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4.0 MANNED TRANSFER VEHICLES

4.1 Lunar Transfer Vehicle Studies – Joseph Keeley, Martin Marietta

Lunar transportation architectures exist for several different mission scenarios. Direct flights from Earth are possible, as the Apollo program clearly demonstrated. Alternatively, a space transfer vehicle could be constructed in space by using the Space Station as a base of operations, or multiple vehicles could be launched from Earth and dock in LEO without using a space station for support. Similarly, returning personnel could proceed directly to Earth or rendezvous at the Space Station for a ride back home on the Space Shuttle. Multiple design concepts exist which are compatible with these scenarios and which can support requirements of cargo, personnel, and mission objectives. Regardless of the ultimate mission selected, some technologies will certainly play a key role in the design and operation of advanced lunar transfer vehicles. Current technologies are capable of delivering astronauts to the lunar surface, but improvements are needed to affordably transfer the material and equipment that will be needed for establishing a lunar base. Materials and structures advances, in particular, will enable the development of more capable cryogenic fluid management and propulsion systems, improved structures, and more efficient vehicle assembly, servicing and processing.

Advanced materials such as aluminum-lithium and graphite epoxy composites are anticipated to reduce the weight of vehicle structures and increase the payload mass fraction of space transfer vehicles. Even without optimizing the component design to most advantageously use the improved properties of these materials, a comparison of the weights of system elements indicates that component dry mass could be reduced by 15% to 55%. The greatest weight savings are available on items such as tanks and Lunar Excursion Vehicle lander legs.

Additional studies are needed to assess and prioritize technology development efforts. The assessment of alternative concepts must include more than just life cycle costs. Performance, schedule and other factors, such as operational life, producibility, maintainability, and fault tolerance, are also key discriminators. Nonetheless, affordability is undeniably important, and a careful examination of the life cycle costs of aeroassisted vs. all-propulsive systems reveals that payoffs may exist for the use of aerobrakes for reusable manned lunar transfer vehicles. If aerobrakes are used as part of the propulsion system, advanced structural and material sciences will play a key role in their development.

LUNAR TRANSFER SYSTEMS

TECHNOLOGIES

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Agenda

Space Transfer Objectives

Lunar Transfer Concept

Technology Applications/Benefits

Aerobrake Technology

"Design of Experiments" for Materials

Program Summary

Lunar Transfer Options

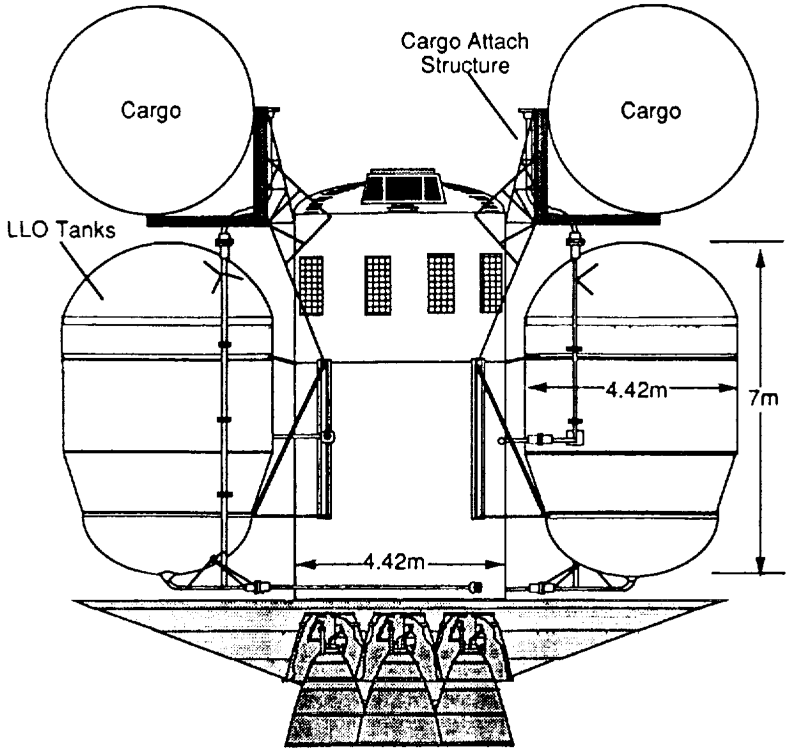
To the Moon

- Direct Flight and Return (Apollo)
- Space Based (90 Day SEI Study)
- Ground Based Rendezvous & Docking in LEO

