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SPACE BASED OTV SERVICING*

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Space based servicing of an Orbit Transfer Vehicle (OTV) has been outlined in sufficient detail to arrive at OTV and support system servicing requirements. Needed space station facilities and their functional requirements have been identified. The impact of logistics and space servicable design on the OTV design is detailed.

INTRODUCTION

The President's proposed Space Station (SS) will provide an excellent base from which to operate a reusable space based Orbit Transfer Vehicle (OTV). Using the SS as a launch and refueling platform will allow the decoupling of the Space Transportation System (STS) earth to low earth orbit (LEO) and the OTV LEO to geosynchronous earth orbit (GEO) legs of payload delivery to GEO. The shuttle will no longer be forced to launch in a window dictated by the payload delivery, but rather on a periodic basis which would allow optimization of ground resources for routine flow. The burden of meeting the launch window then falls upon the SS/OTV system. This implies the need for a highly dependable OTV and OTV support system if the launch windows are to be reliably met.

The OTV support system will in part consist of SS facilities capable of doing routine maintenance and certain contingency repair procedures. It will need an efficient logistics function, as well, to provide needed spares and consumables in a cost effective, timely manner. Implied by this is a highly developed health monitoring system for the OTV and its subsystems. This system must be capable of diagnosing items in need of attention early enough so that the necessary preventative action can be scheduled and lengthy downtimes avoided. All this is made very challenging by the fact that the SS will be able to provide only very limited manned support due to the restricted number of men available, the extreme difficulty of working in the space environment, and the demands of other SS activities.

GROUND RULES AND ASSUMPTIONS

Since none of the hardware actually exists, it is necessary to make a few assumptions and establish sensible ground rules to allow the task to proceed. These are shown in Table 1 and will be briefly discussed below. Since the objective of the present study is to identify engine impacts with regard to servicing, detailed design of the SS support facilities, etc., won't be attempted. Also, assumptions which ease the task of determining representative OTV design and subsequent engine impacts will be made fully realizing that they may not be real.

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For instance, all refueling operations are assumed to be performed on the SS instead of at a remote propellant farm. Operationally, the only impact is to the timeline. The operations to be performed remain similar. The major assumptions show up in Table 1 while many of the smaller assumptions will be noted in the text, as appropriate.

The present study ground rules are: the use of the space station as the OTV base, STS shuttle as the launch vehicle, manrating of the OTV, LO_2/LH_2 propellants, and the use of an aerobrake with a low lift to drag ratio. From a servicing standpoint, LO_2/LH_2 propellants, manrating, and the aerobrake present the greatest drivers. While the aerobrake itself may not need much servicing, a fixed aerobrake restricts OTV maneuvering about the SS, drives hangar design, and complicates engine servicing. Manrating implies a high degree of reliability/redundancy which in turn impacts the integrity of servicing operations. LO_2/LH_2 propellants have a major impact on the propellant storage and transfer systems and to a lesser extent impacts the engine servicing requirements. Principally, the latter will be concerned only with engine changeout implications and the required health monitoring system and its requirements.

As mentioned above, all space based OTV servicing is assumed to be at the SS and means to maneuver the OTV about the SS are provided. Specifically, the hangar and refueling depot are assumed attached and controlled from a permanent OTV control station at the SS. The OTV control station will control all OTV related operations: data-handling, refueling, line of sight (LOS) proximity operations, maintenance scheduling and procedures (except extra-vehicular activity (EVA)), and SS inventory control. The OTV is assumed to be under ground control for the LEO-GEO-LEO phase of the delivery missions. Both the baseline Rev 6 mission model and the SS Mission Model (ref. 1 Vol. 3) indicate an OTV launch frequency of one every two weeks to one month. Therefore, a two week turnaround will be used as the groundrule.

OTV MISSION FLOW

Given the above assumptions and ground rules, the general OTV servicing flow can be sketched as shown in Table 2. From this list of operations, those pertinant to engine and OTV servicing are further broken out so that an operational and functional analysis can be performed which will reveal the SS facilities needs and the engine servicing impacts. These will be used as a baseline against which alternate servicing concepts will be explored/evaluated.
Also, contingency operations such as unscheduled maintenance will be discussed relative to the impact on the baseline functional flow.

A "top down" approach was first used to divide up the nominal two week turnaround so that the maximum available time to do tasks could be delineated. Next, specific individual tasks were considered "bottom up" in that actual times and equipment needed to perform comparable tasks on the ground were determined. In this fashion, areas of further research were identified. For the purposes of this study, the shorter of the two times were used to assemble the timelines shown. Included with the operational analysis are columns indicating facilities needs, and intra-vehicular activity (IVA), EVA and delta time.

Tables 3 and 4 indicate tasks, facilities, and time data for the baseline OTV turnaround. Table 2 presents a top level OTV servicing flow while Tables 3 and 4 break out OTV servicing and engine servicing in further detail, respectively. Complete mission turnaround is shown to take approximately 10 days. This is driven primarily by the LEO-GEO-LEO time and the OTV post mission processing.

The following discussion will cover the OTV mission flow. The "generic" OTV mission is anticipated to begin early with the mission planning activities and other operations by the payload program. The SS begins its preparations 2 to 3 days before the payload is delivered by the STS. The payload is delivered a nominal one week early principally at the convenience of the shuttle and is stored on-board the SS awaiting pre-mission processing. Facilities for handling the payload are presumed available. Their exact manifestation is immaterial, but should include means of mechanically restraining the payload, providing dormant power, data handling, and thermal protection.

A day before the mission the payload is moved into the servicing hangar for final check-out operations. No EVA is anticipated, but could be used if the payload had non-standard interfaces or required some minor contingency repair. For normal operations all pre-mission payload check-out operations shall be handled remotely. The four hours of check-out time are primarily to allow for P/L operations which may be more economically performed on the SS than on the ground. For example, payloads could be launched without fluids to relieve designing for launch loads.

