SECTION 5
PROXIMITY OPERATIONS TECHNIQUES RATIONALE

PROX OPS include stationkeeping, flyarounds, final approach to grapple, and separation.

One mission commander had made this extremely perceptive observation about PROX OPS: "This is not just a knowledge type operation, it's a skill-type operation that requires continuous training to develop and maintain at skill level. Knowing how to do it is not enough. You have to develop the skill so you can do it time and time again and be repeatable."

5.1 STATIONKEEPING

During PROX OPS, stationkeeping techniques are required to maintain the Orbiter in a desired position relative to the TGT, either in a TGT-inertial or LVLH-referenced frame. The zone of proximity stationkeeping operations is limited to ranges and relative velocities within which RNDZ operations are not required to achieve repeated close approach. Typically, $R \leq 1000$ feet, with rates in each axis ≤ 1 ft/s.

Under the requirement that the Orbiter maintain a position in the TGT-centered LVLH frame, the Orbiter is usually positioned along the TGT +V-BAR, with UNIV PTG controlling the Orbiter attitude as -X to Earth and omicron of zero (PLB to TGT). Thus, the TGT will be trailing the Orbiter. Assuming zero differential drag between the Orbiter and the TGT, V-BAR positions are the only ones which are theoretically stable. This results in the most efficient type of stationkeeping, because minimal propellant is required to maintain the Orbiter c.m. at the same altitude and coplanar with the target c.m. SES experience shows one can maintain a position at 1000 ± 30 feet on the V-BAR for about 100 pounds of propellant per REV, using an optimum VCRS/PRCS technique (NORM Z).

Stationkeeping on the TGT radius vector (R-BAR) is usually undesirable due to operational complexity and the high propellant usage penalty required to stay on the R-BAR (theoretical analysis provides a rule of thumb for extra usage, above and beyond normal stationkeeping usage, as approximately 0.5 lb/ft of separation, per REV).

5.1.1 Stationkeeping Control

During stationkeeping activities, the crew must judge when Orbiter attitude and/or translation corrections are necessary, and make corrections manually.

5.1.1.1 Attitude Control

Depending on the type of stationkeeping, the Orbiter attitude is maintained automatically either in an inertial or an Earth TRK mode. The Orbiter attitude control system, which provides the Orbiter with the capability to maintain the proper attitude for stationkeeping, consists of the UNIV PTG function, the LVLH mode, and the inertial attitude hold mode.

The size of the ATT DB is also of concern in stationkeeping since it must be selected based on a compromise between two conflicting trends. For attitude considerations alone, the basic tradeoff has always been between narrow DB's (which give high attitude precision and incur high propellant usage for attitude control) and wide DB's (which saves propellant for attitude control). However, from the point of view of maintaining a desired stationkeeping position, a narrow DB allows the pilot to more easily discern actual position errors (and make immediate translation corrections) while a relatively large DB tends to mask increasing position errors. If a large altitude differential is allowed to build up, this creates relative orbital mechanics forces which drive the Orbiter off its desired position and requires costly translation burns to counteract. Thus the most economical DB must be selected based on a compromise between attitude control propellant usage (which suggests narrower DB's) and translation propellant usage. Normally, 2° PRCS and 1° VRCS DB's are used as the "best compromise." See section 3.2.1.

Universal Pointing - UNIV PTG, which is defined MM201 keyboard entries and activated via the AUTO pb, provides for maintaining a specified attitude with respect to a reference frame (such as LOS to center of Earth). The main contribution of UNIV PTG to stationkeeping is this ability to automatically maintain a desired attitude or to maneuver to a specified attitude. This reduces the number of degrees of freedom of the Orbiter from six to three (translation only), so the crewmember can concentrate on a more manageable piloting task.

LVLH Mode - The LVLH mode keeps the Orbiter in a fixed position relative to a rotating reference frame.

An example of use is an out-of-plane flyaround in the local horizontal plane of a TGT which is LVLH-stabilized. The MNVR is performed with pulses in the Orbiter roll axis, while pitch and yaw are automatically maintained relative to LVLH (see section 5.2.2).

Inertial hold - The inertial attitude hold mode is needed when the Orbiter is required to be fixed in the inertial frame. The inertial attitude hold mode is primarily for close-in stationkeeping or approach to grapple to an inertially stabilized payload.

5.1.1.2 Translation Control

During stationkeeping, translation control is necessary to help maintain the position of the Orbiter relative to the TGT. The primary purpose of the translation control is to maintain the Orbiter c.m. in the vicinity of the target V-BAR within some predetermined range limits.

Using COAS cross-field-of-view drift, or RR digital angle rates, or CCTV, a crewmember knows the direction of normal LOS rates and can perform corrections using the THC. RR data may provide much more precise readings which allow the crewmember to avoid overshooting/undershooting corrections and thus avoid rates propagating into large trajectory dispersions. In the Orbiter body frame, these rates represent the normal to the LOS (NLOS) motion of the Orbiter trajectory relative to the TGT, and thus the required information for making NLOS translation corrections to the trajectory. Also, by appropriate attitude orientation of the Orbiter, the EL and AZ will represent the Orbiter in-plane and out-of-plane position, respectively, of the Orbiter relative to the TGT V-BAR.

A confined ("tight") form of stationkeeping performed during short and medium range ($R < 1000$ ft) operations maintains the Orbiter within relatively small limits (e.g., ATT DB $\pm 1^{\circ}$) around the optimum stationkeeping point by appropriate thrusting in all Orbiter axes. A less confined form of manual stationkeeping ("loose") used during medium and long range ($R > 1000$ ft) operations makes more efficient use of orbital mechanics forces as an aid to translation control, thereby reducing the need for translating in certain Orbiter axes.

The two basic types of translation guidance are automatic and visual. This refers to the method of determining required corrections, which are then always executed by the crew manually.

- Automatic translation guidance is accomplished by using navigated (i.e., GPC filter processed) relative state data to determine where crew-executed translation inputs are required for relative position corrections. The sensor data is used to update the relative state, which is then used to compute corrective MNVR's based on the orbit targeting algorithms.

- Visual translation guidance is accomplished by crew processing of TGT relative position information for determination of the approximate translation corrections. This relative state information comes from direct visual contact with the TGT (NLOS sense and approximate rates), and from raw RR data for LOS/NLOS value and rates information.

5.1.2 Classification of Techniques

For convenience, stationkeeping operations are classified by range (close in, short, medium, and long), and there are significant differences between these techniques used at different ranges. These differences are summarized in tables 5-1 and 5-2.

TABLE 5-1.- SUMMARY OF STATIONKEEPING CLASSIFICATIONS

Type	Close-in	Short	Medium	Long
Range	~35 ft	< 200 ft	200-1000 ft	1000 - 2000 ft
Duration (roughly)	≤ 1 rev	≤ 1 rev	1-2 rev's	2 revs to 1 day
Primary source of relative state information	Eyeball, EE CCTV	CCTV, RR, COAS + eyeball	CCTV, RR, COAS + eyeball	CCTV, RR, COAS + eyeball
Direct visual contact*	Required	Required	Required **	Desirable **
Orbital mechanics effects on maneuvers	Ignored	Ignored	Utilized	Efficiently utilized
Plume impingement concerns	Usually in quiet zone	Significant	Usually insignificant	insignificant
Control technique	• Manual • Tight	• Manual • Tight	• Manual • Tight or loose	• Automatic (elliptical) • Manual (loose)
Application	• Trim/align relative ATT for grapple/ manhandling • 3 body OPS(MMU) • Photography/ activation of disabled PL	• Final stage of retrieval • Short term TGT checkout • Set up proper Orbiter/TGT geometry • 3 body OPS (MMU)	• Final approach preparation • Short term TGT checkout • Three-body operations (MMU) • RMS preparation • Waiting for proper lighting • Troubleshoot Orbiter problems	• Stand off • Long term TGT checkout

*Must have RR or visual/CCTV contact at all times.

**TGT must have lights or reflectors if night operations required. Momentary loss of contact acceptable if under stable conditions, precise stationkeeping.

TABLE 5-2.- SUMMARY OF STATIONKEEPING CONTROL

Type	Close-in	Short	Medium	Long
Range	~ 35 ft	< 200 ft	200-1000 ft	1000 - 2000 ft
RMS	Ready to grapple	Ready to grapple	Ready to grapple	Stowed
Attitude hold	As required (combination of free/IAH or free/LVLH)	Usually matched to TGT	LVLH with -Z toward TGT	LVLH with -Z toward TGT
Orbiter X axis	As required	As required for approach	In TGT orbital plane	In TGT orbital plane
DAP	Usually NORM Z	LOW Z	NORM Z if outside plume sphere of influence	NORM Z

5.1.2.1 Close In

Close in stationkeeping techniques are required after the Orbiter has achieved a stable position near the TGT. Alignment with the desired TGT axis may or may not have been achieved.

Since close-in stationkeeping is done at 35 feet, orbital mechanics effects are ignored. Flying is done strictly from a combination of out-the-window and RMS EE CCTV camera views, still in the -Z sense.

At 35 feet, most payloads will remain in the "quiet zone," safe from plume impingement effects. Therefore all operations can be done in the "norm Z" mode. However, for very large PL's, such as the Hubble Space Telescope (HST) or LDEF, low Z may be necessary, especially if some type of Orbiter/TGT alignment maneuver is required. Also, if the payload drifts forward or aft of the "quiet zone," low Z should be selected until it resumes its position over the PLB.

Close-in stationkeeping is a "tight" stationkeeping technique, which, although easy to fly, requires the pilot's constant attention. Its common uses are waiting for proper PL geometry for grapple or preparing for final Orbiter/TGT alignment maneuvers, MMU flyover operations, or close-inspection activation of a disabled payload.

5.1.2.2 Short Range

Short range stationkeeping techniques are generally required after the Orbiter has already been positioned on the correct TGT final approach axis (i.e., that axis along which the Orbiter must approach in order to execute RMS grapple), or in the case of checkout operations, on any designated TGT axis. They may also be required immediately after TGT release.

The range is generally within the plume sphere of influence (60 ft $< R <$ 200 ft). At these ranges, orbital mechanics effects can be effectively ignored. The time interval associated with close-in operations is usually less than 1 orbit.

Two primary tasks involved during short range operations are matching the attitude rates of the Orbiter with those of the TGT (to within 0.1° deg/s and translating to maintain the correct relative position on the desired TGT axis. Thus, short-range stationkeeping generally requires visual translation guidance techniques.

"Tight" stationkeeping is the suitable technique used for short-range operations, which put emphasis on the use of the COAS for maintaining the Orbiter relative position on the desired TGT axis. The CCTV's are the primary source of LOS control during the last 200 feet of the final approach to grapple (see figs. 3-25 and 3-27). After the RR loses lock, they also become the primary source of range and range rate polarity information.

The different types of short-range stationkeeping techniques are:

- Orbiter stationkeeping with respect to an inertially stabilized TGT
- Orbiter stationkeeping with respect to a TGT fixed in the LVLH frame (while rotating at orbit rate).
- Orbiter stationkeeping with respect to a TGT rotating at an arbitrary rate relative to the LVLH frame or the inertial frame.

5.1.2.2.1 Inertially stabilized target.- This method presumes that the TGT is inertially stabilized, with the aid of some type of control system, or is spin-stabilized (fig. 5-1). In order to keep the same relative attitude geometry, the Orbiter must also maintain inertial hold. This then requires that the Orbiter translate continuously (with respect to the LVLH frame centered on the TGT) to stay on the desired TGT axis and maintain the desired range.

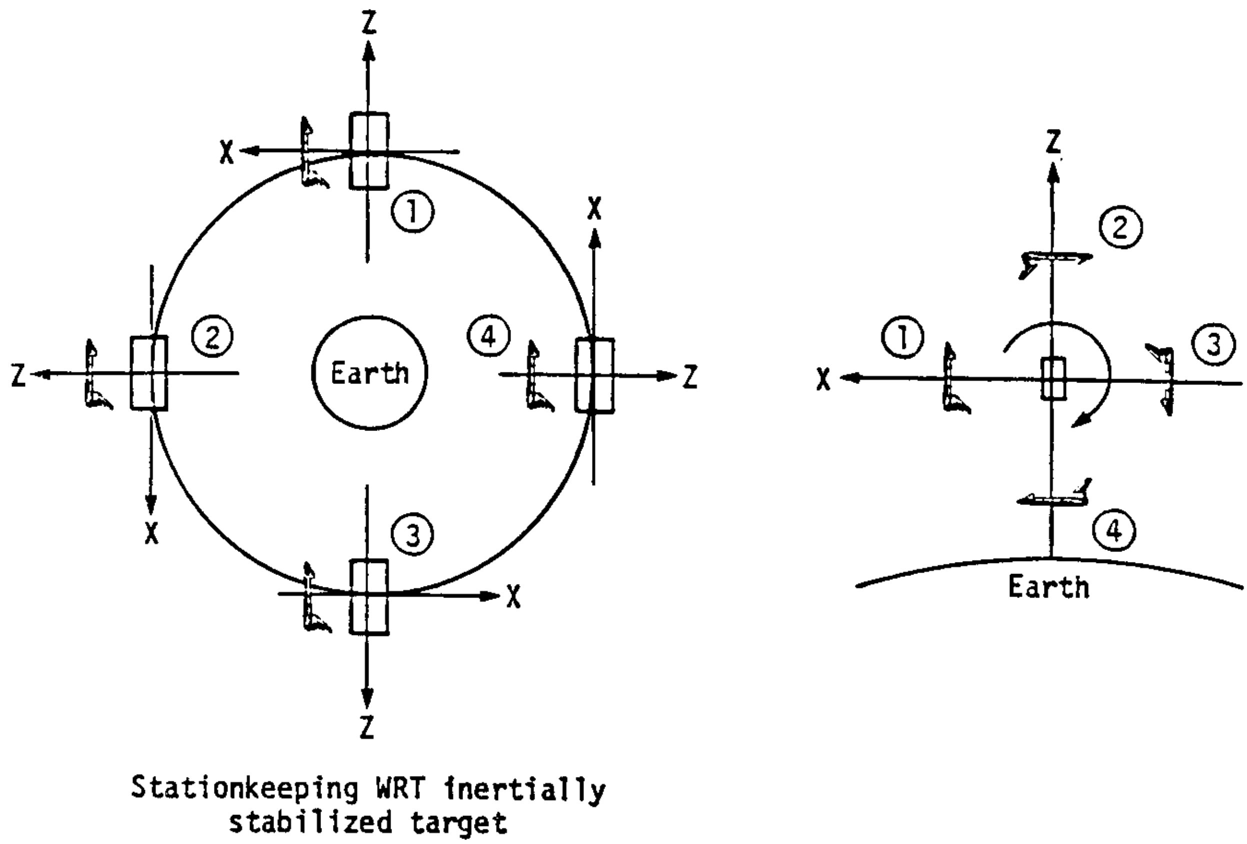
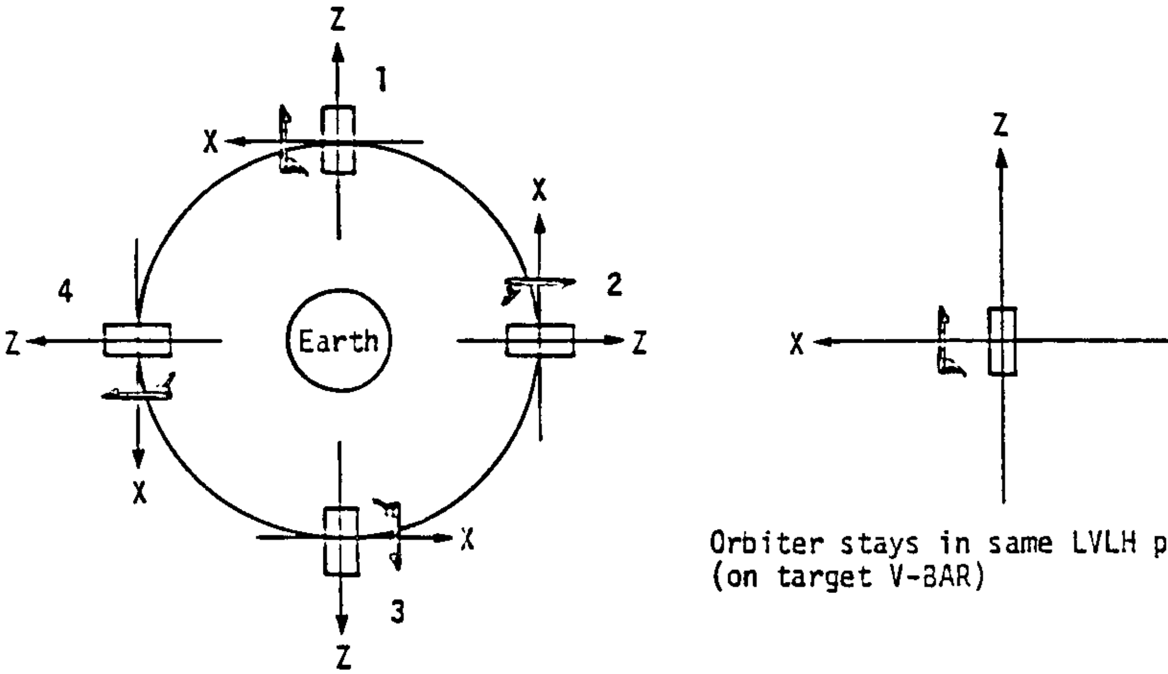


Figure 5-1.- Inertially stabilized TGT.

The Orbiter DAP automatically maintains inertial hold, while the crew uses the COAS and CCTV for NLOS and LOS translation correction information.

5.1.2.2.2 Target attitude fixed relative to LVLH frame.- A TGT may be maintaining a constant attitude relative to the LVLH frame (and therefore rotating in the inertial frame at orbit rate). The TGT attitude may be controlled either actively with an attitude control system or passively by gravity gradient torques. In either case, the Orbiter maintains a fixed position and attitude with respect to the TGT LVLH reference frame (fig. 5-2).



Station keeping WRT target rotating in inertial frame at Orbital rate (i.e., target attitude fixed relative to LVLH frame)

Orbiter stays in same LVLH position (on target V-BAR)

Figure 5-2.- TGT fixed in LVLH reference frame.

Orbiter attitude is controlled automatically by either UNIV PTG (with selection of a proper Orbiter body vector pointed at the Earth) or by selection of the LVLH mode (UNIV PTG is the preferred technique). Translation is controlled manually as in the previous case; however, the amount of thrusting required is considerably reduced, due to the stable nature of LVLH fixed position stationkeeping.

Note: This applies only if the Orbiter is close to the V-BAR of the TGT. If we have LVLH stationkeeping with a large out-of-plane offset, and/or above/below the V-BAR, then this does not apply.

5.1.2.2.3 <u>TGT rotating at arbitrary rate</u>.- Under certain circumstances, the Orbiter may be required to perform short-range stationkeeping with a TGT which is rotating at an arbitrary rate about an arbitrary axis, relative to the LVLH frame. This type of stationkeeping would be needed if the TGT experienced the loss of its control system (active system failed, or passive system disturbed by some external torque such as plume impingement) causing the TGT to rotate at an arbitrary rate inertially about a principal axis of inertia, thus making it difficult for the Orbiter to initiate grapple procedures.

5.1.2.3 Medium Range

Medium-range stationkeeping is required primarily during preparation for final approach, and generally at a range outside of the TGT plume sphere of influence (approximately 200 < R < 1000 ft). Other situations which may require medium-range stationkeeping operations include three-body operations (such as operations with an MMU crewmember), RMS activation, delay to await proper final approach lighting conditions, or troubleshooting Orbiter systems problems. The time period associated with medium-range stationkeeping is approximately one to two orbits.

Medium-range operations are controlled using manual translation techniques. The technique emphasizes maintenance of the c.m. of the Orbiter about the TGT ± V-BAR and direct visual contact with the TGT (i.e., tight stationkeeping as described in section 5.1.2.2). Since the CCTV is relatively inaccurate and ineffective over this range interval, the primary source of relative state information is the radar. With a visible TGT, the COAS and CCTV would still be useful for NLOS position determination.

