National Aeronautics and Space Administration

Waking a Giant: Bringing the Saturn F-1 Engine Back to Life

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marshall

www.nasa.gov

Agenda

- Marshall Space Flight Center
- What is the F-1 engine?
- Why study the F-1?
- F-1 Engine History
- F-1 Disassembly
  - Using New Technology
  - Hardware assessment
- F-1 Gas Generator Testing
- The Next Step – Where do we go from here?

Marshall Profile

NASA FY2012 Budget: $17.8 B
MSFC FY2012 Budget: $2.28 B

Nearly 6,000 employees
(FY12 2,490 civil service)

3rd largest employer
in the Huntsville – Madison County area

26 core capabilities and more than 125
unique and specialized facilities and labs

Part of a technological community

Redstone Arsenal – home to 22 primary federal/international organizations

Cummings Research Park –
2nd largest in US and 4th largest in the world

Huntsville's Concentration of High-Tech Workers is 2nd in the Nation

Marshall impacts the community and the nation.

Robin Henderson – MSFC Associate Director

Marshall's Role in Space Exploration

Lifting from Earth

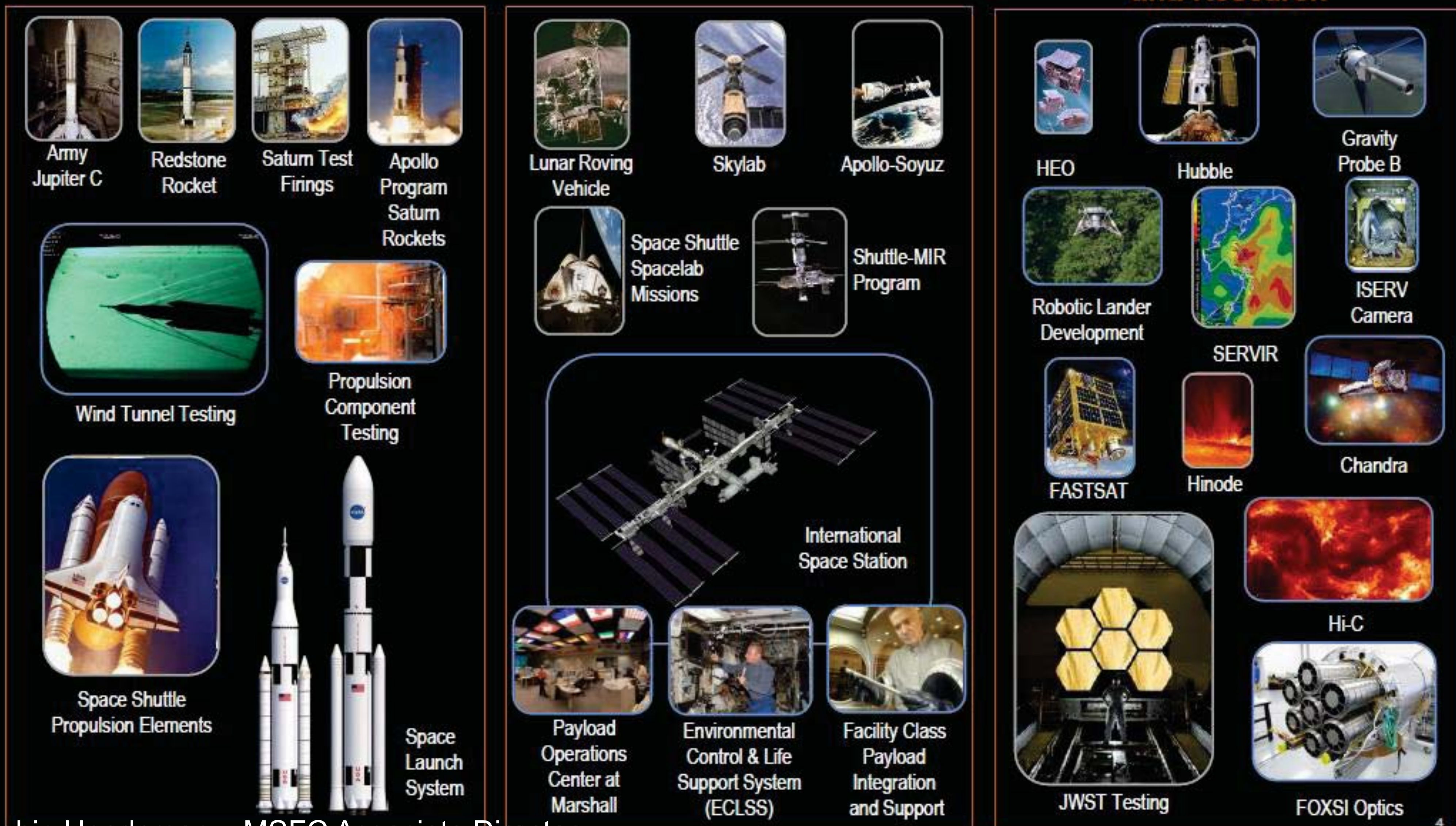
Propulsion and Transportation Systems

Living and Working in Space

Human Exploration Systems and Operations

Understanding Our World and Beyond

Scientific Spacecraft, Instruments and Research



Robin Henderson – MSFC Associate Director

Marshall Organization

Center Director's Office
Center Director: Patrick Scheuermann
Deputy Center Director: Vacant
Associate Center Director Management: Robin Henderson
Associate Center Director Technical: Dale Thomas
Senior Executive for Technology & Integration: Jim Reuter
Chief Technologist: Andrew Keys

Chief Financial Office
Dir: William Hicks (Act)
Dep: William Hicks

Office of Procurement
Dir: Kim Whitson
Dep: David Iosco (Act)

Office of Chief Council
Dir: Audrey Robinson
Dep: Jim Frees

Chief Information Officer
Dir: Jonathan Pettus
Dep: John McDougle
Dep. Neil Rodgers

Office of Human Capital
Dir: Tereasa Washington
Dep: Digna Carballosa

Office of Diversity and Equal Opportunity
Dir: Susan Cloud (Act)
Dep: Willie Love

Office of Strategic Analysis & Communications
