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Aircraft Technology Opportunities for the 21st Century

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TABLE OF CONTENTS

Page

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SUMMARY

New aircraft technologies are presented that have the potential to expand the air transportation system and reduce congestion through new operating capabilities, and at the same time provide greater levels of safety and environmental compatibility. Both current and planned civil aeronautics technology at the NASA Ames, Lewis, and Langley Research Centers are addressed. The complete spectrum of current aircraft and new vehicle concepts is considered including rotorcraft (helicopters and tiltrotors), vertical and short takeoff and landing (V/STOL) and short takeoff and landing (STOL) aircraft, subsonic transports, high speed transports, and hypersonic/transatmospheric vehicles. New technologies for current aircraft will improve efficiency, affordability, safety, and environmental compatibility. Research and technology promises to enable development of new vehicles that will revolutionize or greatly change the transportation system. These vehicles will provide new capabilities which will lead to enormous market opportunities and economic growth, as well as improve the competitive position of the United States aerospace industry.

INTRODUCTION

The increase in demand for air transportation has resulted in tripling of world-wide airline traffic since 1970 and it is expected to double by the year 2000 (ref. 1). This rapid growth (fig. 1) will place increased stress on the already strained aviation system. Unless improvements are made, increased congestion and more flight delays will continue at the major hub airports. Aviation in the U.S. is highly concentrated; airline hubs have become popular since deregulation of the airline industry in 1978. Under this practice, passengers from a number of cities are funneled into a central location, where they change planes for their final destination. This hub concept allows the airlines to fill the planes but strains the air-traffic control and runway system. In 1978, the airlines carried 275 million passengers; in 1987, the total was more than 468 million. Operations at 17 large metropolitan and regional U.S. airports have already exceeded their practical annual capacity, thus leading to an unacceptable number of delays. For example, airlines logged an average of 2000 hours of delays per day in 1986. Besides being a great inconvenience to the traveller, the monetary cost of these delays is high. In 1984, the Council of Airport Operators estimated that delays cost air carriers and passengers over $3.2 billion. In 1987, annual delays had increased to the point of being equivalent to suspending all commercial air service for one month. Delays at these key airports are not only local problems; the effects ripple outward to other airports with flights connecting to these hubs and ultimately to the entire network.

Since air travel is expected to grow at over 5% per year through the year 2000, this rapid growth will result in the saturation of the air traffic control system and runways unless steps are taken now to expand airport operations. With this predicted annual growth rate, operations at some 65 major U.S. airports are expected to exceed capacity before the year 2000. Airport expansion is difficult because of environmental concerns, availability of real estate, and cost. Safety is also of concern to the general public. Technology offers not only solutions to these transportation problems but can provide an improved air transportation system for the next century.

The primary goal of NASA aeronautical technology is to maintain the preeminence of U.S. civil and military aviation by conducting research and technology programs that support development of superior U.S. aircraft and a safe, efficient, and environmentally compatible air transportation system. The White House Office of Science and Technology Policy has defined national aeronautical goals to clarify and focus the direction for the U.S. aeronautical research and development (refs. 2 and 3). These goals are categorized into three areas: 1) subsonics, 2) supersonics, and 3) transatmospherics. The subsonics goal calls for a new generation of U.S. subsonic aircraft operating in a modernized national airspace system with the aim of safe, congestion-free air transportation at greatly reduced cost. Subsonic aircraft include large transports, commuters, rotorcraft, and V/STOL aircraft. The supersonics goal recommends technology development for future long-range high speed civil transports. The transatmospherics goal provides for technology to pursue research vehicles with the capability of single stage-to-orbit using air-breathing engines, with takeoff and landing from conventional runways. These goals lay the framework for the critical technology needs of civil aircraft for the 21st century.

The purpose of this paper is to discuss new aircraft technologies that have the potential to expand the air transportation system and reduce congestion through new operating capabilities, and at the same time provide greater levels of safety and environmental compatibility. It discusses current and planned civil aeronautics technology at the NASA Ames, Lewis, and Langley Research Centers. While this paper does not address advances resulting from programs undertaken by industry alone or by other government laboratories, it is expected that the technologies described cover most of these. The complete spectrum of current aircraft and new vehicle concepts is considered including subsonic transports, rotorcraft (helicopters and tiltrotors), V/STOL and STOL aircraft, high speed transports, and hypersonic/transatmospheric vehicles. Proposed technology to expand airport operations through use of rotorcraft and V/STOL aircraft along with the development of alternate landing facilities is discussed. New technologies applied to current aircraft can improve efficiency, affordability, safety, and environmental compatibility. A recent study of technology opportunities for advanced vehicle concepts is given in reference 4.

Current research and the development of new technology can generate new vehicles that will revolutionize or greatly change the transportation system. These vehicles are expected to provide new capabilities which will lead to substantial market opportunities and economic growth, as well as improve the competitive position of the United States aerospace industry.

SUBSONIC TRANSPORTS

The subsonic transport market is the largest aviation market and the mainstay of this country's air transportation system. In the subsonic transport area NASA is working on 1) an entirely new generation of fuel-efficient, affordable aircraft including large transports and commuters, and 2) automation technology for improved safety and increased capacity of the National Airspace System.

Aircraft Technology

Many high-leverage technologies, which are part of the fundamental NASA research activities, are now ready for more focused effort to accelerate their transition into superior U.S. transport aircraft. Key technology challenges as shown in figure 2 involve reduction of fuel consumption with ultra-high-bypass engines, drag reduction with laminar flow control and turbulence control, reduction of structural weight with advanced composites, and fully integrated fly-by-light flight controls and operating systems that interface with a modernized National Airspace System.

Proposed propulsion technology thrusts include the development of ultra-high-bypass ducted propulsors and advanced high-pressure, higher temperature turbine cores. The critical elements for the ultra-high-bypass ratio propulsors include lightweight, high efficiency blades and short, lightweight, low drag nacelles. The use of composite materials is a key to achieving maximum stiffness at minimum weight. The key technologies to be developed for increased core efficiency include compression systems with very high pressure ratios, combustors and turbines with much higher temperature capability to drive the higher-work compressors, advanced secondary systems (e.g., bearings, seals, and lubrication) and engine management controls. The combination of these advanced engine-core and ultra-high-bypass technologies could provide a 40% improvement in fuel efficiency resulting in a significant reduction in operating cost. An example of an ultra-high-bypass engine recently demonstrated is the GE 36 engine on the McDonnell Douglas MD-80 aircraft shown in figure 3.

A major research emphasis for commuter aircraft is being planned in the area of propulsion system technologies. Plans include development of advanced axial and centrifugal compressors, advanced high-temperature turbines, and lower-weight heat exchangers. These technologies have the potential of providing up to 35% reduction of fuel savings.

Current NASA structures technology includes the development of integral skin-stiffened fuselage structures, emphasizing low-cost processing and fabrication approaches such as filament winding and extrusion of thermoplastics. Also included is the development of high-temperature (600° F) materials and improved composite analysis and life prediction methodology. Technology validation near-term will be directed at integral composite structures and aeroelastically tailored high-aspect-ratio wing structures, both emphasizing low-cost fabrication and testing of large-scale structures. Far-term validation will focus on pressurized composite fuselage structures and large-scale wing/fuselage intersection components. The development of innovative fuselage structures and tailored-wing structures could provide up to 35-40% reduction in structural weight.

Research in aerodynamics is directed at operationally usable high-aspect-ratio, laminar flow wings, turbulent drag reduction, and high lift systems. NASA research has resulted in technology validation of both active and passive laminar flow control in flight. Figure 4 shows a Jetstar aircraft modified with two partial-span leading edge sections containing alternative system designs for laminar flow control incorporating suction, anti-icing and anti-insect contamination. One leading edge was designed by McDonnell Douglas Aircraft and the other by Lockheed-Georgia. (Both designs employed suction to promote laminar flow.) These tests demonstrated effective systems for laminar flow control for future transport aircraft (ref. 5).

Development and validation of technology for the reduction of fuselage turbulent skin-friction drag offer significant reduction in aircraft drag. Turbulent drag can be reduced by use of "riblets" which are tiny V-shaped grooves like the grooves on a phonograph record. These riblets provide a 6 to 8% reduction in turbulent skin friction drag, as demonstrated in wind tunnel tests and full-scale flight tests. Fuselage turbulent drag reduction requires acceleration of the technology development and validation efforts of riblets, combined with large-eddy-breakup devices. The combined impact of laminar flow control and turbulent drag reduction can provide up to 30-40% reduction in aircraft drag.

The application of advanced fiber optics technology for "fly-by-light" flight controls and power systems offers the potential of improved reliability and savings in weight, maintenance, and acquisition costs.

Fly-by-light technology development will focus on: fiber optics material and components, systems architecture for application to flight control functions; functional integration; and data communications including automated diagnostics. Power systems technology development will include power generation, conditioning, control, and distribution, with emphasis on uninterruptible power.

Successful incorporation of all of these individual technology advances offers the potential for developing advanced subsonic transport aircraft with a 25% reduction in operating cost, improved efficiency, and improved safety relative to current transports. In addition, this technology should provide superior future subsonic transport aircraft which are essential for the U.S. to remain competitive and increase market potential.

Safety and Automation Technology

The capacity of the aviation system is currently strained because of the growth in air travel in the last decade. In the last two years, there has been a 100% increase in the number of reported near misses, which are now occurring at an average rate of more than one per day. Several recent tragic airline accidents costing hundreds of lives have emphasized the role of human error and the problems of man/machine interface, automation, and situational awareness in aviation accidents. A review of the data from the last 10 years reveals that 65% of commercial jet accidents and 85% of general aviation accidents have been directly or partly attributed to human error. These factors, coupled with increasing flight delays, have led to growing concern for safety of commercial air transportation in the National Airspace System.

The problems of aviation safety being addressed in NASA's Aviation Safety/ Automation Program can be represented by contributions in three areas: 1) human, 2) vehicle, and 3) the aviation system and its interactions as illustrated in figure 5. The human-element problems are associated with human error and judgment, inexperience, and runway incursions. Vehicle problems are associated with flight restrictions, unplanned contingencies, and effects of automation in the cockpit. The aviation system problems are associated with weather hazards, traffic conflicts, limited capacity of the airspace, increasing traffic and pressures from schedules.

The NASA Aviation Safety/Automation research program being conducted in cooperation with the FAA is intended to provide technology which, when applied by the aviation system, will result in safer and more effective operations. The three major elements of the program are human-automation interaction, intelligent error-tolerant systems, and air traffic control (ATC) automation and aircraft-ATC integration as shown in figure 6. The technology objective is for automation to assist humans to attain increases in performance within the cockpit and at the ATC workstation. Thus, the function of human-centered automation is to assist rather than to supplant the human. The objective of the intelligent error-tolerant systems research is to develop and evaluate cockpit systems that provide flight crews with safe and effective ways to plan and replan flights, manage aircraft systems, and effectively respond to the external environment in dealing with contengencies.

One system that will assist flight crew members in maintaining increased awareness of their external environment is the second generation Traffic-Alert Collision Avoidance System (TCAS II) being evaluated by NASA in simulated air carrier operations (fig. 7). The study concluded that TCAS II can appreciably lessen the danger of conflicting air traffic without imposing unacceptable increases in flight crew workload (ref. 6).

Another system that has potential to improve safety is the Takeoff Performance Monitoring System (TOPMS) which provides improved pilot awareness and flight safety during takeoff. TOPMS is a multifunction graphic cockpit display that provides advisory information that assesses normal and abnormal takeoffs. At any point during the ground roll prior to takeoff, the projected stop-point using maximum braking is displayed. Figure 8 shows the heads-up and heads-down TOPMS display in the NASA Transportation Systems Research Vehicle simulator. Experienced pilots using a simulator have evaluated its performance very favorably.

Air Traffic Control Automation and Aircraft/ATC Integration research is aimed at the development of controller-compatible ATC automation concepts, the evaluation in both simulated and real environments, and the integration into the ATC system. Potential aids for ATC controllers being developed include flow management and scheduling, single-feeder-fix traffic management, tactical ATC management and final approach spacing (ref. 7). Plans include testing these aids in an operational environment by utilizing the FAA Denver Air Route Traffic Control Center with data links to ground-based simulators followed by actual evaluations at the Denver Center (fig. 9).

A more futuristic example of an advanced human factors research tool that has potential for application to ATC information management is shown in figure 10. This virtual-environment display system enables the operator to explore virtual objects and environments in real time from multiple viewpoints (ref. 8). This display could inform the pilot of air traffic flying nearby as if he were flying under visual flight conditions. Advisories can also be used to alert and advise the pilot. This virtual-environment display system is currently being developed for the Space Station application, but this technology should be readily applicable to all classes of aircraft. This technology should be especially useful for aircraft configurations that have low visibility cockpits and aircraft flying under instrument meteorological conditions.

The expected benefits from the aviation safety and automation research program are a 50% reduction in human error accidents and incidents, 20% increase in capacity in the airspace system including decreased fuel usage, and aircrew and controller workload optimization for improved efficiency and productivity.

ROTORCRAFT

Rotorcraft are a class of aircraft that uses rotors for vertical lift. This class includes conventional helicopters and high speed rotorcraft, hybrid aircraft that have both helicopter and fixed-wing airplane characteristics.

Helicopters

Civil uses and benefits of helicopters have increased significantly in the last two decades, and are expected to continue to increase in response to increasing transportation needs. Rotary wing aircraft technology is not as mature as fixed-wing aircraft technology; hence, large improvements are possible that would open up new markets and applications.

Programs are currently under way which will produce improvements in safety, reduced operating costs, reduced noise and vibration, all weather operation, and improved reliability. Helicopter technology research areas are illustrated in figure 11, and recent research results are described in reference 9.

Aerodynamics and acoustics research will enable future rotorcraft designs that reduce external noise by tenfold, improve hover efficiency by 10%, and improve cruise efficiency by 20%. During this past decade, there has been a tremendous growth in rotorcraft acoustic technology. Major advances have been made in the identification and characterization of helicopter noise sources. Currently the emphasis is on reducing both the external and internal noise. An example of a test vehicle for which the external noise was reduced is the UH-1, shown in figure 12. By contouring the blade tip into an "ogee-tip" configuration, the annoying peak-level impulsive noise during descent can be greatly reduced. The reduction with this tip design is such that the annoyance region can be entirely avoided by helicopter operating procedures, whereas it is virtually impossible to avoid operating in a high annoyance condition with the standard blade tip (ref. 10).

Vibration reduction research is producing improvements in rotor and airframe design methodology and hub and rotor technology which could substantially reduce airframe vibration at the source by 80-90%, and thereby reduce complexity, cost, maintenance, and weight while improving ride qualities and reducing crew fatigue. One promising method of vibration control is Higher Harmonic Control (HHC). Vibration is suppressed by changing blade pitch at harmonics of the rotor rotation frequency to alter the aerodynamic and inertia loads experienced by the rotor blade. The HHC method for reducing vibrations was demonstrated by comparing the vibration levels with and without HHC in an OH-6A helicopter as shown in figure 13. With HHC on, the vibration level is comparable to that of a jet transport (ref. 11).

Composite primary-structure technology programs emphasize the improvement of design methodology applicable to advanced composite materials. Benefits from this research include 25% cost reduction resulting from a 60% reduction in number of parts and simpler fabrication methods, 25% weight reduction, and enhanced crashworthiness, damage tolerance, and a vastly increased fatigue life. Use of composites will also lead to less dependence on strategic materials.

Propulsion technology opportunities center on engine design and methodology, power transfer technology, and systems integration (ref. 9). Current engine design methodology promises component analytical prediction methods and technology improvements (including engine diagnostic and controls research) that will lead to improvements of life, reliability, maintainability, and efficiency of future small gas-turbine engines by using composites for critical components such as compressors, turbines, and combustors. Power transfer technology research promises improvements in the service life, reliability, and maintainability of future rotorcraft transmissions and other power transfer components, as well as reductions in size, weight, noise, vibration, and cost. Systems integration emphasizes full integration of the propulsion/control system over the entire range of vehicle operations, enabling quicker engine responses and allowing safe operation close to the vehicle envelope limits.

Human factors research is a major component of system technology programs. The three major program elements of this research are pilot/vehicle interface, situation awareness, and mission management. Research under way which applies revolutionary advances in sensors, electronic cockpits, and modeling of mission environments and vehicle systems will result in a low pilot workload and ability to operate under all weather conditions. Simulation and in-flight visual research is being conducted to assess the effects of cockpit automation and workload on pilot decision-making abilities. An example of research that addresses human factors issues in emergency medical services (EMS) operations is shown in figure 14. The goal of this research is to establish computer aids to improve decision making and to provide staffing guidelines for improved crew shift schedules. The approach includes establishment of a national reporting system of incidents in EMS operations and measurement of the impact of workload, fatigue, and stress on performance. Proposed solutions to improve safety will be evaluated in an operational setting (ref. 12).

In summary major helicopter technical improvements are possible. They include: 1) reduction of external noise to contain the noise within the heliport boundaries, 2) reduction of vibrations from the present rate of 0.1-0.3 g to 0.01-0.05 g, 3) improvement of reliability and maintainability by a factor of three of major systems, 4) achievement of all-weather operations capability at remote and high density terminal sites with less than 1% lost time due to weather, 5) improvement of safety to obtain a fivefold reduction in the accident rate, and 6) improvement of fuel consumption from 10-20 seat-miles/gallon to 30-40 seat-miles/gallon. These advancements will enhance the community, passenger, and pilot acceptance and economic viability of helicopters.

High Speed Rotorcraft

Conventional helicopters are limited to maximum operational speeds of around 200 knots because of the inherent phenomenon of retreating blade stall for a horizontal rotor. However, speeds of greater than 300 knots (fig. 15) can be obtained by high speed rotorcraft at the present time. The high speed rotorcraft configuration that shows the most promise is the tiltrotor aircraft, which combines the low-disk-loading VTOL capability of a helicopter with turboprop aircraft cruise-speed capability. The design concept has been proven in the XV-15 Tiltrotor Research Aircraft (fig. 16). This aircraft features two large, three-bladed proprotors mounted at the tips of the wings. For takeoff, the proprotors and their engines are rotated to the vertical position where the developed thrust completely supports the aircraft weight. The tiltrotor has the ability to fly in three different modes: in the helicopter mode, in the partially converted tiltrotor mode, and in the fully converted airplane mode. The XV-15 converts from the helicopter mode to the airplane mode rapidly by continuously tilting the proprotors from the helicopter rotor position to the conventional airplane propeller position. During the 10- to 15-sec conversion period, the lift is transferred from the rotors to the wing as the aircraft speed increases. To land, the proprotors are rotated to the helicopter position and the aircraft is flown as a helicopter to vertical landing. The ability of the tiltrotor to rotate its proprotors to different angles also makes it possible to operate as a STOL aircraft. Proprotor tilt angles of 60°-70° produce lift from both the proprotors and wings. Heavier payloads can be lifted in this STOL mode operation than in helicopter-mode operation.

