

Aerospace Castings

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National Aeronautics and
Space Administration



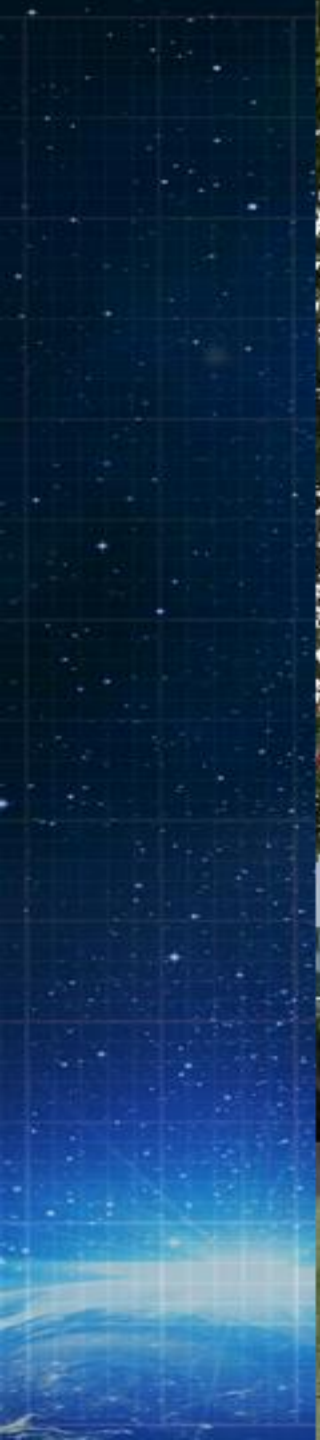
MARSHALL
SPACE FLIGHT CENTER



Overview



- Marshall Space Flight Center (MSFC)
- Space Launch System (SLS)
- RS-25 Engine
- Castings in RS-25
- Turbopump castings
- Advanced Casting Technology
- Casting Quality Considerations
- Casting Trends and Outlook



Jet Propulsion Laboratory

Deep Space Robotic Rovers and Networks
Pasadena, Calif.

Armstrong Flight Research Center

Atmospheric Research and Testing
Edwards, Calif.

Ames Research Center

Aerospace and Small Spacecraft
Moffett Field, Calif.

Glenn Research Center

Aeronautics and Spacecraft Technology
Cleveland, Ohio

Goddard Space Flight Center

Science Missions and Telescopes
Greenbelt, Md.

NASA Headquarters

Washington, D.C.

Langley Research Center

Aviation and Space Research
Hampton, Va.

Kennedy Space Center

Space Vehicle Launch and Landing
Cape Canaveral, Fla.

Johnson Space Center

Human Space Flight Operations
Houston, Texas

Stennis Space Center

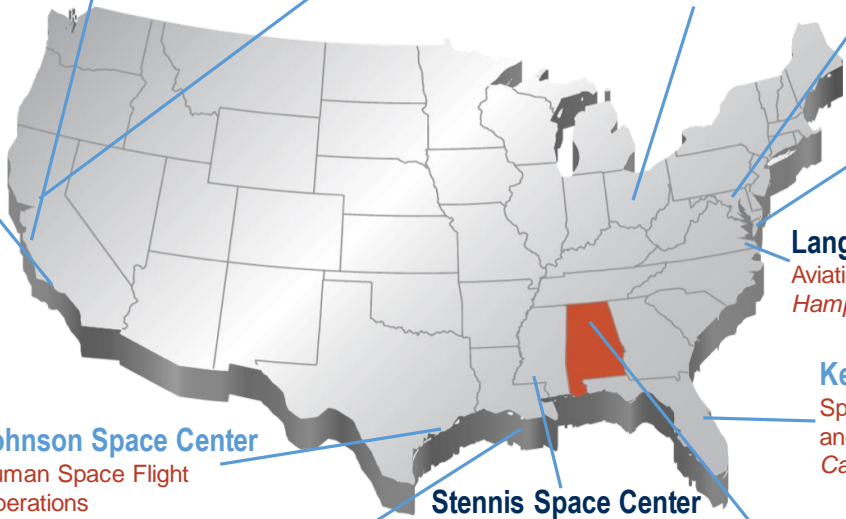
Vehicle Engine Testing
Bay St. Louis, Miss.

Michoud Assembly Facility

Large Vehicle Manufacturing
New Orleans, La.

Marshall Space Flight Center

Space Transportation, Propulsion Systems, Space Systems, and Science
Huntsville, Ala.