From the Moon

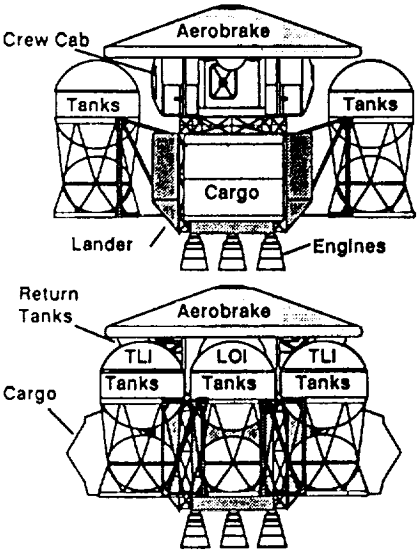
- Return Direct to Earth (Apollo)
- LEO Rendezvous at Station/Shuttle Deorbit/Landing

LTV Configuration with Cargo



Mass Properties Summary (t)	
Structure	1.00
DropTanks	6.50
Core Propulsion	.97
Main Engines	1.24
RCS	.14
GN&C	.12
C&DM	.26
Power	.45
Thermal Control	.15
Aerobrake	1.81
Crew Module	6.63
Contingency	2.89
Total Dry Weight	22.16

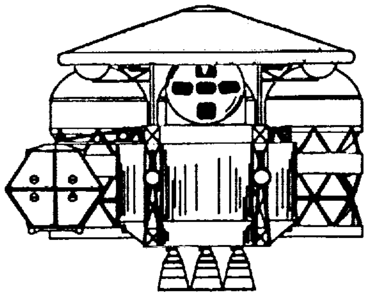
Single Propulsion Lunar Transportation System



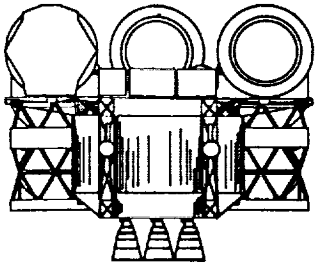
Side View

- Single Stage Yields Low Life Cycle Cost
  - Single Propulsion System
  - Single Crew Module
  - High Reusability Of Elements
- No Aerobrake Penetrations
- Piloted Configuration Supports 33.0 mt "Cargo-Only" Requirement
- Single Stage Yields Lowest Number of Mission Failure Modes
  - No Crew Transfers
  - No Cargo/Crew Transfer
- Potential For Reusable "Cargo-Only Vehicles"
- 25 ft x 100 mt ETO Capability Requirement

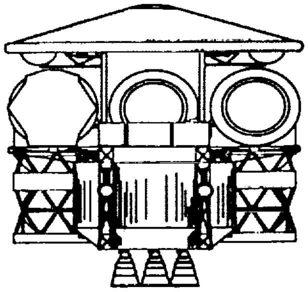
LTS Configuration Family



Piloted Configuration



Cargo (Expendable) Configuration

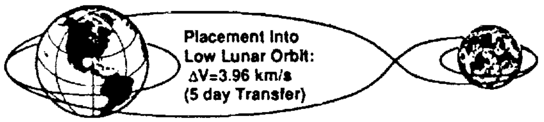


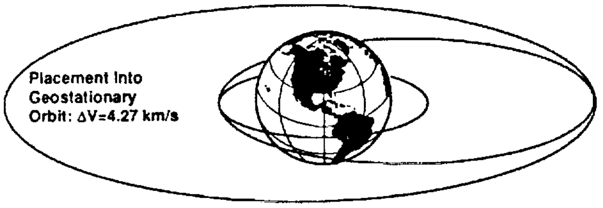
Cargo (Reusable) Configuration

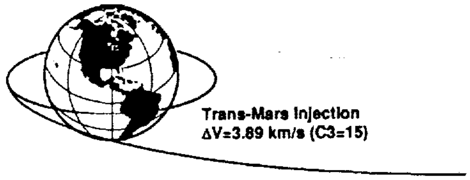
- Single Propulsion System
- Common Propulsion/Avionics Core
- Single Crew Module
- Large Cargo Platform ~ 14.8 m x 10.5 m
- Rigid Aerobrake - 13.7 m
- Piloted Cargo - 14.6 t
  - w/Propellant Mass - 174.0 t
- Expendable Cargo - 33.0 t (max - 37.4 t)
  - w/Propellant Mass - 146.5 t (max - 161.3 t)
- Reusable Cargo - 25.9 t
  - w/Propellant Mass - 169.3 t

