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

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

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)
ASRM DESIGN PARAMETERS

- Average Vacuum Thrust (Web Time) 624,031 LBS
- Specific Impulse (Vacuum) 70.3 SEC
- Area Ratio \( \frac{A_e}{A_t} \) 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.
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**

<table>
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<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>OXYGEN</td>
<td>470,000 LBS</td>
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<tr>
<td>HYDROGEN</td>
<td>512,300 LBS</td>
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<tr>
<td>Weight</td>
<td>7,000 LBS</td>
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<tr>
<td>Specific Impulse</td>
<td>453.5 SEC</td>
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<tr>
<td>Chamber Pressure</td>
<td>3200 PSIA</td>
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<td>Mixture Ratio</td>
<td>6.03 : 1</td>
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<td>Flow Rates</td>
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<tr>
<td>Oxygen</td>
<td>973 LB/SEC</td>
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<td>Hydrogen</td>
<td>161 LB/SEC</td>
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<tr>
<td>Throttle Range</td>
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<tr>
<td>Minimum Power Level (MPL)</td>
<td>305,500 LBS</td>
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<tr>
<td>Full Power Level (FPL)</td>
<td>512,300 LBS</td>
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<td>Weight</td>
<td>7,000 LBS</td>
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<tr>
<td>Design Life</td>
<td>27,000 SEC</td>
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<tr>
<td>Overall Height</td>
<td>14 FEET</td>
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<tr>
<td>Nozzle Diameter @ Exit</td>
<td>7.5 FEET</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.

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
- NOMINAL VACUUM THRUST
- CHAMBER PRESSURE
- MIXTURE RATIO
- SPECIFIC IMPULSE
- INLET PRESSURE
- RATIO (A_o/A_t)
- LIFE

<table>
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<tr>
<th>PRIMARY</th>
<th>VERNIER</th>
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<tr>
<td>MMH/N_2O_4</td>
<td>MMH/N_2O_4</td>
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<tr>
<td>870 LBS</td>
<td>24 LBS</td>
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<tr>
<td>152 PSIA</td>
<td>110 PSIA</td>
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<tr>
<td>1.6</td>
<td>1.65</td>
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<tr>
<td>280 SEC (22:1 AREA RATIO)</td>
<td>265 SEC</td>
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<tr>
<td>238 PSIA</td>
<td>246 PSIA</td>
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<tr>
<td>22:1 TO 30:1</td>
<td>20.7:1</td>
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<tr>
<td>100 MISSIONS</td>
<td>CHAMBER LIMITED</td>
</tr>
<tr>
<td>20,000 CYCLES</td>
<td>330,000</td>
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<tr>
<td>12,800 SEC</td>
<td>125,000</td>
</tr>
<tr>
<td>16 LBS</td>
<td>9.4 LBS</td>
</tr>
<tr>
<td>COLUMBIUM/TITANIUM</td>
<td>COLUMBIUM/TITANIUM</td>
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</table>
ORBITER OMS & REACTION CONTROL SYSTEM

38 Primary Thrusters (14 Forward, 12 per Aft Pod)
Thrust Level = 870 Pounds Vacuum
8 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

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
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 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 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
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