NATIONAL AERONAUTICS R&D GOALS

Technology for America's Future

Executive Office of the President
Office of Science and Technology Policy
February 1987

ACTION PLAN SUMMARY

The Committee believes that now is the time for the United States to organize a long-term, aggressive, and positive thrust to remain competitive in the world aeronautics marketplace and secure in our national defense. The new era of global competition and the constrained United States fiscal environment pose a national challenge for sustained U.S. leadership. The agenda for achievement of the National Aeronautical R&D Goals will require concerted effort by the Federal Government, industry, and the nation's universities. Specific recommendations for action are:

1 Increase innovative industry R&D efforts given the certainty of intensifying global competition and the importance of new technology for U.S. competitiveness

2 Aggressively pursue the National Aero-Space Plane program, assuring maturation of critical technologies leading to an experimental airplane.

3 Develop fundamental technology, design, and business foundation for a long-range, supersonic transport in preparation for a potential U.S. industry initiative.

4 Expand domestic research and development collaboration by creating an environment that reflects the new era of global competition.

5 Encourage government aeronautical research in long-term emerging technology areas which promise high payoffs.

6 Strengthen American universities for basic research and science education through enhanced government and aerospace industry support and cooperation.

7 Improve the development and integration of advanced design, processing, and computer-integrated manufacturing technologies to transform emerging R&D results into affordable U.S. products.

8 Enhance the safety and capacity of the National Airspace System through advanced automation and electronics technology and new vehicle concepts, including vertical and short takeoff and landing aircraft.

FOREWORD

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Almost two years ago, the Aeronautical Policy Review Committee&emdash;composed of sixteen leaders of government, industry, and universities&emdash;considered the evolving international scene in aeronautics and America's future in it. In their March 1985 report, "NATIONAL AERONAUTICAL R&D GOALS: TECHNOLOGY FOR AMERICA'S FUTURE," the Committee recommended that all sectors of American aeronautics direct their skills and energies toward the highest-payoff technology areas to sustain the nation's leadership position.

Toward that end, three specific goals&emdash;in subsonic, supersonic and transatmospheric flight regimes&emdash;were established. In the intervening time, these goals have been accepted by the American aviation community as the centerpiece of national aeronautics strategy, and have attracted global attention. Action on all three goals is in progress.

However, the Committee believes that the depth of foreign aeronautical resolve and the concerted national effort required to preserve American competitiveness are still largely underestimated. Sustained U.S. leadership will require greater achievement by all sectors&emdash;government, industry, and academia. Both the opportunity and challenge are unprecedented. Accordingly, the Committee believes that this challenge to our competitiveness is so important&emdash;not just to the nation's diverse aeronautics industry, but to the nation as a whole&emdash;that it now issues this call to action. This sequel presents a cohesive U.S. strategy and an eight-point action plan to achieve the National Goals and remain a viable competitor in the world aviation marketplace.

William R. Graham, Science Advisor to the President and Director, Office of Science and Technology Policy

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U.S. AERONAUTICS: A CHANGING PERSPECTIVE

The Challenge

Innovation in science and technology has been the driving force for American growth and power since World War II. It has given us military strength, a high standard of living, and&emdash;until recently&emdash;a broad range of superior products which dominated world trade.

That picture has changed dramatically over the past decade. We are challenged by a new global economy with technologically equal, well-organized competitors actively backed by foreign governments. European and Pacific Rim nations recognize that science and technology hold the key to their future economic and military well-being, and they are expanding investments in upgrading their capabilities.

Instead of trade surpluses, the United States has huge trade deficits. Most Americans are awakening to the serious dangers in this decline, notably in steel, automobiles, and electronics. The trade deficit has meant slowed economic growth, business failures, and permanent loss of millions of jobs.

Even in high technology, the United States has steadily lost market share since 1980. In 1986, for the first time, high-technology imports exceeded exports. These losses can do enormous damage to our future competitiveness and national security. We must never again take our economic superiority for granted.

On balance, the United States is still the world leader in aviation. The aeronautics industry has long held a unique position in its contribution to trade and to national security, and as a symbol of U.S. technological power. Aircraft incorporate many advanced technologies and stimulate the development of high technology on a broad front.

Aerospace trade surplus of $11.8 billion in 1986, the highest of all U.S. export sectors, contrasts to the trade deficit in manufactured goods of $136 billion. Aircraft and parts comprise over 90 percent of this surplus. These export sales are vital to amortize huge R&D expenditures and to achieve economies of scale. Aerospace total shipments exceeded $96 billion in 1986.