For medium range, brief loss of direct visual contact is acceptable as long as stable stationkeeping has already been established. This was done on 51-F when loss of contact was approximately 4 minutes. This should be considered the longest allowable "blind" period.

5.1.2.4 Long Range

Long-range stationkeeping becomes appropriate during long-term ground or internal payload checkout and/or activation, or during three-body operations where a free-flyer is sent over from the Orbiter to perform some payload-related task. The ranges associated with long-range operations are between 1000 feet and radar acquisition range (however, for ranges greater than approximately 2000 feet the stationkeeping would not be considered a pure PROX OPS task and a rendezvous would most likely be required). The time period may range from two orbits to approximately 1 day.

Long-range stationkeeping operations can be automatically controlled, relying primarily on the use of navigated state data. For long-range stationkeeping the TGT appears visually as a point source of light, and direct uninterrupted visual contact with the TGT may not be possible (e.g., night time stationkeeping). However, the radar can provide the majority of the required relative position information. Use of one of the manual V-BAR control techniques is possible if raw radar data is available. Direct visual contact would serve as a useful supplement to the radar, but would not be sufficient alone as a source of long-range stationkeeping information (range and rates are needed).

For longer ranges and longer stationkeeping periods, manual techniques become somewhat laborious and expensive, and it is desirable to utilize some form of automated techniques whereby the Orbiter NAV system is utilized to determine when corrective maneuvers are required. The radar system is still required as a sensor for purposes of keeping the REL Orbiter/TGT SV current. A typical AUTO technique (fig. 5-3) uses an algorithm which attempts to maintain the Orbiter c.m. within some predefined boundary centered at some range on the TGT V-BAR. Whenever the Orbiter c.m. approaches the boundary, a maneuver based upon the current navigated REL state is computed and executed to drive the c.m. back to the center. Upon arriving at the center, a maneuver is computed and executed to null all rates relative to the TGT. The process repeats itself again after the Orbiter c.m. again drifts out to the boundary.

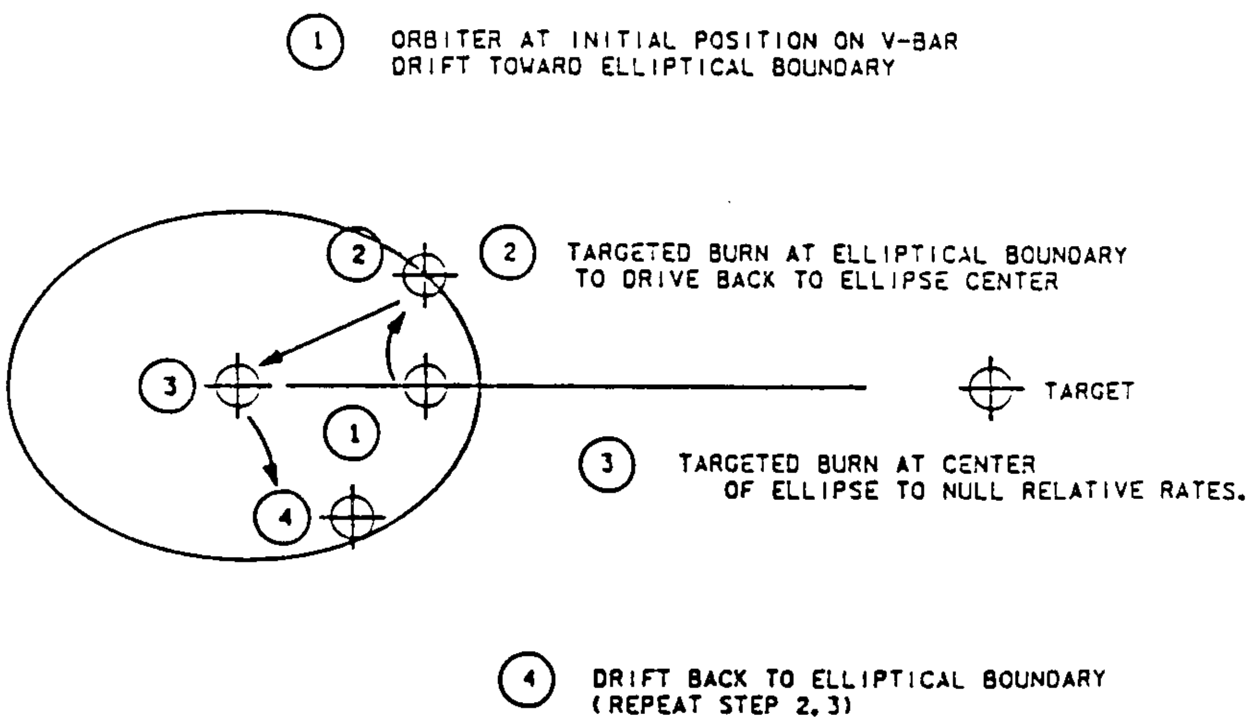


Figure 5-3.- Point stationkeeping.

5.1.2.5 Very Long Range

Under certain circumstances it may be desirable to perform stationkeeping at ranges from 1 mile to maximum radar track range and for periods of several REV's to a full day. In practice it has always been preferred to initiate a slow separation and perform another rendezvous the following day. However, requirements may force such very long-range stationkeeping and its resulting complications (e.g., 24-hour crew awake cycles and intermittent TDRS COMM). This falls outside of true PROX OPS.

5.1.3 Operational Groundrules and Constraints

For planning actual stationkeeping operations, the following groundrules and constraints should be observed (source, MOD memo DM4-86-62, Nov. 25, 1986).

Manual stationkeeping on the V-BAR axis for ranges on the order of or less than 1000 feet may be planned for a duration not to exceed a full crew workday, (i.e., Crew Scheduling Constraints, Crew Procedures Management Plan, appendix K). This would require dedication of two qualified crewmembers and could not be scheduled on consecutive days. Due to disturbance from the FRCS firings, stationkeeping should not occur when any member of the crew has a sleep shift. This stationkeeping could be further limited by forward RCS propellant limitations which depend on other mission activities and details of the mission specific stationkeeping activities such as low-Z stationkeeping, failed VRCS, etc.

As a gauging point, it should be noted that with a full forward RCS loading available for the stationkeeping activity, the duration of the stationkeeping on the V-BAR will be limited to less than 20 hours due to stationkeeping costs of about 100 pounds per revolution plus retrieval at the end of the crew day followed by redeployment for additional stationkeeping. Stationkeeping will cost considerably more if not on the V-BAR.

5.2 FLYAROUND/TRANSITION

Flyaround is a PROX OPS task which generally involves maneuvering the Orbiter (active vehicle) from one point to another point relative to the TGT (passive vehicle). In particular, flyarounds require that the Orbiter, with appropriate translation corrections, maintain approximate constant range from a TGT while moving from one relative position to another in the TGT LVLH reference frame. Generally, the Orbiter maintains a specified body vector pointed toward the TGT throughout this phase. This axis is generally the Orbiter -Z axis since it provides COAS LOS TGT visibility and is the optimum radar track axis (fig. 5-4).

"Transition" is more general in scope in that it includes any operation which results in Orbiter movement from one point to any arbitrary point relative to the TGT in the TGT LVLH reference frame (i.e., range is not necessarily maintained constant). Whereas flyaround maneuvers are generally flown in a manual mode since they require constant maneuvering, transition maneuvers may be automatically targeted.

The requirement to perform a transition or a flyaround may result from several situations such as the need to perform payload inspection, the requirement to support detached PL experiment operations by appropriate Orbiter relative positioning, or the requirement to move from a final RNDZ point (initial stationkeeping point) to a final stationkeeping point from which grappling operations can be initiated.

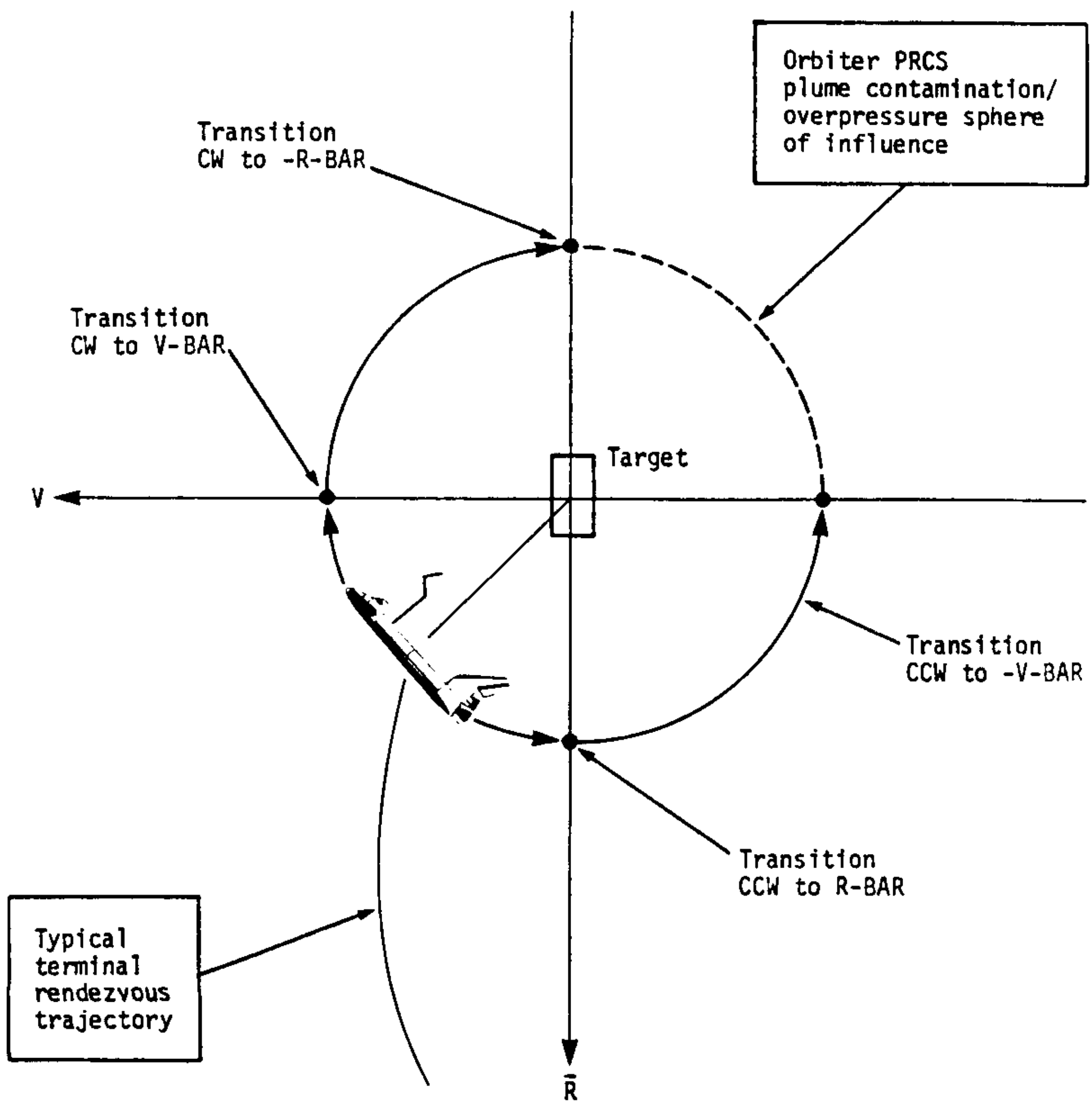
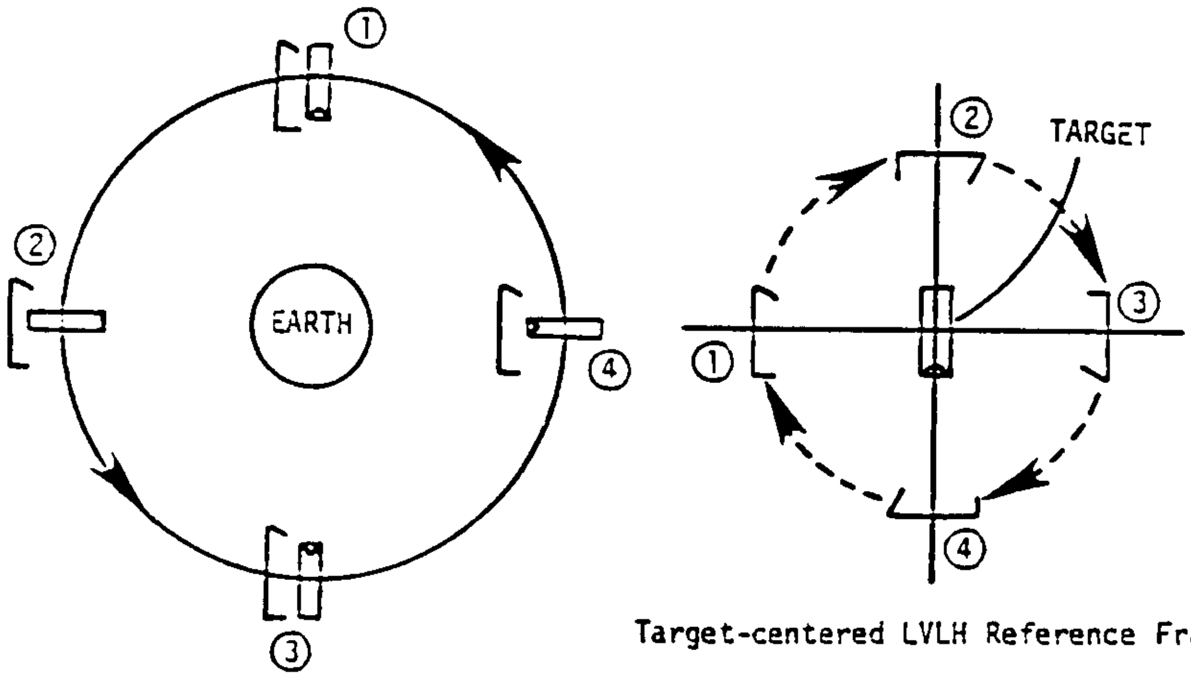


Figure 5-4.- Transition geometry.

5.2.1 LVLH ORB-Rate In-Plane Flyaround

An Orbiter LVLH in-plane flyaround (fig. 5-5 or 5-6) follows a trajectory which remains in the TGT orbit plane. The technique employed to execute this trajectory is dependent on the angular displacement between the initial and final stationkeeping points as well as the required time of transfer. Generally, the shortest path consistent with minimum propellant usage is chosen. When time of transfer must be minimized, an arbitrary flyaround rate greater than orbit rate may be selected.



Target-centered LVLH Reference Frame

Inertial Reference Frame

Figure 5-5.- Flyaround of an LVLH attitude hold TGT.

5.2.1.1 Clockwise Orbit Rate Flyaround

Whenever possible, a CW flyaround (fig. 5-5) is selected since it takes advantage of orbital dynamics forces which tend to assist the angular change required to establish and maintain the flyaround (i.e., posigrade maneuvers assist below the TGT and retrograde maneuvers assist above the TGT). The flyaround technique is further simplified by selecting the flyaround rate to be orbit rate (approximately 4 deg/min at 150 n. mi.). For example, an orbit rate flyaround of a TGT would imply a 360° rotation around the TGT in exactly one orbit of travel. The LOS from the Orbiter to the TGT would remain inertially fixed throughout this type of flyaround.

Procedurally, the orbit rate flyaround requires that the Orbiter initiate, by "seat of the pants" flying, the proper X axis translation ΔV for a 360° flyaround in one orbit for the desired flyaround range (as indicated by zero inertial elevation angle rate from the radar or by maintaining the TGT stationary in the COAS), and then simply maintain the Orbiter in inertial attitude hold. This proper rate is shown on the PROX OPS cue card (section 4.3.6). Due to initial MNVR dispersions, cross-coupling effects, orbital mechanics effects, and differential drag, small translation corrections must be made (done manually out the window) during the flyaround to maintain the appropriate range and flyaround rate.

5.2.1.2 Counterclockwise Orbit Rate Flyaround

In certain cases, a CCW rotation flyaround may be executed (fig. 5-6), within a significantly shorter transfer time than using a CW rotation, and there is not an appreciable propellant penalty. This was the case on STS 51-D. In fact, it is cheaper and quicker to go from the V-BAR to the R-BAR by a CCW rotation than a CW rotation. Plume impingement on the target is also reduced because the thruster firings required due to orbital mechanics are toward the target. However, for a given angular displacement (measured clockwise) and transfer time, the CCW rotation requires more propellant. This is due to the fact that (1) the Orbiter must now maintain a pitchdown rate in order to keep the TGT along the -Z COAS LOS (twice orbit rate for a CCW orbit rate flyaround), and (2) the orbital dynamics forces are now operating in conflict with the desired trajectory motion. That is, when the Orbiter is below the TGT and performs the appropriate retrograde X axis translation ΔV for the orbit rate CCW rotation, the resulting trajectory is downward, and considerable translation corrections must be made to force the trajectory back to a constant range, in an upward direction. Most flyarounds are therefore executed in the CW direction.

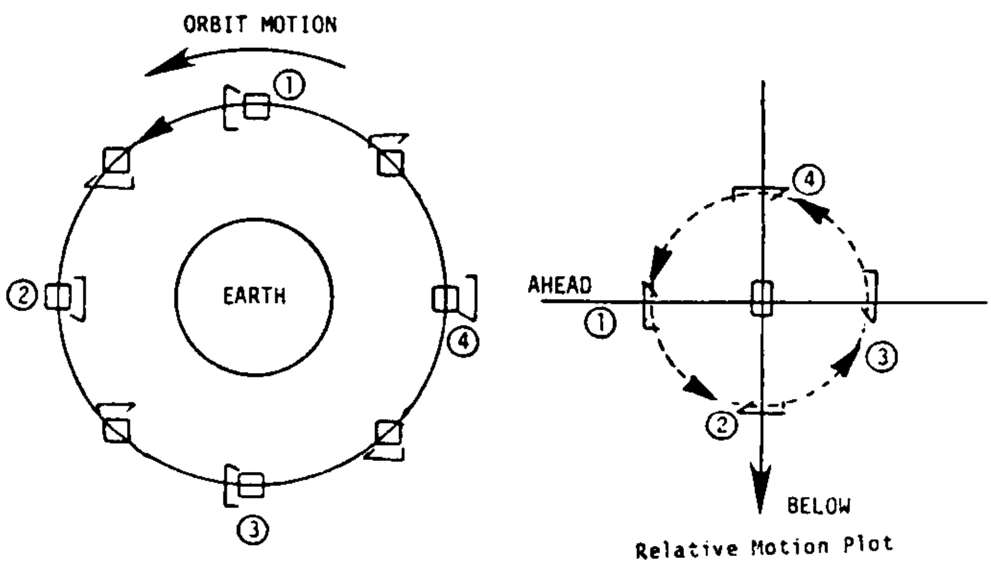


Figure 5-6.- Counterclockwise flyaround.

5.2.2 LVLH out of Plane

A flyaround may also be executed out of plane (in the TGT local horizontal plane). The Orbiter is placed in manual ROT (free drift) PULSE mode in one axis and maintains AUTO attitude hold in the other two axes. For example, if roll is the axis that is to be maintained manually by the crew, pitch and yaw would be in LVLH hold and the Orbiter translations would be performed as required to maintain the proper flyaround rate.

5.2.3 Arbitrary Rate Flyarounds

5.2.3.1 Single Axis

Some situations require a flyaround in a shorter time than ORB rate will allow. In this case, several options are available. One option, called AUTO ROTATION, uses the single-axis AUTO ROT option of UNIV PTG. Although the pilot probably would not mix modes, the task is then to use the THC as required to keep the TGT in the COAS and maintain constant range. This option is limited to pure in-plane flyarounds, performed one axis at a time, since the ROT option fixes the two nonrotating axes inertially. A second option called MANUAL ROTATION can be used in either an inertial (DAP MAN) mode or LVLH (DAP LVLH) mode. In this case, the desired axis of rotation is placed in free (PULSE) and the other two in hold (DISC RATE). The pilot task here is to use the RHC to maintain the desired flyaround rate (pilot would monitor rate on UP and the appropriate rate needle), and then use the THC to accomplish the flyaround. Complicating this technique is the fact that rotation and translation maneuvers cross-couple significantly, which makes it difficult for the pilot to maintain the flyaround rate and still do the required translations. Constant monitoring and correction of rotation rate is required.

