Combustion Device Technology Development at Marshall Space Center

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Project Emphasis

- NASA's goals of achieving low cost access to space via Highly Reusable Launch Vehicles have focused near-term (2nd Generation) ETO efforts on :
  - High Thrust/Weight LOX/Hydrogen Engine
  - Rocket Based Combined Cycle (RBCC) Engine Ejector Ramjet Engine
- Long-Term (3rd Generation) efforts include PDRE's, RBCC/TBCC Ramjet/Scramjet
- Current 2nd Generation funding in Combustion Devices technology focused primarily on RBCC Ejector Ramjet

In-House Emphasis

- As a support organization in the Space Transportation Directorate for combustion devices we address industry needs with an independent perspective
- Our intent is the fill the holes in reusable ***rocket*** combustion devices (RRCD) technology
  - Direct in-house support
  - Coordination with other organization
- Provide innovative, high payoff options
- Strengthen the industries ability to develop new technology at low cost

Current State of RRCD technologies

<u>Hardware</u>

- SSME thrust chamber and preburners
  - High Specific Impulse, Moderate T/W
  - Moderate Reusability
  - High Cost
  - No combustion stability concerns

<u>Design Tools</u>

- Steady state prediction of performance and thermal environment
  - Highly empirical, narrow extrapolation band
- Transient Environment and HF Combustion Stability Prediction
  - Little if any reliable predictive capability

