CHAPTER I
AIR PLATFORMS

A. INTRODUCTION

1. Definition and Scope

The Air Platforms technology area includes efforts devoted to piloted and uninhabited air vehicles. The five subareas are shown in Figure I–1. The fixed-wing vehicle subarea includes technology efforts in aerodynamics, flight control, structures, subsystems, and integration (including flight demonstration). It does not include aircraft propulsion, power, human systems, avionics, weapons, materials, or manufacturing technology developments, but does consider the overall integration of these disciplines with the airframe. Similarly, the rotary-wing vehicle subarea includes technology efforts in aeromechanics, flight control, drive systems, structures, and subsystems and excludes the same disciplines that are excluded within the fixed-wing subarea. Integrated high-performance turbine engine technology (IHPTET) includes technology efforts in compression systems, combustion systems, turbine systems, exhaust systems, controls and accessories, and mechanical systems as well as full-scale demonstrations. The aircraft power subarea includes technology efforts in power generation, power distribution, energy storage, and system integration. The high-speed propulsion and fuels subarea includes technology efforts in air-induction systems, combustors/ramburners, nozzle/expansion systems, fuels and fuel systems, and structures and materials.

Air Platforms technology interfaces with other technology areas impacting air vehicle system capability, including Information Systems Technology; Materials/Processes; Sensors, Electronics, and Battlespace Environment; Human Systems; and Weapons.

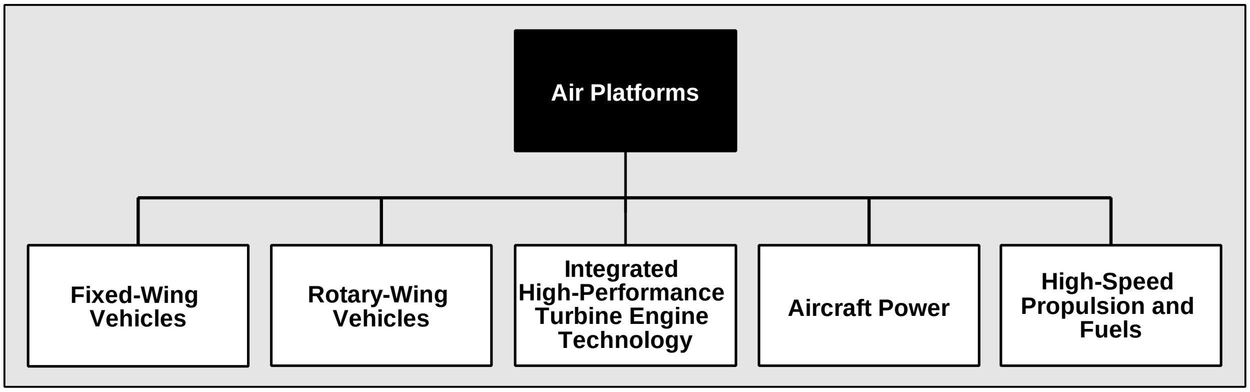

Figure I–1. Planning Structure: Air Platforms Technology Area

2. Strategic Goals

Table I–1 illustrates some of the Air Platform technology transition opportunities.

Table I–1. Air Platform Technology Transition Opportunities

Current Baseline	5 Years	10 Years	15 Years
FIXED-WING VEHICLES SUBAREA			
F–22, F/A–18/E/F	F–22, F/A–18E/F Upgrades, JSF	F–22, F/A–18E/F Improvements, JSF Upgrades	JSF Improvements, Global Strike A/C
C–17, P–3, B–2, MC–130H, AV–8B	C–17, B–2 Upgrades	C–17, B–2 Improvements	Medium-Range Bomber, SOF, UAVs (URAVs, UCAVs), Space Op Veh
ROTARY-WING VEHICLES SUBAREA			
AH–64A	AH–64D, OH–58D, RAH–66	AH–64D, RAH–66, OH–58D	AH–64D (upgrade), RAH–66 (upgrade)
CH–47D, V–22	V–22, CH–53E	V–22, CH–53 (upgrades)	JTR, V–22
UH–60A, H–60B/F	UH–1N/AH–1W, CH–60, UH–60A/L, SH–60R	UH–1N/AH–1W, UH–60A/L, CH–60, SH–60R	UH–60, JRA
IHPTET SUBAREA			
YF–119 (Turbofan/ Turbojet)	F–22, F/A–18E/F Upgrades, JSF VSTOL	F–22, F/A–18E/F Improvements, C–17 Improvements, B–2 Improvements, JSF Upgrades	Global Strike A/C, JSF Improvements, SOF, Medium-Range Bomber
J402/F107 (Expendable/Limited-Life Turbine Engines)	Supersonic Weapon, Longer Loiter UAV, JASSM, Tactical Tomahawk	Long Loiter UAV, MA UAV, Multi-Mode Missile	Ultra Low-Cost Standoff Weapon, Very Long-Range/Long-Loiter UAV, UCAV
T700/T406 (Turboshaft/Turboprop)	V–22, H–60 Upgrade, SH–60	RAH–66	RAH–66 (upgrade), JRA, JTR, MMA
AIRCRAFT POWER SUBAREA			
Aircraft Power Components	C–130J, E–8 JSTARS, MEA Components	C–5 Upgrade, C–130 Upgrade, JSF Upgrades, MEA Integration	Global Strike A/C, JSF Improvements, SOF, Medium-Range Bomber, UAVs
HIGH-SPEED PROPULSION AND FUELS SUBAREA			
Ramjet/Scramjet Propulsion	Adv AMRAAM, Cheap Mach 4 Weapon	Combined Cycle Engine, Mach 4–6 Missile	Mach 8 Missile
SR–71		Combined Cycle Engine	Mach 5+ Aircraft
Space Shuttle (STS)		Commercial Access to Space	Military-Specific Access to Space
JP–8, JP–10	JP–8+100 for the Existing Fleet	JP–8+225/JP–900	Chemically Reacting Fuel

The overarching strategic goal for Air Platform S&T investments is to maintain worldwide military aircraft and missile superiority by providing technologies by 2005 that will enable options for a 65% increase in range, a 35% reduction in takeoff gross weight for the same mission capability, a one-half reduction in acquisition and support costs, and doubling of DoD air vehicle life, all while maintaining current survivability levels and enhancing reliability. These payoffs can be achieved through the pursuit of specific technology goals in each of the major Air Platforms subareas by improving aerodynamics, reducing structural weight fraction, doubling propulsion system capability, increasing efficiency and reducing weight of power systems, reducing production and support costs, and increasing the thermal capability of fuels.

3. Acquisition/Warfighting Needs

Aircraft-related acquisition, operation, and support costs constitute about one-third of the DoD budget, and about two-thirds of these costs are associated with the basic air platforms. The relative importance of air platforms in the force structure is not expected to change since there are no foreseeable substitutes for the combination of firepower and mobility provided by aircraft.

Air Platforms subareas are critical to providing a military operational capability for strike, military airlift, early warning, reconnaissance, command and control, ground attack, sea control, and access to space. Air Platforms subareas are also critical to many operational tasks including air defense, air superiority, close air support, C^3, disaster assessment and relief, electronic warfare, information warfare, interdiction, medical evacuation, missile defense, reconnaissance and surveillance, sea lane control, search and rescue, special operations, strategic and theater airlift, strategic attack, strategic deterrence, and weather observation.

The DoD *Joint Warfighting Science and Technology Plan* (JWSTP) identifies contributions to the JCS's *Joint Vision 2010* in the areas of dominant maneuver, precision engagement, focused logistics, and full-dimensional protection. The foundation for these contributions will come from innovations in several technology areas. Specific contributions from the technology area of Air Platforms include the capability to (1) destroy selected targets over wide areas and long ranges; (2) deliver nonlethal weapons, precise weapons, and surveillance in urban areas; (3) disrupt or degrade enemy defenses across the entire electronic, IR, and visual spectrums; (4) destroy enemy theater ballistic missiles and cruise missiles; (5) provide early detection of biological weapons from long range; and (6) provide enhanced readiness and logistics through improved operating and maintenance (O&M) and life-cycle costs in support of the Joint Readiness and Logistics needs.

In addition, Air Platforms technologies have strong dual-use application in the civil sector, thus strengthening U.S. international competitiveness and significantly enhancing our economic security. Commercial applications of these technologies are in aerodynamics; gas turbines; power-by-wire controls; electrically driven subsystems (e.g., electric actuators); low-cost transparencies; and aging aircraft life extension, low-cost lightweight structures, and multidisciplinary design optimization.

B. DEFENSE TECHNOLOGY OBJECTIVES

The DTOs applicable to the Air Platforms subareas are as follows:

Fixed-Wing Vehicles

AP.01	Advanced Aerodynamic Concepts for Increased Flight Efficiency
AP.02	Fixed-Wing Vehicle Structures Technology
AP.03	Aircraft Support/Sustainment Reduction
AP.04	Flight Control Technology for Affordable Global Reach/Power
AP.05	Maturity Demonstration of Advanced Fixed-Wing Vehicle Technologies
AP.20	DARPA Micro Air Vehicles Program

Rotary-Wing Vehicles

AP.06	Helicopter Active Control Technology
AP.07	Demonstration of Advanced Rotor Concepts
AP.12	Rotorcraft Drive
AP.14	Rotary-Wing Vehicle Structures Technology

Integrated High-Performance Turbine Engine Technology

AP.08	Fighter/Attack/Strike Propulsion
AP.09	Transport/Patrol/Helicopter Propulsion
AP.10	Cruise Missile/Expendable Propulsion

Aircraft Power

AP.11	Aircraft Power (MEA)

High-Speed Propulsion and Fuels

AP.18	Improved JP–8 Fuel
AP.19	High-Heat-Sink Fuels (JP–900/Endothermic)

C. TECHNOLOGY DESCRIPTIONS

1. Fixed-Wing Vehicles

a. *Warfighter Needs*

Fixed-wing vehicle (FWV) technologies focus on providing aircraft that meet DoD operational capability and affordability requirements, both now and for the future. All DoD S&T in this subarea is accomplished by the Air Force and Navy (including the Marine Corps). Some of the expected payoffs in the FWV area are presented in Table I–2. Significant transitions of fixed-wing S&T to meet current and future requirements include:

- Flight and propulsion integration technology developed/matured and demonstrated to the degree that it is being proposed as a baseline for the Joint Strike Fighter (JSF), including the flight control system and compact inlet configurations.
- A deterministic fatigue analysis and failure prediction model named AFGROW has been transitioned to the air logistics centers (ALCs). This capability is used by the ALCs as the standard for predicting crack growth failures.
- Transitioned design and manufacture of low-cost composites technology for lightweight, low-cost carbon composite structures for next-generation air vehicle structure.
- Demonstrated a low-cost powder metallurgy repair and replacement of primary structure for an operating air vehicle (T–38) to reduce life-cycle cost through improved durability and corrosion resistance.

