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NASA's Advanced Space Transportation Hypersonic Program

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Abstract

NASA's has established long term goals for access-to-space. NASA's third generation launch systems are to be fully reusable and operational in approximately 25 years. The goals for third generation launch systems are to reduce cost by a factor of 100 and improve safety by a factor of 10,000 over current conditions. The Advanced Space Transportation Program Office (ASTP) at NASA's Marshall Space Flight Center in Huntsville, AL has the agency lead to develop third generation space transportation technologies. The Hypersonics Investment Area, part of ASTP, is developing the third generation launch vehicle technologies in two main areas, propulsion and airframes. The program's major investment is in hypersonic airbreathing propulsion since it offers the greatest potential for meeting the third generation launch vehicles. The program will mature the technologies in three key propulsion areas, scramjets, rocket-based combined cycle and turbine-based combination cycle. Ground and flight propulsion tests are being planned for the propulsion technologies. Airframe technologies will be matured primarily through ground testing.

This paper describes NASA's activities in hypersonics. Current programs, accomplishments, future plans and technologies that are being pursued by the Hypersonics Investment Area under the Advanced Space Transportation Program Office will be discussed.

Introduction

NASA's Office of Aerospace Technology (OAT) is focused to encourage revolutionary advances in air and space transportation[2]. The advanced Space Transportation Program (ASTP) at NASA's Marshall Space Flight Center (MSFC) focuses on future space transportation technologies. ASTP's primary goals for third generation launch systems are to reduce cost by a factor of 100 and improve safety by a factor of 10,000 over current conditions. The Hypersonic Investment Area (HIA), one of three investment areas in ASTP, focuses on third generation reusable launch vehicles (RLV). The plan to achieve these challenging goals is to increased design and operability margins to improve hardware robustness by operating well below the hardware design limits. This approach will increase life, reduce maintenance and refurbishment requirements, and improve reliability.

Hypersonics airbreathing systems, along with advancements in vehicle technologies, may allow these challenging goals to be met. The performance advantage of airbreathing propulsion over rocket propulsion is the increase in performance efficiency provided by the airbreathing vehicle. These vehicles provide an increase in propulsion efficiency (see Figure 1), described by specific impulse (I_{sp}). Isp indicates how many pounds of thrust (lbf) are produced per pound of propellant (fuel + oxidizer) mass injected into the engine per second. The increased propulsive efficiency for airbreathing vehicles significantly reduce the propellant required and could enable horizontal takeoff for

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space access. Horizontal takeoff also allows lower thrust loading thereby reducing overall engine weight.

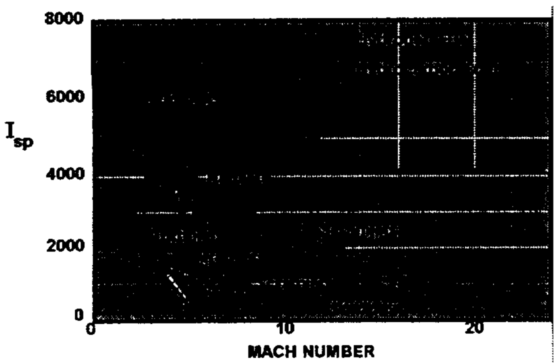

Figure 1. Airbreathing Hypersonic Propulsion Cycles Provide Enhanced Propulsion Efficiency.

Airbreathing propulsion offers a 2-4 times increase in structural mass fraction and design robustness over rocket powered vehicles[1]. This structural mass fraction improves the design/operating margin. Airbreathing vehicles offer improvements in several capabilities over existing vertical take-off rockets.

Airbreathing vehicles offer capability for expanded launch windows. During flight within the atmosphere, aerodynamic forces generated by the flight vehicle can efficiently convert kinetic energy into cross range, or change inclination to achieve or intercept an alternate orbit allowing airbreathers a greatly expanded launch window compared to that of a rocket powered vehicle. The launch window for an airbreathing vehicle could be on the order of hours, compared to only minutes for rocket-powered vehicles, depending on inclination angle (see Figure 2).

