

The Space Congress® Proceedings

1987 (24th) Space - The Challenge, The Commitment

Apr 1st, 8:00 AM

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OMV Servicing Missions from Space Station

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ABSTRACT

The Orbital Maneuvering Vehicle (OMV) will provide a means of bringing large observatories to the Space Station for servicing and redeployment to their operating altitudes. However, there are many constraints which must be met in mission planning. The missions must be designed so that propellant consumption is within the usable allowance, but contingency operations can still be accomplished. The vehicle was designed specifically to accommodate such missions, with emphasis upon servicing the Hubble Space Telescope.

The OMV has been designed for operations from the Shuttle Orbiter and the Space Station. It will readily accommodate basing at the Space Station and executing observatory retrieval and redeployment missions. Mission profiles have been designed which allow retrieval with contingency hold before descent, and which allow contingency return of the observatory if it fails to reactivate properly. This capability will be a major addition to the Space Transportation System and will increase the utility of the Space Station.

INTRODUCTION

When the Space Station becomes operational in the mid 1990's, the OMV will be needed to retrieve and redeploy satellites and platforms which are being serviced at the Space Station. The OMV is a versatile vehicle designed for a wide range of operations from the Orbiter or Space Station.

Mission operations will be conducted in a manner differing from previous orbital missions. The OMV can be based at the Space Station with an ability to conduct varied missions with short turn around times. Missions will be designed at the ground control center and mission data loaded through telemetry. The OMV can be deployed from the Space Station for a spacecraft retrieval mission or attached to a payload prior to deployment for a placement mission. The OMV has a substantial degree of autonomy in conducting its missions, with an ability to adjust its trajectory to meet revised target location data. The control center can also participate in making substantial alterations in the mission profile in real time.

OMV Characteristics

The OMV has three propulsion systems. One is a bipropellant system using four variable thrust engines for orbit changes. These engines provide a soft, low-acceleration transfer for sensitive spacecraft such as the Hubble Space Telescope (HST). Each engine can operate from 13 to 130 pounds of thrust. Usable bipropellant is 6600 pounds.

The reaction control system (RCS) uses both hydrazine and nitrogen. The hydrazine system uses 28 thrusters with an average thrust level of 5 pounds operating in a blow-down mode. Usable hydrazine is 1000 pounds. The nitrogen system uses 24 thrusters and is pressure-regulated at 5 pounds of thrust. Usable nitrogen is 165 pounds. The nitrogen system is used for docking with contamination-sensitive spacecraft. The RCS provides both attitude control and translation capability. Vehicle masses are summarized in Table 1.

The OMV navigates using the global positioning system with an inertial reference system for attitude determination. Sun and horizon sensors are used for attitude reference updates. Radar is used for relative navigation. Video cameras are used for pilot operations. Communications are through the Tracking and Data Relay Satellite System (TDRSS).

Mission Characteristics

The OMV will be deployed from the Space Station or Orbiter at the beginning of a servicing mission. The OMV will autonomously follow a mission profile to rendezvous with the spacecraft to be serviced. Approach and docking are done under pilot control, then the OMV returns to the base with the spacecraft. Following servicing of the spacecraft, the OMV will carry it back to its operating orbit. This servicing profile has been investigated in detail for the HST servicing mission. Profiles were also investigated for the Advanced Xray Astronomy Facility (AXAF) and the Space Infrared Telescope Facility (SIRTF).

The HST is assumed to weigh 25,000 pounds and be in an orbit at 380 nautical miles while the Space Station is at 250 miles, both orbits inclined at 28.5 degrees. Similarly, AXAF is 30,000 pounds at 325 miles and SIRTF is 10,500 pounds at 415 miles. HST is sensitive to acceleration levels, so the OMV is restricted to a limit of 0.002 g. The low acceleration adds to the complexity of mission profile design by requiring long duration burns. The reduced thrust levels cause the engines to operate with reduced specific impulse, increasing propellant consumption for the mission.

