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HISTORY OF THE NUMERICAL AERODYNAMIC SIMULATION PROGRAM

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ABSTRACT

NASA's Numerical Aerodynamic Simulation (NAS) program has reached a milestone with the completion of the initial operating configuration of the NAS Processing System Network. This achievement is the first major milestone in the continuing effort to provide a state-of-the-art supercomputer facility for the national aerospace community and to serve as a pathfinder for the development and use of future supercomputer systems. The underlying factors that motivated the initiation of the program are first identified and then discussed. These include the emergence and evolution of computational aerodynamics as a powerful new capability in aerodynamics research and development, the computer power required for advances in the discipline, the complementary nature of computation and wind tunnel testing, and the need for the government to play a pathfinding role in the development and use of large-scale scientific computing systems. Finally, the history of the NAS program is traced from its inception in 1975 to the present time.

INTRODUCTION

The Numerical Aerodynamic Simulation (NAS) program is an outgrowth of the discipline of computational fluid dynamics. However, the NAS system is now recognized to be an important facility for advancing all of the computationally intensive aerospace disciplines and for serving in a pathfinder role for the development and use of future supercomputer systems. In fact, the NAS Program began to influence both discipline-oriented users and developers of supercomputers even before the system was first assembled. The NAS has drawn national attention to the importance of scientific computers to the country's technology base and has served as a focal point for the large-scale scientific computing community.

The NAS program will provide a leading edge computational capability to the national aerospace community. It will stimulate improvements to the entire computational process ranging from problem formulation to publication of results. The program has been structured to focus on the development of a complete computer system that can be upgraded periodically with minimum impact on the user and on the ever increasing inventory of applications software. The NAS system, in its initial operating configuration, is already serving over 200 users nationwide at over 20 remote locations. These numbers will continue to increase as the system matures to its extended operating configuration including two powerful supercomputers, all of the necessary supporting equipment, and well established communications links.

The objectives of this paper are twofold: 1) to identify the factors that led to the initiation of the NAS Program, and 2) to review the evolution of the NAS Program from its inception in 1975 to the present time. Included in the discussion are brief reviews of the evolution of computational aerodynamics, computer requirements for future advances, the complementary roles of computation and experiment, and the historical role of the government in the development and use of large-scale scientific computing systems.

FACTORS MOTIVATING THE NAS PROGRAM

The underlying motivations for the NAS program are a composite of four principal factors: 1) the emergence and evolution of computational aerodynamics as a powerful new capability in aerodynamics research and development; 2) the demands that this relatively new discipline places on computer systems; 3) the use of computation as a complement to wind-tunnel testing; and 4) the long standing, recognized need for the government to play a pathfinding role in the development and use of large-scale scientific computing systems. Each of these factors will be briefly discussed prior to describing the evolution of the program.

Emergence and Evolution of Computational Aerodynamics

Electronic computers were used to assist with aerodynamic analyses ever since they became available to the aeronautical researchers in the 1950s. Prior to 1970, aerodynamic analyses were limited primarily to the solution of the linearized inviscid flow equations and to the equations governing the behavior of the viscous boundary layer adjacent to an aerodynamic surface. Computers of the IBM-360 and CDC-6600 class permitted these equations to be solved for the flows about idealized complete aircraft configurations, but only for situations where the flows were everywhere either subsonic or moderately supersonic and everywhere attached to the surfaces over which they passed. Some attempts were made to include the nonlinear terms in the inviscid flow equations and solve for transonic flows about airfoils, but these were limited to the very restrictive situations of either nonlifting airfoils or airfoils with detached bow shock waves.

The year 1970 marked the beginning of a series of advances in computational aerodynamics that would not have been possible without computers. The first major advance in solving for the nonlinear transonic flows about practical lifting airfoils with embedded shock waves was reported in the literature by Magnus and Yoshihary (1970). Subsequent milestones in the development of the technology for treating the nonlinear inviscid equations, and enabled only by the computer, are shown in figure 1. By about 1973, solutions for wing-body combinations treated with the steady-flow, small-disturbance equations were being published. Results of the first treatment of unsteady flows about airfoils appeared in the literature by Ballhaus, Jr., et al. (1975), and the first flutter analysis for a swept wing was published about 6 yr ago by Borland and Rizzetta (1981). Research on the aeroelastic behavior of wings is still limited by the performance of currently available computers to the treatment of the equations governing inviscid flows. These equations, with corrections for boundary-layer effects, are still used extensively for a wide range of aerodynamic problems. However, the really important problems facing the designers today require the use of the Reynolds-averaged, Navier-Stokes equations, both with and without the inclusion of the additional equations governing real-gas chemistry.

Milestones in the use of the Reynolds-averaged, Navier-Stokes equations for treating compressible viscous flows are shown in figure 2. These equations account for most of the physics of interest in fluid-dynamic flows. The process of time-averaging the Navier-Stokes equations over a time interval that is long relative to turbulent eddy fluctuations, yet small relative to macroscopic flow changes, introduces new terms representing the time-averaged transport of momentum and energy, which must be modeled using empirical information. Very powerful computers are required for simulations with this level of approximation, but the potential advantages over the inviscid equations are enormous. Realistic simulations of separated flows and of unsteady viscous flows, such as buffeting, will become commonplace as the ability to model the turbulence terms matures. Combined with computer-optimization methods, these simulations should make it possible to develop designs optimized for various missions while adhering to practical constraints such as available engine power and sufficient fuel volume to meet range requirements. Landmark advances include the investigation of a shock-wave interaction with a laminar boundary layer reported by MacCormack (1971), the treatment of high-Reynolds-number transonic airfoil flows by Deiwert (1974), the first turbulent flow over a lifting wing by Mansour (1984), and the first turbulent flow over a realistic fighter configuration at angle of attack by Flores et al. (1987). Relatively large amounts of computer time are still required for the application of these equations to practical problems, but advances in technology continue to improve computational efficiency.

