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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

- 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

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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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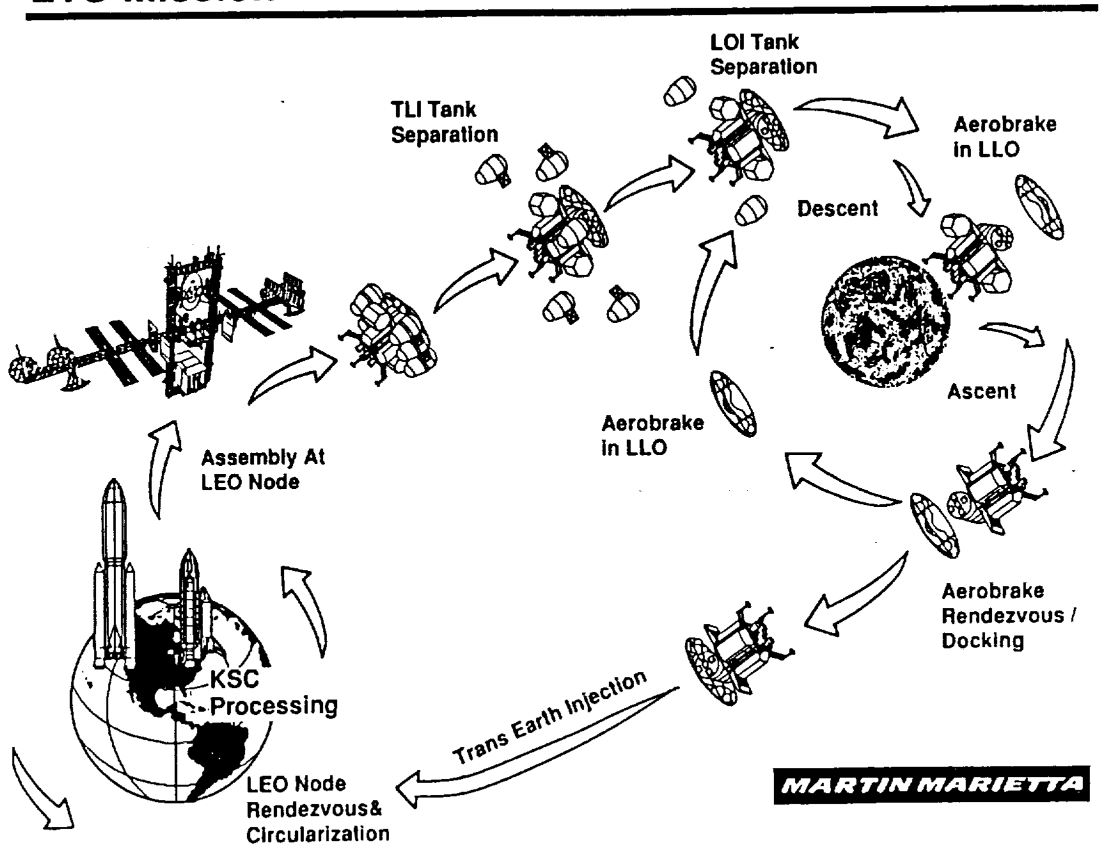
Benefits Assessment

- 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)

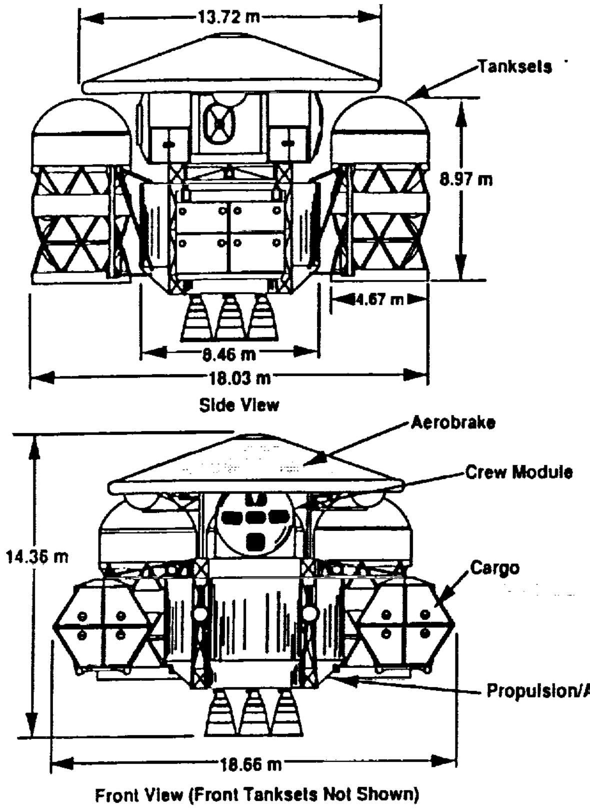
- State-of-the-Art Assumptions for Benefit Assessment
  - Thermal control: 1/2 inch MLI with foam substrate
  - Pressure control: Shuttle Centaur system design criteria
  - Liquid transfer: No orbital capability (tanks loaded on ground) therefore, space-based/reusable concept precluded

- Mass Savings (Technology Benefits) accrue from boiloff reductions and decreases in tankage volume/mass

LTS Mission



Selected Concept - Piloted Configuration



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)