Since the observatories will be at altitudes above the Space Station, nodal regression of the orbits will allow only periodic opportunities for servicing missions. The duration of an opportunity is an important mission planning factor which can affect the practicality of a mission. This duration (window) is analogous to the launch window for planetary and other missions. A missed opportunity could delay servicing by a year or more, depending upon the altitude difference.

Nodal regression is caused by the oblateness of the Earth, and results in all posigrade orbits precessing westward (secular perturbation). The regression rate is a function of orbit altitude and inclination, with lower orbits regressing faster than higher orbits. Thus the Space Station orbit regresses faster than those of the observatories. The relative regression rate with HST results in a servicing opportunity approximately every 15 months.

Orbit period is also a function of orbit altitude, with lower orbits having shorter periods (faster orbital rates). The difference in orbital rates between spacecraft results in an angular separation called the phase angle, Figure 1. Obviously the phase angle must be zero when a rendezvous takes place.

The wedge angle is the angle between orbit planes which results from a difference of ascending nodes, Figure 2. The mission profile must be planned so that the wedge angle is zero when a rendezvous takes place.

In the mission analyses reported here, mission reserves are deducted from the usable propellant quantities. In addition, all computed velocity changes are increased by 5 per cent as an allowance for guidance, navigation, and control needs.

HST SERVICING MISSION PROFILE

Mission profiles have been developed which meet the conditions necessary for the initial rendezvous with the observatory and the subsequent rendezvous with the Space Station for retrieval of the observatory. These profiles have been designed with sufficient time allowances to accommodate backup tracking by TDRSS, radar search and acquisition, and lighting constraints for docking.

The mission requires the use of two sorties, one for spacecraft retrieval and one for redeployment. The return leg of each sortie is controlled by the in-plane phasing between the OMV and the Space Station.

Sortie 1 Description

An ascent and rendezvous profile is illustrated in Figure 3, which shows each of the orbit change maneuvers. Sortie 1 begins with deployment at the Space Station altitude, as shown

in Figure 4 as a general mission strategy. The ascending node of the Space Station is still east of the observatory node at the start. A direct full thrust ascent is made which includes a plane change to enable a rendezvous in the orbit plane of the observatory. This transfer is done by maneuvers 1 and 2 in Figure 3. The size of this initial plane change is set by propellant availability. An intermediate orbit (nominally 20 miles below the target) can be included to allow for phase correction, lighting conditions, and possible TDRSS tracking in the event of GPS failure. Any residual plane change is removed during the next transfer by maneuvers 3 and 4. This places the OMV nominally 2 miles below and 7 miles behind the estimated target position to prepare for the rendezvous.

Radar search and acquisition are done in this coasting interval. Once the relative location of the target is established by radar, the final transfer is done by maneuvers 5 and 6, which place the OMV approximately 1000 feet from the target. At this point, piloted docking is done under ground control.

The OMV and observatory remain at altitude until the phasing conditions are correct for descent. Then a low thrust descent is initiated using a series of burn and coast segments. The burn arc segments are done near the latitude extremes of the orbit and contain out-of-plane yaw components of thrust which are optimized over the entire descent maneuver. The yaw thrusting changes the ascending node to match that of the Space Station. Additional coast periods can be included to insure proper phase conditions with the Space Station for rendezvous.

At the Space Station, the OMV is berthed while the observatory is being serviced. When ready, the OMV is reconnected to the observatory and the vehicle is deployed for the start of sortie 2 which carries the observatory back to its operating altitude.

Sortie 2 Description

The ascent leg is a direct low thrust maneuver with no ascending node modification. The simplicity of this transfer allows the use of two burns. The first burn is quite long and establishes the apogee at the operating altitude. Following a coast, a second burn circularizes the orbit.

