LIFE CYCLE COST BASED
PROGRAM DECISIONS

J. S. DICK
JUNE 26, 1990

• BACKGROUND
  - SPACE PROPULSION FACILITY ASSESSMENT TEAM
    FINAL REPORT

• CHANGES
  - ADVANCED LAUNCH SYSTEM
  - NATIONAL AEROSPACE PLANE
  - SPACE EXPLORATION INITIATIVE

• LIFE CYCLE COST ANALYSIS RATIONALE
• RECOMMENDATION TO PANEL
1983 - FACILITY ASSESSMENT TEAM

- CHARTER
- KEY ISSUES
- TEST FACILITY VARIABLES
- SCOPE
- LAUNCH VEHICLE PROPULSION PROGRAMS
- ORBITAL TRANSFER PROPULSION PROGRAMS
- SPECIALIZED VEHICLE PROPULSION PROGRAMS
- SPACE STATION AUXILIARY PROPULSION PROGRAMS

- LARGE ENGINE THRUST LEVEL - PROGRAMS & FACILITY NEEDS
  - DEFICIENCIES
- MEDIUM ENGINE THRUST LEVEL - PROGRAMS & FACILITY NEEDS
  - DEFICIENCIES
- LOW ENGINE THRUST LEVEL
- CONCENTRATE ON FACILITIES AT GOVERNMENT SITES
- CONCLUSIONS

ASSESSMENT TEAM CHARTER

ASSESS STATUS OF NATION'S LIQUID CHEMICAL SPACE PROPULSION TEST FACILITIES AND THEIR ADEQUACY TO SUPPORT CURRENT, NEAR-TERM, AND LONG-RANGE NATIONAL PROGRAM REQUIREMENTS.
KEY ISSUES

- What facilities are required?
- What facilities are available?
- What are the facility deficiencies?
- How can the deficiencies be accommodated?
- What is the proper balance between government and contractor facilities?
- Why similar facilities?

LIQUID CHEMICAL SPACE PROPULSION TEST FACILITY VARIABLES

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>RANGE/SCOPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>THRUST (LBS.)</td>
<td>MINI ($10^1$) LOW ($10^3$) MODERATE ($10^4$) LARGE ($10^6$)</td>
</tr>
<tr>
<td>RUN TANKAGE</td>
<td>CRYOGENIC MEDIA VOLUME PRESSURE</td>
</tr>
<tr>
<td>PRESSURANT</td>
<td>MEDIA CAPACITY PRESSURE</td>
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<tr>
<td>TEST PRESSURE</td>
<td>SEA LEVEL ALTITUDE</td>
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<tr>
<td>DATA ACQUISITION</td>
<td>NO. CHANNELS ANALOG/DIGITAL MODERNIZATION PLANS</td>
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<tr>
<td>SYSTEM LEVEL</td>
<td>COMPONENTS ENGINES PROPULSION SYSTEMS STAGES</td>
</tr>
<tr>
<td>DUTY CYCLE</td>
<td>MIN./MAX. BURN DURATION THRUST RANGE MISSION DURATION</td>
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### LAUNCH VEHICLE PROPULSION PROGRAMS

<table>
<thead>
<tr>
<th>Year</th>
<th>Launch Vehicles (Earth-to-LEO)</th>
<th>Propulsion Systems</th>
<th>Orbital Transfer Propulsion Programs</th>
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<tr>
<td>1980</td>
<td>Expendables Space Shuttle</td>
<td>SSME Technology/Development/Upgrading/FLT. Support</td>
<td>CENTAUR Modular OTV AERO-ASSIST OTV HANDED OTV ADVANCED OTV</td>
</tr>
<tr>
<td>1990</td>
<td>Shuttle Derived Cargo Vehicle</td>
<td>ADV. O₂/H₂ Technology SUBSCALE TECHNOLOGY DEVELOPMENT FLT. SUPPORT</td>
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<tr>
<td>2000</td>
<td>ADV. O₂/HC Technology SUBSCALE TECHNOLOGY DEVELOPMENT FLT. SUPPORT</td>
<td>ADV. EXPANDER TECHNOLOGY DEVELOPMENT FLT. SUPPORT</td>
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<td>2010</td>
<td>Advanced Launch Vehicle Heavy Lift Launch Vehicle</td>
<td>DUAL FUEL TECHNOLOGY SUBSCALE TECHNOLOGY DEVELOPMENT FLT. SUPPORT</td>
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### ORBITAL TRANSFER PROPULSION PROGRAMS

<table>
<thead>
<tr>
<th>Year</th>
<th>Orbital Transfer Vehicles</th>
<th>Propulsion Systems</th>
<th>AUX. Propulsion</th>
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<tr>
<td>1980</td>
<td>CENTAUR Modular OTV AERO-ASSIST OTV HANDED OTV ADVANCED OTV</td>
<td>O₂/H₂ RL-10 A-3-3A PIP/DEVELOPMENT DEVELOP./FLT. SUPPORT</td>
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<tr>
<td>1990</td>
<td></td>
<td>ADV. EXPANDER TECHNOLOGY DEVELOPMENT FLT. SUPPORT</td>
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<td>2000</td>
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<td>2010</td>
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<td>DEVELOPMENT TECH. DEVELOPMENT FLT. SUPPORT</td>
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</table>
# LARGE ENGINE THRUST LEVEL

## SYSTEM LEVEL SUMMARY

<table>
<thead>
<tr>
<th>GENERIC ENGINES</th>
<th>LOCATION</th>
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<tbody>
<tr>
<td></td>
<td>AFRPL</td>
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<tr>
<td>SSME (CURRENT BASELINE)</td>
<td>N/A</td>
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<tr>
<td>TECHNOLOGY TEST BED</td>
<td>←  NONE REQUIRED  →</td>
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<tr>
<td>HORIZONTAL TEST</td>
<td>TS1-56 ***</td>
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<tr>
<td>ADVANCED O₂/H₂</td>
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<tr>
<td>DUAL FUEL</td>
<td>N/A</td>
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</table>