The success of the XV-15 program has led to the development of the V-22 Osprey tiltrotor multimission aircraft by Bell Helicopter Textron and Boeing Helicopter for the Department of Defense. A photograph of the V-22 at its rollout is shown in figure 17. The V-22 is expected to fly before the end of 1988 and become operational in late 1991. Operational experience with this vehicle will aid in development of a civil tiltrotor. A civil tiltrotor transport offers an opportunity to introduce this unique capability into the transportation system. In a recent study of civil tiltrotor missions and applications conducted by the FAA, NASA, and DOD, it was concluded that the tiltrotor has a large world-wide civil market potential, particularly in the pressurized-fuselage versions. Market penetration was estimated at as many as 700 units for direct V-22 derivatives or 1400 for all-new-design vehicles. (ref. 13).

To develop a viable market, however, not only the aircraft, but an entire infrastructure for the tiltrotor transportation system is required. At Congressional request, a national plan of action is being developed which considers all aspects of a transportation system. The challenges to development of a civil tiltrotor are shown in figure 18. The tiltrotor needs to be acceptable to both the community and the passenger and must be perceived as safe, with low noise and vibration. Costs of the tiltrotor must be economically justifiable in terms of the time saved and the total cost for the trip. The system cost must be competitive with other means of transportation. Recent results of system cost comparison for the Northeast Corridor are shown in figure 19 (a follow-on to the study of ref. 13). The study indicated that a

VTOL system consisting of 40 tiltrotor aircraft, along with 18 strategically located vertiports, can be developed for less cost than one new commercial airport or an upgraded high speed train-transportation system. The most difficult challenge is the development of an infrastructure which integrates the tiltrotor operation into the National Airspace System. This development includes certification methodology, operational procedures and navigation aids, and heliport/vertiport enhancements. The FAA has begun to address all of these challenges.

Continued tiltrotor technology development elements include advanced structures, aerodynamics, and flight systems (figure 20). Advanced composite materials with improved processing and low-cost fabrication offers the potential for structural weight savings of 10% relative to current V-22 composites technology. Also advanced composite structures could result in further weight reductions for pressurized fuselage. Aerodynamic refinements, such as improving the rotor/wing flow interactions resulting in reduced wing download and drag, could improve the cruise efficiency of the vehicle. Commercial viability can also be enhanced by further concentration on noise reduction. Full realization of the civil tiltrotor potential, however, will require the development and validation of technology for advanced cockpit flight control, navigation and display systems, operating procedures, and ATC interface to allow the tiltrotor to operate in high-density city-center airspace. The proposed tiltrotor technology makes possible efficient, effective integration in the air traffic control environment, and offers the potential for reduction of more than 25% in operating cost from V-22 technology. The tiltrotor adds a new dimension to the air transportation system which can provide congestion relief to the current transportation system and can provide a competitive aircraft in the world-wide market.

The XV-15 research aircraft has demonstrated the tiltrotor's operational readiness; however, it was not optimized for high speed. Studies under way indicate that it will be possible to operate tiltrotor configurations to 400 knots with advanced technology. An improved aeroelastically stable rotor-hub configuration is required along with a lower drag configuration. Beyond 400 knots, rotor drag is severe. However, if the rotor is slowed, stopped, and folded, while the forward thrust is provided by a convertible turbofan engine, this configuration (fig. 21) could feasibly attain speeds approaching 500 knots. Considerable effort has been expended in analyzing and testing convertible engines. In figure 22, the TF-34 modified into a convertible engine is shown with test results (ref. 14).

Besides folding tiltrotors, other stowed-rotor concepts have been investigated where the rotor is stopped, folded, and stowed in the fuselage and the aircraft is then operated as a conventional fixed-wing aircraft. Both subscale and full-scale wind tunnel tests have been conducted to demonstrate the feasibility of this concept (fig. 23). Mission vehicle studies of the stowed rotor configuration indicated that it can obtain speeds similar to the folding tiltrotor. An example of a stopped rotor aircraft is the X-wing aircraft that will provide a low-disk loading VTOL capability similar to that of a conventional helicopter, combined with high subsonic cruise speed (fig. 24). The rotor is stiff, four-bladed, and utilizes circulation-control blowing over the trailing- and leading-edge surface of its symmetrical blades for lift and control. A satisfactory empty weight fraction must be developed for this class of high speed rotorcraft to be economically viable.

V/STOL AND STOL AIRCRAFT

The V/STOL and STOL aircraft configurations considered here are those fixed wing propulsive-lift concepts powered by propellers, fans, or jets, but not rotors.

V/STOL Aircraft

There is a long history of V/STOL and vertical takeoff and landing (VTOL) aircraft developments in the United States. A summary of research for these aircraft is given in reference 15. One example of V/STOL aircraft that has potential for civil applications is the lift cruise fan. Lift-cruise-fan aircraft are generally characterized by utilizing high-bypass-ratio fans aligned with the longitudinal axis of the airplane for thrust in cruise. For lift in hover and in transition, the lift-cruise fan thrust vector is rotated to the vertical by rotation of the entire nacelle, or by rotation of the nozzle exits and louvers. The concept discussed here is one in which the entire nacelle rotates, as in the full-scale tilt-nacelle model designed and built by Grumman for the Navy and NASA. The design incorporates two tilting, high-bypass turbofan engines with controllable inlet guide vanes and a system of control vanes in the exhaust flow (fig. 25). Aerodynamic vanes located behind the nacelles in the fan-bypass exit flow provide pitch and yaw control; thrust modulation provides height and roll control. Hover control is achieved through direct modulation and angling of the thrust vector, thereby eliminating the need for a reaction control system.

The tilt-nacelle configuration was tested extensively, using small-scale wind-tunnel models and using a large-scale model in both the hover facility and the NASA 40- by 80-foot wind tunnel. The wind-tunnel results indicate that the configuration can operate over a broad transition corridor with ample maneuvering capability. The tilt nacelle offers moderate hover endurance capability, a less complex control system because of no-engine-bleed requirement, and a good propulsion-airframe match throughout the flight envelope. It is particularly suited for long endurance, moderate hover, and high-altitude missions with high subsonic cruise speed capability. Many missions, particularly civil missions, require no hover endurance, but do require vertical flight capability. An artist's conception of a civil tilt-nacelle aircraft is shown in figure 26. A comparative study of civil transportation missions for various aircraft types showed that the tilt-nacelle transport is most cost-effective at ranges greater than 800 miles because of its high cruise speed.

The V/STOL challenges are depicted in figure 27. These include minimization of adverse effects of engine exhaust when in vertical takeoff mode due both to the ground surface and to ingestion of the hot exhaust gas and ground debris. In addition, V/STOL aircraft must have noise levels that are acceptable to the community, economy of design and the capability of meeting certification requirements. The FAA has recently issued a powered-lift transport category airworthiness criteria document that was developed with NASA assistance (ref. 16).

STOL Aircraft

A STOL aircraft is generally defined as one that can take off or land over a 50-foot obstacle at sea level at its maximum takeoff or landing weight in a distance of about 2,000 feet (or less). Historically, operational STOL aircraft have achieved their short-field performance through low-wing-loading (25 lb/ft^2 or less) and extensive use of high lift devices such as flaps and slats, at the expense of poor cruise efficiency and poor ride qualities. Various designs have been powered by turboprop, turboshaft, and pure jet propulsion systems. Typically, these aircraft have accommodated fewer than 60 passengers and cruise at speeds less than 250 knots.

Future, larger STOL aircraft must have the necessary short-field and maneuvering envelope to get into and out of hub airports separately from conventional takeoff and landing (CTOL) aircraft runways and have minimal environmental effects at the small secondary urban airports. Promising technology for future designs was developed under the U.S. Air Force Advanced Medium STOL Transport Program which produced the YC-14 and YC-15 military prototype aircraft, and the NASA augmentor-wing research aircraft and quiet short-haul research aircraft (QSRA) Programs. This technology can be applied to a new generation of larger higher-speed STOL transport airplanes with outstanding short-field capability.

Figure 28 shows these aircraft and simplified schematics of the lift-augmentation systems. The externally-blown-flap system concept from the YC-15 prototype is being used on the C-17, now under development for the Air Force. The lift augmentation is achieved by flaps that deflect the engine thrust downward on takeoff and landing, with the flaps retracted during high-speed cruise flight. The Augmentor-Wing aircraft concept ejects fan bleed air between wing flap upper and lower flap segments for increased circulation and lift augmentation. The high performance of upper surface blowing (USB) aircraft is achieved by installing the engines over the forward portion of the wing. A faired mixing nozzle directs the exhaust gases over the wing upper surface and flaps to provide increased aerodynamic lift. Lift is improved by taking advantage of the Coanda effect, where air adhering to the surface of the wing continues down over a highly deflected flap, converting a large portion of the jet thrust into propulsive lift. An example of the USB design is the twin-engine YC-14 aircraft. These three concepts utilize high wing loading which results in improved ride qualities over those of the current low-wing-loading aircraft.

The four-engine QSRA was developed for proof-of-concept verification of the USB low-speed-flying characteristics and has been used extensively to investigate terminal-area operations for STOL aircraft. This four-engine USB configuration offers better performance (especially engine-out) than a two-engine configuration. The QSRA nominal takeoff and landing distances are 750 feet and 650 feet, respectively. However, during carrier trials, the QSRA demonstrated unassisted takeoff distances less than 300 feet and landing distances less than 200 feet. Also, flight research with the QSRA has confirmed that landing performance at relatively short field lengths can be achieved at thrust-to-weight ratios comparable to those used in conventional transport aircraft.

The QSRA uses the Lycoming YF-102 engine which has a relatively high bypass ratio (6 to 1), which, in turn, reduces noise. The installation has been designed specifically to attenuate the engine noise by including tuned acoustic linings in the inlet and fan duct. In addition, placement of the engine above the wing provides noise shielding to ground observers. These design features result in an extremely quiet airplane, as exemplified by comparing the 90-EPNdB footprint of a "scaled-up" QSRA airplane to that of a commercial jet transport (fig. 29) with thrust cutback. Studies have shown (ref. 17) that the noise reaching the surrounding community will be well below the 90-EPNdB level. For example, even for this "scaled-up" QSRA, the 90-EPNdB noise level has been calculated to be essentially contained within typical airport boundaries.

Since transport aircraft generally fly at cruise speeds, cruise drag associated with USB must be minimized. This is one of the challenges associated with STOL aircraft (fig. 30). Computational analysis, wind-tunnel testing, and flight measurements will likely be required before a commitment is made to a USB civil transport. Some in-flight verification is being obtained from the Asuka aircraft which was developed by the Japanese National Aerospace Laboratory and a consortium of Japanese companies. The Asuka, which uses USB technology, is designed to operate at Mach 0.7, with a ceiling of 30,000 feet and a maximum range of 1,000 miles. Flight testing was begun in October 1985. Another challenge associated with high-wing-loading STOL aircraft is to meet certification requirements. As previously mentioned, the FAA has developed airworthiness requirements for powered-lift transport aircraft.

In summary, large transport aircraft that utilize powered lift can offer impressive short-field performance, increased payload for CTOL operations, and reduced noise level. They can increase the capacity of existing airports by providing service on STOL runways using alternative-airport approach paths. These aircraft may also provide airline service to secondary airports that currently have no airline service.

AIRPORT CAPACITY EXPANSION/ALTERNATE LANDING SITES

Airport Capacity Expansion

As air and ground congestion increases, short-haul intercity air transportation should increase in importance, because of improved efficiency, flexibility, reliability, importance of time to the traveler, and wider distribution of services. However, the addition of new, large, and conveniently located airports will be increasingly constrained by environmental, ground access, and economic factors. Making better use of existing transportation hubs and secondary and small community airports will become more important to prevent serious air transportation congestion and ultimately business and economic stagnation. In the future, even with the use of advanced ATC technology and wide-body aircraft technology, runway capacity limits will be reached in many of the major hub airports.

Full benefits of the new aircraft technologies and opportunities described in this paper can only be achieved by having an accommodating infrastructure. This requires comprehensive transportation plans to be fully integrated with these new aircraft technologies. It is essential to establish a mechanism to provide a continuing forum for planners and technologists to develop the infrastructure to meet the demands and projected growth.

Communities should also consider the high-payoff transportation opportunity offered by rotorcraft, V/STOL, and STOL aircraft which can use alternate landing sites such as vertiports and STOLports.

Vertiports

Significant airport congestion relief may also be achievable through the use of rotorcraft and V/STOL vehicles because they do not require conventional airports, but instead carry passengers almost point-to-point using vertiports. Figure 31 illustrates potential rotorcraft and V/STOL aircraft alternate landing facilities (ref. 17). These include seaports along rivers or lakes that may use existing piers or barges; facilities located adjacent to or above other existing transportation nodes, such as railroads, light rail or subways; and highways enabling a highly efficient intermodal transfer. Existing urban and remote heliports can also be used for most future rotorcraft. Coupling these facility possibilities with existing general aviation airports could create an extensive vertiport ground-facility system. An example of research to improve vertiport operation is illustrated in figure 32. Research elements include the development of the pilot's control strategy and visual perception to specify the range of acceptable rotorcraft or V/STOL approach angles and to develop conceptual designs for vertiport surface markings.

Figure 33 is an artist's rendition of an airport expansion possibility where an airport is saturated with CTOL traffic and is constrained from expanding externally. Rotorcraft and V/STOL aircraft can provide high-frequency, short- and medium-haul service, operating on vertipads or short runways that generally can be placed on existing airports. The CTOL runways can then be used for the longer-haul, wide-body aircraft. Thus, the airport capability can be significantly increased.

STOLports

Short takeoff and landing aircraft also have the potential for relieving congestion at hub airports. STOL aircraft can avoid the problems of landing-slot allocation and long arrival and departure delays by utilizing the short segments of inactive runways, stub runways, or special STOL runways which are typically 2,000 feet long (fig. 33). STOLports can be categorized as two basic types; 1) CTOL ports consisting of one or more STOL runways situated at a CTOL airport and 2) independent STOLports consisting of one or more STOL runways situated at a site removed from a CTOL airport.

Short takeoff and landing aircraft offer a distinct advantage over the CTOL aircraft by their ability to use shorter runways and to descend and climb steeply (fig. 34). STOL operations to and from a STOLport offer a great deal of flexibility in providing discrete routes to facilitate traffic flow. Airspace required by STOL aircraft for takeoff and landing in terminal-area maneuvering is significantly less than that required by CTOL aircraft. These characteristics not only facilitate operation of the ATC system in segregating STOL and CTOL traffic, but also assist in carrying out obstruction-clearance and noise-abatement procedures. The curving, steep-gradient flightpaths of STOL aircraft can be arranged to avoid adverse wake vortices from heavy CTOL aircraft.

Suitable sites for STOLports can be found even in congested cities. In a manner similar to V/STOL aircraft, STOLports could be located along rivers, along the shores of large bodies of water, along transportation rights-of-way, or in wasteland areas within cities that are unsuitable for housing or industry. For example, a STOL landing pad could be located along the riverfront (e.g., as is the new STOLport in London), or could be built on the roofs of existing waterfront buildings or on unused piers. In remote areas STOL aircraft could be used on short, unpaved runways that are relatively easy to construct.

HIGH SPEED TRANSPORTS

The emergence of a global economy is leading to a substantial growth in long-range transoceanic travel—especially trans-Pacific travel. The largest growth projection is a 370% increase in revenue passenger miles between the United States and the Pacific Basin from 1985 to 2000. If technology enables the development of viable vehicles, the market will include a significant quantity of high-speed civil transports. It is expected that post-2000 demand for high speed transports will even be larger due to growth in international travel (fig. 1). High speed transports with cruise speeds from two to three and one-half times the speed of sound with trans-Pacific range can link the U.S. with the farthest reaches of the Pacific Rim in four to five hours. High speed transport concepts from a NASA design and a contractor study are shown in figures 35 and 36, respectively.

The current objectives are to develop an economically viable and environmentally acceptable high-speed civil transport (HSCT) and to greatly improve the capabilities of high speed transports compared to the 20 year-old British Concorde as illustrated in figure 37. Provided that the environmental issues of sonic boom, airport noise, and ozone depletion can be successfully resolved, technology can provide major increases in speed, range, and payload. Development of high speed transports competitive with subsonic transports is also a major challenge.

In 1986 NASA awarded contracts to Boeing Commercial Airplanes and McDonnell Douglas Aircraft to assess the potential for future high-speed commercial flight. The objectives of the studies were to assess market opportunities and economic viability of HSCT concepts and to identify the high-payoff technologies and subsequent research needed to reduce the technological risks to industry. The results of these market and mission studies defined design goals of an aircraft with a 300-passenger capacity and a range of 6500 nautical miles (which could serve most of the Pacific rim) and a target cruise speed between Mach 2 and 3+. Beyond Mach 5, the percentage of time actually spent at cruise speed decreases significantly and thus the aircraft productivity is not appreciably changed as speed increases. Also technologies required for flying a high-speed commercial transport at Mach 4 or faster will be very expensive and are believed not achievable until well beyond the near-term window of opportunity between the years 2000-2010.

A major requirement for development of high speed transports is environmental research addressing the issues of ozone depletion, airport noise, and sonic boom (ref. 18). Atmospheric models to analyze potential ozone depletion by a fleet of HSCTs are needed to define technology requirements. Low emission combustors need to be designed to minimize NO_x production which is the primary concern as a catalyst for ozone destruction. Low noise engine and suppressor research is needed to develop technology for achieving FAR 36 Stage 3 noise requirements. Sonic boom minimization research is essential to evaluate the potential for achieving acceptable supersonic overland flight, which probably requires a level less than 1 psf relative to the Concorde level of approximately 2.5 psf. The objective of acceptable in-flight noise levels necessitates designing the vehicle shape so that the impact of the sonic boom will be minimal. This can be achieved by aerotailoring. By changing the aircraft planform so the sonic boom energy is distributed more uniformly and over a longer period of time, the boom intensity can be significantly reduced.

Another challenge is to design an HSCT that does not adversely impact the ozone layer. The ozone layer extends from approximately 48,000 feet altitude to over 140,000 feet and protects the Earth's surface from harmful amounts of ultraviolet rays. Ozone concentrations vary with altitude, latitude, longitude, hemisphere, and time. Ozone is in a cycle of continual production and destruction—a very delicate and complex process that is not well understood. A better understanding is essential for an HSCT to operate without adversely affecting the ozone layer. Environmental issues are the early emphasis of the NASA HSCT program. The principal HSCT environmental concern is the NO_x engine exhaust emission that acts as a catalyst in destroying the ozone. Hence, research on the combustor design is of paramount importance.

Major technologies for high speed transports are illustrated in figure 38. They include research in propulsion, aerodynamics, structures, and systems. Technology challenges include a satisfactory propulsion system, supersonic laminar flow and turbulent drag reduction, high temperature materials and structures, advanced integrated controls, advanced cockpits, and active controls.

