



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

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Propulsion Systems Engineer



marshali



# 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



**\$2.3B expenditures in nation (FY2011)** ★

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

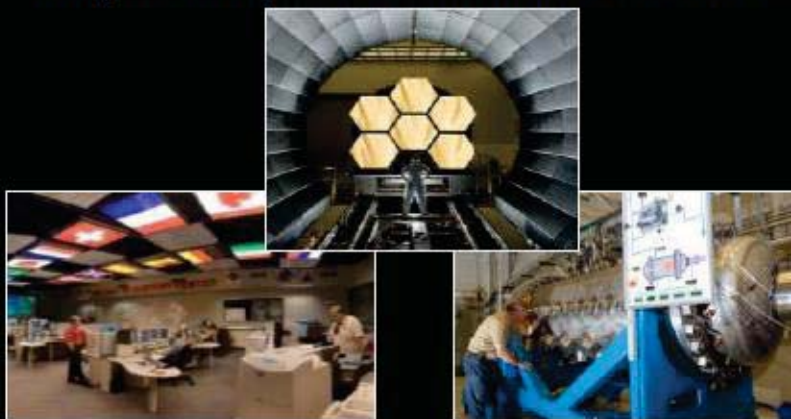


**Nearly 6,000 employees**  
**(FY12 2,490 civil service)**



**3<sup>rd</sup> 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 –**  
**2<sup>nd</sup> largest in US and 4<sup>th</sup> largest in the world**

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

***Marshall impacts the community and the nation.***



# Marshall's Role in Space Exploration

## Lifting from Earth

### Propulsion and Transportation Systems



Army Jupiter C



Redstone Rocket



Saturn Test Firings



Apollo Program Saturn Rockets



Wind Tunnel Testing



Propulsion Component Testing



Space Shuttle Propulsion Elements



Space Launch System

## Living and Working in Space

### Human Exploration Systems and Operations



Lunar Roving Vehicle



Skylab



Apollo-Soyuz



Space Shuttle Spacelab Missions



Shuttle-MIR Program



International Space Station



Payload Operations Center at Marshall



Environmental Control & Life Support System (ECLSS)



Facility Class Payload Integration and Support

## Understanding Our World and Beyond

### Scientific Spacecraft, Instruments and Research



HEO



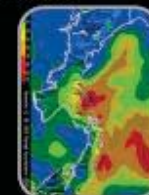
Hubble



Gravity Probe B



Robotic Lander Development



SERVIR



ISERV Camera



FASTSAT



Hinode



Chandra



JWST Testing



Hi-C



FOXSI Optics



# 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 Tosco (Act)

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

**Chief Information Officer**  
 Dir: Jonathan Pettus  
 Dep: John McDougale  
 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

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- <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

18.4 ft tall



12 ft wide



# 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 (fuel hydraulic 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





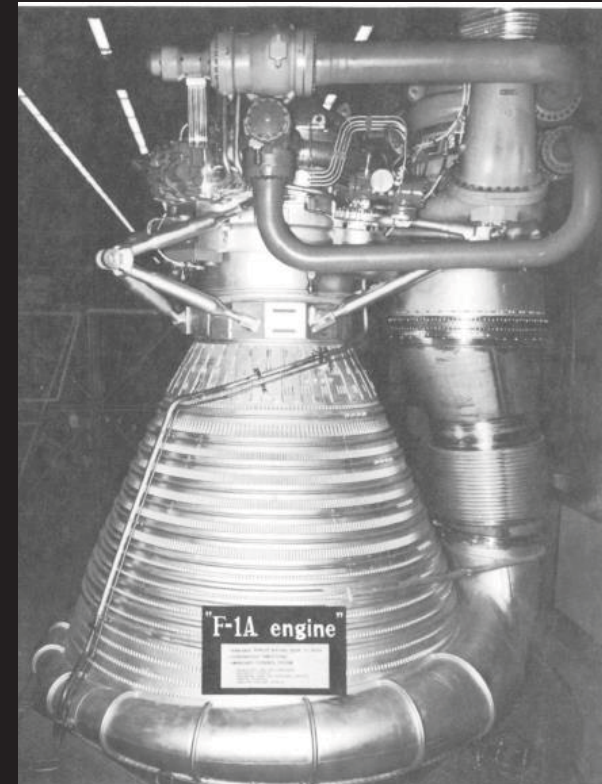
# F-1 Engine History – Culture

- 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 updated 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.