STV as HLLV Upper Stage

- Several STV DRMs Require Similar ΔVs







- Future HLLV's Will Need a Generic High Energy Capability
- Any New HLLV Will Be At Least 27.6' Diameter (Same as ET)
- Upper Stage (STV) Should Be Designed to Maximize Payload To Commonly Used Destinations: GEO, LLO, X-Mars
- Burning Upper Stage to LEO Drives Stage to Different Design

STV Objectives

- Define the Preferred Concept(s) and Programmatics of a Space Transfer Vehicle System to Accomplish Unmanned Delivery and Manned Exploration Missions

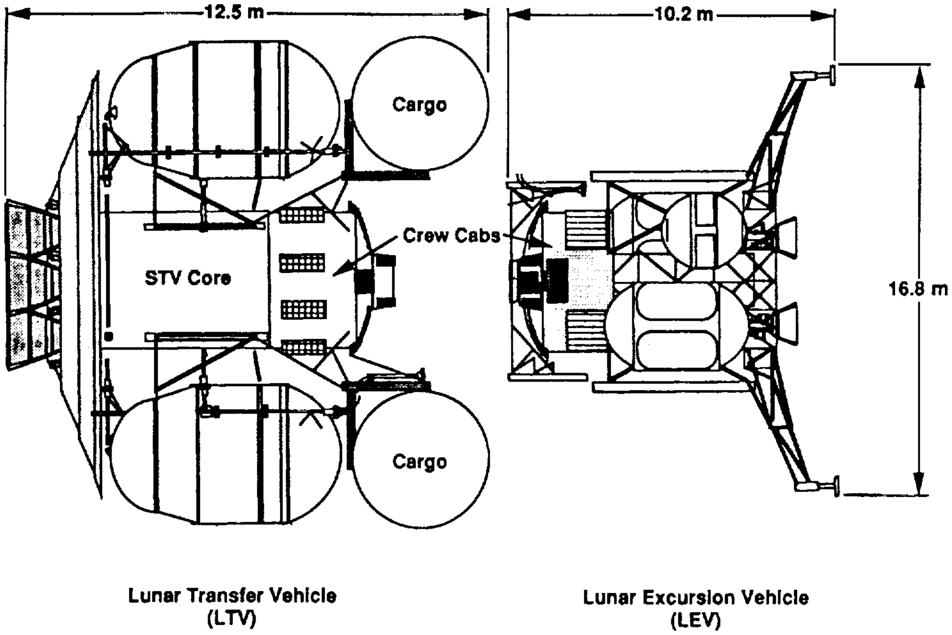
- Evolve from an Initial Vehicle that Captures National Unmanned Earth Orbit and Planetary Missions (DOD and NASA)

- Identify Critical Technology Requirements and Provide Technology and Advanced Development Program Planning Data

- Expand Space Transfer Vehicle Interfaces/Interactions For:
  - Operating at Space Station, or LEO Node
  - A Range of Launch Vehicles
  - Manrated Reusable Vehicles
  - NASA & Air Force Joint Use

Provide a Cost-Effective Space Transfer Vehicle System Capable of Meeting National Goals for Unmanned Space Transfer and Meeting the Needs of a Manned Exploration Program Leading to Human Presence on the Moon and Evolution to Mars

LTV/LEV Configuration



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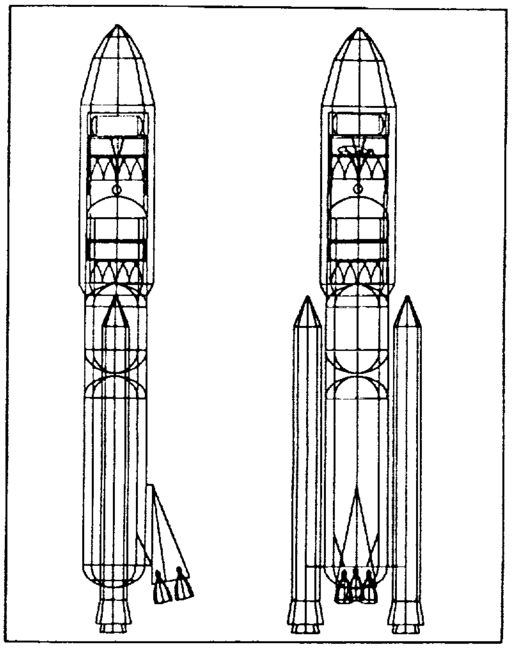
STV As HLLV Upper Stage

