N93-25513

NASA
National Aeronautics and Space Administration

Report Documentation Page

1. Report No. DRD MA-182TE/No. 13	2. Government Accession No. N/A	3. Recipient's Catalog No. N/A
4. Title and Subtitle "Space Transfer Vehicle (STV) Concepts & Requirements Study Phase I Final Report"		5. Report Date 4-1-91
		6. Performing Organization Code PT, NASA MSFC
7. Author(s) T. Vinopal, Boeing Aerospace and Electronics		8. Performing Organization Code No. N/A
		10. Work Unit No. N/A
9. Performing Organization Name and Address Boeing Aerospace and Electronics, Business Development, P.O. Box 3999 - Seattle, WA 98124		11. Contract or Grant No. NAS8-37855
		13. Type of Report and Period Covered Final Report, Phase I 8/1/89 - 4/1/91
12. Sponsoring Agency Name and Address NASA George C. Marshall Space Flight Center, Huntsville, AL 35812		14. Sponsoring Agency Code N/A

15. Supplementary Notes

N/A

16. Abstract

This report presents the results of systems analyses and conceptual design of space transfer vehicles (STV). The missions examined included piloted and unpiloted lunar outpost support and spacecraft servicing, and unpiloted payload delivery to various earth and solar orbits. The study goal was to examine the mission requirements and provide a decision data base for future programmatic development plans. The final lunar transfer vehicles provided a wide range of capabilities and interface requirements while maintaining a constant payload mission model. Launch vehicle and space station sensitivity was examined, with the final vehicles as point designs covering the range of possible options. Development programs were defined and technology readiness levels for different options were determined. Volume I presents the executive summary, Volume II provides the study results, and Volume III the cost and WBS data.

17. Key Words (Suggested by Author(s)) Lunar Transfer Vehicle, Upper Stage, SSF, SEI, Manned Spacecraft, Launch Escape System, Operability, 90	18. Distribution Statement N/A

19. Security Classif. (o

Unclassified

NASA FORM 1626 OCT 8

BOEING

[redacted]

DAAP

19738

P-18

SPACE TRANSFER VEHICLE CONCEPTS AND REQUIREMENTS STUDY

Phase I Final Report
Volume II, Book 3
STV System Interfaces
D180-32040-2
April, 1991

D180-32040-2

DPD NUMBER-709
DR NUMBER-4
CONTRACT NAS8-37855

Submitted to
The National Aeronautics and Space Administration
George C. Marshall Space Flight Center
By
Boeing Aerospace & Electronics
Seattle, Washington 98124

FOREWORD

This final report of the first phase of the Space Transfer Vehicle (STV) Concept and Requirements Study was prepared by Boeing for the National Aeronautics and Space Administration's George C. Marshall Space Flight Center in accordance with Contract NAS8-37855. The study was conducted under the direction of the NASA Contracting Officer Technical Representative (COTR), Mr Donald Saxton from August 1989 to November 1990, and Ms Cynthia Frost from December 1990 to April 1991.

This final report is organized into the following seven documents:

Volume I EXECUTIVE SUMMARY

Volume II FINAL REPORT
Book 1 - STV Concept Definition and Evaluation
Book 2 - System & Program Requirements Trade Studies
Book 3 - STV System Interfaces
Book 4 - Integrated Advanced Technology Development

Volume III PROGRAM COSTS ESTIMATES
Book 1 - Program Cost Estimates (DR-6)
Book 2 - WBS and Dictionary (DR-5)

The following appendices were delivered to the MSFC COTR and contain the raw data and notes generated over the course of the study:

Appendix A	90 day "Skunkworks" Study Support
Appendix B	Architecture Study Mission Scenarios
Appendix C	Interface Operations Flows
Appendix D	Phase C/D & Aerobrake Tech. Schedule Networks

The following personnel were key contributors during the conduct of the study in the disciplines shown:

Study Manager	Tim Vinopal
Mission & System Analysis	Bill Richards, Gary Weber, Greg Paddock, Peter Maricich
Operations	Bruce Bouton, Jim Hagen

Key Contributors Continued

Configurations	Richard Kolesar, Craig Hosking, George Dishman, Mike Furlong, Bob Kiliz, Jack Olson
Propulsion	Wayne Patterson, Noel Christensen, Phillip Knowles
Avionics	Rich Flannagan, Tim Mosher, Carl Malec
Structures	Peter Rimbos, Martin Gibbins
Electrical Power	Chris Johnson
Cryo Fluid Management	Ogden Jones, Jere Meserole
Mass Properties	Jeff Cannon, David Raese, Karl Heilborn
Aerothermodynamics	Richard Savage, Peter Keller
Thermal Protection	Anna Baker, Paul Nedervelt
Guidance	Lisa Skalecki, Jere Bradt
Controls	Mark Castellicio
Performance/Astrodynamics	Ted Hanson, Ralph Risdall, Steve Paris, Mark Martin
Aerodynamics	Stan Ferguson
Crew Systems	Tom Slavin, Brand Griffin, Bill Pogue, Gerry Carr
Station Accomodations	John Palmer, Ron Rao, Carl Case
Cost Estimating	Thom Walters, Al Peffley, Hal Boggs, Jim Owens
Programmatics	Al Peffley, Don Benson, Lori Todd, Bob Croken
Documentation Support	Symantha Rodenbach, Darlene Glubrecht

For further information contact:

Cynthia Frost
NASA MSFC/PT41
MSFC, AL 35812
(205)544-0628

Tim Vinopal
Boeing Aerospace
M/S 8K-52, P. O. Box 3999
Seattle, WA 98124-2499
(206)773-6363

CONTENTS

ACRONYMS

AC	attitude control
ACS	attitude control system
ALS	Advanced Launch System
APU	auxiliary power unit
ASIC	application-specific integrated circuit
ATC	active thermal control
ATDRSS	advanced TDRSS
BIT	built-in test
BOLT	Boeing Lunar Trajectory Program
CASE	computer-aided software engineering
CNDB	civil needs database
CNSR	comet nucleus sample return
CT	communications and tracking
CTE	coefficient of thermal expansion
DAK	double aluminized Kapton
DDT&E	design, development, test, and evaluation
(delta) T	change in event duration
(delta) V	change in velocity
DoD	Department of Defense
DMR	design reference missions
DRS	design reference scenario
DSN	deep space network
ECLSS	environmental control and life support system
EOS	Earth observing system
EPS	electrical power system
ESA	European Space Agency
ETO	Earth to orbit
EVA	extravehicular activity
FC	fluid control
FEPC	flight equipment processing center
FOG	fiber-optic gyro
FSD	full-scale development
GB	ground based
GC	guidance control
GEO	geosynchronous orbit
GLOW	gross liftoff weight
GNC	guidance, navigation, and control
GO	ground based, on orbit
GPS	global positioning system
GSE	ground support equipment
HEI	Human Exploration Initiative
HEO	high Earth orbit
HESR	Human Exploration Study Requirements
HLLV	heavy lift launch vehicle

ICI	Integrated Systems Incorporated
ILD	injection laser diode
IMU	inertial measurement unit
IUS	Inertial Upper Stage
IVA	intravehicular activity
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
KSC	Kennedy Space Center
LAD	liquid acquisition device
LAN	local area network
LCC	life cycle cost
LCD	liquid crystal display
L/D	lift to drag
LECM	lunar excursion crew module
LED	light-emitting diode
LEO	low Earth orbit
LES	launch escape system
LEV	lunar excursion vehicle
LLO	low lunar orbit
LMS	lunar mission survey
LO	lunar orbiter
LOD	lunar orbit direct
LOI	lunar orbit injection
LOR	lunar orbit rendezvous
LOX/LH	liquid oxygen/liquid hydrogen
LTS	lunar transportation system
LTV	lunar transfer vehicle
MEOP	maximum expected operating pressure
MET	mission elapsed time
MEV	Mars excursion vehicle
MLI	multilayer insulation
MPS	main propulsion system
MSFC	Marshall Space Flight Center
MTPE	mission to planet Earth
MTV	Mars transfer vehicle
NEP	nuclear energy propulsion
NPSH	net positive suction head
NTR	nuclear thermal rocket
ORU	orbit replaceable unit
P/A	propulsion/avionics
PC	propulsion control
PCM	parametric cost model
PDT	product development team
PODS	passive orbital disconnect strut
PSS	planet surface system
PVT	pressure-volume-temperature