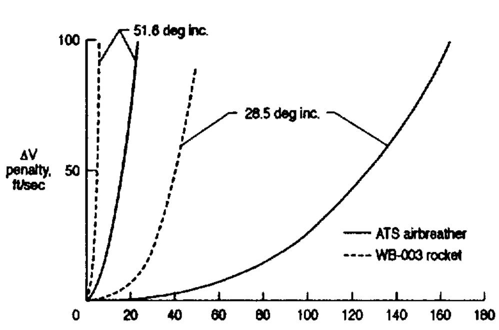

Figure 2: Expanded launch window for airbreathing access-to-space vehicles

Launch window benefits allow significant increases in mission flexibility, which traces back to efficient flight within the atmosphere. Offset launches for rapid rendezvous up to 15° are achievable, compared to only 2° for rocket systems.[1] Other launch benefits of airbreathing vehicles include lower orbital inclination access; changing orbit on demand during launch; synergistic plane changes; and mission recall. Basing flexibility also favors airbreathing vehicles because of runway vs. launch pad requirements. Likewise, on reentry, the airbreathing vehicle's large cross range (over 2.5 times that for rocket vehicles) allows rapid/immediate de-orbit to a safe landing. Unlike the Space Shuttle, the airbreathing vehicle may also has self-ferry capability, which greatly expands the number of potential affordable recovery sites and eliminates the need for a carrier vehicle to return the vehicle to its home base. Horizontal takeoff airbreathing vehicles provide rapid orbital rendezvous. Much of the difference arises because the rocket must wait for orbit alignment, whereas the airbreather can change orbital plane efficiently during ascent.

Validated operational cost models for airbreathing launch systems do not exist. However, there are several factors regarding horizontal takeoff access-to-space vehicles that will reduce operational costs over existing rocket launch vehicles. These vehicles could use existing runways to take-off and land, which results in reduced infrastructure costs over vertical takeoff configurations. Runway take-off would eliminate the need for large ground support equipment requirements of vertical launch vehicles such as the gantry, flyaway quick disconnects, blast protection, and other expensive and complicated equipment. Horizontal processing could also reduce vehicle turn around, significantly impacting operational cost. Additionally, the amount of oxidizer that must be handled and loaded is drastically reduced, resulting in savings in both propellant and handling operations cost.

Safety improvements can be made in several areas of a typical access-to-space mission, especially for abort scenarios and a powered landing/go around. Horizontal take off and landing airbreathing launch vehicles can abort during or soon after takeoff because the vehicle can be designed to land partially loaded or, if necessary, fuel can be dumped. Furthermore, cross range capability of airbreathing vehicles (thousands of miles) enhances safety by dramatically increasing the number of potential recovery sites. Options for aborting a mission are greatly increased as a result of the increase in the number of recovery sites. This is particularly true of de-orbital departures in an emergency. In most cases, no delay will be required because alternate landing sites are readily available. Recent unpublished studies performed under contract with NASA-Marshall Space Flight Center (MSFC) show that horizontal takeoff airbreathing vehicles offer an order of magnitude decrease in failure rates over vertical take-off rocket configurations. The referenced study was performed on a pure rocket-powered vehicle and a horizontal takeoff RBCC-powered vehicle. Scramjet engine failure rates are expected to be lower since they operate at thermal loading conditions that are a quarter of the peak and one tenth of the average compared to rocket engines[2].

Only safe, reliable, low-cost launch vehicles, potentially possible with airbreathing systems, will enable growth in commercial markets.[3,4] Markets affected will include civil and government (DoD) communication satellite networks that require reliable and sometimes rapid, low-cost space access for both delivery and replacement/repair. Recent business models indicate that commercialization of space may be furthered by the tourist industry, which can only happen with safe, reliable, low-cost, horizontal takeoff and landing airbreathing systems.

NASA's Hypersonic Investment Area is focused on Propulsion Technology, Airframe Technology, Systems Analysis, and Flight Demonstration. Other technology, such as avionics, IVHM, power, and flight operations are carried within the four focus areas listed above.

The remainder of this paper provides an overview of program approach, including recent accomplishments of the HIA Program.

Approach

ASTP-HIA approach to resolving the current technology shortfalls for third generation launch systems are shown program roadmap, see Figure 3. Although some of this program plan is over current NASA budget guidelines, the near term (till FY06) is generally within guidelines. This roadmap is designed to complete technology development by 2017, leading to a new, 3^{rd} generation air-breathing launch vehicle with an initial operational capability (IOC) of 2025. This focused technology development and demonstration program has a three-pronged approach: system studies for vision vehicles; incremental ground and flight demonstrations; and research and focused technology development. A key element of the plan is the "Large Scale Reusable Demonstrator," which is scheduled to start about 2010. This sets the major technology development schedule goal since most technologies for the operational vehicle should be integrated into this flight demonstrator.