Payload Capabilities to LLO (4 km/s) (All Masses in tonnes)	34.6
Height (m)	82.3
Gross Mass	2,172
Stage-0	
2 Advanced Solid Rocket Boosters	1,214.5
Stage-1	
External Tank & SSME Engine Pod	780.5
Stage-2 (Ignited Sub-Orbital)	
Usable Propellant	106.1
Inert Mass	14.6
Total Engine Thrust (kN)	392
Specific Impulse (sec)	468
Payload Fairing (ALS Design)	20.4



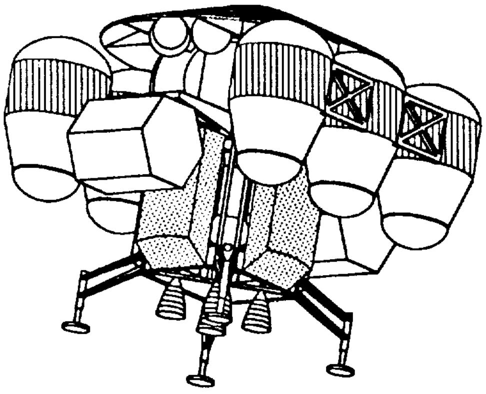
STV Represents Potential Upper Stage Candidate to Support On-going HLLV Development

STV Technology & Advanced Development Areas

- Cryogenic Fluid Management
- Avionics, Power, Software and Vehicle Health Mgt
- Cryogenic Engines and Propulsion
- Vehicle Structure and Tankage
- Aerobrake
- Flight Operations
- Ground Operations
- Advanced Propulsion
- Vehicle Assembly, Servicing & Processing
- Crew Module
- Environmental Control & Life Support System
- Lunar and Mars Surface Operations

STV Space-Based Zero Base Technology Concept

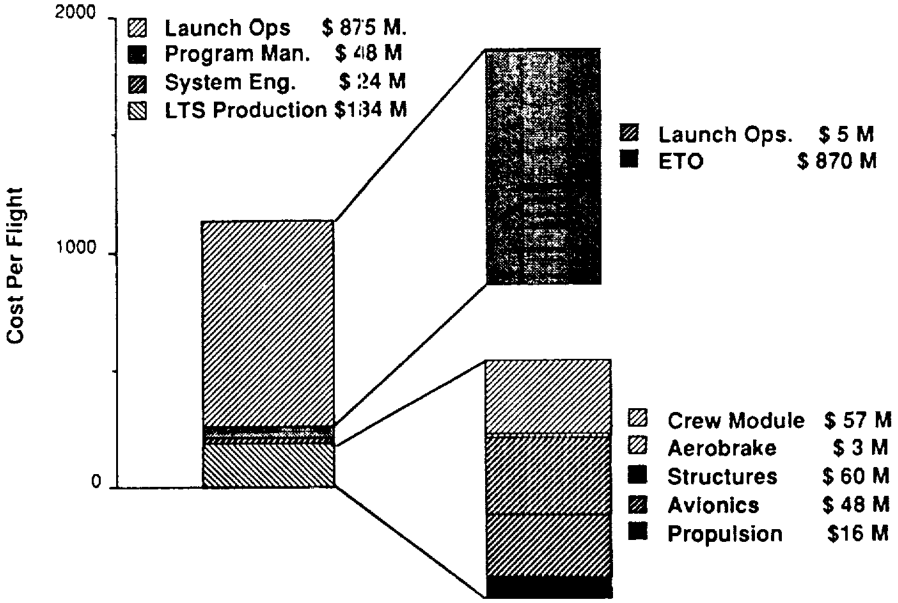
STV Phase 1 Lunar Study Reference Vehicle
With State-Of-The-Art Technology



- RL10A-4 Engine (Man-Rated & Space-Base Certified)
- Aluminum Tanks and Structure
- Centaur Cryogenic Fluid Management/Wet Tanks
- Off-The-Shelf Aluminum/Mylar MLI
- Space Station Avionics
- Nickel Zinc Batteries
- Apollo Thermal Protection System
- Hydrazine Auxiliary Propulsion System