A major challenge is development of an engine which provides acceptable noise levels, a substantial reduction in fuel consumption, and extended life at high sustained engine-operating temperatures. The HSCT may be required to fly over land subsonically or at reduced supersonic speeds; therefore, the engine required must have excellent subsonic-cruise or reduced-supersonic-speed cruise performance characteristics. Thus, the engine must have a high-bypass ratio (BPR), coupled with good supersonic-cruise performance characteristics of a low-BPR engine. An unconventional engine concept referred to as a variable cycle engine (VCE) has the ability to tailor its BPR to whatever values are optimum at any particular flight condition. Since 1971 much progress has been made on reducing supersonic transport engine thrust-specific fuel consumption (TSFC). However, a very large improvement in propulsion system efficiency is still needed both at supersonic cruise and subsonic cruise conditions. As indicated in figure 39, technology advances in mixed compression inlets, high efficiency cores, supersonic throughflow fans, low emission cycles and combustion, high performance and low noise nozzles, thermally stable jet fuel, and advanced component technologies promise at least 40% improvement in efficiency over the Concorde engine (ref. 19). Airport noise remains a tough challenge because previous research concepts have fallen short of achieving FAR 36-Stage 3 noise levels. Innovative solutions may be necessary to reach acceptably low noise levels. Similarly, achieving low exhaust emissions will require cycle compromises and unconventional combustor approaches. The propulsion technical challenges are formidable and require an aggressive propulsion research program.

The quest for higher productivity through speeds above about Mach 3 is thwarted by the lack of conventional, low-priced fuel that is thermally stable at the higher temperatures associated with faster flight. The studies have also considered fuels for HSCT. Current JP-type fuels are practical at Mach numbers up to about 2.3. Recent research results suggest that JP-fuel compatible with the thermal environment of cruise at Mach 3+ will be commonly available in time for HSCT. At higher speeds, JP-type fuel has inadequate weight-specific energy content and capability as a heat sink (ref. 20). Potential alternate fuels include endothermic fuels (which absorb heat to break down into combustible products), liquid methane, and liquid hydrogen. However, endothermic fuels may be too expensive, may require excessive complexity in thermal management, and may not provide an adequate heat sink over the entire flight. Liquid methane is attractive in terms of energy content and heat-sink capacity, but would require extensive engineering to handle safety and operating considerations, particularly at the airports. HSCT operations with liquid hydrogen may be far from economical. A survey of fuel technology suggests, therefore, that nearer-term HSCT will be limited to the Mach number range compatible with JP-type fuels.

Representative HSCT configurations are shown in figure 40. The top configuration is a Mach 2.2 vehicle using conventional Jet A fuel. The middle configuration is a Mach 3.2 aircraft which is seen to be the current limit for JP fuel with a thermally stable additive. The bottom configuration shows a representative Mach 5 aircraft which would use liquid methane gas. Note it is a blended body configuration.

One of the most promising areas of aerodynamic research which has significant potential for improving the performance of a HSCT is supersonic laminar flow control. If significant amounts of supersonic laminar flow can be obtained, the resulting drag reduction could greatly improve range and payload. In addition, the reduced heating associated with laminar flow may in itself provide significant performance benefits in material life, thermal management, and structural weights.

Another high payoff area is materials and structures. Studies indicate that substantial reductions in takeoff gross weight are achieved through reductions in empty operating weight, and hence, structural weight. The major technological challenge for low-weight, high-temperature materials may be the high utilization required for commercial success. Many materials promise at least adequate specific strength at the elevated temperatures associated with high-speed flight. However, there are generally inadequate data on the effects of heat soak and heat cycles. These factors are expected to degrade material properties from the levels typically used for conventional aerospace engineering applications.

The technologies in flight systems include research in the areas of integrated control, advanced displays, and active controls. The overall efficiency and operating economy of a long-range high-speed civil transport will be dependent on optimum simultaneous performance of control systems governing a variety of functions including flight controls, engines, inlets, autopilots, navigation, and environmental control. The development and validation of technology for integration of all control systems will result in improved system performance and efficiency as well as increased safety, reliability, maintainability, and cost effectiveness. Advances in cockpit display, information, and flight management technology will improve the efficiency and safety of high-speed flight and landing operations. It will replace the inherently limited cockpit window visibility with a virtually unrestricted enhanced visual scene—at no compromise in high-speed aerodynamic or structural design. Substantial weight savings and economy will result from technology validation permitting design approaches that fully utilize active controls for relaxed stability, load alleviation, flutter suppression, and variable-geometry tailored aerodynamics.

The combined impact of advances in aerodynamics, propulsion, structures, and subsystems is dramatic (ref. 21). Figure 41 shows the projected takeoff gross weight/design range trade for 1988, 1995, and 2015 technology for a Mach 3.2 concept. The structures included in these results represent the use of advanced materials only. For 2015 technology, the impact of laminar flow technology is illustrated by a separate curve. The 2015 technology laminar flow concept has a takeoff gross weight less than half that of the current technology design. These figures show aircraft designed for minimum gross weight and did not include any specific penalties associated with noise and environmental constraints. These penalties make it virtually impossible to develop an economically viable vehicle using 1988 technology. Environmental areas critical to high speed transports will also be affected by technology advances. The magnitude of sonic boom and airport community noise are strongly affected by aircraft weight. Hence, gross weight reductions made possible by advanced technology will reduce the magnitude of the problem.

An aggressive integrated technology development and validation program which addresses environmental concerns about the atmosphere, sonic boom, and noise should enable development of a high speed transport vehicle in the Mach 2-3.5 range. A California-to-the-Orient trip in less than four hours, with a fare competitive with subsonic transports, should be possible in the early 21st century.

HYPERSONIC AND TRANSATMOSPHERIC VEHICLES

The merging of aeronautics and space technologies provides the potential for an entirely new class of vehicles for the next century, ranging from hypersonic aircraft to a single-stage-to-orbit space transportation system. These vehicles will have the ability to take off from and land on conventional runways, sustain hypersonic cruise flight in the atmosphere, or accelerate into space. A representative hypersonic/transatmospheric vehicle is shown in figure 42. The enabling technology is being developed under the National Aerospace Plane (NASP) program. The official NASP goal is "technology development and demonstration to provide the basis for hypersonic flight vehicles leading to space transportation systems, superior U.S. military aircraft, and civil transports that will have technical, cost, and operational advantages over existing systems." The immediate NASP objective is "to develop, and then demonstrate in an experimental flight vehicle (the X-30), the requisite technologies to permit the nation to develop both military and civil vehicles capable of operating at sustained hypersonic speeds within the atmosphere and/or operating as space launch vehicles for delivering payloads into orbit" (ref. 22). This program is a national effort by DOD and NASA, led by the Air Force with five major contractors.

This technology would enable an aerospace plane to use conventional runways, fly up to 25 times the speed of sound into low-earth orbit and return. Vehicles based on the technology developed on the X-30 may operate as space launch vehicles to carry supplies and building materials to other vehicles and installations orbiting the Earth, such as the U.S. Space Station. Mixed mode air-breathing engines with a small rocket for orbit insertion would propel the vehicle.

Although the idea for an aerospace plane was proposed in the 1960s, the technologies were not in hand, particularly the propulsion concept, materials, and the supercomputers needed to design such a vehicle. Today we have the capability in these areas, but the achievement of a single-stage airbreathing aircraft will still require meeting many major technology challenges.

A number of crucial technologies, as shown in figure 43, must be developed before the aerospace plane becomes viable. These include the development of an air-breathing, mixed mode propulsion system, new high-temperature materials, actively cooled thermal structures for peak and sustained heat loads, concepts for highly integrated airframe and propulsion systems, and computational methods to address complex flow, structures, and the integration phenomena associated with very high-speed vehicles.

One major propulsion technology required is the development of the scramjet. The scramjet is a supersonic extension of the ramjet which has been used to power some U.S. missiles since the 1950s. However, with innovative new materials, new analysis capability, and successful laboratory experiments, it is believed that the scramjet will operate successfully to Mach 25 or about 18,000 miles per hour enabling flight into low earth orbit. A scramjet model that was successfully tested is shown in figure 44. The scramjet is essentially a ramjet combustion taking place supersonically rather than subsonically. Scramjets are designed so that air rushing into the inlet at supersonic speeds compresses itself. Regulating such a flow at hypersonic speeds to "capture" shock waves and to keep engine ignition stable and efficient is difficult. Unlike a rocket, the aerospace plane will not have to haul tons of liquid oxygen as an oxidizer for its fuel; it will draw its oxygen from the air intakes. (A very small amount of oxygen will be aboard for on-orbit maneuvers.) The airframe will have to be an integral part of the propulsion system because its shape determines the paths in which air will flow around and through the vehicle. Hence, this vehicle will require the most integrated propulsion system and airframe ever to be flown by man.

The integration of the aerospace planes structural design, liquid-hydrogen tanks, and thermal protection system is also a challenge. But protecting the structure from the extraordinary heat load that it will encounter will be even more difficult. During a two-hour cruise in the atmosphere at hypersonic speeds, an aircraft will generate 1000 times as much total heat as the shuttle on its 12-minute glide down from orbit. Cold structures such as the shuttle are characterized as basically an aluminum primary structure with thermal protection overlaid on the skin to enable insulation of the interior from the re-entry heat. However, this approach keeps the heat outside the vehicle whereas scramjets operating above approximately Mach 12 need to recover the heat and transfer it to the hydrogen fuel. This demands "hot-structure" design, with an outer skin insulated from the aircraft interior and its cargo, propellant, and crew. Thus, a great challenge is to cool critical areas like the engine and leading edges which is believed to be accomplished by flowing liquid hydrogen fuel under the skin. This is known as an active cooling system. A highly efficient energy management system is also required that is integrated with the thermal controls and vehicle flight and propulsion controls. Because of the criticality of maintaining a precise flightpath, a highly adaptive, intelligent control system is a necessity. As mentioned, the plane's materials will have to be able to withstand temperatures that would melt conventional metals. Materials being developed must be much lighter and stronger than any previously fabricated for an aircraft. Breakthroughs such as metal matrix ceramics will make such structures possible.

NASA is evaluating the aerospace plane's basic shape and propulsion system with the use of wind tunnels and the supercomputing system—numerical aerodynamic simulation system. Before the first flight test, scientists must simulate flight of the aerospace plane on computers because no wind tunnel can reliably simulate the flow conditions for combinations of geometric aircraft scale, altitude, and velocity for conditions at higher Mach numbers—especially Mach 12 to 25. An example of the flow around a candidate configuration generated by computer graphics at Mach 25 is shown in figure 45. This calculation was performed using the NASA Cray 2 supercomputer. Wind tunnel aerodynamic data for Mach numbers to Mach 12 are shown in figure 46 for the subscale model. The final validation of the analyses may require complementary hypersonic test bed experiments.

A concentrated national program of technology development and design studies is under way. Providing that this effort indicates the operational NASP is feasible, an X-30 research aircraft will be built and flown. Thus, the X-30 could lead to a revolution in space transportation enabling the dreams of space commercialization to be realized. It would provide low cost, flexible, on demand access to space.

CONCLUSIONS

New aircraft and aircraft system technologies have great potential to expand the air transportation system, enabling achievement of projected growth, reducing congestion through new operating capabilities, and at the same time providing greater levels of safety and environmental compatibility. The major benefits of these vehicles and technologies are summarized in table 1.

New technologies for current subsonic transport aircraft will reduce operating cost by 25%, improve efficiency, safety, and environmental compatibility. Key technologies include fuel consumption reduction by use of higher-temperature engine cores, ultra-high-bypass engines, drag reduction with laminar flow control and turbulence control, reduction of structural weight with advanced composites, and fully integrated fly-by-light flight controls and operating systems that interface with a modernized National Airspace System. Technology from the Aviation Safety/Automation Program will provide increased capacity in the expanded airspace system, while at the same time significantly reducing human error accidents and improving aircrew and controller efficiency and productivity through reduced workload. Three major technology elements are human-automation interaction, intelligent error-tolerant systems, and air traffic control (ATC) automation and aircraft-ATC integration. The technology for helicopters will result in quieter, smoother, safer, more affordable operations under all weather conditions. Key technologies include advanced rotor designs with low-noise blade tips and lower drag, active vibration suppression, lightweight composite structures, fuel efficient engines, and advanced cockpit flight systems.

Research and technology promises to enable development of new vehicles that will revolutionize or greatly change the transportation system. One example is the tiltrotor which takes off and lands like a helicopter, but is quieter and cruises like a turboprop. The development of multiservice V-22 Osprey provides additional background for development of a civil tiltrotor. Technology developments, including advanced structures, aerodynamics, and flight systems, will make possible a civil vehicle that is efficient, quiet with low vibration, and effectively integrated in the ATC system with 25% reduction in operating cost relative to V-22 technology. It will relieve congestion by providing a more point to point transportation. Other high speed rotorcraft concepts promise higher speeds and will increase the range much further than the conventional tiltrotor. These concepts include folding tiltrotors, stopped- and stowed-rotor aircraft. These aircraft are still in early level of technology development and feasibility stages, but could be accelerated by strong military interest. An example of a V/STOL potential aircraft concept is the tilt nacelle, lift-cruise fan which has been successfully tested full-scale. It has high jet subsonic cruise speed capability with a 2000 mile range. However, further technology refinement and a flyable demonstrator are required before a civil tilt nacelle aircraft becomes a reality. STOL aircraft using powered lift with a high wing loading design will enable large aircraft to operate on short runways at existing airports or small reliever airports with minimum environmental impact outside the airport. Especially promising is the upper surface blowing aircraft, for which investigation is required to minimize cruise drag. Rotorcraft and

V/STOL aircraft can offer significant relief of airport saturation and can save airport space by transporting passengers point-to-point using vertiports.

Current studies indicate high speed civil transports can be developed with Mach 2 to 3+ speeds with a range of 6500 miles, enabling trans-Pacific travel in less than four hours at competitive costs and efficiency comparable to subsonic transports. Environmentally compatible issues of acceptable noise and sonic boom, and non-adverse impact of the ozone layer are being addressed. Also, high payoff technologies of supersonic laminar flow control, the variable cycle engine, lighter materials and structural concepts, and integrated controls promise to result in a takeoff gross weight less than half of the weight of an aircraft built with today's technology and be vastly superior to the Concorde.

Hypersonic and transatmospheric vehicles taking off and landing as conventional airplanes and utilizing air breathing propulsion show promise for low cost, flexible, on-demand access to low earth orbit. The enabling technology is being developed under the NASP program led by the U.S. Air Force with NASA as a team member. Numerous crucial technologies such as air breathing, mixed mode propulsion system, new high temperature materials, actively cooled structural concepts, and vehicle systems integration must be developed, and the integrated technologies demonstrated in a planned X-30 research aircraft. Success of this program would result in operational aerospace planes—with potential for both military and civil applications.

All of these new vehicles are not only expected to provide new capabilities, but also provide enormous market opportunities and economic growth, as well as improve the competitive position of the United States aerospace industry. In order to realize the technology benefits discussed in this paper, the nation must commit to developing the technology. It is also vital that state and national transportation planners, officials, and policy makers are kept abreast of new developments and potential applications in the future. This information could be provided by establishing a continuing forum for planners and technologists. This is especially critical for decisions to plan and implement the supporting ground infrastructure, including takeoff and landing sites that must be strategically located and environmentally compatible. Since long lead times are required, it is essential to develop an infrastructure for these new vehicles so we can reap their enormous benefits for the U.S. transportation system and the U.S. economy.

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TABLE 1.– MAJOR TECHNOLOGY BENEFITS

BENEFITS VEHICLES	IMPROVED SAFETY	CONGESTION RELIEF	NOISE REDUCTION	PROVIDE REAL ESTATE EFFICIENCY	IMPROVE AIRCRAFT EFFICIENCY	REDUCTION IN COST	NEW CAPABILITY	PROVIDE MARKET OPPORTUNITIES
SUBSONIC TRANSPORTS	X				X	X		X
HELICOPTERS	X	X	X	X		X		X
HIGH SPEED ROTORCRAFT (TILTROTOR)		X	X	X	X	X	X	X
V/STOL AND STOL AIRCRAFT		X	X	X			X	X
HIGH SPEED TRANSPORTS			X		X	X	X	X
HYPERSONIC/ TRANSATMOSPHERICS						X	X	X

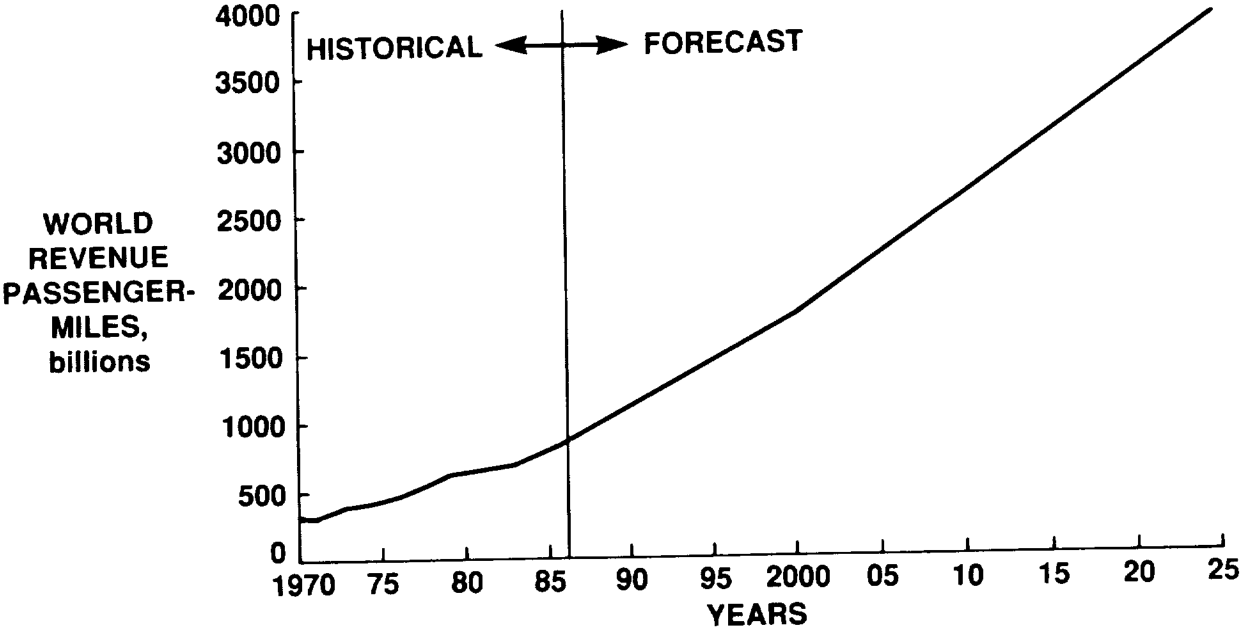
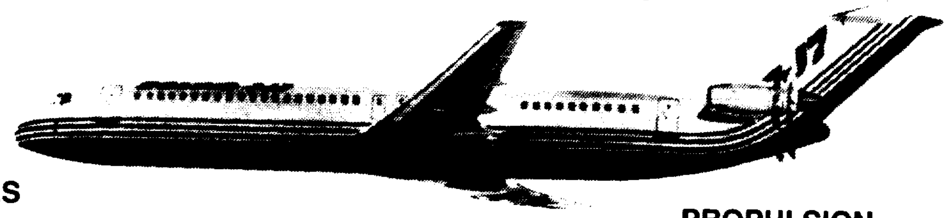