Following successful payload check-out, the OTV will be moved to the servicing hangar for mating with the payload. A final health check will be made of the OTV and the mission parameters will be loaded into the OTV main computer. The OTV to payload interface (I/F) is assumed to be primarily mechanical with a minimal electrical I/F provided. The electrical I/F would be standardized as well as the mechanical I/F. If non-standard I/F's were used, the timeline would need to be modified to allow for OTV I/F modification. No fluid I/F's are anticipated. Two P/L interfaces are implied here: one for the OTV and one for the STS. Once mated and the I/F's verified, the OTV and payload will be moved to the OTV refueling area.

Refueling is performed as the last major operation in the pre-launch flow to avoid bringing a fully loaded OTV into the hangar and to minimize boil-off. This implies a refueling area capable of accommodating the OTV, aerobrake, and payload. The OTV is docked and refueled on the aft end. A fixed aerobrake will complicate the refueling area design. Presumably, a door will be provided in the aerobrake to allow the fluid umbilicals access to the OTV fluid interfaces. The refueling operation itself is the subject of much debate and is simplified here into a tank chilldown operation followed by the bulk fluid transfer. Simultaneous fluid transfer is assumed. Non-hypergolic fluids and "no leak" quick-disconnects (QD's) should allow this. Also, reaction control system (RCS) propellants and pressurants are resupplied in parallel with the main propellants. Pressurant needs should be minimized as much as possible due to the inordinate costs of resuppling pressurants.

Following resupply, a final OTV checkout can be performed (gimbal actuators, pressure checks, etc). The OTV and payload are then disconnected from the refueling area and deployed from the SS. The timeline shown assumes that the SS remote manipulator system (RMS) releases the OTV and payload combination with a small delta-V relative to the SS. The OTV uses a "small" RCS burn to give additional delta-V (about 3 fps) allowing swifter OTV and SS separation. At a safe distance from the SS the OTV control is passed to the ground and the delivery mission begins. An orbital maneuvering vehicle (OMV) could be used to accomplish the same thing.

Space Station control resumes following the return of the OTV to a safe area within LOS of the SS. Here, OTV safing is performed. This may be comprised of venting the OTV propellant residuals. However, this timeline assumes that the cost of propellants is of sufficient importance to warrant recovery. Safing would then entail, primarily, deactivation of the main engines (and the RCS if an OMV is used to recover the OTV). The OTV is returned to the SS following safing either by the OTV RCS or an OMV. The OTV is berthed at the refueling area.

If safing were to entail venting of propellants, this may have a major impact on the OTV. Non propulsive vents must be provided with the appropriate valving and controls. Venting through the engines would be possible but could impose undesirable characteristics on the engine. Additionally, the resulting thrust would need to be accounted for. An OMV would not be able to do this as the OMV would likely be mated to the aft end of the OTV (so its thrust can act through the OTV-P/L center of mass).

Post mission processing is essentially the reverse of the pre-mission flow. The residual propellants are removed after docking at the refueling area. Liquid propellants are returned to the SS cryogen tanks and gaseous propellants are recovered for use by the SS. RCS propellants would also be returned to storage to aid in the accuracy of pre-mission loading (mass measurement errors would otherwise accumulate). It may be desirable to leave a blanket pressure of propellant gases in the tanks for structural reasons.

During the propellant off-loading the SS data handling system will down link mission data from the OTV and return the bulk of this data to the ground where it will be processed. Additional data will have already been sent to the ground during the mission. Some data will also be retained by the SS computer to allow SS personnel to begin post processing scheduling. Quick data analysis and turnaround will be essential to efficient OTV servicing. The bulk of the analysis software is assumed to reside on the ground because it isn't cost effective to burden the SS computer or personnel with this task. Two days are allowed for the ground to return to the SS a preliminary post mission maintenance schedule. During these two days, the OTV would be returned to the hangar if it still has a payload attached. Otherwise, the OTV is moved to its storage area (which may be the servicing hangar - more on this later).

Since post mission OTV servicing is highly dependent upon which maintenance needs to be performed, the routine servicing flow will be discussed along with a separate discussion of major contingency operations such as engine removal or aerobrake repair. Crew time is expected to be an extremely valuable commodity, therefore, routine operations will be highly automated. In addition, the ground processing of mission data will perform an optimization of servicing tasks and return a time table detailing the exact operations to be performed. An approximation is only possible now because both routine, (every mission) and contingency operations will be interwoven to effect the optimization. This approximation appears in Table 2 made up of the scheduled maintenance tasks from Tables 3 and 4.

While the OTV is still berthed at the refueling area, a propulsion system check will be performed. This check will be in support of ground analysis of flight data to determine items in need of maintenance and to execute tests designed to isolate any anomalies detected in the flight data. The objective of this checkout is to drive out any failures which can be remedied in the OTV maintenance to follow. Also, tests which require pressurants will need to be performed here. If the OTV was equipped with removable tanks, the tank operations would be performed in this area. However, removable tanks are not currently envisioned.

All maintenance operations will be performed in the servicing hangar after the schedule has been returned. The first operation will be an overall OTV visual inspection. This could be done EVA, but will likely be done with a closed circuit TV (CCTV) and monitor. In this case, sufficient mobility must be given to the CCTV to allow it to reach all areas of the OTV. Most likely, only specific areas will routinely be inspected such as the engine nozzles, aerobrake, and OTV exterior. CCTV movement could then proceed in a pre- programmed manner and the crew would only override to inspect questionable areas.