Tech./Adv. Dev. Cost & Perform. Benefits

Zero Base Technology Concept Recurring Cost Profile : 90 day Reference Vehicle



STV Technology & Adv. Dev. Assessment Criteria

- Cost
  - Life Cycle Cost - Recurring and Nonrecurring
  - Recurring Savings per Vehicle
  - DDT&E and R&T Costs
  - Cost Benefit - LCC/R&T Cost
  - Net Present Value @ 5%
- Performance
  - Satisfy Operation Requirements
  - Satisfy Safety Requirements
  - Reliability
  - STV Impacts
  - Launch Vehicle and Infrastructure Impacts
  - Robust Design - Large Margins
- Schedule
  - Readiness Level 6 by STV Preliminary Design Review
  - Risk - Lead Time
- Other
  - Operational Life - Reusability
  - Producibility
  - Maintainability
  - Adaptability
  - Ability to Man-Rate
  - Fault Tolerance Capability
  - Ability to Space-Base

Aeroassist vs All Propulsive

Objectives

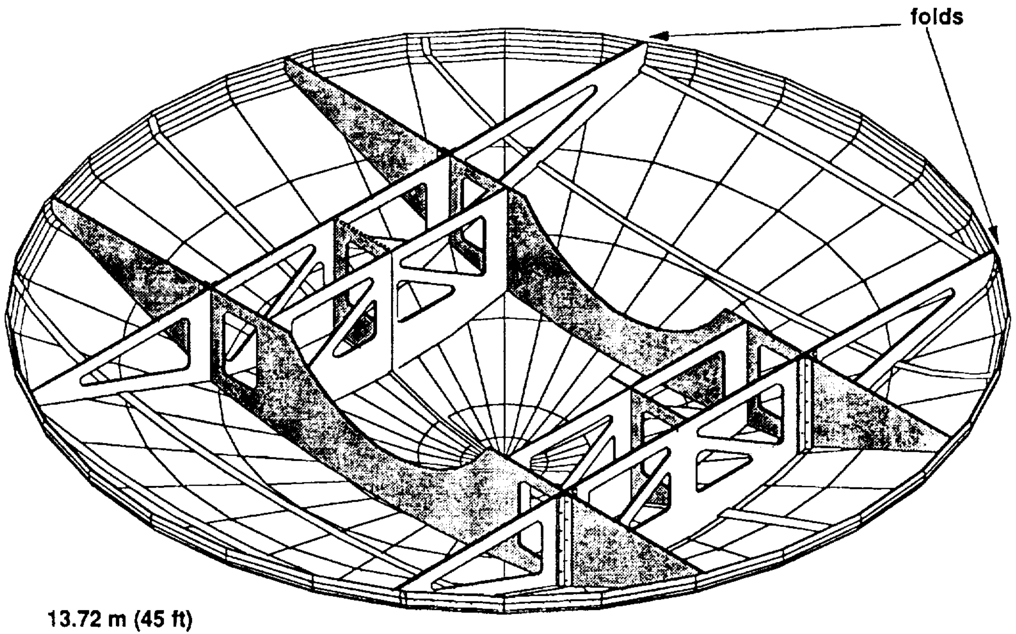
- Determine Relative LCC Benefits of Aeroassist as a Function of:
  - Aerobrake Mass Fraction
  - ETO Cost per Pound
  - Aerobrake Development Cost

Ground Rules

- Return to LEO From Lunar Mission
- Rigid AB, 5 Reuses
- Concept
  - Single Propulsion Module
  - Single Crew Compartment
  - AB Stays in LLO for Aeroassist Version
  - TEI/LEO Propellant Tanks Stay in LLO for All Propulsive Version
- ASE Engines; Isp = 476 sec.
- Piloted Vehicle Missions Only, 21 Flights
- 14.6 t Cargo in Addition to Crew
- ΔV from Aeroassist = 3150 M/Sec (10,332 ft/sec)
- AB Recurring Cost = $12M
- AB Development Cost = Variable
- ETO Cost ($/lb) = Variable
- AB Weight Fraction = Variable
- AB Weight Fraction Definition:

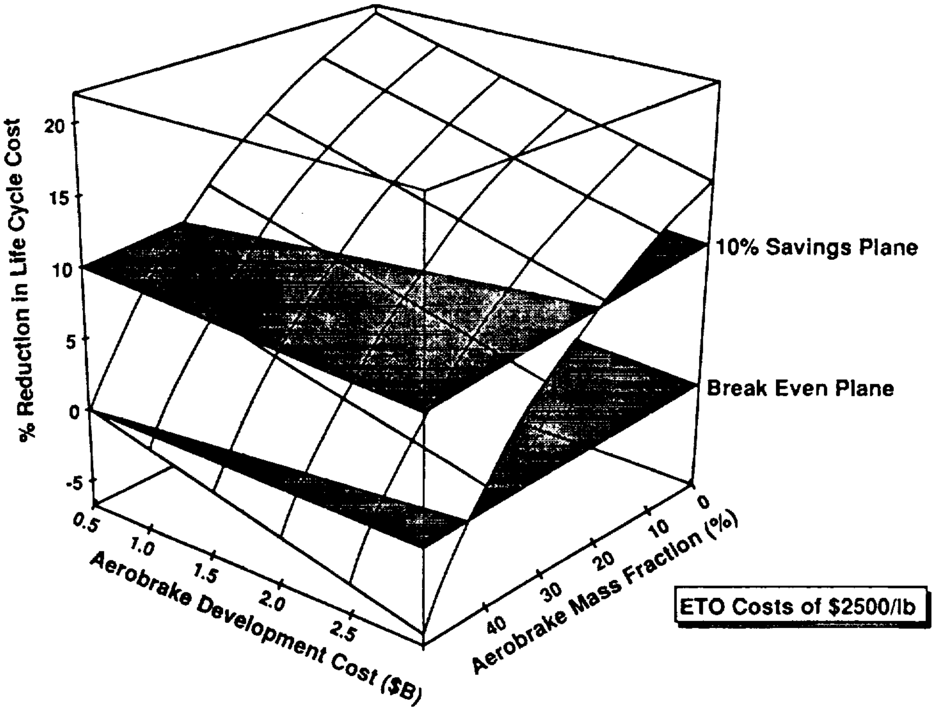
$$\frac{\text{AB Str/TPS Mass}}{\text{Total Entry Mass}}$$

LTV Aerobrake



13.72 m (45 ft)
Diameter Rigid
Aerobrake
Folds In 2 Places

Aerobrake LCC Savings Relative to All Propulsive



LTV Aerobrake Technology Needs

Aerobrake/Aeroassist Structures/Materials

TPS - Rigid/Flexible, Temps to 3500°F,
Reusable, Human Safe, Repairable in Space,
Propellant Resistant, High Q

Backup Structure - Stiff, Heat Resistant > 600°F
Light Weight, Foldable

Hinge and Lock Mechanisms - Erectable,
Automated Foldout/Lock Up,
Failure Redundant, Backup/Dual System,
Human Operator Backup

NDE/NDI - Pre Flight Configuration, Mfg Inspection,
In Flight or Space-Based Certification

Thermal Control

Solar Cells - Flex Deployment/Retraction

Debris/Environment Protection

Aerobrake Summary

Results

- Rigid vs Flexible

  Rigid Retained as Baseline
  - 3-Piece Hinged Concept Minimizes Rigid A/B on-Orbit Assembly Operations
  - Rigid Brake Technology More Mature
  - Flexible Brake Technology Should Be Developed Since It Offers Better (Lower Cost) ETO Manifesting, Fewer Joints, and Assembly Advantages

- Aerobrake vs All Propulsive

  Life Cycle Cost Payoffs Exist for Aerobraking Over a Wide Range of Aerobrake Efficiencies

Issues

- Flight Testing Prior to Full Scale Vehicle Flights
- Reusability
- Shape - Wake Heating / Packaging

Structures DOE Analysis

- Evaluated Structural Components of the STV Phase I Configuration
  - Core Structure, Aerobrake, Drop Tanks, Crew Cab, Core Tanks, Lander Legs and Drop Tanks Support Structure

- Evaluated Three Materials
  - Aluminum, Aluminum-Lithium and Composites (Graphite Epoxy)

- Maintained Same Design Configuration for All Materials
  - Did Not Optimize Component Design for Al-Li or Composites
  - Composite Sizing Based on Constant Material Properties, Not Adjusted for Ply Direction or Minimum Ply Thickness

- DOE L27 Matrix Used to Evaluate Combinations of the Seven Structural Components with the Three Materials
  - Response is the Vehicle Dry Mass
  - 15% Growth Factor Included in Dry Mass