Dir: Bobby Watkins
Dep: Johnny Stephenson

Center Operations
Dir: Steve Doering
Dep: Bob Devlin

Science & Technology Office
Dir: Dan Schumacher
Dep: Corky Clinton

Flight Programs & Partnerships Office
Dir: Teresa Vanhooser
Dep: Paul Gilbert

Space Launch System Program Office
Dir: Todd May
Dep: Jody Singer

Shuttle-Ares Transition Office
Dir: Roy Malone
Dep: Mike Allen
Dep: Mike Vanhooser

Safety and Mission Assurance
Dir: Steve Cash
Dep: Steve Wofford

Engineering Directorate
Dir: Chris Singer
Dep: Preston Jones

Michoud Assembly Facility
Dir: Roy Malone
Dep: Robert Champion

Chief Engineer
Dir: Scott Croomes
Dep: Nelson Parker

Spacecraft & Vehicle Systems
Dir: Helen McConnaughey
Dep: Jim Turner

Space Systems
Dir: Steve Pearson
Dep: Larry Leopard

Propulsion Systems
Dir: Tom Williams
Dep: Mary Beth Koelbl

Mission Operations Laboratory
Dir: Jay Onken
Dep: Lewis Wooten

Test Laboratory
Dir: Ralph Carruth
Dep: Matt Hammond

Materials & Processes Laboratory
Dir: Wendell Colberg
Dep: Surendra Singhal

What is the F-1 Engine?

- 5 F-1 engines were used as the first stage engines, Saturn V moon rocket
- Took the Apollo vehicle (363 ft tall, 6 million lbs):
  - 50 miles downrange
  - 40 miles altitude
  - At Mach 7
  - In 2.5 minutes
  - Burning 4.5 million lbs of propellant

Saturn V Launch – Apollo 8

- http://www.youtube.com/watch?v=FzCsDVfPQqk

What is the F-1 Engine?

- Propellants: LOX and RP
- Thrust:1,522,000 lbf sea level; 1,748,200 lbf vacuum
- Specific Impulse: 265.4 sea level; 304.1 vacuum
- Chamber Pressure: 982 psia
- Engine Mixture Ratio: 2.27
- Engine Propellant Flow Rate: 5,737 lb/s
- Weight: 18,616 lb
- Cycle: Gas Generator, pump fed
- Fixed power level – no control system

What is the F-1 Engine?

- Turbopump: Single turbopump assembly
- Gas Generator turbine drive
- RP fuel used as:
  - Main propellant
  - Bearing lubrication
  - Valve working fluid (fueldraulic valve actuation)
- Tank head start
- Nozzle: regen cooled to 10:1, nozzle extension film cooled using turbine exhaust gas to 16:1
- Ignition: TEA-TEB
- Injector: 13 baffled compartments, impingement, 2 LOX inlet and 2 fuel inlets

Why is it important to study the F-1?

