ROBERT R. BARTHELEMY

THE NATIONAL AEROSPACE PLANE PROGRAM: A REVOLUTIONARY CONCEPT

The National AeroSpace Plane program is aimed at developing and demonstrating hypersonic technologies with the goal of achieving orbit with a single-stage vehicle. This article describes the technological, programmatic, utilitarian, and conceptual aspects of the program.

INTRODUCTION

The National AeroSpace Plane (NASP) is a look into the future. It is a vision of the ultimate airplane, one capable of flying at speeds greater than 17,000 miles per hour, twenty-five times the speed of sound. It is the attainment of a vehicle that can routinely fly from Earth to space and back, from conventional airfields, in affordable ways. It represents the achievement of major technological breakthroughs that will have an enormous impact on the future growth of this nation. It is more than a national aircraft development program, more than the synergy of revolutionary technologies, more than a capability that may change the way we move through the world and the aerospace around it. It is a revolutionary technical, managerial, and programmatic concept.

The NASP program can be described in several ways: technological, programmatic, utilitarian, and conceptual. In each case, NASP has departed from the traditional evolutionary path. To achieve the vision of NASP, innovative and revolutionary approaches are required.

1. The technical challenges require the synergism of several major technology breakthroughs.
2. The programmatic challenges require a fundamental change in the development, management, and implementation of this strategic, high-technology program.
3. The utility challenge requires a transformation of our thinking about aeronautical and aerospace systems.
4. The conceptual challenge requires a paradigmatic shift in national planning, collaboration, and commitment.

Each of these challenges, and the NASP response to them, is explored in this article.

THE TECHNICAL CHALLENGE AND RESPONSE

The goal of the NASP program is to develop and demonstrate the feasibility of horizontal takeoff and landing aircraft that use conventional airfields; accelerate to hypersonic speeds; achieve orbit in a single stage; deliver useful payloads to space; return to Earth with propulsive capability; and have the operability, flexibility, supportability, and economic potential of airplanes. To achieve this goal, technology must be developed and demonstrated that is clearly a quantum leap from the current approaches being used in today's aircraft and spacecraft.

The NASP demonstration aircraft, the X-30 (Fig. 1), will reach speeds of Mach 25, eight times faster than has ever been achieved with airbreathing aircraft. As it flies through the atmosphere from subsonic speeds to orbital velocities (Mach 25), its structure will be subjected to average temperatures well beyond anything ever achieved in aircraft. While rocket-powered space vehicles like the shuttle minimize their trajectories through the atmosphere, the X-30 will linger in the atmosphere in order to use the air as the oxidizer for its ramjet and scramjet engines. The NASP aircraft must use liquid or slush hydrogen as its fuel, which will present new challenges in aircraft fueling, storage, and fuel management. To survive the thermal and aerodynamic environment, the X-30 will be fabricated from a combination of highly advanced materials: refractory composites, metal matrix composites, and extremely-high-temperature superalloys. Because no large-scale test facilities exist to validate experimentally aerodynamic and propulsion operation above Mach 8, the design and operability of NASP aircraft must be carried out in "numerical wind tunnels" that use supercomputer-aided computational fluid dynamics (CFD). Propulsion systems based on subsonic and supersonic ramjet combustion will propel the NASP FX-30, and, although these types of engines have been investigated in laboratories on the ground, there has been no significant flight testing. In the areas of aerodynamic

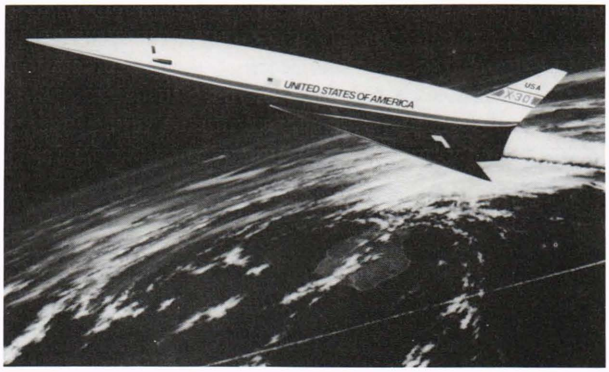


Figure 1. Artist's concept of the X-30, which is the National AeroSpace Plane demonstration aircraft.

