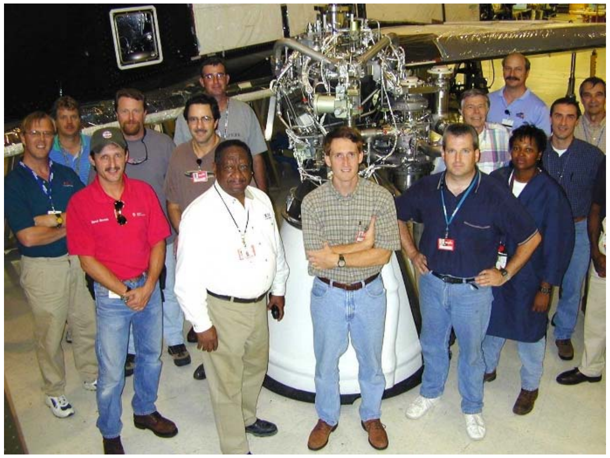
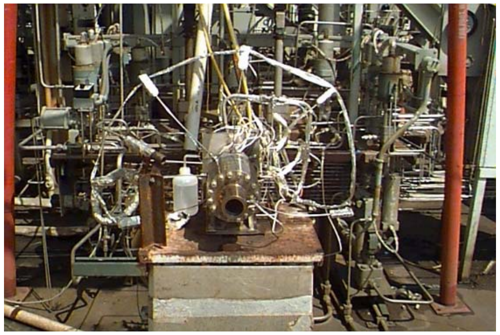
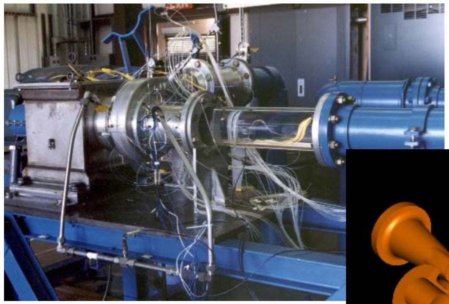
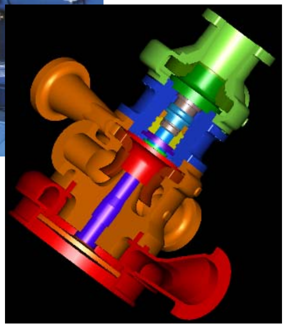
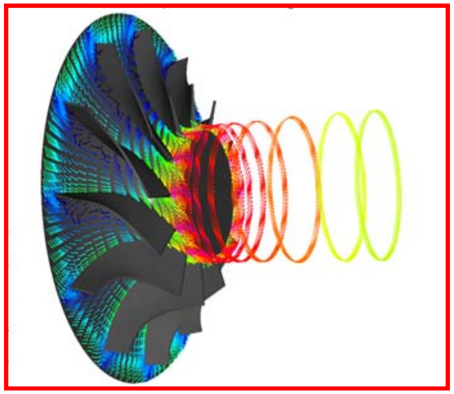
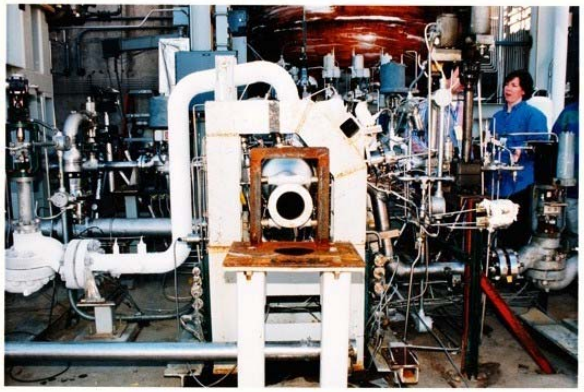