It is anticipated that the servicing hangar will provide for checkout umbilicals more extensive than those provided at the refueling area so that specific tests can be run on the avionics. All umbilical actuation will be automated to avoid EVA costs. EVA is anticipated only for non-routine module change out operations, non-routine inspection, and other infrequently performed operations where it won't be cost effective to automate. In any case, after checkout umbilicals are attached the avionics will be checked via checkout software and equipment carried for this purpose. Any anomalies will be noted and factored into the maintenance schedule relayed from the ground. Any EVA operations would be performed following schedule finalization. EVA module changeout would be performed on all items so identified in the preceding checks. This assumes that the proper modules are already on board the SS and the modules were designed for EVA replacement. Both of these assumptions will be discussed more completely later. No modules have yet been identified which will require changeout after every mission. If this were the case, this would likely be accomplished robotically using only one IVA crew man; once again, to avoid EVA costs. A candidate list of EVA replaceable modules is shown in Table 5. This table includes estimated times and anticipated interfaces. Since RCS modules may involve fluid disconnects, two operations are shown to illustrate the differences. The fluid QD's lengthen the time due to the additional effort required to assure the crew's safety (installation of spill containment shrouds and check out following installation).

Two major contingency operations identified are engine removal (which could also be routine) and aerobrake repair. Aerobrake repair is included at this point as a possibility. It is too early to say exactly what aerobrake repair implies or what type of failure it may suffer. Holes could be repaired either by patching or panel replacement. Aerobrake removal to ease servicing would be desirable but isn't a contingency operation. This would be included in overall processing flow near the end of pre-mission processing and the beginning of post mission processing.

ENGINE SERVICING

Several levels of engine maintenance are identified as detailed in Table 4. Two types of scheduled maintenance are shown, operations performed after every flight and those performed every 10 missions. The latter operations are more extensive and performed in addition to the regularly scheduled maintenance. They also include EVA operations (turbo pump inspection and line replaceable unit (LRU) replacement). The engine removal and replacement operation is detailed as well as three possible unscheduled engine repair operations. Unscheduled maintenance could occur on the engine while it is attached to the OTV. This would involve essentially replacement of an LRU that failed prematurely. A removed engine could have a failed LRU repaired in a SS workshop if future analysis showed this to be desirable. Any major repair of the engine will entail removal and return to earth for repair.

The tasks listed are indicative of the types of operations viewed as feasible. Table 6 is an example of the ground maintenance planned for the RL-10 Space Tug Engine (ref. 2). When the engine is further defined, the tasks will need to be re-evaluated. The turnaround maintenance tasks are to be fully automated so they may be performed with IVA. The inspection tasks will need manned involvement, hence the greater man hours assigned to the tasks. These tasks are listed separately from the OTV tasks previously discussed simply for ease of discussion. They would be fully integrated with the OTV tasks as part of the ground timeline optimization performed to arrive at the appropriate maintenance schedule. If an engine removal were scheduled, the inspection would be eliminated.

The engine is expected to be the major item to be serviced and is also the main topic of the present study. The view just presented is the baseline and represents a middle ground; one between the two extremes of the long life, zero maintenance engine and a fully modular, space rebuildable engine. The baseline engine has some LRU's specified (but not identified) so they may be included in the timelines. These LRU's are envisioned to be small items such as transducers or ignitor boxes which can be scarred with EVA compatibility without encurring a large weight or functional penalty. No major items like turbopumps, heat exchangers, thrust chambers etc., are included as LRU's. Failure of these items would entail engine changeout and ground servicing of the failed engine. The weight and functional penalty of making these LRU's is felt to outweigh the advantage of making these EVA compatible. The one major item which may lend itself to EVA (or remote) replacement would be the radiation cooled portion of the nozzle if there were a proven advantage to this. Therefore, the philosophy developed here is that any engine failure other than in a LRU will result in the replacement of that engine. In fact, engines will be replaced prior to failure if the health monitoring system detects an impending failure.

Now that engine removal has been specified, some discussion is warranted on what this will entail. An experienced ground crew under ideal conditions (air conditioned test cell fully equipped with the necessary tools) can remove an RL-10 in about five hours. The EVA crewmen are expected to replace an engine in four hours in the SS hangar. This short time is a goal which makes efficient OTV turnaround a possibility. Two concepts for the engine-OTV interface are shown in Figures 1 and 2. Concepts of this nature will be required. It will be necessary to simplify the OTV-engine interface as much as possible to enable both the engine removal itself and provide the necessary functional integrity to the interface once the engine replacement has been effected. For this reason, it is desirable to eliminate pressurant activated components as this eliminates a gaseous QD from the OTV-engine interface. If the propellant tanks are left with a blanket pressure, a set of valves will be needed on the vehicle side. The main engine valves should remain with the engine so they can be serviced after the engine has been removed (possibly on the SS, likely on the ground). The simplest interface design has all QD's aligned along a plane which separates the engine and the vehicle. This design type would lend itself to remote engine removal, which is a desirable feature. This approach would likely incur a weight penalty relative to an approach which minimizes weight at the expense requiring EVA assistance. Cost modelling of OTV servicing scenarios is expected to aid in recommending which approach to use.

SPACE STATION FACILITIES

The functional and operational analysis just presented have identified five basic space station facilities which will be needed to support a space based OTV. The facilities are shown in Table 7. While the facilities are treated as separate items dedicated entirely to the OTV, in the actual space station they will be more general purpose facilities designed to support the OTV, OMV and other spacecraft designed for SS servicing. At this point, the facilities are separated more for functional reasons than for hardware reasons. The actual SS facilities will probably recombine the functions into units logically arranged as part of the SS design effort. Therefore, the following facilities discussions emphasize the needed functions divided functionally. Possible overlaps are included in the individual discussions.

The servicing hangar will house all the necessary items used for servicing the OTV and other spacecraft. It should be a general purpose facility with some dedicated items specifically for servicing the OTV and the SS OMV as these two spacecraft will comprise the majority of the servicing requirements. A means of mechanically holding the various spacecraft will be needed. A variety of umbilicals will also be needed, mostly electrical. It may be desirable to provide a pressurant umbilical as well. Propellants and other hazardous fluids will be handled at another facility. Power for lighting and power tools should be supplied as well as means of securing the astronaut, his tools, and any other loose items necessary. One current hangar concept (Figures 3 and 4) involves a translation mechanism for the crewmen and a rotary carriage for the spacecraft. This would allow the possibility of a quasi-EMU (extra-vehiclular maneuvering unit) in which the EMU (or spacesuit) shares the SS atmosphere through an umbilical carried with the translation mechanism. In this hangar, total portability would not be necessary since a combination of translation and spacecraft rotation will allow access to all portions of the spacecraft.