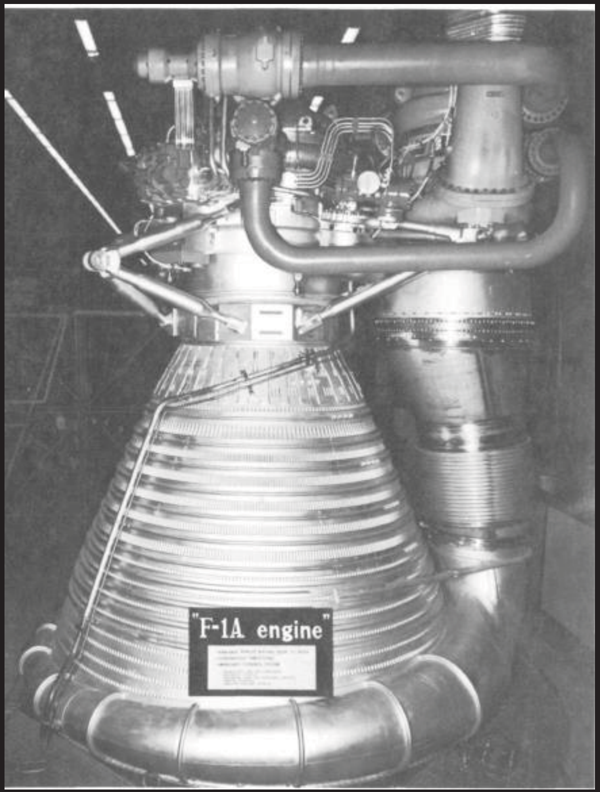
- SLS Heavy Lift trade space
  - Booster, Core Stage
- Commercial Partners
- Training
- Benefits of F-1
  - Proven design
  - Simple design (gas generator cycle)
  - LOX/RP propellants
    - RP is more dense than liquid hydrogen – smaller tanks, smaller vehicle, even though the specific impulse is substantially lower
    - RP is a liquid at ambient conditions – easier to store, handle, & pump, reducing system power and complexity and operational costs
    - RP cost is much less than liquid hydrogen fuel
    - F-1 gas generator cycle is simple (while less efficient) compared to staged combustion

F-1 Engine History – Culture

- F-1 Development 1955-1965
- Young American engineers & German rocket engineers, mostly men
- F-1 Program Manager selected was Sonny Morea – 28 years old
- Engineers were excited about the program, worked long hours, dedicated their lives to the mission
  - Difficult for work-life balance
- International Competition
  - American mission was made very clear
  - Americans were passionate about the mission
  - American $$$ was put behind the program, fully supported and commitments sustained

What about the F-1A?

- Rocketdyne anticipated an uprated version of the Saturn V
  - Developed F-1A
    - 1.5M lbf → 1.65M lbf → 1.8M lbf
    - 2 F-1A engines produced
    - Rocketdyne anticipated "go-ahead" from NASA in 1965, could deliver flight qualified engines by the end of 1969.
    - Funding peaked in 1966 then fell off rapidly due to lack of follow-on missions, need for heavy payloads
- F-1A restart studies
  - 1992 – Rockwell International Rocketdyne Division evaluated enhanced producibility, materials, fabrication, performance improvements
  - 2012 – Advanced Booster Risk Reduction contract awarded to Dynetics/Aerojet-Rocketdyne team for their F-1B booster "Pyrios"
    - Dynetics is executing a NASA contract to perform full-scale, high-fidelity hardware demonstrations to reduce the highest risks for an SLS Advanced Booster



Engine Comparison, F-1 vs. F-1A

Performance Parameter	F-1	F-1A
Thrust, Sea Level (lbf)	1,522,000	1,800,000
Specific Impulse, Sea Level (s)	265.4	269.7
Chamber Pressure, ns (psia)	982	1,161
Engine Mixture Ratio	2.27	2.27
Expansion Ratio	16:1	16:1
Weight (lb)	18,616	19,000

F-1B SLS Advanced Booster Engine

The F-1B engine retains critical features from heritage programs while incorporating the latest technology for improved reliability, efficiency and cost.