The OMV separates from the observatory, but remains in its vicinity during observatory checkout. If the checkout is successful, the OMV makes a return transfer to the Space Station to terminate the mission. If the checkout is not successful, the OMV will dock with the observatory and execute a return to the Space Station in the same manner as the retrieval done in sortie 1. OMV propellant requirements are determined allowing for this contingency return of the observatory.

WINDOW OF OPPORTUNITY ANALYSIS

The most recent analytic effort has focused on determining the windows of opportunity for retrieving the observatory in sortie 1. The concern is that the observatory may be experiencing operational difficulties (which may have prompted the servicing mission), with the potential for complicating the docking maneuver. It is desirable to have several days available for the initial docking and preparation for descent. However, during this time, the ascending nodes of the observatory and Space Station can begin to diverge. If the nodal difference becomes too large, the OMV will be unable to make a direct descent with the observatory.

Total allocated propellant (bipropellant and hydrazine) requirements are shown as functions of ascending node differences in Figure 5. Note that these are westward node differences, that is, when the observatory node is west of the Space Station node. The opening of the window of opportunity for descent is established by the 7500 pound total usable propellant in the OMV.

The HST window of opportunity opens when the node of the observatory is 2.0 degrees west of the Space Station in the case of the low-thrust constraint. High-thrust operation is not allowed with HST, but if it were, the node difference would be 3.0 degrees because of the higher engine specific impulse. Under the low-thrust constraint, if the OMV propulsion module is changed out at the Space Station while the observatory is being serviced (giving the OMV a full propellant load for sortie 2), the descent node difference could be 5.7 degrees.

The HST retrieval window is mapped out in Figure 6. It shows that the OMV transfers to the observatory, waits for the first descent opportunity and then descends with the observatory when the nodal difference is 2.0 degrees. If that descent opportunity is missed, subsequent descent opportunities occur every 1.3 days (the synodic period). The last descent opportunity occurs with the observatory node east of the Space Station node, which makes the descent more difficult (the Space Station orbit moves away from the OMV orbit during the OMV/observatory descent). At the next synodic period after this, the OMV no longer has adequate propellant for a direct descent.

The HST window of opportunity for retrieval is found to be 3.9 days in duration, with 4 descent opportunities. These opportunities occur approximately every 15 months.

If full main engine thrust is used, the window will have 6 descent opportunities and a duration of 6.5 days.

In the first sortie, the OMV spends at least 26 hours at the observatory before descent. In the second sortie, the OMV spends 27 hours with the observatory before executing normal or contingency return.

A similar analysis was done for both AXAF and SIRTF. The AXAF window of opportunity opens when the node of the descent point is 2.9 degrees west of the Space Station in the case of the low-thrust constraint. Subsequent descent opportunities occur every 2.2 days. Six descent opportunities exist during 11 days. If full main engine thrust is used, the window would have 8 descent opportunities during 15.4 days. These opportunities occur approximately every 25 months.

In the first sortie, the OMV spends at least 49 hours at the observatory before descent. In the second sortie, the OMV spends 50 hours with the observatory before executing normal or contingency return.

The SIRTF window of opportunity opens when the node of the descent point is 2.8 degrees west of the Space Station in the case of the low-thrust constraint. Subsequent descent opportunities occur every 0.74 days. Six descent opportunities exist during 3.7 days. If full main engine thrust is used, 8 descent opportunities exist during 5.2 days. These opportunities occur approximately every 9 months.

In the first sortie, the OMV spends at least 12 hours at the observatory before descent. In the second sortie, the OMV spends 12 hours with the observatory before executing normal or contingency return.

It is important to note that for all these missions, indirect returns can be done after the direct return window closes. The indirect returns use an intermediate orbit below the Space Station which results in a relative nodal drift back toward the Space Station. This drift would be continued until the OMV propellant would support a transfer to the Space Station. The indirect returns are not desirable for normal mission planning because of the long mission times, but are readily usable as contingencies.

