DEPARTMENT OF DEFENSE

DEVELOPING SCIENCE AND TECHNOLOGIES LIST

SECTION 1: AERONAUTICS TECHNOLOGY

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PREFACE

The Developing Science and Technologies List (DSTL) is a product of the Militarily Critical Technologies Program (MCTP) process. This process provides a systematic, ongoing assessment and analysis of a wide spectrum of technologies of potential interest to the Department of Defense. The DSTL focuses on worldwide government and commercial scientific and technological capabilities that have the potential to significantly enhance or degrade US military capabilities in the future. It includes new and enabling technologies as well as those that can be retrofitted and integrated because of technological advances. It assigns values and parameters to the technologies and covers the worldwide technology spectrum.

The DSTL is oriented towards advanced research and development including science and technology. It is developed to be a reference for international cooperative technology programs. S&T includes basic research, applied research and advanced technology development.

SECTION 1—AERONAUTICS TECHNOLOGY

Scope

1.1 Aerodynamics 1-3

1.2 Aeronautical Propulsion 1-11

1.3 Aeronautical Structures 1-21

1.4 Aeronautical Vehicle Control 1-25

1.5 Aeronautical Subsystems and Components 1-29

1.6 Aeronautical Design and Systems Integration 1-31

Highlights

- The advanced technologies listed have been chosen because they will reduce weight, vulnerability, accident rates, and operating and support (O&S) costs while providing increased reliability, maneuverability, and overall performance.
- Emphasis on uninhabited systems is increasing.

OVERVIEW

This section covers technologies associated with aerodynamics, propulsion, structures, vehicle control, subsystems and components, and design and integration that might be used in various aeronautics systems. Future aeronautics systems include fixed-wing aircraft, rotary-wing aircraft, hybrid vehicles, uninhabited air vehicles, and any other airborne vehicle that could be used for a military mission.

This section does not address specific vehicles; rather it addresses the technologies used in multiple vehicles or revolutionary new concepts, such as blended wing/body (BWB) and micro air vehicle (MAV). It also does not address space vehicles (see Section 19), but it does cover vehicles that would operate with aircraft-like efficiency, put payloads into orbit, return to earth, and launch again with minimal support.

Several current air-vehicle missions—strategic bombing, air mobility, attack, air superiority, reconnaissance (intelligence gathering), and special operations—will endure for the foreseeable future. In addition, air vehicles may be required to access space on-demand in support of space operations. Air vehicles will need speed, range, lethality, flexibility, and survivability to accomplish these missions.

Advanced aeronautics technologies are expected to provide a decrease in vehicle weight, with an attendant increase in range or payload; an increase in reliability; an increase in maneuverability; a decrease in vulnerability; a decrease in accident rates; a decrease in O&S costs; and a decrease in acquisition costs. In the future, the military will place more emphasis on using unmanned military systems to augment manned military systems. This will include unmanned combat aerial vehicles (UCAVs) for the suppression of enemy air defense and strike missions and MAVs for reconnaissance.

Affordability is a key issue for future aeronautics technologies. On the commercial side, few customers are willing to pay the price for new technology unless it provides a dramatic improvement in the cost of operations. Most developmental work is limited to incremental improvements—much of it focused on reliability, maintainability, and operability. Much work is being done to package existing technologies in new ways and increase capabilities with advances in computational capability. Military systems are increasingly relying on adapting commercial-off-the-shelf (COTS) technologies for mission uses. This is a trend that has occurred recently and is expected to continue in the future as military budgets are pressured.

Unmanned aerial vehicles (UAVs) offer the potential of unique capabilities (size, maneuverability, and agility not constrained by human performance and life-support needs) while also providing cost savings. For the most part, technologies are the same except when they fly beyond manned vehicle operational envelopes. MAVs present technological challenges in miniaturizing components (e.g., actuators, motors, and sensors).

Modularity in vehicle design could be used to provide mission flexibility and extend vehicle life via upgrades and modifications. The benefits would be found at several levels of the production and operational areas. These could include design, manufacturing, flight line, intermediate, and depot maintenance.

Improvements in vehicle and manufacturing process design methods offer the potential for decreased manufacturing cost and design optimization. Advanced composite materials could contribute to a decrease in weight while still providing adequate structural integrity and performance. Reliability can be enhanced with an increased application of electric power while decreasing the use of hydraulics.

Speed of military response can be realized by extending the range and payload of large aircraft. Large (million pound) transonic aircraft with an unrefueled range of 12,000 miles will be possible in the next quarter century. The military might leverage the commercial transport market for its airlift needs. A hybrid airship is being developed to carry extremely large payloads. The half-blimp, half-airplane could fit the lift niche between large transports (Boeing 747 and Lockheed C-5) and ships. Dubbed “Aerocraft,” it is expected to get from the United States to Europe in less than a day. It would haul 1 to 1.5 million lbs at 125 knots and be about 780 ft long.

SECTION 1.1—AERODYNAMICS

Highlights

- Tailless fighters can reduce weight, drag, and radar signature and increase range, maneuverability, and survivability.
- The Canard Rotor Wing (CRW) concept combines the low-speed flight characteristics of a helicopter with high-speed, fixed-wing capabilities.
- Concepts being evaluated for mid-size jet transport aircraft include conventional, high-wing aircraft, BWB aircraft, and box-wing aircraft with multiple refueling booms.
- Improved design methodologies and analysis tools are essential in reducing costs and enhancing vehicle capability in the future.

OVERVIEW

This subsection includes those technologies that relate to designs or innovations that improve the aerodynamic characteristics of surfaces or bodies, with the goal of obtaining better flow patterns (subsonic and supersonic) and achieving improved lift and drag parameters. The technologies may apply to air vehicle external surfaces and to internal flow streams, such as those contained within propulsion units or other devices. The technologies also include flow control and the application of computational fluid dynamics (CFD) to achieve accurate flow prediction for design optimization **.**

Tailless fighters are being pursued as a means to improve agility and stealth characteristics. The design promises a decrease in weight, drag, and radar signature and an increase in range, maneuverability, and survivability for future fighter aircraft.