* Minor deficiencies (structural, piping or system)

** Moderate deficiencies (structural, piping or system plus upgrade fuel system)

*** Major deficiencies (structural, piping or system plus lack fuel capability)
### LARGE ENGINE THRUST LEVEL

#### ENGINE LEVEL SUMMARY

<table>
<thead>
<tr>
<th>GENERIC ENGINE</th>
<th>LOCATIONS</th>
<th>ROCKETDYNE</th>
<th>MSFC</th>
<th>NSTL</th>
<th>AEDC</th>
<th>AFRPL</th>
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<tbody>
<tr>
<td>SSME Baseline</td>
<td></td>
<td>A-3</td>
<td>N/A</td>
<td>A-1</td>
<td>A-2</td>
<td>N/A</td>
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<td>SSME Technology Test Bed</td>
<td></td>
<td>A-3</td>
<td>S-1C **</td>
<td>A-1</td>
<td>B-1 **</td>
<td>J-4 **</td>
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<tr>
<td>SSME Upgrading</td>
<td></td>
<td>A-3  ***</td>
<td>S-1C ***</td>
<td>A-1</td>
<td>B-1 **</td>
<td>J-4 *</td>
</tr>
<tr>
<td>• Altitude Test</td>
<td></td>
<td>A-3</td>
<td>S-1C **</td>
<td>A-2</td>
<td>B-2 **</td>
<td>J-4 **</td>
</tr>
<tr>
<td>• Sea Level Test (Vert)</td>
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<td>A-3</td>
<td>S-1C **</td>
<td>A-2</td>
<td>B-2 **</td>
<td>J-4 **</td>
</tr>
<tr>
<td>• Sea Level Test (Horiz.)</td>
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<td>A-3</td>
<td>S-1C **</td>
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<td>B-2 **</td>
<td>J-4 **</td>
</tr>
<tr>
<td>Advanced O₂/H₂</td>
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<td>B-2 **</td>
<td>J-4 **</td>
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<tr>
<td>Advanced O₂/Hc</td>
<td></td>
<td>A-3  ***</td>
<td>S-1C *</td>
<td>A-2</td>
<td>B-2 **</td>
<td>J-4 **</td>
</tr>
<tr>
<td>Dual Fuel</td>
<td></td>
<td>A-3  ***</td>
<td>S-1C *</td>
<td>A-2</td>
<td>B-2 **</td>
<td>J-4 **</td>
</tr>
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</table>

### LARGE ENGINE THRUST LEVEL

#### COMPONENT LEVEL SUMMARY

<table>
<thead>
<tr>
<th>GENERIC ENGINES</th>
<th>COMBUSTION DEVICES (GAS GENERATORS, PRE-BURNERS, TURBINE BLADES, HEAT EXCHANGERS, THRUST CHAMBERS, NOzzles)</th>
<th>BEARINGS</th>
<th>TURBOPUMPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>O₂/H₂</td>
<td>MSFC * ROCKETDYNE</td>
<td>MSFC</td>
<td>ROCKETDYNE</td>
</tr>
<tr>
<td>O₂/Hc</td>
<td>MSFC * ROCKETDYNE</td>
<td>MSFC</td>
<td>ROCKETDYNE</td>
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</tbody>
</table>

* Minor Deficiencies (Structural, Piping or System)

** Moderate Deficiencies (Structural, Piping or System plus upgrade fuel system)

*** Major Deficiencies (Structural, Piping or System plus lacks fuel capability)

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LARGE ENGINE THRUST LEVEL  
DEFICIENCY #1 - SSME TEST STANDS

**Requirement:** SSME test operations require maintaining more than two active test stands to support (1) the production program (including engine rebuilds), (2) solving current engine problems, (3) the engine product improvement program, (4) an SSME technology test bed, and (5) the need to maintain sufficient test positions to protect the on-going STS operational program.

**Facility deficiency:** Planned closing of Rocketdyne's (RKD's) A-3 test position leaves only NSTL A-1 and A-2.

**Options for additional test stands:**

<table>
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<tr>
<th>Option</th>
<th>Pro</th>
<th>Con</th>
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</thead>
<tbody>
<tr>
<td>Retain RKD A-3</td>
<td>Existing operation.</td>
<td>Operating cost.</td>
</tr>
<tr>
<td>Activate NSTL B-2 or B-1 for single engine testing</td>
<td>Active LOX/LH₂ test site.</td>
<td>Initial facility investment cost (low).</td>
</tr>
<tr>
<td>Activate MSFC S-IC for single engine testing</td>
<td>Develop &amp; maintain in-house engineering expertise &amp; capability.</td>
<td>Initial facility investment cost (moderate).</td>
</tr>
<tr>
<td></td>
<td>Low operating cost.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Cost shared with A-1/A-2).</td>
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</table>

**Recommendation:**

- A comparative study be made immediately of the above options to determine the number and location of test stands considering the proposed phase-out of RKD's A-3 test stand and the requirement to implement an SSME technology test bed. (A joint OSF/OAST study).

- Preserve NSTL B-2 test position in current configuration until comparative study is complete and final decision is made.
LARGE ENGINE THRUST LEVEL
DEFICIENCY #2 - HORIZONTAL SSME TESTING

REQUIREMENT: HORIZONTAL ORBIT-ON-DEMAND CONCEPTS REQUIRE RAPID ENGINE START-UP AND OPERATION IN HORIZONTAL POSITION.

FACILITY DEFICIENCY: HORIZONTAL TEST POSITION FOR SSME/SSME DERIVATIVE ENGINE 1990.