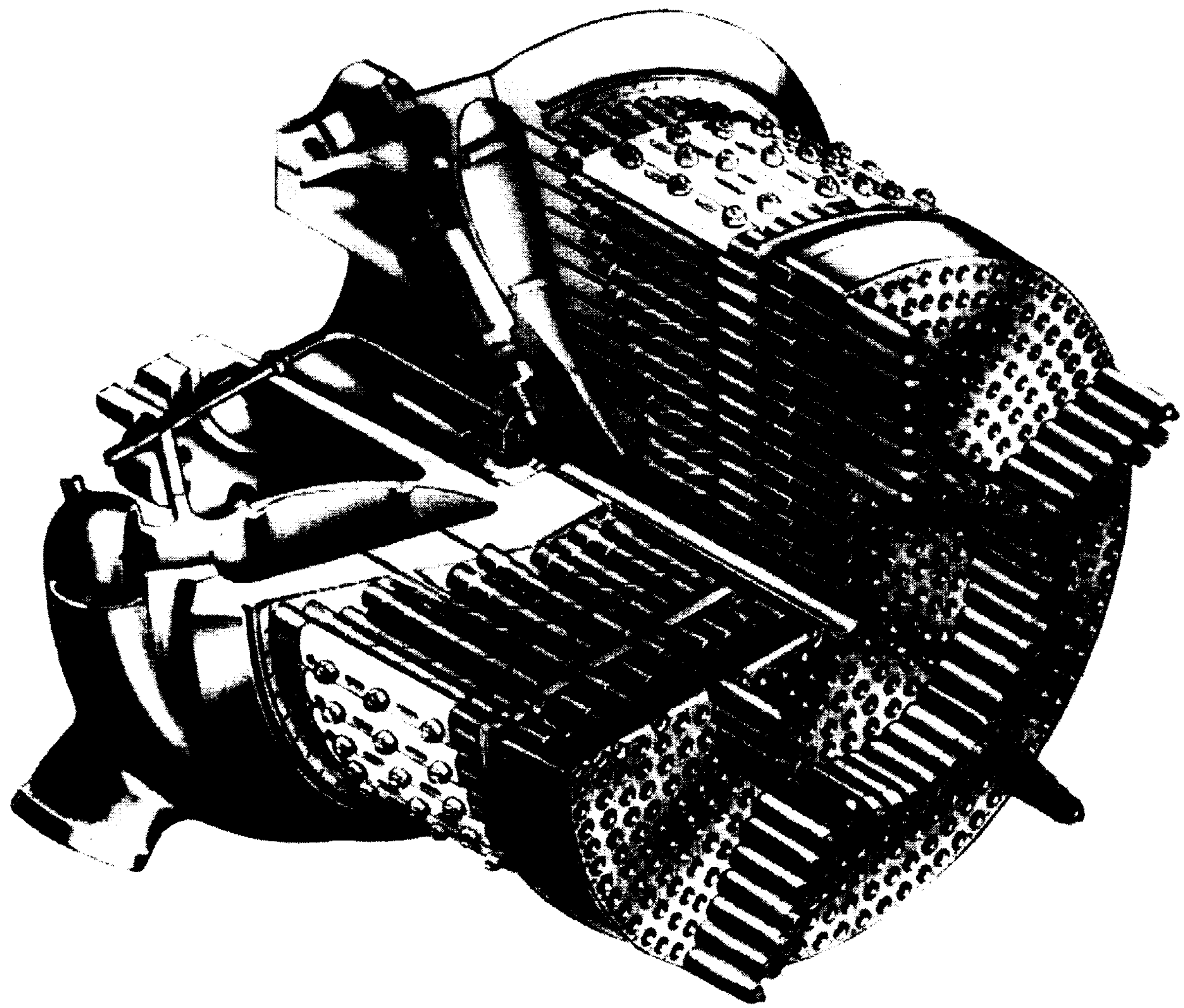
The Challenge

- Make substantial improvements in T/W and reliability over the SSME at minimal development cost in order to make 2nd generation vehicle cost effective and substantially improve crew safety
  - Increase engine life by ~5-10X
  - Increase engine T/W ~ 35%
- A cost/time effective CD technology program is needed in order overcome the weaknesses in design capability
- Test Fail/Fix development cycle based on current tools will prohibit satisfaction of design requirements within current schedule and budget

An Illustrative Example

- A Comprehensive evaluation of the SSME would examine each individual component in order to determine if a potential exists to reduce weight or increase reliability
  - The SSME main injector
    - It has a 99% ERE, with little potential for improvement
    - It's heavy - ~ 400 lbs or ~ 5% of total engine weight
    - It is complex with 600 elements and ~ 3000 parts
    - No design tool exists that can identify weight and reliability advantages of alternate designs