Figure 1.– Aviation growth projection

AERODYNAMICS

- **LAMINAR FLOW CONTROL**
- **TURBULENT DRAG REDUCTION**
- **HIGH LIFT SYSTEMS**
- **HIGH ASPECT RATIO WINGS**



STRUCTURES

- **COMPOSITE MATERIALS**
- **TAILORED WING STRUCTURES**

PROPULSION

- **ULTRA-HIGH BYPASS ENGINE**
- **ADVANCED CORE**

SYSTEMS

- **POWER-BY-WIRE**
- **FLY-BY-LIGHT SYSTEMS**
- **AIRFRAME/PROPULSION INTEGRATION**

Figure 2.– Subsonic transport technology

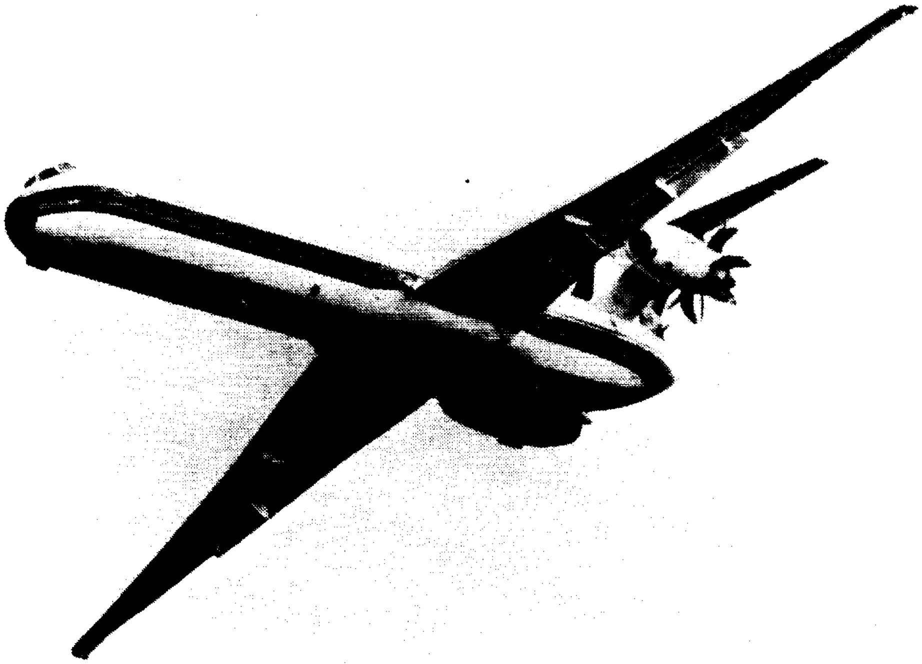


Figure 3.– Ultra-high bypass fan engine

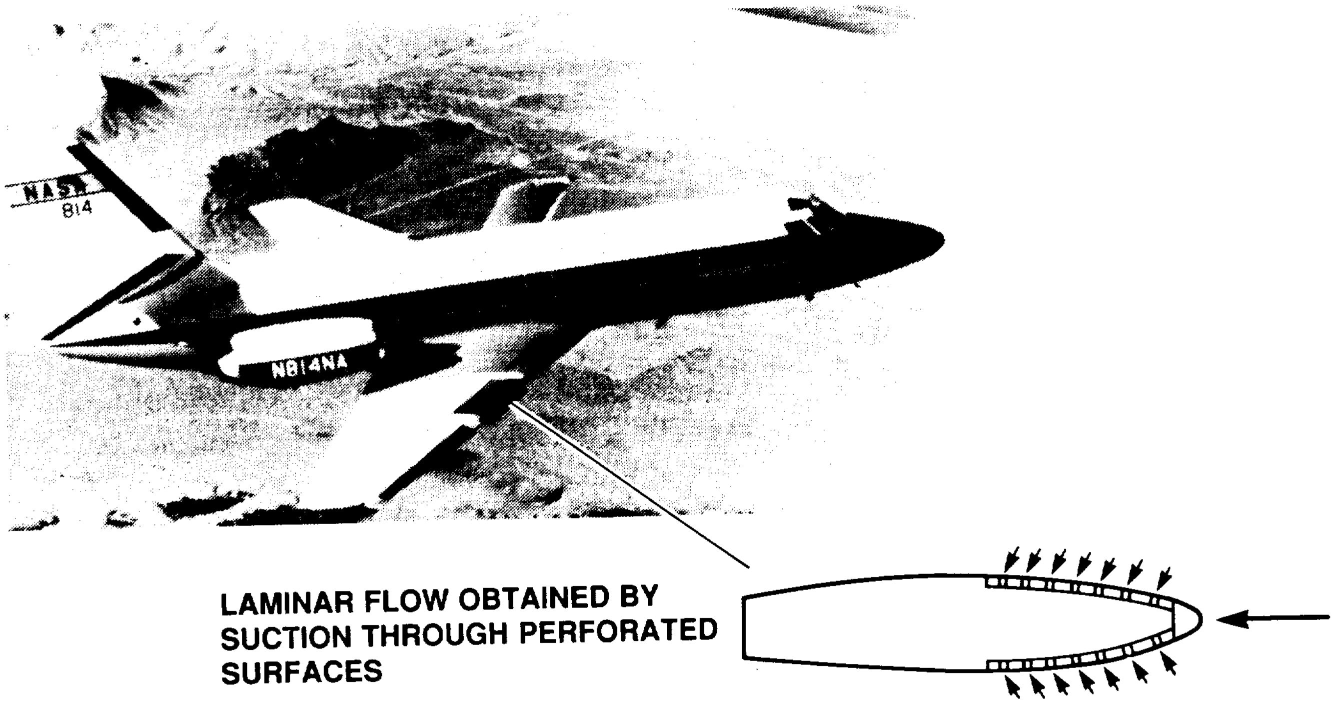


Figure 4.– Laminar flow control flight test

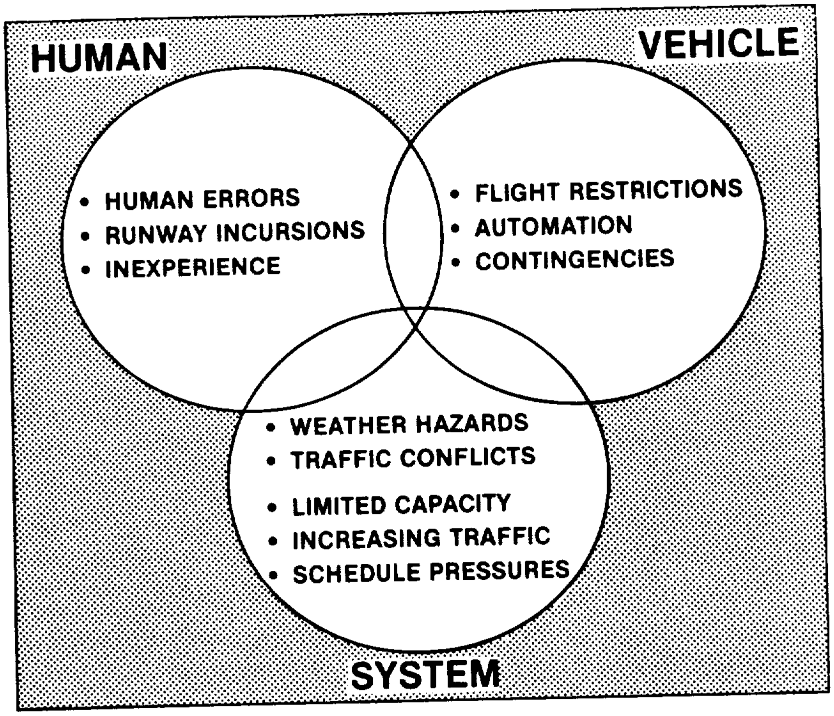


Figure 5.– Aviation safety/automation—the problems

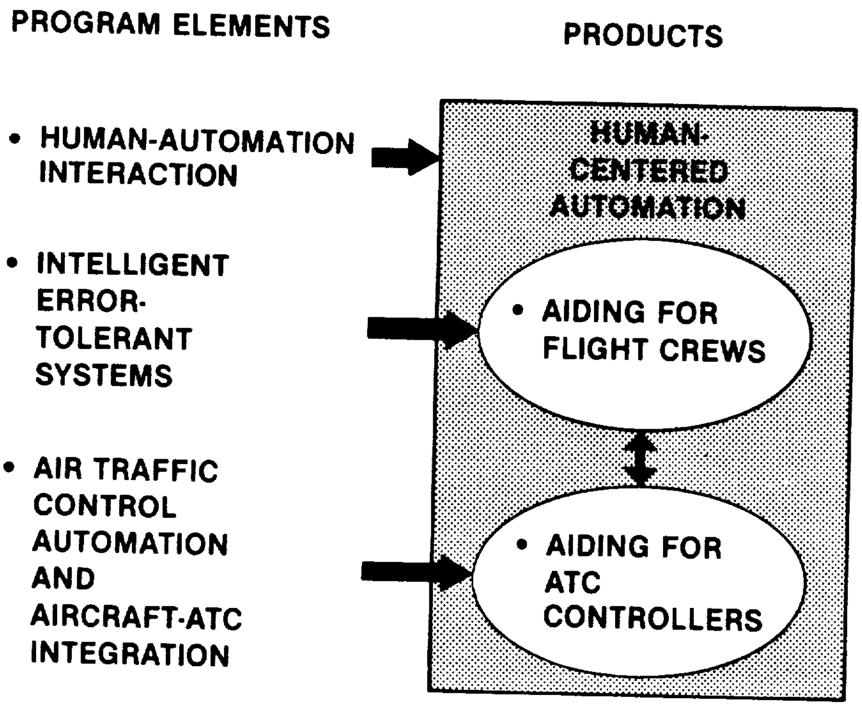


Figure 6.– Aviation safety/automation-technology

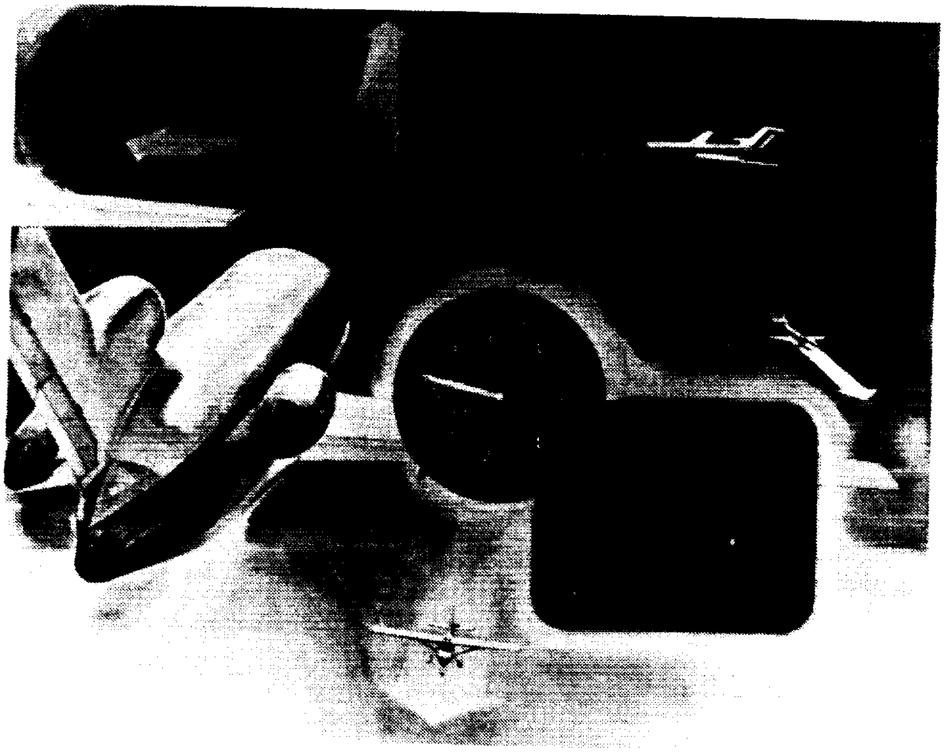


Figure 7.– Traffic alert collision avoidance system

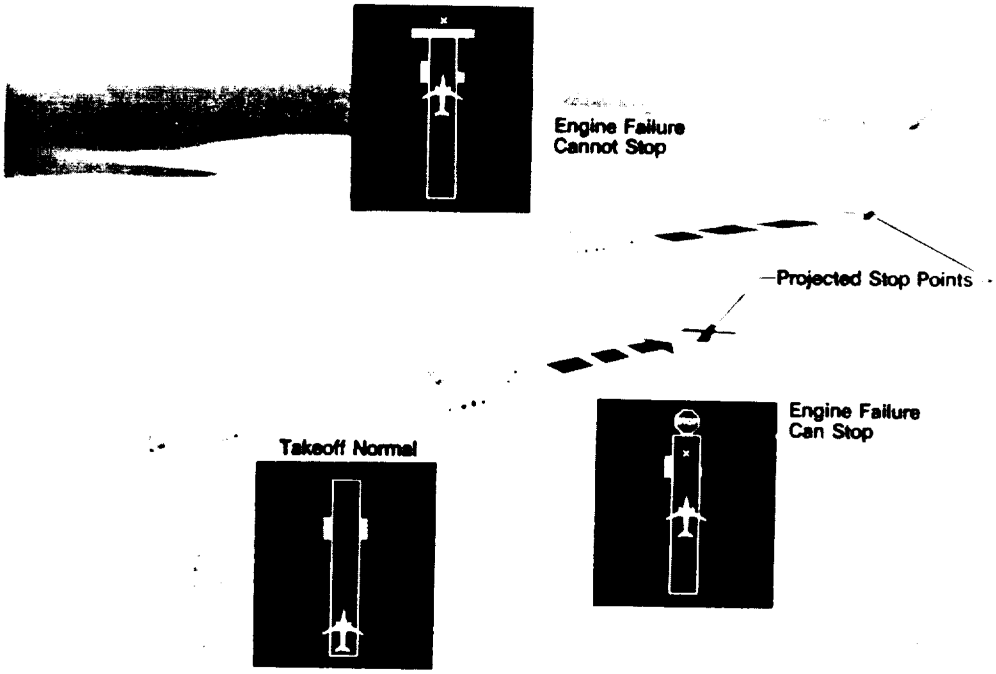


Figure 8.– Takeoff performance monitor

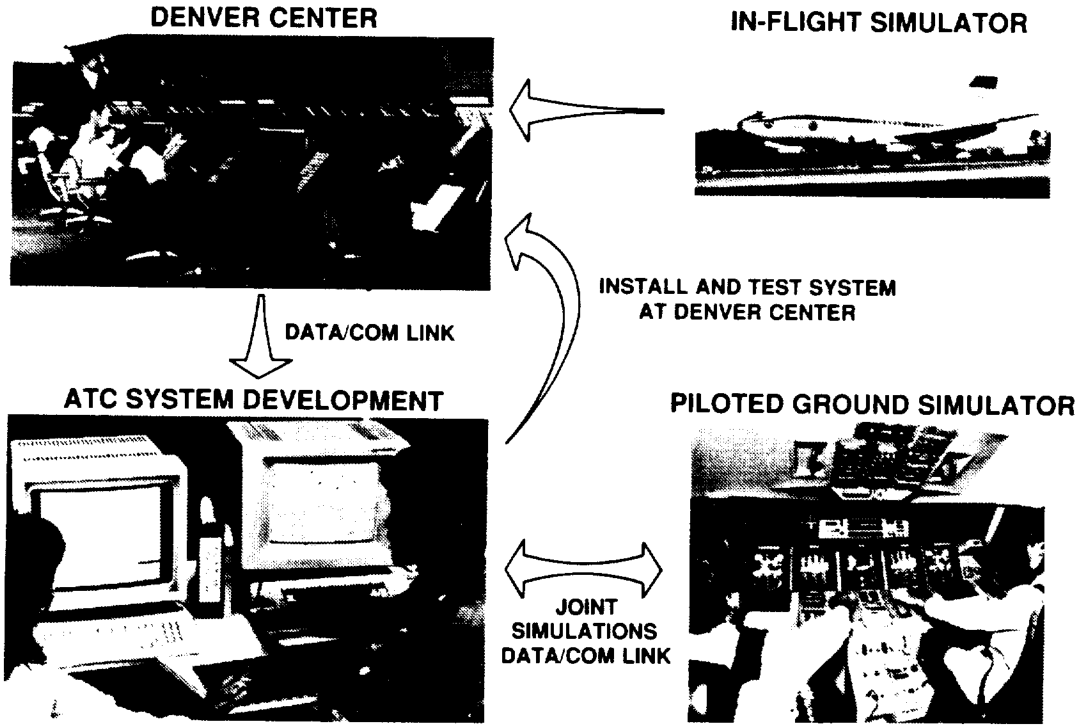


Figure 9.– NASA/FAA automated ATC tests

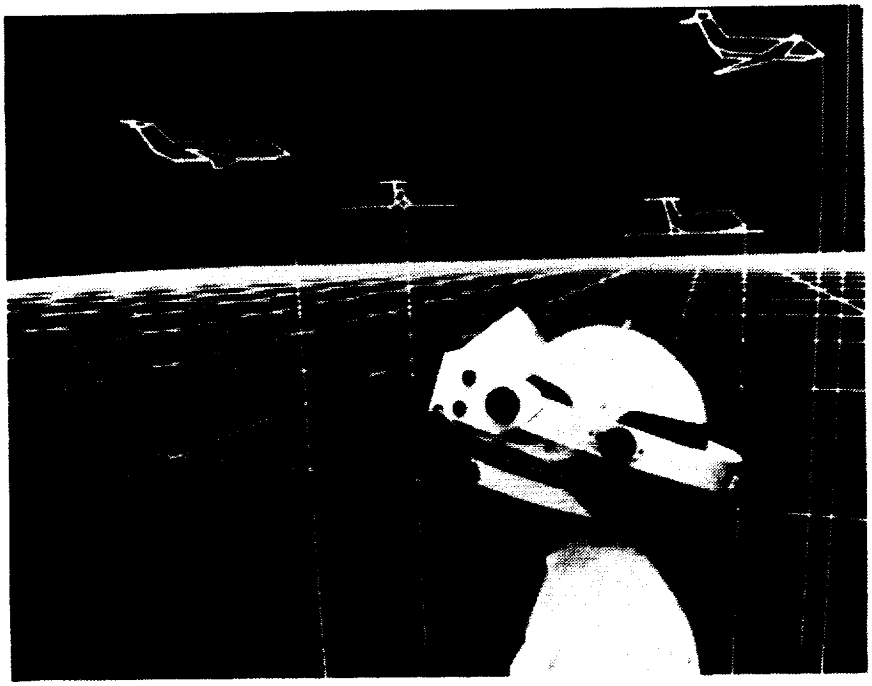


Figure 10.– Virtual environment display system