CONCLUSIONS

The OMV propellant capacity will support large observatory servicing at the Space Station, including allowances for contingency observatory return and contingency hold at the operating altitude of the observatory. Requirements have not been established for the windows of opportunity, but it is thought that a duration of several days is adequate.

The capabilities of the OMV will substantially extend the utility of the Space Station by enabling the servicing of observatories and other spacecraft which for reasons of cost, contamination, etc., will not have their own propulsion capabilities.

The OMV is presently undergoing major trade studies which could result in increases in its propellant capacity. These changes could result in significant increases in the windows of opportunity. The trades should be decided by May 1987.

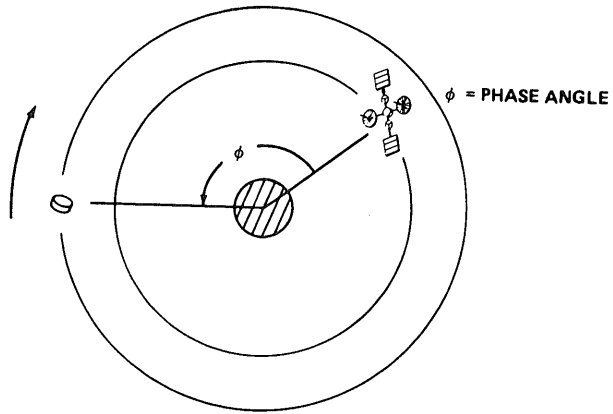


FIGURE 1. PHASE ANGLE

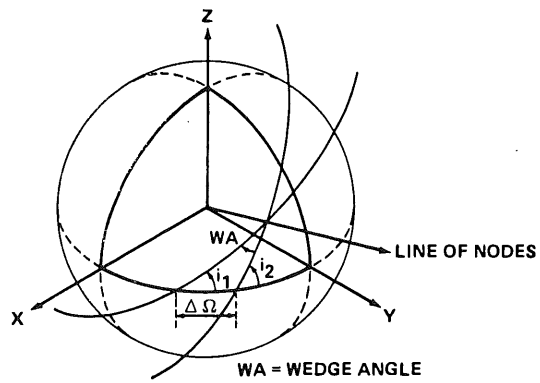


FIGURE 2. WEDGE ANGLE

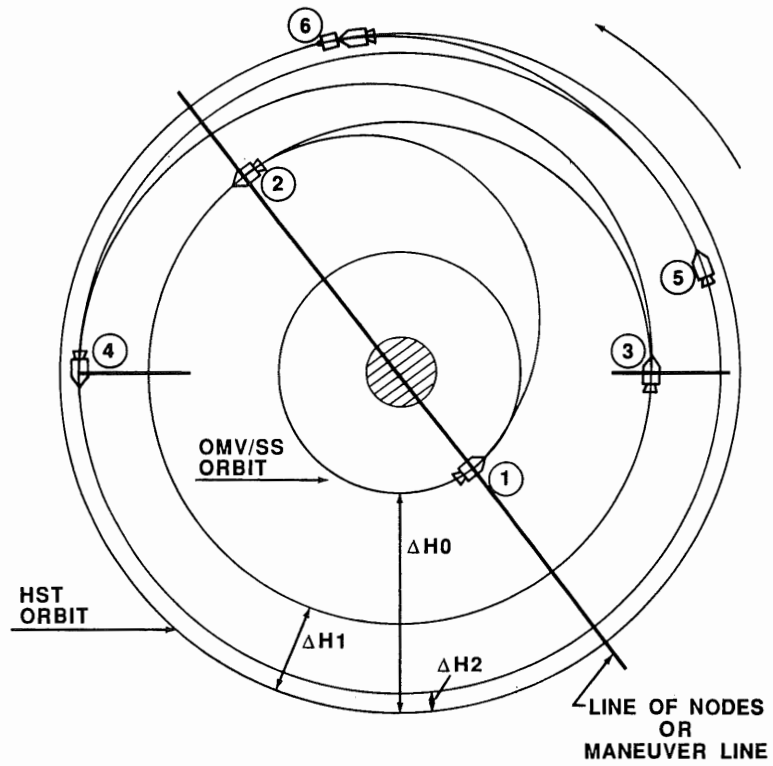


FIGURE 3. OMV ASCENT FLIGHT PROFILE FOR HST RENDEZVOUS

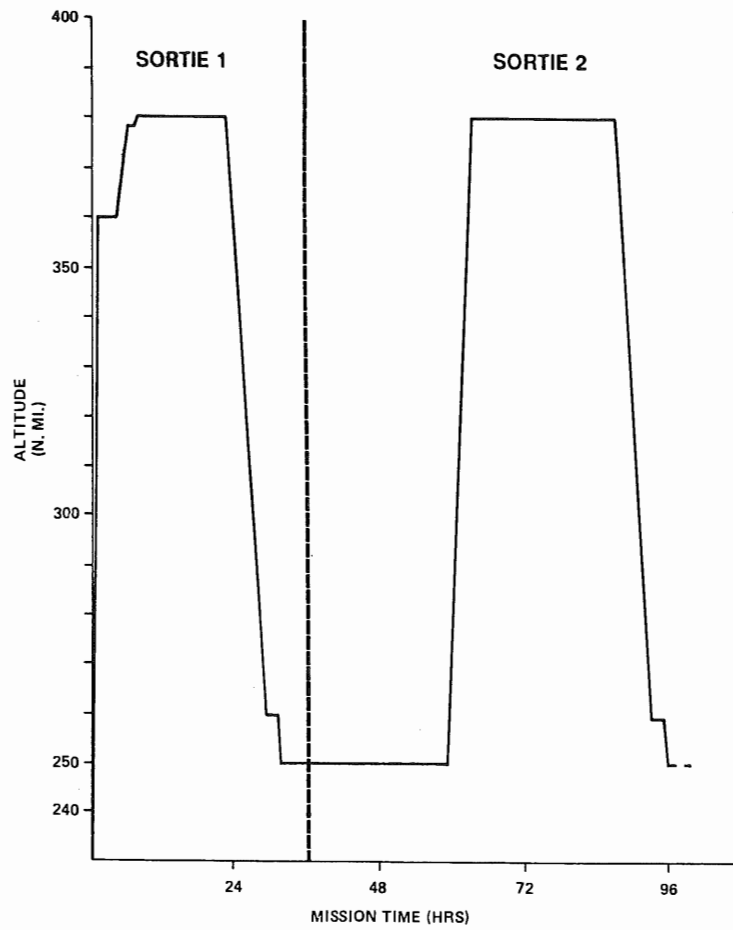


