

Office of  
Aeronautics,  
Exploration and  
Technology

51-863-71874  
157468  
p. 20

# SPACE PROPULSION TECHNOLOGY PROGRAM OVERVIEW

William J. D. Escher  
Manager, ETO & ACE  
Propulsion R&T Programs  
SSTAC/ARTS Meeting  
June 24-28, 1991

## A G E N D A

*Orientation and Background*

*Program New Initiatives and Exemplary  
Augmentation Opportunities/Payoffs*

*Program Element Augmentation Budgets  
and Goals/Objectives*

*Base Research & Technology Elements*

*Focused Technology Elements*

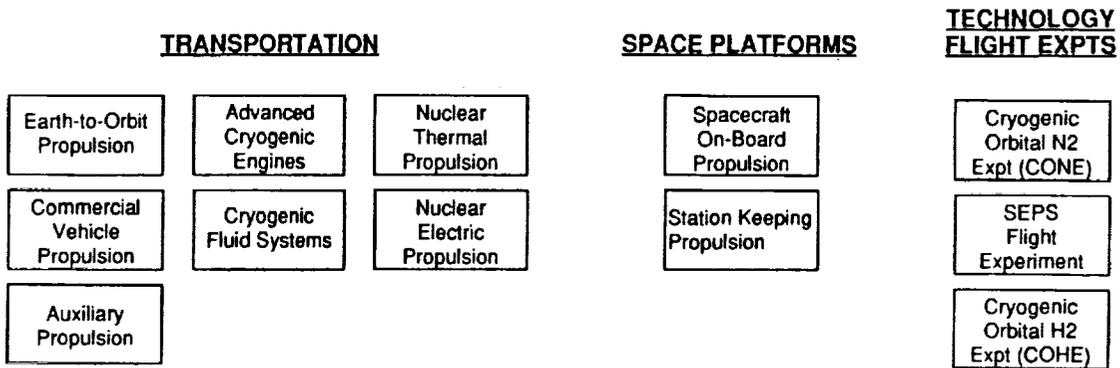
*Flight Test Elements*

# SPACE PROPULSION TECHNOLOGY PROGRAMS

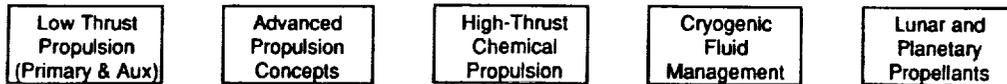
OAET

SPACE PROPULSION

## Focused Program Elements (Technology-User "Pull")

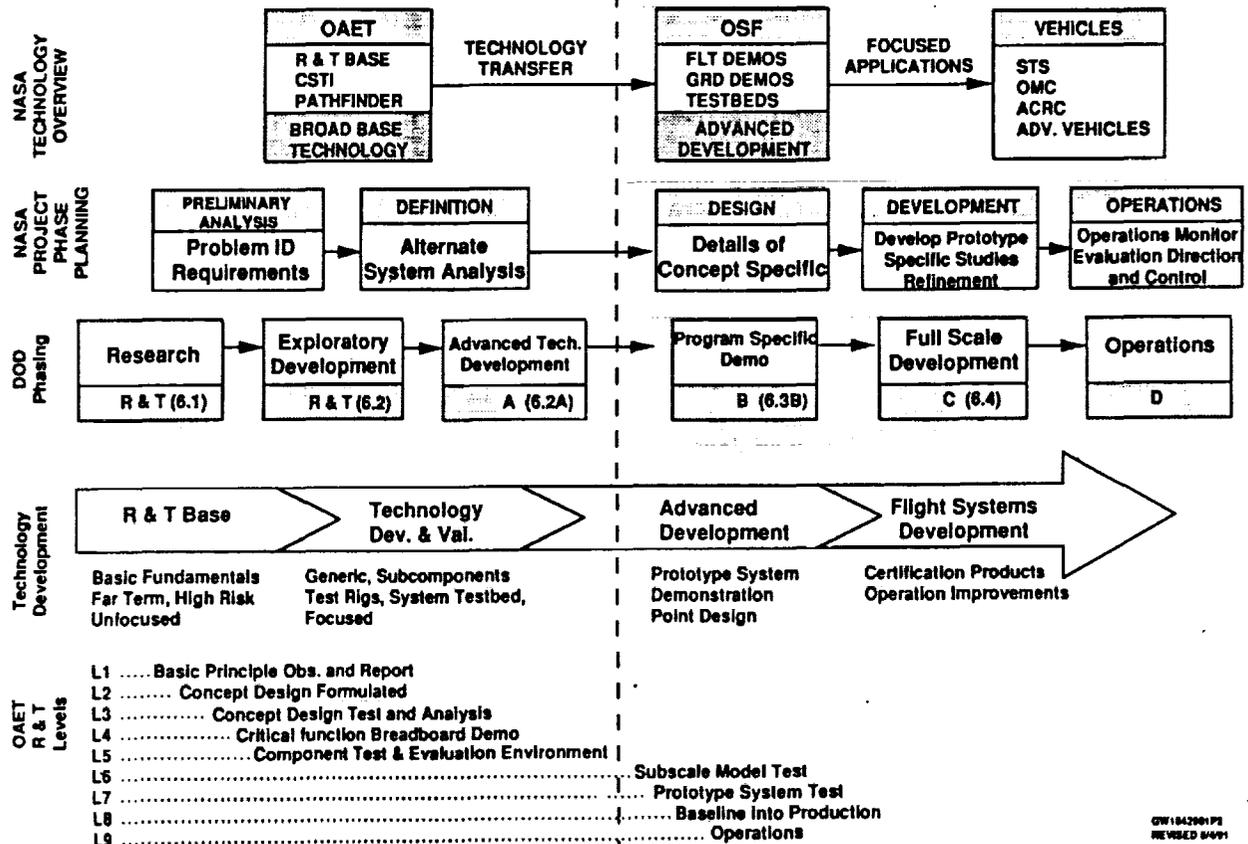


## Base Research & Technology Elements (Technology-Developer "Push")



NASA / John C. Stennis Space Center

## RESEARCH AND TECHNOLOGY CONCEPTS AND MATURATION PROCESS



OW1042001P1  
REVISED 04/91

# SPACE PROPULSION TECHNOLOGY

~~OAET~~

~~SPACE PROPULSION~~

## TECHNOLOGY REQUIREMENT SOURCES

### NASA Office of Space Flight, Office of Space Science & Applications

e.g., OSF's "Mission User Technology Needs & Applications"  
Note: ETO & SCET Basic WBS Structure Match "Top 3" Items

### Development-Stage and Flight Programs

e.g., NLS/STME Critical Task-by-Task Applicability Review  
Status: ETO/SCET 3-day Program Review in March 1991,  
NLS/STME Response in April 1991, Follow-up Meetings  
Underway at Present

### Special Assessments of NASA and Its Programs

- o SSTAC/ARTS & NRC/ASEB Propulsion Program Review Feedback
- o Augustine and Synthesis Group Reports:  
(Transportation & Propulsion Related Recommendations)

