Integrated Technology Plan
for the Civil Space Program

Cryogenic Fluid Management (Base R&T)

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

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
## Apollo - Space Exploration Initiative Comparison

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

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.
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

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
Selected Concept - Piloted Configuration

Mass Properties

<table>
<thead>
<tr>
<th>Components</th>
<th>Mass (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prop/Avionics Core</td>
<td>7.19</td>
</tr>
<tr>
<td>Tanksets (4 TLI &amp; 2 LOI)</td>
<td>9.11</td>
</tr>
<tr>
<td>Crew Module</td>
<td>7.78</td>
</tr>
<tr>
<td>Aerobrake &amp; Equip</td>
<td>3.50</td>
</tr>
<tr>
<td>Vehicle Dry Mass</td>
<td>27.58</td>
</tr>
<tr>
<td>Propellant</td>
<td>174.0</td>
</tr>
<tr>
<td>Personnel/Misc</td>
<td>.66</td>
</tr>
<tr>
<td>Cargo w/Sppt</td>
<td>15.26</td>
</tr>
<tr>
<td><strong>Total Mass</strong></td>
<td><strong>217.50</strong></td>
</tr>
</tbody>
</table>

Cryogenic Fluid Management Technology Benefits Assessment Results

ETO mass savings for nominal mission with 30 day lunar stay

- 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

- 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

- 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)

- 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

Integrated Program
Cryogenic Fluid Systems

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
### 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
  - **Liquid Transfer**: Nonvented fill (zero-g) and optimized low-g fill
  - **Fluid Handling**: Slosh control for vehicle operations

**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
- 1997: 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**

<table>
<thead>
<tr>
<th>Year</th>
<th>Amount ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991</td>
<td>1.5 M</td>
</tr>
<tr>
<td>1992</td>
<td>2.6 M</td>
</tr>
<tr>
<td>1993</td>
<td>2.1 M</td>
</tr>
<tr>
<td>1994</td>
<td>2.2 M</td>
</tr>
<tr>
<td>1995</td>
<td>2.3 M</td>
</tr>
<tr>
<td>1996</td>
<td>2.4 M</td>
</tr>
<tr>
<td>1997</td>
<td>2.5 M</td>
</tr>
</tbody>
</table>

**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

---

### 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
  - **Liquid Transfer**: Nonvented fill (zero-g) and optimized low-g fill
  - **Fluid Handling**: Slosh control for vehicle operations

**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**

<table>
<thead>
<tr>
<th>Year</th>
<th>Amount ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991</td>
<td>1.5 M</td>
</tr>
<tr>
<td>1992</td>
<td>0.0 M</td>
</tr>
<tr>
<td>1993</td>
<td>8.5 M</td>
</tr>
<tr>
<td>1994</td>
<td>11.0 M</td>
</tr>
<tr>
<td>1995</td>
<td>11.3 M</td>
</tr>
<tr>
<td>1996</td>
<td>11.8 M</td>
</tr>
<tr>
<td>1997</td>
<td>11.0 M</td>
</tr>
</tbody>
</table>

**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

---

**Note:** This element is closely coordinated with development efforts in NASA/OSS and other related Government programs; resources shown are NASA/OAET only
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
Technology Area – Pressure Control

**Effort**

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

**Base R&T Activities**

- 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)

**Focused Technology Activities**

- Thermal stratification and self-pressurization rise
- Active TVS performance
- Passive TVS performance
- Pressure control system demonstration
- CONE Flight Experiment
- COHE Flight Experiment
Technology Area – Liquid Supply

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

**Base R&T Activities**
- Generic analytical models
- LAD screen characterization
- VTRE flight experiment (In-Step)
- Autogenous pressurant generation

**Focused Technology Activities**
- 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

Base R&T Activities

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

Focused Technology Activities

- No-vent fill of a flight weight tank
- Large scale system demonstration
- FARE Flight Experiment
- SOFTE Flight Experiment
- CONE Flight Experiment
- COHE Flight Experiment
Technology Area – Fluid Handling

Effort

- Low-g liquid fluid dynamics (slosh)
- Low-g fluid dumping/venting
- Instrumentation (LV 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 LV 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
Fluid Handling Technology Development Plan

Calendar Year

Deliverables
- Analytical Models
- Design Criteria

Test Facilities
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

<table>
<thead>
<tr>
<th>Fluid Systems: Test Fluid</th>
<th>LH₂ or LN₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dewar Capacities</td>
<td>18, 5, and 1.7 ft³</td>
</tr>
<tr>
<td>Tank Operating Pressures</td>
<td>2-30 psia</td>
</tr>
<tr>
<td>LH₂ Flow Rates</td>
<td>5-100 lb/hr</td>
</tr>
<tr>
<td>LN₂ Flow Rates</td>
<td>60-1200 lb/hr</td>
</tr>
<tr>
<td>Pressurants</td>
<td>GH₂, GH₂ and GHe</td>
</tr>
</tbody>
</table>

Insulation Systems:

- Dewars
- 10 layers of MLI

Lines
- Vacuum Jacket or Foam

Data Collection:

Data System
- IBM PC-AT
- 256 Channels

---

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 LH₂ in simulated thermal and vacuum environments.

