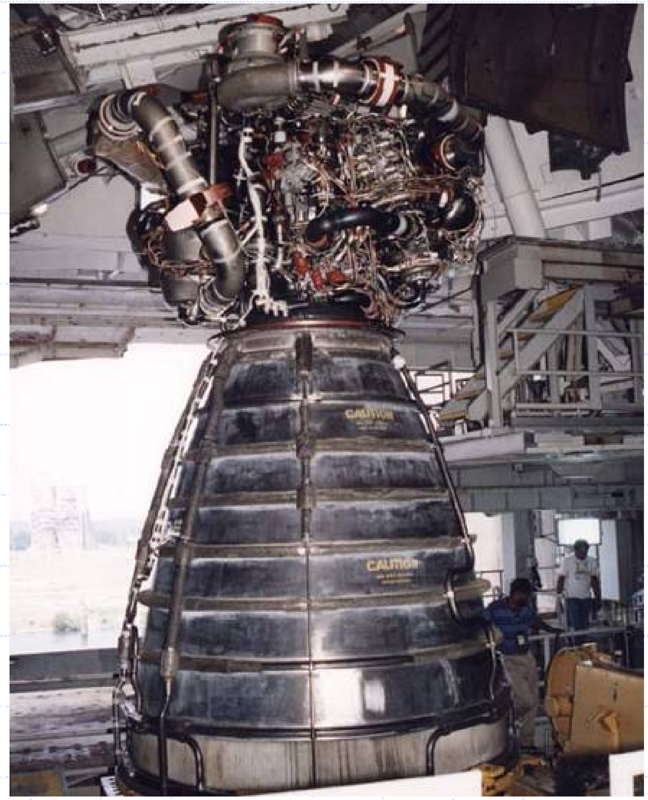
Propulsion System Analysis Team



SSME Improvement Proposal

Junghyun Ahn
Brian Bairstow
Steve Bresnahan
Dan Judnick

Scope and Goals

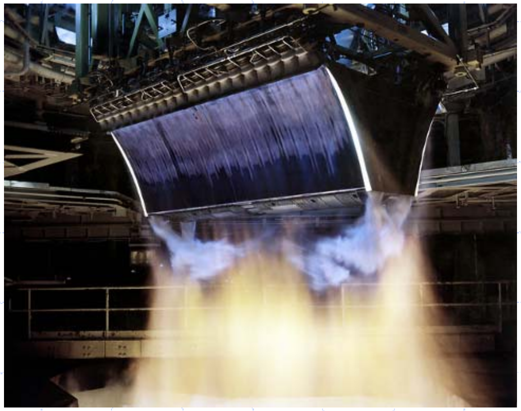
- Focused on the Space Shuttle Main Engines (SSME)
- Investigated opportunities for improving the design
  - Implementation of new technology
  - Addressing lessons learned from development and operation of legacy engines
- Improvements should impact safety, reliability, maintainability, and affordability as well as performance
- Retained key requirements from existing design
  - Reusability
  - Total thrust
  - Engine throttling
  - Fail op
  - Quick turnaround

Trade Studies Performed

- Modest changes to existing engines
  - Open nozzle throat to reduce pressures and improve engine life
  - Replace sensors with more reliable versions of same technology
- Alternative Fuels:
  - Current System
    - Solid rocket boosters and LH2/LO2 main engines
  - Density vs. Specific Impulse trade
    - Higher density means lower tank masses
    - Higher specific impulse means lower propellant masses
  - Different propellants modeled
- Conclusions
  - Specific impulse was dominant
  - LH2/LO2 for both boosters and main engine
  - Increase in payload capability

Trade Studies Performed (continued)

