THE VERSATILE AFFORDABLE ADVANCED TURBINE ENGINES (VAATE) INITIATIVE

An AIAA Position Paper

Authored by the

AIAA Air Breathing Propulsion Technical Committee

And approved by the

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EXECUTIVE SUMMARY

The aircraft gas turbine engine has played a preeminent role in establishing and maintaining the air dominance that U.S. military forces have enjoyed for many years. Future warfighter requirements continue to drive us to more capable, durable, and cost-effective aircraft systems. Although these systems can be achieved only through even greater advancement in jet propulsion capability, U.S. DOD investment in turbine engine research has been drastically reduced over the last few years. Unless this trend is reversed, we will be unable to meet the requirements of the military's new transformational environment.

The Versatile Affordable Advanced Turbine Engines (VAATE) program provides the framework for addressing future turbine engine needs. The program will advance technologies applicable to both military and commercial aviation engines, including turbofan/turbojet engines, turboshaft/turboprop engines, engines for unmanned air vehicles, and expendable missile engines. The technologies planned for development and transition by VAATE are essential to providing U.S. armed forces the ability to conduct their missions in an effective, timely, and affordable manner, and to do so with minimal human cost. VAATE also enables synergy between military and commercial aircraft designs; the VAATE roadmap takes full advantage of the fact that both types of applications need similar propulsion technologies.

VAATE is modeled after the very successful Integrated High Performance Turbine Engine Technology (IHPTET) program, of which AIAA has been a strong proponent[1]. IHPTET concluded in 2005 after significant progress toward very aggressive goals. Despite this progress, there still remains substantial potential for turbine engine improvement. Specific improvements to be achieved through VAATE include:

- 200% increase in engine thrust-to-weight ratio (a key jet engine design parameter)
- 25% reduction in engine fuel consumption (and thus fuel cost)
- 60% reduction in engine development, procurement, and life cycle maintenance cost

VAATE will build on a key feature that made IHPTET so successful – an integrated technology plan between the DOD, NASA, DOE, academia and industry. This approach will allow VAATE to implement strategy at a national level with leveraged funding of the constituent organizations. VAATE features well-developed technology roadmaps leading to high-fidelity hardware demonstrations, and subsequent technology transition into fielded or developmental engines.

Since VAATE is vital to maintaining national defense readiness and keeping the U.S. technological lead in gas turbine propulsion, it is imperative to fully fund the VAATE plan now. The AIAA therefore recommends the following key actions:

- Congress and DOD should establish a funding level for VAATE that provides a reasonable chance of success toward achieving program objectives.
- The Armed Services and Appropriations Committees should provide solid and unrelenting support for the VAATE Program until its completion in 2017.

A clear voice of leadership must emerge from Congress to enunciate a viable plan for VAATE advocating acceptance of the essential challenges, providing unequivocal endorsement of the route to its successful accomplishment, and affirming the future benefits to military and commercial aerospace capabilities

BACKGROUND & PROBLEM STATEMENT

Turbine Engines Are a Critical Military Need - The gas turbine-based jet engine has been in existence over fifty years, and today still remains as the dominant element in aeronautics propulsion. Turbine engines power all high-performance combat aircraft and have revolutionized both military and commercial air transport. The turbine engine's impact is such that nearly every breakthrough in aircraft capability since World War II in some way traces to propulsion advancement. Turbine engines also power many land and sea-based military vehicles, and even drive ground-based electrical generation facilities. In the foreseeable future, there is no known propulsion architecture that will replace the gas turbine engine.

In the earliest days of aviation, pioneers realized that lighter and more powerful engines were essential to meet emerging requirements. It is no different today as both military and commercial objectives require us to fly farther, faster, and higher, all while achieving lower costs and improvements in noise and pollutant emissions.

Over the last several decades, the U.S. gas turbine industry has led the world in development of breakthrough engine technology. Propulsion technological superiority has in turn led to the air dominance that U.S. armed forces have enjoyed in recent conflicts. Future military requirements continue to drive us toward more capable, durable, and cost-effective aircraft systems; yet these systems can be achieved only if propulsion capability continues to advance. A robust U.S. aeronautics propulsion research program is necessary to accomplish these improvements in an affordable and timely fashion. Such a program is critical for national security interests.