Table I–2. Fixed-Wing Vehicles Payoffs (% improvement)

Payoff	2005
Fighter/Attack Baseline Þ F–22, F–18E/F	
Reduce Acquisition Costs	10
Reduce Operations and Support Costs	10
Increase Lethality	5
Increase Mission Range	25
Reduce Susceptibility	15
Increase Payload	25
Increase Operational Readiness	10
Reduce Vulnerability	15
Reduce Takeoff Gross Weight	10
Airlift-Patrol/Bomber/Special Operations Baseline Þ C–17, P–3B–2, MC–130H	
Reduce Acquisition Costs	
Reduce Operations and Support Costs	
Increase Mission Range	
Years Additional Ownership of Aging Aircraft	
Increased Landing Opportunities	
Reduced Transport Time—Warehouse to End User	

- Demonstrated design concepts and manufacturing processes for a lightweight wing primary structure capable of withstanding 220°F.
- Vapor cycle environmental control system developed under the Integrated Closed Environmental Control System program has been transitioned to the F–22 and satisfies cooling requirements for the avionics.
- Aerodynamic solutions have been developed to address the severe unsteady loads in the open weapons bay as well as the acoustic suppression devices that appear as small spoilers in front of the weapons bay on F–117 and B–2 aircraft.
- Low horsepower electrohydrostatic actuators successfully developed and flight demonstrated providing technology option for developmental aircraft. As an enabling technology for all-electric aircraft, operations and support (O&S) costs and logistics footprint will be reduced in comparison to baseline central hydraulic actuation systems.

b. *Overview*

(1) Goals and Timeframes. Goals for 2005 (Table I–3) have been established to provide affordable combat effectiveness of fixed-wing aircraft while maintaining the nation's preeminence in the aircraft industry. The goals for future years (2010–2015) are in the process of revision. The five technology efforts (aerodynamics, flight control, structures, vehicle subsystems, and integration technologies) are clearly focused on overcoming the relevant technology barriers that offer the highest potential for improving overall system capability and cost.

Table I–3. Fixed-Wing Vehicles Technology Development Goals (% improvement over SOA baseline)

Goals	2005	2010	2015
Delta Unit Production Cost at T–1 ($/lb)	0	TBD	TBD
Delta O&S Cost per flight hour ($/flt hr/lb)	0	TBD	TBD
Delta Development Cost (MS 1—MS III)	0	TBD	TBD
Reduce Air Vehicle Weight Fraction	8	12	15
Increase Lift/Drag	10	15	20
Increase Controllable AOA Envelope	20	30	35

Note: New airlift-patrol/bomber/SOF goals are being developed jointly by DoD and NASA through the use of scenario studies.

(2) Major Technical Challenges. The major technology challenges include:

- Controlling vortex flow and flow separation in low-observable (LO) configurations including flow control in weapons bays to enhance small weapons separation.
- Integrating active controls and aerodynamics with wing structural response to improve wing aeroelastic efficiency.
- Flight demonstrating innovative tailless aerodynamic control and airframe-mounted LO thrust vectoring technology.
- Retaining performance in lightweight short inlets.
- Uncertain flight control design models.
- Adequate actuator power and response independent of a central hydraulic system.
- Developing flight-critical, high-throughput, open architectures for flight control with associated software verification and validation techniques.
- Reducing weight of major load-carrying structures while reducing cost and ballistic vulnerability.
- Design concepts to reduce the costs of composite structures.
- Demonstrating injection-molded, frameless transparencies.
- Management of a growing air vehicle heat load.
- Development of lightweight, no maintenance, storable cooling system technology.
- Repair techniques for aging aircraft.
- Developing methods to reduce the design time of air vehicles.
- Ground and flight demonstrations of innovative aerodynamic and structurally integrated concepts for enhanced control system effectiveness.
- Design concepts that enable affordable and aircraft-like operations for routine operations to and from space.

- Development of signature-compatible, high-lift concepts for STOL transport applications.

(3) Related Federal and Private Sector Efforts. Non-DoD activities in the fixed-wing vehicle subarea include the NASA High-Speed Research, Advanced Subsonic Technology, and Airframe Systems programs. NASA participates as an integrated planning partners in numerous joint and cooperative programs while conducting coordinated research in commuter, subsonic transport, and high-speed/hypersonic vehicles (and their propulsion systems) that have application to military aircraft.

Other non-DoD activities include FAA aging aircraft programs and cooperative programs through The Technical Cooperation Program with Canada, the U.K., and Australia/New Zealand in the areas of aerodynamics, flight dynamics, and aircraft/ship interface.

In the private sector, the major air vehicle and weapon system manufacturers are engaged in a broad spectrum of technology efforts. These include concentrated efforts across industry in virtual prototyping for design, manufacturing, and producibility; tailless fighter aircraft designs using thrust vectoring to reduce weight and extend range; and More Electric Aircraft (MEA) component design and validation. Technologies also being worked include active flow control, supersonic laminar flow control, smart structures incorporating both structural health monitoring and load-bearing sensors, and powered lift/vertical/short takeoff and landing (VSTOL). More dramatic configuration design issues include the transfer of fully tailless aircraft technology to military and civilian transport vehicles.

The national Fixed-Wing Vehicle Program (FWVP) has initiated consortia efforts with the aircraft industry and academia in aerodynamic–structures-controls interactions. It also has initiated consortia efforts with the aircraft industry to identify existing technology programs that are applicable to the USAF migration to space initiative, and to define Phase II FWVP requirements and objectives for space operation vehicles and other transatmospheric vehicle concepts.

c. *S&T Investment Strategy*

The largest impact on cost and performance of military fixed-wing aircraft is from the technologies associated with aerodynamics, structures, flight control, and subsystems. These technology efforts are the core for the FWVP—a planned, coordinated program among the Air Force, Navy, DARPA, NASA, industry, and academia, operating as an integrated product team. This program is based on one set of jointly constructed goals that can only be reached through a government-/industry-/academia-coordinated and cost-shared technology approach. The government ensures that the various goals will be met concurrently by integrating individual industry advanced airframe technology plans to meet selected goal sets and by focusing effort on areas not addressed by industry. The national investment supporting the five FWV technology efforts is allocated in proportion to their respective contribution to meeting FWVP goals.

(1) Technology Demonstrations. *Extended-Range Demonstration (ERD) TD*. This technology demonstration addresses DTO AP.05, Maturity Demonstration of Advanced Fixed-Wing Vehicle Technologies. The ERD Technology Demonstration (TD) conducts a full envelope (takeoff, low-level penetration, up-and-away maneuvering, supersonic dash, and landing) military flight evaluation of a fighter aircraft using an optimum blend of control effectors and thrust vectoring to demonstrate the substantial drag reduction/range improvement and cost reduction while retaining fighter maneuverability and not compromising flight safety.

This program was built directly on the joint USAF/NASA and contractor $30 million investment in the F–15 active testbed vehicle. Testing assessed drag reduction and maneuvering capabilities across the entire F–15 operating envelope and built confidence in the use of propulsion control as a major design consideration for future tailless fighter aircraft. Preliminary results show a 3% to 4% reduction in fuel usage over equivalent F–15 operating range.

Variable In-Flight Simulator and Test Aircraft (VISTA) Simulation System Upgrade TD. This TD will augment the current F–16 VISTA in-flight simulator with an integrated control system that includes pitch/yaw thrust vectoring to provide a permanent, militarized facility for high-angle-of-attack in-flight simulation, weapons research, and flight research. With enhanced simulation capability, the VISTA/NF–16D would be used not only for continued research and development into high-angle-of-attack flight, but also serve as a testbed allowing for significant risk reduction demonstrations of technologies for current and future systems.

This effort will build on the integrated controls with the thrust vectoring technology base provided by the Multi-Axis Thrust Vectoring program. Contracts were awarded in early FY95 to design, fabricate, and modify the VISTA/NF–16D with a production-like, full-flight-envelope, axisymmetric-thrust vectoring nozzle. VISTA enhancements will also include the incorporation of a programmable display system (including multifunction displays, a heads-up display, and a helmet-mounted display) and high-bandwidth actuators for increased simulation fidelity. Once this configuration is validated in ground tests, a rigorous, full-envelope flight test program will begin. This flight test program will demonstrate high-fidelity, in-flight simulation over the full flight envelope.

Active Aeroelastic Wing (AAW) TD. This TD addresses DTOs AP.02, Fixed-Wing Vehicle Structures Technology. The objective of this effort is to flight demonstrate key aspects of the highly innovative AAW concept. The AAW concept, which has been developed through exploratory analytical and wind tunnel tests, has a goal of improving maneuverability while reducing aircraft weight. Studies have shown this technology to have the capability of providing a 7% to 20% reduction in aircraft takeoff gross weight, and therefore reduced production cost.

An AAW may be described as an aeroelastically tailored composite wing designed to require only the stiffness necessary for strength, buckling, and flutter. The wing is designed to respond aeroelastically to multiple leading- and trailing-edge control surface deflections and to exploit aeroelastically reversed controls, thus providing never-before-achieved wing flight control responses. An active control system is designed to maximize the utility of this control power, thus providing a high-performance wing with complete control authority and power across the flight envelope. To reduce cost, an available F–18 aircraft with a digital flight control system will be used. Design studies will be performed to identify changes to the F–18 wing that increase the wing’s flexibility and make the wing suitable for an AAW experimental demonstration. A high-rate actuation system will be installed to upgrade the wing’s leading-edge control surface. Concurrent flight control development of AAW flight control strategies will also be conducted. Following modification of the F–18 test aircraft, a full-envelope flight test will demonstrate the performance benefits that may be achieved through implementation of the AAW concept.