As with the servicing hangar, many functions of the SS computer system have already been mentioned. Therefore, they will only be summarized here. Only a small portion of the SS computers' responsibilities will be represented by the OTV activities. The SS computer will function primarily as a link between the OTV computer, ground facilities, and the SS crewmen. OTV data stored during the mission will be down linked to the ground through the SS computer with a portion being retained for the SS crewmen to act upon (SS safety related items, for instance). After ground processing, an estimate of the OTV maintenance schedule will be returned to the SS. The SS computer will then factor in maintenance tasks discovered during post mission processing of the OTV and prepare a final maintenance schedule. The SS computer will also handle loading of the OTV computer with mission specific data prior to the OTV mission. Part of the SS computer will also handle control of the many automated servicing mechanisms. These will include the SS RMS(s), refueling, and CCTV movement.

The above mentioned functions may more logically be part of the OTV control station. Certainly items which are entirely OTV specific will be functions of the OTV control station. The major item here is OTV refueling and OTV LOS control. The SS computer will probably just monitor safety related items so it can respond properly if an emergency were to occur. The bulk of the OTV related software and systems will reside in the OTV control station (functionally at best). The OTV control station will be the primary man-machine link between the OTV and the SS crew. Several OTV display and equipment controllers will be logically arranged here to enable efficient IVA control of the various phases of the OTV mission. The OTV control station, as with the servicing hangar, will probably share hardware with other spacecraft. That, however, is a Space Station issue.

The OTV refueling area will work closely with the control station. The primary function here is, obviously, refueling of the OTV. However, several other propellant and fluid related functions will also be accomplished here. The refueling area will represent a significant portion of the SS mass so its location will be critical to the SS control. The disturbances due to the propellant transfer will also need to be accommodated.

The refueling area will house the cryogen tanks, an OTV mechanical interface, and the necessary umbilicals to allow refueling of all propellants and pressurants. An electrical umbilical is also necessary to allow control of the OTV and down linking of OTV data stored during the OTV mission. It is not envisioned that other spacecraft will be able to utilize this hardware for their refueling. This is due mainly to the physical size of the OTV compared to other spacecraft. Another refueling station will likely be provided by the SS for these smaller spacecraft. (They are also likely to require earth-storable propellants, not cryogens.) Spacecraft wishing to utilize this facility will accomodate the OTV and not vice versa. All the necessary control hardware will reside here (valves, pumps, plumbing, etc.) while the control software will be housed at the OTV control station. One or more CCTV's will be necessary if the refueling area is not visible from the control station.

The space station will need to provide some sort of storage facilities for both the OTV and the various payloads. These facilities will at least provide mechanical hold-down and minimal power and data interfaces to sustain the vehicles in a dormant mode. Desirable features would be thermal and meteoroid protection. The servicing hangar could provide all of these at a loss in utility. These are, of course, space station issues. However, they are worth some discussion here as there are several modifications possible to the baseline timeline. For instance, payload and OTV mating could be performed at the storage area if the proper alignment capability existed. The payload check-out could be performed here as well. This could save time as well as minimizing the movement of masses about the SS thereby saving SS propellant.

As an aside, this brings up the subject of the multiple payload interfaces necessary on the payload that it otherwise wouldn't need. Currently, the STS interface manifests itself as trunnion fittings and an electrical umbilical. The OTV, on the other hand, would require some sort of axially acting mechanical interface and a separate electrical umbilical to that utilized for the shuttle. Presumably one of these two interfaces could be used by the space station storage facility. A trade-off exists between requiring the payload to supply these interfaces and scarring either the shuttle or OTV to eliminate one of the interfaces. Since the payload is launched only once while the STS and OTV make multiple trips, the mass penalty may be best assigned to the payload. This is a subject for further study.

DOWNTIME AND LOGISTICS

The timelines discussed so far are for a routine mission where no major failure has occured which requires a delay to allow the STS to bring up the needed spares or, worse yet, return of the OTV to the ground for extensive servicing. Very few missions are likely to be "routine" and may well require delays which impact the baseline timeline. The learning curve is likely to extend through much of the "routine" mission time frame of the early to late 1990's. A fully debugged OTV-SS system by 1994 is unrealistic and an operational OTV by then is an ambitious goal. However, all the mission analysis to date suggest large payoffs for the ability to fly LEO-GEO missions on a two week schedule. A case for an OTV fleet is emerging.

The other response to downtime impacts is a sufficient spares inventory at the SS to avoid the majority of the delays. Since failures are by nature unpredictable, this implies storing many spares which may never be needed. Unnecessary spares cost both in launch mass for the spares and in the mass of the facilities needed to house them. The space station is not yet envisioned as a flying warehouse. It is bad enough that it is becoming a flying service station - (OTV servicing view point). As a part of the evolving SS and OTV, a comprehensive inventory management effort is recommended which will minimize simultaneously the required mass at the space station and the down time incurred by the OTV. This would entail a high reliability OTV coupled with a component-by-component failure analysis to pin-point likely failures. In addition, grouping the high failure items such that they may be replaced as a unit(s) is required. From day one, the OTV design must adhere to this modular philosophy to some degree. One spare unit capable of remedying several failures will be very valuable. It has already emerged as a conclusion to change out an engine for any major failure rather than repair the engine on the OTV. A reusable space-based OTV cannot be optimized alone. But rather the OTV and its support system should be optimized.

REFERENCES

1. Space Station Needs, Attributes, and Architectural Options Study. Final Report, Vol. III Mission Requirements, Martin Marietta Aerospace, NASA Contract NASW-3686.

2. Design Study of RL-10 Derivatives. Final Report, Vol. III, Part 2, Pratt & Whitney Aircraft, NASA Contract NAS8-28989.

