X-43C PLANS AND STATUS

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ABSTRACT

X-43C Project is a hypersonic flight demonstration being executed as a collaboration between the National Aeronautics and Space Administration (NASA) and the United States Air Force (USAF). X-43C will expand the hypersonic flight envelope for air breathing engines beyond the history making efforts of the Hyper-X Program (X-43A). X-43C will demonstrate sustained accelerating flight during three flight tests of expendable X-43C Demonstrator Vehicles (DVs). The approximately 16-foot long X-43C DV will be boosted to the starting test conditions, separate from the booster, and accelerate from Mach 5 to Mach 7 under its own power and autonomous control. The DVs are to be powered by a liquid hydrocarbon-fueled, fuel-cooled, dual-mode, airframe integrated scramjet engine system developed under the USAF HyTech Program. The Project is managed by NASA Langley Research Center as part of NASA's Next Generation Launch Technology Program. Flight tests will be conducted by NASA Dryden Flight Research Center over water off the coast of California in the Pacific Test Range.

The NASA/USAF/industry project is a natural extension of the Hyper-X Program (X-43A), which will demonstrate short duration (~ 10 seconds) gaseous hydrogen-fueled scramjet powered flight at Mach 7 and Mach 10 using a heavy-weight, largely heat sink construction, experimental engine. The X-43C Project will demonstrate sustained accelerating flight from Mach 5 to Mach 7 (~ 4 minutes) using a flight-weight, fuel-cooled, scramjet engine powered by much denser liquid hydrocarbon fuel. The X-43C DV design flows from integrating USAF HyTech developed engine technologies with a NASA Air Breathing Launch Vehicle accelerator-class configuration and Hyper-X heritage vehicle systems designs. This paper describes the X-43C Project and provides background for NASA's current hypersonic flight demonstration efforts.

BACKGROUND

NASA's Next Generation Launch Technology (NGLT) program is developing and maturing advanced propulsion technologies, vehicle systems technologies, and flight vehicle concepts to enable development of safer and more economic future launch systems. Figure 1 illustrates the NGLT role in NASA's Integrated Space Transportation Plan. Within NGLT, NASA is developing advanced air breathing propulsion systems and demonstrating these systems in hypersonic flight vehicles. The flight demonstrations are necessary to validate these technologies and advance the Technology Readiness Levels (TRLs) to TRL=6, making them ready for application to future space launch vehicles and other hypersonic flight systems.

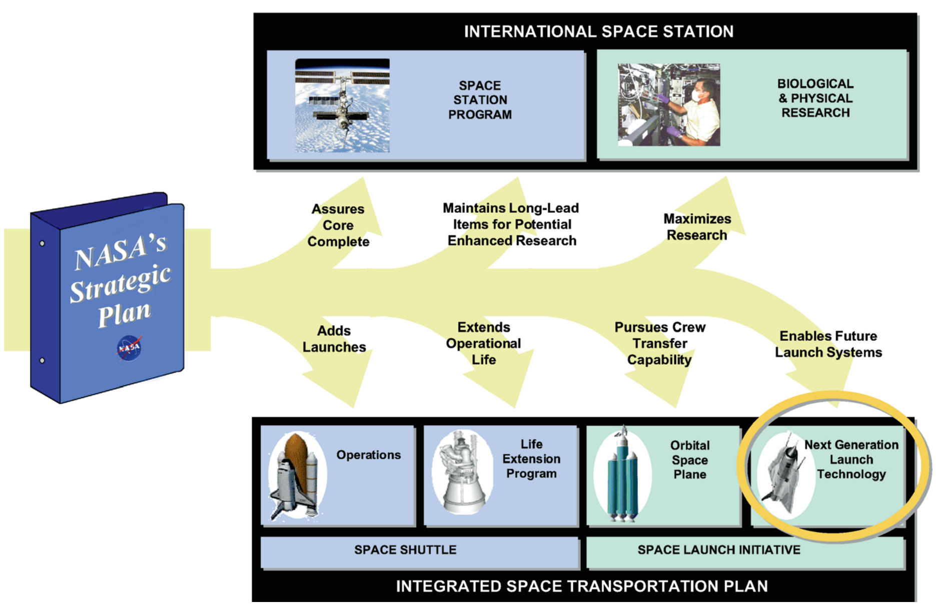

Figure 1. NGLT is a Key Component of NASA's Strategic Plan

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NASA's Hyper-X Program (X-43A) began the effort to flight demonstrate hypersonic air breathing propulsion systems in an effort to provide technologies that will enable development of safer and more economic space access vehicles in the future. Following X-43A, NASA, in collaboration with the Department of Defense (DoD), is developing additional, progressively more complex hypersonic X-vehicles that will demonstrate new air breathing propulsion systems, propulsion-airframe integration, and other vehicle systems technologies required for high speed flight up to Mach 15. These technologies will contribute to safer, more reliable and more economic future launch systems and hypersonic aircraft/missiles. The next logical step beyond the fundamental demonstrations of X-43A will be to demonstrate more robust, sustained flight performance and ram-to-scram transition over an expanded flight envelope.