Improvements Are Needed to Address Future Warfighter Requirements - The U.S. armed force vision for future aviation is to enable the warfighter to anticipate, find, track, target, engage, and assess any target at any time and anywhere. To accomplish this, weapon systems are needed that are capable of persistent and responsive Intelligence, Surveillance, and Reconnaissance (ISR), extreme endurance, responsive strike, persistent attack, global reach, multi-role mobility, and responsive space access.

Many mission requirements of these future weapon systems simply cannot be achieved without propulsion advancements. For example, a responsive strike aircraft should have twice the range at half the aircraft unit cost of current systems. Certain Unmanned Combat Air Vehicle (UCAV) concepts require 2.5 times the mission radius or 3 times the mission persistence (loiter time) of today's manned vehicles. For access to space, a fuel-efficient, on-demand turbine engine accelerator up to a speed of Mach 4+ is required. Such capability does not exist today. For multi-role mobility, a future aircraft must be capable of Short Take-Off Vertical Landing (STOVL) with a 2-to-4 times mission radius increase over today's conventional take-off aircraft.

To meet these mission requirements, future turbine engines must feature improved performance as well as reduced cost. Necessary performance improvements include increased thrust, lower fuel consumption, lower weight, improved durability, and lower exhaust noise and pollutant emissions. Cost reductions must be realized at all program phases – development, procurement, and operations and support.

Current Turbine Engine Research Investment Is Inadequate - Department of Defense funding for turbine engine research and development was sufficient to enable major advances in capability until FY04. Most of this funding came through the U.S. Air Force (USAF). Beginning in FY04 and continuing in FY05, USAF funding for turbine engine technology programs was dramatically reduced – a 35% reduction between those two years. This cut was not replaced by other services. The erosion of DOD funding has led to subsequent reductions in corporate discretionary R&D investment, thereby hurting overall progress even more.

On our current funding path, turbine engine research and development will be reduced to a level that may cause the U.S. to forfeit its leadership in the global $200B turbine engine market. Although most of this market is now commercial engines, the military technology investment is an important factor behind U.S. market share. Since 1970, the European share of the market has increased considerably, from 12% to over 36% in 2002. Continual reduction in Air Force turbine engine technology funding is endangering our technological superiority, threatening our share of the engine market, and risking job loss and critical skill erosion in our 100,000 strong U.S. turbine engine workforce. This situation can be reversed only by improved turbine engine research and development funding.

The Commission on the Future of the United States Aerospace Industry[2] recommended in its November 2002 final report that the federal government significantly increase its investment in basic aerospace research. The Commission went on to say that investment "enhances U.S. national security, enables breakthrough capabilities, and fosters an efficient, secure, and safe aerospace transportation system."

The U.S. Must Maintain International Technology Leadership - It is vital that the U.S. continue to be the international leader in gas turbine engine technology and manufacturing. This need arises from both military and commercial concerns. Propulsion advancement is required to maintain battlefield air dominance in future conflicts, and to minimize the economic and human costs of those operations. Engine technology is also at the forefront in addressing the aggressive noise and exhaust emissions goals that will govern commercial air transport and peacetime military operations. These environmental goals are being developed through international consensus, and will have a huge effect on the design and utilization of future aircraft.

As our economy (and the propulsion industry) becomes more global in nature, the U.S. needs to take a leadership position in establishing environmental goals to ensure that our interests are protected. This can be done only with the influence that a steady, aggressive, and productive gas turbine engine research program yields, and with U.S. research community participation and leadership at both international and national technical symposia. Furthermore, with a global economy, domestic engine manufacturers face ever-increasing competition for sales. A robust technology program will enable our products to remain internationally competitive, thereby retaining market share and economic health for the U.S. gas turbine industry. A healthy commercial industrial base will in turn benefit the military since many base technologies, and often engines themselves, are common between sectors.

Propulsion Investment Requires Time to Pay Off – Because of the complexity and sophistication of modern jet engines, new technologies often take 10-15 years to travel from laboratory environment to production. For example, today's newest combat aircraft, such as the F-22 Raptor, are only now fielding propulsion technologies first envisioned in the early 1990s. Fortunately, propulsion technology advancement has continually proven robust against changing aircraft system-level requirements -- higher thrust, better fuel consumption, and lower development, procurement, and operating cost are of great value regardless of the exact aircraft application.