RCS	reaction control subsystem
RFP	request for proposal
RLG	ring laser gyros
RMS	remote manipulator system
RTV	room temperature vulcanizating
SB	space based
SEI	Space Exploration Initiative
SEP	solar energy propulsion
SEU	single-event upset
SG	space/ground
SIP	strain isolation pad
SIRF	spaceborne imaging radar facility
SIRTF	Space IR Telescope Facility
SLAR	side-looking aperture radar
SOS	silicon on sapphire
SRM	solid rocket motor
SSF	Space Station Freedom
STIS	Space Transportation Infrastructure Study
STS	space transportation system
STV	Space Transfer Vehicle
TDRSS	tracking and data relay satellite system
TEI	trans-Earth injection
TLI	translunar injection
TMI	trans-Mars injection
TPS	thermal protection system
TVC	thrust vector control
TVS	thermodynamic vent system
USRS	Upper Stage Responsiveness Study
VHM	vehicle health monitoring
VHMS	vehicle health management system
ZLG	zero lock gyro

3-1.0 INTERFACE REQUIREMENTS DOCUMENT

3-1.1 SPACE-BASED CONCEPT

Ground Transport. Vehicle elements must be transported from the manufacture to the launch site. Figure 3-1.1-1 lists the STV elements and sizes. Large elements require special modes of transportation and may dictate where final assembly occurs. NASA has access to two modified C5As that can handle Space Station Freedom modules with support cradles (4.5m diameter). Large elements may be carried over public roads, but this method requires extensive route analysis and special permits. Very large elements like the shuttle external tank are manufactured near a sea port and barged to KSC.

ELEMENT	SIZE/DESCRIPTION
Core Vehicle	9.1m-diameter octagon
Crew Module	4.5m x 4.3m
TLI Tanksets	6.1m x 11.9m
Descent Tanks	4.4m x 6.7m
Aerobrake	15.2m diameter x 3m deep (deployed) 15.2m long x 4.9m deep (stowed)
Miscellaneous Hardware	Landing Legs Lunar cargo brackets and mechanisms Satellite adapters
In-line Tankset	TBD

Figure 3-1.1-1. STV Elements and Sizes

Launch Site Facilities and Services. Vehicle concept SB is a space-based, reusable system. This concept was extended to all missions in design reference scenario 3 (DRS3), and facilities are sized accordingly.

Propellant. DRS3 requires approximately 1,000 tons of propellant per year. At a 6:1 mixture ratio, that equates to 143 tons of liquid hydrogen and 857 tons of liquid oxygen. For scale, this is equivalent to 1.3 shuttle external tanks.

STV Processing Facility. The quantity of vehicle elements required to perform the mission model, in conjunction with historical processing data from existing programs, were used to compute the annual processing rates of vehicle elements. Figure 3-1.1-2 lists the average yearly processing rates. There are opportunities to reduce the required amount of ground operations, which should be explored in a more detailed design study.

ELEMENT	YEARLY RATE
Core Vehicle	4
Tanksets	25
Aerobrakes	3
Crew Modules	1/5 years

Figure 3-1.1-2. STV Processing Facility

Other Requirements Worth Noting. Additional yearly processing capability alluded to by the STV mission model includes 10.9 DoD spacecraft, 1.4 civil spacecraft, and 10 to 30 tons of cargo for the lunar base.