Marshall Space Flight Center

Team Redstone



Marshall Space Flight Center

State of Alabama

\$3.8B economic impact FY15
Employment impact more than
20,000 jobs

2nd largest employer

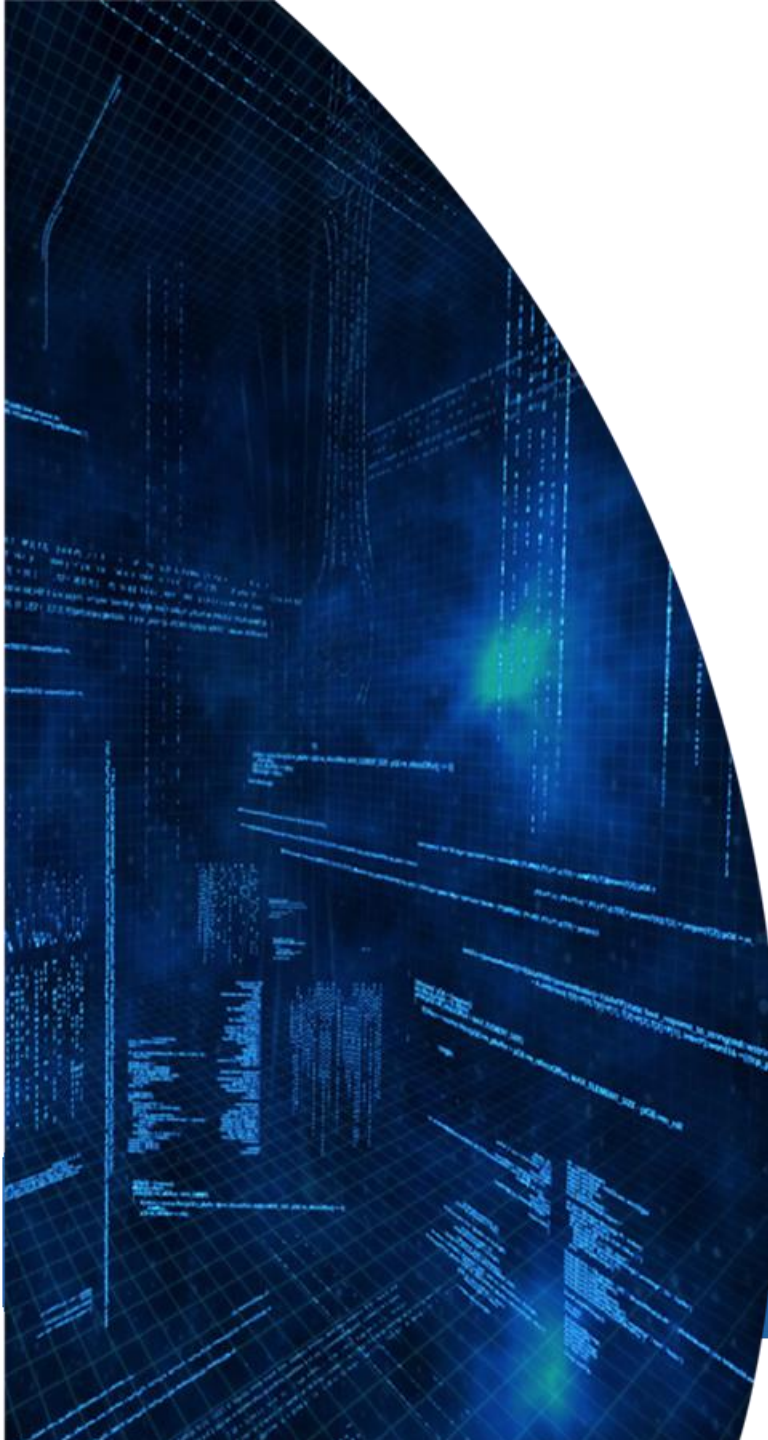
Huntsville / Madison County

Nationwide impact of
more than
38,000 jobs



Fueling the Economy



- 
1. Lead the way into markets that do not yet exist
 2. Enable new markets through exploration – focus beyond LEO
 3. Stay focused on being a DDT&E Center
 4. Emphasis on science as it enables exploration