## F-1 Engine



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

## 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

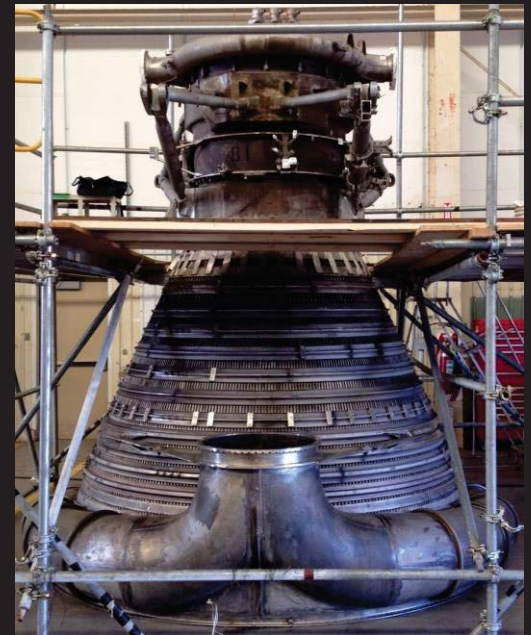
## F-1B Engine





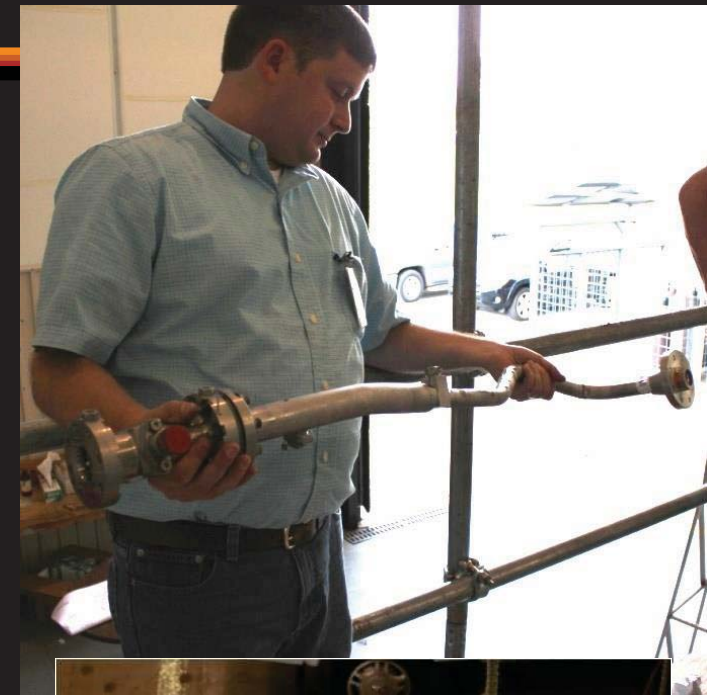
# F-1 Engine Teardown

- 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.



