TO THOSE WHO DEVOTE THEIR LIVES
TO THE PURSUIT OF KNOWLEDGE FOR THE
ENRICHMENT OF MANKIND

NUMERICAL AERODYNAMIC SIMULATION
The rapid advance of the aeronautical sciences continues in much the same way the early days of transforming developments through the formal establishment of a facility to support aeronautical research and development. The trend has always been tied to advances in supporting technology areas. Today, the advanced tools that have been created to help this growth are computational fluid dynamics (CFD) and advanced supercomputers.

A productive bond has formed between these advanced sciences. This has led to an improved understanding of fluid physics and the interdependence between aerodynamics and the thermal and chemical phenomena associated with the extended tests of modern flight.

Computers support evaluations of design configurations and flight conditions that cannot be tested in other ways and can simulate proximity-computer and extends data obtained from wind tunnels and other experimental facilities.

Contemporary aircraft bear the imprint of the computer age. The pilot and aircraft communicate through computer control systems and computers.

Everything must work together in closely timed harmony as aerodynamic shapes undergo dynamic revision and environments shift rapidly during flight. Computational flight control systems are essential to many highly maneuverable but often short-lived aircraft. The national progress and economic advantage hinge on the use of these advanced technologies to support pioneering activities. Aeronautics has always been an area in which the most creative talents were employed in the quest for new ideas. Interdisciplinary efforts will continue with aeronautical sciences linked inseparably to the computer.
The use of computational fluid dynamics in modern aircraft design is a dream that has become a reality. Past aerodynamic developments could not explore all of the dimensions of fluid mechanics during the design process. Numerical Aerodynamic Simulation (NAS) establishes the capability to conduct modern design explorations using the most advanced computers.

Opportunities for the advancement of U.S. leadership in aerodynamics are immediately tied to the exploitation of the science of computational fluid dynamics. The tempo of aerodynamic research and design has increased dramatically in the United States. The scope of problems and applications that can now be addressed continue to inspire technology projections.

The supercomputer is a time machine. Design iterations that formerly required years of development with wind tunnels and experimental flight tests can now be completed on compressed time scales. Today, wind tunnel and experimental flight tests assume a new, more efficient, and productive role. Wind tunnels evaluate models at a later stage of design, and are used to verify and improve numerical codes. Flight testing is conducted with more confidence due to the range and extent of dynamic simulations that have been provided by the computer.

A long-range goal of CFD is to develop software tools that will compute in a few minutes, the actual stresses found around realistic computational models of aircraft and aerospace vehicles. This capability will simulate localized flow phenomena, as well as define the stability and control performance and loads for complete systems, including aircraft, helicopters, missiles, and spacecraft. Increased understanding of these phenomena will result in advanced vehicle designs with substantially increased performance and efficiency.

NAS is a national resource available to support research and development for commercial and military aircraft. Designs can now be modeled with very high fidelity. Design revisions can be evaluated on time scales that were unheard of only a decade ago. Implementation of fluid dynamics algorithms, once thought of as mathematical curiosities, are now commonplace. The full promise of this marriage between two of our most advanced technologies is yet to be realized.
The NAS capability combines several necessary elements to produce an unparalleled scientific computing environment. The ingredients include a supercomputer, various support processing systems, mass storage, graphics, and display systems, and workstations linked with the network via high-speed data networks. The system is complete only when it includes the most important elements of a NAS system. The NAS capability is used by those pursuing advanced R&D in the aerospace sciences and in other areas which require large scale computations.

The high speed processors that form the heart of the NAS system can be effectively accessed by local and remote users. The interactive systems that link users to processors provide a common computing environment, reducing the complexities of computations to understandable outputs, conveniently displayed.

The NAS Processing System Network (NPSN) is accessible to a nationwide community of users. This processing capability provides access to the most powerful computer in the United States for the national aerospace research and development.

The NAS program has three goals:
1. Establish a national computational capability, available to NASA, Department of Defense (DOD) and other government agencies, industry and universities, as a necessity in planning continuing leadership in computational fluid dynamics and related fields.
2. Be a part of an advanced, large scale, computer system through the systematic incorporation of leading edge improvements in computer hardware and software technologies.
3. Provide a testing research tool for the NASA Office of Aeronautics and Space Technology.

The initial operating phase began in the summer of 1986 and continues with the introduction of advanced systems and new facilities.

Implementation planning is evolutionary. The NAS strategy is to incorporate a wide variety of commercially available and powerful prototype or early production model supercomputers as high speed processors. In this way, NAS will continue to meet the expanding needs and capabilities of its users. System access is provided to users at a geographically dispersed NASA center, DOD and other government research installations, aerospace industry sites and universities. Effective use is made of existing communications networks such as ETHERNET, ARPANET and NSFNET. A broad range of communications bandwidths and services allow users access via terminals, workstations or other host computer systems.
The ongoing evolution of digital computers supports the progress of technology in many areas. Computers can be used to gain insight into physical phenomena too complicated to explore experimentally.

For over a century, the equations governing physical phenomena of fluid flow were understood, but we lacked the tools to obtain analytical solutions. Experimental observation was a means of solution, but many problems were too complex to allow investigation. Computers serve as a bridge to the future, providing a capability for studying the basic physics of turbulence, vortex flow, chemical and nuclear reactions, weather prediction, molecular modeling, and other engineering and scientific sciences requiring large scale computations. Computational and experimental techniques can now be applied from complementary perspectives leading to an improved understanding of physical behavior.