OPTIONS:

- RXD A-3
  - DEVELOPMENT ENGR. SUPPORT
  - INVESTMENT COST FOR MODS.
- HSFC S-1C
  - DEVELOPMENT ENGR. SUPPORT
  - INVESTMENT COST FOR MODS AND REACTIVATION.
- HSTL A-1/A-2
  - LOW OPERATING COST (SHARED FACILITY):
  - INVESTMENT COST FOR MODS.
  - INVESTMENT COST TO ADD LH2 CAPABILITY AND REACTIVATION.
- RPL I-56
  - EXISTING HORIZONTAL TEST SITE

RECOMMENDATION:

- CONTINUAL REVIEW OF ORBIT-ON-DEMAND REQUIREMENTS, INITIATE A FACILITY STUDY TRADE #1985/6.

DEFICIENCY #3 - MSFC "BACKYARD CAPABILITY" 

REQUIREMENT: ADEQUATE SPECIALIZED "BACKYARD" FACILITIES ARE REQUIRED TO ENABLE MSFC TO ACCOMPLISH LEAD ROLE IN COMPONENT LEVEL TESTING FOR SSME AND ADVANCED ENGINE TECHNOLOGY DEVELOPMENT. SPECIFICALLY: (1) LH2 TESTING OF LARGE BEARINGS 50 MM, WITH RADIAL AND AXIAL LOAD AT SPEEDS 40,000 RPM AND (2) HIGH PRESSURE 3500 PSI O2/H2 TESTING OF TURBINE DRIVE COMBUSTION TECHNOLOGY, ADVANCED CHAMBER COMBUSTION TECH, EXHAUST PLUME ANALYSIS.

FACILITY DEFICIENCY: 1) NO H2 TEST OPERATION PERMITTED AT MSFC's BEARING TEST STAND, TP-500, UNTIL A PRESSURIZED TERMINAL ROOM IS CONSTRUCTED. (SAFETY ISSUE)
2) CURRENT IDENTIFIED WORK LOAD FOR HI PRESS O2/H2 TESTING REQUIRES TWO TEST POSITIONS - ONLY ONE AVAILABLE (TP 116). THEREFORE, TECHNOLOGY TEST PROGRAMS ARE DELAYED AND/OR DEFERRED TO ACCOMMODATE SPECIFIC ON-GOING PROGRAM DEVELOPMENT ACTIVITIES (SSME TURBINE BLADE TEST) OR UNSCHEDULED ANOMALY RESOLUTIONS (STS OVERPRESSURE PROBLEM).

OPTIONS:

- MSFC TP 500 & 115
  - DEVELOP & MAINTAIN IN-HOUSE TECHNICAL EXPERTISE CONSISTENT WITH ETO ENGINE DEV. ROLE.
  - NONE
  - IMPROVED CAPABILITY FOR ANOMALY RESOLUTION.
  - EXISTING SUPPORTING FACILITIES ARE AVAILABLE.
  - LOW OPERATIONAL COST.

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LARGE ENGINE THRUST LEVEL
DEFICIENCY #3 (CONT'D.)

OPTIONS (CONT'D.):

• OTHER GOVERNMENT SITES.
• CONTRACTOR SITES.

PRO

• NONE.
• EXPAND INDUSTRY BASE AT ONE CONTRACTOR (PROBABLY RKD.)

CON

• BASIC TEST CAPABILITY DOES NOT EXIST.
• INVESTMENT COST SIGNIFICANT.
• OPERATING COST.

RECOMMENDATION:

IMPLEMENT FY 1985 CON MODIFICATION FOR MSFC'S TP 500 & 115.

LARGE ENGINE THRUST LEVEL

ISSUE #4 - ENVIRONMENTALLY COMPLIANT TEST SITES

REQUIREMENT: ADEQUATE ETO ENGINE AND SYSTEM LEVEL TEST SITES ARE REQUIRED TO MEET NATIONAL NEEDS. THEY MUST COMPLY WITH ENVIRONMENTAL REQUIREMENTS.

FACILITY CONCERN: ENVIRONMENTAL CONSTRAINTS LIKELY TO INCREASE FOR TEST SITES LOCATED ADJACENT TO POPULATED AREAS CURRENTLY EXPERIENCING ENVIRONMENTAL CONSTRAINTS ON ENGINE LEVEL TEST AT SEVERAL TEST SITES, E.G. ROCKETDYNE AT SANTA SUZANNA RESTRICTED TO TEST OPERATIONS DURING DAY LIGHT HOURS.

OPTIONS:

• RELOCATE RKD A-3 TEST OPERATIONS.
• PROTECT BUFFER ZONE AT ISOLATED TEST SITES.

PRO

• ELIMINATES ENVIRONMENTAL PROBLEMS.
• PROTECTS CRITICAL NATIONAL ASSET.

CON

• REQUIRES ALTERNATE SITE.
• LOCAL PRESSURE FOR LAND USE.

RECOMMENDATION:

PROTECT NSTL BUFFER ZONE AND PRESERVE OTHER EXISTING GOVERNMENT REMOTE TEST SITES (MSFC).
LARGE ENGINE THRUST LEVEL
DEFICIENCY #5 - LOX/HYDROCARBON TEST SITE

REQUIREMENT:  ADVANCED EARTH TO ORBIT TRANSPORTATION SYSTEMS WILL REQUIRE THE DEVELOPMENT OF LARGE HYDROCARBON AND/OR DUAL FUEL ENGINES & H2 PC. TEST AT ALTITUDE CONDITION MAY BE REQUIRED.

FACILITY DEFICIENCY:  NO FACILITY HAS CAPABILITY TO MEET BOTH PROPELLANT AND ALTITUDE REQUIREMENTS.

OPTIONS:

- GOV'T. TEST SITES: AEDC, MSFC, NSTL, RPL.
- CONTRACTOR TEST SITES: AEROJET, PRATT, RKD.

PRO
- BUILDS ON EXISTING OPERATIONAL BASE.
- MAINTAIN INDUSTRY CAPABILITY.

CON
- INVESTMENT COST.
- INVESTMENT COST.
- COST OF OPERATION.

