ORBITAL TRANSFER VEHICLE

CONCEPT DEFINITION AND SYSTEMS ANALYSIS STUDY

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FOREWORD

This final report of the Orbital Transfer Vehicle (OTV) Concept Definition and System Analysis Study was prepared by Boeing Aerospace Company for the National Aeronautics and Space Administration's George C. Marshall Space Flight Center in accordance with Contract NAS8-36107. The study was conducted under the direction of the NASA OTV Study Manager, Mr. Donald Saxton and during the period from August 1984 to September 1986.

This final report is organized into the following nine documents:

VOL.	I	Executive Summary (Rev. A)	
VOL.	II	OTV Concept Definition & Evaluation	
		Book 1-	Mission Analysis & System Requirements
		Book 2-	Selected OTV Concept Definition - Phase I
		Book 3-	Configuration and Subsystem Trade Studies
		Book 4-	Operations and Propellant Logistics
VOL.	III	System & Program Trades	
VOL.	IV	Space Station Accommodations	
VOL.	V	WBS & Dictionary	
VOL.	VI	Cost Estimates	
VOL.	VII	Integrated Technology Development Plan	
VOL.	VIII	Environmental Analysis	
VOL.	IX	Implications of Alternate Mission Models and Launch Vehicles	

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CONTENTS

		Page
1.0	INTRODUCTION	1
2.0	OVERVIEW	3
3.0	SUMMARY AND CONCLUSIONS	4
4.0	PURPOSE AND NEED	5
5.0	DESCRIPTION	6
6.0	ENVIRONMENTAL IMPACT OF PROJECT AND ALTERNATIVES	8
7.0	REFERENCES	10

ACRONYMS AND ABBREVIATIONS

ACC	Aft Cargo Carrier
AFE	Aeroassist Flight Experiment
AGE	Aerospace Ground Equipment
AL	Aluminum
ASE	Airborne Support Equipment
A/T	Acceptance Test, Auxiliary Tank
AUX	Auxiliary
AVG	Average
B/B	Ballute Brake
B/W	Backwall
CDR	Critical Design Review
CPU	Central Processing Unit
CUM	Cumulative
DAK	Double Aluminized Kapton
DDT&E	Design, Development, Test & Evaluation
DELIV	Delivery
DMU	Data Management Unit
DoD	Department of Defense
EPS	Electrical Power System
FACIL	Facility
FFC	First Flight Certification
FLTS	Flights
FOSR	Flexible Optical Surface Reflector
FRCI	Fiber Refractory Composite Insulation
F.S.	Fail Safe
FSI	Flexible Surface Insulation
FTA	Facilities Test Article
GB	Ground Based
GEO	Geostationary Earth Orbit
GPS	Global Positioning System
GRD	Ground
IOC	Initial Operational Capability
IRU	Inertial Reference Unit
IUS	Inertial Upper Stage

JSC	Johnson Space Center
L/B	Lifting Brake
LCC	Life Cycle Cost
L/D	Lift to Drag
MGSS	Mobile GEO Service Station
MLI	Multilayer Insulation
MPS	Main Propulsion System
MPTA	Main Propulsion Test Article
MSFC	Marshall Space Flight Center
OMV	Orbital Maneuvering Vehicle
OPS	Operations
OTV	Orbital Transfer Vehicle
PAM	Payload Assist Module, Propulsion Avionics Module
PDR	Preliminary Design Review
PFC	Preliminary Flight Certification
P/L	Payload
PROD	Production
PROP	Propellant
RCS	Reaction Control System
REF	Reference
RGB	Reusable Ground Based
R&R	Remove & Replace
RSB	Reusable Space Based
RSI	Reusable Surface Insulation
SB	Space Based
S/C	Spacecraft
SCB	Shuttle Cargo Bay
SIL	Systems Integration Laboratory
STA	Structural Test Article
STG	Stage
STS	Space Transportation System
T/D	Turndown
TDRS	Tracking Data Relay Satellite
TPS	Thermal Protection System
TT&C	Telemetry, Tracking and Control
WBS	Work Breakdown Structure

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1.0 INTRODUCTION

This section provides a description of the study in terms of background, objectives, issues, organization of study and report, and the content of this specific volume.

