THE TRAILBLAZER PROGRAM

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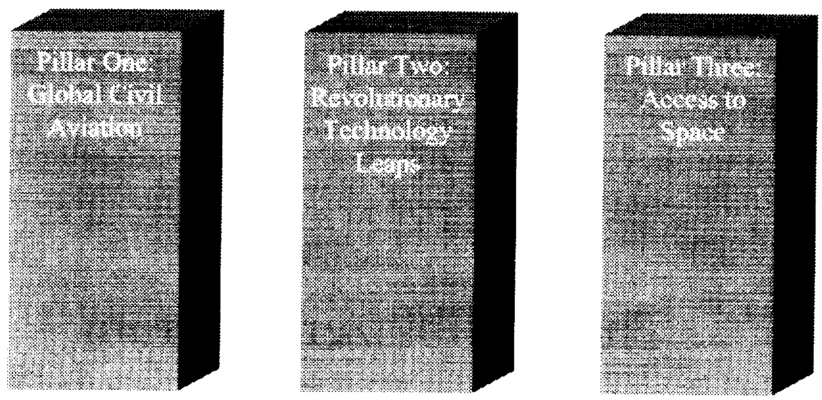
Abstract

The NASA Glenn Research Center is developing Rocket-Based Combined-Cycle (RBCC) propulsion technology for application to reusable launch vehicles in its "Trailblazer" program. This presentation will explain the cost reduction potential of RBCC propulsion, highlight the major technical issues, and describe the elements of the Trailblazer program.

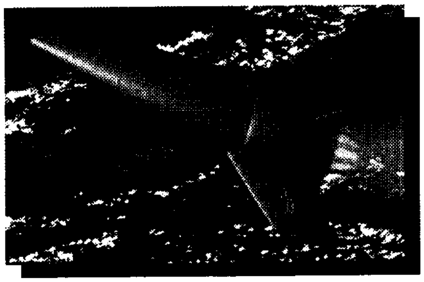
"Three Pillars for Success"

Established in 1997 by the
Office of Aeronautics and Space Transportation Technology (OASTT)
NASA Headquarters, Washington D.C.

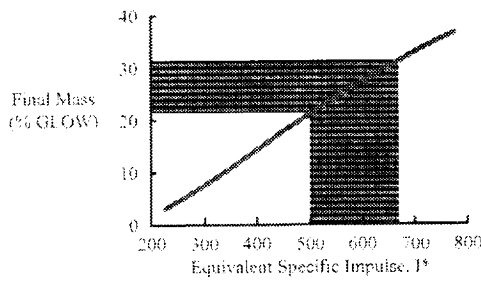


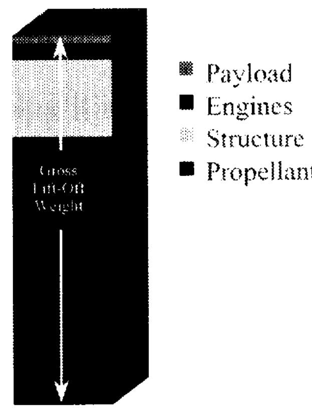
An active area of hypersonic propulsion research at Lewis is the application of air-breathing propulsion to launch vehicles in order to reduce the cost of space access. "Three Pillars for Success" were established in 1997 by NASA's Office of Aeronautics and Space Transportation Technology (OASTT) in Washington D.C. Pillar three, Access to Space, set forth the goal of reducing the cost of space access.

Potential for Reusability



RBCC propulsion provides the potential for reusable SSTO by reducing the fraction of propellant required





As depicted in the figure, RBCC propulsion can increase the structural mass budget, and thereby the potential for a more robust, reusable vehicle design. The range of I* values expected is from 500 to 650. The potential for greater reusability can only be realized however, if a number of mitigating factors related to the use of air-breathing propulsion can be effectively managed.