The SSME Main Injector

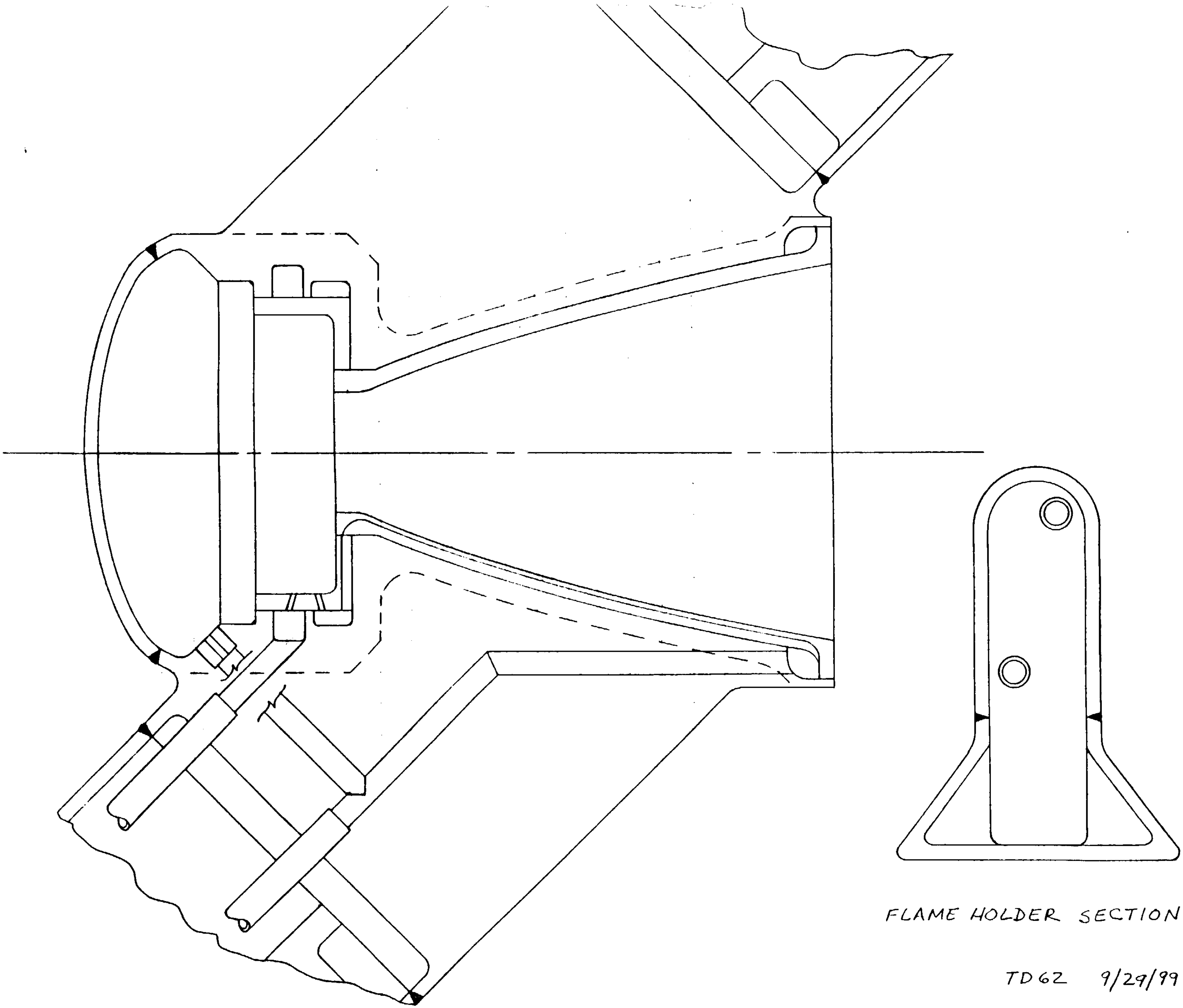


The Strategy

- Organize a multiple organizational plan that coordinates the complementary capabilities available in the industry to generate the required technology to develop 2nd Generation Combustion Devices hardware
- Elements of plan
  - Design Conception
    - Develop a fundamental design philosophy to generate potential design improvements
  - Design Environments
    - Inexpensive test method to evaluate potential hardware improvements
    - Combustion code improvements
    - Fundamental physical model development
  - Material Technology
    - Develop materials that improve design margins

Design Conception

- Develop a fundamental design philosophy to generate potential design improvements
  - Encourage “out-of-the-box” thinking with a physical basis
  - Example- What I call “ The philosophy of physical advantage”
    - Attempt to take advantage of physical phenomena to improve margins
      - Injectors require a minimum pressure drop to decouple feed system, injector design should minimize viscous pressure drop and maximize pressure drop energy used to mix propellants
      - Attempt to allow cooler fluids to flow over structural surfaces without sacrificing mixing efficiency