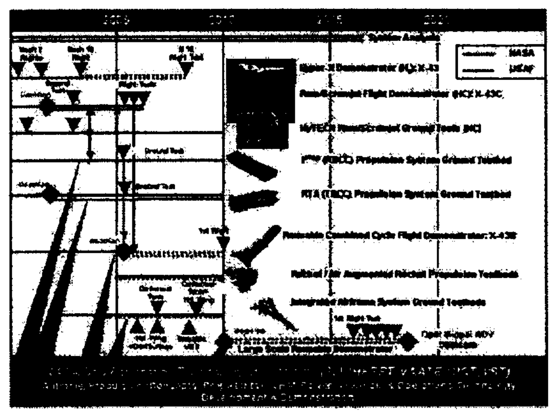

Figure 3. Hypersonic Investment Area Roadmap

Several NASA sponsored teams identified and prioritized technology investment areas for 3^{rd} generation systems. The top eight are:

- Scramjet Propulsion
- High Mach Turbine Propulsion
- Rocket Based Combined Cycle Propulsion
- Turbine Based Combination Cycle Propulsion
- Long life, light weight, efficient airframes
- Long life, light weight propulsion components
- Smart systems
- Highly Operable Systems.

These represent the core programmatic efforts of ASTP-HIA. Ongoing efforts within the program are focused on prioritizing technology development tasks against potential vision vehicles' technology requirements. Key elements of the plan are potential spin-offs during the technology maturation process for near-term applications in areas other than space access.

The ASTP-HIA is comprised of the following seven projects:

- System Analysis Project
- Propulsion Projects
    a. RBCC (ISTAR) Project
    b. TBCC (RTA) Project
    c. PR&T Project
- Airframe Project
- Demonstrator Projects
    a. X-43A Project (included for completeness, but not funded by ASTP)
    b. X-43C Project
    c. X-43B Project
    d. Large Scale Demonstrator (included for completeness, but not currently a project)

Each project is discussed in the following sections.

System Analysis Project

The System Analysis Project is responsible for system studies to screen many 3rd generation vision vehicles goals. Both two stage-to-orbit (TSTO) and single stage-to-orbit (SSTO) vision vehicle concepts are being evaluated. These studies are expanding the figure of merit from the general approach of either dry weight or gross take-off weight to encompass programmatic issues such as safety, reliability, operations, and life-cycle cost. The various concepts will be used to evaluate the technology benefits at a system level and establish the metrics each technology will be required to meet to make the concepts viable. In this process, technology shortfalls are being identified. The final results will be a complete technology portfolio required that is prioritized based on a quantitative rather than qualitative approach.

Propulsion Technology Projects

Propulsion technology is focused on two primary areas: Rocket Based Combined Cycle (RBCC) Engines and Turbine Based Combination Cycle (TBCC) Engine systems. This technology area is broken into three major projects:

- Integrated System Test of an Air-breathing Rocket (ISTAR) Project
- Revolutionary Turbine Accelerator (RTA) Project
- Propulsion Research and Technology (PR&T) Project.

ISTAR Project:
The objective of the ISTAR project is to take the next logical step in combined cycle propulsion development by creating a Rocket-Based Combined Cycle (RBCC) engine system capable of accelerating a self-powered demonstrator vehicle, X-43B, from subsonic air-launch to scramjet take-over. An RBCC engine is one in which rockets are integrated with the airbreathing dual-mode scramjet flowpath such that they thermodynamically impact one another. The rockets provide thrust up to the point where the scramjet achieves enough compression of the ingested air to produce useful thrust, typically about Mach 3. The scramjet operates from Mach 3 to about 6 in ramjet mode, with a thermal throat, and in pure supersonic combustion mode above Mach 6-7. The rocket is re-ignited at Mach $\geq$ 12 for the final boost to low earth orbit.

While rockets and ramjets have been in use since the 1950's, work on scramjets and combined cycle systems has largely been confined to the laboratory. Recent efforts to develop a combined cycle system include the National Aerospace Plane (NASP) and Advanced Reusable Technologies (ART) Projects[5, 6]. These programs made significant advancements in the aerodynamics and combustion physics involved with the flowpath. ISTAR focus is carrying this work to a flight weight engine, addressing challenges such as regeneratively cooled structures, and hot gas valves.

The ISTAR project will implement development of a ground test engine in two phases. Phase I is concept definition and project formulation and will be completed this year. Phase II will be the implementation part of the project with design, fabrication, and ground test activities. ISTAR will continue to contract with the liquid space propulsion consortium of Boeing Rocketdyne, Pratt & Whitney Liquid Space Propulsion, and Gencorp Aerojet (RBC^3) for design, manufacturing, and ground testing of this RBCC engine system. The project will rely on the NASA centers for technical insight and oversight. Figure 4 shows one example of a potential concept with the ISTAR engine system installed on a X-43B flight test vehicle.