Table 1 Ground Rules and Assumptions

Study Ground Rules
STS as launch vehicle
Space Station facilities in place for OTV
Space based, reuseable LO2/LH2 OTV
OTV to be man rateable and to include an aerobrake
Rev. 6 mission model, 1994 IOC
Structural interface only with payload
Study Assumptions
Space Station to provide up to 4 men/day , 8 hrs/day
Hangar, refueling area, and storage facilities attached to Space Station
OTV ground controled except when within Space Station line-of-sight
2 EVA/1 IVA men per EVA operation
Routine tasks automated as much as possible
Space Station to provide storage for necessary spares
OTV missions to average two week intervals
The OTV to be moved about SS by SS RMS(s)
Times for "routine" operation, not development period
OTV RCS to provide OTV control for "prox ops"
Payload mated to OTV prior to OTV refueling

TABLE 2 OTV Mission Flow

OPERATIONS	TIMELINE
PRE MISSION OPERATIONS	*- 7 days*
- Payload and payload ASE delivery to SS by STS	- 7 days
- Uplink mission specific software to SS computor	- 7 days
MISSION PREPARATION OPERATIONS	*- 2 days*
- Move P/L to hangar - perform P/L c/o	- 24 hr
- Move OTV to Hangar	- 20 hr
- Verify OTV readiness - update OTV mission computer	- 19 hr
- Mate OTV and P/L - verify OTV-P/L interfaces	- 18 hr
- Move OTV-P/L to refueling area	- 17 hr
- Secure OTV-P/L and connect umbilicals	- 16.5 hr
- Perform propulsion system check	- 8 hr
- Chill down and fill main tanks with required propellants	- 7 hr
- Resupply RCS and pressurant (if necessary)	- 6 hr
- Disconnect umbilicals - release OTV-P/L - deploy from SS	- 1 hr
- "Small" RCS burn to seperate OTV and space station	- 0.5 hr
- Pass mission control from SS to ground	0.0 hr
PERFORM MISSION, RETURN TO SS LOS	*0 - 3.0 days*
POST MISSION PROCESSING	*3.0- 8 days*
- Pass mission control from ground to SS	80 hr
- Safe main propulsion at TBD miles from space station	80.5 hr
- RCS burn to SS rendesvous	81 hr
- SS capture of OTV-P/L , berth at refueling area	81.5 hr
- Connect umbilicals and off load propellant residuals	82 hr
- Down link OTV mission data to SS and ground computors	83 hr
- OTV exterior visual inspection	85 hr
- Perform post mission propulsion system checks	86 hr
- Disconnect umbilicals and move OTV to Hangar	87 hr
- Demate P/L (if attached)	96 hr
- Prepare P/L for ground return (if necessary)	100 hr
- SS and Ground computors return OTV status and service requirements	120 hr
- Perform OTV service as required	122 hr
- Prepare OTV for storage and move to storage	168 hr

Table 3 OTV Servicing Overview

Operation	Facilities	Tools	Delta Time	SS Man Hours		
				IVA	EVA	Total
Main Propellant-Repupply	Resupply Area,RMS Cryo Tanks,Umbil.	Resupply Software, Control System	7.0	7.0	-	7.0
Avionics - Sched. Maint.	SS Hangar		6.0	6.0	6.0	12.0
- Module Test	SS Computor	Test + Access Tools	3.0	3.0	-	3.0
- Module Replacement	EMU,HPA,Lighting	LRU ASE,Remov. Tools	3.0 (1)	3.0	6.0	9.0
- ACS Update	SS Computor	SS 6 ACS Software	0.5	0.5	-	0.5
Avionics - HM Maint.	SS Hangar					
- Module Replacement	EMU,HPA,Lighting	LRU ASE,Remov. Tools	1.0 (1)	1.0	2.0	3.0
- Module Repair	SS Work Shop	Electronics Tools	1.0 (1)	1.0	2.0	3.0
Avionic-Mission Peculiar	SS Hangar					
- Module Replacement	EMU,HPA,Lighting	LRU ASE,Remov. Tools	1.0 +	1.0 +	2.0 +	3.0 +
- Reconfiguration	EMU,HPA,Lighting	LRU ASE,Remov. Tools	2.0 +	2.0 +	4.0 +	6.0 +
Tanks - Sched. Maint.	Resupply Area		2.0	2.0	-	2.0
- External Inspection	CCTV Monitor	RMS + CCTV	1.7	1.7	-	1.7
- PU and TVS System	SS Computor	Test + Access Tools	0.3	0.3	-	0.3
Tanks - Unsched. Maint.	SS Hangar					
- Tank Removal	Res. Area,RMS Console	RMS, CCTV, Tank ASE	2.0	2.0	4.0 (2)	6.0
- Insulation Repair	EMU,HPA,Lighting	Insul. Rep. Kit	3.0	3.0	6.0	9.0
- X-ducer Replacement	EMU,HPA,Lighting	LRU ASE,Remov. Tools	1.0	1.0	2.0	3.0
- PU and TVS System	SS Hangar, EMU,HPA	LRU ASE,Remov. Tools	2.0	2.0	4.0	6.0
Tanks - Mission Peculiar	Resupply Area					
- Tank Reconfiguration	Res. Area,RMS Console	RMS, CCTV, Tank ASE	2.0	2.0	4.0 (2)	6.0
RCS - Scheduled Maint.	Resupply Area,Umbil.		1.0	1.0	-	1.0
- Leak check	SS Computor,Press	RCS Software	0.5	0.5	-	0.5
- X-ducer Check	SS Computor	RCS Software	0.5	0.5	-	0.5
RCS - Resupply	Resupply Area,Umbil.	RCS Software	2.0	2.0	-	2.0
RCS - Health Maint.	SS Hangar					
- X-ducer Replacement	EMU,HPA,Lighting	LRU ASE,Remov. Tools	2.0	2.0	4.0	6.0
- Thruster Replacement	Hangar,EMU,HPA,Light	LRU ASE,Remov. Tools	2.0	2.0	4.0	6.0
Struc.6 AB - Sched. Maint.	SS Hangar					
- Inspection	CCTV Monitor	RMS + CCTV	1.0	1.0	-	1.0
Struc.6 AB - HM Maint.						
- AB Refurbishment	Resupply Area,EMU,MMU	AB Repair Kit 6 Tools	3.0	3.0	6.0	9.0
- Structure Repair	SS Hangar,EMU,HPA	LRU ASE,Remov. Tools	2.0	2.0	4.0	6.0

