LIFE CYCLE COST BASED PROGRAM DECISIONS

J. S. DICK
JUNE 26, 1990

- BACKGROUND
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- 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>
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<tbody>
<tr>
<td>Thrust (lbs.)</td>
<td>MINI ($10^1$)  LOW ($10^3$)  MODERATE ($10^4$)  LARGE ($10^6$)</td>
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<tr>
<td>(RCS)</td>
<td>(ALTITUDE ADJ.) (OTV) (SSME)</td>
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<tr>
<td>Propellants</td>
<td>CRYOGENIC STORABLES (MONOPROPellant, BIPROPellant)</td>
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<tr>
<td>Run Tankage</td>
<td>MEDIA VOLUME PRESSURE</td>
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<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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<td>System Level</td>
<td>COMPONENTS ENGINES PROPULSION SYSTEMS STAGES</td>
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<tr>
<td>Duty Cycle</td>
<td>MIN./MAX. BURN DURATION THRUST RANGE MISSION DURATION</td>
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SPACE TRANSPORTATION VEHICLE MODEL

PROPULSION SYSTEM REQUIREMENTS

PROPULSION SYSTEM TEST REQUIREMENTS R&T, DEVELOPMENT, OPERATIONS

FACILITY VISITS & ASSESSMENT

AVAILABLE FACILITY CAPABILITY

FACILITY REQUIREMENTS

EVALUATION

FACILITY OPTIONS

INTEGRATED FACILITY PLAN

- REQUIREMENTS
- ASSETS SURVEY
- EVALUATION
- PLAN
LARGE ENGINE THRUST LEVEL - PROGRAMS AND FACILITY NEEDS

**GENERIC ENGINES**
- **BASELINE SSME**
  - DEVELOP./CERT./FLT. SUPPORT
- **SSME TEST-BED**
  - TECHNOLOGY TRANSFER
- **SSME UPGRADE**
  - DEVELOPMENT / FLT. SUPPORT
- **ADV O₂/H₂**
  - TECHNOLOGY / DEVELOPMENT / FLT. SUPPORT
  - SUBSCALE
- **ADV O₂/HC**
  - TECHNOLOGY / DEVELOPMENT / FLT. SUPPORT
  - SUBSCALE
- **DUAL FUEL**
  - TECHNOLOGY / DEVELOPMENT / FLT. SUPPORT

**FACILITY NEEDS**
- **O₂/H₂**
  - BEARING TESTER ENGINE
  - SUBSCALE THRUST CHAMBER
  - HORIZONTAL ENGINE TURBOPUMP
  - ALTITUDE ENGINE
- **O₂/HC**
  - BEARING TESTER (HC)
  - SUBSCALE THRUST CHAMBER
  - ENGINE
  - PROPULSION SYSTEM
- **DUAL FUEL**
  - ALTITUDE ENGINE
  - PROPULSION SYSTEM
## 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>
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<tr>
<td>TECHNOLOGY TEST BED</td>
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<tr>
<td></td>
<td>←</td>
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<tr>
<td>HORIZONTAL TEST</td>
<td>TS1-56 ***</td>
</tr>
<tr>
<td></td>
<td></td>
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<tr>
<td>ADVANCED O₂/H₂</td>
<td>N/A</td>
</tr>
<tr>
<td></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 LARGER FUEL CAPABILITY)
**LARGE ENGINE THRUST LEVEL**

