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COMMUNICATIONS SATELLITE SYSTEMS OPERATIONS WITH THE SPACE STATION

VOLUME I - EXECUTIVE SUMMARY

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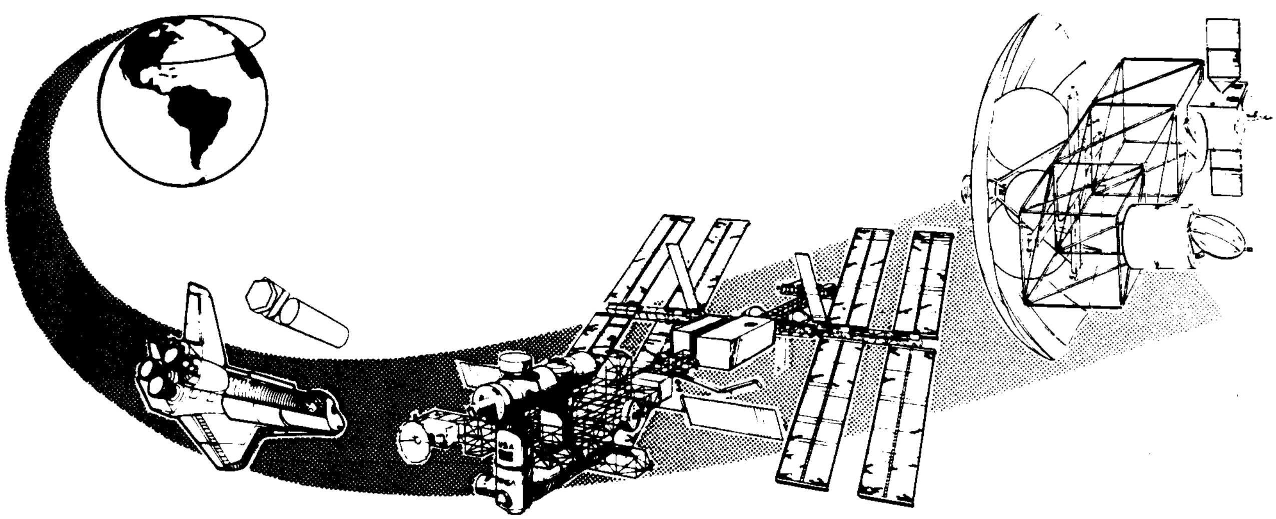

Coopers & Lybrand

Ford Aerospace & Communications Corporation

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ABSTRACT

The NASA Space Station has the potential to provide significant economic benefits to commercial communications satellite operators. This report gives the results of a study to quantify the benefits of new space-based activities and to assess the impacts on the satellite design and the Space Station.

The following study results are described:

- A financial model is developed which describes quantitatively the economics of the space segment of communication satellite systems. The model describes the economic status of the system throughout the lifetime of the satellite. The economic performance is output in terms of total capital cost and rate of return on investment.

- The expected state-of-the-art status of communications satellite systems and operations beginning service in 1995 is assessed and described. The results of the assessment are utilized to postulate and describe representative satellite systems.

- New or enhanced space-based activities and associated satellite system designs that have the potential to achieve future communications satellite operations in geostationary orbit with improved economic performance are postulated and defined. These activities include retrieval, orbital transfer vehicle (OTV) launch, deployment of appendages, checkout, fueling, assembly, and servicing of satellites.

  The financial model is used to determine the economic performance of these different activities and combinations of activities. The use of the space-based OTV to transport satellites from low earth orbit to geostationary orbit offers the greatest economic benefit.

- Three scenarios using combinations of space-based activities are analyzed: (1) a spin stabilized satellite, (2) a three axis satellite, and (3) assembly at the Space Station and GEO servicing. The economic performance of the scenarios is analyzed.

- Functional and technical requirements placed on the Space Station by the scenarios are detailed. Requirements on the satellites are also listed.