---

Test Capabilities

<table>
<thead>
<tr>
<th>Tank Fluid</th>
<th>Liquid Hydrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank Operating Pressures</td>
<td>1-60 psia</td>
</tr>
<tr>
<td>LH₂ Flow Rates</td>
<td>100-2000 lb/hr</td>
</tr>
<tr>
<td>Pressurants</td>
<td>GH₂ and GHe</td>
</tr>
</tbody>
</table>

Facility Capabilities

<table>
<thead>
<tr>
<th>Vacuum</th>
<th>5x10⁻⁷ torr</th>
</tr>
</thead>
<tbody>
<tr>
<td>- with LH₂ Cryoshroud</td>
<td>5x10⁻⁴ torr</td>
</tr>
<tr>
<td>LH₂/LN₂ Cryoshroud Temp.</td>
<td>-423 °F/-320 °F</td>
</tr>
<tr>
<td>LH₂ Capacity</td>
<td>26,000 gal</td>
</tr>
<tr>
<td>Max. Test Package Weight</td>
<td>16,000 lb</td>
</tr>
<tr>
<td>Data System</td>
<td>Escort D</td>
</tr>
<tr>
<td></td>
<td>512 Channels</td>
</tr>
</tbody>
</table>
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
  - GN₂ Supply: 4200 PSIG
  - GH₂ Supply: 4400 PSIG
  - GHe Supply: 4000 PSIG
  - LH₂: 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

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

EXPERIMENT MOUNTS IN GET AWAY SPECIAL CONTAINER

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 lb
  - Locker Kit: 20.0 lb
- Total: 230.8 lb
- Tanks:
  - Material: Acrylic
  - Diameter: 12.5"
  - Volume: 1022 in³
- Test Fluid:
  - Water + Additives
  - Amount: 5.4 gal

Three-Way Flow Control Valve

Upper Module With Integral Lighting

Receiver Tank (12.5 in Diam.) With Total Communication Liquid Acquisition Device and Battled Inlet

Calibrated Cylinder For Expulsion Efficiency Measurement

Supply Tank With Elasticomeric Diaphragm (12.5 in, Diam.)

Lower Module

PR5-18
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

Transportation Technology
Technology Flight Experiments

Cryogenic Orbital Nitrogen Experiment

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 102
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
1996 STS integration and flight completed
1998 Data analyzed and computer models updated
1999 Final report on LN2 and L02 pressure control and liquid transfer issued

Resources

<table>
<thead>
<tr>
<th>Year</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>1993</td>
<td>3.4 M</td>
</tr>
<tr>
<td>1994</td>
<td>15.0 M</td>
</tr>
<tr>
<td>1995</td>
<td>24.0 M</td>
</tr>
<tr>
<td>1996</td>
<td>23.0 M</td>
</tr>
<tr>
<td>1997</td>
<td>18.7 M</td>
</tr>
</tbody>
</table>

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

Note: This element is closely coordinated with development efforts in NASA/OSSF and other related Government programs; resources shown are NASA/OAET only.
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/LN₂ 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-91-53669

CRYOGENIC ORBITAL NITROGEN EXPERIMENT (CONE)

COMMAND AND DATA HANDLING UNIT

HITCHHIKER AVIONICS BOX

POWER DISTRIBUTION UNIT

FLOW METER ELECTRONICS

EXPERIMENT VALVE ELECTRONICS

RECEIVER TANK

VALVE PANEL (RCVR TANK)

PRESSURANT BOTTLE

RECHARGE BOTTLE

HITCHHIKER-M CARRIER

VALVE PANEL (STORAGE TANK)

STORAGE TANK

VALVE PANEL (PRESSURANT BOTTLES)

PR6-20
# Cryogenic Orbital Hydrogen Experiment (COHE)

## Description
- Subcritical liquid hydrogen flight experiment
- Preferred carrier: ELV
- 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
- Validate design equations and generate design criteria for large cryogenic fluid systems
- Apply results to design of future LH2 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

## Resources

<table>
<thead>
<tr>
<th>Year</th>
<th>Budget</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>$3.6 M</td>
</tr>
<tr>
<td>1997</td>
<td>17.0 M</td>
</tr>
</tbody>
</table>

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

## Participants
- Lewis Research Center
  - Responsibilities TBD
- Marshall Space Flight Center
  - Responsibilities TBD

---

**Transportation Technology**

**Technology Flight Experiments**

**Cryogenic Orbital Hydrogen Experiment**

Programmatic Objectives

- Address critical cryogenic fluid management technologies via system demonstration and space experimentation to validate analytical models and to demonstrate critical components and processes.

Technical Objectives

<table>
<thead>
<tr>
<th>Objective</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure Control</td>
<td>Active and passive system demos</td>
</tr>
<tr>
<td>Liquid Supply</td>
<td>Capillary acquisition device demo</td>
</tr>
<tr>
<td>Liquid Transfer</td>
<td>Validate zero-g models for tank chilldown and no-vent fill</td>
</tr>
<tr>
<td>Fluid Handling</td>
<td>Demonstrate liquid dumping in zero-g</td>
</tr>
</tbody>
</table>

Schedule

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

Sample Concept
Program Coordination

Cryogenic Fluid Management
Program Coordination

LeRC
- On-going technical work

LeRC
- Planning for next year

Presentation to NASA HQ
- Budget
- Technical program

MSFC
- On-going technical work

MSFC
- Planning for next year

Coordinating Response Mtg. (Dec/Jan)
- Rephrasing of program to meet new budget

Advisory Committee Mtg.
- Status update on-going programs
- Budget preparation for next FY
  P. Symons, Chair
  J. McCarty, Co-chair
  J. Faddoul  L. Jones
  J. Gaby  S. McIntyre
  J. Aydelott  L. Hastings

Actual Budget Available

Technical Interchange
- Meeting to be held quarterly

LeRC
MSFC
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

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
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.