SPACE SHUTTLE PROPULSION SYSTEMS

SPACE TRANSPORTATION TECHNOLOGY SYMPOSIUM

PENNSYLVANIA STATE UNIVERSITY

RUSSELL BARDOS
NASA
OFFICE OF SPACE FLIGHT
JUNE 26, 1990
THE SPACE SHUTTLE

EXTERNAL TANK

ORBITER

TWO ORBIT MANEUVERING ENGINES

FOURTEEN RCS PRIMARY THRUSTERS
TWO RCS VERNIER THRUSTERS

FOUR BOOSTER SEPARATION MOTORS

TWO SOLID ROCKET BOOSTERS

THREE MAIN ENGINES

FOUR BOOSTER SEPARATION MOTORS

TWENTY: FOUR RCS PRIMARY THRUSTERS
(TWELVE EACH AFT POD)
FOUR RCS VERNIER THRUSTERS
(TWO EACH AFT POD)

REDESIGNED SOLID ROCKET MOTOR
Four Segment Design

PURPOSE: PROVIDES PROPULSIVE THRUST FROM LIFTOFF THROUGH THE FIRST 123 SECONDS OF FLIGHT
SUPPLIER: THIOKOL CORP., WASATCH, UTAH

9 DEGREE OMNIAxIAL DEFLECTION NOZZLE

FIELD JOINTS (3)
RSRM DESIGN PARAMETERS

- AVERAGE VACUUM THRUST (WEB TIME): 2,590,000 LBS
- SPECIFIC IMPULSE (VACUUM): 267.9 SEC
- AREA RATIO \(\left(\frac{A_e}{A_t}\right)\): 7.72
- AVERAGE CHAMBER PRESSURE: 625 PSIA
- ACTION TIME: 123.4 SEC
- MOTOR WEIGHT: 1,255,978 LBS
- PROPELLANT WEIGHT: 1,107,169 LBS
- MASS FRACTION: 0.882
- INERT WEIGHT:
  - CASE: 98,740 LBS
  - NOZZLE: 23,965 LBS
- PROPELLANT TYPE: PBAN
- BURN RATE (at 625 PSIA): 0.368 IN/SEC
- THRUST VECTOR CONTROL: FLEX BEARING
- CASE MATERIAL: D6AC STEEL
- INSULATION MATERIAL: ASBESTOS/NBR

ADVANCED SOLID ROCKET MOTOR
Three Segment Design

PURPOSE: PROVIDES PROPULSIVE THRUST FROM LIFTOFF THROUGH THE FIRST 134 SECONDS OF FLIGHT
SUPPLIER: LOCKHEED MISSILES & SPACE COMPANY, SUNNYVALE, CA.

Field Joints (2)

Dimensions:
- Diameter: 150 in.
- Length: 1,388 in.
- 125 in.
- 1,513 in.
ASRM DESIGN PARAMETERS

- Average Vacuum Thrust (Web Time): 624,031 lbs
- Specific Impulse (Vacuum): 70.3 sec
- Area Ratio ($A_e/A_t$): 7.54
- Average Chamber Pressure: 633 psia
- Action Time: 134.1 sec
- Motor Weight: 1,345,807 lbs
- Propellant Weight: 1,205,807 lbs
- Mass Fraction: 8.96
- Inert Weight:
  - Case: 97,419 lbs
  - Nozzle: 18,947 lbs
- Propellant Type: HTPB
- Burn Rate (@625 psia): 0.345 in/sec
- Thrust Vector Control: Flex Bearing
- Case Material: 9 Ni-4 Co-0.3C
- Insulation Material: Kevlar-Glass-EPDM

SPACE SHUTTLE MAIN ENGINE

Purpose: Provide propulsive thrust from liftoff to orbit
Supplier: Rockwell International Rocketdyne Division, Canoga Park, CA.