### Mission/Vehicle/Propulsion Planning-Visibility Studies (See later chart)

**NASA**

## OSF Technology Requirements Evaluation

### NASA Program Unique Technologies

- |    |  |
|----|--|
| 1  | Vehicle Health Management                                    |
| 2  | Advanced Turbomachinery Components & Models                  |
| 3  | Combustion Devices   |
| 4  | Advanced Heat Rejection Devices                              |
| 5  | Water Recovery & Management                                  |
| 6  | High Efficiency Space Power Systems                          |
| 7  | Advanced Extravehicular Mobility Unit Technologies           |
| 8  | Electromechanical Control Systems/Electrical Actuation       |
| 9  | Crew Training Systems  |
| 10 | Characterization of Al-Li Alloys                             |
| 11 | Cryogenic Supply, Storage & Handling                         |
| 12 | Thermal Protection Systems for High Temperature Applications |
| 13 | Robotic Technologies   |
| 14 | Orbital Debris Protection                                    |
| 15 | Guidance, Navigation & Control                               |
| 16 | Advanced Avionics Architectures                              |

### Industry Driven Technologies

Signal Transmission & Reception  
Advanced Avionics Software  
Video Technologies  
Environmentally Safe Cleaning Solvents, Refrigerants & Foams  
Non-Destructive Evaluation

Office Of Space Flight

# SPACE PROPULSION TECHNOLOGY

~~OAET~~

~~SPACE PROPULSION~~

## SYNTHESIS GROUP

### Key Propulsion-Related Findings/Recommendations

#### General

- o Require Earth-to-Orbit, Interplanetary Transfer and Descent/Ascent Propulsion for Crew and/or Cargo Service

#### Chemical Propulsion

- o Hydrocarbon/Oxygen Propulsion for Boost-stage Applications e.g., F-1 Engines (as updated)
- o Hydrogen/Oxygen Propulsion for Space-stage Applications e.g., Upgraded J-2 Engines, NLS/STME
- o NASP X-30 "...should be vigorously pursued." i.e., hypersonic airbreathing
- o SDIO SSTO concept "...should be carried forward to demonstrate feasibility." i.e., advanced configuration hydrogen, oxygen rockets

#### Nuclear Propulsion

- o Nuclear Thermal Rockets, "... with further development, are the choice propulsion technology for the interplanetary phase of the Mars mission."
- o Nuclear Electric Propulsion, "... where transit time is not an important constraint, low thrust nuclear propulsion systems are attractive because of their very high performance levels..."

~~OAET~~

~~SPACE PROPULSION~~

## NEW/ETO & SCET

### **INTEGRATED MISSION/VEHICLE/PROPULSION PLANNING-VISIBILITY STUDIES**

#### Advanced Manned Transportation Systems (AMTS)

- o LaRC Vehicle Analysis Branch, Space Systems Division
- o Fully Reusable TSTO & SSTO, All-Rocket & Airbreathing

#### Heavy Lift Transportation Systems (HLLV)

- o GD/SRS via MSFC Program Development
- o Boost-stage Propulsion, H<sub>2</sub>/O<sub>2</sub>
- o All-rocket Candidates (SSME Ref.): IME, Plug Nozzle, Full-flow S/C, Split-Expander, etc.

#### Advanced Upper-Stage Systems

- o Martin-Marietta/Aerojet via MSFC Propulsion Lab
- o IME Focused, H<sub>2</sub>/O<sub>2</sub> (Incl. SCET transfer, planetary applications)

# SPACE PROPULSION TECHNOLOGY

OAET

SPACE PROPULSION

## CASE-IN-POINT AUGMENTATION OPPORTUNITY

**SUBJECT:** Applying Emerging Materials Technology to a Turbopump

**Specific Example (ETO):** Fiber-Reinforced Ceramic Matrix Composite Turbine

**Engineering Benefits:** C/SiC Blades survive 50 thermal shock cycles to 3300 F

**Existing Program:** Phase I (GE, Rocketdyne) Feasibility Study completed, Phase II (Rocketdyne) Materials Characterization, Sample Component Fabrication & Test, & Technology Implementation Plan presently underway (44-month effort)

*Plan is to fab and test a representative (static) turbine nozzle ring (only)*

**Proposed Augmented Program:**

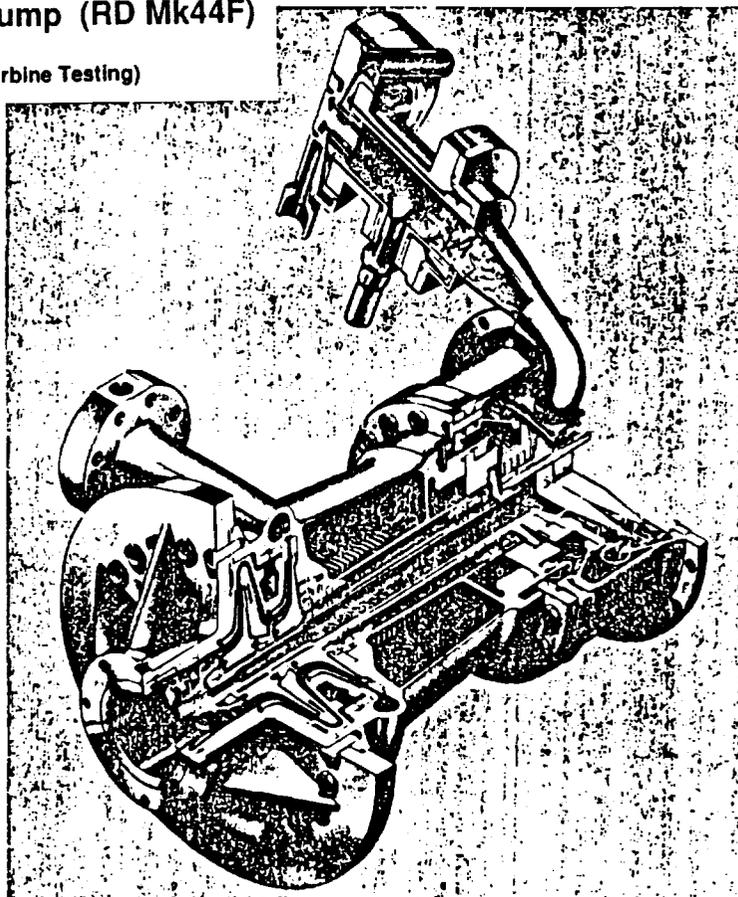
*Using existing LH2 Turbopump (Mk44F), fab nozzle ring and turbine wheel, checkout in hot-gas facility, then install in complete turbopump and run (LeRC)*

**What Does Augmentation Buy?**

- o Accelerates effort into full-scale subsystem operating-environment evaluation
- o Leverages well timewise on other Government-sponsored work (e.g., IHPTET)
- o Provides readiness for overall engine test/flight applications by FY96
- o Contractor team willing to cost share/Government facility gains new capabilities
- o Keeps U.S. competitive internationally (vs. France's SEP, Japanese work)

### Liquid Hydrogen Turbopump (RD Mk44F)

(Proposed for Ceramic Composite Turbine Testing)



# SPACE PROPULSION TECHNOLOGY

~~OAET~~

~~SPACE PROPULSION~~

## EXPANDING THE FOCUSED TECHNOLOGY PROGRAM PURVIEW

Example: Combined-Cycle (airbreathing/rocket) Propulsion

1990 SSTAC/ARTS Recommendation (vis-a-vis ETO Program):

"... our Group recommends that the current charter of the effort be enlarged to include combined-cycle propulsion."