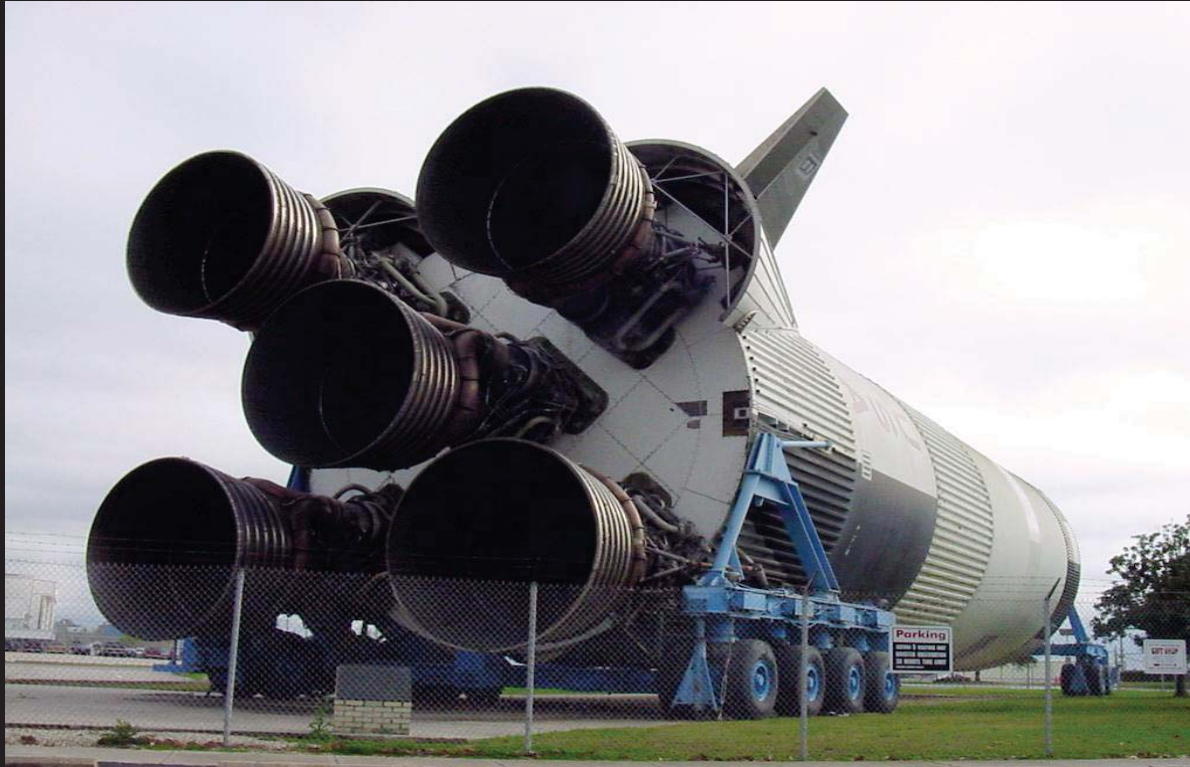
# F-1 Disassembly – What We Did

- 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





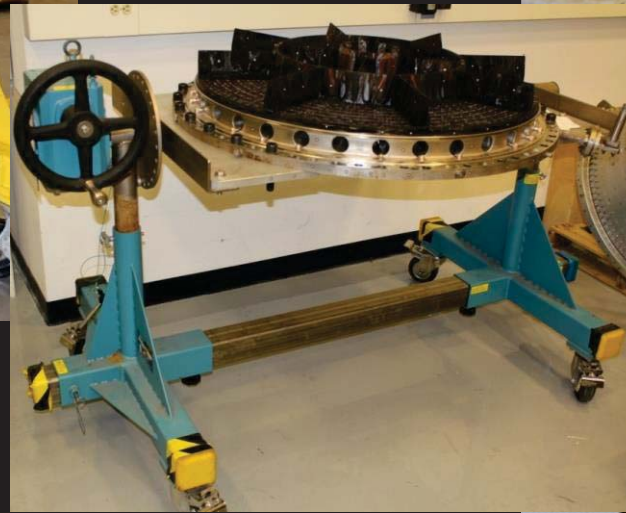
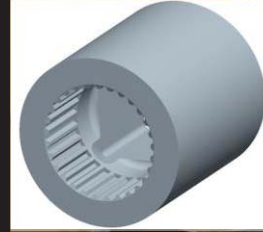
# F-6090 Disassembly