Marshall's Path Forward



250 miles

Commercial
Partners

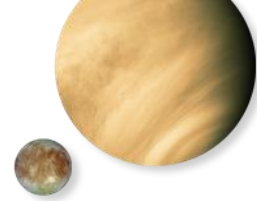
Low-Earth Orbit



Moon
240,000 miles



Mars
90 Million miles



Europa

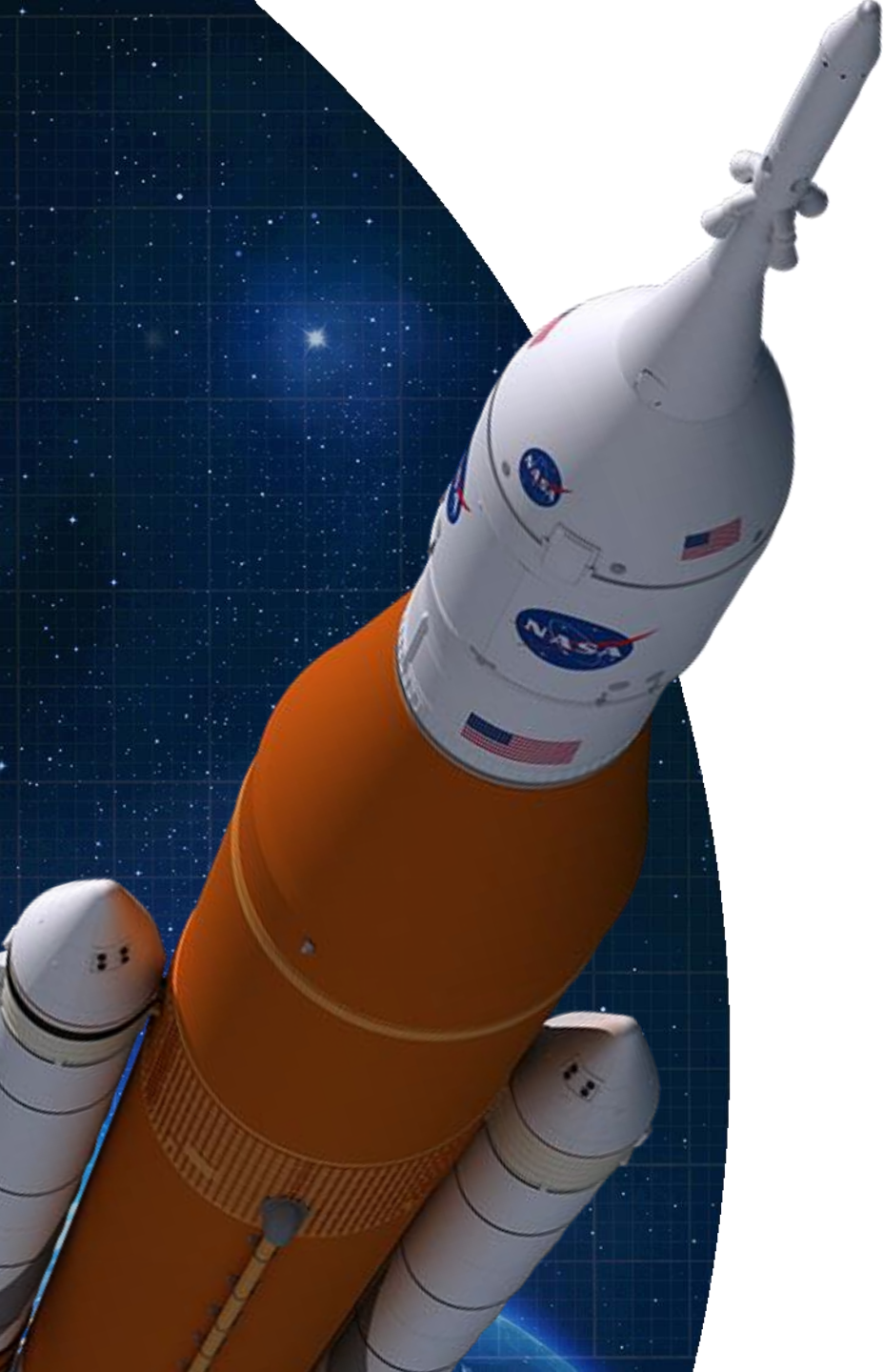


Block I



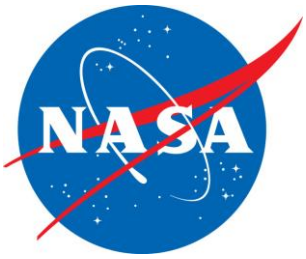
Block II



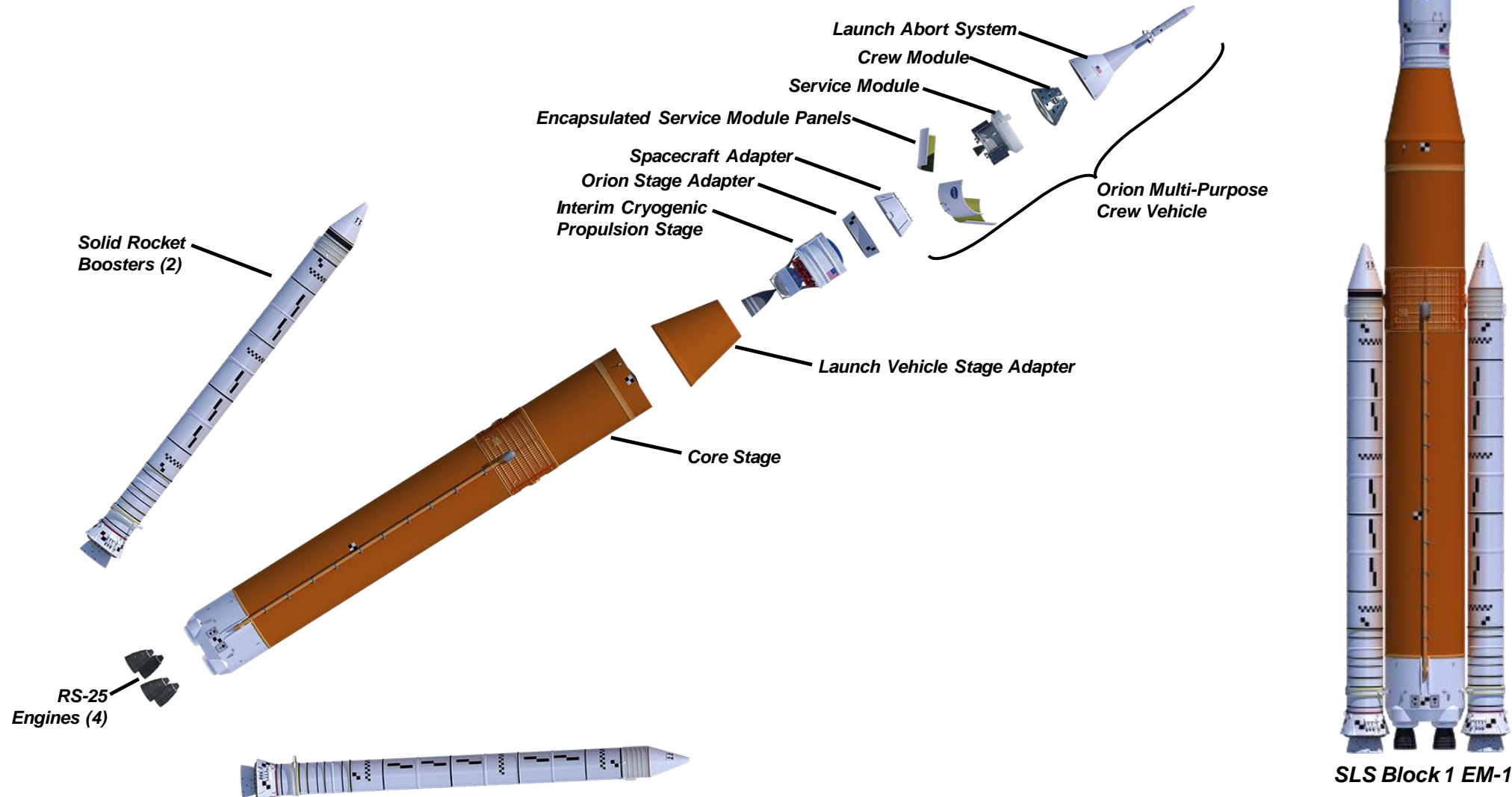


Space Launch System

The **only** vehicle capable of sending humans to deep space **and** the large systems necessary for human exploration