Figure 3 displays a perspective on the effect that increasing computer power has had on computational aerodynamics in a practical engineering sense. Presently available machines are adequate for calculating the flows about relatively complex configurations with the inviscid-flow equations. However, the type of information derived from the computations is limited (e.g., no total drag and no effects of flow separation). The viscous-flow equations, being more complex and requiring finer computational meshes, demand substantially greater computational power to solve. Thus, the types of problems that can be solved with a given computer are necessarily less complex. In effect, a designer has to make the choice between treating simple configurations with complex physics or treating complex configurations with simple physics. Yet, in both inviscid- and viscous-flow situations, each new generation of computers has resulted in advances in the value of computational aerodynamics as a design tool. The discipline will begin to mature when both complex configurations and complex physics can be treated simultaneously with a reasonable amount of computer time.

Computer Requirements

Computer requirements for computational aerodynamics can be related to the four major levels of approximation to the Navier-Stokes equations that were identified in the work by Chapman (1979). Each level of approximation resolves the underlying physics to a different degree, provides a different level of understanding, and requires a different level of computer capability. Table 1 and the works of Chapman (1979) and Peterson (1984) discuss in some depth these approximations, their capabilities to solve problems associated with aircraft aerodynamics, and the computer requirements to solve them in a reasonable amount of time (about 15 min) for flows about relatively complete aircraft configurations. Computer requirements are expressed in terms of the power of a Class VI machine, which is defined here to have a processing speed of 30 million floating-point operations per second (MFLOPS) and a memory of about 8 million words. Machines of this class are widely available at the present time. Computer requirements increase with each higher level of approximation, both because more flow variables are involved and because either more panels or more grid points are required to resolve the flows to a level of detail that is commensurate with the physics embodied in the approximation. Experience indicates that the Reynolds-averaged form of the Navier-Stokes equations probably will be adequate for most design-oriented problems. The effects of all scales of turbulence are modeled in this level of approximation; the development of appropriate turbulence models is the subject of current research by both computational and experimental fluid dynamicists. In fact, the experimentalists are being guided, to a large extent, by computational research programs which are based either on the large-eddy simulation approximation or on the use of the full Navier-Stokes equations for simple flow geometries.

Speed and memory requirements for computing the aerodyamic behavior of shapes of varying complexities are compared with several existing and planned computers in figure 4 . Computers large enough to provide solutions in 15 min or less to the Reynolds-averaged, Navier-Stokes equations for the flow about a complete aircraft are expected to be available before the end of this decade. This advance should mark the time when computers will not be just a supplement to the aircraft design process, but will be an absolute necessity to be competitive in meeting economic and performance requirements. Computers having even more power will be required in the future, however, to treat routine problems involving real-gas chemistry, the coupling of the disciplines of aerodynamics, structures, propulsion and controls, and the optimization of a complete aircraft design.

Complementary Nature of Computation and Experiment

In the early 1970s, computations were recognized by a few visionaries to have the potential for becoming an effective complement to fluid- and aero-dynamic experiments for a number of reasons. First, the physics of fluid flows could be represented by mathematical equations, and computers, beginning with the IBM 360 and the CDC 6600 machines, were becoming sufficiently powerful to solve meaningful approximating sets of these equations in a practical amount of time and at reasonable cost.

Second, wind tunnel costs and computational costs were recognized to be changing in importantly different ways. Increased complexity and broadened performance envelopes of aircraft caused the number of wind tunnel hours expended in the development of new aircraft to increase exponentially with time. In fact, this increase amounts to as much as a factor of about 1,000 over an 80 yr period (50 hr for the Wright Flyer compared to 50,000 hr for the Space Shuttle). Concurrently, the cost per hour of testing also increased by a factor of about 1,000 over the same period. Thus, wind tunnel testing costs escalated by nearly a million fold in 80 yr, while the cost of numerically simulating a given flow is shown by the data in figure 5 to have decreased by a factor of 100,000 in just 15 yr during the period from 1969 to 1984. This decrease was due to improvements in both computers and algorithms.

Third, on the one hand, all wind tunnels are known to have all or some of the fundamental limitations such as model size (Reynolds number), temperature, wall interference, model support interference, unrealistic aeroelastic model distortions under load, stream nonuniformity, unrealistic turbulence levels, and test gas (of concern for the design of vehicles for flight in the atmospheres of other planets). On the other hand, if it is accepted that the physics of fluid flows can be described precisely by mathematical equations, then the only fundamental limitations of the computational approach are the limits of computer speed and memory, and speed and memory appear to be expandable with time by many more orders of magnitude.

Finally, wind tunnels and computers each bring different strengths to the research and development process. The wind tunnel is superior in providing detailed performance data once a final configuration is selected, especially for cases involving complex geometry and complex aerodynamic phenomena. Computers are especially useful for other applications including: 1) making detailed fluid physics studies, such as simulations designed to shed light on the basic structure of turbulent flows; 2) developing new design concepts, such as swept forward wings or jet flaps for lift augmentation; 3) sorting through many candidate configurations and eliminating all but the most promising before wind tunnel testing; 4) assisting the aerodynamicist in instrumenting test models to improve resolution of the physical phenomena of interest; and 5) correcting wind tunnel data for scaling and interference errors. The combined use of computers and wind tunnels captures the strengths of each tool.