A concept called CRW would spin a center wing to take off like a helicopter. The vehicle would accelerate to about 120 kn, when flaps would deploy from the front and rear wings. Flap deployment would offload the spinning center wing, which would stop rotation and be locked into a position across the fuselage to perform as a third wing. The flaps on the other two wings would then be retracted, and all three wings would provide the lift loads for fixed-wing flight. A reverse of these events would transition the CRW back to its rotary wing/VTOL mode for landing on small landing areas.

Figure 1.1-1. BWB Aircraft

A configuration where the wing and fuselage are blended together (see Fig. 1.1-1) into one structural component is attractive for future tanker/transport aircraft. The BWB configuration provides generous internal volume for fuel and cargo and reduced structural weight. The concept can employ multipoint refueling and, by the nature of its basic shape, has low observable (LO) characteristics.

Joined wing (or box wing) aircraft (see Fig. 1.1-2) are being considered for several types of aircraft. A joined-wing aircraft has been studied as a tanker with two refueling booms to increase the number of stations available for refueling aircraft. Smaller joined-wing aircraft could embed advanced sensors in the wing to support aircraft operation and mission needs.

Figure 1.1-2. Joined-Wing Aircraft

Advanced CFD analysis capabilities are critical to the design of advanced aircraft. For example, improved CFD-based (Navier-Stokes) design methodologies and analysis tools enable cost reduction and operational enhancements.

LIST OF TECHNOLOGY DATA SHEETS
1.1. AERODYNAMICS

Advanced Wing Planforms

Blended Wing/Body (BWB) 1-5

Box Wing 1-6

High Aspect Ratio, Strut-Braced Wing 1-6

Tailless 1-7

Airflow Control

Flow Control Employing Microelectromechanical Systems (MEMS) 1-8

Forebody Vortex Flow Control 1-8

Laminar Flow Control (LFC) 1-9

Viscous Drag Reduction 1-9

Viscous Flow Control 1-10

DATA SHEET 1.1. BLENDED WING/BODY (BWB)

Developing Critical Technology Parameter	Compared with current aircraft of similar size: • Greater than 50-percent increase in L/D ratio • 25-percent decrease in fuel consumption • 10-percent decrease in operating weight • 15-percent decrease in direct operating costs
Critical Materials	Low-cost composites.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Advanced control algorithms, such as neural nets, to support flight controls.
Major Commercial Applications	BWB is being developed for commercial use.
Affordability	Would reduce direct operating costs compared with conventional wide-body aircraft using equivalent technology.

BACKGROUND

Efforts are underway to study large BWB aircraft that would carry 800 passengers. The idea behind this design approach is to maximize overall efficiency by integrating the engines, wings, and the body into a single lifting surface. The BWB concept houses a wide double-deck passenger compartment that actually blends into the wing. Adjacent to the passenger section is ample room for baggage and cargo.

Preliminary analyses indicate that the BWB would outperform all conventional large aircraft. It is conceived to carry 800 passengers (almost twice the passenger capacity of the Boeing 747-400) over 7,000 miles at a cruise speed of approximately 560 mph. It would reduce fuel burn and harmful emissions per passenger mile by almost a third in comparison to today's aircraft. Other potential benefits of the BWB include lower operating costs and reduced community noise levels.

DATA SHEET 1.1. BOX WING

Developing Critical Technology Parameter	A 20-percent reduction in ramp space. Acquisition and operating cost improvements exceeding 20 percent over current transport aircraft.
Critical Materials	Low-cost metallic structures.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Equivalent laminated plate solution (ELAPS) (based on Ritz function principle).
Major Commercial Applications	Commercial airliners.
Affordability	Saves on ramp space.

DATA SHEET 1.1. HIGH ASPECT RATIO, STRUT-BRACED WING

Developing Critical Technology Parameter	Structurally sound wings for large aircraft with an aspect ratio greater than 12.
Critical Materials	Low-cost metallic structure; low-cost composite structure; integrally stiffened fuselage panels.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Flight control algorithms.
Major Commercial Applications	Large passenger transports. The high aspect ratio, strut-braced wing configuration is applicable to a wide range of civil aircraft. The increased aerodynamic efficiency will greatly reduce fuel consumption and the aircraft size for a given payload/range requirement.
Affordability	Studies of high aspect ratio, strut-braced wing transport aircraft indicate an acquisition and operating cost improvement of 8–10 percent over current transport aircraft. Other studies showed a 23–26 percent reduction in direct operating costs and 21–23 percent reduction in acquisition costs.

DATA SHEET 1.1. TAILLESS

Developing Critical Technology Parameter	Aircraft overall and side sector radar cross section (RCS) signature reduction of 15 percent. Subsonic and supersonic cruise drag reductions of 15 percent.
Critical Materials	Low-cost, high-temperature materials for vectoring nozzle applications.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Vehicle control algorithm.
Major Commercial Applications	None identified.
Affordability	Tailless aircraft reduce nonrecurring costs in several ways. Eliminating the tail is a direct cost, weight, and drag savings. These savings enable further decreases since the aircraft can be made smaller and less expensive. The drag and weight reductions provide further operational savings in the form of reduced fuel usage.

BACKGROUND

Tailless aircraft are not a new concept. It has been pursued throughout the 1900s by a variety of designers. Flying wings (e.g., the XB-49) have been tailless. Sport planes have been flown tailless. The concept is now being evaluated for future, high-performance aircraft.

The X-36, is a tailless 28-percent scale, experimental aircraft that will dramatically change the design of future stealth fighters. The remotely piloted X-36 has no vertical or horizontal tails, yet it is expected to be more maneuverable and agile than today's fighters. Its revolutionary design was built at a fraction of the cost and schedule typical of other X-aircraft. The tailless design reduces the weight, drag, and RCS typically associated with traditional fighter aircraft. It incorporates new flight control technologies in place of vertical and horizontal tails to improve the maneuverability and survivability of future fighter aircraft. During flight, the X-36 uses new split ailerons and a thrust vectoring nozzle for directional control. The ailerons not only split to provide yaw (left and right) control but also raise and lower asymmetrically to provide roll control. The X-36 vehicle also incorporates an advanced, single-channel digital fly-by-wire control system developed with commercially available components. The X-36 first flew in the summer of 1997 and completed its flight test schedule in November of that same year.