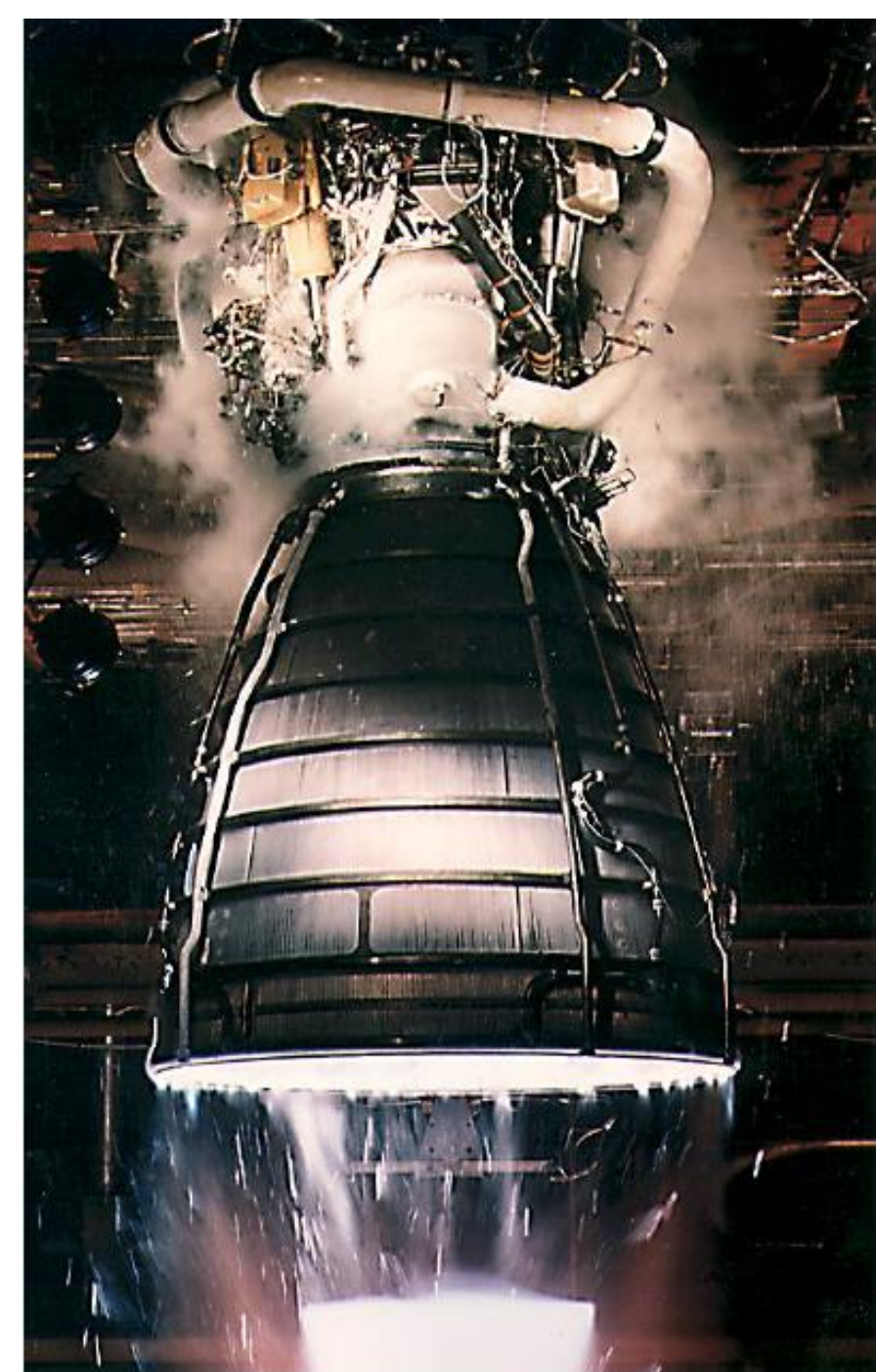
Space Launch System






RS-25 Engine

- Oxygen/Hydrogen Engine – staged combustion cycle
- Each turbine blade powering the RS-25's high pressure fuel turbopump produces more than a Corvette ZR1's 638 horsepower, and its airfoil is the size of a quarter.
- Pressure within the RS-25 is equivalent to an ocean depth of three miles – about the same distance where Titanic lies below the surface of the Atlantic Ocean.
- The combustion chamber reaches +6,000 degrees F. -- hotter than the boiling point of iron.
- The space shuttle's three main engines operated for 8 minutes and 40 seconds for each shuttle flight, with a combined output of 37 million horsepower.
- Four RS-25 engines power the SLS Core Stage