Hydraulic/Pneumatic Interfaces
Gimbals Bearing
Electrical Interface Panel
LPFTP Discharge Duct
Hot-Gas Manifold
Controller
MFV
Nozzle

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SSME COMPONENTS

MAIN ENGINE PARAMETERS

- PROPELLANTS
  - RATED POWER LEVEL (RPL) 100%
  - FULL POWER LEVEL (FPL) 109%
  - MINIMUM POWER LEVEL (MPL) 65%
- THROTTLE RANGE
- CHAMBER PRESSURE
- MIXTURE RATIO
- SPECIFIC IMPULSE
- FLOW RATES:
  - OXYGEN
  - HYDROGEN
- WEIGHT
- DESIGN LIFE
- FULL POWER LEVEL
- OVERALL HEIGHT
- NOZZLE DIAMETER @ EXIT

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<th>PROPELLANTS</th>
<th>OXYGEN/HYDROGEN</th>
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<tr>
<td></td>
<td>470,000 LBS</td>
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<tr>
<td>RATED POWER LEVEL</td>
<td>512,300 LBS</td>
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<tr>
<td>(RPL) 100%</td>
<td>305,500 LBS</td>
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<tr>
<td>FULL POWER LEVEL</td>
<td>65% TO 109% (1% Increments)</td>
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<tr>
<td>(FPL) 109%</td>
<td>3200 PSIA</td>
</tr>
<tr>
<td>MINIMUM POWER LEVEL (MPL) 65%</td>
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<tr>
<td></td>
<td>453.5 SEC</td>
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<tr>
<td>THROTTLE RANGE</td>
<td>973 LB/SEC</td>
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<tr>
<td>CHAMBER PRESSURE</td>
<td>161 LB/SEC</td>
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<tr>
<td>MIXTURE RATIO</td>
<td>7,000 LBS</td>
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<tr>
<td>SPECIFIC IMPULSE</td>
<td>27,000 SEC</td>
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<tr>
<td>FLOW RATES:</td>
<td>55 STARTS</td>
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<tr>
<td>OXYGEN</td>
<td>14,000 SEC</td>
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<tr>
<td>HYDROGEN</td>
<td>14 FEET</td>
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<tr>
<td>WEIGHT</td>
<td>7.5 FEET</td>
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<td>DESIGN LIFE</td>
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<td>NOZZLE DIAMETER @</td>
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SRB BOOSTER SEPARATION MOTOR

PURPOSE: PROVIDES PROPULSIVE THRUST TO SEPARATE SRBS FROM THE ORBITER AND EXTERNAL TANK
SUPPLIER: UNITED TECHNOLOGIES, CHEMICAL SYSTEMS DIV., SAN JOSE, CA.

BSM DESIGN PARAMETERS

- AVERAGE VACUUM THRUST 20,050 LBS
- AREA RATIO 5.8
- AVERAGE CHAMBER PRESSURE 2221 PSIA
- ACTION TIME 0.805 SEC
- TOTAL IMPULSE 15,000 LB - SEC
- MOTOR WEIGHT 167 LBS
- PROPELLANT TYPE HTPB
- CASE MATERIAL 7075 AL
**OMS ENGINE**

**PURPOSE:** Provides propulsive thrust for orbit insertion, orbit circularization, orbit transfer, rendezvous, deorbit, and launch abort.

**SUPPLIER:** AEROJET PROPULSION DIVISION; SACRAMENTO, CA.

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**OMS ENGINE DESIGN PARAMETERS**

- Propellants: MMH/N₂O₄
- Thrust (Vacuum): 6,000 LBS
- Nominal Specific Impulse: 313.2 SEC
- Chamber Pressure: 125 PSIA
- Mixture Ratio: 1.65
- Expansion Ratio: 55:1
- Flow Rates:
  - Fuel: 11.93 LB/SEC
  - Oxidizer: 7.23 LB/SEC
- Dry Weight: 297 LBS
- Life: 100 Missions, 1000 Starts, 15 Hours CUM. FIRING
- Gimbal Capability:
  - Pitch: ±6 DEG
  - Yaw: ±7 DEG
RCS PRIMARY AND VERNIER THRUSTERS

PURPOSE: PROVIDE PROPULSIVE THRUST FOR ORBIT STABILIZATION AND ORIENTATION MANEUVERS

SUPPLIER: THE MARQUARDT COMPANY, VAN NUYS, CA.