DATA SHEET 1.1. FLOW CONTROL EMPLOYING MICROELECTROMECHANICAL SYSTEMS (MEMS)

Developing Critical Technology Parameter	Reducing drag by up to 50 percent.
Critical Materials	Silicon wafers and other materials used in the micro-electronics fabrication industry.
Unique Test, Production, Inspection Equipment	Particle-Imaging Velocimetry (PIV) flow measurement; MEMS fabrication techniques. Production facilities to fabricate and package large arrays of MEMS devices.
Unique Software	Laminar flow control validation.
Major Commercial Applications	Potential in all commercial aircraft for increasing range, payload, and reducing life-cycle cost; specifically, ice-buildup warning sensors, wing laminar flow control and flow separation control, high lift, inlet flow control.
Affordability	Fabrication and packaging of MEMS arrays could significantly affect affordability.

DATA SHEET 1.1. FOREBODY VORTEX FLOW CONTROL

Developing Critical Technology Parameter	Increase maneuverability by 15 percent and increase nose pointing ability by 25 percent.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Major Commercial Applications	None identified.
Affordability	Cost of air supply and control valves for pneumatic systems may have a negative impact on affordability.

DATA SHEET 1.1. LAMINAR FLOW CONTROL (LFC)

Developing Critical Technology Parameter	Reducing drag by up to 50 percent.
Critical Materials	Smart materials, such as shape memory alloys; flexible materials technologies.
Unique Test, Production, Inspection Equipment	Unique wind-tunnel test and measurement facilities.
Unique Software	Advanced CFD methodologies; boundary layer stability analysis codes.
Major Commercial Applications	Can be used for both military and commercial applications. Military application is more difficult because of observables requirements. Minimize flow separation to maximize lift and L/D ratio.
Affordability	Cost of air supply and control valves for pneumatic systems may have a negative impact on affordability.

DATA SHEET 1.1. VISCOUS DRAG REDUCTION

Developing Critical Technology Parameter	Reduce turbulent skin friction drag by 12 percent using passive means; by 20 percent using active means. Passive approaches include riblets, films, and other surface features. Active approaches include MEMS-based actuators and sensors with distributed processing for control.
Critical Materials	Smart materials, such as shape memory alloys; flexible materials; adhesive films.
Unique Test, Production, Inspection Equipment	High resolution, rapid frame optical diagnostic techniques, such as PIV; unique wind tunnel test and measurement facilities.
Unique Software	Advanced CFD; control software for active approaches.
Major Commercial Applications	All large aircraft; ground transportation (e.g., buses, trains).
Affordability	Passive coatings cost must be compared with the cost of painting and periodic paint removal. Increased range and reduced fuel consumption could justify the expense of manufacturing riblets.

BACKGROUND

Viscous drag can amount to 40–50 percent of the total drag, so any decrease can lead to substantially reduced fuel expenditures. This fuel saving can translate directly into millions of dollars of reduced operating costs for the industry.

DATA SHEET 1.1. VISCOUS FLOW CONTROL

Developing Critical Technology Parameter	A 15-percent improvement of L/D at high angles of attack.
Critical Materials	Smart materials, such as shape memory alloys; flexible materials.
Unique Test, Production, Inspection Equipment	Wind tunnel test and measurement facilities, high resolution, rapid-frame, optical diagnostic techniques, such as PIV.
Unique Software	Boundary layer stability codes and active flow control models embedded in advanced CFD analysis and design codes.
Major Commercial Applications	Improvement of landing margins for commercial aircraft. Improvement in the efficiency of control surfaces would allow reduction in control surface size.
Affordability	Cost could be lower because it would be less complex than bleed systems. Cost benefit could be achieved by reducing aircraft weight and eliminating or reducing control surface size.

SECTION 1.2—AERONAUTICAL PROPULSION

Highlights

- Enhanced technologies in turbine engines will result in increased range and payload at lower cost.
- Low cost will be realized by having common core (engine) architecture, ease-of-assembly design, and health monitoring systems.
- Thrust vectoring nozzles will reduce the weight, maintenance, and cost of aircraft and will improve maneuverability.
- Developments in ramjet/scramjet technology may enable hypersonic aircraft to be realized in an economical manner.

OVERVIEW

This subsection covers the propulsion systems and fuels that power all types of air vehicles. Air vehicles include, but are not limited to, fixed-wing aircraft, rotary-wing aircraft, hybrids such as tilt-wing aircraft, and UAVs. The category of UAVs also includes missiles that have their operational envelope within that portion of the atmosphere that can support air-breathing propulsion systems.

The type of propulsion system most prevalent in military air vehicles today is the gas turbine. This subsection covers gas turbines, along with other engines such as the ramjet, scramjet, and pulse-detonation engine (PDE). The engines may be at any scale—from that of the large transport aircraft down to the MAV. Also included, where appropriate, are components of power trains associated with the transmission of power from the power plant to the point of application to the air. This includes power conversion devices, such as gearboxes and transmissions.

The United States has a national program to double the U.S. military's 1988 propulsion capacity: the Integrated High Performance Turbine Engine Technology (IHPTET) program. IHPTET set very aggressive goals for the year 2003: to provide durable performance with low production and maintenance costs for new fighters and upgrade potential for currently fielded systems. Specific performance and cost goals are being considered to the year 2015 and beyond. Development of advanced materials is a critical part of this effort. Increased temperature and strength organic matrix composites, ceramic matrix composites, super alloys, and intermetallic composites are key to increasing engine thrust-to-weight ratio. Reducing fuel consumption through higher component efficiencies and compression system pressure ratios is an important aspect of future turbine engines. Future turbine engines will have very low fuel consumption, high thrust-to-weight ratio, and low cost in all phases of their life cycles. Compared with 1988 technologies, turbine engines in the period 2009–2015 will have 2.5–3.0 better thrust-to-weight ratio, 20- to 30-percent better specific fuel consumption, and 50-percent reduction in total development, production, and maintenance costs.

Other forms of propulsion are also being investigated. The scramjet engine is the key enabling technology for hypersonic flight research program, which seeks to overcome one of the greatest aeronautical research challenges: sustained air-breathing hypersonic flight.

Ramjets operate by subsonic combustion of fuel in a stream of air compressed by the forward speed of the aircraft inlet as opposed to conventional turbojet engines, in which the compressor section (the fan blades) compresses the air. In comparison to turbojets, ramjets have no moving parts exposed to the engine airflow.