RS-25 - Technical Data

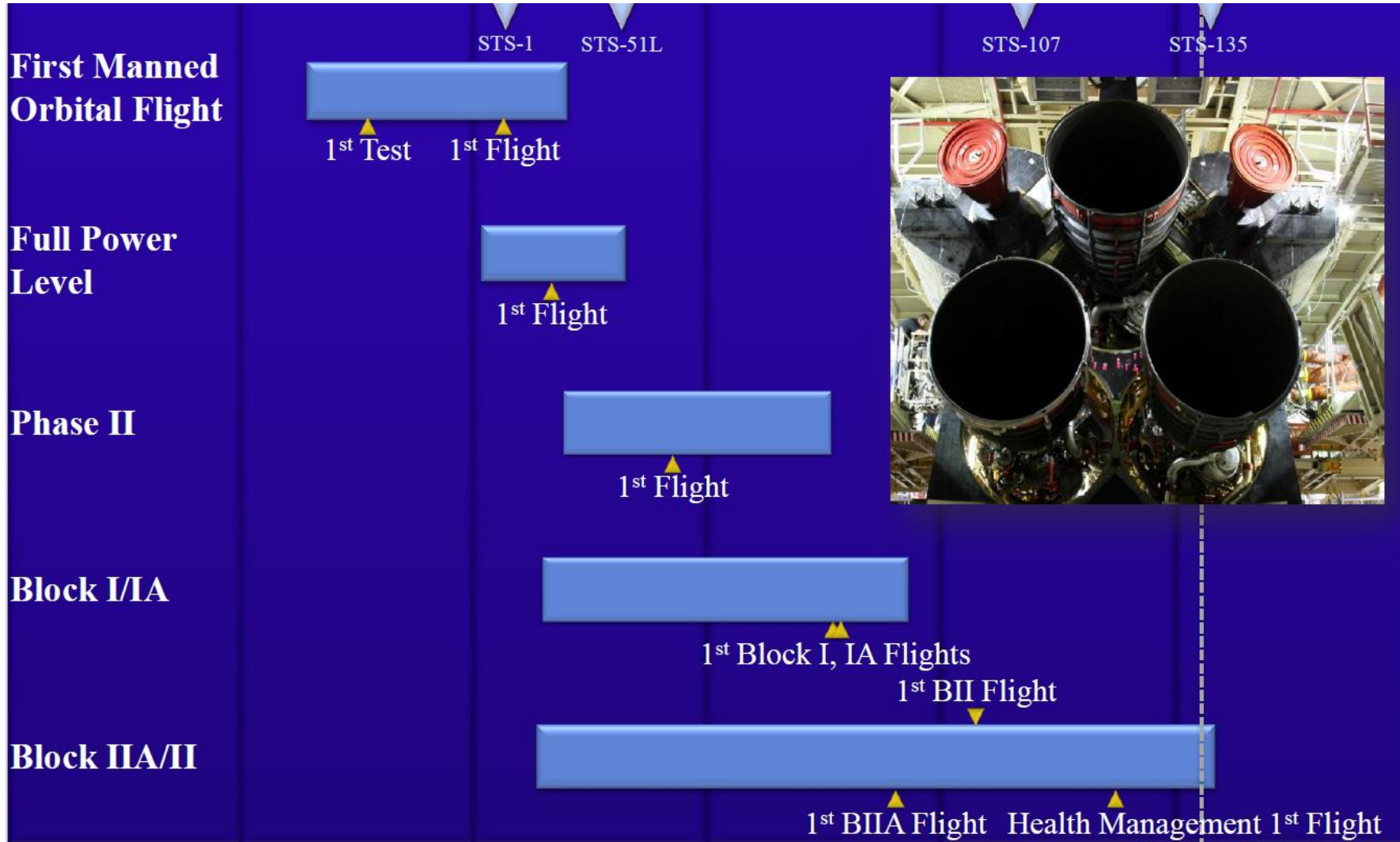


Propellants	O₂/H₂
Rated power level (RPL)	469,448 lb
Nominal power level (104.5% RPL)	490,847 lb
Full power level (109% RPL)	512,271 lb
Chamber pressure (109% RPL)	2,994 psia
Specific impulse at altitude	452 sec
Throttle range (% RPL)	67 to 109
Gimbal range	+/- 11°
Weight	7,748 lb
Service life	55 flights 27,000 sec
Total program hot-fire time	3,171 starts 1,095,677 sec



