A Regeneratively-Cooled Thrust Chamber for the Fastrac Engine

Kendall Brown & Dave Sparks

NASA Marshall Space Flight Center

&

Gordon Woodcock

Space America, Inc.

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Overview

- Introduction and Background
- Design
  - Requirements
  - Integrated Engine Concepts
  - Test Article Design
  - Analyses
- Fabrication
  - Fabrication Processes
  - Fabrication
- Test Program
- Status

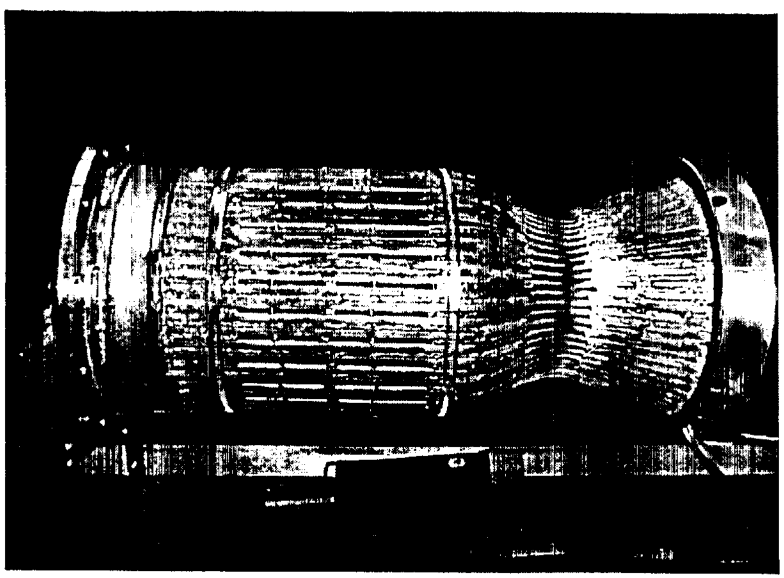
Introduction

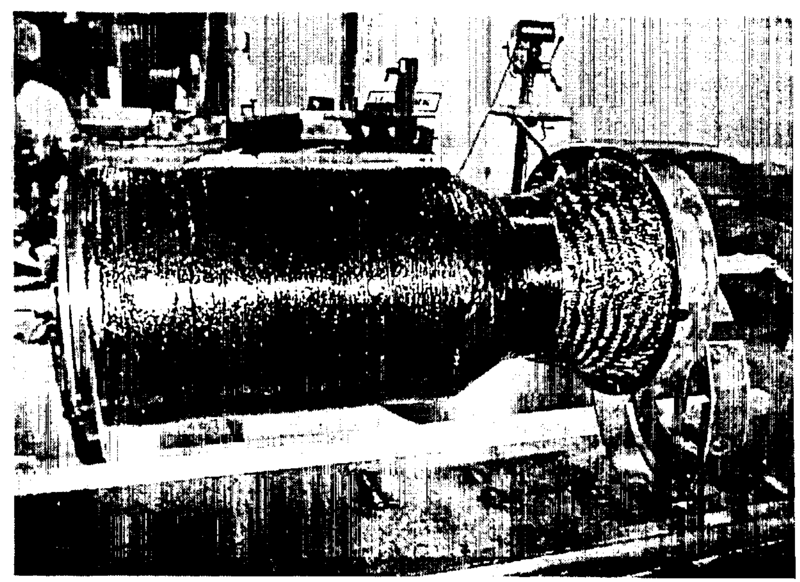
- Fastrac engine was developed to demonstrate low cost design and fabrication methods
- Originally intended for an expendable booster
- NRA 8-21, Cycle 2 solicited low-cost, reusable rocket engine technologies
  - Space America, Inc. proposed and was selected to develop a regeneratively-cooled thrust chamber for the Fastrac engine based on their commercial engine development program
  - Contract ATP 30 August 99
  - Rapid, firm/fixed price contract
- Regen thrust chamber enables more cost efficient test program