The ISTAR Project has completed their System Requirements Review this September.

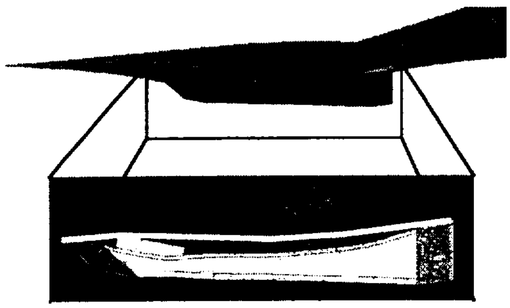

Figure 4. ISTAR Engine System on the X-43B.

RTA Project:
As part of the ASTP program NASA Glenn Research Center is investigating the use of turbine based propulsions systems to provide the low speed system for access to space. Use of turbine-based propulsion provides the potential to realize more aircraft like operations for space flight providing the potential to significantly reduce launch costs and improve systems safety. In addition, if aircraft like operations can be realized, then the potential utilization of existing aircraft ground facilities provides an opportunity to revolutionize access-to-space scenarios.

The objective of the Revolutionary Turbine Accelerator (RTA) project is to develop a Turbine Based Combined/ Combination Cycle (TBCC) propulsion system for space access using a phased approach. Present turbine propulsion systems can propel aircraft and missiles to a speed of Mach 3. These current systems are low in durability, require high maintenance, and are costly. The RTA project seeks to advance the state-of-the-art to a 25% increase in Mach number, 250% higher T/W, and 2 times improved component life by the year 2010. By 2015, this project seeks to advance high Mach turbines to 35% increase in Mach number, 375% higher T/W, and 4 times improved critical component life.

The near term development goals of the RTA project will concentrate on turbine accelerators that will reach at least Mach 4 and provide dramatic increases in maintainability and operability by use of advanced technologies. To meet this goal the RTA project is developing a mid-scale ground-based system level demonstrator to advance the Technology Readiness Level (TRL) of the technologies required to build a turbine accelerator propulsion system. The RTA project is working with other NASA centers, DoD and academia to determine the current readiness level of applicable technologies and synergy between the RTA project and other technology development programs (such as Ultra Efficient Engine Technology-UEET, Integrated High Performance Turbine Engine Technology-IHPTET, and Versatile Affordable Advanced Turbine Engine-VAATE) to make the best use of the funding available. Recently, General Electric Aircraft Engines was awarded the contract to develop the half-scale vision vehicle engine ground test engine. Announcement on the contractor selection for the small engine for the X-43B flight demonstrator should occur this fiscal year. The RTA program also involves a parallel program for highly efficient dual-mode scramjet development. This program will provide a scramjet for integration with the RTA turbine engine. The scramjet is envisioned as a small incremental improvement to the X-43C (HyTech) engine — to allow efficient operation down to Mach 3.5 to 4.2, the turbojet operation limits at full power and reduced power.

In addition the RTA Project provided conceptual level definition of a sub-scale TBCC propulsion system for the X-43B flight demonstrator that was aimed at addressing issues with integrating revolutionary turbine accelerators in high Mach flight vehicles. This would be a flight demonstration of a turbine accelerator in combination with scramjets that will take over at Mach 4. For the X-43B flight demonstrator the turbine accelerator and the scramjets will be thermodynamically independent from one another (i.e. separate flowpaths). The flight demonstration would be used to investigate transition between a low-speed and high-speed propulsion system as well as any critical propulsion/airframe integration issues, such as high mach inlets and nozzles.

PR&T Project:
The goal of the PR &T Project is to develop the propulsion system technologies required to enable low cost 3rd generation hypersonic reusable launch vehicles that operate as safely as today's civil airline transport. The primary objective is to enable propulsion material technologies and component designs that result in high thrust to weight propulsion systems for the vision vehicles. These propulsion systems are to be inherently operable and durable with low maintenance requirements requiring the development of propulsion system health monitoring systems. A secondary objective is to provide for maximum productivity and widest application of base propulsion. The emphasis

will be on airbreathing related propulsion technologies for large class vehicles. Propulsion technology development falls into two areas: Foundation Technologies and Cross-Cutting Components.