RCS PRIMARY & VERNIER THRUSTER PARAMETERS

- PROPELLANTS
  PRIMARY: MMH/N₂O₄
  VERNIER: MMH/N₂O₄

- NOMINAL VACUUM THRUST
  PRIMARY: 870 LBS
  VERNIER: 24 LBS

- CHAMBER PRESSURE
  PRIMARY: 152 PSIA
  VERNIER: 110 PSIA

- MIXTURE RATIO
  PRIMARY: 1.6
  VERNIER: 1.65

- SPECIFIC IMPULSE
  PRIMARY: 280 SEC (22:1 AREA RATIO)
  VERNIER: 265 SEC

- INLET PRESSURE
  PRIMARY: 238 PSIA
  VERNIER: 246 PSIA

- RATIO (Aₑ/Å₁)
  PRIMARY: 22:1 TO 30:1
  VERNIER: 20.7:1

- LIFE
  MISSIONS: 100
  CYCLES: 20,000
  TOTAL FIRING DURATION: 12,800 SEC

- WEIGHT
  PRIMARY: 16 LBS
  VERNIER: 9.4 LBS

- CONSTRUCTION
  PRIMARY: COLUMBIUM/TITANIUM
  VERNIER: COLUMBIUM/TITANIUM

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1.27 Firwiod Reactl_in 38 Primacy Thrustell (14 Folrwmd. 12 per Aft PodlThrust Level - 970 Pounds Vucimm
Control Systiml . Primary Thrustm 114) 6 Vefnil_ Thrustms (2 Froward, 4 Aft)
Thrust Level - 24 Pounds Vacuum

Monomelhyl Hydrszine Fuel

Oxidize Tank
Fuel Tank

Access Cover

Servicing Panel

Helium Tank (2)

Primary Thruster (14)

Electrical Disconnect

Forward Reaction Control System

RCS Primary Thrusters
(112 per Each Aft Pod)

RCS Verrier Thrusters
(2 per Each Aft Pod)

RCS Fuel Tank

RCS Hehmum Tanks

RCS Propellant Manifold Valves

NOTE: Shaded areas part of orbital maneuevering system

38 Primary Thrusters (14 Forward, 12 per Aft Pod)
Thrust Level = 970 Pounds Vacuum
8 Verrier Thrusters (2 Forward, 4 Aft)
Thrust Level = 24 Pounds Vacuum

Propellants: Nitrogen Tetroxide Oxidizer
Monomethyl Hydrszine Fuel
Nominal Forward RCS Full Load
1,477 Pounds Nitrogen Tetroxide
928 Pounds Monomethyl Hydrszine
Nominal Aft RCS Full Load for Each Pod
1,477 Pounds Nitrogen Tetroxide
825 Pounds Monomethyl Hydrszine

Left Aft OMS/RCS Pod
(Right Aft OMS/RCS Pod Contains Idenitical Components)
SPACE SHUTTLE PROPULSION ISSUES

RSRM
- IGNITER SEAL ANOMALIES
- CASE STIFFENER SEGMENT ATTRITION
- IMPROVED O-RING MATERIAL
- ASBESTOS-FREE INSULATION
- FORWARD SEGMENT GRAIN REDESIGN

SSME
- HIGH PRESSURE TURBOPUMP BEARINGS
- HEAT EXCHANGER
- CONTROLLER OBsolescence
- UNINSPECTABLE WELDS

SRB
- AFT SKIRT FACTOR OF SAFETY
- OBsolescence OF ELECTRONIC COMPONENTS
- RECOVERY SYSTEM MARGINS
- DEBRIS CONTAINMENT SYSTEM