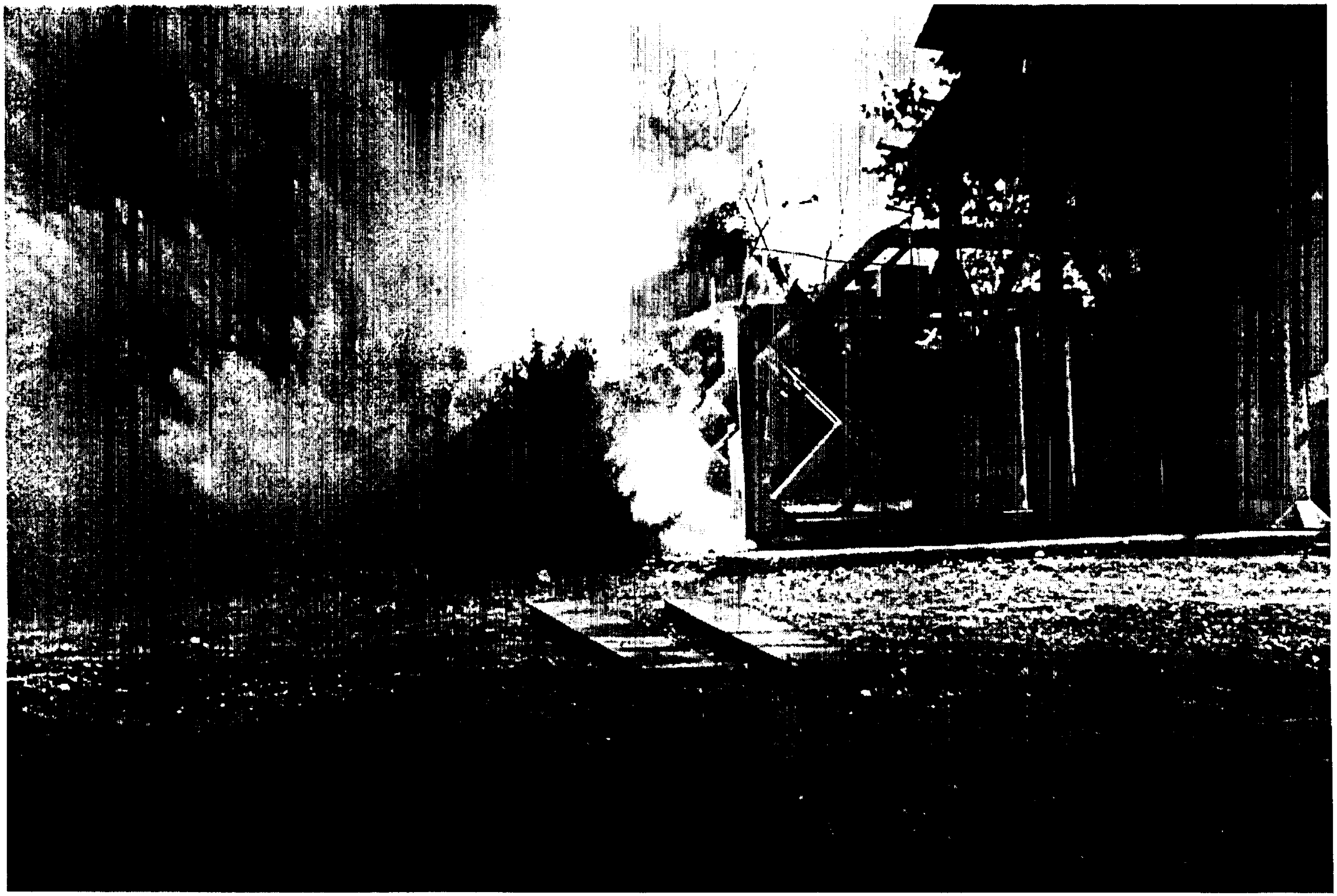
Space America 12K Background

- 12,000 lbf LOX/Kerosene regeneratively-cooled thrust chamber.
- Hydraformed copper tubes, TIG'd together, and brazed to manifolds. Graphite overwrap structural jacket
- 16 starts, 12 to mainstage as-of Nov 99. Still operational
- P_C=250 psia, regen-cooled to ε_e=3:1, 10.5"ϕ cc, 6.9" ϕ throat

  {Fastrac 633 psia, 15:1, 11.3"ϕ cc, 8.25"ϕ throat}







Research Objectives

- Design, develop, and fabricate a regeneratively cooled thrust chamber for the Fastrac engine using the low cost design and fabrication methodology developed by SAI for their 12K regeneratively-cooled chamber.
- Develop conceptual layouts for integrating a regeneratively cooled thrust chamber into the Fastrac engine assembly, with specific application to integration of a regeneratively cooled Fastrac engine into the X-34 flight test program
- Provide a proof-of-concept test article to MSFC for a 3-test series in TS 116.
  - Tested at the same operating conditions.
  - Measure bulk coolant temp increase and the temps at the coolant tube/composite jacket interface.
  - Examine for life limiting hardware issues.