RECOMMENDATION:
INITIATE A TECHNICAL FEASIBILITY/FACILITY TRADE STUDY IN 1984 TO ESTABLISH A TEST PHILOSOPHY, i.e., ENGINE/COMPONENT TEST BED VIS-A-VIS COMPONENT LEVEL TESTING, TO SUPPORT A COF PER IN FY 1987.

LARGE ENGINE THRUST LEVEL
DEFICIENCY #6 - ADVANCED ENGINE TURBOPUMP TESTING

REQUIREMENT:  ADVANCED O2/H2, O2/HC AND/OR DUAL FUEL EARTH TO ORBIT ENGINES REQUIRE TURBOPUMP TESTING.

FACILITY DEFICIENCY:  EXISTING CONTRACTOR FACILITY HAS NOT SATISFACTORY DEMONSTRATED THIS CAPABILITY. TEST POSITION IS PROJECTED TO BE CLOSED BY 1986 AND CRITICAL HIGH PRESSURE TANKAGE LIKELY TO BE MOVED TO OTHER LOCATIONS. NO ALTERNATE GOV'T. TEST POSITION EXISTS.

OPTIONS:

- RKD A-3
- MSFC
- HSTL
- TEST BED ENGINE

PRO
- CURRENTLY EXISTING FACILITY.
- SUPPORTS ETO DEVELOPMENT RESPONSIBILITY.
- UTILIZES EXISTING PROPELLANT SUPPLY FACILITIES.
- MAY BE ONLY PRACTICAL SOLUTION AT REASONABLE COST.

CON
- FACILITY LIKELY TO BE CLOSED IN SPITE OF THIS REQUIREMENT.
- OPERATIONS COST.
- INITIAL INVESTMENT COST.
- INITIAL INVESTMENT COST.
- TURBOPUMP TESTS MUST BE ACCOMPLISHED IN CONJUNCTION WITH ENGINE SYSTEM TESTS.
RECOMMENDATION:

CONDUCT TRADE STUDY TO ESTABLISH TECHNICAL FEASIBILITY AND COST ESTIMATES FOR TURBOPUMP TEST METHOD TO SUPPORT AN FY 1987 CoF PROJECT. THIS STUDY SHOULD BE INITIATED AS AN INTEGRAL PART OF THE PRIOR ENGINE ISSUE.

CATEGORIZATION OF GOVERNMENT FACILITIES

I. ACTIVE - IN CURRENT USE.

II. RETAIN IN CURRENT STATUS FOR POTENTIAL FUTURE USE
   - NOT UNIQUELY REQUIRED BY VEHICLE MODEL.
   - ASSET OF POTENTIAL VALUE TO FUTURE PROGRAM.
   - COSTLY TO DUPLICATE, CONTAIN EXPENSIVE, LONG-LEAD HARDWARE.
   - STANDBY - MAINTAIN TO PERMIT RAPID ACTIVATION.
   - DOWNMODE - MAINTAIN AT MINIMUM LEVEL TO ARREST DETERIORATION.

III. RETAIN AS A SOURCE OF HARDWARE
    - NOT REQUIRED BY VEHICLE MODEL.
    - CONTAIN EXPENSIVE, LONG-LEAD HARDWARE.

IV. INDICATE TO CONTROLLING GOVERNMENT ORGANIZATION THAT FACILITY RETENTION FOR PROPULSION PURPOSES CANNOT BE JUSTIFIED
    - NOT REQUIRED BY VEHICLE MODEL.
    - INCLUDE FACILITIES AT NASA, DOD, AND DOE LOCATIONS AND GOVERNMENT FACILITIES AT CONTRACTOR LOCATIONS.
### MEDIUM ENGINE THRUST LEVEL - ENGINE CHARACTERISTICS

<table>
<thead>
<tr>
<th>Throat Diameter</th>
<th>Thrust (Full/Low, LBS.)</th>
<th>Pc (PSIA)</th>
<th>Expansion Ratio</th>
<th>Duration Class (Sec.)</th>
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<tbody>
<tr>
<td><strong>O₂H₂</strong></td>
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<tr>
<td>RL-10 II B</td>
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<td>205</td>
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<td>ADV Expanders</td>
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<td><strong>N₂O₄/MMH</strong></td>
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<td><strong>O₂/H₂</strong></td>
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<td>ADV OMS</td>
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### MEDIUM ENGINE THRUST LEVEL - ENGINE LEVEL TEST CAPABILITY

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<thead>
<tr>
<th>FACILITY</th>
<th>AEDC</th>
<th>RPL</th>
<th>GSFC</th>
<th>JPL</th>
<th>JSC</th>
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<tbody>
<tr>
<td><strong>O₂/H₂</strong></td>
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* FULL EXISTING CAPABILITY
A EXIST. ALTITUDE CAPABILITY
P EXIST. PROPELLANT SYSTEM
S TEST STAND IN PLACE
### MEDIUM ENGINE THRUST LEVEL

**DEFICIENCY #1 - ENGINE ALTITUDE TESTING**

**REQUIREMENT:**

Very high expansion ratio (E) engines are required for future high performance OTV's (mid-1990's) and for ETO vehicles orbit maneuvering systems (OMS) (post 2000)

- RL-10B (PRODUCT IMPROVEMENT PROGRAM (PIP)) NEED DATE: 1986
- ADV EXPANDER NEED DATE: 1989

**DEFICIENCY:**

Capability to test high E dual thrust engines through full mission duty cycles currently exists only at AEDC J-4.

