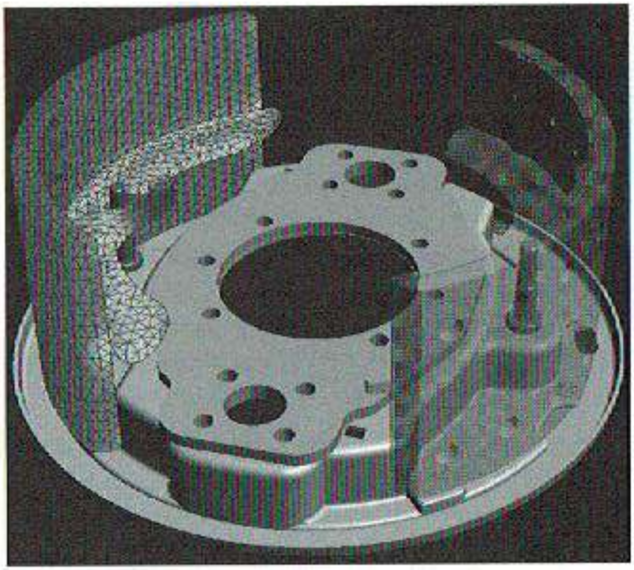
NASTRAN – Advancing the Art of Transportation

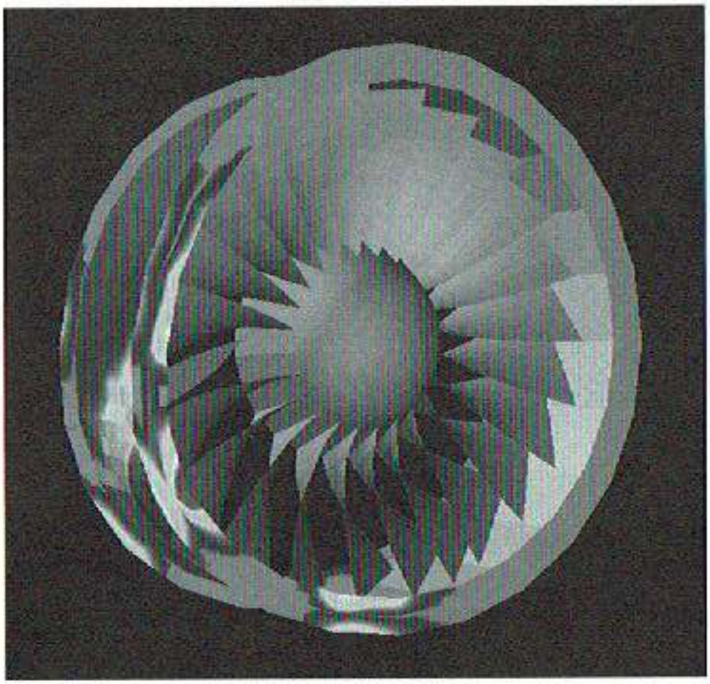
Ask any group of practicing engineers about structural mechanics and the conversation will eventually gravitate to the nature of tools and programs they use to capture the nuances of their discipline and to solve its problems. It is a certainty that Finite Element Analysis will be mentioned, not as a background concept, but rather as the most recognizable of powerful analytical systems currently available — one that has grown perceptibly with their science over the years and now stands as an indispensable adjunct to their investigations.

The most vocal and statistically significant endorsement of FEA continues to resound from the ranks of scientists and researchers involved in advancing the science and technology of transportation. In the majority of cases, these endorsements will be synonymous with NASTRAN, the original NASA Structural Analysis program that translated the Finite Element Method into a simplified and user-compatible computer application. Recognized for its breadth of potential by visionary Thomas G. Butler of NASA, and programmed and implemented for public release by a small but determined computer applications firm headed by Richard H. MacNeal, NASTRAN introduced thousands of engineers worldwide to a new dimension of mathematical precision in evaluating internal and external stresses on complex shapes, structures, and physical properties.

The power of NASTRAN has particularly permeated the development of structures and systems for transportation, bringing solutions to the forefront that have played a key role in maintaining swift and steady progress in this dynamic technological arena. It is appropriate that the prestigious Elmer A Sperry Award recognize the vision and determination of two researchers, Thomas G. Butler and Richard H. MacNeal, who through the development and implementation of NASTRAN have so dramatically advanced the art of transportation.