Earth-to-Orbit Transportation. An ALS-type HLLV with a payload capability of 70 tons and a shroud of 9.1m by 24.4m was used to design the STV. Services required by the STV will include propellant loading (cryogenic hydrogen and oxygen) and telemetry and command feedthrough. Requirements for other services such as power and flight termination interface have not been determined.

HLLV Flights. An estimated 20 to 30 HLLV flights per year are required to support STV missions. Logistics support of STV activities at the SSF has been approximated at two to three times planned SSF IOC levels.

Manned Flights. Some STV missions are manned missions. To transport the STV crew to orbit will require an average of 1.2 flights per year, with a peak of 3 flights in 2005. The STV crew size is four people. The STV processing crew at the SSF is currently planned to be 20 to 25 people. Impact to manned ETO depends on crew rotation rates.

Low Earth Orbit Transportation. A vehicle is required to move STV elements from the HLLV to the SSF because the HLLV is not allowed to rendezvous with the SSF. This service is considered a design reference mission for a member of the STV family. The largest STV element is the translunar injection droptank sets, which are approximately 65 tons each.

Low Earth Orbit Node. All STV configurations that spend any time at the SSF will comply with all the appropriate requirements. Reference documents are listed in Figure 3-1.1-3.

DOCUMENT	**SUBJECT**
NASA-STD-3000	Manned Systems and Rating
SSP-XXXXX	SSF Robotic Systems Integration Standard
?	Pressure Vessel Design (Crew Module)
?	Tank Design (Propellant and Pressure tanks)
JSC19371 Vol III	SSF Proximity Operations

Figure 3-1.1-3. Requirements From the SSF

Communications and Telemetry Systems. STV requires a communications and telemetry receiving system capable of supporting all critical mission phases. Coverage analysis must be done for all STV DRMs. Several missions, such as lunar and nuclear debris disposal leave the sphere of support provided by the current TDRSS.

Navigation and Tracking. The STV may require navigation and tracking support for longer mission. Analysis must be performed to determine the maximum errors of the STV system and the benefits of doing state vector updates from a ground system.

Planetary support systems group has said that the lunar base will provide "simple beacons" as landing aids for unpiloted STVs and that lights and markings will be provided to aid piloted flights. Initial unpiloted STVs must land a certain number of times without these aids, therefore STV may not require the beacons. This would be determined in a detailed navigation system analysis. If STV chooses a beacon-assisted system, the beacons would be required to be placed by a precursor mission to aid the first STV flights. The beacons must be placed such that the pad center can be located with better than 5m resolution.

Lunar Base. See Navigation and Tracking.

STV will require subsystem support for stays longer than 30 days. Expended STV elements will be cannibalized for use by the lunar base. Interfaces and elements will be common between STV and the lunar base whenever possible.

As a design goal, the lunar base will not be required to provide planned maintenance beyond placing the STV into storage mode. Storage services are to be determined but may require support of the cryogenic propellents and meteoroid and thermal protection.

The lunar base will provide for a relay to Earth of STV telemetry whenever the STV is on the surface. The lunar base to STV link will be a safe system like low-power RF. Otherwise the STV would have to broadcast directly to Earth and may present a hazard to an EVA crew.

Lunar Mission Payloads. Cargo scheduled for a piloted STV mission will be divided in two packages of approximately equal mass and center of mass. Both packages will be constrained to an envelope to be determined. Cargo scheduled for an unpiloted STV missions will be constrained to an envelope to be determined and have a center of mass at a location to be determined.

Upper Stage Missions. To be determined.

Other Missions. To be determined.

3-1.2 GROUND-BASED CONCEPT

Ground Transport. Vehicle elements must be transported from the manufacture to the launch site. Figure 3-1.2-1 lists the STV elements and sizes. Large elements require special modes of transportation and may dictate where final assembly occurs. NASA has access to two modified C5As that can handle Space Station Freedom modules with support cradles (4.5m diameter). Large elements may be carried over public roads, but this method requires extensive route analysis and special permits. Very large elements like the shuttle external tank are manufactured near a sea port and barged to KSC.