Factors Mitigating RBCC Performance

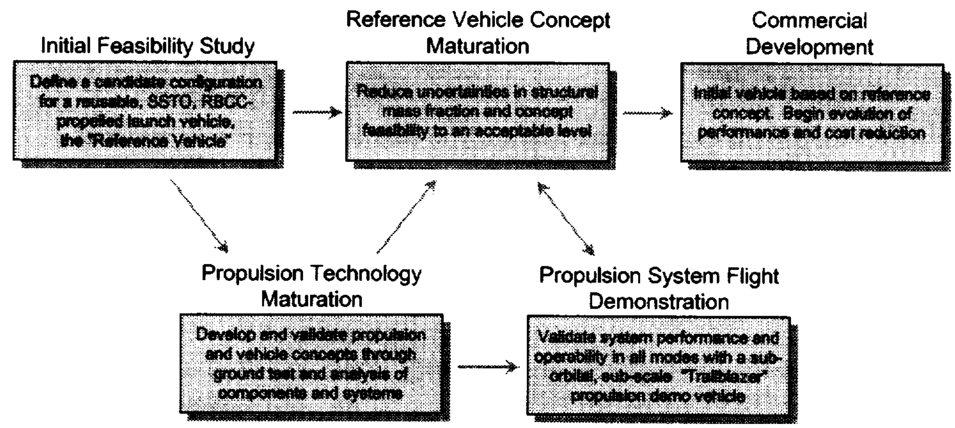
- Weight and complexity of added propulsion components
- Burden of high speed flight within the atmosphere on the vehicle
- Increased fraction of low density hydrogen propellant

Increased I* or "aerothermodynamic" performance is offset by a number of mitigating factors. First, the RBCC engine will be somewhat more complex, and will weigh more than a rocket engine. To provide sufficient thrust for acceleration during the high-efficiency ramjet phase, the air flowpath must be of large cross-section with respect to the vehicle. It is also required that the inlet throat area be varied. The weight and complexity associated with these factors must be minimized by the RBCC designer. A second mitigating factor is the burden of high speed flight within the atmosphere on the vehicle. To accrue the I_{sp} efficiency benefit, the vehicle must fly a much lower altitude trajectory than a rocket-propelled vehicle. The effect of resulting high structural and thermal loads on structural weight must be minimized. Another system-level factor working to offset RBCC efficiency is a reduction in the propellant bulk density due to increased reliance on low-density hydrogen fuel. In ramjet and scramjet phases, only hydrogen is used. Increasing propellant volume results in increasing propellant tank weight, and vehicle drag.

The "Trailblazer" Program

- "Trailblazer" is a reusable, SSTO launch vehicle concept, intended to reduce the cost of space access by making optimum use of air-breathing propulsion
- Development is based on maturation of a specific 300# payload "Reference Vehicle" configuration
- An objective of the program is to *manufacture* and *fly* a sub-scale, sub-orbital X-vehicle to demonstrate *system* performance goals
- Experiments and analysis are currently underway to mature the technologies required for this demonstration, and subsequent application of RBCC engine technology to the third pillar goals

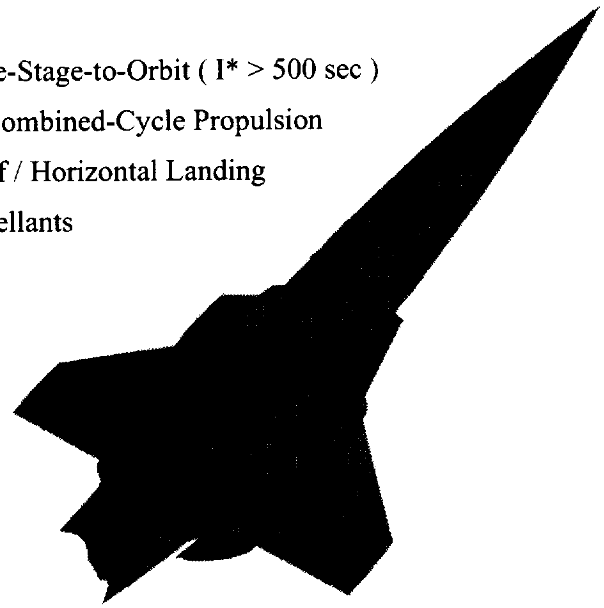
Program Overview



The program began in 1996 with an initial feasibility study. This study defined a preliminary concept and indicated that the application of air-breathing propulsion to a reusable, single-stage-to-orbit, vertical lift-off launch vehicle warranted further study. The initial configuration was used to begin a multi-disciplinary, iterative process to mature the concept through experiments, numerical simulation and system optimization. Once a sufficient level of technical maturity is attained, a sub-scale, sub-orbital flight vehicle that represents the evolved concept will be manufactured and flight tested. All propulsion modes and transitions along the air-breathing trajectory will be demonstrated and an accurate assessment of the reference vehicle structural mass fraction will be possible. The successful completion of this program would allow the commercial development of a vehicle based on the reference concept. Then, through continued evolution in many fields including propulsion, structural design, materials, and multi-discplinary optimization, NASA will approach its third pillar goal of a ten-fold reduction in the cost of space access.