Actions Taken (not necessarily totally ETO instigated):

- o Langley's Vehicle Analysis Branch has now examined airbreathing as well as all-rocket ETO systems assuming both available and improved materials availability (e.g., that accorded to NASP X-30)
- o Headquarters (ARC/Eagle) is conducting special international hypersonics propulsion activities (assessing combined-cycle work being pursued in France, Germany, U.K., U.S.S.R and Japan)
- o ETO Program plans to conduct a Rocket-Based Combined-Cycle (RBCC) SSTO focused Workshop via University of Alabama in Huntsville (there) in November 1991 (FY 91 & 92 supported grant)

# SPACE PROPULSION TECHNOLOGY

~~OAET~~

~~SPACE PROPULSION~~

## *SPECIAL INITIATIVE (ETO shared sponsorship)*

**Operationally Efficient Propulsion System Study**

- o 3-year assessment: Rocketdyne KSC/Cal Team (for KSC)
- o NLS/OSF-MD/OAET-RP Shared Funding (2nd Year just completed)
- o Canvassed Shuttle and ELV Launch Teams Re: "non-operability"
- o Defined 25 Leading Operability Problems; Technological Remedies for each now documented
- o "Rethought" ALS Boost-stage Propulsion System (as example)  
Arrived at IME configuration (vs. standalone engines) for improved operability (this design also is estimated to be superior in terms of reliability, complexity, weight and production costs)
- o Have now evolved a quantifiable Operability Index (OI: 0 to 1.0)
- o Plan to focus on Space-basing challenge next (SCET to track)

# SPACE PROPULSION TECHNOLOGY

~~OAET~~

~~SPACE PROPULSION~~

## NEW/ETO & SCET

### **COOPERATIVE - AGREEMENT PROGRAMS w/ INDUSTRY** *(Low-Cost Commercial ELV Focus)*

#### Hydrodynamic (Foil-type) Bearing Testing

- o Allied Signal/LeRC (SCET)
- o LH2 & LN2 (sim. LO2) Bearing Rig Tests (Completed)
- o Allied Signal/MSFC (ETO)
- o LO2 Materials Compatability and Rig Tests (in Planning)

#### Low-Cost Thrust Chamber Testing

- o TRW/LeRC (ETO)
- o LH2/LO2 Operation (Hardware-build stage; Fall 1991 Testing)

#### Turbopump Testing

- o Allied Signal/LeRC & MSFC
- o LH2 & LO2 Operation (Discussion stage)

# SPACE PROPULSION TECHNOLOGY

~~OAET~~

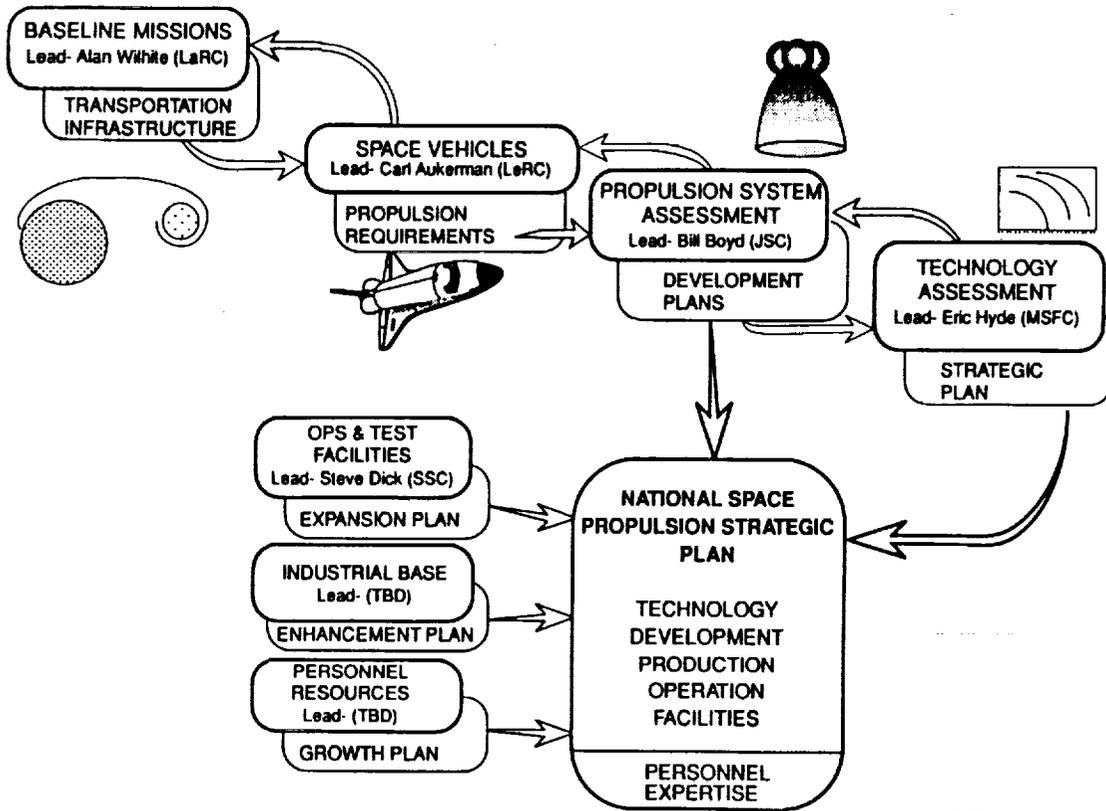
~~SPACE PROPULSION~~

## **SPACE PROPULSION SYNERGY GROUP**

### **A National Level Space Propulsion Technology Developer/User Forum**

- o Sustains the Considerable Momentum of the Penn State Symposium (June 1990)
- o All Propulsion-related NASA (now) and DoD (shortly) Offices and Centers aboard
- o Propulsion and Space Vehicle Industry and university community being invited in
- o Attempting a Vision of the Space Propulsion Future (e.g., via Strategic Planning)
- o Looking for "Smarter, Better" Ways of Doing Space Propulsion Business
- o Making Developers Aware of User Needs; Involving Users in Technology Planning
- o Recognition that our Space Propulsion Institutions Need Rejuvenation (How?)
- o Broad cross-section of NASA/DoD with comon interests -- achieving balanced representation of technologists, systems developers and systems operators
- o Catalyst for free thinking and innovation: cultural change must be achieved