But that industry today faces profound changes: formidable competition for international and domestic sales, challenges to military superiority requiring technically sophisticated yet more affordable weapons systems, and limitations of capital and skilled workers. The implications are unsettling.

Aeronautics has played a crucial role in national security for more than 40 years. With major R&D investments in advanced technology aircraft, aviation will continue to fulfill a major defense role. Though requirements for civil and military aircraft differ, much of the technology base, the production base which is centered in 15,000 company suppliers supporting the major aircraft manufacturers, and many of the skills and processes used are common. A weakening of the civil industry will ultimately result in more expensive military systems, and the reverse is true as well.

Significant sustained foreign competition exists in all three National Goal areas: subsonics, supersonics, and transatmospherics. In fact, other nations now dominate the world general-aviation and commuter-aircraft markets, account for nearly half the world sales of rotorcraft, and are achieving significant market penetration in the large commercial transport market. The R&D endeavor of the Soviet Union is the largest in the world, and aggressive

Soviet aeronautical R&D constantly threatens the U.S. technological margin. Though America is today's world aviation leader, where will we be tomorrow?

The Opportunity For Leadership

Bold new technological thrusts are essential to preserve U.S. aeronautical superiority in the world marketplace and enhance global security through the excellence of our military aircraft.

The National Goals for Aeronautical R&D outline numerous opportunities for dramatic advances in technology that could reshape aviation by the turn of the century. Achievement of these goals will lead to entirely new types of aircraft with vastly superior capabilities. Gains of this order will mean major benefits to our national economy and security, but only if we are the first to exploit them. These opportunities are an equally powerful driving force for foreign competitors.

The constrained U.S. fiscal environment, a continuing and difficult problem, requires a cohesive national strategy and a new sense of collective responsibility for achieving the National Goals. This will challenge the resourcefulness and creativity of the Federal Government, of industry, and of the nation's universities. With their effective cooperation, we must cut the cost of technological advancement and increase the speed at which new aeronautical technologies translate into products and processes. The changes may involve altering traditional approaches. But America holds the key for responding to the challenge: a genius for innovation and a solid foundation in research and development.

Most important, to preserve America's aeronautical leadership we must accord higher national priority to research and development. R&D is the highest leverage for revitalization of American economic and strategic competitiveness. These R&D expenditures must be viewed as long-term investments in the nation's productive capacity, and should weigh heavily in government and boardroom decisions even when resources are tight. Under investment in R&D and facilities during the 1980's and 1970's has contributed heavily to the current loss of competitiveness in many other U.S. industries.

Greater attention must also be focused on the availability and quality of scientific and engineering manpower. Similarly, higher education must be strengthened. The universities are vital, for both new knowledge and trained minds. Disturbing signs, however, suggest that university research capacity is deteriorating.

Stronger cooperation between government and industry within a free market framework will strengthen American competitiveness. Working together, each must fulfill the role for which it is best suited.

Industry must recognize the certainty of intensifying global competition. It must continue to expand its R&D investment while establishing a more risk-taking approach to world leadership in the commercialization of product and process technology. A strong and healthy Independent Research and Development (IR&D) program, which is the source of much of the innovative work in the industry, is essential in expanding the nation's technology base and strengthening American leadership.

Government, for its part, can best support long term, high-risk, high-payoff research. Rapid and effective transfer of this technology to the private sector is essential in capitalizing on these results for U.S. competitive advantage. Government must also create a policy environment which fosters U.S. competitiveness.

The National Aeronautics and Space Administration (NASA) is this country's focal point for aeronautical research and technology and national aeronautical facilities. NASA must strengthen its capabilities and take a more assertive leadership role in coordinating and facilitating long-term U.S. research efforts for maximum effectiveness. The health and productivity of our national facilities are fundamental to meeting the country's growing R&D requirements.

America has to compete in the international arena, but it also has to cooperate. To enjoy a high standard of living we need trading partners with healthy economies. The growing trend toward internationalization of aircraft manufacture will require learning how to work effectively with foreign partners while preserving technological leadership. This leadership need not be threatened if we maintain a vigorous program of basic research and technology development. However, the U.S. government and aeronautical firms must pursue equitable arrangements when actual or potential competitors seek to obtain our skills and technical knowledge.

The Committee clearly recognizes that progress on many other issues such as the federal budget deficit, trade and tax policies, and exchange rates are essential to sustained improvements in America's competitive position. But in formulating an implementation strategy for the National Aeronautical R&D Goals, the Committee focused on R&D-related issues. The following pages detail specific recommendations for action.