5.2.3.2 Multiple-Axis Auto Rotation Maneuver

An arbitrary rate, multiple axes flyaround technique is used primarily for transition to a final approach axis of an inertially stabilized TGT. The approach axis may be pointed in any direction and the TGT may be rotating at a rate other than orbit rate. The flyaround may be an in-plane or an out-of-plane translation, performed manually with the THC and RHC. This is a very challenging task and is not recommended.

This maneuver may be used when the final Orbiter attitude at final approach is known and can be input to the DAP. The Orbiter performs an eigenaxis (i.e., the axis of minimum rotation between two attitudes) rotation maneuver, with manual translations made to keep the TGT centered in the COAS and to maintain a constant range. It is very complex to set up, and therefore manual rotations are generally preferred. However, if done in the proper direction (CW versus CCW for in-plane maneuvers) it can be relatively easy to fly.

5.2.3.3 LVLH (INERTIAL) Orbiter/TGT Alignment Procedure

For an arbitrary (and prerendezvous unknown) TGT attitude, the following procedure was developed for STS 51-I (see fig. 5-7) and was generalized for the contingency book. There are other procedures to accomplish this, but this is very straightforward and is probably the easiest. One axis is corrected at a time. The alternative is to perform a simple inertial approach straight in.

LVLH (INERTIAL) ORBITER/TGT ALIGNMENT

CAUTION

-Z Sense Roll/Yaw (A6U) are the reverse of
+X Sense Roll/Yaw (C3)

Maintain ~0.2 to ~0.3 deg/sec rotation rate

A6U ✓SENSE - -Z
✓DAP TRANS: PULSE/PULSE/PULSE
DAP: B/LVLH (MAN)/NORM
✓DAP ROT: DISC/DISC/DISC

Align ROLL, if reqd
DAP ROT: PULSE/DISC/DISC
RHC (ROLL) and THC as reqd
When Aligned,
DAP ROT: DISC/DISC/DISC

Align PITCH, if reqd
DAP ROT: DISC/PULSE/DISC
RHC (PITCH) and THC as reqd
When Aligned,
DAP ROT: DISC/DISC/DISC

Align YAW, if reqd
DAP ROT: DISC/DISC/PULSE
RHC (YAW) and THC as reqd
When Aligned,
DAP ROT: DISC/DISC/DISC

DAP: B/LVLH (MAN)/VERN, NORM as reqd

Figure 5-7.- Trim Orbiter/TGT alignment.

It must be emphasized that 0.2 deg/s is plenty fast enough as an angle rate, even if it does not look that way out the window. The crew is advised not to go free drift in more than one axis at a time.

5.2.3.4 Manual Rotation Maneuver

A manual rotation maneuver is required when the final necessary Orbiter approach attitude is not known. The pilot gets his cues for starting and stopping the rotational maneuvers either from out-the-window (or CCTV) view of the payload or from checklist procedures. It is performed one axis at a time by repeated application of the ROT techniques described in 5.2.3.

For short-range stationkeeping with a TGT rotating at an arbitrary rate, the Orbiter must manually establish a matched rotation rate (possibly in three axes) while simultaneously translating to stay on the desired TGT axis. While the two previous cases (TGT inertial and TGT LVLH) only required three degrees of manual control (translation), this technique requires six degrees of manual control (ROT and translation). Manual ROT control is required since the AUTO modes require either Orbiter attitude fixed to the inertial or LVLH reference frame (i.e., either zero or orbit rate relative to the inertial frame). This maneuver is tricky since the Orbiter will be rotating about its own c.g., which will be some distance from the nominal grapple position. The best maneuver rate is between 0.2 and 0.3 deg/s. While the vehicle is still controllable at higher rates, fuel usage increases dramatically. In this situation, one may, for instance, prefer to do LVLH stationkeeping on the TGT V-BAR, and perform a rotating grapple.

As already described in section 5.1.2.1, since close-in operations are done at 35 feet, orbital mechanics effects are ignored. Flying is done strictly from a combination of out-the-window and RMS EE CCTV camera views, with delicate eye and hand coordination using the THC and RHC. Attention must also be given to the attitude rates displayed on UNIV PTG (OPS 201) to ensure that the desired rate is achieved and maintained. As in all phases of RNDZ/PROX OPS beginning with the initiation of manual trajectory control, the -Z sense is used exclusively for reasons of consistency and ease of piloting. DAP B/MAN/NORM usually works best.

5.2.4 Auto Targeted Trajectory

This is done (as on STS 5I-F) with a general two-impulse maneuver, which requires good onboard NAV for generation of targeting SV's. It is generally required when there is a ΔT constraint in maneuvering from one arbitrary point to another arbitrary point relative to a payload. The NAV targeting maneuver execute logic is used instead of the thrust monitor function. Certain orbit targeting I-loads need to be "tuned" for operations at PROX OPS ranges (see discussion in section 3.5.4.). The automated rotation maneuvering may be used as a backup in the event of RR failure. However, this must be carefully planned preflight, as on STS 51-F (see discussion in appendix A).

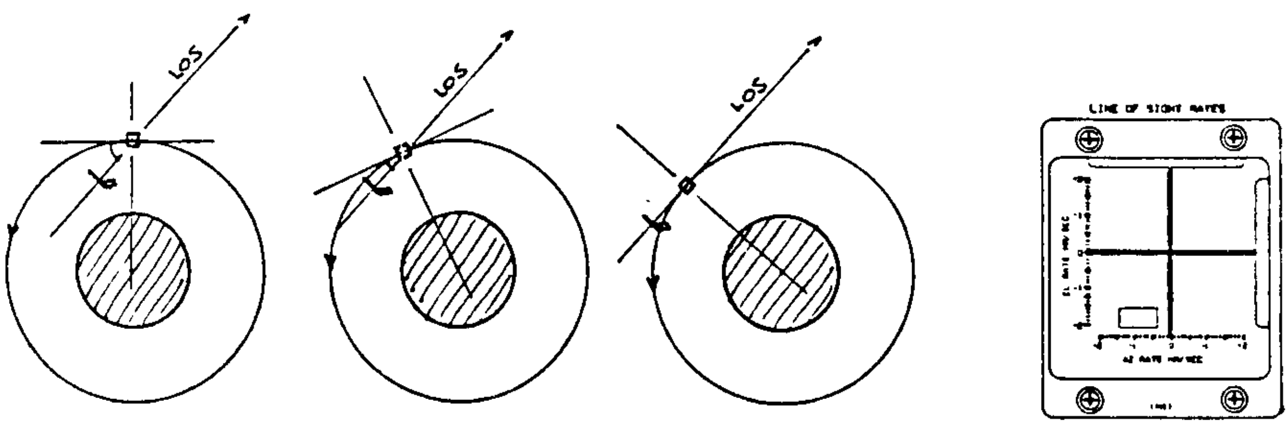
5.2.5 LOS Rate Techniques

The Orbiter-to-TGT radar LOS rate tends to jitter due to beam wandering, but when smoothed (either mentally, via some TGT characteristic, or via some as-yet undeveloped sensor), this parameter may be able to provide a valuable cue for PROX OPS piloting, especially for performing in-plane MNVR's in the vicinity of the V-BAR. The following discussion deals with a candidate procedure not yet validated or flown.

The inertial LOS rates are displayed on the cross pointer as EL and AZ rates on the A2 panel (fig. 3-20) and on SPEC 33 (REL NAV) (fig. 3-31) as ωP (for EL rate) and ωR (for AZ rate) on the RR column. These rates specify how much the LOS, a line from the Ku-band radar antenna to the TGT, is moving with respect to the inertial space, referenced on the RR EL/AZ coordinate system.

First, consider the case of a transition to the V-BAR, as is done at the final portion of a rendezvous maneuver (fig. 5-8). The Orbiter achieves inertial stabilization by selection of DAP MAN/DISC, maintaining the TGT in the COAS FOV by THC inputs. Evidently, for such a transition, the RR EL LOS rate is going to be about zero, depending on the THC corrections required in the +X or -X direction to maintain the TGT in the COAS. The LOS to the TGT, then, is going to rotate with respect to the LVLH TGT centered frame at the orbital rate, that is about 4 deg/min, or 1.16 mrad/sec (in what follows, this value is rounded to 1.1 mrad/sec):

TRANSITION TO THE V-BAR | A2 X POINTER



Orbiter/target at time T | . . . at time T + ~ 5 min | . . . at time T + ~ 10 min

Figure 5-8.- Transition to the V-BAR.

When on the V-BAR (fig. 5-9), to stay there, the Orbiter must null its upward motion. The crewman uses the THC in the -X direction, preferably in the pulse mode, to take away about as many ft/s of +X motion as range to the TGT is in kft (1 ft/s for 1000 ft range, for instance). Previously, of course, the crew must have set up the UNIV PTG to have the -X body vector tracking the center of the Earth upon reaching the V-BAR, at which point

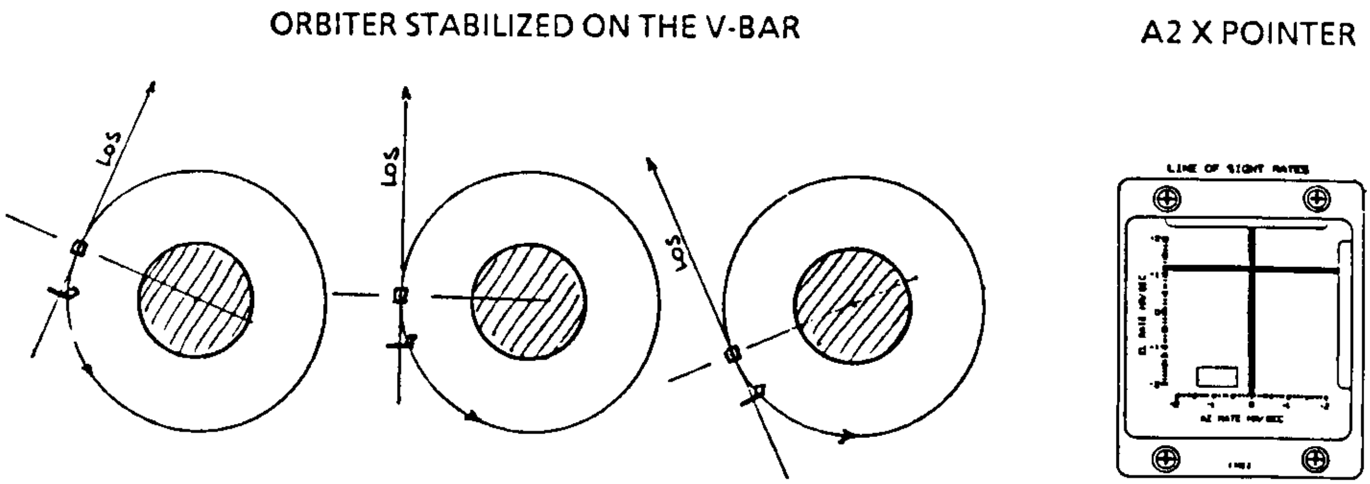


Figure 5-9.- Orbiter stabilized on the V-BAR.

select DAP AUTO. The -X translation MNVR that is performed in order to brake on the V-BAR will cause the EL LOS rate to increase. When it shows 1.1 mrad/sec, or thereabouts, the Orbiter is established on the V-BAR. The LOS, rotating with respect to the inertial space at the orbital rate of 1.1 mrad/sec, will then evidently remain fixed with respect to the TGT centered LVLH frame.

The EL LOS rate is not expected to tell anything about whether the Orbiter is approaching the TGT, or going away from it, or maintaining range. But over a period of time a closing R-DOT will cause a fall below the V-BAR, and the EL LOS rate will become higher than 1.1 mrad/sec. An opening R-DOT will, on the contrary, go above the V-BAR, and EL LOS rate will go below 1.1 mrad/sec (see fig. 5-10).

Instead of using the A2 panel crosspointer, the crew can, of course, use ωP on the REL NAV display. A good value indicating proper stabilization on the V-BAR is 1.1. For any value above that, the Orbiter is going down. For a value below that, the Orbiter is going up.

YOU ARE COMING DOWN, BELOW THE V-BAR

YOU ARE GOING UP, ABOVE THE V-BAR

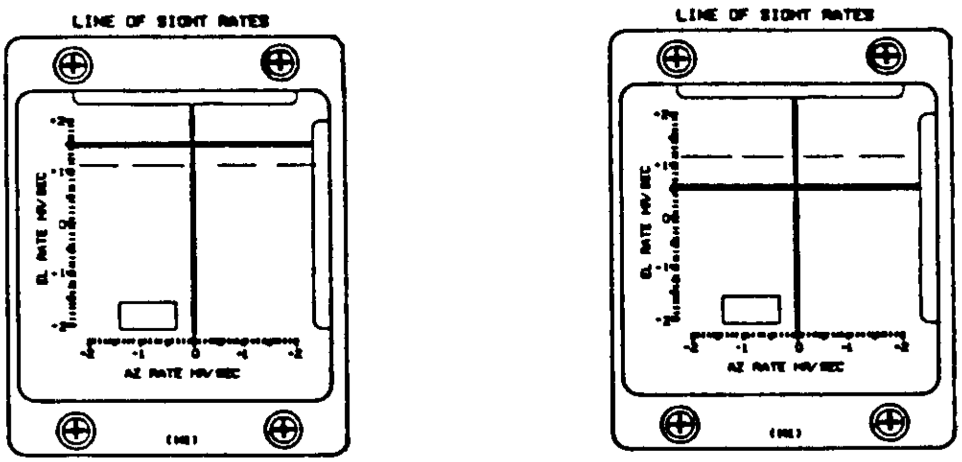


Figure 5-10.- Angle rates versus V-BAR stability

EL LOS rate is also useful to consider in a V-BAR approach (see fig. 5-11). After proper stabilization on the V-BAR, the crew establishes the desired closing range rate with the THC, and initiates a +X translation of such an amplitude as to reduce the EL LOS rate from 1.1 to about 0.7 or 0.8 mrad/sec. The crew knows then that it is getting a small amplitude hop above the V-BAR. EL rate will slowly increase. When the Orbiter gets again 1.1 mrad/sec, the tangent of the trajectory in the LVLH frame is passing through the TGT, but the Orbiter still is above the V-BAR. Whenever the crew visually ascertains that it is again on the V-BAR, they translate in +X again to bring its EL rate below 1.1 mrad/sec. The crew continues that way until it is at the stationkeeping range.

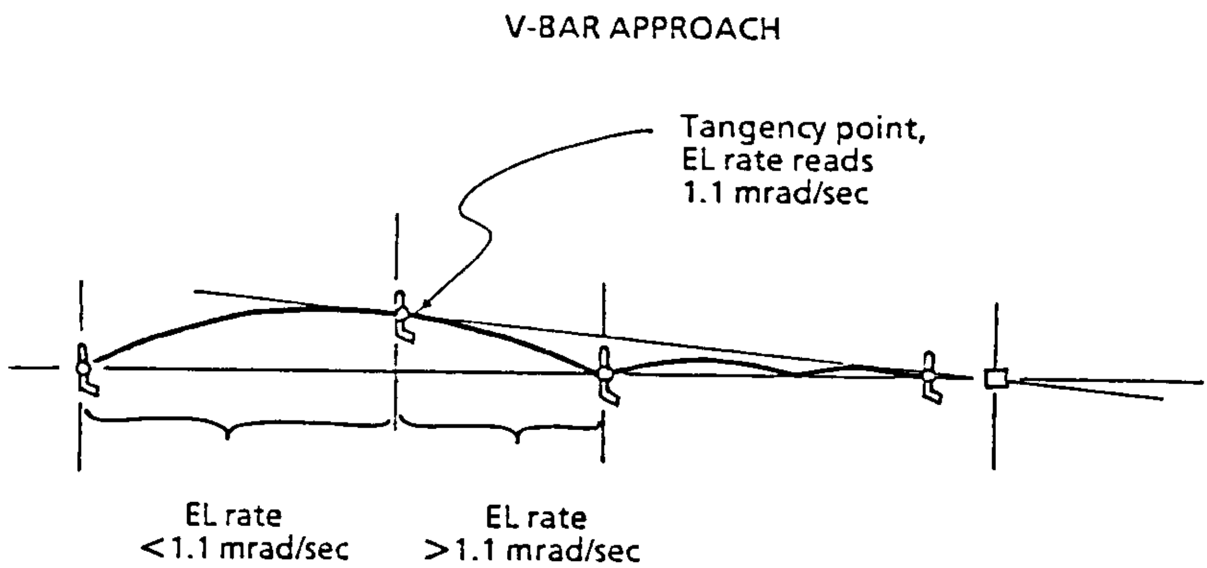


Figure 5-11.- Angle rates versus V-BAR approach

5.3 FINAL APPROACH

The final approach phase includes various braking and approach techniques.

5.3.1 Braking Techniques

The braking segments typically occur near TGT intercept and reduce relative velocity to near zero. The technique to be used for braking is greatly dependent upon the approach trajectory. For example, the technique used for a direct RNDZ intercept must reduce a large relative velocity, whereas the technique used just prior to capture must null only a small closing velocity. It is not the intent of this section to define the possible braking approach profiles, but to describe the thrusting techniques by which the Orbiter can achieve a stabilized relative position. Four techniques will be discussed, three involving the use of the PRCS and one (already discussed in section 2.4.3) using more dynamic orbital mechanics effects.

5.3.1.1 Normal Z-Axis Mode Braking

The normal Z-axis braking technique uses the up-firing PRCS thrusters to achieve a braking force directed in the +Z Orbiter body direction. This technique would be used in the case where the Orbiter -Z axis was pointed along the LOS to the TGT (fig. 5-12). Because the thrusters firing along the -Z axis provide the braking force, this technique results in the greatest amount of PRCS plume impingement on the TGT. Either the TGT must be insensitive to plume contamination/overpressure, or braking must occur outside of a contamination/overpressure sphere where plume effects are negligible. However, this orientation does allow crew monitoring of the TGT through the overhead window and use of the RR.

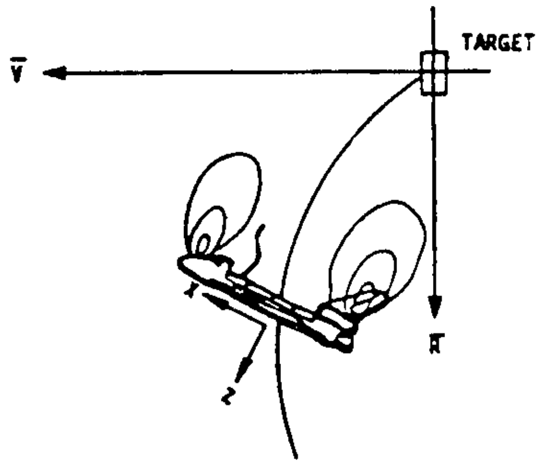


Figure 5-12.- Normal Z axis braking.

The braking force would normally be applied to achieve a range/range rate profile that is optimized to account for Orbiter PRCS acceleration, trajectory dispersions, and TGT sensitivity to PRCS plume. The RNDZ radar is normally used to determine actual range/range rate. Control of the relative velocity normal to the LOS during braking is accomplished by PRCS thrusting to achieve a specified inertial LOS rate. This rate is read directly from the radar LOS rate display (panel A2) or observed by monitoring TGT drift in the COAS reticle.

5.3.1.2 Low Z Mode Braking

The low Z-axis mode braking technique is the standard technique used (as a modification to normal Z axis mode braking) to reduce the PRCS plume in the Orbiter -Z direction. As described in section 3.2.4, the technique uses the cant of the aft firing thrusters and the scarfing of the forward firing thrusters to produce a resultant force in the +Z direction (fig. 5-13). The ±X axis firing is controlled by the DAP to produce a near zero force in the X axis direction. The propellant penalty (12 times NORM Z for same $-\Delta V$) is minimized by using the low Z axis braking mode only in the interval from the boundary of the PRCS plume sphere of influence to the close-in point over the PLB, where the TGT is "shadowed" by Orbiter structure, and reducing the total braking ΔV inside the sphere to the smallest possible value.

Because of severe cross-coupling effects (see section 3.8.1.3), Y-axis translations induce higher closing rates, requiring expensive braking maneuvers. Consequently such translations should be avoided in this mode.

