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
FOUR 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 ($A_e/A_t$) 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
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 NOZZLE**: 97,419 LBS, 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.
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 PROPELLSIVE 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 LBS - SEC
- MOTOR WEIGHT: 167 LBS
- PROPELLANT TYPE: HTPB
- CASE MATERIAL: 7075 AL
**Purpose:** Provides propulsive thrust for orbit insertion, orbit circularization, orbit transfer, rendezvous, deorbit, and launch abort.

**Supplier:** Aerojet Propulsion Division; Sacramento, CA.

**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 PROPELLSIVE THRUST FOR ORBIT STABILIZATION AND ORIENTATION MANEUVERS

**SUPPLIER:** THE MARQUARDT COMPANY, VAN NUYS, CA.

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**RCS PRIMARY & VERNIER THRUSTER PARAMETERS**

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<thead>
<tr>
<th>Parameter</th>
<th>PRIMARY</th>
<th>VERNIER</th>
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<tbody>
<tr>
<td>PROPELLANTS</td>
<td>MMH/N₂O₄</td>
<td>MMH/N₂O₄</td>
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<tr>
<td>NOMINAL VACUUM THRUST</td>
<td>870 LBS</td>
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<tr>
<td>CHAMBER PRESSURE</td>
<td>152 PSIA</td>
<td>110 PSIA</td>
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<td>MIXTURE RATIO</td>
<td>1.6</td>
<td>1.65</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>
<td>246 PSIA</td>
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<td>RATIO (Aₑ/A₁)</td>
<td>22:1 TO 30:1</td>
<td>20.7:1</td>
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<td>LIFE MISSIONS</td>
<td>100</td>
<td>CHAMBER LIMITED</td>
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<td>CYCLES</td>
<td>20,000</td>
<td>330,000</td>
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<tr>
<td>TOTAL FIRING DURATION</td>
<td>12,800 SEC</td>
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<tr>
<td>WEIGHT</td>
<td>16 LBS</td>
<td>9.4 LBS</td>
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<tr>
<td>CONSTRUCTION</td>
<td>COLUMBIUM/TITANIUM</td>
<td>COLUMBIUM/TITANIUM</td>
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*Note:* The images of the thrusters are not included in the text representation. The table includes the parameters for both the primary and vernier thrusters, with specific details for each category.
ORBITER OMS & REACTION CONTROL SYSTEM

38 Primary Thrusters (14 Forward, 12 per Aft Pod)
Thrust Level = 870 Pounds Vacuum
6 Vernier Thrusters (2 Forward, 4 Aft)
Thrust Level = 24 Pounds Vacuum

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

Left Aft RCS Pod
(Right Aft RCS Pod contains identical components)

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

PROPELLION 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 OBDOLENCE, 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
PRIORITYESTABLISHED

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>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 REDSIGN

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 BUSSES FOR BETTER COMMUNICATIONS

ELIMINATE ORDNANCE SYSTEM EMI CONCERNS WITH FIBER OPTIC LINES

ELIMINATE HYDRAZINE CONCERNS

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
ASA PROGRAM
SUMMARY

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