Fastrac Engine: Understanding Technical Implications of Programmatic Decisions

Mary Beth Koelbl
Katherine Van Hooser

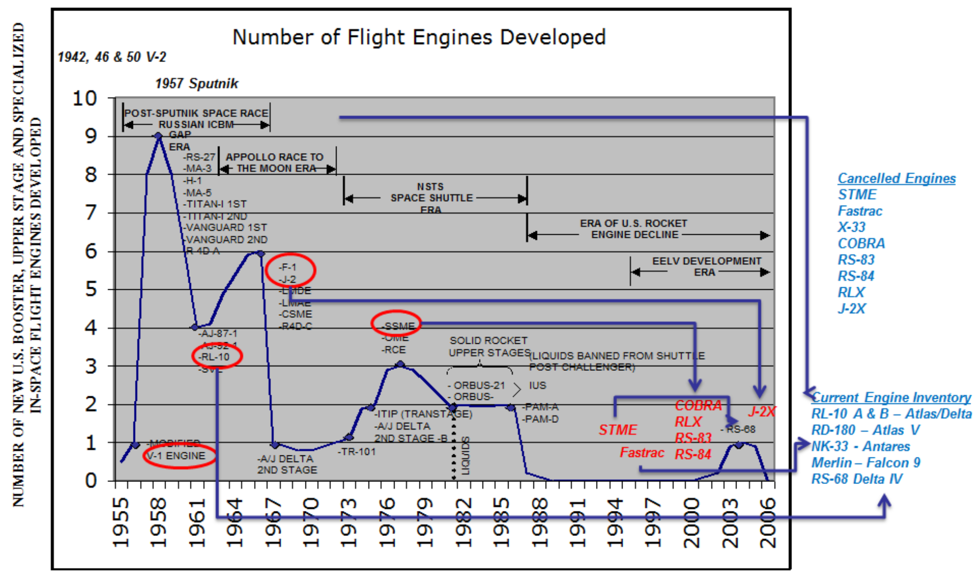
7/28/15

Outline

I. Introduction and Objective of Presentation
II. Background and Landscape
    A. Engine Developments
    B. Fastrac Origins and the Government-Led Approach
    C. Implementation
III. Transition from Manned Space Flight to Faster Better Cheaper
    A. Fastrac Features
    B. Lessons Learned
IV. Fastrac History
V. Program Legacy

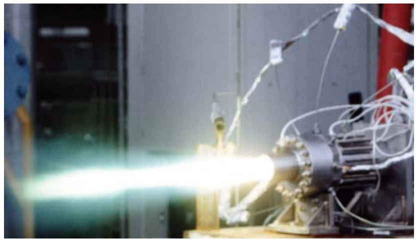
Background and Landscape

- There was significant hiring at MSFC in the late 1980's and early 1990's. The center was immersed in Challenger Return-to-Flight and Shuttle upgrades, but little else
- By the mid 1990's, recognizing the need to train the new generation of engineers who were lacking in development expertise, MSFC management decided to take action
  - Propulsion and Materials management knew that engine developments were difficult and costly
  - They needed to create an opportunity themselves so they focused on in-house designed component technologies
  - Simplex Turbopump and 40k Thrust Chamber Assembly began; focused on 15 to 40k thrust applications such as Bantam



Background and Landscape

- In the Mid 1990s, leveraging the component technology effort, an in-house rocket engine design and development project was initiated
- The Objectives were to
  - o Demonstrate low cost engine in a faster, better, cheaper way of doing business. Including utilizing non-traditional suppliers
  - o Give the younger propulsion engineers real hands-on hardware and cradle-to-grave design experience.