INTRODUCTION

NASA's NGLT program is investing in hypersonic air breathing propulsion systems, along with advancements in vehicle systems technologies that may enable substantial improvements in safety and economy of space launch systems. The performance advantage of air breathing propulsion over rocket propulsion for space access is derived from the increase in performance efficiency provided by the air breathing vehicle. These vehicles provide an increase in propulsion efficiency (see Figure 2), described by specific impulse (Isp). Isp indicates how many pounds of thrust (lbf) are produced per pound mass of propellants (fuel and oxidizer) injected into the engine per second. The increased propulsive efficiency for air breathing vehicles significantly reduces the propellant required and could enable horizontal takeoff for space access. Horizontal takeoff will allow lower thrust loading thereby reducing overall engine weight.[1]

Among the NGLT propulsion technologies are dual-mode ramjets (ramjet/scramjet), Rocket Based Combined Cycle (RBCC) engine system concepts, and Turbine Based Combined Cycle (TBCC) engine system concepts. As these technologies reach appropriate maturity, flight demonstration is required to fully validate such technologies for application to future space launch vehicles.

FLIGHT DEMONSTRATIONS

NGLT is also developing hypersonic flight demonstration projects that are required to incrementally advance selected key propulsion and vehicle system technologies to TRL of 6. These flight demonstrations are tailored to validate propulsion system, selected vehicle systems technologies, and vehicle flight characteristics, not specific vehicle concepts or prototypes. Technology to be validated also includes the design and computational tools and ground test methods required for development of future operational hypersonic vehicles. The flight demonstration vehicles are focused primarily on propulsion systems, so they 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 system technologies as these reach appropriate TRL. 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

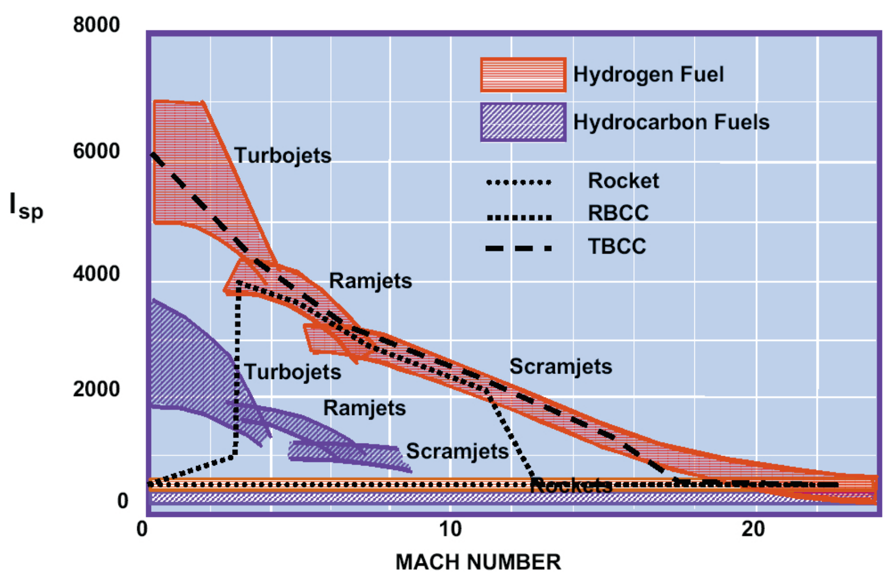

Figure 2. Air Breathing Hypersonic Propulsion Cycles Provide Enhanced Propulsion Efficiency

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 combustion mode transition
- Combined-cycle testing
- Powered operation over larger flight envelope
- Hypervelocity (Mach > 15)
- Integrated vehicle health monitoring (IVHM)
- Expansion of operational knowledge
- Validation of design and analytical tools
- Development of validated cost models

The building block approach for the ground and flight demonstrators is illustrated in the roadmap of Figure 3. The NGLT hypersonic flight demonstration projects build on the Hyper-X (X-43A) research vehicle and the United States Air Force (USAF) HyTech scramjet engine technology programs. They will go beyond Hyper-X to expand the flight envelope to both lower and higher Mach number regimes, to demonstrate flight-weight, fuel-cooled engine systems with increasingly complex propulsion technologies, and to progress to fully reusable systems. These demonstrators will seek to enhance operational knowledge with longer duration missions and maneuvering flight, advancing research objectives toward more realistic flight operations.