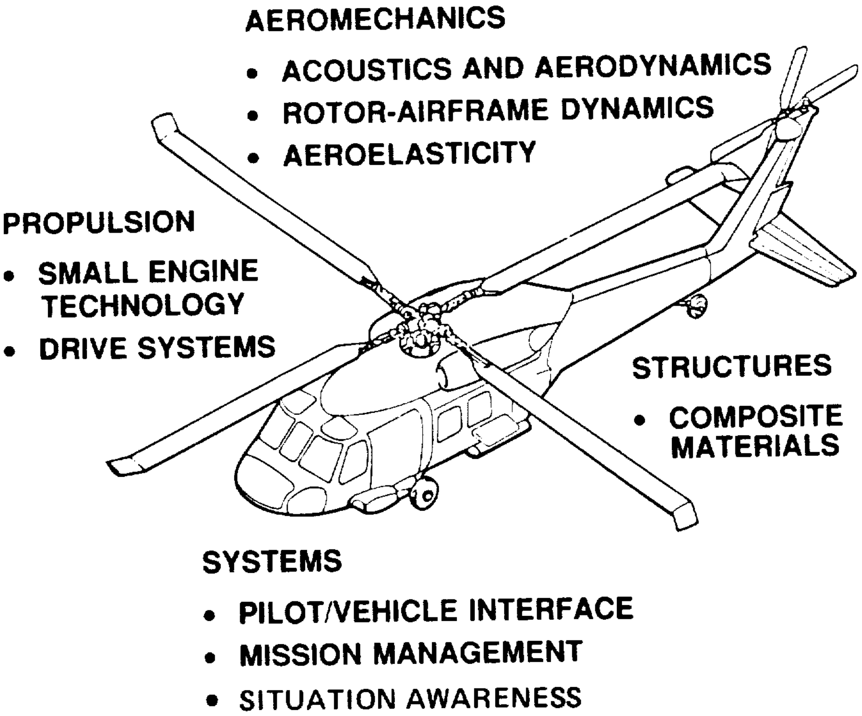


Figure 11.– Helicopter technology

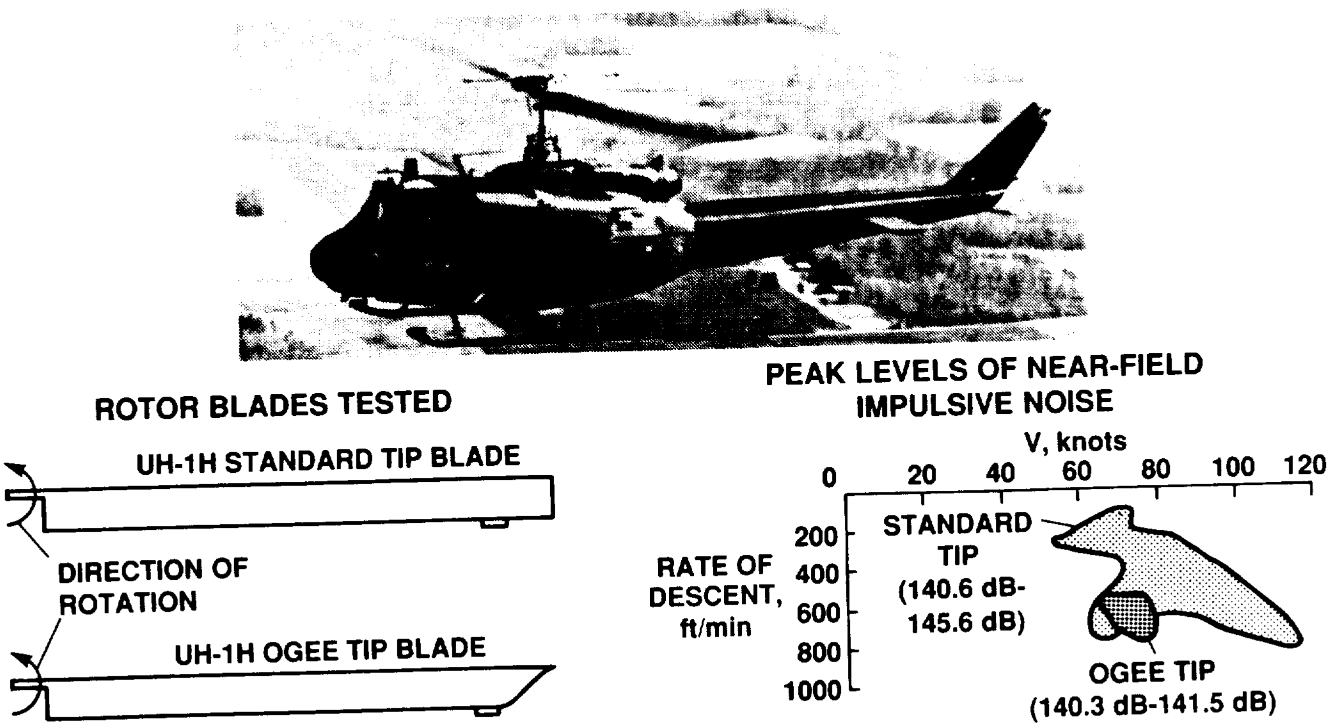


Figure 12.– Noise reduction

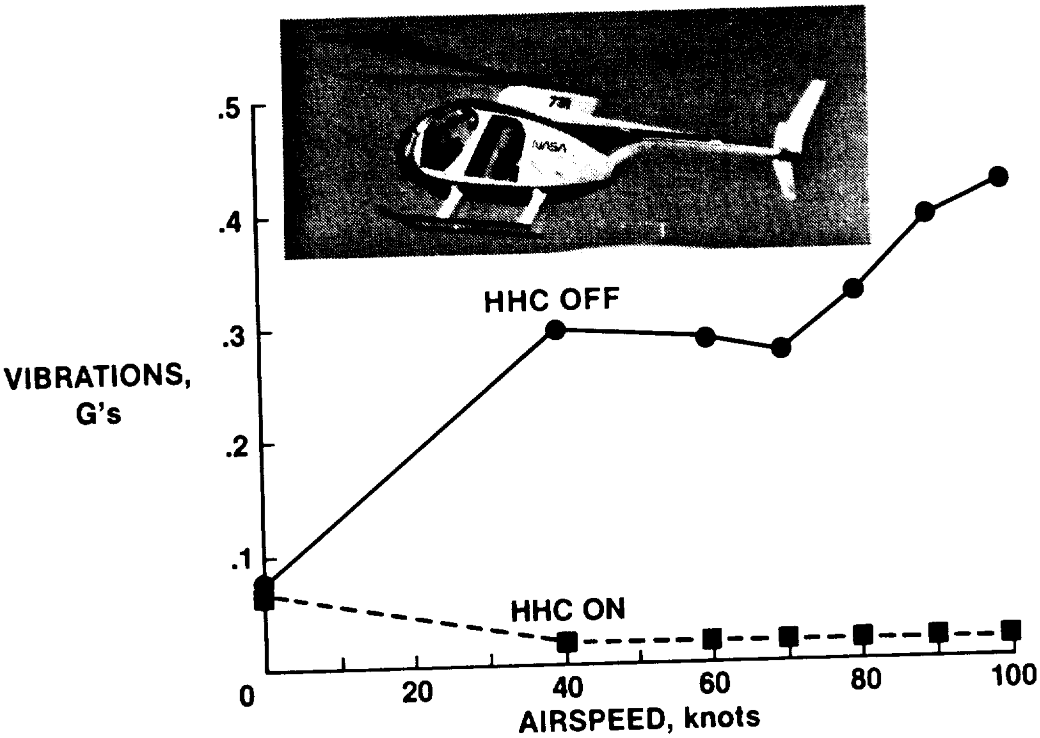


Figure 13.– Vibration reduction

GOALS:

- COMPUTER AIDS TO IMPROVE DECISION-MAKING, SITUATIONAL AWARENESS
- IMPROVED CREW SHIFT SCHEDULES, STAFFING GUIDELINES

APPROACH:

- PERFORM FIELD STUDIES
- ESTABLISH NATIONAL REPORTING SYSTEM
- QUANTIFY IMPACT OF WORKLOAD, FATIGUE, STRESS ON PERFORMANCE
- TEST CANDIDATE SOLUTIONS IN SIMULATION, OPERATIONAL ENVIRONMENTS

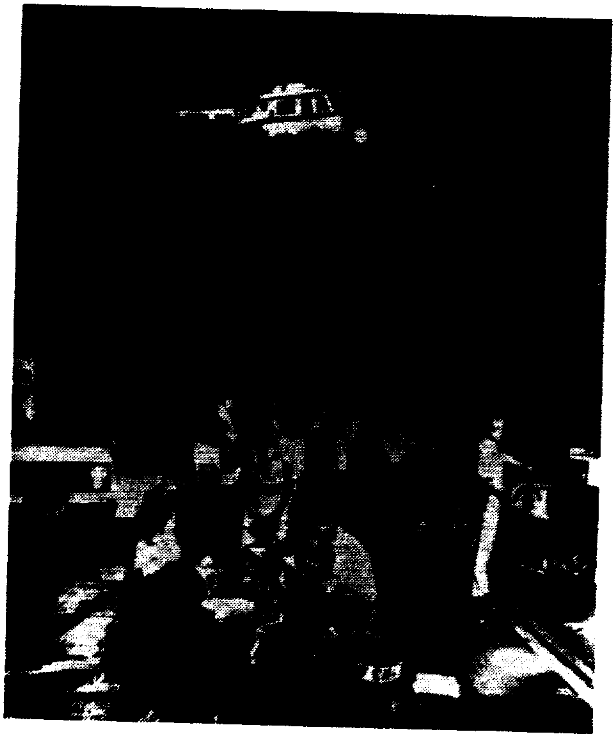


Figure 14.– Medevac safety improvement

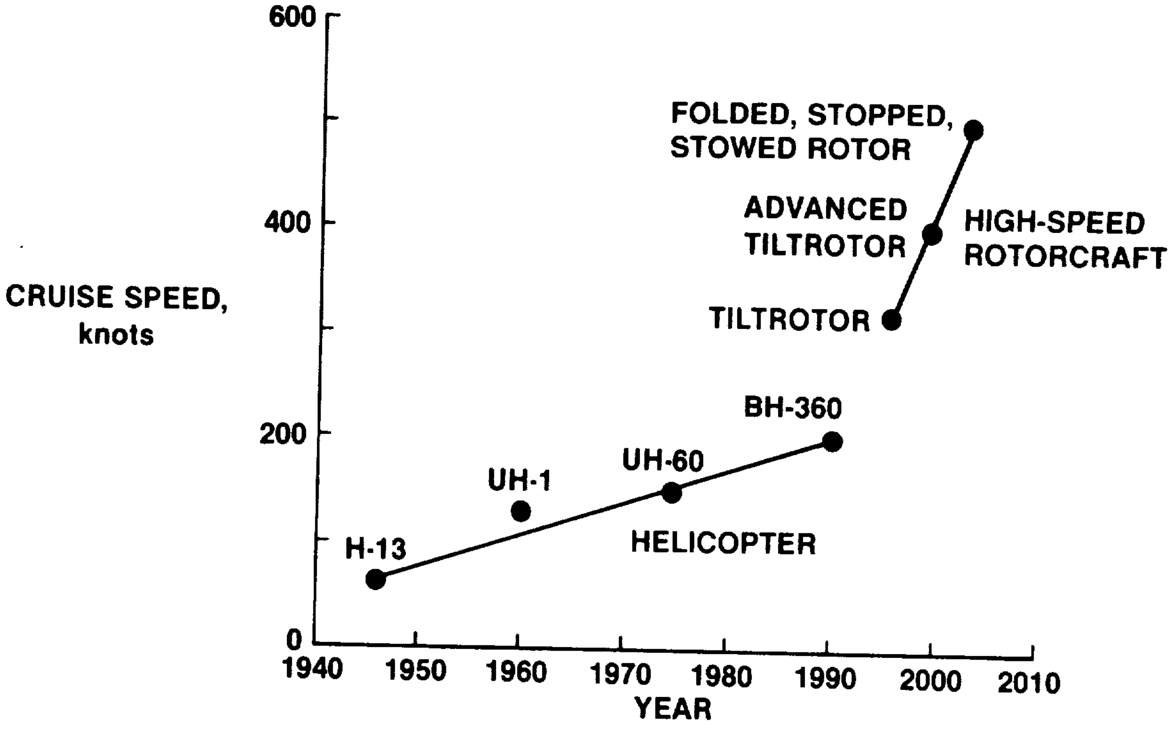


Figure 15.– Rotorcraft speed capability

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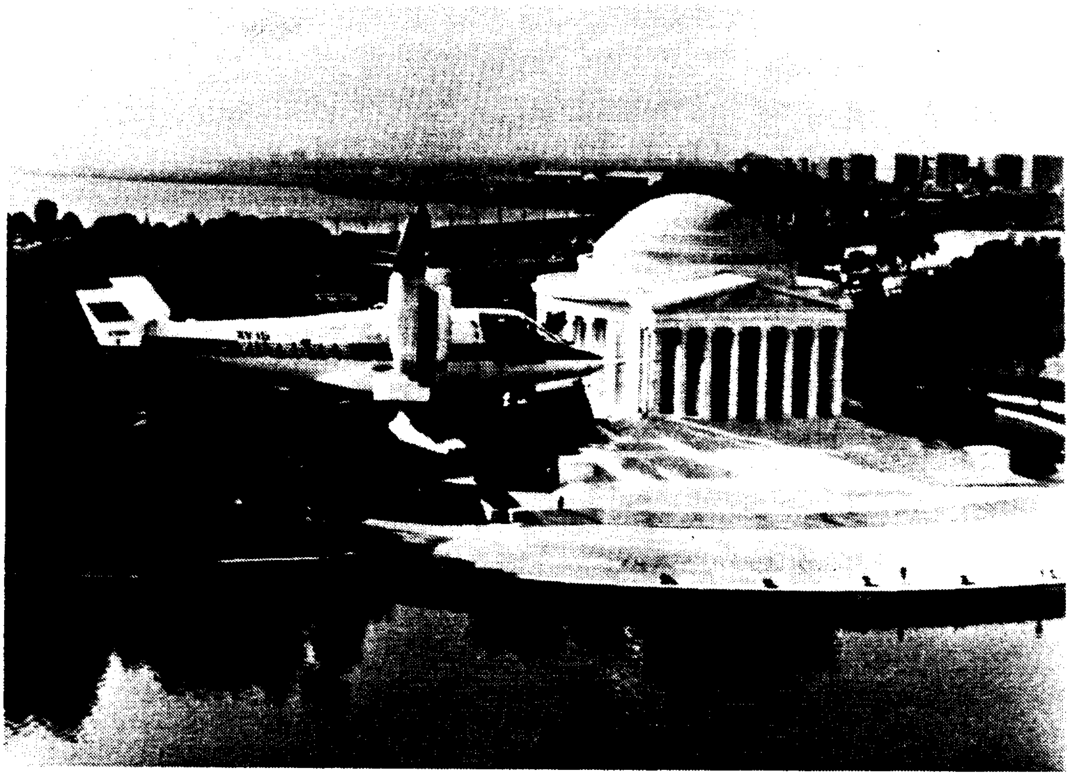


Figure 16.– XV-15 Tiltrotor

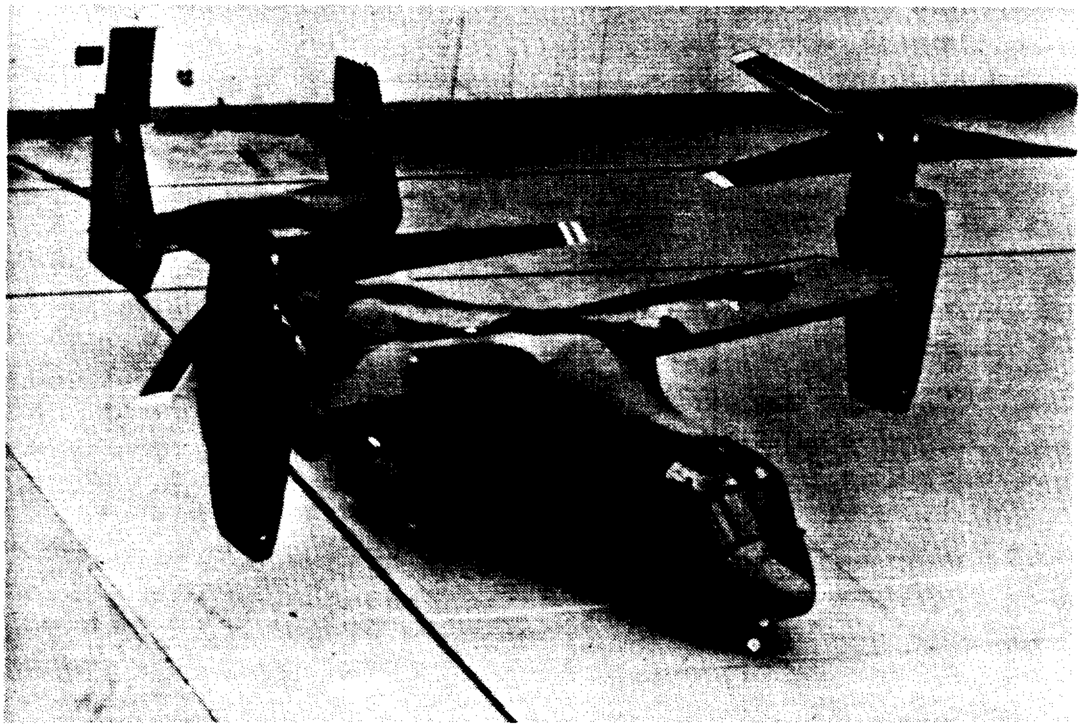


Figure 17.– V-22 Tiltrotor

ENVIRONMENTAL

- COMMUNITY ACCEPTANCE
- PASSENGER ACCEPTANCE

INFRASTRUCTURE

- INTEGRATED OPERATION IN NATIONAL AIRSPACE SYSTEM
- SUPPORT AND ACCEPTANCE BY REGIONAL AUTHORITIES
- CERTIFICATION METHODOLOGY