# SPACE PROPULSION SYNERGY GROUP STRATEGIC PLANNING SUPPORT WORKING PANEL ACTIVITIES

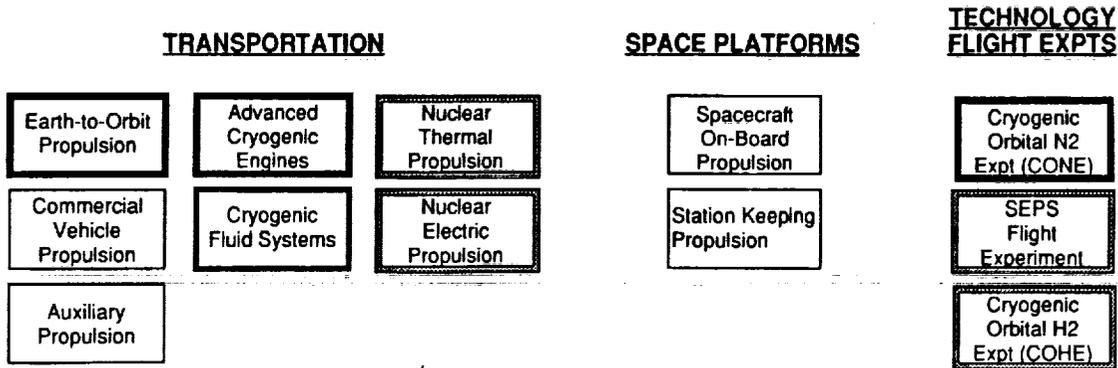


June 28, 1991  
MSFC/Space Synergy Op 1 SP50 St. Plan Group WP Am

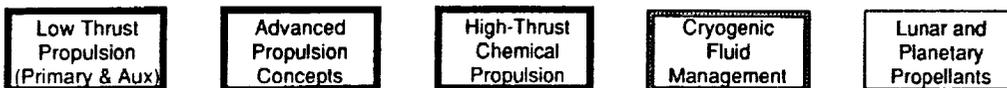
OAET

SPACE PROPULSION

## Focused Program Elements



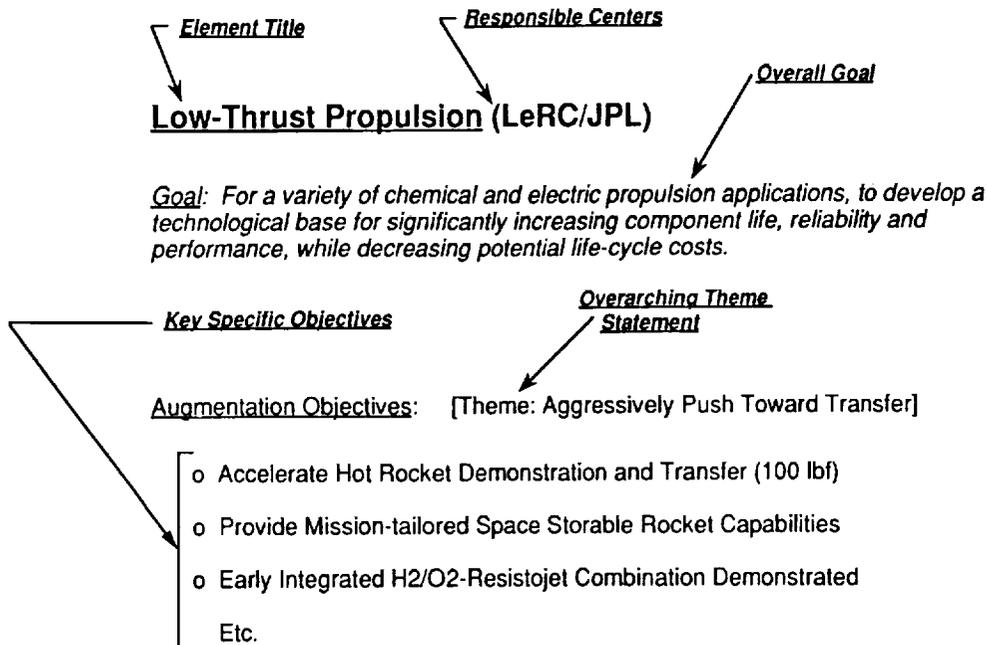
## Base R&T



- Ongoing, Extensively Planned (With Updating)
- Recent-start, Planning Mostly Underway
- Prospective, Basically Unplanned

**PURPOSE OF AUGMENTATION FACT SHEET - FORMAT**

*Special Note Re: Funding (If Needed)*



**PROPULSION R&T BASE FUNDING**  
(\$M)

Lunar/Janetary  
FY95 \$2.0M  
FY96 \$3.1M  
FY97 \$4.0M

<b>OAET</b>		<b>SPACE PROPULSION</b>						
<b>SUB-ELEMENTS</b>		<b>FY1991</b>	<b>FY1992</b>	<b>FY1993</b>	<b>FY1994</b>	<b>FY1995</b>	<b>FY1996</b>	<b>FY1997</b>
LOW THRUST PROPULSION	Current	5.8	5.2	5.4	5.6	5.8	6.1	6.3
	3X	5.8	5.2	7.0	9.8	11.0	12.5	14.5
	Strategic	5.8	5.2	8.0	11.0	11.0	12.5	14.5
ADVANCED CONCEPTS	Current	1.2	1.4	1.5	1.5	1.6	1.6	1.7
	3X	1.2	1.4	3.2	4.0	4.7	5.0	6.0
	Strategic	1.2	1.4	3.5	4.0	4.7	5.0	6.0
HIGH-THRUST CHEMICAL	Current	3.5	3.5	3.6	3.8	3.9	4.1	4.3
	3X	3.5	3.5	4.0	5.5	6.6	7.1	7.4
	Strategic	3.5	3.5	4.8	6.1	7.4	8.2	9.2
CRYO FLUID MANAGEMENT	Current	1.5	2.6	2.0	2.1	2.2	2.2	2.3
	3X	1.5	2.6	2.1	2.2	2.3	2.4	2.5
	Strategic	1.5	2.6	2.1	2.2	2.3	2.4	2.5
<b>SUB-ELEMENT TOTALS</b>	Current	<b>12.0</b>	<b>12.7</b>	<b>12.5</b>	<b>13.0</b>	<b>13.5</b>	<b>14.0</b>	<b>14.6</b>
	3X	<b>12.0</b>	<b>12.7</b>	<b>16.3</b>	<b>21.5</b>	<b>24.6</b>	<b>27.0</b>	<b>30.4</b>
	Strategic	<b>12.0</b>	<b>12.7</b>	<b>18.4</b>	<b>23.3</b>	<b>27.4</b>	<b>31.2</b>	<b>36.2</b>
PROGRAM SUPPORT	Current	2.4	2.5	2.6	2.7	2.8	2.9	3.0
	3X	2.4	2.5	2.3	2.6	3.0	3.2	3.6
	Strategic	2.4	2.5	2.3	2.9	3.4	3.8	4.4
SPECIAL REQUIREMENTS	Current	0.4	1.5	2.1	2.3	2.5	2.8	3.0
	3X	0.4	1.5	1.8	2.1	2.5	2.7	2.9
	Strategic	0.4	1.5	2.3	2.5	2.9	3.0	3.3
<b>TOTALS</b>	Current	<b>14.8</b>	<b>16.7</b>	<b>17.2</b>	<b>18.0</b>	<b>18.8</b>	<b>19.7</b>	<b>20.6</b>
	3X	<b>14.8</b>	<b>16.7</b>	<b>20.4</b>	<b>26.2</b>	<b>30.1</b>	<b>32.9</b>	<b>36.9</b>
	Strategic	<b>14.8</b>	<b>16.7</b>	<b>23.0</b>	<b>28.7</b>	<b>33.7</b>	<b>38.0</b>	<b>43.9</b>

