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SSTAC/ARTS REVIEW OF THE DRAFT INTEGRATED TECHNOLOGY PLAN (ITP)

Volume II: June 26-27

Propulsion Systems

Briefings from the
June 24-28, 1991 Conference
McLean, Virginia

National Aeronautics and Space Administration
Office of Aeronautics, Exploration and Technology
Washington, D.C. 20546

SSTAC/ARTS REVIEW OF THE DRAFT ITP
McLean, Virginia
June 24-28, 1991

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Propulsion Systems

TABLE OF CONTENTS

SSTAC/ARTS REVIEW OF THE DRAFT INTEGRATED TECHNOLOGY PLAN (ITP)

Space Propulsion Technology

TABLE OF CONTENTS

Office of
Aeronautics,
Exploration and
Technology

51-20
N93-71874
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

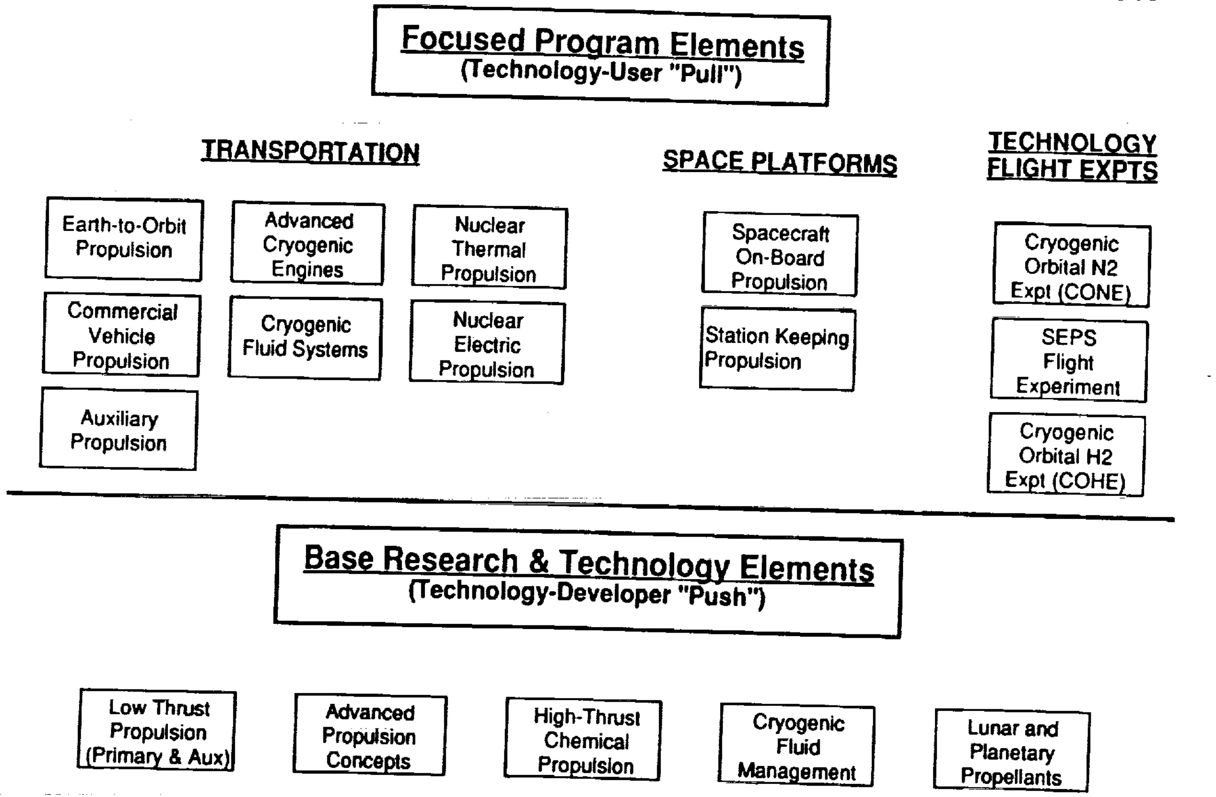
Program New Initiatives and Exemplary Augmentation Opportunities/Payoffs

Program Element Augmentation Budgets and Goals/Objectives

- *Base Research & Technology Elements*
- *Focused Technology Elements*
- *Flight Test Elements*

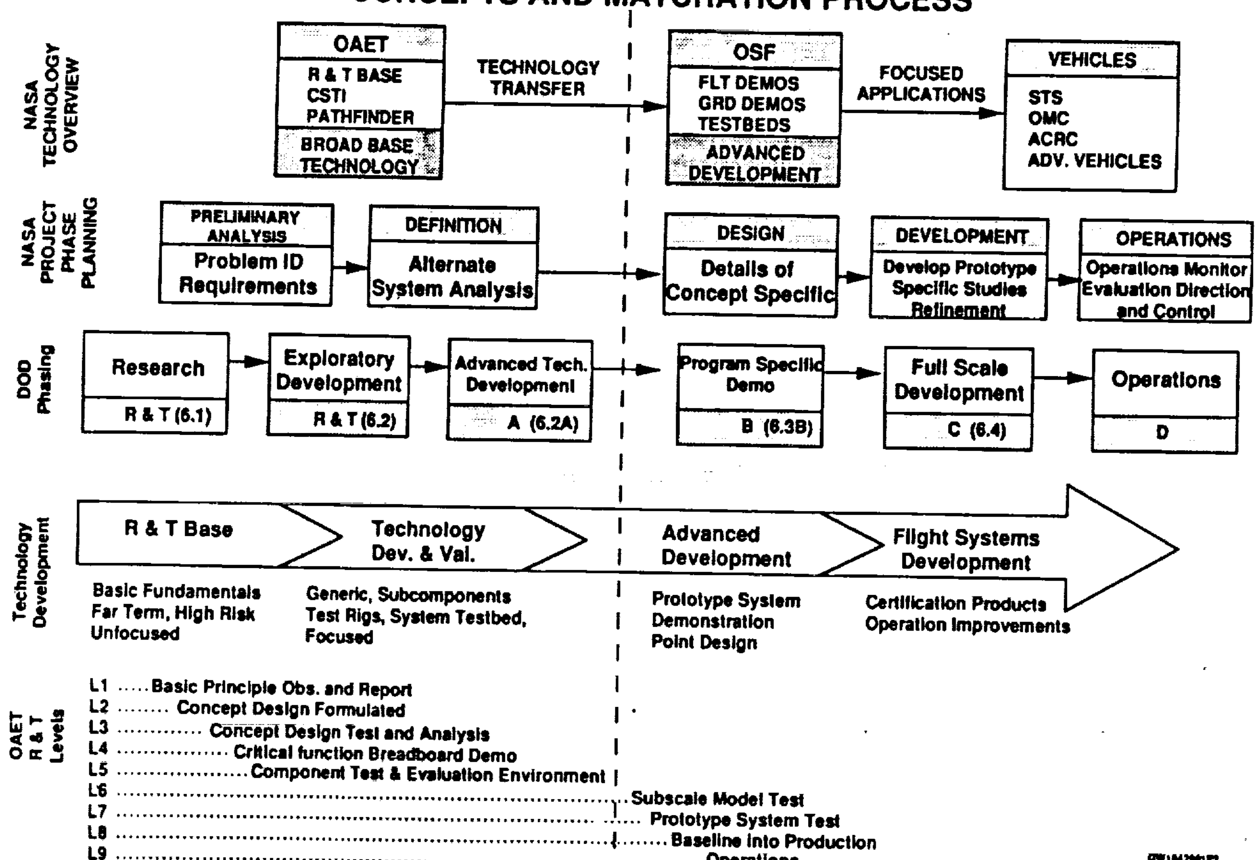
SPACE PROPULSION TECHNOLOGY PROGRAMS

OAET — SPACE PROPULSION



NASA /John C. Stennis Space Center

RESEARCH AND TECHNOLOGY CONCEPTS AND MATURATION PROCESS



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

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 opf their very high performance levels. . ."

NEW/ETO & SCET

INTEGRATED MISSION/VEHICLE/PROPULSION PLANNING-VISIBILITY STUDIES

Advanced Manned Transportation Systems (AMLS)

- 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, H2/O2
- 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, H2/O2 (Incl. SCET transfer, planetary applications)

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:

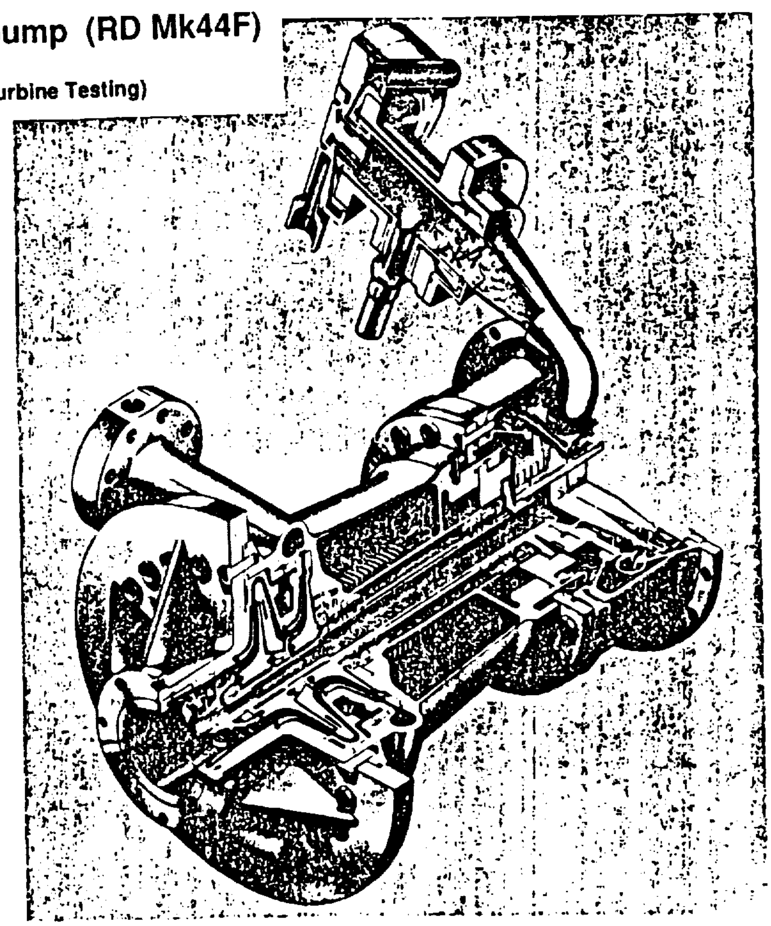
Using existing LH2 Turbopump (Mk44F), fab nozzle ring and turbine wheel, checkout in hot-gas facility, then install in complete turbopump and run (LeRC)

What Does Augmentation Buy?

- o Accelerates effort into full-scale subystem 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

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

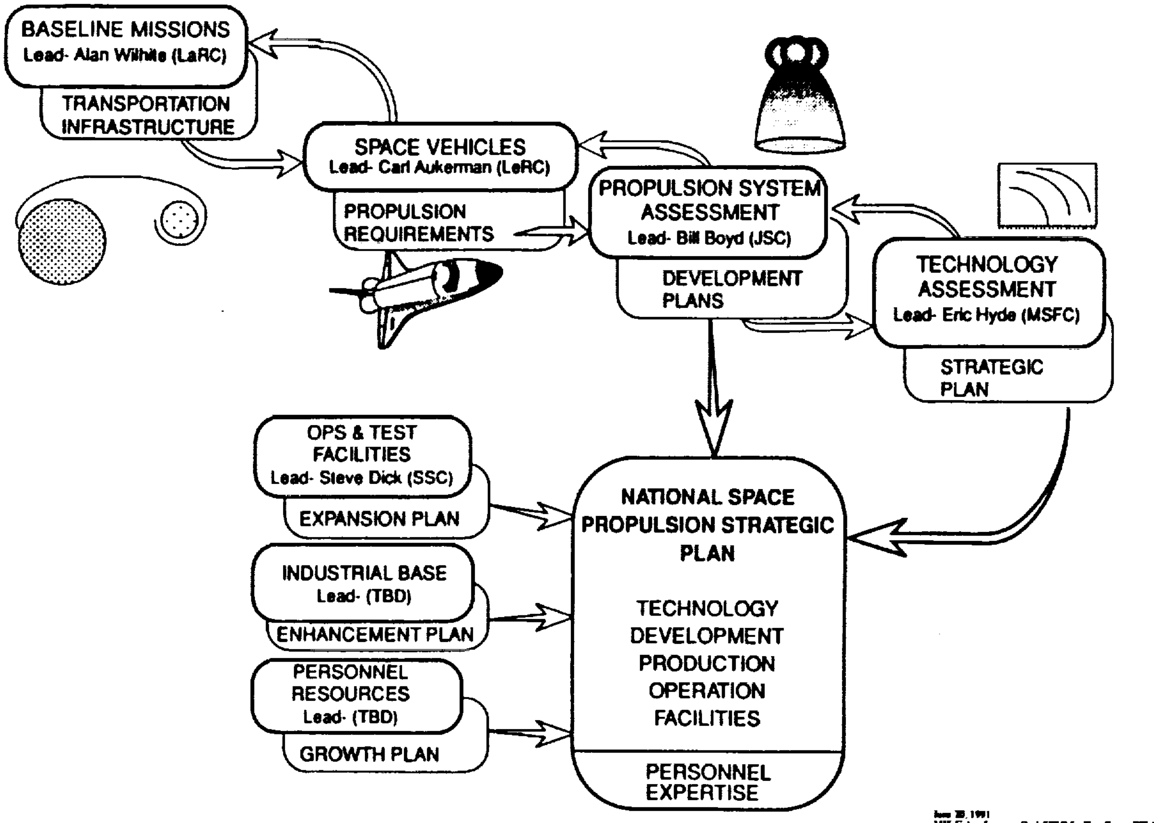
OAET SPACE-PROPULSION

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



OAET — SPACE PROPULSION

Focused Program Elements

TRANSPORTATION

- Earth-to-Orbit Propulsion
- Advanced Cryogenic Engines
- Nuclear Thermal Propulsion
- Commercial Vehicle Propulsion
- Cryogenic Fluid Systems
- Nuclear Electric Propulsion
- Auxiliary Propulsion

SPACE PLATFORMS

- Spacecraft On-Board Propulsion
- Station Keeping Propulsion

TECHNOLOGY FLIGHT EXPTS

- Cryogenic Orbital N2 Expt (CONE)
- SEPS Flight Experiment
- Cryogenic Orbital H2 Expt (COHE)

Base R&T

- Low Thrust Propulsion (Primary & Aux)
- Advanced Propulsion Concepts
- High-Thrust Chemical Propulsion
- Cryogenic Fluid Management
- Lunar and Planetary Propellants

☐ 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)

Element Title *Responsible Centers*

Overall Goal

Low-Thrust Propulsion (LeRC/JPL)

Goal: For a variety of chemical and electric propulsion applications, to develop a technological base for significantly increasing component life, reliability and performance, while decreasing potential life-cycle costs.

Key Specific Objectives

Overarching Theme Statement

Augmentation Objectives: [Theme: Aggressively Push Toward Transfer]

- o Accelerate Hot Rocket Demonstration and Transfer (100 lbf)
- o Provide Mission-tailored Space Storable Rocket Capabilities
- o Early Integrated H2/O2-Resistojet Combination Demonstrated
- Etc.

PROPULSION R&T BASE FUNDING

($M)

Lunar/Planetary
FY95 $2.0M
FY96 $3.1M
FY97 $4.0M

OAET — SPACE PROPULSION

SUB-ELEMENTS		FY1991	FY1992	FY1993	FY1994	FY1995	FY1996	FY1997
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
SUB-ELEMENT TOTALS	Current	12.0	12.7	12.5	13.0	13.5	14.0	14.6
	3X	12.0	12.7	16.3	21.5	24.6	27.0	30.4
	Strategic	12.0	12.7	18.4	23.3	27.4	31.2	36.2
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
TOTALS	Current	14.8	16.7	17.2	18.0	18.8	19.7	20.6
	3X	14.8	16.7	20.4	26.2	30.1	32.9	36.9
	Strategic	14.8	16.7	23.0	28.7	33.7	38.0	43.9

R & T BASE PROGRAM ELEMENTS

OAET — 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 H2/O2 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

OAET — 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 Electrodeless 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

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 MajorReliability and Operability Improvements (Example: High-Temperature Superconducting Magnetic Bearings)
- o Open the Way to all-pervasive Propulsion Health Mangement 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 FlightTesting (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 Extraterretrial 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)

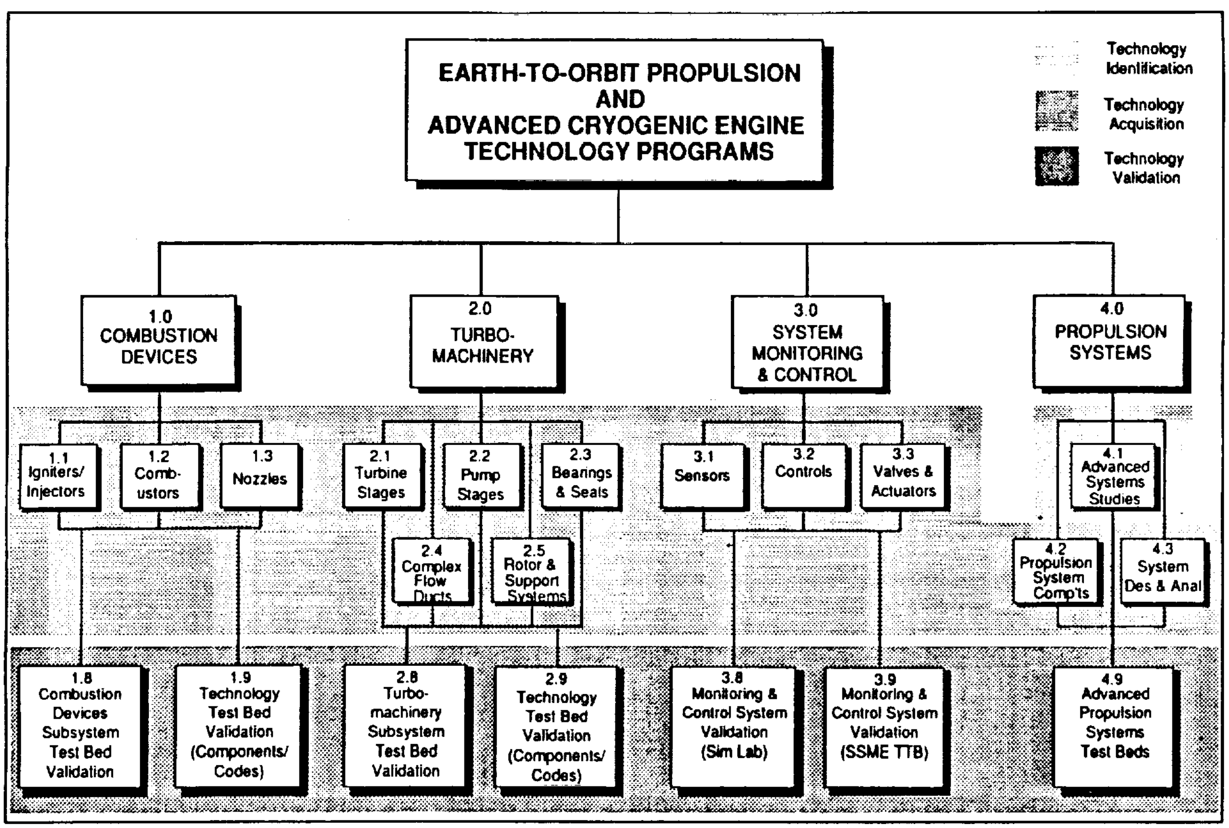
OAET — SPACE PROPULSION

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
TOTALS	Current	27.8	44.7	65.5	76.2	102.4	118.6	124.0
	3X	27.8	44.7	83.7	117.5	163.1	182.1	194.3
	Strategic	27.8	44.7	102.2	164.0	234.7	283.5	321.9



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)

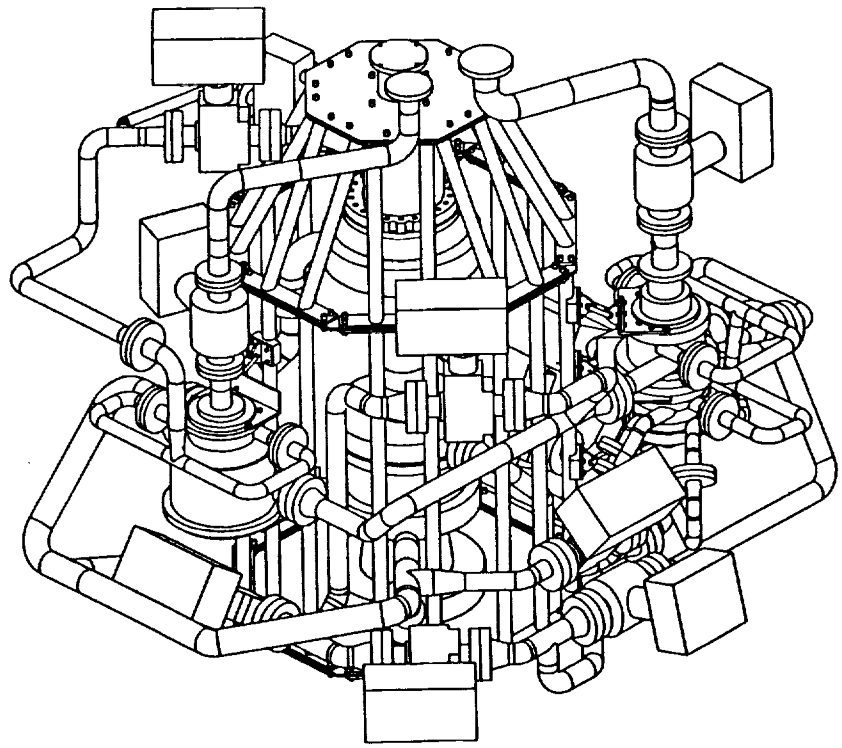
Goal: "Restore to Health" this just-initiated and ambitious Program which was funding-decimated in association with the FY 1991/92 SEI-program budgets as actually realized (vs. planned).

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 Propulson Programs

ADVANCED EXPANDER TEST BED

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



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

COMSTAC KEY PROPULSION NEEDS
(Commercial Space Transportation Advisory Committee)

1. **Low Cost Liquid Booster Engines - LO2/LH2 (New Expander Cycle)**
2. **Low Cost Liquid Booster Engines - Hydrocarbon (Evolutionary)**
3. **Hybrid Propulsion Strap-On Boosters WithTransition to High Regression Rate Non-Oxidized Fuel**
4. **Advanced Low Cost LO2/LH2 Upper Stage Engine (30-50K Lbs Thrust)**
5. **Advanced Low Cost LO2/LH2 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**

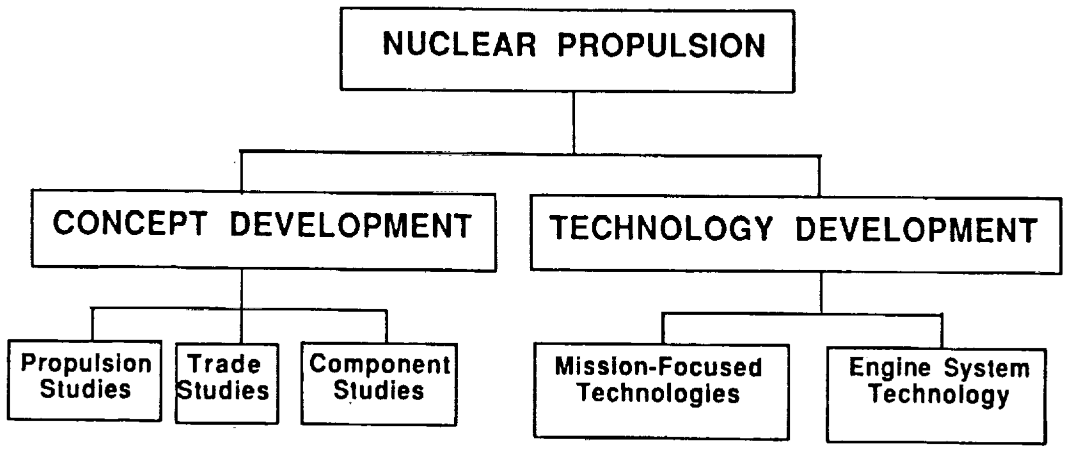
Cryogenic Fluid Systems (LeRC, MSFC)

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

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

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 technolgoy 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 Thrustors & 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 thrustors
- 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 Demostrate 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 guaging in zero-g operation
- o Establish effectiveness of passive pressure-control

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 Thrustor 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?

Office of Aeronautics, Exploration and Technology

Fact Sheets:
Element Characterization and Funding Schedules

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p. 3

SPACE PROPULSION TECHNOLOGY PROGRAM OVERVIEW

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

PROGRAM ELEMENT MATURITY, EXTENT PLANNED

OAET — SPACE PROPULSION

Focused Program Elements

TRANSPORTATION

- Earth-to-Orbit Propulsion
- Advanced Cryogenic Engines
- Nuclear Thermal Propulsion
- Commercial Vehicle Propulsion
- Cryogenic Fluid Systems
- Nuclear Electric Propulsion
- Auxiliary Propulsion

SPACE PLATFORMS

- Spacecraft On-Board Propulsion
- Station Keeping Propulsion

TECHNOLOGY FLIGHT EXPTS

- Cryogenic Orbital N2 Expt (CONE)
- SEPS Flight Experiment
- Cryogenic Orbital H2 Expt (COHE)

Base R&T

- Low Thrust Propulsion (Primary & Aux)
- Advanced Propulsion Concepts
- High-Thrust Chemical Propulsion
- Cryogenic Fluid Management
- Lunar and Planetary Propellants

Legend:

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

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)

OAET — SPACE PROPULSION

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
TOTALS	Current	27.8	44.7	65.5	76.2	102.4	118.6	124.0
	3X	27.8	44.7	83.7	117.5	163.1	182.1	194.3
	Strategic	27.8	44.7	102.2	164.0	234.7	283.5	321.9

PROPULSION R&T BASE FUNDING
($M)

OAET — SPACE PROPULSION

SUB-ELEMENTS		FY1991	FY1992	FY1993	FY1994	FY1995	FY1996	FY1997
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
SUB-ELEMENT TOTALS	Current	12.0	12.7	12.5	13.0	13.5	14.0	14.6
	3X	12.0	12.7	16.3	21.5	24.6	27.0	30.4
	Strategic	12.0	12.7	18.4	23.3	27.4	31.2	36.2
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
TOTALS	Current	14.8	16.7	17.2	18.0	18.8	19.7	20.6
	3X	14.8	16.7	20.4	26.2	30.1	32.9	36.9
	Strategic	14.8	16.7	23.0	28.7	33.7	38.0	43.9

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P-18

LOW THRUST PROPULSION

INTEGRATED TECHNOLOGY PLAN

EXTERNAL REVIEW

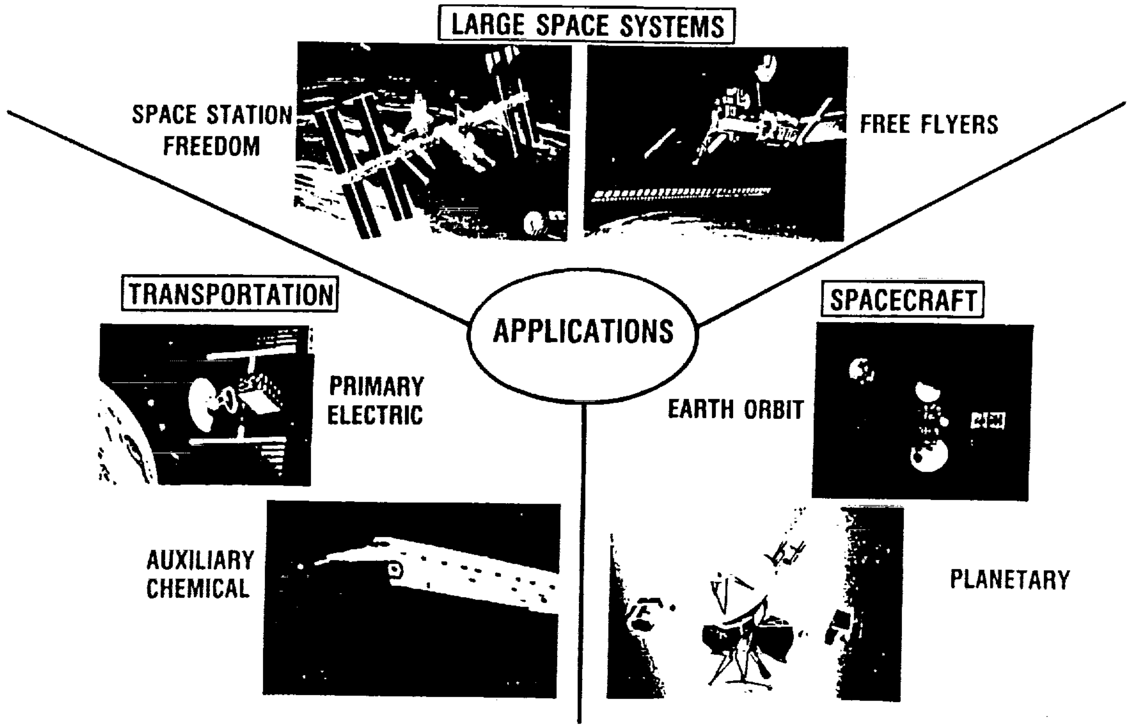
JUNE 26, 1991

LOW THRUST PROPULSION

AGENDA

- APPLICATIONS
- OBJECTIVE
- STATE-OF-ART MISSION IMPACTS
  - EARTH SPACE
  - PLANETARY
- PROGRAM
  - APPROACH
  - CONTENT
    = "STRATEGIC"
    = "CURRENT"
- ADVANCED TECHNOLOGY BENEFITS
- SUMMARY

LOW THRUST PROPULSION



AEROSPACE TECHNOLOGY DIRECTORATE

SPACE PROPULSION TECHNOLOGY DIVISION

NASA
Lewis Research Center

LOW THRUST PROPULSION

OBJECTIVE

PROVIDE TECHNOLOGIES FOR A BROAD RANGE OF FUTURE SPACE SYSTEMS

- SPACECRAFT
  - —PLANETARY
  - —EARTH-ORBITAL
- LARGE SPACE SYSTEMS
  - —SPACE STATION
  - —TENDED
- VEHICLES
  - —EARTH-TO-ORBIT
  - —ORBIT TRANSFER

CD-90-47460

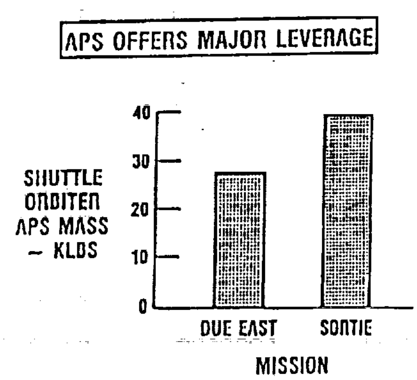
STATE-OF-ART

LOW THRUST PROPULSION

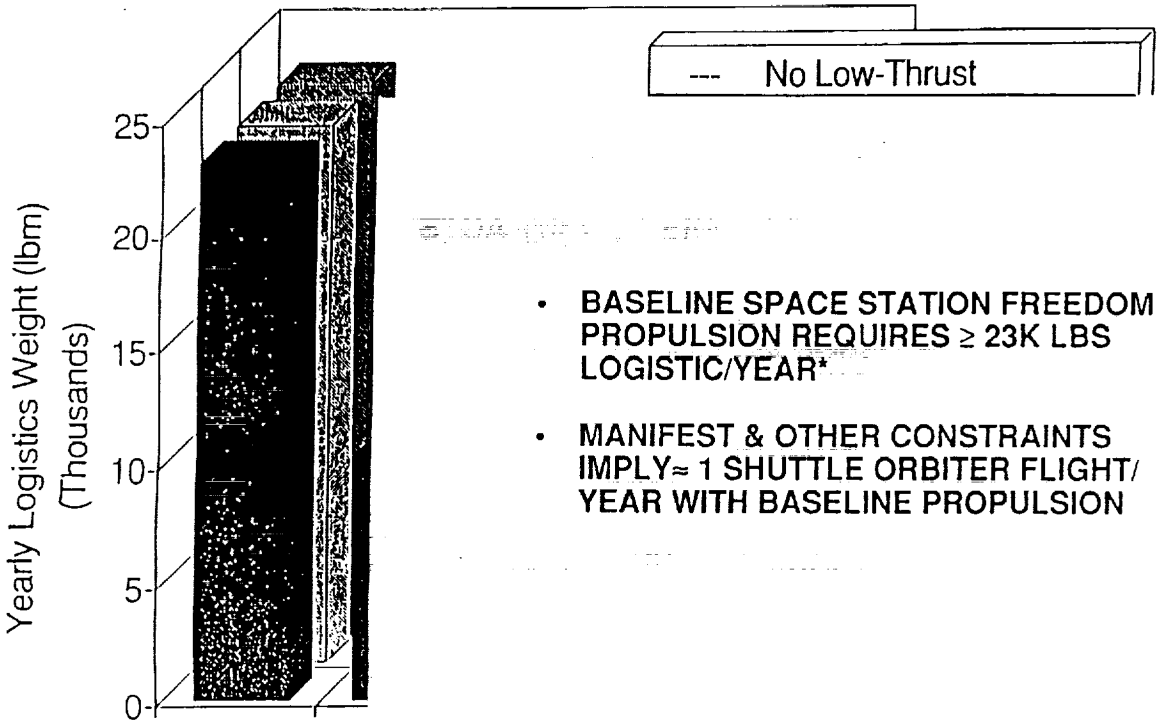
MISSION IMPACTS

- LOW EARTH ORBIT (LEO):
  - ORBITER APS
  - SPACE STATION
- GEOSYNCHRONOUS (GEO):
  - TRANSFER ORBIT (GTO)
  - SATELLITES
- PLANETARY

LOW THRUST PRIMARY AND AUXILIARY PROPULSION



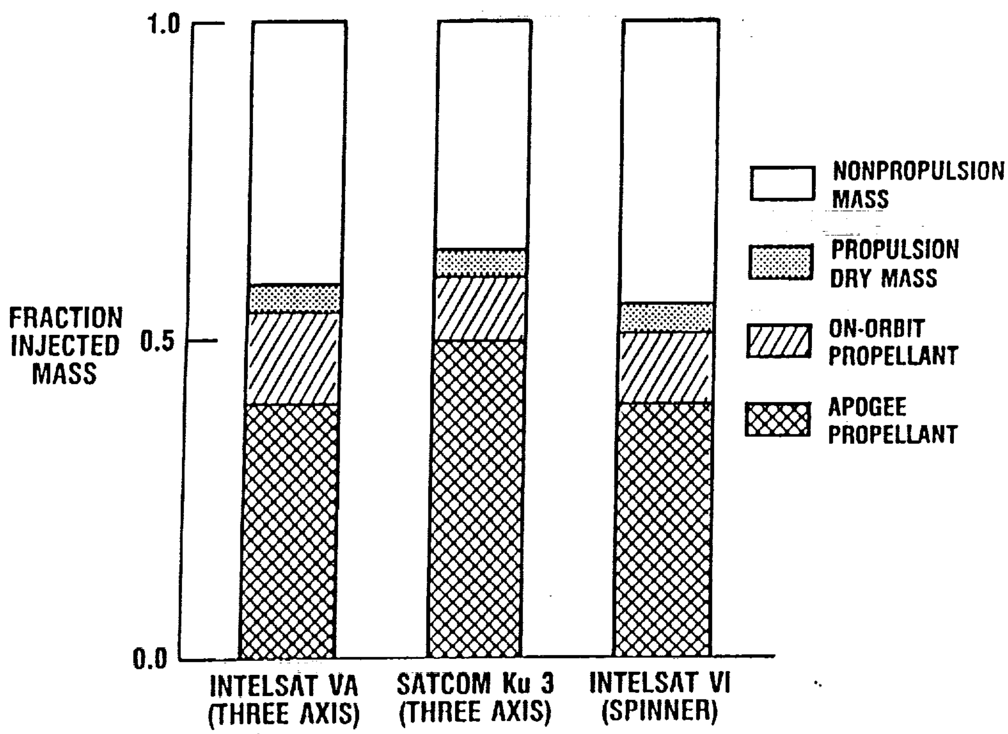
- APS MASS IS 11.4% TO 10.6% OF ORBITER



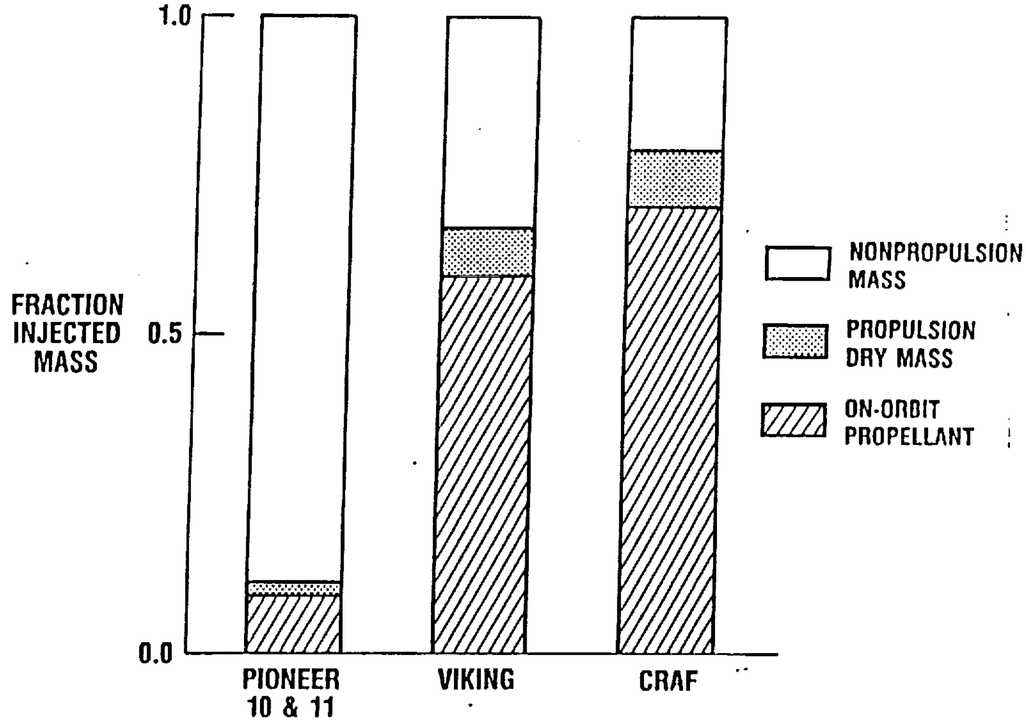
- BASELINE SPACE STATION FREEDOM PROPULSION REQUIRES ≥ 23K LBS LOGISTIC/YEAR*
- MANIFEST & OTHER CONSTRAINTS IMPLY≈ 1 SHUTTLE ORBITER FLIGHT/ YEAR WITH BASELINE PROPULSION

* AVERAGED OVER 11 YEAR CYCLE

GEOSYNCHRONOUS TRANSFER ORBIT MASS FRACTIONS FOR RECENT COMMUNICATIONS SATELLITES



PLANETARY SPACECRAFT INJECTED MASS FRACTIONS



STATE -OF-ART

LOW THRUST PROPULSION

MISSION IMPACTS

LEO

- 12-19% OF ORBITER DELVERED MASS (> 50% OF PAYLOAD)
- ~ ORBITER/YEAR FOR SPACE STATION LOGISTICS

GEO

- 55-65% OF MASS DELIVERED TO GTO
- ON-ORBIT LIFE LIMITER

PLANETARY

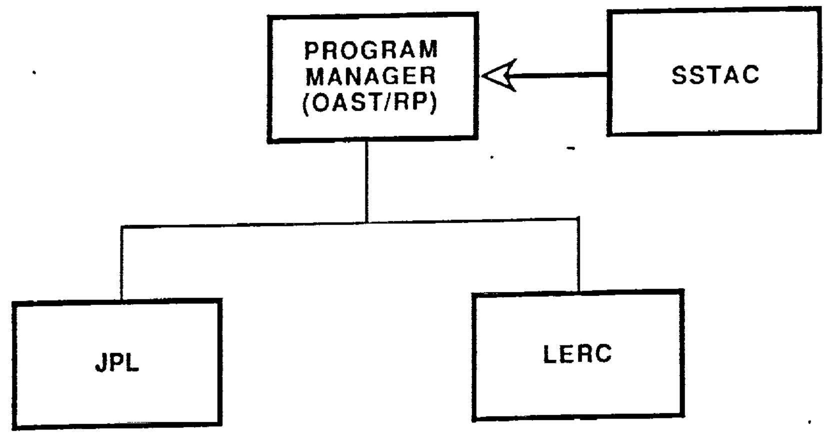
- OVER 80% OF INJECTED MASS FOR PLANNED MMII MISSIONS

IN-SPACE FRACTIONAL MISSION PENALTIES REDUCED ONLY BY IMPROVED IN-SPACE PROPULSION

LOW THRUST PRIMARY & AUXILIARY PROPULSION

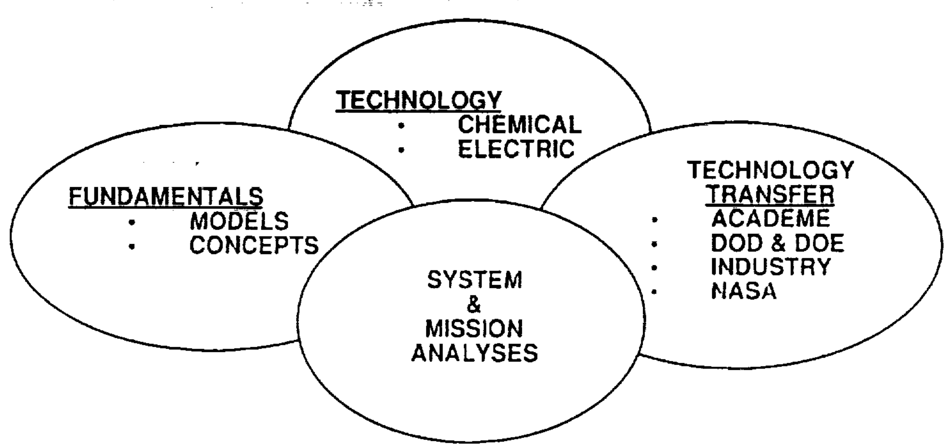
MANAGEMENT STRUCTURE

506-42-31



LOW THRUST PROPULSION

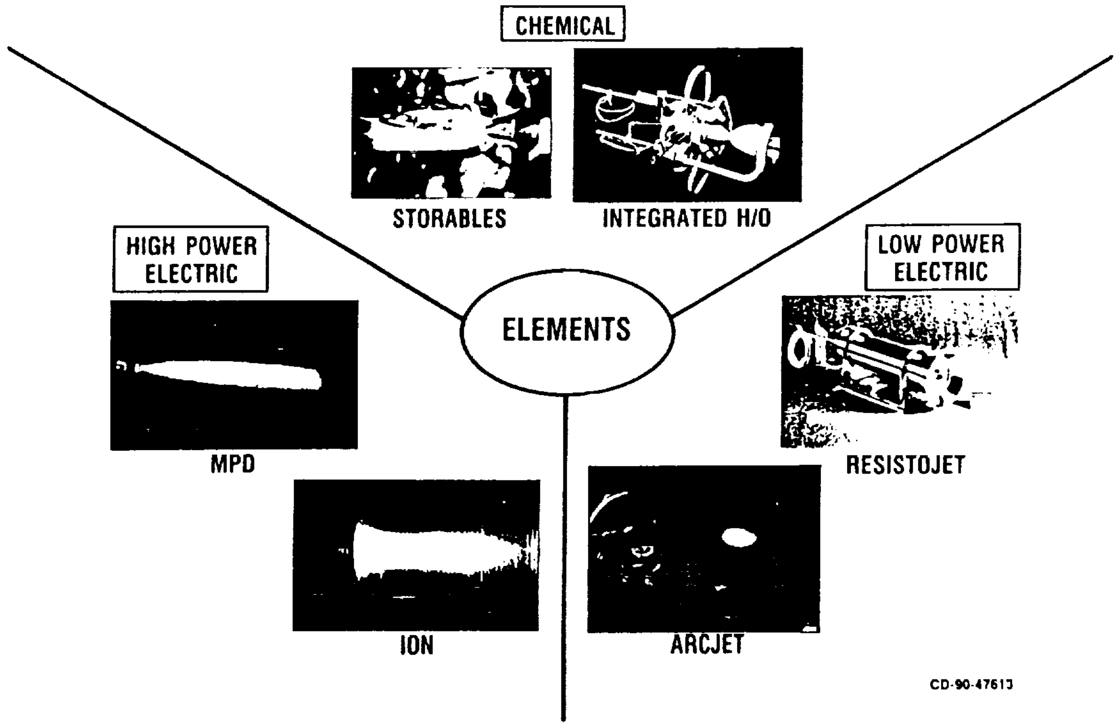
PROGRAMMATIC APPROACH



PROGRAM STRUCTURED TO SUPPORT:

- TECH TRANSFER & APPLICATIONS VERSUS TIME
- MAJOR BENEFITS FOR FUTURE MISSIONS

LOW THRUST PROPULSION



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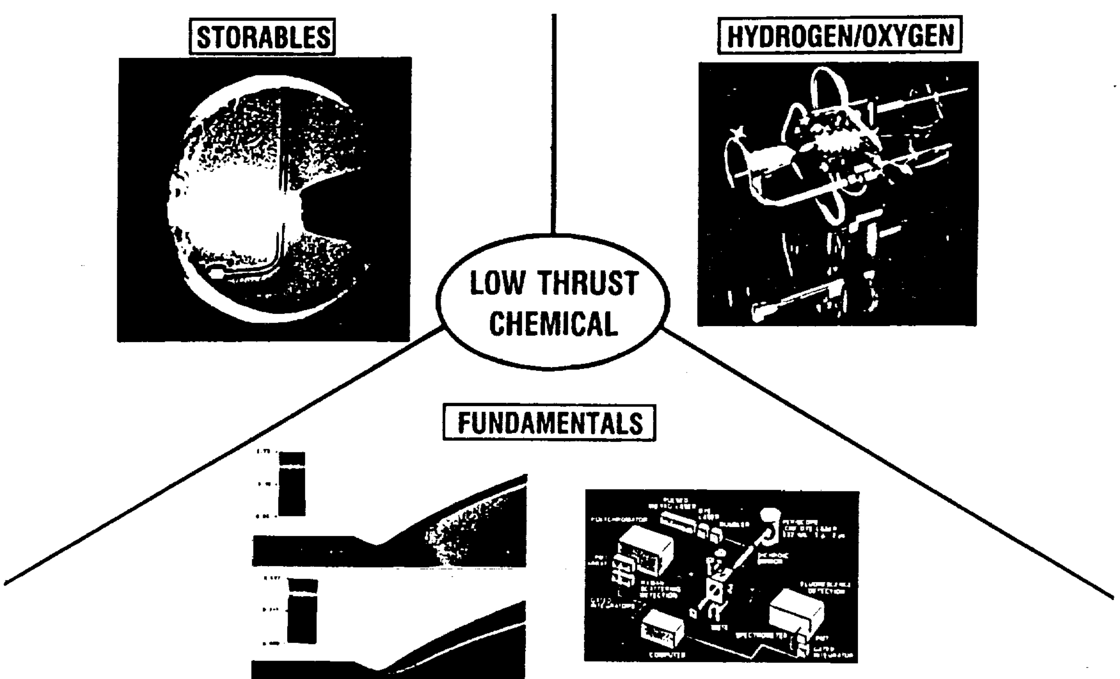
LOW THRUST PROPULSION



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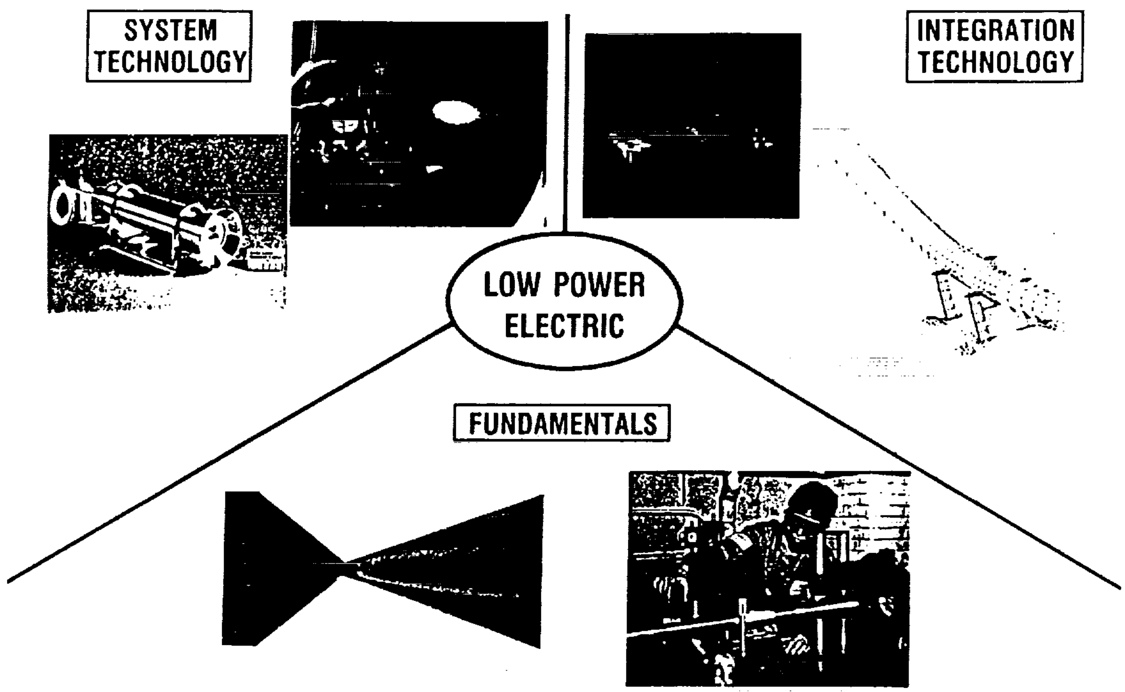
LOW THRUST PROPULSION



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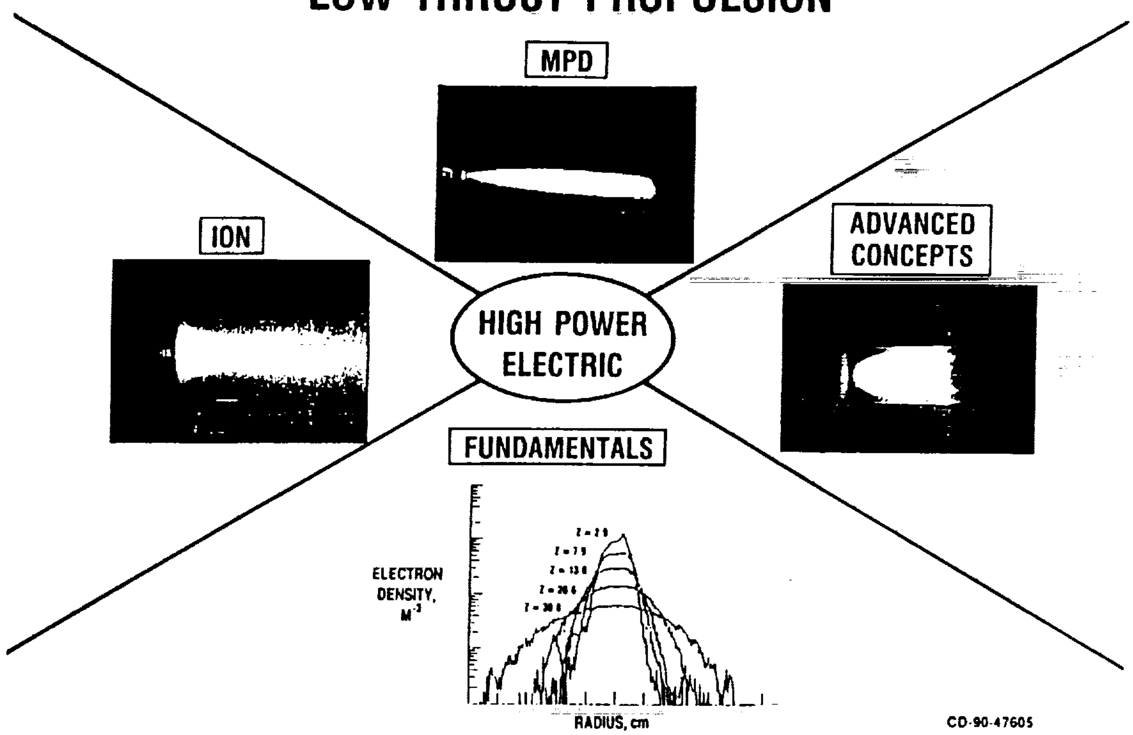
LOW THRUST PROPULSION



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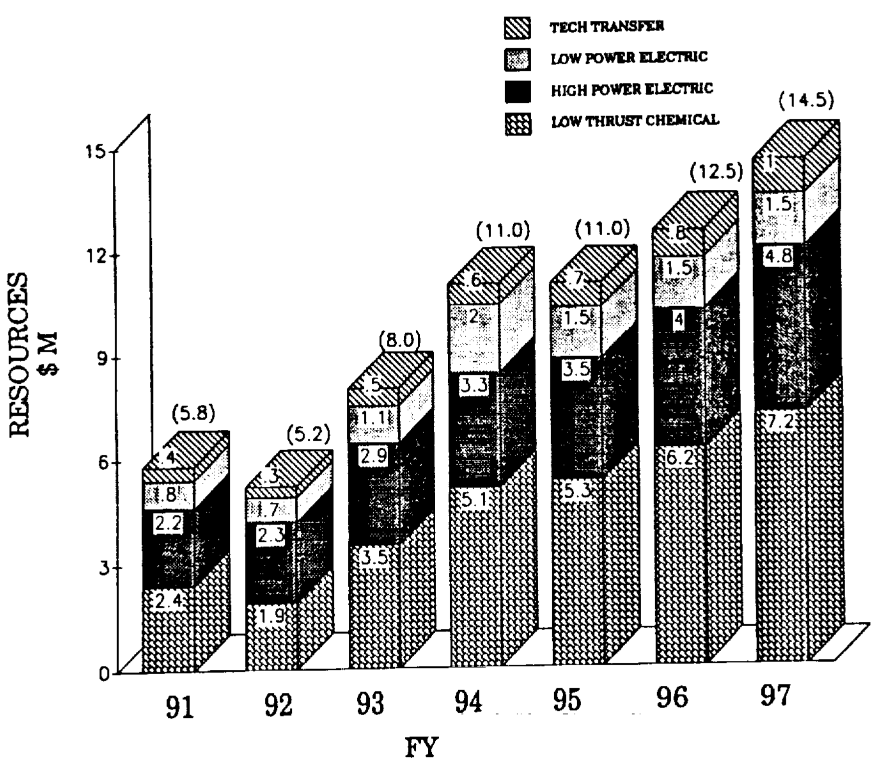
TECHNOLOGY TRANSFER

MECHANISMS/EFFORTS

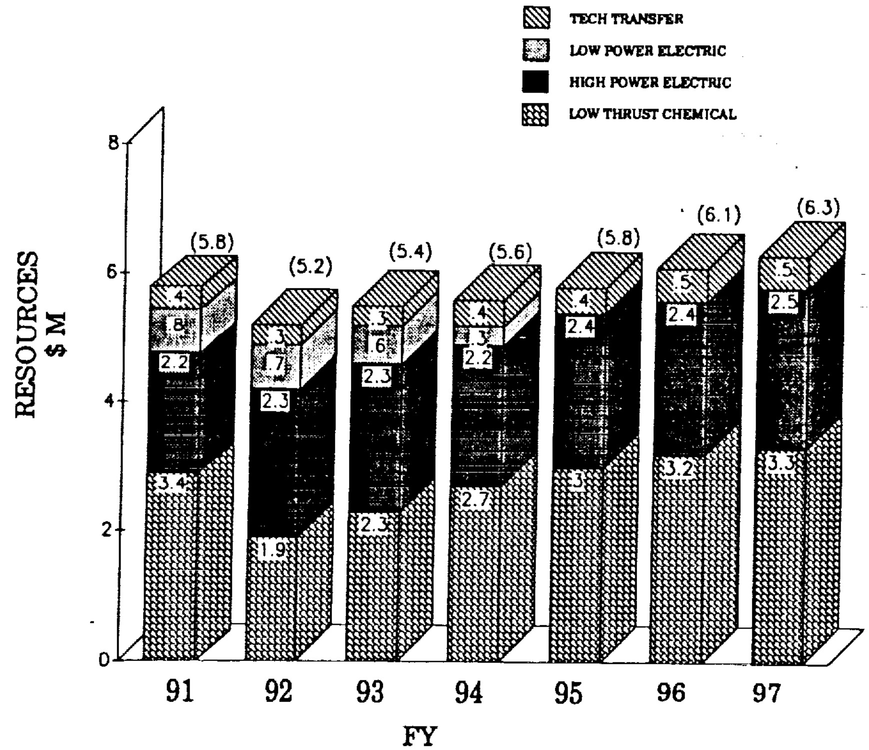
- SPACE ACT AGREEMENT (NASA/INDUSTRY)
  - FOUR IN PLACE
  - THREE IN NEGOTIATION
- BAILMENT AGREEMENT (NASA/INDUSTRY)
  - ONE IN PLACE
- MOA (INTRA AGENCY)
  - TWO IN PLACE
- "OUTREACH" (ACADEME & DOE)
  - FIVE ARCJET SYSTEMS PROVIDED
  - ION SYSTEMS IN FAB

LOW THRUST PROPULSION
" STRATEGIC " PROGRAM (1)



(1) ASSUMES PROPOSED NEP & DEEP SPACE PLATFORM PROPULSION FOCUSED PROGRAMS

LOW THRUST P[illegible]PULSION
" CURRENT " PROGRAM (1)



(1) ASSUMES PROPOSED NEP & DEEP SPACE PLATFORM PROPULSION FOCUSED PROGRAMS

LOW THRUST PROPULSION

"STRATEGIC" VERSUS "CURRENT" PROGRAM

LOW THRUST CHEMICAL

TECHNOLOGIES	PROGRAM "CURRENT"	PROGRAM "STRATEGIC"
EARTH-STORABLE		
NTO/MMH NTO/N_2H_4	• VALIDATE 100LBF ROCKET FOR MMII (1)	• VALIDATE 100LBF ROCKET FOR MMII • COMPLETE 15LBF ROCKET VALIDATION • APOGEE VERSION DEMO (1)
SPACE STORABLE LOX/N2H4 LOX/HC	• ROCKET DEMO	• ROCKET VALIDATION • VEHICLE APS ROCKET DEMO
INTEGRATED H/O		• RAD-COOLED ROCKET VALIDATION • VEHICLE APS PROGRAM INITIATED

"STRATEGIC" PROGRAM ENABLES AGGRESSIVE SPACE STORABLE AND INTEGRATED H/O LOW THRUST CHEMICAL PROGRAMS

(1) ASSUMED FOCUSED PROGRAM

LOW THRUST PROPULSION

"STRATEGIC" VERSUS "CURRENT" PROGRAM

LOW POWER ELECTRIC

TECHNOLOGIES	PROGRAM "CURRENT"	PROGRAM "STRATEGIC"
ARCJET >600s, 1-2kW <1KW & 2-5KW	• ROCKET VALIDATION	• ROCKET, PPU, & GASSIFIER VALIDATION • SYSTEM TECHNOLOGY VALIDATIONS
DERATED" ION	• THRUSTER DEMO	• THRUSTER/PPU DEVELOPMENT
"HALL THRUSTER"	• TECHNOLOGY EVALUATION	• TECHNOLOGY EVALUATION

"STRATEGIC" PROGRAM ENABLES SECOND GENERATION ARCJET AND STATIONKEEPING ION OPTIONS

LOW THRUST PROPULSION

"STRATEGIC" VERSUS "CURRENT" PROGRAM

HIGH POWER ELECTRIC (1)

TECHNOLOGIES	PROGRAM "CURRENT"	PROGRAM "STRATEGIC"
SEPS	• THRUSTER VALIDATION	• SYSTEM VALIDATIONS - THRUSTER - PPU - THERMAL & PROP. MGT. - INTERFACES • SYSTEM INTEGRATION INITIATED
NEPS (ROBOTIC)	• THRUSTER DEMO'S	• SYSTEM R&T INITIATED

"STRATEGIC" PROGRAM ENABLES SEP & ROBOTIC NEPS SYSTEM R&T

(1) MW CLASS NEPS FOCUSED PROGRAM ASSUMED

SPACECRAFT ON-BOARD PROPULSION (LERC, JPL)

- GOAL: PROVIDE DUAL-MODE (NTO/N_2H_4) PROPULSION FOR PLANETARY MISSIONS
- AUGMENTATION OBJECTIVE: [ASSURE DUAL MODE PROPULSION READINESS]
  - DEVELOP DUAL MODE HOT ROCKET
  - DEVELOP ADVANCED TANKAGE

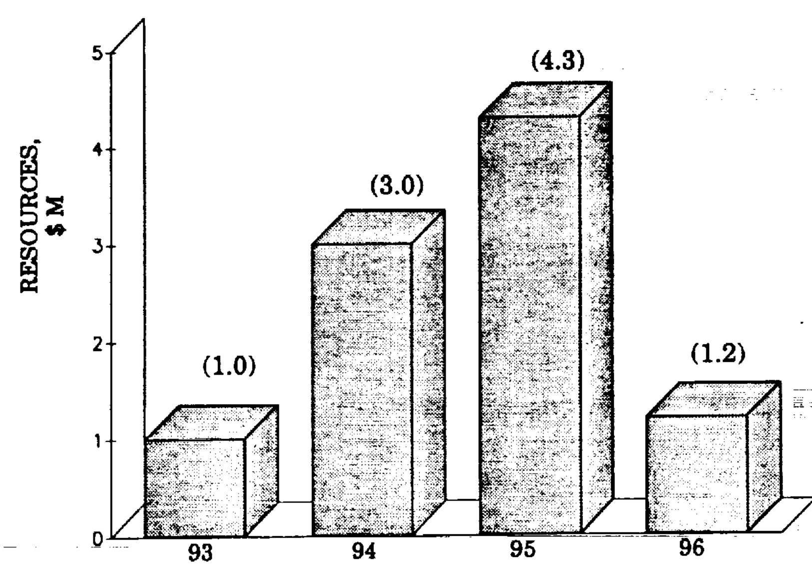
STATIONKEEPING PROPULSION (LERC, JSC)

- GOAL: PROVIDE INTEGRATED H/O & RESISTOJET SPACE STATION PROPULSION
- AUGMENTATION: [ENABLE LOGISTICS OPERATIONS BENEFITS FOR SPACE STATION]
  - DEVELOP H/O ROCKETS
  - DEVELOP LOW PRESSURE ELECTROLYSIS
  - DEVELOP SINGLE RESISTOJET FOR H_2O & WASTE GAS

AUXILIARY PROPULSION (JSC, LERC)

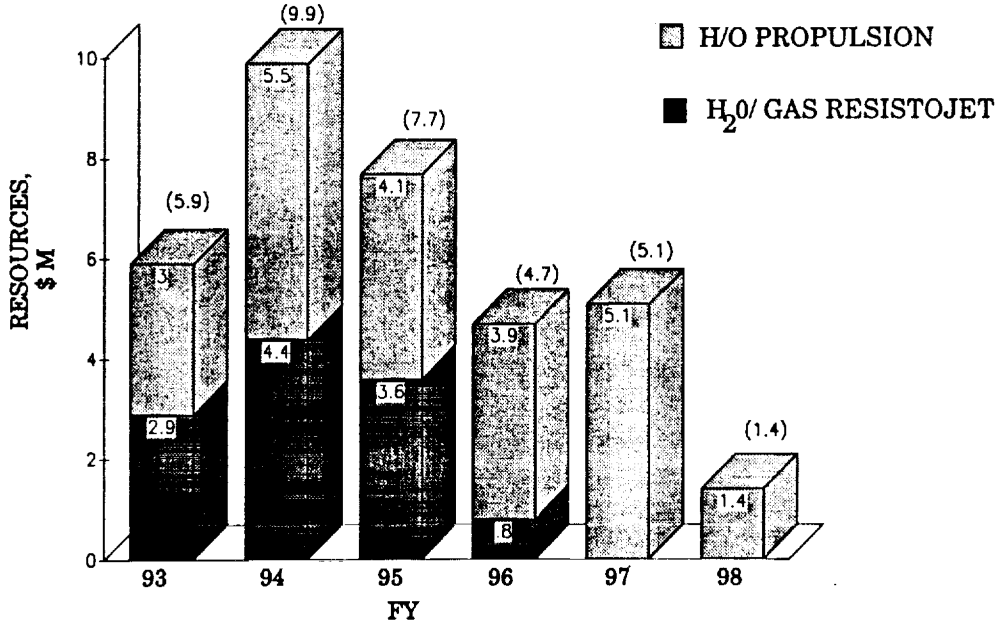
- GOAL: PROVIDE ADVANCED AUXILIARY PROPULSION FOR EARTH LAUNCH VEHICLES
- AUGMENTATION GOAL: [PROVIDE EVOLUTIONARY HI PERFORMANCE OPERATIONALLY EFFICIENT AUXILIARY VEHICLE PROPULSION]
  - PROVIDE RAD COOLED EARTH & SPACE STORABLE PROPULSION
  - PROVIDE INTEGRATED H/O PROPULSION