ELEMENT	SIZE/DESCRIPTION
Core Vehicle	7.8m x 16.2m
Crew Module	4.3m x 6.9m
TLI Hydrogen Tanks	4.4m x 8.5m
TLI Oxygen Tanks	2.7m x 2.5m
Descent Hydrogen Tanks	2.7m x 5.8m
Miscellaneous Hardware	Landing Legs Lunar cargo brackets and mechanisms Satellite adapters

Figure 3-1.2-1. STV Elements and Sizes

Launch Site Facilities and Services. The quantity of vehicle elements required to perform the mission model, in conjunction with historical processing data from existing programs, were used to compute the annual processing rates of vehicle elements. Figure 3-1.2-2 lists the average yearly processing rates. There are opportunities to reduce the required amount of ground operations, which should be explored in a more detailed design study.

ELEMENT	**YEARLY RATE**
Core Vehicle	15
Tanksets	18
Crew Modules	1/5 years

Figure 3-1.2-2. STV Processing Facility

Other Requirements Worth Noting. Additional yearly processing capability alluded to by the STV mission model includes 10.9 DoD spacecraft, 1.4 civil spacecraft, and 10 to 30 tons of cargo for the lunar base.

Earth-to-Orbit Transportation. A rubber HLLV with a payload capability of up to 250 tons was used to design the STV. Services required by the STV will include propellant loading (cryogenic hydrogen and oxygen) and telemetry and command feedthrough. Requirements for other services such as power and flight termination interface have not been determined.

Low Earth Orbit Transportation. Not required.

Low Earth Orbit Node. Not Required.

Communications and Telemetry Systems. The STV requires a communications and telemetry receiving system capable of supporting all critical mission phases. Coverage analysis must be done for all STV DRMs. Several missions, such as lunar and nuclear debris disposal leave the sphere of support provided by the current TDRSS.

Navigation and Tracking. STV may require navigation and tracking support for longer mission. Analysis must be performed to determine the maximum errors of the STV system and the benefits of doing state vector updates from a ground system.

Planetary support systems group has said that the lunar base will provide "simple beacons" as landing aids for unpiloted STVs and that lights and markings will be provided to aid piloted flights. Initial unpiloted STVs must land a certain number of times without these aids, therefore STV may not require the beacons. This would be determined in a detailed navigation system analysis. If STV chooses a beacon-assisted system, the beacons would be required to be placed by a precursor mission to aid the first STV flights. The beacons must be placed such that the pad center can be located with better than 5m resolution.

Lunar Base. See Navigation and Tracking.

STV will require subsystem support for stays longer than 30 days. Expended STV elements will be cannibalized for use by the lunar base. Interfaces and elements will be common between the STV and lunar base whenever possible.

As a design goal, the lunar base will not be required to provide planned maintenance beyond placing the STV into storage mode. Storage services are to be determined but may require support of the cryogenic propellents and meteoroid and thermal protection.

The lunar base will provide for a relay to Earth of STV telemetry whenever the STV is on the surface. The lunar base to STV link will be a safe system like low-power RF. Otherwise the STV would have to broadcast directly to Earth and may present a hazard to an EVA crew.

Lunar Mission Payloads. Cargo scheduled for a piloted STV mission will be divided in two packages of approximately equal mass and center of mass. Both packages will be constrained to an envelope to be determined. Cargo scheduled for an unpiloted STV missions will be constrained to an envelope to be determined and have a center of mass at a location to be determined.

Upper Stage Missions. To be determined.

Other Missions. To be determined.

