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

NUMERICAL AERODYNAMIC SIMULATION

ORIGINAL CONTAINS
COLOR ILLUSTRATIONS
The rapid advance of the aeronautical sciences continues in much the same way that the early days of transforming developments through the formal establishment of the society for aeronautics research and development program has been the key to advances in supporting technology areas. Today, the advanced tools that have been created to feed this growth are computational fluid dynamics (CFD) and simulation software.

A productive bond has formed between these advanced sciences. This has led to an improved understanding of fluid physics and the interdependence of 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 treated in other ways and can provide additional insights and redundant 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 software.

GLIDER TESTS PRECEDE THE "WRIGHT FLYER".

THE ROCKET POWERED X-15.

BOEING 707.

ENTRY BALLISTICS ON A BLUNT BODY.

LIFTING BODY UNDERGOING WIND TUNNEL TESTING.

COMPUTED SPACE SHUTTLE FLOW FIELD.

JOVIAN ATMOSPHERIC PROBE (GALLILEO) HEAT SHIELD.

THE X-29 EXPERIMENTAL FORWARD SWEPT WING AIRCRAFT.

THE FUTURE NATIONAL AEROSPACE PLANE (NASP).

THE CONCORD FIRST OF THE NASA CONTRIBUTIONS.

KOREAN WAR JET FIGHTER THE BANSHIE.

X-1 BREAKS THE SOUND BARRIER.

DOUGLAS DC-3.

FIRST MEETING OF THE NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS 1915.

COMPUTATIONAL FLUID DYNAMICS BEGINS USING THE ILLIAC IV COMPUTER.

NORTH AMERICAN XB-70 SUPersonic TRANSPORT.

Since the very beginning of flight, man has relied on testing and development of new concepts before taking the first steps of large scale design and implementation. Nearly all great technical advances are the product of innovative minds leveraged by the machines they design to realize their dreams. The first step, the "Wright Flyer", was the result of many hours of scale model testing in an early wind tunnel accompanied by improved experimental glider flights.
The use of computational fluid dynamics in modern aircraft design is a dream that has become a reality. Past aerodynamical 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 exploitation of the sciences of computational fluid dynamics. The tempo of aerodynamical research and design has increased dramatically in the United States. The scope of problems and applications that can now be addressed continue to expand 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 confident, and productive role. Wind tunnels evaluate models at a mature stage of design and are used to verify and improve numerical codes. Flight testing now proceeds with more confidence due to the range and extent of dynamic simulations that have been provided by the computer.

The large scale goal of CFD is to develop software tools that will compute in a few minutes, the exact response from 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 improved 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 message between two of our most advanced technologies is yet to be realized.

MODEL OF A VERTICAL / SHORT TAKEOFF AND LANDING (V/STOL) FIGHTER AIRCRAFT FORCES AERIAL ARMED VERSUS 50 FOOT WIND TUNNEL.

THE CONTOURS OF THE F-16 AIRCRAFT ARE MODELED BY OUTLINES OF THE AIRCRAFT ON THE SURFACE TO FORM A GRID. THE GRID IS THEN SIMPLIFIED TO LOCATIONS CONSISTENT WITH THE COMPLEXITY OF LOCALIZED FLOWS.
The NAS capability combines several necessary elements to produce an unparalleled scientific computing environment. The elements include a supercomputer, various support processing systems, mass storage, graphics, and identity systems, and work stations 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 used only when they can be effectively accessed by local and remote users. The interactive systems that link users to processors provide a common operating communication system, reducing the complexities of computations to understandable outputs creatively displayed.

The NAS Processing System Network (NPSN) is accessible to a nationwide community of researchers. The networking capability provides a large-scale computing for United States aerodynamics 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 necessary element in placing continuing leadership in computational fluid dynamics and related technologies.
2. Be a partner in advanced, large scale computer systems through the systematic incorporation of leading edge improvements in supercomputer hardware and software technologies.

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 range of state-of-the-art, powerful prototype or early production model supercomputers at 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 geographically dispersed NASA centers, DOD, and other government research institutions, 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, work stations 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, seismic phenomena, 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, there have been 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 require computational progress with speed. The speed of modern computers eclipse their predecessors every few years. At the same time, computers become smaller. However, the unacknowledged 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 original architectures have arisen to match the problems that they are designed to solve. It is difficult to project the conclusion of this counterpart 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 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 are benchmark experiments to verify the computer code.

Surface plots will be compared with data from mach·2.5. Improvements in these flow field interactions will result in reduced drag and enhanced aircraft performance. Structural blade performance is assessed numerically in terms of deformation, stresses and vibratory natural frequencies. Constant displacement contours are shown for a modal frequency of 4487 Hz.

Three dimensional simulations improve understanding of the complex interactions between the jet exhaust and the surrounding flow field. Displayed in red is the velocity field for the wing surface panel analysis techniques are used to evaluate propeller aerodynamic interference design. High pressure, low velocity regions are shown representing subsonic stagnation, yellow sonic velocities and red supersonic velocities. The velocity field for the wing section depicts freestream velocities and red supersonic velocities. The Faraday view of the tip released at the tip of a wing form a vortex, then braid and roll up as they decrease downstream.

Developments of modern fighter aircraft rely on computational analysis. This flow field model of the F-16A fuselage and wing assembly. While red traces hug the body, blue and yellow streams show the increasing height.

Computational results are being used to provide a "microscope" to follow the evolution of vortex development and guide the design of the resistojet, which is a space-based small low thrust rocket engine. Particles developed by the authors are released from the tip of a wing in a vortex, then braid and roll as they decrease downstream.

Turbulent mixing can have a strong effect on engine exhaust ducts and nozzles. Turbulent mixing can have a strong effect on engine exhaust ducts and nozzles. Turbulent mixing can have a strong effect on engine exhaust ducts and nozzles.
The phenomena associated with the evolution of the universe affect the fundamental aspects of our survival and existence. The initial conditions set by the Big Bang and the subsequent interactions of matter and energy have determined the development of life as we know it. Computational methods are being used to simulate these processes, allowing us to understand the behavior of the universe on a macroscopic scale.

Computational techniques for examining the behavior of our world are becoming increasingly sophisticated. The study of turbulence, for example, is crucial for understanding the flow of air around aircraft and the movement of fluids in engines. Special evaluation tools are being developed to assess the performance of pathfinding projects, such as the navigation of space telescopes and the interaction of hot gases in turbines. The phenomena of hot streaks encountered in these applications are being accurately modeled to improve performance and efficiency.

The release of weapons from high-speed aircraft can be a dangerous operation. Reverse airflow and the just-separated body present unique challenges for numerical methods. These processes are difficult to evaluate experimentally, but computational investigations offer a valuable alternative. The phenomena of hot streaks and their impact on structural stresses can be successfully evaluated using these methods. The bursting vortex process is a sequence of events occurring in the wall region of turbulent flows. These processes are responsible for most of the turbulence, and computational investigations have shown that two different structures coexist in the flow field.

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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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McDONNELL DOUGLAS CORPORATION
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.