Pathfinding Role of the Government

A concern in the mid-1970s was that computer power was only marginally adequate for calculating the aerodynamics of simple aircraft shapes at cruise conditions. More power was needed to provide both for increased resolution of geometry and for including more complete flow physics in the analyses to predict performance during maneuvers and near performance boundaries. In fact, treatment of these more complex problems in an effective manner required advances not only in computing engines, but also in operating systems, languages, compilers, central storage capabilities, networking, remote communications, graphics, and user workstations. There seemed to be no assurance that the advances required to meet government needs would be provided without government stimulus. In fact, this view was reinforced by the information summarized in table 2 which shows the historical role of the government in stimulating the development of advanced computers. Every major new digital computer from the IBM 701 to the current Cray and Control Data Corporation (CDC) machines has evolved from technology developments accelerated by a government-sponsored pioneering computer development undertaken to satisfy a driving need. The need for a superior design capability for aerospace vehicles was, and still is, a strong driver for the NAS Program.

NASA first became involved with the pathfinding role in large-scale scientific computers in a formal way when, in 1972, it joined with the Advanced Research and Development Projects Agency (now DARPA) to test the feasibility of the ILLIAC-IV computer. The ILLIAC Project was originally undertaken for the purposes of exploring the feasibility of parallel processing and advanced-computer-logic circuit technology, and researching new ideas for high-speed computer memory. When ARPA started the ILLIAC Project, their driving need was for an anti-ICBM control system. NASA's motivation for later joining in the development was, of course, the need for more computer power for the development of computational aerodynamics.

The CDC was experimenting with the STAR-100 computer at the same time the ILLIAC-IV was being tested. Only four of these machines, featuring new ideas in pipeline architecture, were produced. Three of these were obtained by Government laboratories and one was retained by CDC. Cray Research, Inc. had yet to produce a machine and IBM elected not to compete in the large-scale scientific computer market. Two other companies, Burroughs and Texas Instruments, were on the verge of discontinuing their supercomputer efforts. Technology surveys showed that computers having many times the power of the ILLIAC-IV and the STAR-100 could be developed, but the development would not happen without Government sponsorship since the market for supercomputers was still very small and limited primarily to government laboratories. In the mid-1970s, ARPA's interests had been largely satisfied with the ILLIAC-IV, and no government organization other than NASA appeared to be interested in first defining long-range requirements for supercomputers and then strongly urging their development.

The experience gained with the ILLIAC-IV project and the clear benefits derived from it provided further motivation for proceeding with a major thrust to develop an advanced computational system and the confidence that success could be achieved. Benefits from the ILLIAC-IV Project accrued in four major areas. First, in computer technology, the ILLIAC-IV was the first large machine to have multiple processors working in parallel, the first to employ emitter-coupled logic (ECL), and the first to have multilayered (12 layers) printed circuit boards designed with automated methods. Second, in algorithm technology, the existence of the machine forced the development of numerical methods for parallel processing. This new method also led to the revelation that some principles of parallel algorithms could be utilized to obtain faster execution of problems on conventional computers of that time period that could perform some functions simultaneously, such as the CDC 7600, than could be obtained using algorithms based on sequential computing concepts. Third, a deeper understanding evolved from the problems associated with large one-of-a-kind scientific computers. These problems included operating-system software costs, problems associated with applications software transportability to machines having different architectures, and a need to provide extensions to the common FORTRAN language to obtain maximum performance gains. In fact, the NASA Ames Research Center's investigators developed a language called "CFD" which enabled fluid dynamics codes to be run efficiently on the parallel-processing architecture. For problems that could be structured in parallel, the ILLIAC-IV was substantially more powerful than the other scientific computers of its era.

This advanced computer power enabled a number of pioneering advances in CFD, including the first simulation of viscosity-induced unsteady flow (buffett) about an airfoil, the first simulation of control-surface buzz, and detailed simulations of turbulent flows. The ILLIAC-IV experience provided the foundation and motivation for continuing to advance both CFD and supercomputer systems technology, which led to the conception of the NAS program.

EVOLUTION OF THE NAS PROGRAM

The potential value of the computational approach to aerodynamics research and development was clearly established by the mid-1970s. Also clear was the importance of pursuing every conceivable opportunity for improving aerospace vehicle design tools to maintain a leadership position in the intensifying international competition in both the commercial and military aircraft arenas. Thus, in 1975, a small group of people associated with the computational fluid dynamics effort at the Ames Research Center conceived the NAS program as a vital underpinning of the country's future in aeronautics.

The group recognized the importance to computational aerodynamics of a sustained effort to increase computer power as rapidly as technology would allow. They also recognized the need for the government to assume some responsibility for a pathfinding role to accelerate the attainment of new milestones in computer performance.

The initial proposal called for the development of a special-purpose processor called the Navier-Stokes Processing Facility. The central processor was to have a minimum effective speed of one-billion floating-point operations per second when operating on the three-dimensional, Reynolds-averaged, Navier-Stokes equations and to have performance comparable to the best general-purpose computers when used for processing the equations of other scientific disciplines. Its main memory had to accommodate a problem data base of

31-million 64-bit words. To keep development risks low, the goal of the project was to assemble existing computer component technologies into a specialized architecture rather than to develop new electronic components. Finally, the machine had to be user-oriented, easy to program, and capable of detecting systematic errors when they occurred. The proposal was endorsed in principle by NASA management in November, 1975; then in-house studies began to gather momentum and the name of the project was changed to the Computational Aerodynamic Design Facility (CADF).

Computational Aerodynamic Design Facility Project

The first formal exposure of NASA's objectives occurred in October, 1976 when proposals were requested from industry to "perform analysis and definition of candidate configurations for a computational facility in order to arrive at the best match between aerodynamic solution methods and processor system design." These analyses were to be directed toward the selection, preliminary design, and evaluation of candidate system configurations that would be best suited to the solution of given aerodynamic flow models. Design requirements that were established for this study included: 1) the capability to complete selected numerical solutions of the Navier-Stokes equations for grid sizes ranging from 5×10^5 to 1×10^6 points and wall-clock times (exclusive of input-data preparation and output-data analysis) ranging from 5 to 15 min; 2) a working memory of 40×10^6 words; 3) an archival storage of at least 10×10^9 words; and 4) 120 hr/wk of availability to the users.