design, flight control, thermal management, cooling systems, man–machine interface, and many other subsystems, NASP requires a major increase in capability to reach its objectives. The technical and system integration necessary to achieve single-stage-to-orbit aircraft operations will be more difficult than any yet attempted and will require a fundamentally new approach to aircraft design. In essence, NASP depends not on a single advance in technology, but on the synergism of breakthroughs in several major technical areas associated with aerospace vehicles (Fig. 2).

The NASP program has been carefully orchestrated to achieve the technological advances and integration needed to accomplish the goals of the X-30. Five key areas of technology are the focus of the NASP development program: engines, aerodynamics, airframe/propulsion integration, materials, and subsystems. Significant development activities are underway in each area and major advances have resulted. In the first three areas, approaches that were initiated at the start of the NASP program in 1986 are beginning to pay off. The work in materials and subsystems development was substantially accelerated in 1988, and there have been major breakthroughs since then in these critical technologies.

The feasibility and operability of the high-speed propulsion system are the key developments required in the NASP program, and those activities are receiving the greatest attention. The basic engine approach for NASP is a combined ramjet/scramjet airbreathing propulsion system that will provide high-efficiency thrust for much of the region between takeoff and orbit (Fig. 3). Various low-speed systems and the use of rocket systems at very high Mach numbers and for orbital insertion are being investigated. Over 20,000 hours of engine wind-tunnel tests and more than 500 shock tunnel experiments have been conducted on more than fifty engine components and integration test rigs. The feasibility of several low-speed and rocket systems has been demonstrated, and the ability of ramjet/scramjet engines to power the NASP vehicle is no longer in question. Experimental data have confirmed the predicted specific impulses, combustion efficiencies, and thrust levels at vehicle velocities up to Mach 8 using the program's industrial and government engine test facilities. More than ten different test programs are currently underway in steady-state wind tunnel and shock tunnel facilities to characterize the performance of various inlet, combustor, and nozzle components, as well as the integrated performance of full-scale ramjet and scramjet systems. The remaining two and one-half years will be spent gathering empirical data on large-scale, final configuration components and a full-scale ground demonstration engine that will demonstrate the flow path and heat transfer performance of the NASP engine up to flight speeds of Mach 8.

During the first half of the NASP development phase, several key material systems were identified as being critical to the feasibility of an airbreathing, single-stage-to-orbit aerospace vehicle. Because of the high-temperature, high-strength requirements of the NASP airframe and engine systems, most of the interesting configurations used combinations of high-temperature titanium aluminum alloys, carbon–carbon or ceramic composites, metal matrix composites, high-creep-strength materials, and high-conductivity composites. Although the development of these materials has been underway for several decades, it was determined that the progress being made was insufficient to meet the requirements of the NASP program.

The formation of a national materials consortium accelerated the development of all five material systems (Fig. 4). The consortium fabricated, characterized, tested, and developed materials in each category. Significant progress has been made on super alpha 2 titanium aluminide, titanium-aluminide/silicon-carbide metal matrix composites, and oxidation-resistant coated carbon–carbon composites. These three materials have been developed and fabricated in quantities large enough to have shown properties sufficient to achieve the NASP goals. Large-scale fabrication and processing development will

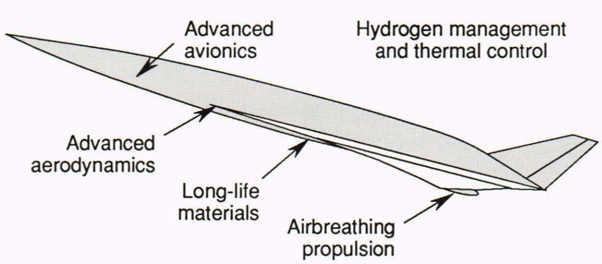


Figure 2. Key NASP technologies.