Self-Adaptive Flight Control Experiment TD. This TD addresses DTO AP.04, Flight Control Technology for Affordable Global Reach/Power. The objective of this effort is to flight demonstrate key aspects of the Reconfigurable Control for Tailless Aircraft 6.2 development program. The payoffs of this flight control technology include continuous performance optimization of signature, drag, or maneuverability; greatly enhanced fault and damage tolerance; carefree control; and reduced development and life cycle cost. Current flight control technology does not have the ability to adapt to changes or unforseen events. This rigidity prevents the optimal use of the aircraft capability and results in costly and time-consuming control redesign after every aircraft upgrade.

The major task of this effort is to design and certify for flight a fully adaptive flight control system. Being adaptive, a broad range of actuator faults and battle damage can be identified and compensated for—significantly improving safety of flight. The flight control system consists of online system identification, online-designed control laws, and online control allocation and optimization. A nonlinear aircraft model and full performance specifications are carried onboard. The control law is continuously redesigned online to meet the specifications. Any desired changes need only be reflected in the model or the specifications—the control system is automatically redesigned accordingly. Emulated faults such as a missing control effector will be inserted during critical mission phases to demonstrate performance recovery, landing, and continued mission capability.

Joint USAF/DARPA Unmanned Combat Air Vehicle (UCAV) Advanced Technology Demonstration (ATD) Program: This technology demonstration addresses DTO AP.05, Maturity Demonstration of Advanced Fixed-Wing Vehicle Technologies. Phase one of the UCAV ATD (FY98–99) is exploring the integrated cost-benefits of application of FWV program technologies to a missionized weapon system concept. Through analysis of postulated concepts of operations, the program will analytically predict the relative "life cycle cost per target kill" that various integrated technology vehicles would have in performing a suppression of enemy air defense (SEAD) role. The SEAD mission has been selected as a mechanism of focusing the technology integration and maturation efforts in preparation for an engineering manufacturing development (EMD) decision likely to be made in FY05. Various FWVP technologies will be explored, and those having greatest system-level payoff will be selected for further development.

In phase two of the ATD (FY99–02), a demonstrator vehicle will be designed, fabricated, and tested to assure validity of weapon system technical goals. This vehicle will mature those selected technologies that require flight validation. Technologies that can be adequately demonstrated in a laboratory environment will be developed without flight test. At the end of phase two, a follow-on effort (not currently funded) is proposed that will further reduce technology risk of an EMD program. Also proposed is a 2005 decision whether an EMD/production program could be performed with an acceptable level of certainty; by that point, adequate experience with each developmental FWV technology and unmanned vehicles is expected to provide a high level of confidence.

F–15 Continuous Moldline Technology (CMT) Rudder Flight Test. This TD addresses DTOs AP.02, Fixed-Wing Vehicle Structures Technology. This joint NASA/USAF technology demonstration addresses the application of CMT to a single F–15 rudder and hinge line. CMT is an innovative structural technology that enables the design of moving components for high-payoff airframe applications while maintaining an unbroken moldline. Continuous control surfaces using this technology provide enhanced control effectiveness with unbroken aircraft skin surfaces. A NASA F–15 is scheduled to have this technology incorporated on one vertical stabilizer rudder and be flight tested in 2000. The program is intended to prove the flight readiness of the aero-dynamic/structural concept, establish durability, and demonstrate aerodynamic effectiveness. Once the maturity of the technology is advanced, numerous applications are envisioned, including weapons bays and inlets.

More Electric Aircraft Technology Validation (MTV) TD. This technology demonstration addresses DTO AP.04, Flight Control Technology for Affordable Global Reach/Power, and DTO AP.11, Aircraft Power (MEA). The MTV TD conducts a full-envelope flight demonstration on a NASA F/A–18 of an integrated system consisting of an electric stabilator actuator, advanced 270-Vdc electric power management and distribution system, and advanced, open architecture vehicle management system. Technology development is underway for all three subsystems, and flight testing is scheduled for FY01 and FY02. This TD is on the FWV and the MEA roadmaps.

This program builds on two DARPA technology reinvestment projects, as well as an existing advanced development program. It is demonstrating the ability to eliminate the need for a central hydraulic system on future air vehicles. Studies have shown that eliminating the central hydraulic system results in a 15% reduction in maintenance manpower needs, 20% reduction in deployment loads due to reduced ground support equipment, 15% reduction in vulnerability, and reduction to a two-level maintenance of flight actuation subsystems (no hydraulic maintenance).

(2) Technology Development. *Aerodynamics.* Aerodynamics technology will significantly improve aircraft performance by improving lift/drag ratio during cruise and maneuvers, reducing drag while carrying weapons, increasing lift coefficient during landing approach, reducing nozzle weight and cost, reducing inlet weight and volume, and reducing aerodynamic design cycle time. Efforts are focused on improving the versatility and efficiency of modeling advanced air vehicles. Technologists will use the computing power that has been developed over the last few years to explore and more fully understand those flight regimes that are characterized by highly dynamic, nonlinear aerodynamic flow (e.g., very high angle-of-attack maneuverability).

Flight Control. Flight control technology provides air vehicle maneuverability, stability, and flightpath control (including multiship control), while ensuring safety of flight in all flight regimes, including hypersonic. Technology development will reduce the weight and drag of lifting and control surfaces, hardware weight, control-related accidents, development time and cost, and maintenance actions. Reduced acquisition costs are supported through efforts in low-cost modeling and low-cost control system design techniques. Reduced O&S costs are addressed by technology developments in electric actuation, optical air data systems, and photonic vehicle management systems.

Structures. Airframe structures technology covers the development of improved lower cost or lower weight structures for all classes of fixed-wing aircraft, from analysis through concept development and experimental demonstration to incorporation into the aging operational fleets and advanced air platforms. Improvements will be achieved by increasing structural fatigue life (e.g., structural repairs, nondevelopment items/equipment) and by reducing structural weight, manufacturing support, assembly costs, and development time. The scope covers aging aircraft, adaptive or smart structures, affordable composites and advanced metallic structures, extreme environment structures, new assembly methods, multidisciplinary design optimization, and exploitation of advanced materials and manufacturing techniques in design.

Subsystems. Vehicle subsystems technology focuses on a balance of developments in aircraft subsystems to decrease aircraft weight, increase mission range, reduce cost of ownership, and enhance survivability and safety. This will be achieved by (1) reducing thermal energy management system weight, support costs, transparency production cost, repair time, and component design time, and (2) increasing tire life and applying electric actuation to utility subsystems.

*Integration***.** Integration technology examines and exploits the interrelationships among fixed-wing vehicle technologies (aerodynamics, flight control, structures, and subsystems) and non-FWV areas (propulsion, materials, weapons, and human systems). Integration technology generally requires major ground or flight test and evaluation to validate the needed technology readiness level.

(3) Basic Research. Specific basic research programs in robust, multivariable flight control support reduced acquisition cost and increased combat survivability. Work in real-time parameter identification and online control law design directly supports increased combat survivability. Research in computational fluid dynamics and computational electromagnetics supports improvements in combat range and survivability. Research in experimental aeromechanics will provide a validation database and advanced diagnostics permitting improved modeling and simulation for future USAF high-speed systems. Plasma flow research may offer a revolutionary capability to the system designer. Research in ballistic impact of composites will reduce combat vulnerability. Research in fluid–structure interactions will increase maneuverability. Research in life predictions in combined thermal and acoustic environments will reduce support cost for existing and advanced air vehicles. (See the DoD *Basic Research Plan.*)

2. Rotary-Wing Vehicles

a. *Warfighter Needs*

Operational capability improvements to both military and civil rotorcraft fleets will tremendously impact the overall cost of ownership and the acceptance of rotorcraft by the defense community and commercial passengers. Reducing acquisition and operation costs, diminishing vibration and noise levels, and improving the ability to operate at night and in adverse weather all highlight the vast potential of rotary-wing technology advancements. These improvement goals were developed in concert with both the user and the rotorcraft industry through the development of the government–industry–academia rotary-wing vehicles (RWVs) Technology Development Approach (TDA). This document outlines the DoD approach for executing a program to achieve goals that will result in the highest payoffs (Table I–4) for the rotary-wing aviation community.

Table I–4. Rotary-Wing Vehicles Payoffs (% improvement)

Payoff	Cargo			Utility			Attack/Recon		
	2000	2005	2010	2000	2005	2010	2000	2005	2010
Increase Range (for a fixed payload)	39	91	151	41	90	146	38	82	137
Increase Payload (for a fixed-range)	30	66	103	28	58	89	43	91	144
Increase Maximum Cruise Speed	2	6	10	2	6	10	2	5	8
Increase Maneuverability/Agility	45	65	100	45	65	100	45	65	100
Reduce System Acquisition Costs	0	11	17	0	9	16	0	4	8
Reduce O&S Costs	11	21	30	9	18	26	7	14	20
Increase Mission Reliability	10	20	30	10	20	30	10	20	30
Increase Probability of Survival	20	30	40	20	30	40	20	30	40
Reduce Major Accident Rate	12	20	30	12	20	30	12	20	30

Future operational capabilities, as defined by the combat development user community, serve to identify the areas of rotorcraft performance and cost drivers that will most benefit from technological advancements. They also provide rationalization for the pursuit of technologies that provide solutions to real-world problems, avoiding work done “at the margin” that does not provide leap-ahead improvements to the effectiveness and affordability of military (and civilian) rotorcraft. Specific RWV payoffs have been established for three classes of rotorcraft: cargo, utility, and attack/reconnaissance (Table I–4). These operational capability improvements are derived from the subsystem-level technology development goals (Table I–5), which are derived from the technology effort objective defined in the RWV TDA.