The major study results are as follows:

1. Economic benefits are realizable for the commercial communications satellite industry with use of the Space Station.

2. A space-based OTV is necessary to carry out APOs in a timely and cost-effective manner.

3. A study of the economics of retrieval missions and the influence of retrieval on the insurance industry is required in order to accurately demonstrate the value of retrievability for the satellite.

4. Further NASA-sponsored study of a modular satellite design capable of being assembled in LEO (at the Space Station) and serviced in GEO is required.

5. Space Station hardware required for satellite missions should be installed as soon as possible to demonstrate NASA commitment.

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TABLE of CONTENTS

LIST of TABLES

1 Program Description

1.1 Introduction

Commercial communications satellites form a high visibility, high benefit use of space and require a large capital investment. The NASA Space Station may have the potential to provide significant economic benefits to the commercial communications satellite operators, probably with considerable change in satellite design and operation.

The diverse objectives and lack of standardization in the commercial sector will require NASA coordination and direction to maximize Space Station benefits. NASA has taken the lead with this study which seeks to quantify the benefits of new space-based activities and assess the impacts on the satellite design and the Space Station.

1.2 Objectives of Study

There are three objectives of this study:

- Develop a quantitative methodology to assess the viability of a broad range of new space-based activities, procedures, and operations (APOs) when utilized in commercial communications satellite system operations;
- Apply the developed methodology to select which of these APOs can be competitively provided by the Space Station and its associated operating systems; and
- Determine the economic and functional requirements imposed on the Space Station through the provision of these selected APOs.

1.3 Approach

The technical work is divided into four tasks:

1. Develop Communications Satellite Financial Model
   - A. Develop Basic Financial Model
   - B. Assess Impact of System Characteristics on Financial Model Output
2. Determine Economic Performance of Baseline 1995 Scenario
3. Assess Economics of New Space-Based Activities for 1995
   - A. Postulate New Space-Based APOs
   - B. Evaluate Economics of APOs
4. Develop Space Station Scenarios and Requirements

2 Financial Model

A communications satellite financial model (the Financial Model) that describes quantitatively the economics of the space segment of U. S. domestic fixed satellite service communication satellite systems was developed by Coopers & Lybrand under subcontract to Ford Aerospace. (Ground terminals and terrestrial system costs are excluded from consideration except for satellite telemetry, tracking, and control systems.)

The Financial Model describes the economic status of the system throughout the lifetime of the satellite beginning with its design and continuing through its construction, launch, and commercial operations. It can be applied to the range of satellite sizes, communications payloads, and lifetimes expected to be implemented in the 1985 to 1995 time frame.

The Model was calibrated by analysis of three 1985 satellite systems and validated by comparison with actual satellite system economic performance. Significant satellite system characteristics were identified and a sensitivity analysis of the impact on system economic performance was performed.

3 Baseline Economic Performance

3.1 Definition of 1995 Systems

The economic performance for the following four 1995 satellite types was analyzed:

- Ku-band spin-stabilized satellite;

	Spinner	Ku-Band	Hybrid	Large
Baseline satellite	Hughes 393	RCA K2	Ford FS-1300	Hectosat
Design life (yr)	10	10	10	10
BOL mass (kg)	1377	1044	1540	2144
Payload mass (kg)	261	261	342	747
– Antenna (kg)	29	29	52	161
– Transponder (kg)	232	232	290	586
EOL power (W)	2900	3000	4200	3100
Stabilization	Spin	3-axis	3-axis	3-axis
Frequencies	Ku-band	Ku-band	C/Ku-bands	Ku-band
Number of transponders:				
– C-band			24	
– Ku-band	24	24	24 & 6	108
Transponder bandwidth:				
– C-band (MHz)			36	
– Ku-band (MHz)	54	54	36 & 72	36
Transponder power:				
– C-band (W)			10	
– Ku-band (W)	50	50	35	20
Antenna coverages:				
– C-band			2	
– Ku-band	3	3	3	9
Satellite EIRP (Conus):				
– C-band (dBW)			36	
– Ku-band (dBW)	46	46	46	46
Launch vehicle(s):	Ariane 4 STS/PAM D2	Ariane 4 STS/PAM D2	Ariane 4 STS/Ford	Ariane 4 STS/IUS
Satellite Cost ($M, 1985)	54.2	50.9	64.6	88.1

Table S–1: Summary of 1995 Satellite Characteristics

- Ku-band 3-axis satellite;
- Hybrid (C and Ku-bands) 3-axis satellite;
- Large Ku-band 3-axis satellite.