Scramjets (supersonic-combustion ramjets) are ramjet engines in which the airflow through the whole engine remains supersonic. Testing scramjet engine technology is challenging because only limited duration (i.e., 1–3 min) testing can be performed in ground facilities because of the extremely high-energy requirements. Long duration, full-scale testing requires flight tests above Mach 5. Hyper-X (X-43) will build knowledge, confidence, and a technology bridge to Mach 10. The fuel for the X-43 will be gaseous hydrogen.

Rockets carry their own oxygen (liquid) for combustion. An air-breathing scramjet engine burns oxygen scooped from the atmosphere in the same manner as normal jet engines. Using conventional turbojet technology, air-breathing hypersonic vehicles should carry more cargo/payload than equivalent rocket-powered systems since they have more weight and payload space available because of not having to carry oxidizer onboard.

One of the propulsion advances that will be put in future aircraft are thrust vectoring engines. These engines have flown in aircraft since the 1970s. They are expected to be used in fighters, UCAVs, BWB aircraft, and commercial aircraft.

LIST OF TECHNOLOGY DATA SHEETS
1.2. AERONAUTICAL PROPULSION

Gas Turbine Engines

Ceramic Matrix Composites (CMCs) 1-13

Cooled Cooling Air 1-13

Fluidic Nozzle 1-14

Higher Blade-Cooling Effectiveness 1-14

Intermetallic Turbine Blade 1-15

Magnetic Bearings 1-15

Other Aeronautical Power Sources

Pulse-Detonation Engines (PDEs) 1-16

Ramjets/Scramjets 1-17

Fuels Technology

Cryogenic Fuels 1-19

New-Capability Fuels 1-19

Endothermic Fuel-Cooled Technology 1-20

DATA SHEET 1.2. CERAMIC MATRIX COMPOSITES (CMCs)

Developing Critical Technology Parameter	Develop CMCs to withstand increases in combustor temperatures and turbine blades to 2,500 °F without the requirement for cooling.
Critical Materials	SiC/SiC; Silicon nitride.
Unique Test, Production, Inspection Equipment	Non-Destructive Evaluation (NDE) methods for new and fielded CMC components.
Unique Software	None identified.
Major Commercial Applications	Civil aviation and industrial gas turbine engines.
Affordability	Advanced fabrication and joining methods, fiber costs. Performance/cost trade will become favorable with further development.

DATA SHEET 1.2. COOLED COOLING AIR

Developing Critical Technology Parameter	Lightweight, low-volume heat exchangers with a temperature differential between inlet and outlet of approximately 400 °F. Heat exchanger compactness: 0.5 W/cm^3-K.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Diffusion bonding technology.
Unique Software	None identified.
Major Commercial Applications	Next generation turbofans (high operating ratio); nuclear reactors; environmental control systems.
Affordability	Extends capability of current materials used in compressor disks, turbine blades, and vanes if heat exchanger technology does not impose weight and volume penalty.

DATA SHEET 1.2. FLUIDIC NOZZLE

Developing Critical Technology Parameter	Thrust vector angle and rate changes to provide maneuvering with minimum airfoil control effectors. Nozzle weight reduced 50 percent; a 70-percent reduction in overall parts count.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Major Commercial Applications	Low potential; possible technology application to civil transport aircraft (lower noise).
Affordability	Lack of moving parts and the simplified structural integration combine to improve nozzle maintainability and reduce life-cycle cost.

DATA SHEET 1.2. HIGHER BLADE-COOLING EFFECTIVENESS

Developing Critical Technology Parameter	Blade-cooling effectiveness (q) greater than 0.75 and cooling parameter less than 2 (ϖ) (see Fig. 1.2-4); turbine inlet temperature greater than 2,500 °F.
Critical Materials	Advanced single-crystal materials.
Unique Test, Production, Inspection Equipment	Core fabrication; casting process; core removal; inspection process.
Unique Software	None identified.
Major Commercial Applications	Next-generation turbofans.
Affordability	Extended hot section life.

DATA SHEET 1.2. INTERMETALLIC TURBINE BLADE

Developing Critical Technology Parameter	Turbine blades that can achieve increased performance through reduced blade weight and material capable of higher temperatures (to 2,500 °F).
Critical Materials	TiAl, NbAl, molybdenum disilicide, and niobium disilicide.
Unique Test, Production, Inspection Equipment	Being developed.
Unique Software	None identified.
Major Commercial Applications	Fixed- and rotary-wing commercial aircraft that use gas turbine engines.
Affordability	Increased turbine life.

DATA SHEET 1.2. MAGNETIC BEARINGS

Developing Critical Technology Parameter	Magnetic (non-lubricated) bearings that can maintain or improve on the loads and environmental conditions (available in current bearing technology).
Critical Materials	Superconducting materials at high temperatures or magnetic materials that maintain high flux density at temperatures up to 1,000 °F. Robust, high-temperature insulation material that can be easily thin-coated onto magnetic coil windings.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	5-axis control feedback.
Major Commercial Applications	First applications for marine and industrial; turbine, generator, and automotive industry.
Affordability	Until this technology is mature and many units are produced, magnetic bearings will be less affordable than conventional bearings. Elimination of lubrication circuits will reduce leaks and servicing requirements.

DATA SHEET 1.2. PULSE-DETONATION ENGINES (PDEs)

Developing Critical Technology Parameter	Air-breathing PDEs: practical design configurations without pre-detonator or required pre-detonator volume less than 2 percent of total detonation tube. Operating frequency above 40 Hz per detonation tube.
Critical Materials	High-temperature materials for uncooled propulsion structures.
Unique Test, Production, Inspection Equipment	Supersonic/hypersonic testing of integrated inlet-combustor-nozzle over a wide range of simulated flight conditions (altitudes and Mach numbers).
Unique Software	CFD; optical diagnostic techniques; ultra high-speed framing Schlieren photography.
Major Commercial Applications	Space-launch vehicles.
Affordability	Air-breathing PDEs have the potential to be much simpler—hence, less expensive—than gas turbine engines for similar performance levels.