Two parallel contracts were awarded in February 1977 to develop preliminary designs for the most promising configurations and to develop performance estimates, risk analyses, and preliminary implementation cost and schedule estimates for each of the designs. During these initial studies, which lasted about 12 mo, it became apparent that the overall approach to developing the facility was sound and that performance goals could be reached with new architectural concepts and proven electronic components.

A 3-day workshop on Future Computer Requirements for Computational Aerodynamics was held at the Ames Research Center in October 1977 for the purposes of further clarifying the need for a large-scale computer system for computational aerodynamic work, for confirming that the design goals were consistent with the needs of the projected users of the facility and for validating the feasibility of meeting the requirements with emerging technology. Representatives from all of the appropriate technical communities were invited, including aircraft companies, computer companies, software houses, private research institutions, universities, the Departments of Defense and Energy, and other NASA Centers. An unanticipated large attendance of over 250 peopl confirmed the existence of broad national intere and need for more powerful computers in science and engineering. The feasibility of meeting processing speed and memory requirements was further solidified, although it was clear that the goals could only be met with a multiple-processor architecture. Projected near-term advances in electronic component performance would not permit the goals to be met with a single-processor machine. The workshop also confirmed that computer industry economics at that point in time would not support the development of large specialized processors without the infusion of government capital. The market at that time was uncertain, and it was not clear that enough machines could be sold to amortize the development costs. Finally, the aircraft industry reaffirmed the need for the proposed facility for use in solving special design problems and for serving as a pathfinder for the development and use of large-scale scientific computer systems. The workshop proceedings were edited by Inouye (1978).

An assessment of the utility of the Computational Aerodynamic Design Facility for disciplines of interest to NASA, other than fluid- and aerodynamics, was also conducted in 1977. This assessment was initiated to provide assurance that the facility would not be so highly optimized for solving the fluid dynamic equations that it would not be useful for other work. It would also provide guidance as to how the design could be altered, if required, to make it useful for general science and engineering calculations without seriously impacting its capabilities for the originally intended problems. Experts involved with research on weather and climate, structures, chemistry, astrophysics, and propulsion reviewed the proposed architectures and analyzed how the various solution algorithms peculiar to those disciplines could be mapped onto the designs. Results of the assessment confirmed the expected conclusion that the CADF would provide a powerful new capability for a broad range of problems of importance to NASA.

Numerical Aerodynamic Simulation Facility Project

After it was recognized that the facility would be used primarily for computational research rather than for routine aircraft design, the name was changed during the course of the first study contracts to the Numerical Aerodynamic Simulation Facility (NASF). Even though it became apparent after the workshop that a computational resource of this magnitude would be a valuable tool for the solution of complex problems in other technical areas of interest, aerodynamics would still be the discipline used to drive the requirements. However, before the conclusion of the first round of contracted efforts, the need for further studies with greater emphasis on a computer suitable for a broader range of disciplines was recognized.

Accordingly, 12-mo follow-on feasibility study contracts were awarded in March 1978. The results of these efforts were expected to provide data of sufficient accuracy to permit formulation of a definitive plan for the development of the facility. Several events occurred during the period of these studies which resulted in some revisions to the basic performance specifications and a deeper involvement of the user community in the project activities.

The discipline of computational aerodynamics had matured significantly in the 3 yr since the project was first conceived. New numerical methods were developed and existing methods were refined. This led to the realization that if the size of the on-line or working memory was increased to 240×10^6 words, the facility could be used not only to estimate the performance of relatively complete aircraft configurations, but also to serve as an effective tool to study the physics of turbulent flows, a subject that had eluded researchers for more than 80 years. A corresponding increase in the off-line file storage from 10×10^9 to approximately 100×10^9 words was required to accommodate the larger data sets.

A User Steering Group was formed in July 1978 to provide a channel for the dissemination of information regarding project status, a forum for user-oriented issues needing discussion, and a sounding board by which the project office could obtain feedback from future user organizations. Examples of user-oriented issues of interest were: 1) selection of user languages; 2) management policy; 3) equipment required for remote access; and 4) data protection. The User Steering Group was composed of representatives of the aerospace industry, universities, and other government agencies. The group is still active, although its name was eventually changed to the User Interface Group to reflect its current role more accurately. Organizations currently represented on the User Interface Group are shown in table 3.

The feasibility studies were completed in the spring of 1979. Each study produced a refined baseline configuration, a functional design, and rough estimates of cost and schedule. Both studies concluded that about 5 yr would be required to complete the detailed design and to develop, integrate, and test the facility. While preparations were being made to continue the contracted development process, the name of the project was changed once again to the Numerical Aerodynamic Simulator (NAS) Project.

Numerical Aerodynamic Simulator Project

A detailed plan for the design-definition phase of the activity was prepared during the winter of 1979 by the NAS Project Office, which was established at Ames Research Center earlier in the year. This plan included refining the specifications for: 1) the computing engine; 2) the support processing system; and 3) the collection of other peripherals, including intelligent terminals, graphical display devices, and data communication interfaces to both local and remote users. Two 40-week, parallel, design-definition contracts were awarded in September 1980. Upon their completion in July 1981, the contractors were awarded follow-on contracts related to further design definition. These were concluded in April 1982 when the proposals for the detailed design, development, and construction were submitted by the contractors for evaluation.

After an evaluation of the proposals, the decision was made in June 1982 to discontinue the procurement. This decision was based on evaluation findings which were that the risks involved in achieving the proposed technical objectives within the critical resource and schedule limitations were unacceptable. Following this decision, efforts began to chart a new course of action. A reassessment was made of the needs of the user community and the evolving state of the art in computer technology. Three principal conclusions resulted from this reassessment.