Table S-1 summarizes the characteristics of the four satellites.

3.2 Economic Performance

Tables S-2 and S-3 give the economic performance of the 1995 baseline satellites. The initial rates-of-return were adjusted to account for a postulated 33% transponder price reduction from 1985 to 1995. Capital costs are stated in 1985 dollars and are the total of all costs associated with building and launch of the satellite.

Table S-2 gives the dual terminal rate-of-return (DTRR) for the four satellite types that are analyzed. (See Volume II, Technical Report, Subsection II-3.3 for an explanation of DTRR.) The 1985 column gives the Financial Model results for the 1985 launch satellites with a basic transponder price of $1.9 M per year (C-band, 5.5 W, 36 MHz bandwidth).

The "initial" 1995 returns are for the 1995 satellite designs (50% more capacity) and the same basic transponder price. The "final" 1995 returns were adjusted 4.4 points lower so that the average return equals the average 1985 return. This required a 33% decrease in basic transponder price.

The Large satellite is a 1995 design. Its "initial" and "final" returns are 29.6% and 25.1% respectively. The higher return implies that transponder prices could be further reduced.

Table S-3 gives the capital costs of the baseline satellites. The greater costs of the 1995 satellites are due to the increased number and power of the transponders.

Satellite Design	DTRR Return, %		
	1985	1995	
		Initial	Final
C/Ku Spinner	18.1	23.4	18.9
Ku 3-axis	19.8	23.3	18.8
Hybrid 3-axis	21.9	26.5	21.9
Large 3-axis	–	29.6	25.1

Table S–2: DTRR for Satellite Systems

Satellite Design	Capital Cost, $ M	
	1985	1995
C/Ku Spinner	76.5	115.1
Ku 3-axis	104.3	116.8
Hybrid 3-axis	83.1	138.8
Large 3-axis	–	215.4

Table S–3: Capital Costs for Satellites

3.3 Discussion of Economics

There is little to choose between the capital costs and rates of return for the spinner and 3-axis Ku-band systems. However, due to its greater number of transponders, the hybrid system has a 3% greater rate of return.

This is achieved without selling any cross-connected transponders; i.e. transponder prices are based on all C and all Ku-band sales. As discussed in Subsection III-4.8 of the Technical Report, sales of hybrid pairs of transponders bring a 30% premium and would further increase the return. For the purposes of this analysis, we take the conservative assumption that revenues from sales of hybrid pairs will be offset by a decrease in utilization of the remaining "wrong way" pairs.

The impressive results for the large satellite are due to economies of scale. The implication is clearly that this is the satellite design of the future. An 18% transponder price reduction from the best performing 1995 satellite is achieved, and a 45% price reduction from the 1985 satellite systems.

4 New Space-Based APOs

4.1 Postulation of APOs

New or enhanced space-based Activities, Procedures, and Operations (APOs) and associated satellite system designs that have the potential to achieve future communications satellite operations in geostationary orbit with improved economic performance have been defined.

The criteria for selection of the APOs are increased communications satellite technical and economic performance. The selection of APOs is made based on predicted available technology and judgment of economic value. There were eleven APOs considered.

1. Emergency retrieval from LEO
2. Ground-based orbital transfer vehicle (OTV) launch to geostationary transfer orbit (GTO)
3. Ground-based OTV launch to geosynchronous earth orbit (GEO)
4. Deployment of appendages at shuttle
5. Space-based OTV launch to GTO
6. Space-based OTV launch to GEO
7. Deployment of appendages at Station
8. Checkout at Space Station
9. Fueling at Space Station
10. Assembly at Space Station
11. Servicing/replacement for GEO satellites
    - Transport to low earth orbit (LEO) for servicing
    - Servicing in GEO

The APOs are listed in order from simplest to most complex, which is approximately the same as chronological for availability.