NOTES :

(1) Mission average expected for all avionics modules, 1 hr for contingency

(2) Tank replacement only for Modular OTV, Some EVA assistance anticipated

Table 4 Engine Servicing Overview

Operation	Facilities	Tools	Delta Time	SS Man Hours		
				IVA	EVA	Total
Engine-Turnaround Maint.	Space Station Hangar		3.4 hr	5.4	-	5.4
- Analysis of Flight data	SS & Grnd Computor	Engine Software	2 days	2	-	2
- Lock up pressure decay	SS Computor,Refuel	Engine Software	0.5 hr	0.5	-	0.5
- Engine valve op check	SS Computor,Refuel	Engine Software	0.5	0.5	-	0.5
- Nozzle visual inspec.	SS Computor,Refuel	RMS + CCTV	0.6	0.6	-	0.6
- Nozzle extension check	SS Computor,Refuel	RMS + CCTV	0.2	0.2	-	0.2
- Gimbal actuator check	SS Computor,Refuel	RMS + CCTV	0.2	0.2	-	0.2
- Connect Umbilicals	SS Hangar	RMS	0.3	0.3	-	0.3
- Turbopump torque check	SS Computor	Engine Software	0.2	0.2	-	0.2
- Ignition system check	SS Computor	Engine Software	0.3	0.3	-	0.3
- Instrumentation c/o	SS Computor	Engine Software	0.5	0.5	-	0.5
- Solenoid c/o	SS Computor	Engine Software	0.3	0.3	-	0.3
- Disconnect Umbilicals	SS Hangar	RMS	0.2	0.2	-	0.2
Engine - Periodic Maint.	SS Hangar		4.0	4.0	6.0	10.0
- Setup operations	SS hangar	Engine tools,LRU ASE	0.5	0.5	1.0	1.5
- Turbopump boroscope	Power,Lights	Boroscope	1.0	0.5	1.0	1.5
- Thrust chamber inspec.	CCTV Monitor	RMS,CCTV	1.0	1.0	-	1.0
- Engine LRU replacement	Power,Lights,EMU,HPA	Engine Tools,LRU ASE	2.0	1.5	3.0	4.5
- Tool stowage	SS hangar	Engine tools,LRU ASE	0.5	0.5	1.0	1.5
Engine -OTV Engine Remove and Replace	SS Hangar,RMS,EMU Foot restraint Lighting	Engine Fixture, Engine Discon. tools, Protective covers	5.0	3.8	6.0	9.8
- Setup tools			0.5	0.5	1.0	1.5
- Attach engine fixture			0.5	0.5	1.0	1.5
- Disconnect engine			0.5	0.5	1.0	1.5
- Move engine to storage			0.2	0.2	0.4	0.6
- Pickup replacement			0.1	0.1	0.2	0.3
- Align and attach			0.7	0.7	1.4	2.1
- Check/verify QD's			2.0	0.8	0.5	1.3
- Store tools			0.5	0.5	0.5	1.0
Engine - Unsched. Maint.						
- Repair in hangar	SS Hangar,RMS,EMU,HPA	Above	2.0 +	2.0 +	4.0 +	6.0 +
- Repair LRU in SS	SS Hangar,RMS,EMU,HPA	Above plus LRU ASE	3.0 +	4.0 +	4.0	8.0 +
- Repair on Ground	SS Hangar,RMS,EMU,HPA	Above plus Engine ASE	2.0	1.7	3.4	5.1

Table 5 EVA Replaceable Modules;

SUBSYSTEM	MODULE	CONTENTS	INTERFACES	R&R TIME
Avionics	Main computor	CPU, I/O unit, Memory	Mech, Elec.	0.5 hour
	TT & C	Antenna (s)	Mech, Elec.	0.2 hour
	C &DH	RF Electronics	Mech, Elec.	0.5 hour
	Guidance	Gyros	Mech, Elec.	0.4 hour
Reaction Control System	RCS Module	Tanks, valves, thrusters heaters, & transducers	Mech, Elec	0.6 hour
	Thruster	REA valves, thrust chamber, heater	Mech, Elec & Fluid	1.5 hour
Electical Power System	Power supply	Fuel cells, valves, tanks heat exchanger,& pumps	Mech, Elec	0.5 hour
	Fuel cell	Fuel cell module	Mech, Elec & Fluid	1.5 hour
Structure & Aerobrake	Aerobrake	Aerobrake module	Mechanical	1.0 hour

Table 6 RL10 Derivative Rocket Engine Inspection Task Times

Inspection Area	Type of Inspection	Type of Fault	Inspection Technique	Access	ML	Total MMH	Elapsed MMH	
			Periodic/Phase Inspection Operations					
Thrust Chamber Assembly	External-Thrust Structure	Deformation and Structural Integrity	Tolerance Measurement, Dye Penetrant and Radiography	Directly Accessible	I	1.50	0.75	2 men
Extendible Nozzle	External-Structure	Thermal Damage	Visual	Directly Accessible	I	.17	.17	
Turbopump Assembly	Internal-Bearings	Signs of Thermal Damage, Cage Damage	Use of Borescope	Typical Access Ports No. 1, 2, and 3	I	2.00	1.00	2 men
	Internal-Seals	Excessive Seal Leakage	Pressurize Sub-System	Turbopump As Installed	I	.50	.50	
	Internal-Seals	Excessive Wear	Radioisotope	Turbopump As Installed	I	1.50	.75	2 men
	Turbopump Gears	Signs of Excessive Tooth wear	Use of Borescope	Typical Access Ports No. 1, 2, and 3	I	Include with bearings		
Turbopump	Torque-Check	Bearings and Shaft Fit	Torque Tool	Oxidizer Pump Closure Plate	I	.25	.25	
Helium System	Internal Configuration	Internal Leaks	Helium Consumption Rate	Engine-As Installed	I	.17	.17	
Flow Control	External-Total Valve Inventory	Leak Check (Internal) and Actuation Cycle	Pressure to Verify Seal Operation and Position Indicators	Engine-As Installed	I	.50	.50	
	Automatic Checkout	Actuation Timing, Position Indications	Comparison to Historical Data	Engine-As Installed	I	.25	.25	
	External-Valve Weldments & Flanges	Leak Check (External)	Visual - Leaks	Engine-As Installed	I	Include with eng. plumbing		