First, the application and essential importance of computational aerodynamics to aeronautical research and development had grown significantly since the mid-1970s. Thus, it was deemed important to establish and to maintain a leading-edge computational capability as an essential step toward maintaining the nation's leadership in aeronautics. To achieve this goal the NAS project was to be restructured as an on-going NAS program in which significant advances in high-speed computer technology would be continuously incorporated as they became available.

Second, the supercomputer environment had changed since the inception of the NAS activity in the mid-1970s. Increased interest in supercomputing, advances in computer technology stimulated in part by the NAS Program, and the increasing threat of foreign competition changed the environment to the extent that it no longer appeared necessary for the government to directly subsidize the development of the next generation of scientific computers. These factors provided an environment permitting a more systematic, evolutionary approach toward developing and maintaining an advanced NAS computational capability.

Third, the importance of coupling advancements in the state of the art of supercomputers with advanced system networks and software architectures was recognized. This capability is necessary to accommodate successive generations of supercomputers from different vendors and to provide the capabilities needed to enhance productivity of the user. This step led to a strategy that minimizes the dependence of the entire system on single vendors and to the establishment of a strong in-house technical capability to direct the initial and ongoing development efforts.

This reassessment highlighted the importance of the pathfinding role of the NAS program. It would be particularly challenging to develop a system with components ranging from supercomputers to user workstations that could be maintained at the leading edge of the state of the art, while simultaneously providing uninterrupted service to a large community of users working on important national problems.

Numerical Aerodynamic Simulation Program

A plan for the redefined program was approved in February 1983. It included: 1) the design, implementation, testing, and integration of an initial operating configuration of the NAS Processing System Network; 2) the systematic and evolutionary incorporation of advanced computer-system technologies to maintain a leading-edge performance cappability; and 3) the management and operation of the complex.

The new plan was presented to the various NASA Advisory Groups, the Office of Management and Budget, the Office of Science Technology and Policy and appropriate Congressional Subcommittees. It received strong support, and the Program was approved by Congress as a new start for NASA in the President's budget for fiscal year 1984. The Administrator of NASA at that time termed the NAS Program "the Centerpiece of NASA's Aeronautical Program."

Following Program approval, the development of the initial operating capability began in earnest. The in-house project team was expanded, and it was supplemented by a force of on-site contractor personnel. Procurements of both hardware and software were initiated and the evolving test-bed network was ready to receive the first High-Speed Processor, the Cray-2, in the Fall of 1985. After about 9 mo of test and integration, and with the help of a select group of users, the system was unveiled for national use in its Interim Initial Operating Configuration in July 1986. Within a few months the system was being used effectively by over 200 national users located both at Ames Research Center and at 20 remote sites.

The term "Interim Initial Operating Configuration" was selected to emphasize the fact that the system would not reach its first stage of maturity until it could be located in the new building that was being constructed as its ultimate home. Construction of this new building started in the Spring of 1985, and it was ready for occupancy at the end of 1986. The system was shut down for several weeks, dismantled, reassembled in the new building, and brought back into operation prior to meeting the goals of the Initial Operating Configuration. This conference celebrates the achievement of the goals of the Initial Operating Configuration, and commemorates the dedication of this new national capability. Plans are now well along for expanding the system and installing the second high-speed processor prior to reaching the goals of the first Extended Operating Configuration in 1988.

SUMMARY AND CONCLUDING REMARKS

A major milestone in aerodynamics research and development was reached in 1970 when, for the first time, computers began to solve problems not previously amenable to solution. Within several years, it became apparent that insufficient computer power would impose serious limitations on the growth of computational aerodynamics as a useful discipline. It was possible to calculate the flows about three-dimensional shapes such as wings and simple wing bodies, but only with highly approximate forms of the governing equations that neglected full treatment of important nonlinear and viscous phenomena. Consideration of more comprehensive physics forced the analyses to be restricted to simple two-dimensional shapes, such as airfoils or axisymmetric aircraft components. Even in this primative state, computational aerodynamics was recognized to have the potential to become a major complement to wind-tunnel testing. Working together, computers and wind tunnels would provide a formidable capability for designing aerospace vehicles.

Recognizing the potential importance of computational methods to the aerodynamics design process, a group of people at the Ames Research Center initiated an effort in 1975 to drive the development of a computer system powerful enough to take the next major step in the development and use of computational aerodynamics. This small initial effort grew with time and, in the fall of 1983, it became a major new program for NASA with two principal objectives: 1) to provide a supercomputer facility for the national aerospace community that would be maintained as close to the state of the art as possible, and 2) to serve as a pathfinder for the development and use of future supercomputer systems. The NAS Program will reach its first major milestone in March of 1987 when its initial capability was declared operational. Already, it was serving over 200 users nationwide, and plans were well underway for its extended operating capability having two powerful supercomputers, all of the necessary supporting equipment and well-established communications links.

Computational aerodynamics was in a relatively immature stage when the NAS Program was conceived in 1975. Even so, initial forecasts of the importance of the discipline to the country's aeronautics program and of the amount of computer power required to reach various plateaus have been remarkably accurate. Nothing has transpired in the intervening 12 yr that would temper the desire to push the developement of large-scale computer systems for the country's aerospace program as fast as the technology will allow. In fact, supercomputers are now recognized as being absolutely essential for many fields of science and engineering, and all are benefiting from the efforts of the NAS Program to develop and maintain a leading-edge computational system.

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Table 1.- Governing equations, results, and computer requirements for computational aerodynamics.