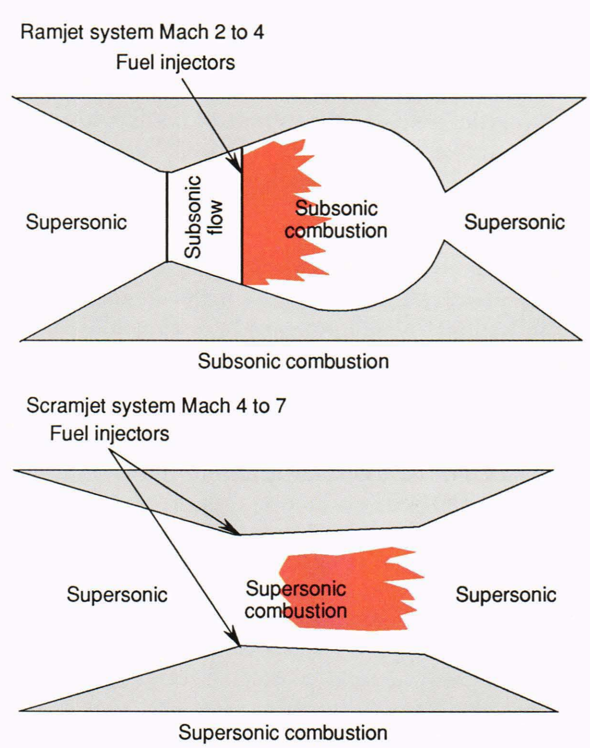


Figure 3. Schematic diagrams of the ramjet and scramjet systems.

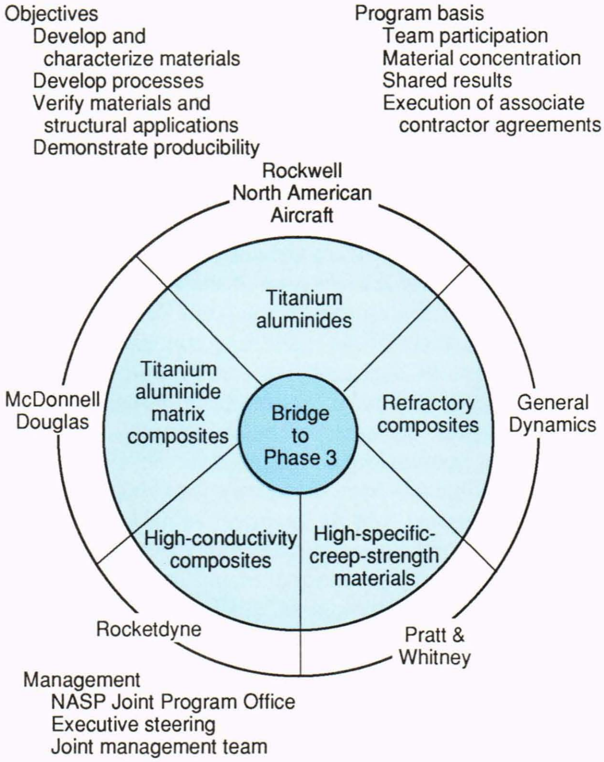


Figure 4. The NASP materials/structures maturation program reduces risks and uncertainties.

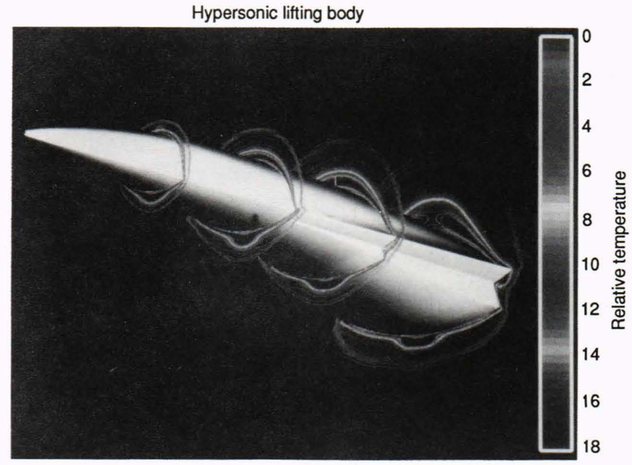


Figure 5. Computational fluid dynamics temperature distribution around a hypersonic vehicle at Mach 19.2. Angle of attack = 0°, Re = 30,000/in.