Trailblazer Reference Vehicle Characteristics

- Reusable, Single-Stage-to-Orbit (I* > 500 sec)
- Rocket-Based Combined-Cycle Propulsion
- Vertical Lift-Off / Horizontal Landing
- LOX/LH2 Propellants
- 300# Payload

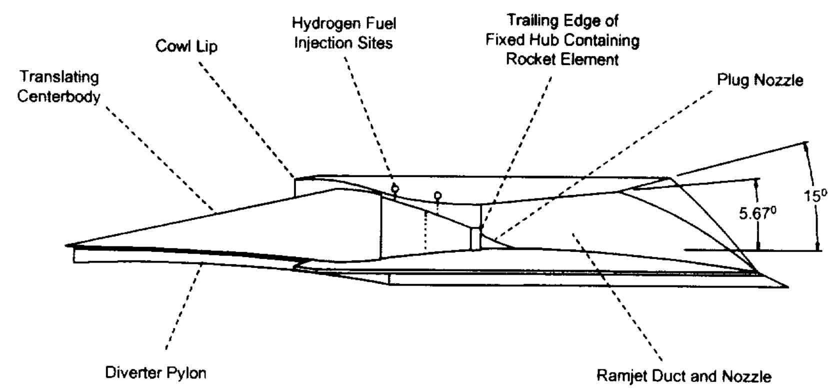


The Trailblazer reference vehicle is a reusable, single-stage-to-orbit concept intended to take advantage of air-breathing cycle performance while minimizing the negative impacts of additional components, higher complexity, and flight within the atmosphere. The axi-symmetric architecture is intended to maximize the potential for structural and volumetric efficiency, and to reduce design and analysis uncertainty.

The vehicle is designed for vertical lift-off, and unpowered horizontal landing to minimize the weight associated with landing gear and wings. Safety and structural issues associated with high-speed taxi are eliminated by VTO. A by-product of VTO is a minimization of time spent in the atmosphere and therefore total heat load to the vehicle due to the high thrust-to-weight ratio required. A small-payload class is appropriate for air-breathing SSTO development. Scaling to large payloads can be accomplished without regard to runway length and load limits.

Liquid oxygen and liquid hydrogen propellants (LOX/LH2) are used. The cooling capacity and energy per unit weight of hydrogen are required. Hydrogen is also an ideal fuel from the standpoint of ignition, and flame stabilization due to its high flame speed. A drawback of hydrogen is its low density which results in structural weight and drag penalties.

Cut-Away View of Propulsion System

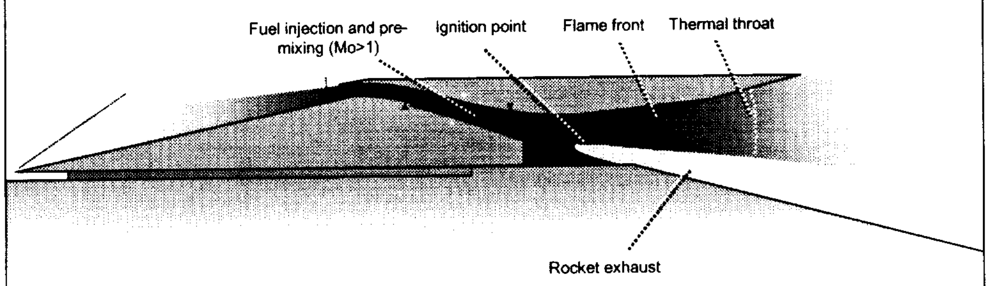


The flowpath cross-section is an axi-symmetric sector with its axis on the boundary-layer diverter radius. Primary considerations leading to the choice of this geometry over a 2-D planar design are structural efficiency, simplicity in sealing and actuation, and design and analysis risk. As opposed to fully axi-symmetric designs, the centerbody is more easily supported and the nozzle is more easily integrated with the vehicle. The flowpath cross-section is not strictly axi-symmetric since the endwalls are not radial planes of symmetry.