The Foundation Technologies area includes technology development at the fundamental level that has potential to enable or enhance propulsion system concepts. These include advanced materials and structures technologies, the development of design tools, measurement system technologies, and auxiliary propulsion system technologies. Within this emphasis area are the following sub-projects:

- Long Life Light Weight Propulsion Materials & Structures
- Safe Life Design
- Enabling Airbreathing Technologies (e.g., inlets, compressors, turbines, combustors, nozzles, and thermal management)
- Numerical System Simulation
- Information Rich Test Instrumentation
- Advanced Propellants
- Auxiliary Propulsion Technologies

The Crosscutting Components area involves the application of foundation technologies and advanced concepts to propulsion system components that are then applicable to a wide range of propulsion system concepts. The components will be developed to TRL 5 and transitioned to a demonstrator or testbed.

Airframe Technology Project

The goal of the Airframe Technology project is to develop and demonstrate airframe technologies for 3rd generation vision vehicles. There are three main objectives for the Airframe project:

- Increased weight margin
- Increased combined loads margin
  - Thermal
  - Structural
  - Aerodynamics/aerothermodynamics
- Increased operational margin

The technical challenges associated with achieving the Airframe Project goals and objectives for airbreathing hypersonic vehicles include low drag, minimum weight, flight from Mach 0–25–0 (takeoff, flight to and from orbit, and landing), tight aerodynamic control margins, high volumetric efficiency, and high dynamic pressure flight.

The approach to address the airframe technical challenges is to focus on structures, materials, and aerodynamics/aerothermodynamics technologies as illustrated in Figure 5. The structures and materials technology development includes tasks in the areas of Integrated Airframe Design, Integrated Thermal Structures and Materials, and Thermal Protection Systems (TPS), e.g., multiple aspects of an integrated wall structure and a wing with a sharp leading edge and control surface are being worked. The aerodynamics/ aerothermal development includes aerodynam-ics, aerothermodynamics, and tunnel testing at NASA's Langley Research Center and Ames Research Center. A mix of medium and low TRL technologies are being addressed. The approaches taken to address the technical challenges and increase performance margin and reusability include:

- Conformal tanks
- Thin control surfaces
- Hot structures
- High Mach number staging
- Boundary layer transition
- Sharp leading edges
- Thin thermal protection systems
- High fidelity design and analysis tools
- Dynamic seals
- Airframe health monitoring

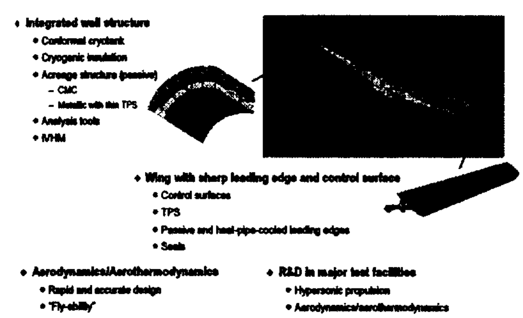

Figure 5. Airframe Technical Focus.

The Airframe project is also focused on solving the problems associated with the fly-ability of airbreathing vehicles, as shown in figure 6. Technical challenges exist from take off to orbit and back to landing. Drag reduction, boundary layer transition, high angle of attack heating, and reaction control system (RCS) interactions are technical challenges that are being worked in the Airframe project.

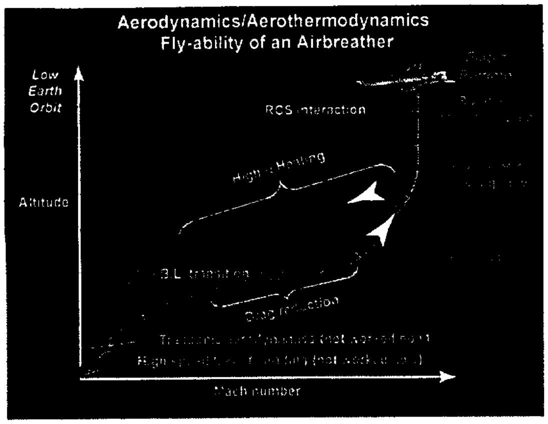

Figure 6. Illustration of the fly-ability of an airbreathing vehicle.

Some of the Airframe Technology Program ground demonstrators are highlighted on the HIA Roadmap, Figure 3. One of these is a large-scale conformal, integral hydrogen tank structure with mechanically attached thermal protection system (TPS). This is envisioned as full scale for the "Large Scale Reusable Demonstrator."