DATA SHEET 1.2. RAMJETS/SCRAMJETS

Developing Critical Technology Parameter	Air-breathing engines to operate at speeds in excess of Mach 5.
Critical Materials	High-temperature materials.
Unique Test, Production, Inspection Equipment	Hypersonic wind tunnel engine test capability.
Unique Software	None identified.
Major Commercial Applications	Supersonic transport (SST); high-speed civil transport (HSCT); space-launch vehicles.
Affordability	Ramjet/scramjet engine would be cheaper than gas turbine engines. Vehicle development/integration will dictate cost (expensive).

BACKGROUND

The ramjet engine, which was invented in France in 1913, is the simplest type of the all-jet engines because it has no moving parts. It achieves compression of intake air by the forward speed of the air vehicle. The aerodynamic diffusion created by the inlet and diffuser slows the air entering the intake of a supersonic aircraft to velocities comparable to those in a turbojet augmentor. The expansion of hot gases after fuel injection and combustion accelerates the exhaust air to a velocity higher than that at the inlet and creates positive push. The ramjet has to be traveling through the air at high speed before it can be started; therefore, it has to be boosted to the proper speed by some other type of propulsion. In theory, the ramjet engine has no maximum speed and can accelerate indefinitely as long as it stays within the atmosphere. In reality, ramjets are limited to about Mach 6, above which the combustion chamber becomes so hot that the combustion products (water) decompose. The biggest drawback of the ramjet engine is its high rate of fuel consumption.

Scramjet is an acronym for supersonic combustion ramjet. The scramjet (see Fig. 1.2-1) differs from the ramjet in that combustion takes place at supersonic air velocities through the engine. By not slowing down the engine airflow to subsonic speeds for combustion (as in a ramjet), scramjet engines can operate more efficiently at Mach numbers above 5. It is mechanically simple, but more complex aerodynamically than a jet engine. The biggest structural challenge of a scramjet engine is thermal protection of the internal engine walls and fuel injector components.

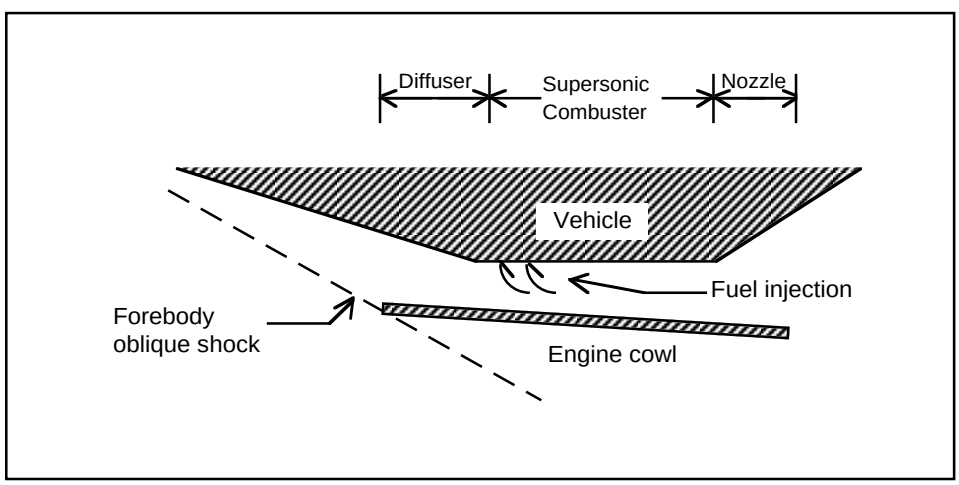

Figure I.2-1. Scramjet Diagram

Scramjets or ramjets can use a variety of cryogenic or storable fuels. Hydrogen fuel offers the highest specific impulse but requires cryogenic tankage and fuel-handling capabilities (see Data Sheet on Cryogenic Fuels). During the 1990s, substantial progress was made on the development of storable hydrocarbon fuels that use chemical bond breaking (endothermic reaction) in the presence of catalysts to double the heat sink capability of the fuel from its physical heat sink alone. This breakthrough allows the scramjet engine thermal balance to be sustained up to Mach 8 flight by using fuel cooling of the combustor components (see Data Sheet on Endothermic Fuel-Cooled Technology, page 1-20).

DATA SHEET 1.2. CRYOGENIC FUELS

Developing Critical Technology Parameter	Achieving hypersonic (above Mach 6) or very long-range capability.
Critical Materials	Graphite epoxy composites.
Unique Test, Production, Inspection Equipment	Cryogenic fuel measurement system.
Unique Software	None identified.
Major Commercial Applications	SST, HSCT, space launch; heavy duty trucks, buses, and automobiles.
Affordability	Large cost for demonstration and development but enables the use of fully reusable space-launch vehicles and long-range strike missiles from tactical aircraft.

BACKGROUND

Cryogenics is the science of very low temperatures. An accepted temperature used to distinguish between refrigeration and cryogenics is –73.3 °C (–100 °F). Low temperatures in the cryogenic range are generally obtained by the liquidification or solidification of gases. The boiling point of liquid hydrogen is –252.7 °C.

DATA SHEET 1.2. NEW-CAPABILITY FUELS

Developing Critical Technology Parameter	Fuels that function at higher temperatures with increased performance and stability for turbine engines.
Critical Materials	Various additives; composition and synthesis techniques of additives, initiators, catalysts, and coagulation and soot suppressants.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Major Commercial Applications	Increased fuel heat sink for aircraft designed to take advantage of higher fuel-tank temperatures and reduced engine coking; all present and evolving military and civilian aircraft.
Affordability	Projected cost is pennies per gallon. Requires but a small amount of additive.

DATA SHEET 1.2. ENDOTHERMIC FUEL-COOLED TECHNOLOGY

Developing Critical Technology Parameter	Heat sink [e.g., British Thermal Units (BTUs/lb)] as a function of fuel conditions—temperature, residence time, pressure, and so forth; increased vehicle thermal management capacity.
Critical Materials	Catalysts, coke-inhibiting structural materials; coatings (initiators and inhibitors); anticoagulant additives.
Unique Test, Production, Inspection Equipment	Production of structures and engines that incorporate fuel passages for cooling.
Unique Software	Flow-control software to ensure proper temperature of flow before it enters combustor.
Major Commercial Applications	Hydrocarbon-fueled hypersonic vehicles (none at present); launch vehicles and HCST.
Affordability	Enables the use of fully reusable space-launch vehicles and long-range strike missiles from tactical aircraft.