MSC/Aries heat transfer model showing temperature distribution within a bonded brake shoe assembly. (Courtesy MSC)



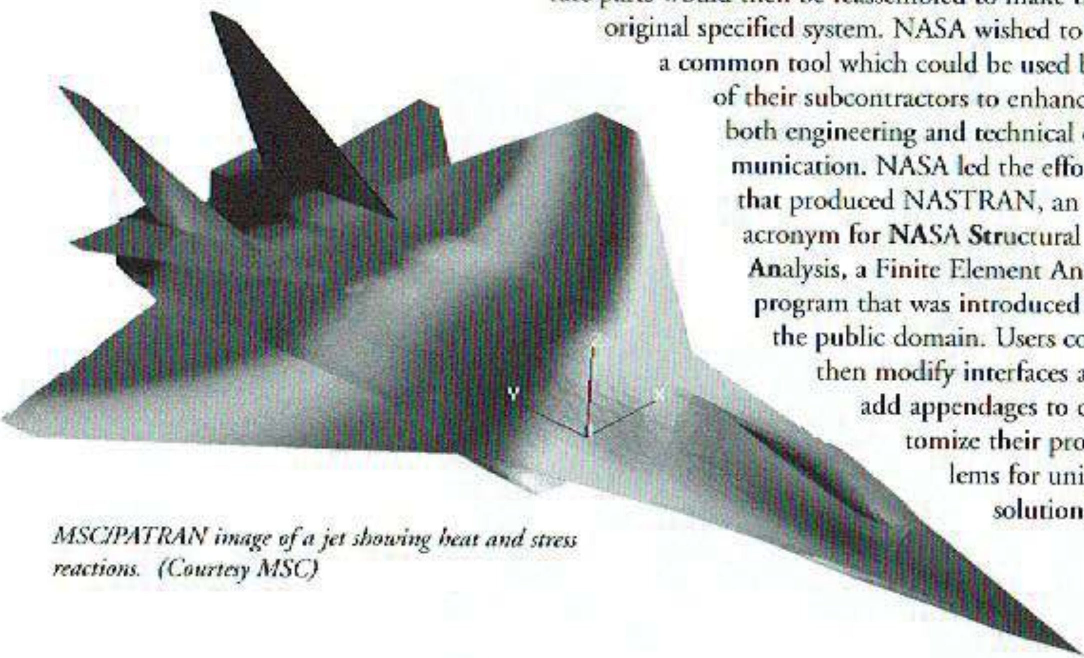


MSC/DYTRAN model of airplane turbine engine ingestion and impact showing deformation damage. (Courtesy MSC)

Introduction

Finite Element Analysis, or FEA, is a tool used by scientists and engineers to mathematically solve large complex structural analysis problems of many interacting variables that could not be efficiently solved (if at all) by earlier conventional methods. Unlike classical methods, which look at complete structures in deriving analytical solutions, FEA makes assumptions about the stress distributions within small regions, known as finite elements. By joining the elements together and transferring boundary values across from element-to-element, even the most complex shapes, surfaces or solids, or even other physical phenomena such as acoustics or thermal properties, could be integrated into a total solution.

In the early years, many users developed proprietary versions of FEA for their own use. A principal user of FEA, the National Aeronautics and Space Administration (NASA), would subdivide large systems into parts, with each part being developed by a different company. The separate parts would then be reassembled to make the original specified system. NASA wished to have a common tool which could be used by all of their subcontractors to enhance both engineering and technical communication. NASA led the effort that produced NASTRAN, an acronym for **NASA Structural Analysis**, a Finite Element Analysis program that was introduced into the public domain. Users could then modify interfaces and add appendages to customize their problems for unique solutions.



MSC/PATRAN image of a jet showing heat and stress reactions. (Courtesy MSC)

NASTRAN enabled scientists and engineers to design lighter, stronger, and larger units than ever before. It affected all engineering disciplines, specifically transportation, with examples such as longer and safer bridges, lighter and larger aircraft, spacecraft, ships and automobiles. Countless other engineering problems containing numerous interacting variables were also swiftly and accurately solved through NASTRAN applications. All of society has gained, and continues to benefit, by the contributions this tool has made.

On the following pages the development of NASTRAN and examples of its application will be presented. Our Elmer A. Sperry Award honorees, Tom Butler and Dick MacNeal, will be specifically identified as two individuals with the foresight, technical knowledge, and persistence to develop NASTRAN into the widely accepted working tool it is today.

Car mesh model of a car body. (Courtesy MSC)

NASTRAN: The Historical Background

ORIGIN OF FINITE ELEMENT ANALYSIS

There is no consensus agreement from practitioners as to the precise origin of the Finite Element Method, but credit for demonstrating the potential of the concept is generally ascribed to a Boeing team headed by Jonathan Turner in 1956. The team's recommendations were documented in a paper submitted to the *Journal of the Aeronautical Sciences* and titled "Stiffness and Deflection Analysis of Complex Structures." Assisting Turner in the effort were Boeing engineers and scientists Ray Clough, Hal Martin, and Dick Topp. The article proposed a technical derivation of the Finite Element Method based on mathematical models and recommended where practical applications could be applied to aircraft structures.