NASA's Hyper-X Program (X-43A) is the first in a series of vehicles that are envisioned to flight validate air breathing propulsion systems that will operate from the ground to Mach 15 and beyond, as shown in Figure 4.

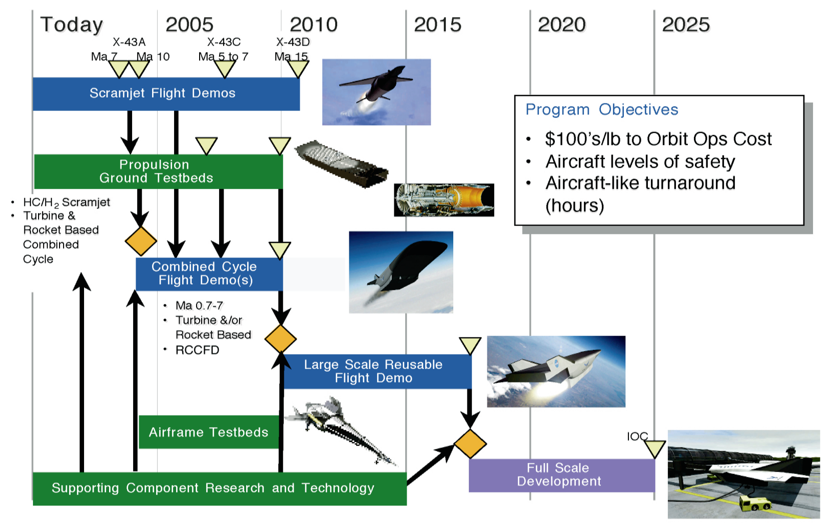

Figure 3. Air breathing Hypersonics: Access to Space Roadmap Shows Building Block Approach

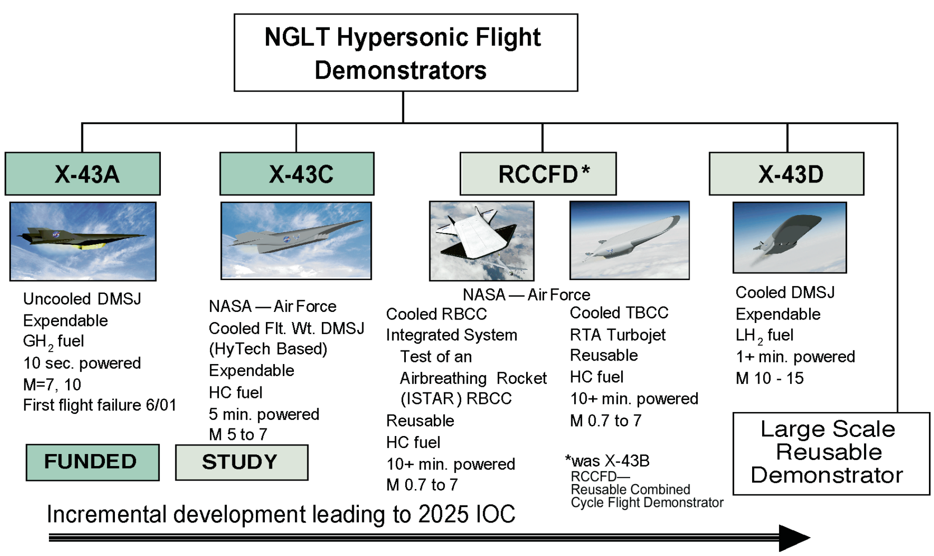

Figure 4. Hypersonic Demonstration Projects

X-43C PROJECT

The X-43C Project follows the X-43A as the next flight demonstration project. The X-43C Project will demonstrate Mach 5 to Mach 7 acceleration with a vehicle powered by a flight-weight, fuel-cooled scramjet engine using hydrocarbon fuel. The X-43C Demonstration Vehicle (DV) is being developed by NASA and the USAF in a joint project, managed by NASA Langley Research Center. Development of the X-43C DV, with its hydrocarbon fuel-cooled scramjet propulsion system, uses technology from the NASA Hyper-X Program (X-43A) and the USAF HyTech Program.[2]