Reductions in propulsion Science & Technology (S&T) funding are tempting, because the pain may not be felt immediately. However, that pain will be extreme in the next decade if decisions today result in the loss of U.S. turbine engine leadership. Consistent and continued S&T investment in turbine engine research is required now to sustain the momentum needed to keep our technological advantage in the future.

SOLUTION

VAATE Provides the Framework to Address Future Turbine Engine Needs - VAATE, the Versatile Affordable Advanced Turbine Engines Program, is the technology-based research and development effort that addresses all concerns identified above. Initiated in 1999, VAATE is a joint DOD, National Aeronautics and Space Administration (NASA), Department of Energy (DOE), and industry effort, and is led by a joint Government/Industry Steering Committee.

VAATE's Vision Statement captures the essence of the program: "To develop, demonstrate, and transition **advanced** multi-use **turbine engine** technologies that provide a revolutionary improvement in **affordability** to a broad range of legacy, pipeline, and future military propulsion and power needs, with explicit **versatility** for dual-use applications." VAATE is designed to address not only classic turbine engine component improvements, but also the changing requirements of propulsion systems specifically towards higher altitude and long endurance applications.

The VAATE Plan, described herein, has been lauded as the model for future turbine engine research, and received strong endorsement from The Commission on the Future of the United States Aerospace Industry, which stated: "VAATE; a model for public-private partnerships."

VAATE's Single Goal is A Tenfold Improvement in Affordable Capability – The evolving demands being placed on our military will dictate a future force structure that must be leaner and less expensive, but also more versatile, lethal, and survivable. The VAATE program goal reflects these requirements, specifically, that by 2017 the military user will realize a factor of ten ("10X") improvement in turbine engine-based propulsion system affordable capability. "Affordable capability" is defined as the ratio of propulsion system capability to cost. "Capability" in this context measures technical performance parameters including thrust, weight, and fuel consumption. "Cost" quantifies the total cost of ownership, and includes development, procurement, and life cycle maintenance cost. These improvements are to be realized relative to a baseline representative of year-2000 state-of-the-art systems.

The VAATE program addresses numerous military and commercial aviation engine classes including turbofan/turbojet engines, turboshaft/turboprop engines, engines for unmanned air vehicles, and expendable missile engines. Specific measurable technical improvements, or "goal factors," have been identified for each class of engine so that progress toward the overarching 10X goal can be measured. Examples of goal factors for the large turbofan/turbojet class include:

- 200% increase in engine thrust-to-weight ratio (a key jet engine design parameter)
- 25% reduction in engine fuel consumption (and thus fuel cost)
- 60% reduction in engine development, procurement, and life cycle maintenance cost

VAATE Is Organized into Three Specific Focus Areas - VAATE is organized into three broad Focus Areas of interest. For each area, detailed technology roadmaps have been developed that, taken together, lead to achieving the 10X program goal. Each roadmap features maturation of an array of technologies and culminates in high-fidelity hardware demonstrations that render each technology ready for transition into a large-scale engine development program. The three VAATE Focus Areas are: (1) Versatile Core, (2) Intelligent Engine, and (3) Durability.

The Versatile Core Focus Area concerns the most fundamental part of a gas turbine propulsion system, the engine "core." Within the core, engine pressure, temperature, and rotational speed reach maximum value, as do the resultant thermodynamic and structural design requirements. The core is the heaviest, most complex, and highest cost component of the propulsion system – and thus a component where technology advancement has great payoff. In addition to fuel consumption, thrust, and emissions improvements, Versatile Core technologies will reduce engine cost by allowing engines optimized for different applications to be built around identical core hardware. In one scenario, the engines for a large subsonic transport aircraft would have significant parts commonality with that for a high-performance supersonic fighter, thereby spreading nonrecurring costs over a larger customer base. Such explicit emphasis on dual-use capability will increase competitiveness of U.S. products in the demanding civil market.