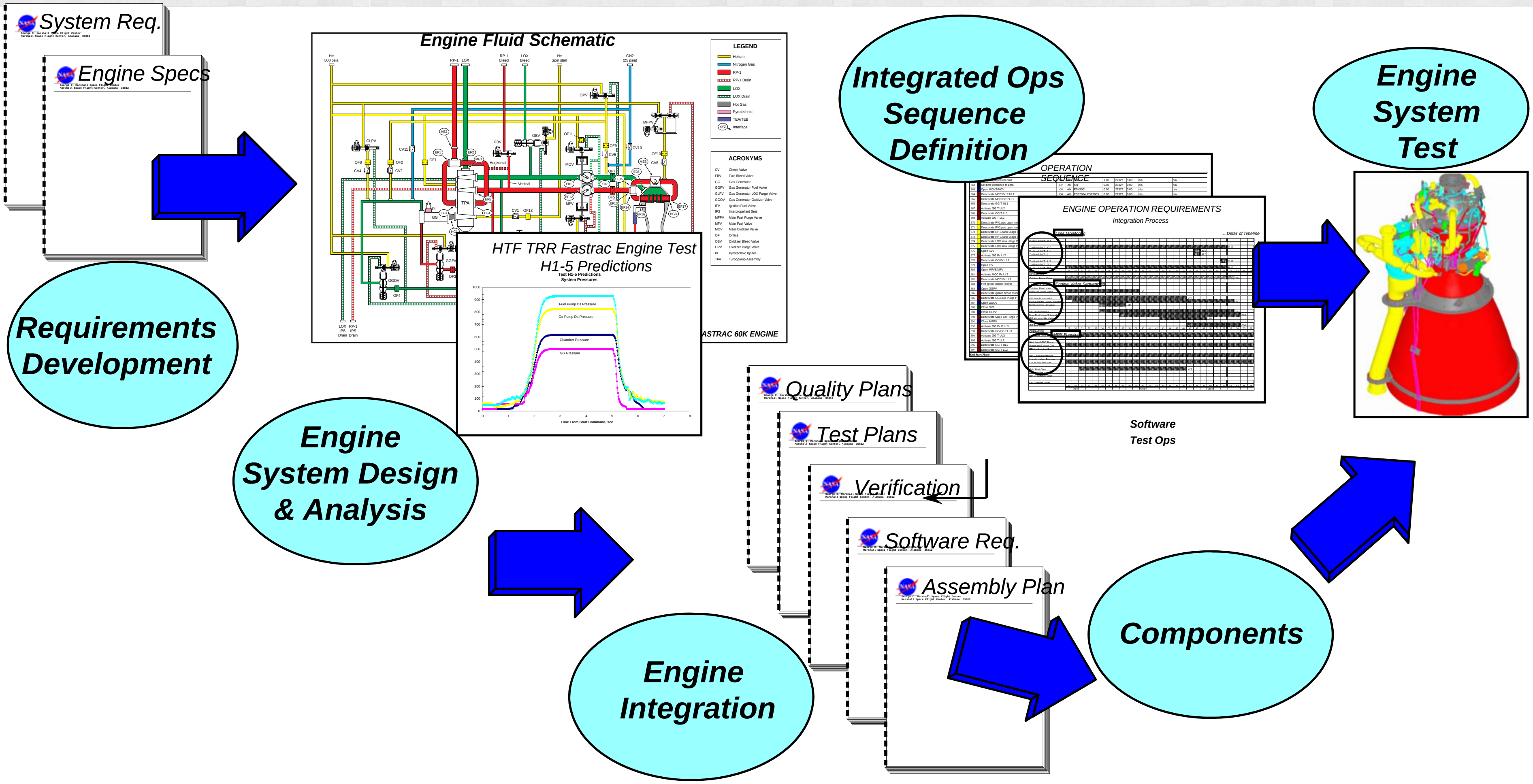


- A test-bed / prototype engine design and hardware project, conducted entirely in-house, was chosen as an effective way of accomplishing these objectives

- Initially envisioned a test-bed for the Bantam Booster, low cost design with a 2 Year Development; eventually became a 60k engine design

First and Only Large Rocket Engine Developed in-House at NASA

Background and Landscape



Government Led Required Cradle-to-Grave Implementation

Transition From Manned Space Flight to Faster Better Cheaper

Engine Features

- **Cycle**
  - Simple and Proven Gas Generator Engine Cycle
  - Booster Type Engine with LOX and RP-1
  - Ancillary Hardware – Off the Shelf Parts and Material with Non Traditional Vendors
  - Known Materials
- **Turbomachinery**
  - Clean Sheet Design Manufactured by Non Traditional Vendor
- **Combustion Devices**
  - Injector: Simple Design with Non Traditional Vendor – Not Performance Driven
  - Chamber/Nozzle: Integral Chamber and Nozzle with Traditional Vendor
  - Gas generator: Robust Design with Non Traditional Vendor
- **Valves**
  - Valves – Commercial Off-the-Shelf
- **Engine Controller**
  - Simple Off-the-Shelf Non Traditional Vendor
- **MPS & Tanks**
  - Lines and Valves – Non Traditional
  - Composite RP-1 Tank, LOX tank Metal
- **System Testing & Vehicle Integration**
  - SSC MPTA, SSC Horizontal, Santa Susana and X-34

Features of Low Cost Approach Implemented
Based on Manned Experiences and Lessons Learned