- 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

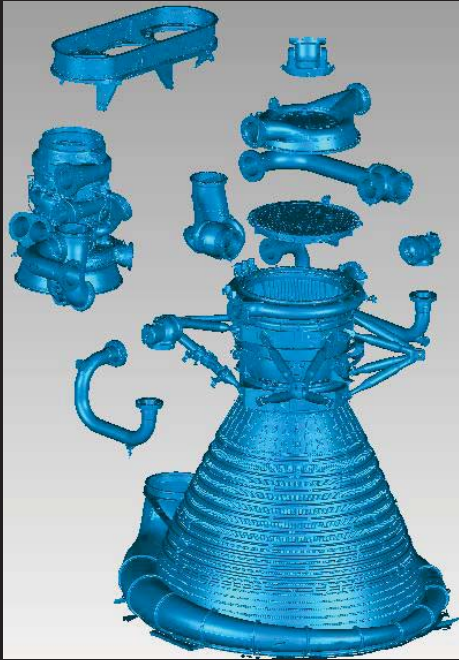


We used a combination of old (refurbished) and new tooling and GSE

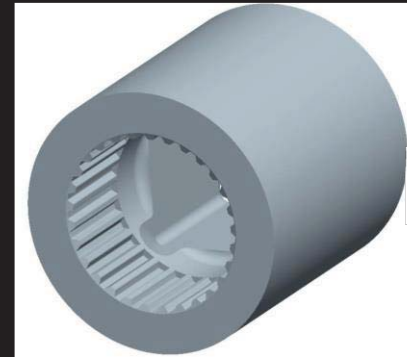


# Using Available Technologies

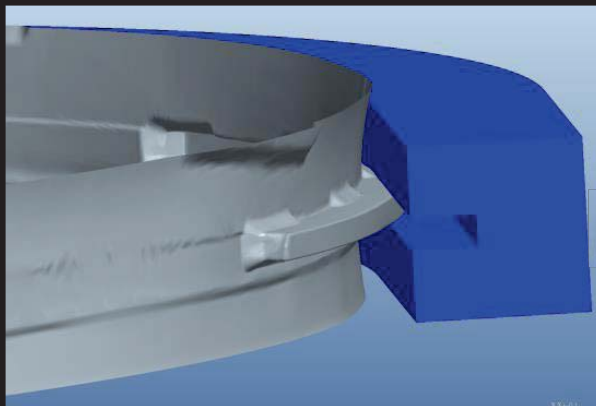
Structured Light Scanning System used to document the engine assembly and components.



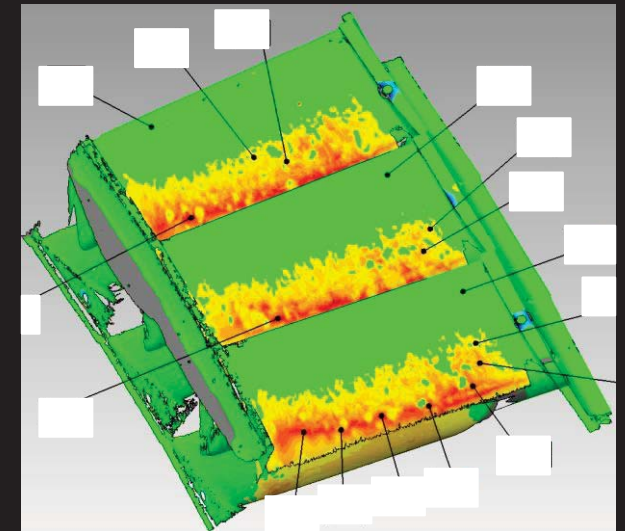
Electron Beam Melting (EBM) used to generate unique tooling for the turbopump disassembly