**OPTIONS:**

- **MODIFY P&W TEST STAND E-6**
  - **PRO:** ALLOWS CURRENT SCHEDULE
  - **CON:** NOT AVAILABLE TO OTHER CONTRACTORS

- **USE AEDC J-4 FOR ALL HIGH E TESTING**
  - **PRO:** NO COF FUNDING REQUIRED
  - **CON:** VERY HIGH OPERATING COSTS (CHARGES)

- **MODIFY OTHER GOVERNMENT FACILITY (AEDC J-3, WSTF, LeRC, HSFC, NSTL)**
  - **PRO:** COST EFFECTIVE LONG-TERM SOLUTION
  - **CON:** SINGLE POINT FAILURE

---

**ENGINE CLASS**

<table>
<thead>
<tr>
<th>Engine Class</th>
<th>Pump Fed</th>
<th>Bearing Testers</th>
<th>Turbo Pumps</th>
<th>Thrust Chambers</th>
<th>Nozzles</th>
<th>Engine Test Altitude</th>
<th>Stage Test Altitude</th>
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<td>O₂N₂</td>
<td>GOV'T</td>
<td>LeRC</td>
<td>LeRC MSFC</td>
<td>LeRC MSFC</td>
<td>AEDC J-4</td>
<td>AEDC AFRPL WSTF</td>
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<td>R/D AFRPL</td>
<td>AFRPL LeRC</td>
<td>AFRPL J-3</td>
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<td>AEDC AFRPL WSTF</td>
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**1004**
**MEDIUM ENGINE THRUST LEVEL**
**DEFICIENCY #1 (CONT'D.)**

**RECOMMENDATION:**
- ACCOMMODATE NEAR TERM TEST REQUIREMENTS (RL-10 IIB PIP) AT AEDC J-4.
- CONDUCT TRADE STUDY TO DETERMINE MOST COST/SCHEDULE EFFECTIVE LOCATION FOR PERMANENT HIGH ALTITUDE TEST FACILITY(S), WHICH CAN ALSO ACCOMMODATE HIGH E NOZZLE TESTING.
- COMPLETE STUDY IN TIME TO IMPACT FY 86 CoFF (COULD MEET RL-10 IIB PIP REQUIREMENTS, IF DELAYED).

**MEDIUM ENGINE THRUST LEVEL**
**ISSUE #1 - ENGINE TESTING**

**CONSIDERATION OF POTENTIAL FACILITIES**

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<thead>
<tr>
<th>MINOR MODS</th>
<th>MODERATE MODS</th>
<th>MAJOR</th>
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<td>AEDC (J-3)</td>
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1005
MEDIUM ENGINE THRUST LEVEL
DEFICIENCY #2 - NOZZLE TESTING

REQUIREMENT:
HIGH EXPANSION RATIO (ë) ENGINES REQUIRED FOR FUTURE HIGH PERFORMANCE OTV’S (MID-1990’S) AND ETO VEHICLE ORBIT MANEUVERING SYSTEMS (OMS) (POST 2000)

DEFICIENCY:
CAPABILITY TO TEST HIGH ë NOZZLES AT ALTITUDE WITH PRESSURE FED THRUST CHAMBERS DOES NOT EXIST AT ANY TEST FACILITY - INITIAL NEED DATE (R&T): 1988

OPTIONS:
PRO
CON

• PROVIDE HIGH PRESSURE TANKAGE TO AEDC (J-3) OR WSTF
  PROVIDES REQUIRED CAPABILITY
  COST OF HIGH PRESSURE TANKS

• TEST AT ENGINE LEVEL AT GOVERNMENT FACILITY.
  LOW PRESSURE TANKS IN PLACE OR AVAILABLE
  PUMP LIFE/MAINT./CONTROL

• TEST SUBSCALE HARDWARE AT LERC, ALRC, RKD
  IN-PLACE CAPABILITIES
  EXTRAPOLATION OF RESULTS TO FULL SCALE NOZZLES

RECOMMENDATION:
CONDUCT STUDY IN CONJUNCTION WITH ENGINE SYSTEM TEST FACILITY OPTIONS TO DEVELOP MOST COST EFFECTIVE SOLUTION

MEDIUM ENGINE THRUST LEVEL
ISSUE #2 - NOZZLE TESTING

CONSIDERATION OF POTENTIAL FACILITIES

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<tr>
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<td>E.G., ALTITUDE SYSTEM</td>
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1006
MEDIUM ENGINE THRUST LEVEL
DEFICIENCY #3 - TURBOMACHINERY TESTING

REQUIREMENT: DEVELOP TECHNOLOGY FOR HIGH PRESSURE, HIGH SPEED TURBOPUMPS REQUIRED FOR HIGH PERFORMANCE OTV ENGINES (MID-1990'S) AND ORBIT MANEUVERING SYSTEM ENGINES (POST 2000).

DEFICIENCY:
- NO GOVERNMENT CAPABILITY EXISTS AT REQUIRED PressURES AND Speeds
- CONTRACTOR CAPABILITY EXISTS ONLY AT ROCKETDYNEx

OPTIONS:

<table>
<thead>
<tr>
<th>PRO</th>
<th>CON</th>
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<tbody>
<tr>
<td>• RELY ON RKD FOR TECHNOLOGY AND DEVELOPMENT</td>
<td>• MINIMUM INVESTMENT</td>
</tr>
<tr>
<td>• PROVIDE CAPABILITY WITHIN GOVERNMENT</td>
<td>• PROVIDES EXPERTISE THRU NONE &quot;BACKYARD&quot; Capability</td>
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CONSIDERATION OF POTENTIAL FACILITIES

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<thead>
<tr>
<th>MINOR MODS</th>
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<td>JSC-TTA</td>
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<tr>
<td>ALRC</td>
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<td>P&amp;H</td>
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<tr>
<td>RKD</td>
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RECOMMENDATION: FUND FY 85 LERC CoF SUBMISSION TO SUPPORT LERC'S R&T RESPONSIBILITY.
MEDIUM ENGINE THRUST LEVEL

DEFICIENCY #4 - BEARING TESTER

ISSUE

REQUIREMENTS:

ADV HIGH PRESSURE PUMP-FED H₂O₄/MMH ENGINES REQUIRED FOR FUTURE HIGH PERFORMANCE OTV'S AND FOR ETO VEHICLE ORBIT MANEUVERING SYSTEMS (OMS) BY MID-1990'S

DEFICIENCY:

CAPABILITY TO TEST SMALL, HIGH SPEED H₂O₄ AND MMH BEARINGS DOES NOT EXIST AT ANY GOVERNMENT FACILITY--ONLY AT ROCKETDYNE

OPTIONS:

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<th>PRO</th>
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<tr>
<td>PROVIDE CAPABILITY AT LERC OR AFRPL</td>
<td>AVAILABLE TO TEST ALL CONTRACTOR DESIGNS.</td>
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<td>MINIMUM EXPENSE TO INSTALL</td>
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RECOMMENDATION:

PROVIDE CAPABILITY AT LERC OR AFRPL FOR BEARING R&T (NEED DATE: 1985)

OAST AND AFRPL DETERMINE BEST LOCATION PRIOR TO JAN, 1984.

