# HYPERSONIC MISSILE PROPULSION SYSTEM



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## Abstract

*Pratt & Whitney is developing the technology for hypersonic components and engines. A supersonic combustion ramjet (scramjet) database was developed using hydrogen fueled propulsion systems for space access vehicles and serves as a point of departure for the current development of hydrocarbon scramjets. The Air Force Hypersonic Technology (HyTech) Program has put programs in place to develop the technologies necessary to demonstrate the operability, performance and structural durability of an expendable, liquid hydrocarbon fueled scramjet system that operates from Mach 4 to 8. This program will culminate in a flight type engine test at representative flight conditions. The hypersonic technology base that will be developed and demonstrated under HyTech will establish the foundation to enable hypersonic propulsion systems for a broad range of air vehicle applications from missiles to space access vehicles. A hypersonic missile flight demonstration is planned in the DARPA Affordable Rapid Response Missile Demonstrator (ARRMD) program in 2001.*

## Introduction

The United Technologies Corporation is developing hypersonic propulsion for application to expendable missile systems, initially, with long-term application to reusable hypersonic vehicles. Plans are in place for a hypersonic missile demonstration starting in 2001. An Engineering and Manufacturing Development (EMD) program for a hypersonic missile propulsion system is feasible starting in 2003.

The development of scramjet technology began at the United Technologies Research Center (UTRC) in the 1960s. Hypersonic propulsion activity enjoyed a resurgence at Pratt & Whitney (P&W) in the 1980s with the onset of the National Aerospace Plane (NASP) Program. A broad technology base was established under NASP in hydrogen scramjets and scramjet design systems. Meanwhile, UTRC was exploring basic research in hydrocarbon fueled scramjets and hydrocarbon fuel endothermic cooling. The P&W Chemical Systems Division had been developing liquid and solid fueled ramjet technologies during this same time period. All of these activities have been brought together under the current Air Force HyTech Storable Fuel Scramjet Flowpath Concepts (SFSFC) program to develop and demonstrate the operability, performance and durability of a Mach 4-8 hydrocarbon scramjet propulsion system. The flight test of a hypersonic missile powered by a hydrocarbon scramjet is planned under the current Defense Advanced Research Projects Agency (DARPA) Affordable Rapid Response Missile Demonstrator (ARRMD) program. Boeing' is teamed with P&W on one of two concepts being pursued in ARRMD. The primary goal of the ARRMD program is to design and build a missile that could fly at least 400 nautical miles at Mach 6 and have an average unit flyaway cost of only $200,000 in a production program of 3,000 missiles.

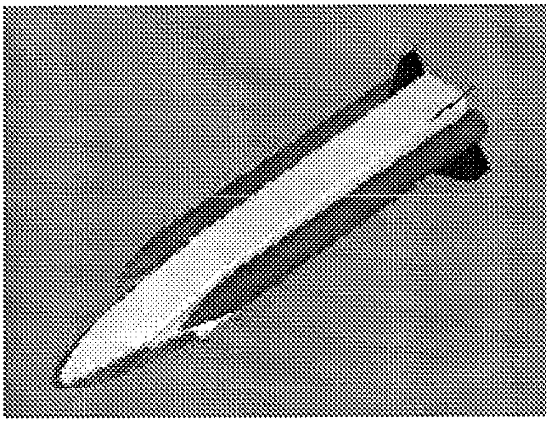

Figure 1: Hypersonic Missile Design

## Design

The SFSFC scramjet propulsion system preliminary design is based on the vehicle design shown in Figure 1. The vehicle uses twin, side-mounted solid rocket boosters that accelerates the missile to Mach 4 after being air launched. Next, the inlet start door is opened and the airbreathing scramjet is started. The solid boosters are jettisoned and the scramjet accelerates the missile to the Mach 8-cruise condition. After a sustained cruise, a pushover maneuver is initiated and the missile is steered into the ground.

The scramjet flight engine design, shown in Figure 2, includes a dual-mode ramjet/scramjet combustor consisting of a mixed compression inlet, isolator, pilots for ignition and stabilization, fuel-cooled combustor and nozzle structure, and engine subsystems. A mechanical start door is used to establish supersonic flow in the engine at the Mach 4 takeover condition at contraction ratios that are higher than the self-starting limit.

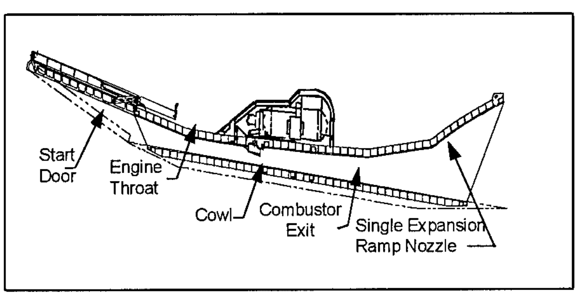


Figure 2: Scramjet Cross-Section

## Technology Development

During Phase I of the SFSFC program, 121 runs were performed in a subscale inlet rig (Figure 3) tested in the NASA Lewis Research Center 1' x 1' Supersonic Wind Tunnel.