Table I–5. Rotary-Wing Vehicles Technology Development Goals (% improvement)

Goals	2000	2005	2010
Reduce RWV Empty Weight Fraction	7	15	22
Increase Cruise Efficiency (ηL/D)	4	11	20
Increase Maneuverability/Agility	48	66	112
Reduce Development Time	0	15	25
Reduce RWV Flyaway Cost	0	14	22
Reduce RWV Maintenance Cost	18	35	50
Reduce Signature	35	50	60

Recent accomplishments in rotary-wing S&T to meet current and future operational capability and affordability requirements include:

- Developed, validated, and released Control Designers Unified Interface (CONDUIT) software supporting up to 5X reduction in flight control system development and evaluation.
- Evaluated advanced airfoil concept in dynamic stall environment (configuration showed no stall). Supports achievement of four RWV goals.
- Demonstrated improved prediction accuracy for rotorcraft dynamic blade root torsional loads using comprehensive analysis. Supports reduced cost for experimental development of “passive” low-vibration rotor concepts.

- Completed integrated fire/flight control hardware-in-the-loop simulation and analysis. Supports 80% reduction in weapons' aiming error and reducing first-shot engagement time by 7–10 seconds.
- Demonstrated 25% reduction in weight of landing gear component. Supports system weight and acquisition cost reduction.
- Demonstrated "adaptive cure monitoring" via embedded sensors with feedback control for optimal cure. Supports reduced manufacturing labor hours and structural weight.

b. *Overview*

(1) Goals and Timeframes. Aggressive goals (Table I–5) have been established to increase the combat effectiveness of DoD rotorcraft and maintain the nation's preeminence in the rotorcraft industry. Five technology efforts (aeromechanics, flight control, structures, drive systems, and subsystems) focus on overcoming technology barriers that offer the highest potential for improving overall system capability and reducing cost.

(2) Major Technical Challenges. The major technology challenges include:

- Accurate prediction and control of stall, drag, and compressibility characteristics that will lead to overall rotorcraft performance improvements.
- Determining optimal rotorcraft response types, control laws, and control law synthesis methods to achieve better handling qualities and shorten the design and development process.
- Nonintrusive monitoring components and techniques, sensors, algorithms, and methods to improve design and manufacturing processes and to permit real-time monitoring of flight loads and damage.
- Actuators constructed using smart materials for primary control and vibration control of rotorcraft rotor blades.
- The tailoring/mixing of rotor and control technology concepts on a full-scale rotorcraft system.
- Development of very compact and durable high-reduction ratio gear configurations with +99.5% efficiency and extremely low-vibration and -noise characteristics.
- Application of advanced steel alloys, coatings, and processing methods with increased high-temperature fracture toughness, bending fatigue strength, and surface durability to gears and bearings.
- Increasing the load capacity and durability of high-reduction ratio gearing.
- Eliminating bearing and housing maintenance and replacement due to corrosion and fatigue failure.

(3) Related Federal and Private Sector Efforts. Independent R&D efforts are conducted by the nation's three major helicopter manufacturers. These efforts have been coordinated with the technology efforts described above, and many topics are being worked jointly through cooperative R&D agreements. NASA has a related rotary-wing technology development program. An Army/NASA joint agreement provides essential personnel and facility resources that supplement, and in many cases simply make possible, the Army laboratory in-house efforts directed at the described goals.

The National Rotorcraft Technology Center (NRTC)—a unique partnership of government, industry, and academia—develops, manages, and executes a research program that is focused on ensuring the continued superiority of rotorcraft systems for DoD, while concurrently strengthening the U.S. rotorcraft industry's ability to compete in the world market. The projects performed by the Rotorcraft Industry Technology Association are funded by the Army, NASA, and industry. Since DoD (Army) funding equals approximately 25% of total funding in NRTC projects, this equates to a four-to-one leverage in the technology investment.

c. *S&T Investment Strategy*

The investment in RWV S&T is an integral part of the overall strategy to improve the military worth of rotorcraft, in concert with S&T investments in avionics, engines, human–system interface, and weapons. RWV S&T focus on the facets of rotorcraft that can be improved, either in increments or in generation leaps. This is accomplished through the various disciplines represented within the rotorcraft platform itself: reducing the cost of ownership, expanding upon the already highly versatile capabilities inherent with vertical-lift aircraft, and increasing the public acceptance of rotorcraft through improvements to safety, noise, vibration, and reliability. Coupled with—and anticipating—the coming improvements in mission equipment, engine performance, and economy, and the range and lethality of tomorrow's weapons, RWV S&T is carefully coordinated among the Army, Navy/Marines, NASA, and industry to provide timely benefits to both new developments and upgrades to current systems over the next 15 to 20 years.

(1) Technology Demonstrations. *Helicopter Active Control Technology (HACT) TD.* This technology demonstration fulfills DTO AP.06. The HACT TD brings together advanced concepts and components to demonstrate the potential improvements from second-generation active control technology. Specifically, HACT will exploit and develop refined concepts for control law design, distributed architecture, software development, and failure management coupled with advanced components for fly-by-light and smart actuators. These have high potential to provide increased safety and reliability with shortened development times. In addition, the pilot will be provided with active cockpit flight controls and advanced displays. The total capability will be used to provide task-tailored handling qualities to demonstrate improved mission effectiveness in critical tasks in all weather and night operations. These technologies would be applied as ingredients in current system upgrades or as a package in a new system such as the Joint Transport Rotorcraft (JTR).

The workload on a vertical-lift pilot and on flight management inhibits pilot situational awareness and response. These limitations directly impact night, adverse-weather, and low-altitude operations. Lack of complete control integration (fire/flight/fuel) prevents exploitation of full rotorcraft capabilities, restricts maneuverability/agility, and impacts safety and survivability. Simplified implementation of digital flight control permits customer system-specific tailoring, fleet retrofits, and system upgrades; reduces development and modification costs; and will be available for use in future military systems, as well as in the civil arena.

*Rotary-Wing Vehicle Structures Technology (RWST) TD***.** The RWST TD supports DTO AP.14, exploiting emerging technologies—including toughened epoxies, smart materials, and metal-matrix composites—to demonstrate advanced airframe concepts that are structurally tailored for efficiency, affordable to produce, and supportable in the field. Robust designs and associated manufacturing processes and tooling to produce high-quality, repeatable structural components will be demonstrated. Simulation models enabling virtual prototyping of structural components and manufacturing/assembly methods will be used for rapid, affordable risk mitigation. Smart materials applications to structural components enabling real-time, in-flight monitoring of structural integrity will be evaluated. RWST technologies will be a key contributor to the JTR ATD and will have direct application to the commercial aviation industry. The highly efficient structural concepts and repair technology developed by RWST will also transition seamlessly to the commercial rotorcraft aircraft industry.

The RWST TD will support reductions in manufacturing fabrication and assembly labor hours through designing for six-sigma manufacturability, process controls, and flexible manufacturing. Operations and support costs will be reduced through advanced prognostics/ diagnostics, with the goal of achieving on-condition maintenance requirements in the airframe system.

Survivable, Affordable, Repairable Airframe Program (SARAP) TD. The SARAP TD will demonstrate advanced structures and airframe technologies for JTR/Army After Next (AAN) requirements to include improvements in weight, development time, production, and O&S costs. SARAP will enable development, procurement, and fielding of medium-to-heavy-lift (up to 50-ton) class rotary-wing vehicles for AAN. The program will develop fuselage concepts for fabricating demonstrator hardware for the JTR. The program will integrate the Rotary-Wing Structures Technology TD technologies and configuration information generated by the JTR concept development effort. Rapid technology development will be pursued in a highly synthetic environment using virtual prototyping and the virtual factory to reduce time to market, allowing technology demonstrations to transition directly to EMD.

Variable Geometry Advanced Rotor Demonstration (VGARD). The VGARD TD will flight-demonstrate affordable leap-ahead rotor system performance for JTR/AAN requirements as well as for future systems and current systems upgrades. From the rotor concepts developed under Advanced Rotorcraft Aeromechanics Technology (ARCAT) and Variable Geometry Advanced Rotor Technology (VGART), a rotor design will incorporate the affordable, fieldable characteristics of one or more of the variable geometry concepts. The ARCAT is developing high-risk rotor concepts including the variable geometry concepts and on-blade active controls to increase rotor performance and aerodynamic efficiency and reduce noise, blade loads, and vehicle vibration at the source. The rotor concepts developed under ARCAT have critical subcomponent (e.g., on-blade actuators) and scaling barriers that will be addressed under the VGART program to enable the full-scale rotor system required for the VGARD TD.

The VGARD system predesign and critical loads will be assessed early in the program followed by detailed design, component fabrication, and bench tests. Ground and wind tunnel tests will precede hover tests. Flight tests will be conducted as the final element of the demonstration. VGARD expands current boundaries of high-payoff variable geometry concepts to include both helicopter and tilt-rotor operations.

Advanced Rotorcraft Transmission II (ART II) *TD*. This technology demonstration will fulfill the objectives of DTO AP.12, Rotorcraft Drive. ART II is a system-level demonstration of advanced mechanical power transmission technologies which focuses on improving the power-to-weight, noise, reliability, and cost characteristics of the rotorcraft main reduction gearbox.

The goals of the ART II program are to demonstrate a 25% improvement in SHP/Wt, a 10-dB reduction in gearbox generated noise, a 2X increase in mean time between unscheduled removals, and a 10% reduction in production costs. The SHP/Wt and noise goals will be demonstrated in planned development and durability testing during the year 2000. The reliability goal will be validated by comparison of measured stresses and wear rates to the design intent values.

To achieve the ART II program goals requires the application of advanced features to the gearbox components and subsystems of the gearbox. The gear train will utilize an innovative split torque configuration for reduced weight and parts count. The gears will utilize high-contact ratios, high hot hardness steel, and double helical designs for increased load capacity, loss of lubrication tolerance, and reduced noise. The planetary gears will be precision forged for reduced cost and increased strength, and an investment cast titanium planet carrier will be utilized. Hybrid ceramic bearings with PEEK injection molded cages will be utilized throughout the design. The lubrication system will operate at elevated temperature and reduced flow rates for weight reduction. The housings will be fabricated from a high-temperature, corrosion-resistant magnesium. The baseline sprag overrunning clutch will be replaced with a lightweight, highly reliable positive engagement clutch.