**ENGINE LEVEL SUMMARY**

<table>
<thead>
<tr>
<th>GENERIC ENGINE</th>
<th>LOCATIONS</th>
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<tbody>
<tr>
<td></td>
<td>ROCKETDYNE</td>
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<tr>
<td>SSME BASELINE</td>
<td>A-3</td>
</tr>
<tr>
<td>SSME TECHNOLOGY TEST BED</td>
<td>A-3</td>
</tr>
<tr>
<td>SSME UPGRADING</td>
<td>A-3</td>
</tr>
<tr>
<td>ALTITUDE TEST</td>
<td>A-3</td>
</tr>
<tr>
<td>SEA LEVEL TEST (VERT)</td>
<td>A-3</td>
</tr>
<tr>
<td>SEA LEVEL TEST (HORIZ.)</td>
<td>A-3</td>
</tr>
<tr>
<td>ADVANCED O₂/H₂</td>
<td>A-3</td>
</tr>
<tr>
<td>ADVANCED O₂/Hc</td>
<td>A-3</td>
</tr>
<tr>
<td>DUAL FUEL</td>
<td>A-3</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 * ROCKE TEDYNE</td>
<td>MSFC</td>
<td>ROCKE TEDYNE</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>NO GOV'T TEST SITE</td>
</tr>
<tr>
<td>O₂/Hc</td>
<td>MSFC * ROCKE TEDYNE</td>
<td>MSFC</td>
<td>ROCKE TEDYNE</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(HI Pc 3000 psi) NO GOV'T TEST SITE</td>
</tr>
</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)
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.


OPTIONS FOR ADDITIONAL TEST STANDS:

<table>
<thead>
<tr>
<th>PRO</th>
<th>CON</th>
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</thead>
<tbody>
<tr>
<td>• RETAIN RKD A-3.</td>
<td>• OPERATING COST.</td>
</tr>
<tr>
<td>• ACTIVATE NSTL B-2 OR B-1 FOR SINGLE ENGINE TESTING.</td>
<td>• INITIAL FACILITY INVESTMENT COST (LOW).</td>
</tr>
<tr>
<td>• ACTIVATE MSFC S-1C FOR SINGLE ENGINE TESTING.</td>
<td>• INITIAL FACILITY INVESTMENT COST (MODERATE).</td>
</tr>
<tr>
<td>• DEVELOP &amp; MAINTAIN IN-HOUSE ENGINEERING EXPERTISE &amp; CAPABILITY.</td>
<td></td>
</tr>
<tr>
<td>• LOW OPERATIONAL COST.</td>
<td></td>
</tr>
</tbody>
</table>

LARGE ENGINE THRUST LEVEL
DEFICIENCY #1 (CONT'D.)

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:**

<table>
<thead>
<tr>
<th></th>
<th>PRO</th>
<th>CON</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>RKD A-3 DEVELOPMENT ENGR. SUPPORT</td>
<td>INVESTMENT COST FOR MODS.</td>
</tr>
<tr>
<td>2</td>
<td>HSFC S-1C DEVELOPMENT ENGR. SUPPORT</td>
<td>INVESTMENT COST FOR MODS. AND REACTIVATION.</td>
</tr>
<tr>
<td>3</td>
<td>HSTL A-1/A-2 LOW OPERATING COST (SHARED FACILITY)</td>
<td>INVESTMENT COST FOR MODS.</td>
</tr>
<tr>
<td></td>
<td>B-1/B-2 EXISTING HORIZONTAL TEST SITE</td>
<td>INVESTMENT COST TO ADD LH₂ CAPABILITY AND REACTIVATION.</td>
</tr>
</tbody>
</table>

**RECOMMENDATION:**

---

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 TECHNOLOGY, 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 (STRESS OVERPRESSURE PROBLEM).

**OPTIONS:**

<table>
<thead>
<tr>
<th></th>
<th>PRO</th>
<th>CON</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MSFC TP 500 &amp; 115 DEVELOP &amp; MAINTAIN IN-HOUSE TECHNICAL EXPERTISE CONSISTENT WITH ETO ENGINE DEV. ROLE,</td>
<td>NONE TECHNICAL EXPERTISE CONSISTENT WITH ETO ENGINE DEV. ROLE,</td>
</tr>
<tr>
<td></td>
<td>IMPROVED CAPABILITY FOR ANOMALY RESOLUTION,</td>
<td>IMPROVED CAPABILITY FOR ANOMALY RESOLUTION,</td>
</tr>
<tr>
<td></td>
<td>EXISTING SUPPORTING FACILITIES ARE AVAILABLE.</td>
<td>EXISTING SUPPORTING FACILITIES ARE AVAILABLE.</td>
</tr>
<tr>
<td></td>
<td>LOW OPERATIONAL COST.</td>
<td>LOW OPERATIONAL COST.</td>
</tr>
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</table>
LARGE ENGINE THRUST LEVEL
DEFICIENCY #3 (COH'D.)