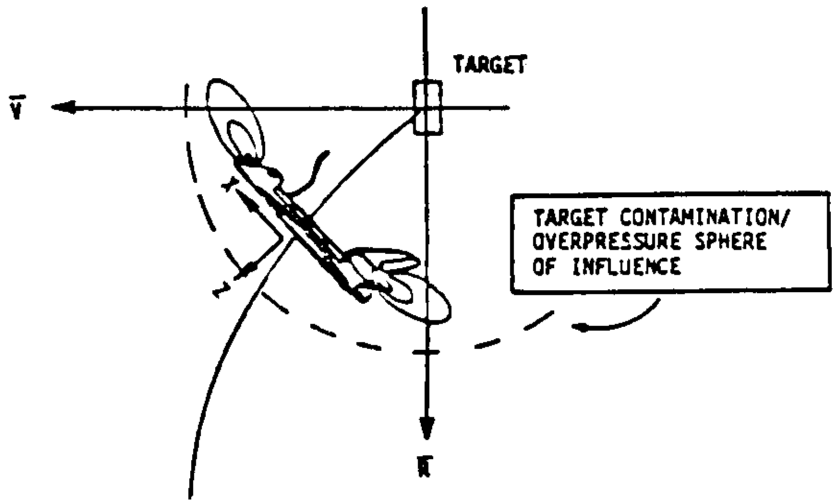


Figure 5-13.- Low Z axis braking.

5.3.1.3 X-Axis Mode Braking

The +X or -X axis thrusters could provide the braking force; however, operational constraints would normally preclude their usage. The +X axis braking mode (nose first) would not be desirable since it requires almost totally forward-pod propellant usage, which should be minimized. The -X (tail first) braking mode has the advantage that it minimizes forward-pod propellant usage; however, TGT visibility (crew and radar) would not be possible when thrusting along the TGT LOS (fig. 5-14). This technique of braking is not recommended for use due to the limited visual capabilities and plume concerns. Another concern with this type of braking is the safety issue involved with the clearance between the Orbiter tail and the TGT.

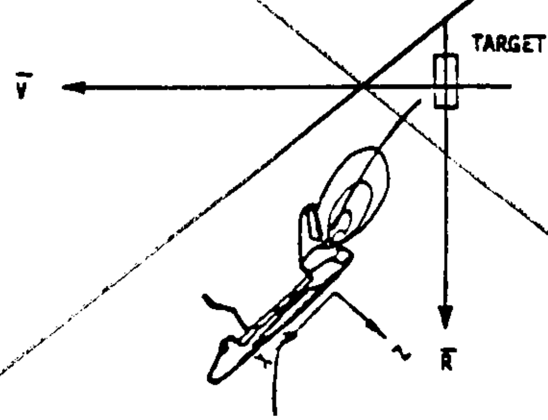


Figure 5-14.- +X axis braking.

5.3.1.4 Orbital Mechanics Effects Braking

Although not strictly a braking technique, orbital mechanics effects can provide a small separation force (see section 2.4.3). The relative position of the Orbiter with respect to the TGT can result in range opening or closing tendencies during PROX OPS.

For example, a TGT approach along R-BAR (from above or below the TGT) will result in a braking force which is a function of the differential altitude or range to the TGT (fig. 5-15). The greater the range, the greater the constantly acting separation force. The technique for establishing an approach trajectory to produce this R-BAR braking force is discussed in section 5.3.2.3. Compare the sizes of that "thrust" to RCS effects: two -X jets cross-couple into a momentary 240-pound +Z thrust; two +X jets cross-couple into a momentary 300-pound +Z thrust. In practice, the RCS cross-coupling dominates the small orbital mechanics forces for ranges less then several hundred feet. Outside that range, the forces are significant when one notes that they are constantly acting, whereas Orbiter jets are only sporadically fired.

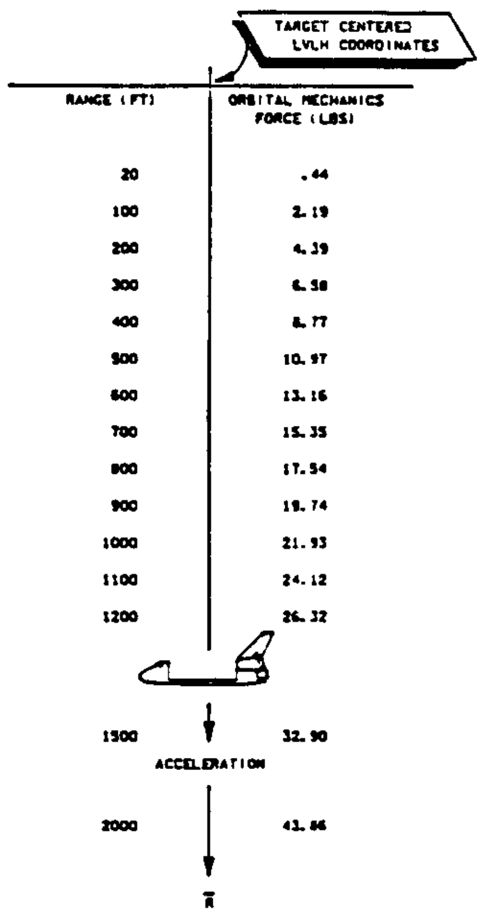


Figure 5-15.- Orbital mechanics forces during an R-BAR approach.

5.3.2 Final Approach Techniques

The selection of a final approach technique is greatly dependent upon the TGT sensitivity to Orbiter thruster plume impingement. Several techniques have been evaluated and shown to be operationally feasible. Each requires a different amount of ΔV to be nulled by thrusting in the direction of the TGT using one of the braking methods discussed above.

The approach techniques are illustrated in figure 5-16.

- Direct approach - used on rendezvous intercept trajectory with relatively large ΔV to be nulled (not typically used in the STS program).
- V-BAR approach - used for approach from ahead (+V-BAR) or behind (-V-BAR) with relatively small ΔV to be nulled.
- R-BAR approach - used for approach from above (-R-BAR) or below (+R-BAR) with theoretically zero ΔV to be nulled.
- Inertial approach - used for approach to an inertially stabilized TGT which is rotating relative to the LVLH reference frame.

Current analysis, simulations, and actual flight experience have led to the choice of V-BAR as the preferred approach technique. However, the flight procedures techniques associated with all these approaches are discussed in detail below.

5.3.2.1 Direct Approach

The direct approach can also be described as rendezvous intercept to a close-in stationkeeping position (fig. 5-17). The magnitude and direction of the intercept ΔV to be nulled are dictated by the maneuver targeting which produced an intercept trajectory. The intercept ΔV is gradually reduced by a series of braking thrusts that follow the low range/range rate profile as shown. Throughout the approach, the Orbiter is either in inertial (preferred) or LVLH attitude hold with the TGT centered in the COAS. The crew applies thrust normal to the LOS as needed to null off-nominal LOS rates. (Intercept targeting can be designed to produce either zero or ORB rate inertial LOS rates during the braking phase, although the advantage of the latter has never been demonstrated.) The radar would normally be used to determine range and LOS angle rate data.

The most efficient braking method would be the normal Z-axis mode since it provides maximum translation control authority. The low Z-axis mode can be used to significantly reduce PRCS plume effects on the TGT during the last few range/range rate gates; however, the substantial propellant consumption penalty must be considered in using this technique.

This technique has not been used since the Skylab program, when plume impingement concerns were much less than today (due to the small mass of the Apollo and the large size and mass of Skylab), and when the robust in-line docking mechanisms provided safety margins to closing rate dispersions.

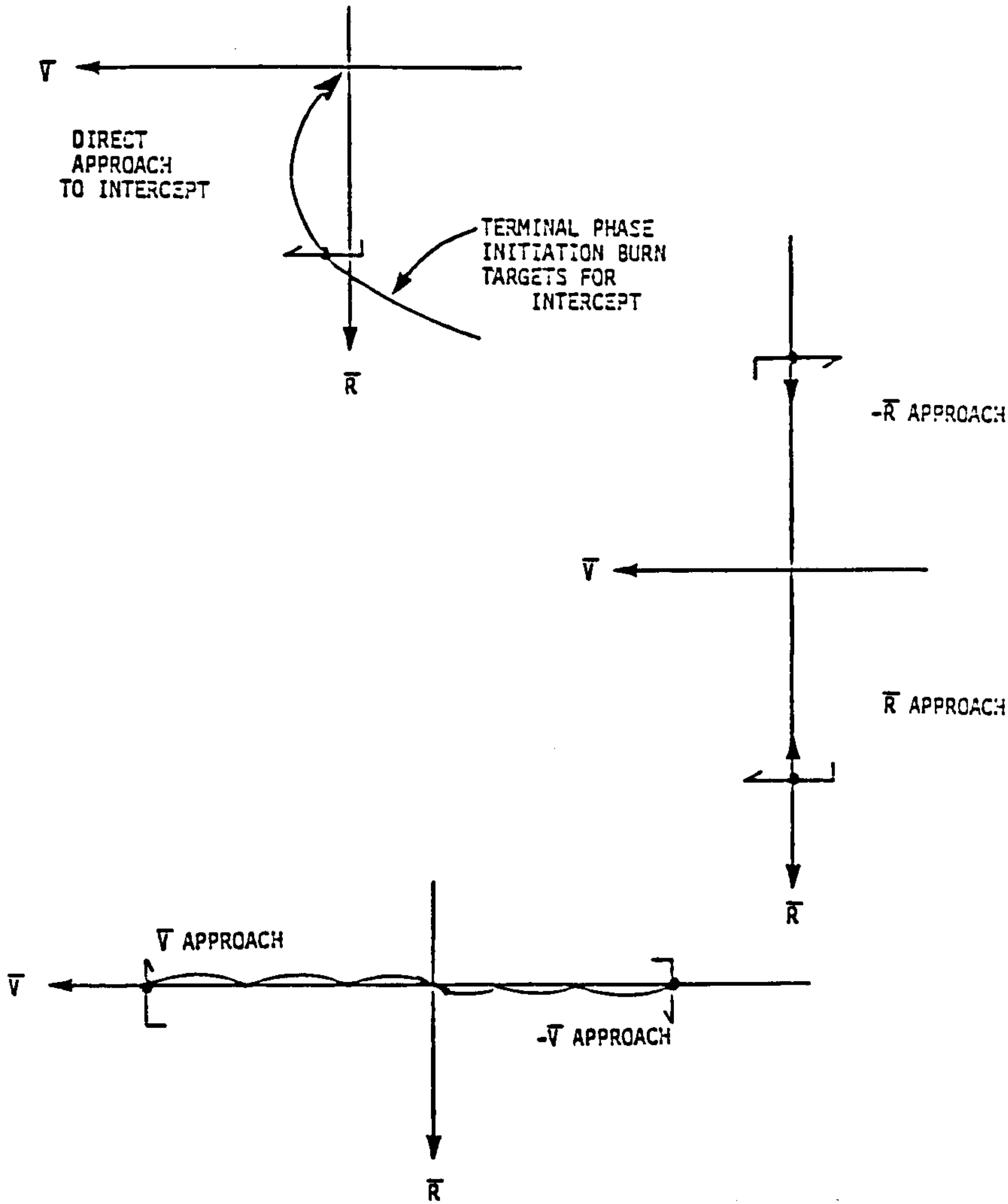


Figure 5-16.- Typical final approach techniques.

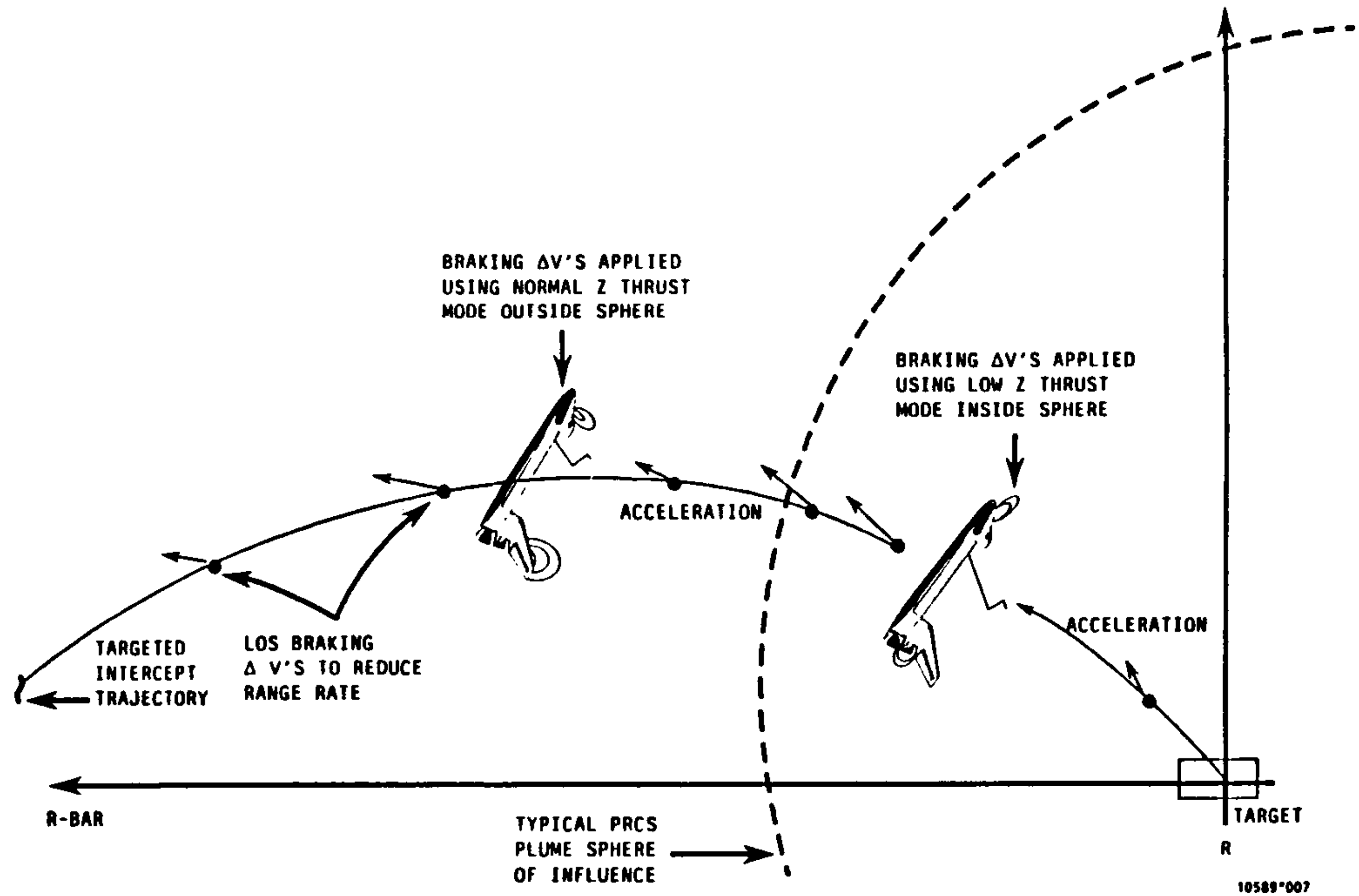


Figure 5-17.- Direct approach to close-in stationkeeping.

5.3.2.2 V-BAR Approach

The V-BAR approach technique assumes medium-range stationkeeping on V-BAR has been established ahead of the TGT (fig. 5-18); no -V-BAR (trailing the TGT) technique has ever been attractive. The approach is initiated with a ΔV directed toward the TGT (and with some +X from cross-coupling). Orbital mechanics effects (section 2.4.3.3) tend to slow the approach, making the Orbiter fall below the V-BAR and then reverse motion away from the TGT. Therefore, to maintain a closing rate for a +V-BAR approach, the crew must thrust up (normal to the TGT LOS) at each V-BAR crossing to maintain the Orbiter above the V-BAR axis. This then produces a series of trajectory hops until capture distance is achieved. The magnitude of the initial and intermediate ΔV's is a function of range and magnitude of the NLOS rates.

During the approach, the Orbiter attitude is being automatically pitched at orbit rate (using a -X to Earth attitude hold mode), with the X-, Z-body axis continuously aligned with the R-BAR and V-BAR axes, respectively. The crew monitors the TGT drift in the COAS (or CCTV aligned along -Z) and applies the X-axis translations as required.

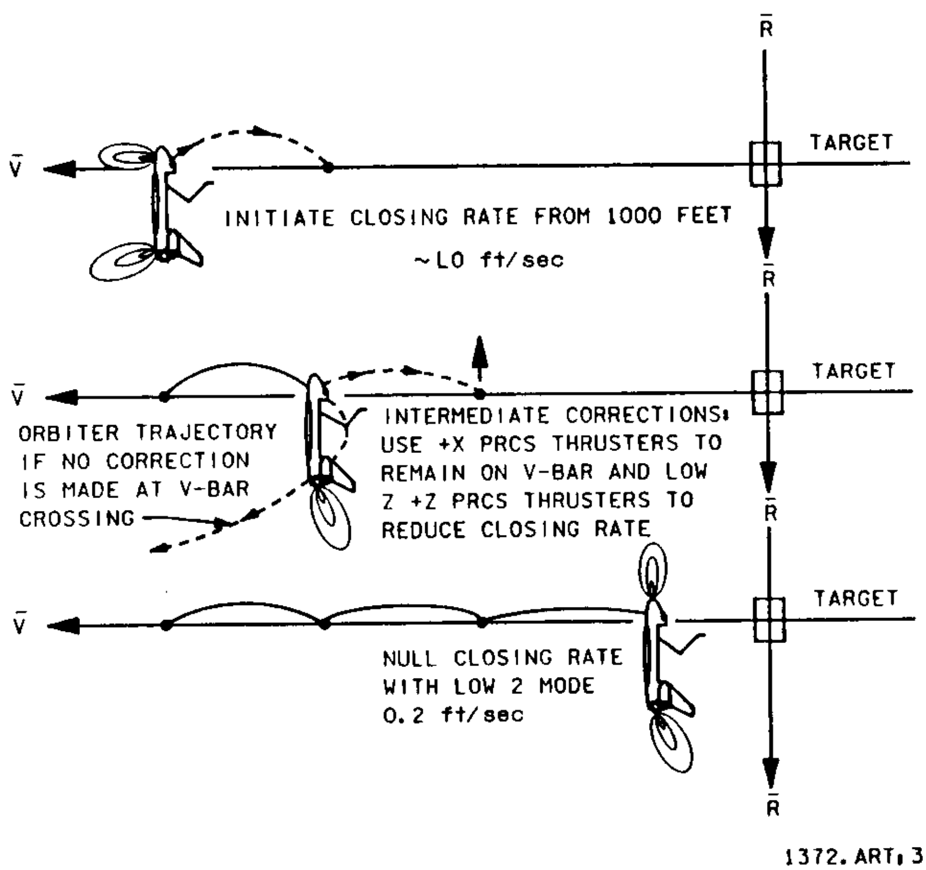


Figure 5-18.- V-BAR approach.

Predetermined braking gates will be used to null the closing rate (established to initiate the approach) prior to RMS grapple. This closing rate should be gradually nulled, with the NORM Z/low Z braking mode as required, to minimize PRCS plume effects on the TGT.

The +V-BAR approach procedures and rationale are described in detail at the end of the RNDZ in chapter 4, beginning at section 4.1.63 through section 4.1.71.

The +V-BAR approach is the preferred choice for a number of operational reasons. Current RNDZ methods schedule optical tracking so that V-BAR arrival occurs at noon. Also, +V-BAR arrival allows use of Orbiter attitude already held during manual phase RNDZ. For stationkeeping, +V-BAR also facilitates the quickest visual TGT acquisition at sunrise.

5.3.2.3 R-BAR Approach

The R-BAR approach utilizes both PRCS thruster cross-coupling and orbital mechanics effects to provide the braking force. This technique minimizes PRCS thrusting toward the TGT (practically zero). In practical application, however, the crew applies a series of small thrusts to "walk" up the radius vector (fig. 5-19). This piecemeal approach allows correction for errors made while initially determining and applying the proper closing rate.