FLAME HOLDER SECTION

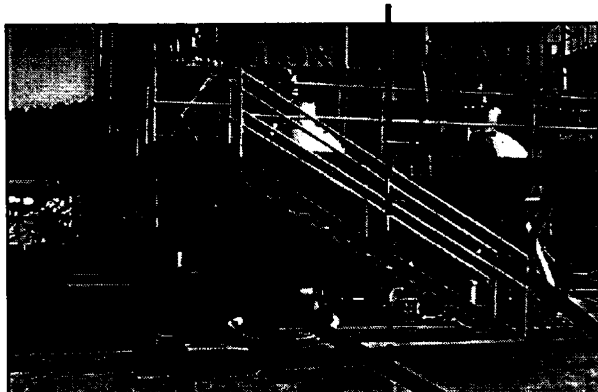
TD62 9/29/99

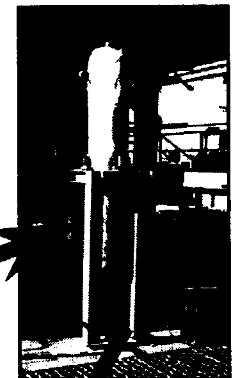
Design Environments

- Inexpensive test method to evaluate potential hardware improvements
  - A test capability should include
    - Small scale, quick turnaround hot-fire tests
    - Simultaneous specific impulse and mixing efficiency measurements
      - Thrust, Flowrate, Heat Flux, Chamber Pressure, and Plume Species
    - Operating conditions and size scale must be reasonable enough to allow scaling to full-scale conditions
    - A method for scaled stability testing should be developed
    - Hardware design should consider system and component aspects of ignition
    - THIS TESTING IS DISTINCTLY DIFFERENT THAT THE TESTING NEEDED TO VALIDATE PHYSICAL MODELS AND COMBUSTION CODES

Test Stand 115: Facility Thrust Chamber Technology

Liquid Methane Storage System
- Tank: 2200 gal, 1500 psi



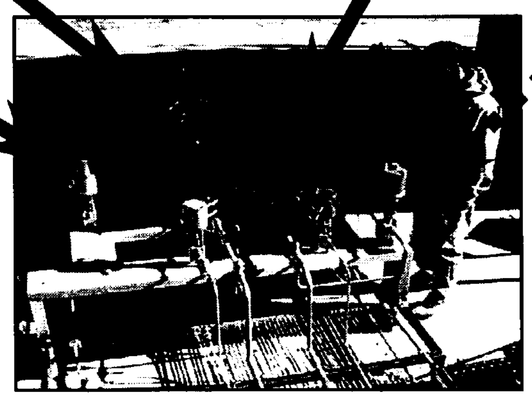


Liquid Methane Run Tanks
- Tank #1: 20 gal, 3000 psi
- Tank #2: 500 gal, 3000 psi