4.2 Economics of APOs

The Financial Model was used to analyze the economics of the individual and combination APOs for the 1995 spinner and 3-axis hybrid satellite designs. Table S-4 gives a summary of APO economic performance.

The APO value is defined as the "fee" NASA could charge for the APO that would result in the same economic performance as for the business-as-usual scenario. The major influences on economic value are the following:

- Savings in STS launch costs due to decrease in mass.
- Savings in insurance costs (20% nominal rate).
- Increase in satellite cost.

The combination APOs have an additional value due to the fact that some of the same satellite equipment is required for different APOs.

The conclusion is that use of the space-based OTV for transport of two or more 3-axis satellites from LEO to GEO is the high value APO that can make commercial satellite operations with the Space Station a reality. Once at the Space Station, other APOs of marginal value but important to the particular mission can be done.

5 Space Station Scenarios

Three communications satellite system operating scenarios implementing different combinations of APOs are analyzed. The economic performance of these scenarios is evaluated and compared to the baseline performance. Finally the sensitivity of the results to different insurance and launch cost assumptions is analyzed.

The following scenarios are chosen for evaluation:

- Spinner satellite scenario:
- 3-axis satellite scenario:
- Assembly/servicing scenario:

The spinner satellite APO scenario is not economically attractive but is included for completeness. It is our belief that satellites will have a 3-axis design in order to best utilize the capabilities of the Space Station.

The assembly/servicing scenario requires a completely new satellite design which will not evolve until the Space Station is in orbit. Its IOC (initial operational capability) is unlikely to be 1995 but rather the year 2000.

APOs at Shuttle	Spinner Satellite ($115 M)			3-Axis Satellite ($139 M)		
	Value	$M	Major Reasons	Value	$M	Major Reasons
Capability for LEO Retrieval	yes	1.1	Insurance -1%	yes	1.3	Insurance -1%
GB-OTV from LEO to GTO	yes	12.5	Insurance -2%	–	–	LEO-GEO better
GB-OTV from LEO to GEO	–	–	Spinner design	yes	37.2	Insurance -5%
Deploy appendages	no	–	Spinner design	yes	1.7	Insurance -1%
3-Axis Combination	–	–		yes	38.8	STS cost/Ins. -6%

APOs at Space Station	Spinner Satellite ($115 M)			3-Axis Satellite ($139 M)		
	Value	$M	Major Reasons	Value	$M	Major Reasons
Capability for LEO Retrieval	yes	.5	Insurance -1%	yes	.7	Insurance -1%
SB-OTV from LEO to GTO	yes	13.0	Insurance -2%	–	–	LEO-GEO better
SB-OTV from LEO to GEO	–	–	Spinner design	yes	39.5	Insurance -5%
Deploy satellite appendages	no	–	Spinner design	no	–	Sat. cost increase
Checkout of satellite	no	–	Spinner design	no	–	Sat. cost increase
Add fuel to satellite	no	–	Spinner design	no	–	Sat. cost increase
Capability for GEO Retrieval	no	–	Sat. cost increase	yes	1.3	Insurance -1%
Spinner Combination	yes	15.9	STS cost/Ins. -6%	–	–	
3-Axis Combination	–	–		yes	41.2	STS cost/Ins. -9%

Table S–4: Summary of APO Economics

5.1 Spinner Satellite Scenario

The following APOs are utilized with the 1995 spinner satellite design:

- Checkout at Station
- Fueling at Station
- Space-based OTV to GTO
- Retrieval capability from GEO

Table S-5 gives a comparison of the capital expenditures for the spinner scenario with the Space Station compared to the baseline spinner scenario. The OMV/OTV fees are for use of the Orbital Maneuvering Vehicle and the Orbital Transfer Vehicle. A total insurance benefit of 6 points is hypothesized for this scenario. Launch insurance is 20% for the baseline case and 14% for the Space Station scenario. Insurance appears twice in the table, first for the upper group of capital expenditures and second for the lower group.