Flight Demonstrators Projects

The Hypersonics Investment Area (HIA) within ASTP is developing several potential hypersonic flight demonstration projects that are required to incrementally advance the required propulsion and airframe technologies to TRL of 6. These flight demonstrations are tailored to validate specific concepts, computational tools, and ground test methods required for development of future operational hypersonic vehicles. The flight demonstration vehicles that are focused on primarily propulsion systems (X-series) will be built with existing vehicle technology where possible to provide the most cost-effective designs. However, they may also provide a limited flight test bed for other developing vehicle technologies. The overall plan provides an incremental building block approach with structured decision points and off-ramps to allow cost-effective technology development and demonstration. These propulsion systems flight demonstration projects (X-series) are focused on propulsion technologies and issues such as:

- Flight-weight, actively fuel-cooled structures
- Reusability and durability testing
- Scramjet operation over a larger Mach range, including mode transition
- Combined-cycle testing
- Powered-vehicle operation over large flight envelope
- Hypervelocity (Mach > 15)
- Integrated vehicle health monitoring (IVHM)
- Expansion of operational knowledge
- Validation of analytical tools
- Development of validated cost models

The building block approach for the highly visible ground and flight demonstrators is illustrated in the roadmap of Figure 3. The HIA hypersonic flight demonstration projects build on the Hyper-X research vehicle and the USAF HyTech scramjet engine technology program. They will go beyond Hyper-X to expand the flight envelope to both lower and higher Mach numbers, as well as demonstrate flight weight cooled engine systems with increasingly complex propulsion technologies. These demonstrators will seek to enhance operational knowledge with longer duration missions and maneuvering flight, moving research objectives toward more realistic flight environments.

X-43A Project:
The Hyper-X Program[7], started in 1996, developed the first scramjet powered hypersonic flight vehicle, the X-43A[1]. The X-43A will demonstrate both powered and un-powered flight at Mach 7 and Mach 10, using gaseous hydrogen fuel. Powered flight of the X-43A research vehicles is limited to about 10 seconds by both fuel capacity and limited heat-sink capacity of the un-cooled engine structure. First flight of the X-43A, at Mach 7, was attempted on June 2, 2001. The flight was terminated after a booster failure 13.5 seconds into the mission. Figure 7 shows the Hyper-X Launch Vehicle at about 7 seconds into the flight. The "Incident Review Board" final report is currently in final review at NASA Headquarters, so findings must be reported at a later date. The return to flight activities are continuing, and fixes are expected to allow the second flight, at Mach 7, in 2003. These flights will provide the first data to validate design methods for highly integrated hypersonic airbreathing vehicles. Scramjet propulsion and slender body aerothermodynamic analytical, computational and experimental methods will be validated in flight. These tests will also provide risk reduction for follow on demonstrators. This is most critical for the complex high-dynamic pressure stage-separation that will also be used for the X-43C.

Though the Hyper-X program is not funded by ASTP, the Hyper-X flight is a critical first element in our development roadmap and a major risk mitigator for the X-43C flight demonstration.

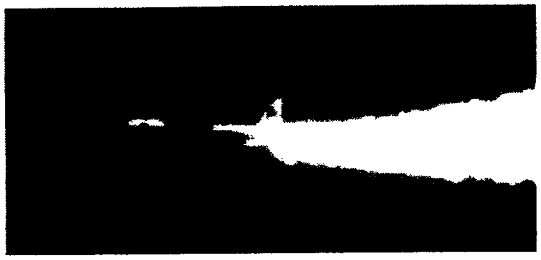

Figure 7. First flight of the X-43A, June 2, 2001.

X-43C Project

The first of the follow on hypersonic flight demonstrators is the X-43C Project. Development of the X-43C demonstrator vehicle with its hydrocarbon fuel-cooled scramjet propulsion system is a joint effort between NASA and the Air Force, using technology developed in the NASA Hyper-X Program and the Air Force HyTech Program[4]. Building off of Hyper-XA and HyTech, the X-43C, will utilize hydrocarbon fuel in a flight weight, fuel-cooled scramjet to power a 16' long vehicle (Hyper-X is 12' in length). Use of hydrocarbon fuel allows substantially longer powered operation than possible using hydrogen in this small scale. The X-43C Project will fly three expendable demonstration vehicles, utilizing a three-module engine (three flowpaths integrated into a single engine) developed from a single HyTech engine module. Each demonstration vehicle will be boosted to Mach 5 using the Hyper-X approach and hardware where the X-43C engine will be started to accelerate the vehicle to Mach 7. The powered flight duration will be approximately 5 minutes. Each flight will demonstrate propulsion system performance, dual-mode scramjet operation, and successively more demanding flight maneuvers to expand the flight envelope. Currently, the X-43C Project has completed a successful Project Requirements Review and is driving toward a System Requirements Review late this year. The X-43C project started at low level in Fiscal Year (FY) 2001 and will continue through FY 2007.