3-1.3 GROUND-BASED WITH ON-ORBIT ASSEMBLY CONCEPT

Ground Transport. Vehicle elements must be transported from the manufacture to the launch site. Figure 3-1.3-1 lists the STV elements and sizes. Large elements require special modes of transportation and may dictate where final assembly occurs. NASA has access to two modified C5As that can handle Space Station Freedom modules with support cradles (4.5m diameter). Large elements may be carried over public roads, but this method requires extensive route analysis and special permits. Very large elements like the shuttle external tank are manufactured near a sea port and barged to KSC.

ELEMENT	SIZE/DESCRIPTION
Core Vehicle	9.1m x 9.1m
Crew Module	4.3m x 6.9m
TLI Tanksets	4.4m x 12.9m
Descent Tanks	4.4m x 8.0m
Miscellaneous Hardware	Landing Legs Lunar cargo brackets and mechanisms Satellite adapters
In-line Tanksets	TBD

Figure 3-1.3-1. STV Elements and Sizes

Launch Site Facilities and Services. The quantity of vehicle elements required to perform the mission model, in conjunction with historical processing data from existing programs, were used to compute the annual processing rates of vehicle elements. Figure 3-1.3-2 lists the average yearly processing rates. There are opportunities to reduce the required amount of ground operations, which should be explored in a more detailed design study.

ELEMENT	**YEARLY RATE**
Core Vehicle	15
Tanksets	18
Crew Modules	1 / 5 years

Figure 3-1.3-2. STV Processing Facility

Other Requirements Worth Noting. Additional yearly processing capability alluded to by the STV mission model includes 10.9 DoD spacecraft, 1.4 civil spacecraft, and 10 to 30 tons of cargo for the lunar base.

Earth-to-Orbit Transportation. An ALS-type HLLV with a payload capability of 70 tons and a shroud of 9.1m by 24.4m was used to design the STV. Services required by the STV will include propellant loading (cryogenic hydrogen and oxygen) and telemetry and command feedthrough. Requirements for other services such as power and flight termination interface have not been determined.

Low Earth Orbit Transportation. Two options are being considered for on orbit assembly. One method would require a tug capable of moving up to a 70-ton elements. The tug would be used to retrieve elements from the HLLV, transfer them to the partially integrated STV, and assist in the integration process by "docking" the vehicle element to the STV.

Low Earth Orbit Node. In this option the STV is a self-node. The tug, if used, would probably be based at the SSF.

Communications and Telemetry Systems. The STV may require navigation and tracking support for longer mission. Analysis must be performed to determine the maximum errors of the STV system and the benefits of doing state vector updates from a ground system.

Planetary support systems group has said that the lunar base will provide "simple beacons" as landing aids for unpiloted STVs and that lights and markings will be provided to aid piloted flights. Initial unpiloted STVs must land a certain number of times without these aids, therefore STV may not require the beacons. This would be determined in a detailed navigation system analysis. If STV chooses a beacon-assisted system, the beacons would be required to be placed by a precursor mission to aid the first STV flights. The beacons must be placed such that the pad center can be located with better than 5m resolution.

Lunar Base. See Navigation and Tracking.

The STV will require subsystem support for stays longer than 30 days. Expended STV elements will be cannibalized for use by the lunar base. Interfaces and elements will be common between the STV and lunar base whenever possible.

As a design goal, the lunar base will not be required to provide planned maintenance beyond placing the STV into storage mode. Storage services are to be determined but may require support of the cryogenic propellents and meteoroid and thermal protection.

The lunar base will provide for a relay to Earth of STV telemetry whenever the STV is on the surface. The lunar base to STV link will be a safe system like low-power RF. Otherwise the STV would have to broadcast directly to Earth and may present a hazard to an EVA crew.

Lunar Mission Payloads. Cargo scheduled for a piloted STV mission will be divided in two packages of approximately equal mass and center of mass. Both packages will be constrained to an envelope to be determined. Cargo scheduled for an unpiloted STV missions will be constrained to an envelope to be determined and have a center of mass at a location to be determined.

Upper Stage Missions. To be determined.

Other Missions. To be determined.