ECONOMICS

- COMPETITIVE SYSTEM COST

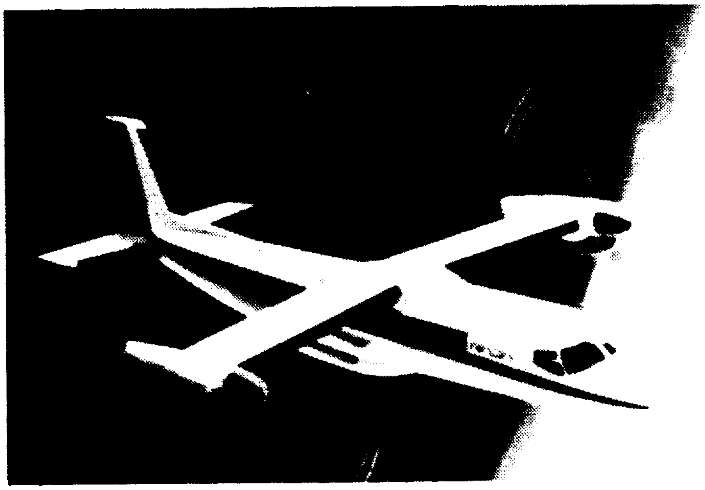


Figure 18.– Tiltrotor challenges

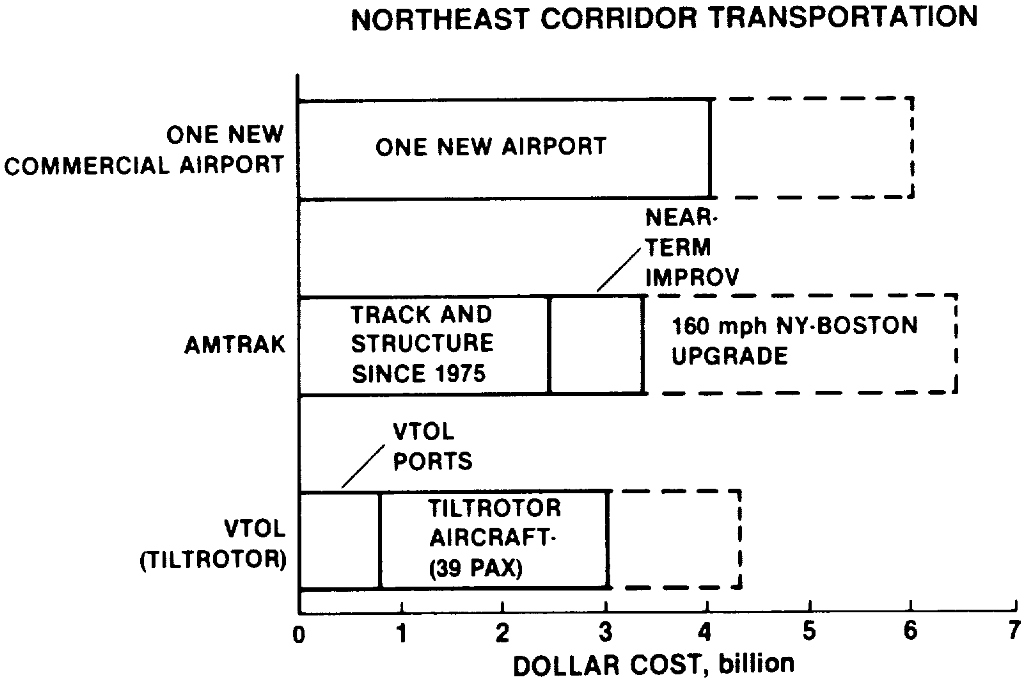


Figure 19.– System cost comparison

STRUCTURES

- **PRESSURIZED FUSELAGE**
- **COMPOSITE STRUCTURES**

AERODYNAMICS

- **WING AND ROTOR AERO**
- **VIBRATION AND NOISE**
- **DRAG REDUCTION**

SYSTEMS

- **GUIDANCE AND CONTROLS**
- **PILOT/VEHICLE INTERFACE**
- **CERTIFICATION METHODOLOGY**

Figure 20.– Tiltrotor technology

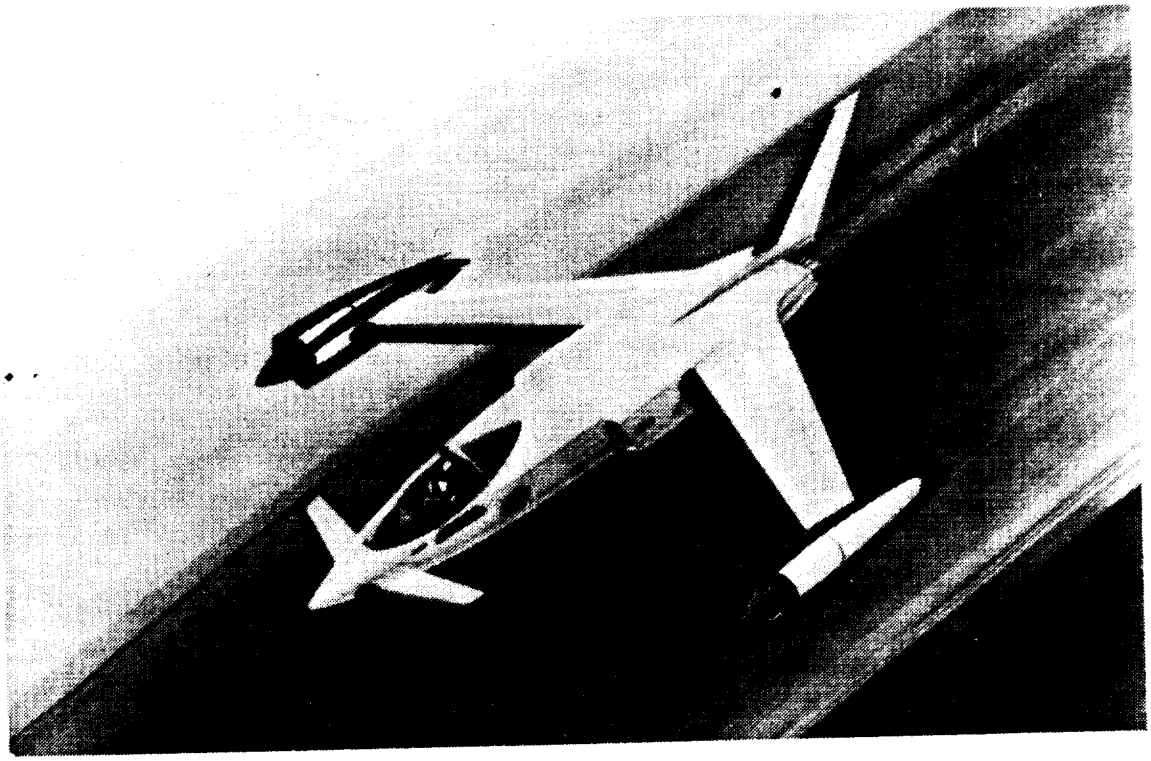
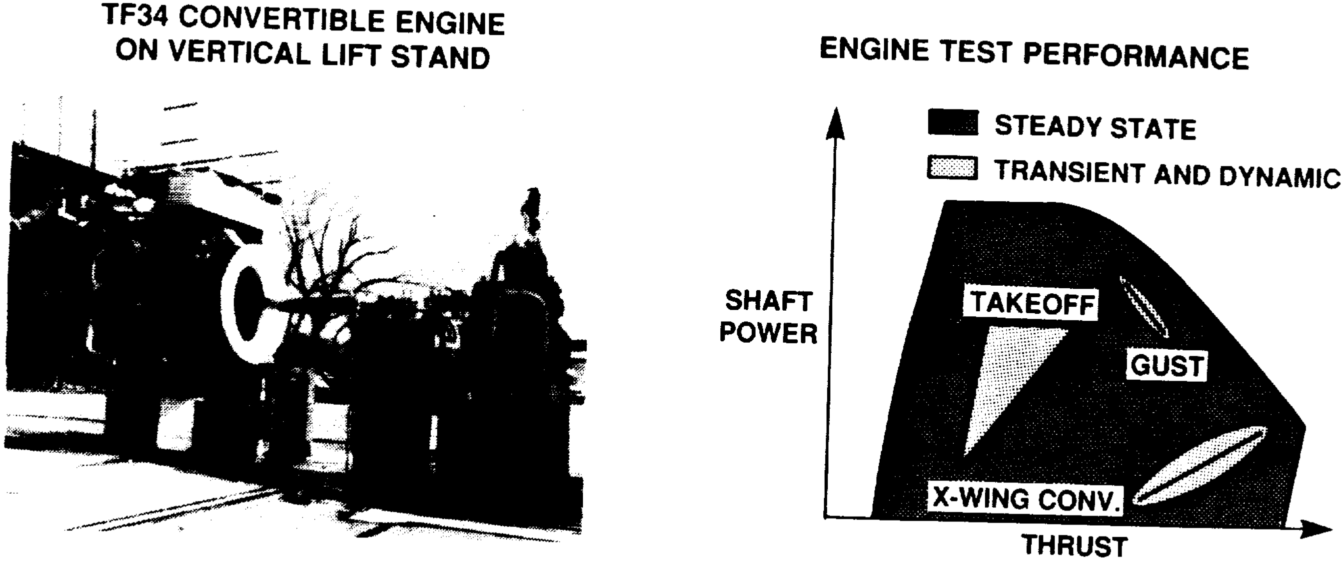


Figure 21.– Folded tiltrotor aircraft concept


TF34 CONVERTIBLE ENGINE ON VERTICAL LIFT STAND

ENGINE TEST PERFORMANCE

Figure 22.– Convertible engine system technology

Figure 23.– Stowed rotor aircraft concept

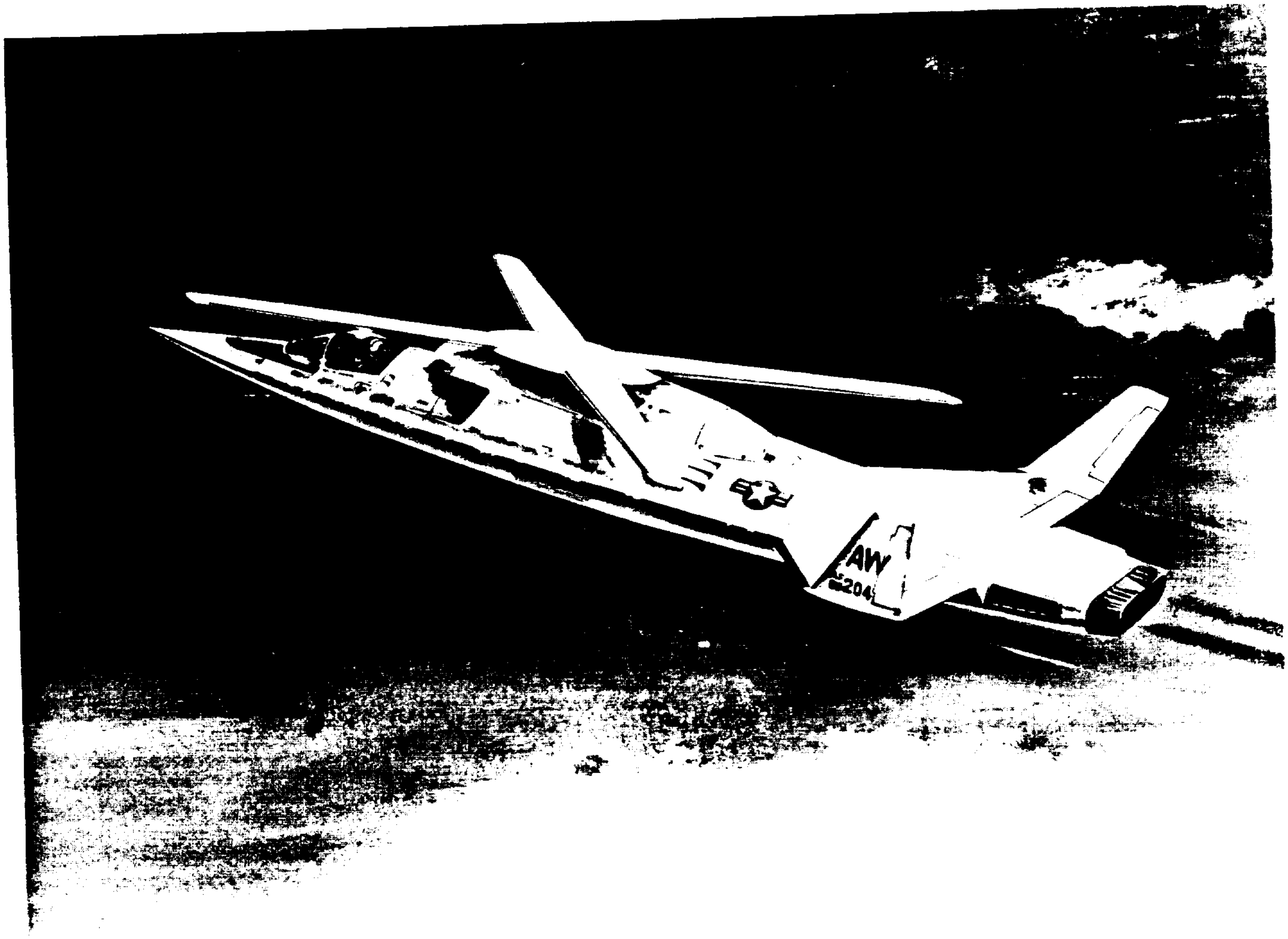


Figure 24.– Stopped rotor aircraft concept

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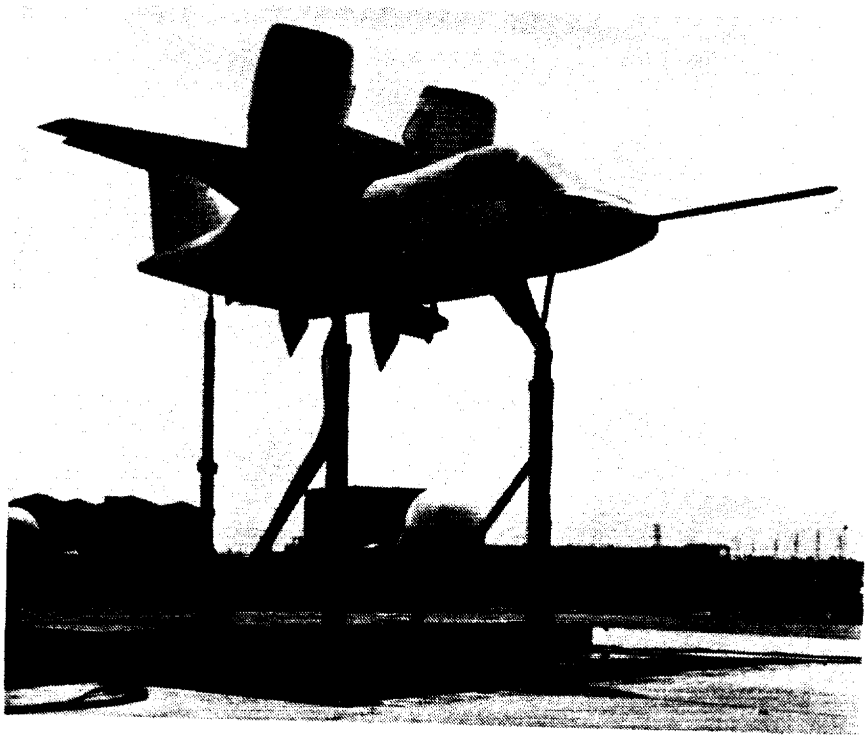
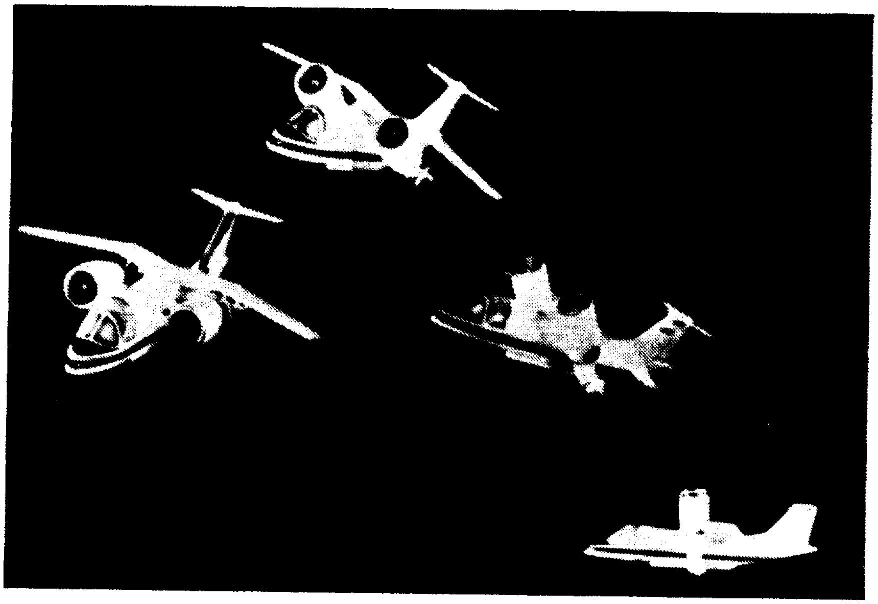