OPTIONS (CONT'D.):

PRO
- OTHER GOVERNMENT SITES.
- CONTRACTOR SITES.

COH
- BASIC TEST CAPABILITY DOES NOT EXIST.
- INVESTMENT COST SIGNIFICANT.
- OPERATING COST.

EXPAND INDUSTRY BASE AT ONE CONTRACTOR (PROBABLY RKD.).

RECOMMENDATION:
IMPLEMENT FY 1985 COF MODIFICATION FOR MSFC'S TP 500 & 115.

LARGE ENGINE THRUST LEVEL
ISSUE #4 - ENVIRONMENTALLY COMPLAINT 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. ROCKETFYIE AT SANTA SUZANNA RESTRICTED TO TEST OPERATIONS DURING DAY LIGHT HOURS.

OPTIONS:

PRO
- RELOCATE RKD A-3 TEST OPERATIONS.
- PROTECT BUFFER ZONE AT ISOLATED TEST SITES.
- 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 & HI PC. TEST AT ALTITUDE CONDITION MAY BE REQUIRED.

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

OPTIONS:

PRO  CON

- GOV'T. TEST SITES  AEDC, MSFC, NSTL, RPL.
- CONTRACTOR TEST SITES.  AEROJET, PRATT, RKD.
- BUILDS ON EXISTING OPERATIONAL BASE.
- MAINTAIN INDUSTRY CAPABILITY.
- INVESTMENT COST.
- INVESTMENT COST.

RECOMMENDATION:


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

REQUIREMENT:  ADVANCED O₂H₂, O₂/HC AND/OR DUAL FUEL EARTH TO ORBIT ENGINES REQUIRE TURBOPUMP TESTING.

FACILITY DEFICIENCY:  EXISTING CONTRACTOR FACILITY HAS NOT SATISFACTORILY 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:

PRO  CON

- RKD A-3  CURRENTLY EXISTING FACILITY.
- MSFC  SUPPORTS ETO DEVELOPMENT RESPONSIBILITY.
- HSTL  UTILIZES EXISTING PROPELLANT SUPPLY FACILITIES.
- TEST BED ENGINE  MAY BE ONLY PRACTICAL SOLUTION AT REASONABLE COST.
- FACILITY LIKELY TO BE CLOSED IN SPITE OF THIS REQUIREMENT.
- 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>O₂H₂</th>
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<tr>
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<td>400</td>
<td>205</td>
<td>1,400</td>
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<tr>
<td>ADV EXPANDERS</td>
<td>15,000/500</td>
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<td>1,800</td>
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<td>600</td>
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<th>N₂O₄/MMH</th>
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<td>ADV PUMP-FED</td>
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<td>CURRENT OMS</td>
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<tr>
<td>ADV OMS</td>
<td>6,000</td>
<td>1,500</td>
<td>400</td>
<td>600</td>
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<table>
<thead>
<tr>
<th>O₂/HC</th>
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<tbody>
<tr>
<td>ADV OMS</td>
<td>6,000</td>
<td>600</td>
<td>300</td>
<td>600</td>
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### MEDIUM ENGINE THRUST LEVEL - ENGINE LEVEL TEST CAPABILITY

| FACILITY | AEDC | RPL | GSFC | JAF | JPL | JSC | LBRC | P.B.C | MSFC | NSTL | NSTF | AERL | BELL | BOE | BRL | STC | TNC | PHA | RKO | RR | TRW |
| RL-10 IIB | A | A | P | SP | P | P | A | P | P | P | A | A | A | A | A | A | A | A | A | A | A |
| O₂/H₂ | ADV EXPANDER | A | A | P | SP | P | P | A | P | P | A | A | A | A | A | A | A | A | A | A | A | A |
| O₂/H₂ | OMS | A | A | P | SP | P | P | A | P | P | A | A | A | A | A | A | A | A | A | A | A | A |
| N₂O₄/MMH | OMS | * | * | P | * | * | A | A | * | * | A | A | A | A | A | A | A | A | A | A | A | A |
| N₂O₄/MMH | ADV PUMP-FED | * | * | * | P | * | * | A | A | * | * | A | A | A | A | A | A | A | A | A | A | A |

* FULL EXISTING CAPABILITY
A EXIST. ALTITUDE CAPABILITY
P EXIST. PROPELLANT SYSTEM
S TEST STAND IN PLACE

1003
### 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 & dual thrust engines through full mission duty cycles currently exists only at AEDC J-4.