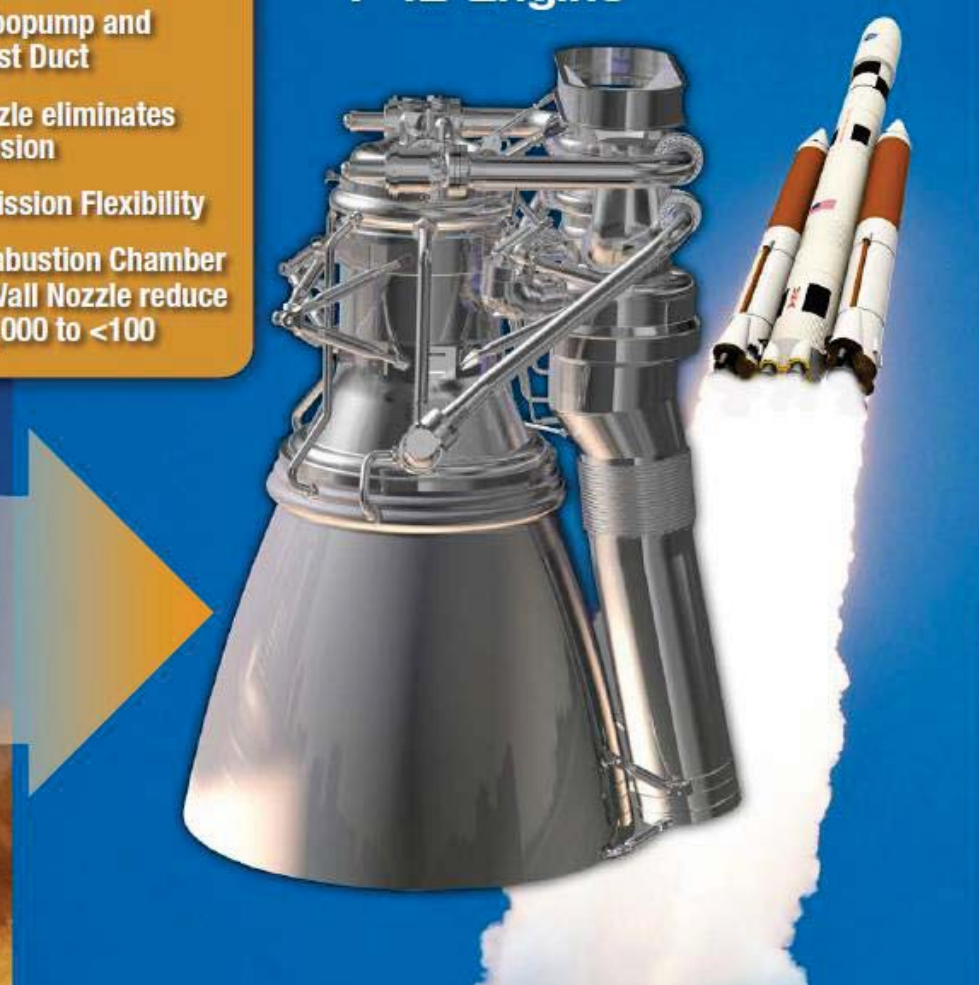
Enhancements

- Modern fabrication processes
- Simplified Turbopump and Turbine Exhaust Duct
- Optimized Nozzle eliminates need for Extension
- Throttling = Mission Flexibility
- New Main Combustion Chamber and Channel Wall Nozzle reduce parts from >5,000 to <100

F-1 Engine

Demonstrated on 13 Saturn V flights (65 flight engines with no failures)

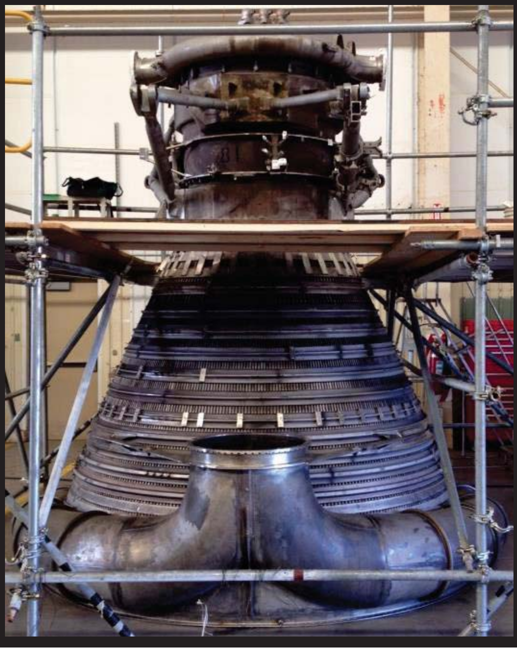
F-1B Engine



Pratt & Whitney
A United Technologies Company
Pratt & Whitney Rocketdyne

F-1 Engine Teardown

- The purpose of the F-1 engine teardown activity was to:
  - Capture knowledge about the F-1,
  - Understand the mechanical layout of the engine and the hardware designs,
  - Test components to understand the F-1 engine performance,
  - Help the team to design a new, improved, large LOX/RP engine.
- The goal was to clean and inspect the hardware, replace items that cannot be re-used, and perform component testing.
- The engine may be re-assembled for hot-fire testing.
- Team Philosophy
  - Small, focused team
  - "Badgeless" environment, everyone turns wrenches
  - Be smart and safe, but work with a small budget
  - This engine is a National Asset, hardware is treated as such.