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NATIONAL AERONAUTICAL R&D GOALS: FRAMEWORK FOR ACTION

SUBSONICS GOAL:

A NEW GENERATION OF SUPERIOR U.S. AIRCRAFT

Subsonic aircraft dominate the world market, exceeding $35 billion annual sales by U.S. manufacturers alone, and are expected to remain the largest aerospace market into the next century. They include all commercial transport categories, from general aviation and commuter aircraft to intercontinental transports; all military airlifters; and a large array of helicopters and emerging high-speed rotorcraft.

Commercial subsonic aircraft rank first among U.S. manufacturing exports, with a $9.6 billion average trade surplus over the past five years. The immense subsonic market is the foundation for sustaining the major U.S. airframe manufacturers and their 15,000-company suppliers, who support both civil and military needs. American preeminence in this market will be critical to generate capital for investments in modern manufacturing and to exploit opportunities in supersonic and transatmospheric flight. It is in this pivotal worldwide market that foreign competition is having the most impact.

This first National Goal envisions an entirely new generation of fuel-efficient U.S. aircraft operating in a flexible and modernized National Air-space System. Its aim is a safe, congestion-free interstate system, offering superior air transportation at reduced cost. The subsonics goal also envisions the development of advanced military airlift capabilities, tankers, long-endurance aircraft, rotorcraft and other spin-off military requirements. Recent declines in fuel prices have heightened the importance of aircraft affordability. Even with rising fuel prices, cost of ownership, including acquisition, will dominate the economics of the intensely competitive world aircraft markets.

At present, the subsonic industry is busy with advanced R&D activities for next generation systems. Major aircraft and engine manufacturers are accelerating technology readiness for application to new aircraft carrying some 150 passengers for the early 1990's. These aircraft will incorporate revolutionary superbypass engines with 30% better fuel consumption. Flight tests of some of these advanced propulsion systems are already under way.

A new military transport for the early 1990's, the C- 17, is also ongoing. This and other developments of advanced military aircraft will have an important impact on gas turbine engines, composite structures, microelectronics, and fiber-optics technology, and will contribute to future cost superiority.

The Department of Defense (DOD), NASA, and the rotorcraft industry are making substantial investments in revolutionary, high-speed automated rotorcraft now finding their way into military systems. These include the tilt rotor, which combines the advantages of a helicopter and a turboprop. Another is the X-wing, whose X-shaped rotors lift the craft on takeoff and serve as wings in forward flight.

Civil derivatives of some of these high-speed rotorcraft, operating in the vertical or short takeoff modes, are foreseen with the economy, productivity, and maintainability of fixed-wing passenger aircraft. Advanced craft of this kind can provide improved inter-city and inter-region transportation, reducing congestion in U.S. airports without major investments in new runways.

Key advances in drag reduction, composites, and automation must be readied by the early 1990's. Several exciting laminar-flow concepts, that greatly reduce drag by smoothing air flow over wing surfaces, have been successfully tested in NASA wind tunnels and in small-scale flight experiments. However, large-scale flight experiments under realistic conditions and operating environments are needed before introduction in new transport aircraft.

New composite materials offer greater toughness and processability, and a 30-40% potential reduction in structural weight. However, we lack a comprehensive body of knowledge on how these materials will behave in highly loaded structures and in long-term operation. As new materials emerge from the laboratories, significant investment for validation is essential. This endeavor would clearly benefit from joint NASA, DOD, Federal Aviation Administration (FAA), and industry cooperation.

Today's frequent and costly delay's at metropolitan airports will become worse with the projected growth in aviation. Aggressive pursuit of automation, artificial intelligence, and electronic advances for both aircraft and the National Airspace System are vital. Full realization of the National

Goals will depend on how fast the National Airspace System can incorporate these advances and accommodate new vehicle capabilities such as tiltrotor, V/STOL, supersonic, and hypersonic aircraft.

Technology validation is currently the weak link in the R&D chain. Validation enables designers to incorporate new advances into a product with confidence in its performance, integrity, and certificability. It is the longest and most expensive stage in advancing new technology. It is also the point where U.S. R&D momentum has become most vulnerable. Joint industry, NASA, and DOD programs have traditionally played an important role in this area. In this constrained fiscal environment, greater industry mobilization as well as enhanced industry-government cooperation in the subsonic arena is vital. The aviation industry has recently accelerated technology readiness for product application early in the 1990's. This trend must continue if the U.S. is to maintain its competitive momentum into the next century.

NASA should focus primarily on long-term fundamental research. Difficult and demanding decisions must continue to emphasize emerging technology areas that promise major improvements in future aircraft. NASA must also strengthen its capabilities and exert stronger leadership national research efforts and rapidly disseminate information to U.S. industry. While the potential advancements in range and payload made possible by development of key technologies will have significant benefit to growing military requirements for global operations, the DOD is appropriately channeling much of its current subsonic R&D into more specialized stealth, rotorcraft and cruise missile technology.