The theoretical R-BAR technique requires the use of an analytically derived R-BAR approach profile chart (fig. 5-20), or handheld calculator program (currently nonexistent). Sample data has been plotted on the chart (dashed line) to show a typical approach where the initial closing rate at 1000 feet (R-DOT = 1.5 ft/s) was sized to take the Orbiter to 600 feet; the next correction applied at 670 feet (R-DOT = 1.0 ft/s) was sized to take the Orbiter to 400 feet; the next correction applied at 500 feet. (R-DOT = 0.7 ft/s) was sized to take the Orbiter to 300 feet, and so forth. Range and range rate measurements must, of necessity, be very accurate at short ranges; hence, radar data is recommended.

Because of the sensitivity of the R-BAR technique to range/range rate errors, a supplemental PRCS braking method may have to be used. If the R-DOT at the retrieval position exceeds the limit for RMS capture, the low Z axis braking mode is recommended to null R-DOT without producing direct PRCS plume impingement on the TGT.

This technique has not been operationally used to date. However, -R-BAR approach techniques have been developed in the SES for planned use during the LDEF retrieval mission and were documented in the original STS 51-D FDF.

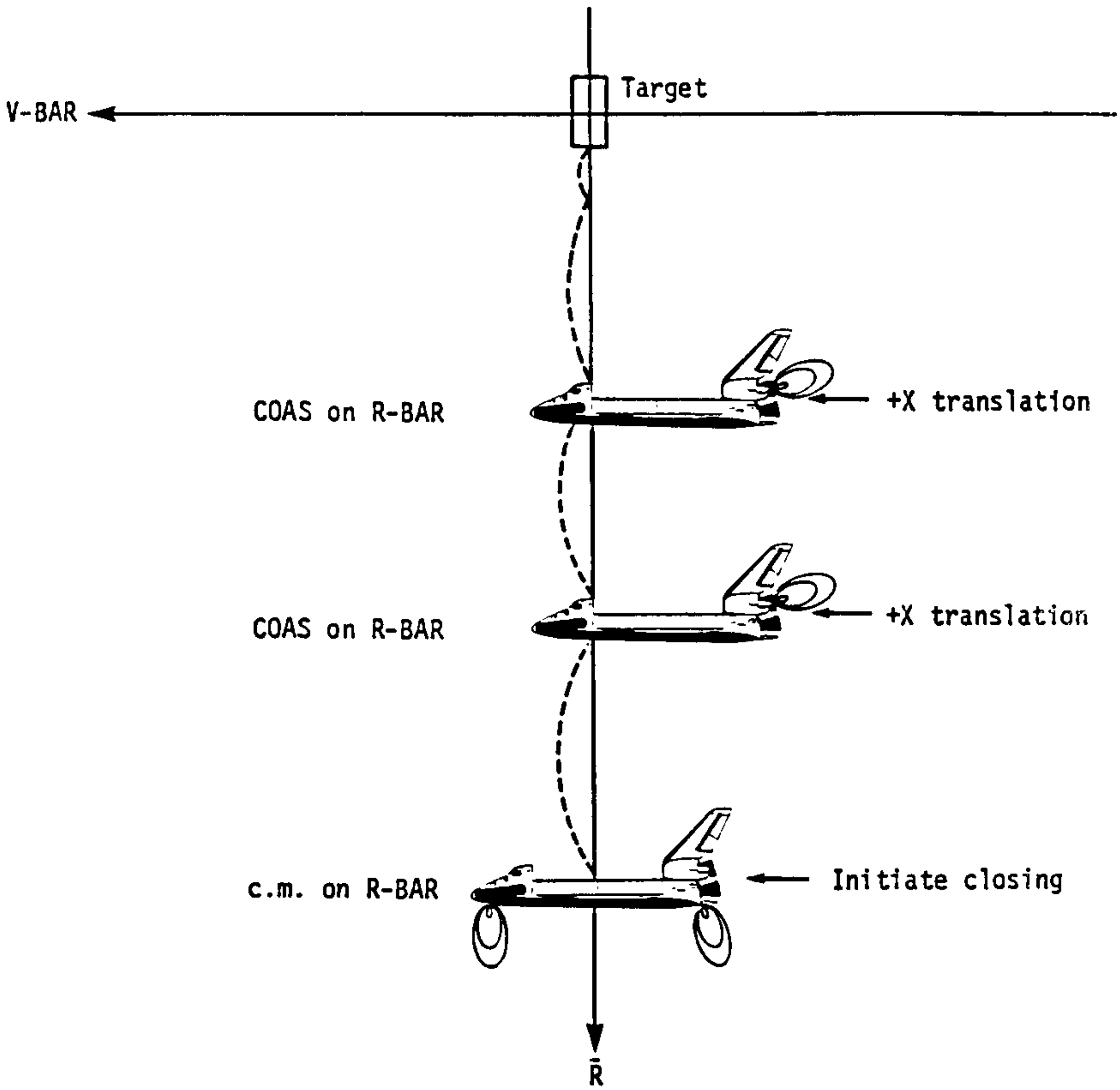


Figure 5-19.- Generic R-BAR approach technique.

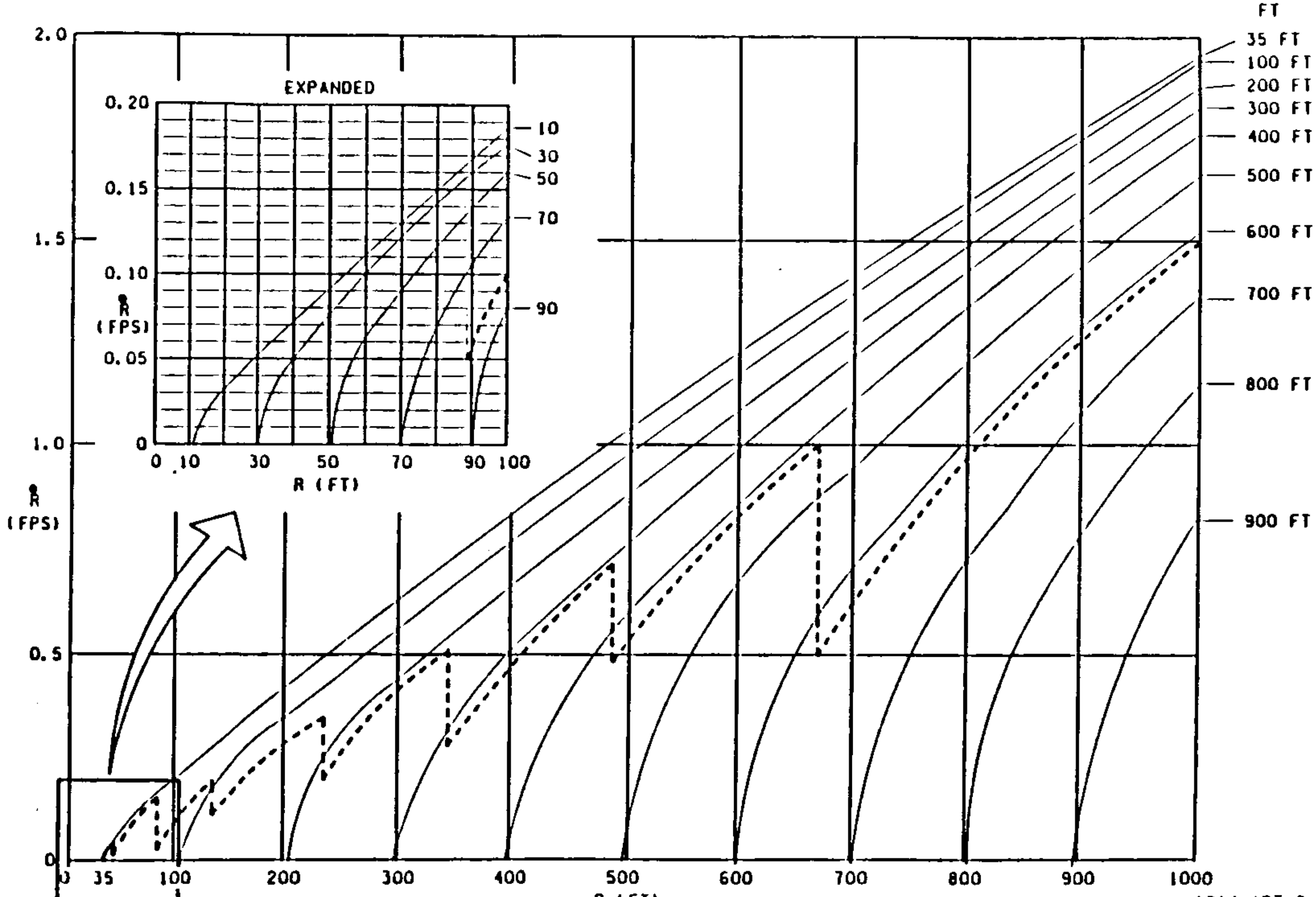


Figure 5-20.- Typical R-BAR approach profile.

Rendezvous and manual phase procedures are identical to those described in section 4, up through establishment of inertial LOS rates (section 4.1.61); braking gates are the same as those described in section 4.1.64.

Due to contamination concerns for LDEF, DAP low Z is selected at a range of 1000 ft.

The next stage is to configure for final approach, and this follows closely the standard "Reconfigure RR" (section 4.1.62), "Configure UNIV PTG for V-BAR" and "Configure DAP for PROX OPS" (section 4.1.66), with one exception. The BODY VECT ID on UP is selected as +3 (the -Z axis) if the -R-BAR approach is intended (otherwise it is +2, as usual).

The approach profile is illustrated in figure 5-21.

The "400 FT TRANSITION" occurs at R = 400 feet, which nominally occurs at the V-BAR crossing. The R-DOT is nulled while the Orbiter is in inertial hold, and an inertial flyaround begins as the THC is commanded as required to maintain TGT in top of COAS. The 90° flyaround should take about 22

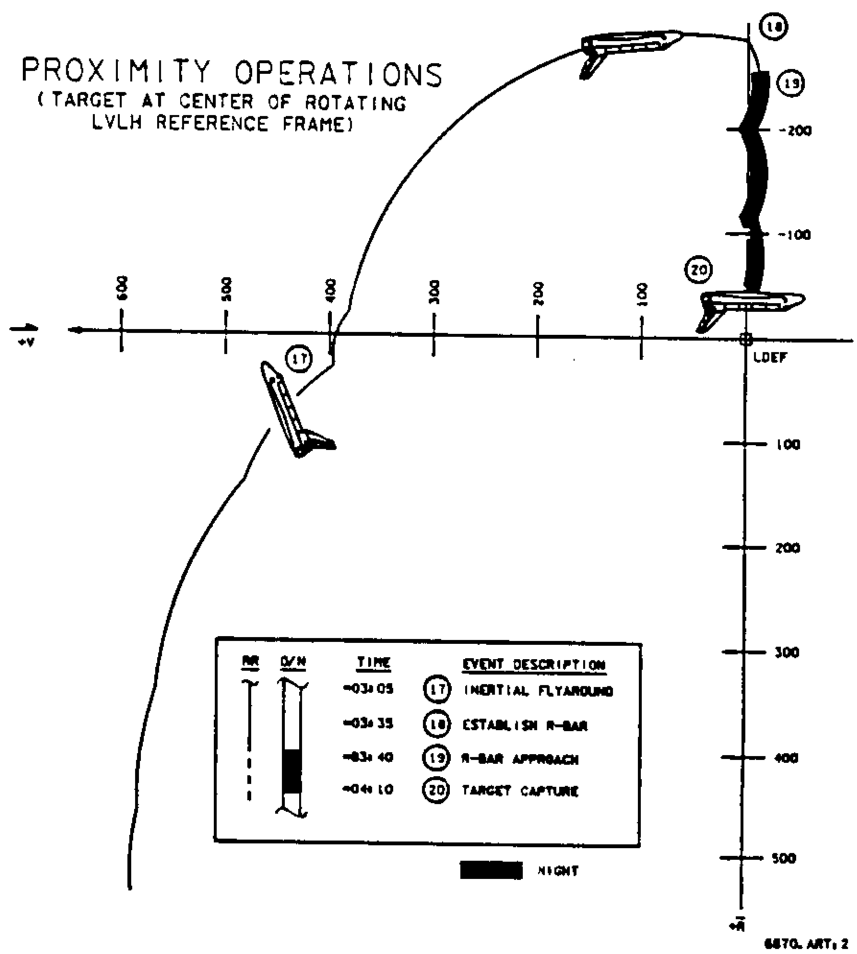


Figure 5-21.- LDEF R-BAR approach.

minutes and terminates with the Orbiter 350 feet directly above the TGT in bay-to-Earth tail-forward attitude, just prior to sunset. Cue is the ADI LVLH pitch = 270°.

The "ESTABLISH -R-BAR" block is shown in figure 5-22.

```
CRT   ✓UNIV PTG TOT ERR - small
A6U    DAP: A/AUTO/NORM
       THC -X (down) as reqd (-.1ft/s/100' R)
       THC - -Z (in) as reqd to null +RDOT
       Maintain TGT in lower half of COAS, R-DOT≤ 0
       DAP: B/AUTO/VERN, NORM as reqd
............IF YAW REQUIRED.................
.                                           .
.      | GNC UNIV PTG |                     .
.                                           .
.CRT   OM   + (reqd angle)                  .
.     ✓Tgt low in COAS                      .
.      TRK - ITEM 19 EXEC (CUR - *)         .
.      THC - as reqd to maintain TGT        .
.            in bottom of COAS              .
.                                           .
.      When yaw complete, continue with     .
.       INITIATE CLOSING RATE               .
.............................................
```

Figure 5-22.- ESTABLISH -R-BAR procedure.

At sunset, INITIATE CLOSING RATE is performed by using THC inputs to establish the required R-DOT (if at 400 feet, -0.4 ft/s; if at 300 feet, -0.3 ft/s; etc) and then as required to maintain the TGT in the lower half of the COAS. Low Z braking is performed as required through the last braking gate (at 200 feet, -0.2 ft/s). From 300 feet, approach should take about 20 minutes.

When RR breaks lock, perform CONFIGURE KU-BAND FOR COMM exactly as in section 4.1.69.

When TGT is in EE camera, then perform THC +Z to null rates (as in section 4.1.71). Perform RMS capture (as in section 4.1.73) and DISABLE RNDZ NAV (as in section 4.1.74).

Once the TGT is grappled (about at sunrise), adjust attitude as follows with maneuver to -ZLV, -XVV, as shown in figure 5-23 checklist.

	When LOEF in HOVER position: BRAKES - ON.
CDR	MNVR TO -ZLV,-XVV
	Config DAP B to B8
	GNC UNIV PTG
CRT	✓TGT ID +2
	✓BODY VECT +3 (-Z)
	OM +0
	TRK - ITEM 19 EXEC (CUR - •)
A6U	DAP: B/AUTO/VERN
	When attitude MNVR complete,
CDR	✓DAP ROT: PULSE/PULSE/PULSE
	DAP: B/MAN/VERN
MS1	LDEF BERTH

Figure 5-23.- Post-grapple maneuvers

5.3.2.4 Inertial Approach

The inertial approach technique is required for payloads which are inertially stabilized in at least two axes. The technique breaks down into two phases: a constant range flyaround to the appropriate payload approach axis and the final approach to RMS grapple range. The two phases could be combined.

The flyaround phase is performed at some range (such as 35 feet) close enough to allow CCTV ranging and to keep the target in the plume shadow (minimizing plume effects). Two types of flyaround techniques are utilized, depending on whether the target attitude, relative to the Orbiter reference frame, is known or not. If the TGT attitude is known, the multiaxis Auto rotation maneuver flyaround technique, described in section 5.2.3.2, would be used. If the TGT attitude is unknown, one of the manual rotation maneuver techniques, described in section 5.2.3 would be used. The multiaxis rotation maneuver technique is obviously the more efficient, as it rotates the Orbiter about the optimum axis (eigenaxis), thereby minimizing the translation corrections required to achieve the payload final approach axis. Manual rates up to 0.2 to 0.3 deg/s are utilized.

Upon arrival on the target final approach axis, the final approach phase begins. The Orbiter is maintained in inertial attitude hold and a closing rate of about 0.2 ft/s is initiated toward the target. During the approach, NLOS rates, as detected in the COAS, are nulled by THC deflections. Upon arrival at the desired grapple range, all relative rates are nulled and capture operations commence.

5.4 SEPARATION

Separation is a PROX OPS task involving the execution of a translation maneuver or sequence of translation maneuvers, which result in an opening (separation) rate between two orbiting satellites. Either or both of the satellites may take an active role in performing these maneuvers. Since one of the two satellites is usually a PL, originally located (berthed) in the Orbiter PL bay, the term "PL" is normally used (vs. TGT) in separation techniques discussions.

The separation problem differs significantly from other phases of PROX OPS. These differences can be summarized as items which either simplify (advantage) or complicate (disadvantage) this task relative to the other PROX OPS tasks.

In some cases, only appendages of a PL are to be jettisoned so that the main body can be returned to Earth. Since the PL may still be on the RMS, the Orbiter would not be able to perform an active separation maneuver. However, the Orbiter would prefer to perform an attitude maneuver such that the appendages would separate in the most advantageous direction to avoid both near-term and long-term recontact. Here, preflight analysis of relative drag characteristics and jettison ΔV is crucial.

<u>Advantages</u>:

- The problem begins with a well known REL SV.
- Orbiter burns and attitude maneuvers can be expected to follow a canned sequence, making propellant consumption predictable.
- Confidence in the separation trajectory reduces crew monitoring requirements. (Dispersions have not yet had a chance to build up.)

<u>Disadvantages</u>:

- Many PL's have tight deploy attitude and rate error requirements.
- Some PL's have upper stage boosters which pose a potential hazard to the Orbiter.
- For RMS deployed PL's, checkout may not be completed until after deploy, requiring an Orbiter recapture capability, sometimes for several hours or days. This may require contingency RNDZ planning.

- There may be relatively low confidence in PL control system characteristics.

A review of these points indicates that flying the Orbiter is a simpler task for separation than it is for the other PROX OPS tasks. On the other hand, the frequency of deploy missions versus retrieval missions points out the importance of an efficient solution to the separation problem.

In the design of a separation sequence, many factors must be considered, but five general concerns stand out:

- Orbiter/PL (or appendage) recontact, both short term and long term.
- Crew visibility of the PL.
- Orbiter plume impingement on the PL, both RCS and OMS.
- PL plume impingement on the Orbiter, particularly for PL's on an upper stage such as the PAM or IUS.
- Crew safety relative to hazardous PL control system performance.

For many PL's, these may be somewhat contradictory and require a relative weighing on a case by case basis.

5.4.1 Nominal

PL's may be nominally deployed by spring ejection or RMS release.

5.4.1.1 Spring Ejection (PAM)

Since most deployments involve spring ejection, this clearly calls for a simple, standardized, efficient separation sequence which minimizes training requirements. This will result in a sequence which may not necessarily be optimized for a specific mission, but will reduce mission preparation effort.

For payload assist modules (PAM-D's) deployment, there are two important booster characteristics which drive separation sequence design. First, attitude control is accomplished solely by spinning the upper stage at a high rate, e.g., 50 rpm. This fixes the Orbiter attitude at deployment in two axes, leaving the third free to rotate about the deploy LOS. Second, this is a solid rocket booster, which for the PAM-D has a built-in 45-minute "fuse" which cannot be safed postdeploy.

To further constrain the deploy situation, in general the PAM-D will burn very nearly posigrade, with an out-of-plane component determined by PL weight and orbital inclination. Thus, 45 minutes (1/2 rev) earlier, the PAM-D must usually be ejected retrograde, as indicated in figure 5-24.