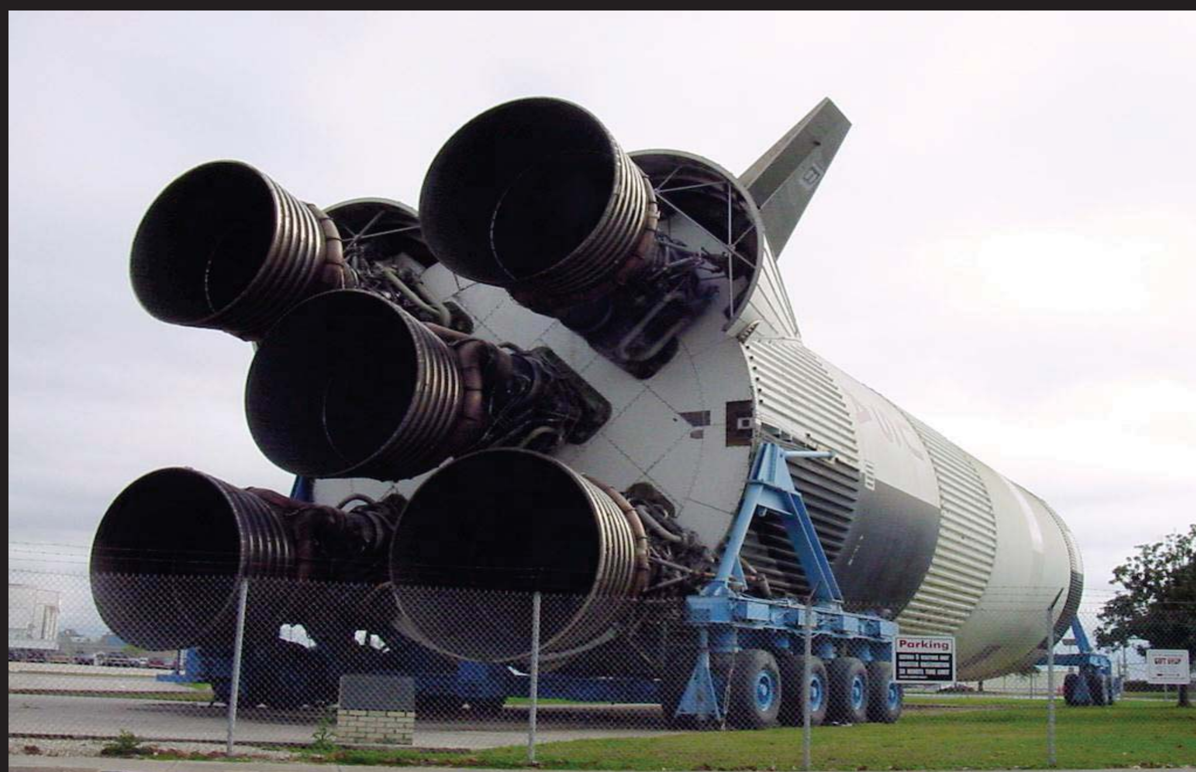


F-1 Disassembly – What We Did

- Retrieved original F-1 documentation
- Took engine F-6090 apart, documenting each step
- Photographed and documented all components
- Created a library with a full inventory of the engine
- Created many digital models – structured light scan data, virtual assemblies, ProE models
- Retrieved Engine F-6049 from the Smithsonian
  - Disassembled gas generator for hot-fire test
- Hot fire tested F-1 gas generator