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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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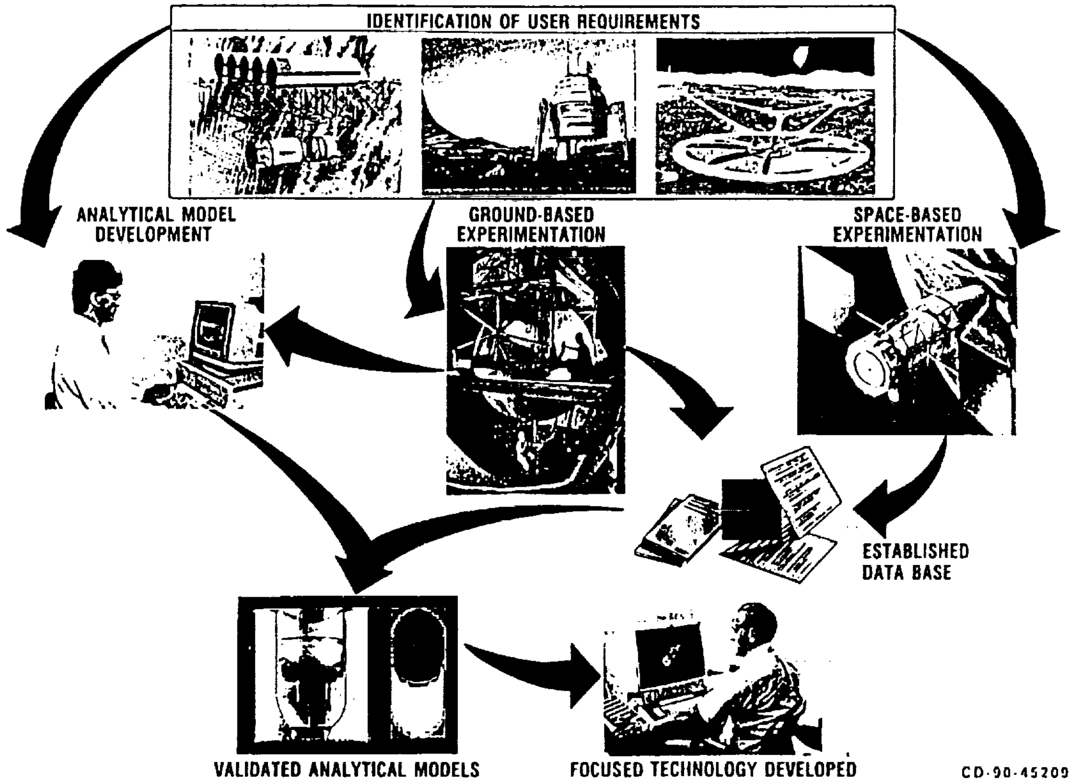
Integrated Program

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 childown 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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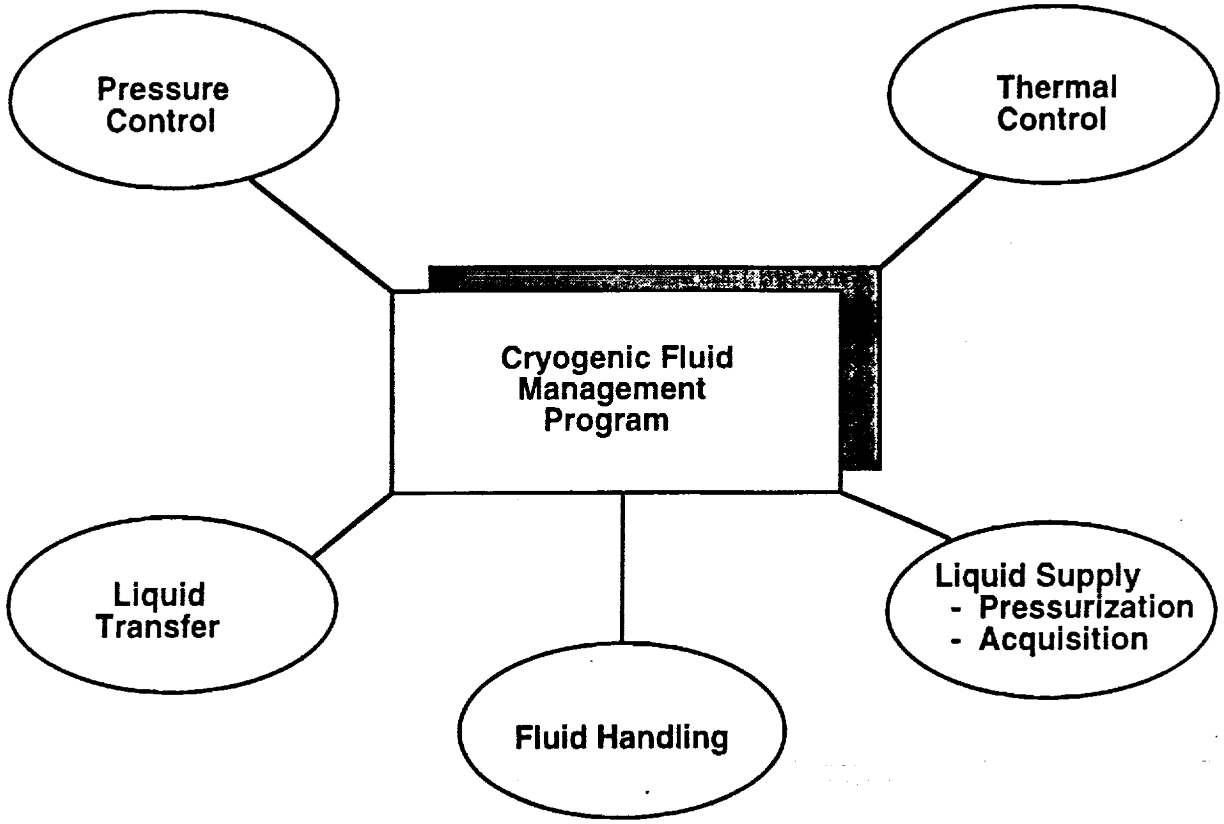
Major Technology Areas