New TS115 Control Room

LOX System
- Tank: 500 gal/3000 psi

Water System
- Small Tank: 10 gal/3000 psi
- Large Tank: 500 gal/3000 psi

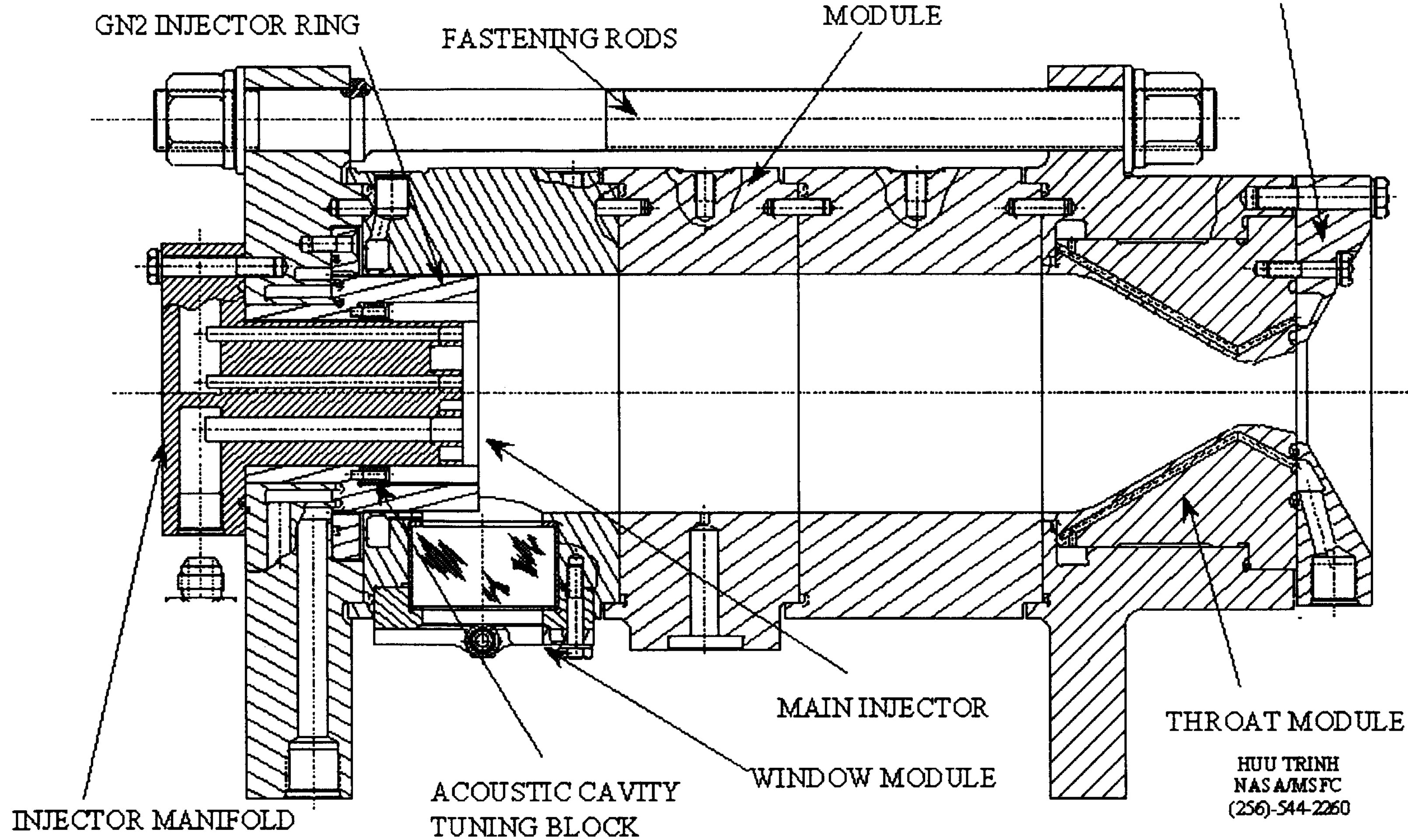


Test Rig
- MCTA Installed
- Facility Run Valves Installed

National Aeronautics
and Space Administration

Marshall Spa
Flight Cente

MCTA
Modular Combustion Test Article



MCTA in Hot-Fire

Design Environments

- Combustion code improvements
  - Near term objective of code is to guide sub-scale hardware design and help scale data to full-scale
  - Greatly improve turnaround to allow parametric evaluation of design concepts
    - Massively parallel computations
    - Efficient numerical algorithms
  - Minimize or eliminate empirically “tuned” parameters
    - Robust turbulence and chemistry models
    - Real Fluid Properties
  - Provide detailed experimental data to validate rigorous physical models and “tune” empiricisms
    - Experimenters, modelers, and diagnostic system developers must work together to develop usable data

Design Environments

- Fundamental physical model development
  - Develop robust physical sub-models that do not require empirically "tuned" parameters
  - The most relevant issue is the mixing physics involved in the injection of propellants into a combustion chamber of many chemical species at pressure well above the single component critical pressure
  - Rigorous physical models are needed
  - Experiments must be designed for model validation