The X-43C Project is organized as depicted in Figure 5. The project will utilize a Government-Industry team to execute overall project objectives under Government leadership. There are four main sub-projects that will deliver the products, ground tests, and flight tests of the overall project. Project management is located at NASA Langley Research Center (LaRC) along with two sub-projects for DV development and propulsion/ aerodynamic testing. Booster and launch services will be provided by a sub-project located at Marshall Space Flight Center (MSFC). Flight test and operations will be provided by a sub-project located at Dryden Flight Research Center (DFRC). The project's structure enables full Government partnership with the X-43C industry participants. The Government Technical Teams (GTT) cut across the subprojects to monitor technical progress with appropriate levels of technical involvement at all locations. The GTT activity will provide necessary insight to assure the successful fulfillment of the X-43C mission. An overall schedule for the project is shown in Figure 6. First flight is planned for 2007.

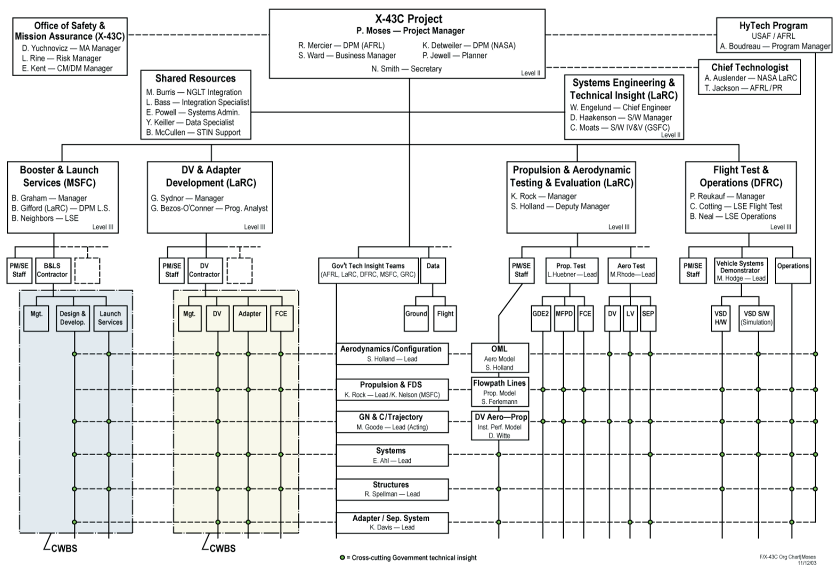

Figure 5. X-43C Project Technical Insight

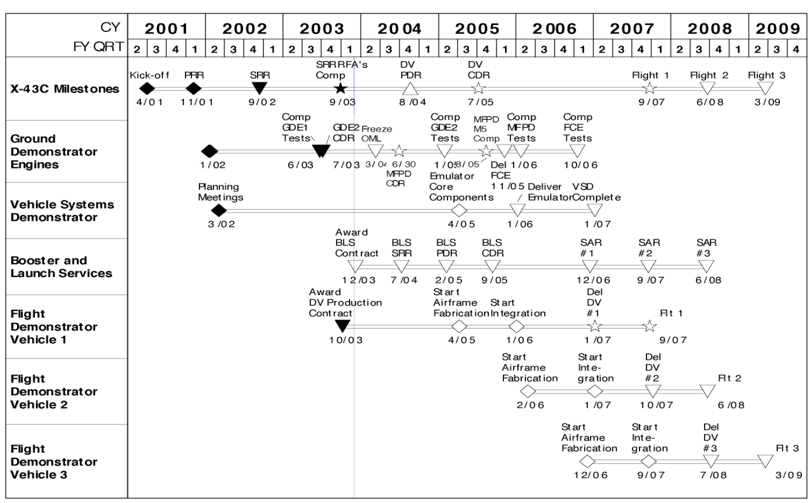

Figure 6. Schedule for X-43C Project

Figure 7. X-43C Demonstrator Vehicle

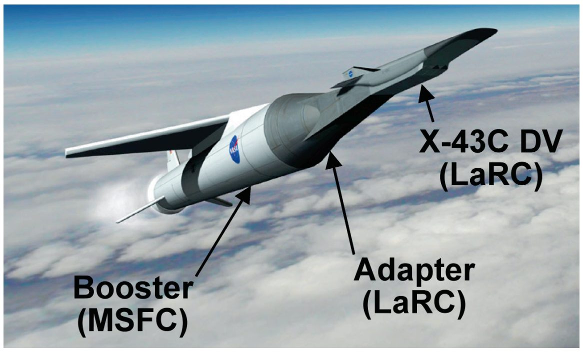

Figure 8. X-43C Flight System Hardware

FLIGHT VEHICLE DESIGN

Building off X-43A and HyTech, the X-43C Project, will utilize hydrocarbon fuel in a flight-weight, fuel-cooled scramjet to power a 16' long DV shown in Figure 7 (X-43A 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 DVs, utilizing an engine with three flowpaths integrated into a single propulsion system. It will be developed using technology from the single-flowpath engine of the HyTech Program.