Design Requirements

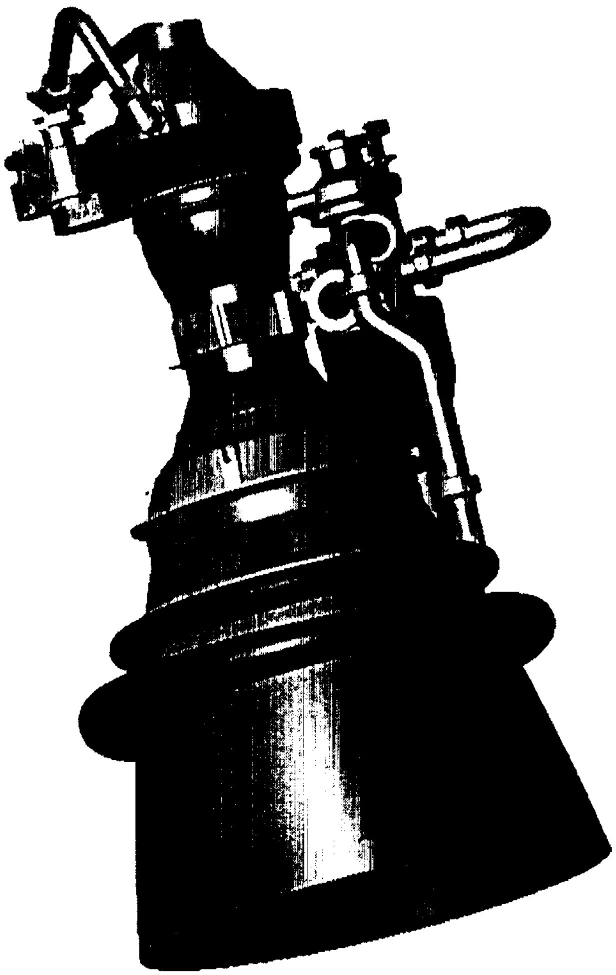
- Direct comparison to 15:1 ablative nozzle tests, thus 15:1 regeneratively-cooled thrust chamber
  - Interface to MSFC test stand and injector
- Path to integrated engine with regen chamber
- Similar, low-cost fabrication processes as 12K, but modified as needed
  - Single production test article vs production
  - Tube bifurcation required
    - Trade study evaluated 1-pass, 1-1/2 pass, 2 pass
    - 1 pass selected, with 2:1 splice ring

Integrated Engine Concepts

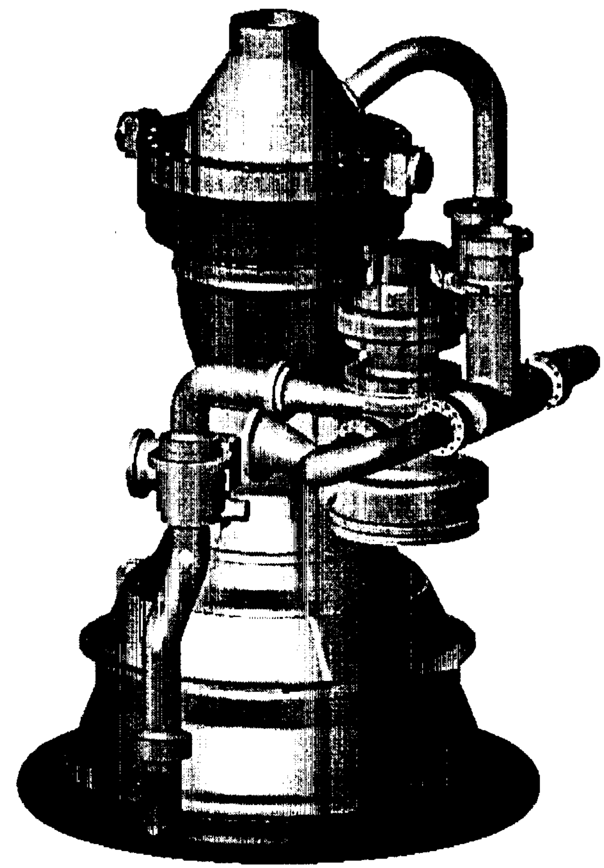
- Turbopump relationships remain unchanged
  - Existing propellant inlets to the engine
  - Existing orientation with respect to the injector
  - Existing MOV position
  - Existing belly band
  - Maintain pressure drop within existing fuel orifice delta-P
- Horizontal start capability
  - Coolant jacket primed at engine start
- MFV can be repositioned
- Existing ignition system
- Maintain injector feed (splitter block and steer horns) as similar to existing as possible
- Use existing TVC actuator bracket
- Ancillary engine components subject to relocation
  - igniter valves, bypass valves, purge valves, TCA igniter assembly, etc.