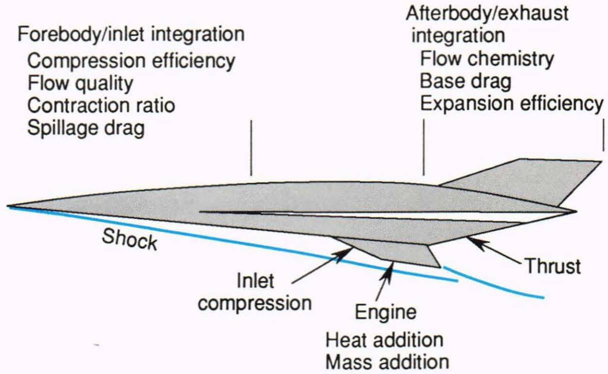


Figure 6. Airframe–engine integration.

now proceed in these three materials areas, which, if successful, will lead to manufacturing technology development to assure X-30 program readiness. In addition, development work will continue on other promising, high-temperature materials as alternatives to the primary choices.

The aerodynamics of hypersonic aircraft and aerospace vehicles has been the subject of considerable government, university, and industry attention for the past thirty years. Much is known about this subject, and the NASP program is taking advantage of the wealth of information available in the United States. The aerodynamic requirements of NASP vehicles, however, are extremely stressful and sensitive to small changes in vehicle configuration and performance. In addition, the specific flight regime of the X-30 has not been extensively examined through ground experimentation or flight testing. Because the X-30 itself will examine the aerodynamics of airbreathing aerospace vehicles, effort on the current development program has focused on developing detailed CFD models (Fig. 5) and on verifying them using several experimental tests. A massive CFD effort, using a significant fraction of the total U.S. supercomputer capability, is underway to develop experimentally valid models to predict the inlet, combustion, and nozzle operation of the NASP. Three-dimensional, full Navier–Stokes codes that account for real-gas effects, chemical kinetics, and turbulent flow are being refined using shock-tunnel, wind-tunnel, and archival flight data to predict the critical NASP aerodynamic parameters to well within 1% of the desired values.

Because the airframe and engine systems development for the NASP has been pursued by separate organizations, the level of airframe–engine integration required by hypersonic aircraft necessitated a major emphasis in this area (Fig. 6). Since the program began, this integration has commanded great attention and an enormous amount of government and contractor resources. For the remainder of the program, integration activity will be further intensified within the national airframe and engine contractor team.

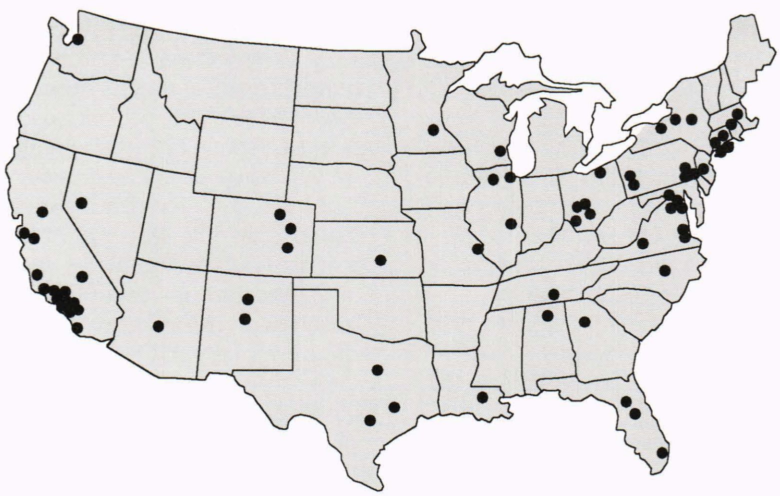
Although these four areas have demanded most of the resources of the NASP program, every subsystem of a hypersonic aircraft will be advanced to the point where it will support the testing of an experimental vehicle. Major efforts are underway to develop slush and liquid hydrogen systems, cryogenic tankage, fuel delivery systems, heat exchangers and turbopumps, avionics and cockpit systems, flight controls, and the instrumentation required to conduct the X-30 program. Specific efforts in each of these areas have been underway for several years and are being intensified as the experimental phase of the program approaches.