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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

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

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

<u>Focused Technology Activities</u>

- 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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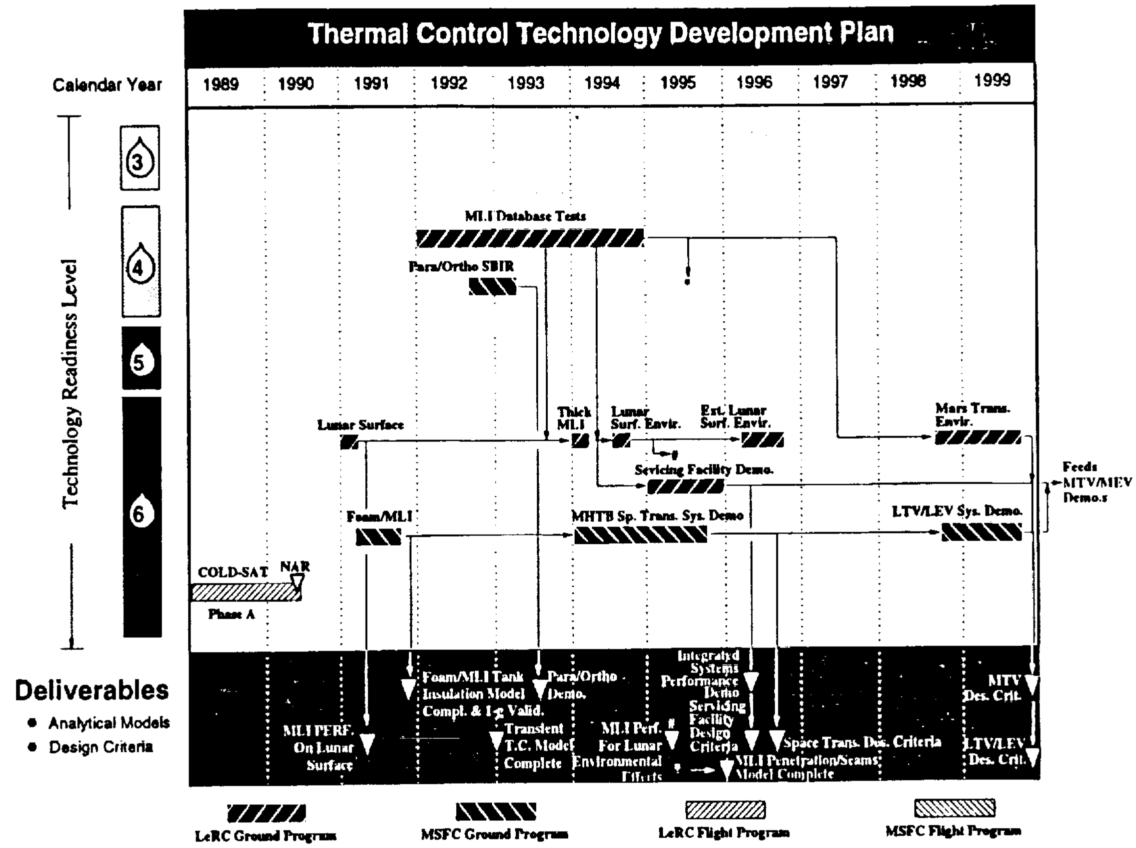

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Technology Area – Pressure Control