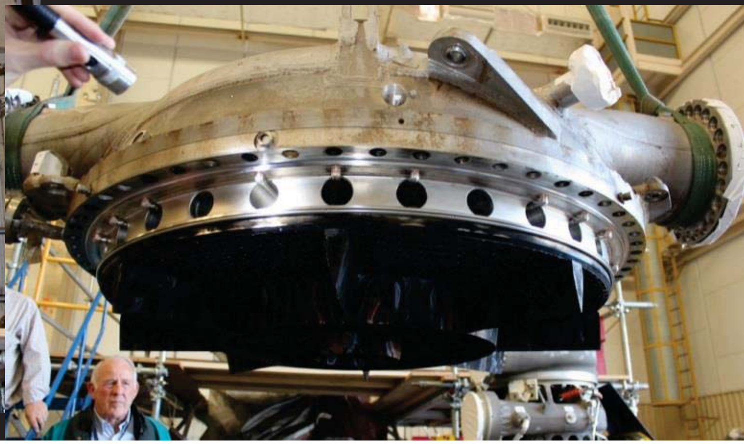
F-1 Disassembly

- Engine F-6090
  - Engine built in 1967
  - 3 acceptance tests, 250 seconds
  - Engine accepted on 2/3/1969
  - Originally allocated to S-1C-14 stage, Position 105 (center position)
  - Eventually allocated as flight spare in 1971

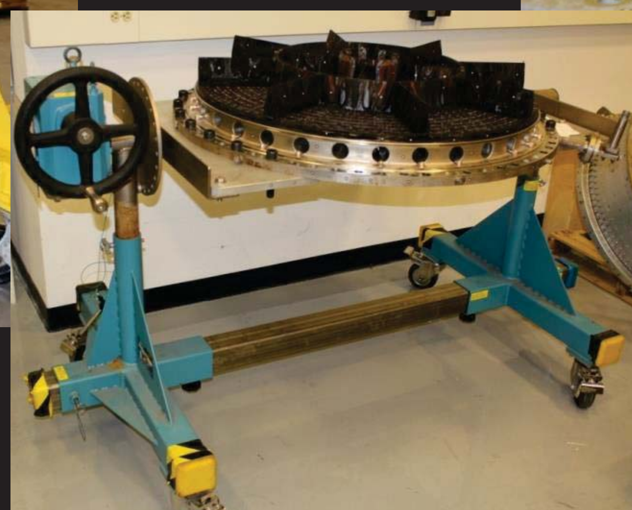


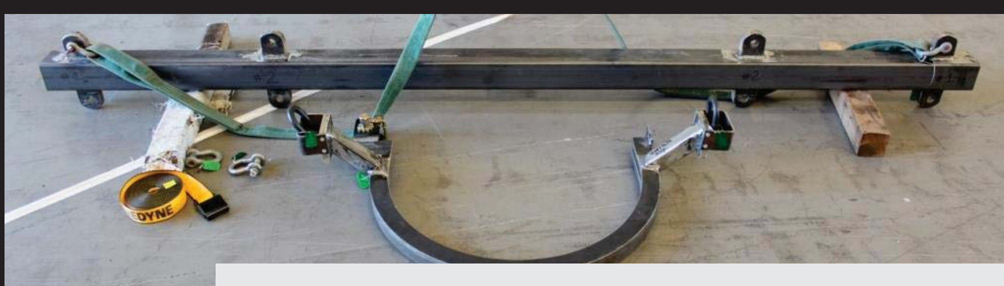
F-6090 Disassembly

- Borescope inspections, drained lines
- Removed:
  - Gas Generator (GG) system
  - Thermal blanket brackets
  - High pressure lines
  - Interface panel
  - Inlet ducts
  - Electrical lines
  - Main valves
  - Heat exchanger (HEX)
  - Turbopump
  - Gimbal block
  - LOX dome
  - Main injector
  - Hydraulic lines and drains