Lessons Learned

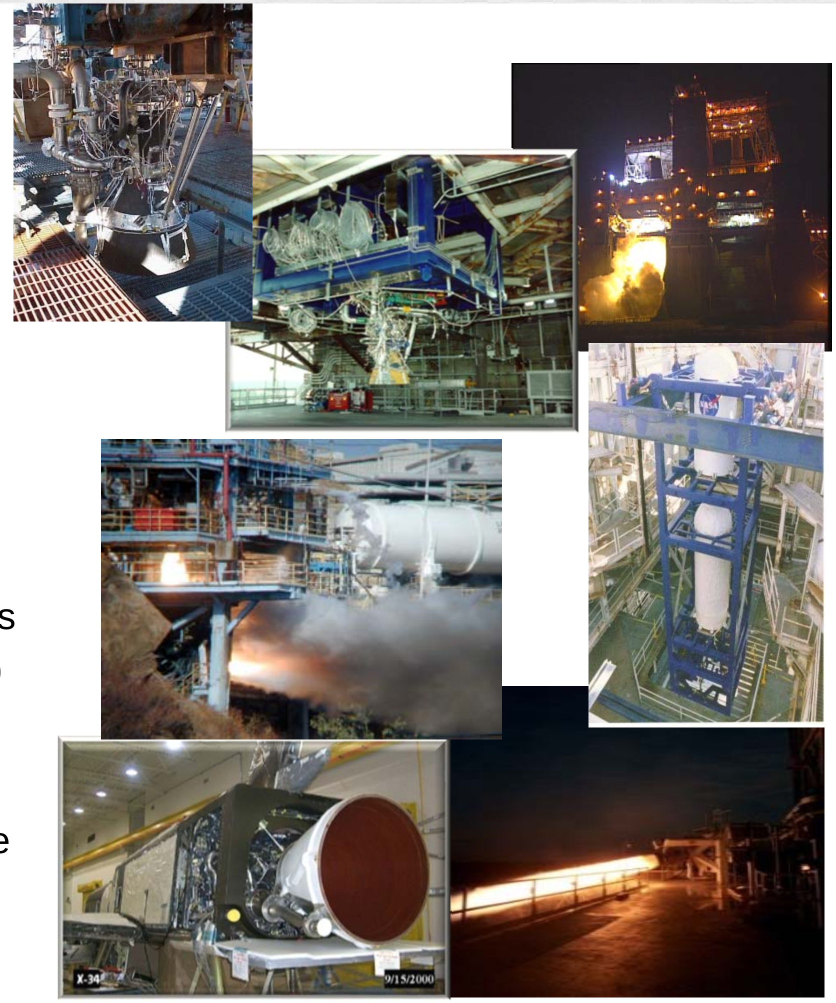
- **Engines and Vehicle Integration Lessons**
  - Leveraged Systems Engineering and Integration Mind Set from Shuttle
  - Engine Integration with X-34 Suffered from Inadequate Requirements Definition and Mission/Vehicle System Engineering
  - Changing Vehicles had major impact on Design and Test Program

- **Design Team Lessons**
  - In-House Subsystems and Components Teams were Empowered and Operated in an IPT Structure with Accountability to Systems for Rapid and Final Decisions
    - In-Line Management functioned as Mentors; vast Saturn and Shuttle Program Experiences
  - Technical Focus on Simple and Low Part Counts with COTS and Commercial Manufacturing
    - Realized additional testing would be required and likely Test-Fail-Fix
    - Concurrent Manufacturing with Detailed Design
    - Leveraged Existing NASA Standards but Tailored as Required
  - Failures were allowed albeit handled inconsistently

IPT approach and simple design allowed rapid development

Fastrac History

- ATP to first engine delivery in 28 Months
  - ATP April 1996
  - SRR June 1996
  - PDR Aug 1996
  - CDR April 1997
  - TRR 1st Engine Aug 1998
- 5 complete engines assembled; 50 ablative nozzles
- 57 complete engine system hot-fire tests
  - 888 total seconds of test time
  - Constructed and activated 4 new engine test positions
- First engine hot fire Dec 1998, last test Dec 2000
- X-34 Flight Engine CDR Jan 2000
  - Fit checked an engine in X-34 vehicle – Sept 2000
  - Acceptance/calibration tested first flight quality engine
- Closeout Report Dec 2001



Fastrac was Faster and Cheaper… Better is in the Eye of the Beholder

Program Legacy

- Fastrac Started with a Legacy:
  - Challenger Return to Flight Members in all Areas
  - Leveraged In-House Engine Component TRL Maturation
  - Strong Institutional Capabilities in areas such as Thermal, Structural, Mechanical, CFD, Stress, Materials, Operations, and Test

- Fastrac created a Legacy
  - Foundation for the workforce that supported Second Gen RLV (Cobra, RS83, RS84), J-2X, and SLS RS-25
  - Team Members became Next Generation of PM, CE, SEI Leads and SSM
  - Enabled non-traditional Suppliers and Manufacturing partners: Summa, Metals Research, Thiokol, Honeywell, Barber Nichols
  - Suppliers and Manufacturing Partners contributed to US Industry

Fastrac was Critical for Future Engines in the 21st Century