The Intelligent Engine Focus Area concerns achieving the maximum utility from the engine through improved engine control systems, advanced prognostics and health maintenance, and integration of the engine, airframe, and power management subsystems. Advanced engine architectures utilizing pulse detonation combustion or hybrid gas turbine/fuel cell concepts will also be examined. By focusing on the Intelligent Engine area, VAATE allows capture of benefits that can be realized only through air vehicle system-level optimization of propulsion and power architectures and hardware.

The Durability Focus Area concerns reducing engine maintenance and part replacement costs by doubling component life while providing a significant increase in hot-time capability. Durability improvements are pervasive and not only benefit future systems, but also can often be retrofitted into legacy aircraft engines. An additional aim of this Focus Area is to prevent component failures, increase engine life and reliability, enhance reparability, and improve system readiness.

Success of IHPTET Provides Credibility to the VAATE Program Plan – The Integrated High Performance Turbine Engine Technology (IHPTET) program, the forerunner of VAATE, has successfully concluded after several years of progress toward very aggressive goals. To date, through coordinated DOD and industry effort, IHPTET has validated numerous revolutionary propulsion technologies that are providing performance, durability, and cost improvements for new aircraft systems and significant upgrade potential for currently fielded systems. One example of a capability derived from IHPTET technology is the ability of the new F-22 fighter to cruise at supersonic speeds without the use of a fuel-hungry afterburner. No other combat aircraft in the world has this capability. IHPTET engine technology will also provide efficient vertical lift for STOVL versions of the F-35 Joint Strike Fighter, and enhanced range and carrying capability for a variety of rotary wing vehicles. IHPTET is considered a model program because it addressed critical defense technology objectives, developed dual-use technologies, had well-defined goals with attendant milestones, relied upon close coordination between government, industry, and academia, and provided continuous technology transition opportunities through its phased approach as well as significant performance and mission capability improvements for current and future weapon systems.

VAATE has been structured to take advantage of the features that made IHPTET so successful. These include coordination among DOD, NASA, academia and industry, with the Federal Aviation Administration and DOE joining the effort as well. The breadth of this integrated team allows the VAATE program to coordinate gas turbine technology development strategy at a national level while leveraging funding of the constituent organizations. VAATE also has an appropriately increased scope over IHPTET in that the entire propulsion system (including airframe components) is considered in the program, rather than just the engine turbomachinery. Toward this end, major aircraft manufacturers are included on the VAATE industry team.

Like IHPTET, VAATE will utilize joint service technology demonstration programs to validate improvements in advanced engine concepts, design tools, performance, life, and cost. Technology demonstrator engines provided low-risk technology transition, resulting in high readiness and increased safety and performance for the warfighter.

VAATE Offers an Advanced Construct over IHPTET – Although based on the success of previous programs, VAATE **is not** a continuation of IHPTET. Whereas IHPTET focused on bottom-up component technologies for engine performance improvement, VAATE will prioritize investments by emphasizing a top-down, air vehicle system-level approach. This approach is embodied in VAATE's organization by Focus Area rather than engine component, and ensured by the program's 10X affordable capability goal, which emphasizes cost in addition to performance. Finally, the VAATE industry team has been expanded over that of IHPTET to include not only the principal U.S. military turbine engine companies, but the aircraft system manufacturers as well. A leading strength of VAATE is its total inclusion of turbine engine developers, producers, and integrators.

The Military Payoff of VAATE – The technologies planned for development and transition by the VAATE program are essential to enabling U.S. armed forces to conduct their missions in an effective, timely, and affordable manner, and to do so with minimal human cost. VAATE's payoffs will be realized both in the long term, for new air systems now on the drawing board, and in the near term, for systems currently fielded (e.g. F-16 and F-18), in production (e.g. F-22), or in the system development phase (e.g. F-35 Joint Strike Fighter).