RCS THRUSTERS
- COMBUSTION INSTABILITY
- CONTamination

PROPULSION SYSTEM IMPROVEMENTS IN WORK

RSRM
- IGNITER-TO-CASE JOINT REDESIGN

SRB
- ENHANCED MULTIPLEXER/DEMULTIPLEXER
- DEBRIS CONTAINMENT SYSTEM FRANGIBLE LINK
- MAIN PARACHUTE RIPSTOP
- HDP/AFT SKIRT BIAS

SSME
- PHASE II + POWERHEAD
- HPOTP/HPFTP LIFE IMPROVEMENTS
- ALTERNATE TURBOPUMP DEVELOPMENT
- BLOCK II CONTROLLER
- SINGLE COIL HEAT EXCHANGER

ORBiter
- IMPROVED AUXILIARY POWER UNIT
- IMPROVED AUXILIARY POWER UNIT CONTROLLER
- IMPROVED MULTIPLEXER/DEMULTIPLEXER
ASA PROGRAM
DEFINITION

OBJECTIVE: EXTEND THE LIFE OF THE SPACE SHUTTLE PROGRAM TO THE YEAR 2020

BENEFITS: PLANS FOR OBSOLETEANCE, IMPLEMENTS CURRENT TECHNOLOGY
INCREASES SAFETY MARGINS
INCREASES MISSION SUCCESS PROBABILITY
MAINTAINS A HIGH LEVEL OF TECHNICAL EXCELLENCE
IMPROVES VEHICLE TURNAROUND AND OPERATIONS COSTS
DEVELOPS AND QUALIFIES ALTERNATE SOURCES

ASA PROGRAM
SELECTION METHODOLOGY

PROBLEM AREAS IDENTIFIED
CANDIDATES SUBMITTED
VIABLE CANDIDATES CATEGORIZED
FEASIBILITY STUDIES BEGUN ON SOME CANDIDATES
CANDIDATES BEING PRIORITIZED
ASA PROGRAM
PRIORITIES

PROGRAM PRIORITIES ESTABLISHED

PRIMARY: ASSURANCE OF SYSTEM SUPPORTABILITY AND SAFETY MARGIN IMPROVEMENT
SECONDARY: IMPROVEMENTS IN SYSTEM RELIABILITY, ECONOMY AND PERFORMANCE

ASA PROGRAM
CANDIDATES

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<td>INTEGRATED THERMAL CONTROL</td>
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<td>FWD SEGMENT MANDREL REDESIGN</td>
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<td>ALUMINUM LITHIUM ALLOYS</td>
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<td>ELECTROMECHANICAL ACTUATORS</td>
<td>ORB/SSME</td>
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ASA PROGRAM
CATEGORIES

A. HIGHEST PRIORITY
NEAR TERM SUPPORTABILITY ISSUES
SAFETY MARGIN INCREASES

B. HIGH PRIORITY-SYSTEMS IMPROVEMENTS WITH IMPLEMENTATION OPPORTUNITIES

C. OTHER IMPROVEMENTS WITH INDEFINITE SCHEDULE DRIVERS

D. IMPROVEMENTS WITH NO SCHEDULE DRIVER AND/OR HIGH PROGRAM RISK

ASA PROGRAM
PROPULSION PROGRAM CANDIDATES

SRB CONTROL SYSTEM REDESIGN
SSME ADVANCED FABRICATION
AFT SKIRT REDESIGN
INTEGRATED OMS/RCS
ASA PROGRAM
SRB CONTROL SYSTEM REDesign

DESCRIPTION:
REPLACE OBSOLETE ELECTRONIC CONTROL SYSTEMS (FORWARD & AFT IEA'S) WITH SINGLE INTEGRATED MICROPROCESSOR SYSTEM