A translating centerbody provides the required area variation. Fully-forward, it provides a maximum throat area and efficient spillage for low speed operation. In the aftmost position, it completely closes-off the flowpath for high area ratio rocket-mode operation. Intermediate positions are set for optimum inlet contraction ratio. Existing design and analysis tools for mixed-compression, axi-symmetric inlets have been used to generate the inlet contours. The maximum duct cross-section is sized to accomodate Mach 2 combustion in ramjet mode. See AIAA 99-2239 for further details.

Based on consideration of weight, simplicity, and reliability, each flowpath contains only one rocket element. This element is mounted in a hub that is fixed to the vehicle. The low speed cycle under consideration does not require that the air and rocket streams mix. The rocket operates at a fixed O/F and variable chamber pressure. The single rocket approach also results in better rocket-mode performance than multiple element designs.

Propulsion Mode I - Lift-Off and Low Speed

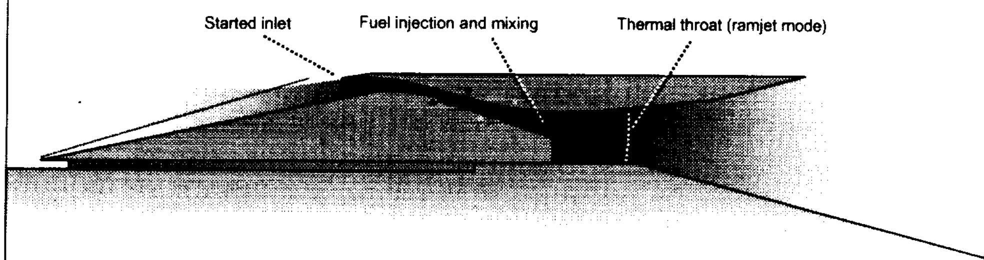


At lift-off, the open inlet ventilates the duct to prevent overexpansion of the rocket. Below Mach one, there is no benefit to fueling the air stream. As flight speed increases, the ram air is pre-mixed with hydrogen fuel in the inlet diffuser upstream of its confluence with the rocket. The rocket provides the ignition source, and the rate of flame propogation determines the length of duct required. At Mach 2 and above, the air stream is fueled to stoichiometric proportion. The constant O/F rocket can be throttled for optimal system performance without regard for ramjet fueling requirements. The compact, high thrust rocket cycle used exclusively for lift-off gives way to the more efficient ramjet cycle as flight speed increases.

The issues associated with this mode of operation are flashback to the injectors, and control of the thermal throat location. Radial variations in fuel distribution are being examined numerically and expermentally as a possible approach.

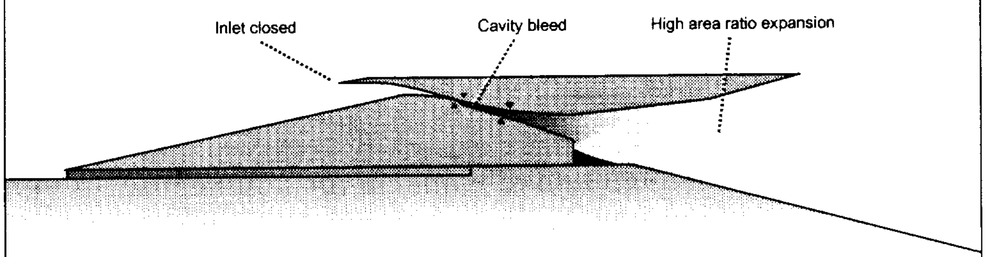
See AIAA 99-2393 for further discussion and a complete description of the cycle analysis method used.