# R & T BASE PROGRAM ELEMENTS

~~DAEF~~

~~SPACE PROPULSION~~

## Low-Thrust Propulsion (LeRC/JPL)

*Goal: For a variety of chemical and electric propulsion applications, to create a technological base toward increasing component life, reliability and performance, while decreasing program risk and life-cycle costs.*

Augmentation Objectives: [Theme: Assure Readiness for Technology Transfer]

- o Accelerate Advanced Earth-storable Rocket Applications
- o Provide Mission-tailored Space Storable Rocket Capabilities
- o Develop Integrated H<sub>2</sub>/O<sub>2</sub> propulsion systems (Vehicles & Platforms)
- o Provide Advanced Electric Platform Station-keeping Propulsion
- o Demonstrate Ion Engine readiness for SEP & Robotic NEP Flight Tests

# R & T BASE PROGRAM ELEMENTS

~~DAEF~~

~~SPACE PROPULSION~~

## Advanced Propulsion Concepts (LeRC, JPL)

*Goal: For long-range, high-risk/payoff propulsion concepts of all kinds, to accelerate aggressive feasibility studies and proof-of-concept experiments to provide mission-oriented programs a firm basis of confidence to select new kinds of propulsion systems technologies for focused development.*

Augmentation Objectives: [Theme: Expand Concepts, Researcher Pool]

- o Identify and Experimentally Explore High Energy-Density Propellants
- o Develop and Life Test Electroless Electric Thrusters
- o Demonstrate Beamed-Energy Feasibility
- o Evaluate Fusion/Anti-Proton Propulsion
- o Demonstrate Multi-MWe High-Performance Plasma Propulsion
- o Demonstrate Carbon-60 Molecular Ion Propulsion

# R & T BASE PROGRAM ELEMENTS

~~OAET~~

~~SPACE PROPULSION~~

## High-Thrust Chemical Propulsion (LeRC, MSFC, JSC)

*Goal: In the generic analysis/design tools, combustion-device, turbo- machinery and integrated controls and monitoring arenas, to identify and explore, through feasibility studies, code development and critical experiments, "quantum-leap" opportunities to advance the overall Earth-to-orbit and Space Chemical Propulsion state-of-the-art.*

Augmentation Objectives: [Theme: Broaden, Deepen and Accelerate]

- o Expand modeling efforts and code development in the subsystem areas and initiate systems-level work, e.g., toward full engine dynamic operational simulation (Example: a Reliability Predictor)
- o Explore Innovative Injector/Combustor/Nozzle Concepts and Provide for High-Fidelity Performance-Predictive Capabilities
- o Innovate Advances in Turbopump Elements, Components and Subsystems Toward Major Reliability and Operability Improvements (Example: High-Temperature Superconducting Magnetic Bearings)
- o Open the Way to all-pervasive Propulsion Health Management and Intelligent Control Capabilities (e.g., Prognostics, Sensor Self-check) including VHM Interfacing
- o Attack Non-Engine Propulsion System Problem Areas and Advocate Potential Solutions to Users

# R & T BASE PROGRAM ELEMENTS

~~OAET~~

~~SPACE PROPULSION~~

## Cryogenic Fluid Management (LeRC, MSFC)

*Goal: To Complement Focused Technology and Flight-Test Programs with Validated Analytical Models and small-scale test data to meet future subcritical cryogen storage and handling design challenges (e.g., Zero-g Venting, Years-duration Cryogen Maintenance)*

Augmentation Objectives: [Complement and Underpin Focused Efforts]

- o Develop Pertinent Thermofluid Models for Subcritical Cryogens in Space and Validate with Small-scale Laboratory Experiments
- o Achieve Fundamental Understanding of the Role Gravity/No-Gravity Plays in Subcritical Cryogen Containment and Handling Systems
- o Make Available Improved Thermal Insulation and, if Feasible, Active Refrigeration Technologies (toward zero-loss containment)
- o Pursue New Gauging Techniques and Sensor/Network Concepts
- o Address Space-environment Subcritical Cryogenic Fluid Storage and Supply, Transfer and State-assessment Problems and Develop Hardware Solutions to be Ultimately Verified in the Cryo Fluid Systems focused Program and in adequate-scale Flight Testing (viz., CONE)

# R & T BASE PROGRAM ELEMENTS

~~OAET~~

~~SPACE PROPULSION~~

## Lunar and Planetary Propellants (LeRC, JPL)

*Goal: Provide a Verified Technological Strategy for Reaping the Large Logistical Benefits of Utilizing Indigenous Extraterrestrial Energy Materials and Propellants*

Augmentation Objectives: [Theme: Monitor In-Situ Resource Utilization Efforts/Initiate Work Later]

- o Focus on Probable Requirements and Mission Payoffs of Indigenous Lunar and Planetary Propellants Production and Utilization
- o Identify and Critically Assess the Enabling Technologies
- o Experimentally Explore Key Production and End-use Processes (Example: Test LO2/Al "Monopropellant Slurry" in Engine)
- o Explore Ramifications of Terrestrial Energy Use of Indigenous Planetary Energy Resources (e.g., Lunar He3)