The ART II technologies are directly applicable to all rotorcraft in the current military and commercial fleet and will provide a solid technology base upon which new rotorcraft drive systems can build. The benefits provided by the ART II technology will allow significant improvements in vehicle mission capability (payload or range), reduced internal noise, and lower cost of ownership.

Rotorcraft Drive System for the 21st Century (RDS–21) TD. This program will demonstrate key technologies required to realize major weight, O&S cost, and noise reductions for the very high power transmissions required by the JTR. The objectives of the RDS–21 will exceed those of DTO AP.12, Rotorcraft Drive. The objectives are to demonstrate by the year 2005 the potential for a 35% increase in drive system power-to-weight ratio, 25% reduction in production costs, 25% reduction in O&S costs, and 15-dB reduction in transmission-generated noise. The RDS–21 program will seek to demonstrate new speed reduction concepts that will provide the required reduction in parts count and manufacturing complexity to achieve affordable breakthrough levels of performance for rotorcraft drive systems. The program will capitalize and build upon technologies demonstrated by the ART II program and extend their benefits to the very high torque levels expected for the JTR. It will consist of design, manufacturing, and development testing necessary to validate the achievement of the program objectives. The RDS–21 technologies are directly applicable to all rotorcraft in the current military and commercial fleet and will provide a solid technology base upon which new rotorcraft drive systems can build. The benefits provided by the RDS–21 technology will allow significant improvements in vehicle mission capability (payload and range), reduced internal noise, and lower cost of ownership.

Full-Spectrum Threat Protection (FSTP) TD. The FSTP TD will demonstrate on a fielded AH–64 Apache helicopter the synergistic benefits that can be obtained in integrated state-of-the-art technologies related to advanced active electronic warfare and decoy countermeasures (CMs), advanced passive signature reduction technology, and advanced aircrew situational awareness and tactics. The program will capitalize on existing and in-process technical developments while identifying and pursuing advanced technologies necessary to support areas where advanced threat development is expected to surpass current capabilities. The primary challenge is to integrate active and passive CMs that can produce a mission-effective, survivable, rotary-wing vehicle that is both supportable and affordable. The FSTP program will integrate passive features such as innovative IR suppressors, multispectral paints and coatings, lightweight insulative materials, advanced camouflage, and low-glint canopy coatings along with the suite of integrated infrared countermeasures. Demonstrated technologies can be integrated into future rotorcraft during design and existing legacy systems via fleet upgrades.

(2) Technology Development. *Aeromechanics*. Aeromechanics S&T seeks to improve the performance of rotorcraft by reducing vibration loads, adverse forces, and acoustic radiation while increasing blade loading, aerodynamic efficiency, rotor inherent lag damping, and prediction effectiveness. Efforts are focused on refining analytical prediction methods and testing capabilities, improving the versatility and efficiency of modeling advanced rotorcraft, and achieving breakthroughs through concept applications.

*Flight Control***.** Flight control technology defines the aircraft flying qualities and pilot interface to achieve desired handling qualities in critical mission tasks, synthesizes control laws to facilitate a particular configuration achieving a desired set of flying qualities, improves weapons pointing accuracy, reduces flight test development time, and integrates advanced pilotage systems into the aircraft to exploit agility and maneuverability. Through advanced concepts, the revolution in the power and miniaturization of computers, smaller and more reliable sensors, and production-capable fiber optic components holds tremendous promise for realizing the full potential of the rotorcraft's performance envelope and maintaining mission performance in poor weather and at night.

Structures. Structures S&T focuses on the durability, safety, survivability, and affordability of critical rotary-wing vehicle components. Structures technology efforts provide reductions in manufacturing labor hours per pound while improving structural efficiency, displacement capacity of smart actuators, structural load prediction, and accuracy of cumulative fatigue damage prediction. Improvements in structures technology enhance structural efficiency and performance while reducing both acquisition and operating costs of existing and future rotary-wing vehicles. Without low-cost manufacturing, composites technology cannot reach a level of maturity to compete with metals in providing strength, stiffness, and durability benefits. “Virtual prototyping” will be incorporated to optimize structural designs and to minimize risk in exploring new concepts for future RWV development programs.

Drive Systems. Drive system technology reduces the weight of the power transmission system required to transmit torque from the engines to the main thrust-producing rotors and thus increases the rotorcraft’s payload and range capability. The technology developed also has a large impact on reducing the noise generated by the power gearing. This noise is the primary source for the internal cabin noise that interferes with speech and causes hearing loss. The development of improved durability gears, bearings and housings materials, and configurations will significantly reduce the maintenance time required by the drive system and significantly extend the time the major drive module stays installed on the aircraft. The increased high temperature and wear resistance will also increase the survivability of the drive system in loss of lubrication situations due to ballistic impacts during combat operations.

Subsystems. Rotary-wing vehicle subsystems encompass a broad range of S&T topics related to the support, sustainment, and survivability of increasingly complex aircraft systems and to the unique problems associated with the application of high-performance weapons on rotorcraft. Efforts include addressing reductions in signatures and improvements in detection of mechanical component failure as well as hardening to threats through improved crash worthiness and ballistic tolerance.

(3) Basic Research. The RWV basic research program is focused on aeromechanics and structures technology. The aeromechanics efforts are directed toward rotor performance and acoustics, computational fluid dynamics, aeroelastic stability, and structural dynamics. Deliverables include an improved understanding of physical phenomena, mathematical models, and complex computer codes that are disseminated to government, academia, and industry. The structures basic research program develops advanced structural analyses, failure criteria, and inspection methods that address fundamental technology deficiencies in both metallic and composite rotorcraft. The overall thrust is to provide an integrated stress–strength–inspection technology for life extension and durability of existing and future rotary-wing vehicles.

Complementing the in-house and contracted RWV basic research effort is the Rotorcraft Center of Excellence program. This program is managed by a joint Army/NASA office of the NRTC through funded cooperative agreements with the Georgia Institute of Technology, Pennsylvania State University, and University of Maryland. The current projects consist of efforts related to efficient low-noise rotors, affordability, low-vibration dynamic systems, advanced drive trains, smart and composite structures, day/night adverse-weather capability, highly reliable and safe operations, and digital-optical integrated flight controls.

3. Integrated High-Performance Turbine Engine Technology

a. *Warfighter Needs*

It is well understood, as well as implied in JCS's *Joint Vision 2010,* that low-casualty battlefield victory is achieved through air dominance. Air dominance is maintained by fielding affordable and durable high-performance air platforms capable of delivering payload when and where needed by the field command. Key to successful air platforms is the propulsion system. Gas-turbine engines have no equal in providing excess power for air platform performance, maneuverability, armament control, and mission flexibility at the lowest overall cost (production, maintenance, deployment, and fuel). The IHPTET program is providing the enabling propulsion research and development to produce the necessary low-risk propulsion technologies to continue the U.S. air dominance position through the next half century. These technologies will enable propulsion upgrades to currently fielded systems and development of future fighter/attack, bomber, and cargo aircraft; rotorcraft; subsonic and supersonic missiles; and unmanned aerial vehicles of many configurations.

The DoD JWSTP identifies contributions to JCS's Joint Vision 2010. As discussed in the JWSTP, there is no foreseeable substitute for the firepower and mobility of aircraft and rotorcraft, nor is there a substitute on the horizon for gas-turbine engines as the primary propulsion system. Achievement of IHPTET goals will provide new weapon systems with the capability to:

- Destroy selected targets over wide areas in support of Precision Force needs.
- Deliver nonlethal weapons, precise weapons, and surveillance in urban areas in support of Military Operations in Urbanized Terrain needs.
- Disrupt or degrade enemy defenses across the entire electronic, infrared (IR), and visual spectrums in support of Electronic Warfare needs.
- Destroy enemy theater ballistic missiles and cruise missiles in support of Joint Theater Missile Defense needs.
- Detect biological weapons from long range in support of Chemical/Biological Warfare Defense and Protection needs.
- Provide enhanced readiness and logistics through improved O&M and life-cycle costs in support of the Joint Readiness and Logistics needs.

Some typical examples of system payoffs from IHPTET in support of these needs are shown in Table I–6 and are enabled through the engineering application of the technologies developed to meet IHPTET goals (Table I–7). In addition to meeting the above-identified needs, IHPTET enables advanced turbine engines for New World VISTA and Air Force 2025 futuristic systems—in the near-term, for advanced short-takeoff/vertical landing (ASTOVL) and sustained supersonic cruise; in the far-term, for advanced UAVs, global reach transports, global strike bombers, and rapid reaction fighters. In addition, excess engine power will enable future "electric" directed-energy weapons and new nonhydraulic, nonmechanical aircraft control capability.

Examples of successful IHPTET technologies that have been applied to current propulsion systems include:

- Thrust (power) growth with lower fuel burn for the F100, F110, T800, F404, F414, F119, and F120 engine families (technologies include swept, high-efficiency aerodynamic fan and compressor blading; high-efficiency, low-leakage air seals; lightweight components through innovative design and composite materials; high-velocity, full-flight-envelope noncoking fuel nozzles; high-stability, high-temperature rise, full-fight-envelope re-light combustors; high-temperature, long-life turbines through advanced cooling designs; and innovative exhaust nozzles with low-signature benefits).
- New F100 and F110 fan designs with enhanced field damage and life limits.
- Improved manufacturing for low-cost turbine blades, vanes, and rotors for the F100, F110, T800, F404, and F414 engines.