Figure 25.– Tilt nacelle wind tunnel model

Figure 26.– Tilt-nacelle aircraft concept



- HOT GAS RECIRCULATION
- GROUND EFFECT
- ACOUSTICS
- ECONOMICS
- CERTIFICATION

Figure 27.– V/STOL challenges

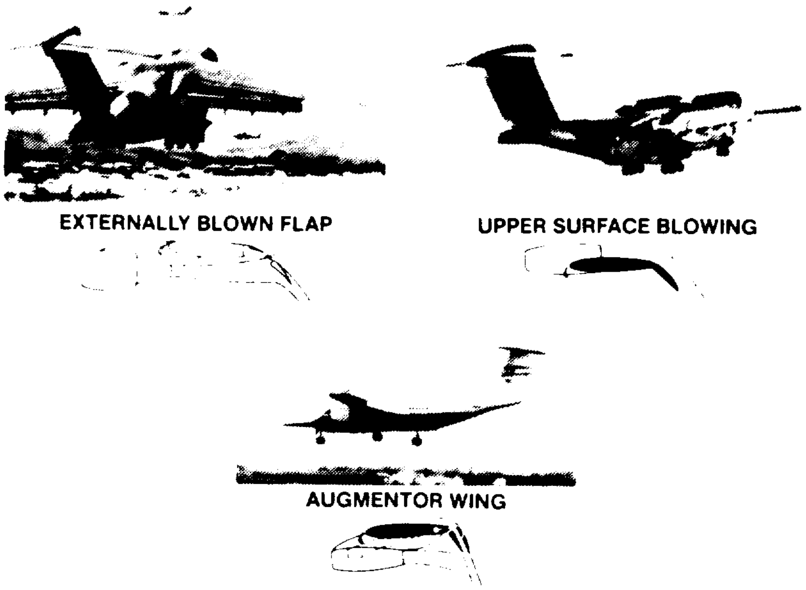


Figure 28.– STOL aircraft configurations

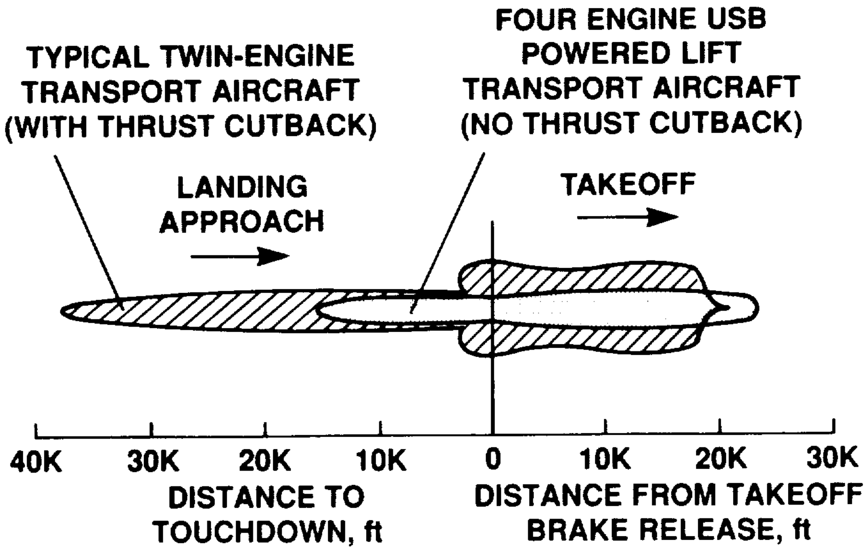
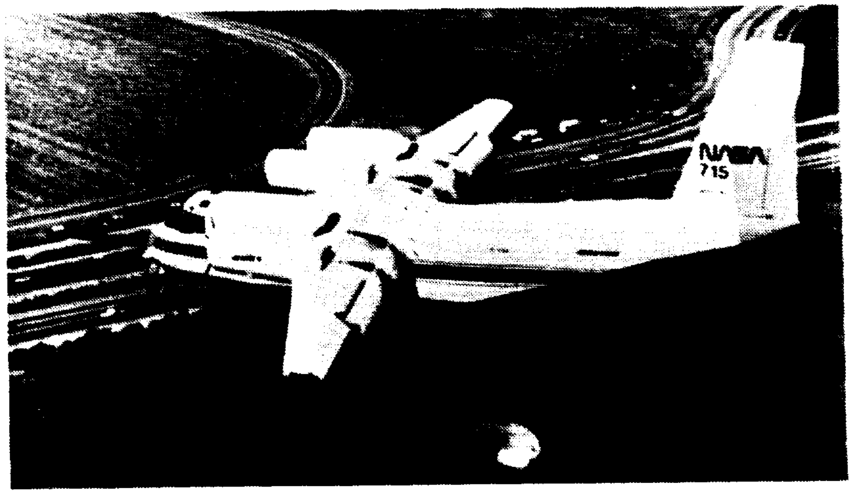
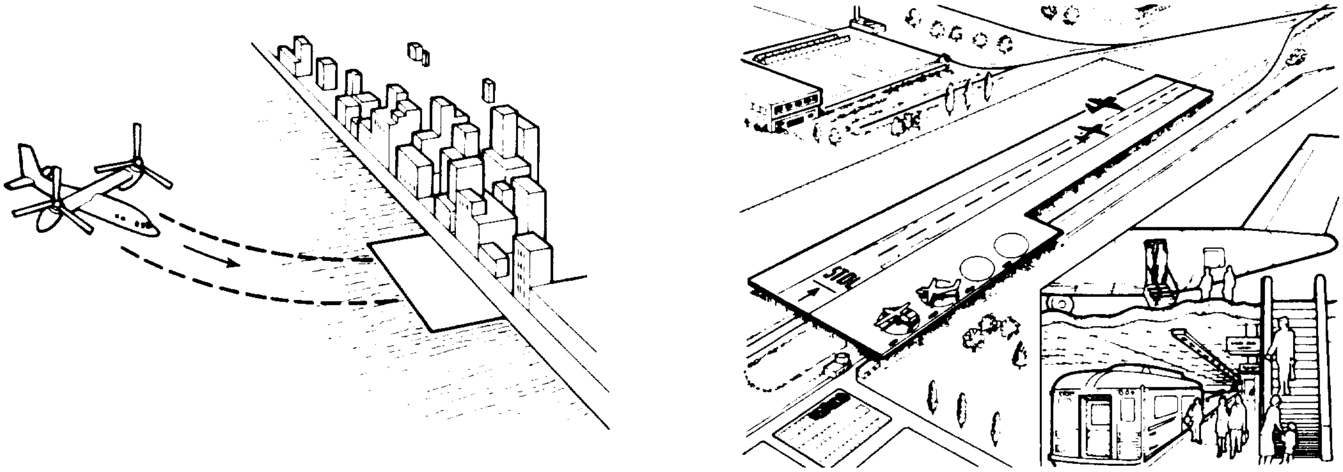


Figure 29.– Comparison of noise footprints



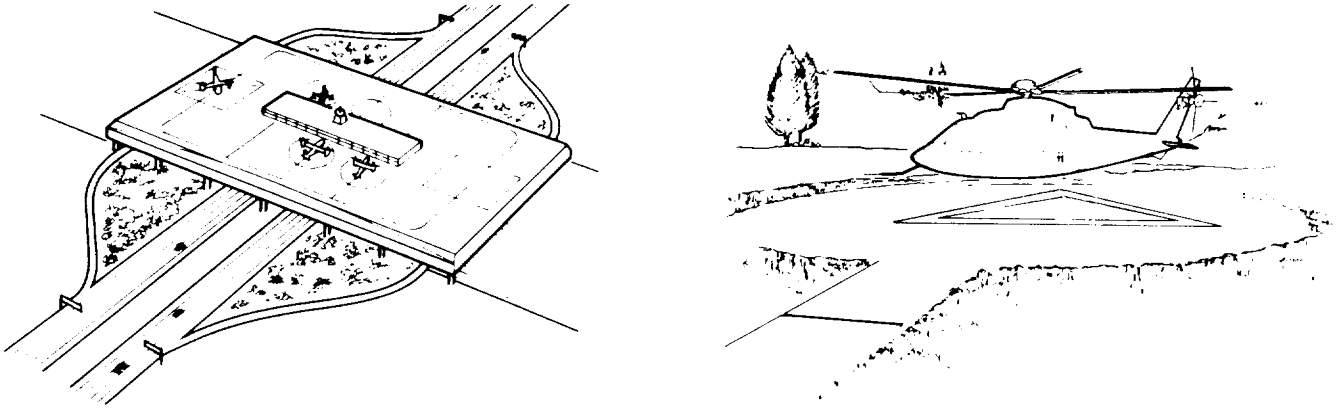
- HIGH SPEED EFFICIENT CRUISE
- CERTIFICATION

Figure 30.– STOL challenges



(a) SEAPORT

(b) RAILWAY PORT



(c) FREEWAY PORT

(d) HELIPORTS

Figure 31.– Alternate landing facilities

MODELS OF PILOTS' VEHICLE CONTROL STRATEGIES AND VISUAL PERCEPTION WILL BE USED TO:

- **SPECIFY RANGE OF ACCEPTABLE APPROACH ANGLES**
- **DEVELOP CONCEPTUAL DESIGNS FOR VERTIPORT SURFACE MARKINGS**

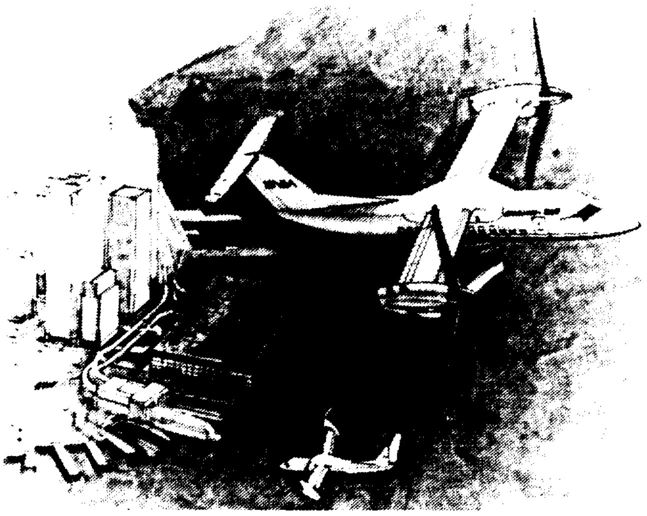


Figure 32.– Vertiport operations—human factors research

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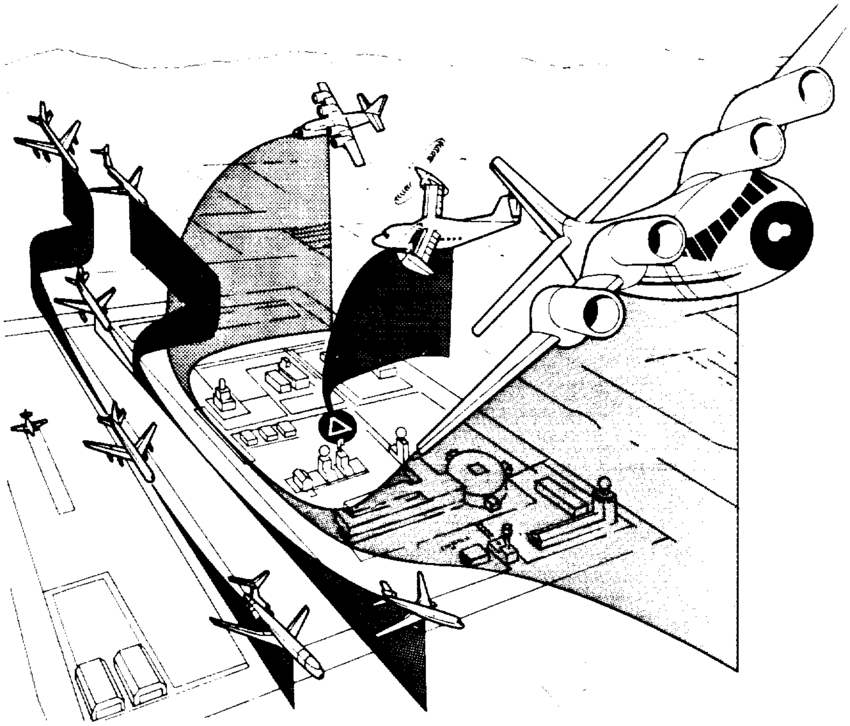


Figure 33.– Expanded airport operations

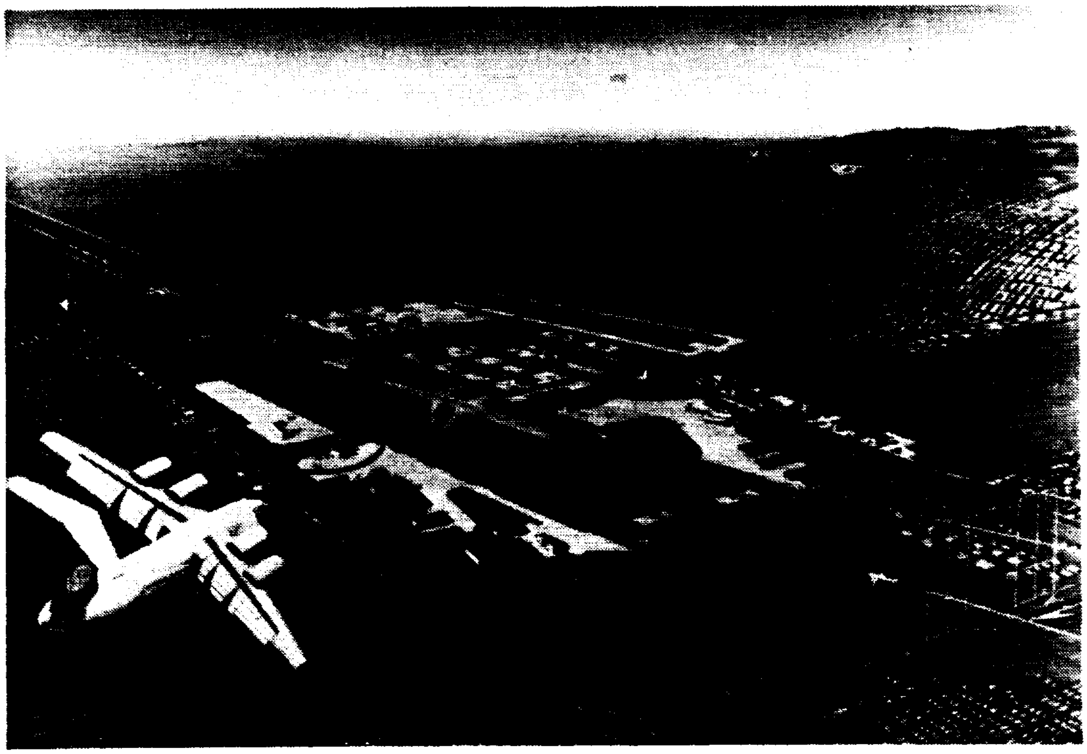


Figure 34.– STOL aircraft approach to airport

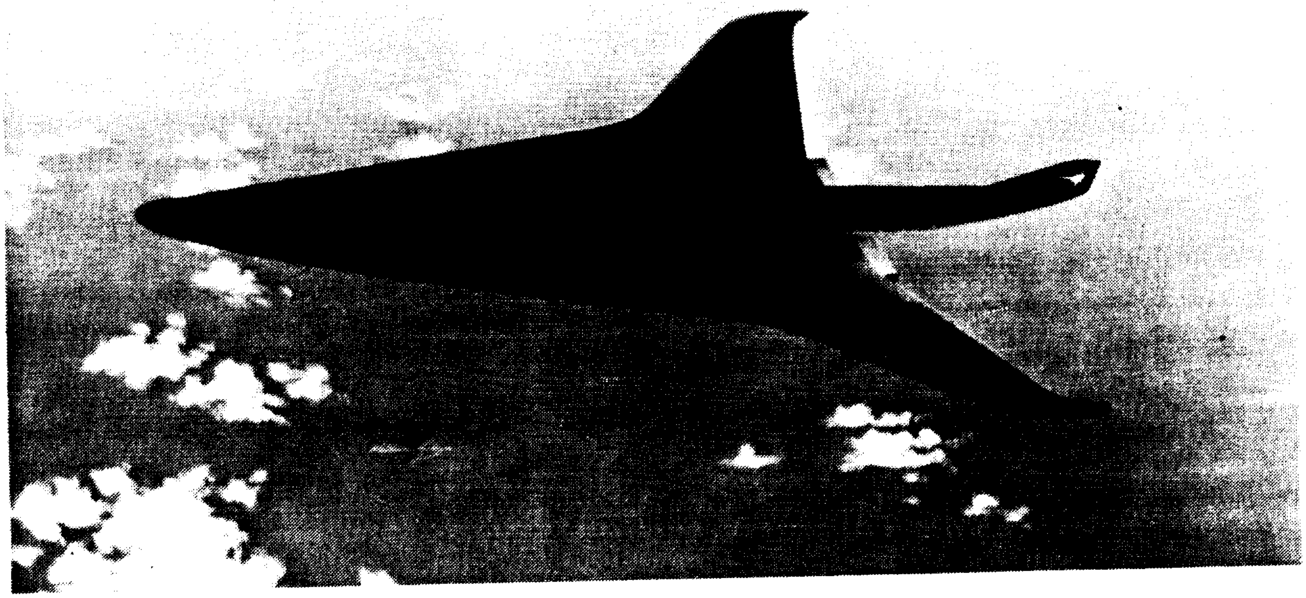


Figure 35.– NASA high speed transport concept

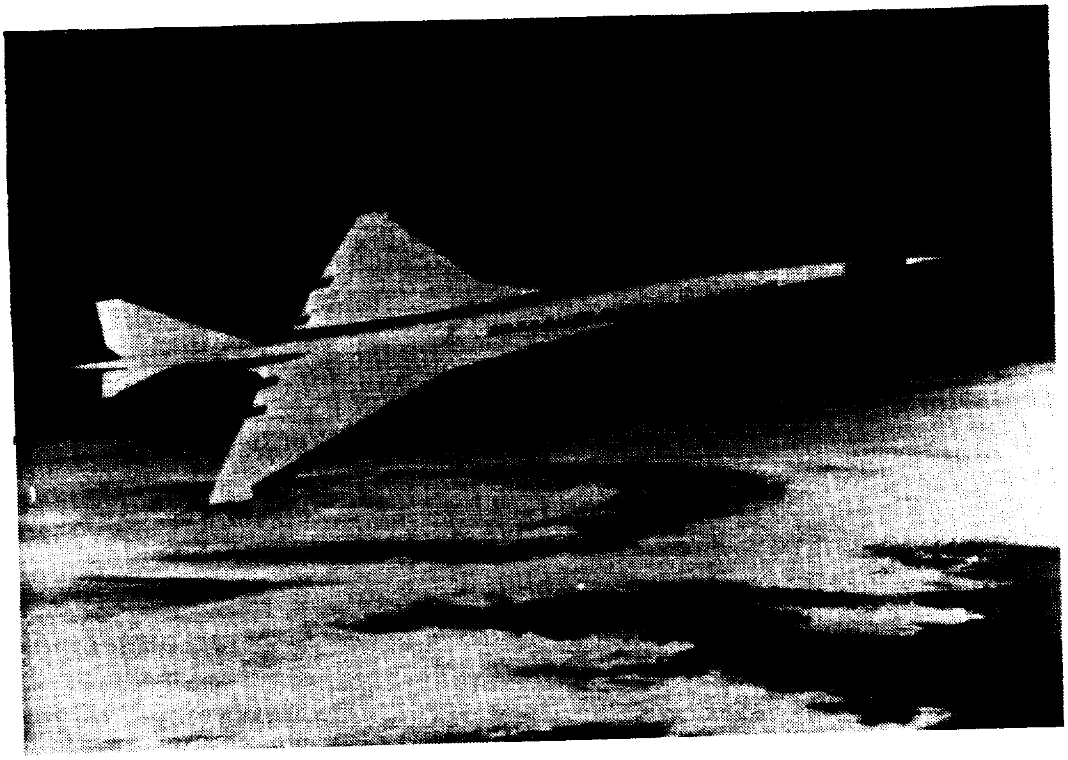
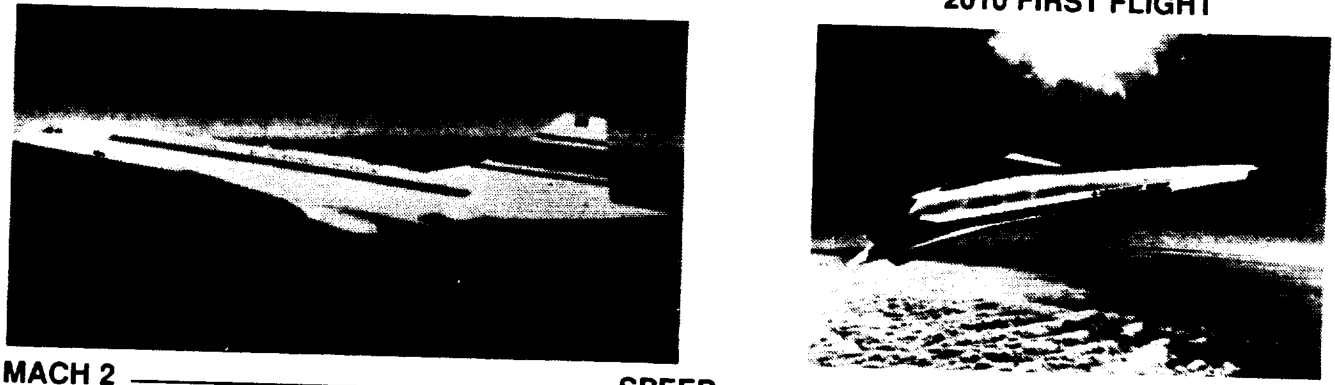