**OPTIONS:**

- **MODIFY P&W TEST STAND E-6**
  - Pro: Accommodates current schedule
  - Con: Not available to other contractors

- **USE AEDC J-4 FOR ALL HIGH E TESTING**
  - Con: No CoF Funding Required
  - **MODIFY OTHER GOVERNMENT FACILITY (AEDC J-3, WSTF, LeRC, MSFC, NSTL)**

- **MODIFY OTHER GOVERNMENT FACILITY (AEDC J-3, WSTF, LeRC, MSFC, NSTL)**
  - Cost effective
  - Long-term solution

- **USE AEDC J-4 FOR ALL HIGH E TESTING**
  - No CoF Funding Required
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 85 Coff (COULD MEET RL-10 IIB PIP REQUIREMENTS, IF DELAYED)

CONSIDERATION OF POTENTIAL FACILITIES

<table>
<thead>
<tr>
<th>MINOR MODS</th>
<th>MODERATE MODS</th>
<th>MAJOR</th>
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</thead>
<tbody>
<tr>
<td>AEDC (J-3)</td>
<td></td>
<td>MSFC</td>
</tr>
<tr>
<td>LeRC (PSL)</td>
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<td>NSTL</td>
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<td>WSTF</td>
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<tr>
<td></td>
<td>P&amp;W</td>
<td>ALRC</td>
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<td>BELL</td>
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<td></td>
<td></td>
<td>RKD</td>
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MEDIUM ENGINE THRUST LEVEL

DEFICIENCY #2 - NOZZLE TESTING

REQUIREMENT:
HIGH EXPANSION RATIO (€) 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 € NOZZLES AT ALTITUDE WITH PRESSURE FED THRUST CHAMBERS DOES NOT EXIST AT ANY TEST FACILITY - INITIAL NEED DATE (R&T): 1988

OPTIONS:

PRO
- PROVIDE HIGH PRESSURE TANKAGE TO AEDC (J-3) OR WSTF
- TEST AT ENGINE LEVEL AT GOVERNMENT FACILITY.
- TEST PUBSCALE HARDWARE AT LERC, ALRC, RKD

CON
- COST OF HIGH PRESSURE TANKS
- LOW PRESSURE TANKS IN PLACE OR AVAILABLE
- IN-PLACE CAPABILITIES
- PUMP LIFE/MAINT./CONTROL
- 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

MINOR MODS
E.G., PROPELLANT SYS
AEDC J-4
AEDC J-3
AFRPL
LERC PSL
WSTF

MEDIUM MODS
E.G., ALTITUDE SYSTEM
MSFC
NSTL

MAJOR MODS
E.G., ALTITUDE SYSTEM
BELL
RKD
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 ROCKETDYNE

OPTIONS:

**PRO**
- REPLY ON RKD FOR TECHNOLOGY AND DEVELOPMENT
- PROVIDE CAPABILITY WITHIN GOVERNMENT

**CON**
- MINIMUM INVESTMENT
- LIMITED GOVERNMENT EXPERTISE
- NO CONTRACTOR COMPETITION
- PROVIDES EXPERTISE THRU "BACKYARD" CAPABILITY
- MINOR MOD
- AVAILABLE TO ALL CONTRACTORS
- SUPPORTS PROGRAM REQUIREMENT WITH TECHNOLOGY

RECOMMENDATION:
FUND FY 85 lERc COFF SUBMISSION TO SUPPORT lERc'S R&T RESPONSIBILITY.