Tooling and GSE

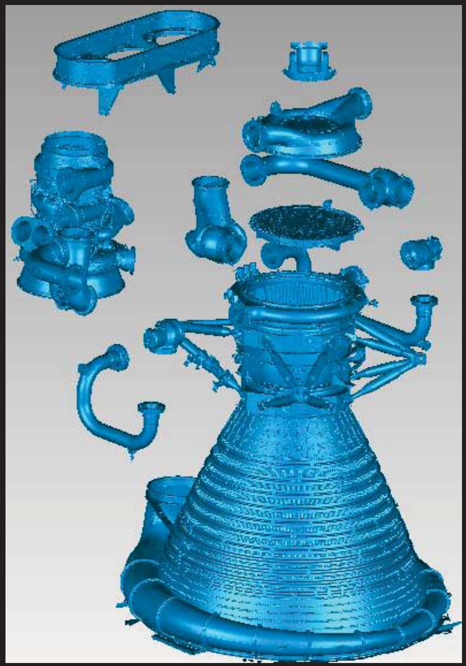


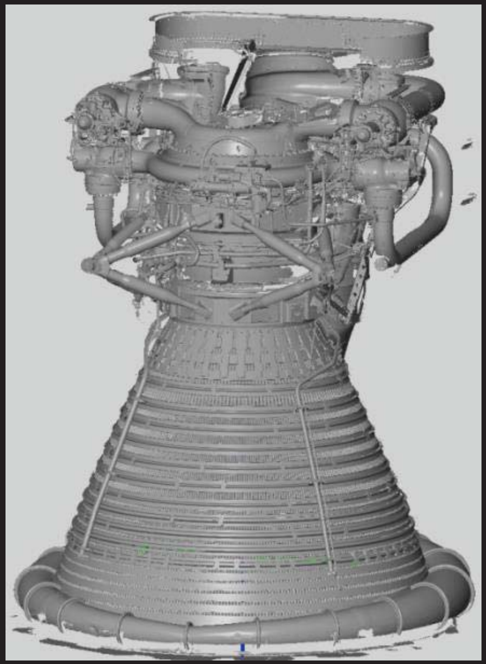


We used a combination of old (refurbished) and new tooling and GSE

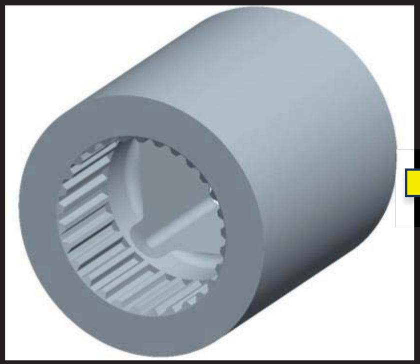
Using Available Technologies

Structured Light Scanning System used to document the engine assembly and components.

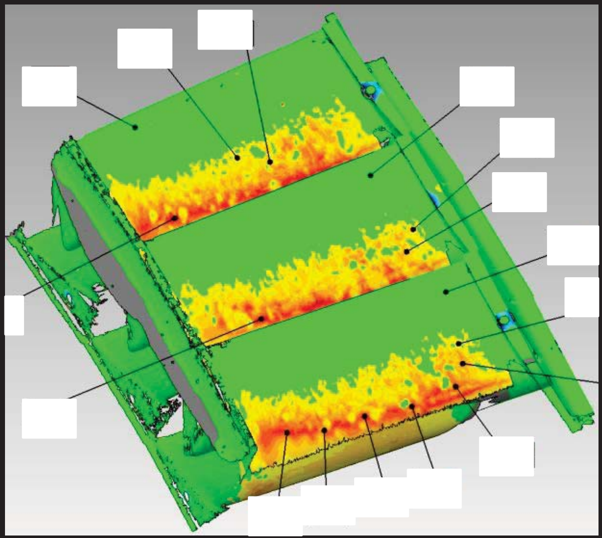




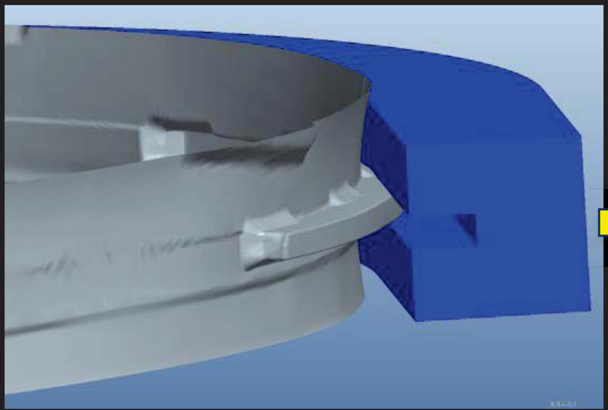
Electron Beam Melting (EBM) used to generate unique tooling for the turbopump disassembly