THE PROGRAMMATIC CHALLENGE AND RESPONSE

It has been more than eighty years since man first flew and more than forty years since aircraft flew supersonically. For the past forty years, airplane speeds have advanced from Mach 1 to Mach 2, with only a few notable exceptions: the SR-71 was capable of Mach 3+ flight, and the rocket-powered X-15 achieved speeds of about Mach 6. In general, however, it has taken us eighty years to go from Mach 0 to Mach 2. In contrast, NASP is attempting to increase the speed range of airbreathing airplanes to Mach 25 by means of a ten-year development and demonstration program. During the 1950s and 1960s, much activity was aimed at the exploration of hypersonic vehicles and their possible configurations. Wind tunnels, shock tunnels, and experimental aircraft were fabricated and used to examine the key parameters of hypersonic flights. Unfortunately, that activity ended early in the 1960s, and the development of hypersonic aircraft virtually ceased until the NASP program began. A few government researchers and even fewer university and industry scientists kept the flame alive during those years, but progress in hypersonics has been extremely slow. Although research in the critical areas of materials, CFD, and combustion has progressed because of other demands, the national capability at the beginning of the NASP program was extremely limited, dispersed, and disorganized.

To conduct a challenging program like NASP, an extensive, competent, well-integrated, and focused national team from industry, government, and academia needed to be developed. A prime task of the development phase of the NASP program is not only to bring the key technologies to a point that will allow an X-30 airplane, but to form the team required to do the job. There are now more than 5000 professionals working on the NASP program, in contrast to 250 in 1985 (Fig. 7). Although the principal goal of the NASP program is to demonstrate an aerospace vehicle capable of aircraft-like operations while achieving single-stage-to-orbit, the program has also become the basis for all hypersonic technology in the United States. Although the program must be focused on the goals of the NASP X-30 demonstrator, it must also generate the technology that will allow a broad basis for future hypersonic vehicles and derivatives of the NASP demonstrator.

The management of the NASP program has emphasized collaborative, participative approaches because the goal of the program is to develop a national team that



Government

DARPA
NASA
- Langley
- Lewis
- Ames
- Dryden

Air Force – AFSC
Navy
- NAVAIR
- ONR
- SPAWAR

SDIO
National Institute of Standards and Technology
and many others

Universities/research laboratories

Argonne National Lab
Los Alamos National Lab
University of California/SB
Carnegie–Mellon University
Harvard University
University of Illinois
Johns Hopkins University/APL
University of New Mexico
State University of New York
North Carolina State University
University of Pittsburgh
Stanford University
University of Texas
Virginia Polytechnic Inst.
University of Wisconsin
and many others

Industry

Aerojet Techsystems
Air Products
Alcoa
American Cyanamid
Astech Inc.
Astronautics Inc.
Avco
Boeing
Calspan
CVI
Directed Technologies
Dupont Aerospace
Dupont Chemical
Englehard Chemical
Garrett Airesearch
General Applied Science
General Dynamics
General Electric
Gould
Kentron
Lockheed
Martin Marietta
Marquardt
McDonnell Douglas
Minneapolis Honeywell
Pratt & Whitney
Rockwell International
SAIC
Sikorsky
Sundstrand
Union Carbide/Linde
UTC Energy Systems
UTC Research Center
Virginia Research Inc.
and many others

Figure 7. Participants in the NASP program.