## FOCUSED PROGRAMS FUNDING (\$M)

~~OAET~~

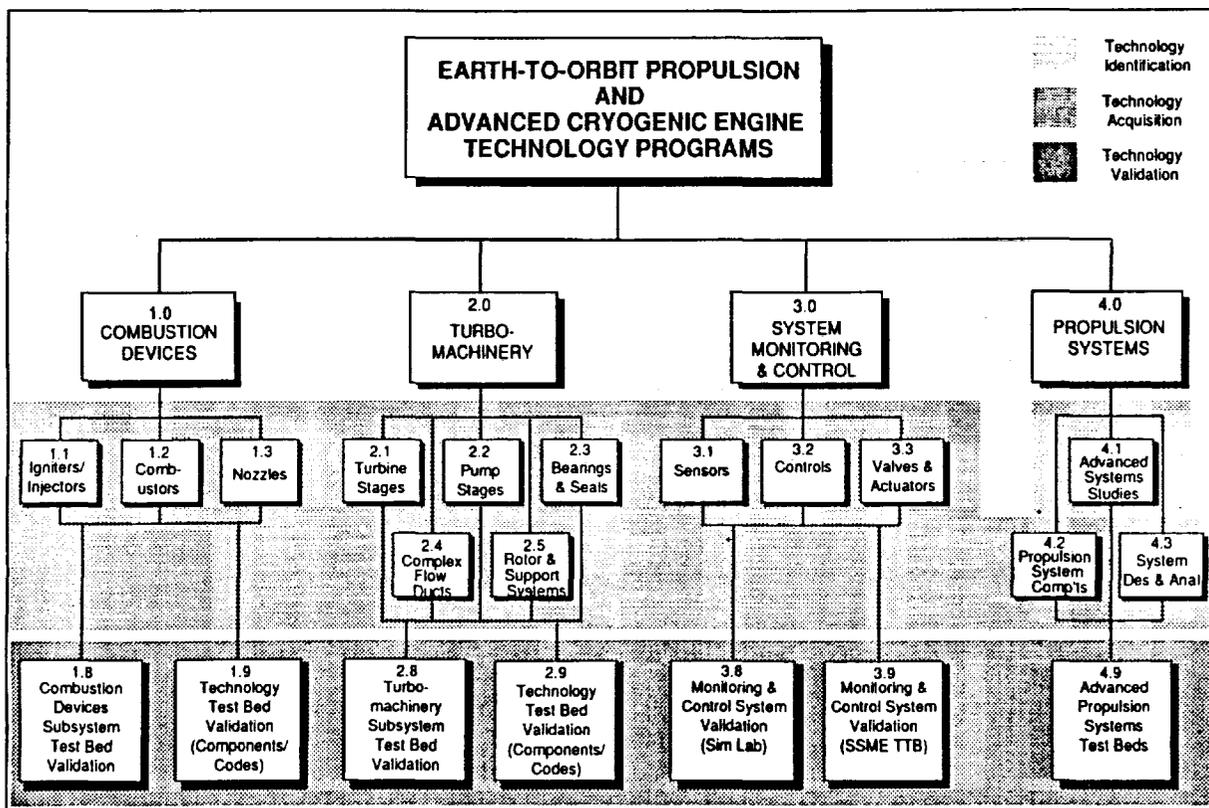
~~SPACE PROPULSION~~

PROGRAM ELEMENT		FY1991	FY1992	FY1993	FY1994	FY1995	FY1996	FY1997
ETO PROPULSION	Current	21.8	28.7	33.9	25.1	26.4	27.6	28.8
	3X	21.8	28.7	33.9	25.1	26.4	27.6	28.8
	Strategic	21.8	28.7	33.9	35.4	36/9	42.7	45.1
COMMERCIAL VEHICLE PROPULSION	Current	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	3X	0.0	4.2	10.0	17.0	23.0	29.0	28.8
	Strategic	0.0	0.0	12.0	15.0	44.1	57.7	47.1
AUX PROPULSION	Current	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	3X	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Strategic	0.0	0.0	0.0	2.3	5.4	10.9	15.9
ADV CRYO ENGINE	Current	4.0	9.0	12.6	13.2	14.0	14.7	15.4
	3X	4.0	9.0	14.9	16.7	19.6	20.2	28.0
	Strategic	4.0	9.0	15.0	24.0	31.0	45.8	42.4
CRYO FLUID SYSTEMS	Current	1.5	0.0	0.0	0.0	0.0	0.0	0.0
	3X	1.5	0.0	7.4	10.0	10.3	10.8	10.0
	Strategic	1.5	0.0	8.5	11.0	11.3	11.8	11.0
NUCLEAR THERMAL	Current	0.5	5.0	13.0	22.0	39.0	50.3	52.6
	3X	0.5	5.0	13.0	22.0	39.0	50.3	52.6
	Strategic	0.5	5.0	13.0	22.0	39.0	50.3	83.0
NUCLEAR ELECTRIC	Current	0.0	2.0	6.0	15.9	23.0	26.0	27.2
	3X	0.0	2.0	6.0	15.9	23.0	26.0	27.2
	Strategic	0.0	2.0	6.0	15.9	23.0	26.0	45.0

# FOCUSED PROGRAMS FUNDING (Cont'd)

(\$M)

PROGRAM ELEMENT		FY1991	FY1992	FY1993	FY1994	FY1995	FY1996	FY1997
STATION-KEEPING PROPULSION	Current	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	3X	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Strategic	0.0	0.0	2.9	4.4	3.6	0.9	0.0
S/C ON-BOARD PROP	Current	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	3X	0.0	0.0	1.0	3.0	4.3	1.2	0.0
	Strategic	0.0	0.0	1.2	3.0	4.3	1.2	0.0
CONE FLT EXPT	Current	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	3X	0.0	0.0	3.3	14.8	23.5	26.0	27.2
	Strategic	0.0	0.0	3.4	19.4	24.6	25.0	14.5
SEPS FLT EXPT	Current	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	3X	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Strategic	0.0	0.0	6.3	11.6	11.5	7.6	0.9
COHE FLT EXPT	Current	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	3X	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Strategic	0.0	0.0	0.0	0.0	0.0	3.6	17.0
<b>TOTALS</b>	Current	<b>27.8</b>	<b>44.7</b>	<b>65.5</b>	<b>76.2</b>	<b>102.4</b>	<b>118.6</b>	<b>124.0</b>
	3X	<b>27.8</b>	<b>44.7</b>	<b>83.7</b>	<b>117.5</b>	<b>163.1</b>	<b>182.1</b>	<b>194.3</b>
	Strategic	<b>27.8</b>	<b>44.7</b>	<b>102.2</b>	<b>164.0</b>	<b>234.7</b>	<b>283.5</b>	<b>321.9</b>



Work Breakdown Structure

# FOCUSED PROGRAM ELEMENTS

~~OAET~~

~~SPACE PROPULSION~~

## Earth-to-Orbit (ETO) Propulsion Technology (MSFC, LeRC)

*Special Note: Augmentation refers to "Strategic" funding plan; "X" is presently identical to "Current"*

*Goal: For all Engine Subsystem areas to Provide Advanced Test-Validated Analysis and Design Tools, Materials and Fabrication Processes, and Hardware/Software-Specific New Technologies such that Next-generation ETO Propulsion Systems can be more promptly and systematically developed at significantly lower risk and cost, while being more reliable and operable than current systems, all without compromising performance*

Augmentation Objectives: [Theme: Expand the Time-Horizon and Purview]

- o Increase the Relevance and "Technology Products" Contribution of the Combustion Device, Turbomachinery and ICHM work-areas to both Ongoing and Planned New ETO (+ in-space) Propulsion Systems
- o Redouble Program efforts to mechanize Large-scale Experimental Subsystem Validation Thrusts in Combustion Devices and Turbomachinery areas; complete/operate MSFC "SimLab" (ICHM)
- o Expand Program purview into the "beyond-engine" Propulsion System Arena, e.g., Technology for both Ground and Flight components such as zero-leak connections and disconnects (Poor-operability "pull")
- o Increase Program technical coverage to include promising non-traditional propulsion systems, e.g., Hybrid and Combined-cycle (airbreathing/rocket) Propulsion (requires systems studies)