Effort

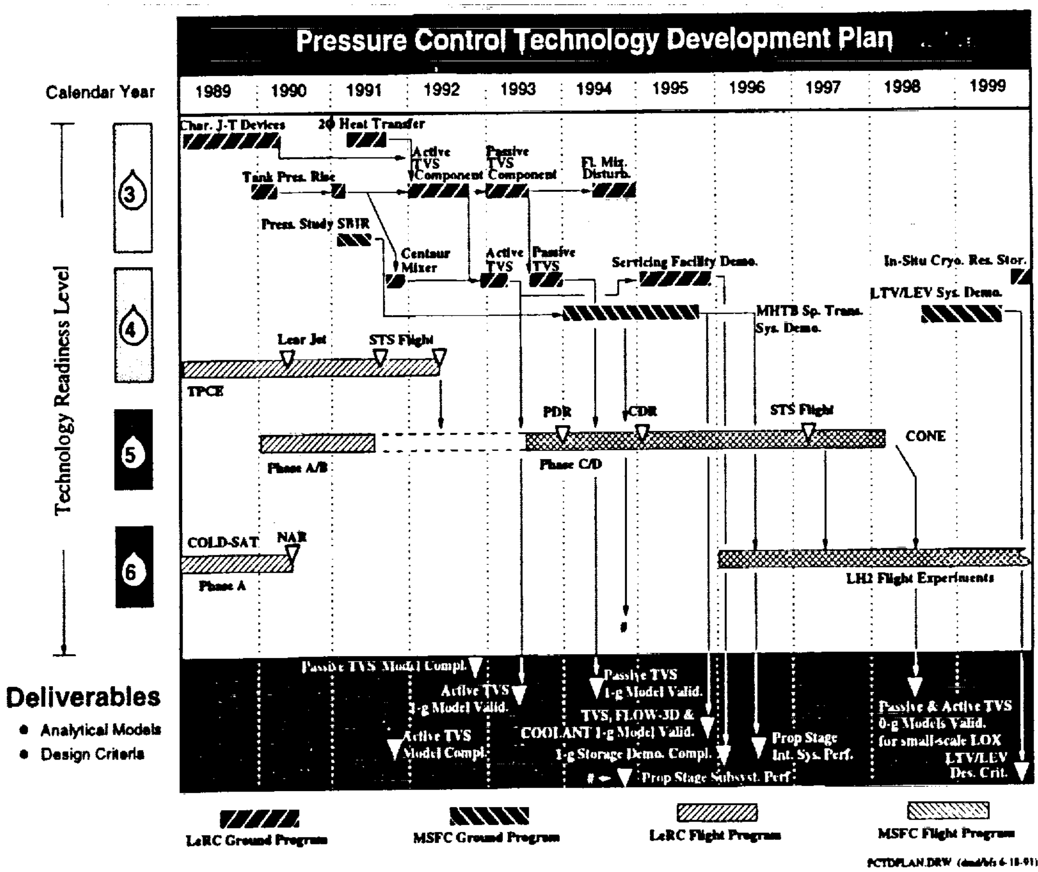
- Passive TVS thermal performance
- Active TVS fluid mixing
- Active TVS heat exchanger thermal performance
- Thermal stratification and self-pressurization

<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



Technology Area -- Liquid Supply

Effort

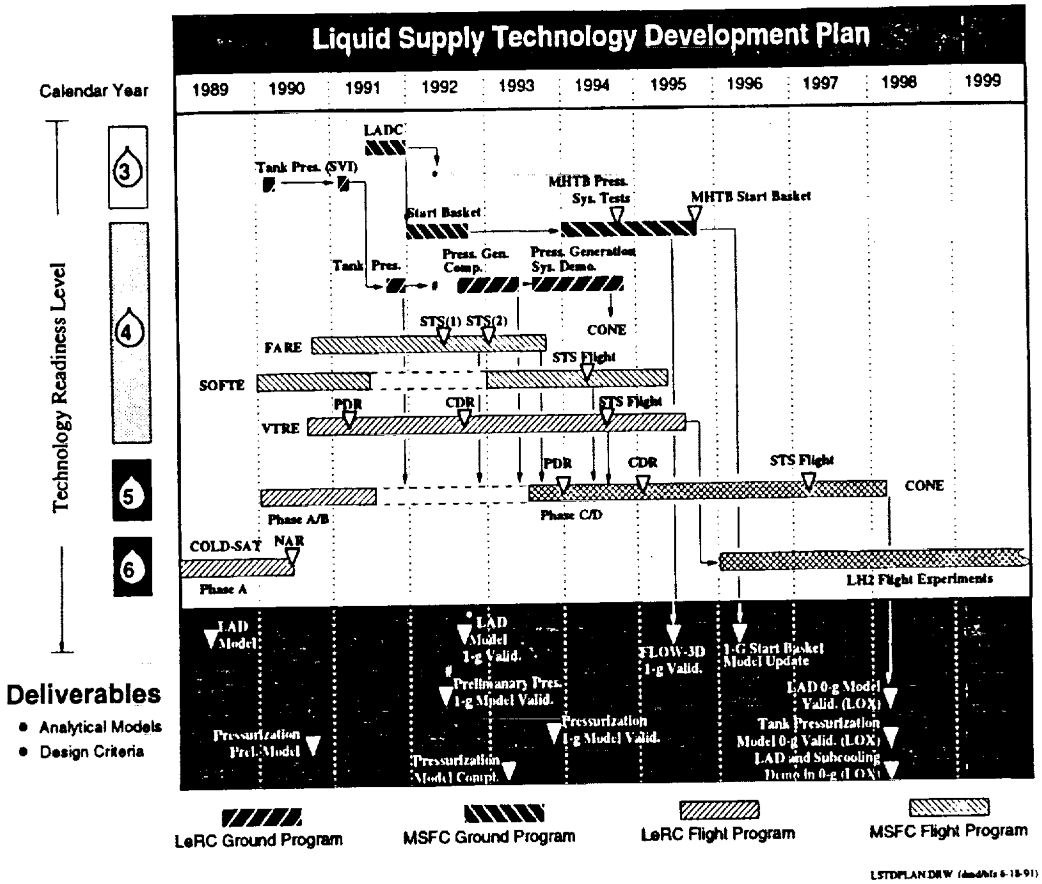
- LAD performance characteristics
- Autogenous tank pressurization for liquid transfer
- Autogenous tank pressurization for engine start/run
- Autogenous pressurant generator