BACKGROUND

Endothermic fuel technology using operational jet propulsion (JP) fuels has been under development. Fuels tested for endothermic cooling capabilities and scramjet engine combustion include JP-7, -8, -10, NORPAR-12, and methylcyclohexane (MCH). Various catalysts are used to enhance the endothermic process, and several catalytic heat exchanger/reactor (CHER) designs and material systems have been developed and tested. Recently, low-cost catalytic coating processes have been successfully demonstrated on complex scramjet engine heat-exchanger and fuel-injector components.

SECTION 1.3—AERONAUTICAL STRUCTURES

Highlights

- Smart structures and materials will enable a new generation of vehicles that have highly integrated structures and actuators.
- On-board health monitoring systems will reduce time between removal and replacement of structural components.
- Active load control will result in increased service life and reliability.

OVERVIEW

This subsection covers production techniques and methodology, maintenance technologies, and in-flight technologies associated with the air-vehicle structures. It does not include the development and production of materials used in the structures but rather the application and the processes necessary to fabricate and assemble the end-use structures. These structures may be applicable to any and all parts of an air vehicle, including lifting surfaces and bodies and other subsystems and components.

LIST OF TECHNOLOGY DATA SHEETS
1.3. AERONAUTICAL STRUCTURES

Production Techniques and Methodology

Conformal Load Bearing Antenna Structures 1-22

Smart Structures/Materials 1-22

Smart Composite Rotorcraft Structures 1-23

Maintenance Technologies

Structural Prognostics and Health Management (PHM) 1-23

In-Flight Technologies

Active Aeroelastic Wing 1-24

Active Load/Buffet Alleviation for Flight Surfaces 1-24

DATA SHEET 1.3. CONFORMAL LOAD BEARING ANTENNA STRUCTURES

Developing Critical Technology Parameter	Elimination of 100 percent of the drag associated with externally mounted antennas.
Critical Materials	Materials providing structural and dielectric properties; radome materials having strength and stiffness yet providing low dielectric and magnetic loss. Materials exhibiting high dielectric and/or magnetic loss, while matched to free-space impedances, would provide critical antenna-loading capabilities.
Unique Test, Production, Inspection Equipment	**Test:** Equipment that tests the electrical performance of the antennas while subjecting the device to the environment (e.g., heat, stress, reduced air pressure, increased water pressure, vibration, structural loads, and so forth). **Production:** Similar test equipment with increased throughput. **Inspection:** Hand-held, portable, or increased speed test equipment that performs checks on the test functions.
Unique Software	Software linking multiple antennas, or antenna array elements, would aid the development of conformal, load-bearing antennas. Any software that could, in real time or near-real time, provide control, analysis, or synthesis functions to reconstruct direction or identification of type of the energy incident upon the antennas would provide critical developmental technologies.
Major Commercial Applications	Could be applied to commercial vehicles currently constrained in performance by the current sensor's field of view caused by vehicle structures or outer mold line constraints.
Affordability	Affordability can occur by reducing the number of sensors necessary (because of increased efficiencies in field of view) and by reducing life-cycle cost [sensors capable of structural integrity will have increased mean time between failures (MTBFs)].

DATA SHEET 1.3. SMART STRUCTURES/MATERIALS

Developing Critical Technology Parameter	Smart structures will reduce the air vehicle empty weight by 10 to 25 percent.
Critical Materials	SMAs and actuator forms; ferroelectric ceramics, particularly single crystal variants of piezoelectric ceramics.
Unique Test, Production, Inspection Equipment	Test equipment and particularly standardized *test methods* to provide total life/performance data under realistic loading (mechanical, thermal, and electrical) conditions; production equipment for large-scale, low-cost production of high-quality piezoceramics, particularly single crystal and fiber forms.
Unique Software	Modeling piezoceramics, including effects of aging and use at high field levels; three dimensional (3–D) modeling of SMAs, including shear.
Major Commercial Applications	Medical applications of SMAs; piezoceramics for speakers, ultrasonic transducers, and sensors.
Affordability	Active fibers are highly promising but not currently affordable. SMAs are generally affordable unless temperatures above about 90 °C are required. Then, expensive doping materials (Pd, Pt, Hf) are required.

DATA SHEET 1.3. SMART COMPOSITE ROTORCRAFT STRUCTURES

Developing Critical Technology Parameter	Main rotor "smart" actuation of rotor controls yields reduced blade loading, vibration levels, and design complexity. Noise cancellation to reduce acoustic signature by 10 dB.
Critical Materials	Nitinol torsion actuators, active fiber composites (piezoelectric), piezoelectric stacks; high fatigue-strength embeddable electrical wire buses.
Unique Test, Production, Inspection Equipment	Production of piezoceramic actuator forms, including stacks, fiber composites, and single-crystal stacks and fibers.
Unique Software	Advanced rotor analysis software.
Major Commercial Applications	Variety of helicopters.
Affordability	Reduced maintenance costs.

DATA SHEET 1.3. STRUCTURAL PROGNOSTICS AND HEALTH MANAGEMENT (PHM)

Developing Critical Technology Parameter	A 20- to 40-percent reduction in maintenance manpower; 50-percent reduction in logistics footprint; 25-percent increase in sortie generation rate (compared with current aircraft).
Critical Materials	No materials issues, except those relating to high reliability sensors.
Unique Test, Production, Inspection Equipment	MEMS for integrated sensor and data processing.
Unique Software	PHM is a software-intensive system. Information processing methods including failure models that enable prognostics.
Major Commercial Applications	Civil Infrastructure (bridges, dams, buildings, offshore oil rigs); helicopters; large, high-value equipment (e.g., large earth-moving equipment). Commercial aircraft can benefit by increased safety and reduced operating cost but will require major change in approach to structural integrity assurance.
Affordability	Affordable PHM system recurring costs will vary greatly with application. In all cases, cost savings will involve reduction of structural inspections. If PHM systems are not near 100-percent reliable, they will be unused in favor of the current manual inspection methods of ensuring structural integrity.