- All Pressure Vessels Sized for Burst Pressure

Structural Component Mass Summary

- Structural Component Mass (kg) Based on Material Selection

Component	Aluminum ρ=2.85g/cm^3	Aluminum-Lithium ρ=2.70 g/cm^3	Composites* ρ=1.80 g/cm^3
Core Structure	6235	5078	4979
Aerobrake	5768	4521	4194
Drop Tanks	4965	2634	2412
Crew Cab	11644	8290	7978
Core Tanks	951	501	458
Lander Legs	239	118	105
Drop Tank Support Structure	7493	6305	6165

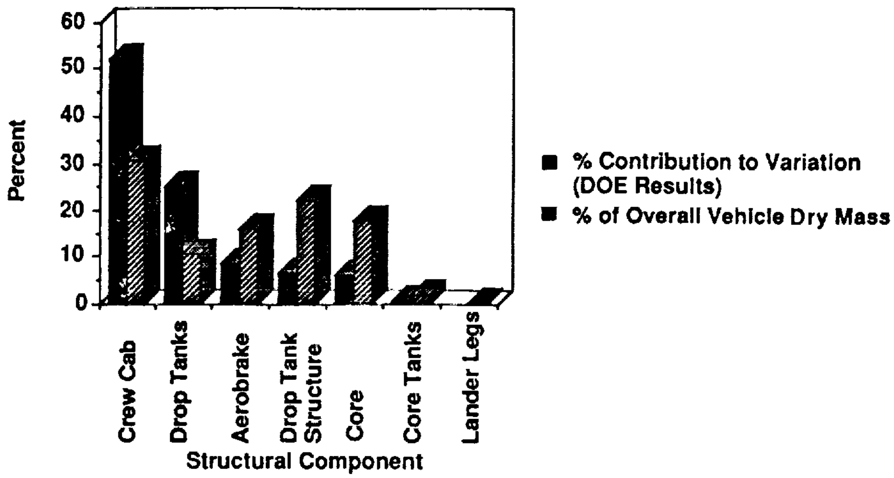
- Aluminum-Lithium Structure Reduces Component Dry Mass By 16 to 50%
- Composite Structure Reduces Component Dry Mass By 18 to 56%

* Composite Structure Not Optimized - Greater Mass Reduction Possible if Structure Redesigned

Structures DOE Analysis Results

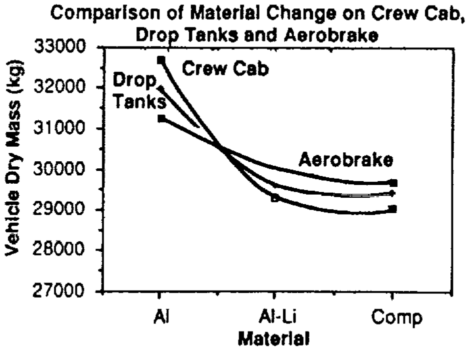
- DOE Reduced Number of Analysis Combinations from 343 to 27
  343 = 7 Components with 3 Combinations

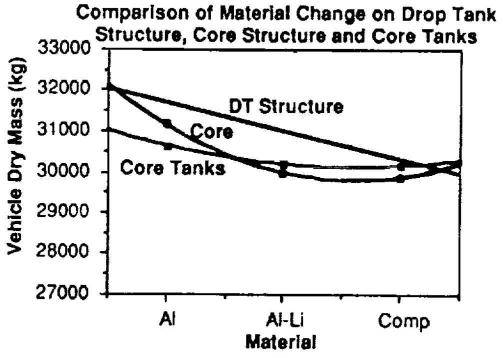
- Comparison of Component DOE Results to the Percent of Overall Vehicle Mass Indicates Which Component Was Influenced Most by Materials Change