MEDIUM ENGINE THRUST LEVEL
ISSUE #3 - TURBOMACHINERY TESTING

CONSIDERATION OF POTENTIAL FACILITIES

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<thead>
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<td>JSC-TTA</td>
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1007
MEDIUM ENGINE THRUST LEVEL

DEFICIENCY #4 - BEARING TESTER

ISSUE

REQUIREMENTS:
ADV HIGH PRESSURE PUMP-FED $\text{H}_2\text{O}_4$/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 $\text{H}_2\text{O}_4$ AND MMH BEARINGS DOES NOT EXIST AT ANY GOVERNMENT FACILITY--ONLY AT ROCKETDYNE

OPTIONS:

<table>
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<th>PRO</th>
<th>CON</th>
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<tbody>
<tr>
<td>PROVIDE CAPABILITY AT LERC OR AFRPL</td>
<td>AVAILABLE TO TEST ALL CONSTRUCTOR DESIGNS. MINIMUM EXPENSE TO INSTALL</td>
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</tbody>
</table>

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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ALRC
RKD
P&HA
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<td>F.S.</td>
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<td>DEV</td>
<td>F.S.</td>
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<tr>
<td>25 PRESS RCS</td>
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<td>DEV</td>
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<td>DEV</td>
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<td>ABV. OTV</td>
<td>DEV</td>
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<td>TELE.</td>
<td>DEV</td>
<td>F.S.</td>
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<td><strong>SYSTEM TECHNOLOGY</strong></td>
<td>O2/H2</td>
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1009
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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</thead>
<tbody>
<tr>
<td>B1PROP STORABLE</td>
<td>• NO DEFICIENCY.</td>
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<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>
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<tr>
<td>MONOPROP (N2H4)</td>
<td>• NO DEFICIENCY.</td>
</tr>
<tr>
<td>100 &amp; LESS</td>
<td>• MULTIPLE GOVERNMENT &amp; INDUSTRY SITES AVAILABLE.</td>
</tr>
<tr>
<td>O2/H2</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 (LF2)</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>
</table>
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
RATIONAL 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.
02/H2 DEFIENCIES AT GOVERNMENT SITE

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

_RPL_

- IMPLEMENTATION OF REQUESTED FY 1985 MCP ($5.M) 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 LH2 TANKAGE.
  - RECOMMEND APPROVE RELOCATION OF SURPLUS LH2 TANKAGE SYSTEM AT HSFC TO INCREASE JPL’S CAPABILITY TO 2 HOURS AND PROVIDE TOTAL LOW THRUST CAPABILITY AT VERY LOW COST ($100.K).

_WSTF, NSTL, 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 OCCUPANCY 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 "back-yard" 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 other 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

#### NATIONAL AERO-SPACE PLANE PROGRAM SCHEDULE AND MILESTONES

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<td>Future Operational Systems Development</td>
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- Concept Definition
- Development of Airframe and Components
- Design and Build X-30
- Flight Test X-30

Technology Maturation Program

Source: U.S. General Accounting Office

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ORIGINAL PAGE 18 OF POOR QUALITY
ADVANCED LAUNCH DEPARTMENT
PROGRAM SCHEDULE
(March 28, 1990 Aldrich Study)

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19 April 90
SEI Candidate Unmanned Vehicles

0 t  50 t  100 t  150 t  200 t

Launch Facilities

1 Booster  2 Boosters  3 Boosters  4 Boosters

Other Ideas and Innovations

Other ALS Elements

ALS Design & Technology Innovations

ALS Family

SPV

Sh-C ASRM's 3 SSME's

Sh-C ALSM's 3 SSME's

2 ASRM's ET Core 3 SSME's

2 ASRM's ALS Core 3 SSME's

2 LRB's ET Core 4 STME's

2 LRB's ALS Core 4 STME's

4 LRB's ET Core 3 STME's

4 LRB's ALS Core 4 STME's

4 ASRM's 30" Dia. Core, 3rd Stage MTV

4 ASRM's 5 SSME's

LRB
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

---

**ET CORE**

**90t**

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**ET GROWTH**

**108t**

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**BOOSTER**
- SH NOZ STE

**CORE**
- EXP SSME

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**86t**

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**93t**

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**104t**

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**BOOSTER**
- SH NOZ STE

**CORE**
- STE

---

**80t**

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**78t**

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**92t**

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181L PROP

200L PROP

363L PROP
Lunar excursion vehicle refueled by lunar transfer vehicle (cargo exchange).

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
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