Soot Characterization

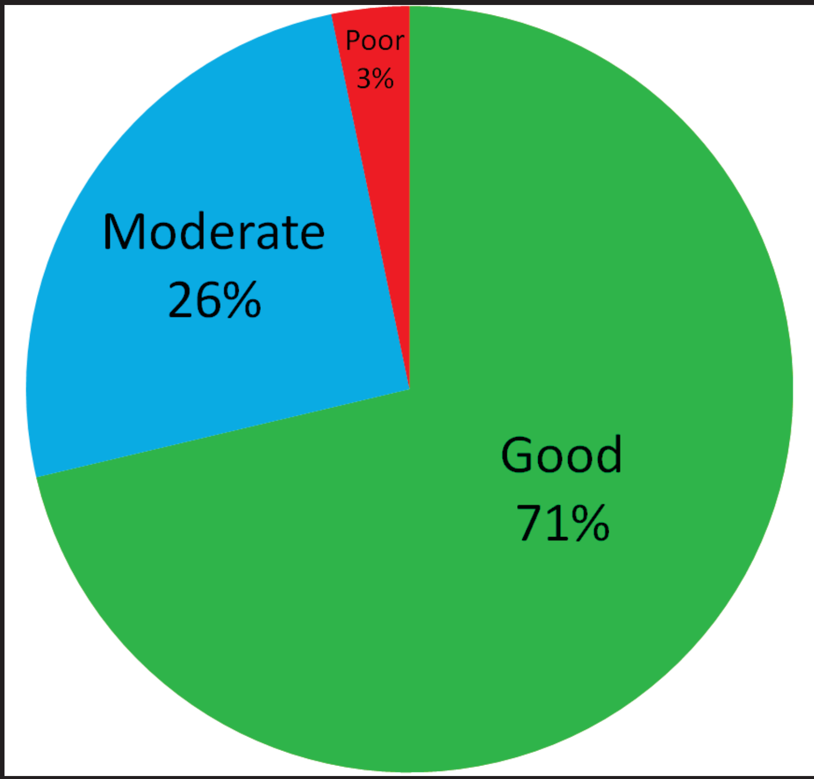


Scan data used for GSE design



Hardware Assessment, Engine F-6090

- Replace
  - Some fasteners (~4%)
  - Some turbopump components (some bearings and seals)
  - Valve soft goods
- Minor repairs
  - Combustion devices
- In-depth evaluations (NDE, proof) needed on major components before re-use

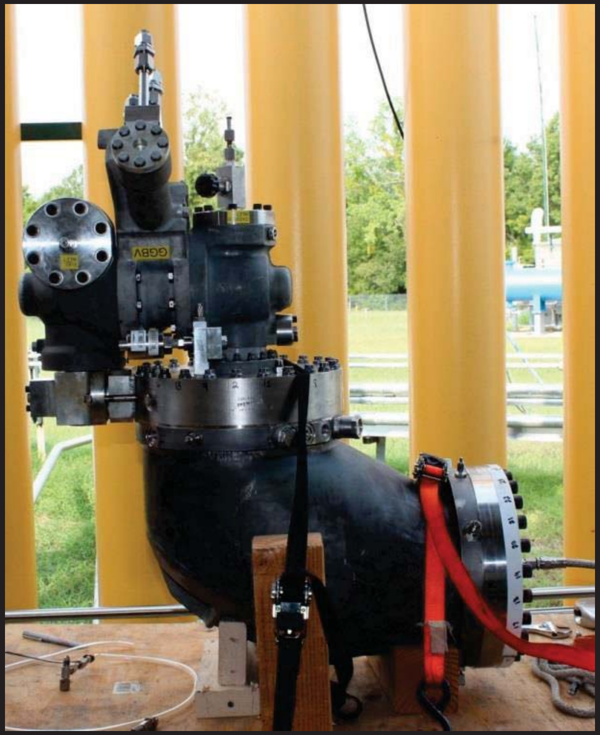


No “Show Stoppers” Discovered

Bringing Engine F-6049 back to MSFC

Component Testing

- Valve acceptance testing
- GG Injector water flow testing
- Proof Testing



Gas Generator Testing

- MSFC Test Series – 11 Tests
  - Primary Goals:
    - 1. Demonstrate a test using original F-1 hardware (GG injector, combustion chamber, valves)
    - 2. Further test facility capability in order to support future LOX/RP testing needs
  - Secondary Goals:
    - 1. Gather data to build and anchor stability models
    - 2. Gather performance data on the GG valves under engine conditions
    - 3. Gather data on GG soot production as a function of Mixture Ratio
- Dynetics/Rocketdyne Test Series – 10 Tests
  - Goal: to evaluate GG performance at F-1A/F-1B conditions

We were able to collect new data that wasn't previously available

Video

The Next Step – Where do we go from here?

- Working with Dynetics and Aerojet Rocketdyne to execute SLS Advanced Booster Risk Reduction contract
  - F-1B engine
  - Letter of Agreement tasks for MSFC Engineering
- Continue to feed F-1 information to SLS for trade studies
- Provide input to commercial companies as requested
- F-1 hardware in a storage facility at MSFC
- We're ready…

References

1. Young, Anthony. “The Saturn V F-1 Engine: Powering Apollo into History,” Praxis Publishing, 2009.
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3. Aldrich, D.E. “F-1A Task Assignment Program Final Report (Rocketdyne)”, NASA-CR-138312, Rocketdyne North American Rockwell, California, 1970.

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