Integrated Engine Concepts

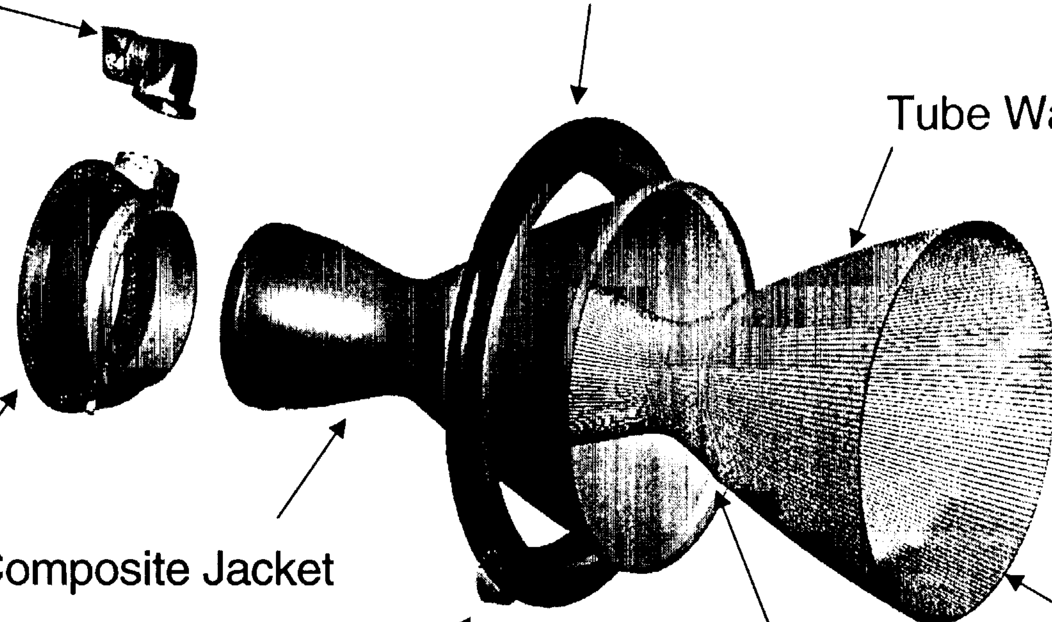
Altitude Application (i.e. X-34)



Booster Application



Test Article Design



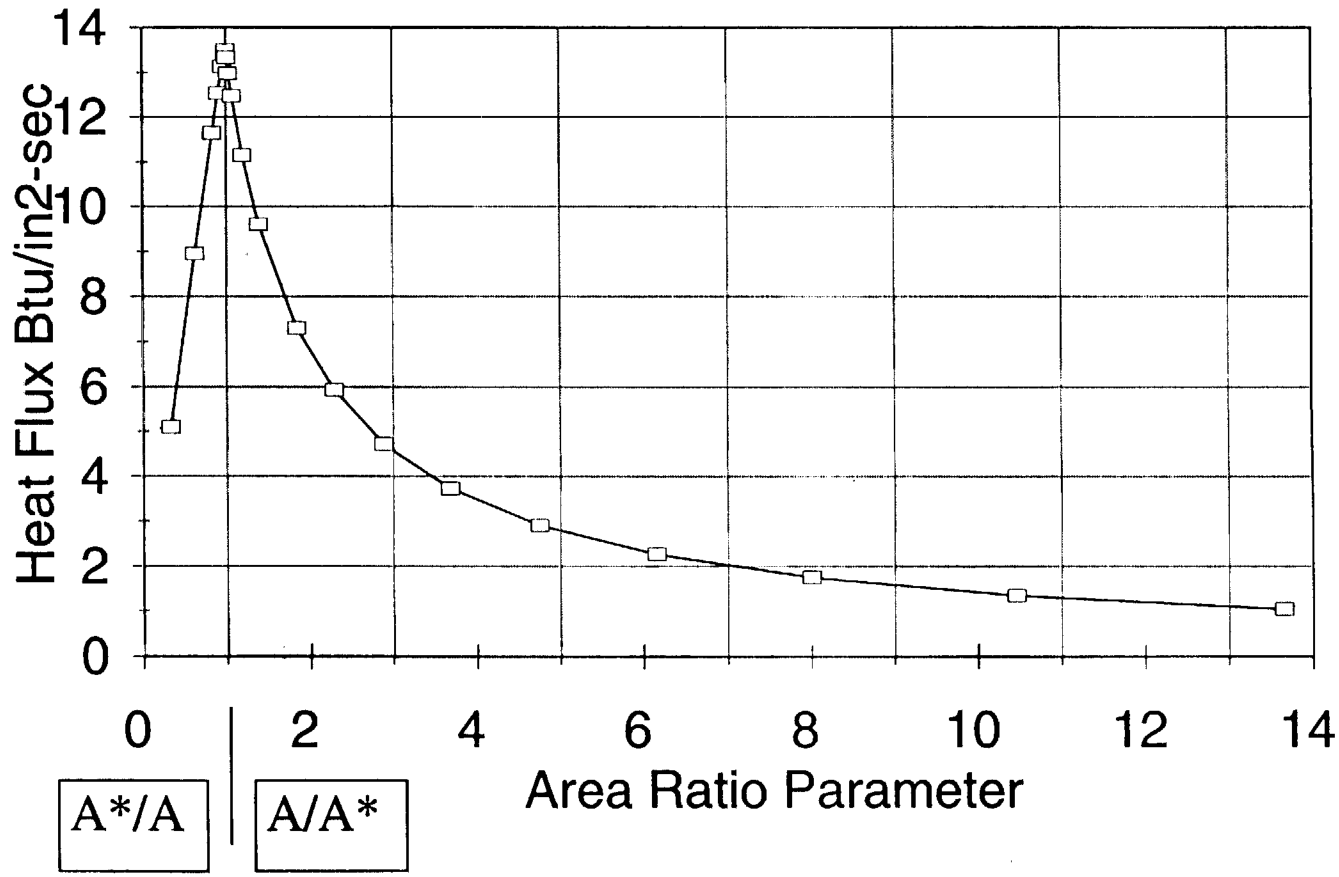
Test Article Design and Fabrication

- Coolant tubes
  - Hydraformed C122 Copper tubes
    - Copper selected for high conductivity and formability
- Tubewall assembly
  - Trade study evaluated tube joining processes
    - Welding, torch brazing, furnace brazing, electroplating
    - Selected TIG welding for test article
- Structural jacket
  - Trade evaluated composite jacket
    - Composite jacket vs electroplating
    - Selected composite for test article
      - Fabrication process trade study selected involute method for single production test article
  - Design for TVC actuator loads from X-34