Propulsion Modes II & III - Ram and Scramjet



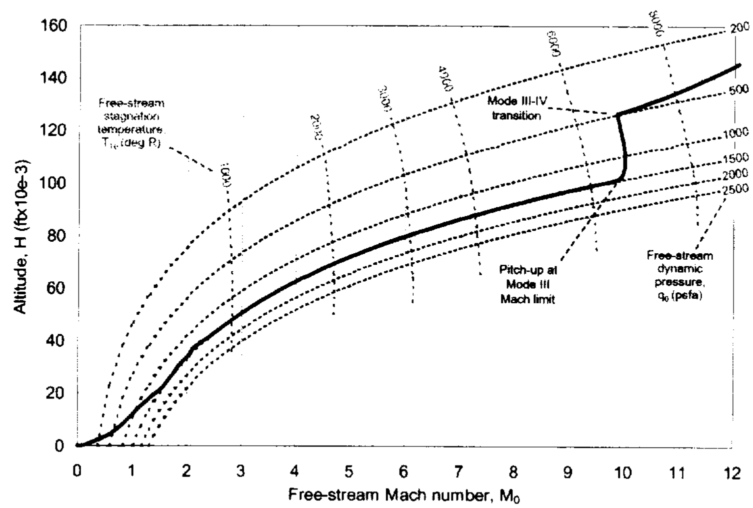
The ram and scramjet cycles operate in the traditional manner. The inlet is started in these modes. A large thermal throat area is required for efficient ramjet mode operation at low Flight Mach numbers. Although the duct cross-section is sized accordingly, fuel distribution and flameholding in the large cross-section are an issue. Pre-mixed operation is being examined as possible solution in the propulsion technology maturation effort.

Propulsion Mode IV - Rocket



Mode IVis a high area ratio rocket, taking advantage of the 400:1 area ratio between the vehicle projected area and rocket element throat. A portion of this area ratio is necessarily free-expansion however. The impingement of the plume on the flowpath surface is managed using a small amount of cavity bleed. System performance is very sensitive to mode IV Isp, since this mode accounts for over 50% of the total ΔV.

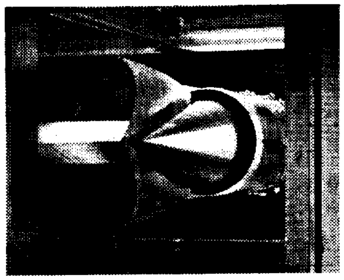
Optimal Trajectory



The air-breathing portion of the trajectory is characterized by acceleration at the constrained maximum dynamic pressure of 1500 psfa to the constrained maximum air-breathing Mach number of 10. The vehicle then climbs at constant Mach number to the constrained minimum dynamic pressure of 500 psfa at which point transition to rocket mode occurs. The remainder of mode IV, the coast phase, and the circularization burn are not shown.

Effective Isp and therefore I* tend to increase with vehicle thrust-to-weight ratio. This is why the optimal trajectory tends toward the maximum allowable dynamic pressure.

Inlet Development and Validation (Rig 2)



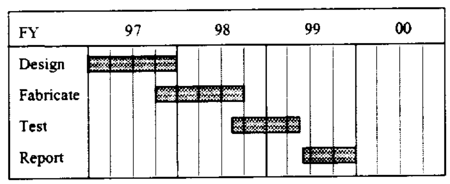
Objectives

- Determine performance of bleedless design from Mach 2.5 to 6
- Determine maximum contraction ratios and back-pressures
- Assess validity of 2-D (axisymmetric) calculated performance
- Acquire data for comparison to 3-D FNS calculations

Description

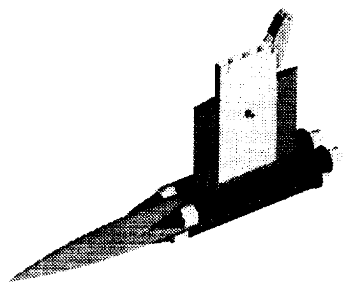
Scale: 5% of 130,000# ref veh (2.65" R_c)
Facility: LeRC 1x1 Supersonic Wind Tunnel
Test cond: Mach 2.5-6.0 (aerodynamic)
Features: Actuated centerbody and flow plug
Cold-pipe mass flow measurement
Static, pitot, and dynamic pressures

Schedule



Point of Contact: Charles.J.Trefny@GRC.NASA.gov

Forebody-Inlet Integration (Rig 3.1)