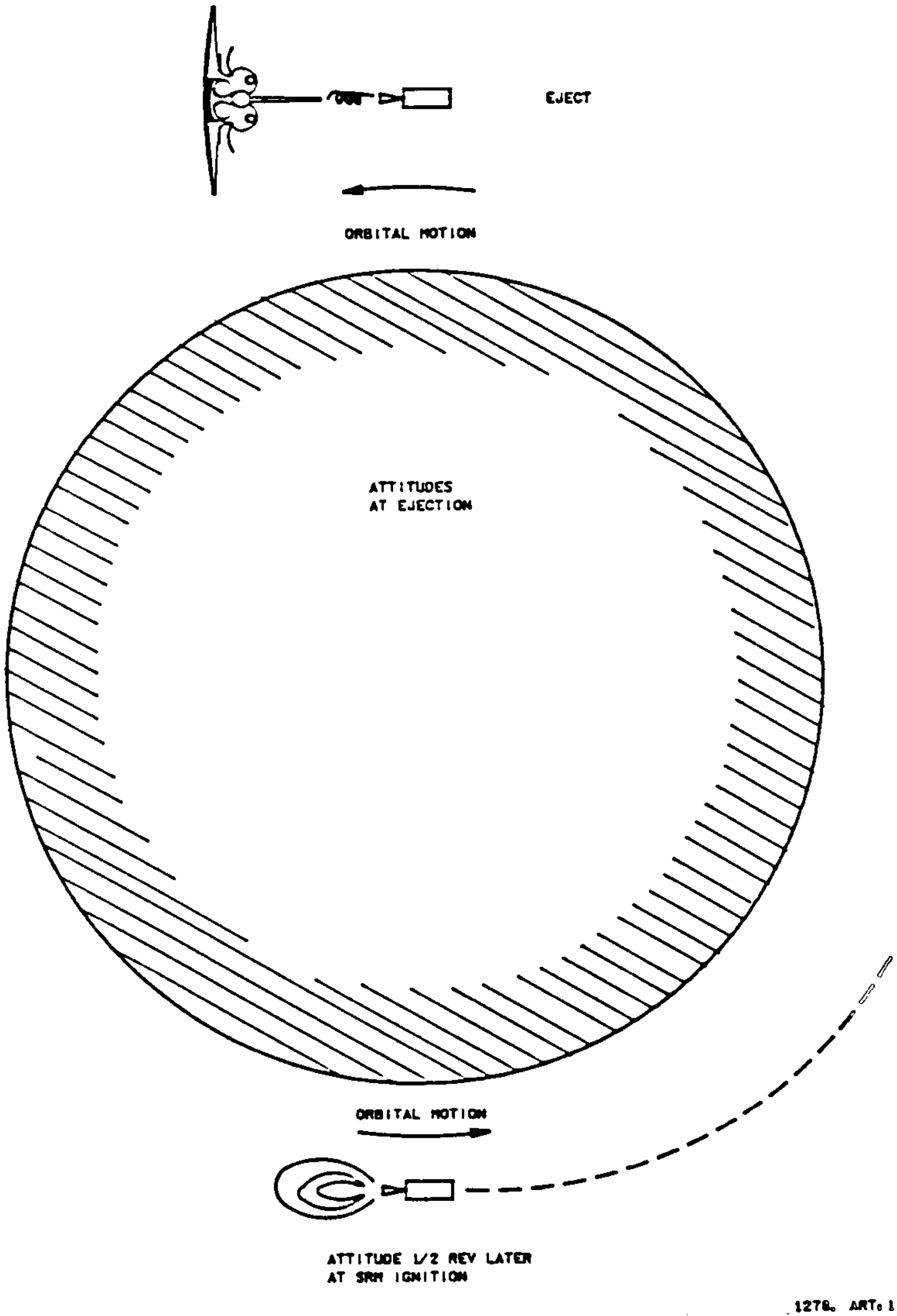


Figure 5-24.- PAM/Orbiter ejection attitude.

The ejection velocity is on the order of 2.4 to 2.8 ft/s (1.5 to 2.0 ft/s for PAM-D-II's), resulting in a relative motion trajectory as shown in figure 5-25 with the coordinate system rotating at ORB rate and centered on the PL. From the figure it can been seen that in 1/2 REV, at SRM ignition, the Orbiter will be above and behind the PAM-D. Given this initial data, analysis was conducted to determine what Orbiter separation was required to ensure a lifetime TPS erosion of < 10 percent based on design lifetime of 100 STS missions. (This number is based on MDTSCO Design Note No. 1.4-3-016.) Using a manifest which at that time indicated a total of 135 upper-stage firings over the first 100 STS flights, a criteria of 0.074 percent erosion per flight was established. If no additional ΔV is added by the Orbiter, the separation resulting from the spring ejection alone will result in a plume impingement on the Orbiter TPS of about eight times the accepted level. Although this is not a safety problem for one flight, it is clear that in general an Orbiter burn is required to increase separation distance.

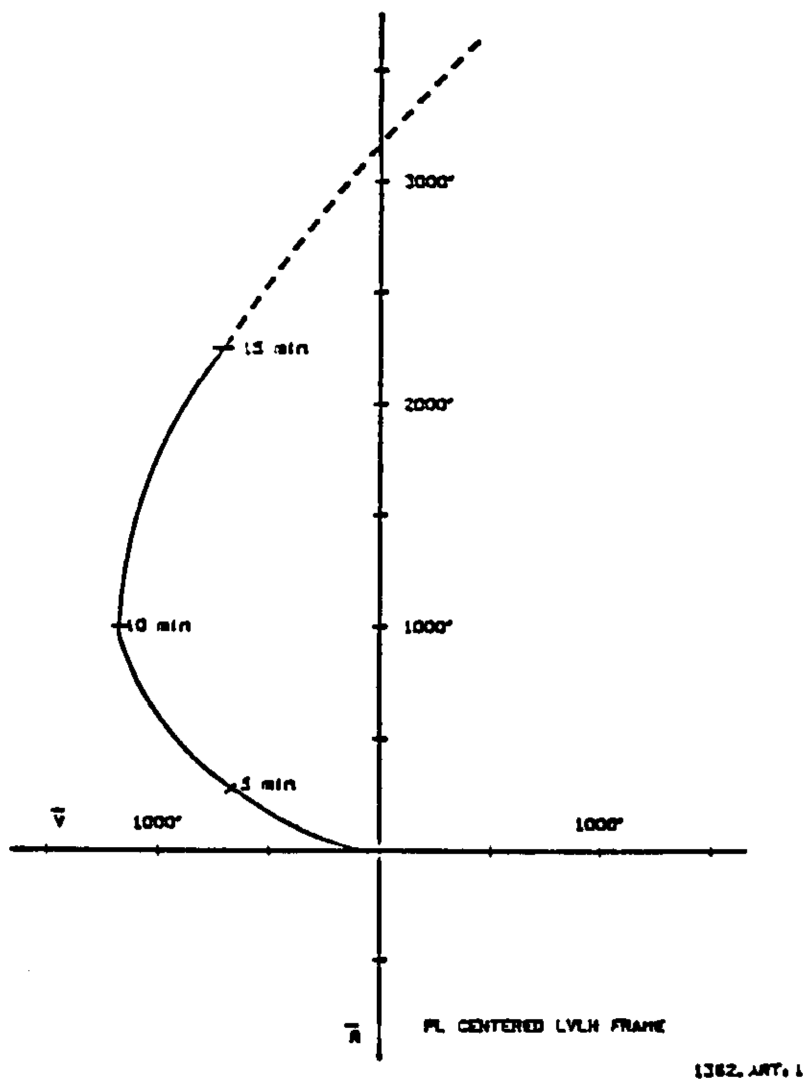


Figure 5-25.- Orbiter/PAM-D separation trajectory (due to ejection ΔV only).

To achieve maximum separation at SRM ignition, the Orbiter OMS burn should be scheduled as early as possible after deploy, although about 10 minutes are required to get ready for the burn. Estimating then that SRM ignition will occur about 35 minutes after the OMS burn, it can be shown that the plume impingement on the Orbiter can be minimized if the upper stage thrust vector is about 15° above posigrade. With this choice made, it is then possible to determine a time for the OMS burn, based on acceptable Orbiter plume impingement on the TGT. If the burn is delayed until deploy +15 minutes, the plume overpressure on the PL will be < 10^{-4} lb/ft^2, which was chosen as an acceptable level (fig. 5-26). Coincidentally, due to the 16° cant of the OMS engines, which places the thrust vector through the Orbiter c.g., it is possible to do the burn in -ZLV, wings level. This allows for a convenient manual "out the window" backup burn.

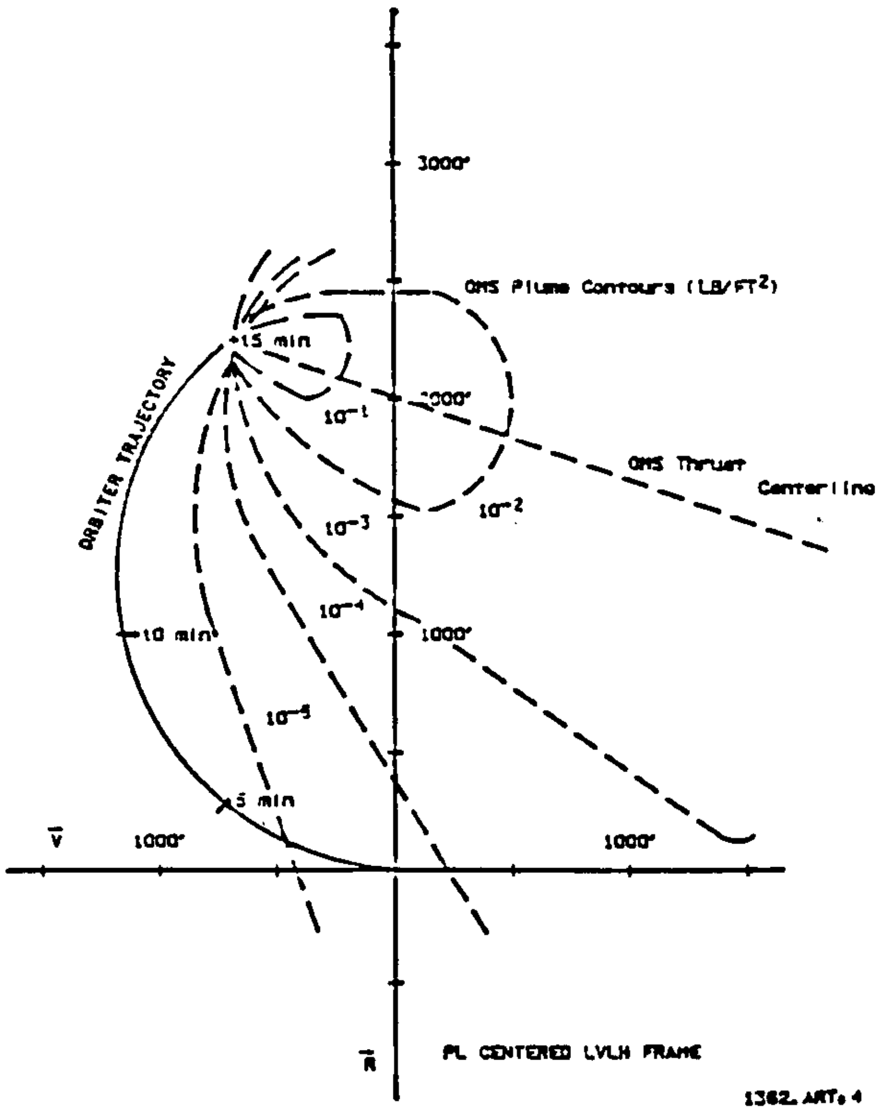


Figure 5-26.- OMS plume on PAM-D at SEP burn initiate.

Continuing to work backwards to deploy, we can now constrain the third Orbiter degree of freedom to minimize the maneuver to the OMS burn attitude, resulting in a -XLV deploy attitude. However, since the PAM-D must be ejected near orbit noon (or midnight) to meet thermal constraints, this may, for some beta angles, violate the groundrule of no Sun within ±20° of the PL LOS during deploy and SEP. To solve this problem, the Orbiter is rotated such that the X-axis is out of plane at deploy, as shown in figure 5-27.

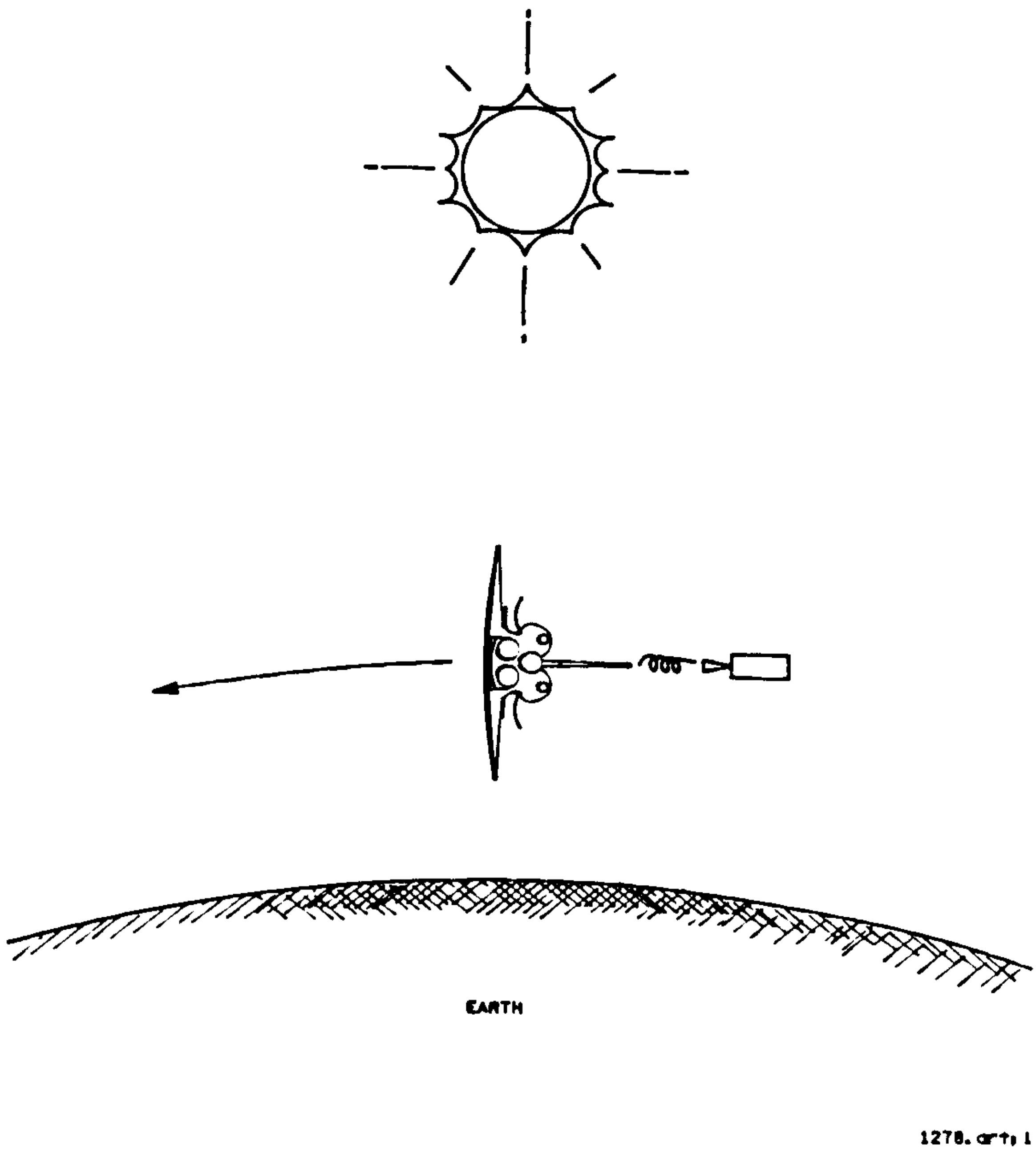


Figure 5-27.- Orbiter attitude at PAM ejection.

It should also be pointed out that this entire sequence was designed around the requirement for direct crew visual acquisition of the PL until completion of the OMS burn, and the track of the PL through the overhead window is shown in figure 5-28.

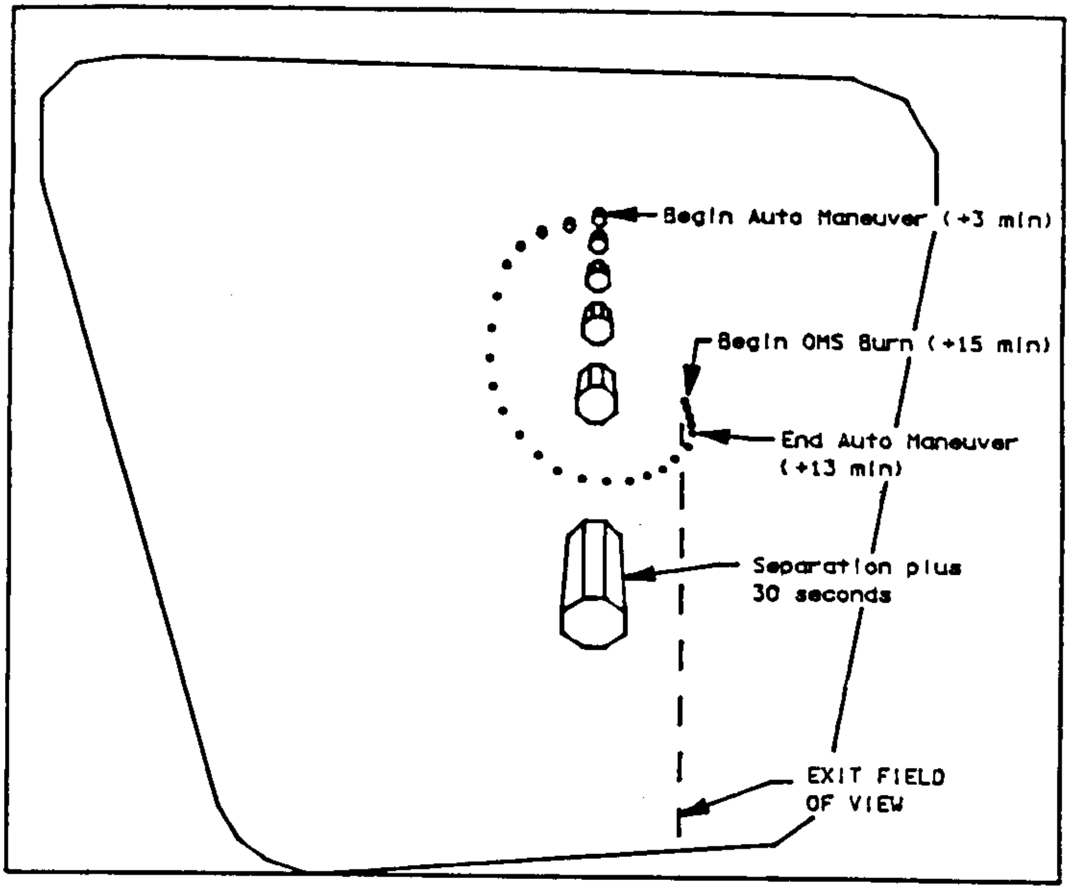


Figure 5-28.- View of PAM-D SEP from aft station through overhead window (PL shown every 30 sec).

The final issue is the Orbiter protection attitude to be maintained during the PAM-D SRM firing. Tile damage is minimized by placing the PL LOS at an angle to the Orbiter belly, as shown in figure 5-29. This attitude is maintained inertially for about 6 minutes after SRM ignition to allow the Orbiter to pass through the flow field. Current planning places the Orbiter at an angle of 50° to the PL LOS. The orientation is maintained through use of REL NAV functions.

Separation sequences are described in detail in the "Payload Assist Module Delta Class (PAM-D) Flight Procedures Handbook," JSC-20315, Final, May 15, 1985.

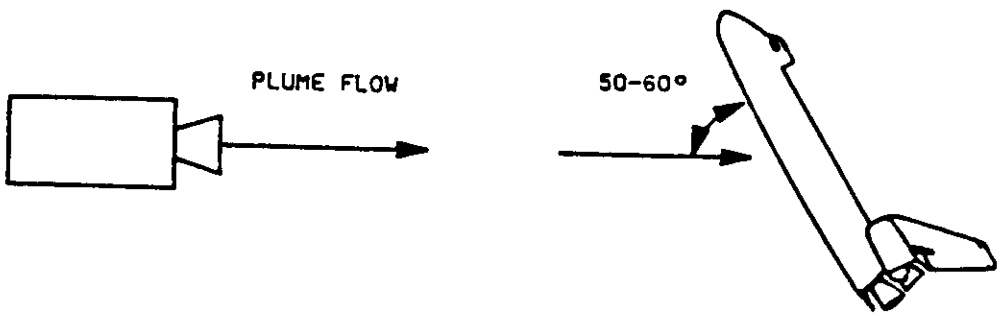


Figure 5-29.- Orbiter window protection attitude at SRM ignition.