Capital Expenditure	Cost ($M 1985) Baseline	Station Scenario
Satellite	54.3	56.9
STS Launch	29.9	21.1
Perigee stage	3.8	.7
Launch support	1.6	1.6
Mission ops.	2.6	2.3
Insurance	23.0	13.5
Total	115.1	96.1
OMV/OTV	–	10.3
Station support	–	3.0
Insurance	–	2.2
Total	115.1	111.6

Table S–5: Spinner Scenario Economics

The result is a \$3.5 M savings for the scenario versus the baseline satellite. The Financial Model indicates this corresponds to a 0.2 point increase in the rate-of-return (DTRR) from 18.9% for the baseline to 19.1% for the spinner scenario with the Space Station. Considering the uncertainties in the inputs to this calculation, this scenario has marginal value.

5.2 3-Axis Satellite Scenario

The following APOs are utilized with the 1995 hybrid 3-axis satellite design:

- Deploy appendages at Station
- Checkout at Station
- Fueling at Station
- Space-based OTV to GEO
- Retrieval capability from GEO

Table S-6 gives a comparison of the capital expenditures for the 3-axis scenario with the Space Station compared to the baseline 3-axis scenario. A total insurance benefit of 9 points (a rate change from 20% to 11%) is hypothesized this scenario. Space Station support costs for handling, deployment, checkout, and fueling are estimated.

The result is a \$21.5 M savings for the scenario using the Space Station versus the baseline case. The Financial Model indicates this corresponds to a 1.4 point increase in the rate-of-return (DTRR) from 21.9% for the baseline to 23.3% for the 3-axis scenario with the Space Station. This indicates substantial economic value.

Capital Expenditure	Cost (\$M 1985) Baseline	Station Scenario
Satellite	64.6	62.5
STS Launch	35.4	16.1
Perigee stage	6.9	.6
Launch support	1.6	1.6
Mission ops.	2.6	1.6
Insurance	27.8	10.2
Total	138.8	92.6
OMV/OTV	–	18.5
Station support	–	3.5
Insurance	–	2.7
Total	138.8	117.3

Table S–6: 3-Axis Scenario Economics

5.3 Assembly/Servicing Scenario

The following APOs are utilized with the 1995 hybrid 3-axis satellite payload that is incorporated into a redesigned satellite:

- Assemble satellite at Space Station
- Checkout at Space Station
- Fueling at Space Station
- Space-based OTV to GEO
- Service satellite in GEO

In order to be serviced in orbit by an Orbital Maneuvering Vehicle (OMV) plus servicer front end, the satellite must be designed in a different manner. The concept is to have a satellite design with modules that are replaced during servicing. This leads to a less highly integrated satellite design that consists of pieces that can be transported separately and then assembled at the Space Station. Thus the concept of servicing a satellite leads to the potential for assembly.

The servicing mission is planned to occur after nine years and to result in extension of the satellite life by another nine years. The modular satellite design would be 10% heavier than the baseline satellite of the same capacity. The servicing mission would replace 40% of the mass of the modular satellite.

Table S-7 gives a comparison of the capital expenditures for an 18 year assembly/servicing scenario with the Space Station compared to a baseline scenario with two successive hybrid 3-axis satellite launches each having a nine year lifetime. The baseline scenario uses the 1995 3-axis hybrid satellite with 9 year lifetime and scenario per Subsection VIII-3 of the Technical Report. It is assumed that the second satellite has the same cost as the first. The insurance rate is assumed to be the same (11%) for assem-

Capital Expenditure	Cost ($M 1985) Baseline 1st or 2nd	Scenario 1st	Scenario 2nd
Satellite	62.5	68.9	34.8
STS Launch	16.1	15.4	8.0
Perigee stage	.6	.6	.3
Launch support	1.6	1.6	.5
Mission ops.	1.6	1.6	1.6
Insurance	10.2	10.9	5.6
Total	92.6	99.0	50.8
OMV/OTV	18.5	19.9	16.5
Station support	3.5	5.0	3.0
Insurance	2.7	3.1	2.4
Total	117.3	127.0	72.7

Table S-7: Assembly/Servicing Economics

bly/servicing scenario as for the baseline case.