USE OF FEA PRIOR TO NASTRAN

Following the Turner paper, variations on the arbitrarily shaped elements comprising a structural shape became increasingly sophisticated, and by 1964 several aircraft companies had developed their own finite element programs to varying degrees of refinement. Most of them (notably those written at Douglas in Santa Monica, Lockheed in Burbank, and Martin in Baltimore) used what was known as the Force Method, which relegated the variables in the equations to forces inside structural members. A minority of researchers (particularly Boeing in Seattle and Bell Aerospace in Buffalo) endorsed the Displacement Method, in which the variables in the system equations were the *motions* at points on the boundaries between elements. Early codification efforts into formats suited to the computer began emerging in this time frame, notably the ASKA program under the direction of John Argyris in Europe.

THE ROLE OF NASA IN PROMOTING FEA

In 1964 there were no finite element programs available to the public on a regular basis through the payment of fees. In January of that year, Tom Butler, a research scientist at the NASA Goddard Space Flight Center in Virginia, invited managers of structural research from the various NASA centers to a meeting at NASA's Office of Advanced Research and Technology in Washington. Tom's purpose in convening the meeting was to discuss and gather input leading to a research program that could improve structural analysis, particularly as it applied to the shells used in aircraft construction.

Each representative described how his group had written special-purpose computer programs with particular emphasis on simplifying assumptions to analyze shell configurations. At the meeting, Tom proposed that finite elements be used to obtain engineering solutions and that analytic methods be upgraded to make fewer simplifying assumptions. While his suggestion was rejected by the group, it had a better reception by NASA Headquarters personnel, and Tom was asked to chair an ad hoc committee to investigate the state of analysis in the aerospace industry. He was to survey both digital and analog computer methods and, if appropriate, find an existing finite element program worth recommending to all NASA centers.

Thomas G. Butler

The ad hoc committee's visits to the aircraft companies revealed that no single computer program incorporated enough of the best attributes of the finite element method to represent a satisfactory "find" for the team. Its recommendation to NASA Headquarters then, was that NASA sponsor the development of its own finite element program as a means to upgrade the analytical capability of the entire aerospace industry. NASA Headquarters endorsed the recommendation and selected Goddard Space Flight Center to manage the program under Tom Butler's direction.

THE NASA SPECIFICATION AND MSC CONTRACT

NASA issued the Request for Proposal (RFP) in July 1965. There were fifteen pages of detailed technical specifications for the "General Purpose Structural Analysis" program, or GPSA, covering every aspect of structural analysis. The specifications called for both the Force and Displacement Methods, static analysis, several forms of dynamic analysis including interaction with control systems, and features to make the program "user friendly." It was to also be modular in its basic architecture, and easily modified so that the longevity of the program would be assured.

Dr. Richard H. MacNeal

Dick MacNeal's fledgling MacNeal-Schwendler Corp. (MSC), formed in 1963, was asked to help NASA *evaluate* the proposals being submitted by the major aerospace companies. MSC, however, boldly announced that it would be assembling a team, including Computer Sciences Corp. and Martin Baltimore, in preparing a proposal response of its own. Other bidders included a team consisting of three subsidiaries of General Dynamics, another team from General Electric and TRW, and a fourth team led by Douglas which included Bell Aerospace, Philco, and Computer Usage Corp.

In early 1966, the final phase of the contract for actual programming of NASTRAN was down to a final competition between the MSC/CSC/Martin team and the Douglas team. In June of 1966, Tom Butler notified Dick MacNeal that he and his team had been awarded the contract.

THE LAUNCHING OF NASTRAN

As the MSC team worked their way through the development of NASTRAN, the Force Method was abandoned in favor of exclusive use of the Displacement Method, although both were specified in the RFP. The program was completed in 1969 and was delivered to NASA centers throughout the United States. In November of 1970, the program was released for public use through the COSMIC distribution center at the University of Georgia. The concept of finite elements was then officially in the public domain, at a reasonable cost, and with a support system and network of user groups rapidly forming.