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

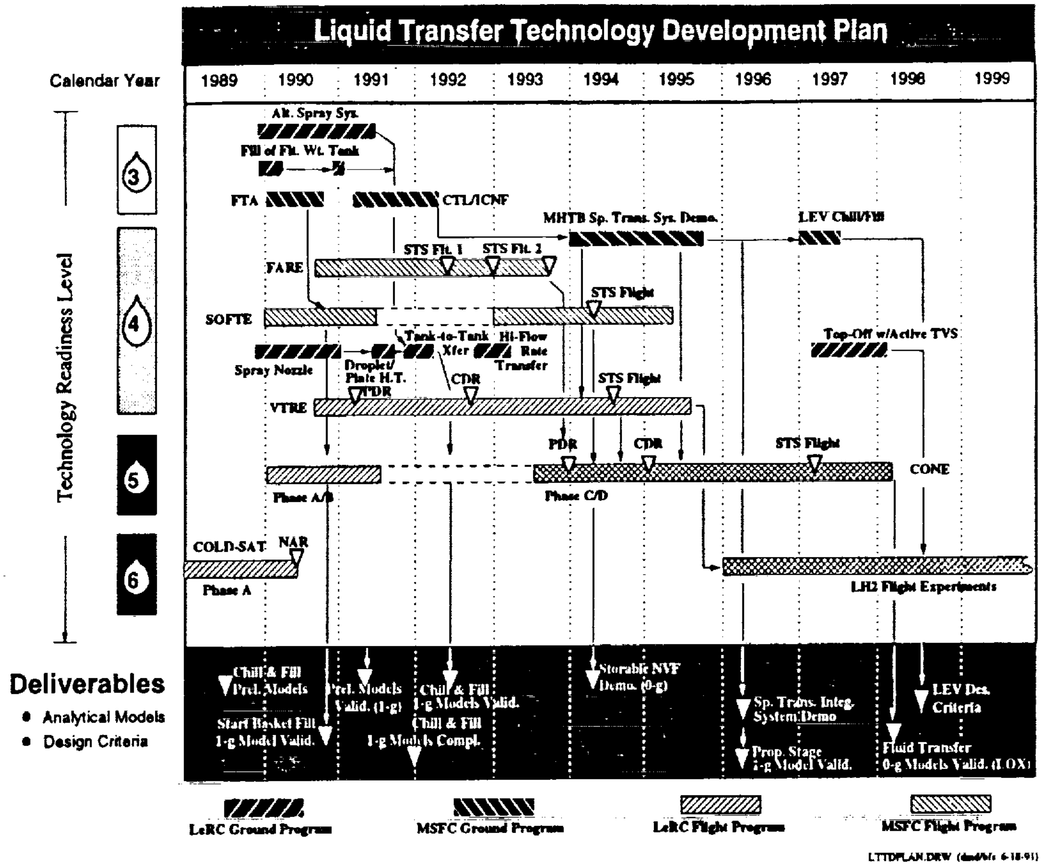
- Tank Chilldown
- Ullage Condensation
- Tank no-vent fill
- LAD Fill

<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



Technology Area -- Fluid Handling

Effort

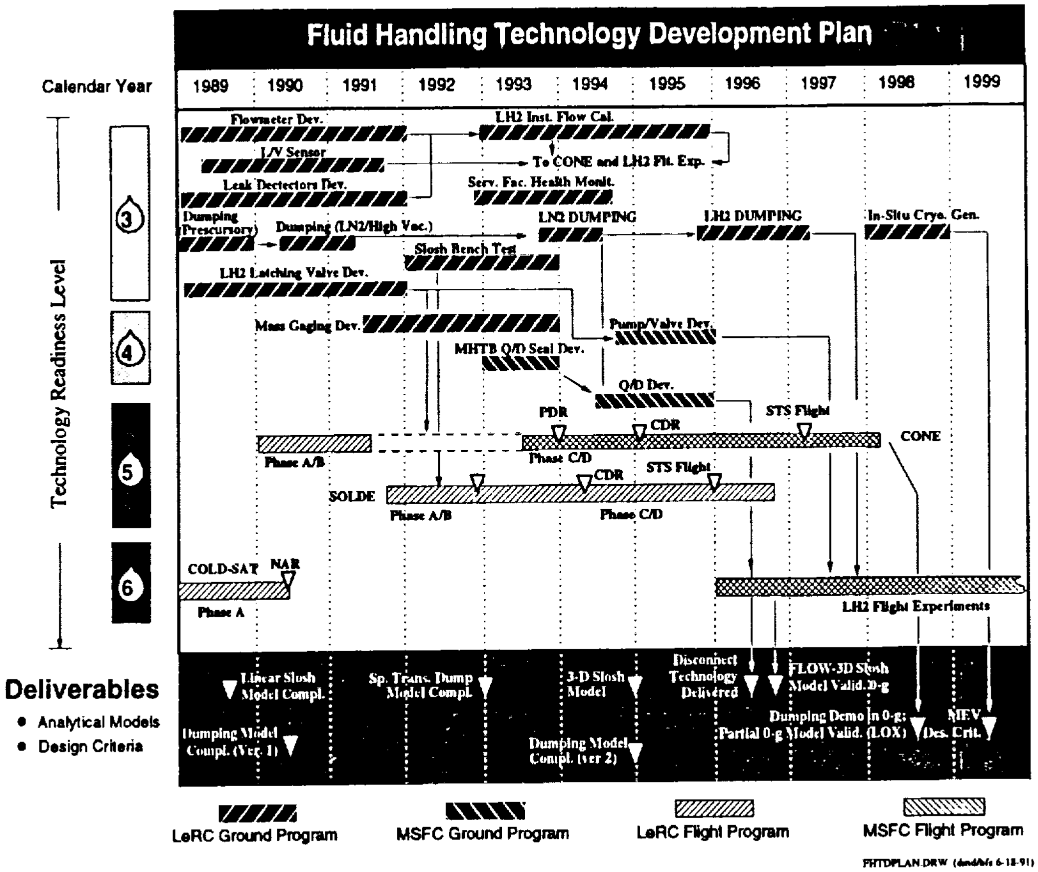
- Low-g liquid fluid dynamics (slosh)
- Low-g fluid dumping/venting
- Instrumentation (L/V sensors, mass gauging, leak detectors, health monitoring)
- Components (valves, flowmeters, quick disconnects, pressurant generator, TVS mixer)