FOCUSED TECHNOLOGY
SPACECRAFT ON-BOARD PROPULSION
PLANETARY DUAL-MODE PROPULSION
"3X" PROJECT

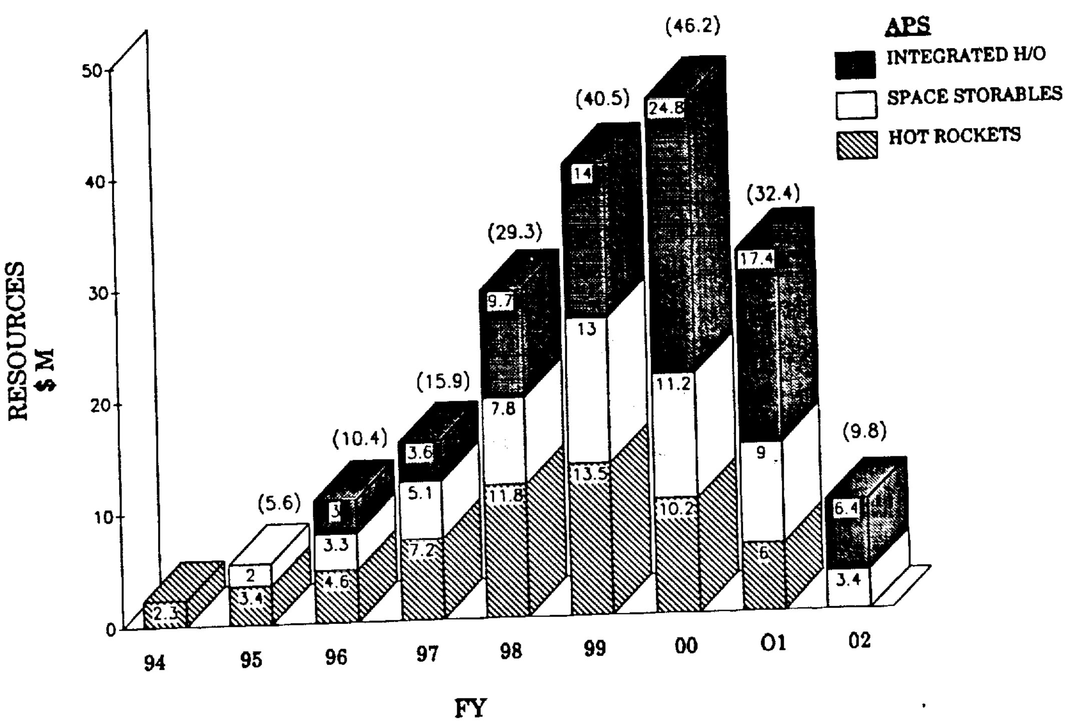


JOINT JPL/NASA LeRC PROJECT PROPOSED

FOCUSED TECHNOLOGY
SPACECRAFT ON-BOARD PROPULSION
SPACE STATION FREEDOM
"STRATEGIC"

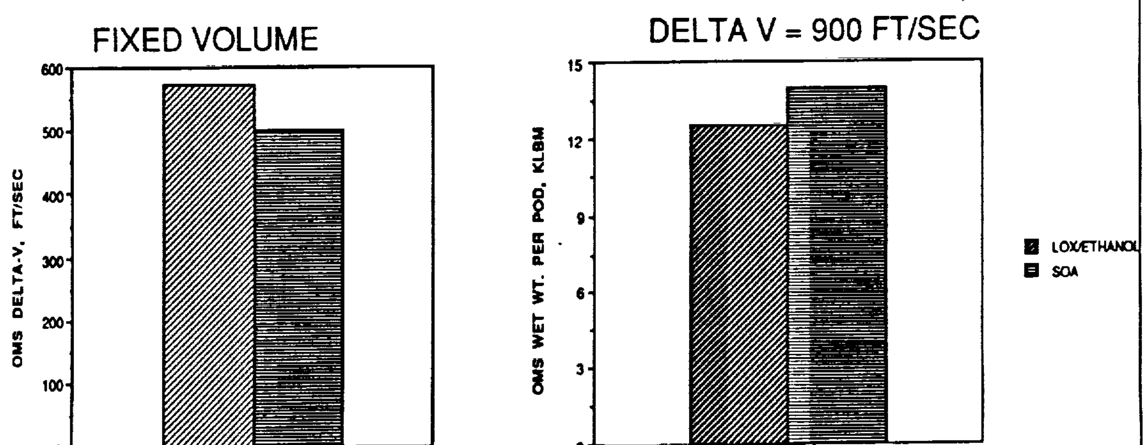


FOCUSED TECHNOLOGY
TRANSPORTATION
AUXILIARY PROPULSION
"STRATEGIC"



	Current Baseline	Potential Baseline
Propulsion Element Upmass	1 flight per year	1 flight per 5 years
Ground Processing (Man-Hours)	$200 K/Year	$200 K/ 5 Years
Dedicated SSF Hazardous Processing Facility	$50 Million	N/A

SPACE STORABLE IMPACT (1)

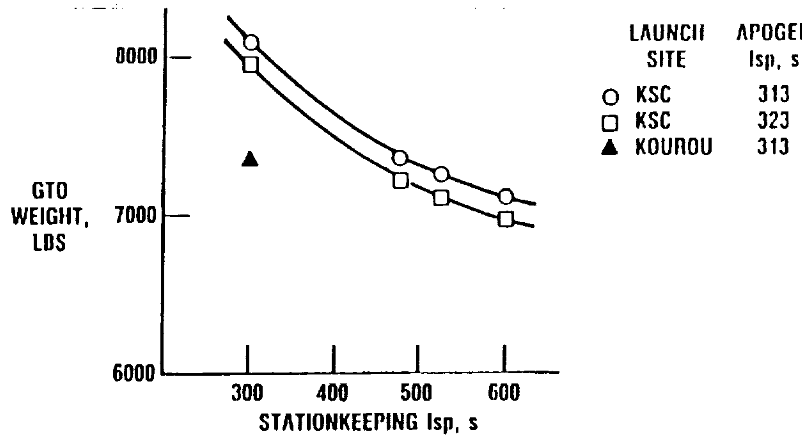


SPACE STORABLES

- OFFER SIGNIFICANT BENEFITS FOR FUTURE ETO VEHICLES

(1) REF: McDONNEL DOUGLAS STUDY FOR JSC (MDC E0713)

ON-BOARD PROPULSION IMPACTS(1)

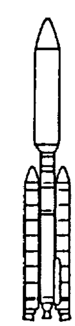


ADVANCED STATIONKEEPING AND APOGEE PROPULSION
- REDUCE GTO REQUIREMENTS
- MITIGATE LAUNCH SITE IMPACTS

(1) 15 YEAR GEO LIFE, 3500 LBS EOL WEIGHT

CD 90 47467

ADVANCED ORBIT TRANSFER PROPULSION IMPACTS(1)



	ELECTRIC	CHEMICAL
MLEO, Lbs	10307	37782
TRIP TIME, DAYS	180	1
LAUNCHER	DELTA II	TITAN IV
OTV	SEPS	IUS

ELECTRIC PROPULSION OFFERS 3X MLEO REDUCTION

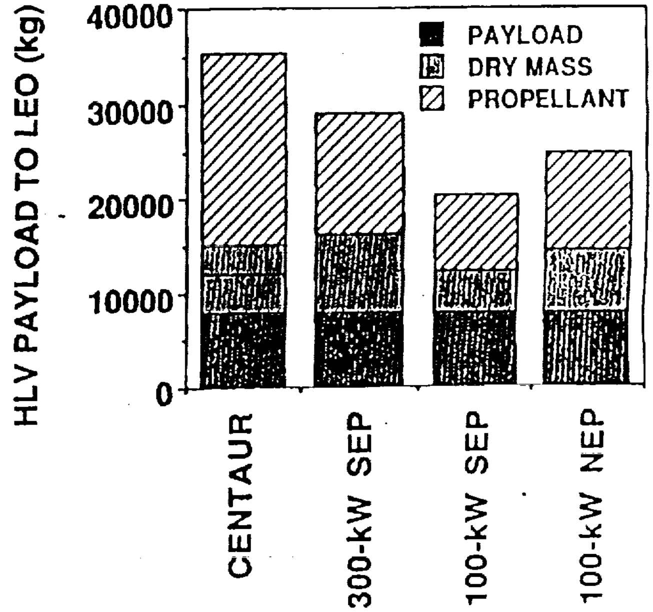
(1) AIAA 89-2496 "Electric Orbit Transfer Vehicle - A Military Perspective", S. Rosen and J. Sloan /AFSD. 5250 Lbs to GEO

JPL

ADVANCED PROPULSION
FOR THE
MARS ROVER SAMPLE RETURN MISSION

Significant Launch Mass Reductions Are Possible Using Electric Propulsion

- Electric Propulsion Reduces the LEO Launch Mass by 18 to 42 Percent
- A 300-kW SEP System Provides the Best Trip Time Performance
- Centaur Injection Is Replaced With Low-Thrust Escape



JPL STATUS OF ELECTRIC PROPULSION FOR PLANETARY MISSIONS

MBAR TRAJECTORY WITH SOLAR ELECTRIC PROPULSION ENABLES FIVE ASTEROID RENDEZVOUS PER MISSION

- FIVE ASTEROIDS CAN BE VISITED ON THE SAME MISSION WITH ELECTRIC PROPULSION; ONLY ONE ENABLED WITH NTO/MMH
- EXAMPLE ASTEROID TOUR INCLUDES:

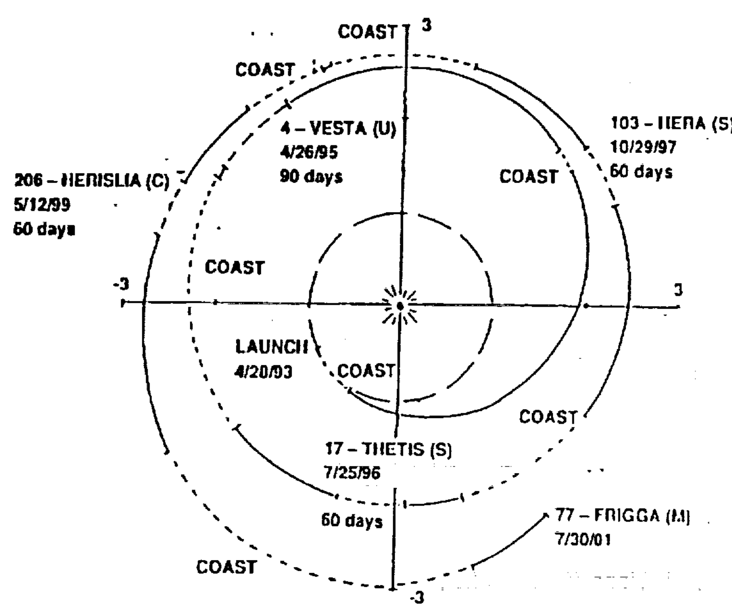
  4 – VESTA (90 days)

  17 – THETIS (60 days)

  103 – HERA (60 days)

  206 – HERISLIA (60 days)

  77 – FRIGGA (TO EOM)



NEP MISSION VS BALLISTIC - KEY EXPECTED IMPROVEMENTS
FLIGHT TIME PAYLOAD MASS SCIENCE

1) NEPTUNE ORBITER/PROBE

- SHORTER FLIGHT TIME - 11 YRS VS > 18 YRS
- TRITON SCIENCE - ORBITER MISSION VS 41 FAST FLYBYS (4-5 KM/S)
- RING SCIENCE - POSSIBLE TO SPIRAL INWARD TO RING ZONE
- ATMOSPHERE SCIENCE - OBSERVATION FROM CLOSE (E.G. 3 R_N) ORBIT

2) PLUTO ORBITER/PROBE

- ORBITER MISSION VS FAST (13 KM/S) FLYBY FOR BALLISTIC MISSION
- SPIRAL INWARD AS LOW AS DESIRED
- RENDEZVOUS WITH CHARON
- DEPLOY NEPTUNE LANDER OR PROBE
- SHORTER FLIGHT TIME, 10.5 YEARS
- NEP IS ENABLING (BALLISTIC MODE TAKES > 36 YRS TO DO ORBITER)

3) JUPITER GRAND TOUR

- ORBITER MISSION FOR CALLISTO, GANYMEDE, EUROPA AND IO (IF RADIATION PROBLEM CAN BE TACKLED)
- DEPLOYMENT OF SOME LANDERS OR PENETRATORS

NEP MISSION VS BALLISTIC - KEY EXPECTED IMPROVEMENTS (CONTINUED)

3) MULTIPLE ASTEROID RENDEZVOUS

- MINIMUM OF SIX RENDEZVOUS WITH PREFERRED ASTEROIDS (SIZE, TYPE) VS ONE MAJOR TARGET PLUS ONE OR TWO SMALL TARGETS OF OPPORTUNITY
- ON AN AVERAGE OF ONE RENDEZVOUS EVERY TWO YEARS VS ~ ONE EVERY 4 YEARS

4) JUPITER POLAR ORBITER

- ADVANTAGE EXISTS IN LARGE PAYLOAD - POTENTIAL FOR MULTI-SPACECRAFT FIELDS AND PARTICLES EXPERIMENTS

5) COMET NUCLEUS SAMPLE RETURN

- BETTER PERFORMANCE AND ACCESSIBILITY TO LARGER NO. OF COMETS (MORE OPPORTUNITIES)
- PRESERVATION OF SAMPLE
- LOWER APPROACH SPEED WHEN RETURNING TO EARTH (V_∞=0 km/s)
- IF ALLOWED TO SPIRAL BACK INTO EARTH THEN ORBITAL SAMPLE RECOVERY INSTEAD OF HIGH VELOCITY (V_∞=15km/s) DIRECT ENTRY

LOW THRUST PROPULSION

- ESSENTIAL FOR SPACE MISSIONS
  - EARTH SPACE
  - PLANETARY
- PREDOMINANT LAUNCH & SPACE VEHICLE "PAYLOAD"
- HI LEVERAGE TECHNOLOGIES DEFINED
  - INITIAL TRANSFERS ACHIEVED
- BROAD & MAJOR BENEFITS ASSURED WITH SUPPORT:
  - SPACECRAFT
  - PLATFORMS
  - TRANSPORTATION

N93-71877

ADVANCED PROPULSION CONCEPTS

54-81
157471
p. 18

Presented to the
Integrated Technology Plan External Review

JPL

June 26,1991

Joel C. Sercel

Advanced Propulsion Systems Group
Jet Propulsion Laboratory

ADVANCED PROPULSION CONCEPTS

OBJECTIVES

PROGRAMMATIC

ESTABLISH THE FEASIBILITY OF PROPULSION TECHNOLOGIES FOR VASTLY EXPANDED SPACE ACTIVITY

TECHNICAL

REVOLUTIONARY PERFORMANCE SOUGHT:
- ≈1kg/kW specific mass
- Specific impulse tailored to mission requirements
- Ability to use in-situ resources
- Round-trips to Mars in months
- Round-trips to outer planets in 1 to 2 years
- The capability for robotic missions beyond the solar system

SCHEDULE

1991 COMPLETE FIRST ECR PLASMA ENGINE THEORY
1992 MEASURE CARBON-60 ION PROPERTIES
1992 TEST 25-kW ELECTRODELESS ROCKET
1993 TEST SUPERSONICALLY-HEATED μWAVE ROCKET
1994 RESOLVE KEY PLASMA PLUME PHYSICS ISSUES
1995 TEST SUSTAINED MW-CLASS PLASMA ROCKET
1996 PROVE LIFE/PERFORMANCE OF C-60 ION ENGINE
1996 SUSTAIN CONFINEMENT OF ATOMIC HYDROGEN
1997 APPLY MICRO-FISSION DEMONSTRATION TO ICAN FISSION/FUSION PROPULSION FEASIBLITY ISSUES
004+ LABORATORY SCALE ATOMIC HYDROGEN ROCKET
004+ 10 MW-CLASS PLASMA ENGINE & S.S. μWAVE ROCKET
004+ ICAN SYSTEM PROOF-OF-CONCEPT
004+ 100 kW GROUND-TO-SPACE PHASE CONJUGATE BEAM

RESOURCES ($M)

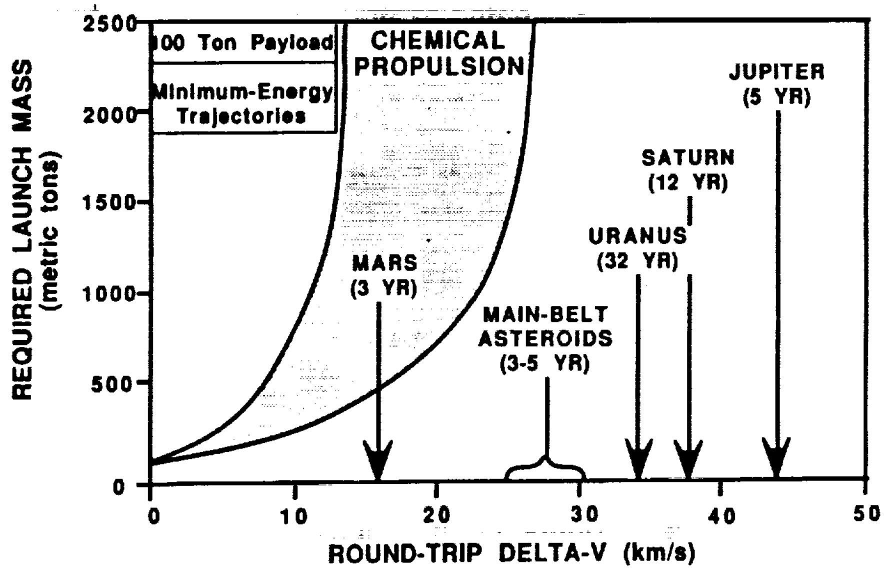
	CURRENT	3X	STRATEGIC
1991	1.2	1.2	1.2
1992	1.4	1.4	1.4
1993	1.5	3.2	3.5
1994	1.5	4.0	4.0
1995	1.6	4.7	4.7
1996	1.6	5.0	5.0
1997	1.7	6.0	6.0

PARTICIPANTS

JPL
- ECR PLASMA ENGINE
- C-60 MOLECULAR ION THRUSTER
- SUPERSONICALLY-HEATED MICROWAVE ROCKET
- TANDEM MIRROR PLASMA ROCKET
- COMPUTATIONAL PLASMA PHYSICS
- MICRO FISSION/FUSION (ICAN) PROPULSION
- PLASMA PLUME PHYSICS RESEARCH
- SYSTEMS ANALYSIS

LeRC
- MW-CLASS PLASMA ROCKET
- E-M FIELD/PLASMA INTERACTIONS
- ELECTRODELESS ROCKETS
- BEAMED ENERGY FOR PROPULSION
- ATOMIC HYDROGEN

ADVANCED PROPULSION CONCEPTS
The Limits of Chemical Propulsion

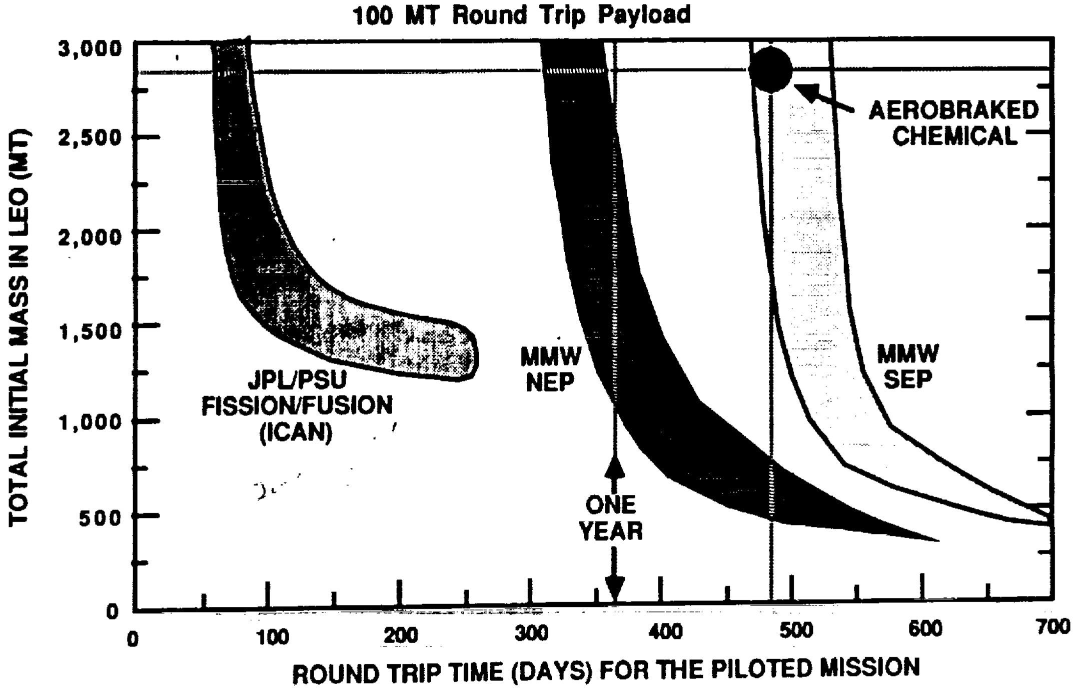


JPL

ADVANCED PROPULSION CONCEPTS

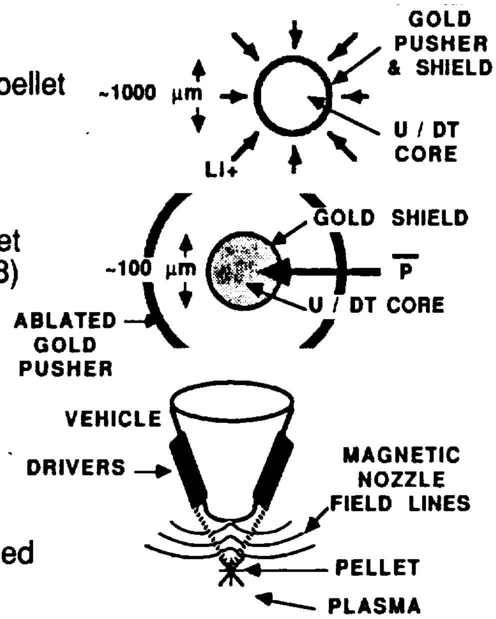
MAJOR BENEFITS FOR FUTURE NASA MISSIONS

100 MT Round Trip Payload



PENN STATE ION-COMPRESSED ANTIMATTER-CATALYZED NUCLEAR (ICAN) PROPULSION

CONCEPT DESCRIPTION



- Uranium (or Pu) enriched DT (or D-He3) pellet is compressed using a megajoule-class light ion (Li) driver
- At the time of peak compression, the target is bombarded with a small number (~10^8) of antiprotons to catalyze fission
- The fission energy release triggers a high-efficiency fusion burn to heat the propellant
- The resulting expanding plasma is deflected by a magnetic nozzle to produce thrust

RECENT RESULTS FROM PENN STATE FISSION/FUSION (ICAN) WORK

- THE TECHNOLOGY FOR A 10 GW SYSTEM MAY BE FEASIBLE IN 2010 TIME FRAME ...GIVEN ADEQUATE RESOURCES
- ANTIPROTON QUANTITIES REQUIRED ACHIEVABLE
  - 10^8 ANTIPROTONS PER PELLET CAN BE PRODUCED NOW IN TEN MIN. AT CERN
  - SOLID ANTI-H2 STORAGE NOT NEEDED
- RADIATION FLUENCE MAY BE MUCH LOWER THAN FUSION PROPULSION
- ≈100 DAY ROUND-TRIP TO MARS
- AFOSR INITIATIVE TO DEMONSTRATE SCIENTIFIC FEASIBLITY OF MICRO-FISSION IN FIVE YEARS ($3.5M LEVERAGED THUS-FAR)

JPL

PENN STATE FISSION/FUSION (ICAN) WORK
Program Goals

THIS YEAR

DEVELOPED MICRO-FISSION AND FISSION/FUSION CONCEPTS THROUGH DETAILED PELLET MODELING

CONVINCED AFOSR TO ESTABLISH INITITIVE TO PROVE SCIENTIFIC FEASSIBLITY IN ≈5 years

NEXT YEAR

CONTINUE THEORETICAL RESEARCH TO ADDRESS MINIMIZING RADIATION FLUENCE FROM PROPULSION SYSTEM (D-HE3 FUEL)

IMPROVED MODELS OF UP-COMING EXPERIMENTS AT SHIVA STAR

DETAILED EXPERIMENTAL DESIGN AND PLANNING

FUTURE YEARS

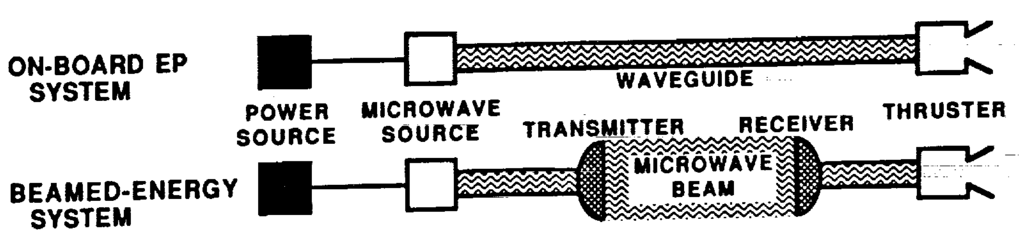
ADDRESS CRITICAL TECHNOLOGIES IN SUPPORTING SUBSYSTEMS

CONTINUE TO DEVELOP CONCEPT TO ESTABLISH FEASIBILITY FOR FLIGHT IN 2010-2020 TIME FRAME

JPL

ELECTRODELESS ELECTRIC PROPULSION THRUSTERS

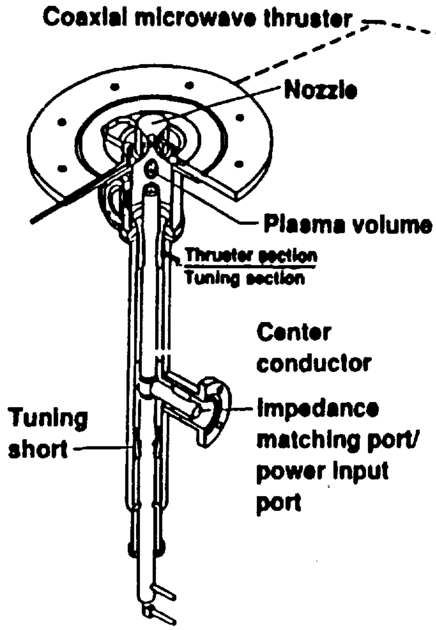
- May dramatically improve EP thruster life by eliminating electrodes and their associated erosion
- Absorb microwave energy into propellant
  - Examples
    - Electron-Cyclotron Resonance Thruster (JPL)
    - Microwave Electrothernal Rockets (LeRC & JPL)
    - Variable-Isp Plasma Rocket (MIT)
- May be able to use extraterrestrial-produced propellants (e.g., O2)
- Can be used as an electric propulsion system (with on-board microwave source) or as a beamed-energy system (with a remote microwave transmitter)

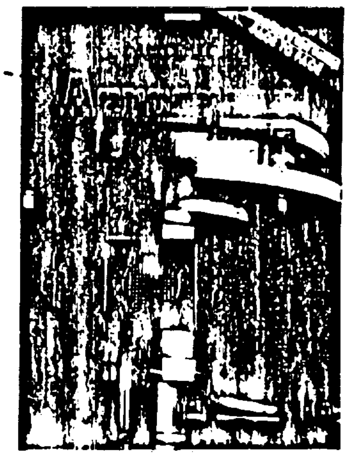


AEROSPACE TECHNOLOGY DIRECTORATE — SPACE PROPULSION TECHNOLOGY DIVISION — NASA Lewis Research Center

ADVANCED PROPULSION CONCEPTS

ELECTRODESELESS ROCKETS- MICHIGAN STATE UNIVERSITY





The potential for high power absorption (>90%) into the propellant can be realized using external impedance matching with the coaxial microwave thruster

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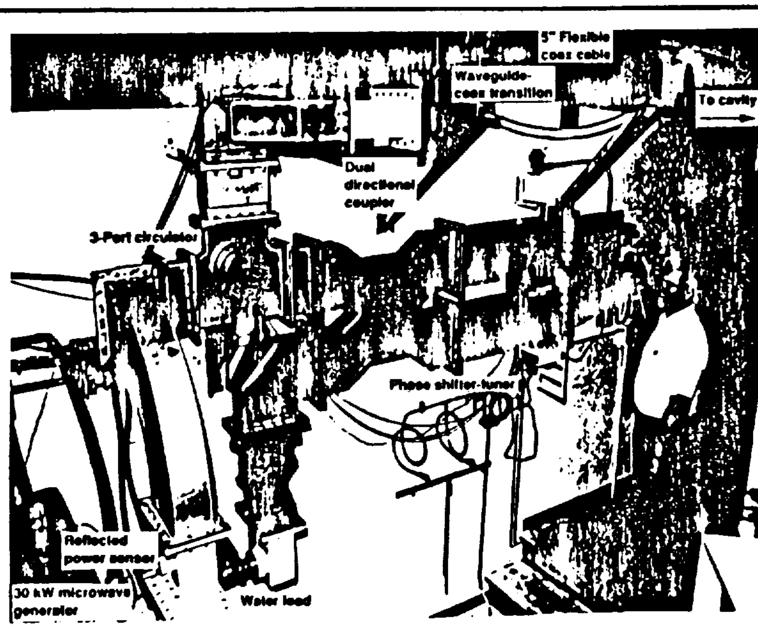
ADVANCED PROPULSION CONCEPTS

POWER CIRCUIT FOR ELECTRODELESS THRUSTER COMPLETED



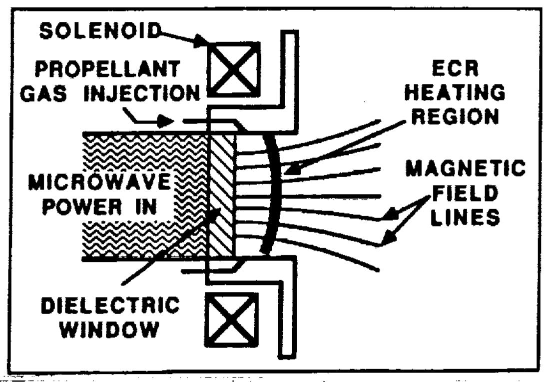
CD-90-51117

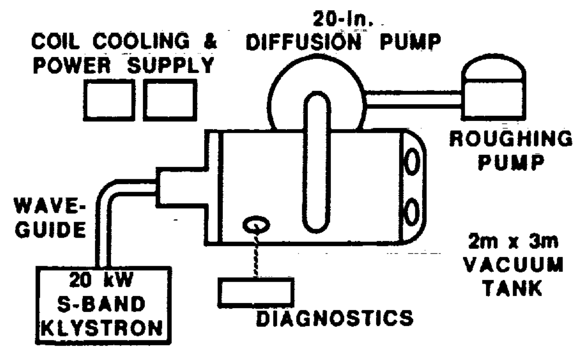
ELECTRON-CYCLOTRON RESONANCE (ECR) PLASMA ENGINE

- Recent Work
  - Quasi 1-D Plasma Model
  - Axisymmetric Magnetic Nozzle Model
  - Completed assembly of test facility and preliminary experiments

- Near-term plans
  - Optimize magnetic field configuration
  - Automate experimental facility
  - Improve theoretical models

- Future plans
  - Optimized devices
  - Higher power levels
  - Alternate propellants





ELECTRODELESS ELECTRIC THRUSTERS
Program Goals

THIS YEAR

COMPLETE ECR PLASMA ENGINE BASIC PHYSICS RESEARCH WITH GO/NO-GO DECISION

NEXT YEAR

TEST 25-kW ELECTRODELESS ROCKET CONCEPT

INITIATE DEVELOPMENT OF HIGH-EFFICIENCY AND/OR HIGH THRUST ECR DEVICE (CONTINGENT ON DECISION)

FUTURE YEARS

DEMONSTRATE APPLIED-FIELD ELECTRODELESS DEVICES AT HIGH SPECIFIC IMPULSES AND EFFICIENCIES

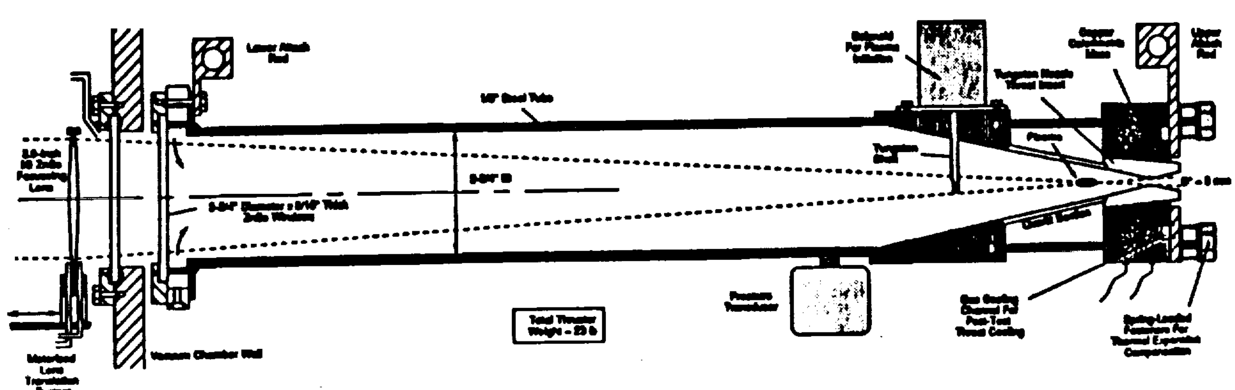
BEAMED ENERGY PROPULSION

- Improve propulsion system performance by removing the power source from the vehicle
  - Locate the source (laser) on ground or in orbit
- Various combinations of source, source location, and propulsion system possible
  - Near-visible vs microwave
  - Ground-based vs space-based transmitter
  - Direct (thermal) thruster vs indirect (beam -> electric) EP thruster
- All concepts limited by transmission capability
  - Atmospheric effects for ground-based lasers
  - Diffraction effects for long distances (probably)

Combustion Sciences, Inc.
Space Propulsion Division

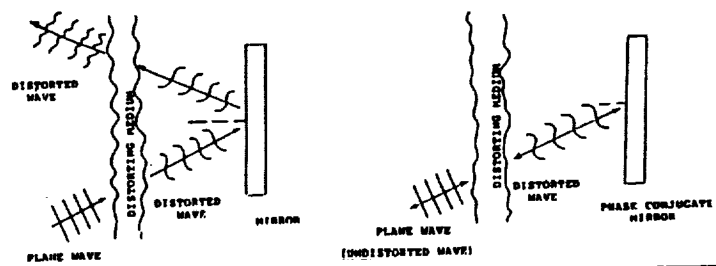
Thruster Layout

- Specific Impulse = 600 - 700 sec
- Pressure = 1.0 atm
- Plasma Efficiency ~ 35%
- Overall Efficiency ~ 20%
- Mass Flow = 0.1 g/sec
- Throat D* = 3 mm
- Thrust ~ 0.5 N



PHASE CONJUGATION

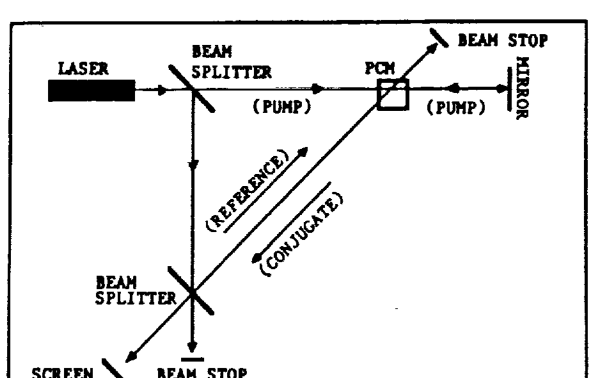
- ALTERNATIVE TO ADAPTIVE OPTICS
- NON-LINEAR OPTICAL EFFECT
  - "DYNAMIC HOLOGRAPHY"
  - EXACTLY REVERSES DIRECTION, PHASE OF INCIDENT BEAM
  - ELIMINATES EFFECTS OF DISTORTING MEDIUM



ATD AEROSPACE TECHNOLOGY DIRECTORATE
SPACE PROPULSION TECHNOLOGY DIVISION
NASA Lewis Research Center

PHASE CONJUGATION

IN-HOUSE PHASE CONJUGATION EXPERIMENTS



ADVANCED PROPULSION CONCEPTS

BEAMED ENERGY PROPULSION
Program Goals

LASER ROCKET

BUILD & DIRECTLY TEST A 10 kW LASER ROCKET (AT U. of ILL.)
- ANCHOR THERMAL & PERFORMANCE MODLES
- DIRECTLY EVALUATE THRUST VS GEOMETRY & CONDITIONS

DESIGN AND FABRICATE A 100 kW LASER ROCKET

PHASE CONJUGATE OPTICS

CONTINUE IN-HOUSE LeRC PHASE CONJUGATION EXPERIMENTS
- 3,4 WAVE MIXING
- LOW POWER HeNe LASER
- $BaTiO_3$ PHOTOREFRACTIVE CRYSTALS

WORK TOWARD 100 kW GROUND-TO-SPACE DEMONSTRATION

ADVANCED PROPULSION CONCEPTS

LeRC MULTIMEGAWATT PLASMA ROCKET PROGRAM

JOINT DOE-NASA PROGRAM INITIATED WITH LOS ALAMOS

- LEVERAGES FUSION REACTOR PROGRAM BY USING 100 MW SPHEROMAK TECHNOLOGY
- HAVE DEMONSTRATED OPERATION AT 10 MW
- WILL ESTABLISH POWER BALLANCE AND SCALING CHARACTERISTIC OF LARGE SCALE (0.5m) ROCKETS OPERATED WITH EXTERNAL MAGNETIC FIELDS

PROGRAM GOALS

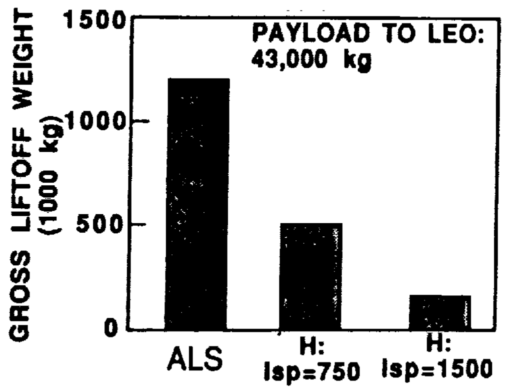
- 1995: DEMONSTRATE SUSTAINED MW-CLASS PLASMA ROCKET
- 1998-2003: DEMONSTRATE SUSTAINED 2 MW PLASMA ROCKET
- BEYOND 2004: DEMONSTRATE 10 MW PLASMA ROCKET

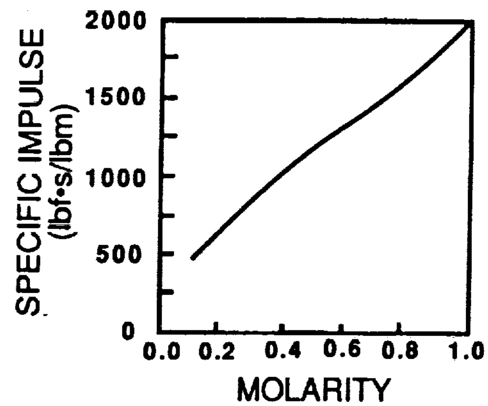
ADVANCED PROPULSION CONCEPTS

LeRC ATOMIC HYDROGEN ROCKET PROGRAM

CONCEPT:

FREE RADICAL ATOMIC HYDROGEN IS STORED IN A SOLID MATRIX OF MOLECULAR HYDROGEN UNDER HIGH MAGNETIC FIELD AND LOW CRYOGENIC TEMPERATURE





ADVANCED PROPULSION CONCEPTS

LeRC ATOMIC HYDROGEN ROCKET
Program Goals

APPROACH

CONTRACT WORK AT LLNL, U. of HAWAII, AND OAK RIDGE

LeRC SYSTEMS ANALYSIS AND VEHICLE STUDIES

1995

IDENTIFY ATOMIC HYDROGEN CONFINEMENT TECHNIQUE

1996

DEMONSTRATE SUSTAINED CONFINEMENT

BEYOND 2004

TEST LABORATORY SCALE ATOMIC HYDROGEN ROCKET

SUPERSONICALLY-HEATED MICROWAVE ELECTROTHERMAL ROCKET

CONCEPT:

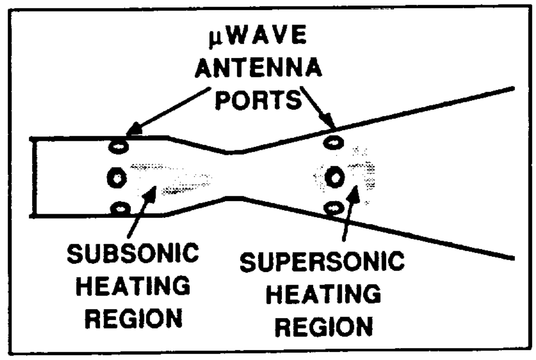
MICROWAVE ENERGY IS COUPLED TO A GAS IN SUPERSONIC FLOW DOWNSTREAM OF THE THROAT - A "MICROWAVE AFTERBURNER"

POTENTIAL BENEFITS:

MAY CIRCUMVENT HEATING LIMITS TO ROCKET PERFORMANCE
- 2X IN SPECIFIC IMPULSE
- 2X IN EFFICIENCY

HISTORY:

A QUALITATIVE EXTENSION OF LeRC, P.S.U., and M.S.U. MICROWAVE ROCKET RESEARCH



SUPERSONICALLY-HEATED μWAVE ROCKET
Program Goals

YEAR ONE

VERIFY THEORETICAL CONCEPT BENEFITS BY MODELING:
- SUPERSONIC HEATING REGION
- VISCOUS EFFECTS
- ENERGY TRANSFER KINETICS AND GAS EXPANSION

YEAR TWO

- MODIFY JPL APPARATUS TO DEMONSTRATE S.S. HEATING
- INVESTIGATE DIFFERING ANTENNA SCHEMES AND ENGINE PERFORMANCE

FUTURE YEARS

- DEVELOP FLIGHT-LIKE NEAR-TERM SYSTEMS
- DEVELOP ADVANCED CONCEPT ENGINES
- STUDY APPLICATION TO OTHER ROCKET SYSTEMS

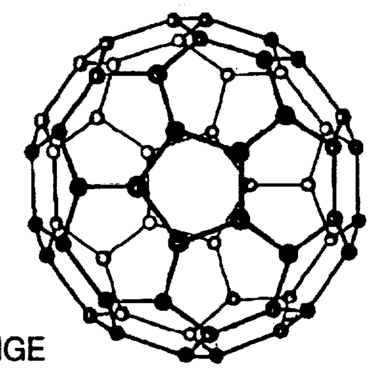
JPL

ADVANCED PROPULSION CONCEPTS

CARBON-60 ION PROPULSION

CONCEPT:

BUCKMINSTERFULLERENE IS SUBLIMATED, IONIZED AND ELECTROSTATICALLY ACCELERATED TO PRODUCE THRUST



POTENTIAL BENEFITS:

- FIRST CLUSTER PROPULSION CONCEPT TO PROMISE HIGH PROP. UTILIZATION, MONO-MASS DISTRIBUTION, MINIMAL FRAGMENTATION, LARGE ION MASS, AND LOW IONIZATION ENERGY
- HIGH EFFICIENCY EVEN IN 1000 - 3000 s RANGE
- DRAMATICALLY RELAXED GRID SPACING AND DISCHARGE CURRENT FOR ULTRA-HIGH-POWER ION ENGINES

JPL

ADVANCED PROPULSION CONCEPTS

CARBON-60 ION PROPULSION
Program Goals

YEAR ONE

VERIFY THEORETICAL CONCEPT BENEFITS BY MEASURING:
- IONIZATION CROSS SECTIONS
- VAPOR PRESSURE CURVES
- FRAGMENTATION EFFECTS

YEAR TWO

ADDRESS PRACTICAL DEVELOPMENT ISSUES
- SELECT BEST IONIZATION/ACCELERATION SCHEMES
- MEASURE CHARGE-TO-MASS DISTRIBUTIONS
- INVESTIGATE CONDENSATION AND SPUTTERING

FUTURE YEARS

- DEVELOP FLIGHT-LIKE NEAR-TERM SYSTEMS
- DEVELOP ADVANCED CONCEPT ENGINES
- EXAMINE HIGHER-MASS CARBON CLUSTERS

JPL

U.S. ADVANCED PROPULSION RESEARCH

JPL

- Mission Studies
- ECR Plasma Engine
- Carbon-60 Engine
- Supersonic μWave Rocket
- University Research
  - PSU - Fission/Fusion Hybrid
  - CIT
    - Magnetic Nozzles for ICF
    - Computational Plasma Physics
  - MIT - Tandem Mirror Plasma Engine
  - Brown U. - H2 Magnetic Lervitation

LeRC

- Magnetic Nozzles
- Microwave Thruster
- Beamed Energy Optics Analysis
- High-Energy Density Chemical Propellants
  - Metallized Propellants
- ET Resource Thrusters
  - O2/CO
- University Research
  - OSU - Magnetic Nozzles
  - U. Ill. - Laser Thruster
  - U. Hawaii - Atomic Hydrogen

Air Force

- Fusion
  - Dense Plasma Focus
  - Cluster Ion
- Field Propulsion Concepts
- Solar Thermal Propulsion Thruster
- High-Energy Density Propellants
  - Chemical
  - Antimatter

Others

- ET Propellant Production
  - Moon : JSC
  - Mars : U. of Arizona, Old Domin. U.
- Solar Sails
  - World Space Found.
- Mass Drivers
  - Coaxial : SSI
  - Rail Guns : SDIO
  - Ram Accel. : U. of Wash.
- Laser Propulsion
  - Lasers : SDIO, LLNL, LANL
  - Thrusters : U. of Tenn., RPI
- Fusion
  - U. of Illnois
  - AFOSR
  - LLNL
- Antimatter
  - LANL
  - Penn State U.

Note: Does not address fission research

ADVANCED PROPULSION CONCEPTS SUMMARY

TECHNICAL CHALLENGE:

STATE-OF-THE-ART AND EMERGING PROPULSION TECHNOLOGIES DO NOT MEET THE REQUIREMENTS FOR MANY AMBITIOUS 21st CENTURY SPACE MISSIONS. FOR EXAMPLE, BIOMEDICAL CONSIDERATIONS MAY RULE OUT TRIPS TO MARS WITH FLIGHT TIMES GREATER THAN ONE YEAR – HENCE APC MAY BE REQUIRED EVEN FOR SEI

TECHNOLOGY MANAGEMENT APPROACH:

- IN-HOUSE SYSTEMS STUDIES (BENFIT V.S. TECHNOLOGY NEEDS)
- IN-HOUSE PROOF-OF-CONCEPT RESEARCH (EXPERIMENTS AND THEORY)
- CONTRACTED RESEARCH (ESPECIALLY EXPERIMENTS AND THEORY AT UNIVERSITIES)

PAYOFF: REVOLUTIONIZE SPACE TRAVEL

- ROUND-TRIPS TO MARS IN A FEW MONTHS
- PILOTED ROUND-TRIPS TO OUTER PLANETS IN 1 TO 2 YEARS
- ROBOTIC MISSIONS BEYOND THE SOLAR SYSTEM

RATIONALE FOR AUGMENTATION:

- MAY BE THE MOST IMPORTANT TECHNOLOGIES FOR 21st CENTURY SPACE ACTIVITES
- CURRENT PROGRAM FUNDING IS SUBCRITICAL - 3x PLAN IS VITAL

RELATIONSHIP TO FOCUSED ACTIVITIES AND OTHER PROGRAMS:

- CONNECTIONS TO PROGRAMS SUCH AS SEI MADE VIA SYSTEMS STUDIES AND MEETINGS
- RESEARCH COMPONENT OF THIS PROGRAM STILL NEW
- HAS LEVERAGED SIGNIFICANT PROGRAMS FROM OTHER AGENCIES:

i.e. JPL's SUPPORT OF ICAN AT PENN STATE RESULTED IN A $3.5M AFOSR INITIATIVE TO DEMONSTATE FEASIBILITY OF MICRO-FISSION

ADVANCED PROPULSION TECHNOLOGY

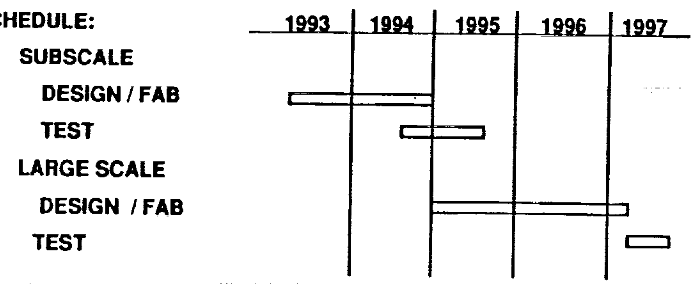
TITLE: ADVANCED HIGH THRUST EXPANDER CYCLE THRUST CHAMBER TECHNOLOGY

OBJECTIVE: INVESTIGATE AND VERIFY AT LARGE SCALE THE TECHNOLOGIES NEEDED TO ALLOW OPERATION OF AN O2/H2 EXPANDER CYCLE THRUST CHAMBER AT HIGH THRUST LEVELS

APPROACH: SUPPLIMENT EXPANDER CYCLE WORK TO EXPLORE ALTERNATE HEAT TRANSFER ENHANCEMENT APPROACHES FOR HIGH THRUST APPLICATIONS. PURSUE SUBSCALE INVESTIGATIONS TO CHARACTERIZE THE APPROACHES. SELECT THE MOST PROMISING FOR VERIFICATION AT LARGE SCALE. TESTING TO BE DONE AT THE MSFC TEST CELL 116.

FUNDING REQUIREMENT:	FY93	FY94	FY95	FY96	FY97
$K	500	1500	3000	3000	2500

SCHEDULE:



APPLICATION: APPLICATIONS FOR HIGH THRUST EXPANDER CYCLE ENGINES INCLUDE UPPER STAGES, ORBIT TRANSFER, INTERPLANETARY TRANSFER VEHICLES

ADVANCED PROPULSION TECHNOLOGY

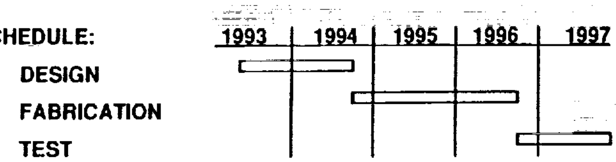
TITLE: LARGE SCALE PLATELET CHAMBER DEMONSTRATION

OBJECTIVE: VALIDATE FORMED PLATELET COOLING LINER CONSTRUCTION IN A LARGE SCALE COMBUSTION CHAMBER

APPROACH: SUPPLIMENT EXISTING WORK UNDER CONTRACT NAS8-37456 TO CONSTRUCT A LARGE SCALE THRUST CHAMBER AND TEST FIRE THE CHAMBER TO VERIFY THE PLATELET DESIGN APPLICATION. CHAMBER SIZE WILL BE BASED ON A DESIGN THAT IS COMPATIBLE WITH USING AN EXISTING HIGH THRUST METHANE INJECTOR (750KLB). THE TESTS WILL EMPLOY O2/H2 AT A THRUST LEVEL OF ABOUT 450 KLB. THE CHAMBER STRUCTURE WILL BE BASED ON EITHER CASTING TECHNOLOGY BEING DEVELOPED UNDER THE ADVANCED MAIN COMBUSTION CHAMBER ACTIVITY OR A GENERAL WORKHORSE CONSTRUCTION APPROACH. TESTING WILL BE CONDUCTED AT THE MSFC TEST CELL 116.

FUNDING REQUIREMENT:	FY93	FY94	FY95	FY96	FY97
$K	500	1000	1500	2000	500

SCHEDULE:



APPLICATION: APPLICATIONS FOR FORMED PLATELET CONSTRUCTION INCLUDE ANY ROCKET ENGINE NEW DEVELOPMENT OR EXISTING ENGINE MODIFICATION WHICH CAN BENEFIT FROM LOW HOT WALL TEMPERATURES IN THE RANGE OF 400°F TO 700°F.

TITLE: ADVANCED CAST HOT GAS MANIFOLD FOR HIGH PRESSURE PREBURNER CYCLE ENGINES

OBJECTIVE: DEMONSTRATE TECHNOLOGY NECESSARY FOR DEVELOPMENT OF A LOW COST, HIGH RELIABILITY HOT GAS MANIFOLD.

APPROACH:

- SELECT THE SSME AS A DESIGN POINT:
  - DESIGN COMPONENT IN-HOUSE
    - STRUCTURAL & DYNAMIC ANALYSIS
    - THERMAL ANALYSIS
  - PROCUREMENT - STRUCTURAL CASTING
  - MANUFACTURE AND ASSEMBLY IN-HOUSE
  - TEST AND VERIFICATION IN-HOUSE

SCHEDULE:

• DESIGN AND ANALYSIS	JUNE 91 - JAN 92
• PROCUREMENT OF STRUCTURAL CASTING	JAN 92 - JAN 93
• MANUFACTURE & ASSEMBLY	JAN 93 - JAN 94
• TEST & VERIFICATION	JAN 94 - DEC 94

COST: 4 M

TITLE: ADVANCED GAS GENERATION FOR MULTI-PHASE OPERATION (O_2/H_2 PROPELLANTS)

OBJECTIVE: DEVELOPMENT AND DEMONSTRATION OF A O_2/H_2 GAS GENERATOR WHICH IS STABLE AND HAS HIGH PERFORMANCE UNDER "ANY" OPERATION CONDITION OR PROPELLENT PHASE.

APPROACH:

- USE INJECTOR DESIGN CODES TO SELECT POTENTIAL CANDIDATES
- EVALUATE CANDIDATE ELEMENT CONCEPTS AT THE MSFC COMBUSTION PHYSICS LABORATORY FACILITY (COLD FLOW SCREENING)
- POTENTIAL CANDIDATES WILL BE HOT FIRE TESTED AT TS 116 PREBURNER POSITION.

SCHEDULE:

• CANDIDATE SELECTION	JUNE 91 - JUNE 92
• COLD FLOW SCREENING	JAN 93 - JUNE 93
• HOW FIRE EVALUATION	JAN 94 - JUNE 94

COST: 1M

TITLE: ADVANCED MAIN COMBUSTION CHAMBERS CYCLE LIFE DEMONSTRATIONS

OBJECTIVE: DEMONSTRATE THE CYCLE LIFE CAPABILITY OF PROMISING CONCEPTS FOR ADVANCED CHAMBER DESIGN

- VACUUM PLASMA SPRAYED LINERS
- * PLATELET LINERS
- LIQUID METAL DIFFUSION BONDED LINER (REDUCED MATERIAL PROPERTIES)
- HIGH ASPECT RATIO COOLANT CHANNELS - EDM FORMED
- GRADATED OXIDATION RESISTANT (BLANCHING) METALLIC COATING (VACUUM PLASMA SPRAYED)
- GLIDCOP (MATERIAL) LINER
- POWDER METAL

APPROACH: FABRICATE "40K THRUST" SUBSCALE CHAMBERS AND TEST FOR 100+ THERMAL CYCLES EACH AT TS116 AT MSFC.

SCHEDULE: SIX MONTH TEST SERIES EACH

COST:

* CURRENTLY SCHEDULED

COMBUSTION STABILITY FOR HYBRID ROCKET ENGINES

LIQUID-SOLID HYBRID ROCKET ENGINES MAY BE SUBJECT TO COMBUSTION INSTABILITIES RELATED TO LIQUID OXIDIZER FEED LINES, COMBUSTION PROCESSES, AND FLOW PROCESSES.

DATA ARE REQUIRED ON THE OXIDIZER ATOMIZATION PROCESSES, BURNING RATES, FLOW ENHANCEMENT OF BURNING RATES, EFFECTS OF SUSPENDED DROPLETS AND PARTICLES, VORTEX SHEDDING EFFECTS, AND OTHER COMBUSTION CHAMBER PROCESSES.

COMBUSTION STABILITY MODEL CAN BE DEVELOPED AND VALIDATED USING THE DETAILED PHYSICAL DATA.

COST - ABOUT $200K PER YEAR (2 YEARS)

ADVANCED DIAGNOSTICS FOR COMBUSTION AND FLOW

LASERS AND OTHER OPTICAL EQUIPMENT ARE REQUIRED TO SUPPORT MEASUREMENTS RELATED TO COMBUSTION STABILITY AND COMBUSTION PHYSICS AND CHEMISTRY. THREE DIMENSIONAL PHASE DOPPLER PARTICLE ANALYSIS CAPABILITY IS REQUIRED FOR ATOMIZATION, EVAPORATION, AND DROPLET BURNING STUDIES.

DATA WILL BE USED FOR COMBUSTION AND COMBUSTION STABILITY MODEL VALIDATION, AND FOR DESIGN STUDIES ON PROTOTYPE INJECTOR ELEMENTS.

COST - ABOUT $200K PER YEAR (3 YEARS)

PERFORMANCE ANALYSIS FOR HIGH TEMPERATURE ENGINES

CURRENTLY USED ROCKET ENGINE PERFORMANCE ANALYSIS MODELS REQUIRE UPGRADING TO DEAL WITH HIGH TEMPERATURE WORKING FLUIDS SUCH AS THOSE IN NUCLEAR POWERED ENGINES FOR A MARS MISSION. SPECIFICALLY, UPDATED CHEMISTRY DATA ARE NEEDED.

COST - $100K (1 YEAR)

TITLE: INJECTOR / MAIN COMBUSTION CHAMBER WALL COMPATIBILITY OPTIMIZATION STUDIES

OBJECTIVE: EVALUATE INJECTOR EFFECTS ON CHAMBER WALL COMPATIBILITY TO DESIGN FOR INCREASED CHAMBER LIFE.

APPROACH: BY USING EXISTING "40K" CALORIMETER HARDWARE, EVALUATE THE EFFECT ON WALL HEAT FLUX & RESULTING WALL TEMPERATURE ON THE FOLLOWING

- LOX COAX SWIRL vs. LOX COAX SHEAR ELEMENT
- OUTER ROW ELEMENT SCARFING
- OUTER ROW ELEMENT CANTING (INBOARD)
- FILM COOLING vs. MIXTURE RATIO BIAS
- OUTER ROW WALL GAP

SCHEDULE :

- HARDWARE FABRICATION - ONE YEAR
- TESTING & DATA EVALUATION - ONE YEAR

COST: 1M

N93-71878

INTEGRATED TECHNOLOGY PLAN

FOR THE CIVIL SPACE PROGRAM

S5-81
157472
p, 13

SPACE R&T BASE: PROPULSION

HIGH THRUST CHEMICAL

S. Gorland

6/26/91

SPACE R&T BAS. ?ROPULSION
HIGH THRUST CHEMICAL

OBJECTIVES

PROGRAMMATIC

Provide a technology base and maintain an institutional capability for continued advances in the development of advanced space propulsion systems to support launch, upper stage, orbit transfer and ascent/descent engines.

TECHNICAL

Validated design and analytical codes for cryogenic turbopump bearings and seals.
Full 3D codes for turbopump internal flow and heat transfer.
Design methodologies and diagnostic capabilities for combustion stability.
Reduced Operations cost, increase life, safety.
Higher energy density propellants.
In-situ engine concepts.

MILESTONES - (BASE PROGRAM)

- FY93 - Demonstrate metallized RP-1 performanc
- FY94 - Complete 3D Pump Code Development
- FY94 - Complete H/O Stability Model
- FY94 - Complete Subscale testing of Ceramic Brush seals.
- FY95 - Complete assessment of cryogenic magnetic bearings.
- FY96 - Complete combined cycle analysis.
- FY96 - Complete atomic hydrogen engine/feed system fabrication.
- FY97 - Complete generation of tribomaterials da base for turbopump bearings.