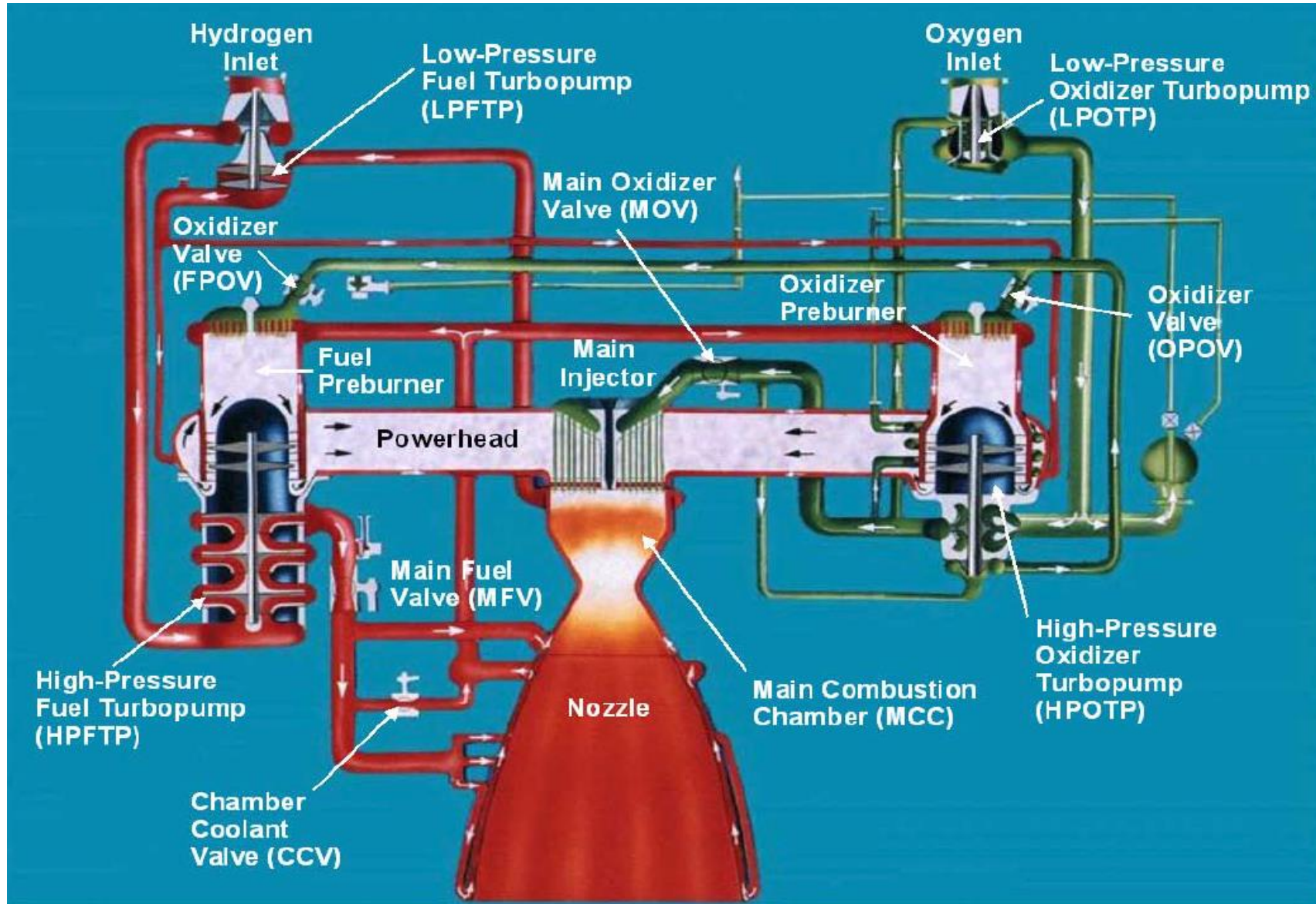
RS-25 Flight History

30 years of Space Shuttle – 135 flights



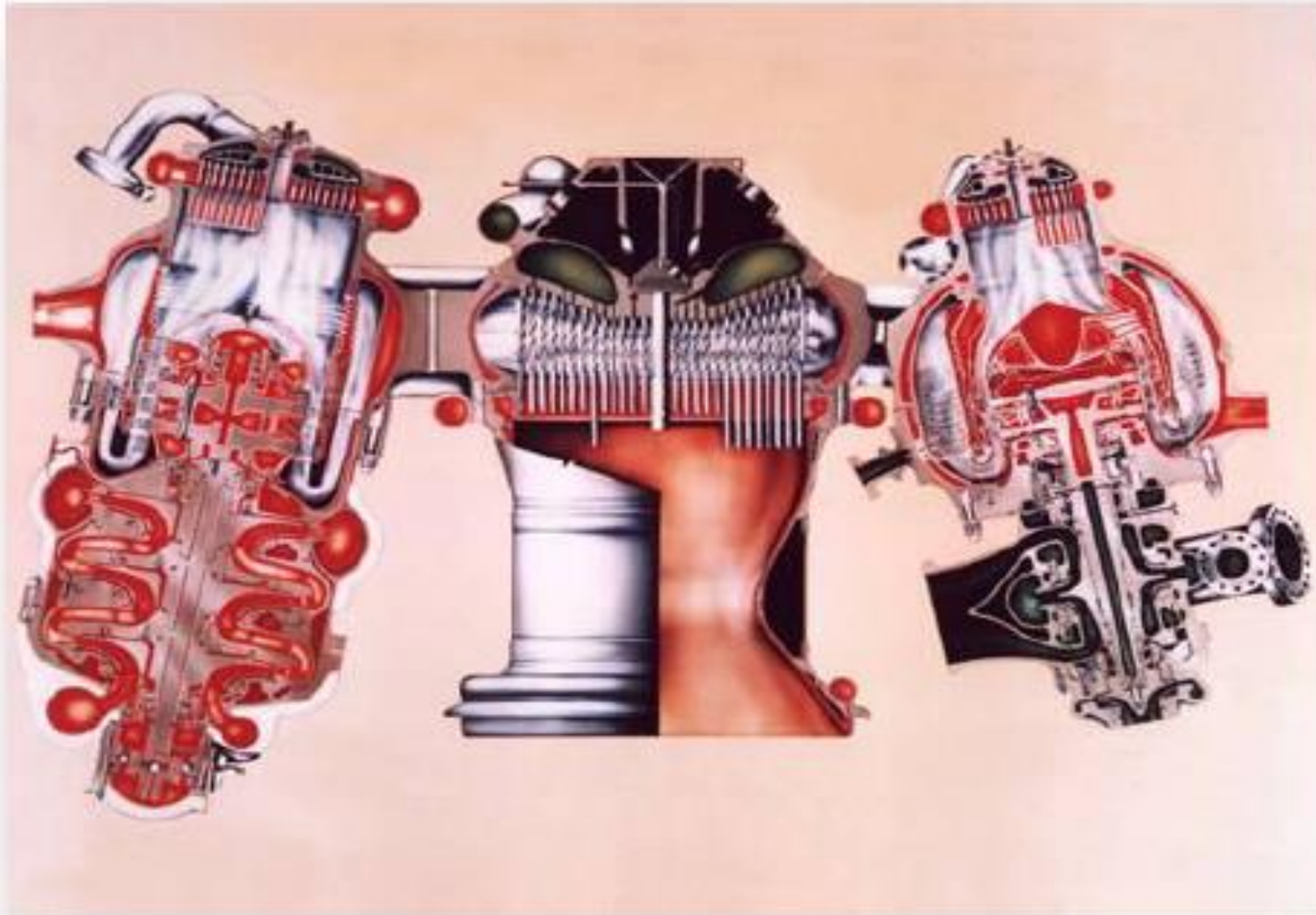


RS-25 Simplified Flow Schematic



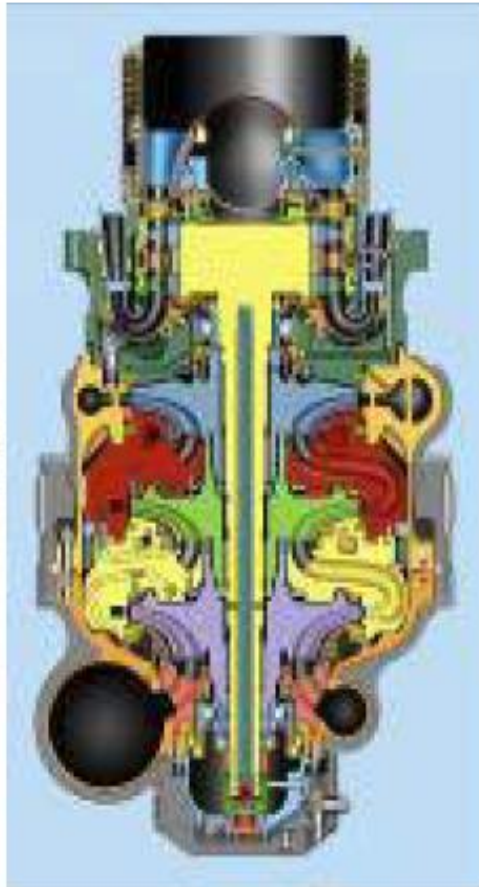


RS-25 Powerhead





Turbopumps



HPFTP (High Pressure Fuel Turbopump)



HPOTP (High Pressure Oxidizer Turbopump)



Why Castings?



- Castings are critical for current and future engine designs
- Castings improve producibility – best option for several components
- RS-25 Liquid Engine relies on advanced casting technology
- Block changes to RS 25 included implementation of precision castings
 - Reduced number of welds
 - Reduced part count
 - Near net shape parts
 - Increased reliability
- RS-25 Selected as the Core Stage Engine for SLS
 - First Iteration Castings Complete for Production Re-start Contract
 - Opportunity for Incorporating Lessons Learned