Use of trade names, names of manufacturers, or recommendations in this report does not constitute an official endorsement, either expressed or implied, by the National Aeronautics and Space Administration.

And finally, it should be recognized that this study was conducted prior to the STS safety review that resulted in an STS position of "no Centaur in Shuttle" and subsequently an indication of no plans to accommodate a cryo OTV or OTV propellant dump/vent. The implications of this decision are briefly addressed in section 2.2 of the Volume I and also in Volume IX reporting the Phase II effort which had the OTV launched by an unmanned cargo launch vehicle. A full assessment of a safety compatible cryo OTV launched by the Shuttle will require analysis in a future study.

1.1 BACKGROUND

Access to GEO and earth escape capability is currently achieved through the use of partially reusable and expendable launch systems and expendable upper stages. Projected mission requirements beyond the mid-1990's indicate durations and payload characteristics in terms of mass and nature (manned missions) that will exceed the capabilities of the existing upper stage fleet. Equally important as the physical shortfalls is the relatively high cost to the payload. Based on STS launch and existing upper stages, the cost of delivering payloads to GEO range from $12,000 to $24,000 per pound.

A significant step in overcoming the above factors would be the development of a new highly efficient upper stage. Numerous studies (ref. 1, 2, 3, 4) have been conducted during the past decade concerning the definition of such a stage and its program. The scope of these investigations have included a wide variety of system-level issues dealing with reusability, the type of propulsion to be used, benefits of aeroassist, ground- and space-basing, and impact of the launch system.

1.2 OBJECTIVES AND ISSUES

The overall objective of this study was to re-examine many of these same issues but within the framework of the most recent projections in technology readiness, realization that a space station is a firm national commitment, and a refinement in mission projections out to 2010.

During the nineteen-month technical effort the specific issues addressed were:

a. What are the driving missions?

b. What are the preferred space-based OTV characteristics in terms of propulsion, aeroassist, staging, and operability features?

c. What are the preferred ground-based OTV characteristics in terms of delivery mode, aeroassist, and ability to satisfy the most demanding missions?

d. How extensive are the orbital support systems in terms of propellant logistics and space station accommodations?

e. Where should the OTV be based?

f. How cost effective is a reusable OTV program?

g. What are the implications of using advanced launch vehicles?

1.3 STUDY AND REPORT ORGANIZATION

Accomplishment of the objectives and investigation of the issues was done considering two basic combinations of mission models and launch systems. Phase I concerned itself with a mission model having 145 OTV flights during the 1995-2010 timeframe (Revision 8 OTV mission model) and relied solely on the Space Shuttle for launching. Phase 2 considered a more ambitious model (Rev. 9) having 442 flights during the same time frame as well as use of a large unmanned cargo launch vehicle and an advanced Space Shuttle (STS II).

The study is reported in nine separate volumes. Volume I presents an overview of the results and findings for the entire study. Volume II through VIII contains material associated only with the Phase I activity. Volume IX presents material unique to the Phase II activity. Phase I involved five quarters of the technical effort and one quarter was associated with the Phase II analyses.

1.4 DOCUMENT CONTENT

This document reports the impact on the environment resulting from development and use of the OTV. The purpose and need for the OTV are explained, the proposed project is described, and the environment impact of the OTV project is assessed.

2.0 OVERVIEW

This report provides an analysis of the potential environmental effects that would result from the operation of either a ground-based or space-based Orbital Transfer Vehicle (OTV) system beginning operations in the mid 1990's time period, and from the conduct of ground and space-based testing necessary to develop the technologies associated with the OTV program.

OTV operations include activities such as ground launch of OTV/propellant tankers, OTV fueling, checkout, OTV/payload integration, propellant transfer and storage, OTV launch, pre-launch/post-launch processing, and on-orbit operations, including aeromaneuvering. The testing program encompasses development of equipment and procedures to effectively accomplish these operations, including on-orbit maintenance and aeroassist technology.

This analysis considers the potential impact on the broad objectives of the National Environmental Protective Act (NEPA) that may result from OTV servicing operations, and from the necessary development program.