RESOURCES ($M)

	PLANNED	3X GUIDELINE
FY91	3.5	3.5
FY92	3.5	3.5
FY93	3.6	4.8
FY94	3.8	6.1
FY95	3.9	7.4
FY96	4.1	8.2
FY97	4.3	9.2

PARTICIPANTS

LEWIS RESEARCH CENTER
- High Thrust Chemical

LUNAR AND PLANETARY PROPELLANTS

NEEDS

- Reduce cost of SEI missions
- Validate performance potential of In-situ propellants
- Demonstrate compatibility between production and propulsion systems

CHALLENGE/APPROACH

- Develop propulsion technology for engines that operate on propellants produced at the moon and Mars
- Insure engines operate with high degree of reliability and autonomy

BENEFITS

- Significantly reduce Earth launch-to-orbit mass requirements
- Increase self-sufficiency of planetary bases
- Significantly reduce trip-time for manned Mars missions

SPACE R&T BASE PROPULSION
HIGH THRUST CHEMICAL

LUNAR AND PLANETARY PROPELLANTS

CURRENT PROGRAM

- Complete Carbon Monoxide/Oxygen sub-scale combustion experiments
- Identify technology issues for dual-fuel engine design
- Define Metal/oxygen monopropellant hazard classification
- Establish Metal/Oxygen monopropellant formulation

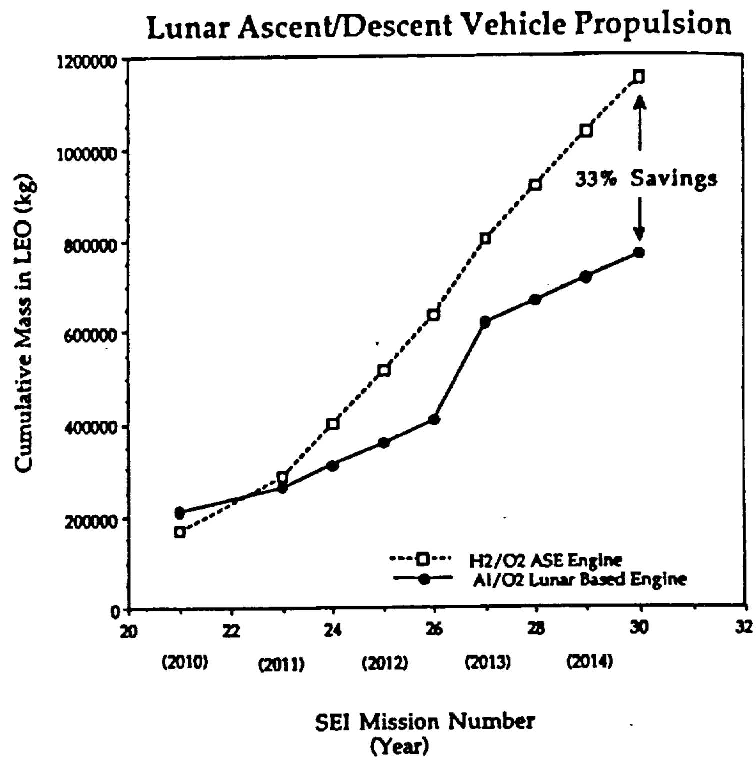
AUGMENTED PROGRAM

- Validate Sub-Scale Metal/Oxygen monopropellant combustion
- Demonstrate Carbon Monoxide/Oxygen engine at large scale
- Demonstrate capability for Large-batch production of Metal/Oxygen monopropellant

Benefits

In Situ Propellant Utilization

- Reduces Earth Launch Mass Requirements (see figure)
- Decreases Mars Mission Time
- Reduces Mission Complexity
- Establishes Self-Sufficiency of Lunar and Mars Bases



SPACE R&T BASE PROPULSION HIGH THRUST CHEMICAL

Metallized Propellants:

- Metallized Propellants Offer

  Higher Specific Impulse and Higher Propellant Density
  Safer Propellants (Gelled)

- Significant Performance Increases Are Possible

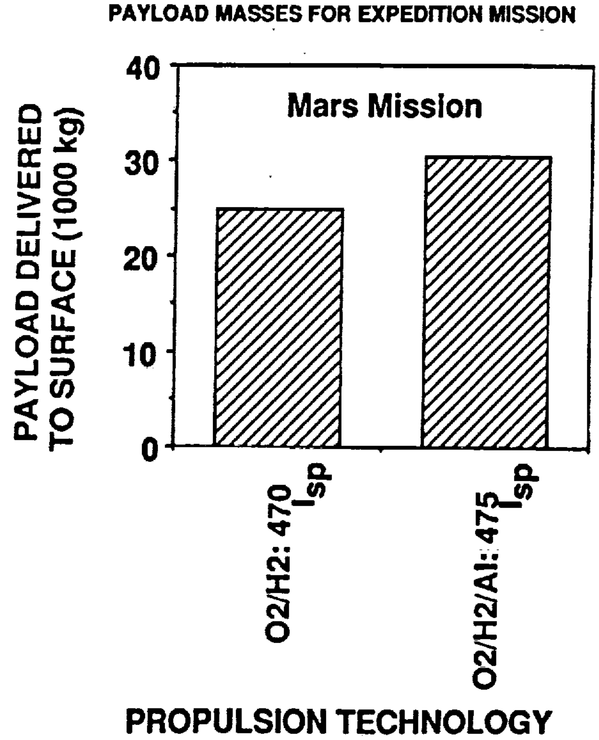
  Higher Delivered Payload
  Lower Initial Mass in LEO

Oxidizer +	Fuel +	Metal
O_2	H_2	Al
O_2	Hydrocarbon	Al
N_2O_4	MMH	Al

Metallized Propellants:

Areas of Application and Benefit

- Mars:
  - Payload To Surface Increased By 20 to 33 Percent
  - High I_{sp} Storable NTO/MMH/Al for Mars Ascent
- Lunar:
  - Payload To Surface Increased By 3 Percent
- Robotic Planetary:
  - Enables Fast Missions
- Earth to Orbit:
  - Liquid Rocket Boosters
    Added Payload
    Safety Enhanced With Gels



SPACE R&T BAS PROPULSION
HIGH THRUST CHEMICAL

Current and Needed Technology for Metallized Propellants

Current	Needed
• Combustion /Testing: Preliminary Subscale O_2 /RP-1 /Al	Complete Characterization: O_2 /H_2 /Al, O_2 /RP-1 /Al
• Rheology: Preliminary Understanding of Rheology: RP-1 /Al	Complete Understanding: H_2 /Al Gels (60 % Al) RP-1 /Al (60 % Al)
• Formulation: Large-Batch Formulation	Large-Scale Manufacturing

SPACE R&T BASE: PROPULSION
HIGH THRUST CHEMICAL

COMBUSTION

TECHNOLOGY REQUIREMENTS
- Develop Atomization, Supercritical Vaporization, Mixing Models
- Develop Damping Device Models
- Develop Diagnostics To Make Measurements In The Combustor
- Develop Performance & Stability Database

TECHNOLOGY CHALLENGES
- Designing High Performance Stable Engines
- Reducing The Amount Of Development & Qualification Testing

BENEFITS
- Reduced Engine Weight
- Increased Engine Design Margin
- Reduced Engine Development Time

SPACE R&T BASE: PROPULSION
HIGH THRUST CHEMICAL

AUGMENTED PROGRAM

INJECTOR ATOMIZATION CHARACTERIZATION
- Develop Supercritical Spray Combustion Model

ROCKET ENGINE COMBUSTION DIAGNOSTICS
- Develop Devices To Measure Rocket Combustor Fluid Properties

NEW STABILITY RATING TECHNIQUES
- Develop High Energy Frequency Controlled Technique

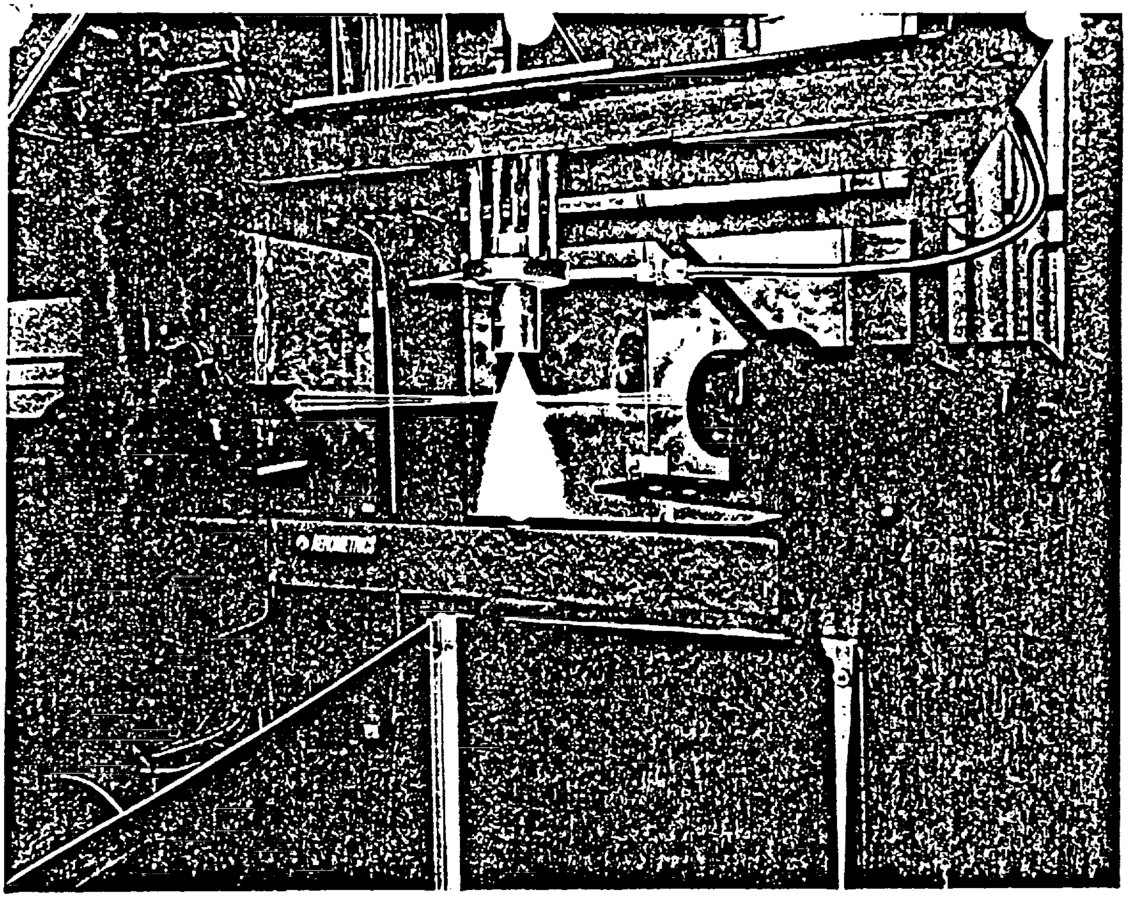
PERFORMANCE & STABILITY DATABASE
- Create Standardized Reporting Format & Database

INTEGRATED BAFFLE/CAVITY MODEL
- Develop Hub Baffle & Baffle/Cavity Interaction Model

CURRENT PROGRAM

SHEAR COAXIAL INJECTOR ATOMIZATION CHARACTERIZATION
- Compare Cold Flow & Hot Fire Atomization Measurements
- Verify Existing Models & Develop New Model If Appropriate

INJECTOR/CHAMBER FREQUENCY COUPLING INVESTIGATION
- Investigate LOX Tube Resonance Coupling Instability
- Create Validation Database For Model & CFD Code Development



SPACE R&T BASE PROPULSION
HIGH THRUST CHEMICAL

TURBOMACHINERY CODES/TOOLS

NEEDS

- Model secondary flows in the turbomachinery of liquid propellant rocket engines.
- Integrate these models into current design techniques

CHALLENGE/APPROACH

- Reduce the prohibitive CPU time of numerical simulation
- Use approximation techniques until the availability of massively parallel processing

BENEFITS

- Improved turbomachinery reliability, performance and life
- Decreased time and cost of development

TURBOMACHINERY CODES/TOOLS

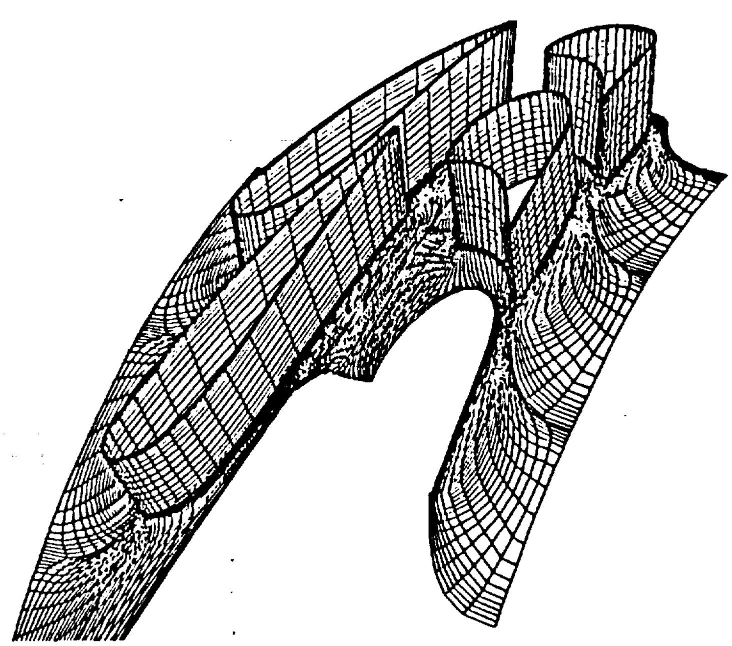
CURRENT PROGRAM

- Develop alternative approaches to numerically simulate 3D, unsteady viscous flow in space turbopumps to better predict aerothermal loads and component efficiencies

AUGMENTED PROGRAM

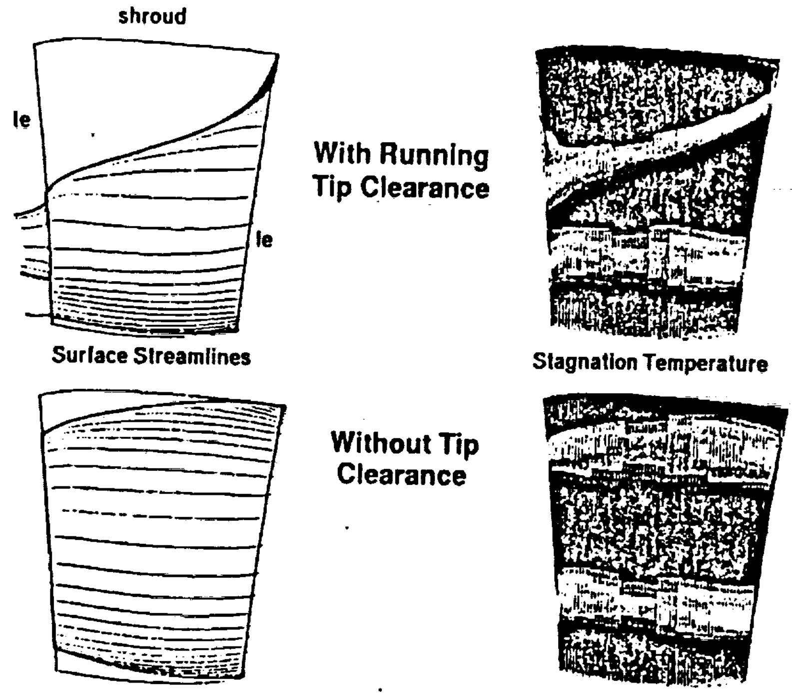
- Develop parallel processing capability for turbine design
- Develop deep throttling capability for space turbopumps
- Complete unsteady model for analysis of complete pump stage
- Verify aerodynamic performance for unique, space propulsion turbine blades

SPACE CHEMICAL PROPULSION PROGRAM
Advanced Expander Test Bed (AETB)
Hydrogen Turbine (First Stage)



Pratt & Whitney SSME HPFTP Second Vane Suction Side

Effect of First Blade Leakage Vortex on Second Vane Flow



BEARINGS

TECHNOLOGY NEEDS:

- Validated design codes and methodologies
- Advanced materials and coatings
- Improved bearing and bearing damper design
- Improved thermohydrodynamic models

TECHNOLOGY CHALLENGES:

- Measure complete bearing fluid mechanic and thermal properties to thoroughly validate codes
- Standardize measurement techniques to determine bearing dynamic coefficients
- Identify propellant compatible and wear resistant materials
- Develop bearing designs tolerant to wide operating ranges and pump transients

TECHNOLOGY BENEFITS:

- Longer Life: Increased reliability, improved maintainability, multi-mission capability
- Improved Performance: Higher speeds, greater stiffness & damping, improved stability

SPACE R&T BASE PROPULSION
HIGH THRUST CHEMICAL

BEARINGS

CURRENT PROGRAM

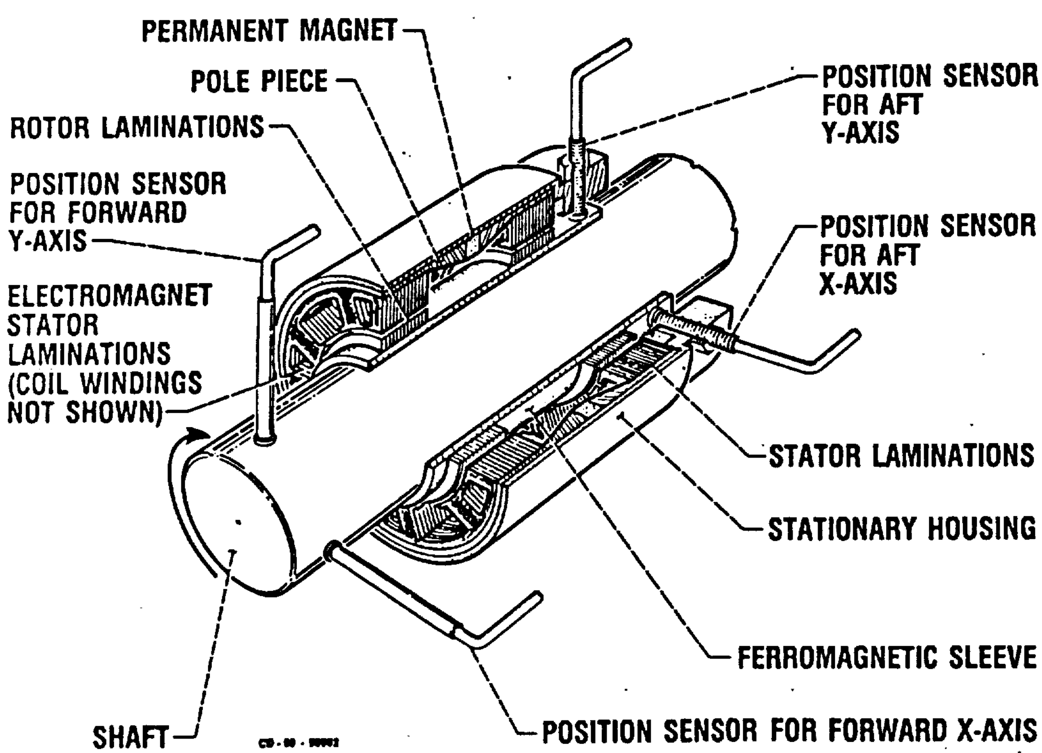
- Experimental testing of LH2 Foil Bearings
- Development of Foil Bearing design and performance prediction code
- Development of dynamic coefficients measurement technique
- Development of hydrostatic bearing steady state and dynamic characteristics code
- Flow visualization experiments of fluid film bearings for code validation
- Experimental testing of a hybrid magnetic bearing to identify technical issues

AUGMENTED PROGRAM

- Demonstration testing of foil bearings in a turbopump
- Experimental testing of LOX foil bearings
- Development of advanced hydrodynamic, hydrostatic and hybrid bearing concepts
- Experimental testing of fluid film bearings to validate codes
- Development of magnetic and superconducting magnetic bearing technology
- Demonstration of magnetic bearings in a turbopump
- Advancement of cryogenic fluid flow and thermal fundamentals to model bearing thermohydrodynamics (turbulence modeling, two-phase flow, cavitation, inertia)
- Establishment of tribomaterials design data base and methodology

SPACE R&T BASE PROPULSION
HIGH THRUST CHEMICAL

HYBRID MAGNETIC BEARING



FOIL BEARING PERFORMANCE IN LH2

OBJECTIVE:

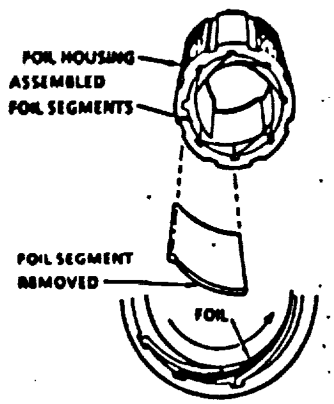
- CHARACTERIZE FOIL BEARING LOAD CAPACITY AND TORQUE IN LH_2

APPROACH:

- COOPERATIVE AGREEMENT WITH AIRESEARCH UNDER 1958 SPACE ACT
- AIRESEARCH PROVIDES ANALYSES CODES AND FIOL BEARING TESTER
- LERC PROVIDES LH_2 TEST FACILITY

JUSTIFICATION

- LONG-LIFE, HIGH LOAD CAPACITY BEARING IS NEEDED FOR CRYOGENIC TURBOPUMPS
- AIRESEARCH HAS DEMONSTRATED LOAD CAPACITY OF 200 + psi IN GN2



PROGRAM HIGHLIGHTS:

- ACHIEVED 240 PSI LOAD CAPACITY IN LH_2
- RAN STABLY AT ALL SPEEDS (10-97 KPRM)
- OVER 150 START/CYCLES WITH NO NOTICEABLE BEARING WEAR
- ACHIEVED 300 PSI LOAD CAPACITY IN LN_2
- ACCUMULATED RUN TIME: 4 HRS IN LH_2 AND 5 HRS IN LN_2

TURBOPUMP SEALS TECHNOLOGY

TECHNOLOGY NEEDS:

- Longer life
- Lower leakage - especially over wide throttling ranges in small turbopumps
- Higher pressure capability
- Dynamic stability, high shaft speed
- Compatible materials

TECHNOLOGY CHALLENGES:

- Low density, wear-resistant materials or material combinations
- Low leakage, non-contacting seals
- High dynamic response of seals to shaft excursions
- Oxygen compatible materials
- Actively controlling clearance

TECHNOLOGY BENEFITS:

- Space Basing capability due to improved reliability and maintainability
- Increased payload by reducing purge gases needed
- Increased component efficiency
- Improved reliability and maintainability

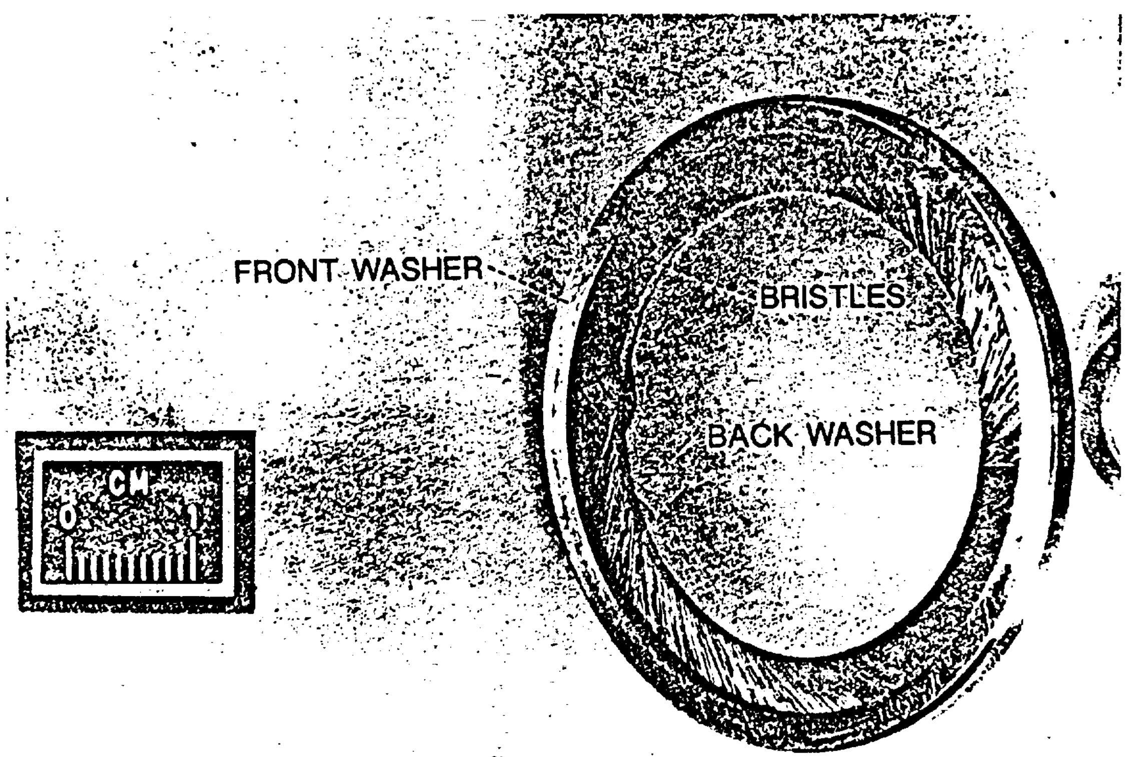
TURBOPUMP SEALS TECHNOLOGY

CURRENT PROGRAM

- BRUSH SEALS FOR CRYOGENIC APPLICATIONS (IN-HOUSE)
  FABRICATION INITIATED FOR TESTER MODS.
- BRUSH SEALS FOR HIGH TEMPERATURE APPLICATIONS (IN-HOUSE)
  ACQUIRED TEST RIG FROM THE AIR FORCE.
- NUMERICAL, ANALYTICAL, EXPERIMENTAL STUDY OF FLUID DYNAMIC FORCES IN SEALS (MECHANICAL TECHNOLOGY, INC.)
  THREE INDUSTRIAL CODES READY FOR USER EVALUATION

PROPOSED AUGMENTATION

- DEFINE AND EXPERIMENTALLY VALIDATE CERAMIC BRUSH SEALS
- EXPERIMENTALLY VALIDATE ANALYSIS AND DESIGN CODE FOR 2-PHASE CRYOGENIC SEALS
- DESIGN AND DEMONSTRATE ACTIVELY-CONTROLLED OR "SMART" SEALS FOR AEROSPACE APPLICATIONS AND DEVELOP THE NECESSARY ANALYSIS AND DESIGN TOOLS



A TYPICAL BRUSH SEAL

Space R & T Base: Propulsion
High Thrust Chemical

Systems Analysis and Engine Cycles

- ***Technical Needs***
  - Higher Performance
    - Combined Cycle
    - Altitude-Compensating Nozzles
    - Full-Flow Staged-Combustion Cycle
    - High-Mixture-Ratio Operation
  - Optimization of Coolant-Side Heat Transfer

- ***Technical Challenges***
  - Higher Gas-Gas Injector Performance
  - Combined-Cycle System Integration
  - High-Aspect-Ratio Cooling Channel Database
  - Mixture Ratio Control

- ***Technical Benefits***
  - Higher Performance
  - Simpler Subsystems
  - Less Severe Operating Conditions
  - Enhanced Heat Transfer

Space R & T Base: Propulsion
High Thrust Chemical

Systems Analysis and Engine Cycles

- ***Current Program***
  - Altitude-Compensating Nozzles
    ⇒ Database on most promising concepts
  - High-Mixture-Ratio Operation
    ⇒ Capability to Operate at High Mixture Ratio Reliably
  - High-Aspect-Ratio Cooling Channels
    ⇒ Database for Future Designs

- ***Augmented Program***
  - Combined-Cycle Engine
    ⇒ Engine Concept That Uses Both Air and Oxygen as Oxidizer
  - Full-Flow Staged-Combustion Cycle
    ⇒ Development of Technology for Gas-Gas Injection and Ox-Rich Preburner
  - Liquid-Air Rocket
    ⇒ Technology to use Liquefied Air as a Propellant
  - CFD Modelling of Coolant Flow in Coolant Passages
    ⇒ CFD Model

SUMMARY

TECHNICAL CHALLENGE

- Long life turbopump components.
- Improved stability and performance of combustion devices.
- Reduced launch mass and cost, enabling SEI missions.

APPROACH

- Validated models, codes and algorithms for component design and analysis.
- Develop benchmark data for supercritical spray dynamics.
- Evaluate advanced turbomachinery sub-components (seals and bearings) design concepts.
- System and cycle analysis for design optimization.
- Fundamental combustion research and material characterization.

PAYOFF

- Improved life, durability, performance and safety in the evolution of high thrust chemical propulsion systems, e.g., SSME and liquid rocket boosters, through advanced concepts and methodologies.
- Reduce SEI costs.

RELATIONSHIP TO FOCUSED ACTIVITIES AND OTHER PROGRAMS

Develop fundamental technologies in direct support of earth-to-orbit, orbit transfer and upper stage propulsion programs. Efforts are coordinated with other Centers and DOD as appropriate.

TECHNOLOGY CONTRIBUTIONS

- Expertise and technology in turbomachinery code development utilized by ATD and NLS designers.
- Combustion stability methodology applied to MSFC TTB and RCS thrusters at JSC.

Integrated Technology Plan
for
the Civil Space Program

N93-71879

Cryogenic Fluid Management (Base R&T)

Cryogenic Fluid Systems
Cryogenic Orbital Nitrogen Experiment
(CONE)
Cryogenic Orbital Hydrogen Experiment
(COHE)
(Transportation Focused Technology)

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June 1991

Presented by: Pat Symons

Agenda

- Technology Requirements vs. SOA
- Benefits Assessment
- Integrated Program
  - Objective
  - Approach
  - Content
- Concluding Remarks
- Summary

Cryogenic Fluid Systems
Element Introduction

- All known future manned space missions and most future unmanned space missions require or could substantially benefit from the use of subcritical cryogenic liquids
    - As propellants
    - As life support fluids
    - As reactants
    - As coolants

- The current SOA is based on Centaur and Saturn upper stage technology and Apollo technology which is 15-20 years old

- Continued use of existing SOA technology imposes enormous cost and performance penalties on future missions, neither of which can be successfully borne by the Agency

- To meet the need, a NASA Cryogenic Fluid Systems Technology Program has been formulated with LeRC as Lead Center and substantial involvement and participation from MSFC

- The funding for the program is provided by both the Base R&T program and the Focused Program in Transportation

TECHNOLOGY REQUIREMENTS VS. SOA

State of the Art vs. Future Requirements
System-Level Comparisons

Capability	Flight Proven SOA: Saturn/Centaur	Future Requirements
Mission Operations	Ground: Assembly, Propellant Loading Check-out and Launch Space: Short Coast and Engine Restart	Space: Final Assembly, Propellant Loading, Check-out and Entire Mission Operation for Reusable Space-based stage
Mission Duration	Hours	Months (Moon) to Years (Mars)
Fluid Management		
- Thermal Control	3 Layers MLI	50-200 layers MLI Refrigeration (Lunar surface/Mars)
- Pressure Control	Prop. settling (low-g) & Vent	Thermodynamic Vent (Zero-g) compatible with mission ops.
- Liquid Acquisition	Prop. settling (low-g)	Capillary (Zero-g) compatible with mission operations
- Pressurization	Prop. settling (low-g) & GHe GH_2 after engine ignition (high-g)	Zero and low-g autogenous (GH_2/GO_2)
- Liquid Transfer	None	Nonvented (Zero-g) preferred; optimized prop. settling (low-g) may be acceptable
- Slosh Control	Baffles for launch and stage separation (accel. dominated)	Space operations (capillary dominated)
- Mass Gauging	One to high-g	Zero to low-g

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Apollo - Space Exploration Initiative Comparison

Mission & Transportation Vehicle Characteristics	Apollo	Space Exploration Initiative	
		Lunar	Martian
Total Duration (1st Launch to crew return)	12 Days	3-15 months	3-5 years
Crew Size	3	4-6	4-16
Duration on Surface	3 days	1-12 months	1-2 years
Cargo Mass	0.7 mt	13-32 mt	TBD
No. of Propulsion Systems	4	1-2	1-2
- Trans Lunar/Mars Injection Propellant - Lunar/Martian Orbit & Earth Return Prop. - Surface Departure/Ascent Propellant	LOX/LH2 Storable Storable	LOX/LH2 or LH2 (nuclear) LOX/LH2 or LH2 (nuclear) LOX/LH2	
LEO Departure Mass (75-80% propellant)	140 MT	160-280 mt	300-2000 mt
Mission Objectives	Init. Manned Presence	Conduct Science & Surface Exp.	

Key Space Exploration Initiative transportation system technology requirements (engines, aerobrake, and cryogenic fluid systems) are not based on "Apollo-type" mission scenarios

Use of Apollo technology to meet SEI mission requirements is not possible

Symons\TP\Apollo SEI comp.kad 6 12 91

Criticality of Technology

- Exploration of the Moon and Mars requires cryogenic fluids for propulsion (both Chemical and Nuclear Thermal)

- Advanced cryogenic fluid systems should be classified as enabling to achieve necessary system performance and to reduce mission costs

    - Long-term fluid storage (Thermal Control)
    - Refill/contingency capability (Liquid Transfer)
    - Tank pressure control

- Recently completed assessments of technology required for exploration has shown cryogenic fluid management to be the highest priority from both Level II and Level III

- Office of Space Flight technology requirements assessment identified cryogenic storage, supply and handling as one of their highest priority technologies

- Synthesis committee report identifies cryogenic transfer and long-term storage as one of fourteen critical technologies for exploration

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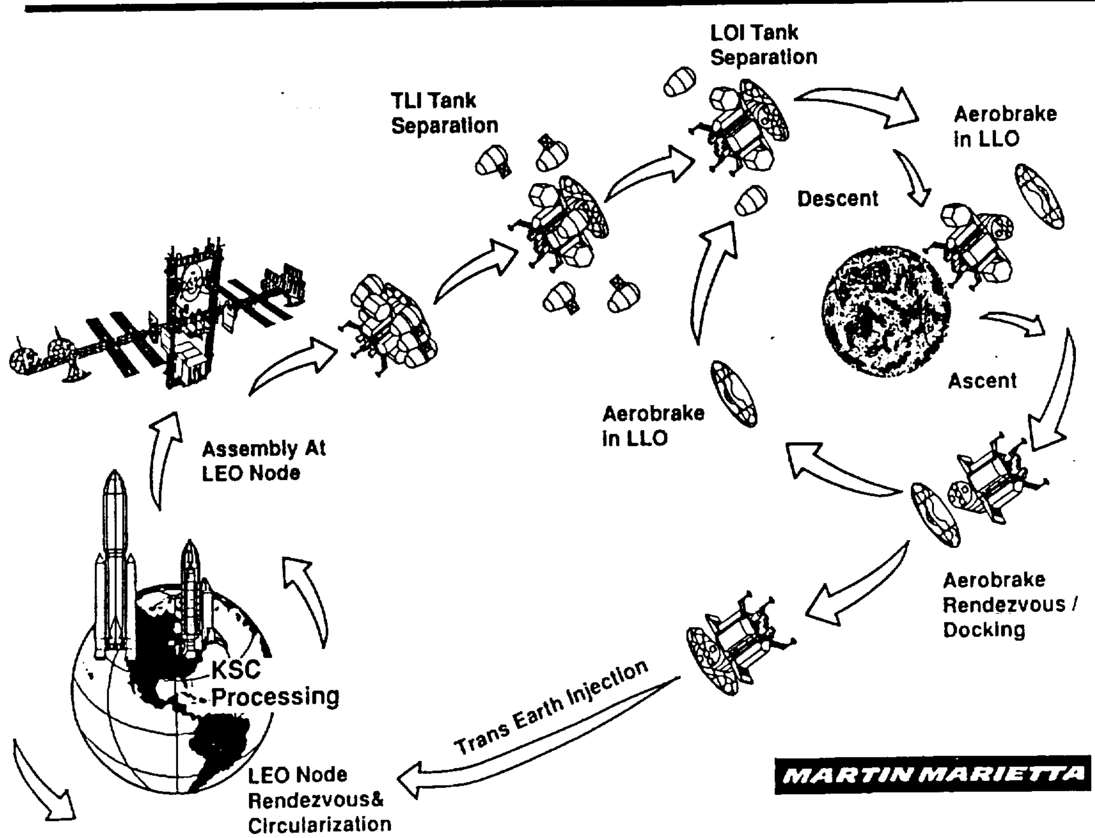
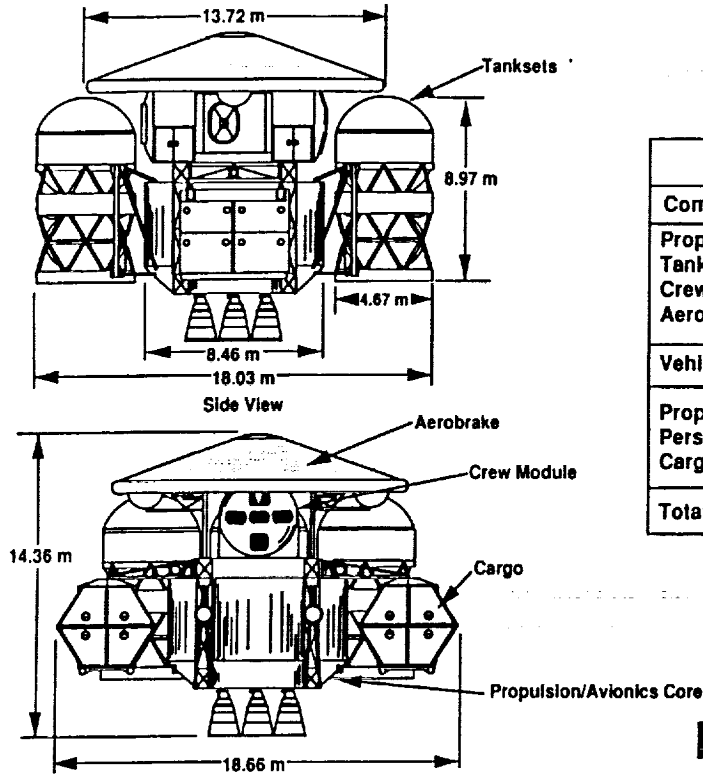
Benefits Assessment

- Baseline: Lunar Transfer System (LTS) Concept and Mission Scenario Developed by Martin Marietta
  - Assumes three ETO launches at 45 day intervals (480K lb. total mass)
  - Allows 60 days for pre-Leo departure ops. (no contingency)
  - Assumed significant technology advances (Aerobrake, advanced space engine, thick MLI, zero-g cryo transfer, and pressure control)
- State-of-the-Art Assumptions for Benefit Assessment
  - Thermal control: 1/2 inch MLI with foam substrate
  - Pressure control: Shuttle Centaur system design criteria
  - Liquid transfer: No orbital capability (tanks loaded on ground) therefore, space-based/reusable concept precluded
- Mass Savings (Technology Benefits) accrue from boiloff reductions and decreases in tankage volume/mass

LTS Mission



Selected Concept - Piloted Configuration



Front View (Front Tanksets Not Shown)

Mass Properties	
Components	**Mass (t)**
Prop/Avionics Core	7.19
Tanksets (4 TLI & 2 LOI)	9.11
Crew Module	7.78
Aerobrake & Equip	3.50
Vehicle Dry Mass	27.58
Propellant	174.0
Personnel/Misc	.66
Cargo w/Sppt	15.26
Total Mass	217.50

MARTIN MARIETTA

Cryogenic Fluid Management Technology Benefits Assessment Results

ETO mass savings for nominal mission with 30 day lunar stay

$2.95B

- Thermal control	=	28,700 lbm
- Pressure control	=	18,500 lbm
Total mass savings	=	47,200 (10% LEO mass growth)
Potential cost savings	=	$118 M/mission (at $2500/lbm ETO cost)

Benefit of adding a 45 day pre-LEO departure contingency

$ .75B

- Thermal control	=	7100 lbm
- Pressure control	=	4700 lbm
Total mass savings	=	11800 lbm (2.5% of LEO mass growth)
Potential cost savings	=	$29.5 M/mission (at $2500/lbm ETO cost)

Cryogenic Fluid Management Technology Benefits Assessment Results (continued)

Additional benefit for 6 month lunar stay

$7.8B

- Thermal control = 58,000 lbm
- Pressure control = 52,000 lbm
- Advanced thermal control = 14,700 lbm

Total mass savings = 124,700 lbm (26%LEO Mass growth)
Potential cost savings = $312M/mission (at $2500/lbm ETO cost)

Additional Benefit of a tanker/depot (top-off, core & aerobrake tank fueling)

$1.6B

- For nominal mission with 30 day lunar stay = 5,600 lbm
- For 45 day pre-LEO departure contingency = 18,500 lbm
- For 180 day lunar stay = 1,800 lbm

Total mass savings = 25,900 lbm (5.4% of LEO mass growth)
Potential cost savings = $64.75M/mission (at $2500/lbm ETO cost)

Major benefit of transfer technology is enabling of reusable LTS concepts (Life Cycle Cost Savings of approximately $10B estimated by Martin Marietta)

Total Benefit for 25 Lunar Missions = $23 B

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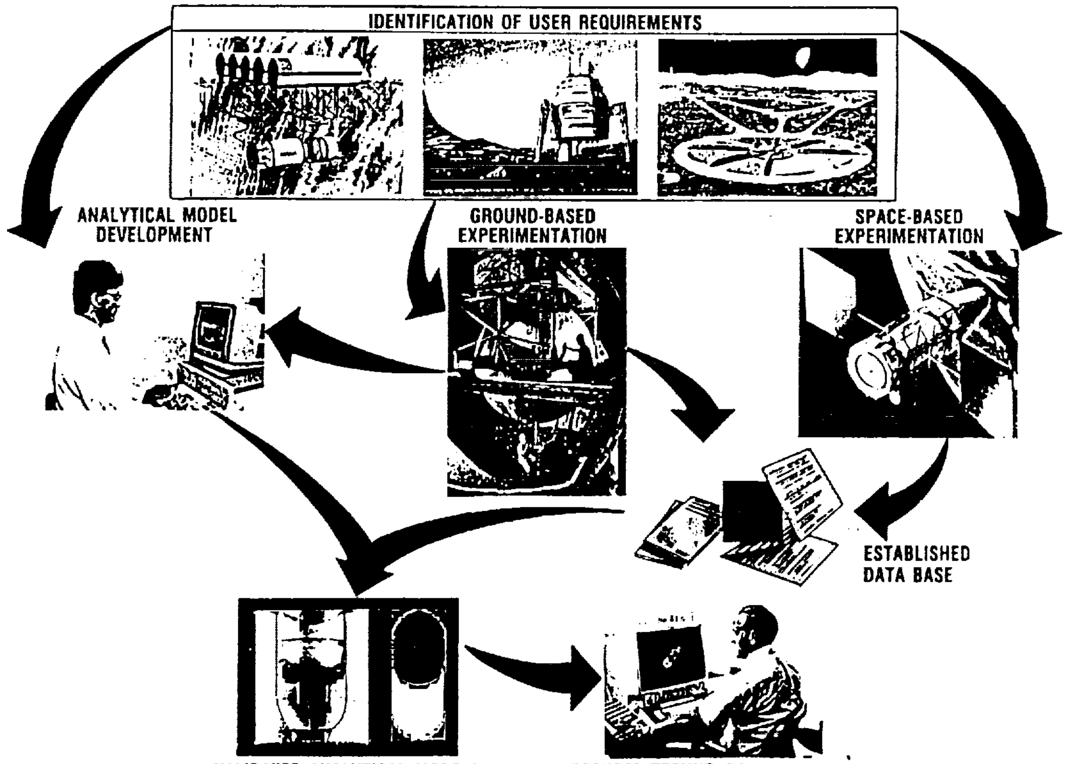
Integrated Program

LeRC CRYOGENIC FLUID MANAGEMENT PROGRAM APPROACH



Cryogenic Fluid Systems

Technology Development Approach

Technology Development Approach:

- Analytical model development efforts to identify key parameters and model basic fluid dynamic,thermodynamic and heat transfer processes
- * Analytical model development efforts to enable the performance predictions of future cryogenic fluid systems
- Small scale ground-based experiments to investigate the basic thermodynamic and fluid dynamic processes; provide proof of concept; parametric testing
- * Large scale system testing to provide a more controlled environment for the collection of data for partial analytical model validation and refinement of operational procedures
- * Large subscale system demonstrations to integrate flight type components and processes in space simulated thermal and vacuum conditions using fluids of interest in a one-g environment
- Small scale flight experiments to provide low gravity data necessary to initiate analytical model validation and to provide low-g demonstrations of actual processes with a simulant fluid
- * Cryogenic Orbital Nitrogen Experiment (CONE), a subscale cryogenic test bed to provide low-g data necessary for the partial analytical model validation and low-g demonstration of critical components and processes
- * Cryogenic Orbital Hydrogen Experiment (COHE), a subscale cryogenic test bed to provide low-g data necessary for completion of analytical model validation

* Included in Transportation Technology Program

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Base Research and Technology

Cryogenic Fluid Management

Objectives

Programmatic

Develop analytical models of pertinent thermodynamic and fluid dynamic processes required to utilize subcritical cryogenic fluids in space and to conduct small scale tests to confirm concepts

Technical

Thermal Control - Thick MLI and Foam/MLI Systems
Pressure Control - Zero-g venting and fluid mixing
Liquid Supply - Low-g settling and capillary devices
- Zero-g and low-g autogenous pressurization
Liquid Transfer - Nonvented fill (zero-g) and optimized low-g fill
Fluid Handling - Slosh control for vehicle operations
- Mass gauging in zero-g and low-g

Schedule

1992 Data available/transfer models one-g validated
1992 LAD model one-g validated
1993 Pressurization model one-g validated
1994 TVS models validated for one-g
1996 MLI seams/penetrations model validated
1996 3-D slosh model validation for zero-g
1997 Thick MLI generic model validated
• 1998 Partial low-g validation of CFS model (LN2)
• 2004 Low-g CFS model validation (LH2)
• 2005 Technology complete

• Milestones depend on successful flight of CONE and COHE

Resources

1991	$ 1.5 M
1992	2.6 M
1993	2.1 M
1994	2.2 M
1995	2.3 M
1996	2.4 M
1997	2.5 M

Note: This element is closely coordinated with development efforts in NASA/OSF and other related Government programs; resources shown are NASA/OAET only

Participants

Lewis Research Center
Lead Center - MLI database, pressure control components, tank pressurization components, and liquid spray characterization

Marshall Space Flight Center
Participating Center - Integrated chilldown and no-vent fill, pump and valve development

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Transportation Technology

Space Transportation

Cryogenic Fluid Systems

Objectives

Programmatic

Provide technology necessary to proceed in the late 1990's with the development of cryogenic storage and supply systems for various transportation applications including space transfer vehicles and propellant storage systems for planetary surfaces

Technical

Thermal Control - Thick MLI and Foam/MLI Systems
Pressure Control - Zero-g venting and fluid mixing
Liquid Supply - Low-g settling and capillary devices
- Zero-g and low-g autogenous pressurization
Liquid Transfer - Nonvented fill (zero-g) and optimized low-g fill
Fluid Handling - Slosh control for vehicle operations
- Mass gauging in zero-g and low-g

Schedule

1991 MLI characterized for Lunar thermal conditions
1993 One-g and zero-g transfer technique completed
1994 3-D slosh model completed
1995 Foam/MLI design database (Lunar applications)
1996 Servicing facility design criteria established
1996 Propulsion integrated system performance demo.
1997 LN2 fluid handling components available
2000 LH2 fluid handling components available
2001 Mars insulation systems performance demo.
2005 Technology Complete

Resources

1991	$ 1.5M
1992	0.0M
1993	8.5M
1994	11.0M
1995	11.3M
1996	11.8M
1997	11.0M

Note: This element is closely coordinated with development efforts in NASA/OSF and other related Government programs; resources shown are NASA/OAET only

Participants

Lewis Research Center
Lead Center - Thick MLI, pressure control technology database, slow pressurization, liquid transfer technology database, fluid dumping and slosh control

Marshall Space Flight Center
Participating Center - Foam/MLI, specific vehicle demonstrations, engine feed systems and quick disconnects

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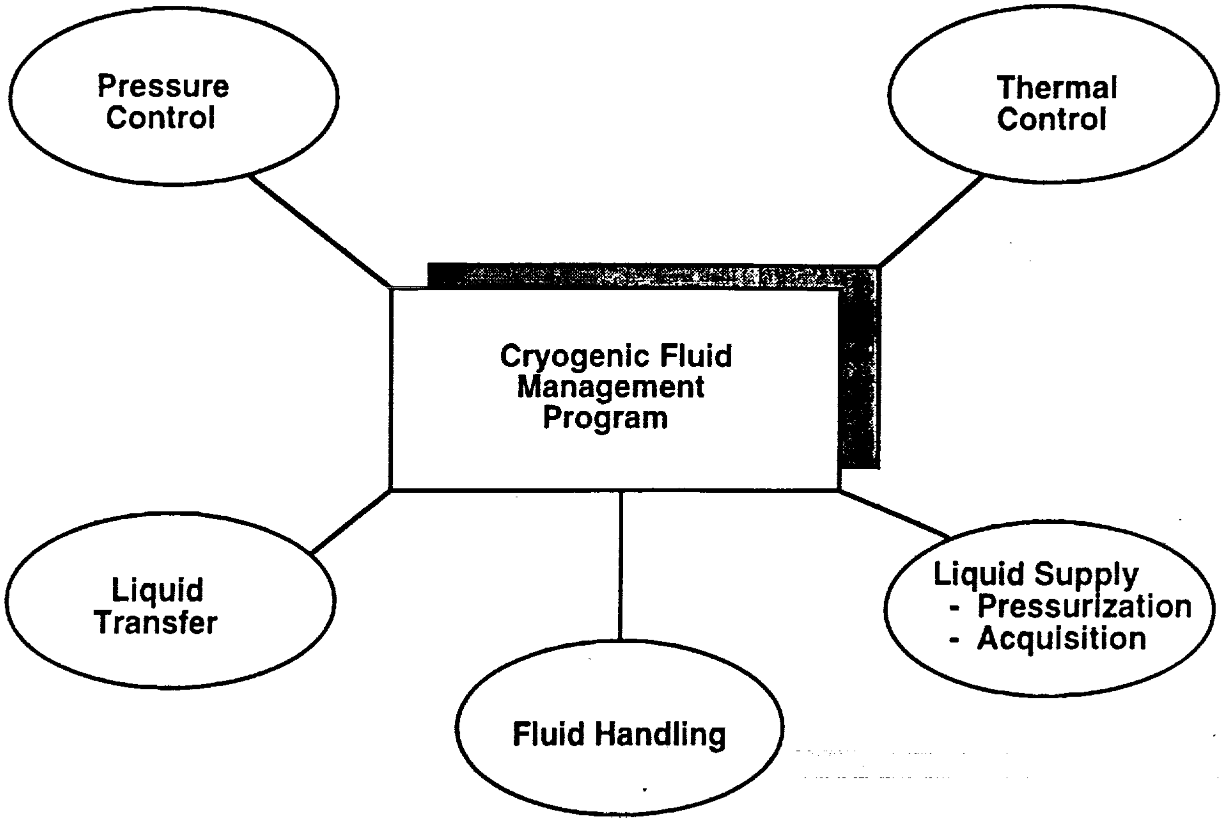
Major Technology Areas



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Technology Area - Thermal Control

Effort:

- Thermal performance of thick MLI
- Purged MLI & foam/MLI ground-hold thermal performance
- Purged MLI earth-to-orbit venting
- MLI/vapor shield performance
- MLI system performance for Lunar/Mars transfer and surface storage

Base R&T Activities

- Generic Analytical Models
- Candidate MLI screening
- MLI seam/penetration tests
- Thick MLI base performance
- Para/ortho conversion (SBIR)

Focused Technology Activities

- Applied analytical models
- Foam/MLI earth-to-orbit performance
- Purged MLI earth-to-orbit performance
- MLI/Vapor Cooled Shield performance
- Large-scale system level tests

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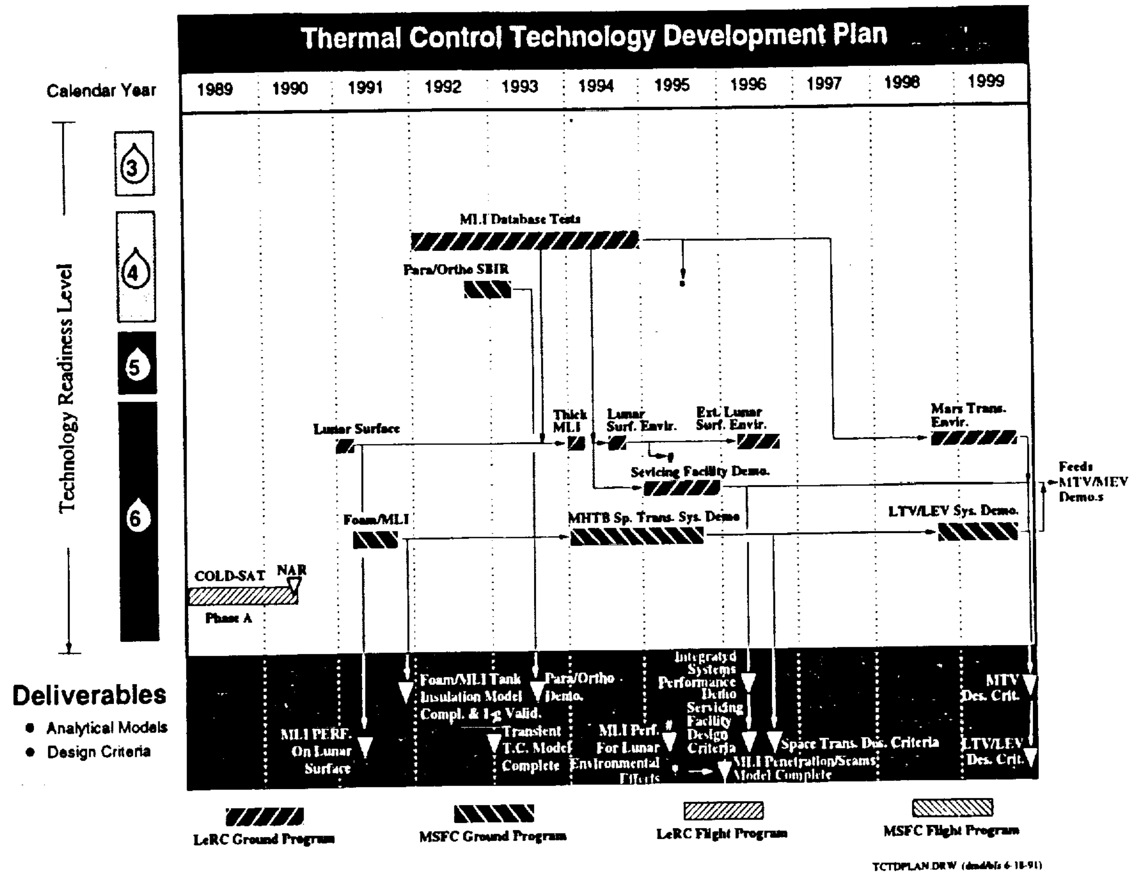

Technology Area – Pressure Control

Effort

- Passive TVS thermal performance
- Active TVS fluid mixing
- Active TVS heat exchanger thermal performance
- Thermal stratification and self-pressurization

<u>Base R&T Activities</u>

- Generic Analytical models
- Passive Heat Exchanger 2-phase heat transfer
- J-T device flow tests
- Active/passive TVS component checkout/performance
- TPCE flight experiment (In-Step)

<u>Focused Technology Activities</u>

- Thermal stratification and self-pressurization rise
- Active TVS performance
- Passive TVS performance
- Pressure control system demonstration
- CONE Flight Experiment
- COHE Flight Experiment

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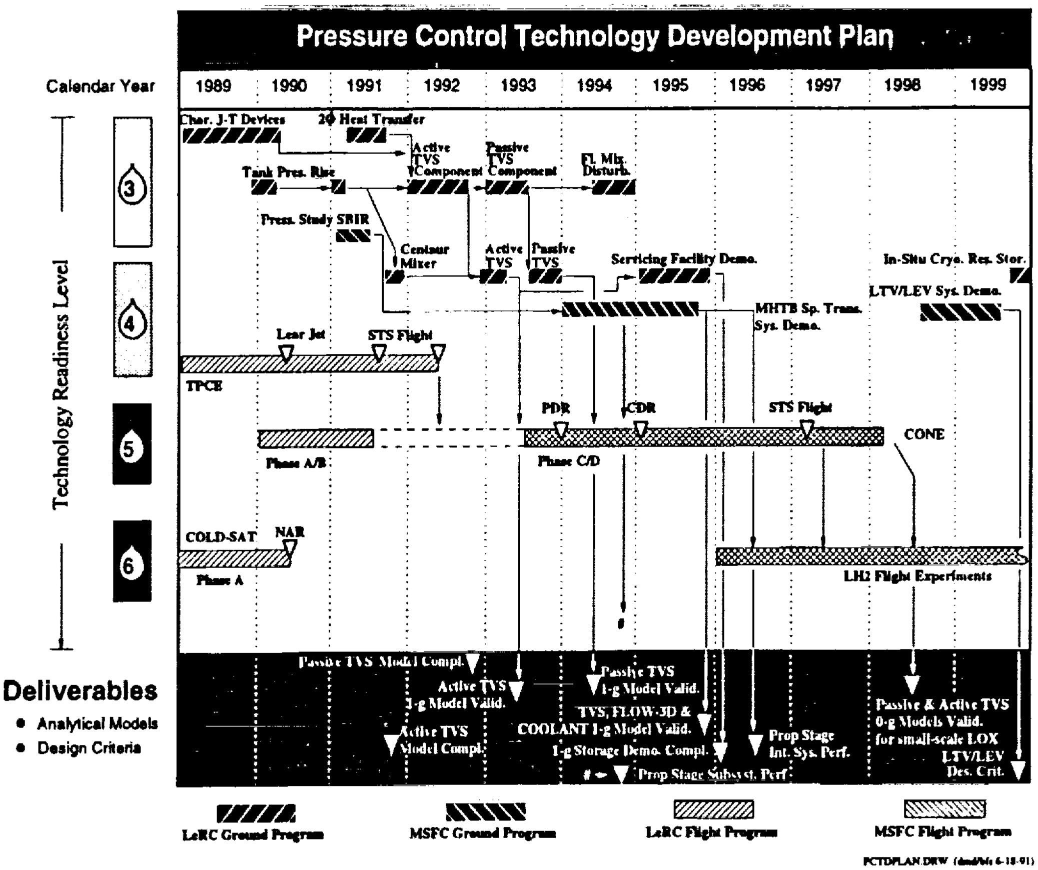


Technology Area -- Liquid Supply

Effort

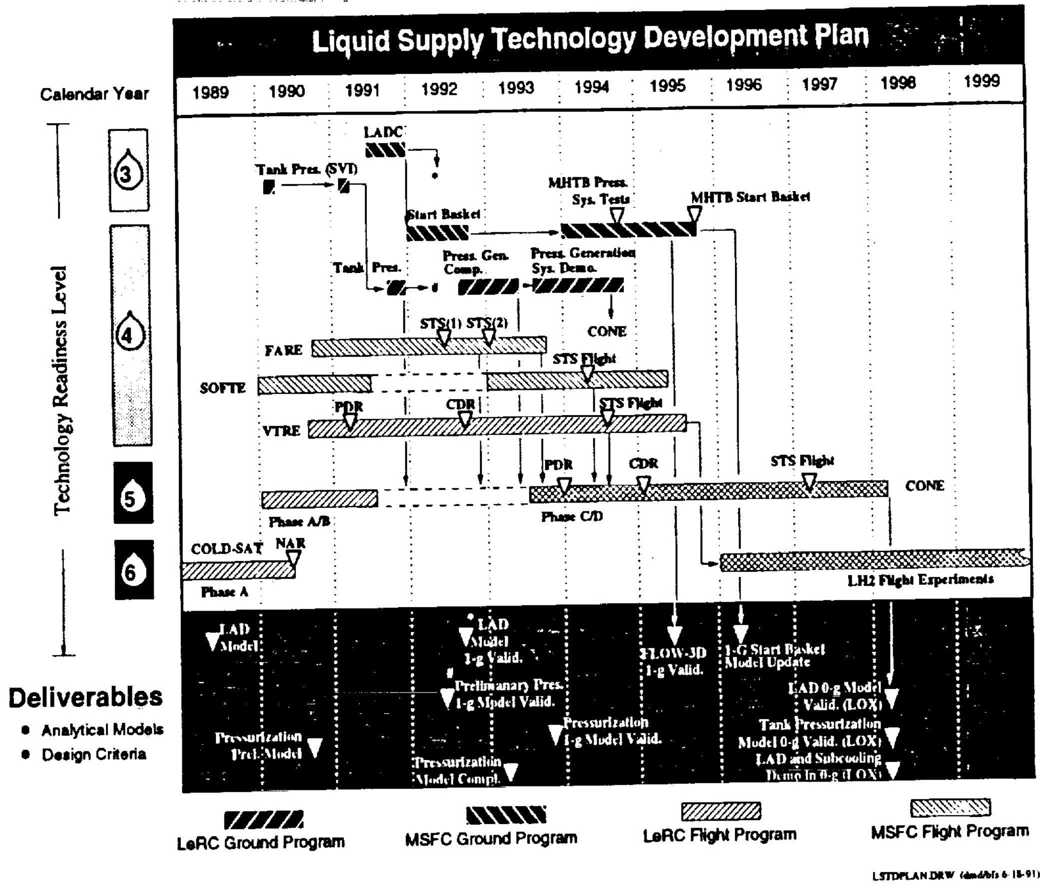
- LAD performance characteristics
- Autogenous tank pressurization for liquid transfer
- Autogenous tank pressurization for engine start/run
- Autogenous pressurant generator

<u>Base R&T Activities</u>

- Generic analytical models
- LAD screen characterization
- VTRE flight experiment (In-Step)
- Autogenous pressurant generation

<u>Focused Technology Activities</u>

- Start basket characterization
- Autogenous tank pressurization
- FARE flight experiment
- SOFTE flight experiment
- CONE flight experiment
- COHE flight experiment



Technology Area -- Liquid Transfer

Effort

- Tank Chilldown
- Ullage Condensation
- Tank no-vent fill
- LAD Fill

<u>Base R&T Activities</u>

- Generic Analytical Models
- Alternate spray system performance
- Spray nozzle condensation rates
- Precursory no-vent fill tests
- VTRE flight experiment (In-Step)

<u>Focused Technology Activities</u>

- No-vent fill of a flight weight tank
- Large scale system demonstration
- FARE Flight Experiment
- SOFTE Flight Experiment
- CONE Flight Experiment
- COHE Flight Experiment

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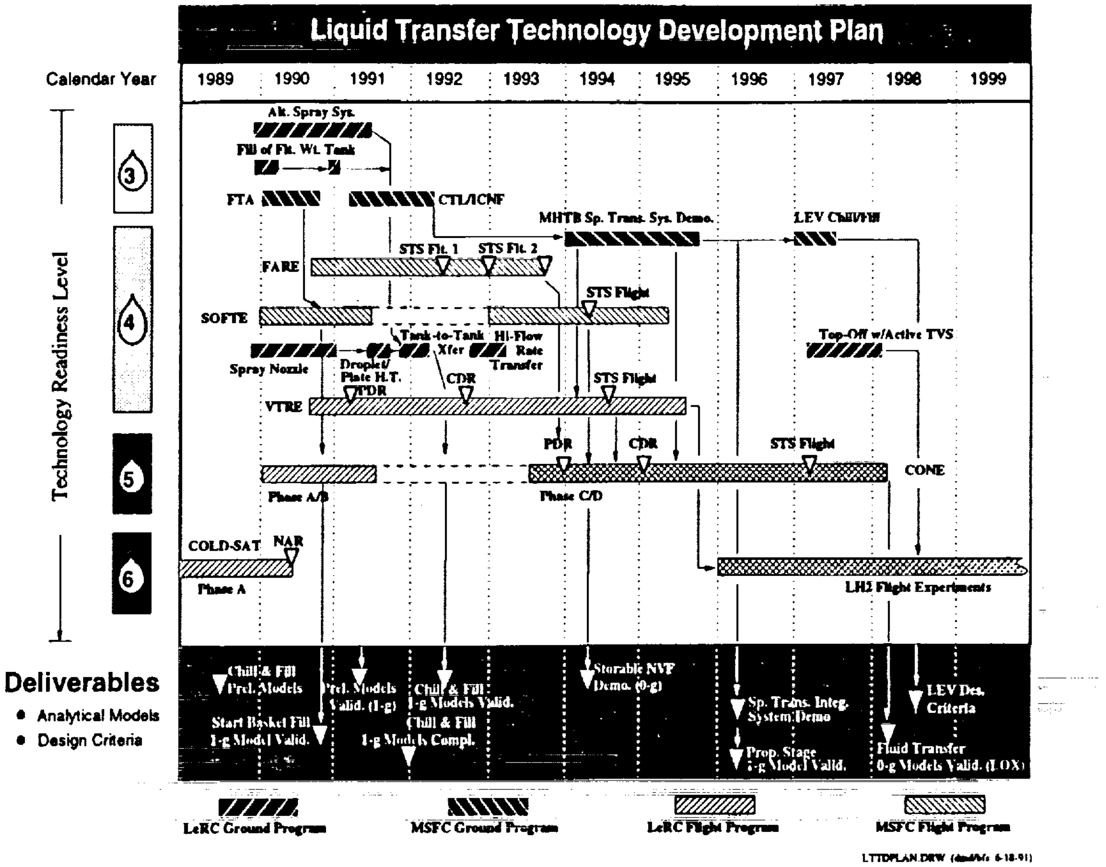


Technology Area – Fluid Handling

Effort

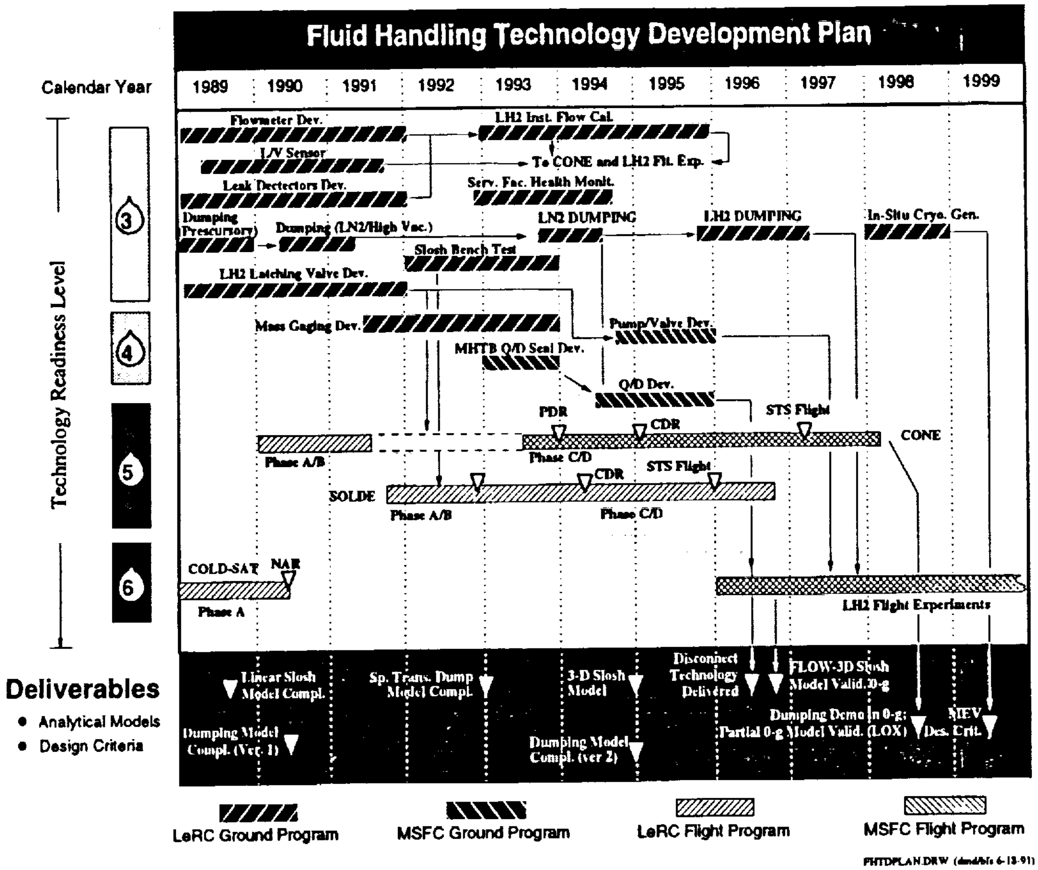
- Low-g liquid fluid dynamics (slosh)
- Low-g fluid dumping/venting
- Instrumentation (L/V sensors, mass gauging, leak detectors, health monitoring)
- Components (valves, flowmeters, quick disconnects, pressurant generator, TVS mixer)

Base R&T Activities

- Generic analytical models
- Latching valve and two-phase flow meter development
- Fluid dynamics and L/V sensor characterization
- Mass gauging characterization
- Dumping/venting characterization
- Leak detector development (SBIR)

Focused Technology Activities

- Quick disconnect development
- Pressurant generator and TVS mixer development
- Health monitoring development
- SOLDE flight experiment



Test Facilities

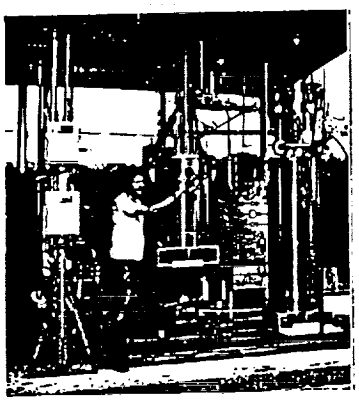
C-2

CCL-7

Portable Cryogenic Research Test Rig

NASA Lewis Research Center
Cleveland, Ohio

Purpose: Provide a liquid hydrogen flow facility for the collection of engineering data for the development of cryogenic components and processes.



