SPACE SHUTTLE PROPULSION SYSTEMS

SPACE TRANSPORTATION TECHNOLOGY SYMPOSIUM
PENNYSYLVANIA STATE UNIVERSITY

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

EXTERNAL TANK

ORBITER

TWO ORBIT MANEUVERING ENGINES

THREE MAIN ENGINES

FOUR BOOSTER SEPARATION MOTORS

FOUR RCS PRIMARY THRUSTERS
TWO RCS VERNIER THRUSTERS

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 in.
- 480 in.
- 384 in.
- 1,388 in.
- 125 in.
- 1,513 in.
ASRM DESIGN PARAMETERS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVERAGE VACUUM THRUST (WEB TIME)</td>
<td>624,031 LBS</td>
</tr>
<tr>
<td>SPECIFIC IMPULSE (VACUUM)</td>
<td>70.3 SEC</td>
</tr>
<tr>
<td>AREA RATIO ($A_e/A_t$)</td>
<td>7.54</td>
</tr>
<tr>
<td>AVERAGE CHAMBER PRESSURE</td>
<td>633 PSIA</td>
</tr>
<tr>
<td>ACTION TIME</td>
<td>134.1 SEC</td>
</tr>
<tr>
<td>MOTOR WEIGHT</td>
<td>1,345,807 LBS</td>
</tr>
<tr>
<td>PROPELLANT WEIGHT</td>
<td>1,205,807 LBS</td>
</tr>
<tr>
<td>MASS FRACTION</td>
<td>8.96</td>
</tr>
<tr>
<td>INERT WEIGHT: CASE NOZZLE</td>
<td>97,419 LBS</td>
</tr>
<tr>
<td>PROPELLANT TYPE</td>
<td>HTPB</td>
</tr>
<tr>
<td>BURN RATE (@625 PSIA)</td>
<td>0.345 IN/SEC</td>
</tr>
<tr>
<td>THRUST VECTOR CONTROL</td>
<td>FLEX BEARING</td>
</tr>
<tr>
<td>CASE MATERIAL</td>
<td>9 Ni-4 Co-0.3C</td>
</tr>
<tr>
<td>INSULATION MATERIAL</td>
<td>KEVLAR-GLASS-EPDM</td>
</tr>
</tbody>
</table>

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
3200 PSIA
7,000 LBS
27,000 SEC
14,000 SEC
55 STARTS
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 LB - 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.

- 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
- NOMINAL VACUUM THRUST
- CHAMBER PRESSURE
- MIXTURE RATIO
- SPECIFIC IMPULSE
- INLET PRESSURE
- RATIO (Ae/A1)
- LIFE
  - MISSIONS
  - CYCLES
  - TOTAL FIRING DURATION
- WEIGHT
- CONSTRUCTION

**PRIMARY**
- MMH/N2O4
- 870 LBS
- 152 PSIA
- 1.6
- 280 SEC (22:1 AREA RATIO)
- 238 PSIA
- 22:1 TO 30:1
- 100 MISSIONS
- 20,000 CYCLES
- 12,800 SEC
- 16 LBS
- COLUMBIUM/TITANIUM

**VERNIER**
- MMH/N2O4
- 24 LBS
- 110 PSIA
- 1.65
- 265 SEC
- 246 PSIA
- 20.7:1
- CHAMBER LIMITED
- 330,000
- 125,000
- 9.4 LBS
- COLUMBIUM/TITANIUM
ORBITER OMS & REACTION CONTROL SYSTEM

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

Left Alt OMS/RCS Pod
(Right Alt OMS/RCS Pod Contains Identical Components)

Propellants: Nitrogen Tetroxide Oxidizer
Monomethyl Hydrazine Fuel
Nominal Forward RCS Full Load
1,427 Pounds Nitrogen Tetroxide
928 Pounds Monomethyl Hydrazine
Nominal Alt RCS Full Load for Each Pod
1,427 Pounds Nitrogen Tetroxide
925 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

PROPELLION SYSTEM IMPROVEMENTS IN WORK

**RSRM**
- IGNITER-TO-CASE JOINT REDESIGN

**SRB**
- ENHANCED MUX/DEMUX
- 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 MUX/DEMUX
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

<table>
<thead>
<tr>
<th>TITLE</th>
<th>PROJECT</th>
</tr>
</thead>
<tbody>
<tr>
<td>COCKPIT DISPLAYS AND CONTROLS</td>
<td>ORBITER</td>
</tr>
<tr>
<td>EPD&amp;C SUBSYSTEM REDESIGN</td>
<td>ORBITER</td>
</tr>
<tr>
<td>CONTROL SYSTEM REDESIGN</td>
<td>SRB</td>
</tr>
<tr>
<td>INTEGRATED COMMUNICATIONS</td>
<td>ORBITER</td>
</tr>
<tr>
<td>AFT SKIRT REDESIGN</td>
<td>SRB</td>
</tr>
<tr>
<td>INTEGRATED OMS/RCS</td>
<td>ORBITER</td>
</tr>
<tr>
<td>REDESIGNED STIFFENER RING</td>
<td>RSRM</td>
</tr>
<tr>
<td>IGNITER JOINT IMPROVEMENT</td>
<td>RSRM</td>
</tr>
<tr>
<td>INTEGRATED NAVIGATION SYSTEM</td>
<td>ORBITER</td>
</tr>
<tr>
<td>PROCESS CHEMICALS</td>
<td>SSME</td>
</tr>
<tr>
<td>LONG-LIFE FUEL CELLS</td>
<td>ORBITER</td>
</tr>
<tr>
<td>COMPOSITE STRUCTURES</td>
<td>SRB</td>
</tr>
<tr>
<td>POWERHEAD UPGRADE</td>
<td>SSME</td>
</tr>
<tr>
<td>ENHANCED CONTROLLER</td>
<td>SSME</td>
</tr>
<tr>
<td>LIGHTWEIGHT STRUCTURES</td>
<td>ORBITER</td>
</tr>
<tr>
<td>INTEGRATED THERMAL CONTROL</td>
<td>ORBITER</td>
</tr>
<tr>
<td>FWD SEGMENT MANDREL REDESIGN</td>
<td>RSRM</td>
</tr>
<tr>
<td>ALUMINUM LITHIUM ALLOYS</td>
<td>ET</td>
</tr>
<tr>
<td>ELECTROMECHANICAL ACTUATORS</td>
<td>ORB/SSME</td>
</tr>
</tbody>
</table>

162
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 INTEGRADED 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

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