The X-43C demonstration vehicle, shown in Figure 8, has matured into a functional conceptual design with substantial margin in mission performance, which is appropriate at this stage of development. In part, the added length, relative to Hyper-X (X-43A), is due to the longer engine required for hydrocarbon fuel combustion. The vehicle is also deeper and more volumetrically efficient to carry required fuel. In comparison to X-43A, the X-43C engine is wider to provide the greater air capture and higher thrust required for robust acceleration. Air vehicle sub-systems are similar to the X-43A vehicle, except for fuel delivery. During FY02, a Government-led design team is continuing to mature the vehicle conceptual design and perform system trade studies to reduce risk and develop appropriate system requirements. In addition, launch vehicle design and trajectory development are ongoing to aid in requirements development.

Figure 8. X-43C Flight Demonstration Vehicle.

The engine design for X-43C is based on Air Force HyTech Program technology[4]. The HyTech Program is an ongoing effort, with its first flight-weight, fuel-cooled Ground Demonstrator Engine (GDE#1) going into test in July 2002. This engine is a single module (one flowpath), fixed-geometry that will provide structural validation, performance measurements, and overall risk reduction for X-43C engine development. GDE#1 will be followed by another single-module, test engine (GDE#2) that will be developed for the X-43C flight vehicle geometry, with the goal of proving closed loop control of the propulsion system, thermal management characteristics, and variable geometry performance. Test results from GDE#2 will validate the final flight engine flowpath design. The X-43C flight engine will utilize three of the HyTech derived modules placed side-by-side to provide a full-width engine. Finally, a flight clearance engine will be produced and tested in the actual flight engine configuration and size, prior to final flight engine production. Figure 9 shows the current design of the flight engine system, complete with its three flowpath modules and engine-mounted system components.

X-43B — Combined Cycle Engine Flight Demonstrator Vehicle

Combined-cycle propulsion systems will be required for future operational vehicles. As

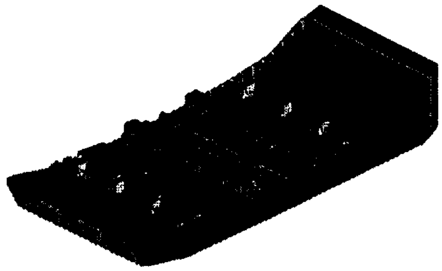

Figure 9. X-43C Flight Engine Configuration.

discussed above, both ISTAR (RBCC engine) and RTA (TBCC propulsion systems) are developing propulsion systems in ground based technology programs. These flight weight ground test articles are being developed at a scale to support flight of a 35 to 45' demonstrator vehicle, currently called the X-43B. To keep the vehicle small, it will be air launched and accelerate on combined cycle power from Mach 0.7 to 7. This vehicle will utilize hydrocarbon fuel like the X-43C, but will be large enough to demonstrate all propulsion modes from subsonic flight through hypersonic flight under scramjet power (Mach 0.7 to Mach 7). It will also be the first fully reusable hypersonic demonstrator, allowing many more flights to explore the operational envelope, extended flight duration, and prove system durability. The X-43B demonstrator vehicle will build on the technology developed in the previous ground and flight projects. A selection between RBCC and TBCC engines for the first X-43B demonstrator vehicle is currently scheduled around 2006. The X-43B first flight test is scheduled for 2010. These reusable vehicles will demonstrate all mode transitions through scramjet operation, and help establish operational procedures and cost models for air-breathing launch vehicles.

The RBCC version of the X-43B vehicle is illustrated in figure 10. The vehicle currently closes at 33 feet in length. Because of the high density (small scale and LOX load, the lifting body requires large wings and canard. On the vehicle side, system definition and packaging has continued on the conceptual level to provide the flight weight engine its vehicle interface requirements. As seen in figure 4, the RBCC X-43B vehicle maintains traceability to the vision vehicles and X-43C.

Figure 10. RBCC X-43B Vehicle Conceptual Design.

During conceptual design studies, concern about the transonic pitching moments led to powered testing of the ABLV vehicle in the NASA LaRC 16 foot Transonic Tunnel (see figure 11). These tests, completed in Feb. 2002, provided experimental anchoring and validation of the design methods. Note that the larger wings and canard were not included. An existing model was selected for this study. This extended the vision vehicle database, and provided timely data for methods validation.