Table I–6. Propulsion System Payoffs (% improvement)

Payoff	Phase I (1991)	Phase II (1997)	Phase III (2003)
Baseline: Global Strike Aircraft/Bomber with "IHPTET Phase I" Propulsion			
Increase Radius @ Constant TOGW	Baseline	7	14
Decrease TOGW @ Constant Radius	Baseline	11	25
Reduce Aircraft Acquisition Cost	Baseline	10	21
Reduce O&M Cost	Baseline	10	23
Baseline: Global Reach Transport with GE90/PW4000 Technology Propulsion			
Increase Range @ Constant Payload	Not Assessed	Not Assessed	23
Critical Global Drop Sites Covered	Not Assessed	Not Assessed	21
Increase Payload @ Constant Range	Not Assessed	Not Assessed	25
Baseline: Future Air Force Air Superiority Fighter with F119 Technology Propulsion			
Reduce TOGW @ Constant Radius	19	28	33
Reduce Fuel Burned	23	32	38
Baseline: Future ASTOVL Fighter with F119 Technology Propulsion			
Reduce TOGW @ Constant Radius	20	29	36
Reduce Fuel Burned	22	32	42
Baseline: Future Navy CAP Fighter with F119 Technology Propulsion			
Reduce TOGW @ Constant Radius	21	30	36
Reduce Fuel Burned	27	37	44

Table I–7. IHPTET Development Goals

Fiscal Year	Technology*	Goal
1991	TF/TJ	+30% thrust/weight; +100°F combustor inlet temperature
	TS/TP	+40% power/weight; -20% specific fuel consumption
	EXP	+35% thrust/airflow; -20% specific fuel consumption; -30% cost
1997	TF/TJ	+60% thrust/weight; +200°F combustor inlet temperature; -20% acquisition cost; -20% maintenance cost
	TS/TP	+80% power/weight; -30% specific fuel consumption; -20% acquisition cost; -20% maintenance cost
	EXP	+70% thrust/airflow; -30% specific fuel consumption; -45% cost
2003	TF/TJ	+100% thrust/weight; +400°F combustor inlet temperature; -35% acquisition cost; -35% maintenance cost
	TS/TP	+120% power/weight; -40% specific fuel consumption; -35% acquisition cost; -35% maintenance cost;
	EXP	+100% thrust/airflow; -40% specific fuel consumption; -60% cost

*TF/TJ—turbofan/turbojet; TS/TP—turboshaft/turboprop; EXP—expendable engine (cruise missile)

- Innovative engine control sensors and logic for improved reliability to the F100, F110, T800, and F414 engines.
- Lower cost new engine and maintenance replacement parts through better design and analysis tools for improved wear and life, more efficient manufacturing methods, higher quality material inspections, and processing methods.

Individual service requirements focus on major engine upgrades that are relatively frequent but whose timing is hard to predict. There are two reasons for this. First, engine capability has a large impact on the capability of an existing aircraft. Second, upgrades are dictated by the pace of both threat and technology development. Declining defense budgets are delaying, but not eliminating, the introduction of new vehicles. Thus, we can expect even greater reliance on engine upgrades to maintain superiority against emerging threats. IHPTET is specifically planned in three phases so that advanced technology is available for transition to nearer term system needs. Therefore, any existing system is a candidate for major upgrade including the F–14, F–15, F/A–18, P–3, C–130, H–60, AH–64, and Tomahawk missile. Systems currently in development, like the F–22, F/A–18E/F, V–22, JSF, and RAH–66, will inevitably be upgraded in the future; thus, they will also continue to be recipients of IHPTET technologies.

b. *Overview*

(1) Goals and Timeframes. The IHPTET program, initiated in FY88, is aimed at specific and aggressive goals for all three military engine classes in three time phases (Table I–7). The goals are referenced to the 1987 state of the art and include current and planned DTOs as previously listed. To date, IHPTET has achieved its Phase I goals, and progress has been good toward achieving the Phase II goals. Historically, industry funding devoted to the IHPTET goals has slightly exceeded government funding.

(2) Major Technical Challenges. The general path to doubling propulsion system capability is well known. Higher temperatures at combustion initiation are required to decrease fuel consumption (via increased compression system pressure ratio) or increase maximum flight speed thereby expanding the flight envelope. Higher maximum temperatures are required to increase the output-per-unit airflow (specific thrust). Less weight-per-unit airflow is required to increase the output-per-unit weight (thrust/weight or power/weight ratio). And all of these advances must be accomplished while maintaining or increasing component efficiencies, durability, and life and by reducing cost. Specific technology development areas include advanced materials that exhibit higher temperature capability and higher strength per unit weight; improved aero-thermodynamic design capability for improved component efficiencies and control of heat transfer; innovative structural concepts for part-count reduction and improved durability; and compatibility of these developments with lower cost manufacturing processes and maintenance requirements.

(3) Related Federal and Private Sector Efforts. Both NASA and industry participate in the IHPTET program. NASA investment is approximately $15 million in FY99. Industry's discretionary funding focused on IHPTET efforts is estimated to be approximately $105 million in FY99. NASA’s High-Speed Civil Transport (HSCT) and Advanced Subsonic Technology (AST) programs are directed specifically at civil engine technology that builds upon IHPTET.

c. *S&T Investment Strategy*

The program was undertaken in recognition of the large impact of engine performance on the cost and capability of military aircraft. IHPTET is a jointly planned and coordinated program among the Army, Navy, Air Force, DARPA, NASA, and industry. There is one government plan, and the six aircraft turbine engine manufacturers have complementary advanced turbo-propulsion plans that address IHPTET goals in their respective military market segments. National investments among the various technology demonstrations and technology efforts are allocated in proportion to their respective contribution to meeting IHPTET goals.

(1) Technology Demonstrations. Technology demonstrations for IHPTET are divided into the three fundamental classes of gas-turbine engines: man-rated turbofan/turbojet (TF/TJ) engines for fighter/attack/strike applications; man-rated turboshaft/turboprop (TP/TS) engines for transport/patrol/helicopter applications; and expendable/limited-life engines for cruise missile and UAV/UCAV applications. In all cases, the technology demonstrations have two broad objectives. First is to evaluate, in an actual engine environment, individual component performance resulting from the synergistic effect of each technology acting upon the other. These results form the basis for demonstrating the achievement of the IHPTET performance and cost reduction goals, and help guide further component technology development. The second objective is to credibly validate that the desired component life is achievable—through a combination of modeling and testing—to ensure that the desired durability can be reproduced in other configurations (i.e., only single-point results are demonstrated).

Turbojet/Turbofan Engine Class TD. This technology demonstration fulfills DTO AP.08, Fighter/Attack/Strike Propulsion. Individual TF/TJ core components (high-pressure compressor, combustor, and high-pressure turbine) are assembled in building-block fashion in the highly instrumented advanced turbine engine gas generator (ATEGG) effort. Ultimately, the remaining components (low-pressure fan, low-pressure turbine, exhaust nozzle, and controls/accessories) are added to the ATEGG core and demonstrated in the Joint Technology Demonstrator Engine effort.

Turboshaft/Turboprop Engine Class TD. This TD fulfills DTO AP.09, Transport/Patrol/Helicopter Propulsion. Individual TS/TP components are also assembled in building-block fashion, and the demonstration occurs in a gas generator configuration within the Joint Turbine Advanced Gas Generator effort.

Expendable/Limited-Life Engine Class TD. This TD fulfills DTO AP.10, Cruise Missile/UAV Expendable Propulsion. Individual expendable components are also assembled in building-block fashion, and the demonstrations are in a full engine configuration within the Joint Expendable Turbine Engine Concepts effort.

(2) Technology Development. Technology advances in all of the constituent areas of a gas-turbine engine are required to achieve the IHPTET performance and cost reduction goals. The IHPTET goals are to be achieved without compromise to component lives (e.g., 2,000-hour hot section/4,000-hour cold section for the TF/TJ engine class). These constituent areas, identified in the six technology efforts below, are the basis for individual technology development efforts that address specific time-phased objectives that, when achieved, will collectively result in achievement of the IHPTET goals.

Compression Systems. Compression systems consist of fans, compressors, and internal (secondary) flow systems. The major advances required in compression systems are increases in efficiency, increases in specific output of a compression stage (measured by stage loading), reductions in weight, reductions in leakage flows, and operation at higher compressor exit temperatures.

Combustion Systems. Combustion systems are divided into two areas: combustors and augmentors. For combustors, the major advances required are increases in both inlet and outlet temperature capability, reductions in weight, and reduced cost. For augmentors, the major advances required are increases in temperature capability, reductions in weight, and increased efficiency.

Turbine Systems. Turbine systems include turbine vanes, blades, shrouds, disks, cases, support frames, and internal cooling flow hardware. The major advances required for turbine systems are increases in temperature capability, reductions in cooling flow requirements, increases in work done per stage (measured by work produced per unit mass flow), and increases in thermodynamic efficiency.

Exhaust Systems. Exhaust systems include exhaust nozzles, associated structure, and signature reduction features. The major advances required for exhaust systems are decreases in weight for both treated and untreated nozzles, reductions in leakage, and improved functionality in thrust vectoring.

Controls and Accessories. Controls and accessories include the engine fuel management systems, engine/nozzle variable geometry controls, and associated pumps, valves, piping, sensors, actuators, cabling, and digital control computers. The major advances required for controls and accessories are improved control system functionality (thrust vectoring, stall/surge control), and significant reductions in component and control subsystem weight.

Mechanical Systems. The primary components of mechanical systems are bearings, seals, shafts, gearing, and lubrication systems. The major advances required for mechanical systems are increases in the temperature capability of lubricants, increases in the speed capability of bearings and air and oil seals, efficient methods of rotor thrust control, and reductions in weight.

(3) Basic Research. IHPTET places a high priority on the quality, content, support, and successful conduct of basic research. The products of the basic research represent significant independent contributions to the national technology base and are normally intended to achieve new knowledge and understanding, develop and maintain technical expertise/capability, and provide new options and approaches for future efforts. Current focus is in the areas of turbine aerodynamic research, turbomachinery fluid mechanics, and combustion research to support gas-turbine engine development.

4. Aircraft Power

a. *Warfighter Needs*

Efficient and reliable aircraft power is needed to support all aircraft applications and mission requirements. In 1998, under an initiative called the More Electric Aircraft (MEA), the ability to eliminate the need for a central hydraulic system through electric power was technologically demonstrated. MEA showed a 2.5X increase in aircraft electrical system reliability, a 50% reduction in engine bleed air, and a 100% increase in power system fault tolerance. By 2005, technology will demonstrate a 2X increase in power densities for the integrated power unit; environmentally safe 28-Vdc batteries; 10-year-life, high-power-density, 270-Vdc batteries (>1 kg/kW); no airframe-mounted gearbox; a 20X increase in electrical power system reliability; a 2X increase in power reliability; and a 200% increase in power system fault tolerance for electric flight control and brake actuation systems. This program will push superconducting generator performance from 0.08 kg/kW at 30 K to 0.03 kg/kW at 80 K thereby providing the electric power needed for visionary directed-energy weapon (DEW) systems.