APPROXIMATION	CAPABILITY	GRID POINTS REQUIRED	COMPUTER REQUIREMENT
LINEARIZED INVISCID	SUBSONIC/SUPERSONIC PRESSURE LOADS VORTEX DRAG	3×10^3 PANELS	1/10 CLASS VI
NONLINEAR INVISCID	ABOVE PLUS: TRANSONIC PRESSURE LOADS WAVE DRAG	10^5	CLASS VI
REYNOLDS AVERAGED NAVIER-STOKES	ABOVE PLUS: SEPARATION/REATTACHMENT STALL/BUFFET/FLUTTER TOTAL DRAG	10^7	30 × CLASS VI
LARGE EDDY SIMULATION	ABOVE PLUS: TURBULENCE STRUCTURE AERODYNAMIC NOISE	10^9	3000 × CLASS VI
FULL NAVIER-STOKES	ABOVE PLUS: LAMINAR/TURBULENT TRANSITION TURBULENCE DISSIPATION	10^{12} TO 10^{15}	3 MILLION TO 3 BILLION CLASS VI

Table 2.- Historical role of the Government as a prime driver in advancing computer capability.

TIME	DRIVING NEED	SPONSOR	COMPUTER DEVELOPED	KEY TECHNOLOGY	COMMERCIAL FOLLOW-ONS
MID 1940'S (WW II)	MULTITUDE OF BALLISTIC TABLES	BRL	ENIAC	VACUUM TUBE ELECTRONIC COMPUTING	IBM 701, UNIVAC I
EARLY-MID 1950'S	DEW AIR DEFENSE FOR TRACKING BOMBER FLEET	USAF	AN FSQ-7	MAGNETIC CORE MEMORY	IBM 709
EARLY 1960'S	SUPERIOR DESIGN CAPABILITY FOR SMALL NUCLEAR DEVICES	AEC	CDC 6600	INTEGRATED CIRCUITS	CDC 7600, IBM 370
LATE 1960'S	ANTI ICBM CONTROL SYSTEM (NEED ELIMINATED POLITICALLY PRIOR TO COMPLETION IN 1972)	DARPA	ILLIAC IV	SEMICONDUCTOR MEMORY AND PARALLEL PROCESSING	CDC STAR, CRAY 1
CIRCA 1980	SUPERIOR DESIGN CAPABILITY FOR AIRCRAFT	NASA	NAS PROCESSING SYSTEM NETWORK	NETWORKING OF SUPERCOMPUTERS COMMON USER INTERFACE	

Table 3.- NAS User Interface Group.

FUNCTION

- INFORMATION CHANNEL BETWEEN USER COMMUNITY AND PROJECT
- IDENTIFY AND DISCUSS USER-ORIENTED ISSUES, e.g., REMOTE ACCESS

PARTICIPATING ORGANIZATIONS

- AIRFRAME COMPANIES
  BOEING AEROSPACE, GENERAL DYNAMICS, GRUMMAN AEROSPACE, LOCKHEED-CALIF., LOCKHEED-GA., McDONNELL DOUGLAS, NORTHROP, ROCKWELL, VOUGHT
- ENGINE COMPANIES
  DETROIT DIESEL ALLISON, GENERAL ELECTRIC, PRATT AND WHITNEY
- DEFENSE DEPARTMENT
  AFWAL, AEDC, BRL, DTNSRDC, NUSC
- GENERAL AVIATION
  GENERAL AVIATION MANUFACTURERS ASSOC. (GATES-LEARJET)
- ROTORCRAFT
  AMERICAN HELICOPTER SOCIETY (UNITED TECHNOLOGY CORP. RES. CENTER)
- UNIVERSITIES
  STANFORD, UNIVERSITY OF COLORADO, SCRIPPS INSTITUTION OF OCEANOGRAPHY, PRINCETON, MASSACHUSSETTS INSTITUTE OF TECHNOLOGY
- NATIONAL SCIENCE FOUNDATION (NSF)
- NATIONAL CENTER FOR ATMOSPHERIC RESEARCH (NCAR)
- NASA
  AMES, GODDARD, LANGLEY, LEWIS

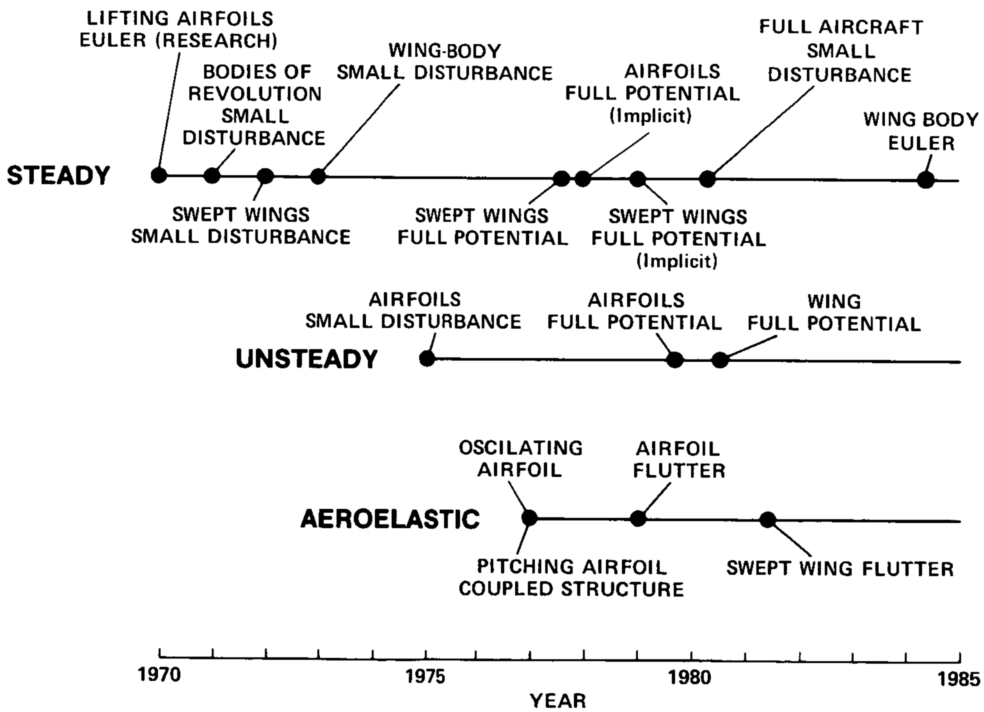

Figure 1.- Milestones in the development of computational aerodynamics; inviscid transonic flows.