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

- 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)

<u>Focused Technology Activities</u>

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



Test Facilities

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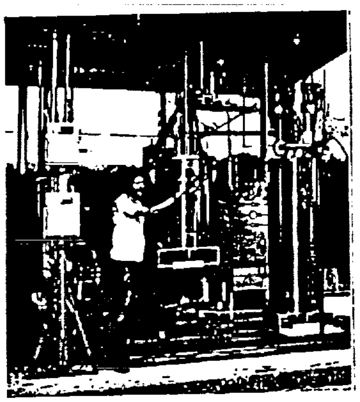
Portable Cryogenic Research Test Rig

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.



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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

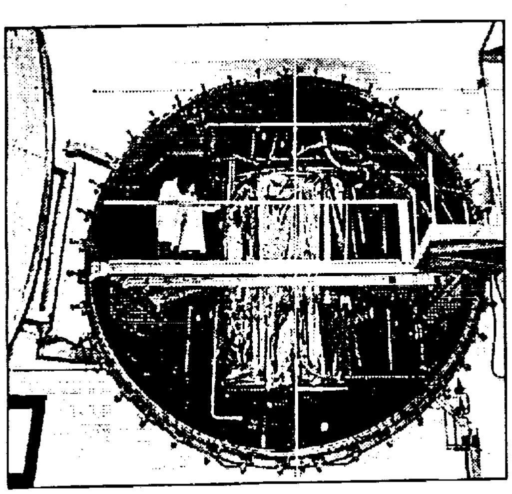
NASA
Lewis Research Center
Cryogenic Fluids ›chnology Office
Space Flight Systems Directorate
CF,O

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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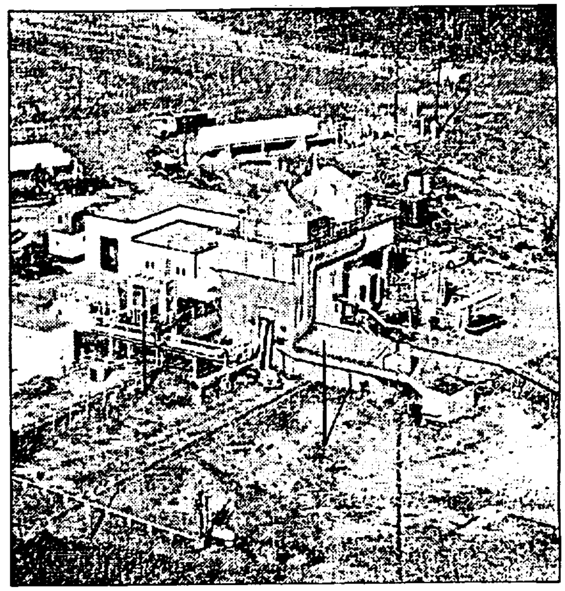
MSFC Cryogenic Fluid Management Test Facilities
Test Stand 300