3.0 SUMMARY AND CONCLUSIONS

The objective of the proposed project is to provide a reusable OTV system to provide cost-effective payload delivery to high energy orbits beginning in the mid 1990's time period. The project also provides a program of ground and space-based testing to develop the technologies necessary for OTV operations.

From an environmental standpoint, operation of a resuable LO_2/LH_2 OTV should introduce no adverse environmental conditions since most emissions are limited to oxygen and hydrogen propellants and water which dissipate quickly without affecting Earth's environment. OTV engine exhaust emissions are the same as for Shuttle-launched cryogenic expendable stages and are more benign than solid propellant upper stages. A small amount of ammonia, hydrogen, and nitrogen is created as a result of the reaction control system exhaust but will also dissipate quickly.

The testing required for development of OTV servicing technologies is fundamentally an extension of existing environmentally compatible ground and space test and operations activities, and as such, introduce no new environmental conditions.

All environmental issues that were identified as a result of this analysis have been evaluated adequately using internal technical personnel. Therefore, the need has not arisen to consult with other individuals or agencies on environmental matters.

An Environmental Impact Statement for the proposed program is judged not to be required, because operation of an OTV introduces no new environmental conditions and improves current conditions. The testing required is an extension of current operations that meet environmental requirements. The only potential impact is on the Space Station environment, whose true requirements have not yet been clearly defined.

4.0 PURPOSE AND NEED FOR OTV

Currently, all upper stages and/or orbital transfer stages used to deliver payloads to GEO and HEO missions are of the expendable type. With the operational capability of the Space Shuttle, it is expected that upper stages will become reusable for economic reasons. The manned Space Station will also allow space-basing of the reusable OTV which will be able to handle larger payloads, and provide the benefits of manned servicing, checkout, and repair at the Space Station prior to LEO launch.

The objective of the proposed project is to develop an operational OTV system and related support capabilities. Achieving this objective will require a program of ground and space-based testing to develop the necessary technologies - primarily the on-orbit recovery, transfer, and storage of cryogenic propellants, the performance of various assembly, servicing, and repair operations, automated OTV rendezvous and docking, and aeroassist technology.

The major milestones of the proposed program are as follows:

1988 - Start Aeroassisted Flight Experiments to demonstrate aeroassist technology.

1994 - First ground-based OTV flight.

2001 - First OTV flight with auxiliary tank (requires integration at the Space Station) or first space based OTV flight.

All testing and operational activities associated with the OTV program are expected to support the broad objectives of the National Environmental Protection Act; no adverse environmental conditions resulting from development or use of a space-based OTV have been identified.

5.0 DESCRIPTION

The proposed project covers two principal phases: (1) the development, test, and validation of OTV technologies and designs, and (2) routine operation of the integrated OTV system, including both ground and space operations. Both the technology development testing and routine OTV operations are comprised of four parts: (1) ground operations, (2) launch operations, (3) LEO on-orbit operations, and (4) flight operations.

Technology Development Testing. Several OTV operations will require testing to develop and demonstrate the technology involved. These are primarily on-orbit recovery, transfer and storage of propellants, automated OTV navigation, including flight operations and rendezvous and docking procedures, on-orbit OTV/payload integration, OTV servicing/fueling, and demonstration of aeroassist technology. Of the required program of testing, only those operations associated with propellant handling, and possibly the aeromaneuver, appear to have potential environmental effects. As with the operational case, all other testing involves "self-contained" man-machine systems, with no pollutants in ground testing, and no debris or re-entry products generated during space-based testing.

OTV Operations. Ground operations include maintenance and refurbishment of OTV systems and subsystems, payload checkout and integration (GB OTV only), and launch vehicle integration of the GB OTV and payload or propellant tanker if a SB OTV program exists. All of these operations are conducted in clean room environments. The only operations posing potential environmental hazards involve handling of toxic RCS propellant (N_2H_4), which can be accommodated by following current safety procedures.

Launch operations include loading of cryogens (O_2,H_2) at the launch pad into the GB OTV or propellant tanker (SB OTV) and launch vehicle operations. Principal environmental impacts during launch involve venting of cryogens to the atmosphere. The cryogens (O_2, H_2) are non-toxic and form ice and water vapor.