Table 6 RL10 Derivative Rocket Engine Inspection Task Times (Continued)

Inspection Area	Type of Inspection	Type of Fault	Inspection Technique	Access	ML	Total MMH	Elapsed MMH	
Gimbal Assembly	Load Checkouts	Excessive Wear	Gimbal Power Requirement Check	Engine-As Installed	I	.50	.60	
Engine Plumbing	Leak Check	Leaks	Visual	Engine-As Installed	I	2.00	1.00	2 men
				TOTALS		9:34	6.09	
			Turn Around Inspection Operations					
Engine Assembly	External-Weldments, Ducts, Components, Fluid Lines, and Hardware	Damage, Component Security, Loose Hardware	Visual	As Installed	I	.50	.25	2 men
	Diagnostic Review	All	Computer Comparison of Operating Signature	N/A	I	.25	.25	
Thrust Chamber Assembly and Extendible Nozzle	Internal Combustion Chamber Wall and Injector Face	Signs of Thermal Damage (Corrosion, Cracking, Plugging)	Visual	Throat	I	.17	.17	
"Hot Section"	Weldments, Ducts, Manifolds and Chamber Tubes	Damage	Visual	Directly Accessible	I	.25	.25	
	Expansion Nozzle	Tube Cracks, Splits, Holes	Visual	Directly Accessible	I	.17	.17	
	Extendible Nozzle	Signs of Thermal Damage	Visual	Directly Accessible	I	.17	.17	
Ignition System	Internal-Spark Ignition	No spark	Visual	Directly Accessible	I	.17	.08	2 men
				TOTALS		1.68	1.34	

Table 7 Space Station OTV Servicing Facilities

SPACE STATION HANGAR

- Provides meteor and thermal protection for OTV and payloads.
- Provides power, data, command, and pressurant umbilicals
- Storage and use of OTV and payload handling cradles
- General purpose RMS's, astronaut foot restraint/positioning aid (HPA), tool and LRU caddies

SPACE STATION COMPUTOR

- Refers to entire SS C&DH system, including ground and S/C links as appropriate
- Stores and executes routine servicing tasks, updating as needed from ground
- Assumes major portion of task scheduling operations
- Assumes major portion of RMS control and other robotics

OTV CONTROL STATION

- Used for OTV-P/L control for LOS operations
- Allows mission monitoring while OTV-P/L are under ground control
- Used to monitor/control OTV refueling operations

OTV RESUPPLY AREA

- Provides all mechanical, electrical, and fluid interfaces for OTV main engine and RCS
- Provides propellant storage and fluid transfer control hardware
- OTV removable propellant tank handling hardware

OTV STORAGE AREA

- Provides mechanical Hold-down , dormant power ,and health monitoring
- Could provide thermal and meteoroid protection