FIGURE 4. OMV/HST MISSION PROFILE

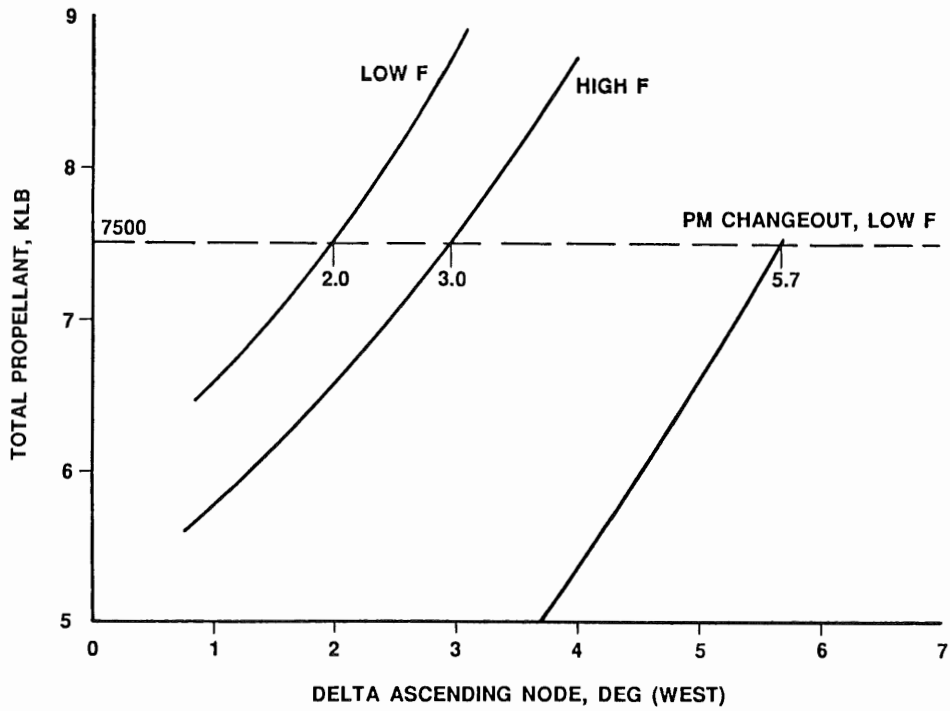


FIGURE 5. HST PROPELLANT REQUIREMENTS

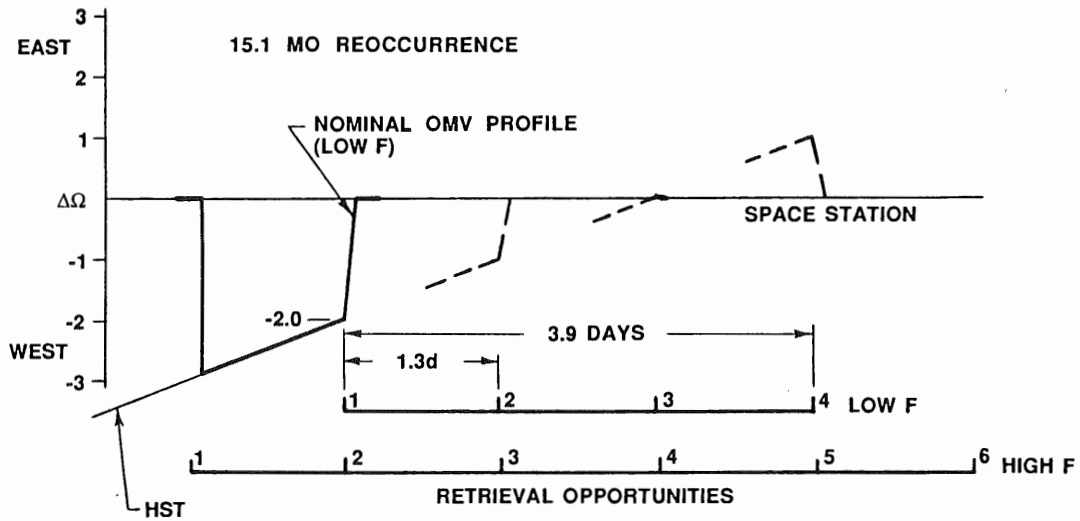


FIGURE 6. HST RETRIEVAL

TABLE 1. OMV MASS AND PROPULSION ASSUMPTIONS

A) MASS

OMV FLIGHT VEHICLE	5203	
BIPROPELLANT	6600	
HYDRAZINE	1000	
NITROGEN	165	
RMS DOCKING MECHANISM	121	
3-POINT DOCKING MECH	150	
	13239	lb
ASE	125	lb

B) PROPULSION

VARIABLE THRUST ENGINES (BIPROPELLANT)		
a) HIGH THRUST Isp	300	sec
b) LOW THRUST Isp	280	sec
HYDRAZINE RCS Isp	220	sec
NITROGEN RCS Isp	65	sec