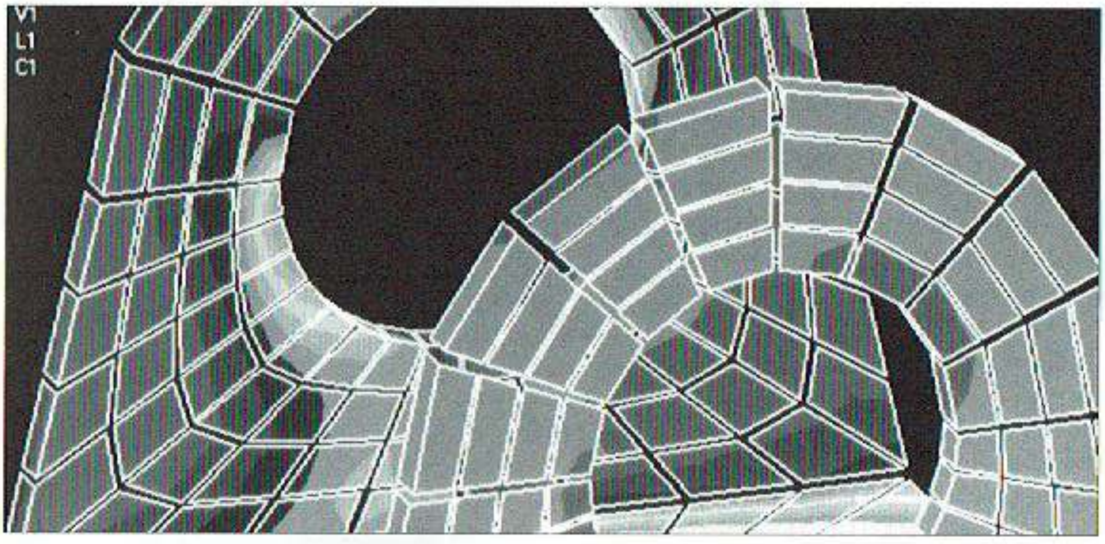
With NASTRAN, engineers and scientists suddenly found a powerful new tool at their disposal which they could easily and rapidly deploy into their workplace. In many instances, initial uses were relegated to validity checks of previous analyses which had struggled for solution using conventional slower and less accurate systems. As the new methodology swept through the technical domain, broader and more innovative applications were exercised with a growing confidence that soon recognized NASTRAN as not only an exploratory medium, but a tool that could be used as the principal design engine of any development effort. Even in its early utilization, there were but a few restrictions on its breadth of application or accuracy of execution and NASTRAN became a tool that achieved astounding successes "out of the box."

EARLY APPLICATIONS OF NASTRAN IN THE TECHNICAL COMMUNITY

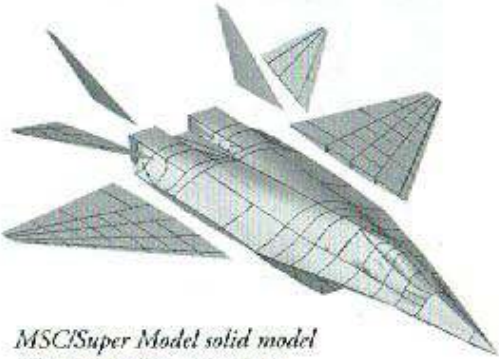
The guiding criteria for the Sperry Award clearly specifies that the achievement being honored "advances the art of transportation whether by land, sea, or air." In recognizing the development and public availability of NASTRAN to the engineering and scientific community, it is appropriate to note that various transportation engineering problems utilized the very first applications for NASTRAN, and continued to account for the major percentage of its user base to the present day. While the three forms of transportation (land, sea, and air) did not share equally in the initial successes that NASTRAN could offer, it was only a matter of time:

TRANSPORTATION BY AIR

The earliest applications utilizing NASTRAN were closely linked to aerospace technology that gravitated out of NASA programs and were provided visibility through the active network of



FEA model showing sress contours of a clevis part used in automotive and aerospace industry. (Courtesy MSC)

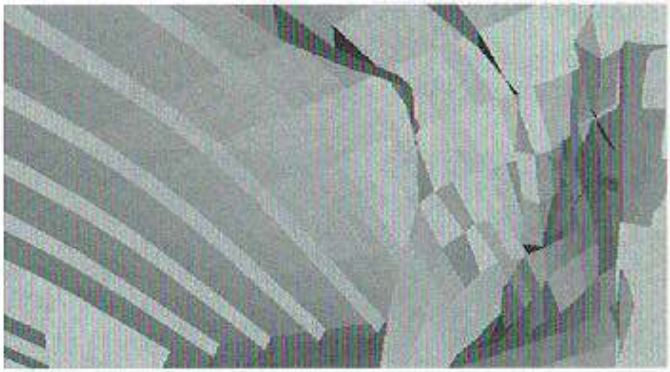


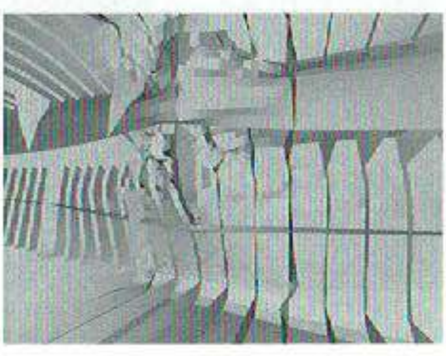
MSC/Super Model solid model with mesh of jet. (Courtesy

NASA communications, including technical journals and symposia. Airframe manufacturers found NASTRAN to be a resource that could address design applications ranging from load and deflection analyses of thin shell fuselage sections, to total airplane dynamic response as influenced by many external loading variables. Every aspect of structure could now be critically evaluated through the ability of FEA to define and map surfaces to any degree of "micro" definition specified by the engineer. Virtually all major aerospace programs that began their gestation periods in the early 70's were introduced to NASTRAN applications at some phase of their development. Included in these pioneering breakthroughs were such familiar accomplishments as the Boeing SST, 767, Lunar Lander, and 747 derivatives.