- 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

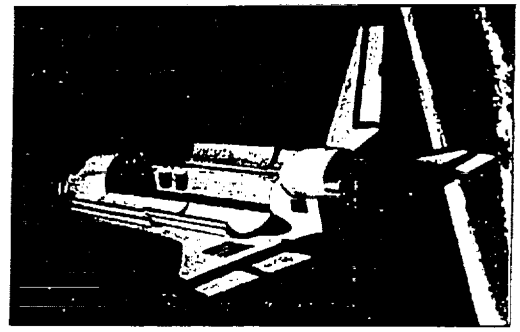


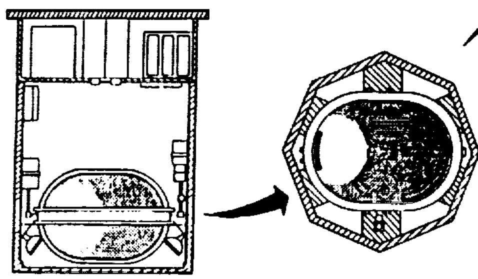
Technology Flight Experiments

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

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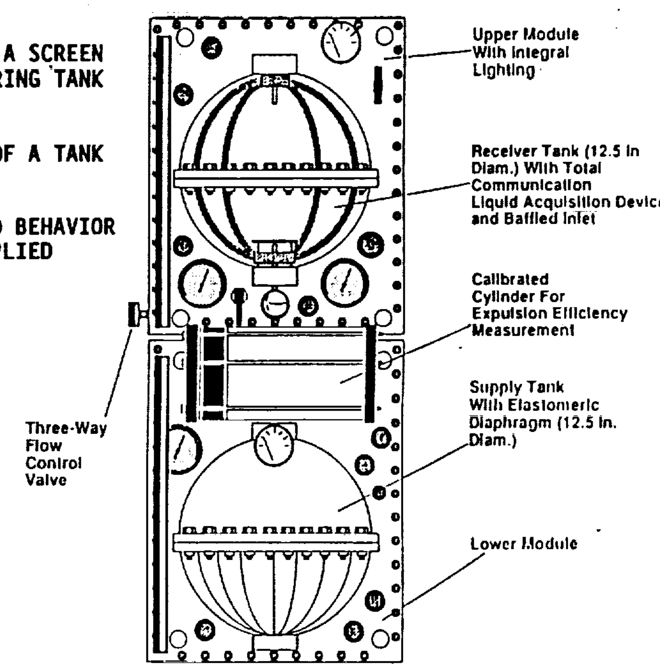
Fluid Acquisition and Resupply Experiment (FARE)

FARE I TEST OBJECTIVES

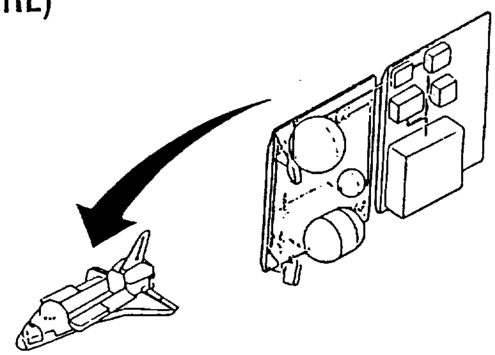
- DEMONSTRATE LOW GRAVITY OPERATION OF A SCREEN CHANNEL LIQUID ACQUISITION DEVICE DURING TANK EXPULSION AND REFILL
- DEMONSTRATE THE LOW GRAVITY VENTING OF A TANK WHILE FILLING
- DEMONSTRATE STATIC AND DYNAMIC LIQUID BEHAVIOR DURING LOW GRAVITY CONDITIONS AND APPLIED ACCELERATIONS

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

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



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 LO2 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 childown 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

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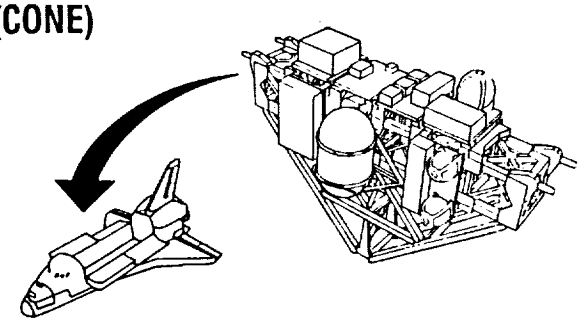
CRYOGENIC ORBITAL NITROGEN EXPERIMENT (CONE)



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

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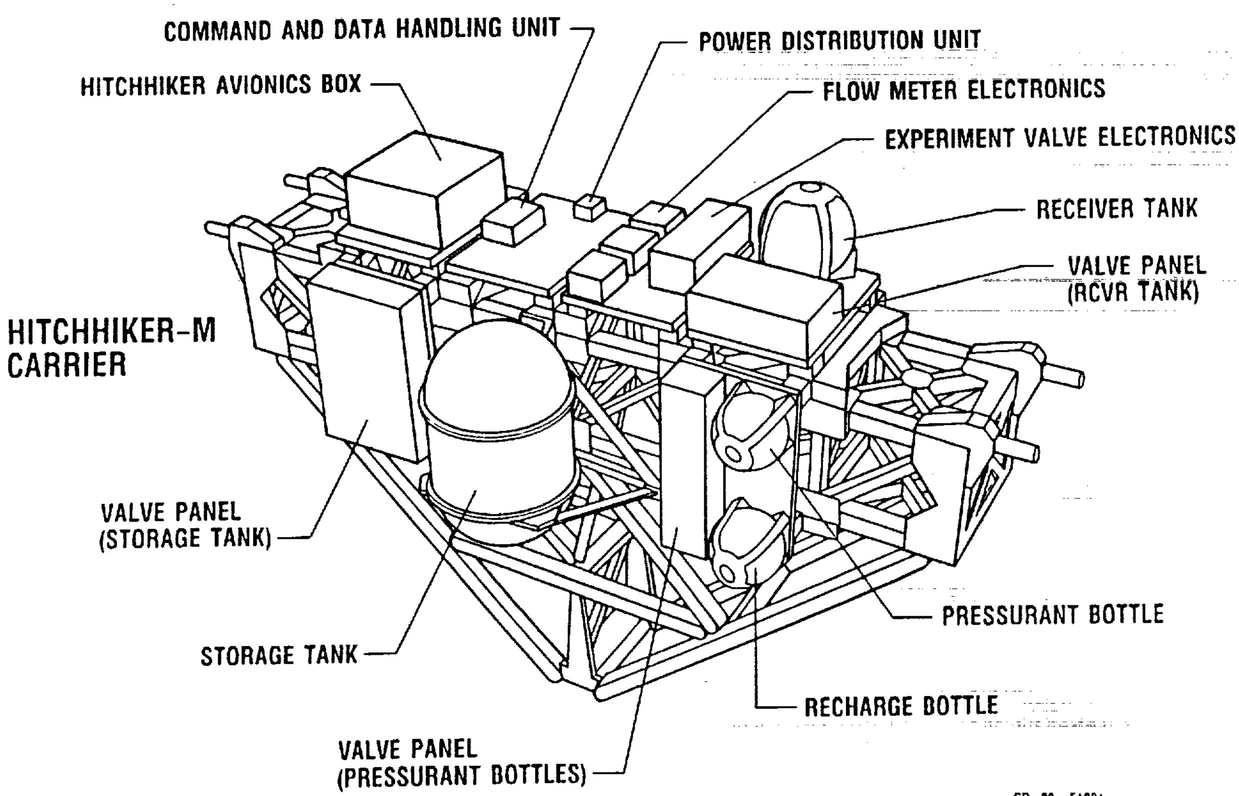
CRYOGENIC ORBITAL NITROGEN EXPERIMENT (CONE)