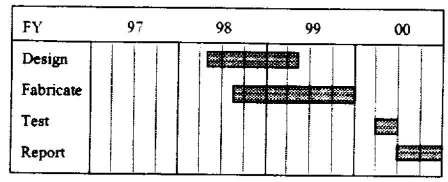
Objectives

- Determine effects of AOA on mass capture and inlet operability
- Assess effectiveness of, and need for boundary layer diverters
- Determine the severity and effects of pod-to-pod and pod-to-body shock interactions
- Validate 3-D FNS CFD calculations

Description

Scale: 13% of 130,000# ref. vehicle
Facility: GRC 10'x10' Supersonic W/T
Test cond: Mach 2.0-3.5, Alpha +/-9°
Features: Fixed inlets (phase 1)
Removable boundary layer diverters
Inlet mass flow rate measurements
Oil flow, press sens paint, laser sheet

Schedule



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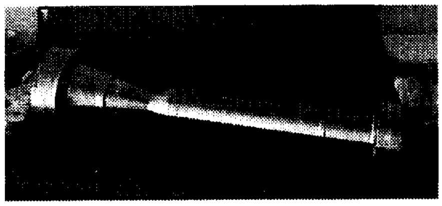
Rocket Element Development (Rig 6)



Rig 1 Rocket During Fabrication

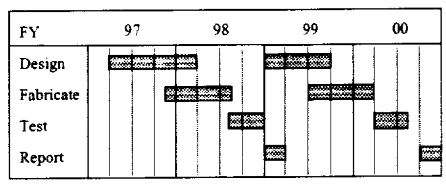
Objectives

- Mutiple projects for rocket element maturation
- Develop rocket element for use in Rig 1 testing
- Quantify performance and heat transfer characteristics
- Subscale development of internal semi- annular rocket
- Subscale evaluation of rocket injector element designs and chamber cooling configurations for use in full scale engine.

Description

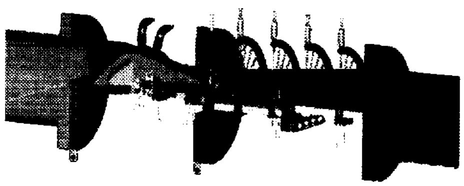
Scale: Variable
Facility: GRC CRL32
Test cond: $P_c < 1200$ psia; O/F 3-7; 2000# Thrust
Features: Oxygen and Hydrogen propellants
Water or liquid hydrogen cooling
High speed and dynamic data

Schedule



Point of Contact: Timothy.D.Smith@grc.nasa.gov

Direct-Connect Mixer/Combustor (Rig 1)



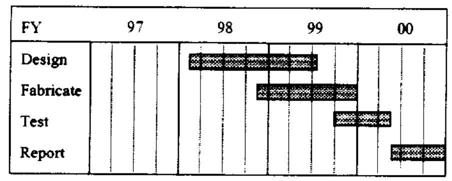
Objectives

- Evaluate performance and operability of both the SMC and IRS mode 1cycles
- Determine the combustor length required for both mode 1 cycle options
- Demonstrate transition from mode 1 to 2, and develop mode 2 fuel injection and flameholding strategy
- Evaluate performance of internal nozzle in mode 4
- Evaluate actively-cooled, flight-weight flowpath segments

Description

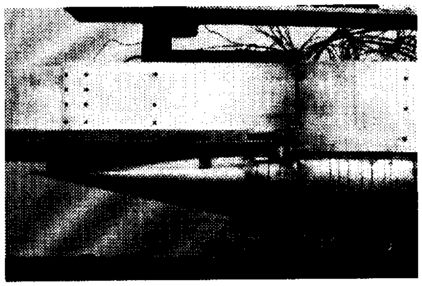
Scale: 20% of 130,000# ref vehicle
Facility: GRC ECRL
Test cond: SLS to Mach 3 (true temperature)
Features: Gaseous H2/O2 rocket
Variable combustor length
Movable centerbody
Various fuel injectors and stations

Schedule



Point of Contact: Scott.Thomas@GRC.NASA.gov

Integrated Propulsion System Pod (Rig 4)