The initial capital expenditure is $10 M more but the second launch is $45 M less than the baseline approach. The Financial Model gives a rate-of-return (DTRR) approximately the same for this scenario as for the baseline (21.07% versus 21.10%).

The conclusion is that the economics of the assembly/servicing scenario are less favorable than launching two successive conventional satellites with the OTV. However, our satellite costs derived using Price H are based on a very preliminary design of a assemblable, serviceable satellite. We recommend that more work be done on design of such a satellite. In particular, relaxation of constraints on compactness may lead to substantial savings in integration and test costs.

5.4 Sensitivity Analysis

5.4.1 Launch Insurance

The important point is the difference, if any, between the Space Station scenario and the baseline case insurance rate. The scenarios assume a 6 point and a 9 point difference respectively for the spinner and 3-axis scenarios.

If it is assumed there is no difference in insurance rates due to the scenarios, the cost of the spinner scenario increases by $8.3 M to $119.9 M, versus $115.1 M for the baseline. The 3-axis scenario increases in cost by $13.2 M to $130.5 M, versus $138.8 M for the baseline.

3-Axis Satellite	Cost ($ M)	Rate-of-return (%)
Baseline (20%)	138.8	21.9
Scenario (11%)	117.3	23.3
Scenario (20%)	130.5	22.5

Table S-8: Influence of Insurance Rate

Cost Change	Cost ($M 1985) Baseline	Scenario	Delta
Original case	138.8	117.3	21.5
OTV plus 50%	138.8	127.7	11.1
STS minus 50%	116.7	108.3	8.4
OTV minus 50%	138.8	106.9	31.9
STS/OTV -50%	116.7	97.9	18.8

Table S-9: Influence of Launch Costs

The conclusion is that without insurance benefits the spinner scenario is definitely not viable. The 3-axis scenario continues to show benefits, although reduced greatly from $21.5 M to $8.5 M. Table S-8 summarizes the satellite cost and rate-of-return (DTRR) changes for the 3-axis scenario with 20% insurance rate.

5.4.2 Launch Costs

Table S-9 summarizes the effects of some substantial changes in launch charges on system costs. The baseline and 3-axis scenario costs are compared for each launch cost assumption. The scenario continues to show value regardless of the launch cost change. The economics are very sensitive to changes in OTV costs. The assumption of STS charges being reduced by 50% also has a large negative effect on scenario economics.

5.5 Conclusions

The spinner scenario has a small nominal value with the hypothesized costs, but is sensitive to changes in insurance and launch costs. This scenario is judged to be not economically viable.

The 3-axis scenario shows substantial value which continues to be positive under worst case insurance and launch cost assumptions. This scenario is judged to be economically viable.

The assembly/servicing scenario has equal value to two successive launches of the 3-axis scenario. Considering our relatively crude analysis of the satellite design, we believe this scenario has promise of better performance and should be analyzed in more detail.

6 Space Station Requirements

6.1 Hardware Requirements

6.1.1 Servicing and Storage Bay

The primary requirement on the Space Station is the inclusion of a servicing/storage bay in the initial design. An early servicing bay would be used for unscheduled retrieval missions where a perigee motor or ELV upper stage fails, leaving the satellite in an orbit not accessible to the OMV.

The economic and environmental advantages of retrieval missions to the Space Station justify the initial inclusion of this area. The servicing/storage bay would later be used for storage of satellites prior to using the OTV and for storing and assembling small satellites.