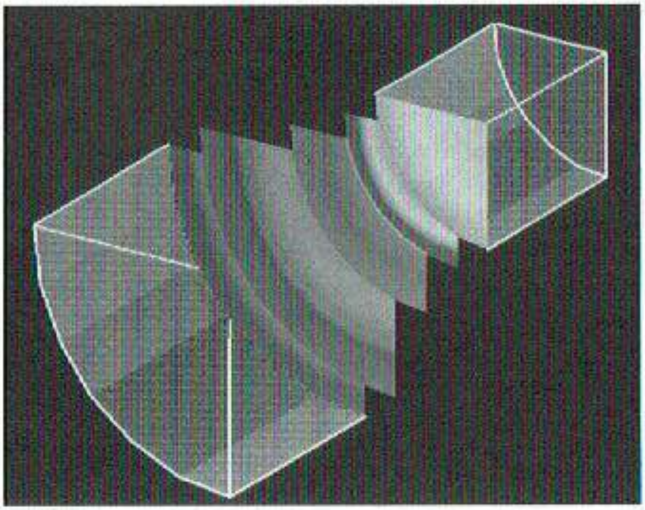
TRANSPORTATION BY SEA

Although not generally acknowledged to demand the efficiency of structure normally attributed to aircraft, NASTRAN program implementations were warmly welcomed by marine engineers and scientists who had waited patiently for the opportunity to depart from coarse-grain calculation techniques that attempted to analyze structures with surface areas that often measured in acres, not square feet. The analytical challenge was often made more complex due to the random and non-homogenous nature of external fluid and wind forces on vessels at rest, as well as in motion. With the power and flexibility of the new NASTRAN codes at hand, marine architects





MSC/ DYTRAN high speed collision results from inside a tanker as another ship hits the side. (Courtesy MSC) and engineers were able to analyze virtually every aspect of their discipline, from total mapping of stresses on new hull designs to the evaluation of strength and buckling phenomena of moored vessels.



Animated FEA Model showing deformations. (Courtesy MSC)

TRANSPORTATION BY LAND

In similar fashion to aerospace applications, design engineers responsible for automobile, truck, and heavy equipment development welcomed a fresh analytical capability that could cater to the need for paring weight from mechanisms and structures without compromising strength or functionality. Only the most robust designs were capable of withstanding the severe operating environment imposed from contact with imperfect roadbeds, rail systems, and conveyor systems, and applications of NASTRAN readily accommodated the full spectrum of investigation that this technology required. In 1973 the emergence of NASTRAN into the automotive community was perfectly timed, as the Oil Embargo triggered virtually overnight a flurry of creative engineering for lightweight automobile bodies, rapid transit vehicles, and fuel-efficient engines.

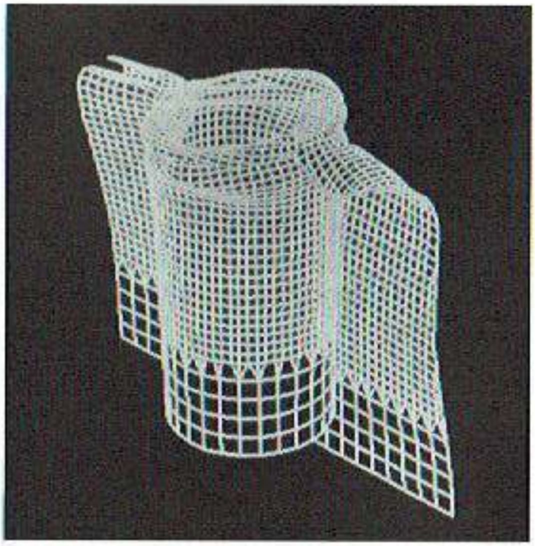
TRANSPORTATION INFRASTRUCTURE APPLICATIONS

Not to be overlooked in NASTRAN's major and continuing contribution to transportation design is an equally vigorous effort in providing increased capability for the analysis of support structures and systems which would interface to the people/product movers. For every transportation design effort invoking NASTRAN problem-solving assistance, whether for an airplane, ship, automobile, or train, there would be an infusion of adjunct engineering accomplishment (civil engineering, electrical engineering, etc.) coming to fruition in support of the total system. Airport infrastructure requirements have created runways, taxiways, terminal and maintenance facilities. Marine facilities have required gigantic cranes, drydocks, and moorages, and the domains of the automotive and rail systems have involved freeways, interchanges, bridges, tunnels, roadbeds, train yards, and the like. All of these infrastructure developments have found faster, more accurate solution paths through utilization of NASTRAN applications.