Each DV will be boosted to starting conditions using a similar approach and similar hardware to X-43A, Figure 8. After rocket boost to Mach 5 starting conditions and booster separation, the expendable X-43C vehicles will accelerate from Mach 5 to Mach 7 and then descend un-powered to splash down into the Pacific Ocean. The powered flight duration will be 3 to 5 minutes. Each flight will demonstrate propulsion system performance, dual-mode scramjet operation, and successively more demanding flight maneuvers to expand the flight envelope. A typical mission profile is shown in Figure 9.

The X-43C Project completed a successful Project Requirements Review in 2001 and a System Requirements Review in 2002 prior to beginning selection of Industry partners in 2003. Allied Aerospace of Tullahoma TN was competitively selected to develop the X-43C Demonstrator Vehicles and vehicle-to-booster Adapters. Allied Aerospace is teamed with major subcontractors Pratt & Whitney and Boeing.

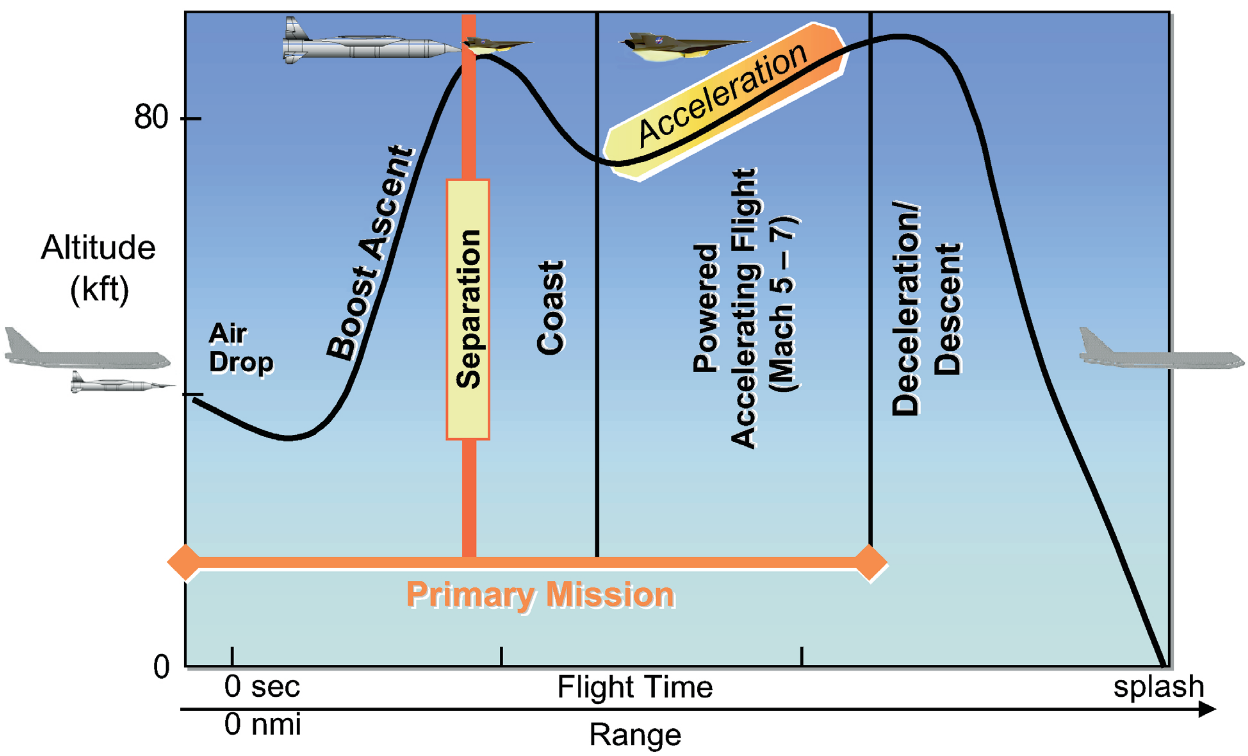

Figure 9. X-43C Mission Profile

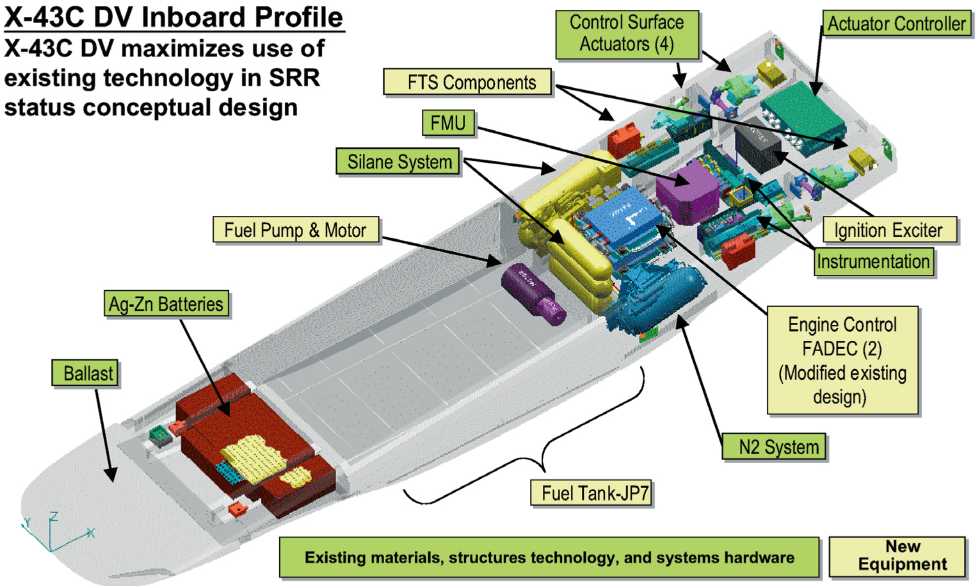

Figure 10. DV Inboard Profile and Systems Packaging

During FY02, a Government-led design team matured the vehicle conceptual design and performed system trade studies to reduce risk and develop appropriate system requirements. In addition, launch vehicle design and trajectory development were conducted to aid in requirements development.

The X-43C DV configuration was matured into a functional design with substantial margin in mission performance, which is appropriate at this stage of vehicle development. In part, the added length, relative to 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 for robust acceleration. Air vehicle subsystems are similar to the X-43A vehicle, except for fuel delivery. The DV inboard profile and systems packaging are illustrated in Figure 10.

RISK

Flight testing in the Mach 5 to Mach 7 speed range is an inherently risky effort. There are gaps between what can be effectively tested in relevant environments on the ground and the actual flight conditions that will preclude development of a fully tested flight system before flight. Thus, a risk reduction plan will be established to minimize the risks consistent with prudent engineering judgment, available budget, and reasonable schedule.

The X-43C Project will undertake a substantial risk reduction effort to develop and validate the propulsion and vehicle systems of the DV, as well as the booster and stage separation systems that will deliver the DV to its test conditions. Elements of the risk reduction effort will include propulsion and aerodynamic wind tunnel testing, ground tests of specific hardware designs, and an extensive computational/analytical program.

FLIGHT SYSTEM DEVELOPMENT AND TESTING

The flight engine design for X-43C, shown in Figure 11, is based on Air Force HyTech Program technology. The X-43C flight engine utilizes three of the HyTech derived modules placed side-by-side to provide a full-width engine. The design incorporates a variable geometry inlet to facilitate improved performance across the speed range and HyTech combustor.

A carefully structured test program is planned to validate the engine design as it is developed. The test efforts will combine USAF and NASA efforts to provide efficient utilization of Government resources. The initial schedule for the overall test plan is shown in