can lead us into the aerospace era of the twenty-first century (Fig. 8). From the onset, government laboratories and centers have been an integral part of the NASP team. Much of the initial expertise on the NASP program resided with government researchers, who will continue to play vital roles as consultants, contributors, and evaluators for the program. When the program began, only a few industries and academic institutions worked in the hypersonic area. These few not only had to be supplemented, but some of the leading aerospace companies had to be added to the field. Five major airframe companies (General Dynamics, Rockwell International, McDonnell Douglas, Lockheed, and Boeing) and three leading engine companies (Pratt & Whitney, General Electric, and Rocketdyne) were heavily involved in the initial stages of the effort. In 1987, McDonnell Douglas, General Dynamics, Rockwell, Pratt & Whitney, and Rocketdyne were selected to continue the program. Even before this, significant efforts to manage the program using innovative management concepts were made.

Joint government/industry decision making has been the norm for the program. Consortia were formed, the development of generic government/industry technology has been fostered, and strong associate-contractor agreements among all appropriate parties have been effected. In 1988, a materials consortium of the five major companies was formed to accelerate the development of NASP airframe and engine materials. Each company was allowed to lead the development of a specific material system technology, for example, titanium aluminides, but had to share the results of the government- and company-funded activity with the competing companies. Government funding in the materials area was quadrupled to $60 million per year, and company-funded programs nearly matched the government funding. The program was a success, resulting in major materials advances and excellent cooperation among the companies.

The success of the materials consortium, coupled with the need to develop a strong national industrial base for future hypersonic aerospace systems development, led in late 1988 to the consideration of a single NASP team. Progress and corporate contributions by the three airframe companies and both engine companies had been excellent, and a single team comprising all five leading contractors seemed highly desirable. Although each company had pursued its own unique configuration approach, a national NASP team would allow a single synergistic configuration to emerge and all development efforts could focus on that concept. Another major advantage of a single team would be the guarantee of a broad industrial competitive base in the United States for future operational hypersonic and aerospace vehicles. Early attempts to foster such a national team paid off when the program schedule was extended in 1989 by two and one-half years. With increased time for research and development and a spending rate that was essentially constant from 1988 through 1993, the idea of a single national NASP team took hold. In late 1989, the NASP Joint Program Office (JPO) began procedures to form such a team. The five contractors were most responsive and agreed to form a joint venture partnership. Although the specifics of the NASP team are still being formulated, this novel programmatic response should be highly beneficial to the successful execution of the NASP Phase 2 research and development program.

On the government side, innovative integrated management has been the program standard. A single government program office, the NASP JPO at Wright–Patterson Air Force Base in Ohio, has been the only government execution agency since 1987. Kept to a manning level of about 75 and using streamlined management techniques, the JPO has minimized bureaucratic aspects of a government-funded program. Several hundred government technical experts outside the JPO are being used principally to assist the contractors, rather than to evaluate them. About 20% of the program resources has been and will be spent in government research and development to enhance the contractors' research and development efforts. The JPO's principal role has been to focus the efforts of thousands of personnel in hundreds of companies and universities toward the program goals. Executive direction is provided by a steering group of senior-level DoD and NASA officials, which meets biannually to guide the program (Fig. 9). The JPO is manned with program and technical managers from the Air Force, Navy, and NASA and operates as a unified government organization with a strong total quality and high-performing team culture. The vision of the X-30 and of the experimental demonstration of the aerospace plane drives the program and assures a successful and unique programmatic response.

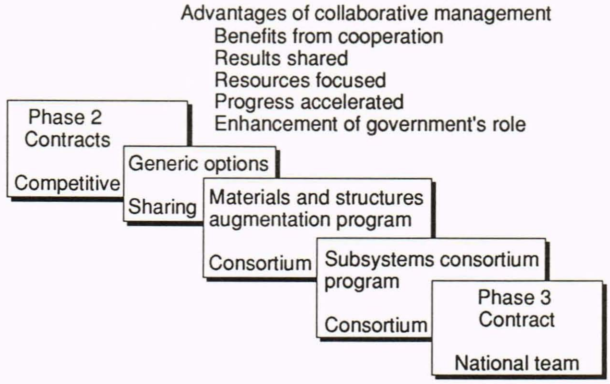


Figure 8. Collaborative strategy in the NASP program.