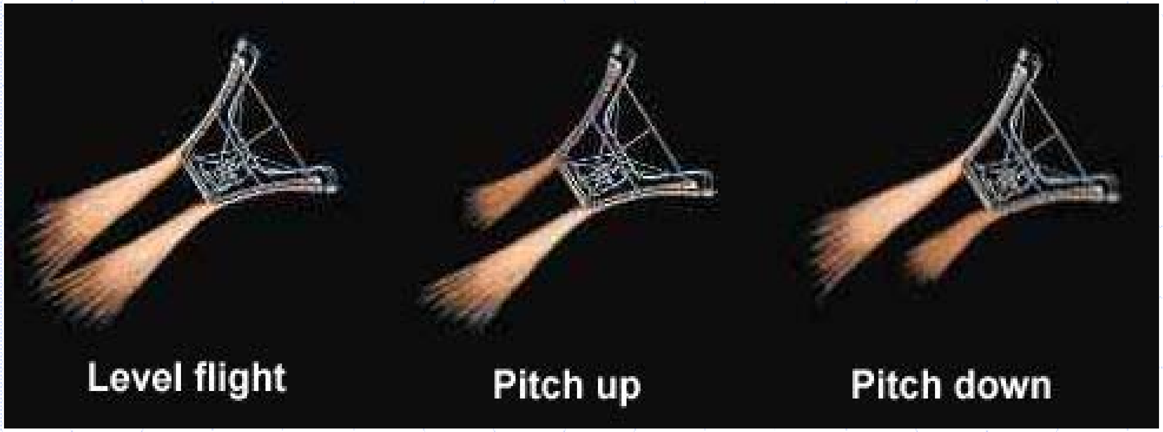
Aerospike Engine Design:

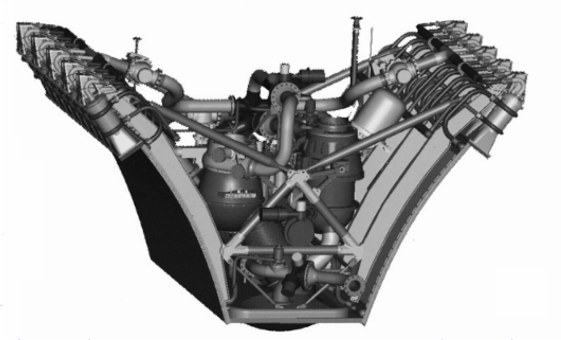


- Instead of directing exhaust through middle of large bell, uses cone or wedge shape
- Bell design optimum for one altitude only
- "Virtual bell" created by aerospike self-adjusts with external conditions

Advantages:

- Optimum thrust over more conditions
- Low pressure cycle inherently safer
- Weighs more but allows lower weight of total aircraft
- Potential for thrust vectoring (eliminates gimbals)





Disadvantages:

- Heat management
- Complexity
- Cost

Trade Studies Performed (continued)

- Alternative Engine Cycles
  - Single mode engines
  - Dual mode engines
- Controller improvements
  - Modernization of digital electronics
  - New sensor technology
  - Software techniques for fault detection and accommodation

Integrated Powerhead Demonstrator (IPD)

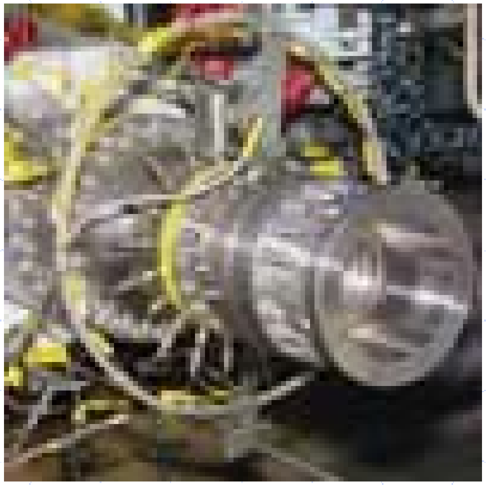
- Part of NASA and Air Force program to develop new reusable engine technology
  - 5 sec improvement in Isp
  - 30% increase thrust to weight
  - 15% reduction in cost
  - 25% improvement in reliability
- Full-flow, hydrogen-fueled, staged-combustion rocket engine
  - 250,000 lb class
  - Throttle down to 20%
  - Chamber pressure: 3,000 psia
  - Propellant mixture ratio: 6.5