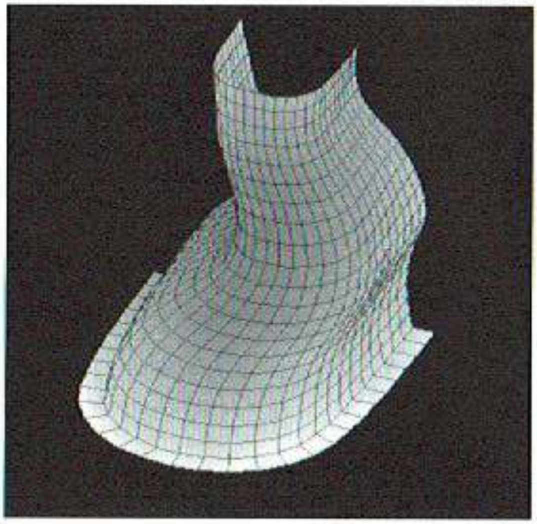
FURTHER DEVELOPMENT AND REFINEMENTS

In the following years, as MSC further refined the NASTRAN code in serving an expanding network of worldwide users, the concept was soon recognized as the preferred choice for structural analysis by engineers and researchers in fields from aeroelastics to hydraulics. As each new technical discipline "discovered" the problem-solving potential of NASTRAN, the MSC team responded with new applications that offered computational speed and accuracy improvements at a pace commensurate with the rapid growth of digital computer technology. One of the new improvements was a heat transfer package that included conduction, convection and radiation for steady state and transient conditions — NASTRAN was already showing its power and reach far beyond the original concept involving shell structures in aerospace applications.

Dick MacNeal and his MSC team successfully bid and were awarded follow-on maintenance contracts for NASTRAN, which also extended to making major efficiency improvements to the programs already in use. Today, MSC continues to develop, configure, and service hundreds of MSC/NASTRAN program variants for thousands of users worldwide.



FEA model showing deformation of a cylinder. (Courtesy MSC)



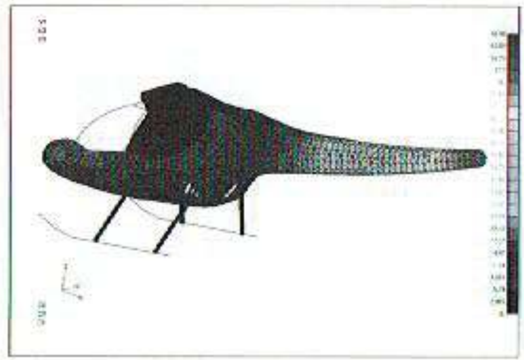
FEA model of a nozzle showing stress contours. (Courtesy MSC)

Current Applications of NASTRAN in the Engineering of Transportation

The utilization of NASTRAN as a problem-solving tool supporting the science and technology of transportation encompasses a breadth of applications that is both numerous and diverse. Although NASTRAN today strategically involves engineering and scientific disciplines on a broad and global basis, these practitioners are virtually co-located as a community of interest through user conferences, worldwide web sources, and the dissemination of technical papers that describe applications that range from the transportation of fluids to major bridge structures and orbiting solar arrays. It is interesting to note some contemporary applications of NASTRAN in supporting each of the three transportation mediums defined for the Sperry Award:

AIR

- Dynamic response of a redesigned solid rocket booster in liftoff phase.
- Design of a lightweight orbiting telescope, including mounts and metering structure.
- Modeling of wing deformation behavior with selected composite materials.
- Non-linear analysis of a propeller blade retention system.
- Prediction of relative motion of avionics module connector contacts through FEM.
- Analysis of three-dimensional waveguide components.



MSC/NASTRAN for Windows helicopter model showing stress contour results. (Courtesy MSC)

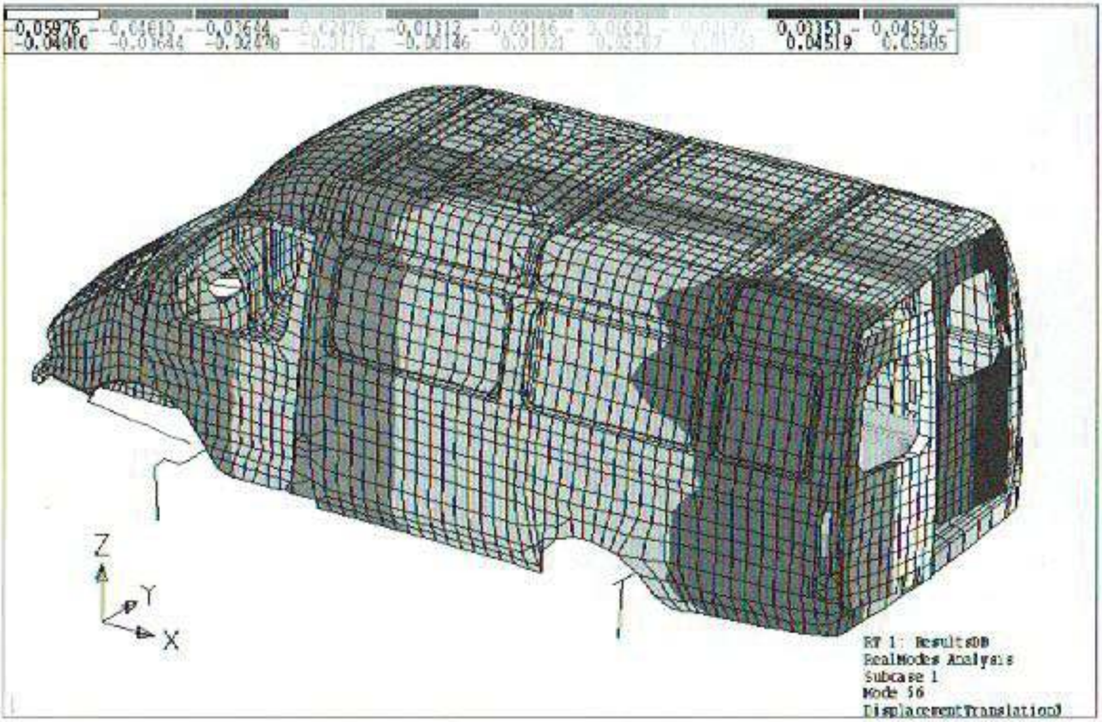
- Determination of reactions in a turbogenerator set shaft due to electrical disturbances.

