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)

152
RSRM DESIGN PARAMETERS

- AVERAGE VACUUM THRUST (WEB TIME): 2,590,000 LBS
- SPECIFIC IMPULSE (VACUUM): 267.9 SEC
- AREA RATIO ($A_e/A_t$): 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 (@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)

150 In. Diameter

524

480

384

125 in.

1,388 in.

1,513 in.
# ASRM Design Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Average Vacuum Thrust (Web Time)</td>
<td>624,031 LBS</td>
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<tr>
<td>Specific Impulse (Vacuum)</td>
<td>70.3 SEC</td>
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<tr>
<td>Area Ratio ((A_e/A_i))</td>
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<tr>
<td>Average Chamber Pressure</td>
<td>633 PSIA</td>
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<tr>
<td>Action Time</td>
<td>134.1 SEC</td>
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<tr>
<td>Motor Weight</td>
<td>1,345,807 LBS</td>
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<tr>
<td>Propellant Weight</td>
<td>1,205,807 LBS</td>
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<tr>
<td>Mass Fraction</td>
<td>8.96</td>
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<tr>
<td>Inert Weight: Case Nozzle</td>
<td>97,419 LBS</td>
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<tr>
<td>Inert Weight: Nozzle</td>
<td>18,947 LBS</td>
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<tr>
<td>Propellant Type</td>
<td>HTPB</td>
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<tr>
<td>Burn Rate (@625 PSIA)</td>
<td>0.345 IN/SEC</td>
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<tr>
<td>Thrust Vector Control</td>
<td>Flex Bearing</td>
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<tr>
<td>Case Material</td>
<td>9 Ni-4 Co-0.3C</td>
</tr>
<tr>
<td>Insulation Material</td>
<td>Kevlar-Glass-EPDM</td>
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</table>

# Space Shuttle Main Engine

**Purpose:**
Provide propulsive thrust from liftoff to orbit.

**Supplier:**
Rockwell International Rocketdyne Division, Canoga Park, CA.

![Diagram of Space Shuttle Main Engine](image-url)
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

OXYGEN/HYDROGEN

- 470,000 LBS
- 512,300 LBS
- 305,500 LBS
- 65% TO 109% (1% Increments)
- 3200 PSIA
- 6.03 : 1
- 453.5 SEC
- 973 LB/SEC
- 161 LB/SEC
- 7,000 LBS
- 27,000 SEC
- 55 STARTS
- 14,000 SEC
- 14 FEET
- 7.5 FEET
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 PROPELLSIVE THRUST FOR ORBIT INSERTION, ORBIT CIRCULARIZATION, ORBIT TRANSFER, RENDEZVOUS, DEORBIT, AND LAUNCH ABORT

SUPPLIER: AERJET PROPULSION DIVISION; SACRAMENTO, CA.

OMS ENGINE DESIGN PARAMETERS

- PROPELLANTS
  - MMH/N₂O₄
  - 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
- NOMINAL VACUUM THRUST
- CHAMBER PRESSURE
- MIXTURE RATIO
- SPECIFIC IMPULSE
- INLET PRESSURE
- RATIO (A_e/A_t)
- LIFE

<table>
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<tr>
<th>PRIMARY</th>
<th>VERNIER</th>
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<tbody>
<tr>
<td>PROPELLANTS</td>
<td>MMH/N_2O_4</td>
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<tr>
<td>NOMINAL VACUUM THRUST</td>
<td>870 LBS</td>
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<td>CHAMBER PRESSURE</td>
<td>152 PSIA</td>
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<td>MIXTURE RATIO</td>
<td>1.6</td>
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<td>SPECIFIC IMPULSE</td>
<td>280 SEC (22:1 AREA RATIO)</td>
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<tr>
<td>INLET PRESSURE</td>
<td>238 PSIA</td>
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<tr>
<td>RATIO (A_e/A_t)</td>
<td>22:1 TO 30:1</td>
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<tr>
<td>LIFE</td>
<td>MISSIONS 100</td>
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<tr>
<td></td>
<td>CYCLES 20,000</td>
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<tr>
<td></td>
<td>TOTAL FIRING DURATION 12,800 SEC</td>
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<td>WEIGHT 16 LBS</td>
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<td>CONSTRUCTION COLUMBIUM/TITANIUM</td>
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**ORBITER OMS & REACTION CONTROL SYSTEM**

- **Primary Thrusters (14 Forward, 12 per Alt Pod)**
  - Thrust Level: 8700 Pounds Vacuum
- **6 Verrier Thrusters (2 Forward, 4 Aft)**
  - Thrust Level: 24 Pounds Vacuum

- **Propellants:**
  - Nitrogen Tetroxide Oxidizer
  - Monomethyl Hydrazine Fuel
- **Nominal Forward RCS Full Load:**
  - 1477 Pounds Nitrogen Tetroxide
  - 928 Pounds Monomethyl Hydrazine
- **Nominal Alt RCS Full Load for Each Pod:**
  - 1477 Pounds Nitrogen Tetroxide
  - 825 Pounds Monomethyl Hydrazine

**NOTE:** Shaded areas part of orbital maneuvering system
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 OBSOLESCENCE, 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

TITLE
COCKPIT DISPLAYS AND CONTROLS
EPD&C SUBSYSTEM REDESIGN
CONTROL SYSTEM REDESIGN
INTEGRATED COMMUNICATIONS
AFT SKIRT REDESIGN
INTEGRATED OMS/RCS
REDESIGNED STIFFENER RING
IGNITER JOINT IMPROVEMENT
INTEGRATED NAVIGATION SYSTEM
PROCESS CHEMICALS
LONG-LIFE FUEL CELLS
COMPOSITE STRUCTURES
POWERHEAD UPGRADE
ENHANCED CONTROLLER
LIGHTWEIGHT STRUCTURES
INTEGRATED THERMAL CONTROL
FWD SEGMENT MANDREL REDESIGN
ALUMINUM LITHIUM ALLOYS
ELECTROMECHANICAL ACTUATORS

PROJECT
ORBITER
ORBITER
SRB
ORBITER
SRB
ORBITER
RSRM
ORBITER
RSRM
ORBITER
SSME
ORBITER
SRB
SSME
SSME
ORBITER
ORBITER
RSRM
ET
ORB/SSME
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