MEDIUM ENGINE THRUST LEVEL

ISSUE #4 - BEARING TESTER

CONSIDERATION OF POTENTIAL FACILITIES

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<tr>
<td>System Technology</td>
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</table>
SCHEDULE SUMMARY

- All planned vehicles require engines in the 2000 lbs or less class
  - 13 new engine developments required.
- All planned new vehicles (17 total) require new systems (which involve system level tests) between 1983 and 2010.
- In 1985 - 1990 time period:
  11 new engine developments
  8 new systems
- These programs will result in significant facility test loads.

LOW ENGINE THRUST LEVEL
SUMMARY ASSESSMENT

<table>
<thead>
<tr>
<th>ENGINE CLASS</th>
<th>ASSESSMENT</th>
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<tbody>
<tr>
<td>BIPROP STORABLE</td>
<td>• No deficiency.</td>
</tr>
<tr>
<td>2K &amp; LESS</td>
<td>• Multiple government &amp; industry sites available.</td>
</tr>
<tr>
<td></td>
<td>• Currently underutilized - several already inactive.</td>
</tr>
<tr>
<td>MONOPROP (N_2H_4)</td>
<td>• No deficiency.</td>
</tr>
<tr>
<td>100 &amp; LESS</td>
<td>• Multiple government &amp; industry sites available.</td>
</tr>
<tr>
<td>(O_2/H_2)</td>
<td>• Two contractors with capability (Aerojet and Rocketdyne).</td>
</tr>
<tr>
<td>2K &amp; LESS</td>
<td>• Inadequate capability at government sites.</td>
</tr>
<tr>
<td>HIGH ENERGY (LF_2)</td>
<td>• No deficiency.</td>
</tr>
<tr>
<td>2K &amp; LESS</td>
<td>• Government &amp; industry site available.</td>
</tr>
<tr>
<td></td>
<td>• Currently inactive but capability should be retained.</td>
</tr>
</tbody>
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1010
LOW ENGINE THRUST LEVEL
CLASSIFICATION OF GOV'T. FACILITIES

SIGNIFICANT DIFFERENCES IN SUITABILITY FOR LOW THRUST ENGINES DUE TO SIZE, PRIMARY FUNCTION, CENTER ROLE AND FACILITY CHARTER.

- TECHNOLOGY DEVELOPMENT (R&T)
  - LERc
  - RPL
- FLIGHT PROGRAM SUPPORTING DEVELOPMENT ("BACKYARD")
  - JSC - TTA
  - MSFC
  - JPL *
- GOVERNMENT-OWNED TEST SERVICE SITES
  - JSC - WSTF
  - NSTL
  - AEDC
  - JPL *
- CURRENTLY UNDERUTILIZED FOR PROGRAM SUPPORT AND IS BIDDING FOR USE AS A TEST SERVICE SITE.

LOW ENGINE THRUST LEVEL
RATIONALE FOR EXISTENCE OF SIMILAR GOV'T. FACILITIES

- TECHNOLOGY DEVELOPMENT (R&T)
  - PROVIDE TECHNICALLY COMPETENT PROCUREMENT & MANAGEMENT OF CONTRACTED R&T PROGRAMS.
  - PROVIDE COMPARATIVE EVALUATION OF COMPETING CONCEPTS.
  - ALLOW INNOVATIVE IDEAS TO BE EXPLORED AT LOW COSTS.
  - PERFORM IN-HOUSE R&T.
- FLIGHT PROGRAM SUPPORTING DEVELOPMENT (BACKYARD)
  - PROVIDE TECHNICALLY COMPETENT PROCUREMENT & MANAGEMENT OF CONTRACTED FLIGHT HARDWARE PROGRAMS.
  - PROVIDE REAL-TIME ENGINEERING INVESTIGATIVE SUPPORT.
  - ASSIST IN DEVELOPMENT & REFINEMENT OF MISSION RULES & CONTINGENCY PROCEDURES.
- GOVERNMENT OWNED TEST SERVICE SITES
  - PREVENTS REQUIRING CONTRACTORS TO HAVE FULL-UP FACILITIES IN ORDER TO BE COMPETITIVE. USE AS REQUIRED TO PREVENT BUILDING OF NEW FACILITIES AT NON-GOVERNMENT SITE.
RECOMMENDATIONS

$O_2/H_2$ DEFICIENCIES AT GOVERNMENT SITE

- TECHNOLOGY DEVELOPMENT (R&T)
  
  **LERC**
  
  - IMPLEMENTATION OF APPROVED FY 1984 CoF ($995K) AT LERC WILL INCREASE TOTAL CAPABILITY FROM NONE TO ONE HOUR DURATION.
  - **RECOMMEND CONTINUE.**

  **RPL**
  
  - IMPLEMENTATION OF REQUESTED FY 1985 MCP ($5M) AT RPL TO INCREASE ALTITUDE DURATION CAPABILITY FROM 15 MIN. TO 5 HOURS.
  - **RECOMMEND CONSIDER USE OF JPL IN LIEU OF MOD AT RPL (CAPABILITY REQUIRED).**

- FLIGHT PROGRAM SUPPORTING DEVELOPMENT ("BACKYARD")
  