ADD SOLID PROPELLANT APU GAS GENERATOR TO REPLACE HYDRAZINE SYSTEM

ADD NEW LASER INITIATED ORDNANCE TO REPLACE CURRENT SYSTEM

BENEFITS:
SMART INTEGRATED ELECTRONICS ASSEMBLIES (IEA) AND RANGE SAFETY DISTRIBUTER (RSD) CONTROLLERS AND LASER ORDNANCE CONTROLS ELIMINATES COMPONENTS, FAILURE MODES AND REDUCES COSTS

EXTERNALLY PROGRAMMABLE MICROPROCESSOR SYSTEM

HIGHER LAUNCH PROBABILITY FROM REDUCED WING LOADS DUE TO ELIMINATION OF AFT IEA PROTRUBERANCE

FIBER OPTIC DATA BUSES FOR BETTER COMMUNICATIONS

ELIMINATE ORDNANCE SYSTEM EMI CONCERNS WITH FIBER OPTIC LINES

ELIMINATE HYDRAZINE CONCERNS

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ASA PROGRAM
SRB AFT SKIRT REDESIGN

DESCRIPTION:
NEW AFT SKIRT, DESIGN TO:
- INCREASE STRUCTURAL FACTOR OF SAFETY (1.28 TO 1.4)
- ENHANCE HOLDDOWN MECHANISM
- ADD INTEGRAL STIFFENER RINGS TO MINIMIZE WATER IMPACT DAMAGE

BENEFITS:
SAFETY MARGIN ENHANCEMENT
ELIMINATE STUD HANGUP AND LAUNCH LOADS
REDUCTION IN WATER IMPACT DAMAGE
ASA PROGRAM
SSME ADVANCED FABRICATION

DESCRIPTION:

MAJOR REDESIGNS EMPLOYING ADVANCED FABRICATION AND CASTING TECHNIQUES TO RESOLVE MAJOR ISSUES:

- FINE GRAINED INVESTMENT CASTINGS
- VACUUM PLASMA SPRAY FOR MAIN COMBUSTION CHAMBER

BENEFITS:

IMPROVE THE INSPECTABILITY OF CRITICAL WELDS
ELIMINATE 3000 UNINSPECTABLE WELDS
REDUCE FABRICATION COSTS OF MAJOR COMPONENTS
INCREASE DESIGN PERFORMANCE MARGIN

ASA PROGRAM
INTEGRATED OMS/RCS

DESCRIPTION

REDESIGN SEPARATE OMS/RCS SYSTEMS INTO ONE INTEGRATED SYSTEM
ELIMINATE RCS TANKS/PRESSURIZATION SYSTEM
ALLOW OMS TANK PLUS ENTRY SUMP USE FOR BOTH OMS AND RCS PROPELLANT
IMPROVE ABORT DUMP CAPABILITY
ALLOW LANDING WITH INCREASED RESIDUAL PROPELLANT
INCREASE CHECKOUT/MAINTENANCE CAPABILITY WITH POD ON ORBITER

BENEFITS

IMPROVE SAFETY MARGIN
REDUCE COST
SIMPLIFIED MISSION PLANNING
350 LB DRY WEIGHT REDUCTION
RETAIN CONTRACTOR/SUBCONTRACTOR DESIGN/PRODUCTION SKILLS
THE SHUTTLE LIFE CYCLE CAN BE EXTENDED FROM 20 TO 40 YEARS

SIGNIFICANT BUDGET SAVINGS CAN BE REALIZED OVER A NEW SHUTTLE II

SUBSYSTEM MANDATORY UPGRADES FOR OBSOLESCENCE, SAFETY MARGIN,
AND PERFORMANCE IS REQUIRED TO EXTEND THE SHUTTLE LIFE

UPGRADE PROGRAMS WILL HAVE A DEDICATED MANAGEMENT SYSTEM

UPGRADES WILL BE TIMED FOR EFFICIENT IMPLEMENTATION
UPPER STAGES/PROPULSION