Clearly, the nation needs to establish a collective commitment among industry, DOD, NASA, FAA, the universities, and Congress to assure American leadership in this pivotal subsonic areas. The huge market can provide the resources for private-sector investment in technology and manufacturing innovation for all three goals. We are approaching an important crossroad: one path leading to steady erosion of U.S. participation in world markets; the other to economic growth, and job creation. Industry creativity, leadership, and resolve will be the decisive factors.

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SUPERSONICS GOAL:

LONG-DISTANCE EFFICIENCY AND ENVIRONMENTAL COMPATIBILITY

This national goal is a great market-driven opportunity. Trends into the next century almost certainly will brighten the outlook for long-range, high-speed transportation.

One trend is rapid growth of world population.

More than 75% of this growth will be in distant developing nations. Another trend sees the axis of global economy and technology shifting farther and farther to East Asia and the Pacific Basin. Mutual security bonds are of increasing importance in this region in light of a potential Soviet buildup.

Yet, U.S. access to the vast Pacific area is constrained by distance. With subsonic planes, travel time between these countries and their major trading partners in the United States and Europe is from 12 to 18 hours. As travel and trade increase, demand is mounting for more productive forms of air travel. Substantial reduction of flying time means great reduction in human fatigue and improved effectiveness at the destination.

Supersonic cruise technology has important application to future combat aircraft as well as to transports. Efficient supersonic cruise, coupled with high maneuver capability, would mean considerable increase in military aircraft effectiveness and survivability. Even though military forerunners are often essential to advanced commercial undertakings, future military requirements will differ significantly from a commercial supersonic transport. Economic and performance considerations, operational requirements such as airport and community noise levels and sonic boom restrictions, as well as stringent operational life, reliability and safety requirements are vital differences. However, recent military developments have resulted in advances in propulsion, materials and systems which will benefit advanced supersonic transports.

The U.S. aeronautics industry must strive to be the leader of the advanced high-speed transport enterprise. It should identify the most promising concepts and the necessary technology for economic competitiveness, safety, and environmental compatibility at reasonable business risk. Decisions must be based on a full understanding of the potential market, economics, environmental implications, the future navigation and air traffic control system, and a wide range of design options such as flight speeds and fuel types. For the airlines, the bottom line for any high-speed transport will be economic performance&emdash;competitive earnings capability and operating costs compared with long-range subsonic jets.

As the timing and need for high-speed transport come into better focus, the industry must begin to explore creative ways to assemble the required know-how and capital resources. Because of the risks and the extremely heavy funding, a high-speed transport is probably beyond the capabilities of a single U.S. aircraft or engine company. It may require pooled resources, or perhaps an international consortium. If any arbitrary governmental impediments to such development and production collaboration by major commercial competitors are encountered, they should be identified and eliminated.

On the engineering side, key technologies for advancing supersonic cruise capability have not been aggressively pursued by the U.S. since the 1971 termination of the U.S. Supersonic Transport program. However, the NASA-funded Supersonic Cruise Research program, which ended in 1981, established a constructive base for further advancement. Operational experience with the Concorde and SR-7 1 also provides a stepping stone for a second-generation supersonic transport.

If the U.S. is to take the lead, a coordinated and disciplined approach by industry and government is necessary. NASA and industry must hasten the development of promising technologies such as supersonic laminar flow, thermoplastics, metal matrix composites, and supersonic through-flow and variable-cycle engine technology. Airport and community noise standards present difficult challenges, but solutions can be found through technology, design and flight management. Further research is urgently needed on the generation, propagation and public perception of low-level sonic booms. The FAA and our air traffic management and control capabilities must keep pace so that new aircraft can be certified in a timely manner and operated efficiently within the National Airspace System.

Without question an economically viable and environmentally compatible supersonic transport, which would cut flying times to the Pacific Rim by 70 to 80 percent, could be available by the late 1990's or early next century. This holds tremendous potential for the American aviation industry, the world airlines, and the traveling public. It will create a multi-billion dollar market for its participants, not only in the Pacific but by potentially capturing a majority of all long-range intercontinental markets. An efficient supersonic transport represents a logical and essential link between the subsonics of this century and the hypersonics of the next.

The latest Airbus models from Europe are a constant reminder that we have no corner on using advanced technology in competitive aircraft. Japan and European nations are keenly interested and can be expected to expand their R&D investments in this area. Aeronautics remains a dynamic, competitive industry in which those who choose to stand still are quickly left behind.