  **JSC**
  
  - NO CRYO ENGINE CAPABILITY AT ALL AT TTA - UNDERSUPPORTS JSC CENTER ROLE AS FLIGHT PROGRAM DEVELOPMENT AND MANAGEMENT CENTER.
  - **RECOMMEND FY 1985 CoF UPGRADE BY ADDING CAPABILITY FOR SUB-SCALE ENGINES (BELOW 250 LB. THRUST).**

  **MSFC**
  
  - NO APPROPRIATE ENGINE ALTITUDE CAPABILITY AT MSFC - UNDERSUPPORTS MSFC CENTER ROLE AS FLIGHT PROGRAM DEVELOPMENT AND MANAGEMENT CENTER.
  - **RECOMMEND THAT MSFC IDENTIFY BEST METHOD AND INCLUDE IN FY 1986 CoF.**

- GOVERNMENT-OWNED TEST SERVICE SITES
  
  **JPL**
  
  - JPL HAS TOTAL CAPABILITY EXCEPT FOR RUN DURATION (3 MINUTE CAPABILITY VS. HOUR(S) REQUIREMENT) DUE TO LIMITED VOLUME HIGH PRESSURE LH$_2$ TANKAGE.
  - **RECOMMEND APPROVE RELOCATION OF SURPLUS LH$_2$ TANKAGE SYSTEM & NTS TO INCREASE JPL'S CAPABILITY TO 2 HOURS AND PROVIDE TOTAL LOW THRUST CAPABILITY AT VERY LOW COST ($100K).**

  **WSTF, NSSL, MSFC**
  
  - IMPLEMENTATION OF OTV FACILITY DECISION WILL ALSO PROVIDE FULL SCALE LOW THRUST CAPABILITY AT ONE OF THESE SITES.
CONCENTRATE ON FACILITIES AT GOVERNMENT SITES

- SPECIFICALLY: MAJOR, EXPENSIVE, ENGINE & STAGE FACILITIES.
- GOVERNMENT FACILITIES (AT GOVERNMENT SITES) AVAILABLE TO ALL USERS
  - CONTRACTOR & GOVERNMENT
  - R&T, R&D, OPERATIONAL PROGRAMS
- GOVERNMENT FACILITIES AT CONTRACTOR SITES GENERALLY LIMITED TO HIS USE
  - ALTERS COMPETITIVE ADVANTAGE
  - REDUCES HEALTH OF INDUSTRY

TEAM RESULTS

- DETERMINED STATUS OF NATIONAL PROPULSION TEST FACILITIES (COMPiled FACILITY DATA PACKAGE).
- DEVELOPED BASELINE SPACE TRANSPORTATION VEHICLE MODEL.
- ESTABLISHED TEST REQUIREMENTS FOR THE GENERIC PROPULSION SYSTEMS IN THE VEHICLE MODEL.
- DEVELOPED INTEGRATED FACILITY PLAN (SHORT/LONG TERM).
- IDENTIFIED SURPLUS EQUIPMENT AVAILABLE FOR UTILIZATION AT OTHER FACILITIES.
- PROVIDED ASSESSMENT OF PROPULSION INDUSTRY HEALTH.
- ENHANCED COMMUNICATION CHANNELS BETWEEN LIQUID ROCKET TEST ORGANIZATIONS.
RECOMMENDATIONS:

- HQS. PROGRAM OFFICES PROVIDE MEANS OF DEVELOPING AND MAINTAINING INTEGRATED "TOP LEVEL PLANS".
  - REQUIRES TOP MANAGEMENT INVOLVEMENT.
  - REQUIRES DEDICATED LEAD STAFF.
  - MUST BE DEVELOPED BY THOSE RESPONSIBLE FOR MANAGING THE EXECUTION OF THE PLAN.
  - OFTEN REQUIRES INVOLVEMENT AND INTERACTION OF MORE THAN ONE HQS. PROGRAM OFFICE/SOMETIMES DOD.

- PLANS SHOULD INCLUDE:
  - NATIONAL MISSION REQUIREMENTS.
  - PROGRAM OBJECTIVES, APPROACHES, MAJOR MILESTONE, ETC.
  - CENTER RESPONSIBILITIES.
  - TECHNOLOGY REQUIREMENTS.
  - FACILITY REQUIREMENTS.

- INTEGRATED FACILITY PLANNING
  - DRIVEN AND SUPPORTED BY INPUTS FROM PROGRAM PLANS.
  - MUST INCLUDE PROGRAM MANAGEMENT AND FACILITY MANAGEMENT.
  - CONSIDERATION OF FACILITY OPTIONS/BY TRADE-OFF STUDIES.
  - EARLY R&D FUNDS NEEDED TO BE EFFECTIVE.
  - CENTRALLY (HQS) CONTROLLED REVIEW OF TRADE-OFF STUDY RESULTS AND CONCLUSIONS.

TEAM OBSERVATIONS OF NASA PLANNING

- A GENERALLY ACCEPTED TOP-LEVEL SPACE TRANSPORTATION SYSTEM PLAN DOES NOT EXIST; WOULD INCLUDE:
  - MISSION OBJECTIVES AND REQUIREMENTS
    - MAJOR EXCEPTION PERMANENT MAN OCCUPANY OF SPACE.
  - PROGRAM PLANS/MAJOR MILESTONES
    - PLANS FOR APPROVAL OF ONGOING PROGRAMS ARE INADEQUATE.
    - FUTURE PROGRAM PLANS ARE NEAR NONEXISTENT.

- THERE IS NO CLEAR ORGANIZATION MECHANISM TO DEVELOP AND VALIDATE PLANS
  - AD HOC PROPULSION FACILITY TEAM - REQUIRED TO DEVELOP PLAN FOR PROPULSION PROGRAM.
  - REVIEW AND CONCURRENCE BY TOP NASA AND AF MANAGEMENT INCOMPLETE.