5.4.1.2 Spring Ejection (IUS)

The IUS class of spring ejected payloads presents a different kind of problem from the PAM. Standardization is equally important, and two generic deploy sequences have been designed; they are called "ascending node solid rocket motor (SRM)" and "descending node SRM". The IUS has an active attitude control system (ACS), which allows greater flexibility for Orbiter attitude at ejection. The IUS/PL is spring ejected at 0.4 ft/s, at an angle of 58° above the Orbiter +X axis, with the Orbiter holding a solar track attitude via a selectable body vector that places the Sun on the belly of the Orbiter. This allows the IUS/PL to depart along the Orbiter shadow (until soon after the -X burn). Thus, the IUS/PL deploy vector has a marked out-of-plane component. The small Orbiter separation burn also has a large out-of-plane component. In fact, the Orbiter attitude at deploy is such that the relative motion between the IUS/PL and the Orbiter after the backoff maneuver is purely out of plane (the IUS/PL departs horizontally to one side of the V-BAR, while the Orbiter departs horizontally to the other side). These characteristics require that the Orbiter will have to be more active during IUS separation than during PAM separation.

Both ascending node and descending node SRM sequences have similar separation profiles. Deploy occurs with DAP in free drift and low Z mode. There is a 1-minute coast following ejection, followed by a 2.2 ft/s -X RCS burn (8 seconds on THC), still in free drift. Cross-coupling provides a negative pitch rate (0.8 deg/s), and the crew nulls this rate when the Orbiter has pitched down 70° by selecting inertial attitude hold (DAP ROT: DISC/DISC/DISC). This places the IUS line of sight out the overhead windows. The solar tracking option on UP is canceled (ITEM 21 EXEC). To minimize RCS contamination on the PL, the Orbiter stays in low Z mode and delays maneuver to the OMS burn attitude until deploy + 8:00 minutes. This attitude is computed so that a line of sight exists between the IUS and the Orbiter payload interrogator (PI) antenna for postdeploy commanding (including SV transfers) and telemetry.

The OMS burn is computed considering both Orbiter/PL separation at SRM ignition and also subsequent orbit management (e.g., deorbit burn requirements and cross-range for landing). This specialized planning is done because the size of the OMS burn for the IUS is greater than for a PAM deploy (a larger separation is needed since the IUS SRM is larger than the PAM SRM). In general the burn for ascending injections will be about 38 ft/s pitched down 20° from local horizontal, and for descending injections it will be about 30 ft/s pitched down 5°. No low Z is selected just prior to entering the OMS 2/ORBIT OMS BURN cue card.

Following the OMS burn the Orbiter maneuvers to a payload viewing attitude which tracks the IUS with the Orbiter -Z axis (the maneuver is performed in NORM jets). Loss of IUS/PI lock occurs about +32:00. At deploy + 39:00 the Orbiter maneuvers (in NORM) to window-protect attitude, which is identical to that of the PAM attitude described above, and maintains attitude for at least 6 to 10 minutes after SRM TIG. The minimum safe range for SRM ignition is 10 n. mi.; after nominal separation and 55 minutes, range is 25.1 n. mi., and after 67 minutes range is 51.6 n. mi.

Note that rendezvous navigation (SPEC 33) is utilized for Orbiter pointing after the separation maneuver. RNDZ NAV is enabled about 30 minutes prior to deploy, after MCC (FDO) has uplinked a target state vector. About 5 minutes before deploy, the crew must perform an ORB to TGT SV transfer (SPEC 33, ITEM 10 EXEC) to refresh the target SV. The IUS spring separation ΔV is not represented in this SV but is small enough to ignore due to its being lost in the noise of the large OMS separation burn. This attitude pointing is required to maintain PI lock for data exchange between IUS and Orbiter. Target track also simplifies maneuvering to window protect attitude, by simply selecting body vector = 5 (Orbiter defined pitch/yaw) and loading P = 310, Y = 0, OM = 0.

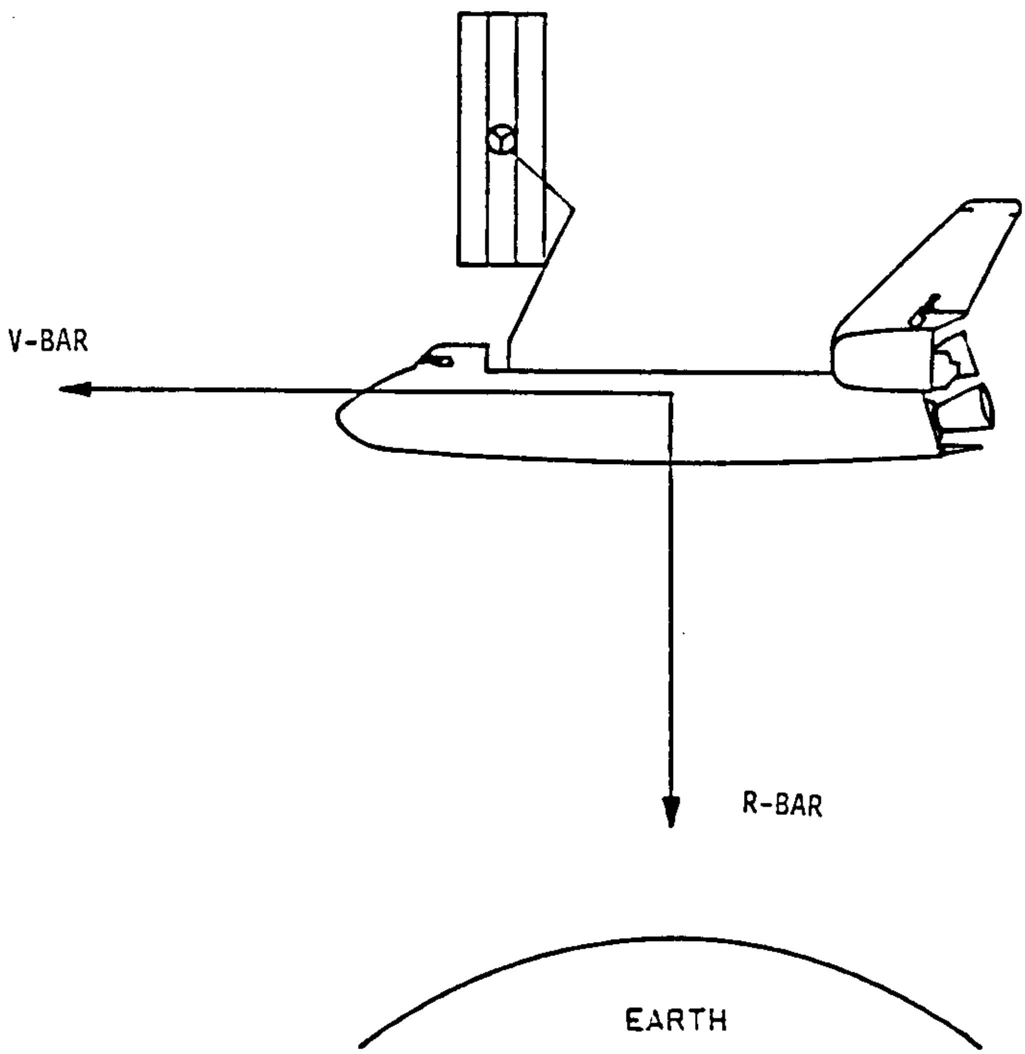
IUS SRM ignition occurs over the Equator for equatorial geosynchronous missions (interplanetary missions will not be so constrained). For the ascending node option, SRM ignition is 67 minutes after deploy, and for descending node it is 55 minutes after deploy. These times are set in order to maintain Orbiter perigee in the northern hemisphere following the OMS burn scheduled at deploy + 19 minutes. However, if there are to be significant postdeploy maneuvers which affect perigee, this consideration loses weight. For many new payloads, these considerations are also not significant and the TIG may follow deploy by anywhere between 55 and 67 minutes. A future standardized TIG of +60 minutes is under consideration.

IUS guidance can actually accommodate an off-nominal deploy at any point in the orbit. In this contingency, the IUS knows to delay ignition until the next opportunity.

For IUS deploy procedures detailed rationale, see "IUS Flight Procedures Handbook", Basic, Rev B, March 1985, JSC-18392, sections 3.4.3 ("Deploy IUS/TDRS") and 3.4.5 ("Postdeploy Separation Maneuver"), and "Inertial Upper Stage Deploy Procedures for Flight Dynamics Officers", IUS PROC 2142, Rev B, January 24, 1986. The foregoing discussion only summarizes the procedures and rationales.

5.4.1.3 RMS Deploy - Generic

PL's deployed by the RMS will typically be unique, with specific requirements that must be handled on a case-by-case basis. However, for many PL's it is anticipated that an R-BAR separation will be optimal because of low plume impingement on the PL because of utilization of orbital mechanics effects. In this scheme, the Orbiter begins in a ZLV attitude, above or below the PL depending upon relative drag and/or mission continuation requirements. Assuming for the moment that these constraints place the Orbiter below the PL, we have the relative geometry shown in figure 5-30. This selection criterion is usually required payload attitude.



1277.ART, 2

Figure 5-30.- Typical RMS deploy geometry (Orbiter below PL).

At the time of PL release, a small opening rate will begin to develop, strictly due to the differential orbit altitude. However, this opening rate is so small that it is not practical, in the general case, to depend solely on it. So while the PL is in the "quiet zone," a small opening rate is added using low Z, of <0.5 ft/s. This will tend to force the Orbiter down, and because of orbital mechanics, in front of the PL (fig. 5-31).

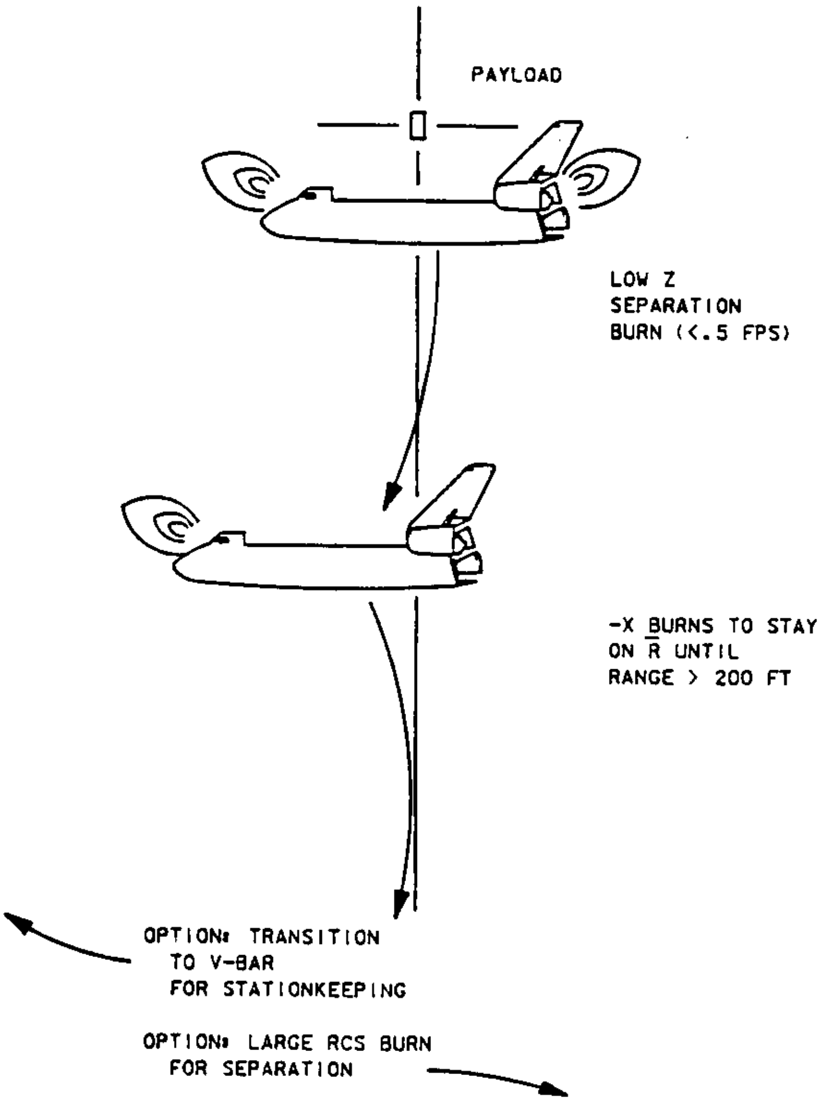


Figure 5-31.- Orbiter separation following RMS deploy (PL-centered LVLH frame of reference).

However, since it is a radial burn, with no other forces acting on the system, recontact would occur in one REV. So until a separation of about 200 feet, retrograde MNVR's are performed as required to keep the Orbiter on the R-BAR. This has the effect of lowering the Orbiter orbit and increasing the opening rate. Then as the Orbiter drifts below and in front of the PL, an option is available. If required, the Orbiter may transition up to the V-BAR and stationkeep during PL checkout. Or a larger separation MNVR with the RCS may be performed, providing a large opening rate and removing the requirement for crew monitoring of the PL.

It can be seen that in this sequence no thrusters are ever fired directly at the PL, reducing plume overpressure and contamination to a minimum.

For a PL which is not plume sensitive at all, it is likely that starting with the Orbiter on the PL V-BAR will be very fuel efficient. In this case, no radial burns are required, and maximum separation can be achieved in an efficient Hohmann fashion.

Many other separation profiles have been proposed, both for the general case and for specific PL's. Due to lack of definition and/or general application, these will be discussed as needed in supplemental documentation.

5.4.1.4 RMS Deploy (SPARTAN-class)

Separation profiles for SPARTAN-type payloads must be individually crafted due to highly variable mission-specific factors. These include payload pointing requirements, grapple fixture locations, and crew constraints on the variety of nominal versus contingency deploy profiles and RMS procedures.

Although the first SPARTAN mission was 51-G, that profile should not be considered a model for later profiles. The 51-L profile would be a much better guide to design such a profile, and the following discussion is based on that mission.

Configuration of aft station for deploy is essentially identical to configuration for rendezvous (fig. 4-4) except that on the SM ANTENNA SPEC following self-test, the "RDR RNG MIN" is selected (ITEM 2), and the -Z COAS and various cue cards are not installed. DPS configuration is also identical (section 6.1.1).

RMS operations to power up, to grapple, and to unlatch, unberth, and maneuver the payload are standardized; see the 51-L SPARTAN book.

Rendezvous navigation is enabled similar to that for rendezvous (section 4.1.6), but with several distinct differences. First, RR is the selected sensor (ITEM 13). Second, an ORB to TGT SV transfer is performed (ITEM 10 EXEC) since the starting point is known.

The Orbiter is maneuvered to release attitude about 45 minutes predeploy. For 51-L the attitude was approximately belly forward, left wing down, nose left of orbit motion.

After release, the Orbiter stationkeeps for about 10 minutes to observe the SPARTAN maneuvers which signify proper payload functioning. If there are no maneuvers, the SPARTAN is retrieved and berthed.

The separation burn is performed "no low Z," 2.0 ft/s +Z, 5 seconds on the THC (out). Low Z is then selected. This is a posigrade burn along the V-BAR.

Following separation, radar acquisition is performed after about 3 minutes. If there is no lock-on within 2 more minutes, the crew performs the "AUTO TRACK ACQ" cue card (section 4.3.2). If the RR fails, the crew waits until the scheduled STRK ACQ block, and performs S TRK NAV.

RR navigation during separation is similar to that performed for the first radar acquisition in rendezvous, section 4.1.31 and figure 4-8, with the following modifications. COVAR REINIT (ITEM 16 EXEC) is immediately performed, since this is the first navigation processing. Since SV SEL initially is PROP, the optional block is performed and SV SEL becomes FLTR. Following that, on the SM ANTENNA display the RDR RNG AUTO is selected (ITEM 1), replacing the previously selected RDR RNG MIN. Since there was no previous S TRK, the "RATIO > 1.0" test fails through to the second test, with "Force 3 marks" being the only corrective action taken. Once NAV data is being accepted, the Orbiter goes to -Z axis target track with OM = +180.

The separation profile looks very much like figure 5-48, with the Orbiter moving forward and higher, then curving back and passing about 2000 feet above the payload at about 19 minutes after separation.

Approximately one REV after deploy, STRK acquisition is performed. In general this procedure is similar to the rendezvous S TRK TARGET ACQ procedure discussed in section 3.3.2.1 (fig. 3-13), with several significant differences as follows. Once a star present is detected, angles (currently in "accept" for RR data) must be inhibited (ITEM 12 EXEC), and the STRK must be selected (ITEM 12 EXEC). Currently, the FLTR SV is selected. Once STRK marks are accepted, the FLTR SV (which has been validated through the accomplishment of a successful STRK lock-on) is saved away in PROP (the same thing is done, for the same reasons, after the second STRK acquisition during nominal rendezvous operations -- see section 4.1.22). If there is no STRK acquisition after 5 minutes, the crew goes to contingency procedure for "S TRK TARGET ACQ - RR FAIL."

After about 2 hours the separation sequence terminates. Rendezvous navigation is disabled much as in section 4.1.74, with some additions: the UP tracking is canceled (ITEM 21 on UP), and IMU DES on GNC 21 IMU ALIGN is performed via ITEM 7 (8,9), (no*); i.e., the deselected IMU is reselected. Finally, Ku-band is configured for COMM (same as section 4.1.69). The specialized rendezvous book is exited until the retrieval rendezvous begins approximately 36 hours later.

5.4.1.5 RMS Deploy (HST Class)

Some payloads are large and heavy and have very stringent contamination constraints during deployment. Examples are the LDEF and the HST (also the SMM and ERBS). The following separation profile is a generic description based on HST preliminary procedures.

There are two burns planned for HST separation, labeled SEP 1 and SEP 2. Deploy pads are prepared for both: SEP 1 is preplanned and the only real-time specified data is TIG; SEP 2 is a second RCS burn which requires TIG plus updated data on TV roll, vehicle weight, plus PEG 7 ΔV's. An IMU DES (deselect) is also specified in anticipation of an STRK pass.

Deploy attitude for HST will be biased +X solar inertial, and deployment occurs near orbit noon. The result will be an approximately belly-forward tail-down Orbiter attitude (-XLV,YPOP), but with the +Z axis somewhat to the left or right of the V-BAR depending on beta angle.

Release accuracy for LDEF and SMM was required to be within 0.01 deg/s of desired rates. For all large payloads (HST included), free drift is maintained for 60 to 120 seconds prior to release, in an effort to minimize attitude rates on the payload following release.

SEP 1 is a 0.5 ft/s low Z mode posigrade burn for LDEF, SMM, and HST. SEP 2 is performed approximately one quarter REV later, when the Orbiter is about 600 feet above the HST on the R-BAR, and is 1 ft/s posigrade NORM Z mode from the -X RCS. A standard RMS powerdown procedure follows the SEP 2 burn.

Alternate candidate separation profiles include a sunrise deploy down the +R-BAR (see the SPAS profile, STS-7), with low Z mode 0.25 ft/s RCS followed by -X firings to maintain position on R-BAR until a range of several hundred feet. At a range of 500 feet a +X burn may be performed to accomplish final separation (other variations are also under consideration). These options are driven almost entirely by payload requirements.

For HST/LDEF/SMM, RR acquisition and navigation are performed similar to Spartan-class deploys. Target track is established with the Orbiter -Z axis. Approximately one REV after deploy, for HST an STRK pass is performed as on the SPARTAN-class deploy missions. At 2 hours into the deploy, rendezvous NAV is terminated and the Ku-band is reconfigured for COMM mode.

5.4.2 Generic Sep Procedure

An all-purpose separation procedure (the "1-2-3 maneuver") has been developed and validated for generic use. Possible applications include PL deploy, postrepair/inspection departure, and some types of PROX OPS breakout. It is especially applicable if the Orbiter is in an inertial hold and has left the TGT V-BAR, or if the Orbiter/TGT relative position is not well known.

The procedure is found in the FDF ORB OPS C/L. Procedural rationale is described in the following sections.