SEA

- Design of a new ship structure concept (for robotics) by Hitachi Zosen of Japan.
- Strength analysis of double-bottom container ships.
- Creation of a dynamic stress system for examining wave loads on a hull structure.

LAND

- Analysis to reposition a "derailed" 5,000 ton gantry crane at Newport News Shipyard.
- Design of 129.5-ton locomotive by Clyde Engineering Motive Power Division in Australia.
- Analysis of low-emissions diesel engine by RABA and AUTOKUT research institute.
- Static and transient analysis of the Desmond Bridge (Long Beach, CA) for seismic retrofit.
- Evaluation of vortex shedding and flutter on long-span bridges in Japan.
- Pipe and ring weld optimization on hydroelectric penstocks near Bogota, Columbia.
- Dynamic response of bridge structure due to passing of vehicles (Taiwan).



Finite element model of a van body showing analysis results.
(Courtesy MSC)

Elmer A. Sperry, 1860-1930

After attending Cornell University in 1879-80, Sperry invented an improved electrical generator and arc light and opened an electric company in Chicago. He invented electric mining equipment, locomotives, streetcars and an electric automobile. He developed gyroscopic stabilizers for ships and aircraft, a successful marine gyro-compass and gyro-controlled steering and fire control systems used on Allied warships during World War I. Sperry also developed an aircraft searchlight and the world's first guided missile. His gyroscopic work resulted in the automatic pilot in 1930. The Elmer A. Sperry Award was established in 1955 to encourage progress in transportation engineering.

The Elmer A. Sperry Award

To commemorate the life and achievements of Elmer Ambrose Sperry, whose genius and perseverance contributed so much to so many types of transportation, the Elmer A. Sperry Award was established by his daughter, Helen (Mrs. Robert Brooke Lea), and his son, Elmer A. Sperry, Jr., in January 1955, the year marking the 25th anniversary of their father's death. An additional endowment to support the award was received in 1978 upon the death of Mrs. Lea. Additional gifts from interested individuals and corporations also contribute to the work of the Board.

Elmer Sperry's inventions and his activities in many fields of engineering have benefited tremendously all forms of transportation. Land transportation has profited by his pioneer work with the storage battery, his development of one of the first electric automobiles (on which he introduced 4-wheel brakes and self-centering steering), his electric trolley car of improved design (features of its drive and electric braking system are still in use), and his rail flaw detector (which has added an important factor of safety to modern railroading). Sea transportation has been measurably advanced by his gyrocompass (which has freed man from the uncertainties of the magnetic compass) and by such navigational aids as the course recorder and automatic steering for ships. Air transportation is indebted to him for the airplane gyro-pilot and the other air navigational instruments he and his son, Lawrence, together developed.

The donors of the Elmer A. Sperry Award have stated that its purpose is to encourage progress in the engineering of transportation. Initially, the donors specified that the Award recipient should be chosen by a Board of Award representing the four engineering societies in which Elmer A. Sperry was most active:

The American Society of Mechanical Engineers
(of which he was the 48th President);
American Institute of Electrical Engineers
(of which he was a founder member);
Society of Automotive Engineers; and
Society of Naval Architects and Marine Engineers.

In 1960, the participating societies were augmented by the addition of the Institute of Aerospace Sciences. In 1962, upon merging with the Institute of Radio Engineers, the American Institute of Electrical Engineers became known as the Institute of Electrical and Electronics Engineers; and in 1963, the Institute of Aerospace Sciences, upon merger with the American

Rocket Society, became the American Institute of Aeronautics and Astronautics. In 1990, the American Society of Civil Engineers became the sixth society to become a member of the Elmer A. Sperry Board of Award.