Comparison of Structural Material Changes

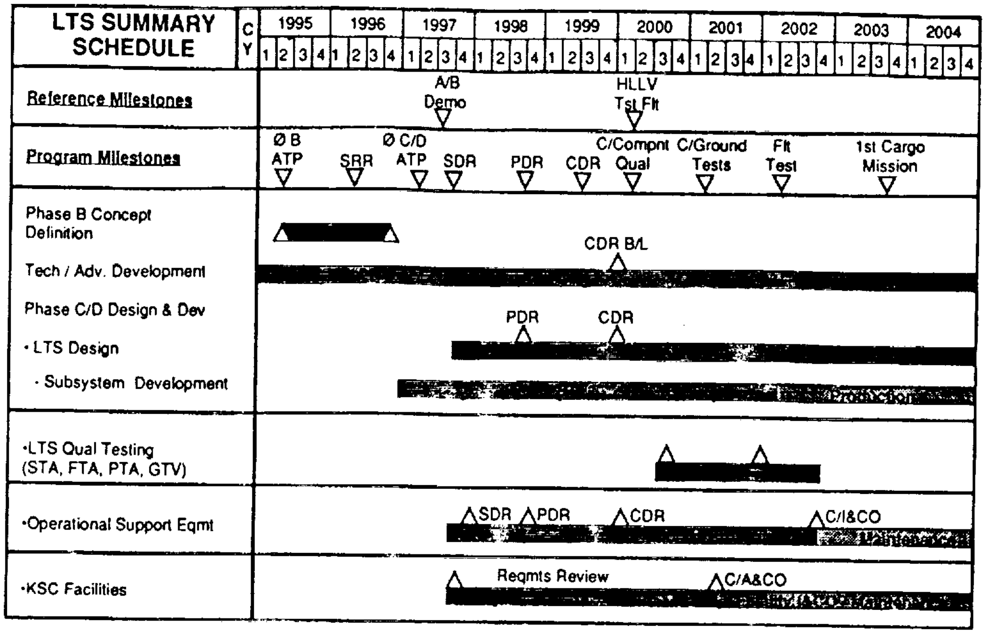
- Comparison of Materials Change on Vehicle Components
  - Aluminum Structure Is the Heaviest Option
  - Overall Vehicle Dry Mass Reduced Approximately 28% By Using Advanced Structures
  - Vehicle Dry Mass Reduction Trends Illustrated in Graphs



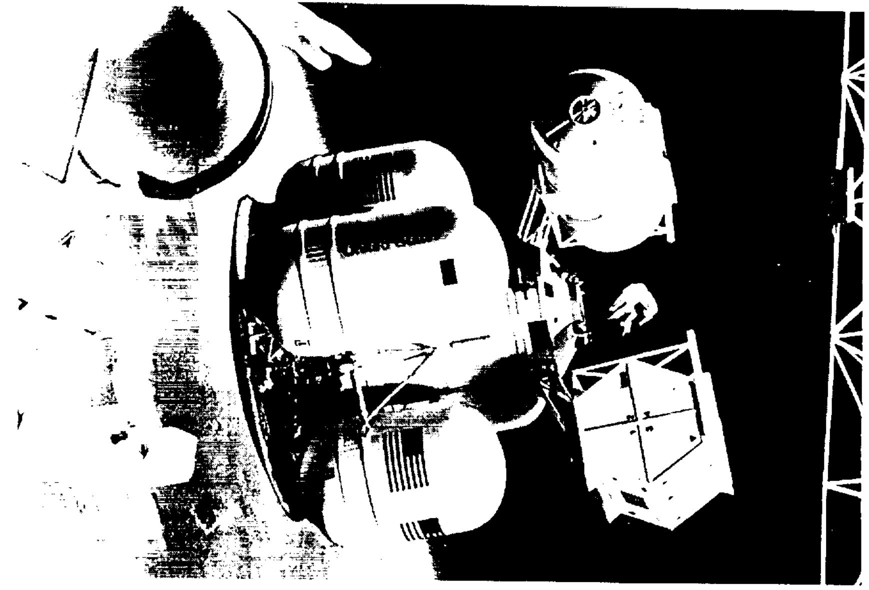


LTS Program Overview

Lunar Transportation System Overview



LTS (90 Day Reference) At LEO



Program Flexibility & Schedule Is Technology Limited

- Study Developing Technology Roadmaps
  - Technology Assessment
  - Improvement Schedules
  - Prioritization
- Schedule & Vehicle Flexibility/Evolution Are Constrained By Technology Maturity.
  - RL-10 vs. ASE
  - Propulsive vs. Aeroassist
  - Expendable Upper Stage vs. Advanced Avionics Architecture
  - Operations Intensive vs. Autonomy
- Aggressive Technology & Advanced Development Program Required To Meet All Objectives.
  - Early Flight Tests For Technology Validations

The STV Study Will Identify The Required Technology Accelerations And Improvements Incorporated via Planned Staged Insertion.