Fluid Dynamic Analyses

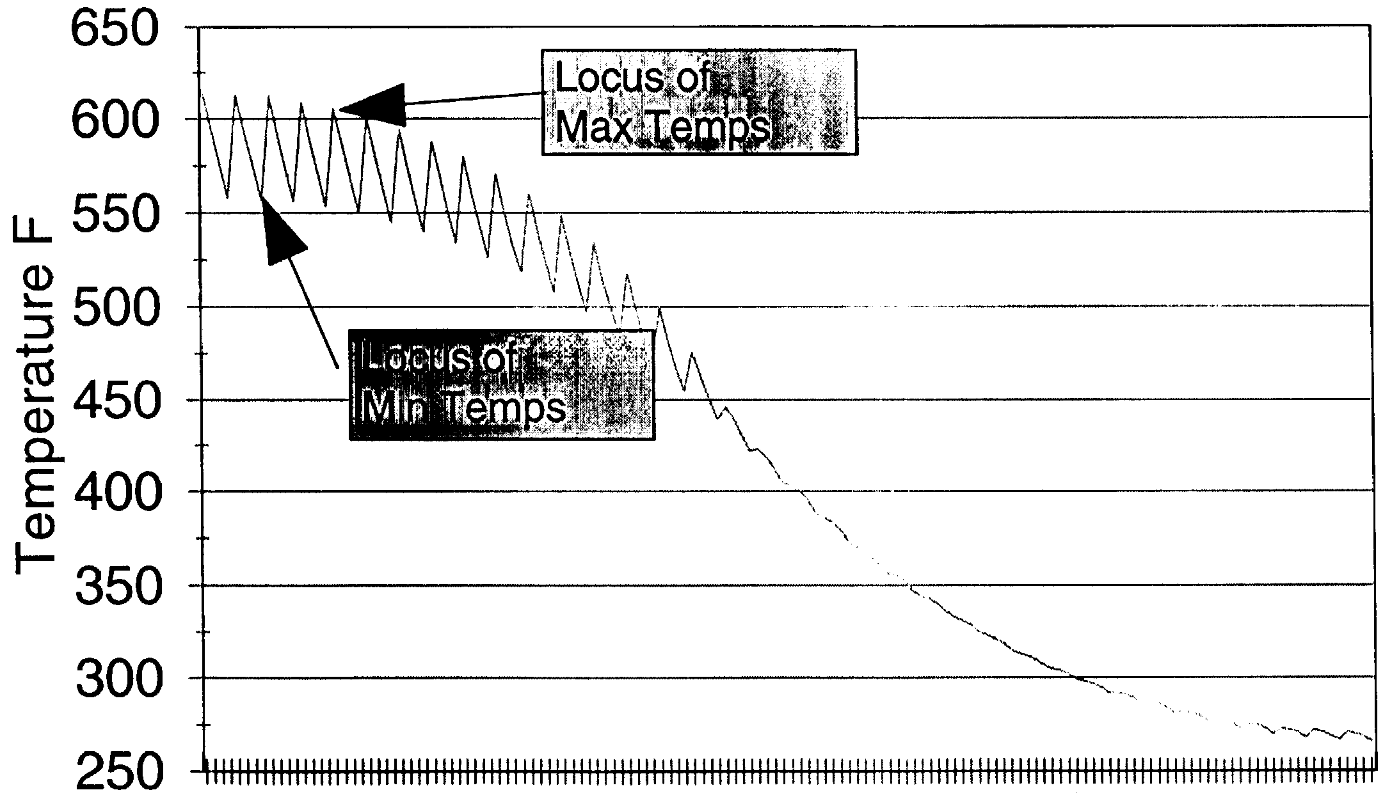
- Analytical/Empirical used to begin design
  - Bartz equation to predict heat flux,
    - Correlation to 12K transient and steady-state test data
  - 2-D transient conduction model around tube
  - Pipe flow correlation for coolant flow
    - ΔP and ΔT
- CFD study of hot gas and individual coolant tube followed
  - Hot gas side, with MR gradient for fuel film cooling
  - Liquid side 3-D Navier-Stokes w/variable properties
    - Used predicted tube wall temp from analytical prediction
    - Bulk ΔP and ΔT compared very well with analytical
    - Boundary layer maximum temp less than coking limit