Important discoveries and engineering advances are often the work of a group, and the donors have further specified that the Elmer A. Sperry Award honor the distinguished contributions of groups as well as individuals.

Since they are confident that future contributions will pave the way for changes in the art of transportation equal at least to those already achieved, the donors have requested that the Board from time to time review past awards. This will enable the Board in the future to be cognizant of new areas of achievement and to invite participation, if it seems desirable, of additional engineering groups representative of new aspects or modes of transportation.

THE SPERRY SECRETARIAT

The donors have placed the Elmer A. Sperry Award fund in the custody of The American Society of Mechanical Engineers. This organization is empowered to administer the fund, which has been placed in an interest bearing account whose earnings are used to cover the expenses of the board. A Secretariat is administered by the ASME, which has generously donated the time of its staff to assist the Serry Board in its work.

The Elmer A. Sperry Board of Award welcomes suggestions from the transportation industry and the engineering profession for candidates for consideration for this Award.

PREVIOUS ELMER A. SPERRY AWARDS

1955 To *William Francis Gibbs* and his Associates for design of the S.S. United States.

1956 To *Donald W. Douglas* and his Associates for the DC series of air transport planes.

1957 To *Harold L. Hamilton, Richard M. Dilworth* and *Eugene W. Kettering* and Citation to their Associates for developing the diesel-electric locomotive.

1958 To *Ferdinand Porsche* (in memoriam) and *Heinz Nordhoff* and Citation to their Associates for development of the Volkswagen automobile.

1959 To *Sir Geoffrey de Havilland, Major Frank B. Halford* (in memoriam) and *Charles C. Walker* and Citation to their Associates for the first jet-powered passenger aircraft and engines.

1960 To *Frederick Darcy Braddon* and Citation to the Engineering Department of the Marine Division of the *Sperry Gyroscope Company,* for the three-axis gyroscopic navigational reference.

1961 To *Robert Gilmore LeTourneau* and Citation to the Research and Development Division, *Firestone Tire and Rubber Company,* for high speed, large capacity, earth moving equipment and giant size tires.

1962 To *Lloyd J. Hibbard* for applying the ignitron rectifier to railroad motive power.

1963 To *Earl A. Thompson* and Citation to his Associates for design and development of the first notably successful automatic automobile transmission.

1964 To *Igor Sikorsky* and *Michael E. Gluhareff* and Citation to the Engineering Department of the Sikorsky Aircraft Division, *United Aircraft Corporation,* for the invention and development of the high-lift helicopter leading to the Skycrane.

1965 To *Maynard L. Pennell, Richard L. Rouzie, John E. Steiner, William H. Cook* and *Richard L. Loesch, Jr.* and Citation to the Commercial Airplane Division, *The Boeing Company,* for the concept, design, development, production and practical application of the family of jet transports exemplified by the 707, 720 and 727.

1966 To *Hideo Shima, Matsutaro Fuji* and *Shigenari Oishi* and Citation to the *Japanese National Railways* for the design, development and construction of the New Tokaido Line with its many important advances in railroad transportation.

1967 To *Edward R. Dye* (in memoriam), *Hugh DeHaven,* and *Robert A. Wolf* for their contribution to automotive occupant safety and Citation to the research engineers of *Cornell Aeronautical Laboratory* and the staff of the Crash Injury Research projects of the *Cornell University Medical College.*

1968 To *Christopher S. Cockerell* and *Richard Stanton-Jones* and Citation to the men and women of the *British Hovercraft Corporation* for the design, construction and application of a family of commercially useful Hovercraft.

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1979 To *Leslie J. Clark* for his contributions to the conceptualization and initial development of the sea transport of liquefied natural gas.

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1981 To *Edward J. Wasp* for his contributions toward the development and application of long distance pipeline slurry transport of coal and other finely divided solid materials.

1982 To *Jörg Brenneisen, Ehrhard Futterlieb, Joachim Körber, Edmund Müller, G. Reiner Nill, Manfred Schulz, Herbert Stemmler* and *Werner Teich* for their contributions to the development and application of solid state adjustable frequency induction motor transmission to diesel and electric motor locomotives in heavy freight and passenger service.

1983 To *Sir George Edwards, OM, CBE, FRS; General Henri Ziegler, CBE, CVO, LM, CG; Sir Stanley Hooker, CBE, FRS* (in memoriam); *Sir Archibald Russell, CBE, FRS;* and *M. André Turcat, L d'H, CG*; commemorating their outstanding international contributions to the successful introduction and subsequent safe service of commercial supersonic aircraft exemplified by the Concorde.

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1987 To *Harry R. Wetenkamp* for his contributions toward the development and application of curved plate railroad wheel designs.

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1991 To *Malcom Purcell McLean* for his pioneering work in revolutionizing cargo transportation through the introduction of intermodal containerization.

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1994 To *Russell G. Altherr* for the conception, design and development of a slackfree connector for articulated railroad freight cars.

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