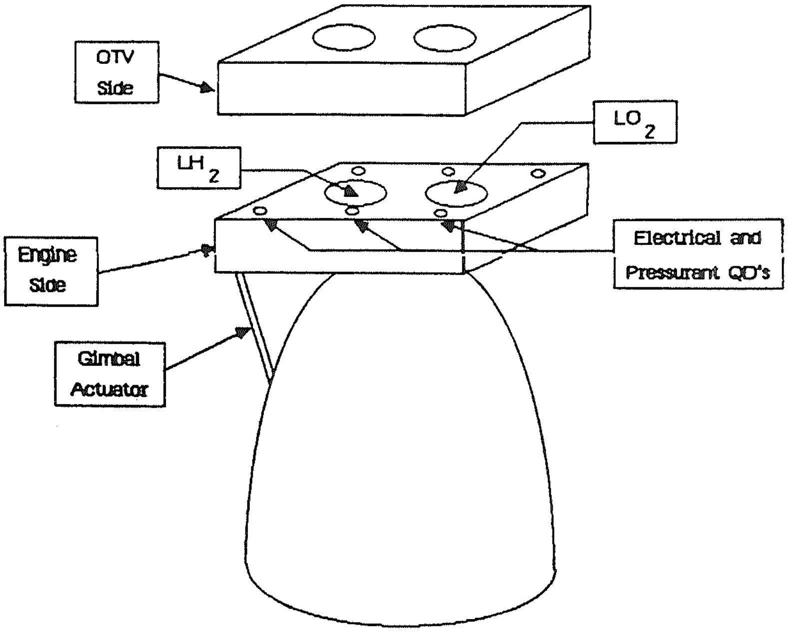

Figure 1 Planar OTV-Engine Disconnect Concept

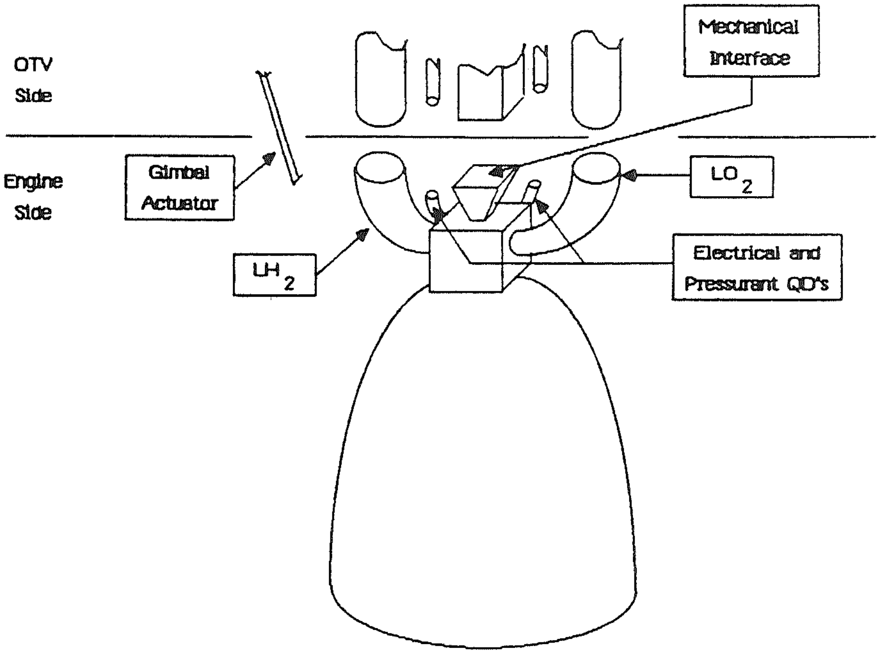

Figure 2 Discrete OTV-Engine Disconnect Concept

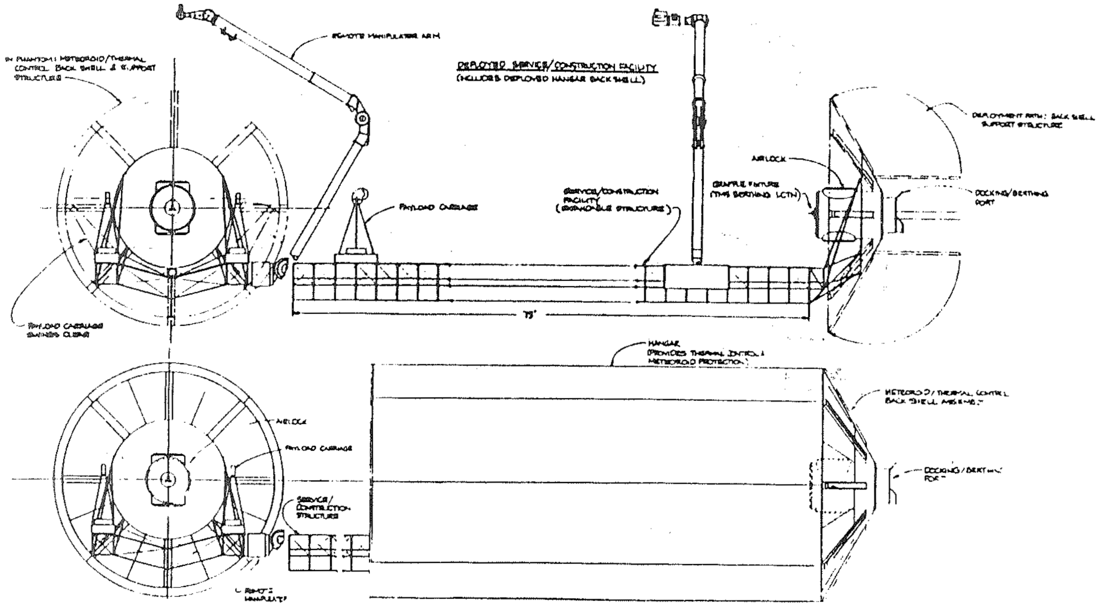

Figure 3 - Deployable Hangar Concept

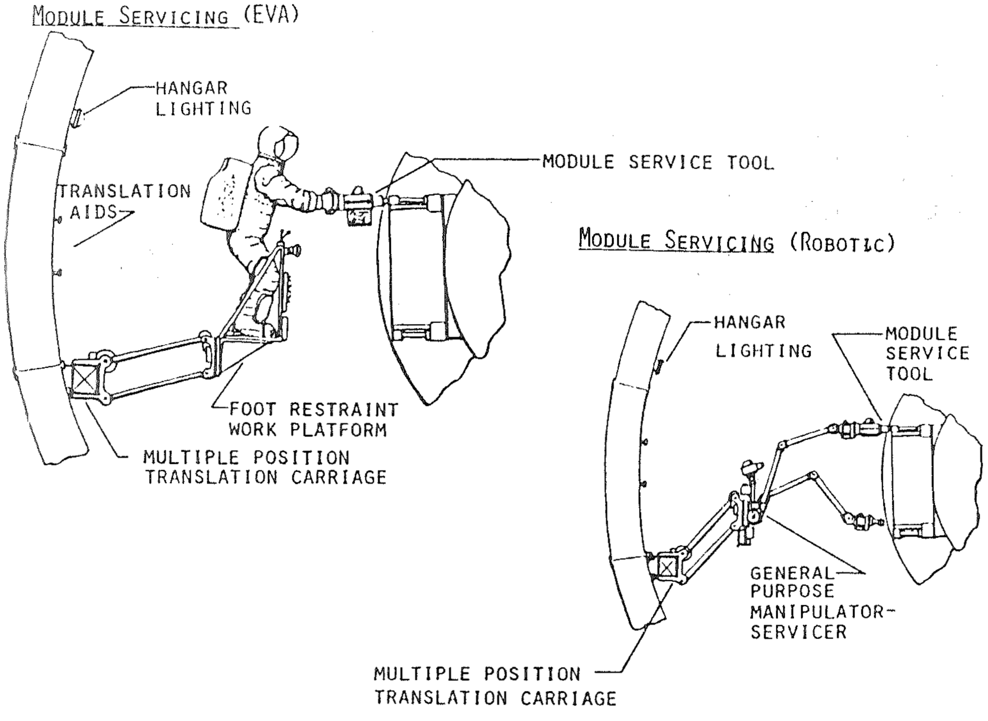

Figure 4 Hangar Servicing Concepts