Major Improvements

- Enhance turbine life
  - Full-flow staged combustion cycle sends all propellant through turbine to achieve same energy
  - Therefore can decrease combustion temperature 500 °F
  - Increase maintenance time to 100 missions (10 for SSME)
  - Total life 200 missions
- Hydrostatic bearings
  - Bearing wear only occurs at engine startup and shutdown
- Dual preburners
  - Oxygen preburner uses all available O2, drives turbopump harder, reaching higher pressures
  - Reduces chance for seal failure between pump and turbine
  - SSME uses only small amount of O2 prior to combustion chamber
- Laser ignition system in the full size main injector
  - Dramatically decrease ignition systems maintenance costs

Preburners

- Designed to decrease cost and weight
  - Low cost processes to etch the injector tubes, no individual fabrication
  - Preburner housings of metal matrix composites or ceramics created using advanced casting processes to reduce weight further
- Increasing temperature uniformity to enhance turbine reliability and life
  - Oxygen added just beyond the mixing element into combustion section
  - Device is compact, eliminates a separate hydrogen mixture
- First large scale demonstrator of a gas-gas rocket engine injector
  - Oxygen cools nozzle, sending warm oxygen to the preburners allowing severe engine throttling
- Oxygen Preburner
  - Extremely hot oxygen environment
  - New base materials resistant to environment, enhance engine reliability

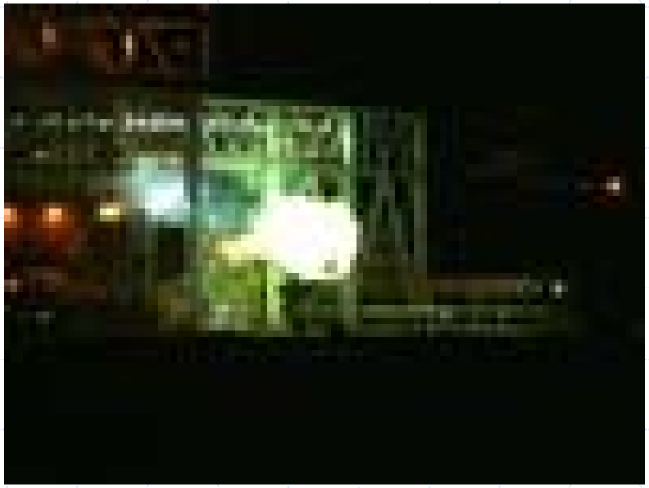


Testing

- Component Level: October 2003
  - Turbopumps and preburners all successful
  - Measure mixing efficiency, temperature uniformity, and hydraulic resistance
- System Level: May 2005
  - Initial full-duration test lasted 4.9 seconds, 3rd of 22 static ground tests scheduled
  - Demonstrate mechanical integrity, restart capability, throttleability, assess durability.
  - Rapid turn-around times between tests to establish cost savings and engine reliability
  - 100 thermal system cycles, 1 and 2 million revolutions of the oxygen and hydrogen turbopumps to demonstrate life goal
- Current IPD is not flight-worthy, only test article

Testing

Hydrogen turbopump
Test 2003



System Testing (1)