America's first step should be a focused and coordinated basic technology development effort by NASA, industry, and academia including comprehensive preliminary design studies. By the early 1990's, the U.S. industry could begin design and development, culminating in a new commercial supersonic transport certification around the turn of the century.

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TRANSATMOSPHERICS GOAL:

TO SECURE FUTURE OPTIONS

Significant progress since the announcement of this goal has brought both its impressive opportunities and its challenges into sharper focus.

By the turn of the century an air-breathing vehicle could take off from an airport runway and fly between 5 and 25 times the speed of sound to the edge of the earth's atmosphere and into low earth orbit. The plane would return to a conventional runway. Such a new class of aerospace vehicle is foreshadowed by recent technical advances. It would save much weight and cost by using oxygen in the air instead of carrying very large quantities of liquid oxygen as in rocket systems.

A decision to go forward with research on an aerospace plane was announced by President Reagan in his State of the Union Address on February 4, 1986. The National Aero-Space Plane program, a bold new technology initiative to carry out the decision, is being conducted jointly by DOD and NASA. These agencies have already stimulated a major expansion of research in all the technologies key to hypersonic and transatmospheric flight. Such rapid mobilization of this degree in both government and industry is unprecedented in recent times. This initiative has reversed more than a decade-long decline in the U.S. hypersonics expertise and technology base in industry and the university community.

The National Aero-Space Plane program is accelerating effort on critical technologies: air-breathing propulsion which must function efficiently from takeoff to near orbital velocities; high-temperature, lightweight materials, and thermal structures that can withstand exposure to extreme heat during ascent or during sustained hypersonic flight in the atmosphere; and new computational tools for analysis of the highly interdependent airframe and propulsion systems. We have the capability to integrate these technologies in the experimental X-30, which should begin validation in actual flight by the early 1990's.

The usefulness of this project is hard to exaggerate. The U.S. military, increasingly dependent on space for communications, intelligence, and early warning, urgently requires such a space vehicle. Transatmospheric craft could place military and civil payloads into orbit and service them more quickly, reliably, and inexpensively than the current Space Shuttle or expendable launch vehicles. Need for massive, fixed launch facilities at a few vulnerable sites would be eliminated. Flexible, fast-turnaround transatmospheric vehicles might cut the cost of delivering payloads into orbit by an order of magnitude.

The extreme altitude and speed capability would make our military aircraft far less vulnerable. Ability to fly to orbit on very short notice while operating from conventional runways would give the advantage of surprise. Flights on unpredicted courses could observe secret installations and activities before they could be hidden. A versatile transatmospheric vehicle could react quickly to any point on the globe in approximately 90 minutes.

A commercial transport derived from this technology could be considered following flight testing of the X-30 research airplane and operational experience with hypersonic military aircraft or space transportation vehicles. It could fly at altitudes of 20 miles or higher and at five times the speed of sound or greater. Travelers would reach most distant destinations within two hours. A hypersonic transport, might prove an attractive option for the long-distance market in the next century. The very significant economic, environmental, safety and operational challenges of a public hypersonic transport necessitate extensive research and technology development to exploit the civil transportation potential of hypersonic flight.

As the United States vigorously pursues space transportation systems, foreign nations are not blind to their potential. They, too, are aggressively working on a broad range of reusable spacecraft. These include the French Hermes space transportation system, advanced horizontal takeoff systems such as the British HOTOL and German Sanger vehicles, and the aerospace plane concepts being actively studied in Japan. The Soviets, who already have more responsive space launch capabilities with an annual launch rate many times greater than ours, are well into developments, some of which are beyond anything we have in either operation or design.

Accordingly, the Committee strongly endorses the National Aero-Space Plane initiative in a broad U.S. and global competitive context involving both aerospace leadership and national security.

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THE AGENDA FOR ACHIEVEMENT

Clearly, now is the time for the United States to organize a long-term, aggressive, and positive thrust to remain competitive in the world aviation marketplace and secure in our national defense. As the leader of the free world, the United States cannot retreat behind protectionist barriers in the face of formidable economic competitors or military adversaries. America has lost momentum but not its basic capability. In aeronautics, the expertise represented by the government, industry, and university partnership that has evolved since the founding of the National Advisory Committee for Aeronautics in 1915 unsurpassed anywhere. The most decisive factor in America's favor is the pace of innovation itself.

The current environment with its resource limitations poses a national challenge to our creativity and resolve to make the difficult choices and necessary commitments for U. S. preeminence. The agenda will require concerted effort and greater achievement by the Federal Government, industry, and the nation's universities. The Committee recommends an eight-point action plan to strengthen U.S. competitiveness in the worldwide aerospace marketplace and strategic arenas.