Test Capabilities

Fluid Systems:	
Test Fluid	LH_2 or LN_2
Dewar Capacities	18, 5, and 1.7 ft^3
Tank Operating Pressures	2-30 psia
LH_2 Flow Rates	5-100 lb/hr
LN_2 Flow Rates	60-1200 lb/hr
Pressurants	GH_2, GN_2 and GHe
Insulation Systems:	
Dewars	10 layers of MLI
Lines	Vacuum Jacket or Foam
Data Collection:	
Data System	IBM PC-AT 256 Channels

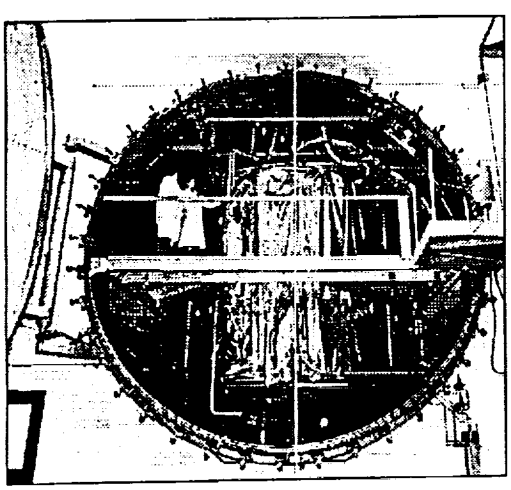
CD-89-44302

K-Site

Cryogenic Propellant Tank Research Facility

NASA Lewis Research Center
Plum Brook Station
Sandusky, Ohio

Purpose: Provide ground-based testing of large-scale cryogenic fluid systems for in-space applications using LH_2 in simulated thermal and vacuum environments



Test Capabilities

Tank Fluid	Liquid Hydrogen
Tank Operating Pressures	1-60 psia
LH_2 Flow Rates	100-2000 lb/hr
Pressurants	GH_2 and GHe

Facility Capabilities

Vacuum	$5x10^{-7}$ torr
- with LH_2 Cryoshroud	$5x10^{-8}$ torr
LH_2/LN_2 Cryoshroud Temp.	-423 °F/-320 °F
LH_2 Capacity	26,000 gal
Max. Test Package Weight	16,000 lb
Data System	Escort D 512 Channels

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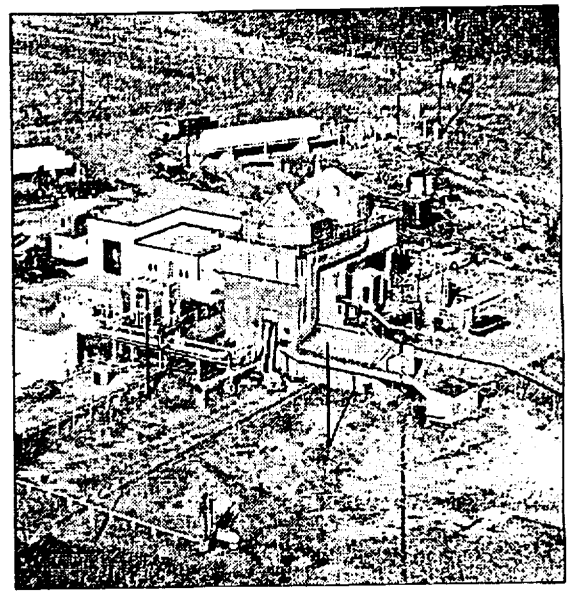
MSFC Cryogenic Fluid Management Test Facilities
Test Stand 300

- Three primary CFM test positions
  - TP 302: 20' by 35' thermal vac. chamber
  - TP 303: 4' by 6' ambient
  - TP 304: 12' by 15.4 ft vacuum chamber
- Utilities
  - GN_2 Supply: 4200 PSIG
  - GH_2 Supply: 4400 PSIG
  - GHe Supply: 4000 PSIG
  - LH_2: 8000 gallons
- Instrumentation and Control
  - 500 data channels conditioned and digitized
  - 26 coax channels
- History
  - Original test position: 1964
  - 20' thermal vac. chamber (TP302): 1969; modified 1981

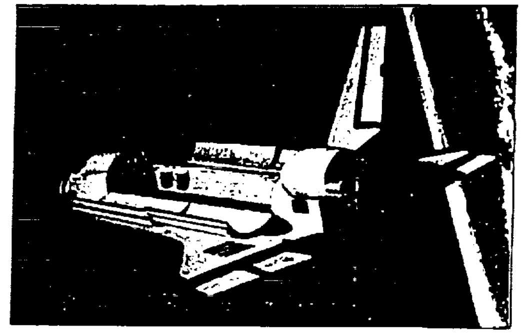


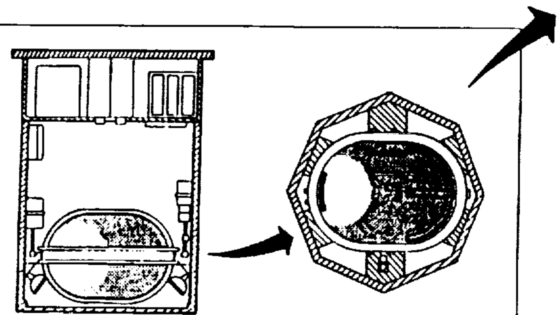
Technology Flight Experiments

TANK PRESSURE CONTROL EXPERIMENT

DESCRIPTION

- Low-g fluid mixing experiment on STS
- Freon in a plexiglass tank is thermally stratified by heaters and then mixed by an axial jet mixer
- Temperature, pressure, and video data





EXPERIMENT MOUNTS IN GET AWAY SPECIAL CONTAINER

OBJECTIVES

- Investigate fluid dynamics and thermodynamics of jet mixing as a means of pressure control for future space cryogenic storage tanks
- Obtain data for comparison with ground-based empirical models and computer codes

CD-90-49831

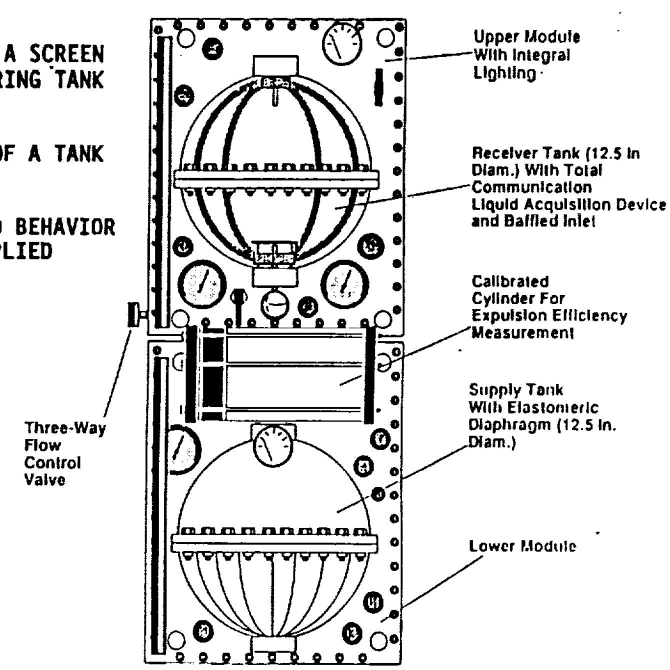
Fluid Acquisition and Resupply Experiment (FARE)

FARE I TEST OBJECTIVES

- DEMONSTRATE LOW GRAVITY OPERATION OF A SCREEN CHANNEL LIQUID ACQUISITION DEVICE DURING TANK EXPULSION AND REFILL
- DEMONSTRATE THE LOW GRAVITY VENTING OF A TANK WHILE FILLING
- DEMONSTRATE STATIC AND DYNAMIC LIQUID BEHAVIOR DURING LOW GRAVITY CONDITIONS AND APPLIED ACCELERATIONS

- Envelope: 45" x 22" x 19"
- Weight:
  - Upper Module: 103.6 lb
  - Lower Module: 115.2
  - Locker Kit: 20.0

  Total: 238.8 lb
- Tanks:
  - Material: Acrylic
  - Diameter: 12.5"
  - Volume: 1022 in3
- Test Fluid:
  - Water + Additives
  - Amount: 5.4 gal



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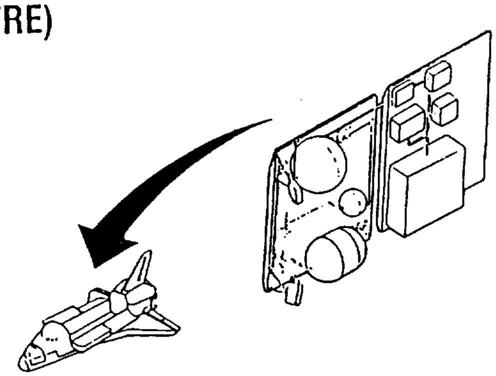
VENTED TANK RESUPPLY EXPERIMENT (VTRE)



DESCRIPTION

- Low-g fluid management flight experiment to be flown in STS Payload Bay
- Storable fluid is positioned by capillary devices in two plexiglas tanks
- Temperature, pressure, and video data
- Self-contained data and control systems

PROGRAM OBJECTIVES

- Investigate fluid dynamics and thermodynamics of tank venting for application to future space cryogenic fluid systems
- Demonstrate capillary device performance in low-g

TECHNICAL OBJECTIVES

- Liquid/Ullage Position Control
- Direct Venting for Tank Pressure Control
- Vented Tank Fill

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Transportation Technology
Technology Flight Experiments
Cryogenic Orbital Nitrogen Experiment

Objectives

Programmatic

Gather zero-g flight data required to validate the cryogenic fluid analysis tools required to design LN2 and L02 pressure control and liquid transfer systems for SSF and Space Transfer Vehicles; where possible, extrapolate the basic data to partially validate LH2 models

Technical

Pressure Control - Extend cryogenic data to low-g
- Reduce required mixer power by 10^2

Liquid Supply - Demonstrate zero-g acquisition with cryogen

Liquid Transfer - Partially validate zero-g models for tank chilldown and fill
- Demonstrate zero-g no-vent fill capability

Schedule

1991 Phase B contract completed (SDR)
1992 System requirements document completed
1993 Phase C/D contract initiated
1994 Preliminary design finalized/approved
1995 Flight hardware fabrication initiated
1995 System-level testing at MSFC initiated
1998 STS integration and flight completed
1998 Data analyzed and computer models updated
1999 Final report on LN2 and LO2 pressure control and liquid transfer issued

Resources

1993	3.4 M
1994	15.0 M
1995	24.0 M
1996	23.0 M
1997	18.7 M

Note: This element is closely coordinated with development efforts in NASA/OSF and other related Government programs; resources shown are NASA/OAET only

Participants

Lewis Research Center

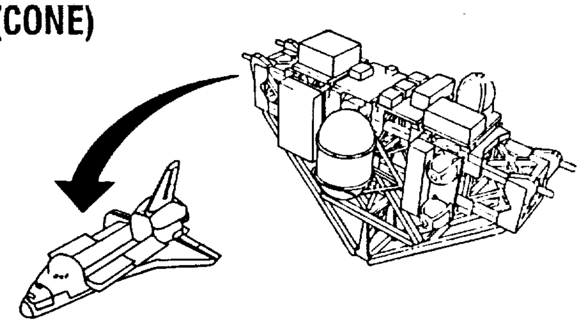
Lead Center for CONE project - project management, program requirements, design, analytical model development, data analysis and model validation

Marshall Space Flight Center

Participating Center - input to program requirements, system test and verification requirements, system-level testing of flight hardware and STS integration

Symons\TP\QUAD3 Lad 6-13-91

CRYOGENIC ORBITAL NITROGEN EXPERIMENT (CONE)



DESCRIPTION

- Subcritical liquid nitrogen experiment to be flown in STS cargo bay
- Currently designed for Hitchhiker-M carrier
- Temperature, pressure, and flow rate data

PROGRAM OBJECTIVES

- Provide experimental data and component demonstration for the operation of a subscale cryogenic fluid management system in space
- Apply results to design of future LOX/LN_2 space systems

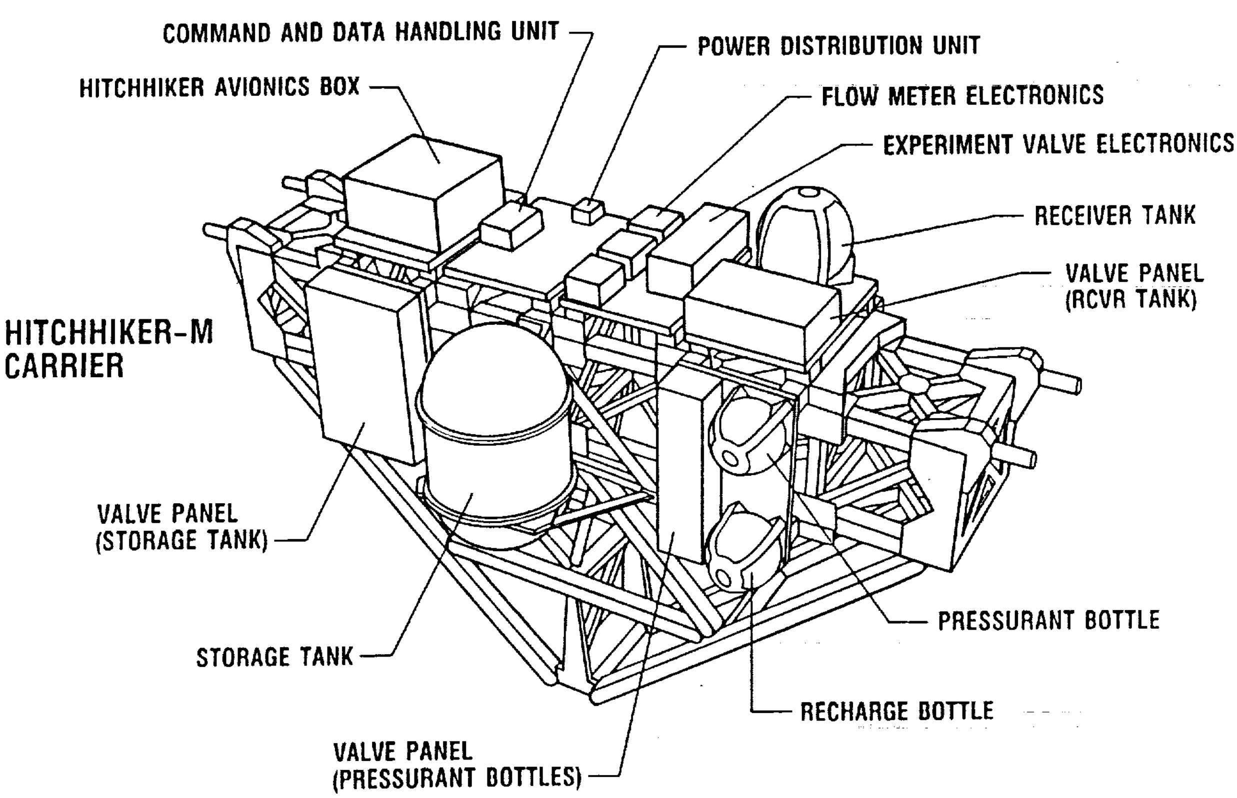
TECHNICAL OBJECTIVES

- Experiments for partial model validation
  - Active TVS
  - Nonvented Transfer*
- Critical component and process demonstrations:
  - Passive TVS
  - Thermal Subcooling
  - LAD Expulsion
  - Fluid Dumping
  - LAD Fill
  - Pressurant Generation
  - Autogenous Pressurization

*Addition of nonvented fluid transfer experiment will occur at beginning of Phase C/D

CD-91- 53869

CRYOGENIC ORBITAL NITROGEN EXPERIMENT (CONE)



CD-90-51091

Technology Flight Experiments

Cryogenic Orbital Hydrogen Experiment

Objectives

<u>Programmatic</u>
Address critical cryogenic fluid management technologies via system demonstration and space experimentation to validate analytical models and to demonstrate critical components and processes

<u>Technical</u>

Pressure Control	- Active and passive system demos
Liquid Supply	- Capillary acquisition device demo - Autogenous pressurization system demo
Liquid Transfer	- Validate zero-g models for tank chilldown and no-vent fill
Fluid Handling	- Demonstrate liquid dumping in zero-g - Mass gauging system evaluation

Schedule

1994 In-house Phase A/B on LH2 experiment
1995 In-house Phase A/B completed
1996 Small scale experiments completed
1996 Phase C/D contract awarded
1997 Procurement/Fab. of long-lead items initiated
1998 Subsystem assembly and testing completed
1999 System assembly and testing completed
2000 Final system checkout complete
2001 Experiment launched
2003 Data analyzed and computer models updated
2004 Final report issued

Resources

1996	$ 3.6 M
1997	17.0 M

Note: This element is closely coordinated with development efforts in NASA/OSF and other related Government programs; resources shown are NASA/OAET only

Participants

<u>Lewis Research Center</u>

Responsibilities TBD

<u>Marshall Space Flight Center</u>

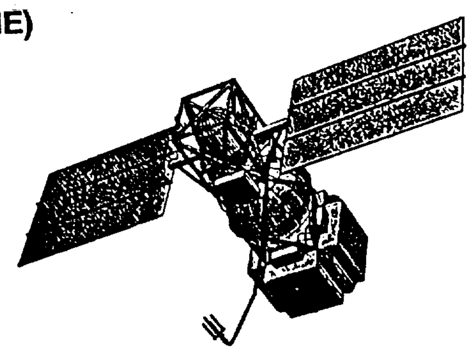
Responsibilities TBD

Symons\TP\QUAD4 ksd 6-13-91

CRYOGENIC ORBITAL HYDROGEN EXPERIMENT (COHE)

DESCRIPTION

- Subcritical liquid hydrogen flight experiment
- Preferred carrier: ELV
- Temperature, pressure, and flow rate data



Sample Concept

PROGRAM OBJECTIVES

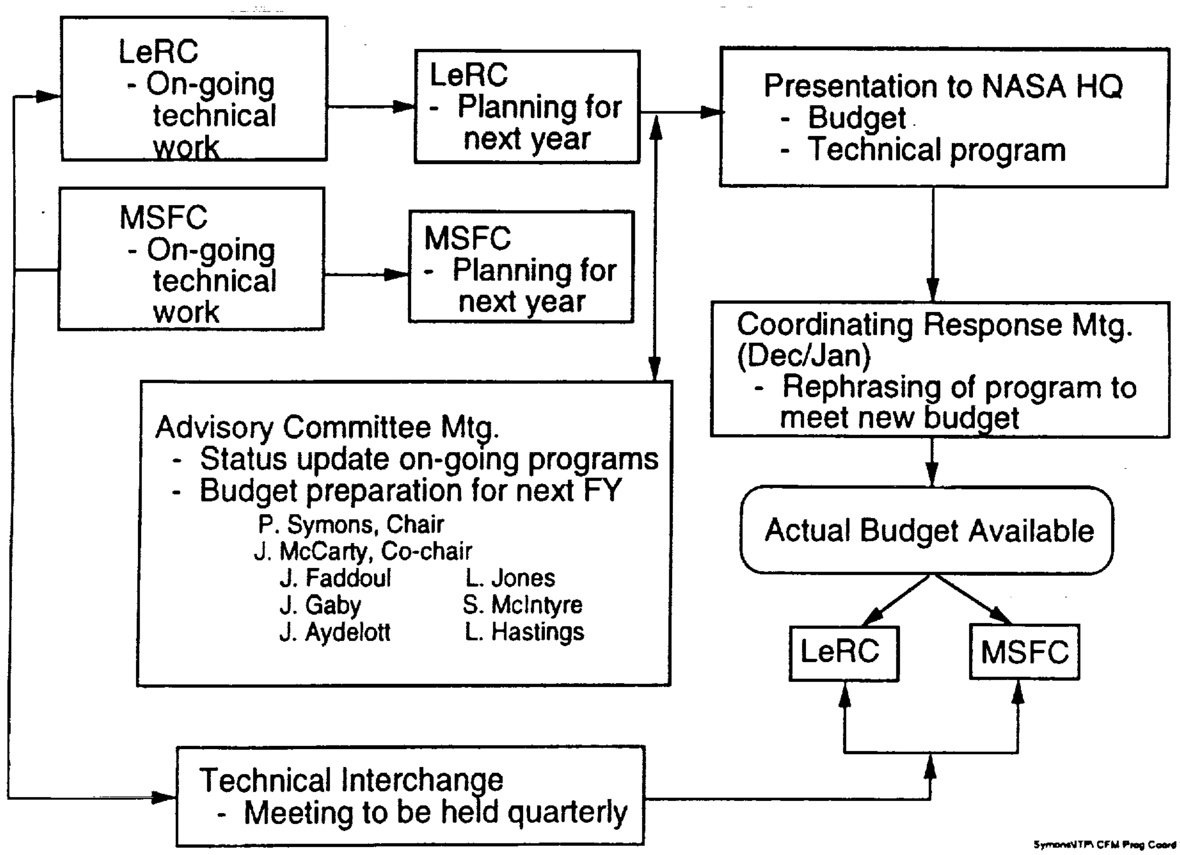
- Provide experimental data and component demonstration for the operation of a subscale cryogenic fluid management system in space
- Validate design equations and generate design criteria for large cryogenic fluid systems
- Apply results to design of future LH_2 space systems

TECHNICAL OBJECTIVES

- Experimentation for analytical model validation
  - Active TVS - Nonvented transfer
  - Autogenous pressurization
- Critical component and process demonstrations:
  - Passive TVS - Thermal subcooling
  - LAD expulsion - Fluid dumping
  - LAD fill - Pressurant generation

Program Coordination

Cryogenic Fluid Management Program Coordination



- Technical Challenge
  - Develop fundamental understanding of the role that gravity plays in a range of fluid dynamic and thermo dynamic processes which govern the behavior of cryogenic fluid systems in space
  - CFM technologies include thermal control, pressure control, liquid supply, liquid transfer, and fluid handling
- Approach
  - Analytical model development and validation, ground-based testing, and small-scale flight experimentation
- Payoff
  - Analytical models and empirical cryogenic data bases will be developed which can be used to define viable options for a wide range of NASA missions and spacecraft designs
  - Parametric characterization of the performance of thermal control and low-g pressure control techniques will provide the data necessary to design optimized systems for long-term cryogenic storage
- Rationale for Augmentation
  - CFM technology advancement requires comprehensive and broad-based programs using cryogenic liquids to provide required advancement in the SOA for all technologies; cryogenic experiments are expensive
- Relationship to Focused Activities and other programs
  - Base and focused activities are synergistic; base program emphasizes analytical model development and parametric component/process testing; focused program emphasizes large-scale test beds and system demonstrations configured for specific future missions
- Technology Contributions
  - Early fluid dynamics research in drop towers and large-scale cryogenic insulation tests were utilized in the design of Centaur and Apollo stages; however these missions were of significantly shorter duration and the cryos were consumed primarily during high-thrust operations

Symons\UTP\Base R&T Summary
6-18-91

Focused Technology: Cryogenic Fluid Systems (CFS) Summary

- Impact
  - CFS provides enabling technology and enormous cost savings to almost all future NASA transportation missions (ASE & NTP); increases safety for certain missions
  - Provides life-cycle cost savings for other missions/operations (e.g. ECLSS)
  - Technology allows for space basing of reusable cryogenic fluid systems
  - Majority of technology not mission or architecture specific
- User Coordination
  - Technology requirements developed jointly by several NASA centers and industry
  - Codes RS, RX, RP, RZ, M and S all have provided funding or technology requirements
  - DOD activities are monitored; DOD requirements worked jointly whenever possible
- Technical Reviews
  - Quarterly technical/financial reports submitted to NASA HQ by LeRC and MSFC
  - Annual reviews by SSTAC/ARTS; ad-hoc Cryogenic Technology Advisory Group
- Overall Technical and Programmatic Status
  - During the past two years, significant strides made in reestablishing a world-class ground-based testing capability and in planning and evaluating overall CFS program
  - Ultimately, in-space testing required to validate analytical models and demonstrate critical components and processes
  - Available technology totally inadequate to meet future needs
- Major Technical/Programmatic Issues
  - Absence of a consistent funding source has greatly inhibited the advancement of this critical technology area
  - Recent technology prioritization efforts consistently rank CFS technology at or near top of lists; commensurate funding has not materialized
  - Misconception that cryo experience on the Centaur, Apollo, and Shuttle provides NASA the capability to design long-term, high performance space cryogenic systems -- this myth must be dispelled

Symons\UTP\Summary bed 6-18-91

Concluding Remarks

- Advanced cryogenic fluid systems technology is enhancing or enabling to **all** known transportation scenarios for space exploration
- An integrated/coordinated program involving LeRC/MSFC has been formulated to address all **known** CFM needs; new needs should they develop, can be accommodated within available skills/facilities
- All required/experienced personnel and facilities are finally in place; data from initial ground-based experiments is being collected and analyzed; small scale STS experiments are nearing flight; program is beginning to yield significant results
- Future proposed funding to primarily come from two sources:

  Base R&T
  Focused Transportation Thrust

- Cryogenic fluid experimentation is **essential** to provide required technology **and** assure implementation in future NASA missions

SymonsII TP\Conclusion kad 6-13-91

1-180 19A

NASA CSTI Earth-To-Orbit Propulsion R&T Program Overview

N93-71880

57-81
157474
P- 8

Presented to the

Space Systems and Technology

Advisory Committee

By
James L. Moses
MSFC

June 26, 1991

Transportation Technology

Earth-To-Orbit Transportation

Earth-to-Orbit Propulsion

OBJECTIVES

- **Programmatic**
  Develop and validate technology, design tools and methodologies needed for the development of a new generation of lower cost, operationally-efficient, long-life, highly reliable ETO propulsion systems

- **Technical**

Manufacturing	- High quality, low cost, inspectable
Safety	- Safe shutdown to fault tolerant ops
Maintainability	- Condition monitoring diagnostics
Ground Ops	- Automated servicing and checkout
Performance	- Max commensurate with life
Advanced Cycles	- Full flow, combined cycle, etc.

SCHEDULE

- 1992 Electronic engine simulation capability operational
- 1993 3D CFD codes for combustion, stability, nozzle and turbomachinery flows validated and documented
- 1995 Low cost manufacturing processes applicable to shuttle and NLS/HLLV propulsion verified and documented
- 1996 System monitoring capability for safe shutdown and for enhanced preflight servicing and checkout demonstrated
- 1999 Probabilistic codes, fatigue methodology and life prediction/damage models validated and documented
- 2005 Advanced manufacturing processes and design methodologies applicable to fully reusable, long-life AMLS propulsion verified and documented; propulsion system monitoring and control for automated operations demonstrated

RESOURCES*

	CURRENT	STRATEGIC AUGMENTATION **
1991	$21.8 M	21.8
1992	$28.7 M	28.7
1993	$33.9 M	33.9
1994	$25.1 M	35.4
1995	$26.4 M	36.9
1996	$27.6 M	42.7
1997	$28.8 M	45.1

* Note: This element is closely coordinated with development efforts in NASA/OSF and other related government programs; resources shown are NASA/OAET only

** Proposed Augmentation elininated from the 3X program

PARTICIPANTS

- **Marshall Space Flight Center**
  Lead Center-technology acquisition, test rig validation, large scale validation, technology test bed
- **Lewis Research Center**
  Participating Center-technology acquisition, test rig validation
- **Langley Research Center**
  Supporting Center-vehicle systems analysis

April 25, 1991
DRS-QUAD1

NASA Earth-To-Orbit Propulsion R&T Program

Purpose

- Provide an up-to-date technology base to support future space transportation needs

Objective

- Continuing enhancement of knowledge, understanding, and design methodology applicable to the development of advanced oxygen/hydrogen and oxygen/hydrocarbon ETO propulsion systems

Justification

- Space transportation systems can benefit from advancements in propulsion system performance, service life and automated operations and diagnostics

2

NASA Earth-To-Orbit Propulsion R&T Program

Contents

- Analytical models for defining engine environments and for predicting hardware life (flow codes, loads definition, material behavior, structural response, fracture mechanics, combustion performance and stability, heat transfer)
- Advanced component technology (bearings, seals, turbine blades, active dampers, materials, processes, coatings, advanced manufacturing)
- Instrumentation for empirically defining engine environments, for performance analysis, and for health monitoring (flow meters, pressure transducers, bearing wear detectors, optical temperature sensors)
- Engineering testing at subcomponent level to validate analytical models, verify advanced materials, and to verify advanced sensor life and performance
- Component/test bed engine for validation/verification testing in true operating environments

1-66ↄ. ↄ-27T

NASA Earth-to-Orbit Propulsion R&T Program

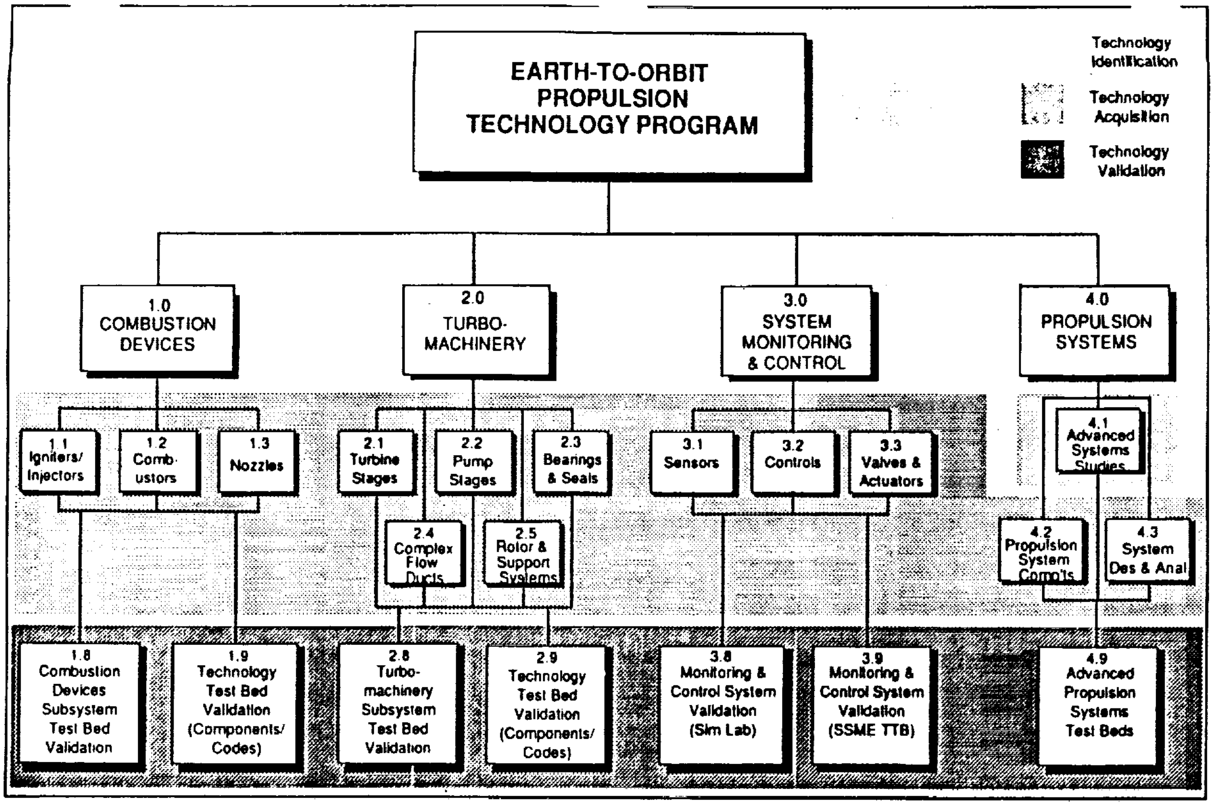
Work Breakdown

- Technology Acquisition phase
  - Seeks improved understanding of the basic chemical and physical processes of propulsion
  - Develops analyses, design models and codes using analytical techniques supported by empirical laboratory data as required
  - Results are obtained through ten discipline working groups
    - Bearings
    - Structural dynamics
    - Turbomachinery
    - Fatigue/fracture/life
    - Ignition/combustion
    - Fluid & gas dynamics
    - Instrumentation
    - Controls
    - Manufacturing/producibility/inspection
    - Materials

1-3941-9-40T

ETO Propulsion Technology Approach

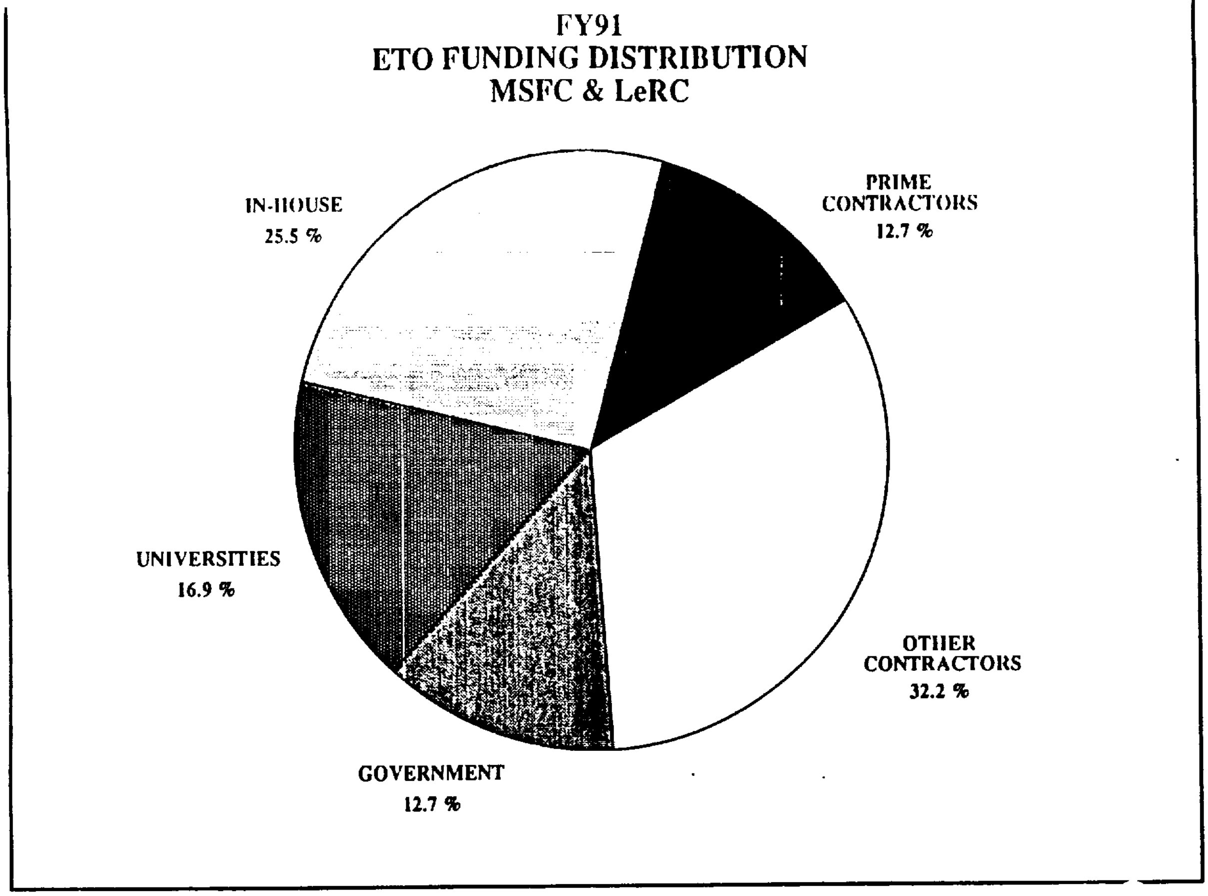
- Civil Space Technology Initiative (CSTI) program emphasizes validated technology delivered on schedule.
- Concepts, codes, techniques obtained in the Technology Acquisition Phase.
- Validated at the appropriate level by means of component subsystem or system level testing (TTB).
- OAET provides technology to TTB. OSF provides integration funds to incorporate technology items into TTB.
- Technology is transferred to industry via papers & conferences such as Biannual Propulsion Conference at MSFC and Biannual Structural Durability Conference at LeRC.
  - Technologists also are working flight programs
- Technology must be generic, but should be applicable to on-going or anticipated programs.
  - Goal is to provide a broad technology base that will support a wide variety of propulsion options

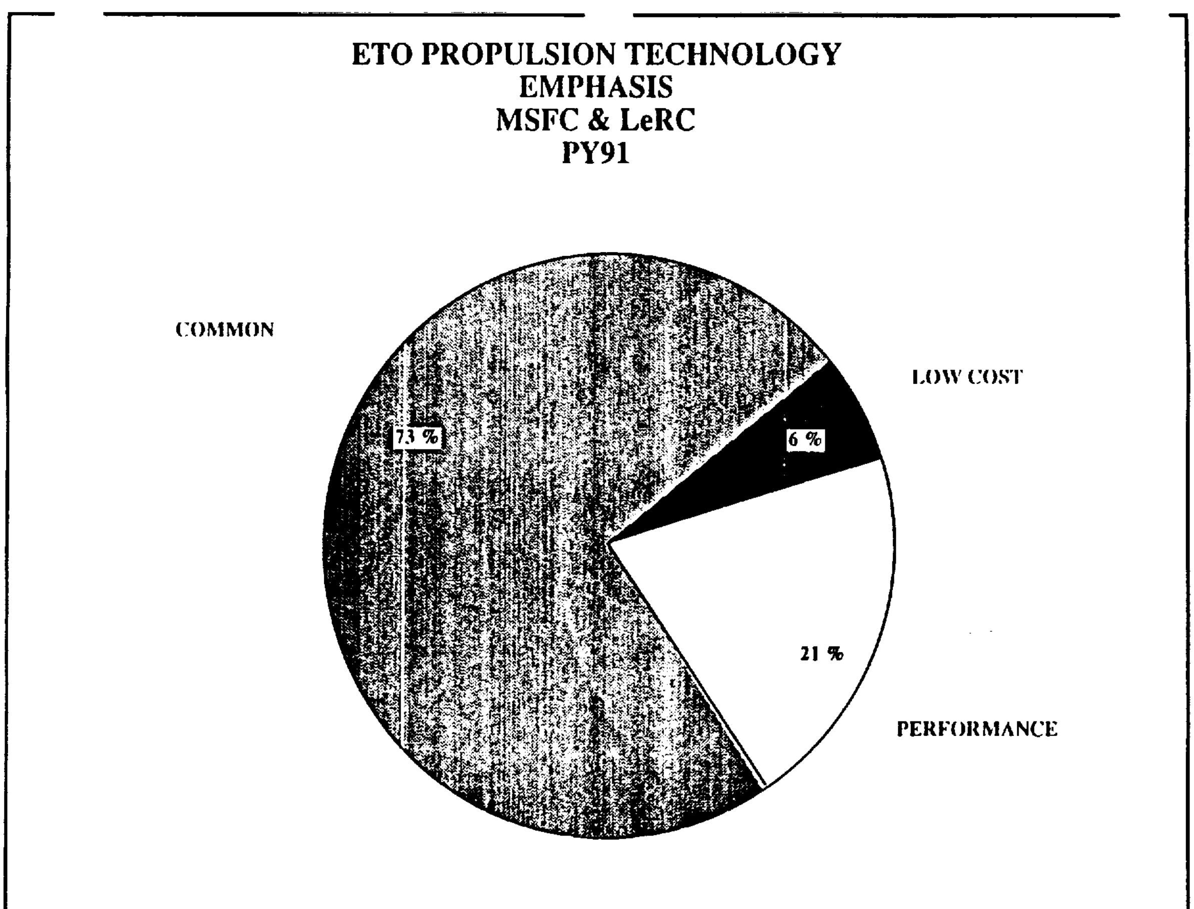


Earth-to-Orbit Propulsion Technology Program Work Breakdown Structure

ETO PROPULSION FUNDIN IMMARY - $K 5/13/91

	FY89	FY90	FY91	FY92	FY93	FY94	FY95	FY96
TECHNOLOGY ACQUISITION								
BEARINGS	2093	1561	1562	1200	1200	800	1000	1200
STRUC. DYNAMICS*	1371	1162	1350	1400	1800	1500	1700	1700
TURBOMACHINERY*	1229	1137	1764	1600	1600	1100	1050	1200
FATIGUE/FRACTURE*	1285	837	1115	1200	1410	1200	1200	1200
COMBUSTION	3123	2875	1126	1700	1960	1200	1000	1200
FLUID & GAS DYN.	1600	989	1697	1300	1200	900	1000	1200
INSTRUMENTATION	1420	836	920	1100	1400	1000	1000	1200
CONTROLS	1753	1182	1455	1800	1600	1000	1050	1200
MANUFACTURING	763	835	1088	1100	1650	1300	1300	1400
MATERIALS*	1580	1020	1270	1000	1400	800	1000	1200
TOTAL TECH. ACQ.	16217	12434	13347	13400	15220	10800	11300	12700
VALIDATION								
COMBUSTION VALID.	2160	622	750	1100	1780	1100	1200	2000
TURBO. VALID.	5285	2412	4619	3000	4700	3600	3600	3600
SYS. MONITOR. VALID.	4578	4459	2606	8000	8800	6000	6500	5300
TOTAL VALIDATION	12023	7493	7975	12100	15280	10700	11300	10900
TOTAL PROGRAM	28240	19927	21322	25500	30500	21500	22600	23600
PMS	3375	3484	2616	3200	3400	3600	3800	4000
CENTER TOTALS	31615	23411	23938	28700	33900	25100	26400	27600

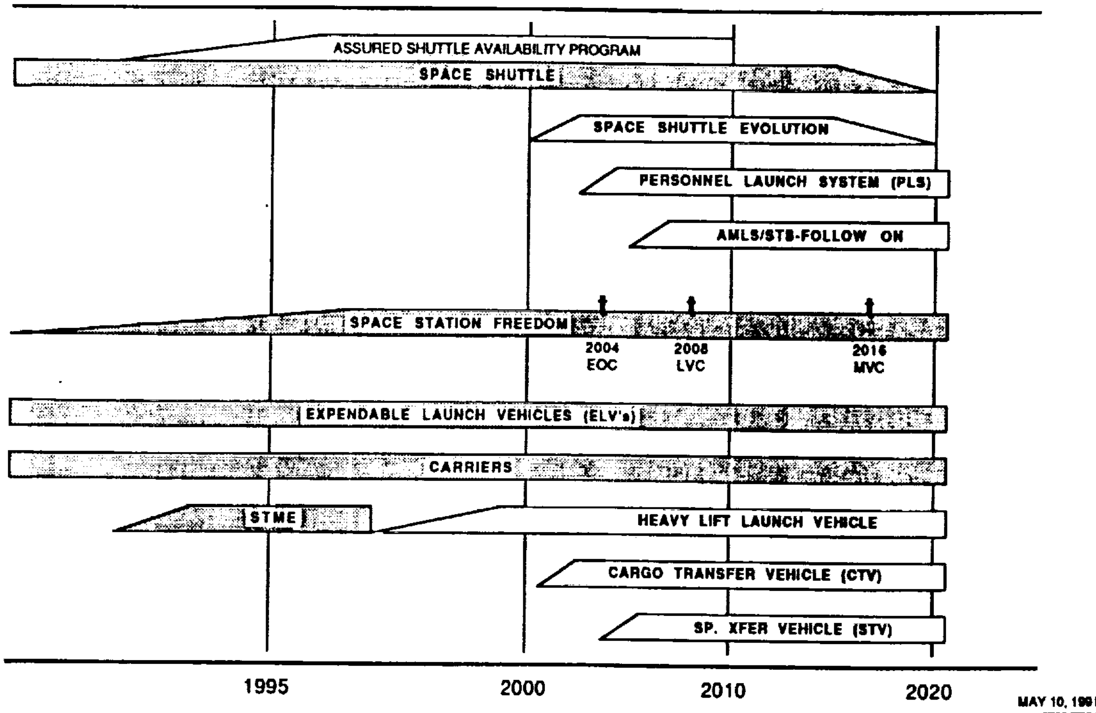

FY91
ETO FUNDING DISTRIBUTION
MSFC & LeRC
PRIME CONTRACTORS
12.7 %
IN-HOUSE
25.5 %
UNIVERSITIES
16.9 %
OTHER CONTRACTORS
32.2 %
GOVERNMENT
12.7 %


ETO PROPULSION TECHNOLOGY
EMPHASIS
MSFC & LeRC
PY91
COMMON
73 %
LOW COST
6 %
21 %
PERFORMANCE

FLIGHT PROGRAMS VISION

OAET

OFFICE OF SPACE FLIGHT



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Earth-To-Orbit Propulsion R&T Program Activities

- Conducted biannual ETO Technology Conference May 15-17, 1990. 123 papers presented. 400 attendees.
- Presented program to Space Technology Interdependency Group (STIG) November 29-30, 1990, Andrews A.F.B.
- Conducted Propulsion Program Review for OAET, December 10-12, 1990.
- Conducted Detailed ALS assessment of ETO Propulsion Project, March 1991, MSFC.
- Conducted 3rd screening of technology items for TTB March 8, 1991.
- Conducted biannual Structural Durability Conference at LeRC, May, 1991.

12

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NASA Earth-To-Orbit Propulsion R&T Program

Recent Program Highlights

- Silicon nitride bearings have shown greatly extended life over SSME flight bearings in MSFC bearing tester.
- Completed assembly of a cryogenic rolling element bearing tester at LeRC.
- Turbopump test stand design complete. Stand is in MSFC FY94 C of F budget.
- First ever measurement of heat flux on a flight type rocket engine turbine blade with a plug type heat flux sensor.
- Management approval obtained for proceeding with advanced main combustion chamber technology (full scale program).
    - Concept adopted by STME and evolutionary SSME
- CFD Consortium turbine team is interactive with ALS Design Process

13

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What Earth-To-Orbit Does Not Address

TOPIC	COMMENTS
• Aerospike nozzle	• Small study efforts • SDIO is spending significant funds on Aerospike SSTO
• Airbreathing/Combined Cycle	• NASP Program • OEAT Workshop is plannned
• Storable propellants	• No identified requirement
• Hybrid propulsion	• Commercial program; augmented for '95
• Pressure fed	• Residual activity at MSFC, no further work planned after current contracts expire

14

Focused Technology: ETO Propulsion

Summary

IMPACT: The ETO Propulsion Technology Program supports all advanced engine programs. Half of the 200 tasks in the Program were judged by an ALS consortium contractor team to be directly applicable to ALS propulsion technology needs. ETO addresses the top 3 priority technology issues of the Office of Manned Space Flight.

USER COORDINATION: Closely tied to SSME/ALS. SSME review held at Tyson's Corner Va. Oct.1989. ALS/SSME review held at MSFC February 1990. A special ALS review was held for ALS at MSFC in March 1991. Interagency coordination provided by Space Technology Interdependency Group (STIG).

TECHNICAL REVIEWS: Annual RTOP review held in Nov/Dec each year, Government only. Covers each task, technical and budget, in the program. Other reviews as required.

OVERALL TECHNICAL and PROGRAMMATIC STATUS: Activities are maturing. Technology items for validation are being developed, such as bearings, sensors, health monitoring algorithms.

RATIONALE for AUGMENTATION: Several areas require additional funding, Advanced Manufacturing, Propulsion System Studies and Additional Testing Capability. In addition the combination of budget constraints and the CSTI emphasis on validated technology starves the program of new technologies.

MAJOR TECHNICAL/PROGRAMMATIC ISSUES: Several propulsion options are available to the U.S. for the next generation of vehicles. The ETO program must maintain a broad base of technology to address a range of options. In addition, the absence of Program Advanced Development programs makes the ETO program the Nation's propulsion Advanced Development Program by default.

15

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p. 6
N93-71881

ADVANCED MAIN COMBUSTION CHAMBER PROGRAM

ADVANCED MCC

PROGRAM OVERVIEW

ADVANCE CURRENT MANUFACTURING TECHNOLOGY FOR SPACE HARDWARE

DESIGN A MAIN COMBUSTION CHAMBER

- INVESTMENT CASTINGS (LOW COST)
  - ROBUST WITH 100% INSPECTABLE WELDS
  - CAPABLE OF UTILIZING ALTERNATE LINERS
    - VACUUM PLASMA SPRAY MATERIALS
    - PLATELET
- USE SSME PROGRAM
  - LARGE DATA BASE - NONCONFORMITIES,ETC
  - AVAILABLE TEST FACILITY - TTB
- USE MSFC PERSONNEL FOR DESIGN EFFORT
  - DESIGN
  - ANALYSIS
  - QUALITY
- USE CONCURRENT ENGINEERING TECHNIQUES

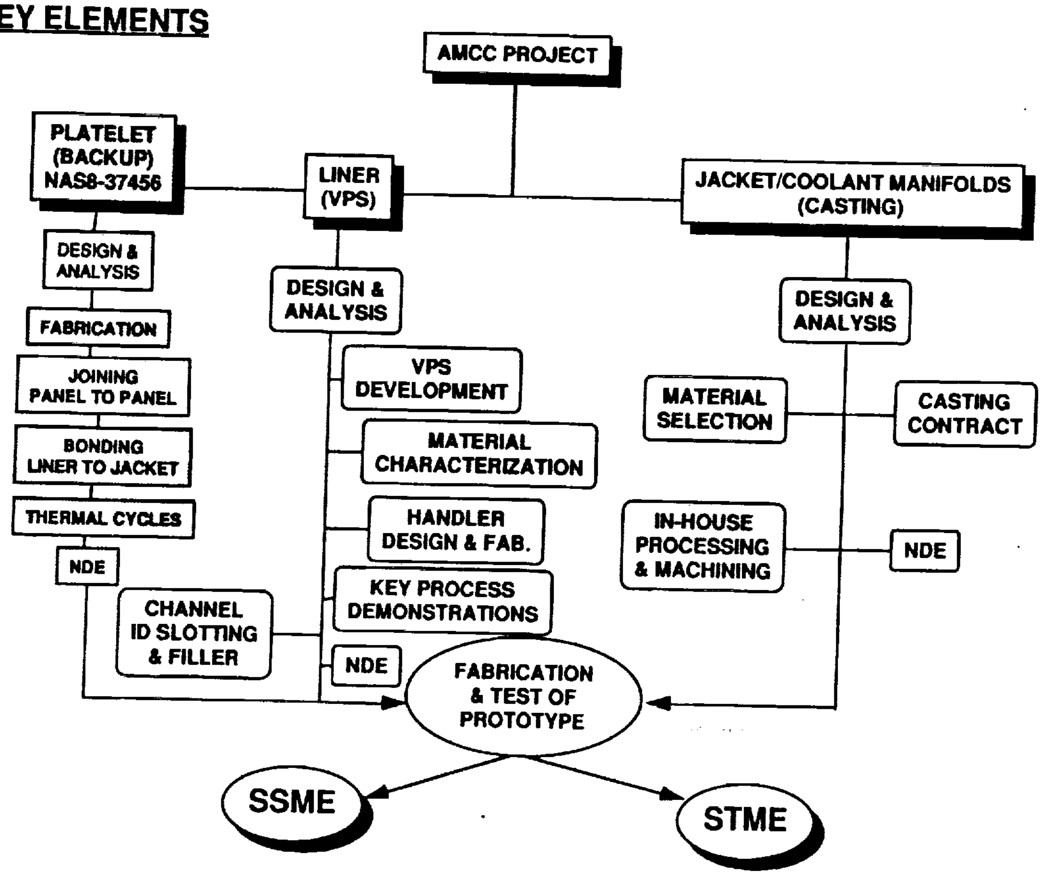
ADVANCED MCC

OBJECTIVES - DESIGN CRITERIA

DESIGN WILL BE:

- **INTERCHANGEABLE WITH SSME MAIN CHAMBER**
- **ROBUST DESIGN WITH 100% INSPECTABLE WELDS**
  - HYDROGEN EMBRITTLEMENT RESISTANT MATERIAL
    - NO COPPER COATINGS OR WELD OVERLAYS
  - FMEA/CIL FAILURE MODES REDUCED
  - INCREASED LINER THERMAL MARGIN
- **REDUCED FABRICATION COST** ($1 MILLION -vs- $3.2 MILLION)
- **REDUCED FABRICATION TIME** (50 WEEKS -vs- 150 WEEKS)

KEY ELEMENTS



ADVANCED TECHNOLOGIES

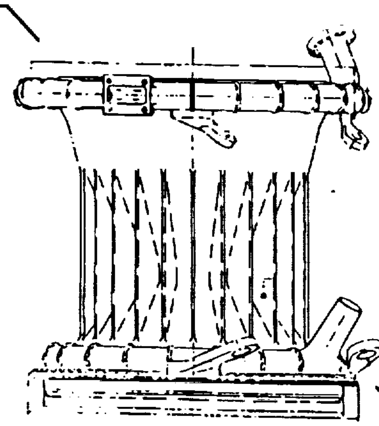
ADVANCED COMBUSTION CHAMBER PROGRAM

(1) **METHODOLOGY**
(LOWER COST) HARDWARE PROGRAM

(2) **FABRICATION TECHNIQUE**
(OUTSIDE-IN)

(3) **CASTINGS**
NEAR-NET STRUCTURAL

(4) **ADVANCED MATERIALS**
(NASA-23)
(GLIDCOP)



(5&6) **LINER DESIGNS**
VPS PLATELET

(7) **ADVANCED COOLING**
(HIGH ASPECT CHANNELS)
- PLATELET
- EDM CHANNELS

ADVANCED MCC

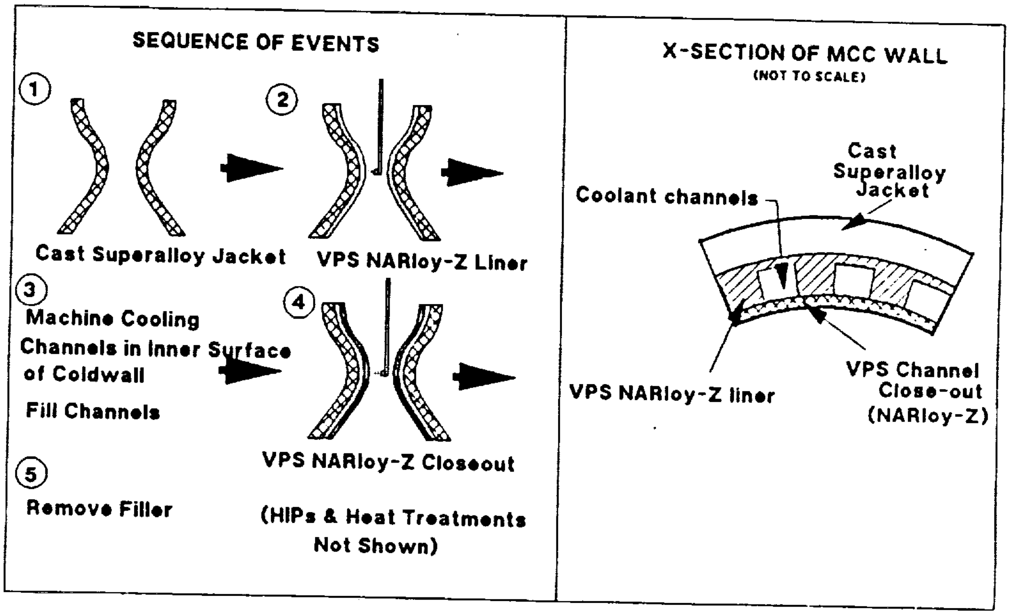
"NEW " APPROACH TO TECHNOLOGY / HARDWARE PROGRAMS

- **INHOUSE - PROOF OF CONCEPT**
  - TQM - DETERMINE PRIORITY, APPROACH, LAY OUT OF PROGRAM
  - DESIGN / ANALYSIS / MANUFACTURING - CONCURRENT ENGINEERING
  - FABRICATION - PRODUCIBILITY FACILITY
  - TEST
- **CONTRACTOR - PRODUCTION**
  - FABRICATION OF ADDITIONAL UNITS
  - DEVELOPMENT & CERTIFICATION
  - MAINTAINABILITY & REFURBISHMENT
- **DEMONSTRATE "SOLUTION" IS VALID**
  - QUALITY PRODUCT
  - COST SAVING IN TIMELY MANNER
  - TRAINING - CONFIDENCE THROUGH ACCOMPLISHMENT
  - TEAMWORK - DEVELOPMENT OF NECESSARY INTER-LABORATORIES COOPERATION

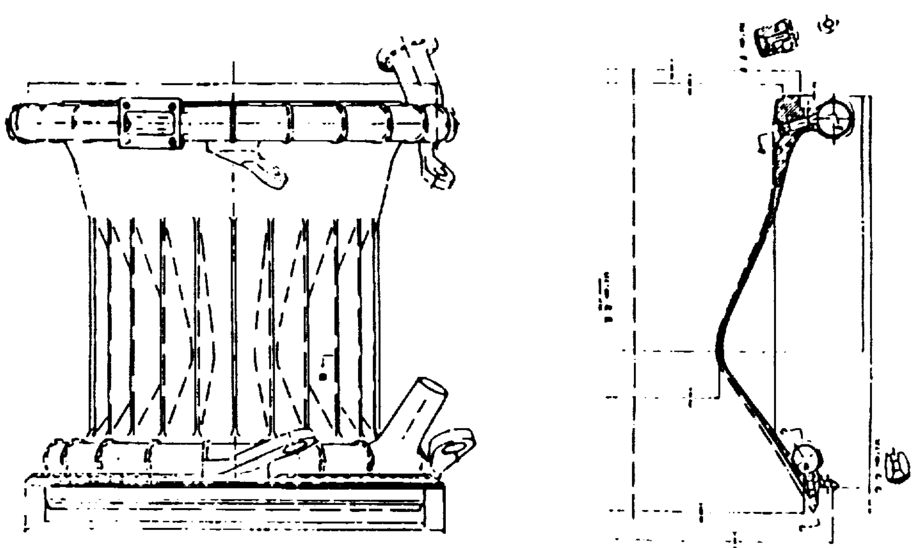
ADVANCED MCC

FABRICATION APPROACH

"OUTSIDE - IN"



ADVANCED MCC



AMCC Conceptual Drawing.

ADVANCED MCC

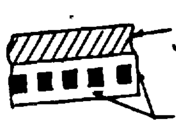
ROOM TEMPERATURE DESIGN ALLOWABLE

		ULT (ksi)	YIELD (ksi)	ELONG. (%)
JBK-75	STD.	105	75	8
	NON-CRIT.	90	65	6
NASA-23		140	110	6

ADVANCED MCC

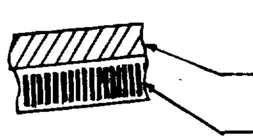
FABRICATION SEQUENCE

BASELINE - VPS



1. CAST MANIFOLDS/JACKET
2. VACUUM PLASMA SPRAY ID (NARLOY-Z
3. SLOT CHANNELS
4. FILL CHANNELS
5. VPS NARLOY LINER
6. CLEAN CHANNELS
7. INSPECT CHANNEL CLEANLINESS & WALL THICKNESS
8. FINISH WALL TO PRINT
9. PROOF

PLATELET



ELIMINATE 2,3,4,5,6,7,8

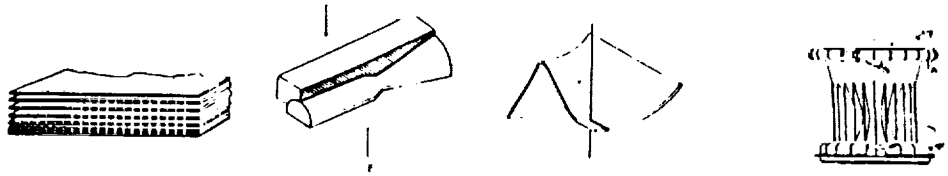
ADD LINER FITUP

ADD JOINING SEGMENTS (LASER WELDS)

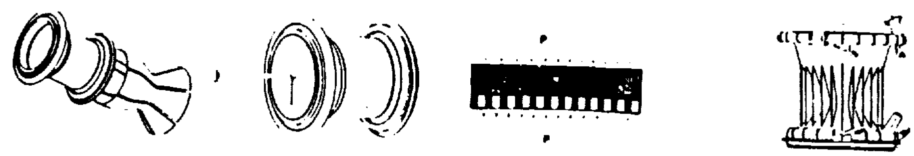
ADD BONDING LINER / JAC.