The storage bay should be large enough to accommodate up to four 1995 satellite designs for storage and an additional area for servicing. A 10 m x 10 m x 20 m volume should be sufficient. The bay should be enclosed for micrometeorite and passive thermal protection which can be augmented by internal satellite thermal systems. In addition, standard power and communications ports should be available so that satellites can use Space Station power and can be monitored from inside the manned modules. Power consumption is expected to be in the range of 10 W to 400 W per satellite and data rates are low (1200 b/s).

The servicing/storage bay should be located near the OTV facility and other transportation nodes for the Shuttle and OMV. Since the MRMS (mobile remote manipulator system) transfer systems are predicted to be slow, the time of transfer becomes a concern for the power, thermal, and telemetry systems. Increasing satellite batteries for this procedure should be avoided. Another issue is the mechanical vibrations and oscillations during satellite transfer, which may affect other operations requiring a stable environment.

6.1.2 Automated Transfer Facilities

A universal retention system should be developed to reduce the required hardware weight on satellite systems, and allow automated docking and release.

Automated systems such as the MRMS (mobile remote manipulator system) are needed to transfer satellites and equipment to and from the Shuttle, OTV, OMV, and storage/servicing bay. Systems with a high level of articulation and control are desired to reduce demand for extra vehicular activity (EVA) such as deployments and connections.

6.1.3 Fueling Facilities

Fueling facilities may be required at the Space Station. Although there is no economic advantage for fueling at the Space Station, other factors such as Shuttle launch safety may require it, as may APOs such as assembly. The issues surrounding fueling should be examined in depth before placing requirements on the Space Station.

6.2 OMV Requirements

The initial use of the Orbital Maneuvering Vehicle (OMV) is as a space tug to retrieve stranded satellites from LEO as well as transfer cargo from expendable launch vehicles (ELVs) to the Space Station. This requires space-basing of an OMV in order to be available for unscheduled events such as emergency retrieval.

The OMV would need to be attachable to a servicing device such as the Smart Front End for GEO servicing. This combination should have the capability of servicing several satellites on each mission. Methods for changing out modules should be standardized and tested in LEO prior to use in GEO.

There should be at least two OMVs in order to be able to retrieve a malfunctioning OMV to the Space Station for repair.

6.3 OTV Requirements

The use of the Orbital Transfer Vehicle (OTV) gives the largest economic advantage of the APOs evaluated. The requirements placed on the OTV by this study are within the scope of the capabilities required by the initial OTV studies. Several satellites must be launched at once in order for the relatively large capacity OTV to be economical. This requires a multiple payload carrier (MPC) which should use a standard retention system compatible with the Space Station servicing bay.

The OTV should provide power and telemetry links to the satellite while in transit. Slow spinning of the OTV will assist in maintaining the thermal environment of the satellites.

The OTV should be capable of maintaining accelerations of 0.1 G or less to allow appendage deployment at the Space Station. This feature would also be required for large communications antennas and platforms not covered in this study.

There should be at least two OTVs in order to be able to retrieve a malfunctioning OTV to the Space Station for repair. An OTV based at the Space Station is preferred to the ground-based alternative in order to respond more rapidly to an emergency retrieval.

6.4 Operations and Policy

There are other requirements that the satellite communications industry places on the Space Station infrastructure beyond hardware or scarring needs. It is important that scheduled use of the Space Station, OMV, or OTV not be interrupted. Many of the APOs using the Space Station will have no alternative if the service is delayed due to higher priority government missions. The Space Station should adopt a set of operations and policies that insure its users a high degree of reliability.

The procedures required on the ground for Space Station safety should become streamlined without hindering the determination of safeness. Present NASA safety requirements for the Shuttle require a large amount of paperwork and additional test time prior to launch. The safety requirements for the Station should be studied far in advance so that an efficient safety regulation program can be utilized.

Space Station policies should be devised so that termination of services will not occur without sufficient lead time to allow satellite manufacturers to phase Space Station APOs out of their designs. Reduction of services due to safety or accidents should not be placed only on the commercial users.