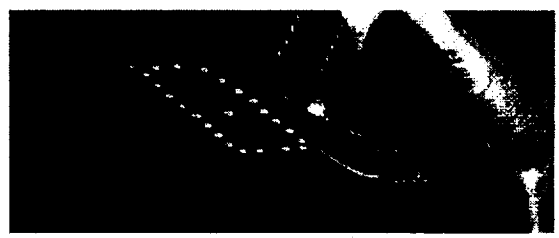

Figure 11. Powered Tests of RBCC Vision Vehicle, for X-43B/ISTAR code validation.

The TBCC version of the X-43B vehicle is illustrated in figure 12. The vehicle closes at 40 feet in length using the RTA Program's small turbojet designs, with a "fully" variable geometry scramjet. This vehicle is not as dense as the RBCC version, so it maintains the ABLV shape, as with the X-43C. System definition and packaging has continued to the conceptual level. This vehicle has room for 4-19" diameter by 67" long RTA turbojets. Inlets, diffusers and nozzle for the turbojets utilize a considerable volume, but the vehicle contains the required fuel, with margin. The turbine installation is also compatible with the scaled up HyTech H/C dual-mode scramjet. System studies are continuing to determine the amount of variable geometry required for the dual-mode scramjet.

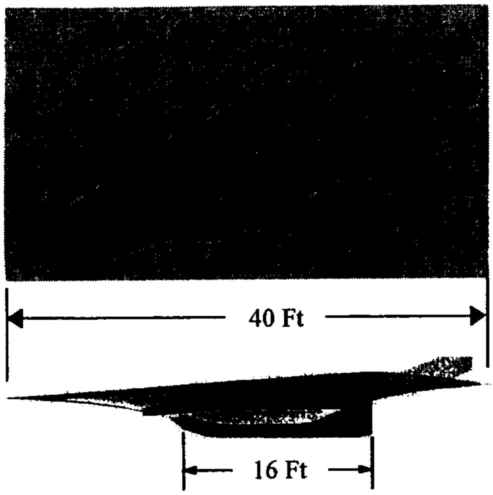

Figure 12. TBCC X-43B Vehicle Conceptual Design.

X-43D – Hypervelocity (Mach 15) Hydrogen Fueled Demonstrator

Following the Hyper-X demonstration of Mach 7 and Mach 10 flight with hydrogen fuel most of the demonstrators use hydrocarbon fuel. Hypervelocity engine technology development (Mach 15 or greater) will be focused with a hydrogen fueled scramjet demonstrator. This is a required risk reduction, before proceeding with a near full-scale demonstrator (LSRD) vehicle. The X-43D flight demonstration vehicle is envisioned to fill that need. The X-43D Project is in a formulation stage, but some elements of the vehicle requirements are evolving. The first major requirement is a scramjet engine capable of performing (accelerating) at Mach 15 with hydrogen fuel. To keep vehicle size reasonable and project costs down, the demonstration would likely be a short duration (30 seconds to several minutes at most) flight from an initial velocity of Mach 15. Packaging liquid hydrogen fuel for a 30 seconds flight will drive the vehicle to at least 24 feet. Boosting this size vehicle will require a 2-stage Peacekeeper class booster.

Large-Scale Reusable Demonstrator (LSRD) Vehicle

This large-scale reusable vehicle is currently envisioned as being the same architecture (SSTO or TSTO, VTHL or HTHL) as the 2025 operational vehicle, and sized capable of operation over all air-breathing propulsion speeds from zero to Mach 15+ (if required). In addition, if a SSTO concept is selected, the vehicle may include the final rocket mode plus sufficient propellant to execute mode transition to rocket. Selection of the vehicle concept will be made about 2010, and first flight is 2016. This will be the first demonstrator to fully integrate both propulsion and airframe technologies in a reusable flight demonstrator.

Summary

The ASTP's HIA will address the key technology issues associated with hypersonic airbreathing propulsion for access to space applications. The HIA supports the NASA's third generation launch vehicle goals. The technology investments leverage other technology and advanced development programs. The activity is product oriented, e.g., both ground and flight demonstrators, and decisions will be driven by sound systems' analysis and systems' engineering. The fundamental approach is to incrementally increase the complexity of the demonstrators by increasing scale, fidelity and expanding the test environment. The program is planned around achieving an operational capability by 2025.

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