Bartz Equation, Fastrac Engine



Fastrac Tube Transient Analysis

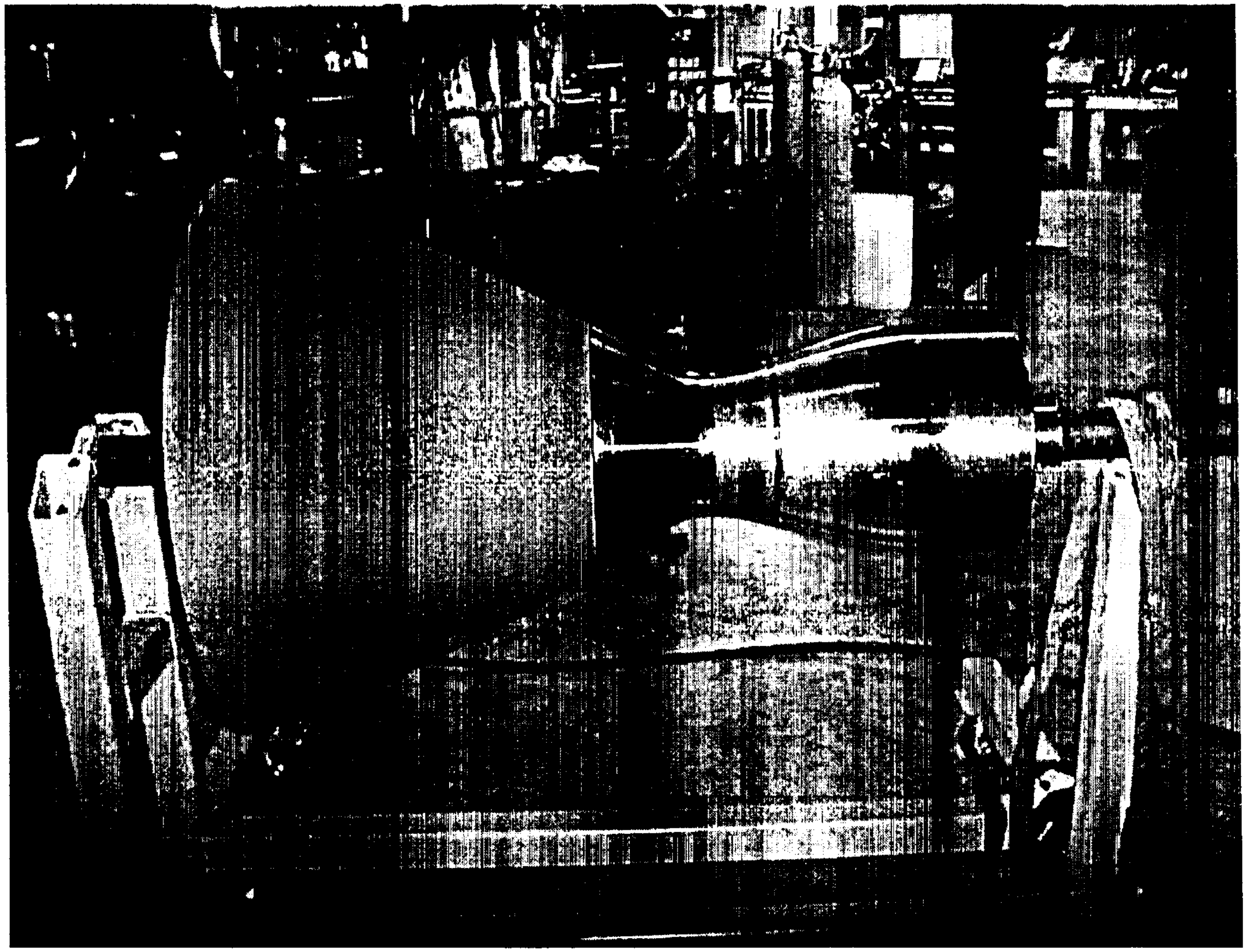
Steady State Temps



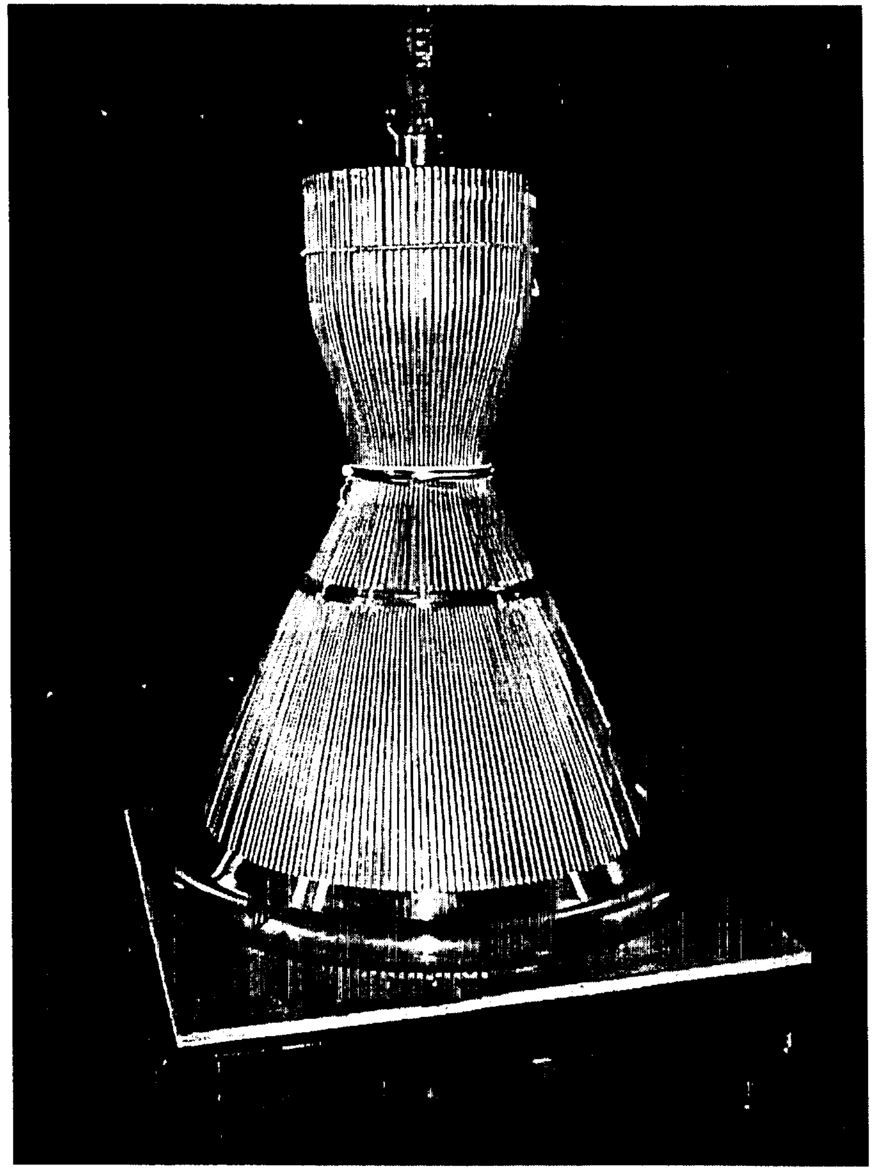
Structural Design and Analysis

- Two-step design and analysis
  - Hand-calc and CADD add-in FEA program for initial design
    - Composite jacket sized for TVC actuator loads
    - Tube cross-sectional profiles modeled with FEA, and analysis validated against 12K geometries.
  - Detailed Finite Element Analysis
    - Included internal chamber pressure, tube internal pressure, TVC actuator load, and thermal.
      - Showed area of concern between throat and splice ring
      - Test article won't have actuator band or tested with actuator loads
      - Requires further analysis