Various studies have shown that propulsion technology advancement can have an enormous impact on the construct, capability, and cost of future military air power. Future scenarios envision a responsive, lethal, survivable force involving diverse platform requirements such as global strike, uninhabited air vehicles, advanced stealth combat, high Mach cruise, low-cost access to space, and Vertical/Short Take Off and Landing (V/STOL). VAATE will provide these systems with multiple benefits, including increased range, decreased logistics footprint, increased readiness, improved noise, emissions, and observability (stealth), and high speed endurance. For a future U.S. Air Force structure, specific benefits of VAATE-class technology (over that of a year-2000 state-of-the-art baseline engine) include: a 100% improvement in range for a manned fighter; a 200% improvement in range-payload per unit cost for a global reach transport; and a staggering $200+B reduction in life cycle cost for the entire future force structure[3].

VAATE's benefits can also be stated in terms more tangible to the U.S. taxpayers who are becoming increasingly sensitive to the cost of overseas military operations required to suppress terrorism and maintain homeland security. Aviation fuel and engine parts are a large portion of this overall cost. VAATE will directly address this issue by reducing fuel consumption and thus the tremendous cost of fuel consumed for aircraft operations. Reducing consumption at the battlefront has a multiplicative effect down the logistics trail as well. VAATE will also increase durability and reduce required maintenance for engines, thereby reducing engine attrition, parts replacement, and overall support costs. Finally, VAATE technology will improve engine reliability and component failure prediction, thereby increasing safety for pilots in the field. With the pervasiveness of the turbine engine throughout the force structure, VAATE's benefits have the potential to improve performance and reduce cost for essentially every aeronautics platform.

VAATE Enables Synergy between Military and Civilian Sectors and Will Help New Commercial Products Emerge – Numerous dual-use benefits are a key payoff of the VAATE initiative. While VAATE investments are directed primarily toward engines for military aircraft, the component and sub-component technology will be used in many commercial engine applications, as was the case in IHPTET. Conversely, VAATE will pull from the commercial sector by leveraging NASA's work on noise and emissions so that DOD assets will be able to operate all over the world without exceeding civilian environmental and noise regulatory limitations. The VAATE roadmap takes advantage of the fact that there are many areas where commercial and military engines need similar propulsion technologies.

Engine component technologies developed under all three VAATE Focus Areas will have direct and pervasive commercial impact. The concept of the Versatile Core will allow greater hardware commonality between military and commercial applications, thereby reducing cost through economy of quantity sales. Prognostics and health maintenance concepts, developed in the Intelligent Engine area, and many Durability Focus Area products, will be directly beneficial to almost all commercial applications. For example, VAATE's investments in weight reduction, improved maintenance time, and reduced parts count for military engines will have complementary effects on commercial products, leading to operating cost reductions. Likewise, advancements in engine thermal management will impact commercial engine development by enabling a more thermally optimized engine cycle, leading to reduced fuel burn characteristics and hence an overall reduction in fuel cost and pollutant emissions.

VAATE not only will provide benefits to current commercial products, but also will aid the emergence of new and revolutionary air transport and access to space products. Recent successful demonstrations of sonic boom reduction technology may enable viable over-land supersonic commercial flights, leading to an entirely new market of premium air travel. Because of their high specific power requirements, the turbine engines needed to accomplish this mission will be derived from military engines and technologies developed under VAATE. Similar engine technology is necessary to yield viable commercial intra-city Vertical Take Off and Landing fixed-wing aircraft. Following successful demonstrations from the NASA X-43 program, we are now one step closer to a reusable hypersonic flight vehicle and affordable civilian access to space. Numerous technologies proposed for VAATE are the essential foundation for such a breakthrough vehicle class.

VAATE's benefits are "dual-use" not only in terms of military and commercial synergy, but also in terms of payoffs to rocket, marine, ground transport, and other non-aircraft applications. Turbomachinery-based rocket fuel pumps share many technologies with jet engines. As happened with IHPTET, turbine and compressor technologies from VAATE will transition to both traditional and hybrid rocket applications. Turbine engines for ground power generation will benefit from the inherent low pollutant emission characteristics of the advanced combustor designs proposed for VAATE. VAATE will also identify manufacturing and operational process improvements, analytical design tools, intelligent engine control systems, and high-temperature durable materials that will benefit turbine engine end users regardless of application.

The Investment Required for VAATE - The AIAA Air Breathing Propulsion Technical Committee believes that a tri-service funding level of $175M per year, including $145M for the U.S. Air Force, is required to provide a reasonable chance of success toward achieving the objectives of VAATE and its associated demonstration programs. This funding level is consistent with the VAATE technology plan and with IHPTET investment levels prior to 2003.