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ACTION PLAN

1. Increase innovative industry R&D efforts given the certainty of intensifying global competition and the importance of new technology for U.S. competitiveness.

The U.S. is challenged by a new global economy, America's ability to compete depends heavily on greater mobilization and commitment of the major aircraft manufacturers and their suppliers. Affordability and quality will be pivotal to the success or failure of U.S. entries in the world markets. With so much of our competitive position dependent on new technology, the Committee recommends that:

- U.S. aeronautics industry continue to expand its own investments in R&D.

- American industry stress affordability and quality during product design, a longer-term perspective in business strategies, and a more risk-taking approach to strengthen American leadership in light of the escalating global competition.

- Government continue to support a healthy Independent Research And Development (IR&D) program as a sound and proven way of stimulating innovative industrial R&D.

2. Aggressively pursue the National Aero-Space Plane program, assuring maturation of critical technologies leading to an experimental airplane.

The Committee strongly endorses the National Aero-Space Plane program. In pursuing this challenging initiative, government and industry partners should strive to:

- Strengthen preliminary design efforts so that attractive vehicle concepts and key technologies can be identified, shaped, and assigned priorities.

- Assure timely development and maturation of the X-30 focused technologies critical to success of the National Aero-Space Plane program.

- Conduct application studies for future operational vehicles of various sizes and missions to provide a comparative assessment with competitive alternatives.

- Assure broadest U.S. technical community involvement consistent with the need to protect certain sensitive information for national security and U.S. competitiveness.

- Broaden the technology base to enable development of a wide range of U. S. hypersonic cruise vehicles.

- Rebuild university expertise base in hypersonics and transatmospherics research.

3. Develop fundamental technology, design, and business foundation for a long-range, supersonic transport in preparation for a potential U.S. industry initiative.

The National Goal for long-distance supersonic efficiency remains a great market-driven opportunity. Second-generation commercial transports which would cut flying times to the Pacific Basin by 70 to 80 percent are possible by the turn of the century. A coordinated and disciplined approach by government and industry is necessary to develop the technology and to mobilize the large capital resources for full-scale development. The Committee recommends that:

- Industry analyze the market needs for an advanced high-speed transport and identify the economic, speed, size, range, and fuel characteristics necessary to become a successful element in international air transportation. Government and industry determine the necessary characteristics for environmental compatibility.

- Industry and NASA determine the most attractive technical concepts and the necessary technology developments for future long-range, high-speed civil transports.

- NASA, industry and academia begin a focused and coordinated approach to ready required technology for U.S. industry development and application.

- Industry provide strong, creative leadership. A high-speed transport will probably require pooled resources of a number of companies, perhaps an international consortium. Arbitrary governmental impediments to collaboration-in design, development, and production by major U.S. commercial competitors should be identified and eliminated.

- The U.S. aeronautics community explore the development and application of new supersonic cruise technologies to advanced technology military aircraft.

4. Expand domestic research and development collaboration by creating an environment that reflects the new era of global competition.

American companies will have to depend more on themselves and on one another, if they are to stay competitive internationally. Because of changes in the worldwide commercial markets and dramatically rising research and development costs, many U.S. aerospace manufacturers have entered into cooperative relationships with foreign companies to gain market share and reduce financial risk. Collaboration among foreign companies, enabled by less restrictive legal environments overseas, is an increasingly powerful competitive force on the international scene.

Much of the research and development envisioned in this report could benefit from several American firms working collaboratively&emdash;sharing the risk while pooling capital, technology, and skilled personnel. The purpose is not to stifle U. S. competition but to enhance international competitiveness. Increased cooperation between federal laboratories and the private sector is also essential. Accordingly, the Committee recommends that:

- The U. S. aeronautics industry consider the advantages of teaming and other collaborative opportunities now permitted by U.S. law. Research cooperatives that are created by private initiative such as the Microelectronics and Computer Technology Corporation might serve as a model. Associations such as the Aerospace Industries Association are beginning to act as a catalyst.

- The Federal Government not impose barriers to discussions and teaming between major U.S. Aerospace competitors for development and production projects as well as research. Such teaming is already commonplace in major military aviation procurements. This is particularly important for a commercial supersonic transport, since the magnitude and complexity of the required R&D efforts will probably require collaboration of a number of companies.

- The U.S. increase rate of technology transfer of government funded R&D to the American private sector for commercial development. Rapid transfer and development are essential in preventing significant loss of that technology to foreign companies. Federal agencies must balance the early open publication of research results with need for early domestic technology transfer. Important new discoveries should receive proper intellectual property protection and early domestic dissemination.