The LEO on-orbit operations include checkout and deployment of the OTV and payload from the Shuttle or an SDV (GB OTV) or transfer of the payload or propellant tanker to the Space Station (for a SB OTV program). At the Space Station the OTV is checked out, the payload integrated/checked and the OTV is fueled and launched. Following payload delivery, the OTV is recovered and serviced/refurbished for re-use. Support operations include the recovery, transfer and storage of propellants, and servicing, assembly, and checkout of payloads. Of this set of OTV operations, only

those involving the handling of propellants are considered as having potential environmental effects. All other operations are "self-contained" man-machine operated, with no emissions, debris, or generation of re-entry products. The principal problem concerning handling of propellants is degradation of the vacuum environment in the immediate vicinity of the Space Station, which could potentially cause degradation of the solar array or sensor performance.

Flight operations include main propulsive burns, RCS burns, payload deployment, and an aeromaneuver. During this period the OTV may also be coasting or performing rendezvous and dock maneuvers. The main propulsive and RCS burns both produce benign exhaust byproducts. The principal concern is avoidance of plume impingement on the Space Station, Shuttle, or other close-by satellites. These problems can be avoided with appropriate flight procedures. The OTV system is designed to be reusable and does not use explosive devices for payload separation, thus avoiding creation of debris. A number of viable aerobrake options are under consideration, most of which are completely reusable. Those which are not completely reusable (e.g. jettisonable ballute) will result in a form of orbital debris until reentry occurs. Because the recommended OTV design includes a jettisonable ballute concept, further detailed analysis will be required to determine the disposition and extent of reentry debris.

6.0 ENVIRONMENTAL IMPACT OF PROJECT AND ALTERNATIVES

The potential impact on the Earth environment has been reviewed for both the operational use of an OTV, and for the testing program necessary to develop technologies associated with the OTV program.

The environmental factors considered include air, water, and noise pollution; solid waste and toxic substances; radiation; safe drinking water; health and safety for the general populace; farmlands; and re-entry debris. other factors contained in NEPA are not considered applicable to this project.

Impact of Proposed Project. The potential impact of a GB reusable aeroassisted OTV on the Earth environment (ground and atmosphere) appears negligible in terms of propellant. The emissions will be limited to small amounts of oxygen and hydrogen which are expected to readily disperse at the altitudes involved with no adverse effect on Earth's atmosphere. The ballute used for aeroassist will re-enter shortly after jettisioning. The thermal protection characteristics of the ballute indicates the potential exists for the ballute to go through re-entry without complete burn-up. An assessment of this situation however is beyond this study.

A reusable aeroassisted SB OTV could have an additional adverse environmental impact due to propellant handling creating an "atmosphere" around the Space Station. Another impact, not discussed above, concerns effects on the Space Station microgravity environment caused by c.g. shifts resulting from transfer of large quantities of propellant and mass of the OTV/payload combination. Both these effects can be mitigated through adoption of a ground-based OTV rather than a space-based OTV concept. However, it should be noted that both of these effects are also caused and to a greater magnitude by the Shuttle during its docking with the Space Station. Further definition of Space Station requirements will show whether these two potential environmental disturbances will be important.

Radiation hazards due to the OTV are not a problem because the OTV does not use a radioactive power source. OTV radiation emissions are restricted to low power communications which do not pose any danger.

During ground-based testing of the propellant transfer and storage operations the same gases discussed above will be emitted into the local atmosphere. However, the amounts will be relatively small considering any polluting effects, and will occur at

contractor and government testing facilities where adequate environmental safeguards are currently in effect.

Therefore, no adverse environmental conditions are expected to result from either the operational use or from the development testing program of a ground- or space-based OTV.

7.0 REFERENCES

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3. NASA Contractor Reports 3535 and 3536, Future Orbital Transfer Vehicle Technology Study, Boeing Aerospace Company, Contract NAS1-16088, May 1982.

4. Report No. GDC-SP-83-052, Definition of Technology Development Missions for Early Space Station, General Dynamics Convair Division, Contract NAS8-35039, June 1983.