# FOCUSED PROGRAM ELEMENTS

~~OAET~~

~~SPACE PROPULSION~~

## Advanced Cryogenic Engines (Space Chemical Engine Technology, SCET) (LeRC, MSFC)

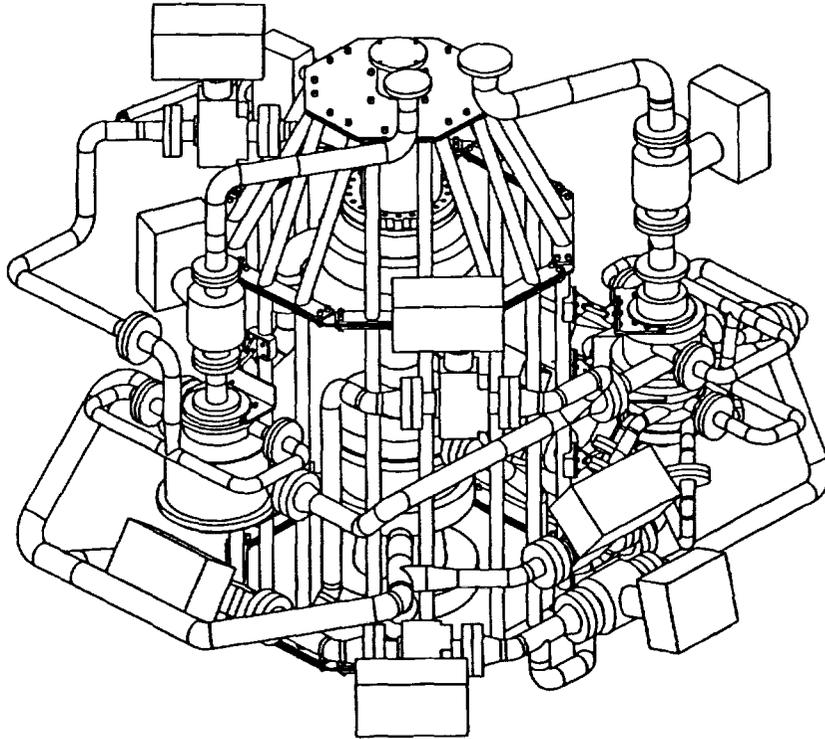
*Goal: "Restore to Health" this just-initiated and ambitious Program which was funding-decimated in association with the FY 1991/92 SEI-program budgets as actually realized (vs. planned).*

Augmentation Objectives: [Theme: Reaccelerate AETB while reparalleling full component technology-advancement by entire propulsion community]

- o Restore AETB contract/government-facility operations to earlier pace and level-of-effort (Contemplate a second AETB?)
- o Via NRA (already developed for release) promptly establish a component/subsystem technology-advancement program effort
- o Initiate efforts on integrated modular engine (IME) versions of SCET applications
- o Better synergize Program taskwork with Base R&T and non-SCET program elements, e.g., Cryogenic Fluid Systems, ETO, Nuclear Thermal Propulsion Programs

# ADVANCED EXPANDER TEST BED

SPACE CHEMICAL ENGINE TECHNOLOGY (SCET) PROGRAM  
[Advanced Cryogenic Engine]



~~OAET~~

~~SPACE PROPULSION~~

## Commercial Vehicle Propulsion (MSFC, LeRC, JSC)

*Note: Presently worked under CSTI Booster and ETO, and SCET Programs*

*Goal: Responsively to COMSTAC recommendations to NASA, to meet Commercial ELV technology needs both near term (existing technology/services) and for new-design low-cost systems (advanced technology)*

Augmentation Objectives: [Theme: Work both *immediate* retrofit-type engineering and out-year new-design enabling technologies]

### Immediate/Near-Term (1-3 years to transfer)

- o Analysis and Design Tools, Fabrication Processes
- o Low Pc Thrust Chambers (e.g., advanced ablatives)
- o Low-Costs, simplified Turbopumps & Pressurization

### Longer Term (4-7 years to transfer)

- o IME, Advanced Nozzles, Expander-cycle at High Thrust
- o Hybrid Solid/Liquid Propulsion for Booster and Upper-stages

# SPACE PROPULSION TECHNOLOGY

~~OAET~~

~~SPACE PROPULSION~~

## COMSTAC KEY PROPULSION NEEDS

(Commercial Space Transportation Advisory Committee)

1. Low Cost Liquid Booster Engines - LO<sub>2</sub>/LH<sub>2</sub> (New Expander Cycle)
2. Low Cost Liquid Booster Engines - Hydrocarbon (Evolutionary)
3. Hybrid Propulsion Strap-On Boosters With Transition to High Regression Rate Non-Oxidized Fuel
4. Advanced Low Cost LO<sub>2</sub>/LH<sub>2</sub> Upper Stage Engine (30-50K Lbs Thrust)
5. Advanced Low Cost LO<sub>2</sub>/LH<sub>2</sub> Upper Stage Engine (100-200K Lbs Thrust)
6. Leak Free Tubing and Ducts
7. Low Cost Pressure Fed Engine & Turbopump Technology
8. Clean Burning Solid Motor Technology
9. Improved LOX/RP-1 and Storable Derivative Engine Components

~~OAET~~

~~SPACE PROPULSION~~

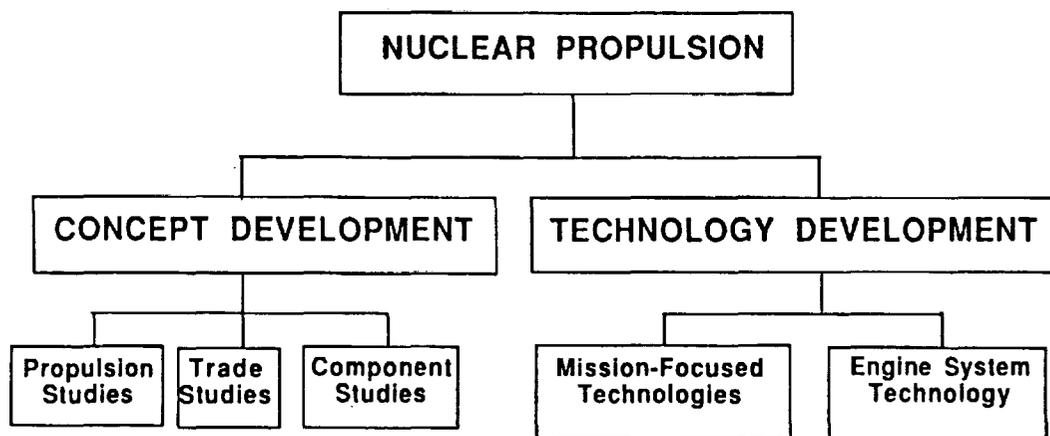
## Cryogenic Fluid Systems (LeRC, MSFC)

*Goal: Closely coordinating with all NASA and other Government related efforts, develop test-verified cryogenic fluid containment and handling technologies as required for extended spaceflight as, and when needed for development.*

Augmentation Objectives: [Theme: Maximizing Collateral Support, Achieve Needed Technology Readiness for Spaceflight and Surface-based Systems]

- o Develop to the technology-readiness stage advanced Cryogenic Insulation systems (e.g., "thick MLI", MLI + foam)
- o Perfect both one-g/zero-g subcritical Fluid Transfer and zero-g control techniques
- o Accurately model Cryo-fluid slosh characteristics for operating systems and develop design criteria for effective slosh-control techniques
- o Establish generically applicable Cryo-servicing Facility design criteria and hardware-acquisition guidelines
- o Document comprehensive Thermal and Pressure-control, Liquid Supply and Handling, and fluid-transfer design/operating guidelines (Dependent on successful conclusion of CONE and CONE flight tests)