- Industry and the national laboratories expand cooperative research, technology development, and licensing arrangements under the terms of the Federal Technology Transfer Act of 1986. This Act offers a variety of new incentives and mechanisms for cooperation and rapid transfer of government-sponsored technology to the private sector. Government and industry should identify those areas where U.S. industry might be interested in sharing the costs&emdash;and benefits&emdash;of technology development.

5. Encourage government aeronautical research in long-term emerging technology areas which promise high payoffs.

Advances in composite materials, propulsion, numerical simulation, and laminar flow will have a profound effect on future vehicles in all three goal areas. NASA provides a unique, central technological resource for this nation's aeronautical preeminence and should now strengthen its capabilities and take a more assertive leadership role in developing the fundamental knowledge base in these emerging areas. Government must also assure the health and availability of critical national facilities to meet the projected increased demands from new aircraft developments across the speed regime.

Composites

Innovative research could yield high-strength, ultra-lightweight, low-cost composite structures for use in advanced subsonic, supersonic and transatmospheric aircraft. To achieve the full potential of composites, the Committee recommends that:

- Government, industry, and the universities intensify development and validation of a comprehensive knowledge base to enable the broad application of composite materials to future aircraft and engine systems.

- NASA and DOD focus research on promising material systems such as thermoplastics and metal matrix composites, and on advanced structural concepts and innovative fabrication techniques to increase damage tolerance and strength and lower cost.

- Civil and military composite development be made a common, mutually supporting national undertaking.

- As new composite materials emerge from the research laboratories, government and industry coordinate national technology validation efforts for large, next-generation primary structures. FAA ensure that appropriate certification standards and rules are developed.

Numerical Simulation

An area of extreme importance for rapid and effective evaluation and optimization of all classes of aircraft and propulsion system designs is numerical simulation, or computer modeling. It is already revolutionizing research in aerodynamics, structures, propulsion, and related areas such as wind shear. The design of highly integrated aerospace vehicles and further improvements in conventional aircraft are dependent on these capabilities.

Because these problems involve large numbers of variables, the development of new powerful supercomputers will accelerate progress. To maintain leadership in this vital technology area, the Committee recommends:

- U.S. fully exploit leadership in supercomputer and numerical simulation technology for improved understanding of fundamental physical phenomena and the optimal, cost-effective design of all future aerospace vehicles. This will require more extensive experimental activity to verify numerical simulation results.

- U.S. industry and government accelerate development of parallel processing hardware and software technology and artificial intelligence to significantly increase the fidelity and accuracy of computer simulations.

Propulsion

Ceramic, carbon-carbon, and metal matrix composite materials promise engine operations at extremely high temperatures with improved performance, weight, and life. Successful development of high-temperature materials will spur efficient supersonic cruise propulsion systems and large increases in fighter capability, including short or vertical takeoff and landing aircraft operations. To realize dramatic improvements for subsonic and supersonic propulsion systems, the Committee recommends that:

- NASA and DOD emphasize high-performance propulsion technology with particular focus on high-temperature composite materials.

- NASA and DOD explore advanced propulsion cycles and determine the practicality of the must promising concepts.

- Government and industry develop the fundamental technology base for significant improvements in fuel efficiency, operating life and acoustics of super-bypass subsonic propulsion systems and supersonic variable-cycle engines.

Laminar Flow

Laminar-flow advances offer dramatic improvements in cruise efficiency of both subsonic and supersonic aircraft. Flight testing of small- scale, subsonic laminar-flow concepts has been completed recently. However, important work remains before these concepts can be introduced in large subsonic transports. Little laminar-flow research has been conducted in the supersonic regime. The Committee recommends that:

- NASA develop fundamental laminar-flow technology for supersonic aircraft, with potential to double fuel efficiency and reduce skin surface temperatures. This should include research on high-lift devices or techniques for highly-swept leading edges used during the approach and landing phases of flight.

- NASA and DOD, in conjunction with industry, pursue the validation of promising subsonic concepts in realistic flight conditions and operating environments.

National Facilities

NASA and DOD are responsible for a large number of unique national facilities that are essential to preserving U.S. leadership in aeronautics. These major government wind tunnels and propulsion facilities, represent the majority of our national aeronautical R&D test capability. They are experiencing significant increases in demand because of new aircraft development programs currently underway across the entire speed range. This demand is expected to grow. Certain of NASA's wind tunnels are aging and in need of modernization. In addition, requirements for higher speeds, higher temperatures, and improved flow and acoustic qualities may require enhanced capabilities. To ensure the health and availability of critical national facilities, the Committee recommends that:

- NASA, in conjunction with DOD and industry, undertake a national assessment of future wind tunnel use requirements and the adequacy of existing wind tunnels to meet these requirements. This assessment should form the basis for developing and implementing a time-phased plan for modernizing, rehabilitating, or removing current NASA wind tunnels from service and for providing new national capabilities.