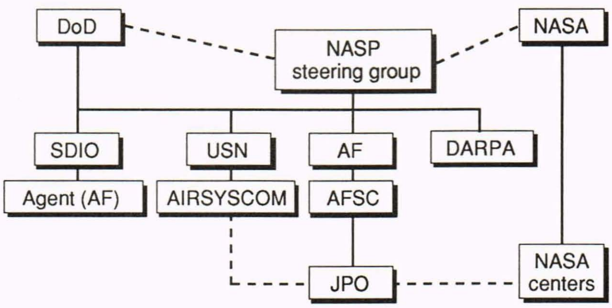


Figure 9. Management structure of the NASP program.

THE UTILITY CHALLENGE AND RESPONSE

Whenever technology fundamentally changes the way we look at our world, it is generally met with confusion and even resistance. The NASP program will result in the development of aircraft and aerospace systems that can fly at any speed, for any distance, from almost any area to any area, in and out of the atmosphere, on demand, with flexible, economical operability. In the traditional sense, this should provide us with enhanced commercial, civil, and military systems to perform the missions that airplanes and space-launch systems now satisfy. The viability and economic advantage of hypersonic commercial aircraft are still under study in this country, but early indications are that the advanced technology and potential systems resulting from NASP should open up new possibilities.

Civil and military space transportation using a single-stage-to-orbit, flexible, fast-turnaround, and on-demand aerospace plane should be attractive for a significant fraction of the anticipated space traffic mission model. If we extrapolate the possibilities for space activities using an aerospace plane, the attractiveness of this type of system should be even greater. There are dozens of current military missions that might use hypersonic or aerospace planes to enhance their effectiveness, and detailed application studies are underway, particularly for space delivery and force enhancement. But the greatest utility of the NASP program is undoubtedly in the application of both the technology and systems to new areas of transportation, delivery, accessibility, and development that do not exist today.

The invention of the airplane was greeted by great skepticism by both the civilian and military communities in the early 1900s. Yet it is arguably the single greatest discovery of the twentieth century and has fundamentally changed our world. In a similar fashion, the aerospace plane may allow us to open up what lies above our world. The challenge, however, is whether the United States, or any other country for that matter, should allocate the funds to produce such a plane. Ultimately, the success of the NASP program will depend on our ability to convince people that the payoff is worth the investment. Although the technical challenges are significant, attainment of the X-30 capability will probably depend on its perceived value to the nation.

To quantify the utility and value of NASP technology and NASP-derived vehicles, several organizations, including the NASP JPO, have been examining the payoff of NASP in a wide variety of commercial, civil, and military applications. In each category, NASP technology and systems not only enhance the mission and mission accomplishment, but in many instances provide an enabling capability or performance feature.

The NASP program research and development activity will develop airbreathing propulsion systems that will be capable of flight speeds that are eight to ten times faster than ever achieved using jet engine propulsion. The aerodynamic window that must be investigated for the aircraft performance parameters ranges from 0 to 300,000 ft altitude, Mach numbers from 0 to 25, and dynamic pressures from 0 to 2000 lb/ft^2. It covers the entire regime of future aeronautical flight. The materials being developed for NASP must be capable of operating at temperatures as low as $-425°F$ and as high as $+5000°F$; be both oxygen- and hydrogen-compatible; and have extremely high performance strength, and strength-to-density, ductility, and fabricability characteristics. The modeling and analytical predictions required for NASP have demanded major breakthroughs in CFD, which will allow precise predictions of future aeronautical and aerodynamic system performance. Because the fuel for NASP will be liquid or slush hydrogen, use of a nonpetroleum fuel in routine operations will be demonstrated. Finally, the level of integration required for NASP has resulted in new methods, techniques, and approaches for handling very complex engineering situations that will be applicable to the sophisticated systems of the future. The technology advances resulting from the NASP program will have wide applicability to the high-technology future of this nation. The techniques, systems, and components developed under NASP will allow breakthroughs in not just the aeronautical and aerospace areas, but also in the automobile, energy, transportation, manufacturing, industrial, and chemical industries. The impact of NASP technologies on more than 200 industries is now being examined, and early results have shown that the potential payback is an order of magnitude more than the cost of the NASP program.