Figure 36.– Contractor high speed transport concept



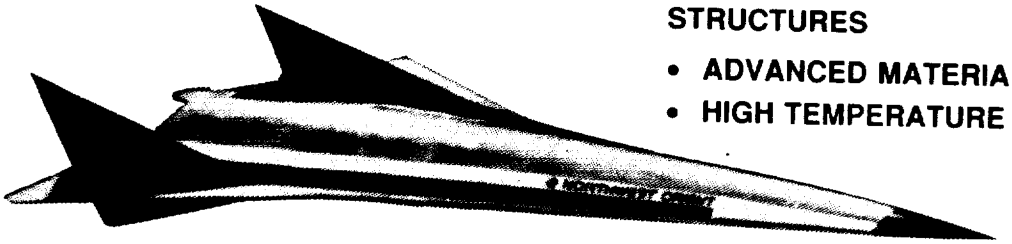
BRITISH CONCORDE
1969 FIRST FLIGHT

U.S. MACH 3-5 TRANSPORT
2010 FIRST FLIGHT

MACH 2	SPEED	MACH 3-5
3200 n. mi.	RANGE	6500 n. mi.
108 PASSENGERS	SIZE	300+ PASSENGERS
2-1/2 psf	SONIC BOOM	<1 psf (OVERLAND CRUISE)
10 dB OVER FAR 36	AIRPORT NOISE	COMPLIANT WITH FAR 36
4x SUBSONIC	TICKET COST @ $1.00/gal	NO SURCHARGE

Figure 37.– High speed transport challenges

AERODYNAMICS
- SUPERSONIC LAMINAR FLOW
- TURBULENT DRAG REDUCTION



STRUCTURES
- ADVANCED MATERIALS
- HIGH TEMPERATURE STRUCTURES

PROPULSION
- SUPERSONIC THROUGH FLOW FAN
- VARIABLE CYCLE ENGINE
- ADVANCED CORE

SYSTEMS
- INTEGRATED CONTROLS
- ADVANCED COCKPIT

Figure 38.– High speed transport technology

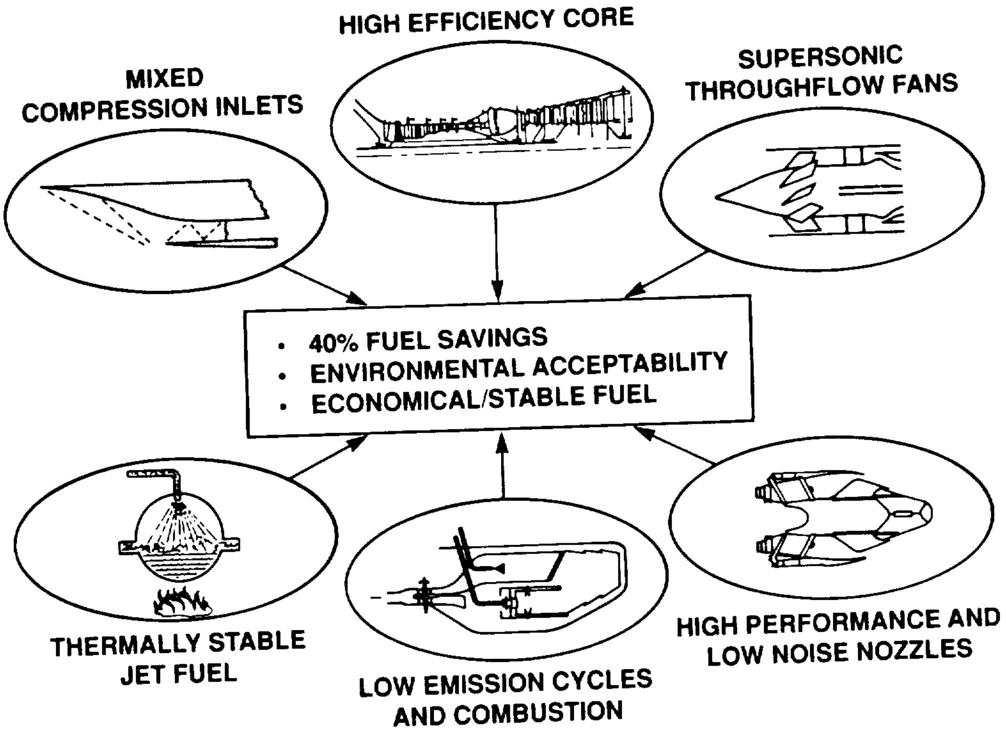


Figure 39.– High speed transport propulsion technologies

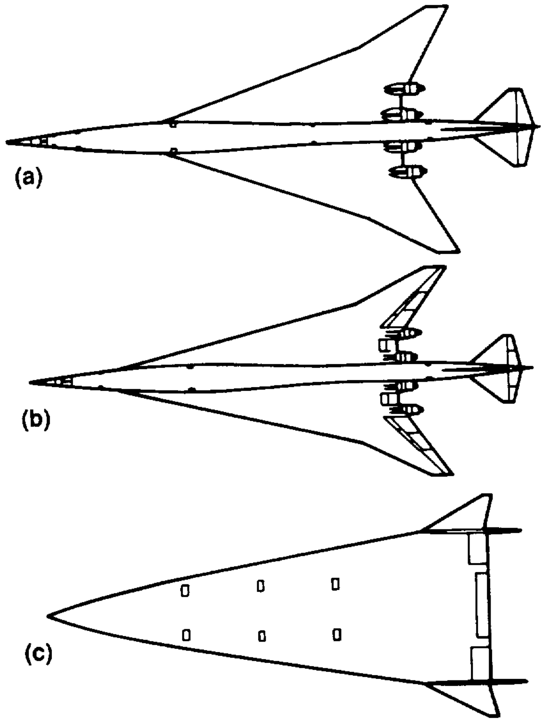


Figure 40.– High speed transport configurations. a) Mach 2.2—Jet A, b) Mach 3.2—Thermally stable jet fuel, c) Mach 5—Liquid methane gas

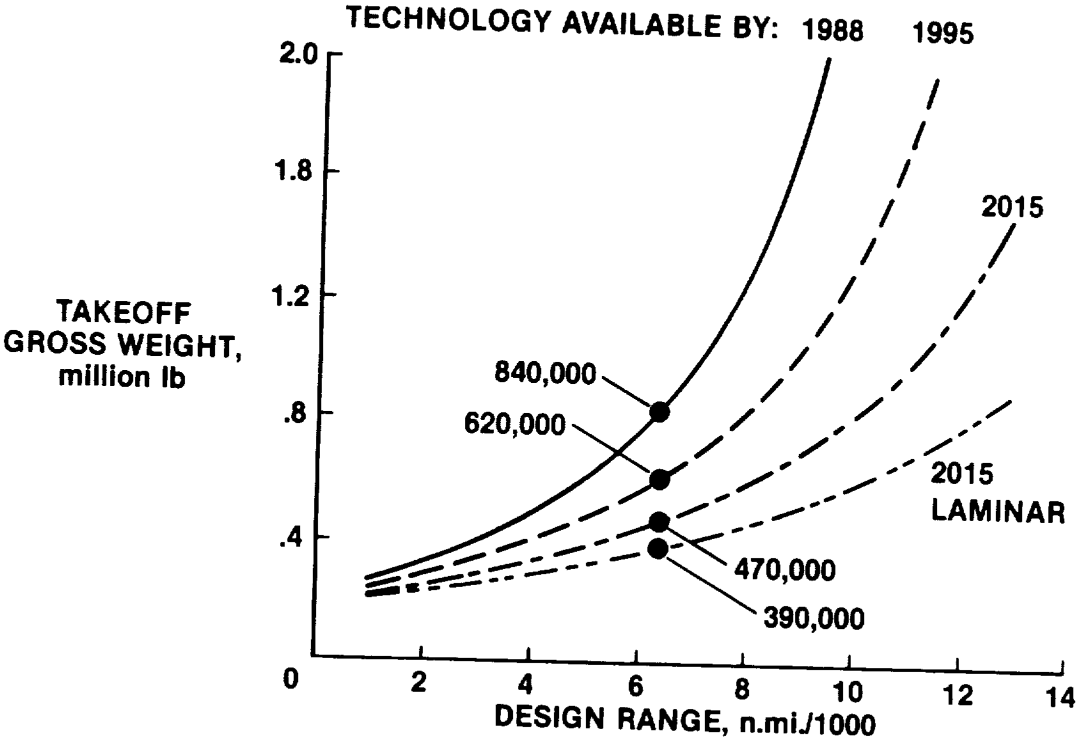


Figure 41.– Combined impact of technologies

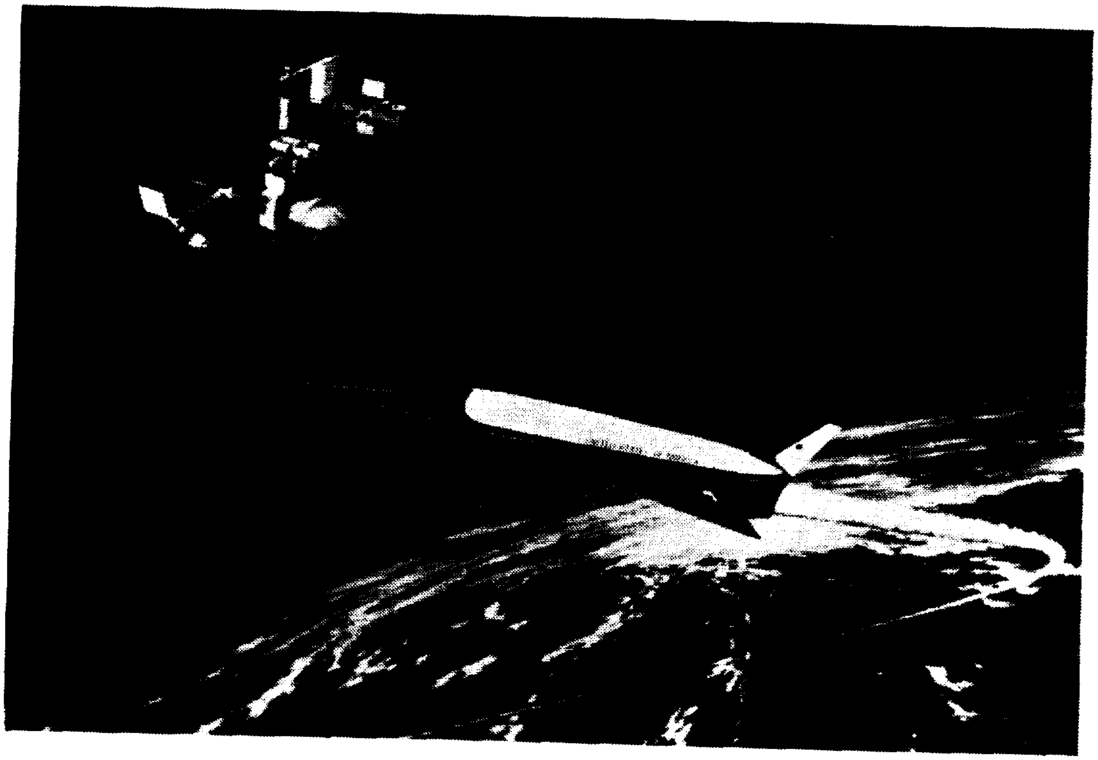


Figure 42.– Hypersonic and transatmospheric vehicle

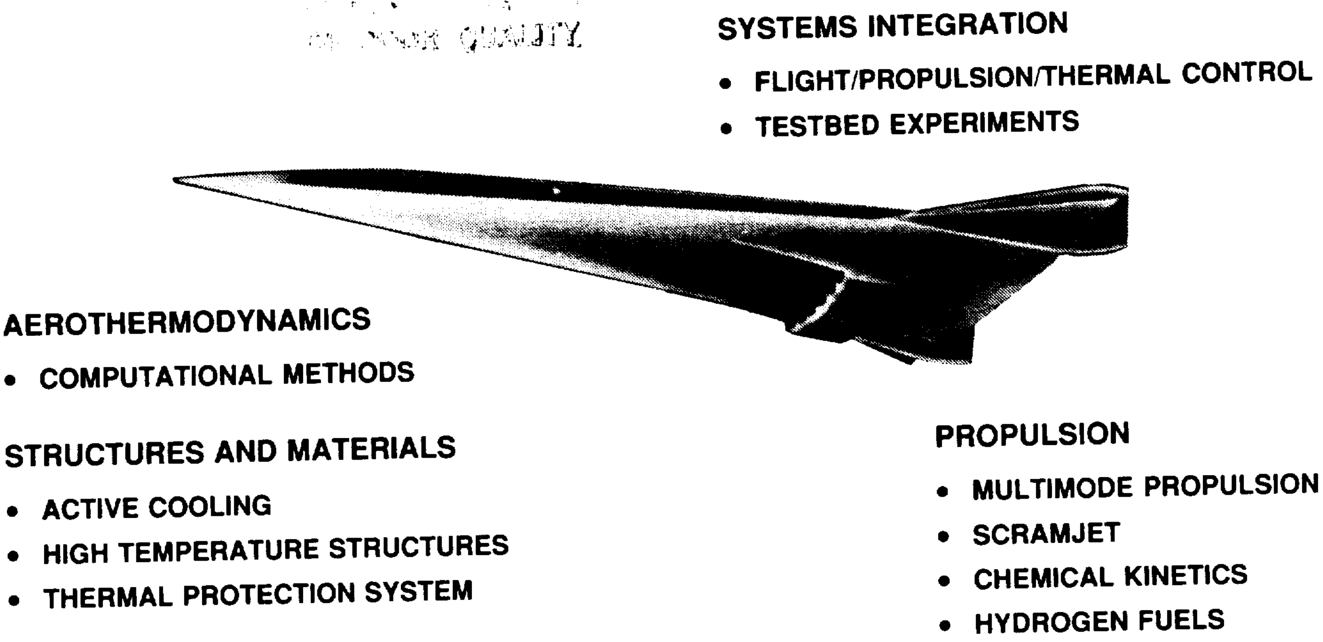


Figure 43.– Hypersonic and transatmospheric vehicle technologies

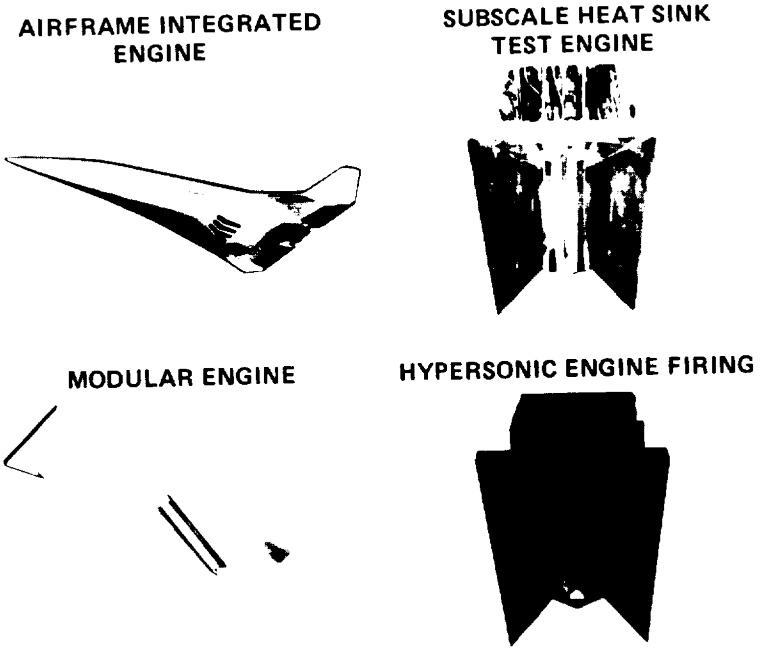


Figure 44.– Airframe integrated dual mode modular scramjet concept

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Figure 45.– CFD streamlines at Mach 25

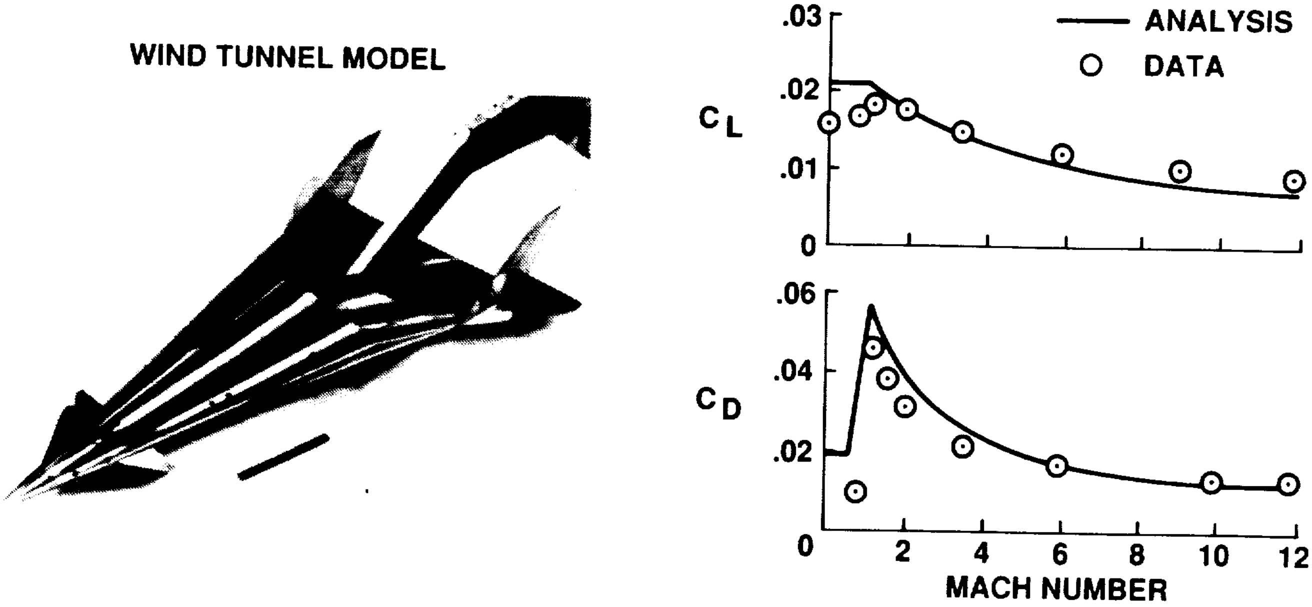

Figure 46.– Wind tunnel model correlations

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16. Abstract

New aircraft technologies are presented that have the potential to expand the air transportation system and reduce congestion through new operating capabilities, and at the same time provide greater levels of safety and environmental compatibility. Both current and planned civil aeronautics technology at the NASA Ames, Lewis, and Langley Research Centers are addressed. The complete spectrum of current aircraft and new vehicle concepts is considered including rotorcraft (helicopters and tiltrotors), vertical and short takeoff and landing (V/STOL) and short takeoff and landing (STOL) aircraft, subsonic transports, high speed transports, and hypersonic/transatmospheric vehicles. New technologies for current aircraft will improve efficiency, affordability, safety, and environmental compatibility. Research and technology promises to enable development of new vehicles that will revolutionize or greatly change the transportation system. These vehicles will provide new capabilities which will lead to enormous market opportunities and economic growth, as well as improve the competitive position of the United States aerospace industry.

17. Key Words (Suggested by Author(s))
Aircraft technology, Subsonic transport, Rotorcraft, V/STOL and STOL aircraft, High-speed transport, Hypersonic vehicles, Safety and automation technology

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