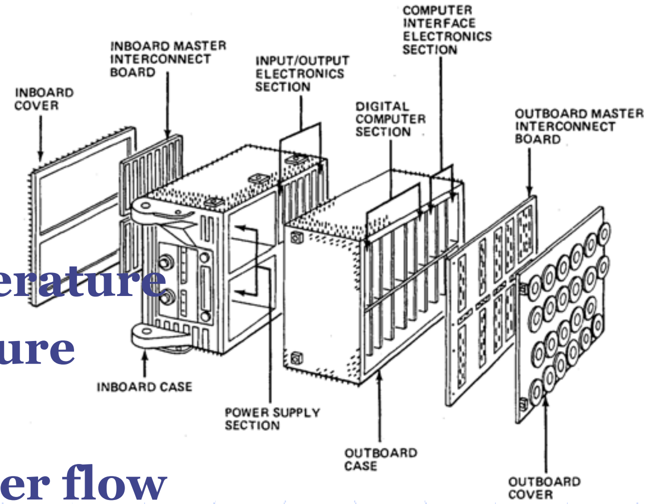
System Testing (2)

NASA

Close-up of 2

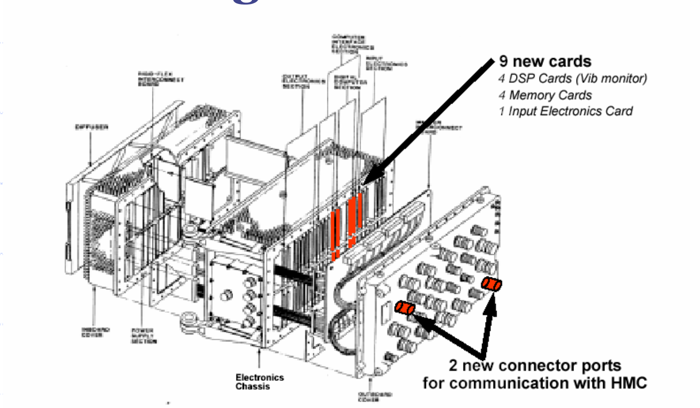
Engine Controller Improvements

- Legacy Computer and I/O
  - 16-bit CPU, 16kb memory, 115V AC power
  - Sensor inputs:
    - Turbopump and combustion chamber temperature
    - Turbopump and combustion chamber pressure
    - Valve position
    - Pulse counter turbine speed and fuel/oxidizer flow
    - Spark Igniter feedback
  - 1Mbps serial link to general purpose computers via interface unit
  - Outputs:
    - Servovalve commands
    - Switches / solenoids / pneumatic valve commands
    - Igniter power
  - Legacy functions
    - Oxidizer and fuel valve control
    - Ignition control
    - Pressure, temperature, and turbine speed monitoring and reporting
    - Built-in self test and ground support



Engine Controller Improvements

- **Digital Electronics Modernization**
  - New engine controller and separate health monitor computer



  - 28Vdc power
  - Controller includes 4 advanced DSP boards, 1Gb memory
  - Non-volatile memory eliminates batteries
- **Added functionality**
  - Engine controller adds vibration monitoring for turbopumps
  - Allows engine throttle down in addition to shutdown
  - Improved sensor fault isolation and accommodation
  - Health monitor adds more comprehensive vibration monitoring and real time engine model

Engine Controller Improvements

- New Sensor Technology
  - Solid state gas detection sensors to monitor hydrogen leaks
    - Aids with valve and line integrity
  - Plume spectroscopy examines exhaust for signs of debris indicating component wear
  - Non-contact temperature sensors like pyrometers for characterizing temperature gradients along turbine blades
  - Rejected: High frequency acoustic monitoring for bearing wear is difficult due to acoustic levels
  - Microwave devices for small distance measurements like tip clearances
  - Polymer film blankets for burn through detection
- Software algorithms for robust operation
  - Sensor validation and multi-sensor data fusion
  - Real-time engine model
  - Fault simulation and failure analysis models

Recommendations

- Replace the 3 SSME's with 4 IPD-derivative engines
- Modernize electronics for increased processing power
- New sensors produce information that reduces need for scheduled maintenance
- Results
  - Increased Performance
  - Higher Reliability
  - Lower Cost
  - Longer Life
  - Less Maintenance/ Quicker turn-around time