6. Strengthen American universities for basic research and science education through enhanced government and aerospace industry support and cooperation.

As centers of basic research, universities play a vital role in creating the basic technological foundation for achievement of the National Goals. Universities provide the dual benefit of scientific advances and the training of future scientists and engineers. Yet there are disturbing signs that our universities R&D infrastructure is deteriorating. The U.S. must revitalize the critically important interactions between universities, government and industry that have served this Nation so well in the past. For these reasons, cooperative efforts between government and industry should be encouraged to help:

- Expand, replace and modernize university R&D equipment, facilities, and instrumentation, to keep pace with research and training needs.

- Support U.S. science and engineering students with adequate long-term stipends to encourage our best students to pursue graduate studies in engineering. Challenging graduate level curricula should be established or strengthened in critical aerospace areas.

- Foster aerospace-oriented centers patterned after such successful ventures as NASA's Centers of Excellence, the National Science Foundation's Engineering Research Centers, and the University Research Initiative of the Defense Department. This will help address critical needs for more multi-disciplinary basic research and encourage greater technology transfer to the private sector.

7. Improve the development and integration of advanced design, processing, and computer-integrated manufacturing technologies to transform emerging R&D results into affordable U.S. products.

Flexible, automated manufacturing technology is a key to affordability and quality in all three goal areas and is a potential major leverage area for U.S. manufacturers. To enhance the U.S. competitive advantage, the Committee recommends that:

- Aerospace industry establish world leadership in advanced processing and computer-integrated manufacturing technology.

- Aerospace industry improve the integration of design with advanced processing techniques and automated factories.

- Federal agencies, particularly DOD, facilitate U.S. manufacturers' use of advanced manufacturing techniques or concepts sponsored by those agencies.

- Industry and government strengthen research activities that can lead to new manufacturing techniques and greater productivity.

8. Enhance the safety and capacity of the National Airspace System through advanced automation and electronics technology and new vehicle concepts including vertical and short takeoff and landing aircraft.

Airport congestion and delay have become substantial problems that will worsen with the expected growth in aviation. New high-performance vehicles will also present significant challenges for the National Airspace System. To realize the benefits of future technology advances, the Committee recommends that:

- Federal Aviation Administration FAA, in conjunction with NASA, accelerate development and integration of advanced automation and electronics technology into the National Airspace System.

- FAA maintain flexibility for early certification of future aircraft, including supersonic and hypersonic vehicles.

- FAA and NASA provide technology for timely detection and avoidance of hazardous weather such as wind shear, and for computerized aids in handling unavoidable encounters.

- NASA and DOD aggressively pursue advanced automation and electronics technology for future aircraft. Effective integration of humans with these highly-automated systems is pivotal for increased safety and performance.

- Industry explore development of timely and affordable civil derivatives of the new generations of military VTOL and STOL aircraft for inter-city and inter-region transportation.

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CONCLUSION

The Committee believes that the most crucial problem facing U.S. aeronautics is that government and industry leaders underestimate the depth and determination of foreign aeronautical commitment and the magnitude of the R&D effort required to achieve the National Goals. Real national growth in R&D is essential.

The changing environment requires a new commitment and a new philosophy, characterized by a collective sense of responsibility and a more cooperative relationship among government, industry, and the university community. Government alone cannot guarantee success. America's ability to compete lies primarily within the private sector which must be effectively mobilized. The recommended U.S. strategy will produce both a strengthened defense and a clear-cut product superiority in the international marketplace.

To hold on to American markets while competing in the new global economy requires changes in the aeronautical community's traditional operating procedures. Policies and approaches which were born when U.S. industry was generally preeminent have little place in a world where many competitors are essentially technological equals and actively backed by foreign governments. major increases in government spending are not required, but necessary outlays will be a prudent investment in America's economic future and national security.

Change is unsettling. Fortunately, many Americans are now recognizing that something different must be done. From education to tax reform, we should be thinking seriously about how to sharpen the country's competitive edge. Otherwise, America's quality of life can only slip relative to the rest of the industrialized world.It is the Committee's hope that all involved will realize that "business as usual" will not carry the U.S. through this world competitive environment successfully.

None of these changes will be easy. The only question is whether they will be made in time with a coherent purpose that will secure lasting U.S. aerospace leadership. Otherwise, far tougher choices will be forced upon us in the heat of a deepening crisis. It is the Committee's firm belief that the central priority for the balance of this century is to regain American competitiveness.

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