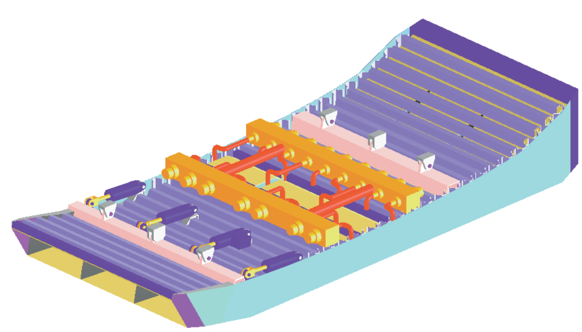

Figure 11. X-43C's Engine

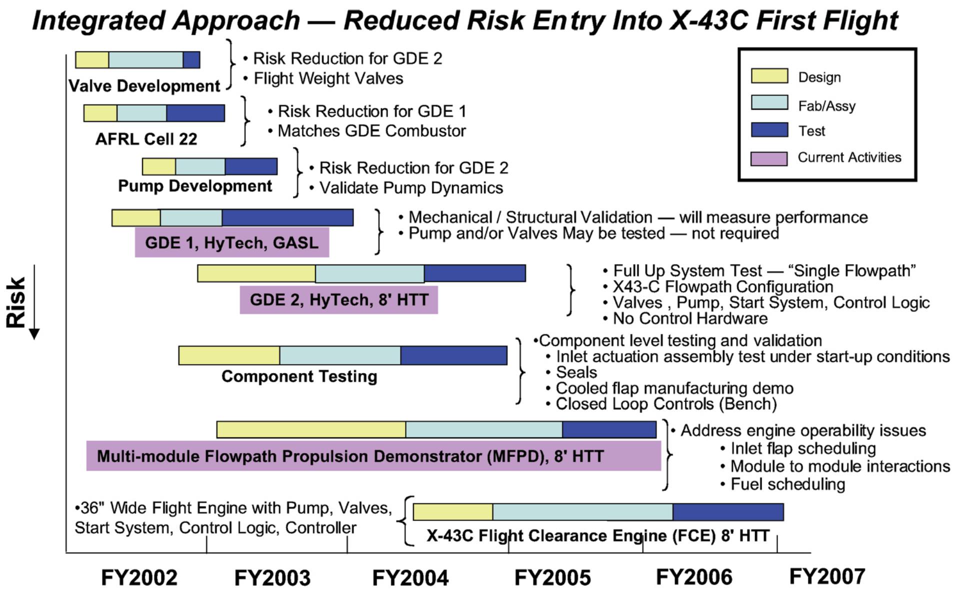

Figure 12. X-43C Propulsion Test Roadmap

Figure 12. The USAF HyTech Program's first flight-weight, fuel-cooled Ground Demonstrator Engine (GDE 1) successfully completed ground testing in July 2003, Figure 13. This engine is a single module (one flowpath), fixed-geometry design that provided structural validation, performance measurements, and overall risk reduction for X-43C engine development. GDE 1 is followed by another single-module, test engine, GDE 2 Figure 14, that will be developed for the specific 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.

Following GDE 2, a Multi-module Flowpath Propulsion Demonstrator (MFPD) model will be designed and tested to determine module-to-module interoperability characteristics and integrated propulsion-airframe performance increments, Figure 15.