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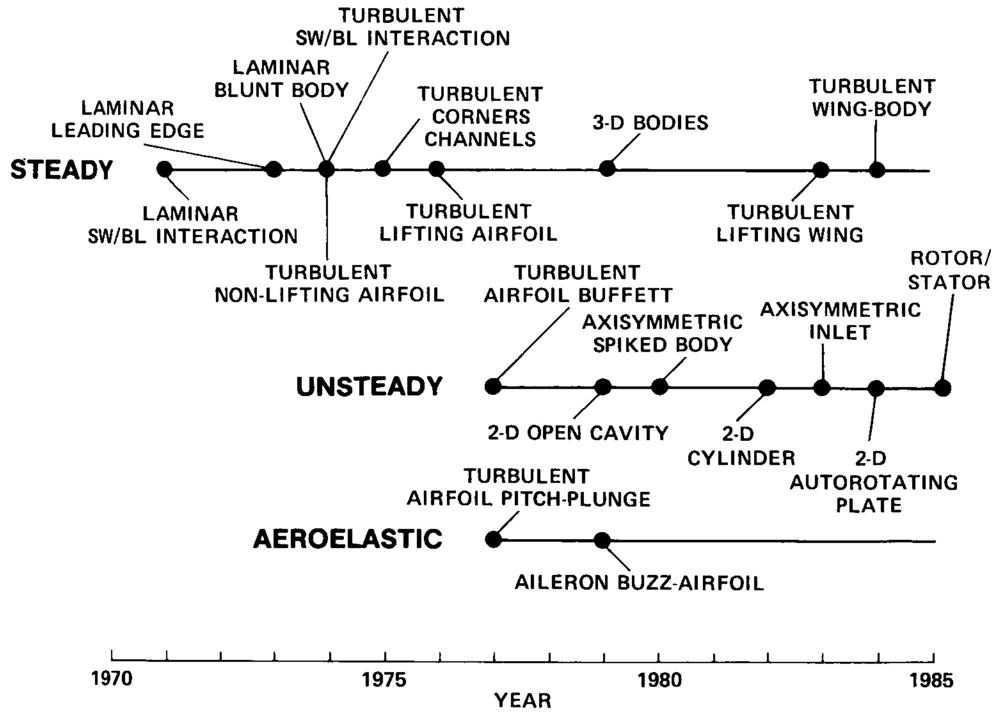

Figure 2.- Milestones in the development of computational aerodynamics; compressible viscous flows.

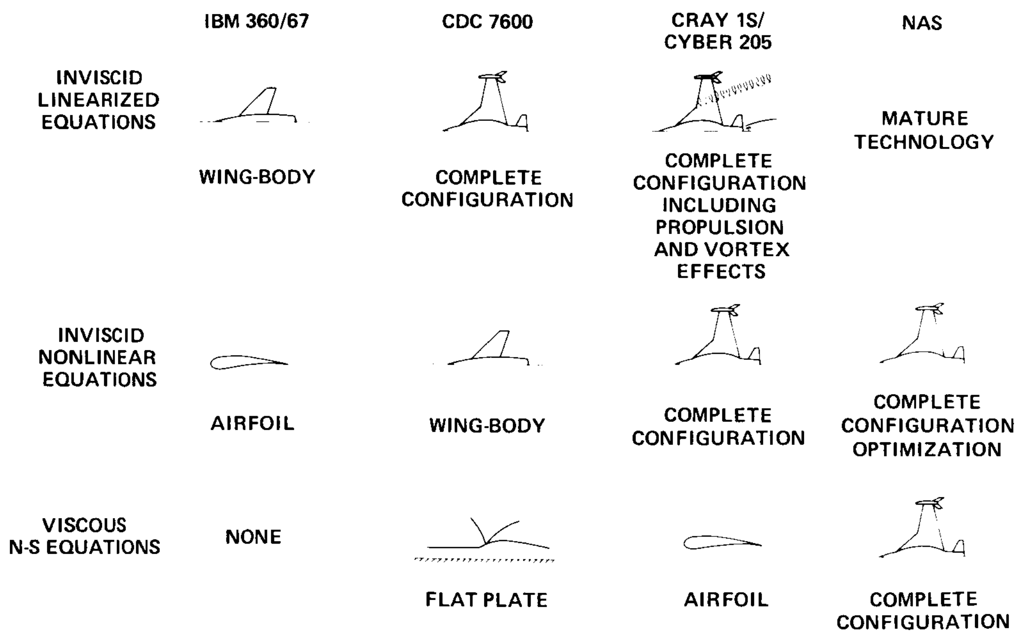

Figure 3.- Pictorial representation of the effect that increasing computer power has had on computational aerodynamics.