ADVANCED MCC

Cast Structural Jacket And Platelet Liners Simplify SSME MCC Fabrication

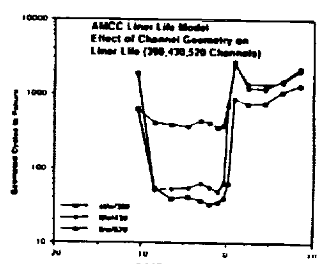


Fabricate Platelet Panels — Form Panels To Contour — Trim Panel Edges By Wire EDM — Prepare Structural Jacket Casting



Assemble Liners Within Casting — Laser Weld Panel Seams — Diffusion Bond Liners To Structural Jacket — Final Machine Chamber And Proof Test

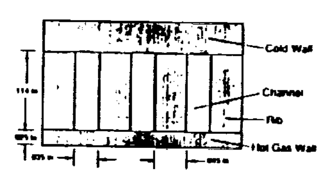
ADVANCED MCC



ISSUE: THRUST CHAMBER LIFE IMPROVEMENT

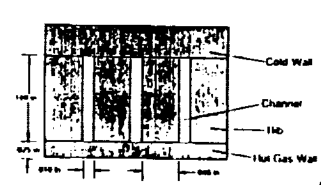
THEORETICAL GAIN WITH **HIGH ASPECT** COOLANT CHANNELS

- LeRC IN-HOUSE PROGRAM
- THERMAL / STRUCTURAL ANALYSIS



430 Channel Geometry

PROBLEM : BEYOND CURRENT MANUFACTURING CAPABILITY



520 Channel Geometry

SOLUTION: MSFC DEVELOPMENT OF THIN HIGH ASPECT CHANNELS BY **EDM**

(DEMONSTRATED ON TEST SAMPLES)

NASA

National Aeronautics and Space Administration
George C. Marshall Space Flight Center

Earth-To-Orbit Turbomachinery Subsystem

N93-71882

Presented to:
Integrated Technology Plan External Review Team
Tysons Corner, McLean, Virginia

59-81
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p. 22

Overview Earth-to-Orbit Propulsion Turbomachinery Subsystem

By:
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Earth-To-Orbit Turbomachinery Subsystem

Overview

- Objectives/Focus
- MSFC/LeRC Teaming
- Determination of Needs and Deliverable Products
- Turbomachinery Technology Components and Disciplines
  - Component Specific Technologies
  - Discipline Specific Technologies
- Turbomachinery Large Scale Validation
- Accomplishments
  - Turbine Stages
  - Complex Flow Paths
- Summary

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Earth-To-Orbit Turbomachinery Subsystem

Objectives/Focus

- Develop the Technology Related to the Turbomachinery Systems of High Performance Rocket Engines
  - Advanced Design Methodologies and Concepts
  - Develop High Performance Turbomachinery Data Bases
  - Validated Turbomachinery Design Tools
- Specific Turbomachinery Subsystems and Disciplines
  - Turbine Stages
  - Pump Stages
  - Bearings
  - Seals
  - Structural Dynamics
  - Complex Flow Paths
  - Materials
  - Manufacturability, Producibility, Inspectability
  - Rotordynamics
  - Fatigue/Fracture/Life

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Earth-To-Orbit Turbomachinery Subsystem

MSFC/LeRC Teaming

Turbomachinery Thrust Co-Managers – L. Schutzenhofer/MSFC
J. Gauntner/LeRc

Working Groups	Co-Chairmen
Bearings	F. Dolan/MSFC J. Walker/LeRC
Structural Dynamics	L. Kiefling/MSFC C. Chamis/LeRC
Fluid and Gas Dynamics	H. Struck/MSFC R. Gaugler/LeRC
Materials	S. Gentry/MSFC R. Dreshfield/LeRC
Manufacturing/Producibility/Inspection	J. Clark/MSFC T. Herbell/LeRC
Turbomachinery	L. Schutzenhofer/MSFC J. Gauntner/LeRC
Fatigue/Fracture/Life	G. Faile/MSFC M. McGraw/LeRC

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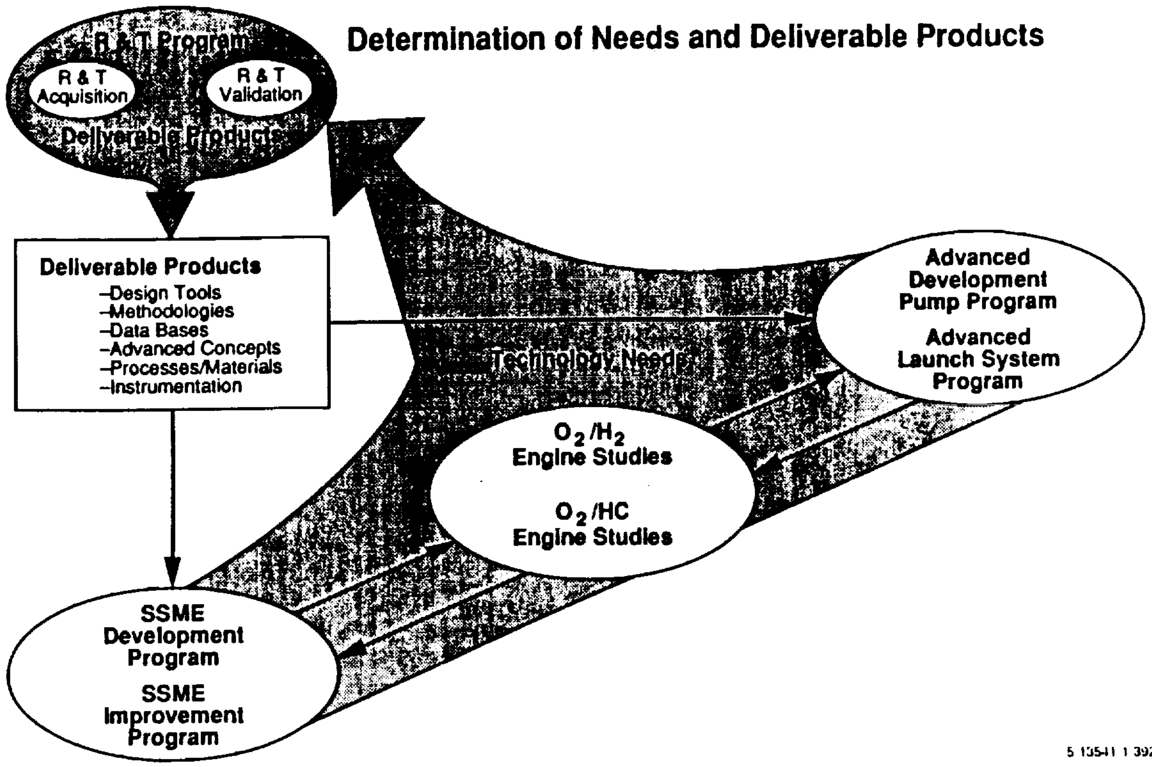
Determination of Needs and Deliverable Products



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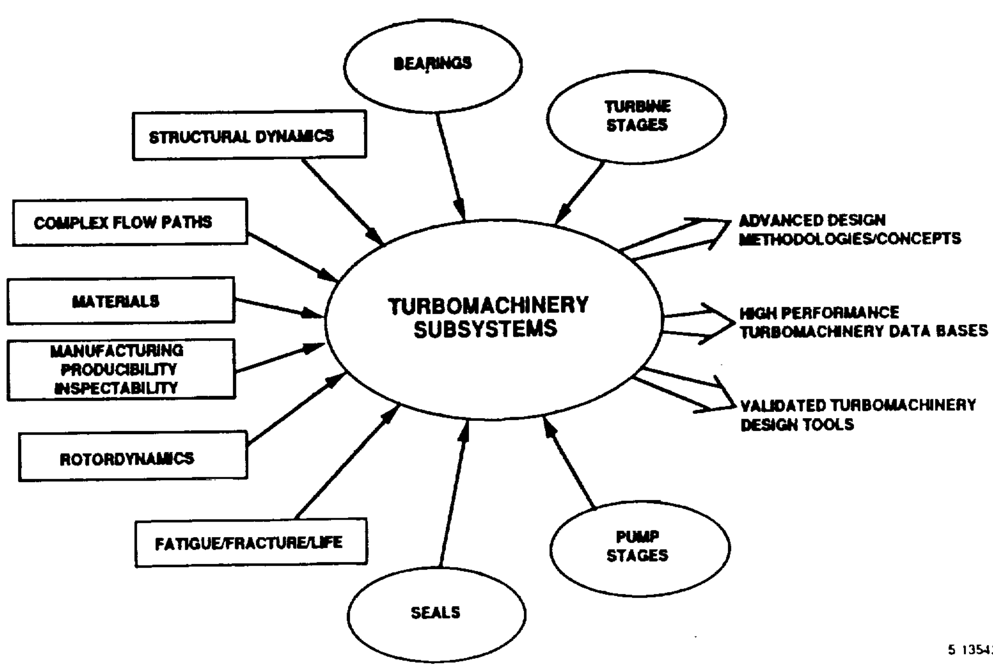
Technology Components and Disciplines



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Earth-To-Orbit Turbomachinery Subsystem

Turbomachinery Component Specific Technologies

- **Turbine Stage Design Methods**

  Modeling of Multistage Turbines For High Efficiency, Reduced Loads, and Reduced Heat Transfer Supported By Experimental Verification

- **Pump Stage Design Methods**

  Modeling of Impellers and Inducers For High Efficiency, Reduced Loads, and Reduced Cavitation Supported by Experimental Verification

- **Bearings**

  Improvement of Life and Performance of Cryogenic Bearing Technology Through Improved Design Concepts, Design Criteria, Materials, Manufacturing Techniques, Lubrication/Cooling Techniques, Dynamic Analysis, Hybrid Suspension Systems, etc.

- **Seals**

  Modeling of Seals For Incompressible/Compressible Flows to Reduce Leakage and Improve Performance; Improve Rotordynamic Characteristics

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Turbomachinery Discipline Specific Technologies

- **Structural Dynamics**

  Modeling Related to Structural Dynamic Characteristics to Increase Lifetime, Decrease Weight, Identify Insipient Failures, Decrease Costs, Assess Retrofitable Design Changes, Develop/Validate Design Tools

- **Complex Flow Paths**

  Improve Modeling of Coolant Flows and Ducts With CFD Supported By Experimental Validation

- **Materials**

  Develop and Evaluate Candidate Materials to Assess Reactivity to High Pressure/Temperature and Oxygen/Hydrogen Environments With Specific Emphasis on Turbine Blades, Bearings, and Seals

- **Manufacturability, Producibility, Inspectability**

  Develop/Evaluate Process Techniques, Improve and Optimize Producibility, Improve In-Service Nondestructive Inspection, etc.

- **Rotordynamics**

  Improve Rotordynamic Modeling, Diagnostic Procedures, Balancing Methods, Probalistic Analysis Methods Along With Experimental Validation

- **Fatigue/Fracture/Life**

  Develop, Test and Verify Analysis Tools Related Fracture Mechanics, Crack Initiation Life Prediction, Associate Materials Data Base, etc. to Improve Service Life Prediction

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Turbomachinery Large Scale Validation

Objective:

- **Provide Validation of Turbomachinery Design Methods and Hardware Concepts Through**
  - Bench Testing
  - Large Scale Subcomponent Testing
    - Rig Tests
    - Turbopump Tests
  - Engine Systems Tests (TTB)
- **Compare Data to Most Advanced Computational Methods**
  - Stress Methods to Limits
  - Parameter Sensitivity Studies
- **Develop Turbomachinery Specific End Products**
  - Validated Design Methods
  - Empirical Data Bases
  - Scaling Laws/Methods
  - Design Criteria; Life Limits, Performance,...
  - Advanced Hardware Concepts

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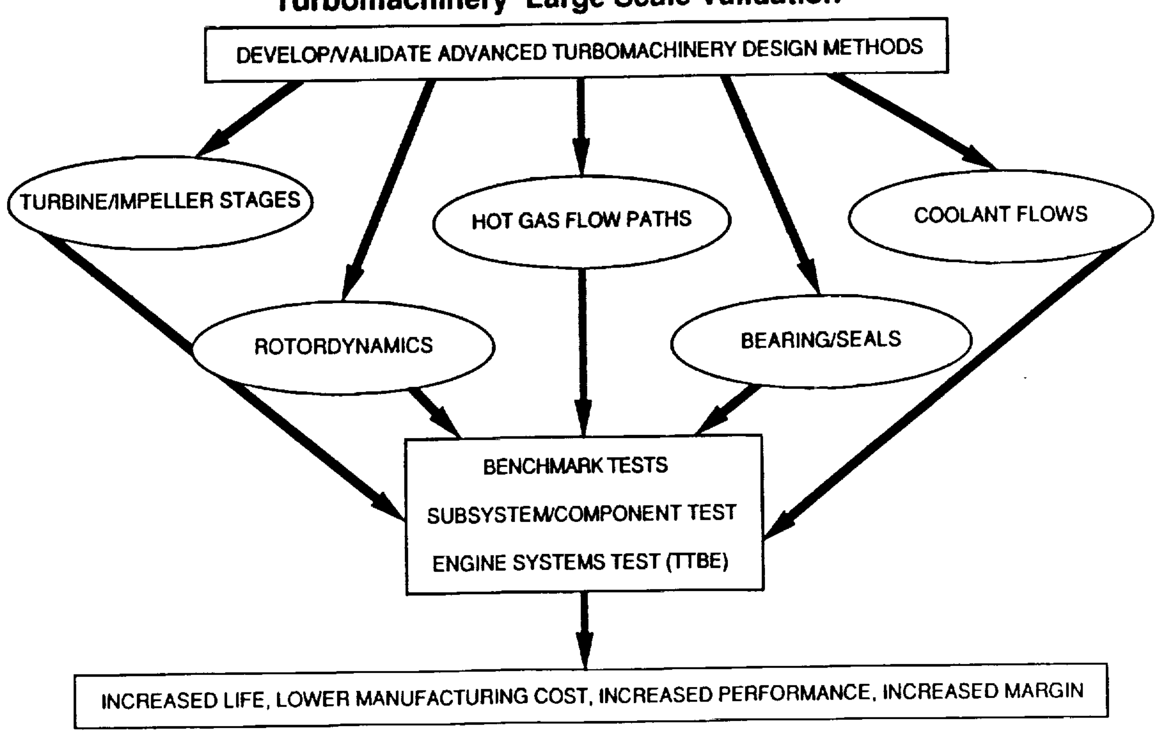
Earth-To-Orbit Turbomachinery Subsystem

Turbomachinery Large Scale Validation



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Earth-To-Orbit Turbomachinery Subsystem

Accomplishments

- **Turbine Stage**

  Computational Fluid Dynamic Analysis and Validation Led to Decision to Implement a Single Stage Turbine Into STME Instead of Two Stages.

- **Complex Flow Paths**

  Technology Flow Testing Led to the Development of the SSME Phase II+ Hot Gas Manifold; CFD Analysis Validated In Air- and Water-Flow Facilities

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Turbine Stage

Consortium for CFD Applications in Propulsion

- **Objectives**
  - Identify needs
  - Development of CFD as a design tool through challenging applications
  - Evaluation/development of advanced hardware concepts
- **Teams in place**
  - Turbine
  - Pump
  - Combustion-driven flows
- **Participants (e.g., Turbine Team)**

NASA	Industry	Small Business	Universities
MSFC	Aerojet	Calspan	Penn. State Univ.
LeRC	General Electric	Rotodata	Miss. State Univ.
ARC	Pratt & Whitney	Sci. Res. Assoc.	Univ. of Ala. (T)
	Rocketdyne	SECA	Univ. of Ala. (Hsv.)
	United Technologies Res. Cen.		

← **Technology Transfer** →

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Turbine Stage – Generic Gas Generator

- **Objectives**
  - Enhance and Validate Turbine Design Tools
  - Transfer Advanced Technology to Turbine Design Process
- **Approach**
  - Develop and Implement Plan Cognisant of STME Program Goals
  - Focus Activity Around STME Turbines but Ensure End Products are Generic
  - Establish a Focused Team of Committed Turbine Experts to Drive Technology Transfer and Focus Deliverable Products toward Design Tools
  - Benchmark Codes With Air-Flow Data
  - Establish and Evaluate Advanced Baseline Turbine Stage
  - Fine Tune Baseline and Validate In Air-Flow Test
- **Results**
  - Code Validated for STME – Type Turbine Stage
  - High Turning (160°) Blade Designed/Evaluated
  - Efficiency Increased by 9.8 Percent
  - Single-Stage Turbine Instead of Two
  - Projected Life-Cycle Cost Savings of $71M

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Turbine Stage – Validation

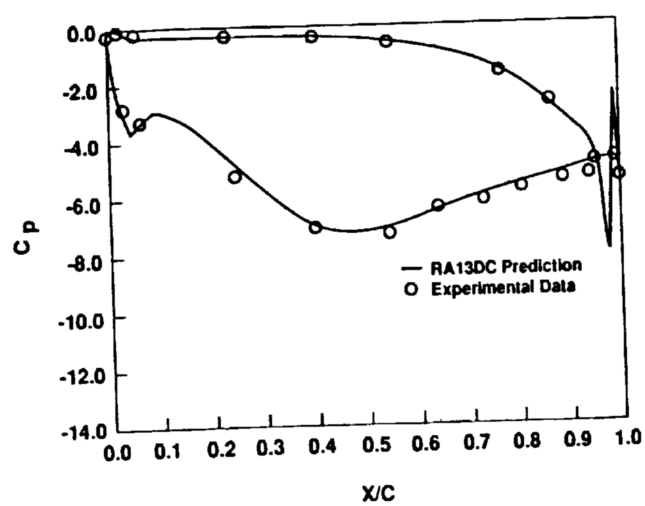

Figure 3b. Pressure Distributions for the Stator at the 50% Spanwise Location

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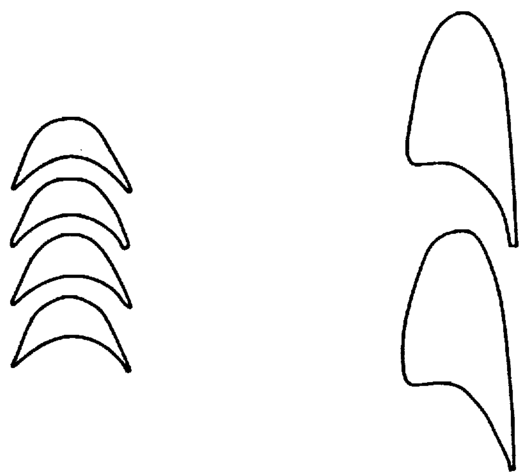
Turbine Stage – Blade Comparison

Traditional Blade Design | Advanced Concept Blade Design



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Turbine Stage – Flow Parameter Comparison

	Previous State-of-the-Art GG Experience	Advanced G³T Design Concept
General Description	70/30 Work Split Nominal Annulus Height	50/50 Work Split Increased Annulus Height
Blade turning	135°	160°
Fluid acceleration	0.9	1.6
Max blade Mach number	1.32	0.87
Efficiency	Base	+9.8 percent
Airfoil count	Base	-55 percent

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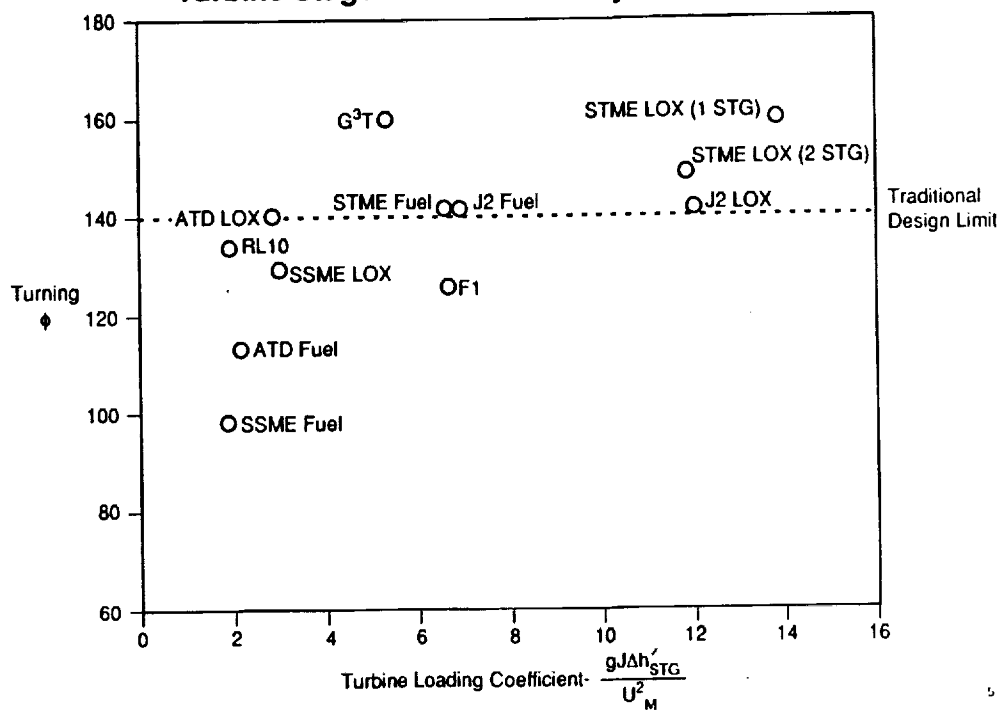
Turbine Stage – Turbine Aerodynamic Loading



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Turbine Stage – Key Milestones

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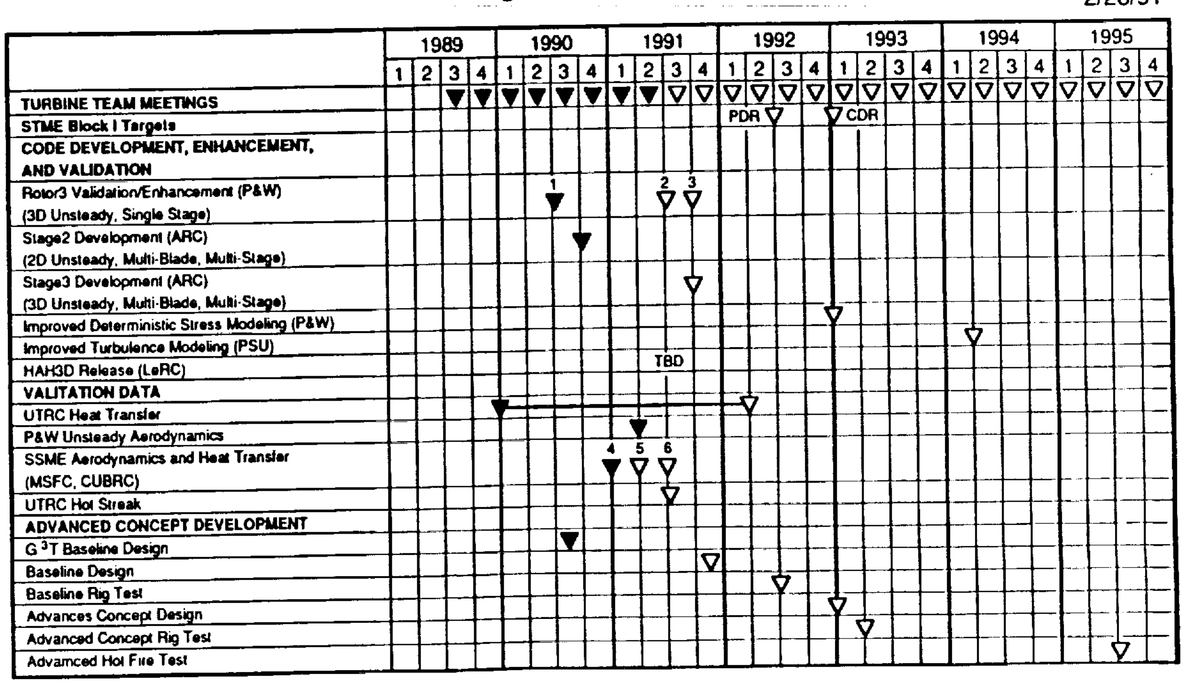

Key

1. Validation against steady aerodynamic and heat transfer data
2. Improved turbulence modeling
3. Validation against aerodynamic data
4. Steady aerodynamic data
5. Unsteady aerodynamic and heat transfer data
6. ATD steady aerodynamic data

Turbine Stage – Technology Transfer

- **STME LOX turbine design decision: one vs. two stage turbine**
  - LCC - favors one stage (reduction in LCC of 71 million dollars)
  - Risk - comparable
  - Rotordynamic - comparable, slightly favoring one stage
  - Hardware simplicity - favors one stage
  - Turbine stage technology team support available for one stage

By concensus of Aerojet, Pratt and Whitney, and Rocketdyne on Novermber 15, 1990, a one stage oxygen turbopump turbine was recommended and subsequently implemented into the STME design.

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Complex Flow Path – SSME Phase II +

- **Objectives**
  - Validate CFD analysis using air- and water-flow data
  - Evaluate 2-duct versus 3-duct HGM design
- **Approach**
  - Compare CFD results to air- and water-flow tests
  - Apply CFD codes and test rigs to 2-duct and 3-duct HGM designs
- **Results**
  - Good agreement between CFD predicted and measured wall pressures
  - 2-duct manifold results in
    - Lower side loads on turbine end
    - Lower turbine temperatures
    - More benign internal flow environment

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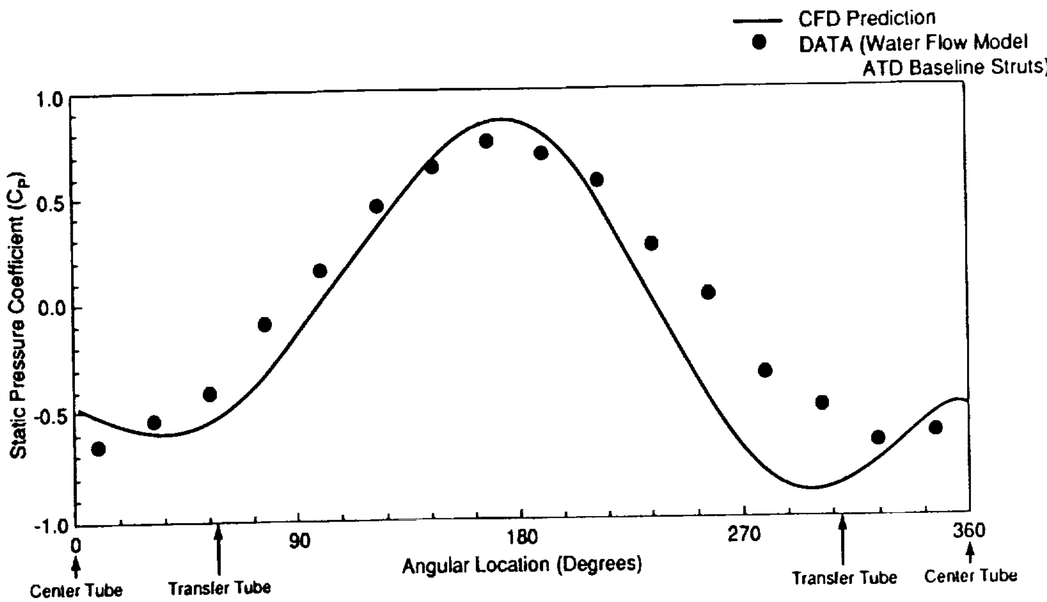
Complex Flow Path - Static Pressure Distribution at Turbine Exit Plane



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Complex Flow Path – Technology Transfer

- **SSME Program Made Key Decision to Develop Two Duct HGM**
  - Developmental Hot Fire Testing In Progress
  - Program Plans Indicate First Flight 1996

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Potential Augmented Work

- Flow Model of Entire Rocket Engine
- Advanced Turbopump
- Casting Technology
- Advanced Materials

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Earth-To-Orbit Turbomachinery Subsystem

Summary

- **Focused Management Milestone Plan In Place Via Cooperative Efforts Between MSFC and LeRC with ARC Participation.**
- **Technology Being Developed That has Potential to Flow Into Ongoing Main Stream Programs.**
- **NLS Distinguishable Technology Products Being Evolved That Also Have Generic Payoffs**
- **Technology Transfer Being Accomplish and Accelerated Via Consortium for CFD Application In Propulsion Technology**

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INTEGRATED TECHNOLOGY PLAN

FOR THE CIVIL SPACE PROGRAM

TRANSPORTATION TECHNOLOGY

EARTH-TO-ORBIT TRANSPORTATION

HEALTH MONITORING & DIAGNOSTICS AND CONTROLS

S. Gorland

6/26/91

INSTRUMENTATION

TECHNOLOGY NEEDS

- o IMPROVED SENSORS AND MEASUREMENT SYSTEMS FOR BOTH CURRENT AND FUTURE SPACE PROPULSION SYSTEMS IN ORDER TO PROVIDE:
  - o DETAILED MEASUREMENTS FOR CODE VALIDATION IN:
    - o SUBCOMPONENT TESTS IN LABORATORIES.
    - o COMPONENT TESTS IN FACILITIES.
    - o TEST BED ENGINE.
  - o IMPROVED TEST AND LAUNCH STAND INSTRUMENTATION.
  - o IMPROVED SENSORS AND SYSTEMS FOR OPERATIONAL ENGINES FOR BOTH:
    - o CONTROL PARAMETERS.
    - o HEALTH MONITORING.

INSTRUMENTATION

CHALLENGES

- THE ENVIRONMENTAL REQUIREMENTS UNDER WHICH THE SENSORS MUST FUNCTION AND THE PARAMETERS TO BE SENSED ARE FREQUENTLY BEYOND CURRENT STATE-OF-THE-ART.
- MEASUREMENT SYSTEMS FOR CODE VALIDATION MUST BE NON INTRUSIVE (E.G. OPTICAL) OR AT LEAST MINIMALLY INTRUSIVE (E.G. THIN FILM) BECAUSE THE CODES DO NOT ALLOW FOR THE PRESENCE OF A SENSOR.
- MEASUREMENT SYSTEMS FOR CODE VALIDATION MUST ALSO PROVIDE HIGH TEMPORAL AND SPATIAL RESOLUTION BECAUSE THE CODES ARE USUALLY FINE MESH SOLUTIONS.
- SENSORS FOR OPERATIONAL ENGINES MUST BE HIGHLY RELIABLE PARTICULARLY WHEN FUTURE LONG TERM MISSIONS ARE CONSIDERED.
- MEASUREMENT SYSTEMS FOR TEST AND LAUNCH PAD OPERATION MUST REQUIRE MINIMUM MANPOWER AND/OR MAINTENANCE WHILE SURVIVING THE EXTREME ACOUSTIC, VIBRATION, AND THERMAL ENVIRONMENTS DURING LAUNCH.

INSTRUMENTATION

APPROACH

- MAXIMIZE THE USE OF OPTICAL SYSTEMS AND FIBER OPTICS.
- DEVELOP THIN, SPUTTER DEPOSITED FILM SENSORS.
- CAPITALIZE ON DEVELOPMENTS IN THE COMPUTER, MICROELECTRONIC, AND LASER TECHNOLOGY FIELDS.
- BALANCE THE PROGRAM AMONG IN-HOUSE, GRANT, AND CONTRACT WORK.
- COORDINATE CLOSELY WITH THE OTHER TECHNOLOGY GROUPS, PARTICULARLY CONTROLS.

INSTRUMENTATION

BENEFITS

- o RELIABLE SENSORS FOR:
  - o CONTROL AND HEALTH MONITORING.
  - o INCREASED CREDIBILITY OF COMPUTER CODES.
- o MORE DIRECT SENSING OF THE PARAMETER REQUIRED RATHER THAN INDIRECT INFERENCE FROM OTHER MEASUREMENTS.
- o MORE EFFICIENT AND SAFER STAND AND PAD OPERATIONS.
- o GENERIC TECHNOLOGY APPLICABLE NOT ONLY TO EARTH-TO-ORBIT PROPULSION SYSTEMS BUT ALSO TO SPACE BASED PROPULSION SYSTEMS INCLUDING NUCLEAR.

INSTRUMENTATION

CURRENT PROGRAM

- o DETAILED MEASUREMENTS FOR CODE VALIDATION IN LABORATORIES, RESEARCH FACILITIES, AND THE TEST BED ENGINE.
  - o THIN FILM THERMOCOUPLES AND HEAT FLUX SENSORS FOR THE TURBINE ENVIRONMENT.
  - o PLUG TYPE HEAT FLUX SENSORS FOR TURBINE TRANSIENTS.
  - o OPTICAL SYSTEMS FOR:
    - o PREBURNER GAS TEMPERATURE.
    - o TURBINE REGION FLOW MEASUREMENT.
    - o 2D STRAIN MEASUREMENTS IN HIGH TEMPERATURE MATERIALS TEST FACILITIES.
    - o HOLOGRAPHIC STRUCTURAL FLAW DETECTION.
    - o OPTICAL SYSTEM ALIGNMENT IN HARSH ENVIRONMENTS USING NEURAL NETWORKS.

INSTRUMENTATION

CURRENT PROGRAM (CONT)

- o IMPROVED TEST AND LAUNCH STAND INSTRUMENTATION.
  - o OPTICAL PLUME ANOMALY DETECTION SYSTEM.
  - o GASEOUS (H2) LEAK DETECTION USING:
    - o SOLID STATE POINT SENSORS.
    - o REMOTE OPTICAL SYSTEMS.

INSTRUMENTATION

CURRENT PROGRAM (CONT)

- o IMPROVED SENSORS AND SYSTEMS FOR OPERATIONAL ENGINES FOR BOTH CONTROL AND HEALTH MONITORING.
  - o OPTICAL COMBUSTION CHAMBER GAS SPECIES MEASUREMENT.
  - o FLOWMETERS:
    - o VORTEX SHEDDING.
    - o ULTRASONIC.
    - o TRIBOELECTRIC.
  - o NON-INTRUSIVE SPEED SENSOR FOR TURBOPUMPS.
  - o BEARING DEFLECTOMETER.
  - o TURBINE BLADE PYROMETER.
  - o BRUSHLESS TORQUEMETER.
  - o PRESSURE SENSOR.

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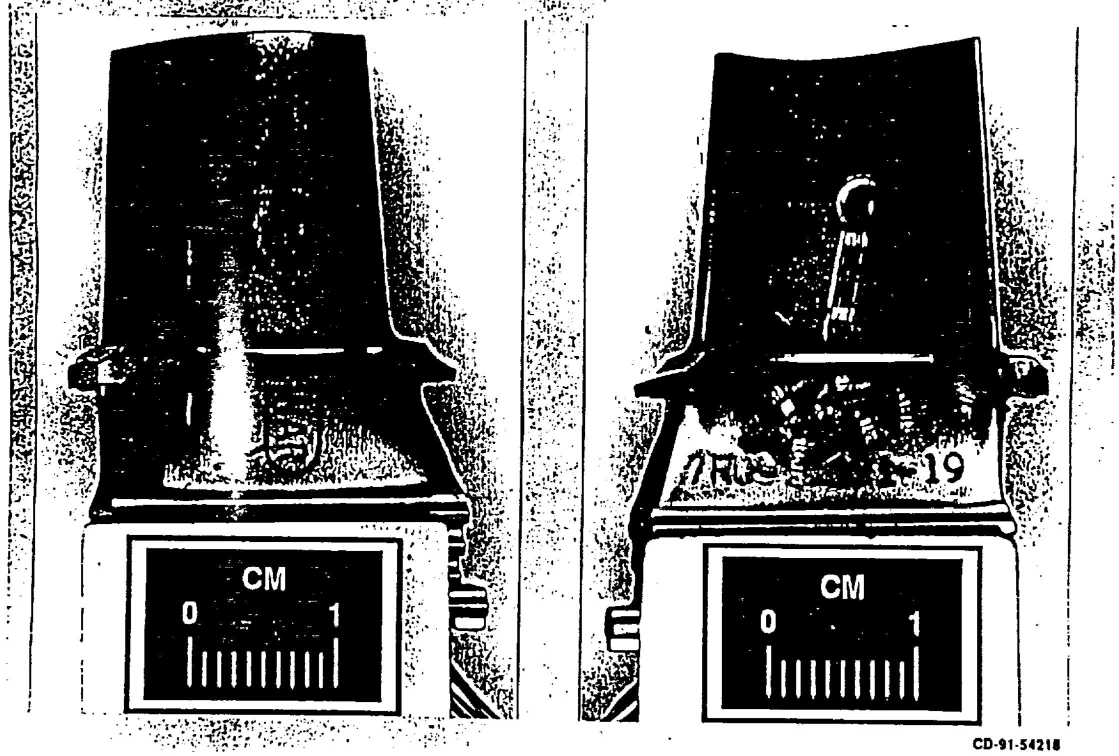
Plug-Type Heat Flux Gage



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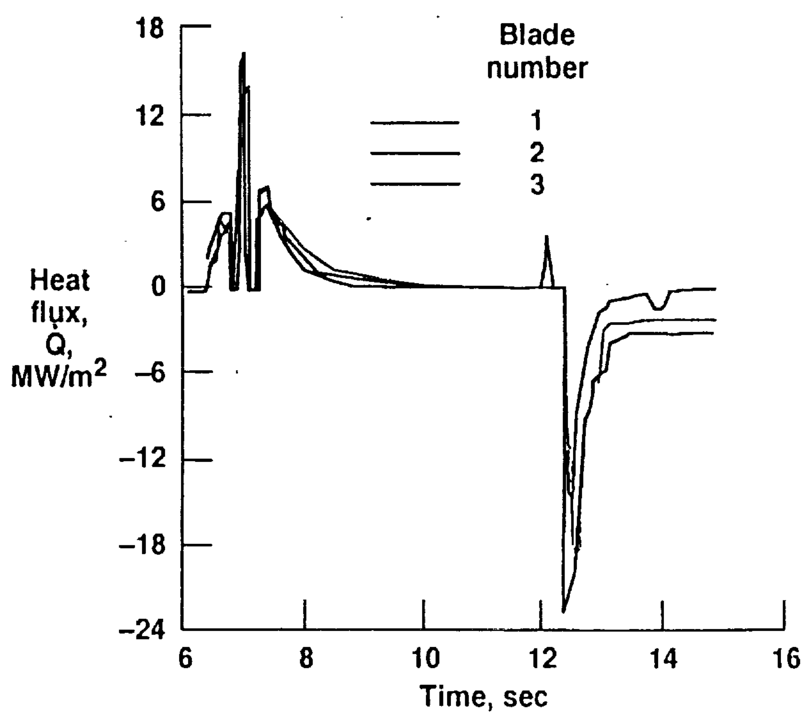
Heat Flux Measured in SSME Turbine Blade Tester



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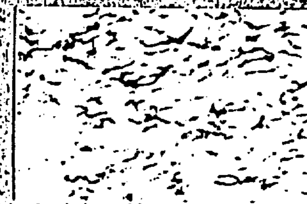
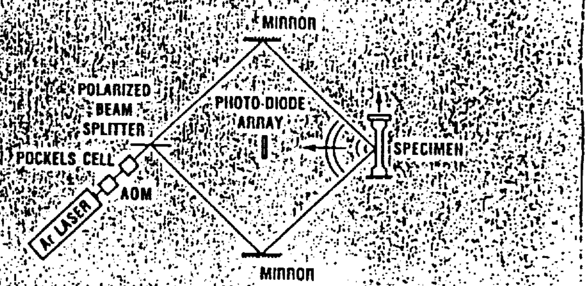
REMOTE STRAIN MEASUREMENTS

GOAL
- RELIABLE MATERIAL AND STRUCTURE TESTING

FEATURES
- NONCONTACT, NONINTRUSIVE
- INDEPENDENT OF TEST MATERIAL
- HIGH TEMPERATURE
- FULL FIELD POTENTIAL
- RIGID BODY MOTION CORRECTING



SPECKLE PATTERN



LASER SPECKLE STRAIN MEASUREMENT SYSTEM

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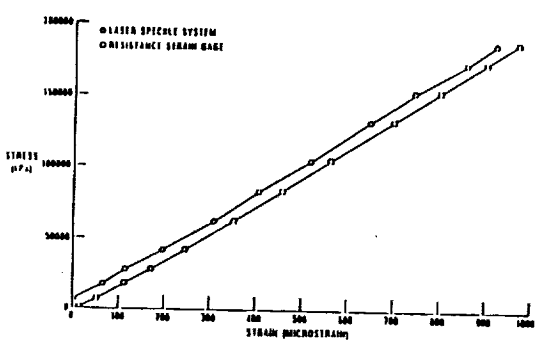
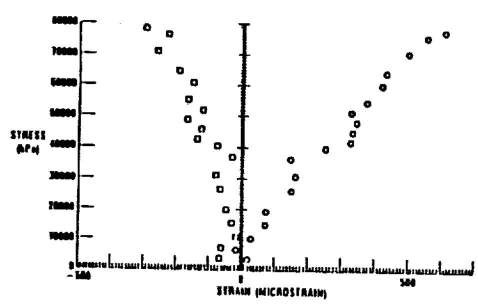
LASER SPECKLE STRAIN MEASUREMENT SYSTEM



ROOM TEMPERATURE COMPARISON
WITH RESISTANCE STRAIN GAGE



MEASUREMENT AT 1300 °F

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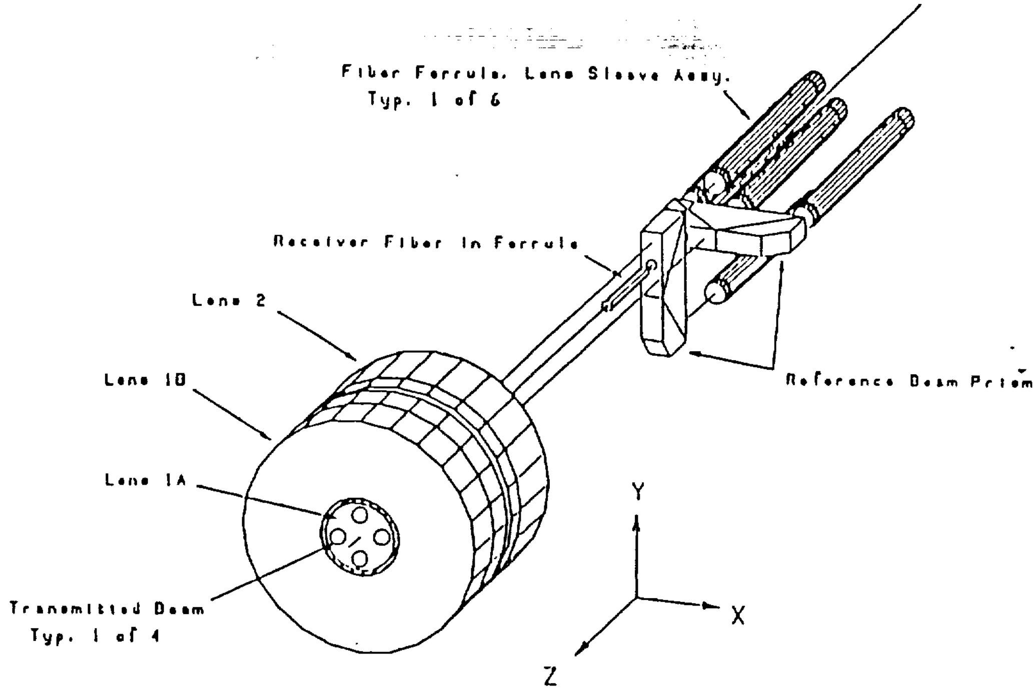
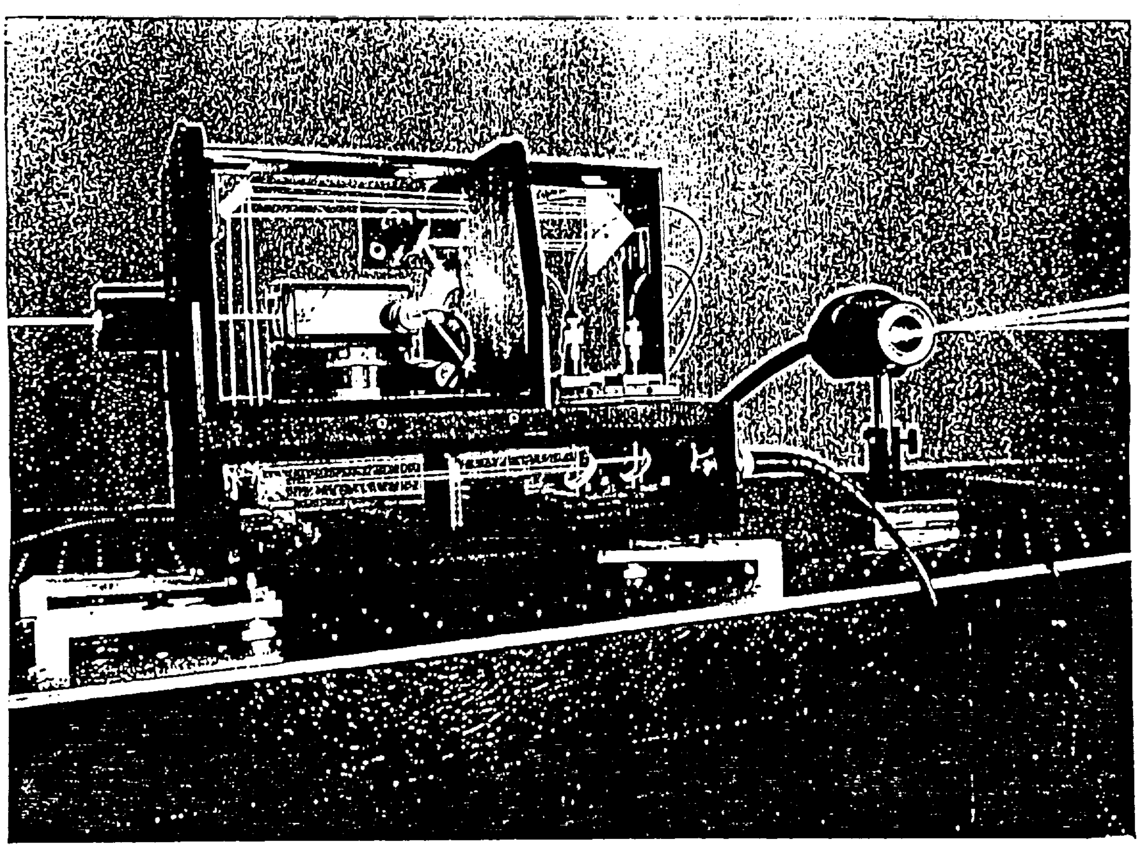


LASER ANEMOMETER PROBE
FOR TURBINE ENVIRONMENT



LASER ANEMOMETER PROBE
FOR TURBINE ENVIRONMENT

Leak Detection

Technology Needs:

- Develop sensors that detect propellant leakage from cryogenic liquid fueled rocket engines.

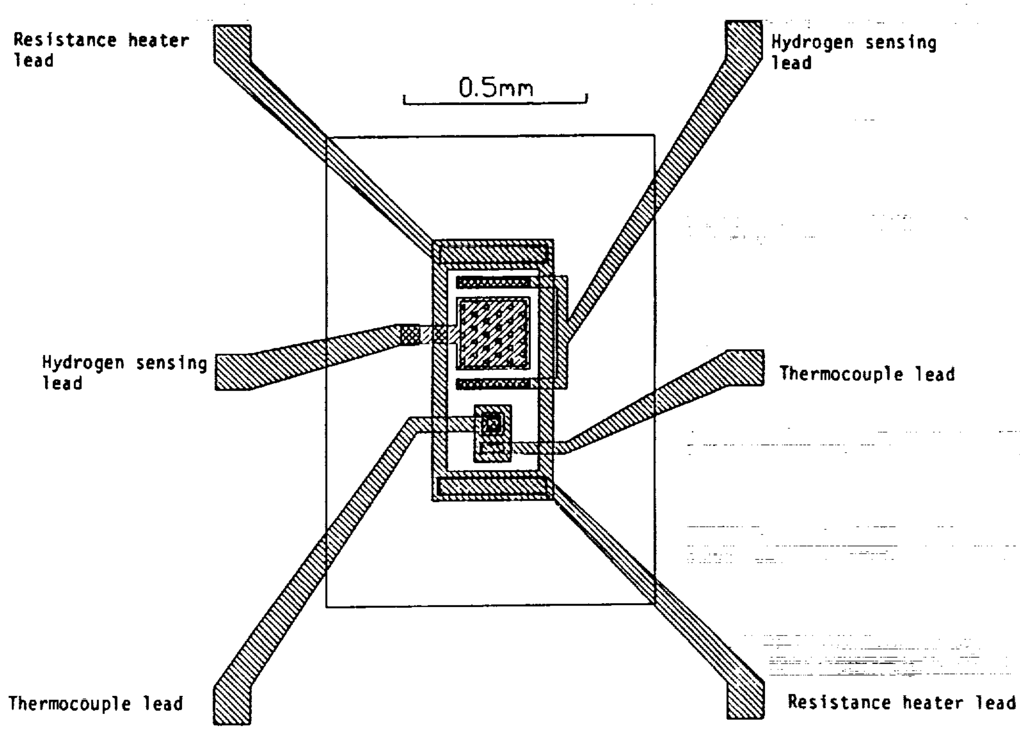
Technology Challenge:

- Develop hydrogen and oxygen sensors exhibitting:
    - Fast response
    - High sensitivity
    - High spatial resolution
- Harden and package sensors for engine environment.

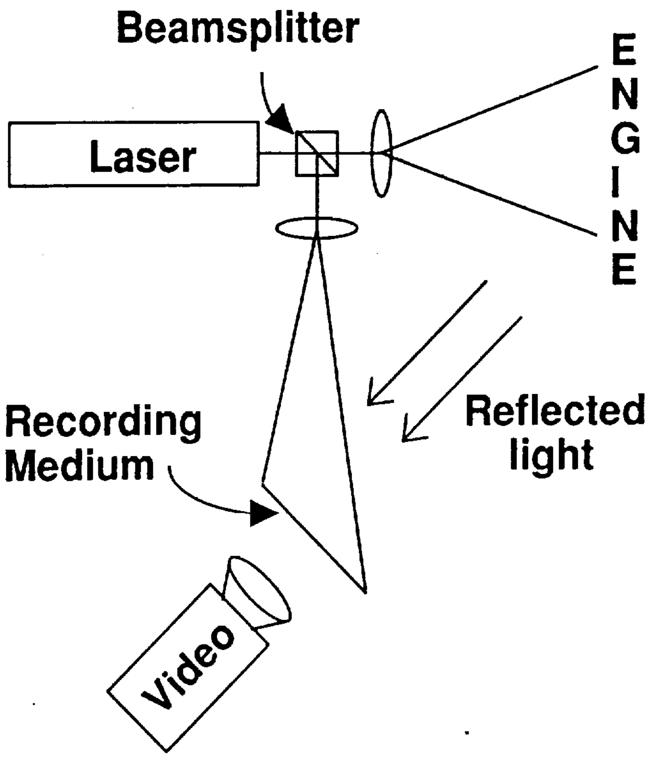
Benefits:

- Enables real time leak detection of propellants.
- Increases engine/mission safety.

Mask for Hydrogen Sensor



HOLOGRAPHIC INTERFEROMETRIC CONFIGURATION FOR LEAK DETECTION



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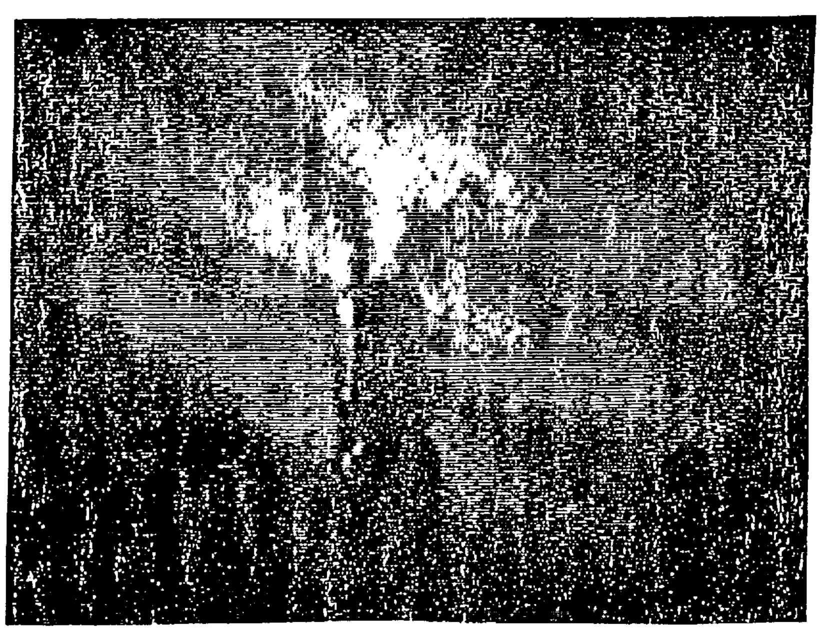
HOLOGRAPHIC INTERFEROMETRY LEAK DETECTION



HOLOGRAPHIC INTERFEROGRAM OF A LEAKY PIPE FITTING

INSTRUMENTATION

AUGMENTED PROGRAM

- o ACCELERATE THE RATE AT WHICH ADVANCED INSTRUMENTATION IS APPLIED.
  - o CURRENT PROGRAM IS FOCUSSED ON DEVELOPING AND VALIDATING NEW MEASUREMENT CONCEPTS IN THE LABORATORY.
  - o CURRENT FUNDING LEVELS PERMIT THE DEVELOPMENT OF ONE (OR A FEW) PROTOTYPE MEASUREMENT SYSTEMS FOR FIELD APPLICATIONS.
  - o AUGMENTED FUNDING WOULD ALLOW MORE RAPID APPLICATION OF NEW MEASUREMENT TECHNOLOGY.
  - o SPECIFIC EXAMPLES INCLUDE:
    - o HYDROGEN LEAK DETECTION SYSTEMS.
    - o THIN FILM SENSORS.
    - o ADVANCED FLOW, TEMPERATURE, AND TORQUE SENSORS.
    - o OPTICAL DIAGNOSTIC SYSTEMS.

INSTRUMENTATION

AUGMENTED PROGRAM (CONT)

- o DEVELOP NEW AND UPGRADE EXISTING INSTRUMENTATION TEST FACILITIES TO ENHANCE RESEARCH PRODUCTIVITY.
  - o NEW FACILITY FOR HYDROGEN LEAK DETECTION SYSTEM TEST AND CALIBRATION.
  - o NEW FACILITY FOR THE EXPOSURE OF SENSORS, MATERIALS SAMPLES, COATINGS, AND OTHER SMALL ITEMS TO HOT (BURNING) HYDROGEN AT ELEVATED PRESSURES AND UNDER TRANSIENT FLOW AND TEMPERATURE CONDITIONS.
  - o UPGRADE THE EXISTING LeRC HEAT FLUX CALIBRATION FACILITY.

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Sensor Autodiagnosis and Autocalibration

Technology Needs:

- Develop capability to enable in-situ, autonomous sensor failure detection/diagnosis and sensor self calibration

Technology Challenge:

- Model sensor with autodiagnostic/autocal capabilities
- Incorporate autodiagnostic/autocal capabilities without major modification or redesign of sensor

Benefits:

- Increased sensor reliability
- Reduced sensor maintenance requirements
- Enables sensors to be fault tolerant
- Eliminates "false alarm" shutdowns

Transportation Technology
Earth-to-Orbit Propulsion

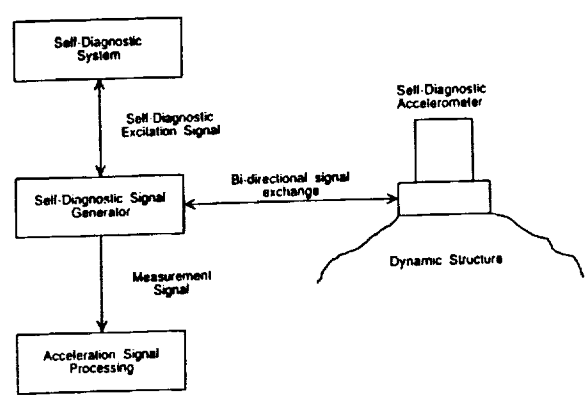
Autodiagnostic and Autocalibration Program

Current Program:

- Develop and implement autodiagnostic/autocalibration capabilities into piezoelectric accelerometer.
- Test on MSFC TTBE.

Augmented Program

- Develop and extend technology to other types of sensors such as:
  Flowmeters
  Thermocouples
  Pressure transducers



Plume Diagnostics

Technology Needs:

- Develop plume diagnostic capabilities for ground test and flight rocket engines.

Technology Challenge:

- Develop engine ground testing plume diagnostic capabilities
- Develop engine mounted optics and spectrometer.
- Develop codes to extract safety, health and performance information from plume spectral data.

Benefits:

- Enables rocket engine safety, health and performance monitoring with a single instrument.

Plume Diagnostics Program

Current Program:

- Monitoring TTBE spectral emisisons (OPAD).
- Monitoring emissions across the TTBE exit plane.
- Development of nozzle mounted optic assembly and high resolution spectrometer for SSME.
- Develop code to extract species/alloy information from plume spectral data.

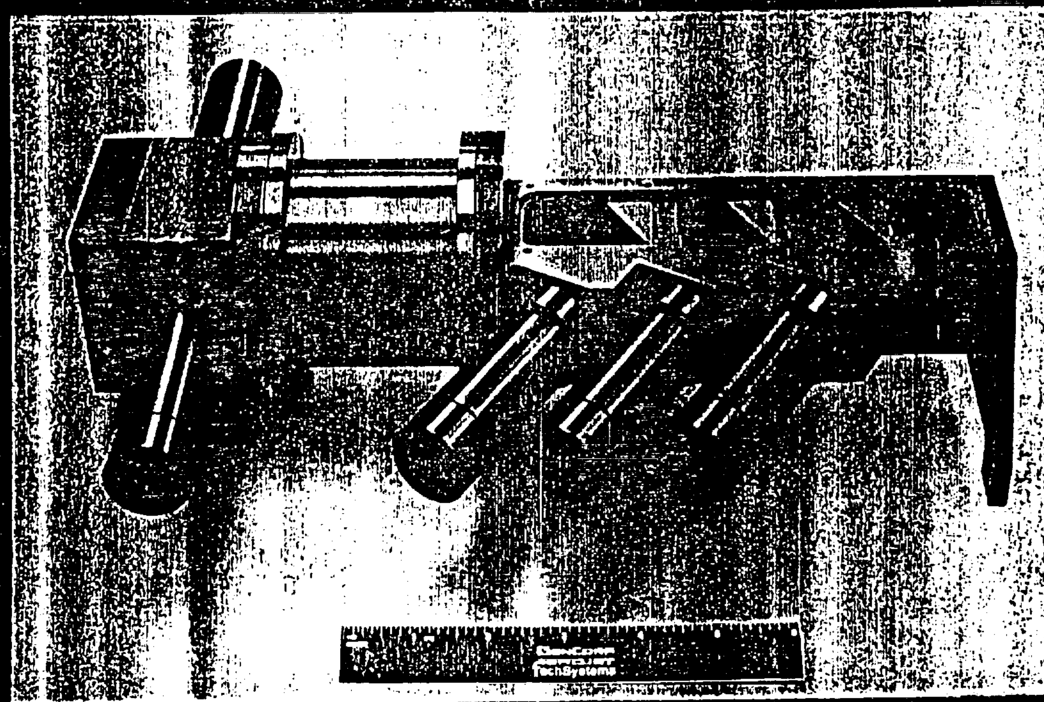
Augmented Program

- Develop code(s) to model and predict spectral emissions from a high pressure/high temperature combustion process.

GenCorp
Aerojet

Breadboard FPI Spectrometer Fabrication Is Complete

Propulsion Division

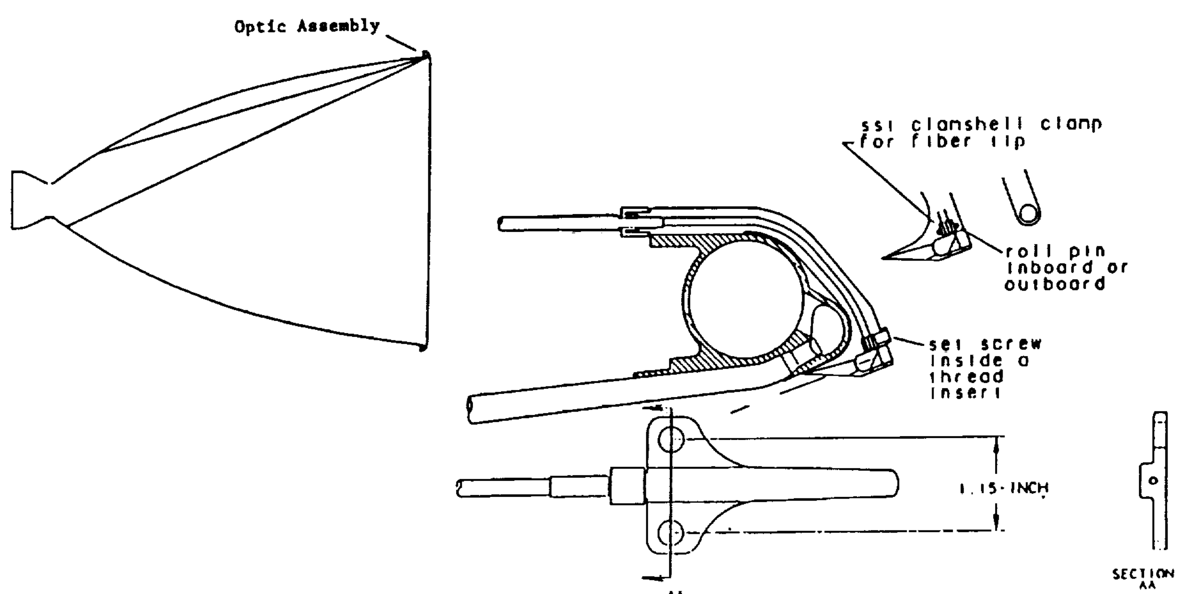


LTD
AEROSPACE TECHNOLOGY DIRECTORATE

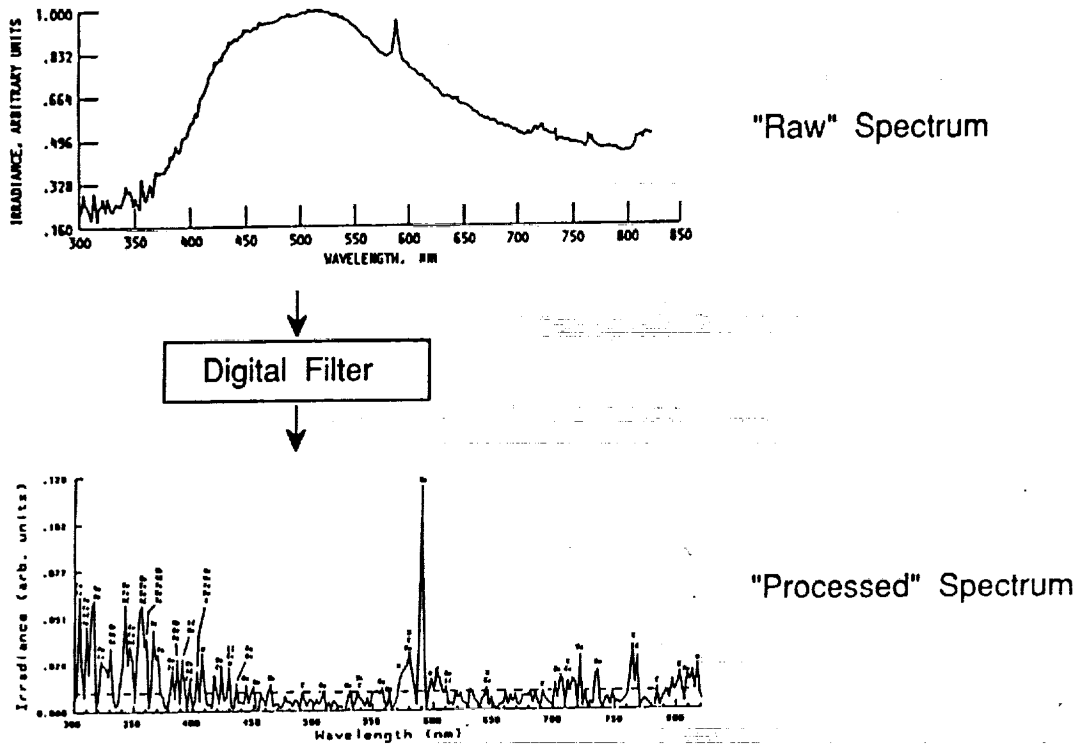
SPACE PROPULSION TECHNOLOGY DIVISION

NASA
Lewis Research Center

SSME Nozzle/throat Optic Assembly



Separation and Extraction of Plume Phenomena



Transportation Technology
Earth-To-Orbit Transportation

FAILURE MODELING

NEED: CAPABILITY TO MODEL FAILURE AND DEGRADATION BEHAVIOR OF ROCKET ENGINE, BOTH STEADY STATE AND TRANSIENT.

APPROACH:

- DEVELOP GENERIC SUB-COMPONENT FAILURE MODELS (BEARINGS, INJECTORS, MANIFOLDS).
- DEVELOP TOOL FOR LINKING SUB-COMPONENT FAILURE MODELS TO DEFINE THE SYSTEM MODEL..
- VERIFY FAILURE MODEL CAPABILITY USING OPERATION DATA FROM BOTH TEST AND FLIGHT ENGINES.
- USE FAILURE MODELS TO DEVELOP DIAGNOSTIC, PROGNOSTIC, AND CONTROL ALGORITHMS TO BE USED IN HEALTH MONITORING SYSTEM FOR PRESENT AND FUTURE ENGINES.
- USE FAILURE MODELS TO PROVIDE FEEDBACK TO THE DESIGN AND DEVELOPMENT PROCESS.

FAILURE MODELING

BENEFIT:
- PROVIDE FAILURE DATA TO DEVELOP ALGORITHMS AND HEALTH MONITORING SYSTEMS PRIOR TO ACTUAL ROCKET ENGINE DEVELOPMENT.
- ACTUAL ROCKET ENGINE FAILURES ARE BOTH COSTLY AND INFREQUENT. FAILURE MODELS CAPABILITY WILL PROVIDE A "RICH" FAILURE DATABASE WITH MINIMUM HARDWARE AND SAFETY IMPACTS.

DELIVERABLE:

Current:
- o TOOL FOR LINKING SUB-COMPONENTS TO DEFINE SYSTEM MODEL
- o INJECTOR FAILURE MODEL SPECIFIC TO SSME

Augmented:
- o GENERIC FAILURE MODELS OF KEY ROCKET ENGINE SUB-COMPONENTS
- o VALIDATE FAILURE MODELS CAPABILITY USING SSME DATA

MASS DATA STORAGE AND RETRIEVAL

NEED:
- o A validated engine flight data recorder, based on either digital or optical theory, that allows for increased bandwidth storage capability. Coupled with validated expert system and data base technologies to provide extensive archival search and retrieval techniques for the massive and disparate data required for diagnostics and prognostics.

APPROACH:
- o Design and develop advanced techniques for fast access and large bandwidth for mass data storage and retrieval.
- o Design and develop techniques and database with smart retrieval capabilities.

MASS DATA STORAGE AND RETRIEVAL

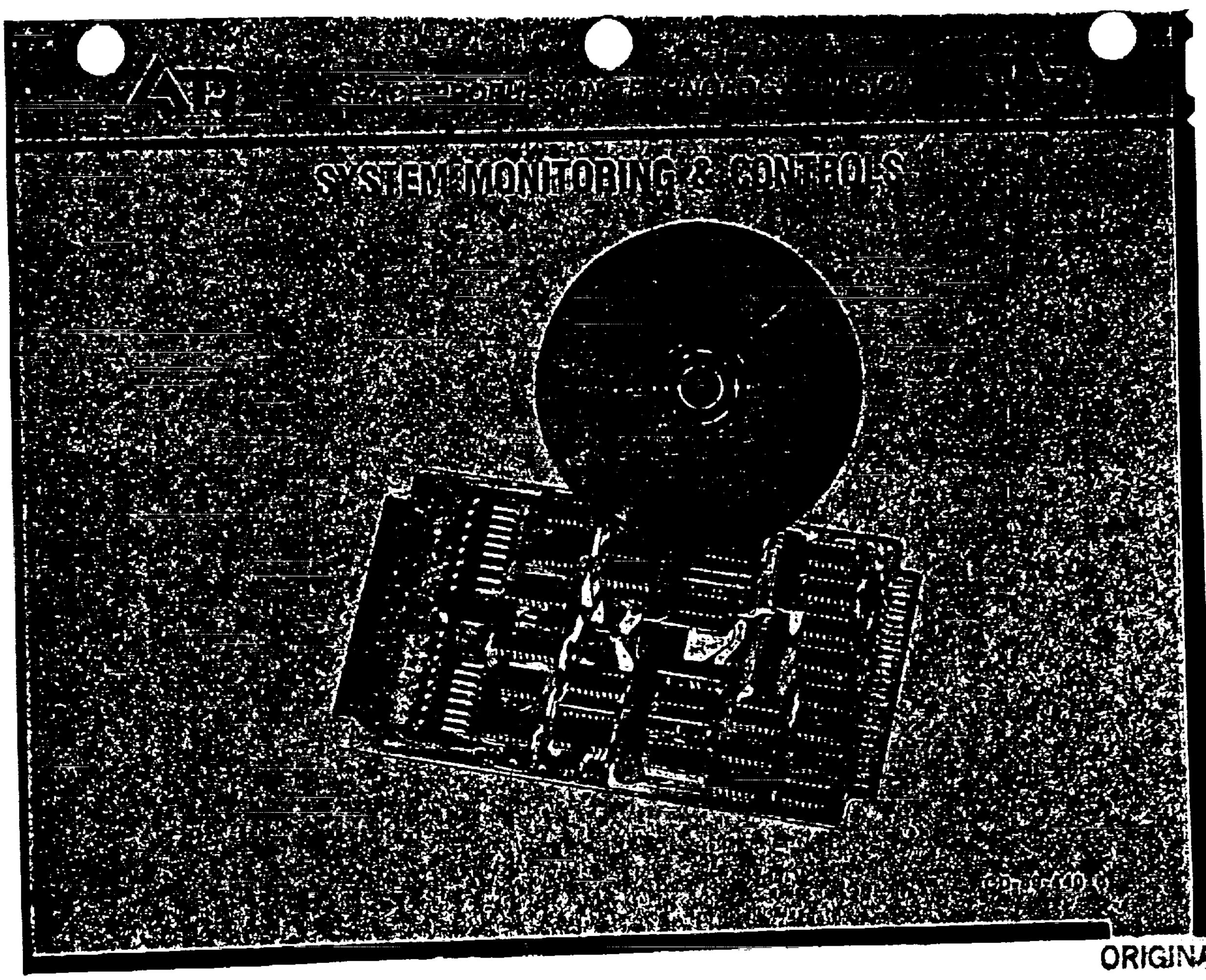
BENEFITS:

- o Ability to provide fast access and large mass data storage capability. Required to accommodate future engine and instrumentation needs.
- o A highly correlated, compatible, and expandable retrieval system that provides more rapid turn around time, more efficient use of resources more thorough use of review data, and more consistent historical trending records.

