Propulsion System Analysis Team

SSME Improvement Proposal

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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)

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