Scan data used for GSE design



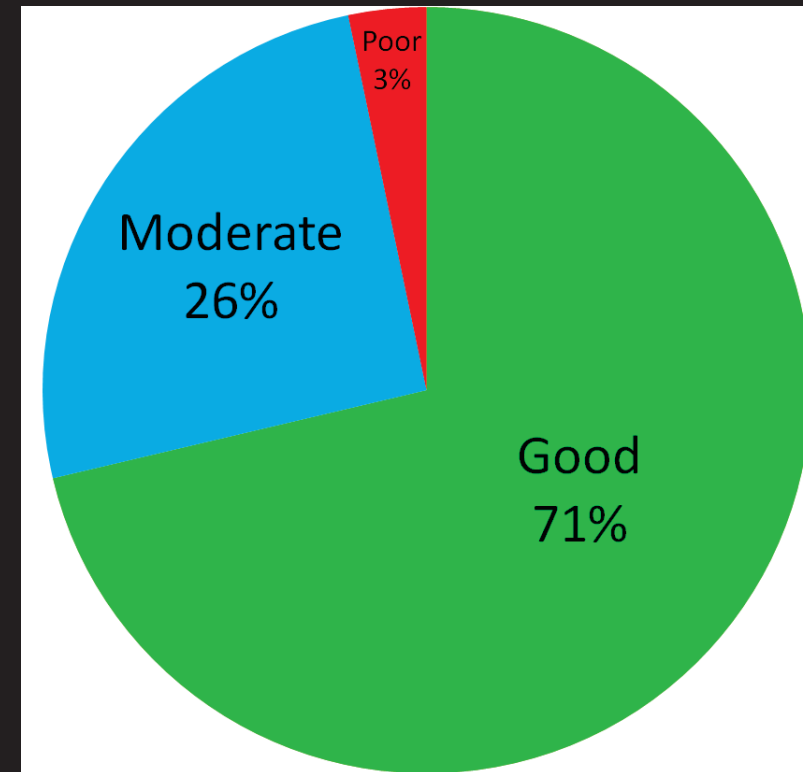
Soot Characterization





# 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

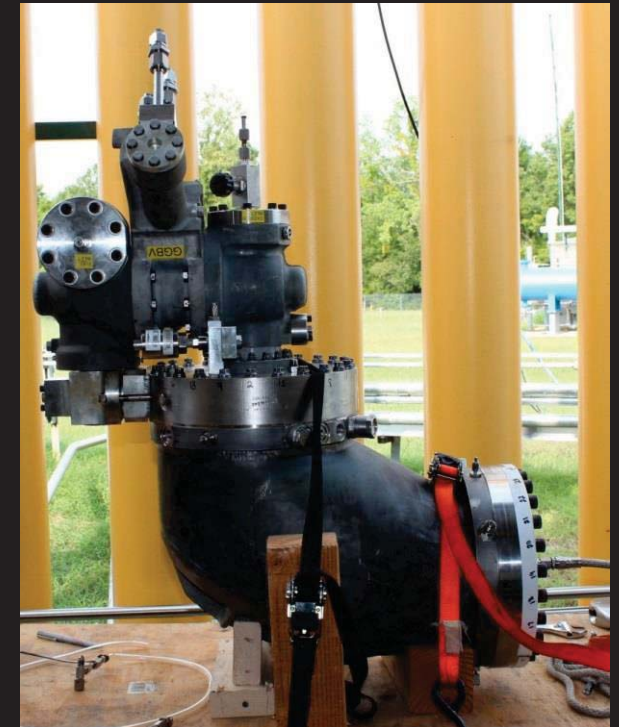
# Bringing Engine F-6049 back to MSFC





# 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

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**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...

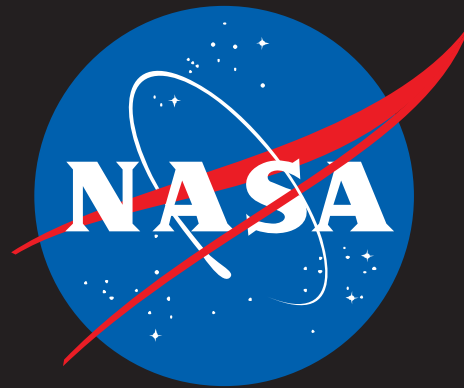


# References

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1. Young, Anthony. “The Saturn V F-1 Engine: Powering Apollo into History,” Praxis Publishing, 2009.
2. Biggs, Robert, Rocketdyne. “F-1 Saturn V First Stage Engine,” Remembering the Giants Apollo Rocket Propulsion Development. The NASA History Series, John C. Stennis Space Center, 2009. NASA SP-2009-4545.
3. Aldrich, D.E. “F-1A Task Assignment Program Final Report (Rocketdyne)”, NASA-CR-138312, Rocketdyne North American Rockwell, California, 1970.





[www.nasa.gov/marshall](http://www.nasa.gov/marshall)