DELIVERABLES:

Current:
- o A flight mass data management and storage system for rocket engines.
- o An integrated test firing, inspection and historical component and engine database that allows for easy access and retrieval of data for diagnostics, prognostics and maintenance.

Augmented:
- o Preprocessing for quicker data retrieval, and sensor measurement validation.



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Transportation Technology
Earth-To-Orbit Transportation

FIBER OPTIC INSTRUMENTATION BUS

NEED: ADVANCED ROCKET ENGINE INSTRUMENTATION SYSTEM THAT OFFERS SAFER, MORE COMPACT, HIGHER-THROUGHPUT, AND EMI-RESISTANT COMMUNICATION.

APPROACH:

- DESIGN A FIBER-OPTIC INSTRUMENTATION SYSTEM SUITABLE FOR ROCKET ENGINE APPLICATIONS.
- SELECT, DEVELOP OR MODIFY SUITABLE COMPONENTS AND EVALUATE IN RELEVANT ENVIRONMENT
- BUILD AND DEMONSTRATE SENSOR BUS ON COMPONENT AND ROCKET ENGINE TEST BEDS.

Transportation Technology
Earth-To-Orbit Transportation

FIBER OPTIC INSTRUMENTATION BUS

BENEFITS:

- PROVIDE INSTRUMENTATION SYSTEM THAT IS FASTER, SAFER, LIGHTER, AND EMI-IMMUNE
- FACILITATE USE OF ADVANCED OPTICAL SENSORS
- IMPROVE STATE-OF-THE-ART IN OPTICAL FIBER TECHNOLOGY

DELIVERABLES:

Current:
- TEST SOME COMMERCIAL FIBER OPTIC COMPONENTS IN CRYOGENIC AND HIGH TEMPERATURES. (ST,MIL-STD, MULTI-FIBER, AND DUAL FIBER CONNECTORS, FIBER CABLES, AND COUPLERS)

Augmented:
- COMPONENTS DEVELOPED AND DEMONSTRATED FOR USE ON ADVANCED ROCKET ENGINES
- INTEGRATED OPTICAL SENSOR BUS DEVELOPED AND DEMONSTRATED FOR ROCKET ENGINE APPLICATIONS

Transportation Technology
Earth-To-Orbit Transportation

MODEL BASED DIAGNOSTICS

NEED: AUTOMATED MODEL-BASED DIAGNOSTIC CAPABILITY FOR ROCKET ENGINES

APPROACH:

- DEVELOP QUALITATIVE REASONING TECHNIQUES FOR ROCKET ENGINE DIAGNOSTICS:
  - DEVELOP GENERIC TOOL FOR CREATING SYSTEM MODELS AND ANALYZING RESULTS.
  - APPLY TOOL TO ROCKET ENGINE COMPONENTS AND SYSTEMS. DEMONSTRATE CAPABILITIES OF TOOL
- INTEGRATE MODEL WITH HEALTH MONITORING TECHNIQUES TO DIAGNOSE THE SOURCE OF A DETECTED FAILURE.

Transportation Technology
Earth-To-Orbit Transportation

MODEL BASED DIAGNOSTICS

BENEFITS:

- PROVIDES MODEL-BASED DIAGNOSTIC ALGORITHMS WHICH CAN EXECUTE IN NEAR-REAL-TIME
- MODEL-BASED DIAGNOSTICS OFFER MORE COMPLETE COVERAGE THAN RULED-BASED TECHNIQUES OF SIMILAR COMPLEXITY

DELIVERABLES:

Augmented:
- ANALYSIS AND DIAGNOSIS TOOLS
- USER INTERFACE FOR SYSTEM DEFINITION AND DISPLAY OF RESULTS
- VERIFICATION OF MODELS OF ROCKET ENGINE COMPONENTS AND SYSTEMS.

SAFETY MONITORING SYSTEM (SMS)

OBJECTIVES:

- Provide increased safety on the test stand, while maintaining a path to flight.
- Complement the current redline system with the SMS to detect anomalies earlier.

APPROACH:

- Validate SMS algorithms.
- Integrate algorithms with hardware.
- Demonstrate anomaly detection on TTB.

SAFETY MONITORING SYSTEM (SMS)

SMS MAJOR RESULTS

- 100% detection of faults for 15 test cases
- Low false alarm rate
- Covers all phases of SSME operation including power transients
- Robust to sensor loss (clustering)
- Significant improvement in fault detection times
- Not complex

ALGORITHM PERFORMANCE - DETECTION TIME IN SECONDS

TEST NO.	901-110	901-436	901-364	901-307	902-198	902-249	901-225	750-168	901-284	750-259	901-173	901-331	901-222	901-340	SF10-01
CLUSTER	-	302.4	42.7	8.6	5.8	5.2	255.6	300.2	5.2	101.5	102.1	50.2	N/A	405.5	N/A
ARMA	16.0	70.0	210.0	9.0	8.5	160.0	16.0	N/A	9.0	101.5	188.0	233.0	N/A	12.2	104.8
CURRENT RED-LINE	74.1	611.0	392.2	75.0	8.5	450.6	255.6	300.2	9.9	101.5	201.2	233.1	4.3	405.5	104.8

CONTROLS & REAL TIME DIAGNOSTICS

TECHNOLOGY NEED

IMPROVE THE SURVIVABILITY AND DURABILITY OF REUSABLE ROCKET ENGINES THROUGH THE USE OF INTELLIGENT CONTROLS AND REAL TIME DIAGNOSTICS

TECHNOLOGY CHALLENGES

- INTEGRATION OF FAULT DETECTION AND CONTROL MODES TO FORM INTELLIGENT CONTROL WITH INCREASED FUNCTIONALITY AND AUTONOMY
- RELIABLE(I.E. NO FALSE ALARMS), REAL TIME FAULT DETECTION ALGORITHMS
- REAL TIME DIAGNOSTIC ALGORITHMS THAT ACCURATELY PORTRAY ENGINE CONDITION
- IMPLEMENTATION OF DIAGNOSTIC AND CONTROL ALGORITHMS IN COMPUTER HARDWARE
- LIFE EXTENDING CONTROL ALGORITHMS WHICH IMPROVE ENGINE PERFORMANCE AND LIFE
- MODELING AND REAL TIME SIMULATION OF ROCKET ENGINES
- SENSORS FOR CONDITION MONITORING
- ELECTROMECHANICAL ACTUATORS

CONTROLS & REAL TIME DIAGNOSTICS

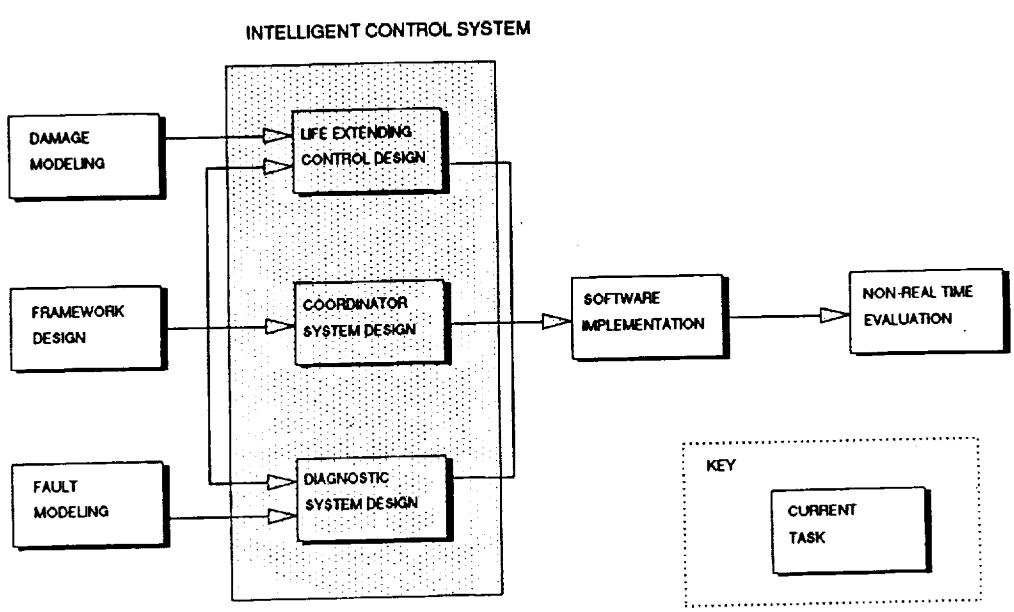
APPROACH

- o DESIGN AND ANALYZE ALTERNATIVE FAULT DETECTION, CONDITION MONITORING, AND CONTROL STRATEGIES.
- o IMPLEMENT THE MOST SUCCESSFUL STRATEGIES IN SOFTWARE/HARDWARE PROTOTYPES
- o INTEGRATE THE PROTOTYPES INTO A VALIDATION SYSTEM
- o VALIDATE THE STRATEGY BY REAL TIME SIMULATION AND ENGINE TEST
- o COORDINATE CLOSELY WITH THE OTHER TECHNOLOGY GROUPS, PARTICULARLY INSTRUMENTATION.

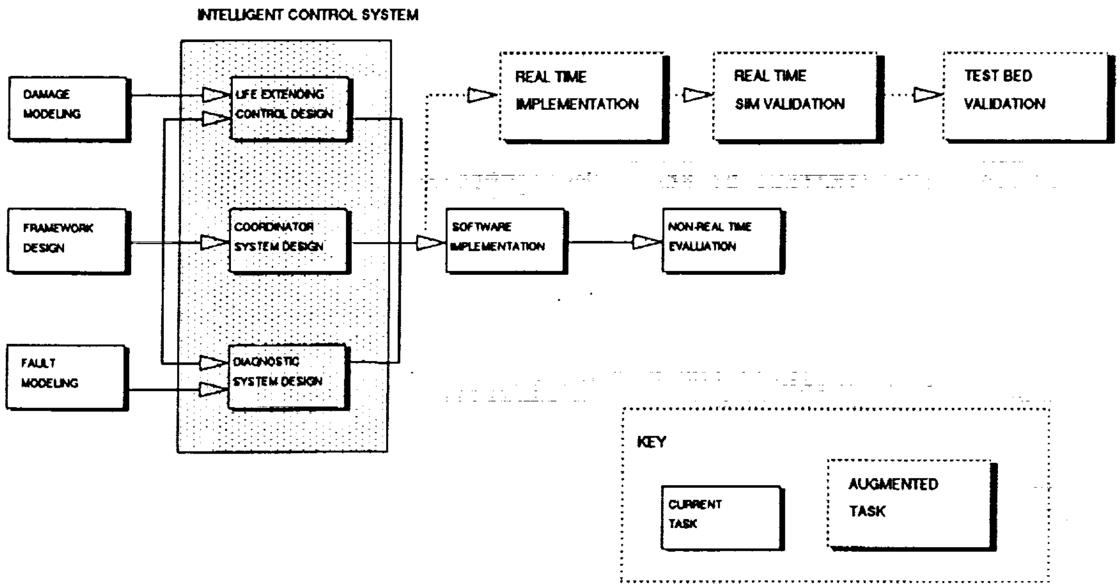
PAYOFFS

- o IMPROVED SURVIVABILITY FOR PROPULSION SYSTEM
- o IMPROVED ENGINE PERFORMANCE AND DURABILITY
- o ENHANCED SAFETY FOR PROPULSION SYSTEM AND VEHICLE
- o ENHANCED SAFETY FOR GROUND TEST OF ENGINES
- o INCREASED CONTROL SYSTEM RELIABILITY, FUNCTIONALITY, AND AUTONOMY
- o REDUCED ENGINE LIFE CYCLE AND MAINTENANCE COSTS
- o REDUCED CONTROL SYSTEM COST AND WEIGHT

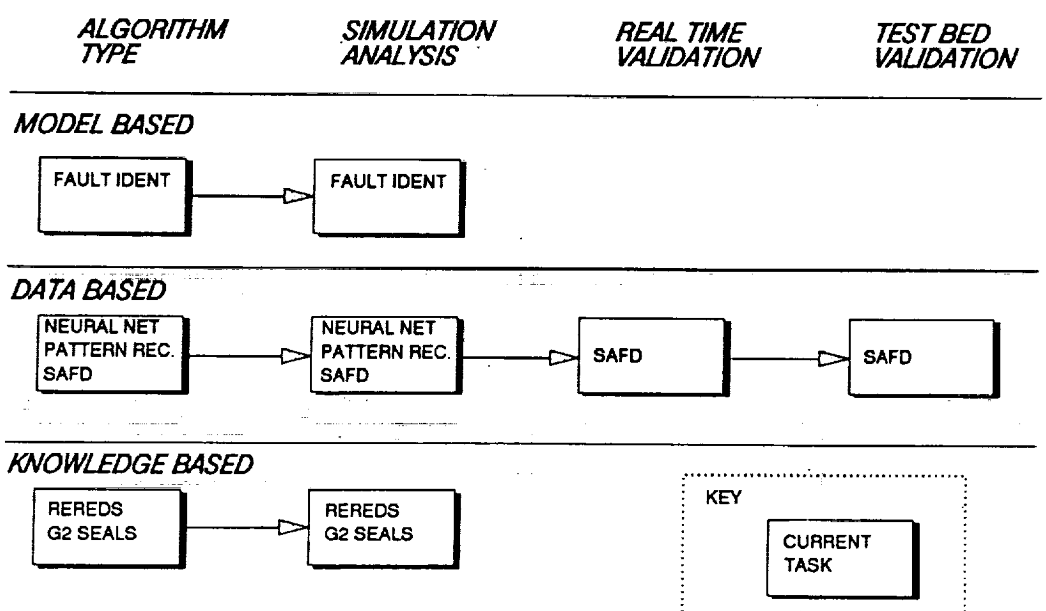
CURRENT INTELLIGENT CONTROLS PROGRAM



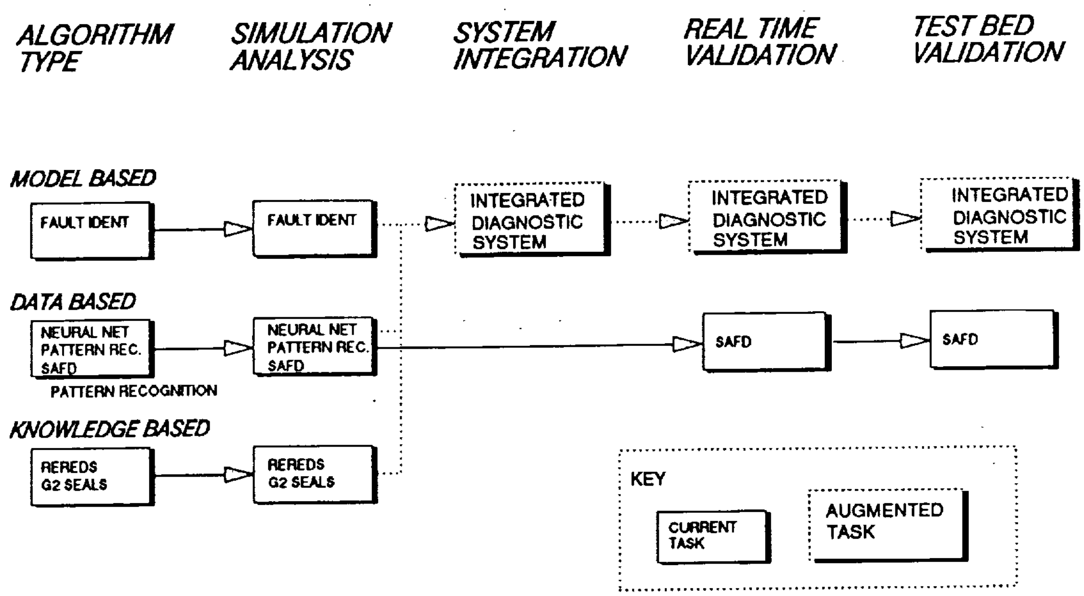
AUGMENTED INTELLIGENT CONTROLS PROGRAM



CURRENT REAL TIME DIAGNOSTICS PROGRAM



AUGMENTED RT DIAGNOSTICS PROGRAM



CONTROL AND DIAGNOSTIC SYSTEM HARDWARE

CURRENT PROGRAM

- o SIMULATION LAB AND TTBE CONTROL COMPUTERS
- o FLOWMETERS
  - TRIBOELECTRIC
  - ULTRASONIC
  - VORTEX SHEDDING
- o NON-INTRUSIVE SPEED MEASUREMENT
- o GAS LEAK DETECTOR
- o MASS DATA STORAGE
- o ADVANCED PROPELLANT CONTROL VALVES
- o ELECTROMECHANICAL ACTUATOR

AUGMENTED PROGRAM

- o COMPLETE TEST BED EVALUATION OF FLOWMETER
- o COMPLETE TESTING OF ELECTROMECHANICAL ACTUATOR
- o PROCURE AND DEMONSTRATE HARDWARE FOR MASS DATA STORAGE SYSTEM
- o PROCURE AND DEMONSTRATE COMPUTERS FOR REAL TIME DIAGNOSTIC SYSTEMS

N93-71884

INTEGRATED TECHNOLOGY PLAN FOR THE CIVIL SPACE PROGRAM

511-81
157478
p-16

SPACE CHEMICAL ENGINES TECHNOLOGY

FRANK D. BERKOPEC

JUNE 24-28, 1991

AGENDA

- INTRODUCTION/OVERVIEW/QUAD CHART
- TERMINOLOGY
- PROGRAM DESCRIPTION
- PROGRAMMATIC REVIEW
- CURRENT PROGRESS
- OBSERVATIONS
- SUMMARY CHART

Space Chemical Engines Technology

OBJECTIVES

PROGRAMMATIC

Provide the technology necessary to proceed in the late 1990's with development of moderate-thrust LOX/LH2 expander cycle engines for various space transportation applications.

TECHNICAL

Reliability:	Adequate Margins, Simplicity
Oper. Efficiency:	ICHM, Auto Servicing, Min Parts
Wide Throttling:	20:1 and Stable
Manufacturing:	Low Cost, High Quality, Inspectable
Performance:	Optimum vs. Other Factors
Materials:	Environ. Durable (Space&Oper.)
Maintainability:	Auto c/o (Space Maintainable)

SCHEDULE

- 1992 - Evaluate (study) modular system concepts
- 1992 - Advanced Expander Test Bed (AETB) DR
- 1996 - AETB Delivered
- 1996 - Complete critical sub-component technology efforts
- 1998 - AETB System characterized
- 1998 - Health Mgt. Sys. & Oper. Eff. Comps. characterized
- 1998 - AETB alternate components characterized
- 1998 - Modular engine system components characterized
- 1999 - Modular engine system characterized
- 1999 - 200 Klbf expander components characterized
- 2001 - 200 Klbf expander system test characterized

RESOURCES ($M)

	CURRENT	3X	STRATEGIC
FY91	4.0	4.0	4.0
FY92	9.0	9.0	9.0
FY93	12.6	14.9	15.0
FY94	13.2	16.7	24.0
FY95	14.0	19.6	31.0
FY96	14.7	20.2	45.8
FY97	15.4	28.0	42.4

PARTICIPANTS

LEWIS RESEARCH CENTER

Lead Center - Propulsion Studies, Technology Acquisition, Component Validation, Advanced Expander Test Bed (AETB)

MARSHALL SPACE FLIGHT CENTER

Participating Center - Propulsion Studies, Technology Acquisition, Component Validation, Test Bed

APPLICATIONS

- EARTH SPACE ORBIT TRANSFER
- SPACE EXPLORATION INITIATIVE

  LUNAR TRANSFER VEHICLE
  LUNAR EXCURSION VEHICLE
  MARS TRANSFER VEHICLE
  MARS EXCURSION VEHICLE
  UNMANNED PLANETARY AND ROBOTIC MISSIONS

- UPPER STAGES

  ATLAS
  TITAN

CRYOGENIC ENGINE OPTIONS

	RL10A-3-3A (Baseline)	RL10A-4	Advanced Space Engine
Vacuum Thrust, lbs	16,500	20,800	7,000 to 50,000
Vacuum Isp, sec	444.4	449.0	> 480
Life (TBO) - # Starts	20	15	> 100
# Hours	1.25	0.8	> 4
Weight, lbs	305	365	TBD
Length, in.	70.1	90	TBD
Thrust/Weight	54	57	TBD
Combustion Pressure, psia	475	578	> 1200
Expansion Ratio	61:1	84:1	> 600:1
Vac. Thrust Throttling Ratio	Not Specified	Not Specified	20:1
Mixture Ratio, O/F	5.0	5.5	6.0
Mixture Ratio Range, O/F	Not Specified	Not Specified	5.0 to 12.0
Basing	Ground	Ground	Space
Man-Rating	No	No	Yes
Hardware Changes from RL10A-3-3A	None	Modified Turbine Strengthened Chamber and Injector Improved Gear Train Modified LOX Pump Improved Injector 20" Nozzle Extension & Mechanism Fuel Pump Tolerance Improved Solenoids	Clean Sheet Design
Development Status	Operational	Flight Qualified	Technology Dev.

CUSTOMERS AND NEEDS

CUSTOMER / NEED	SEI 90-Day Study	SEI Early Lunar	ETO High Energy Upper Stage	ETO Commercial Upper Stage
High Reliability (includes man-rating)	Enabling	Enabling	Very Important	Very Important
Operational Efficiency	Enabling	Beneficial	Beneficial	Enabling
Throttling (to TBD level)	Enabling	Enabling	n/a	n/a
Low cost Manufacturing	Beneficial	Beneficial	Beneficial	Enabling
High Performance	Very Important	Beneficial	Very Important	Beneficial
Storable in Space Environment	Very Important	Very Important	n/a	n/a
Reusable	Very Important	n/a	n/a	n/a
Maintainable in Space	Very Important	n/a	n/a	n/a

SPACE CHEMICAL ENGINES TECHNOLOGY

INTEGRATED TECHNOLOGY PLAN REVIEW

- EMPHASIS IS ON FUTURE PLANS AND DIRECTION
- SOME HISTORICAL PERSPECTIVE IS NECESSARY
- PROGRAM CONTENT BASED ON A STRATEGIC RESOURCE PROFILE
  SATISFIES USERS NEEDS
- COMPARISONS MADE BETWEEN
  STRATEGIC AND CURRENT RESOURCE PROFILES

SPACE CHEMICAL ENGINES TECHNOLOGY

TERMINOLOGY

- ASE: ADVANCED SPACE ENGINE
  BASE R&T (EARLY 1970's)
- OTV: ORBIT TRANSFER VEHICLE (ENGINE TECHNOLOGY)
  BASE R&T (1982-1988)
- CTP: CHEMICAL TRANSFER PROPULSION
  PATHFINDER (1989-1990)
- SBE: SPACE BASED ENGINES
  EXPLORATION TECHNOLOGIES (1991)
- ASE: SPACE EXPLORATION INITIATIVE (1989 ONWARD)
  NEW ENGINE
  20-50 KLBF CLASS, 200 KLBF CLASS
  TRANSFER & EXCURSION VEHICLES (LUNAR, MARS)
- SCET: SPACE CHEMICAL ENGINES TECHNOLOGY
  PRESENT FOCUSED TECHNOLOGY PROGRAM

SPACE CHEMICAL ENGINES TECHNOLOGY

PROGRAM DESCRIPTION

CONCEPT

- CONDUCT A FOCUSED TECHNOLOGY PROGRAM IN SPACE ENGINES:
    - AS RAPIDLY AS RESOURCES PERMIT
    - AS RAPIDLY AS PRIORITIES DICTATE
- CONDUCT THE PROGRAM WITH THE WIDEST POSSIBLE PARTICIPATION
    - INDUSTRY
    - ACADEMIA
    - GOVERNMENT
- INVOLVE THE USERS AS SOON AS PRACTICABLE
    - REQUIREMENTS
    - TECHNOLOGY TRANSFER

PROGRAM DESCRIPTION

PURPOSE

- PROVIDE THE TECHNOLOGY NECESSARY TO CONFIDENTLY PROCEED, IN THE LATE 1990'S WITH THE DEVELOPMENT OF MODERATE THRUST (7.5 TO 200 KLBF) HIGH-PERFORMANCE, LIQUID OXYGEN/LIQUID HYDROGEN EXPANDER CYCLE ENGINES FOR VARIOUS SPACE TRANSPORTATION APPLICATIONS.

PROGRAM DESCRIPTION

MAJOR OBJECTIVES

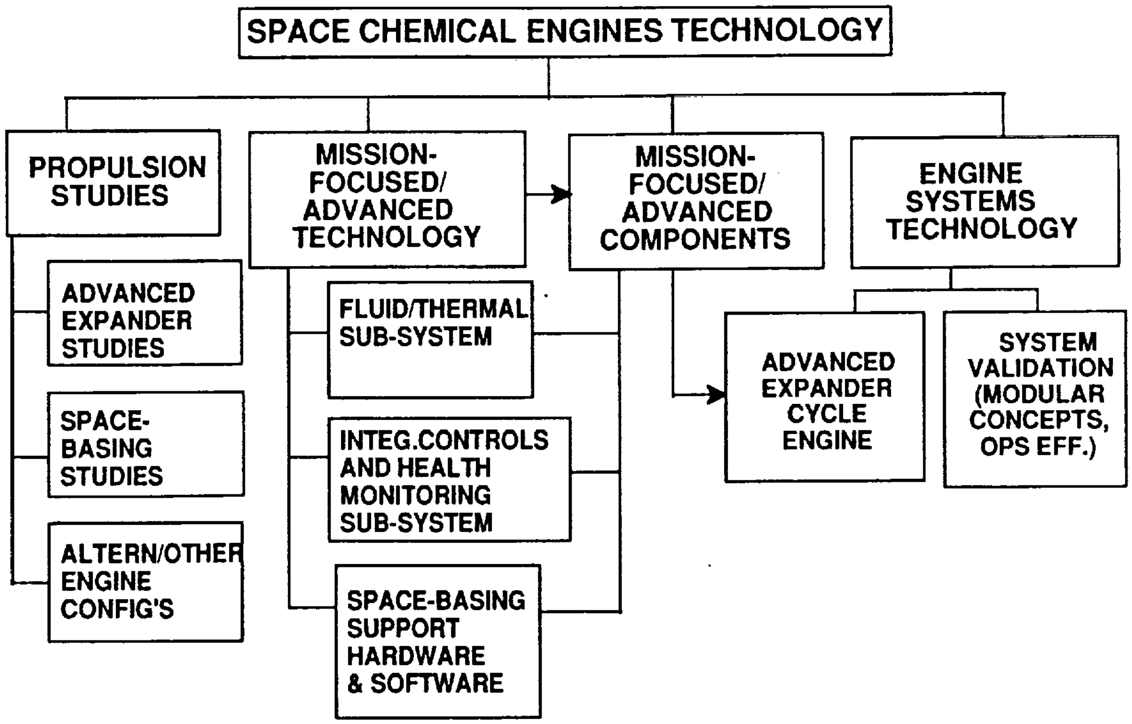
- IDENTIFY, ASSESS TECHNOLOGY REQUIREMENTS
- IDENTIFY, CREATE, AND/OR VALIDATE:
  - DESIGN & ANALYSIS METHODOLOGIES/SOFTWARE
  - MATERIALS WITH REQUIRED/DESIRABLE PROPERTIES
  - RELIABLE, COST-EFFECTIVE MANUFACTURING PROCESSES
- DEVELOP AND VALIDATE ENGINE AND SUPPORT EQUIPMENT SUB-COMPONENT, COMPONENT, AND SYSTEM TECHNOLOGIES FOCUSED ON (IN PRIORITY ORDER):
  - RELIABILITY
  - OPERATIONAL EFFICIENCY
  - WIDE-RANGE THROTTLING
  - LOW-COST MANUFACTURING
  - EFFICIENT PERFORMANCE
  - SPACE-ENVIRONMENT DURABILITY
  - REUSABILITY/OPERATION-ENVIRONMENT DURABILITY
  - IN-SPACE MAINTAINABILITY

PROGRAM DESCRIPTION

APPROACH

- PROPULSION STUDIES TO DEFINE PROPULSION TECHNOLOGY REQUIREMENTS
- TECHNOLOGY EFFORTS ADDRESSING THE TECHNOLOGY NEEDS
- DEVELOPMENT OF ANALYTICAL TOOLS, TECHNOLOGIES, DESIGNS
- VALIDATION IN AN ENGINE SYSTEM ENVIRONMENT

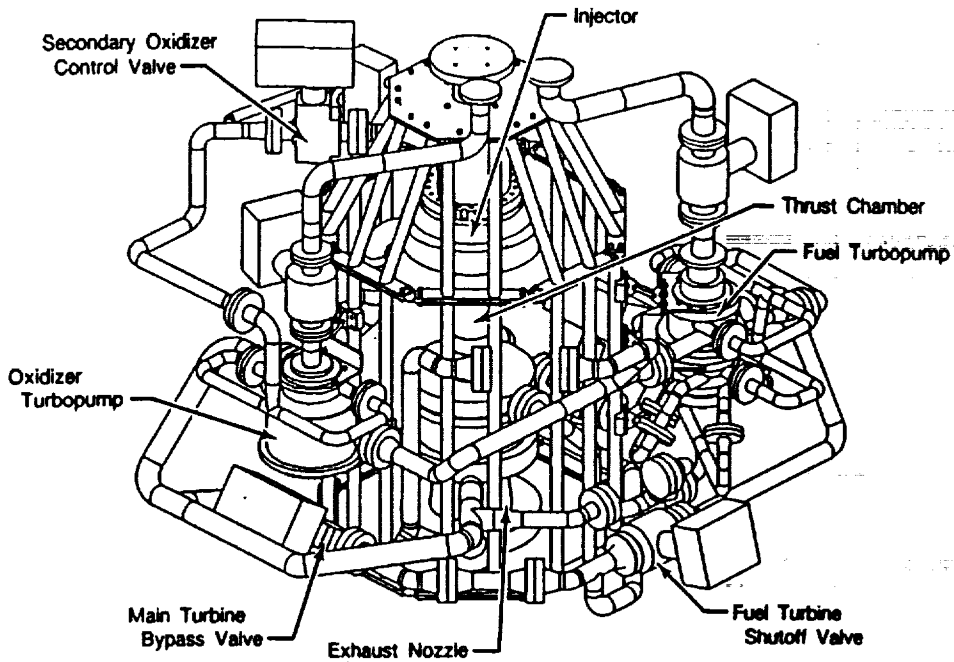
PROGRAM DESCRIPTION



ADVANCED EXPANDER TEST BED (AETB) CHARACTERISTICS

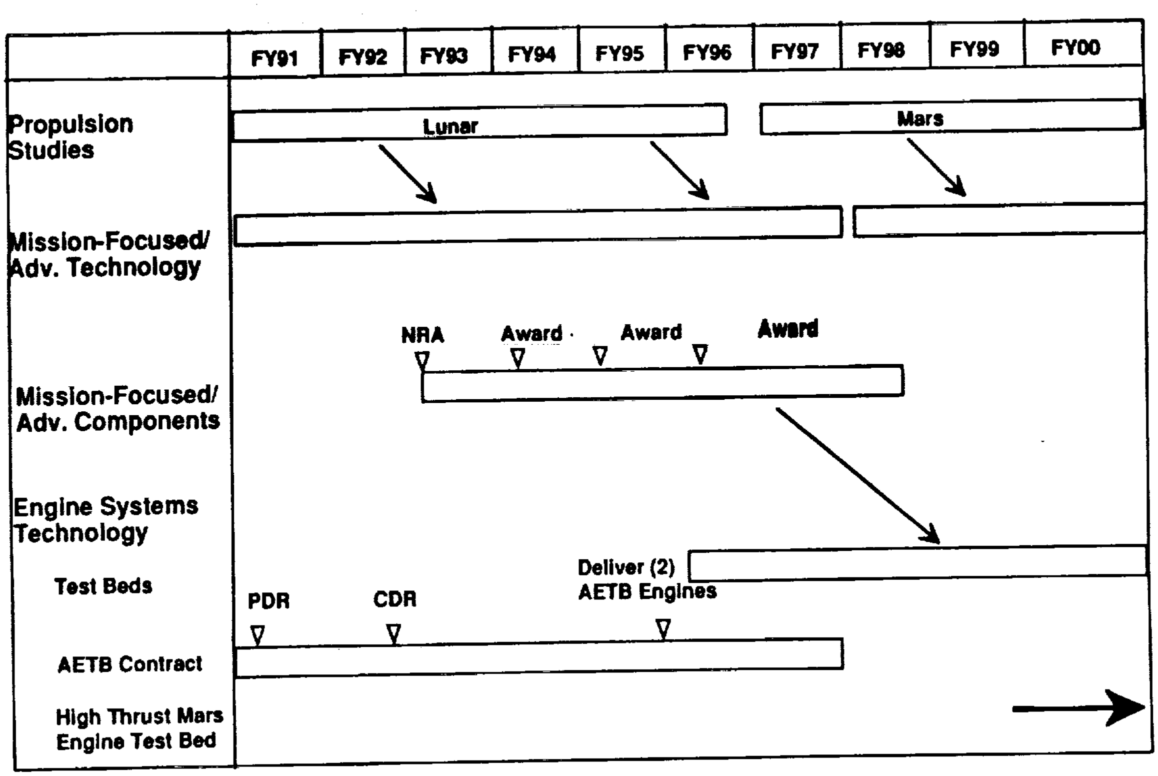
• PROPELLANTS:	HYDROGEN/OXYGEN
• CYCLE:	SPLIT EXPANDER
• THRUST:	25K (DESIGN) 20K (NORMAL OPN)
• CHAMBER PRESSURE:	1500 PSI (DESIGN) 1200 PSI (NORMAL OPN)
• THROTTLING:	125% TO 5% CONTINUOUS
• IDLE MODES:	PUMPED (LOW NPSP) TANKHEAD (NON-ROTATING)
• MIXTURE RATIO (O/F):	6.0 ± 1.0 12.0
• LIFE	100:STARTS/5 HOURS

ADVANCED EXPANDER TEST BED (AETB)

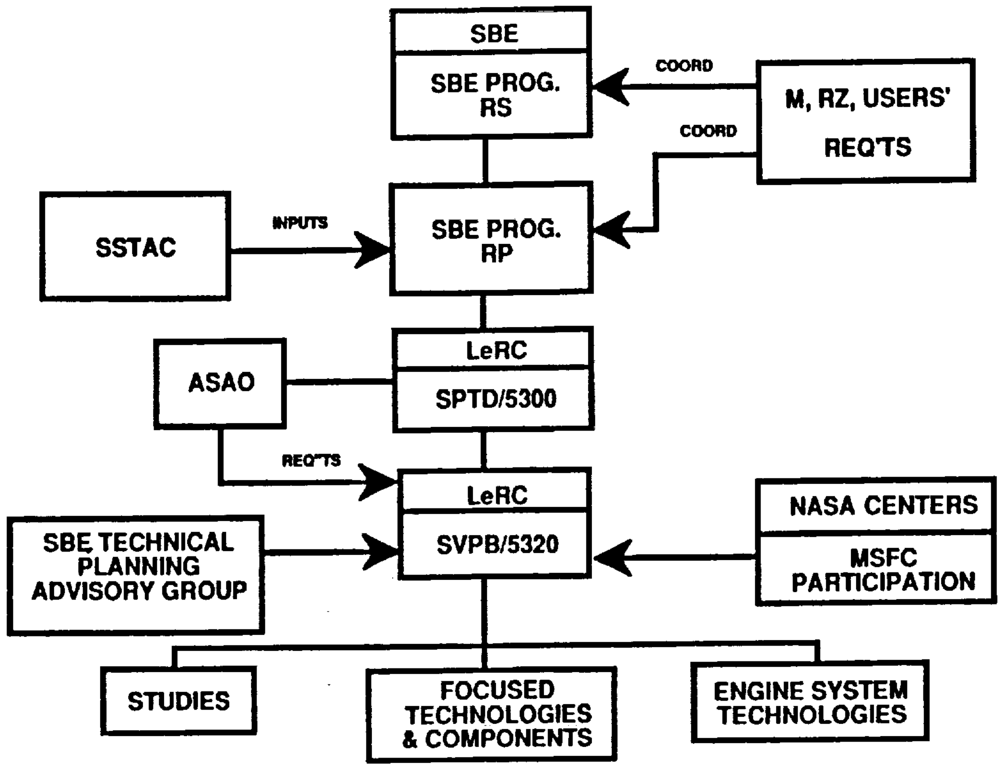


PROGRAM DESCRIPTION

STRATEGIC PROGRAM



PROGRAM DESCRIPTION



PROGRAM DESCRIPTION

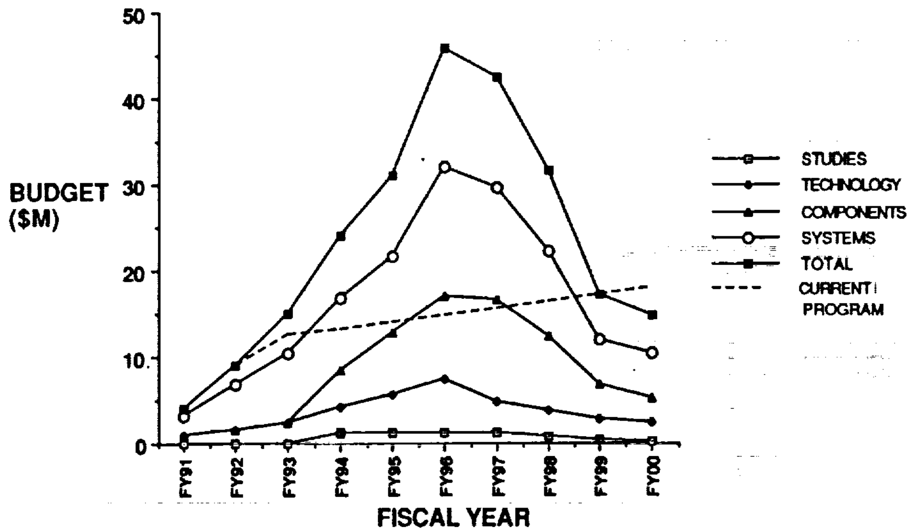
RESOURCE PROFILES

($M)

Program	FY91	92	93	94	95	96	97
Strategic	4.0	9.0	15.0	24.0	31.0	45.8	42.4
"3X"	4.0	9.0	14.9	16.7	19.6	20.2	28.0
Current	4.0	9.0	12.6	13.2	14.0	14.7	15.4

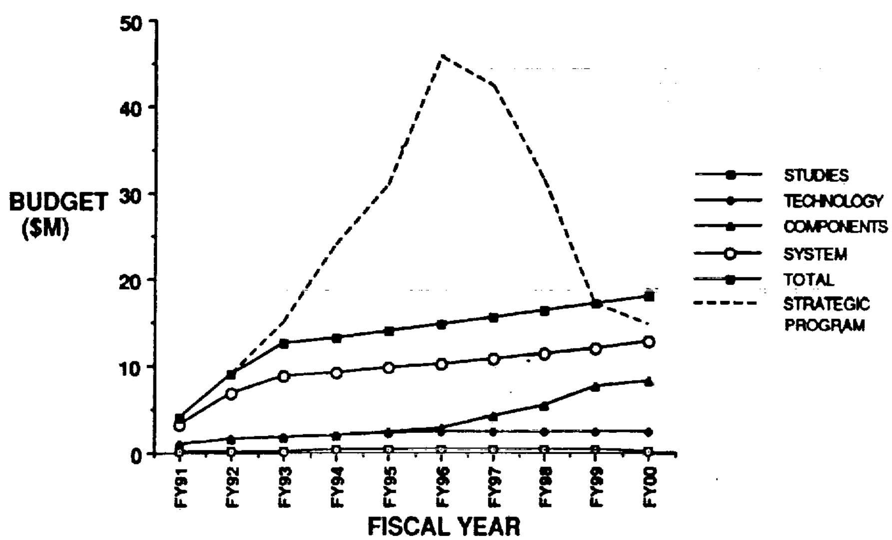
PROGRAM DESCRIPTION

STRATEGIC PROGRAM



PROGRAM DESCRIPTION

CURRENT PROGRAM



PROGRAMMATIC REVIEW

STRATEGIC PROGRAM

- PROGRAM STARTED IN FY89
  - PLANNING UNDERWAY IN FY88
  - PROGRAM CONCEPT FINALIZED
  - AETB PROCUREMENT STARTED
  - STRATEGIC PROGRAM RESOURCE REQUIREMENTS ESTABLISHED
- FY90-92 LEAN YEARS
  - REPLAN, "HOLD-ON" STRATEGY
  - AFFIRM EMPHASIS ON SYSTEMS TECHNOLOGY
- FY90-92 IMPACTS
  - MINIMIZED PARTICIPATION (OTV CONTRACTS, INDUSTRY, UNIVERSITIES)
  - OTV TASK ORDER CONTRACTS END, NRA'S DO NOT START: STRAINS INDUSTRY PARTICIPATION
  - IRREVERSIBLE SCHEDULE IMPACTS (AETB, NRA'S)

NEEDS	STRATEGIC	CURRENT
HIGH RELIABILITY	• 1996 AETB SYSTEMS TESTS • ALTERNATIVE CONFIG. SYSTEMS	• 1997 AETB SYSTEMS TESTS • ALTERNATIVE CONFIG. COMPONENTS
OPERATIONAL EFFICIENCY	• FOCUSED TECH & COMPONENTS • SYSTEM TESTBED • HEALTH MANAGEAMENT SYSTEM	• FOCUSED COMP ON AETB • HEALTH MANAGEMENT COMPONENTS
THROTTLING	• FOCUSED TECH & COMPONENTS • SYSTEM VALIDATION	• FOCUSED COMPONENT TURBOPUMP(S), • TURBOPUMP VALIDATION ON AETB
LOW-COST MFG.	• PUMPS, COMBUSTION DEVICES • SYSTEM VALIDATION	• FOCUSED TECHNOLOGY
HIGH PERFORMANCE	• AETB SYSTEM • FOCUSED COMPONENTS • SYSTEM VALIDATION • ALTERNATIVE SYSTEMS	• AETB SYSTEM
SPACE STORABLE	• MATERIAL VALIDATION • STORABLE COMPONENTS	• FOCUSED TECHNOLOGY
SPACE MAINTAINABLE	• SYSTEM VALIDATION	• STUDIES

STRATEGIC PROGRAM

- PROVIDES TECHNOLOGY TO MEET USER NEEDS
  - SYSTEMS LEVEL TECHNOLOGY (AETB, MODULAR SYSTEMS, OPERATIONAL EFFICIENCY)
  - ADVANCED/ALTERNATIVE COMPONENTS
  - SYSTEMS LEVEL VALIDATION
- ADEQUATELY MEET MOST USER SCHEDULAR NEEDS
  - COMMERCIAL NEEDS MARGINALLY MET
  - HIGH ENERGY UPPER STAGES
  - EXPLORATION MISSIONS
- PROMOTES TECHNOLOGY TRANSFER
  - WIDE NUMBER OF PARTICIPANTS (NRA) (INDUSTRY, ACADEMIA, GOVERNMENT)
  - PARTICIPATION IN PARALLEL
  - EXTENSIVE LEVELS OF PARTICIPATION (ALL ON SYSTEM MODEL LEVEL, ALL WITH COMPONENTS)
  - PERMITS SUBSTANTIAL, MEANINGFUL LEVEL OF PARTICIPATION BY MSFC
  - ENABLES PRODUCTIVE SYNERGISM WITH BASE R&T AND NON-SCET PROGRAMS

CURRENT PROGRAM

- MARGINALLY MEETS USER TECHNICAL NEEDS
  - AETB SYSTEMS TECHNOLOGY (1989)
  - ONE OR TWO ADVANCED COMPONENTS (TURBOPUMPS)
  - LIMITED FOCUSED TECHNOLOGY (COMBUSTION DEVICES, HEALTH MONITORING)
  - STUDIES (MAINTAINABILITY)
- MARGINALLY MEETS SOME USER SCHEDULAR NEEDS
  - COMMERCIAL NEEDS ARE IMMEDIATE (COST AVOIDANCE, EARLY MARKET ENTRY)
  - HIGH ENERGY UPPER STAGES NEEDED NEAR TERM (DOD, UNMANNED MISSIONS)
  - EXPLORATION MISSIONS MOST COMPLICATED, REQUIRE ADEQUATE TECHNOLOGY LEAD TIMES (SYSTHESIS GROUP IOC'S 2003, 2004, 2005)
- INHIBITS TECHNOLOGY TRANSFER ("HANDS ON")
  - VERY LIMITED NUMBER OF PARTICIPANTS (NRA) (ONE OR TWO COMPONENTS)
  - PARTICIPATION LIKELY IN SERIES (ONE OR TWO AT A TIME)
  - LIMITED LEVEL OF PARTICIPATION (STUDIES, FOCUSED TECHNOLOGY)
  - DIFFICULT INTERNASA CENTER TECHNICAL PLANNING (LERC/MSFC)

PROGRAMMATIC REVIEW

SPACE PROPULSION TECHNOLOGY

BASE R&T/FOCUSED R&T

- SPACE CHEMICAL ENGINE TECHNOLOGY REQUIRES A FLOW OF TECHNOLOGIES THROUGH LEVELS OF TECHNICAL MATURITY

- TECHNOLOGIES PASS FROM THE BASE PROGRAM TO THE FOCUSED PROGRAM WHEN THEY REACH ACKNOWLEDGED VIABILITY OF AN ACCEPTABLE LEVEL OF MATURITY

- BASE AND FOCUSED PROGRAMS ARE STRONGLY LINKED, BUT SEPARATE

PROGRAMMATIC REVIEW

SPACE PROPULSION TECHNOLOGY

BASE R&T

- BROAD UTILITY FOR A WIDE RANGE OF APPLICATIONS
- FUNDAMENTAL KNOWLEDGE THAT COULD BECOME PART OF A FOCUSED PROGRAM

  HIGH RISK/HIGH PAYOFF

- SPECIFICS:
  - NETWORK OF TECHNOLOGY INFORMATION
  - ENGINEERING AND SCIENTIFIC ANALYSIS AND DESIGN TOOLS
  - INSTRUMENTATION/DIAGNOSTICS
  - MATERIALS
  - PROPELLANTS
  - PROCESSES
  - SUBCOMPONENTS TO COMPONENTS TO SYSTEMS

SPACE PROPULSION TECHNOLOGY

FOCUSED R&T

- TECHNOLOGIES FOR SPECIFIC MISSION/PROGRAM/APPLICATION
- DEFINED DELIVERABLES, SCHEDULE, RESOURCE
- PRODUCT: TECHNOLOGIES TO SATISFY THE USER REQUIREMENTS
- MULTIDISCIPLINARY CONTENT, PROGRESSION TO A SPECIFIC TECHNOLOGY READINESS LEVEL
- EXTREMELY VISIBLE
- SPECIFICS:
  STUDIES AND ANALYSES TO GUIDE PROGRAM
  METHODOLOGIES FOR THE DESIGN OF PROPULSION SYSTEMS
  COMPONENT AND SYSTEM MODELING
  VALIDATED TECHNOLOGIES THAT MEET USER REQUIREMENTS
  SYSTEM FOCUS
  FLIGHT EXPERIMENTATION

ENGINE SYSTEMS

- TESTBED CONCEPT IS KEY TO SPACE CHEMICAL ENGINES TECHNOLOGY
- TESTBED VALIDATION RECOGNIZED FOCUSED TECHNOLOGY NECESSITY (ETO)
- TESTBED EMULATES HIGHLY SUCCESSFUL AEROPROPULSION PROGRAM
  - ATEGG (ADVANCED TURBINE ENGINE GAS GENERATOR (CORE))
  - JTDE (JOINT TECHNOLOGY DEMONSTRATOR ENGINE)
  - IHPTET (INTEGRATED HIGH PERFORMANCE TURBINE ENGINE TECHNOLOGY)

  - U.S. AEROPROPULSION LEADS THE WORLD
- AETB HAS WIDE APPLICABILITY

LERC/MSFC TECHNICAL PLANNING

- WE HAVE 2 DIFFERENT PERSPECTIVES
  - TECHNOLOGISTS (LERC)
  - DEVELOPERS (MSFC)
- WE COME FROM 2 DIFFERENT CULTURES
  - "BOTTOMS UP" (LERC)
  - "TOP DOWN" (MSFC)
- WE HAVE WORKED TO DIFFERENT END PRODUCTS
  - TECHNOLOGY MATURITY LEVEL, MULTIPLE USERS (LERC)
  - SPECIFIC HARDWARE DEMONSTRATION, SPECIFIC USE (MSFC)
- SPACE CHEMICAL ENGINES FOCUSED TECHNOLOGY PROGRAM
  - TECHNOLOGY PROGRAM
  - BLENDS PERSPECTIVES, CULTURES
  - BEST COMBINATION

CURRENT PROGRESS

- IDENTIFIED POTENTIAL CUSTOMERS
- IDENTIFIED CUSTOMER NEEDS
- IDENTIFIED MEANS OF MEETING NEEDS
- IDENTIFIED MOST IMPORTANT TECHNOLOGY PROGRAM ELEMENTS
- PLANNED AND COSTED PROGRAM ELEMENTS
- FINALIZING NEAR-TERM DETAILS, IMPLEMENTAION

OBSERVATIONS

- SPACE CHEMICAL ENGINES TECHNOLOGY PROJECT IN PLACE
- FY91 AND FY92 LEAN YEARS WITH IRREVERSIBLE EFFECTS
- PROGRAMS HAVE BEEN PLANNED FOR STRATEGIC/CURRENT PROGRAMS
- STRATEGIC PROGRAM HEALTHY (CONTENT, PACE, PARTICIPATION)
- CURRENT PROGRAM MARGINAL
- LERC AND MSFC DETAILED TECHNICAL PLANNING IN PROGRESS
- FY93 FUNDING DETERMINES MAJOR PROGRAM DIRECTION

5/2-31

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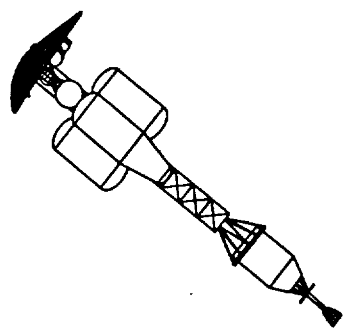
p. 40

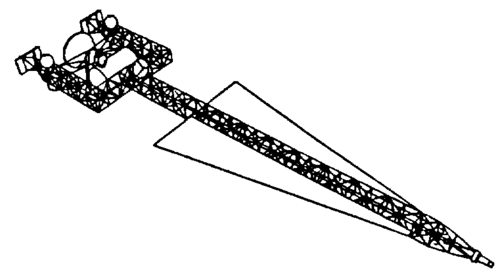
Integrated Technology Plan
for the
Civil Space Program

FOCUSED TECHNOLOGY: NUCLEAR PROPULSION

Nuclear Thermal Propulsion



Nuclear Electric Propulsion



JUNE 27th, 1991
Washington, D.C.

OVERVIEW

Thomas J. Miller
Head, Nuclear Propulsion Office
NASA Lewis Research Center

FOCUSED TECHNOLOGY: NUCLEAR PROPULSION
SUMMARY

- **IMPACT:**
  - Nuclear Propulsion Enables and/or Enhances Space Exploration Missions

	Nuclear Electric Propulsion (NEP)	Nuclear Thermal Propulsion (NTP)
Enables:	Robotic Science Missions	Mars Piloted
Enhances:	*Lunar & Mars Cargo, & Mars Piloted Space Exploration*	*Lunar & Mars Cargo, Lunar Piloted & Robotic Science Space Exploration*

- **USER COORDINATION:**
  - Exploration Studies Identify Nuclear Propulsion as a Key Technology
  - OAET/RZ - Provide Performance Predictions for NASA Studies
  - OSSA Study on NEP for Robotic Science Missions
  - DOE, DoD & NASA Included on Steering Committee (also Astronaut Office)

- **TECHNICAL REVIEWS:**
  - Interagency Design Review Teams will Periodically Review Technical Progress

- **OVERALL TECHNICAL AND PROGRAMMATIC STATUS:**
  - High Priority Technology Areas Identified (some efforts initiated)
  - Budget Deliberations Continue
  - Single Multi Agency Plan Defined for FY92 Implementation

- **MAJOR TECHNICAL/PROGRAMMATIC ISSUES:**
  - Agency/Department Roles
  - Funding to Initiate Technical Efforts
  - Projected Budget Does Not Support Schedules

Nuclear Thermal Propulsion

PERFORMANCE OBJECTIVES

PARAMETER	STATE-OF-THE ART	OBJECTIVE
THRUST (Lbf)	75K (NERVA)	75K-125K/Engine
	250K (PHOEBUS)	(May cluster multiple engines)
SPECIFIC IMPULSE (sec)	825	≥ 925
CHAMBER PRESSURE	450	500 - 1000
EXHAUST TEMP. (°K)	2300-2500	≥ 2,700 (w/ Approp. Safety & Reliability Margin)
POWER (MWt)	1100 (NERVA)	≥ 1,600
	4,200 (PHOEBUS)	1.0
LIFETIME (Hrs) Single Burn	1.0	4.5 (3X Mission req.)
Cumulative	1.5	5
REUSABILITY (No. Missions)	1	

CHALLENGES

- High Temperature Fuel and Materials
- Hot Hydrogen Environment
- Test Facilities
- Safety
- Environmental Impact Compliance
- Concept Development

MISSION BENEFITS

- Short Transit Time Missions are Enabled
- Reduced IMLEO (~ 1/2 of Chemical)
- Crew Safety Enhanced
- Wider Launch Windows
- More Mars Opportunities
- High Thrust Available
- Aerobrake Not Required

Nuclear Electric Propulsion

PERFORMANCE OBJECTIVES

PARAMETER	STATE-OF-THE ART		OBJECTIVE	
POWER	SP-100			
POWER LEVEL (MWe)	0.1		≥10.0	
SPECIFIC MASS (Kg/KWe)	30		≤ 10	
PROPULSION	ION	MPD	ION	MPD
SPECIFIC IMPULSE (sec)	2000-9000	1000-5000	2000-9000	1000-7000
EFFICIENCY	0.7-0.8	0.3	0.7-0.8	>0.5
POWER LEVEL (MWe)	0.01-0.03	0.01-0.5	1 - 2	1 - 5
LIFETIME (Hrs)	10,000	?	10,000	≥ 2000
PMAD				
EFFICIENCY	0.90		0.95	
SPECIFIC MASS (Kg/KWe)	4		≤ 2.5	
REJECTION TEMP. (°K)	400		600	

CHALLENGES

- Long Operational Lifetime
- High Temperature Reactors, Turbines, Radiators
- High Fuel Burn-up Reactor Fuels, Designs
- Efficient, High Temperature Power Conditioning
- High Efficiency, Long Life Thrusters
- Safety
- Environmental Impact Compliance
- Concept Development

MISSION BENEFITS

- Low Resupply Mass
- Availability of Onboard Power
- Reduced IMLEO Sensitivity w/Mission Opportunity
- Broad Launch Windows
- Commonality with Surface Nuclear Power
- Aerobrake Not Required

TRANSPORTATION TECHNOLOGY

SPACE TRANSPORTATION

Nuclear Thermal Propulsion

OBJECTIVES

Programmatic

Develop propulsion technologies capable of fulfilling requirements, such as performance, long life, and multiple starts, for future piloted and cargo missions to Mars and the Moon, and robotic precursor missions.

Technical

Fuel Temperature	2700- 3100K (1995)
Fuel Lifetime	4.5 hrs (cyclic)
Man-Rated	Autonomous Robotic Operation
Ground Testing	Full System (TRL-6) by 2006

SCHEDULE

- 1992 Lab-Scale Demonstration of 2700K reactor fuel
- 1994 Complete conceptual designs of selected concepts for piloted Mars mission
- 1996 Nuclear Furnace Facility Complete
- 1998 Select NTR Concept(s) for Systems Testing
- 1999 Systems Facility Construction Complete
- 2002 First NTR Reactor Test Complete
- 2006 Full System Ground Testing Complete Verifying Technology Readiness Level 6 (TRL-6) for NTR

RESOURCES*

	NASA**	DOE*
1991	$00.4M	
1992	$05.0M	$014.0M
1993	$13.0M	$055.0M
1994	$22.0M	$095.0M
1995	$39.0M	$145.0M
1996	$50.3M	$190.0M
1997	$83.0M	$210.0M

* DOE current estimate for both NTP & NEP

** NASA dollars do not include CoF

PARTICIPANTS

Lewis Research Center
Lead Center

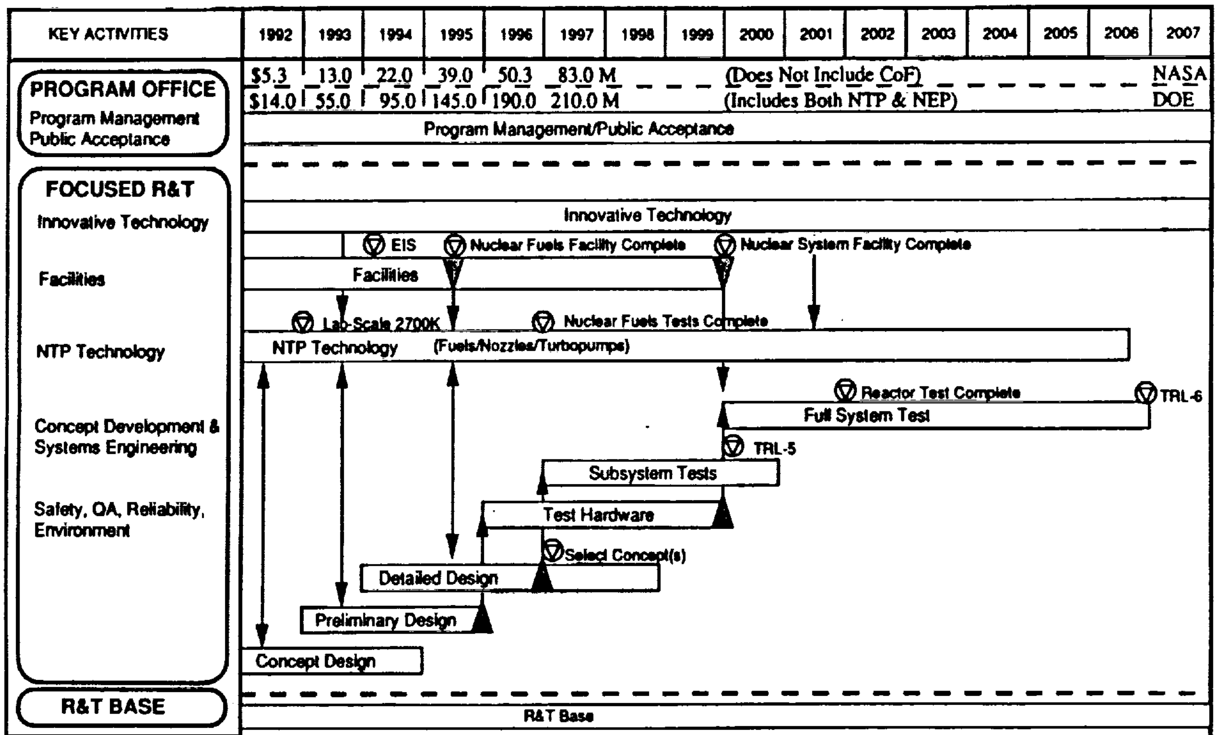
Marshall Space Flight Center
Participating Center

Johnson Space Center
Supporting Center

DOE Laboratories
INEL, LANL, SNL, ORNL, ANL, BNL...

June 17, 1991
NP01-01

NUCLEAR THERMAL PROPULSION ROADMAP/SCHEDULE



TRANSPORTATION TECHNOLOGY
SPACE TRANSPORTATION

Nuclear Electric Propulsion

OBJECTIVES

Programmatic

Develop propulsion technologies capable of fulfilling requirements, such as performance, long life, and multiple starts, for future piloted and cargo missions to Mars and the Moon, and robotic precursor missions.