Material Technology

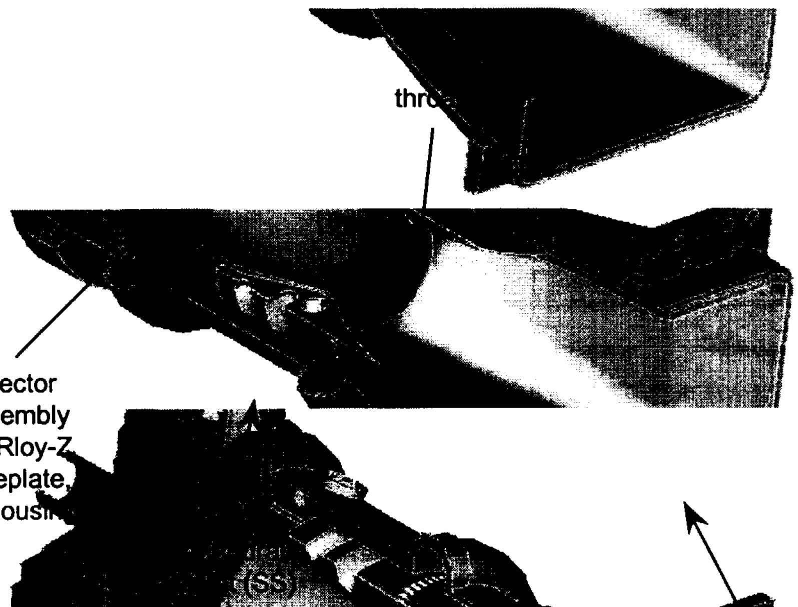
- Develop materials that improve design margins
  - Reduce component weight by increasing specific strength of materials
  - Maintain or improve fatigue capability
  - Reduce cooling requirements by increasing temperature capability while managing thermal stress impact

RLV Focus Technology
NRA8-21
Task 7.2 Lightweight, Long Life Thrust Cell

Objectives:

- Address material., design, & fab issues to reduce weight, maintain acceptable life & operating requirements
- Apply appropriate composite material systems to reduce weight by 20 - 40%

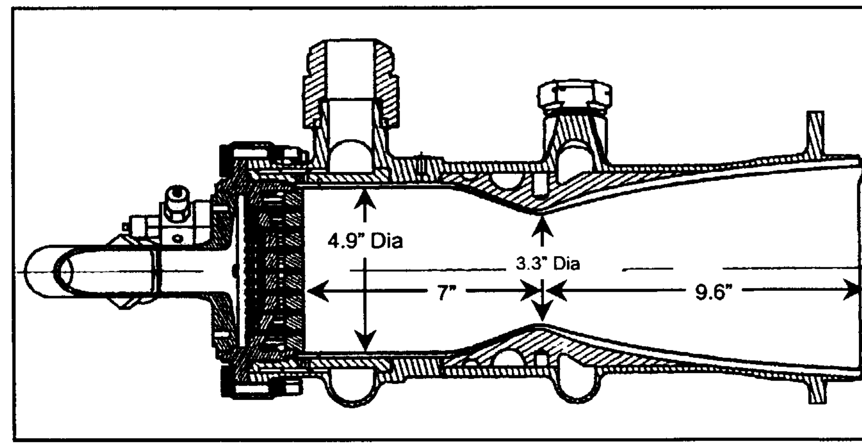
Baseline Thrust Cell Design - X33 (XRS-2200) Thrust Cell:



injector assembly (NARloy-Z faceplate, SS hous

chamber ply cludes: liner, throat supports, & structural jacket (w/manifolding)

liner (NARloy-Z)



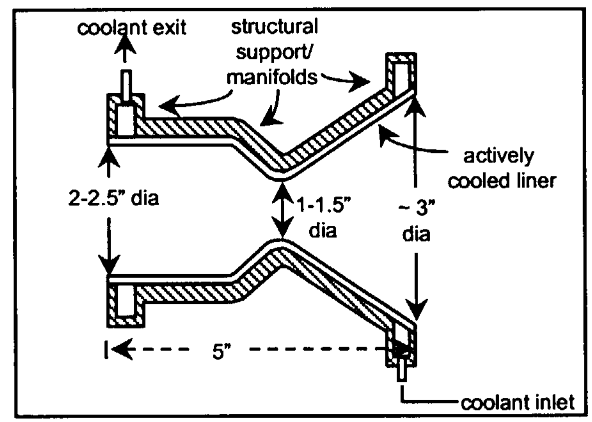
X33 Thrust Cell Design/Operating Conditions -

Injector Assy Weight	16.1 lbs
Chamber Assy Weight	**71.6 lbs**
Liner	14.8 lbs
Jacket	44.1 lbs
Throat Supports	12.7 lbs
Nom. Pc	~ 850 psi
Max. Pc	~ 1000 psi
Mission Duration	250 sec
# of starts	22
Cost	$100.7K