DATA SHEET 1.3. ACTIVE AEROELASTIC WING

Developing Critical Technology Parameter	Potential of up to 20-percent weight reduction.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	CFD tools.
Major Commercial Applications	The commercial industry could make use of the technology for future transport development.
Affordability	The reduction of flight control surfaces and actuators produces savings in manufacturing and maintenance costs.

DATA SHEET 1.3. ACTIVE LOAD/BUFFET ALLEVIATION FOR FLIGHT SURFACES

Developing Critical Technology Parameter	Aircraft service life extension of 20 percent.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Software to implement the developed algorithms.
Major Commercial Applications	Commercial and military aircraft could benefit from this technology for the same reasons.
Affordability	Has the potential for life-cycle cost reduction via increased structural life.

SECTION 1.4—AERONAUTICAL VEHICLE CONTROL

Highlights

- Optical technologies will become more prevalent for flight control system actuation and sensing.
- Multivariate, reconfigurable control systems will enhance survivability.

OVERVIEW

This subsection covers technologies associated with the control of air vehicles. Vehicle control systems are composed of sensors, computers, actuators, and other system components dictated by the architecture, methodologies, and algorithms required by an air vehicle in performing its intended mission.

Technologies critical to the development of future air vehicles include automated closed loop coupling; fly-by-light/power-by-wire (FBL/PBW), helicopter active control, multivariable reconfigurable control, and performance-seeking aircraft control. The requirement for control systems varies between manned air vehicles and UAVs. Some UAVs are meant to fly beyond current vehicle operational envelopes. MAVs introduce regimes that are not paralleled in full-sized vehicles.

In the future, the pilot will control an aircraft's situation via many real or virtual controls in a cockpit. In addition to the standard hand and foot controls, controls will be activated by head movement, eye movement, voice sensing, and brain activity (fly-by-thought).

Aeroelastic wings (see subsection 1.3) are being investigated for the future. In this concept, the entire wing is a control surface. The former high alpha research vehicle (HARV) will be modified to research wing-twisting techniques for flight controls vs. traditional ailerons and flaps. Researchers want to determine if the twisting motion can make future wings lighter and aircraft more fuel efficient.

Flight-control technology defines the aircraft's flying qualities and the pilot interface. Helicopters are inherently unstable, nonlinear, and highly cross coupled. Advances in smaller, more powerful computers hold tremendous promise in this field to allow realization of the full potential of the rotorcraft's performance envelope and maintenance of performance, even in poor weather and at night. Integrating flight control with weapons control is of great interest to permit improved pointing accuracy and the use of lower-cost unguided rockets as precision munitions. Other goals include improved external load handling at night and increased exploitable agility and maneuverability.

LIST OF TECHNOLOGY DATA SHEETS
1.4. AERONAUTICAL VEHICLE CONTROL

Fly-By-Light/Power-By-Wire (FBL/PBW) 1-26

Helicopter Active Control 1-26

Multivariable Reconfigurable Control 1-27

Performance-Seeking Aircraft Control (PSAC) 1-27

DATA SHEET 1.4. FLY-BY-LIGHT/POWER-BY-WIRE (FBL/PBW)

Developing Critical Technology Parameter	FBL: Reduce the weight of flight control system components by 50 percent by using optical wavelength division multiplexing (WDM) systems and sensors. PBW: A 5- to 25-percent reduction in subsystem weight over FBW aircraft.
Critical Materials	Fiber-optic materials.
Unique Test, Production, Inspection Equipment	Optical time domain reflectometers; optical spectrum analyzers; optical network analyzers; fiber-optic fault locators; splicing equipment.
Unique Software	Power system modeling and analysis to compare and evaluate possible architectures and topologies before hardware is actually built; modeling of converters, motor drives, actuators, starter/generators, batteries, and associated controls, and simulations of small systems and large end-to-end systems; signal conditioning and interpretation routines for fiber-optic sensors.
Major Commercial Applications	Subsonic civil transports; high-speed digital data communications—telecom and datacom.
Affordability	Lower initial acquisition and direct operating costs, reduced weight, and the resulting increased aircraft performance and reliability.

DATA SHEET 1.4. HELICOPTER ACTIVE CONTROL

Developing Critical Technology Parameter	A 60-percent improvement in weapons-pointing accuracy; a 50-percent increase in agility and maneuverability; a 30-percent reduction in flight control system flight test development time.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Integration architecture; validation and verification software.
Major Commercial Applications	Commercial rotorcraft.
Affordability	Reduction in major accident rate.

DATA SHEET 1.4. MULTIVARIABLE RECONFIGURABLE CONTROL

Developing Critical Technology Parameter	Multivariable reconfigurable control is a key element in autonomous vehicle control and is necessary for safe vehicle operation. It will significantly reduce aircraft loss rates.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	COTS model-based development tools for developing and maintaining this technology.
Major Commercial Applications	Commercial aircraft would benefit through the increased safety benefit that the technology offers.
Affordability	Not an issue.

DATA SHEET 1.4. PERFORMANCE-SEEKING AIRCRAFT CONTROL (PSAC)

Developing Critical Technology Parameter	In the maximum thrust mode: improvement in thrust (15-percent subsonic; 10-percent supersonic).
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Performance-seeking algorithms are critical.
Major Commercial Applications	Commercial aircraft can benefit from this technology.
Affordability	No added hardware is required for Adaptive Aircraft Performance Technology (AdAPT), making it very affordable.

SECTION 1.5—AERONAUTICAL SUBSYSTEMS AND COMPONENTS

Highlights

- New subsystems and components technology will provide reduced air vehicle weight fraction, development costs, unit production costs, and O&S costs.
- Subsystem-level technology payoffs include an increase in mission reliability and a decrease in major accident rates.

OVERVIEW

Aircraft subsystems typically amount to about 10 percent of a fighter aircraft's empty weight and acquisition cost but cause more than 40 percent of aircraft equipment failures and downtime for repairs. Improvement in the latter factor will have a positive impact on the logistics requirement for maintenance and repair.

This subsection covers technologies used in air vehicle subsystems and components that include advanced air data, integrated vehicle management systems (VMSs), and MEMS.