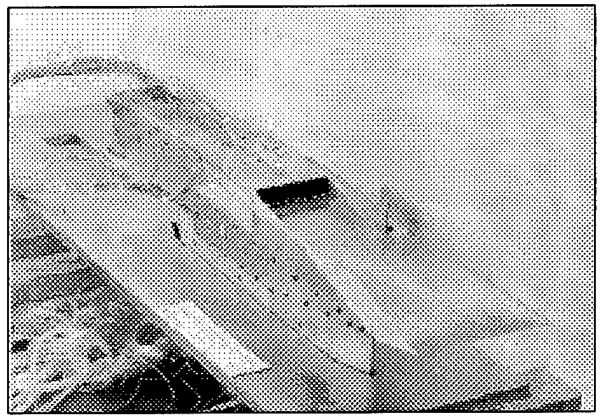

Figure 3: Subscale Inlet Model

The results are shown in Figure 4 relative to the Phase III component objectives. Aerodynamic contraction ratio (CR), kinetic energy efficiency (EtaKE), and weight flow ratio (WR) met or exceeded the end-of-program (Phase III) objectives. Inlet operability, as described by the pressure ratio (P3/P2), fell short of the Phase III objective but is being addressed in Phase II of the program. A second test series is underway in the same rig and facility with the intent of increasing contraction ratio and isolator pressure ratio. An increase in isolator length, a modified cowl, alternate pilots and modified sidewalls will be investigated.

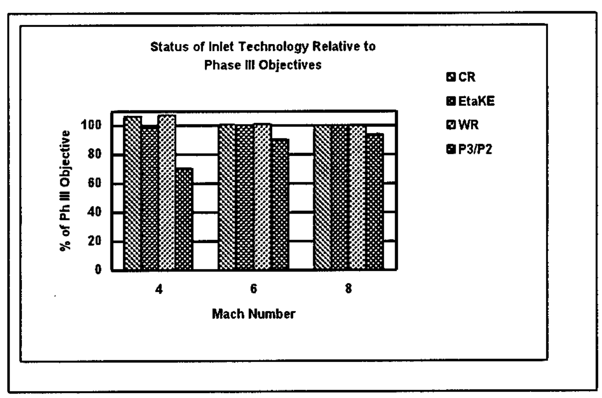


Figure 4: Inlet Test Results

Scramjet combustor performance is being developed in direct-connect (heat-sink) combustor rig tests (Figure 5).

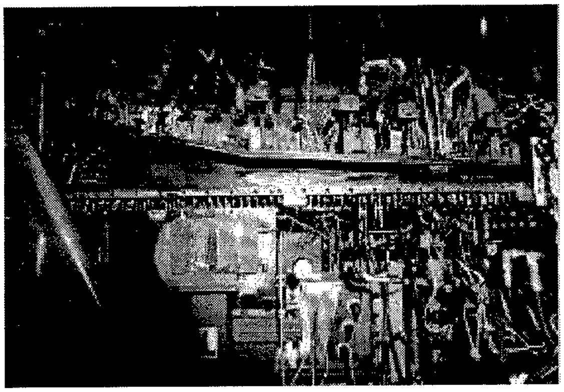

Figure 5: Direct Connect Combustor Rig

In Phase I, 172 combustor runs were performed to study fixed geometry combustor operation using JP-7 at simulated conditions of Mach 4-8. During the Phase I testing, combustion efficiency met the Phase I objective at Mach 4, exceeded it at Mach 6 and fell short at Mach 8 (Figure 6).

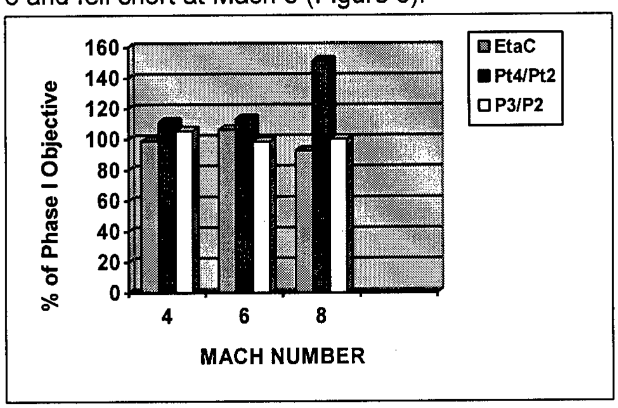


Figure 6: Combustor Test Results

At Mach 4, a small amount of ethylene was required to stabilize combustion. Initial Phase II tests to verify the Phase I baseline showed that the Phase I performance was repeatable without requiring ethylene at Mach 4. Over 100 additional combustor runs have been completed thus far in Phase II. Less complex pilot configurations are being evaluated to potentially reduce drag by at least 25 %.