Task 7.2 Lightweight, Long Life Thrust Cell

Approach:
- Demonstrate several composite material systems with small fabrication units
- Test the demo units at appropriate cold flow and hot-fire conditions
- Select "Best" Material System & Apply results to full size (X33) thrust cell design for fabrication & hot-fire testing in CY00

Lightweight Material Options for Chamber:
- Replace NARloy-Z liner with
  * High Temperature CMC material system
- Retain Copper Alloy Liner & Replace SS structural supports & manifolds with
  * PMC
  * MMC
  * Ceramic or CMC



Conceptual Demo Units for GRC & MSFC Testing

Lightweight Material Options for Injector:
- Ceramic or CMC for structural manifolding and high temperature face plate
- MMC for structural manifolding

Note: Current efforts in this task are concentrated on chamber weight reductions due to limited manpower and funding resources. NRA8-21 Task 7.2 will consider injector material options if/when additional funding is available.

RLV Focus Technology
NRA8-21
Task 7.2 Lightweight, Long Life Thrust Cell

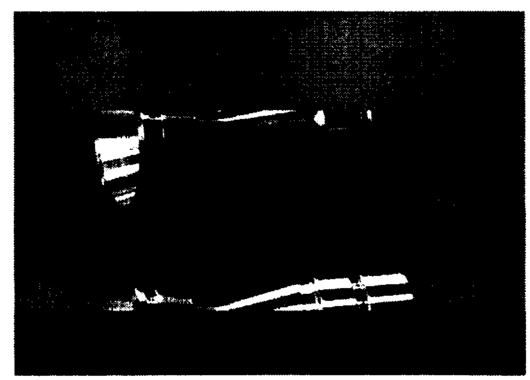
Supporting Chamber Liner Technology:

- Cu-8Cr-4Nb liner w/functional gradient coating fab'ed with Vacuum Plasma Spray (VPS) process
  - * Development pursued under MSFC In-house program & GRC's NRA8-21 Task 7.3
  - * Potentially offers better thermal/strength performance than NARloy-Z
  - * Hot-fire tests at MSFC will provide additional info to evaluate this material & coating
    - Powder Metal (PM) Cu-Cr-Nb properties available from Dave Ellis (GRC)
    - VPS Cu-Cr-Nb properties are TBD

- MSFC is providing (1) VPS Cu-Cr-Nb liner for each MMC & PMC demo unit

Design/Analysis:	MSFC
Fabrication	Plasma Processes & Rocketdyne (Huntsville)
Status:	Fabrication nearly complete

- Liner for MSE includes no close-out
- Completed & shipped to MSE Oct. 14
- MSE will bond directly to channel lands



- Remaining Liners will be closed out
- ECD for delivery to each contractor: Dec '99

MSFC role in Technology Plan

- Help coordinate the plan across the industry
  - Preferred Forum - JANNAF liquid propellant rocket subcommittee
- Contribute resources to specific elements of the plan
  - Design Conception
  - Design Environments through subscale testing
  - Technical monitoring of some portion of contracted activities

FY00 Plans

- Perform weight assessment of SSME injector redesign
- Establish thrust measurement capability at TS115 thrust chamber test positions
- Conduct tests of the actively cooled composite thrust chambers at TS115
- Conduct performance tests of 1250 lbf class vortex thrust chamber
- Obtain MSFC management approval of a plan to activate the JANNAF subcommittee

Summary

- NASA's plan for the next generation of launch vehicles requires enabling combustion devices technology
- Technology funding in recent years has been weak and scattered
- Strong complementary capability exists in other organizations
  - examples -AFRL, GRC, academia, rocketdyne, aerojet
- MSFC would like to serve a key role in coordinating and industry wide plan
- MSFC in-house efforts will focus on "filling holes" that are appropriate for our capabilities and charter