Additional long-term operational payoffs for electrically driven aircraft functions include the equivalent of 60/129 additional aircraft (F–16/F–18, respectively) in a 30-day war due to increased reliability, 15% reduction in maintenance manpower needs, 20% reduction in deployment loads due to reduced ground support equipment, 15% aircraft vulnerability reduction, and reduction to a two-level maintenance of flight actuation subsystems (no hydraulic maintenance). Environmental payoffs include the elimination of aircraft hydrazine usage, a significant reduction in hydraulic fluid and associated cleaning solutions (and, thereby, the need for disposal), and reduction in battery disposal due to an increase in useful life. These reliability, maintainability, and life-cycle cost improvements directly support the JWSTP capability objective of the Joint Readiness and Logistics area and the focused logistics operational concept within Joint Vision 2010.

Predecessor technologies have had an excellent historical record of transition success. Recent examples include transition of battery technology to the E–8, electric equipment to the C–130J, and MEA generation I power technologies to JSF. Additional mid-term transition opportunities include the F–16, F–18, F–22, and B–1 systems. These "accelerated transitions" directly support the strategic investment priorities as stated in the *Defense Science and Technology Strategy*.

b. *Overview*

(1) Goals and Timeframes. The DoD aircraft power program represents a focused development of electrical power technology to significantly reduce costs and improve mission capabilities for DoD aircraft. This is being accomplished by developing new, electrically based, system-level approaches and new technologies that are more reliable, lower in weight, and lower in cost than existing systems. Specific component improvements are in development to achieve the goals listed in Table I–8.

Table I–8. Aircraft Power Goals

Fiscal Year	Goal
2000	0.08 kg/kW, 1-MW synchronous high-temperature superconducting generator at 30 K
2005	2X increase in integrated power unit power density (300 kW/ft^3, 400 hp/ft^3), environmentally safe 28-Vdc batteries, high-power density 270-Vdc batteries (>1 g/kW), no airframe-mounted gearbox, 20X increase in power system reliability, 0.05 kg/kW, 1-MW synchronous high-temperature superconducting generator at 50 K
2012	300-400 Wh/kg life of aircraft 270-Vdc batteries, 0.03 kg/kW, 1-MW synchronous high-temperature superconducting generator at 80 K.

(2) Major Technical Challenges. This activity includes development within four power technology efforts, each with its own unique technical hurdles: power generation, power distribution, energy storage, and systems integration. Power generation focuses on increasing reliability and power density for main power and auxiliary/emergency power. Power distribution focuses on increasing the operating temperature for power management and distribution equipment and electrical components, as well as on increasing efficiency, power density, and fault tolerance. Energy storage concentrates on improved battery electrochemistry and packaging to increase energy density, reliability, and battery life, while reducing size, weight, and environmental impact. Systems integration focuses on combining component technologies—through modeling and demonstration—to enhance reliability and fault tolerance. The electric power technologies under development enable all future DEW systems for DoD.

(3) Related Federal and Private Sector Efforts. The electrically based aircraft power program is coordinated with many related efforts across government and industry. The More Electric Initiative Joint Planning Group, chartered by the Joint Aeronautical Commanders' Group and headed by the Air Force, serves to unify planning and service-specific implementation of the conversion of military systems to electric drive. This team focuses electrical technology for the Air Force's aerospace power and Alternative Fueled Vehicle System Program Office, the Army's electric tank program, the Navy's electric ship and submarine programs, and NASA's power-by-wire/fly-by-light commercial aircraft program. Another beneficial partnership takes place with the Interagency Advanced Power Group, which coordinates all government electrical component activities. Additional close collaboration occurs with the DoD IHPTET program, Air Force Air Vehicles Directorate's electric actuation programs, and the fixed-wing vehicle subarea. There is continuing coordination with DARPA and DOE electric vehicle programs, as well as the U.S. Council for Automotive Research consortium's electric vehicle development activities.

c. *S&T Investment Strategy*

In developing aircraft power, emphasis is maintained on specific technology demonstrations in order that the technology effort at the component level can be focused. National investments among the various technology demonstrations and technology development efforts are allocated based on their potential payoff to warfighting needs and their relative contribution to achieving aircraft power goals.

(1) Technology Demonstrations. There are three technology demonstrations in aircraft power, one of which was successfully completed in FY98. Objectives are to evaluate integrated component behavior in realistic environments, validate that the technology is sufficiently developed and understood to be transferred to new aircraft power developments, and improve existing aircraft power capabilities.

Power Management and Distribution for the MEA TD. This TD addresses the needs of DTO AP.11, Aircraft Power (MEA). It develops a ground-based demonstrator to integrate and test a 270-Vdc fault-tolerant electrical power distribution system. This system has immediate application to the F–22, F–16, F–18, UCAV, and all other future military and commercial aircraft.

More Electric Aircraft Technology Validation (MTV) TD. This TD addresses the needs of DTO AP.11, Aircraft Power (MEA). The MTV program is a joint effort between the Air Force, NASA (both Dryden and Johnson Space Center), and Navy. The objective is to integrate an advanced electrical power system, vehicle management system, and high horsepower actuator for flight validation. The test results of this validation program will serve for both aircraft and spacecraft applications. At completion, this effort will lead to the development of an MEA-based national asset testbed for validation of future MEA technologies that are developed.

(2) Technology Development. Technology advances in the area of aircraft power are required to achieve the aircraft power goals. The aircraft power area is represented by numerous individual technical efforts that are aimed at specific technology objectives. The achievement of these objectives collectively results in meeting aircraft power goals and enabling development of revolutionary weapon systems for DoD. The MEA concept integrates four technology efforts:

- *Power generation*—availability of high-temperature, high-strength magnetic materials for generators; improving the life of electronic components; improving high-temperature tolerance of electronic components; incorporating passive high-heat-flux thermal management techniques; integrating turbo-electric machinery; and controlling power unit rotor dynamics.
- *Power distribution*—thermal management via passive cooling techniques, reducing fault sensing/switching/reconfiguring times, reducing solid-state device leakage currents and "on-state" resistance at high temperatures, increasing diode operation temperatures and speed, and maintaining the scalability of performance with changes in power density.
- *Energy storage*—lightweight battery materials of construction, charge control under uncontrolled temperatures, development of viable high-energy cathode materials, extreme low-temperature operation, and lithium anode rechargeability.
- *Systems integration*—maintaining close current/voltage tolerances, minimizing electromagnetic interference, minimizing the weight and volume of redundant systems, optimizing thermal management, system integration to meet form–fit–function and power density for user, and system-level implications of high-power use.

(3) Basic Research. Aircraft power places a high priority on the quality, content, support, and successful conduct of basic research. The products of the basic research represent significant independent contributions to the national technology base and are normally intended to achieve new knowledge and understanding, develop and maintain technical expertise/capability, and provide new options and approaches for future efforts. Current focus is in the areas of optical measurement techniques, improved plasma-based deposition processes, partial discharge in gases and organic media as a means of simulating high-altitude electrical component behavior and life-limiting phenomena, high-temperature magnetic materials, and high-temperature superconductivity. This research directly supports the development of advanced, electric-based weapon systems for manned and unmanned aircraft.

5. High-Speed Propulsion and Fuels

a. *Warfighter Needs*

Realizing the potential payoff for high-speed airbreathing propulsion and high-heat-sink (HHS) fuels will enable a major step increase in weapon system performance and cost effectiveness. Technology development efforts will enable revolutionary systems that provide long-range, rapid-response capabilities that support the Joint Vision 2010 operational concepts of dominant maneuver, precision engagement, and full-dimensional protection. Achieving the program goals enables the development of revolutionary systems that satisfy a number of JWSTP area needs such as Precision Force, Counter Weapons of Mass Destruction, Joint Theater Missile Defense, and Joint Readiness and Logistics. Within each service, high-speed propulsion technologies are key to the viability of high-payoff concepts that resolve known warfighter deficiencies. Such deficiencies and concepts are documented in operational command documents (e.g., mission needs statements, USAF MAJCOM mission area plans, development plans).

Ramjet missile propulsion systems will revolutionize air combat and surface strike warfare. Ramjets nearly double missile engine total impulse over conventional solid rocket motors. As a result, twofold to fourfold improvements in aircraft air combat exchange ratios are attainable through revolutionary improvements in air-to-air missile (AAM) kinematic capabilities. System concepts highly rated by the warfighters include the dual-range AAM, which will face emerging foreign systems propelled by ramjet engines. Relative to rocket propulsion, the ramjet propulsion state of the art offers 2X missile average velocity, +30% launch range, 2X no-escape range, -30% time-to-missile-active-seek range, and -30% time to target. To maintain superiority over emerging threats, these values will have to be improved (e.g., average velocity of ~5,000 ft/s). Additionally, high-speed strike missile concepts using ramjets provide at least 4X increase in penetration energy against hardened or deeply buried targets, with up to 1,000-nmi standoff ranges. Emerging Air Force and Navy requirements, such as a replacement for the high-speed antiradiation missile, favor the Mach 4–6 speed available from ramjet propulsion systems. Overall, analyses have shown that ramjet-propelled missile systems can provide a 30X increase in weapon effectiveness over fielded systems.

Advanced/combined-cycle engine (CCE) propulsion systems offer enormous payoffs for future missiles, aircraft, and access to space. These systems, whether rocket, turbine, or pulse detonation-based, offer the advantage of self-acceleration (eliminating the need for strap-on or integral rocket boosters) and in the case of weapons applications, the ability to maneuver subsonically while acquiring/destroying the target. When integrated into piloted aircraft, these propulsion units will enable tripling unrefueled tactical aircraft ranges (from 300–500 nmi to 1,000–1,500 nmi) without increasing mission flight times. The Air Force’s hypersonic multirole fighter concept will rely on a Mach 5 turboramjet. Faster CONUS-based aircraft, such as a hypersonic global range reconnaissance/strike aircraft, will be able to reach any military target in 1 to 2 hours. The Navy is interested in the potential of turbine-based CCE propulsion for a Mach 4–6 strike weapon capable of attacking time-critical targets, either fixed or mobile, at ranges in excess of 300 nmi. In order to attack mobile targets while moving, it may be advantageous to slow to subsonic speed and acquire the target autonomously. Combined cycle engines offer this flexibility.