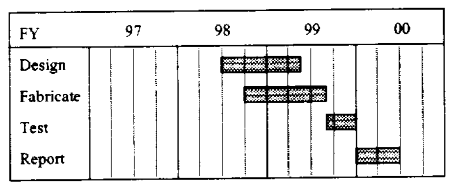
Objectives

- Develop and optimize ram and scram mode fuel injection scheme in the presence of realistic inlet flow profiles
- Determine uninstalled performance from Mach 3.4 to 7
- Establish maximum inlet contraction over a range of temperatures and Re #
- Assess effects of test flow vitiation on engine performance

Description

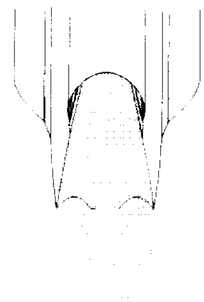
Scale: 10% of 130,000# ref veh (5.13" R_c)
Facility: GASL L4 and GRC Plum Brook HTF
Test cond: Mach 3.4 - 7 (true temperature)
Features: Actuated centerbody
Parametric copper heat sink design
Multiple fuel injection stations
Thrust, static and pitot pressures, wall temperaturess; skin friction

Schedule



Point of Contact: Scott.Thomas@GRC.NASA.gov

Nozzle Performance (Rig 8)



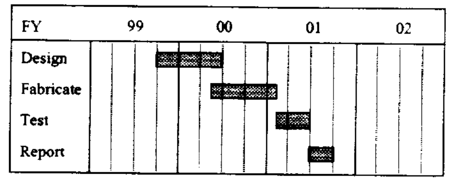
Objectives

- Provide experimental assessment of losses due to under/over expansion, flow divergence, shocks, and base drag for inclusion into a performance model
- Determine effect of secondary flow on mode IV expansion process efficiency

Description

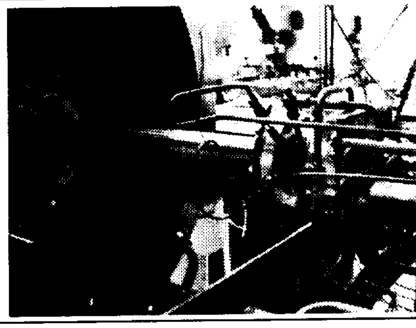
Scale: TBD
Facility: GRC 8x6, Vacuum chamber
Test cond: SLS, Mach .8-2, Vacuum
Features: Dual warm flows simulate rocket and air streams (IRS cycle)
Variable air stream throat area
Single-component force balance

Schedule



Point of Contact: Charles.Trefny@grc.nasa.gov

Rocket-in-a-Duct Code Validation (Rig 7)



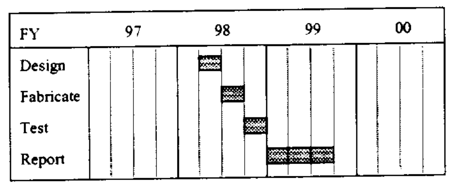
Objectives

- Develop generic expansion efficiency model
- Measure performance of rocket-in-a-duct
- Evaluate geometry with FNS-CFD
- Validate axisymmetric, FNS results

Description

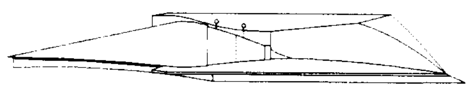
Scale: 1/500
Facility: RCL-11
Test cond: GH/GO, MR=4, Pc=100 psia
Features: Altitude Test, +/-1% Thrust

Schedule



Point of Contact: Steven.Schneider@grc.nasa.gov

Flight-Like Integrated Propulsion Sys. (Rig 5)



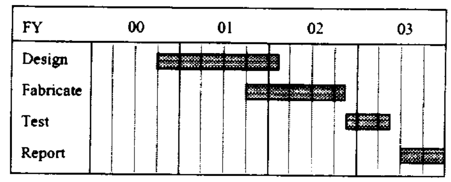
Objectives

- Demonstrate power-balanced operation in all operating modes
- Demonstrate closed-loop control of variable geometry and propellant flows
- Determine uninstalled performance in all operating modes
- Provide sufficient confidence to proceed with flight demonstration

Description

Scale: Largest practical
Facility: 10x10, HTF
Test cond: SLS, Mach 2-7
Features: Flight-like construction
Water or LH2 cooled
Remote centerbody actuation and fuel staging
Closed-loop control system