CONCLUSIONS

Gas turbine engines play an enormous role in establishing U.S. air dominance at the battlefront and are the backbone of the military aviation force that guards our interests both at home and abroad. Turbine engines powered the reconnaissance, transport, and fighter/attack aircraft as well the helicopters, missiles, and many unmanned air vehicles that had great impact in Afghanistan, the Middle East, and other troubled areas of the world. Because of technological superiority gained from programs such as IHPTET, current turbine engines enabled U.S. forces to perform magnificently in these campaigns. To maintain this edge, however, we must meet the increasing demand by our armed forces for more efficient, survivable, and lethal weapon systems. At the same time, we need to make those military systems more affordable to minimize their military impact on our overall federal budget. This can be done only through continual research and development effort in the turbine engine field.

While turbine engine requirements have increased considerably, the DOD funding for new turbine engine research has been dramatically reduced. This trend has to be stopped, and efforts should be made to bolster the development of new turbine engines to meet the requirements of faster, reliable, survivable, and affordable military aircraft. Such investment allows the U.S. not only to maintain its technology leadership, but also to render our commercial products more competitive in the world market, and to enhance our stature as a desirable international team mate.

There is an immediate need for the DOD to invest in turbine engine technologies **now,** since the lead time in this cutting-edge area is 10 to 15 years. With IHPTET having reached successful completion in 2005, a large gap will occur in turbine engine research and development unless a new overarching strategy is adopted. There should be well-defined technology programs put in place now to meet the demands placed on the turbine engines of the future. With the aeronautics investment at NASA on the decline, DOD's leadership is now more imperative than ever.

Recognizing the above needs, The Air Force Research Laboratory, in collaboration with the Navy, Army, DOE, NASA, and turbine engine and airframe industry, has initiated the VAATE program. VAATE's focus is on achieving a tenfold improvement in turbine engine affordable capability in terms of quantifiable capability-to-cost metrics. VAATE's mission is to develop, demonstrate, and transition advanced, multi-use, turbine engine technologies that provide a revolutionary improvement in affordable capability to a broad range of legacy, pipeline, and future military propulsion and power needs, with explicit versatility for dual-use application.

RECOMMENDATIONS

It Is Imperative to Fully Fund the VAATE Plan Now – Recognizing that the VAATE program is vital to maintaining national defense readiness and to keeping the U.S. technological lead in gas turbine propulsion, it is imperative that the program be fully supported. The AIAA therefore recommends the following actions:

- Congress and DOD should establish a funding level for VAATE that provides a reasonable chance of success toward achieving program objectives.

- The Armed Services and Appropriations Committees of the Senate and House of Representatives should provide solid and unrelenting support for the VAATE Program until its completion in 2017. This recognizes the relatively long time scales inherent in any serious aerospace endeavor, transcends possible short-term political concerns, and demonstrably puts the interests of the country first.

- The U.S. gas turbine industry should strengthen its investment in technology development and reaffirm its commitment to long-term employment and guardianship of skilled personnel, educational resources, pursuing an appropriate global market share, and making an invaluable contribution to the national economy.

- The Office of the Under Secretary of Defense (Acquisition), NASA, and DOE should re-establish their strong leadership and oversight of the VAATE Program and advocate its focus on the development and demonstration of high-return turbine engine advancements.

A clear voice of leadership should emerge from Congress to enunciate a viable plan for VAATE, an acceptance of the essential challenges, an unequivocal endorsement of the route to its successful accomplishment, and an affirmation of its future benefits to DOD and commercial aerospace capabilities.

References

(1) AIAA Position Paper, "The Integrated High Performance Turbine Engine Technology (IHPTET) Initiative," August 1991.

(2) Final Report of the Commission on the Future of the United States Aerospace Industry, November 2002.

(3) IHPTET Steering Committee Presentation by Mr. Christopher Norden, "Potential Impact of Propulsion Technology on Affordability of Future Force Structures", Raymond Fredette, Jim Shyder, et al., Technology Assessment Group, Universal Technologies Corporation, August 2000.