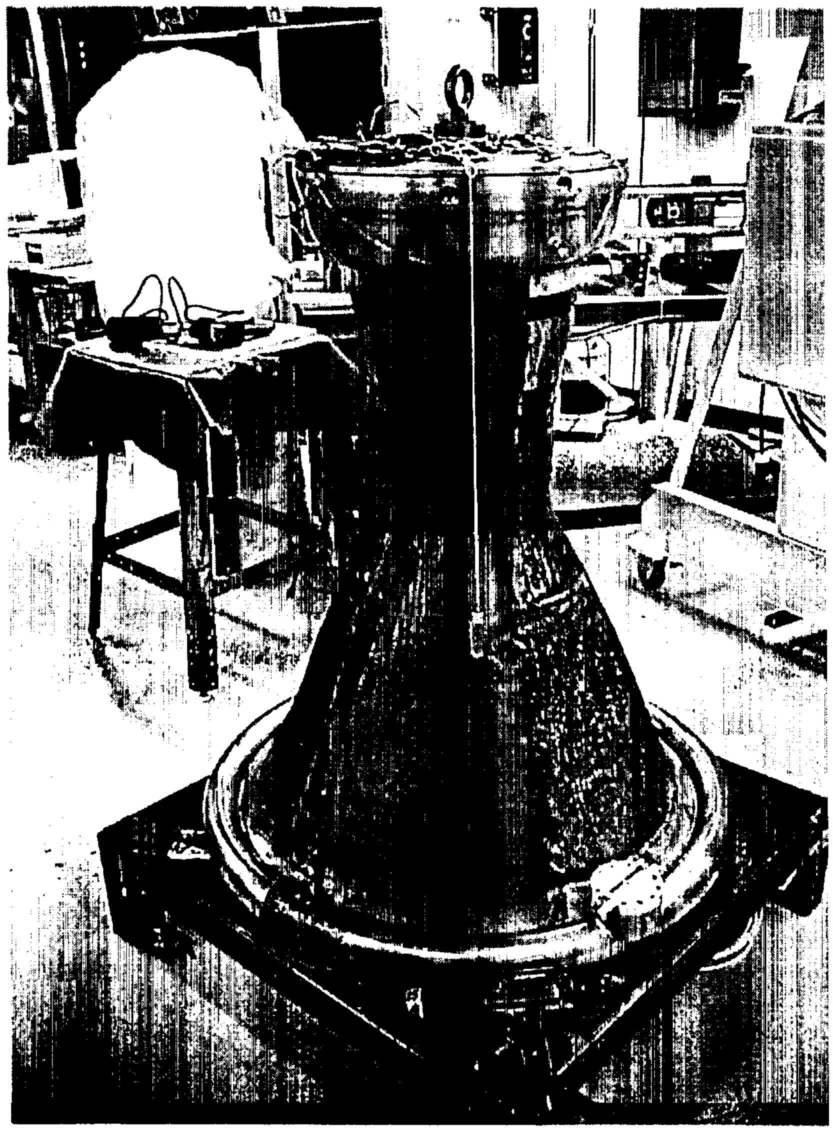
Assembly Mandrel



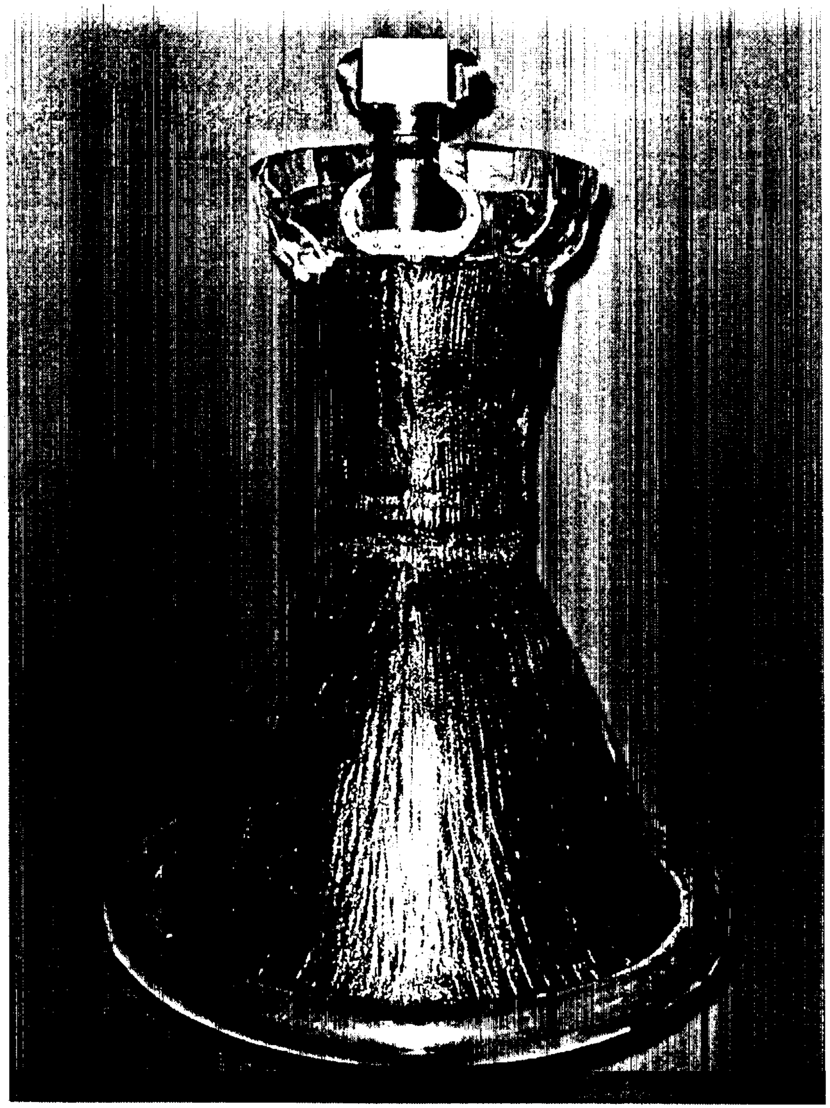
Tubewall Assembly Dry-fit



Involute Jacket Assembly



Completed Regen Thrust Chamber



Test Plan

- 3-test test series at MSFC component test stand
  - 10-second test with LOX flow at stage 1 and full fuel flow. Chamber pressure approximately 400 psia.
  - 30-second mainstage test, targeting nominal chamber pressure 633 psia.
  - 150-second (full duration) mainstage test, targeting the same condition.
- Instrumented for manifold pressures, bulk coolant temp, and tubewall/composite jacket interface at 41 pts.
  - Compare to predicted.
- Inspect for signs of life limiting conditions.
- Awaiting test stand availability
  - Testing expected this Fall

Summary

- Project successfully demonstrated ability to fabricate a low-cost regeneratively-cooled thrust chamber
  - Expected production cost 2.5 to 3.5 times the expendable ablative nozzle, but
  - Expected life equal to or exceeding the 7 full duration test requirement of the balance of engine components
- Testing to verify proof-of concept