# NUCLEAR PROPULSION WBS



## FOCUSED PROGRAM ELEMENTS

~~OAET~~

~~SPACE PROPULSION~~

### Nuclear Thermal Propulsion (NTP) (NASA\*, DOE, DoD)

\*NASA Center Involvement: LeRC, MSFC, JSC

*Special Note: Except 1997\*, "Strategic", "3X" and "Current" funding plans for NTP are identical*

*Goal: Capitalizing on the significant national NTP hardware-demonstrated background (e.g., NERVA), a multi-agency technology investment, seeking out innovative approaches, will develop a state of technology readiness for initiating the development of an NTP system for human missions to Mars.*

Augmentation Objectives: [Theme: National program, building heavily on past achievements and current innovation, will achieve a viable system]

- o Achieve a safe, reliable and high-performance nuclear propulsion system technology base predicated on past accomplishments
- o Seek innovative approaches for improving the NTP S.O.A.
- o Achieve a Government + Public consensus supporting the safe use of Nuclear Propulsion in space as being feasible/acceptable
- o (NASA) Coordinate with DOE and DoD (including appropriate Agency and National Laboratories) to maximize use of total national expertise and physical resources (e.g. test facilities)
- o Conduct a phased, focused NTP technology development and verification program which remains flexibly responsive to Mars precursor and manned missions

# FOCUSED PROGRAM ELEMENTS

~~OAET~~

~~SPACE PROPULSION~~

## Nuclear Electric Propulsion (NTP) (NASA\*, DOE, DoD)

\*NASA Center Involvement: LeRC, JSC, JPL

*Special Note: Except 1997\*, "Strategic", "3X" and "Current" funding plans for NTP are identical*

*Goal: Capitalizing on the significant national hardware-related ongoing nuclear space power efforts (e.g., SP-100), a multi-agency technology investment, seeking out innovative approaches, will develop a state of technology readiness for initiating the development of an NEP system for missions to Mars*

Augmentation Objectives: [Theme: National program, building heavily on current space nuclear power and innovation, will achieve a viable system]

- o Achieve a safe, reliable and high-performance nuclear electric propulsion system technology base predicated partly on ongoing developments
- o Seek innovative approaches for improving the NEP S.O.A.
- o Achieve a Government + Public consensus supporting the safe use of Nuclear Propulsion in space as being feasible/acceptable
- o (NASA) Coordinate with DOE and DoD (including appropriate Agency and National Laboratories) to maximize use of total national expertise and physical resources (e.g. test facilities)
- o Conduct a phased, focused NEP technology development and verification program which remains flexibly responsive to Mars precursor and manned missions

# FOCUSED PROGRAM ELEMENTS

~~OAET~~

~~SPACE PROPULSION~~

## Spacecraft On-Board Propulsion (LeRC, JPL)

*Goal: Provide Dual-mode (NTO/N2H4) Propulsion for Planetary Missions*

Augmentation Objectives: [Theme: Readiness for Planetary Missions]

- o Demonstrate dual-mode "hot rocket" and advanced tankage

## Station-keeping Propulsion (LeRC, JSC)

*Goal: Provide Integrated H2/O2 + Resistojet Capabilities for Platforms*

Augmentation Objectives: [Theme: Enable logistics, operations benefits]

- o Demonstrate H2/O2 Thrusters & Low-pressure electrolysis
- o Demonstrate Single Resistojet for Waste water and gas

## Auxiliary Propulsion (JSC, LeRC)

*Goal: Provide Integrated (common-propellant supply) auxiliary propulsion*

Augmentation Objectives: [Theme: System & Operations simplification]

- o Demonstrate radiation-cooled Earth- & Space Storable thrusters
- o Provide complete-system technologies for integrated system

# TECHNOLOGY FLIGHT EXPERIMENTS

~~OAET~~

~~SPACE PROPULSION~~

## ***Cryogenic Orbital Nitrogen Experiment (CONE) (LeRC, MSFC)***

***Goal:*** Acquire low-g Flight Data needed for Design Tool validation for LO2 and LN2 Pressure-control, Liquid Acquisition and Transfer-system transportation and platform applications; extrapolate to at least partially validate LH2 applications

**Augmentation Objectives:** [Theme: LN2 & LO2 Flight-data Validation]

- o Assess effectiveness of passive pressure control
- o Acquire low-g data for active pressure control system
- o Demonstrate 100:1 reduction in mixer power (active control)
- o Demonstrate effective zero-g liquid acquisition devices (LAD)
- o Demonstrate no-vent fill, and rapid venting and safing
- o Explore zero-g tank chilldown, LAD efficiency and autogenous pressurization
- o Extrapolate to pressure-control, LAD and transfer of LH2

# TECHNOLOGY FLIGHT EXPERIMENTS

~~OAET~~

~~SPACE PROPULSION~~

## ***Cryogenic Orbital Hydrogen Experiment (COHE) (LeRC, MSFC)***

***Goal:*** Acquire low-g Flight Data needed for Design Tool validation for LH2 Pressure-control, Liquid Acquisition and Transfer-system transportation and platform applications

**Augmentation Objectives:** [Theme: LH2 Systems Flight-Data Validation]

- o Validate predictive analysis tools for liquid withdrawal (LADs)
- o Establish criteria and efficiency of no-vent fill
- o Demonstrate effectiveness of insulation systems & components
- o Demonstrate capability to meet system-safety criteria
- o Provide test-proven autogenous pressurization in transfer
- o Demonstrate flight-qualified mass gauging in zero-g operation
- o Establish effectiveness of passive pressure-control

# TECHNOLOGY FLIGHT EXPERIMENTS

~~OAET~~

~~SPACE PROPULSION~~

## **SOLAR ELECTRIC PROPULSION (LeRC, JPL)**

Goal: *Demonstrate Feasibility of SEP via Flight Test*

Augmentation Objectives: [Theme: Evolutionary Risk/Cost to Acceptance]

- o Launch on Delta ELV
- o APSA PV Panels (1-2 kWe) with Two Propulsion Types
  - "Derated" Xenon Ion Thruster and Low-Power H2 Arcjet
  - Subscale Cryo H2 Container (Mod. Orbiter PSRA Tank)
- o Planned Schedule/Costs through Launch
  - Ion: 42 Months, \$8.1M
  - Arcjet 48 Months, \$14.7M

~~OAET~~

~~SPACE PROPULSION~~

## **REVIEW QUESTIONS**

- o Is the program content/approach correct?
- o Is the level of investment correct?
- o Given the available funding are the priorities correct?
- o Is the user interface being properly coordinated?
- o Are the efforts being properly coordinated?
- o Are the participants correct?
- o Is the R&T Base content innovative enough to provide improved capability for future user/mission applications?
- o Does the R&T Base activity maintain or enhance NASA's technical capabilities?