Technical

Power	> 10MWe
Specific Mass	< 10kg/kwe by 2006 < 5 kg/kwe by TBD
Lifetime	3-10 years

SCHEDULE

- 1993 Complete 500 kW electric propulsion testing facility and designs for high power (MW class) electric thrusters
- 1994 Complete candidate systems study for reactor power source, power conversion, power processing, thruster and control concepts
- 1997 Complete breadboard demo of megawatt class electric thruster technology
- 2000 Verify 1000 hours of life for 500 kW electric propulsion system
- 2005 Complete ground tests to verify megawatt class power/propulsion system
- 2006 Verify TRL-6 through flight test of 500 kW subscale NEP vehicle

RESOURCES

	NASA**	DOE*
1991	-	
1992	$02.0M	$014.0M
1993	$06.0M	$055.0M
1994	$15.9M	$095.0M
1995	$23.0M	$145.0M
1996	$26.0M	$190.0M
1997	$45.0M	$210.0M

*DOE current estimate for both NTP & NEP

** NASA dollars do not include CoF

PARTICIPANTS

Lewis Research Center
Lead Center

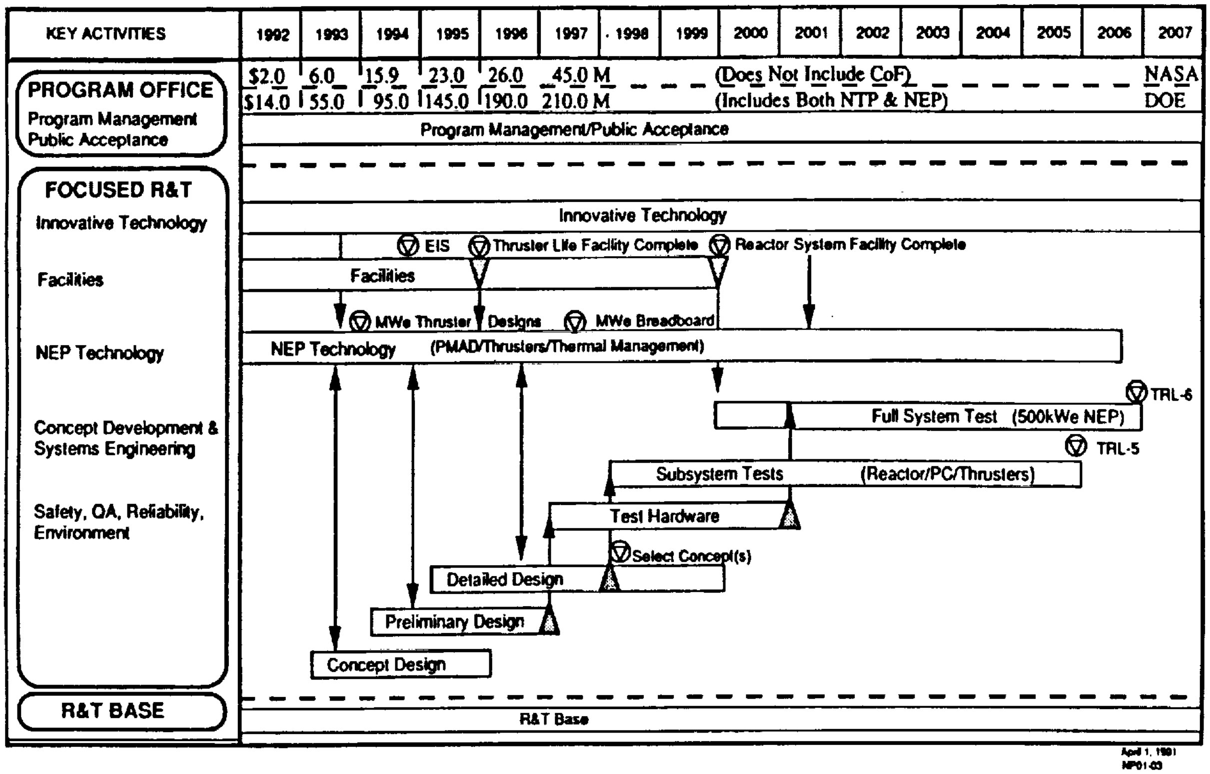
Jet Propulsion Laboratory
Participating Center

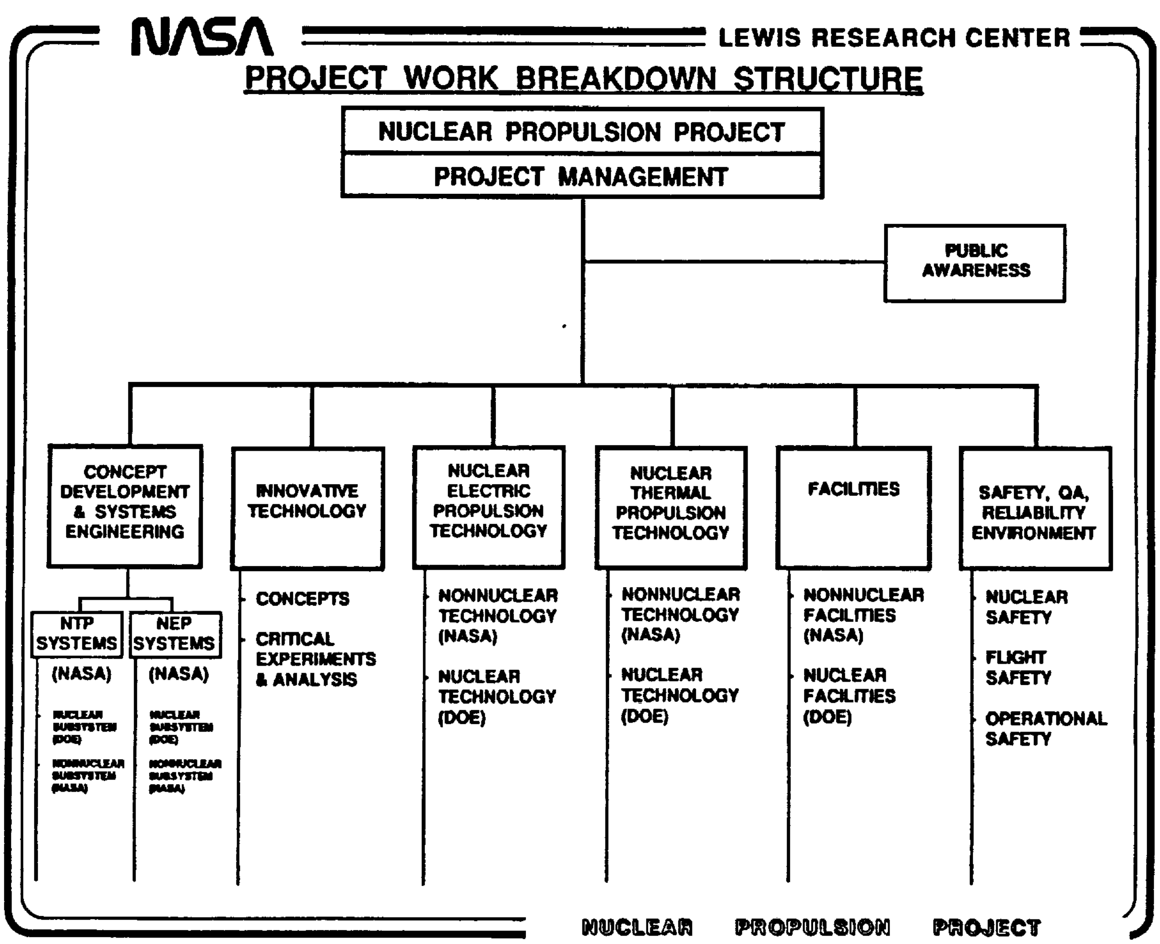
Johnson Space Center
Supporting Center

DOE Laboratories
INEL, LANL, SNL, ORNL, ANL, BNL...

SPACE TRANSPORTATION

NUCLEAR ELECTRIC PROPULSION ROADMAP/SCHEDULE





NUCLEAR THERMAL ROCKET (NTR) PROPULSION

Dr. Stanley K. Borowski

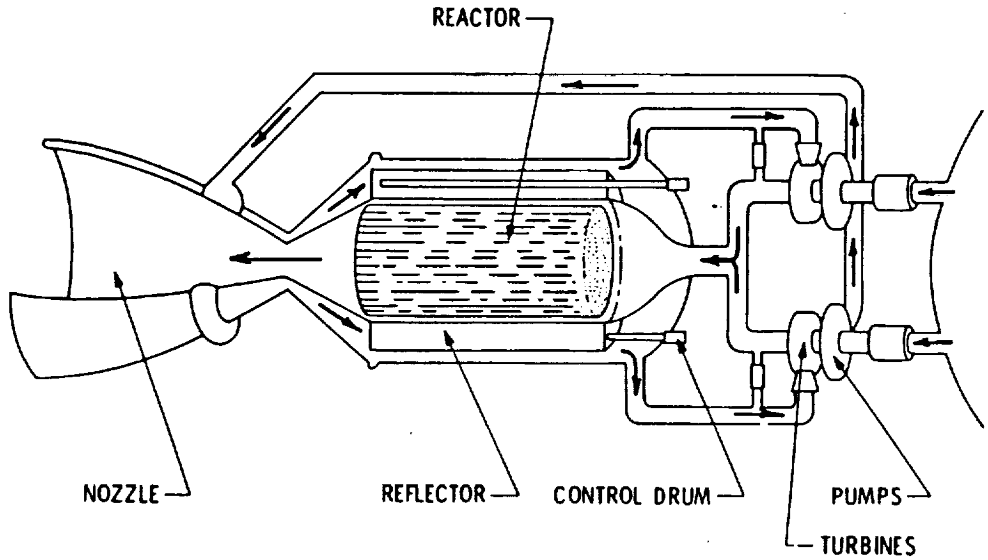
NASA Lewis Research Center

OUTLINE OF PRESENTATION

- RATIONALE FOR NASA DEVELOPMENT OF NTR PROPULSION
- NTR MISSION APPLICATIONS AND BENEFITS
  - LUNAR MISSION BENEFITS
  - MARS MISSION BENEFITS
- ROVER/NERVA PROGRAM ACCOMPLISHMENTS
- NTR TECHNOLOGY NEEDS
- TECHNOLOGY CHALLENGES/APPROACHES FOR RESOLUTION
- "STATE-OF-THE-ART" ASSESSMENT
- TECHNOLOGY PERFORMANCE OBJECTIVES
- SYNERGY WITH OTHER TECHNOLOGY AREAS
- SUMMARY
- SUPPLEMENTAL INFORMATION

NASA LEWIS RESEARCH CENTER

SOLID CORE NTR CONCEPT
(DUAL TURBOPUMPS, EXPANDER CYCLE)



NTR: A SPACE PROPULSION DEVISE WHICH USES HEAT FROM A NUCLEAR FISSION REACTOR TO RAISE THE TEMPERATURE OF A PROPELLANT (LH_2) AND THEN EXPANDS IT THROUGH A NOZZLE TO PROVIDE THRUST.

SP/ E EXPLORATION INITIATIVE OFFICE

NASA LEWIS RESEARCH CENTER

WHY IS NTR PROPULSION NECESSARY?
-SYNTHESIS GROUP OBSERVATIONS-

- **SAFETY TO CREW GREATLY ENHANCED**
  - SHORTER TRIP TIMES REDUCES RADIATION EXPOSURES AND PSYCHOLOGICAL STRESSES
  - FEWER MOVING PARTS AND ELEMENTS INCREASE RELIABILITY, REDUCE RISK
  - WIDER LAUNCH WINDOWS LEAVING EARTH AND FOR MARS RETURN
  - MORE OPPORTUNITIES TO GO TO MARS, ALL TWO YEAR INTERVALS FEASIBLE
  - LESS ASSEMBLY OF MARS SPACECRAFT NEEDED IN EARTH ORBIT
- **REDUCED MISSION COSTS**
  - MASS IN LOW EARTH ORBIT GREATLY REDUCED (ONE-THIRD TO ONE-HALF) WITH A CORRESPONDING REDUCTION IN MISSION COSTS
  - FLEXIBILITY IN SCHEDULES

NUCLEAR PROPULSION PROJECT

NUCLEAR THERMAL ROCKET MISSION APPLICATIONS

- *NTR TECHNOLOGY HAS A WIDE RANGE OF MISSION APPLICATIONS: PROBES, OTVs, CARGO AND PILOTED VEHICLES*
- *"1st GENERATION" NTR FLIGHT ENGINE CAN SATISFY ENTIRE SPECTRUM OF SEI MISSIONS - ADVANCED DESIGNS DESIRABLE BUT NOT REQUIRED FOR CURRENT MISSIONS OF INTEREST*

LUNAR TRANSFER VEHICLES

- CARGO
  - SEP (MULTI - 100kW_e - MW_e CLASS)
  - NEP (MW_e CLASS, $\alpha \geq 15$ kg/kW_e)
  - SC/NTR (≤ 75 klbf "NERVA" CLASS)
  - "DUAL MODE" SC/NTR (≤ 75 klbf & MULTI - 10 kW_e CLASS)
- PILOTED
  - SC/NTR (≤ 75 klbf)
  - "DUAL MODE" SC/NTR (≤ 75 klbf & MULTI - 10 kW_e CLASS)

MARS TRANSFER VEHICLES

- CARGO
  - SEP/NEP (≥ 5 MW_e, $\alpha \leq 15$ kg/kW_e)
  - SC/NTR (≥ 75 klbf)
  - "DUAL MODE" SC/NTR (~ 75 klbf & 10's kW_e-MW_e)
- PILOTED
  - NEP/SEP (≥ 10 MW_e, $\alpha \leq 10$ kg/kW_e)
  - SC/NTR (≥ 75 klbf)
  - "DUAL MODE" SC/NTR (~ 75 klbf - 250 klbf & ~ 10's kW_e-MW_e FOR EP)
  - COMBINED HIGH & LOW THRUST CONCEPTS
- "QUICK PILOTED TRIPS" (≤ 1 YEAR)
  - SC/NTR (SPLIT/SPRINT MISSIONS)
  - "DUAL MODE" SC/NTR + MMW_e EP
  - GC/NTR
  - "SUPER" NEP (10's MW_e, $\alpha \leq 5$ kg/kW_e)

RATIONALE FOR NASA DEVELOPMENT OF NTR PROPULSION

- **THE ROVER/NERVA PROGRAMS ESTABLISHED A SIGNIFICANT DATA BASE ON SC/NTRs**
  - 1.4 B$ INVESTMENT IN 1960-1970 TIME FRAME EQUIVALENT TO >9.5 B$ TODAY
- **THE SC/NTR CONCEPT HAS BEEN SUCCESSFULLY GROUND TESTED (TO TRL 6) AT THE POWER AND THRUST LEVELS, AND HYDROGEN EXHAUST TEMPERATURES/EQUIVALENT SPECIFIC IMPULSES SUFFICIENT TO PERFORM A 434 DAY 2016 MARS MISSION IN "REUSE" MODE i.e., WITH PROPULSIVE RETURN OF ENTIRE VEHICLE TO LEO**
  - A STATE-OF-THE-ART GRAPHITE CORE NTR (AT 1000 psi, ε = 500:1) OPERATING AT 2360 K/850 s HAS IMLEO ~ 725 t, 102 t LIGHTER THAN REFERENCE CHEM/AB VEHICLE WITH ECCV RETURN TO EARTH
- **NTR CAN PROVIDE REDUCTIONS IN TRANSIT TIMES ACROSS THE 15 YEAR CYCLE. MAGNITUDE WILL DEPEND ON TRAJECTORY TYPE, PARTICULAR OPPORTUNITY, MISSION MODE, AND IN-PLACE INFRASTRUCTURE**
  - WITH MODEST TECHNOLOGY ADVANCES BEYOND '72 VINTAGE NERVA (COMPOSITE FUEL DELIVERING 925 s), A 1 YEAR ROUND-TRIP MARS MISSION (2016) IS POSSIBLE, IN SPLIT/SPRINT MODE, WITH ACCEPTABLE TOTAL IMLEO (<1000 t) FOR BOTH PILOTED AND CARGO VEHICLES
- **NTR TECHNOLOGY OFFERS POTENTIAL FOR SIGNIFICANT EVOLUTIONARY GROWTH**
  - SOLID CORE: GRAPHITE (2500 K) → COMPOSITE (2700 K) → CARBIDES (>3000 K)
  - SOLID CORE → LIQUID CORE → GAS CORE

PERFORMANCE CHARACTERISTICS OF NTR SYSTEMS

PARAMETER	GOODNESS	IMPORTANCE
SPECIFIC IMPULSE (SECONDS)	MODERATE → HIGH	IMPROVED FUEL EFFICIENCY
SPECIFIC MASS (RECIPROCAL OF SPECIFIC POWER, kg/kWj)	LOW	ENGINE HAS GOOD POWER PRODUCING CAPABILITY
ENGINE THRUST/WEIGHT	MODERATE → HIGH	OPERATIONAL FLEXIBILITY

NASA LEWIS RESEARCH CENTER

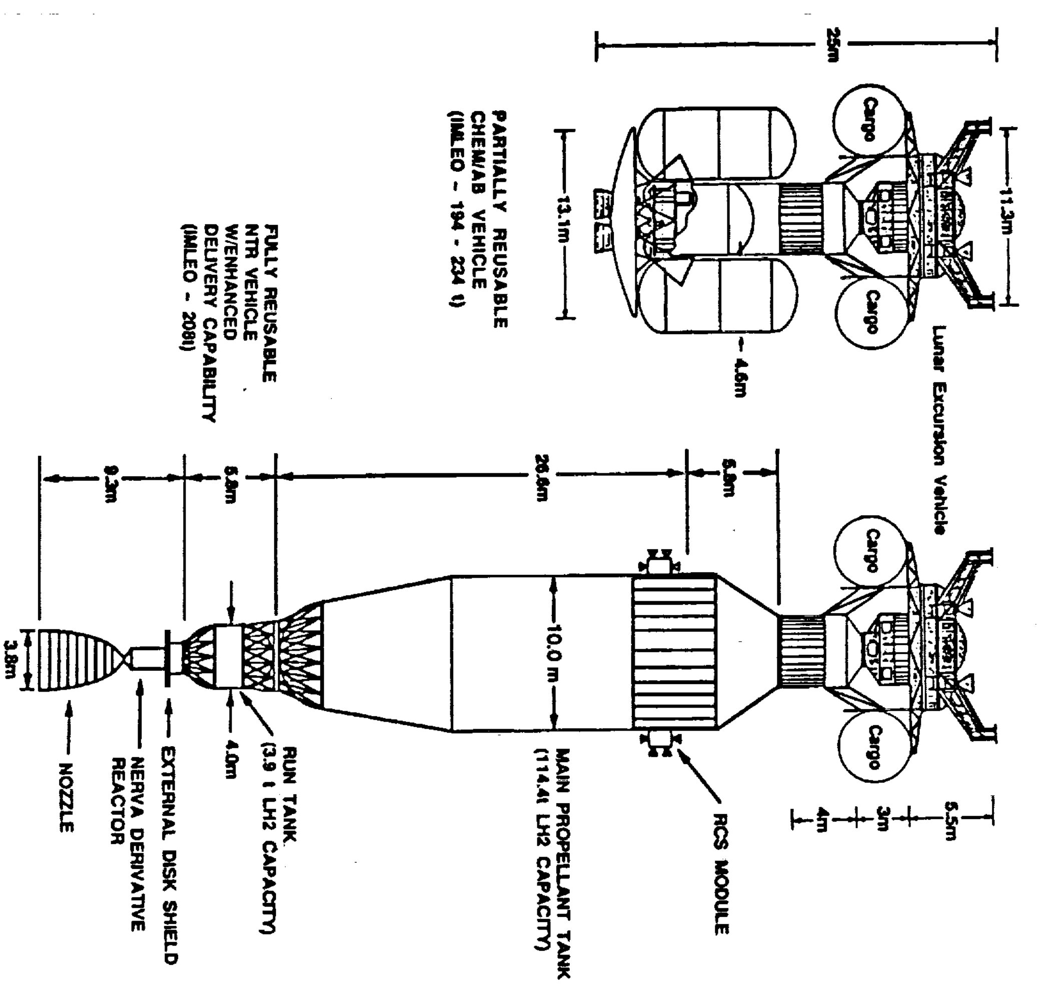
LUNAR NTR APPLICATIONS

SPACE EXPLORATION INITIATIVE OFFICE

WHY NTR FOR LUNAR MISSIONS?

- **Potential Performance Benefits**
  - High Isp and T/W_e allows both piloted and cargo missions
  - Enables single stage, fully reusable lunar transfer vehicle
  - Enables more demanding mission profiles (e.g., "courier" and polar orbit missions with significant plane change)
  - Reduces IMLEO/fewer Earth to orbit launches
- **Early Operations Experience**
  - NTR vehicle assembly
  - Refueling, rendezvous, and docking in radiation environment
  - Disposal of "end-of-life" engines
- **Technology Test Bed and "Dress Rehearsal" for Mars**
  - Interplanetary mission "in miniature" requiring major impulsive maneuvers and multiple engine restarts
  - Reduced performance requirements: ΔV, flight time/thrust time
  - Operations in "nearby" space environment
  - "Free Return" trajectory available without penalty

LUNAR TRANSPORTATION VEHICLE SIZE COMPARISON



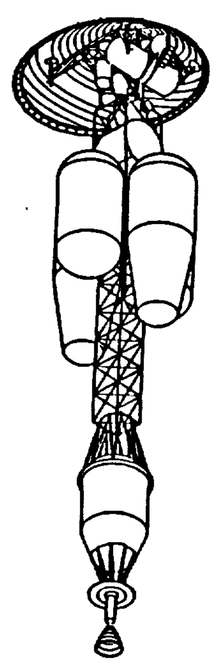
MARS NTR APPLICATIONS

Nuclear Thermal Propulsion Vehicle
Opposition/Swingby Mission Mass Statement

(SOURCE: MSFC)

NERVA: I_{sp} = 925 s
T/W_{eng} = 4.0

ADV. NTR: I_{sp} = 1050 s
T/W_{eng} = 20.0



Crew of 4, 30-day stay;
Inbound Venus swingby;
Elliptic parking orbit
at Mars, 250 km x 24 hrs;
Apsidal rotation
penalty optimized;
25 t. surface cargo;
925 Isp;
Reusable return

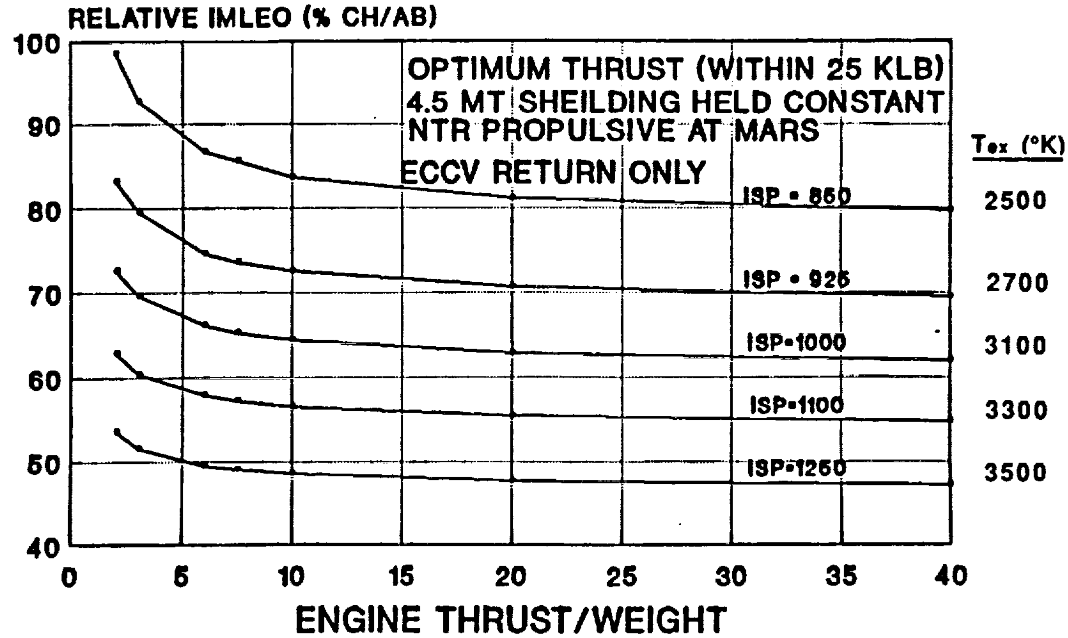
2016 opposition with Venus swingby 434 day mission time

Element	*NERVA* *	*Advanced NTR*
MEV desc aerobrake	7000	7000
MEV ascent stage	22464	22464
MEV descent stage	18659	18659
MEV surface cargo	25000	25000
MEV total	73118	73118
MTV crew hab module 'dry'	28531	28531
MTV consumables & resupply	5408	5408
MTV science	1000	1000
MTV crew habitat system tot	34939	34939
MTV frame, struts & RCS inert wt	4808	4808
Reactor/engine weight	9684	1701
Radiation shadow shield weight	4500	4500
EOC propellant (dV= 1799 m/s)	17598	13075
TEI propellant (dV= 4230 m/s)	61951	44301
EOC/TEI common tank wt (1)	13358	10501
MOC propellant (dV= 2830 m/s)	101810	75163
MOC tanks (2)	19128	15696
TMI propellant (dV=4105 m/s)	237850	165190
TMI tanks (2)	36636	27503
ECCV	7000	7000
Cargo to Mars orbit only	0	0
IMLEO	622380	477495

*PARAMETERS ARE ACTUALLY FOR COMPOSITE FUEL NERVA DERIVATIVE ENGINE SYSTEM

NTR MARS PERFORMANCE THRUST/WEIGHT AND ISP VARIATIONS

MULTI PERIGEE EARTH ESCAPE BURN



NTR TECHNOLOGY

- PAST ACCOMPLISHMENTS
- "STATE-OF-THE-ART" PROJECTIONS
- TECHNOLOGY CHALLENGES AND NEEDS

ROVER/NERVA PROGRAM SUMMARY

- 20 REACTORS DESIGNED, BUILT, AND TESTED BETWEEN 1955 AND 1973 AT A COST OF APPROXIMATELY $1.4 BILLION. (FIRST REACTOR TEST: KIWI-A, JULY 1959)

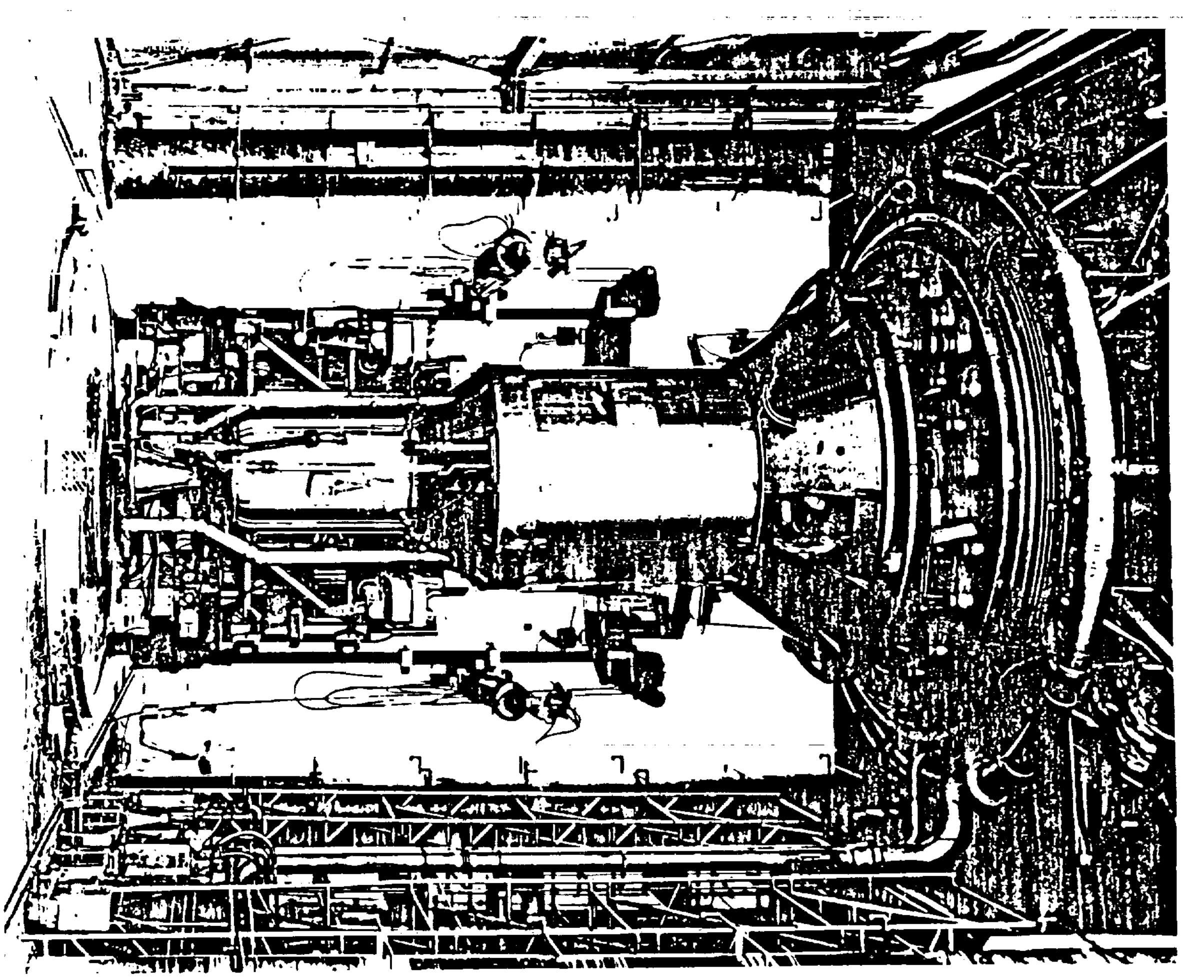
- DEMONSTRATED PERFORMANCE

POWER (MWt)	~1100 (NRX SERIES) - 4100 (PHOEBUS -2A)
THRUST (klbf)	~55 (NRX SERIES) - 210 (PHOEBUS -2A)
PEAK/EXIT FUEL TEMPS. (K)	~2750/2550 (PEWEE)
EQUIV. SPECIFIC IMPULSE(S)	~850 (PEWEE)
BURN ENDURANCE	1-2 HOURS
- NRX-A6	62 MINUTES AT 1125 MWt (SINGLE BURN)
- NUCLEAR FURNACE	109 MINUTES ACCUMULATED (4 TESTS) AT 44 MWt
START/STOP	28 AUTO START-UPS/SHUTDOWNS WITH XE

- BROAD AND DEEP DATABASE ACHIEVED/USED IN PRELIMINARY NERVA "FLIGHT ENGINE" DESIGN (1972)

- ANTICIPATED PERFORMANCE

BURN ENDURANCE	~10 HOURS (DEMONSTRATED IN ELECTRIC FURNACE TESTS AT WESTINGHOUSE)
SPECIFIC IMPULSE	UP TO 925s (COMPOSITE)/UP TO 1020s (CARBIDE FUELS)



PROTOTYPE NERVA ENGINE - THE NRX/XE -

RELATIVE PERFORMANCE CHARACTERISTICS FOR 75klbf CLASS SC/NTR SYSTEMS

PARAMETERS	'72 NERVA	NERVA DERIVATIVES			PBR*
ENGINE CYCLE	HOT BLEED/ TOPPING	TOPPING (EXPANDER)			HOT BLEED
FUEL FORM	GRAPHITE	GRAPHITE	COMPOSITE	CARBIDE	UC_2/ZrC KERNEL
EXHAUST TEMP. (K)	2,350-2,500	2,500	2,700	3,100	3,200
CHAMBER PRESS. (psia)	450	1,000	1,000	1,000	1,000
NOZZLE EXP. RATIO	100:1	500:1	500:1	500:1	100:1
SPECIFIC IMPULSE (s)	825-850/ 845-870	885	925	1,020	971
ENGINE WEIGHT++(kg)	11,250	8,000	8,816	9,313	1702
ENGINE THRUST/ WEIGHT (W/INT. SHIELD)	3.0	4.3	3.9	3.7	20
TECHNOLOGY READINESS LEVEL**	6*	5*	4-5*	3-4*	2*

* PERFORMANCE PARAMETERS/TECHNOLOGY MATURITY ESTIMATES PRESENTED AT THE NTP WORKSHOP HELD AT NASA/LeRC, JULY 10-12, 1990

++ W/O EXTERNAL DISK SHIELD

** TRL = 6 (PRELUDE TO FLIGHT CONCEPT), TRL = 2 (CONCEPT FORMULATION)

NOTE: THRUST-TO-WEIGHT RATIOS FOR NERVA/NDR SYSTEMS ~ 5-6 AT 250 klbf LEVEL

NON-NUCLEAR ENGINE COMPONENTS - PERFORMANCE COMPARISON

-SSME vs. '72 NERVA vs. "STATE-OF-THE-ART" COMPOSITE NTR-

- HYDROGEN TURBOPUMPS: AN EXTENSIVE DATABASE DEVELOPED SINCE NERVA SHOULD ALLOW SIGNIFICANT REDUCTIONS IN WEIGHT, INCREASES IN RELIABILITY AND REDUCED DEVELOPMENT TIME FOR NTR APPLICATIONS
  - SSME: 72.6 KG/S @ 7040 PSI, 350 KG TOTAL MASS
  - NERVA: ~ 40 KG/S @ 1360 PSI, 243 KG TOTAL MASS
  - "SOTA" NTR: ~ 37 KG/S @ 1627 PSI, 304 KG TOTAL MASS
- NOZZLE DESIGN AND COOLING: TYPICAL NOZZLE DESIGNS NOW CAPABLE OF ~ 98% THEORETICAL EFFICIENCY WITH PERFORMANCE SIGNIFICANTLY GREATER THAN THAT USED ON NERVA
  - SSME: T_{ex} ~ 3116°K, Pc ~ 3150 PSI, HEAT FLUX CAPABILITY ~ 16.4 KW/CM^2 (HYDROGEN REGENERATIVE COOLING), NOZZLE MASS ~ 600 KG
  - NERVA: T_{ex} ~ 2350-2500°K, Pc ~450 PSI, HEAT FLUX CAPABILITY ~ 4.1 KW/CM^2, NOZZLE MASS ~ 1050 KG (UNCOOLED GRAPHITE EXTENSION FROM ~ 25:1 TO 100:1)
  - "SOTA" NTR: T_{ex} ~ 2500-3100°K, Pc ~ 1000 PSI, HEAT FLUX CAPABILITY ~ 6.5 KW/CM^2, NOZZLE MASS ~ 440 KG (UNCOOLED CARBON/CARBON EXTENSION FROM ~ 150:1 TO 500:1)

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ELEMENT: NUCLEAR THERMAL PROPULSION

I. TECHNOLOGY NEEDS: TO DEVELOP THE TECHNOLOGIES NECESSARY FOR FLIGHT QUALIFIED NUCLEAR THERMAL PROPULSION SYSTEMS TO SUPPORT SEI MISSIONS

TARGETS:
- **HIGH PERFORMANCE (HIGH T_{ex} AND I_{sp})**
  - REDUCED IMLEO (LESS PROPELLANT REQUIRED)
  - HIGHER PAYLOADS
  - REDUCED TRANSIT TIMES
  - MISSION FLEXIBILITY

  $\left.\begin{array}{l}\text{HIGHER PAYLOADS}\\ \text{REDUCED TRANSIT TIMES}\\ \text{MISSION FLEXIBILITY}\end{array}\right\}$ for given propellent loading
- **SAFE, RELIABLE OPERATIONS**
  - AUTONOMOUS ROBOTIC OPERATIONS
  - MAN-RATED SYSTEMS
  - IMPROVED RETURN-TO-EARTH OPTIONS
- **RADIATION-HARDENED EQUIPMENT**
  - ELECTRONICS
  - TURBOPUMPS, VALVES, ...
  - NOZZLES
  - SHIELDING
- **FULL SYSTEM GROUND TESTING**
  - TECHNOLOGY VALIDATION - FLIGHT QUALIFICATION

NUCLEAR PROPULSION PROJECT

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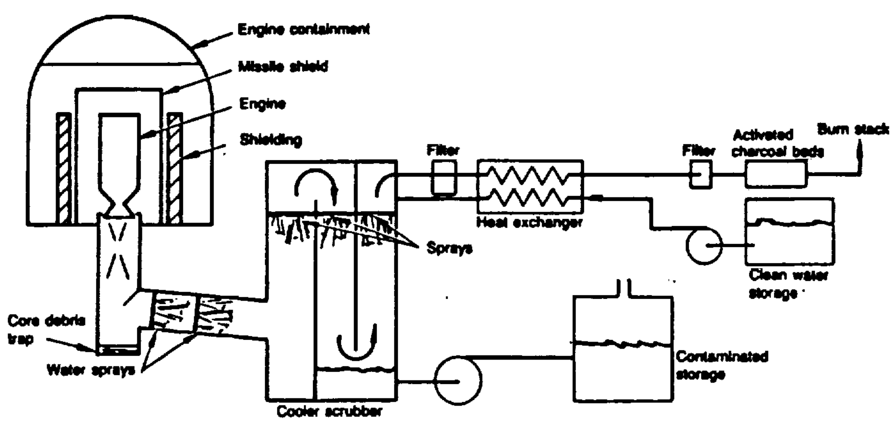
EFFLUENT TREATMENT SYSTEMS



SCHEMATIC OF TEST CELL SHOWING SYSTEMS FOR REMOVING SOLUBLE FISSION PRODUCTS, PARTICULATES, AND NOBLE GAS FROM THE ENGINE EXHAUST

SOURCE: INEL

ELEMENT: NUCLEAR THERMAL PROPULSION

II. TECHNOLOGY CHALLENGES/APPROACHES

CHALLENGE	APPROACH
• HIGH TEMPERATURE REACTOR FUELS	• FABRICATION/PRODUCTION DEVELOPMENT BENCH SCALE TESTING ELECTRIC HEATING TESTS NUCLEAR FURNACE TESTING REACTOR DESIGN/TEST FULL ENGINE SYSTEM TESTING
• HIGH PERFORMANCE NOZZLES	• REGENERATIVELY-COOLED SECTION DESIGN/TEST UNCOOLED SKIRT (TO 500:1)
• IMPROVED TURBOPUMPS	• HIGH PRESSURE (EXPANDER/TOPPING CYCLE) IMPROVED MATERIALS FULL ENGINE SYSTEM TESTING
• IMPROVED REACTOR HEAT TRANSFER	• CONCEPTUAL DESIGNS/TESTING PRELIMINARY DESIGNS/TESTING DETAILED DESIGN/ELEMENT TESTS REACTOR TESTS FULL ENGINE SYSTEM TESTS
• SAFE, RELIABLE AUTONOMOUS OPERATION	• INSTRUMENTATION, CONTROLS DEVELOPMENT/TESTS FULL ENGINE SYSTEM TESTS

ELEMENT: NUCLEAR THERMAL PROPULSION

III. "STATE-OF-THE-ART" ASSESSMENT

- **REACTOR FUELS:**
  - FULL SYSTEM TESTING TO 2500°K (850 SEC I_{sp}) FOR FULL OPERATING LIFE AND MULTIPLE CYCLES WAS COMPLETED IN NERVA/ROVER PROGRAM (CIRCA 1970)
  - COMPOSITE FUEL (2500-2900°K) TESTED IN NUCLEAR FURNACE TO 2450°K (2750°K FOR 10 HRS/60 CYCLES IN ELECTRIC FURNACE TESTS - CIRCA 1972)
  - BINARY CARBIDE FUEL (2900-3300°K) TESTED IN NUCLEAR FURNACE TO 2450°K, FURTHER TESTS/FUEL ELEMENT DESIGN WORK REQUIRED
  - TERNARY CARBIDE FUEL (3300-3500°K) HAVE BEEN PROPOSED BUT NOT VERIFIED
- **NOZZLES:**
  - NOZZLE TECHNOLOGY HAS IMPROVED SIGNIFICANTLY COMPARED TO NERVA DESIGNS. (E.G., SSME CAN ACCOMMODATE EXHAUST TEMPS >3100°K AND NOZZLE HEAT FLUXES 4 TIMES GREATER THAN IN NERVA)
  - UNCOOLED CARBON COMPOSITE NOZZLE SKIRTS ARE USED ON SMALLER NOZZLE APPLICATIONS. MUCH ENGINEERING/ VALIDATION IS REQUIRED FOR SIZES PROPOSED
- **TURBOPUMPS:**
  - 3000-7000 PSI SSME TURBOPUMP REPRESENT THE SOA FOR TURBOPUMP TECHNOLOGY. COMPOSITE ROTOR COMPONENTS HAVE BEEN PROPOSED, BUT NOT VALIDATED

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ELEMENT: NUCLEAR THERMAL PROPULSION

IV. TECHNOLOGY PERFORMANCE OBJECTIVES

- INNOVATIVE CONCEPTS

CLOSED CYCLE GAS CORE	~10,000K	1500-3000
OPEN CYCLE GAS CORE	20,000K	3000-5000

- TURBOPUMPS: HIGH PRESSURES (~500-1000 ATMS) REQUIRED FOR CRITICALITY WILL REQUIRE TECHNOLOGY ADVANCES BEYOND SSME
- MATERIALS: LIGHTWEIGHT, HIGH STRENGTH PRESSURE VESSEL MATERIALS TO IMPROVE ENGINE THRUST-TO-WEIGHT PERFORMANCE
- NOZZLES: TRANSPIRATION-COOLED NOZZLE DESIGNS TO ENABLE HIGH-ISP OPERATION
- LIGHTWEIGHT, HIGH TEMPERATURE RADIATORS TO ALLOW HIGH ISP OPERATION AND IMPROVE ENGINE THRUST-TO-WEIGHT

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SYNERGY WITH OTHER TECHNOLOGY AREAS

- CHEMICAL ROCKET SYSTEMS
  EX: HYDROGEN TURBOPUMPS
  REGENERATIVELY-COOLED NOZZLES
- LIGHTWEIGHT, HIGH STRENGTH CRYOGENIC TANKS
  EX: AL/LI, COMPOSITE MATERIALS
- CRYO FLUID SYSTEMS
  EX: LH_2 STORAGE AND TRANSFER
- THERMAL PROTECTION
  EX: LIGHTWEIGHT SUPER-MLI ("SUPERFLOC") } TO REDUCE/ELIMINATE LH2 BOILOFF
  REFRIGERATION
- "SLUSH HYDROGEN" TECHNOLOGY BEING PURSUED IN NASP PROGRAM CAN IMPROVE PERFORMANCE BY REDUCING TANK VOLUME AND MASS
- "DUAL MODE" NTR OPERATION - LOW LEVEL POWER PRODUCTION (~ 50 kWe) FOR REFRIGERATION MAY LEAD TO MORE "ROBUST" NTR VEHICLE

NUCLEAR PROPULSION PROJECT

FOCUSED TECHNOLOGY: NUCLEAR PROPULSION
SUMMARY

- **IMPACT:**
  - Nuclear Propulsion Enables and/or Enhances Space Exploration Missions

	Nuclear Electric Propulsion (NEP)	Nuclear Thermal Propulsion (NTP)
Enables:	Robotic Science Missions	Mars Piloted
Enhances:	*Lunar & Mars Cargo, & Mars Piloted Space Exploration*	*Lunar & Mars Cargo, Lunar Piloted & Robotic Science Space Exploration*

- **USER COORDINATION:**
  - Exploration Studies Identify Nuclear Propulsion as a Key Technology
  - OAET/RZ - Provide Performance Predictions for NASA Studies
  - OSSA Study on NEP for Robotic Science Missions
  - DOE, DoD & NASA Included on Steering Committee (also Astronaut Office)
- **TECHNICAL REVIEWS:**
  - Interagency Design Review Teams will Periodically Review Technical Progress
- **OVERALL TECHNICAL AND PROGRAMMATIC STATUS:**
  - High Priority Technology Areas Identified (some efforts initiated)
  - Budget Deliberations Continue
  - Single Multi Agency Plan Defined for FY92 Implementation
- **MAJOR TECHNICAL/PROGRAMMATIC ISSUES:**
  - Agency/Department Roles
  - Funding to Initiate Technical Efforts
  - Projected Budget Does Not Support Schedules

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SUPPLEMENTAL INFORMATION

NUCLEAR PROPULSION PROJECT

NUCLEAR THERMAL PROPULSION WORKSHOP RESULTS

- 17 NTR CONCEPTS WERE PRESENTED FOR EVALUATION AT THE NTP WORKSHOP SPONSORED BY LeRC/NASA HEADQUARTERS (JULY 10-12, 1990)

SOLID CORE SYSTEMS
- NERVA
- NERVA-DERIVATIVE
- PARTICLE BED
- PELLET BED
- CERMET REACTOR
- WIRE CORE REACTOR
- ADVANCED DUMBO
- TUNGSTEN/H_2O REACTOR
- LOW PRESSURE CORE
- FOIL REACTOR

LIQUID CORE SYSTEMS
- LIQUID ANNULAR CORE REACTOR
- DROPLET CORE REACTOR

GAS CORE SYSTEMS
- VAPOR CORE REACTOR
- CLOSED CYCLE "NUCLEAR LIGHT BULB"
- OPEN-CYCLE "POROUS WALL" REACTOR

HYBRIDS/IN-SITU PROPELLANT CONCEPTS
- DUAL MODE NTR
- NIMF

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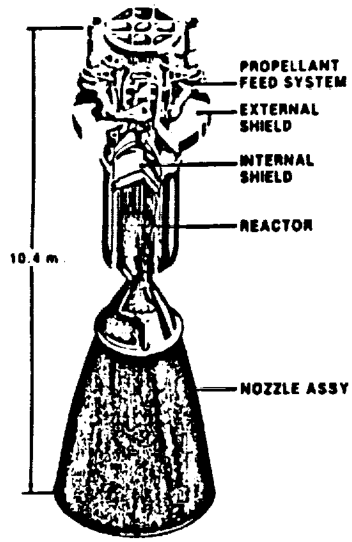
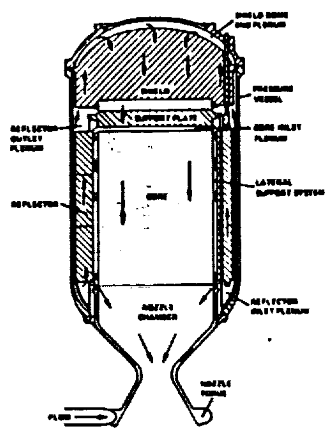
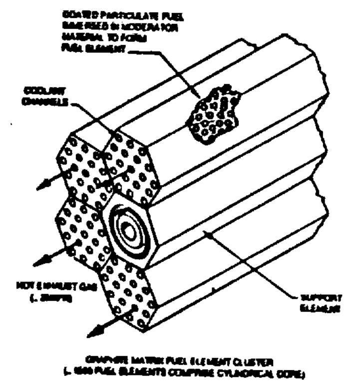
SOLID CORE NTR CONCEPTS

- *ROVER/NERVA*
  - PARTICLES OF COATED URANIUM CARBIDE (UC_2) ARE DISPERSED IN A GRAPHITE MATRIX WITH HEXAGONALLY SHAPED FUEL ELEMENTS PRODUCED USING AN EXTRUSION PROCESS. GRAPHITE FUNCTIONS AS BOTH HEAT EXCHANGER AND MODERATOR.
  - ELEMENTS HAVE 19 AXIAL COOLANT CHANNELS COATED WITH CARBIDES OF NIOBIUM (NbC) OR ZIRCONIUM (ZrC) TO PREVENT HYDROGEN/GRAPHITE REACTION
  - FUEL ELEMENTS CLUSTERED TOGETHER TO FORM A GRAPHITE CORE WITH EACH ELEMENT PRODUCING ~ 1 TO 1.25 MWt. SIX ELEMENT CLUSTERS WERE SUPPORTED BY AN UNFUELED TIE ROD/TUBE TUBE ELEMENT.
  - HIGHER TEMPERATURE "COMPOSITE" AND "CARBIDE" FUEL ELEMENT DESIGNS TESTED IN THE NUCLEAR FURNACE TEST BED REACTOR NEAR THE PROGRAM END

CUT-AWAY AND SCHEMATIC FLOW DESCRIPTION OF THE NERVA BASELINE ENGINE



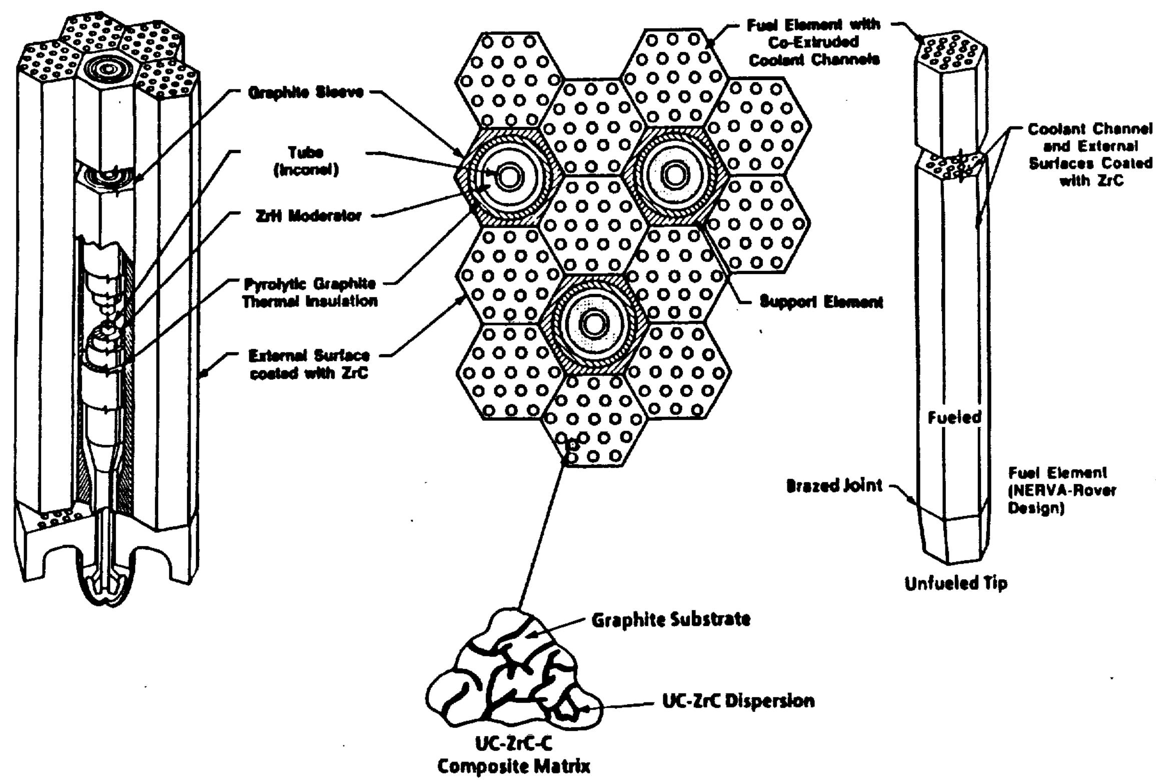




SOLID CORE NTR CONCEPTS (CONTINUED)

- *NERVA DERIVATIVE REACTOR (NDR)*
  - MIXTURE OF UC-ZrC IS BLENDED IN GRAPHITE SUBSTRATE TO FORM A COMPOSITE MATRIX WITH POTENTIAL FOR IMPROVED TEMPERATURE OPERATION (~ 2700K)
  - INCORPORATION OF ADDITIONAL ZIRCONIUM HYDRIDE (ZrH_x) MODERATOR IN "2 PASS" REGENERATIVELY COOLED TIE TUBES REDUCES CRITICAL MASS REQUIREMENT
  - ENERGY EXTRACTED FROM TIE TUBES CAN BE USED TO HEAT TURBINE DRIVE GASES IN AN EXPANDER CYCLE, REDUCE COOLDOWN PROPELLANT REQUIREMENTS, AND GENERATE ELECTRICAL POWER IN A "DUAL MODE" SYSTEM

NDR - BASED ON PROVEN NERVA/ROVER REACTORS



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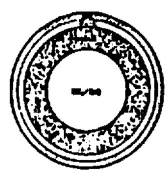
SOLID CORE NTR CONCEPTS

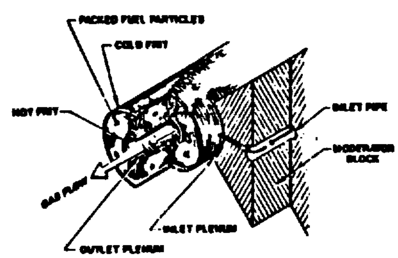
- *PARTICLE BED REACTOR (PBR)*
  - COMPACT HIGH POWER DENSITY CONCEPT PROPOSED BY BROOKHAVEN NATIONAL LABORATORY (BNL)
  - UTILIZES DIRECT COOLING OF SMALL (500-700 μm DIAMETER) COATED PARTICULATE FUEL (CPF) BY THE HYDROGEN PROPELLANT
  - THE CPF IS PACKED BETWEEN TWO CONCENTRIC POROUS CYLINDERS, CALLED "FRITS" WHICH CONFINE THE PARTICLES, BUT ALLOW COOLANT PENETRATION.
  - ANNULAR FUEL ELEMENTS ARE ARRAYED IN CYLINDRICAL MODERATOR BLOCK TO FORM PBR CORE
  - COOLANT FLOW IS RADIALLY INWARD, THROUGH THE PACKED BED AND AXIALLY OUT THE INNER ANNULAR CHANNEL
  - HIGH HEAT TRANSFER SURFACE AREA AND BED POWER DENSITIES OFFER POTENTIAL FOR SMALL, LOW MASS NTR SYSTEMS WITH HIGH THRUST-TO-WEIGHT CAPABILITY

SCHEMATIC REPRESENTATION OF A PARTICLE BED REACTOR BASED ROCKET CONCEPT

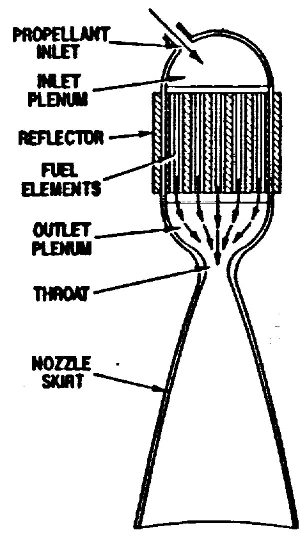
FUEL PARTICLE



BASELINE FUEL ELEMENT & MODERATOR BLOCK

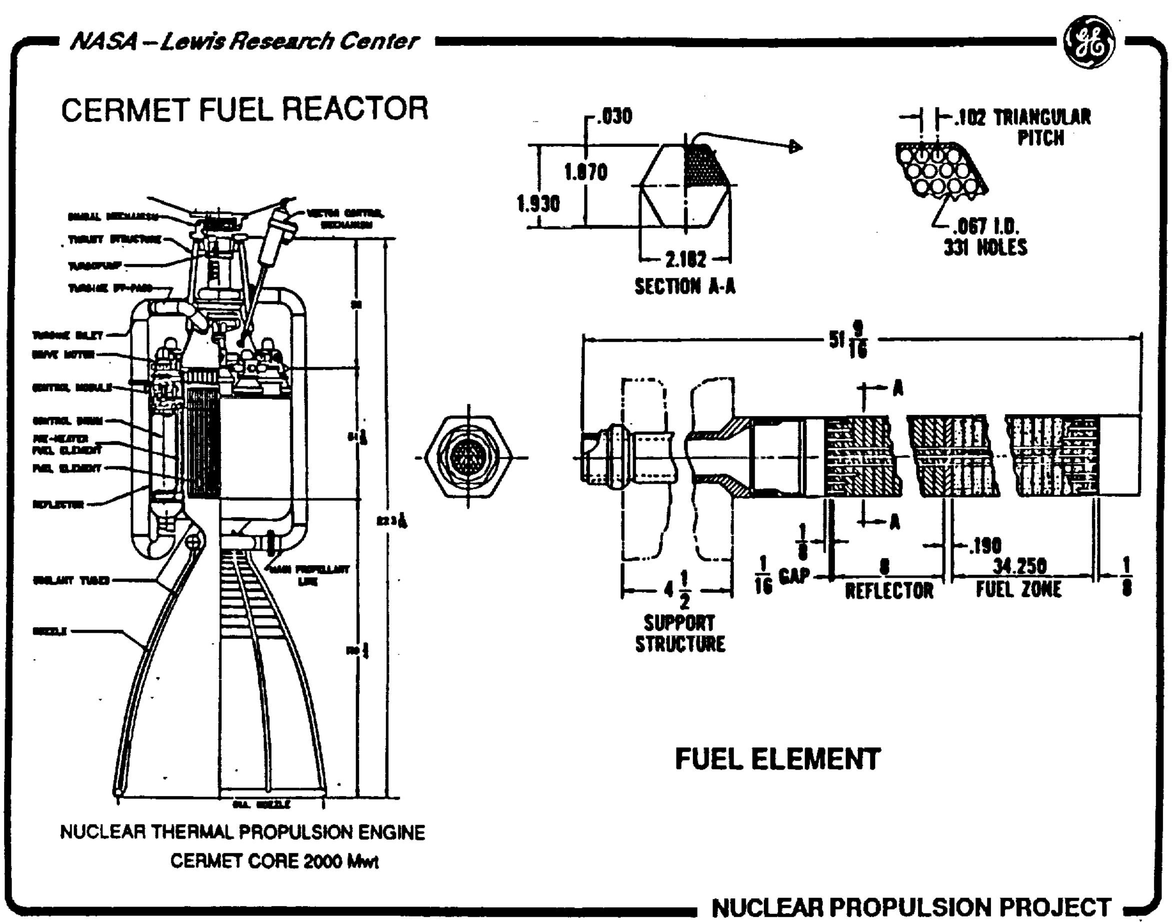


ROCKET

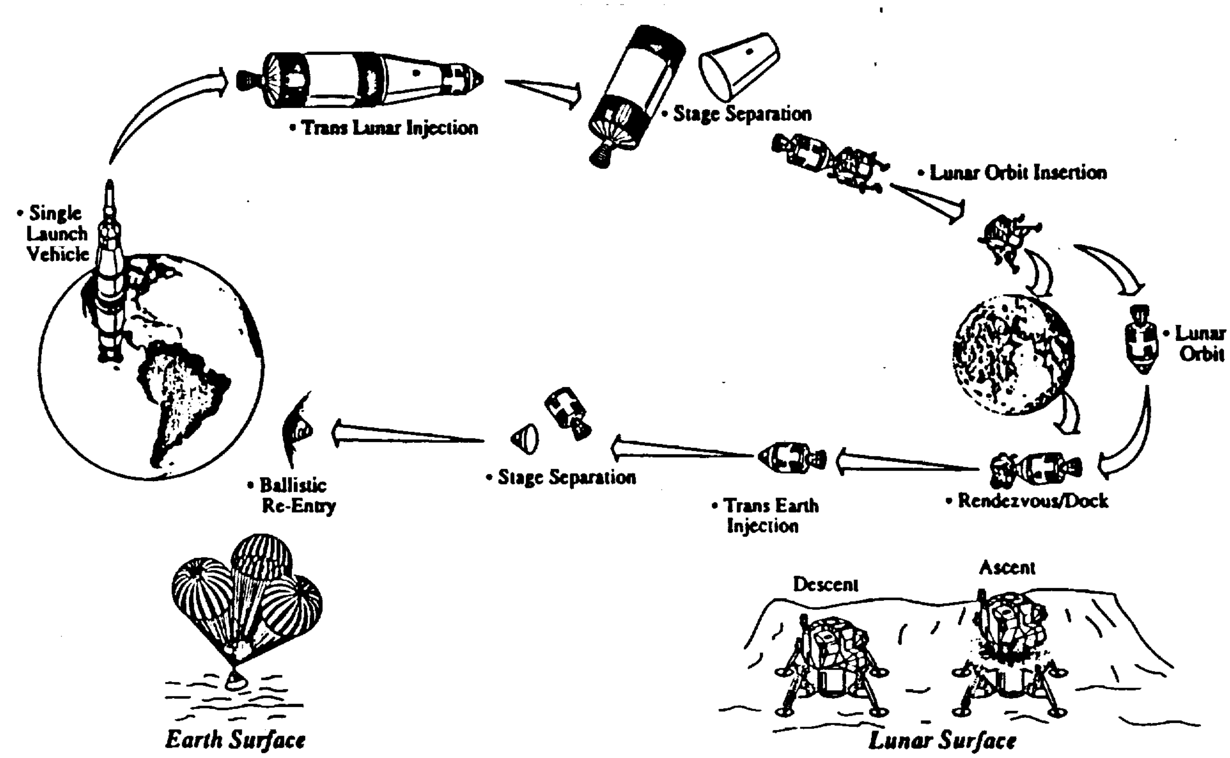


SOLID CORE NTR CONCEPTS

- CERMET REACTOR
  - TECHNOLOGY INVESTIGATED/DEVELOPED BY GE/ANL DURING 1960'S FOR THE ROVER PROJECT AND THE AIRCRAFT NUCLEAR PROPULSION ROGRAM
  - FUEL IS 60% U02/40% TUNGSTEN, HIGHLY ENRICHED IN A FAST REACTOR CONFIGURATION/~163 HEX-SHAPED FUEL ELEMENTS
  - FUEL ELEMENT IS CLAD WITH TUNGSTEN-RHENIUM PROVIDING RETENTION OF FISSION PRODUCT GASES
  - FUEL SPECIMEN TESTS CONDUCTED UP TO ~2800 K
  - SPECIFIC IMPULSE: 832 s WITH CAPABILITY IN THE 800-900 s RANGE /ENGINE THRUST-TO-WEIGHT RATIO: ≤5



Lunar In-Space Transportation
(Apollo Mission Profile - Expendable)



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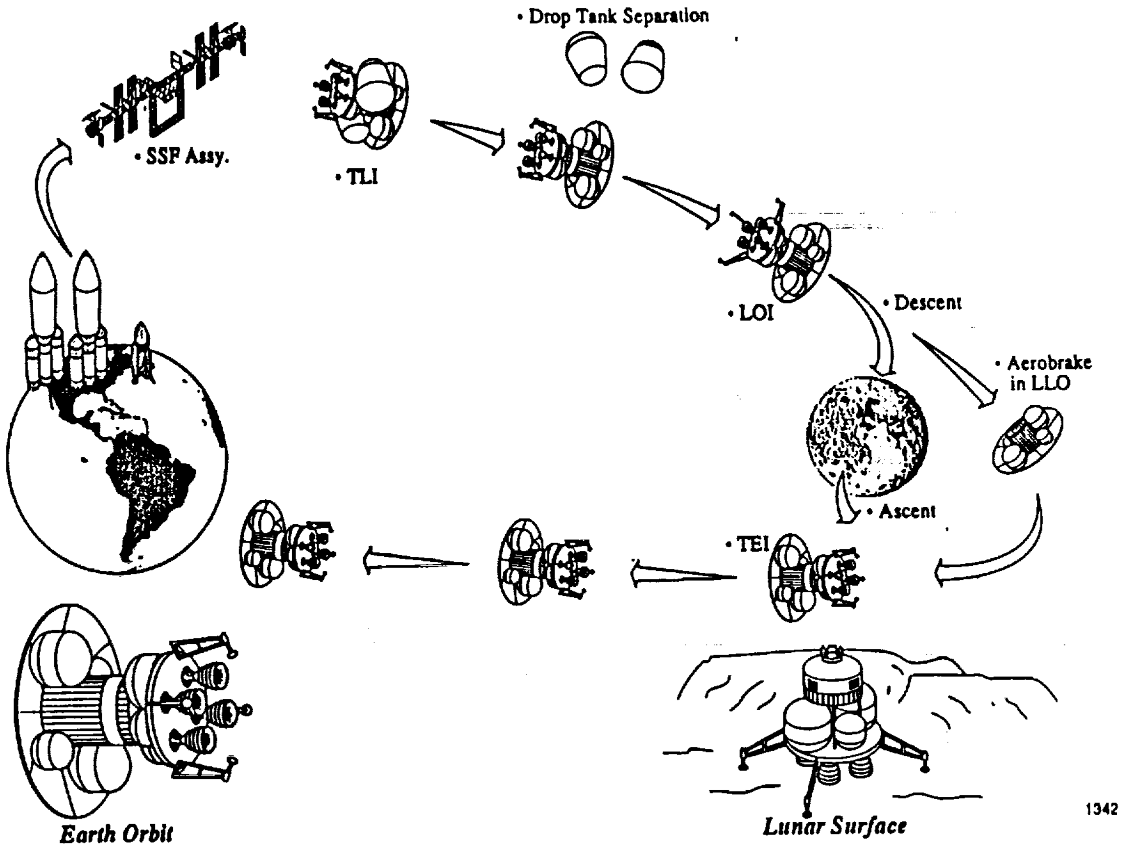
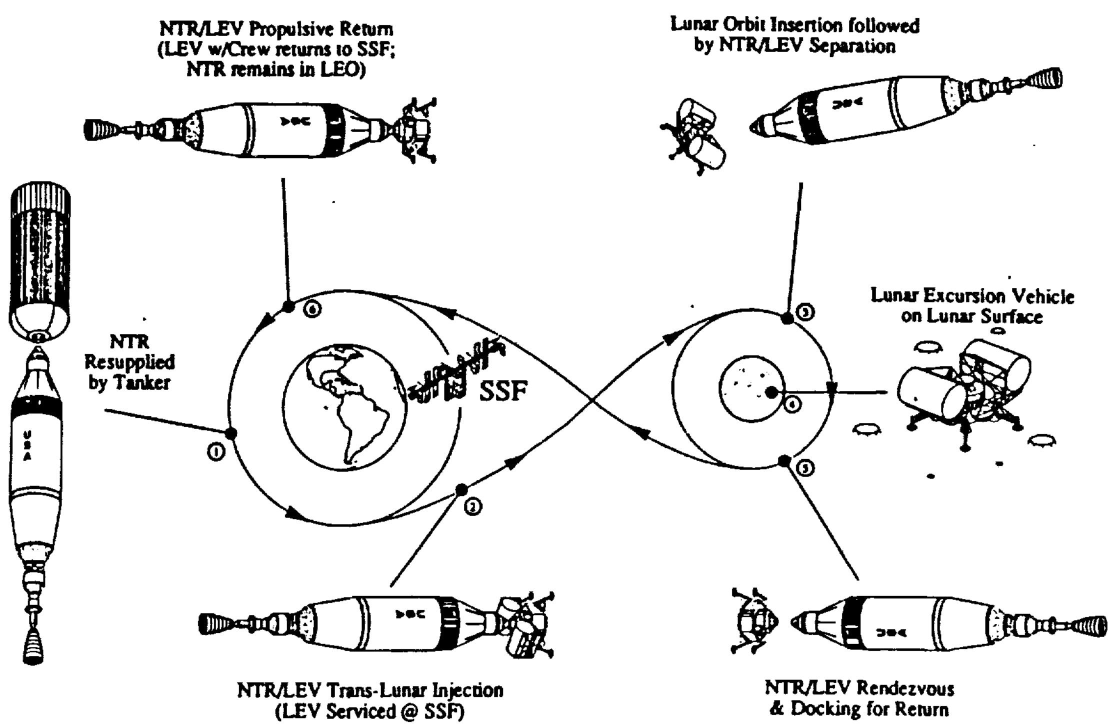
Lunar In-Space Transportation
(FY 90 Lunar Mission Scenario - Partially Reusable)



Lunar In-Space Transportation
(Fully Reusable NTR Scenario)



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LUNAR IN-SPACE TRANSPORTATION SYSTEM COMPARISON

PARAMETERS	APOLLO		CHEM/AB	NTR
• IMLEO (t)	123*		234	208
• MISSION MODE	EXPENDABLE		PARTIALLY REUSABLE	FULLY REUSABLE
• PROPULSION				
- ENGINE/#	J-2/1	SPS+/1	ASE/4	NERVA-DERIVATIVE/1
- PROPELLANT	LOX/LH2	STORABLES	LOX/LH2	LH2
- TOTAL THRUST (klbf)	225	22	80	75
- Isp(s)	425	256	481	915
• BURN DURATION/ENGINE (mins)				
- TLI	5.2	—	26.0/4	28.4
- LOC	-	6.3	4.9/4	7.2
- TEI	-	2.5	1.6/4	4.3
- EOC	DIRECT ENTRY		AEROCAPTURE	9.2
• EARTH ENTRY VELOCITY (km/s)/"g-loading"	11.2/≤ 7g		≤ 11.2/≤ 5g	0.5 g - 0.7 g (begin-end EOC)
• RETURN MASS FRACTION (%)	4.8		11.5	23.4