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Technology Flight Experiments

Cryogenic Orbital Hydrogen Experiment

Objectives

Programmatic

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

Technical

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

Lewis Research Center

Responsibilities TBD

Marshall Space Flight Center

Responsibilities TBD

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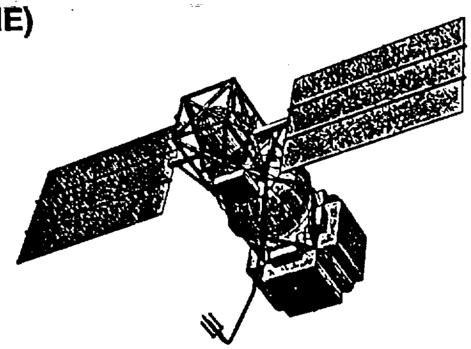
CRYOGENIC ORBITAL HYDROGEN EXPERIMENT (COHE)

DESCRIPTION

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



Sample Concept

PROGRAM OBJECTIVES

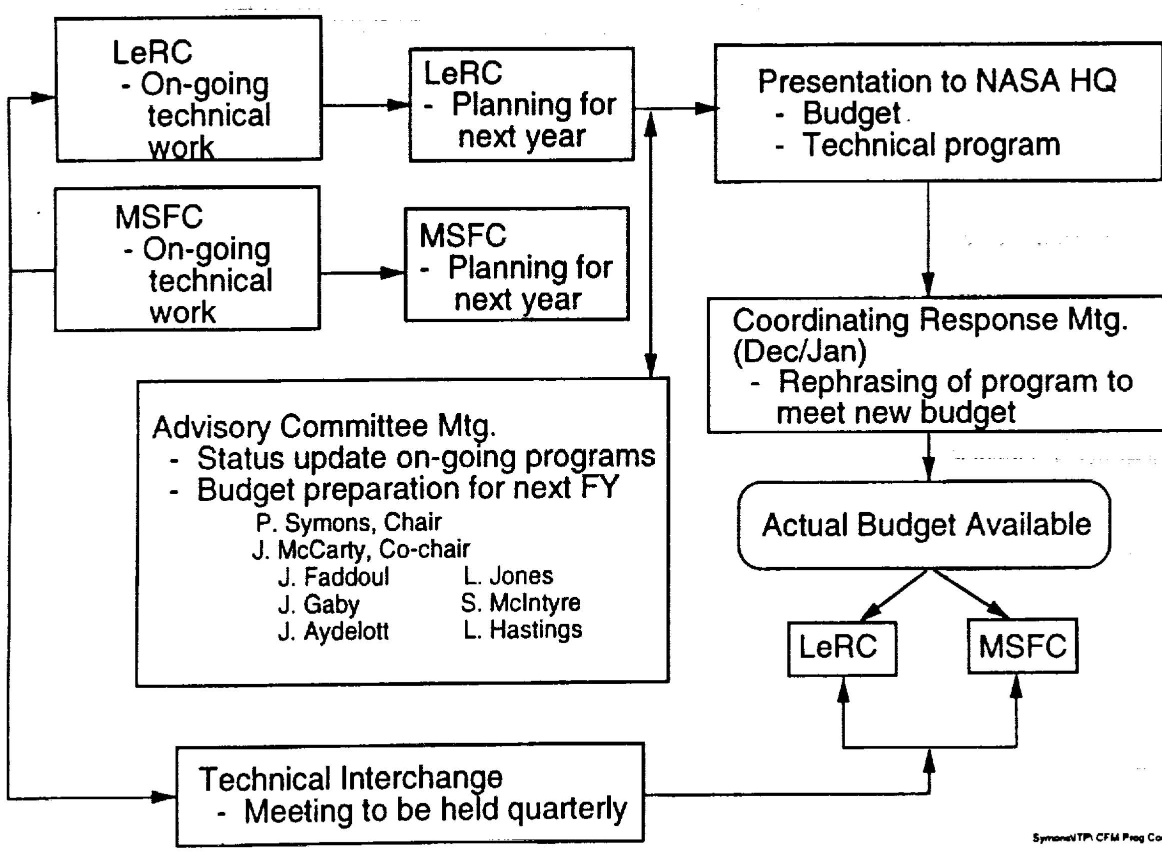
- Provide experimental data and component demonstration for the operation of a subscale cryogenic fluid management system in space
- Validate design equations and generate design criteria for large cryogenic fluid systems
- Apply results to design of future LH_2 space systems

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\TP\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\TP\Summary tad 6-18-91

Cryogenic Fluids Systems Technology

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

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