Scramjet (SCRJ) propulsion systems can resolve documented warfighter range, timeliness, and survivability deficiencies. Fast-reaction standoff weapons using Mach 8 hydro-carbon-fueled SCRJ engines will provide a rapid-response weapon capability to counter highly mobile, Scud-type weapons from 300 nmi in less than 5 minutes or to strike high-value, well-defended targets 1,000 nmi away in 15 minutes. The Air Force favors a SCRJ-propelled, fast-reaction standoff weapon that will be small enough to carry on an F–15E, yet will carry a payload of up to 500 lb. Other high-payoff SCRJ and CCE applications include trans-global aircraft and reusable single-stage- and two-stage-to-orbit launch vehicles. Compared to rocket-powered systems, launch windows can be increased by an order of magnitude—10 hours versus 1 hour—as well as improving ascent maneuverability and launch flexibility for military surveillance missions. Further, air-breathing propulsion for the first stage of two-stage-to-orbit systems, staging at Mach 8, could cut total launch system weight by a factor of two compared to all rocket systems.

Advanced propulsion systems (turbine, ramjet, scramjet, etc.) require high heat sink (HHS) fuels to provide cooling for structural integrity, life, and durability as well as advanced chemical and physical properties to improve operating characteristics over the entire flight envelope. Some advanced propulsion systems will require advanced fuel technologies to enhance ignition and combustion, reduce emissions and signature, and provide more “energetic” materials for wider operating windows. Fuel is also the heat transfer fluid for the thermal management of all aircraft subsystems. Advanced fuels research builds on the lessons learned during the development of JP–8+100, which increased the thermal stability of JP–8 by 100°F and increased fuel heat sink by 50%. Higher heat sink fuels such as JP–8+225 and JP–900 enable the development of improved cooling of the cooling air systems to improve turbine engine performance and durability and structural cooling for some hypersonic applications. Endothermic variants of these fuels enable the development of hypersonic propulsion systems where high heat fluxes must be accommodated and more low molecular weight energetic fuel fractions are required for combustion. The HHS potential of these improved fuels will use advanced additive technology so that the existing logistically supportable commercial kerosene fuel base can be converted into the high-performance fuels required by DoD.

b. *Overview*

(1) Goals and Timeframes. High-speed propulsion and fuels technology programs will achieve the goals shown in Table I–9. High-speed propulsion goals are referenced to the demonstrated state of the art for scramjet missile and larger air vehicle applications. HHS fuel goals are based on projected additionally cooled air requirements for IHPTET Phase III engines, scramjets, and other advanced propulsion cycles. JP–8+225 will be available for use in IHPTET Phase III demonstrators by FY03 and could be fielded to provide margin for the JSF in the FY05–07 timeframe.

Table I–9. High-Speed Propulsion and Fuels Technology Development Goals

Fiscal Year	Engine Class	Goal
2001	SCRJ	Freejet demonstration, Isp=700 s, specific thrust = 47 lb_f/lb_m/s @ M = 8
2005	HHS H/CF	2.5X increase in fuel cooling capacity (JP–225), 5X increase with JP–900, 12X increase in fuel cooling capacity (endothermic fuels)

(2) Major Technical Challenges. The challenge is to develop critical enabling high-speed technologies required to support the development of high-speed weapon systems and HHS fuels for all services. Required are simple, reliable, high-performance inlets (including airframe-integrated inlets); combustors that deliver optimum performance for RJs, SCRJs, and advanced CCEs; nozzle/expansion systems that provide thrust over the entire range of vehicle operation; validated high-temperature structural design methods; and materials and fabrication processes for propulsion flowpath components operating for extended periods above Mach 4.

The challenges of HHS fuel development is to develop advanced fuel additives to eliminate autoxidation (JP–8+225) and pyrolysis (JP–900) reactions that form deposits in aircraft fuel systems. The additives must be low cost and easily mixed with commercial kerosene fuels. Fuel system and component technology that can operate under high heat fluxes, variable fuel properties (density, viscosity, etc.) in the liquid, supercritical, and vapor state also offer significant challenges for the exploitation of the benefits of HHS fuels. Advanced propulsion systems may require additives that enhance combustion, increase energy content, or reduce signature and emissions. This revolutionary fuel additive requirement will enable the fuel performance on both the airframe and the propulsion system over the entire propulsion systems flight envelope.

(3) Related Federal and Private Sector Efforts. In addition to the Air Force Hypersonic Technology (HyTech) program, the Navy and DARPA have ongoing efforts to develop and demonstrate hypersonic cruise missile technologies. The Navy, under their Hypersonic Weapons Technology (HWT) program, is developing and demonstrating a hydrocarbon-fueled, dual-combustor ramjet that can operate up to Mach 6. Additionally, the HWT program is developing the broader range of technologies (e.g., guidance, air vehicle) to field a hypersonic cruise missile. The HWT goals are tied to Navy unique requirements imposed by ship vertical launch systems. DARPA's Affordable Rapid Response Missile Demonstrator (ARRMD) is focused on demonstrating an affordable hypersonic cruise missile. ARRMD has a unit cost goal of <$200,000 per missile. Unlike HyTech and HWT, ARRMD concentrates on the flight test demonstration of hypersonic propulsion rather than on developing and extending the propulsion technology base. ARRMD leverages efforts in both the Air Force HyTech and the Navy HWT programs. Both the Navy HWT and the DARPA ARRMD programs are described in the Weapons DTAP. Additionally, an integrated roadmap is being developed.

NASA has research efforts in advanced CCEs and SCRJs that are closely coordinated or integrated with DoD. NASA and DoD participate jointly in the development of advanced/CCE and SCRJ propulsion systems. Commercial access-to-space programs are providing new dual-use opportunities for both DoD and NASA.

In the fuels area, to address congressional concerns regarding future fuel availability, DoD is working cooperatively with DOE to develop high-temperature, thermally stable fuels from coal.

c. *S&T Investment Strategy*

The focus of this subarea is to maintain specific technology demonstrations in order to demonstrate the technology effort at the component level. National investment among the various technology demonstrations and technology efforts is allocated with their potential payoff to warfighting needs and its relative contribution to achieving high-speed propulsion and fuel goals.

(1) Technology Demonstration. The integrated propulsion system technology demonstrators are divided into three families: ramjets, scramjets, and high-temperature fuels. HHS H/CF demonstrations are integrated into applicable engine demonstrators. The knowledge obtained from the demonstrators will provide additional direction for all future exploratory efforts. Additionally, the results will enable the confident transition of technology.

Ramjet TDs. The major challenge is demonstrating propulsion system performance over representative flight envelopes (speed and altitude). RJ components are initially ground demonstrated as individual components and then integrated into full engine ground testing. The most recent program of this type was the Navy's Fasthawk missile ATD, which was slated for flight test (reported through Weapons TARA). The program was canceled by N–091 in October 1998.

Scramjet TDs. These demonstrations fulfill DTO AP.17, Hydrocarbon Scramjet Missile Propulsion. The major challenge is to demonstrate integrated SCRJ system performance over representative flight envelopes (speed and altitude). Scramjet demonstrator engines will be built upon exploratory development work in the area of storable-fuel, dual-mode RJ/SCRJ technology and will include both sub- and full-scale ground test engines using storable H/CF.

High-Temperature Fuels TDs. DTO AP.18, Improved JP–8 Fuel, has demonstrated that the thermal stability of JP–8 can be increased by 100°F and heat sink by 50%. This program will be concluded in FY99 and has been successfully transitioned to all Air Force fighter and trainer aircraft. AP.19, High-Heat-Sink Fuels, will be demonstrated in laboratory rigs, engine component simulators, reduced scale fuel system/engine demonstrators, and IHPTET engine demonstrators. Evaluations of the improved fuel in current operational aircraft components, engines, and actual aircraft will be required to successfully field this technology.

(2) Technology Development. *Air-Induction Systems.* The air-induction system consists of the engine air inlet and the internal compression region to interface with the engine. Major advances are required to increase overall inlet pressure recovery while minimizing system bleed, reducing system length and weight, and attaining acceptable starting characteristics, flow quality, distortion, and turbulence at the combustor entrance.

Combustors and Ramburners. This area includes ramjet and scramjet combustion systems. Major advances are required to significantly increase combustion efficiencies, increase combustor operability range, and develop technologies to improve fuel vaporization, fuel kinetics, combustor piloting and flameholding, and controlled heat release.

Nozzle/Expansion Systems. This area includes single expansion ramp and conventional axisymmetric nozzles. Future exhaust system technology needs include lightweight, high-temperature nozzle materials and structures, advanced nozzle cooling techniques, increased nozzle efficiencies, variable geometry, and high levels of vehicle integration.

Fuels and Fuel Systems. This area includes JP–8+100, JP–8+225, and JP–900 fuels and endothermic variants of these fuels, controlled chemically reacting fuels for aircraft and high-speed propulsion systems, and the associated fuel system technology to utilize these fuels as coolants. Major advances in fuel additives to improve thermal stability (and cooling capacity), ignition, and combustion and to reduce signature and emissions are required. Advanced fuel system components will be developed to exploit the cooling potential of HHS fuel.

Structures and Materials. This area includes structural design methods, thermal loads, and material and fabrication processes for flowpath components of high-speed propulsion systems. Major advances are required to validate the structural integrity and environmental tolerance of the principal flowpath components of high-speed propulsion systems—such as actively cooled panels, cowl and strut leading edges, fuel injectors, and seals—to operate for extended periods above Mach 4.

(3) Basic Research. High-speed propulsion and fuels place a high priority on the quality, content, support, and successful conduct of basic research. The products of the basic research represent significant independent contributions to the national technology base and are normally intended to achieve new knowledge and understanding, develop and maintain technical expertise and capability, and provide new options and approaches for future efforts. Current focus is in the areas of combustion, supercritical fuels, vapor-phase lubricant mechanisms, and scramjet propulsion.