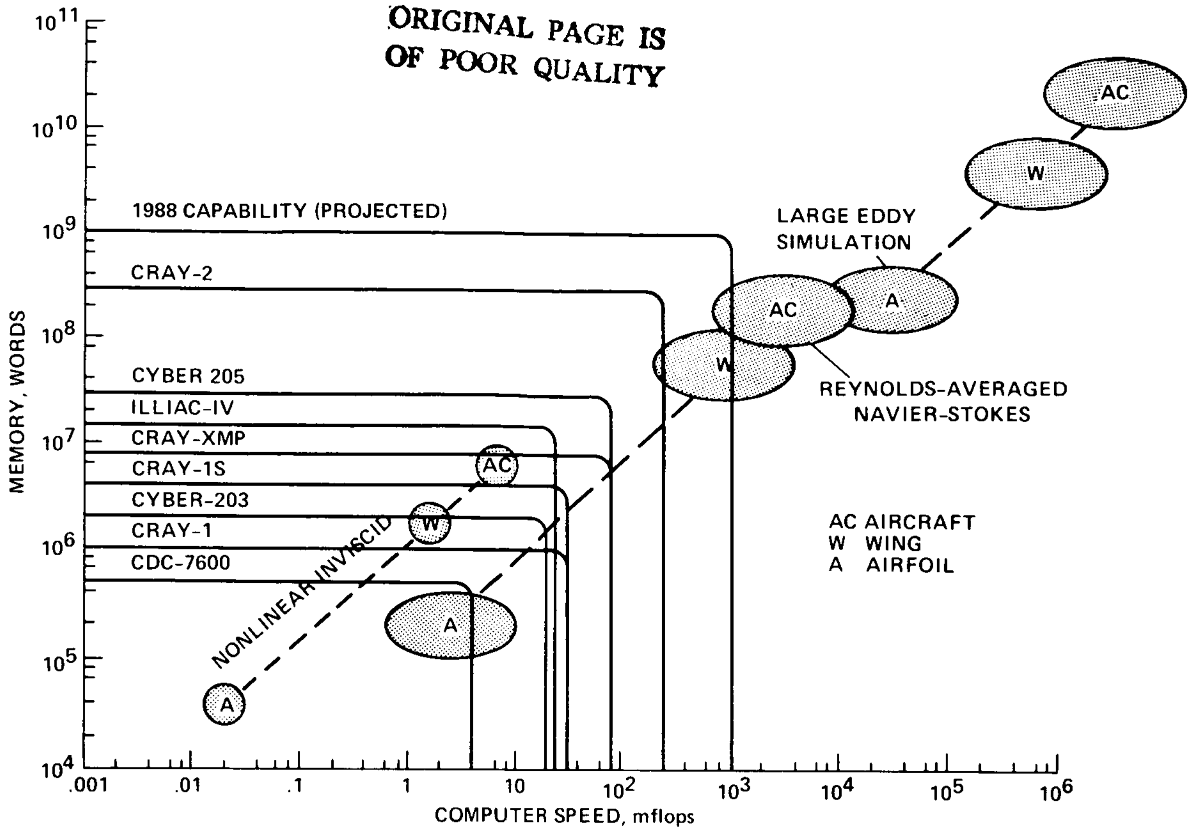

Figure 4.- Computer speed and memory requirements for aerodynamic calculations compared with the capabilities of various machines; 15-min runs with 1985 algorithms.

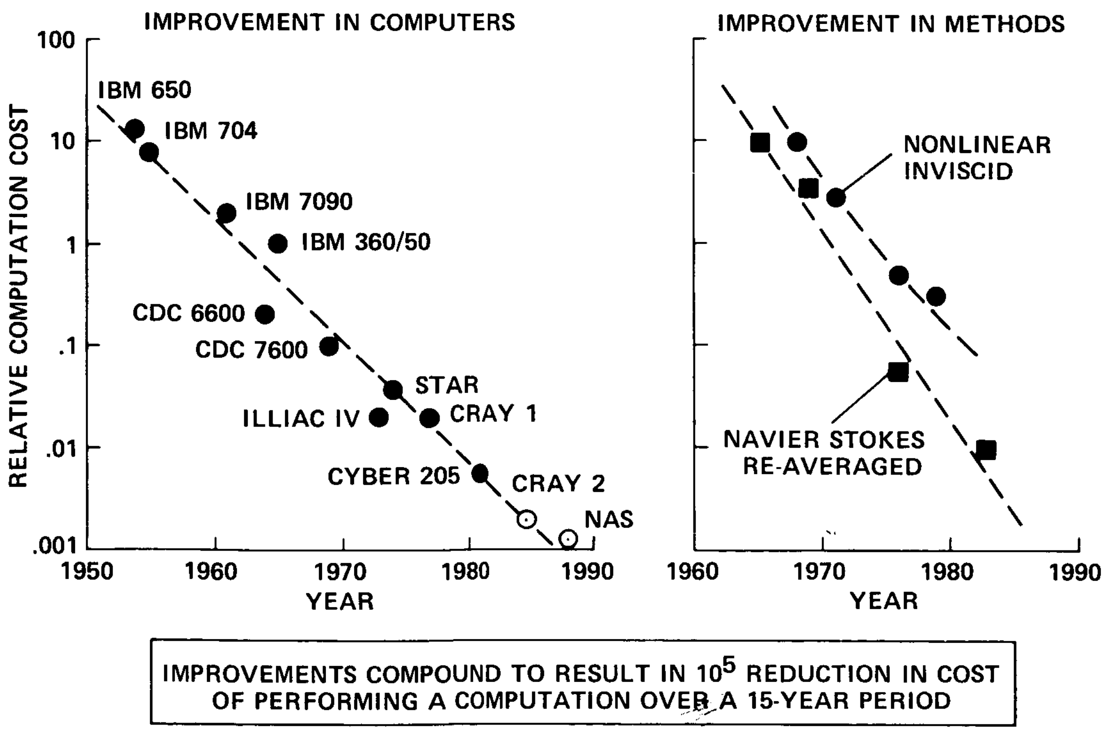

Figure 5.- Comparison of numerical simulation cost trend resulting from improvements in computers with that resulting from improvements in algorithms.