Schedule



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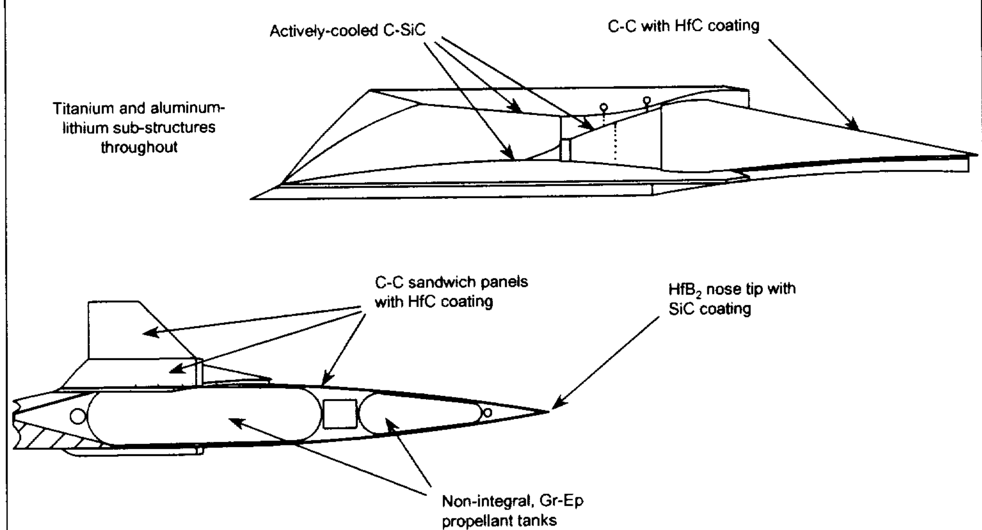
Basis for Structural Weight Estimates



This chart presents an overview of materials assumptions used to arrive at a gross lift-of-weight of approximately 225,000 pounds. Technical challenges associated with manufacturing and coating actively-cooled composites are being addressed by a government-contractor team under a NASA NRA. This team will also further optimize structural architectures and examine various alternatives.

Pratt-Whitney NRA Activity

ABLV RBCC Propulsion System Materials, Structures, and Integrated Thermal Management (NRA-98-LERC-2A)

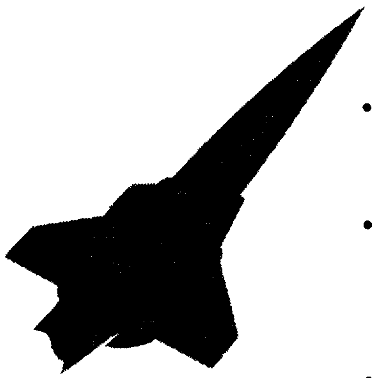
- 18 mo / $2M contract awarded to Pratt-Whitney September, 1999
- Complement to existing NASA in-house activity
- Products

  1) Recommendation of propulsion system architecture including the use of light-weight, high-temperature materials, thermal management, and propellant cycle design

  2) Estimate of the propulsion system flight-weight

  3) Recommendations of areas for further analysis or technology development that may lead to reduced weight or increased reusability

Flight Demo Vehicle Characteristics

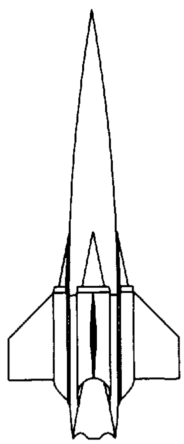


- Geometrically, dynamically similar to the reference vehicle at about 1/2 scale
- 40% propellant mass fraction, required for single-flight, all-mode demonstration to 11000 fps
- Phased, envelope-expansion approach

Trailblazer Program Status

- FY2000 Funding approximately $15M from the NASA Propulsion Base R&T program
- Included in the NASA Headquarters "Spaceliner 100" Roadmap as a candidate for hydrogen SSTO
- Participation by NASA Glenn, Marshall, Langley, and Dryden
- Other contractor and university efforts in-place

Summary



- "Trailblazer" is a reusable, SSTO launch vehicle concept, intended to reduce the cost of space access by making optimum use of air-breathing propulsion
- Propulsion component experiments and advanced analysis is underway to mature reference vehicle design
- A program objective is to flight demonstrate aeropropulsion performance, structural weight, reusability, and operability