- GOOD FACILITY PLANNING AND APPROVAL
  - REQUIRES ADEQUATE AGENCY/CENTER MISSION OBJECTIVES AND PROGRAM PLANS.
CONCLUSIONS

- Adequate facilities are available at both the government and contractor sites to satisfy the testing needs of small engines (spacecraft attitude control and maneuvering) for foreseeable future.
  
  One exception is deficiency in LOX/LH₂ test capability.

- Modifications and additions to existing facilities are required to adequately support the test requirements for developing and operating high performance medium thrust engines for future space vehicles (OTV, etc.).
  
  There are specific needs for improved component test facilities, and engine/propulsion system altitude test facilities.

- The present three active test stands (two at NSTL and one at Rocketdyne, SSFL) may not be adequate or optimum to support all the test needs of the SSME and SSME derivative engine programs. Options being considered for test stand modifications at NSTL and MSFC could satisfy this need.

- Present active or standby large engine test facilities are not configured to satisfy needs of Air Force "Orbit-On-Demand" vehicle.

- There is immediate need for improvements and additions to several center “backyard” facilities to support technology advancement testing, and shuttle development and operations programs support.

- There are a large number of medium and large thrust engine and system test stands not in active use at both government and contractor sites. Many are being maintained; a few not. Some should continue to be maintained because of large investment cost and unknown future; others kept for spare parts; and others have no potential use and should be made available for disposition.

CHANGES

- National Aerospace Plane

- Advanced Launch System

- Space Exploration Initiative
### NATIONAL AERO-SPACE PLANE PROGRAM SCHEDULE AND MILESTONES

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#### Diagram

- **Concept Definition**
- **Development of Airframe and Components**
- **Design, Build and Ground Test Engine**
- **Design and Build X-30**
- **Flight Test X-30**
- **Technology Maturation Program**
- **Future Operational Systems Development**

*Source: U.S. General Accounting Office*
ADVANCED LAUNCH SYSTEM

ADVANCED LAUNCH DEVELOPMENT
PROGRAM SCHEDULE
(March 28, 1990 Aldrich Study)

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19 Apr 90

1917
SEI Candidate Unmanned Vehicles

0 t  50 t  100 t  150 t  200 t

Launch Facilities

ASRM

Sh-C

ET for
Core

ASAM's

3 SSME's

3 SSME's

2 ASRM's

ET Core

4 SSME's

3rd Stage MTV

LRB

Other ALS
Elements

ALS Design
& Technology
Innovations

ALS Family

1 Booster

2 Boosters

3 Boosters

4 Boosters

Other New and Revolutionary Ideas.
SHUTTLE AND LUNAR/MARS TRANSFER VEHICLES

Space Shuttle
Mass = 92 metric tons
(Payload = 22 metric tons)

Lunar Transportation System
Mass = 200 metric tons

Mars Transportation System
Mass = 800 metric tons
LRB/SDV OPTIONS

**Booster**
- EXP SH NOZ SSME

**Core**
- EXP SSME

---

**Booster**
- SH NOZ STE

**Core**
- EXP SSME

---

**Booster**
- SH NOZ STE

**Core**
- STE

---

**ET Core**
- 90t
- 98t

**ET Growth**
- 108t

---

**ET Core**
- 86t
- 93t

**ET Growth**
- 104t

---

**ET Core**
- 80t
- 78t

**ET Growth**
- 92t
Lunar Mission Profile

1. Payload Delivered to Space Station Freedom
2. Lunar Transfer Vehicle Mated with Payload at Freedom
3. Trans-Lunar Phase with Lunar Transfer Vehicle
4. Lunar Transfer Vehicle Rendezvous with Lunar Excursion Vehicle from Moon
5. Excursion Vehicle Returns to Moon with Payload
6. Trans-Earth Phase with Transfer Vehicle
7. Transfer Vehicle Aerobrake Maneuver and Return to Freedom

Mars Mission Profile

1. Payload Delivered to Space Station Freedom
2. Mars Transfer Vehicle Mated with Payload at Freedom
3. Trans-Mars Phase with Lunar Transfer Vehicle
4. Mars Transfer Vehicle Remains in Mars Orbit; Mars Excursion Vehicle Descends to Surface
5. Excursion Vehicle to/from Mars: Surface
6. Trans-Earth Phase with Transfer Vehicle
7. Transfer Vehicle Aerobrake Maneuver and Return
LIFE CYCLE COST BASED DECISIONS
RATIONALE

- FACILITY ASSESSMENT TEAM CHARTER
- FUTURE PROGRAM REQUIREMENTS
- CAPITAL INVESTMENT VS O&M COSTS

SCOPE

SPACE TRANSPORTATION VEHICLE MODEL

PROPULSION SYSTEM REQUIREMENTS

PROPULSION SYSTEM TEST REQUIREMENTS R&T, DEVELOPMENT, OPERATIONS

FACILITY REQUIREMENTS

FACILITY VISITS & ASSESSMENT

AVAILABLE FACILITY CAPABILITY

EVALUATION

FACILITY OPTIONS

INTEGRATED FACILITY PLAN

- REQUIREMENTS
- ASSETS SURVEY
- EVALUATION
- PLAN
LIFE CYCLE COST

THE TOTAL COST OF A FACILITY - INCLUDING THE INITIAL CAPITAL INVESTMENT AND ALL OPERATING AND MAINTENANCE COSTS FOR THE LIFE OF THE PROGRAM.

RECOMMENDATION

- ESTABLISH A PROPULSION TEST WORKING GROUP WITHIN NASA - SEPARATE PANEL OF PROPULSION WORKING GROUP.

- DEVELOP A FINITE MODEL FOR COST ANALYSIS OF ALTERNATE SITES FOR PROPULSION TEST

- SUBJECT ALL CANDIDATE SITES TO INDEPENDENT ANALYSIS - NASA HEADQUARTERS LEAD

- PROGRAM DECISION BASED ON INDEPENDENT ASSESSMENT

APPLICABILITY

- NEW PROGRAM STARTS

- MAJOR PROGRAMMATIC CHANGES