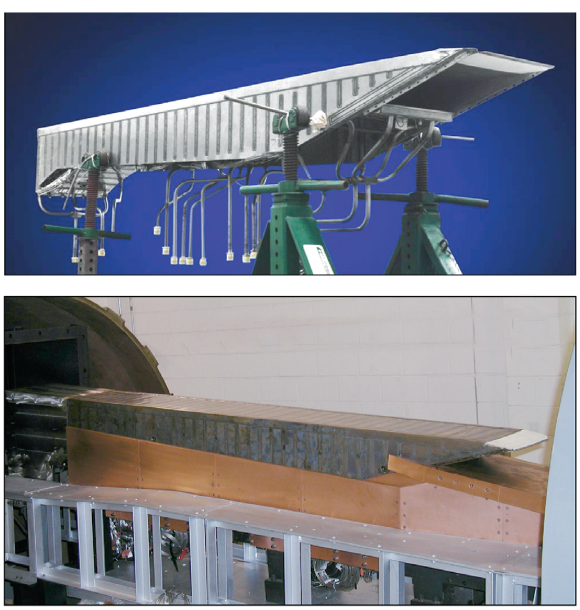

Figure 13. GDE 1 Installed in GASL Leg 6

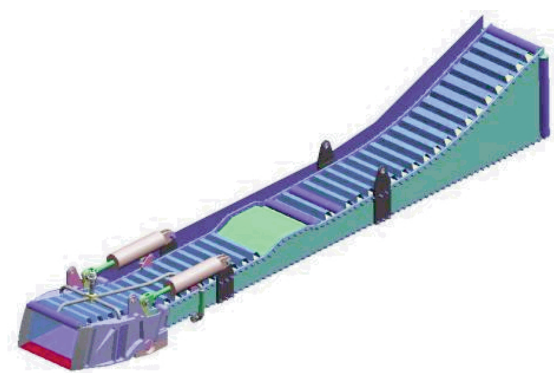

Figure 14. GDE-2 Engine Design

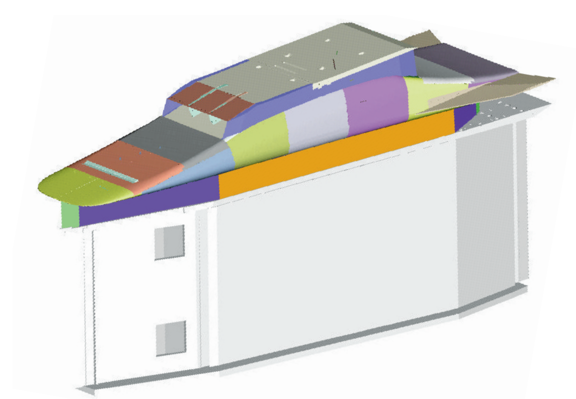

Figure 15. X-43C's Multi-Module Flowpath Propulsion Demonstrator

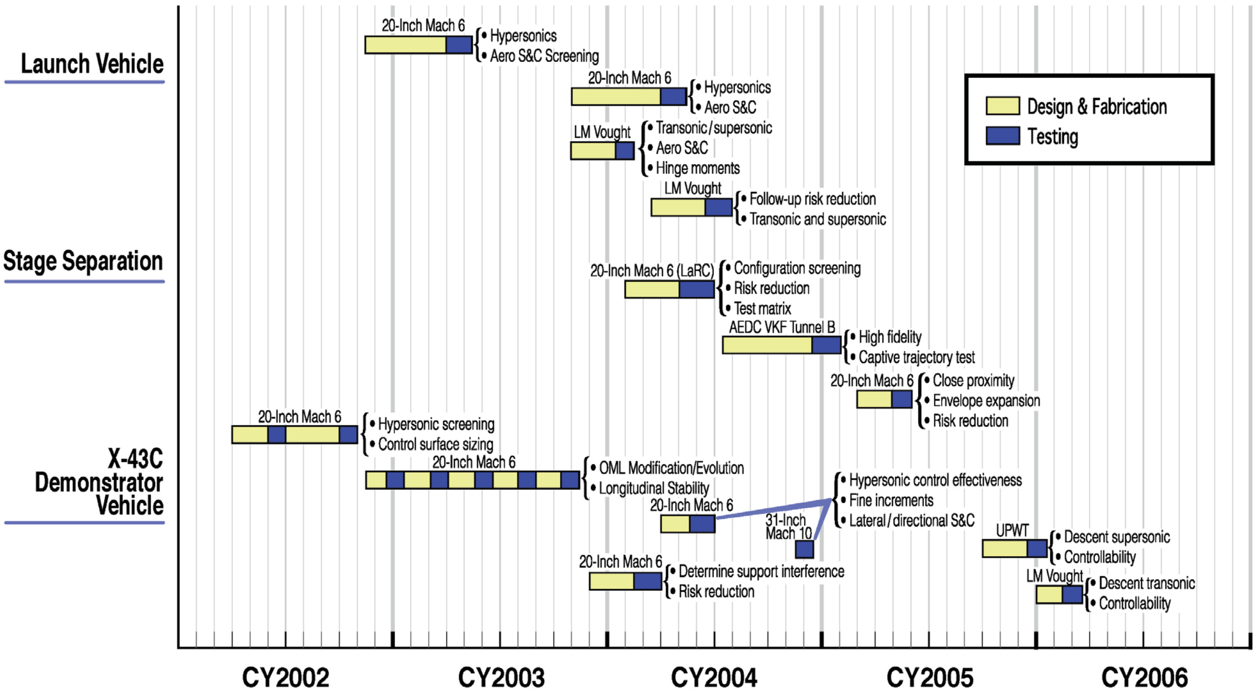

Figure 16. X-43C Aerodynamic Test Roadmap

The MFPD will be about 2/3 of full-scale size and will incorporate the complete lower surface geometry of the DV. This will enable testing of many propulsion-airframe integration (PAI) concerns, including module-to-module interactions and force/moment increments for inlet opening/starting, engine flame-out, and unstart.

A companion aerodynamic testing plan is also proceeding to provide the data for DV flight, booster, and stage separation. Figure 16 shows the aerodynamic test plan and schedule.

Finally, a Flight Clearance Engine (FCE) will be produced and tested in the actual flight engine configuration and size. This test will be the final engine validation prior to the flight test.

SUMMARY

The X-43C hypersonic flight demonstrator will address development and demonstration of key dual-mode scramjet technologies that are associated with air breathing, hypersonic vehicles for access to space applications. The technology investments in X-43C leverage other technology and advanced development programs. The activity is product oriented, e.g., both ground and flight demonstrations, and decisions will be driven by sound analysis and systems testing. Flight system development will be driven by risk reduction activities that have the goal of delivering functional flight hardware in a cost-effective manner.

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