* S-IVB STAGE PRIOR TO TLI W/44.7 t PAYLOAD - CSM, LEM AND 3 CREW

\+ SERVICE MODULE PROPULSION SYSTEM

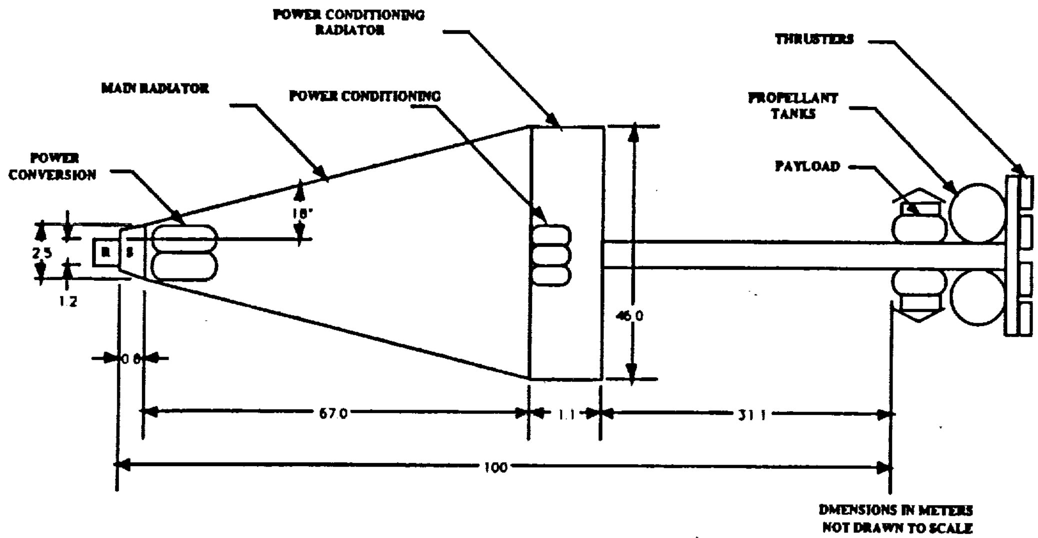
SPACE EXPLORATION INITIATIVE OFFICE

NUCLEAR ELECTRIC PROPULSION

James H. Gilland

NASA Lewis Research Center

NEP VEHICLE SCHEMATIC



NEP TECHNOLOGIES FOR SEI

- Power Systems
  - Reactors
  - Power Conversion - Static, Dynamic
  - Heat Rejection - Heat Pipes
  - Power Management and Distribution
- Propulsion Systems
  - kWe - MWe Thrusters - Ion, MPD, Other
  - Power Processors

NUCLEAR ELECTRIC PROPULSION MISSION ADVANTAGES

- Progressive Technology Development Paths
  - Evolutionary Development to Meet a Wide Range of Missions
  - Commonality with Surface Power Technology
- Low Propellant Requirements
  - Low Vehicle Mass
  - Small Resupply Mass
- Reduced Interplanetary Trip Times
- Tolerant of Mission Variations
  - Changes in Payload
  - Broad Launch Windows
  - Reduced Dependence on Mission Opportunity

NUCLEAR PROPULSION PROJECT

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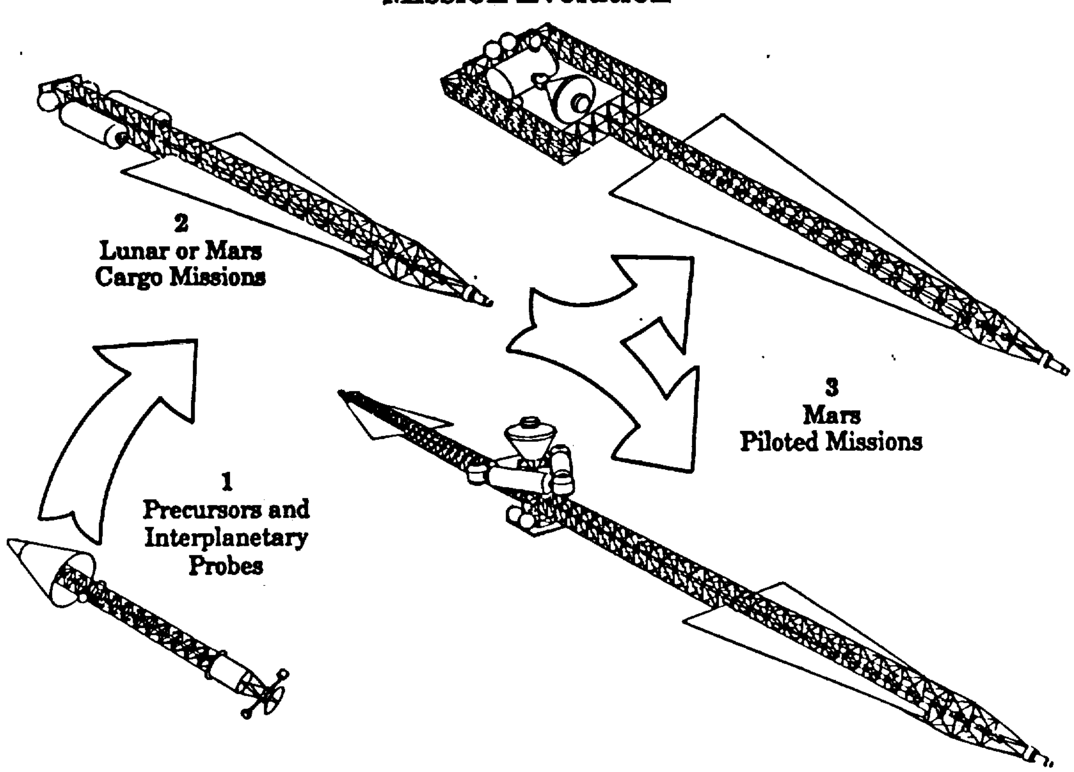
Mission Evolution



ADVANCED SPACE ANALYSIS OFFICE

NEP SYSTEM/MISSION CHARACTERISTICS

NEP Performance Parameters

Specific Impulse (Isp): Determines Propellant Mass

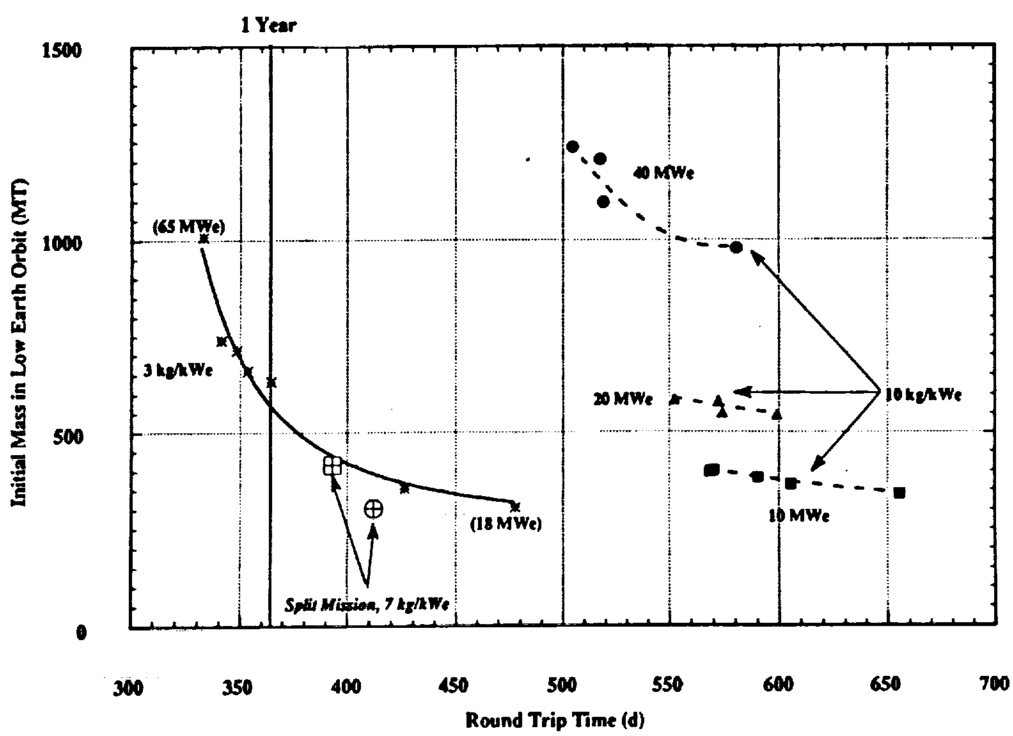
Power Level (P_e): Affects Trip Time

System Specific Mass (α): Determines Trip Time Limits

Thruster Efficiency (η): Affects Trip Time, Vehicle Mass

MISSION BENEFIT	ENABLING PARAMETER	NEP CAPABILITIES
Reduced Propellant Mass	Isp	2000 - 10000 seconds
	α	<10 kg/kWe
	η	>50%
Reduced Trip Time	α	<10 kg/kWe
	Pe	>=10 MWe
	η	>50%
Mission Tolerance	Isp	2000 - 10000 seconds

NEP PERFORMANCE FOR PILOTED MARS MISSION 2016 OPPOSITION



NEP TECHNOLOGY DEVELOPMENT APPROACH

Evolutionary Approach

Earth Orbit => Interplanetary Robotic => Lunar Cargo => Mars Cargo, Piloted

Ultimate Goal: Mars Piloted Mission in 2016 - 2019 Time Frame

Address both Integrated System Design and Subsystem Technologies

Ground Testing of Subsystems, some Integrated Assemblies

Flight Testing of Progressively More Advanced NEP Systems to Obtain Flight Experience

PATHWAYS TO EVOLUTION

MISSION	EVOLVING SP-100 TECHNOLOGY	EVOLVING HIGHER RISK TECHNOLOGIES
INTERPLANETARY PROBES/PRECURSORS	SP-100 THERMOELECTRIC 100 kWe	SP-100 THERMOELECTRIC 100 kWe
LUNAR/MARS CARGO	GROWTH SP-100 K-RANKINE 1-5 MWe	ADVANCED REACTOR ADVANCED POWER CONVERSION 1-5 MWe
MANNED MARS	GROWTH SP-100 K-RANKINE	ADVANCED REACTOR ADVANCED POWER CONVERSION
"ALL UP"	10-20 MWe	10-20 MWe
"QUICK TRIP"	-----	40-60 MWe

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EVOLUTION OF NEP TECHNOLOGIES

	PRESENT		GOAL	
Power				
Nuclear SP-100	100 kWe		>=10 MWe	
	~45 kg/kWe		<= 10 kg/kWe	
	GES 2001		TRL 6 by 2006	
	UN Fuel Pin			
	TE Conversion			
	1350 K			
	K Heat Pipe			
Propulsion				
Thrusters	Ion	MPD	Ion	MPD
Isp (s)	2000 - 9000	1000 - 5000	2000 - 9000	1000 - 7000
η	.7 - .8	.3	.7 - .8	>.5
Pe (MWe)	.01 - .03	.01 - .5	1 - 2	1 - 5
Lifetime(h)	10000	?	10000	>= 2000
Power Management and Distribution (PMAD)				
	$\eta \sim 0.90$		$\eta \sim 0.95$	
	4 kg/kWe		<= 2.5 kg/kWe	
	400 K Rejection Temp.		700 K Rejection Temp.	

NUCLEAR PROPULSION PROJECT

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ASSOCIATED NEP TECHNOLOGY EFFORTS

Space Nuclear Power

DOE MMWe Program - 10's - 100's MWe in Earth Orbit

DoD/DOE/NASA SP-100 Program - 100 kWe, TRL 6 in 1999 - 2001

Electric Propulsion

NASA OAET Base R&T in Electric Propulsion - Resistojet, Arcjet, Ion, MPD Thrusters

Air Force Electric Propulsion Program - Arcjet, MPD Thrusters, SEP Flight Tests

International - USSR (MPD, Closed Drift Hall Thrusters)
Japan (Ion, MPD Thrusters)
ESA (Arcjet, Ion, MPD Thrusters)

NUCLEAR PROPULSION PROJECT

REPRESENTATIVE MARS NEP SYSTEM

POWER (10 MWe):

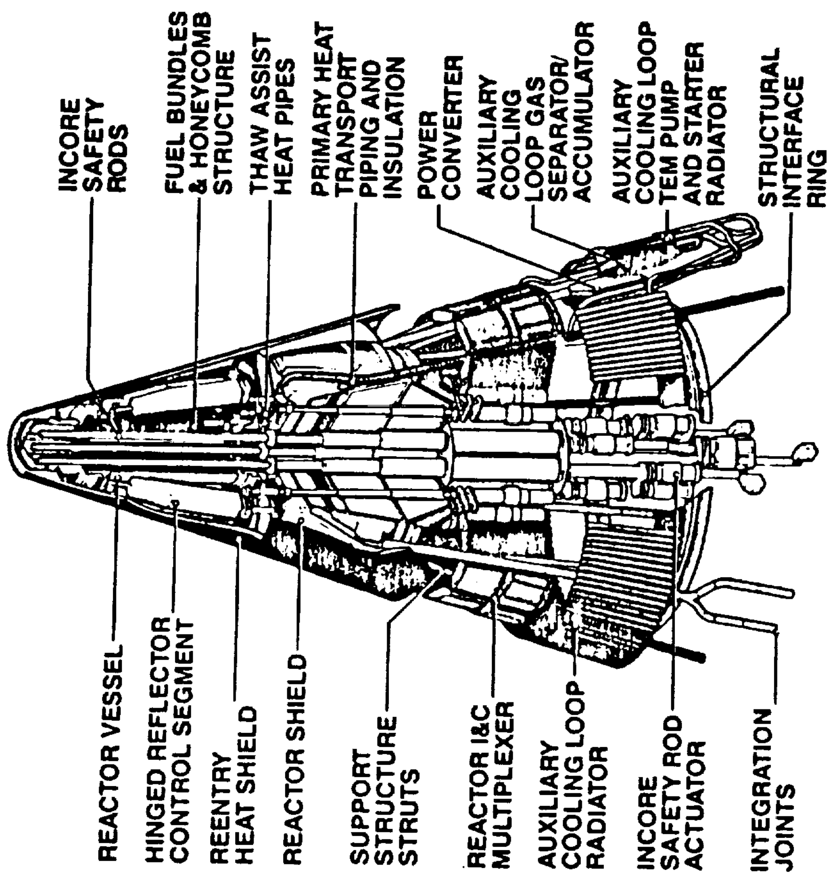
- UN Fuel Pin, Li Cooled Reactor (SP-100 Technology)
- 1350 K Reactor Outlet Temperature
- K-Rankine Power Conversion System
- K Heat Pipe Radiator (5.5 kg/m^2)
- Man-Rated Shadow Shield - 5 Rem/year 100 m from Shield, 40 m Diameter Dose Plane
- 10 Year Lifetime
- 5000 V DC Shielded Coaxial Transmission Line
- 600 K Power Conditioning

PROPULSION:

- Argon Ion Thrusters
  - 1.25 MWe thrusters
  - 5000 - 9000 s Isp
  - 1 m X 5 m Grids
  - 10,000 hours Lifetime

NUCLEAR PROPULSION PROJECT

REACTOR POWER ASSEMBLY



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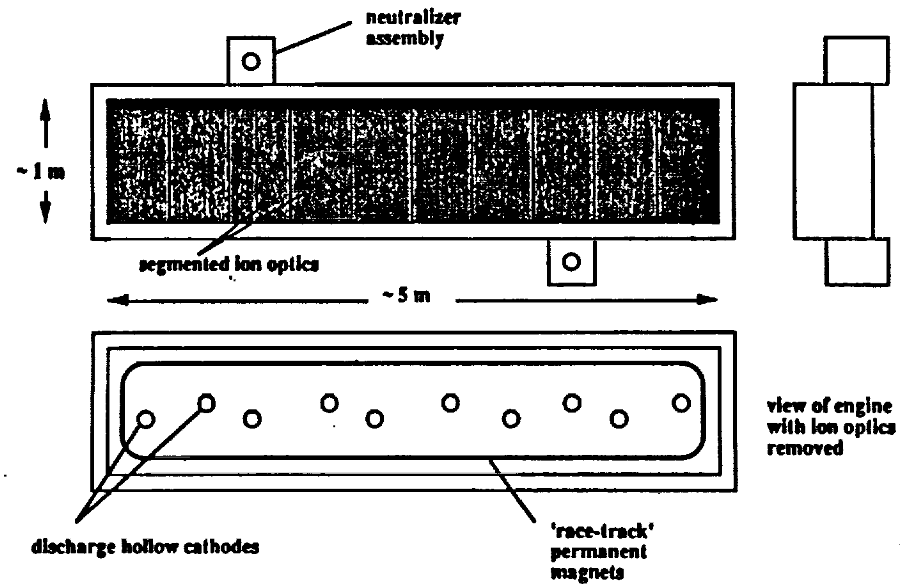
EXAMPLE 1.25 MWe ARGON ION ENGINE DESIGN



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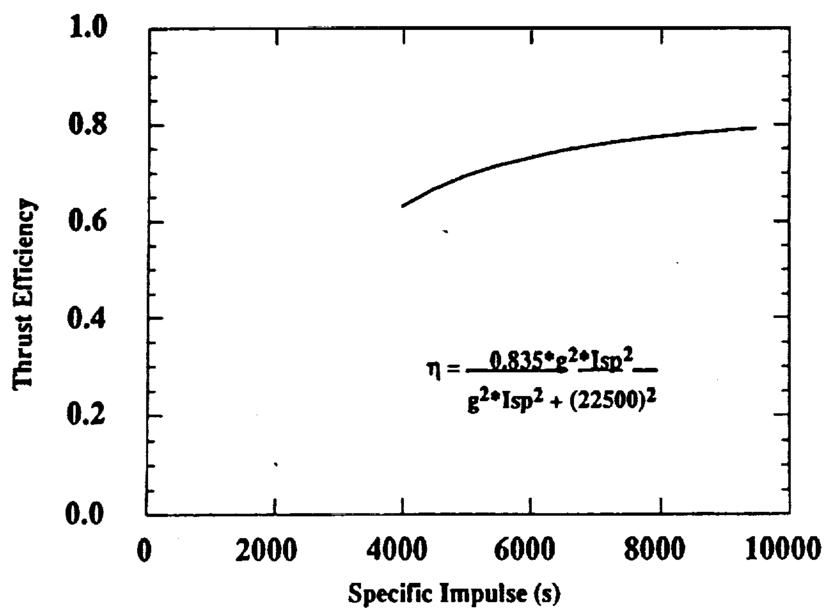
PROJECTED ARGON ION THRUSTER PERFORMANCE



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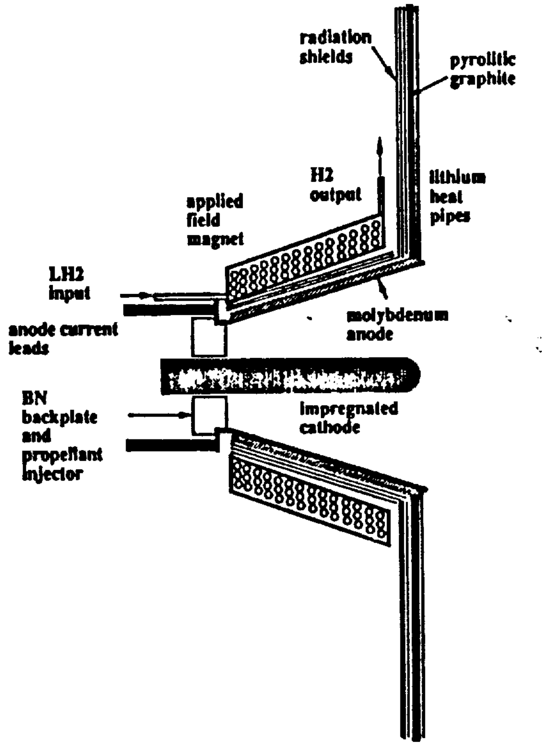
EXAMPLE 2.5 MWe HYDROGEN MPD THRUSTER DESIGN



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NEP SUBSYSTEM TRADE SPACE

Reactor	Power Conversion	Radiator	PMAD	Thruster
Fuel Pin (SP-100)	Themoelectric	Pumped Loop	Si	Ion
Advanced Fuel Pin	Brayton		GaAs	MPD
NERVA- Derived	Rankine	Refractory Metal HP	SiC	Pulsed Inductive (PIT)
Cermet	Adv. Brayton	Carbon Composite HP	AC	Electron Cyclotron Resonance (ECR)
Thermionic	Thermionic		DC	
Particle Bed	MHD/Rankine	Ceramic Fabric HP		Ion Cyclotron Resonance (ICR)
Pellet Bed		Bubble Membrane		Pulsed Electrothermal (PET)
In-Core Boiling K		Liquid Droplet		Deflagration
				VariableIsp
				Pulsed Plasmoid

NUCLEAR PROPULSION PROJECT

NEP TECHNOLOGY EMPHASIS

TECHNOLOGY	SYSTEM IMPACT
Reactor	
High Temperature Fuels, Materials	Low α - reduced radiator mass
High Fuel Burnup	Low α - compact reactor design
Power Conversion	
High Temperature Materials	Low α - reduced radiator mass
Power Management and Distribution (PMAD)	
High Power Electronics	Enabling - Reliability
Radiation Resistant Electronics	Enabling - Reliability
High Temperature Electronics	Low α - reduced PMAD radiator mass
Efficient Electronics	Low α, Pe - reduced PMAD radiator mass ; lower power source requirements

NEP TECHNOLOGY EMPHASIS

TECHNOLOGY	SYSTEM IMPACT
Heat Rejection (Radiator)	
High Temperature, Low Mass Materials	Low α - Dominant mass in MWe space power systems
Thrusters	
High Power	Enabling - System reliability, simplicity
Efficient	Improved vehicle mass, trip time; lower power source requirements
Long Lifetime	Maximize reliability; Minimize complexity; Reduce mass

ADDITIONAL INFORMATION

NEP Mission Charts

- **Mission - System Requirement Guidelines**
- **Robotic Probe Missions**
- **NEP Lunar Cargo Assessment**
  - 10 kg/kWe System compared to Chem Aerobrake over 5 year cargo mission cycle
- **Sensitivity of Mars Mission to α**
  - α values range from 7 to 15 kg/kWe
  - Power, Isp optimized
  - Lines are optimum performance for each α
- **Sensitivity of Mars Mission to Power, Isp**
  - Constant α of ~10 kg/kWe
  - Performance insensitive to Isp above 5000 seconds
  - Dashed line is optimum performance "envelope"

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NEP MISSION GUIDELINES

Mission	Total Power (MWe)	Thruster Power (MWe)	Operating Time (y)	Thruster Time (y)	Isp (s)	η (%)	α (kg/kWe)	Need Date
Orbital Transfer/ Precursor	0.1 - 1	0.01 - 0.05	3 - 10	1 - 2	2000 -8000	>50	10 - 30	1990-2005
Interplanetary Probe	0.1 - 1	0.01 - 0.05	10-12	6 - 10	5000 -10000	>50	30 - 50	1990-2005
Lunar Cargo	0.5 - 5	0.1 - 1	3 -1 0	1 - 2	3000 -10000	>50	10 - 20	2005-
Mars Cargo	2 - 10	0.5 - 2	5 - 10	2 - 3	5000 -10000	>50	10 - 20	2010-
Mars Piloted	5 - 20*	1 - 5	5 - 10	1 - 2	5000 -10000	>50	10 - 20	2014-
Mars Fast	10 - 60*	5 - 10	3 - 10	1 - 2	6000 -10000	>50	1 - 5	2016-

*Total Power Includes Option for Multiple Propulsion Modules

NUCLEAR PROPULSION PROJECT

JPL

ROBOTIC SCIENCE MISSIONS

FUTURE CANDIDATE DEEP SPACE MISSIONS UTILIZING NUCLEAR ELECTRIC PROPULSIONS

- NEPTUNE ORBITER/PROBE
- PLUTO/CHARON ORBITER/PROBE
- URANUS ORBITER/PROBE
- COMET NUCLEUS SAMPLE RETURN (a.k.a. ROSETTA)
- JUPITER GRAND TOUR
- MULTIPLE MAIN-BELT ASTEROID RENDEZVOUS
- INTERSTELLAR PROBE

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NEP Lunar Cargo Mission

- Cargo missions: minimize propellant mass by allowing trip time to vary
- Groundrules
  - Total mass required for 5 year mission
  - 58 MT (LEV and cargo) to LLO per year
  - Compare to 90-day study Chem/AB vehicle
- NEP vehicle
  - One mission to Moon and back per year
  - Return to LEO empty for refurbishment and resupply
  - 10 kg/kWe assumed as specific mass

Optimized Case	Modular Case
Optimal Power	Common 5 MWe
Optimal Isp	Vary Isp to obtain trip time

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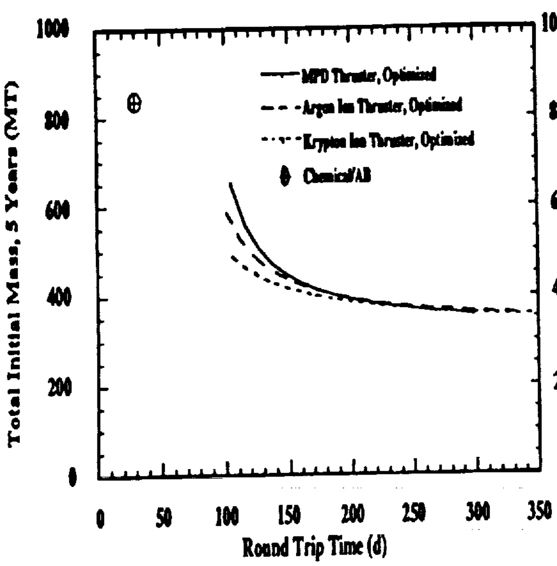
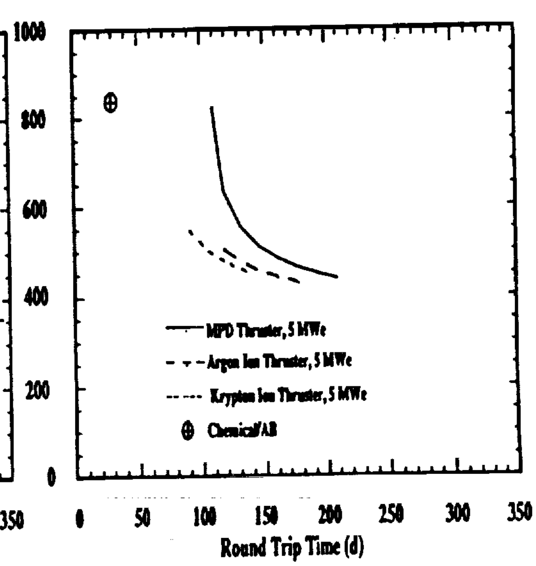
NEP Lunar Cargo Vehicle Mission Performance

"Optimized" Case: Specific Impulse and Power optimized for minimum mass



"Modular" Case: Fixed 5 MWe power, varying specific impulse



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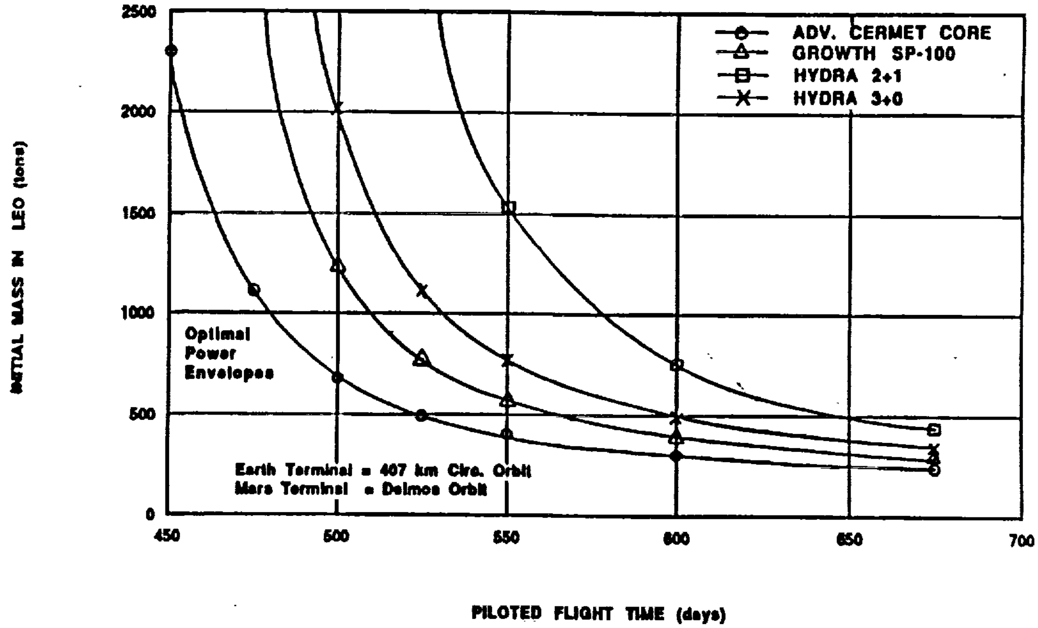
TANKS JETTISONED



NEP PERFORMANCE FOR 2016 OPPOSITION-CLASS MISSION

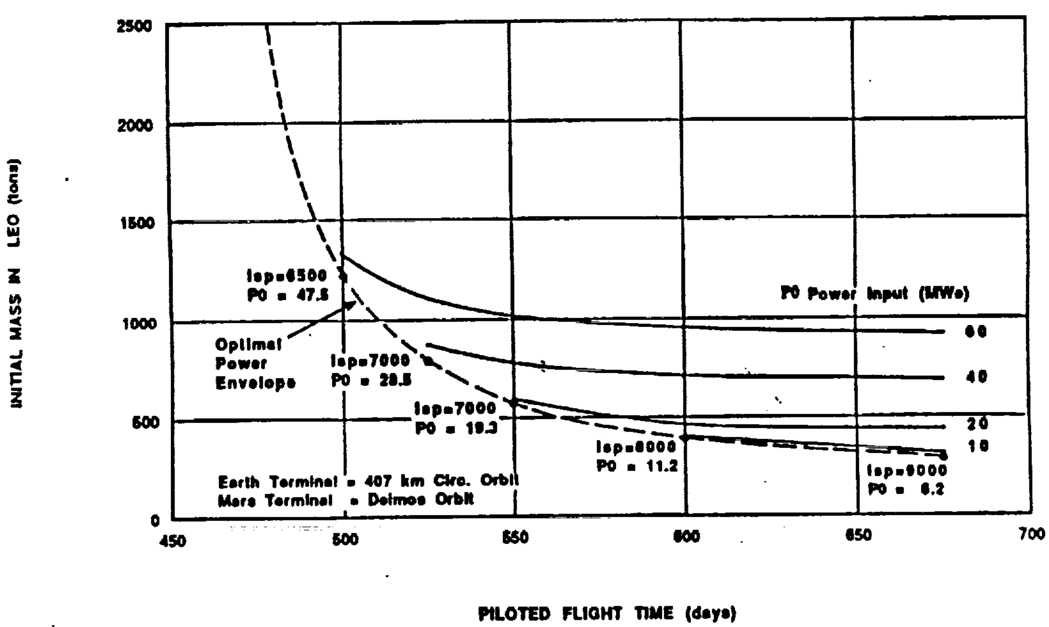
COMPARISON OF POWER SYSTEMS WITH ION THRUSTERS

60 days BETWEEN MARS ARRIVAL/DEPARTURE (STAY TIME > 30 days)

ADVANCED SPACE ANALYSIS OFFICE

NASA LEWIS RESEARCH CENTER

TANKS JETTISONED



NEP PERFORMANCE FOR 2016 OPPOSITION-CLASS MISSION

GROWTH SP-100 REACTOR WITH ION THRUSTERS

60 days BETWEEN MARS ARRIVAL/DEPARTURE (STAY TIME > 30 days)

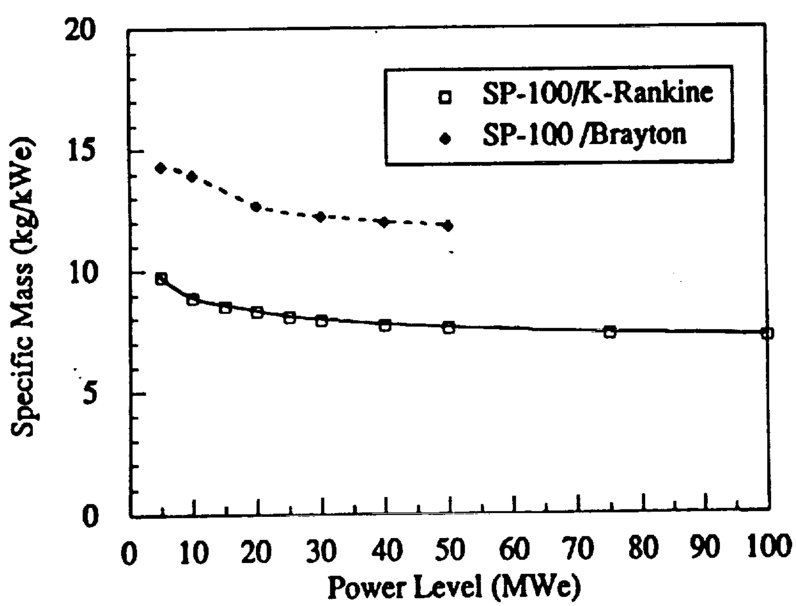
ADVANCED SPACE ANALYSIS OFFICE

NEP Technology Charts

- Scaling of Growth SP-100 System over range of powers
  - Scaling up to 10 - 20 MWe studied by GE for LeRC
  - Little economy of scale beyond 10 MWe; radiator mass dominates
- Range of Power Systems Presented at NEP Workshop
- Range of Thruster Systems Presented at NEP Workshop

Growth SP-100 Manned NEP Power Systems

(1300 K Turbine Inlet, 10 yr life, Man-Rated, 2+2 PCU Redundancy)
(100 m separation distance for Rankine, exceeded by Brayton)



POWER/REACTOR CONCEPTS

Concepts May Be Grouped According to Reactor Type:

Liquid Metal Cooled
- SP-100
- Cermet K/Rankine
- 10 MWe K/Rankine
- RMBLR (In-Core Boiling K)

Gas Cooled
- ENABLER
- Particle Bed
- Pellet Bed
- NEPTUNE

Static Conversion
- In-Core Thermionic
- TORCHLITE
- SP-100 w/HYTEC

Vapor Core
- UF_4/MHD

PROPULSION CONCEPTS

Concepts May Be Grouped According to Acceleration Mechanism:

Electrostatic
- Ion Engine

Steady Electromagnetic
- MPD Thruster
- Electron Cyclotron Resonance Engine
- Ion Cyclotron Resonance Engine
- NEPTUNE (High Power MPD Thruster)
- Variable Isp Plasma Rocket

Pulsed Electromagnetic
- Pulsed Inductive Thruster
- Pulsed Electrothermal Thruster
- Deflagration Thruster
- Pulsed Plasmoid Thruster

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SPACECRAFT ON-BOARD PROPULSION

FOCUSED TECHNOLOGY

INTEGRATED TECHNOLOGY PLAN EXTERNAL REVIEW

JUNE 27, 1991

FOCUSED TECHNOLOGY

AGENDA

- INTRODUCTION
- PLANETARY DUAL MODE
  - CONCEPT
  - IMPACTS
  - PROGRAM
- SPACE STATION H/O AND H_2O/GAS RESISTOJET
  - CONCEPT
  - IMPACTS
  - PROGRAM
- SUMMARY

SPACECRAFT ON-BOARD PROPULSION

FOCUSED TECHNOLOGIES

INTRODUCTION

- FOCUSED TECHNOLOGY PROGRAMS PROPOSED FOR:
  - PLANETARY DUAL-MODE RETRO & "DELTA V"
  - SPACE STATION DRAG MAKEUP

SPACECRAFT ON-BOARD PROPULSION

PLANETARY DUAL-MODE PROPULSION

CONCEPT

- NTO/N_2H_4, 100LBF-CLASS ROCKET(S) FOR MAJOR RETRO & "DELTA V"
- N_2H_4 1LBF-CLASS ROCKETS FOR ACS
- SINGLE N_2H_4 TANK FOR 100LBF & 1LBF ROCKETS
- LIGHTWEIGHT ADVANCED TANKS

TECHNOLOGY IMPACTS

PLANETARY DUAL-MODE PROPULSION

- STUDY CONDUCTED BY JPL FOR MMII CLASS MISSION
  - CRAF USED TO QUANTIFY IMPACTS

- SPECIFIC TECHNOLOGIES EVALUATED
  - DUAL MODE (NTO/N_2H_4) ROCKET
  - ADVANCED PROPELLANT TANKS

TECHNOLOGY IMPACTS

PLANETARY DUAL-MODE PROPULSION

BENEFITS EVALUATED (1)

TRW

320 SCA
330 prob.bl.

- INCREASED SPECIFIC IMPULSE (308 ⟶ 325)
- REDUCED RESERVE REQUIREMENTS
- REDUCED TANKAGE
  - ELIMINATE MONOPROPELLANT ACS TANK
  - REDUCED VOLUME & MASS
- NON QUANTIFIED
  - CONTAMINATION REDUCTIONS

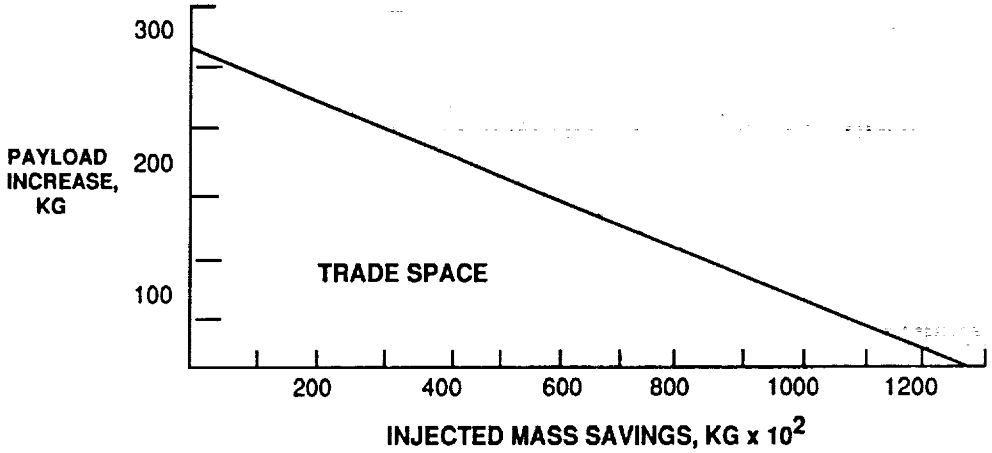
> - WET MASS SAVING OF 283KG ESTIMATED FOR DUAL-MODE CONCEPT
> - SIGNIFICANT CONTAMINATION BENEFITS VIA SWITCH TO N_2H_4

(1) CRAF USED FOR QUANTIFICATION

TECHNLOGY IMPACTS

PLANETARY DUAL-MODE PROPULSION

PAYLOAD MASS VS INJECTION MASS TRADE

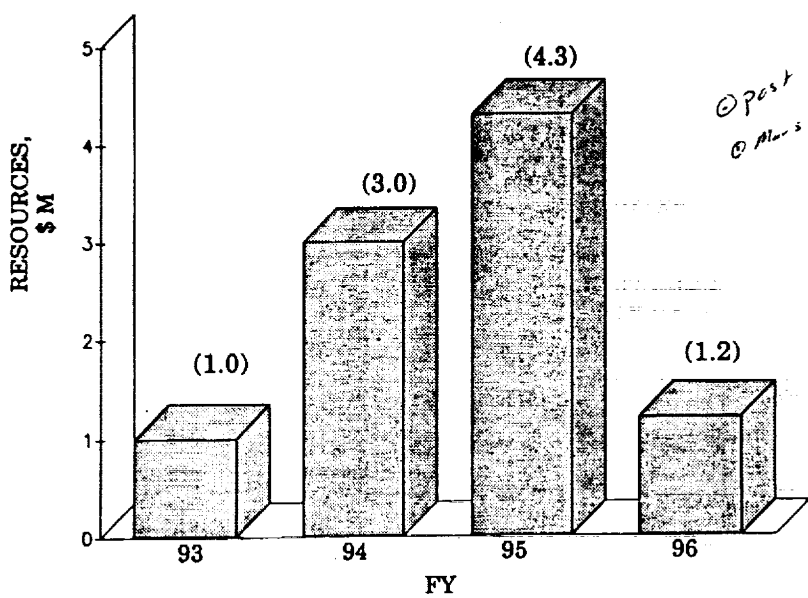


(-) 3000 kg wet mass

DUAL MODE ENABLE SAVINGS UP TO:

- **283KG PAYLOAD**
- **1285KG INJECTED MASS**
- **OR COMBINATION OF BOTH**

FOCUSED TECHNOLOGY
SPACECRAFT ON-BOARD PROPULSION
PLANETARY DUAL-MODE PROPULSION
"3X" PROJECT



① Post Cassini
② Mars Return

JOINT JPL/NASA LeRC PROJECT PROPOSED

TECHNOLOGY IMPACTS

SPACE STATION PROPULSION

- STUDIES OF RESTRUCTURED SPACE STATION CONDUCTED BY SSF PROGRAM PERSONNEL

TECHNOLOGY IMPACTS

SPACE STATION PROPULSION

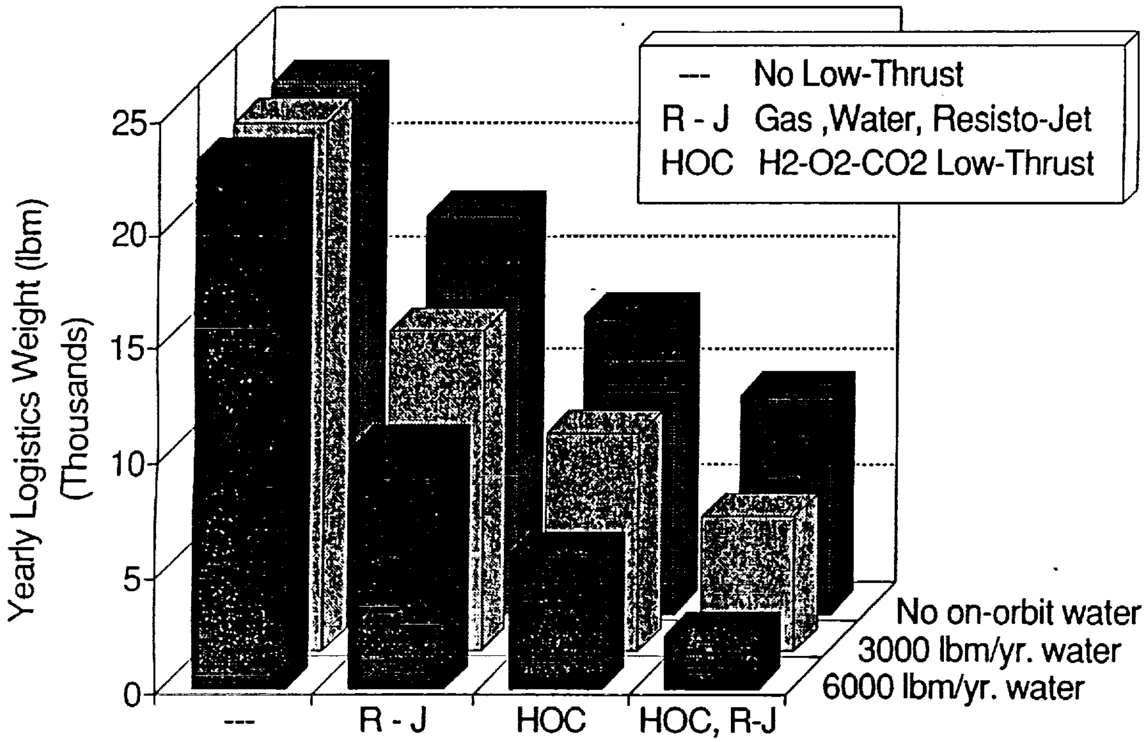
- STUDIES OF RESTRUCTURED SPACE STATION CONDUCTED BY SSF PROGRAM PERSONNEL

NASA

National Aeronautics and Space Administration

SPACE STATION FREEDOM - PMC
Propulsion System Propellant Resupply

FREEDOM

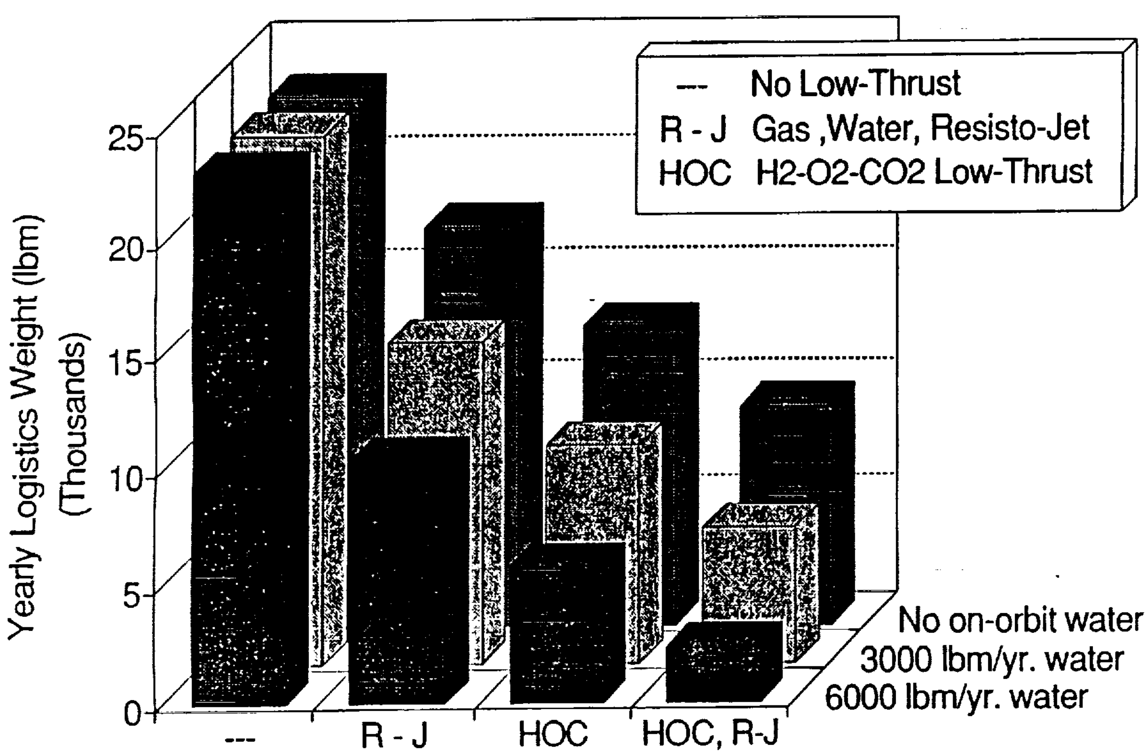


NASA

National Aeronautics and Space Administration

SPACE STATION FREEDOM - PMC
Propulsion System Propellant Resupply

FREEDOM



NASA
National Aeronautics and Space Administration

Potential Cost Savings from Reduced Hydrazine Logistics

FREEDOM

	Current Baseline	Potential Baseline
Propulsion Element Upmass	1 flight per year	1 flight per 5 years
Ground Processing (Man-Hours)	$200 K/Year	$200 K/ 5 Years
Dedicated SSF Hazardous Processing Facility	$50 Million	N/A

Potential Cost Savings from Reduced Hydrazine Logistics

NASA
National Aeronautics and Space Administration

FREEDOM

	Current Baseline	Potential Baseline
Propulsion Element Upmass	1 flight per year	1 flight per 5 years
Ground Processing (Man-Hours)	$200 K/Year	$200 K/ 5 Years
Dedicated SSF Hazardous Processing Facility	$50 Million	N/A

SPACECRAFT ON-BOARD PROPULSION

- FOCUSED PROGRAMS
  - PLANETARY DUAL-MODE "3X"
  - ADVANCED SPACE STATION PROPULSION "STRATEGIC"
- MAJOR BENEFITS IDENTIFIED BY USERS:
  - 280KG PAYLOAD FOR MMII CRAF CLASS MISSION
  - ELIMINATE ~ ORBITER/YEAR & N_2H_4 COF

SPACECRAFT ON-BOARD PROPULSION

- FOCUSED PROGRAMS
  - PLANETARY DUAL-MODE "3X"
  - ADVANCED SPACE STATION PROPULSION "STRATEGIC"
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Commercial Vehicle Propulsion

Objective

Develop and validate technology, design tools and methodologies to enable the low cost commercial development and operational use of hydrogen and hydrocarbon fueled liquid engines, low pressure booster engines and hybrid engines.

SCHEDULE

1993 - Complete analytical studies

1995 - Altitude ignition and low weight pressurization technology verified

1996 - Low cost manufacturing processes demonstrated
- Low cost, low pressure rise turbomachinery demonstrated
- Performance / manufacturing tolerance relationship verified
- Hybrid combustion processes verified

1997 - Low cost, reliable O2/H2 and O2/HC systems demonstrated

RESOURCES

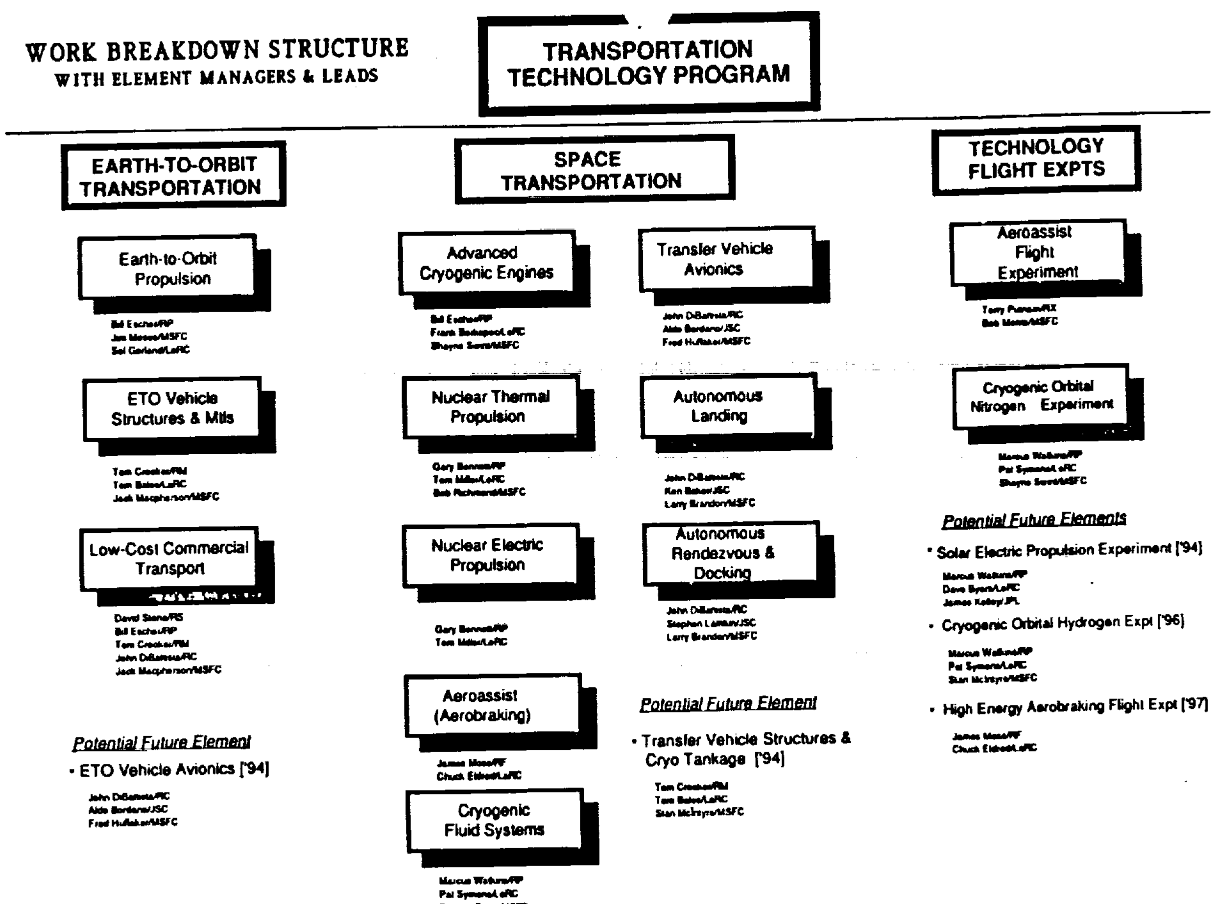
	STRATEGIC	CURRENT	3-X
• 1993	$ 8M	-0-	2.8M
• 1994	$10M	-0-	6.6M
• 1995	$30M	-0-	11.5M
• 1996	$40M	-0-	16.0M
• 1997	$30M	-0-	18.6M

PARTICIPANTS

- Marshall Space Flight Center
  Lead Center-technology acquisition, component level verification, system level verification

- Lewis Research Center
  Participating center-technology acquisition, component level verification

WORK BREAKDOWN STRUCTURE
WITH ELEMENT MANAGERS & LEADS



TRANSPORTATION TECHNOLOGY

EARTH-TO-ORBIT TRANSPORTATION

LOW COST COMMERCIAL TRANSPORT

ELEMENT OBJECTIVE: DEVELOP AND VALIDATE TECHNOLOGIES WHICH SHOW PROMISE FOR SIGNIFICANT REDUCTION IN THE COST OF MANUFACTURING, CHECKOUT AND OPERATION OF COMMERCIAL LAUNCH VEHICLES AND UPPER STAGES WHILE PROVIDING IMPROVEMENTS IN SYSTEM RELIABILITY AND AVAILABILITY (REDUCED TURN AROUND TIME)

TWO KEY AREAS OF CONSIDERATION

TECHNOLOGIES NOT BEING PURSUED IN OTHER ELEMENTS OF SPACE TECHNOLOGY PROGRAM

- TAILORED TO A COMMERCIAL NEED
- CURRENTLY BEING EVALUATED UNDER INDUSTRY SPONSORSHIP
- NASA CAPABILITIES/FACILITIES CAN CONTRIBUTE
- MAY PROVIDE ALTERNATE TECHNOLOGY TO MEET NASA NEEDS

APPLICATION (TRANSFER) OF NASA DEVELOPED TECHNOLOGIES TO MEET SPECIFIC COMMERCIAL NEED

- DEFINITION OF INDUSTRY-UNIQUE REQUIREMENTS
- VERIFICATION IN COMMERCIAL SYSTEM ENVIRONMENT (NASA OR INDUSTRY TEST BEDS)
- MAY PROVIDE EARLY VERIFICATION OF TECHNOLOGIES FOR NASA NEEDS

HC ETOT 1 5/17

TRANSPORTATION TECHNOLOGY

EARTH-TO-ORBIT TRANSPORTATION

LOW COST COMMERCIAL TRANSPORT

GROUND RULES:

- INDUSTRY IDENTIFIED INTEREST
- TECHNOLOGY REQUIRES SIGNIFICANT LEVEL OF DEVELOPMENT AND/OR VALIDATION AT OR NEAR FULL SCALE PRIOR TO DEVELOPMENT (NOT FLIGHT HARDWARE DEVELOPMENT ACTIVITY)
- BENEFIT FROM NASA INVOLVEMENT (NOT JUST $)

IMPLEMENTATION APPROACHES:

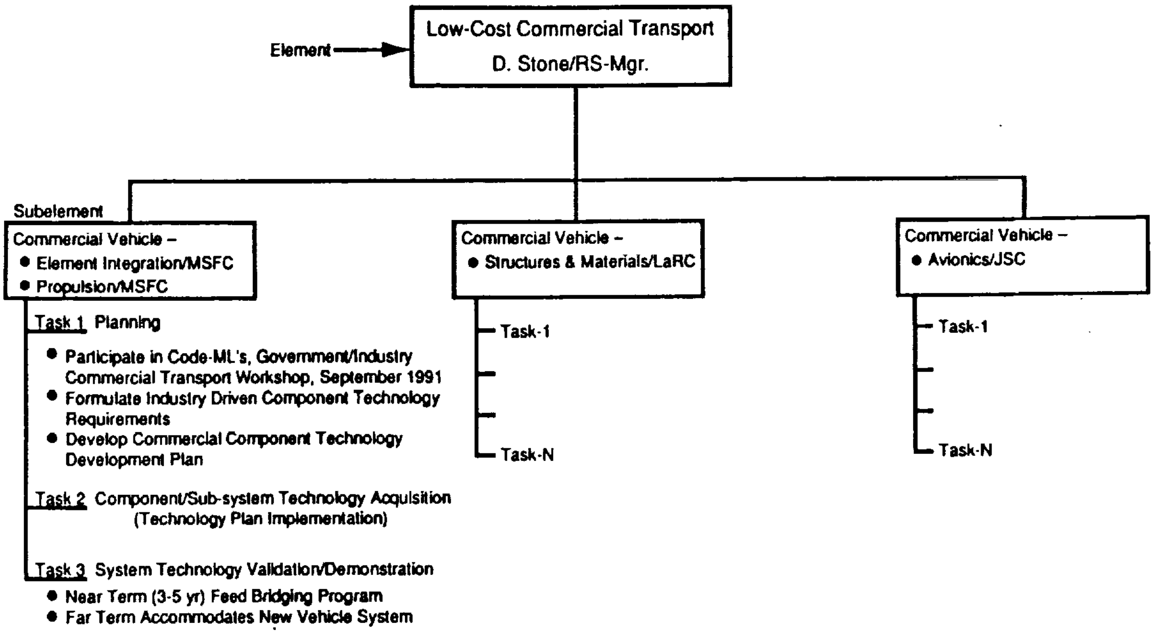
- SPACE ACT AGREEMENT BETWEEN NASA CENTERS AND INDUSTRY (NO NASA FUNDING PROVIDED DIRECTLY TO INDUSTRY)
- JOINTLY PLANNED PROGRAMS UTILIZING NASA FUNDING AND INDUSTRY IR&D (NASA RESEARCH ANNOUNCEMENT TO SOLICIT COMPETITIVE APPROACHES)

CONDUCTS:

- WORKSHOPS WITH INDUSTRY TO DISSEMINATE TECHNICAL DATA EARLY AND MORE EFFICIENTLY

HC ETOT 2 5/17

ELEMENT LEVEL – WORK BREAKDOWN STRUCTURE
CODE-RS



LOW-COST COMMERCIAL TRANSPORT TECHNOLOGY APPROACH

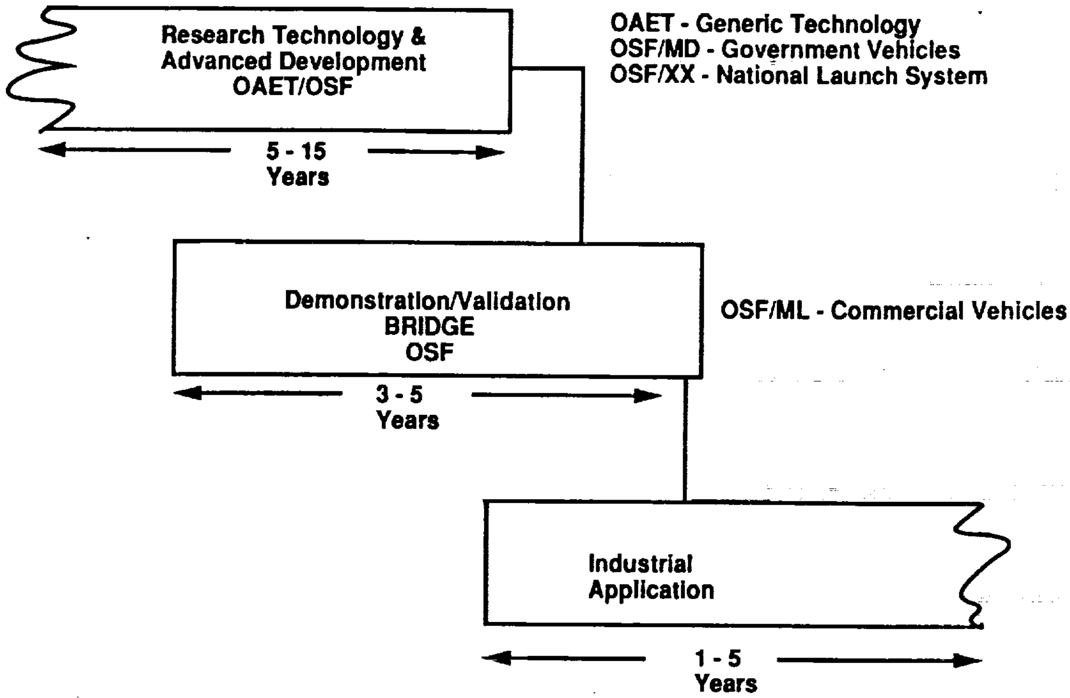
COMSTAC REPORT RECOMMENDATIONS (October, 1990):

- **2/3 of NASA's effort for the next five years should be directed toward the development and infusion of component technology enhancements into the existing fleet of U.S. Commercial ELV's.**
- **1/3 of NASA's efforts should go toward a next generation family of launch vehicles that could serve the future U.S. Commercial, Civil and Military needs; (NLS) !**

NASA's RESPONSE:

- **OSF / Code-ML, proposes a 3-to-5yr, technology demonstration / validation - "Bridging" program to meet the near-term ELV enhancement objectives.**
- **OAET / Code-RS, will support the Code-ML Bridging Program by providing:**
  - Transfer of existing (on-the-shelf) matured technologies to the private sector.
  - Accelerate relevant, on-going technology developments to comply with commercial schedule requirements.
  - Initiate new starts where required to meet the commercial needs.
- **OAET / Code-RS, will work with Industry to plan and implement a comprehensive systems technology program to enable development of the "next generation" low-cost, commercial ELV's.**

EVOLUTION OF SPACE TRANSPORTATION TECHNOLOGY



"COMMERCIAL VEHICLE PROPULSION SYSTEM NEEDS"

Desired Enabling Capabilities	Technology Requirements
• Low-Cost O2/H2 Liquid Booster Engine System	• NLS /STME To Provide
• Evolved Improvements in Existing Hydrocarbon Engine Systems (ATLAS, DELTA)	• Implement existing advancements in materials, mfg.-processes, and mechanical elements to affect modernization of turbomachinery, combustion devices, valves, etc.
• Family of Mid-Sized O2/H2 Upper Stage Engines (35 to 200 K-Lb. Thrust Class)	• Advanced Expander Cycle Engine Technology Issues: - Improved heat transfer methods - Vacuum Start Techniques - Automated Engine System Checkout Processes • Code-RP / LeRC-MSFC Advanced Cryogenic Engine
• Low-Cost, Low-Pressure Pump Fed Liquid Rocket Boosters - O2/HC - O2/H2	• Code-RP / MSFC Component Technology Program - Ablative Thrust Chamber and Nozzles - Simple Low-Cost Injectors - Low Pressure Rise Industrial Grade Pumps - Low-Cost Lightweight Tank Pressurization Systems
• Hybrid Boosters and/or Upper Stage Propulsion Systems	• Hybrid Propulsion Technology Issues: - Ignition System Optimization - Ballistic Assessment; Combustion Process Analyses Performance Prediction, Fuel Formulation, Flow Analy. - Fuel Grain Design; Strength, Support, Producibility - Propellant Tailoring, Oxidizer Injection optimization - Insulation Characterization, Case & Nozzle - High regression rate fuel chemistry

FOCUSED TEC..NOLOGY

LOW-COST COMMERCIAL TRANSPORT / PROPULSION TECHNOLOGIES

SUMMARY

- Impact:
  - Through the transfer of existing technological advancements in materials, manufacturing processes, and mechanical elements the existing cadre of O2/HC engines may be enhanced to provide improved reliability with reductions in manufacturing and operations cost.
  - Technologies that will enable the family of O2/H2 expander cycle engines will provide efficient, low-cost, reliable, robust, competitive upper stage propulsion to minimize the dollar/lb. cost to orbit.
  - Low pressure liquid booster engines (O2/HC & O2/H2) and hybrid engines will provide options and new capabilities to commercial ELV's that will reduce operations cost and improve safety and reliability while mitigating environmental effects.

- User Coordination:
  - Top level commercial needs are reasonably well understood
  - Detail technology requirements, priority, schedule, and level of maturity required, are TBD
  - Implementation strategy with other Codes is TBD
  - Coordination between NASA, USAF, DOT, and the Commercial Industry is required

- Overall Technical and Programmatic Status:
  - Code-ML's Bridging program has merit and momentum
  - Code-RS/RP will participate in the September 1991 Bridging program workshop to drive out technology requirements both near term and long range.

- Major Technical / Programmatic Issues:
  - Absence of firm technical requirements (workshop will rectify)
  - The synergy between propulsion technology elements within related ongoing programs (ETO & NLS/ADP) need to be defined in the context of the commercial requirements
  - Lack of inter- and intra-agency strategy and plan
  - There is a need to establish the scope and bounds of the Code-R participation