This is a stimulating time for fluid dynamicists able to take advantage of the confluence of supercomputers, advances in applied mathematics and the improving science of fluid physics. Innovative computational architectures, coupled with the explosive growth in storage capacity and reductions in operating speeds, make it possible to observe complex, three dimensional flows at increasingly realistic scales and geometries. According to the advances in computer technology, numerical aerodynamic simulation will continue to require increasingly more powerful computers to sustain the rate of progress in the astronautical sciences.

Computers are a part of contemporary life at many levels. Casual observers of this technology usually equate computational progress with speed. The speed of modern computers eclipse their predecessors every few years. At the same time, computers become smaller. However, the unrecognized leaders of computational design are storage capacity and problem specific architectures. Memory capacity has grown at an even faster rate than processing speed and powerful parallel architectures have arisen to match the problems that they are designed to solve. It is difficult to predict the conclusion of this conundrum between applications and computing devices except to recognize that the unfolding scenario has just begun.
It is not the supercomputing machines that will make history, but the people using them. The salient characteristic of the computer age may be the general availability of a relatively rare localized resource.

This availability is in itself the result of another expanding technology, communications. Users are linked to the nucleus machine via high speed communication links that support interactive access for terminals, graphics work stations and other computers. Computers are playing an increasingly important role in all science and engineering disciplines.

World leadership is indelibly linked to computer use in activities ranging from the day-to-day conduct of commerce to the heights of scientific discovery.

At the centerpoint of these endeavors are humans pursuing commercial and scientific goals. Their success is directly tied to the organic link that must exist between mind and machine. In the hands of an explorer, the computer can stimulate global transformation, economic and social revision, and scientific advancement.
Accuracy, fidelity, congruency; words that convey the ability to monitor and perceive the true characteristics of an event usually result from careful observations or simulations within relevant temporal, spectral and spatial scales. Improvements result from an ability to sample finer spatial grids on closely separated time steps. For example, the uppermost exhibit is consistent with three dimensional flow simulations associated with the grid density possible in 1978.

Observations became more refined as time progressed and the intricacies of flow were further revealed for even the simplest of structures. Finally, three dimensional simulations were achieved permitting new revelations about the flow around real world structures.

Detailed structural analysis of the Space Shuttle's solid rocket booster is a complex problem. A 83,000 degree-of-freedom shell model was developed to evaluate overall booster stresses and to study geometric imperfections on shell response. Results of the simulations have been used to guide the redesign activity that is part of the shuttle booster requalification program.
Aerospace Plane places special emphasis on inlet performance. Numerical techniques are being used to study the effects of shock cowl and ramp of a Mach-5 inlet. Numerical results demonstrate the calculated skin friction on a mixed benchmark experiments to verify the computer code.

The hypersonic environment of the National compressions inlets. Surface plots will be compared with data from Mach-2.5 between the jet exhaust and the surrounding density and pressure traces with the solution adapted grid. Contours rapidly expand around the nozzle flow field. A field interactions become nonlinear in critical locations during normal operation. Structural blade performance is assessed numerically in terms of deformation, stresses and vibratory natural frequencies. Constant displacement contours are shown for a modal of turbine blade material characteristics.

Developments of modern high-speed aircraft rely on computational analysis. This flow field illustrates particle height above a model of the F-16A fuselage and wing assembly. While red traces hug the body, blue and yellow streams show the increasing height with blue lead to stall and red trailing edge. Distributions, indicating that the boundary layer along the nozzle wall can grow faster than the nozzle expansion. This results in a maximum mach number occurring upstream of the exit. Researchers are using three-dimensional simulations to provide the required thrust vectoring to provide the required thrust vectoring to offset the forward motion of the aircraft. The modeled condition is a 90-degree angle of attack, with the cruise mass flow rate passing through each inlet.

Surface contour techniques are used to analyze the stationary, turbulent, and rotational flow phenomena. Surface plots, at 9·second intervals, were produced from a simulation of harmonic and subharmonic acoustic noise. Computational results are being used to guide the design of the resistojet, which is a space-based small low-speed engine. Turbulent mixing can have a strong effect on engine exhaust ducts and nozzles. The figures show pressure distributions, indicating that the boundary layer along the nozzle wall can grow faster than the nozzle expansion. This results in a maximum mach number occurring upstream of the exit. The thermomechanical loading with rotational velocity speeds as high as 36,000 r.p.m. Non-linear, three-dimensional, Parabolized Navier-Stokes (PNS) equations to predict aerodynamic and heat transfer characteristics. The figures show pressure distributions, indicating that the boundary layer along the nozzle wall can grow faster than the nozzle expansion. This results in a maximum mach number occurring upstream of the exit.
The prediction of future accomplishments made possible by the computer is a challenge.

The pattern of exponential growth in computational capabilities is expected to continue for some time as a result of large scale electronics integration, storage capacity and computer architecture technologies.

Advancements in computer performance have been closely paralleled by improvements in numerical algorithms.

The results of this partnership have provided five orders of magnitude decrease in the cost of performing a computation in the last fifteen years.
Theory and experimentation are entwined in a reinforcing way. In some cases, the physical observation comes first, in others the situation is reversed.

The relative roles of theory and experiment have reached a new plateau with the introduction of the digital computer.

In the past, computers represented a new tool for the scientist and engineer. They are now indispensable.

Together, the computational and experimental disciplines will yield a more complete understanding of physical phenomena leading to rapid advances in many areas of human endeavor.
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Numerical aerodynamic simulation often enters the domain of art. These particle flows provide the viewer with dashes of color as if from the brushstroke of an artist.

Shown are particle traces of a candidate configuration of the future national aerospace plane. Subsonic, supersonic and hypersonic flow fields about complex vehicles with wings, tails, fins, etc., can be accurately predicted and shown in a very physical manner.