New frontiers in commercial, civil, and military aeronautics will be opened because of the versatility, flexibility, and unique capabilities of hypersonic flight. The ability of aircraft to fly at speeds of Mach 2 to Mach 6 should result in enhanced commercial and military capabilities, and studies are underway to examine both the technological and systems impact of NASP in this regime. The use of a nonpetroleum fuel for high-speed aircraft also offers many advantages and may be necessitated by future world petroleum supplies. Unmanned systems and military concepts using the hypersonic velocity capability of NASP systems appear interesting, and several major studies are underway to examine the value of these concepts. In every case, the hypersonic capabilities of an airbreathing horizontal takeoff and landing craft often enable a rapid response or highly flexible mission that cannot be accomplished using conventional systems.

As an aerospace system, NASP is in a class of its own. Affordable and flexible access to space is the primary utility goal of the NASP program. The ability to take off horizontally from any place on Earth and to deliver a wide variety of payloads, including personnel, to space is uniquely a NASP capability. The flexibility, versatility, operability, and supportability of NASP cannot be equaled by any other space delivery system. Such NASP-derived vehicles, carried to their logical systems development, could open the way for the population of space and the creation of large-scale industrial, research, and manufacturing projects in space. The routine delivery of people and payloads to space platforms from conventional airports is a future possibility, which alone could justify the required investment in the NASP program.

THE CONCEPTUAL CHALLENGE AND RESPONSE

The goals of the NASP program are so challenging that the effort requires a departure from our traditional thinking in research and development management, program development, and national emphasis. As with the man-moon landing, NASP requires a national commitment to a long-term vision. It is a program that will demand a focused effort for more than fifteen years to achieve its goal. The technical challenges are in many ways greater than the Apollo program and will stretch our abilities in almost every area of aerospace technology. The synergistic demands of the concept necessitate our use of unconventional program management techniques to meet our objectives in the most efficient and effective manner. Finally, the future utilization of the resulting technology requires the establishment of a unique government and industrial base that must be developed in concert with the technology advances. These requirements dictate a new kind of cooperation among the government, industrial, and academic communities, some innovative technical and programmatic approaches, and a new concept in the strategic management of research and development.

The NASP program is an experiment that tests the ability of the United States to work together to achieve revolutionary technology development and to translate effectively that technology into viable products. Because it is succeeding in meeting that goal, the program has become an example of government-industry collaboration, effective technology utilization, long-range vision, and focused national commitment. These are the very principles that were at the core of the outstanding progress the nation achieved earlier in this century. They are the same principles that have been so successfully used by our economic competitors during the latter part of this century to capture a significant share of the markets and capabilities that once were ours exclusively. These are the principles for our nation's future growth, and NASP is the foundation for our aerospace leadership in the twenty-first century.

THE AUTHOR

ROBERT R. BARTHELEMY was educated at MIT (bachelor's in chemical engineering, 1962; master's in nuclear engineering, 1963) and Ohio State University (Ph.D. in mechanical engineering, 1975). He was an officer in the Air Force from 1963 through 1967, directing projects and tasks in magnetohydrodynamics at Wright Field. After separation from the Air Force, he continued his technical and managerial contributions at Wright Field, rising from project manager to senior engineer (1971) to Acting Branch Chief (1972) to Assistant Division Director (1975) to Deputy Director and member of the Senior Executive Service (1983), and finally to Technical Director (1986) of the Wright Aeronautical Laboratory. During that time, his technical interests included magnetohydrodynamics, high-powered lasers, heat pipes, and space technology development. In 1987, Dr. Barthelemy was appointed to his current position as manager of the National AeroSpace Plane (NASP) program. He is responsible for organizing and directing the NASP Joint Program Office at Wright Field, which manages the fiscal, technological, and design efforts of a national team of industry, government, and university participants.