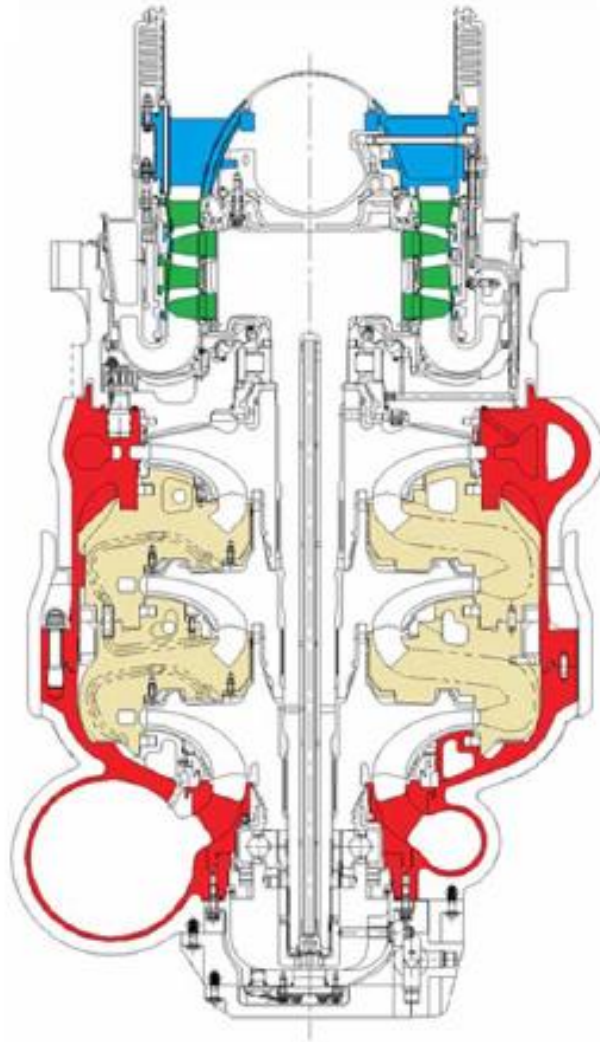
Castings in RS-25 Engine



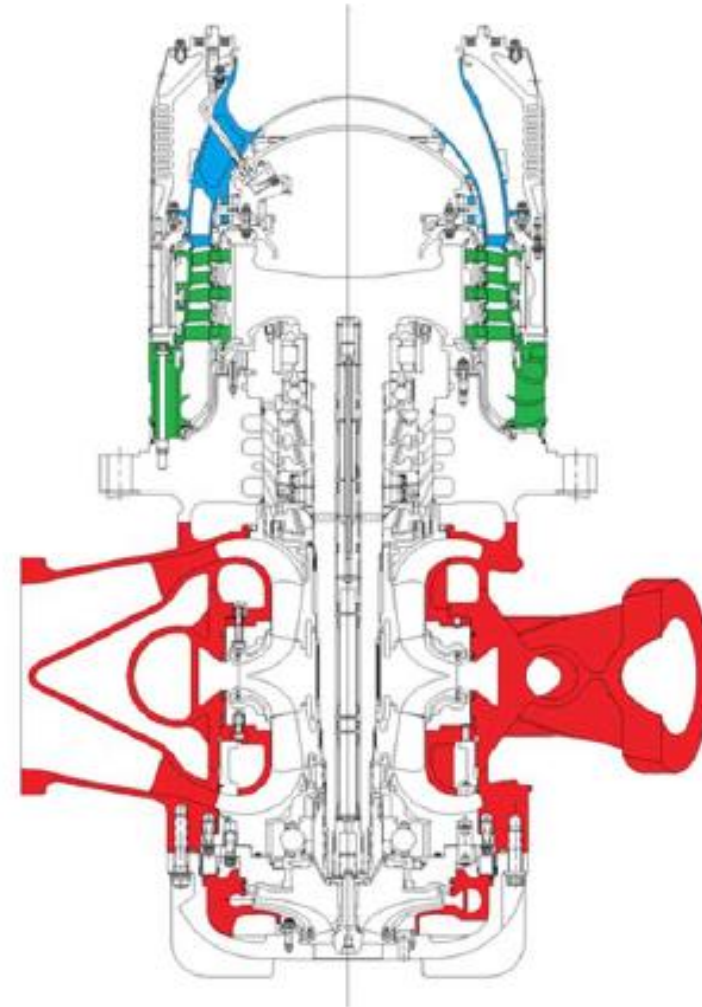
Castparts in RS-25 Engine		
Component	Castparts	Alloy
HPOTP	Main pump housing inlet and discharge volutes	Ni-base superalloy
	Turbine inlet housing	Ni-base superalloy
	Turbine vanes	Ni-base superalloy
	Turbine blades	PWA alloy - SC
	Turnaround duct	Ni-base superalloy
HPFTP	Pump inlet housing	Ni-base superalloy
	Pump discharge housing	Ni-base superalloy
	Diffusers	Al alloy
	Turbine inlet housing	Ni-base superalloy
	Turbine vanes	PWA alloy
LPFTP	Turbine blades	PWA alloy - SC
	Housing	Al alloy
LPOTP	Manifold	Ni-base superalloy
	Housing	Al alloy
Powerhead	Heat exchanger turning vanes	Ni-base alloy



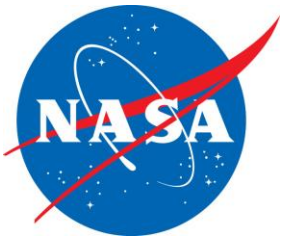
Turbopump Castings - Schematic



HPFTP

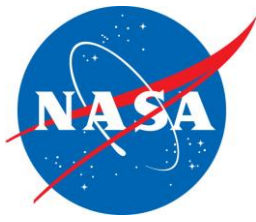


HPOTP



Turbopump Castings - Examples





Advanced Casting Technology



- **Fine grain precision casting technology**
 - ASTM 3-5 grain size
 - Used for making Housing and Turbine Inlet Castings
 - 293 Welds Eliminated on the High Pressure Oxidizer Turbopump
 - No Welds on the High Pressure Fuel Turbopump
 - Consistent Properties, Chemistry, and Precipitate Morphology
 - Near net shape, complex geometry castings
 - Lean Process
 - NASA, Engine Contractor, Casting Supplier Collaboration
 - Chill Approach to Developing Aluminum Sand Casting Mechanical Properties
- **Investment Casting of Single Crystal Blades and Vanes**
 - Airfoil properties are the limiter for high temperature turbine environments
 - Tensile
 - Thermal shock
 - High- and low- cycle fatigue
 - Hydrogen embrittlement
 - Grain boundaries contain undesirable features or defects
 - Act as crack starters
 - Require grain boundary strengtheners that are otherwise undesirable
 - Incipient melting at operating temperature



Casting Quality Considerations



- Aerospace castings tend to be the highest quality castings in the industry
 - Quality is driven by requirements in design, functionality, reliability and safety
 - Cost is always an important factor
 - Cast parts must meet NASA design and construction standards: NASA-STD-6016 (Materials), -5009 (NDE) -5012 (Structures), -5019 (Fracture Control)
- Casting qualification is rigorous and involves several steps
 - Master heat requirements: single furnace charge, vacuum Melted
 - Demonstration Units – help to develop process details
 - Qualification unit for first article cut-up – verification of part
- Quality requirements are specified on purchase order
 - Nondestructive Testing Requirements – X-ray, dye penetrant, ultrasonics, etc.
 - Mechanical properties from specimens cut from castings: tensile, stress-rupture, fracture
 - Microstructure - grain size, undesirable phase/microstructural limits
 - Periodic cut-ups - every certain number of units
- Structural test followed by penetrant inspection



Castings Trends and Outlook



- Casting foundry material much cleaner than 15-20 years ago
 - Electron beam cold hearth refinement not needed
 - Bottom-feed and ceramic filters effective
 - Allows use of revert
 - Master heat w/revert must meet all specification requirements
 - Mechanical properties not affected
- NASA-STD-5009 is tailorable to use best technique for reliable flaw detection
 - Sonic shear wave, digital radiography, industry NDT
 - Thermal etch to expose flaws
 - First article frequency
 - Relaxed from one-year to two-year requirement
 - Chemistry, grain size, mechanical property requirements verified
 - Porosity allowance
- Weld Repair Without Re-HIP
 - Better properties in weld: tensile, LCF, HCF, microstructure
- Unlimited Weld Repair
 - Volume, spacing, quantity, post weld HIP
 - Weld Procedures match supplier's
- Allow as-cast surface finish if structurally acceptable

Acknowledgements

- Robert Lambdin
- SLS - Liquid Engine Office
- OSAC – Marcia Cobun