7 Recommendations

7.1 Need for Space-Based OTV

The space-based Orbital Transfer Vehicle (OTV) is recommended rather than a ground-based OTV for several reasons. Most important is minimization of possible scheduling problems. Operations based at the Space Station such as deployment and assembly would need to be scheduled simultaneously with the ground launch of the ground-based OTV. Delays occurring on the ground (for example, due to weather) could disrupt schedules at the Station due the necessity for preparing and protecting multiple satellites. Conversely, satellite operation delays at the Station could delay the ground launch. The ground-based OTV, if fueled, requires a large amount of power to prevent cryogenic boil-off losses.

Another reason for recommending a space-based OTV is risk. Requiring a ground launch for every OTV launch adds risk to the system which could affect the insurance advantage associated with the OTV.

A concern raised by this study is the operational aspect of interfacing a ground-based OTV with the Station and a return vehicle such as the Shuttle. The logistics and cost of returning, refurbishing, and relaunching an OTV have not been determined. A fueling system of a space-based OTV could possibly be simplified by using ground launched tanks that could be "snapped" into the OTV in space. This concept could decrease the cost of launching and retrieving the entire OTV, and may be more cost effective than scavenging systems with long term space-based fueling depots.

The final OTV issue is the cost comparison between space-based and ground-based operation. The obvious advantage of space-basing is that the OTV structure does not need to be carried from Earth to LEO for each mission. As shown in the sensitivity analysis of Subsection VIII-5 and discussion of launch costs in Subsection VII-2.3 of the Technical Report, economics are very sensitive to launch cost assumptions. Perhaps future reduction in launch costs will make this point academic. A careful analysis of OTV costs is needed.

The feasibility of many APOs may be impacted adversely by use a ground-based OTV due to operational constraints.

7.2 Study of Retrieval Missions

The economics of retrieval missions is discussed in Subsection VII-5 of the Technical Report. There can be substantial benefits in retrieval missions and we see this to be a natural function of the Space Station from its position as a "gateway to space" and transportation node.

We recommend that NASA sponsor a study of the economics of retrieval missions and the influence of retrieval on the insurance industry. The goals of this study would be to more accurately demonstrate the value of retrievability for the satellite and to more closely define the operational aspects of retrievability on the Space Station and the satellite.

Involvement of insurance company representatives in the study is desirable, along with a methodology to assess financial risk (defined as the standard deviation in the rate-of-return) for different retrieval scenarios.

7.3 Modular Satellite Design Study

A modular satellite design is required for implementation of assembly and servicing scenarios. We recommend that NASA sponsor a study in this area in order to stimulate the satellite manufacturing industry to consider these designs.

A future NASA or government satellite should then incorporate a requirement for serviceability and/or assembly in order to demonstrate feasibility.

7.4 Study of ELV Use

NASA has recently said that commercial launches will be phased out of the Shuttle program. Expendable Launch Vehicles (ELVs) will need to be used for transport from Earth to LEO (near the Space Station), instead of using the Shuttle as assumed in this study. There are potential impacts on launch costs and risks, on the APOs, and on the requirements placed on the ELV system.

A study is needed to determine the effect that launching commercial communications satellites to LEO on ELVs would have on the APOs, and the requirements placed on the ELVs. The ELV system needs to be designed to supply regular and reliable transportation form Earth to Space Station in order to facilitate the APOs.

7.5 Technology Developments

The following technology developments are recommended:

- Modular satellite designs
- OTV with low thrust and based in space
- RF interfaces for assemblable satellite
- Telerobotics for IVA operations and servicing

7.6 Purpose of Space Station

We see the highest use of the first Space Station as a transportation node with associated staging and assembly areas. Some requirements like safety are of continuing concern, but the inappropriate placing of instruments or experiments on the initial Station that place further difficult requirements is to be avoided.

The value of the Space Station as transportation node will vanish if it is too difficult to use.

The commercial sector will not use something that places addition financial risks on the operations, such as time delays in on-orbit operation. For instance, a one month launch delay is equivalent to 0.4% rate-of-return (DTRR) or $5 M initial cost.

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