LIST OF TECHNOLOGY DATA SHEETS
1.5. AERONAUTICAL SUBSYSTEMS AND COMPONENTS

Advanced Air Data Systems 1-30

Energy-Management Systems (EMSs) 1-30

Microelectromechanical Systems (MEMS) 1-30

DATA SHEET 1.5. ADVANCED AIR DATA SYSTEMS

Developing Critical Technology Parameter	Provide air data at angles of attack > 35 deg.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Software that will implement the algorithms and interface with vehicle control and redundancy management systems.
Major Commercial Applications	While advanced data systems are not currently used in commercial applications. This technology will be explored by using advanced air data estimation techniques to improve aircraft safety.
Affordability	Not an issue.

DATA SHEET 1.5. ENERGY-MANAGEMENT SYSTEMS (EMSs)

Developing Critical Technology Parameter	Fully integrated subsystem integration.
Critical Materials	High-temperature insulation, advanced composites, and lightweight metallic materials; phase change materials; cryogens.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	On-board software for optimized performance; M&S software for validation and verification of multiple subsystems.
Major Commercial Applications	Helicopters; any heat-transfer application requiring either a large quantity of heat dispersion or significant temperature reductions from high-power density applications.
Affordability	Reduced parts count.

DATA SHEET 1.5. MICROELECTROMECHANICAL SYSTEMS (MEMS)

Developing Critical Technology Parameter	No quantitative parameters are available. The concept is to use extremely small (micron size) devices to perform similar tasks, albeit at a smaller scale, of conventional machines.
Critical Materials	Semiconductor materials.
Unique Test, Production, Inspection Equipment	Semiconductor manufacturing equipment.
Unique Software	None identified.
Major Commercial Applications	Inlet duct flow control and structural health monitoring.
Affordability	Significantly reduces aircraft vulnerability and increases aircraft survivability. MEMS fabrication is less expensive than traditional devices.

SECTION 1.6—AERONAUTICAL DESIGN AND SYSTEMS INTEGRATION

Highlights

- Systems integration is a key in taking existing technologies and using them in new, improved ways.
- Improvements in design integration technology are essential in the development of complex systems.
- Nearly simultaneous design processes are enabled by analytical tools coupled with high-speed computer networks.
- Design and integration simulations will reduce development, maintenance, and repair costs.
- On-board health monitoring systems will improve time between removal and replacement of components.

OVERVIEW

This subsection covers technologies that enable the integration of various aeronautical technologies covered in other subsections into a mission-ready, affordable air vehicle. It includes vehicle and manufacturing process design methods and technologies for the pilot to interface with an aircraft. Integration technology is information based and has become more viable because of advanced analytical tool developments, such as structural finite element methods, CFD, and advanced database management. Computer graphics have also been used, and this avoids expensive physical mockups of new aircraft. Design teams are able to couple analytical tools with high-speed computer networks and data management to work nearly concurrently with each other and to exchange critical design information.

LIST OF TECHNOLOGY DATA SHEETS
1.6. AERONAUTICAL DESIGN AND SYSTEMS INTEGRATION

Advanced External Vision 1-32

Aircraft Design and Synthesis Tools 1-32

Micro Air Vehicle (MAV) 1-32

Single-Stage-To-Orbit (SSTO) Reusable Launch Vehicle (RLV) 1-33

“Health” Monitoring and Diagnostics 1-33

DATA SHEET 1.6. ADVANCED EXTERNAL VISION

Developing Critical Technology Parameter	No quantitative parameters are available. However, the intent of this technology is improved field of view and display of the external environment under conditions too degraded for the human eye.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Equipment for improved image registration and system boresighting.
Unique Software	Software for image blending and matching (required software currently exists in prototype and/or crude fashion).
Major Commercial Applications	Ground operations for commercial aircraft; possibly image presentation for game applications.
Affordability	Not an issue.

DATA SHEET 1.6. AIRCRAFT DESIGN AND SYNTHESIS TOOLS

Developing Critical Technology Parameter	Reduction in overall aircraft design cycle time can be achieved by applying higher order analysis methods in a multidisciplinary design environment for configuration synthesis.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Optimization procedures.
Major Commercial Applications	Commercial aircraft can benefit from this technology.
Affordability	Not an issue.

DATA SHEET 1.6. MICRO AIR VEHICLE (MAV)

Developing Critical Technology Parameter	Size: less than 15 cm (6 in.) in length, width, or height; weight: 50 grams or less; capable of staying aloft for 20 to 60 minutes for a range of 10 km; low aspect ratio wings at Reynolds numbers as low as 10,000.
Critical Materials	Lightweight composites.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Flight control algorithms.
Major Commercial Applications	Air monitoring; rescue; inspection and maintenance of equipment at inaccessible locations; agriculture.
Affordability	Relatively inexpensive.

DATA SHEET 1.6. SINGLE-STAGE-TO-ORBIT (SSTO) REUSABLE LAUNCH VEHICLE (RLV)

Developing Critical Technology Parameter	Reduce cost to low earth orbit (LEO) from $10,000 per pound to $1,000 per pound.
Critical Materials	Carbon-carbon; aluminum-lithium composite liquid oxygen tank.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Aerodynamic databases.
Major Commercial Applications	Commercial space access.
Affordability	Expensive program ($4–10B) that will yield an order-of-magnitude reduction in cost to orbit.

DATA SHEET 1.6. "HEALTH" MONITORING AND DIAGNOSTICS

Developing Critical Technology Parameter	Reduction in "Could Not Duplicates" and "False Alarms" from levels of 30–50 percent to the levels of 5–10 percent; prognostics for mechanical systems that avoids mission aborts and reduces unscheduled maintenance by as much as 25 percent.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Advanced sensors to detect component operation and performance deterioration.
Unique Software	Signal processing to detect anomalies and signatures of degraded systems; fusion/integration algorithms to combine multiple sensor outputs; open software architecture to integrate development tools and provide a run-time framework that can be easily updated with mature algorithms and new technology.
Major Commercial Applications	Commercial aircraft will benefit from this technology by supporting condition-based maintenance, notifying pilots about the cause of aircraft behavioral anomalies (diagnostics), and providing information needed by reconfigurable flight control systems. Nearly every industry with electromechanical devices uses and needs this technology, including processing plants, automobiles, aircraft, and construction/mining equipment. The processing plant, automotive, and heavy machinery manufacturers are technology drivers because of the large volume.
Affordability	Low-cost sensors and plug-and-play software are the central issues here because they would reduce the support costs of air vehicles.