The active fuel cooling of combustor structures was demonstrated in a 6" x 15" heat exchanger panel (Figure 7) that was tested in the direct-connect combustor rig.

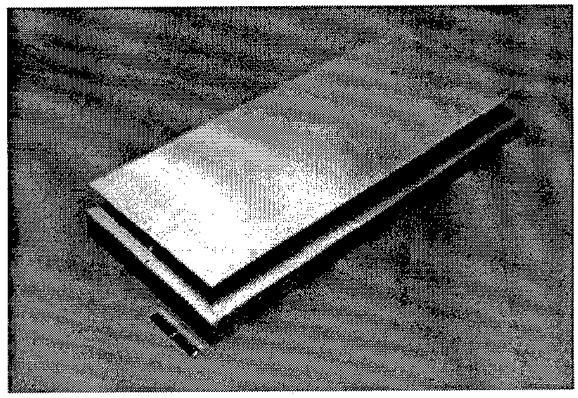

Figure 7: 6" x 15" Heat Exchanger Panel

Figure 8 shows that the panel is in excellent condition after 5 runs. Three more runs were completed in Phase I. The panel was tested at conditions representative of Mach 7 operation. Further tests are planned in Phase II on the same size panel and a larger scale panel. Low cost manufacturing methodology is also being addressed, in parallel.

Figure 8: Panel in Combustor Rig After 5 Test Runs

During Phase I, a heat-sink, semi-freejet engine was designed, fabricated and tested at GASL (Figure 9). The engine incorporated the Phase I flight engine flowpath including the pilot. The test was performed at Mach 8 cruise conditions to demonstrate combustor performance with realistic inlet distortion and to demonstrate the production of positive thrust. The resulting combustor pressure rise and net positive thrust agreed well with pre-test predictions.

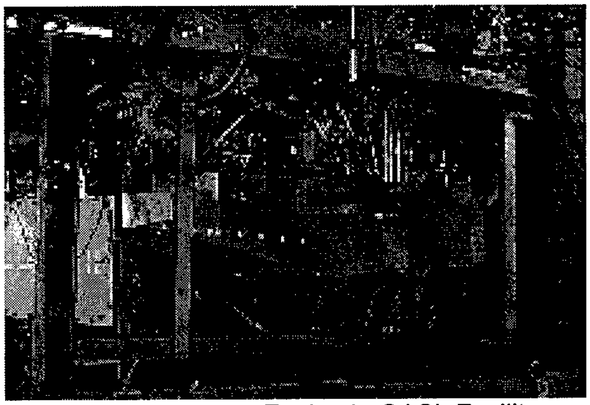

Figure 9: Freejet Engine in GASL Facility

## Future Plans

Phase II of the SFSFC program is scheduled through the end of calendar year 2000. Extensive testing of the hydrocarbon scramjet propulsion system is planned including direct connect combustor rig tests, structures/materials bench tests and freejet engine tests in an Aerothermodynamic Performance Integration Demonstrator (APID). Challenges being addressed include continued advances in fuel-cooled combustor walls and pilot, cowl materials environmental evaluation, and combustor wall structural integrity verification. Combustion enhancements include simplification of the engine start system, improved efficiency through optimized fuel distribution , and an improved pilot to meet performance, operability and durability requirements. Integrated engine performance will be demonstrated in the freejet APID test program. Reformed JP-7 fuel will be evaluated in APID as well as fuel-cooled panels and pilots, an external thermal protection system and composite cowl leading edges. After the successful demonstration of the SFSFC Phase II objectives, Phase III will be initiated. The Phase III effort will include the design, fabrication and test of a flight type engine in the 2003 time period.

P&W will spin-off expendable hydrocarbon scramjet technology from the SFSFC program (which is developing expendable and reusable scramjet technology) for the propulsion system for the Boeing Seal Beach unit's low-cost hypersonic missile concept under the DARPA ARRMD program. The 18-month first phase, which started in July 1998, will culminate in a preliminary design review of two competing concepts. DARPA will pick one concept for the 30-month missile manufacturing and flight-testing phase. Meeting the goals of a 400 nautical mile range at an average speed of Mach 6 results in a flight time of about 7 minutes for the missile.

## Summary

The Air Force Storable Fuel Scramjet Flowpath Concepts program and the DARPA Affordable Rapid Response Missile Demonstrator program will provide hydrocarbon scramjet propulsion system technology development and flight demonstration, enabling the propulsion system to be ready for a missile Engineering, Manufacturing and Development program start. Development of critical and enabling propulsion technologies pertinent to a family of hypersonic vehicles will continue under the SFSFC program through mid-2003.

## Acknowldegements

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