5.4.2.1 Set Up Aft Station

This step is shown in figure 5-32.

```
A6U    ✓SENSE - as reqd
        DAP:  A/MAN/NORM
        DAP TRANS:  as reqd
        DAP ROT:  DISC/DISC/DISC
        FLT CNTLR PWR - ON
```

Figure 5-32.- Set up aft station checklist.

DAP TRANS options are pilot's choice depending on the size of closing rate. Over 1 ft/s should be done in DAP TRANS:NORM, with transition to DAP TRANS:PULSE for the last half foot/second of translation.

5.4.2.2 Obtain Visual Contact Through OVHD Window

This step is shown in figure 5-33.

```
DAP ROT:  as reqd
RHC - as reqd

When adequate visual contact
obtained,
 DAP ROT:  DISC/DISC/DISC
```

Figure 5-33.- Visual contact through OVHD window checklist.

This establishes TGT LOS near the Orbiter -Z axis in preparation for translation maneuvers. The DAP ROT options are chosen based on how far and fast the -Z axis must be rotated.

5.4.2.3 Null Closing Rate

This step is shown in figure 5-34.

```
THC - +Z (dn - -X SENSE)
         (out - -Z SENSE)
as req'd to null closing rate
```

Figure 5-34.- Null closing rate checklist.

Range rate may be known from initial conditions, from known maneuver history, or (most likely) by direct visual observation when very close (inside RR track range) to TGT.

5.4.2.4 Perform RR ACQ (If Desired)

This step is shown in figure 5-35.

```
A1U          KU MODE - RDR PASSIVE
                RADAR OUTPUT - HI
             KU - AUTO TRACK
             KU CNTL - PNL

             Slew antenna to target
            ✓KU TRACK tb - gray

             If no TRK,
              KU SEARCH - SEARCH (tb-gray)

             If no lock-on within one minute,
              repeat SEARCH as convenient
```

Figure 5-35.- Perform RR ACQ checklist.

This may only occur after separating beyond radar track minimum range. Note that radar is in AUTO track since there is no PL SV to automatically provide navigated pointing angles.

5.4.2.5 Obtain ~1 FPS Opening Rate

This step is shown in figure 5-36.

```
A6U          DAP TRANS:  NORM/NORM/NORM
             THC - +Z for 3 sec
             • If Low Z (MCC call)   •
             •  THC - +Z for 12 sec  •
```

Figure 5-36.- Obtain ~1 FPS opening rate.

The THC sense is the same as in section 5.4.2.3 for nulling the closing rate. The 3-second burn imparts the desired opening rate. Actual ΔV may be monitored on the AVG G display on SPEC 33, but such precision is not required for a successful safe separation. This is the "1" part of the "1/2/3" MNVR.

5.4.2.6 Perform Out-Of-Plane MNVR

This step is shown in figure 5-37.

	|GNC UNIV PTG|
CRT	CNCL - ITEM 21 EXEC
	GNC, OPS 202 PRO
	|GNC ORBIT MNVR EXEC|
	RCS SEL - ITEM 4 EXEC (*)
	Set TIG to current time +2:00
	TGT PEG 7 ΔV_x - ITEM 19 +<u>0</u> EXEC
	ΔV_y - ITEM 20 +<u>2</u> EXEC
	ΔV_z - ITEM 21 +0 EXEC
	LOAD - ITEM 22 EXEC
	TIMER - ITEM 23 EXEC
	√VGO Z ≥ 0: if VGO Z <0, then
	* TGT PEG7 ΔV_y - ITEM 20 -<u>2</u> EXEC *
	* LOAD - ITEM 22 EXEC *
	* TIMER - ITEM 23 EXEC *
	*√VGO Z ≥ 0 *
	DO <u>NOT</u> MNVR TO BURN ATT
A6U	At TIG deflect THC to null VGOs

log TIG

Figure 5-37.- Perform out-of-plane MNVR checklist.

If the burn VGO, displayed in body coordinates, shows a -Z component, this means that the intended out-of-plane maneuver will take the Orbiter directly back through the TGT plane. In this case, reload MNVR EXEC with a -2 ft/s Y burn.

The test of VGO Z simply ensures that the out-of-plane burn is away from the TGT. This is the "2" part of the "1/2/3" maneuver.

5.4.2.7 Perform Final SEP

This step is shown in figure 5-38.

	GNC ORBIT MNVR EXEC
CRT	✓RCS SEL - ITEM 4 (•)
	If ΔVY (Block 6) is +2
	TV ROLL - ITEM 5 +2 7 0 EXEC
	If ΔVY (Block 6) is -2
	TV ROLL - ITEM 5 +0 9 0 EXEC
	Set TIG to TIG from last step + 15:00
	TGT PEG 7 ΔV_x - ITEM 19 +3 EXEC
	ΔV_y - ITEM 20 +0 EXEC
	ΔV_z - ITEM 21 +0 EXEC
	LOAD - ITEM 22 EXEC
	TIMER - ITEM 23 EXEC
	DAP: A/AUTO/NORM
	At TIG -8:00; MNVR - ITEM 27 EXEC (•)
A6U	At TIG deflect THC to null VGOs
	AFT FLT CNTLR PWR - OFF

Figure 5-38.- Perform final SEP checklist.

The ΔV Y check determines which direction out of plane was burned on the previous maneuver, to select the most easily reached TVR. The plan is to make this burn about one quarter of a REV later, which is at the point of maximum out-of-plane separation (about 2000 feet for a 2 ft/s burn). The burn is large enough to perform with +X RCS jets. This is the "3" part of the "1-2-3" maneuver.

5.4.2.8 Maneuver To Minimum Drag Attitude (-ZLV)

This step is shown in figure 5-39.

```
A6U         DAP:  A/AUTO/VERN

CRT         GNC, OPS 201 PRO

            |GNC UNIV PTG|

           ✓TGT ID - 2
            BODY VECT -3
            OM - 180
            START TRK - ITEM 19 EXEC (CUR *)
```

Figure 5-39.- Maneuver to minimum drag attitude (-ZLV) checklist.

Drag is of concern because of potential differential drag effects (section 2.7.1). Hence, the -Z axis is pointed to Earth center, and tail is rotated into +V-BAR.

5.4.3 Contingency

Contingency separation procedures can be divided into several broad classes: those which allow an Orbiter maneuver to a planned deploy attitude, and those which result from an inadvertent deployment or must be performed from a random relative position to the TGT.

RNDZ BREAKOUT

NOTE
This procedure may be performed anytime between Ti and VBar arrival and assumes the orbiter is at or near -Z axis TGT TRK attitude (OM = 0)

1. 3 fps out of plane

C3 DAP: A/MAN/NORM, NO LOWZ
✓DAP ROT: DISC/DISC/DISC
DAP TRANS: NORM/NORM/NORM
F7/F8 FLT CNTLR PWR - ON

CRT |GNC 33 REL NAV|
If Y>0:
  FWD THC: +Y (right) 12 sec
    (AFT THC: left)
If Y<0:
  FWD THC: -Y (left) 12 sec
    (AFT THC: right)
F7/F8 FLT CNTLR PWR - OFF
Record out of plane TIG ___/___:___:___

CRT 2. 3 fps retrograde
OPS 202 PRO
|GNC ORBIT MNVR EXEC|
✓RCS SEL - ITEM 4 (*)
TV ROLL - ITEM 5 +0 EXEC
Set TIG to out of plane TIG +15:00
TGT PEG 7 VX - ITEM 19 -3 EXEC
  VY - ITEM 20 +0 EXEC
  VZ - ITEM 21 +0 EXEC
LOAD - ITEM 22 EXEC
TIMER - ITEM 23 EXEC

TIG -8:00
  MNVR - ITEM 27 EXEC
C3 DAP: B/AUTO/NORM
A1U KU - AUTO TRK

TIG
F7/F8 FLT CNTLR PWR - ON
  THC: Trim VGOs < 0.2 fps
F7/F8 FLT CNTLR PWR - OFF
C3 DAP: A/MAN/VERN

CRT OPS 201 PRO
|GNC UNIV PTG|
✓TGT ID +1
✓BODY VECT +3
OM +180 EXEC
C3 DAP: A/AUTO/VERN
CRT TRK - ITEM 19 EXEC (CUR - *)

RNDZ BREAKOUT

5.4.3.1 Rendezvous Breakout Procedure

This breakout has two periods of applicability, from the sunset after Ti until MC2, and from MC3 until PROX OPS. If breakout criteria are met between MC2 and MC3, breakout must be delayed until MC3. The reason for this is that between these intervals an OOP miss cannot be guaranteed (TGT contact may be possible). See figure 5-40.

```
Perform out of plane ΔV = 3 fps away from
 TGT plane
  (THC - 12 sec in DAP TRANS:  NORM)
After 15 min, perform retrograde ΔV = 3 fps

  OPS 202 PRO
  |GNC ORBIT MNVR EXEC       |
✓ RCS SEL - ITEM 4 (*)
  TV ROLL - ITEM 50 +0 EXEC
  Set TIG to out-of-plane burn +15:00
  TGT PEG 7 ΔVx - ITEM 19 -3 EXEC
            ΔVy - ITEM 20 +0 EXEC
            ΔVz - ITEM 21 +0 EXEC

  LOAD - ITEM 22 EXEC
  TIMER - ITEM 23 EXEC
  At TIG -8:00; MNVR - ITEM 27 EXEC (*)
  DAP:  B/AUTO/NORM (✓ ROT DISC RATE = .5)
  At TIG deflect THC to null VGOs
```

Figure 5-40.- Rendezvous breakout procedure checklist.

During flight techniques discussions, there was a strong desire to develop a single, propellant-efficient breakout maneuver sequence independent of relative position. The result was a 3 ft/s out-of-plane maneuver away from the TGT plane, followed 15 minutes later by a 3 ft/s retrograde maneuver. This sequence provides an Orbiter c.m. to TGT c.m. miss distance of at least 500 feet. Because of trajectory dispersions, this sequence cannot be initiated everywhere between Ti and V-BAR arrival. Specific initiation times have been established depending on Orbiter propellant, Orbiter system status, and the TGT sensor data history (sec. 4.6.2).

In section 4.6.2, the note "nominally Orbiter Y body axis" was included to define which propulsion system contained the propellant for the out-of-plane maneuver (bingos). This note assumes a Y-POP, -Z TGT track Orbiter attitude driven by the use of either the RR, -Z STRK, or the COAS. If the -Y STRK is used, the Orbiter attitude would be inconsistent with the Y body thrusters providing an out-of-plane maneuver. A maneuver to burn attitude is prohibited because of the delay in initiating the sequence and the loss of TGT acquisition while still on an intercept trajectory. In this scenario, the propellant for the out-of-plane maneuver would have to come from another propulsion system. Similarly, the note "Orbiter +X body axis" was included for the retrograde maneuver. However, this maneuver is executed in burn attitude.

Further information on this breakout maneuver sequence can be found in Orbit Flight Techniques No. 82 (Nov. 17, 1987) minutes.

5.4.3.2 PROX OPS Breakout Procedure

This procedure is shown in figure 5-41.

```
If on +V-BAR,
   Perform 2 fps posigrade burn
    (THC - +Z, 5 sec in DAP TRANS:  NORM, NO LOW Z)

If on -Vbar,
   Perform 2 fps retrograde burn
    (THC - +Z, 5 sec in TRANS:  NORM, NO LOW Z)

If on -Rbar or in transition +Vbar to -Rbar,
   Perform 1 fps burn away from the target
    (THC - +Z, 3 sec in TRANS:  NORM, NO LOW Z)
   After 10 min, perform 1 fps posigrade burn
    (multi-axis)
     |GNC ORBIT MNVR EXEC|
   √RCS SEL, ITEM 4 - (*)
     TIG = Initial sep + 10 min
     PEG 7 ΔVX = +1, ΔVY = 0, ΔVZ = 0
     LOAD  - ITEM 22 EXEC
     TIMER - ITEM 23 EXEC
     DAP: A/AUTO/NORM
     TIG - null VGOs

If none of the above, or if inertial stationkeeping
 has been initiated, perform SEP MANEUVER (ORB OPS)
```

Figure 5-41.- PROX OPS breakout procedure.

Post-V-BAR arrival, the abort maneuver sequence will be:

A. If stable on the +V-BAR, perform 2 ft/s posigrade MNVR (nominally Orbiter +Z body axis, NORM Z translation mode) ASAP. If stable on the -V-BAR, perform 2 ft/s retrograde MNVR (nominally Orbiter +Z body axis, NORM Z translation mode) ASAP. While on the ±V-BAR where the relative position of the Orbiter and TGT is well defined, a single abort MNVR can be performed. If stationkeeping, 2 ft/s will produce approximately a 5 n. mi. per REV opening rate; if closing or opening when the MNVR is executed, the opening rate will be proportionately smaller or greater, respectively. The direction of the MNVR was chosen to ensure no immediate recontact with the TGT. The note "nominally Orbiter +Z body axis, NORM Z translation mode" was included to define which propulsion system contained the propellant for this MNVR (bingos).

b. If stable on the -R-BAR or initially transitioning from the +V-BAR to the -R-BAR, with the TGT in view out the Orbiter overhead window, perform 1 ft/s away from the TGT (nominally Orbiter +Z body axis, NORM Z translation mode) followed 10 minutes later by a 1 ft/s posigrade MNVR (Orbiter +X body axis). A -R-BAR approach differs from the more standard V-BAR approach by including a transition from the +V-BAR to the -R-BAR and then stationkeeping on the -R-BAR. During this time frame, a more propellant-efficient abort maneuver sequence than the "generic" separation maneuver exists. This sequence is consistent with the V-BAR approach abort maneuver sequence. The 1 ft/s MNVR away from the TGT produces an initial opening rate so the 1 ft/s posigrade MNVR can be performed with no potential for recontact. This sequence will initiate an opening rate of 2.5 to 5 n. mi. per REV depending on the relative position of the Orbiter and TGT when the sequence is executed. The notes "nominally Orbiter +Z body axis, NORM Z translation mode" and "Orbiter +X body axis" were included to define which propulsion systems contained the propellant for these MNVR's (bingos).

c. If neither "a" nor "b" applies, perform separation maneuver in orbit OPS checklist ASAP (see section 5.4.2). If neither condition a nor b, the relative position of the Orbiter is not well-defined. Hence, the "generic" separation maneuver in the Orbit OPS checklist should be used. This procedure is independent of relative position (within PROX OPS) and will initiate an overall opening rate of 5 to 10 n. mi. per REV depending on the relative position when the sequence is initiated.

   During an inertial approach, inertial stationkeeping, or flyaround, the Orbiter crosses the ±V-BAR and 25 percent of the time flies above, and in front of, the TGT. If the Orbiter is at one of these relative positions, the abort maneuver sequences described in a and b could be used and 4 ft/s propellant could be saved. However, it is unwise to have more than one abort procedure during a given piloting task. Hence, only the "generic" separation procedure is used.

5.4.3.3 Jettison

Jettison is the class of contingency procedure where the actual Orbiter/PL separation is accomplished through deliberate crew action. Numerous jettison scenarios can be constructed, including the following:

- RMS - required if the RMS cannot be berthed and/or stowed, and the PLBD therefore cannot be closed.

- Ku-band antenna - required if the antenna cannot be stowed, therefore the PLBD cannot be closed.

- PL - required if a PL which was unberthed (but not intended to be deployed) cannot be reberthed, or if a PL not intended to be deployed has become unsafe for deorbit.

- PL/RMS - may be required if the RMS end effector cannot be removed from the grapple fixture (may be able to remove via EVA).

In all of these jettison situations, a simple efficient Orbiter separation can be performed. This technique places the Orbiter XLV, vertical stabilizer trailing. The jettison, which is nonimpulsive in all of these cases, is performed, followed by a 1 ft/s posigrade Orbiter translation. After about 2 minutes (roughly 130 feet of separation), another 1 ft/s posigrade Orbiter burn is accomplished to achieve a larger opening rate. The rationale for the two-burn sequence is that the first burn initiates opening with minimum tumbling due to plume, and the second burn gives greater desired SEP rate. This was specifically developed for RMS. The subsequent relative motion is shown in figure 5-46.

The RMS jettison procedure is found in the PDRS (All) book, and the KU-BD ANT JETTISON is found in the ORB OPS book. The actual steps and rationale, plus differences between them, are described below (xxx refers to jettisoned object).

1. Prepare for jettison and perform between sunrise and noon if possible. This enhances visibility of xxx during initial separation.

2. AUTO MNVR to -XLV. See figure 5-42.

CRT	|GNC UNIV PTG|
	✓START TIME at least 15 min prior to sunrise
	✓TGT ID +2 (earth center)
	BODY VECT +2 (-X axis)
	OM +0
	Initiate TRK
A6U	DAP:A/AUTO/VERN
A6U	FLT CNTLR PWR - ON
	EVENT TIMER MODE - UP
	CNTL - STOP
	TIMER - RESET
A7U	✓Lighting - as reqd

Figure 5-42.- AUTO MNVR to - XLV checklist.

3. Several pages of xxx systems operations follow. In PDRS, this leads to last step: "Guillotine Wires at Shoulder."

4. Configure CCTV's to monitor jettison. (see figure 5-43).

```
Perform TV ACT, VTR ACT, TV/VTR Cue Card
CCTV MON  1 - A
          2 - B
Point CCTVs as reqd   (FOR PDRS, POINT B CCTV
                                AT RMS SHOULDER JOINT)
Put new tape in VTR
```

Figure 5-43.- Configure CCTV's checklist.

5. At sunrise, "Damp Rates" and check to be in jettison attitude. (See figure 5-44).

```
A6U      DAP ROT: DISC/DISC/DISC
             TRANS:  PULSE/PULSE/NORM
         If VERN jets avail
         |  DAP:  A/MAN/VERN
         If VERN jets not avail
            DAP:  B/MAN/NORM
          Wait until rates damped, then
          DAP  A/MAN/NORM
          for PDRS, DAP ROT:  PULSE/PULSE/PULSE (free drift)
         ✓SENSE - as reqd
          When rates damped, then
          VTR - PLAY/RCD/RUN
```

Figure 5-44.- "Damp Rates" checklist.

A gentle separation is most critical for the PDRS because any attitude disturbances could lead to tumbling and potential recontact with Orbiter while still at close range.

6. Perform jettison (and PDRS, start timer).

7. Separate (see figure 5-45).

> NOTE
> After JETT, initiate opening rate
> ASAP. Minimize other THC/RHC inputs
>
> Maintain xxx in 8 CCTV
>
> JETT+
> 0:01 WHEN JETTISON COMPLETE, TRANSLATE AWAY
> THC +Z, 2 sec (1 ft/sec)
> (-X sense: THC dn)
> (-Z sense: THC out)

Figure 5-45.- Separation checklist.

This second burn (fig. 5-46) can be performed either on time (after 2 minutes, for PDRS) or on range (at 100 ft, for Ku-band). Although they should be equivalent, it is important to observe the jettisoned object and verify that both conditions are met.

> SENSE - as reqd
> THC +Z, 2 sec (1 ft/sec)
> (-X sense: THC dn)
> (-Z sense: THC out)
>
> Maintain visual contact with xxx
> in OVHD window using RHC

Figure 5-46.- Second SEP burn.

The jettisoned body is kept in visual acquisition by the crew as long as possible to verify the opening rate, and from figure 5-48 it can be seen that after about 20 minutes this places the Orbiter in -ZLV. Since all PL's and appendages which have been studied to date have higher relative drag than the Orbiter, and -ZLV is the lowest Orbiter drag profile, this will provide a further long-term opening rate as the other body tends to drop lower and therefore travel faster. In a jettison situation where deorbit will follow closely after jettison, a mirror image separation can be performed such that each burn will be retrograde. In this case the relative drag effects can be ignored.

8. Go to new attitude when xxx no longer visible (see figure 5-47).

A6U	FLT CNTLR PWR - OFF	
	|GNC UNIV PTG|	
	✓TGT ID	+2
	BODY VECT	+3
	OM	+0
	START TRK - ITEM 19 EXEC (CUR *)	
A6U	DAP: A/AUTO/VERN	

Figure 5-47.- New attitude checklist.

9. Perform systems cleanup.

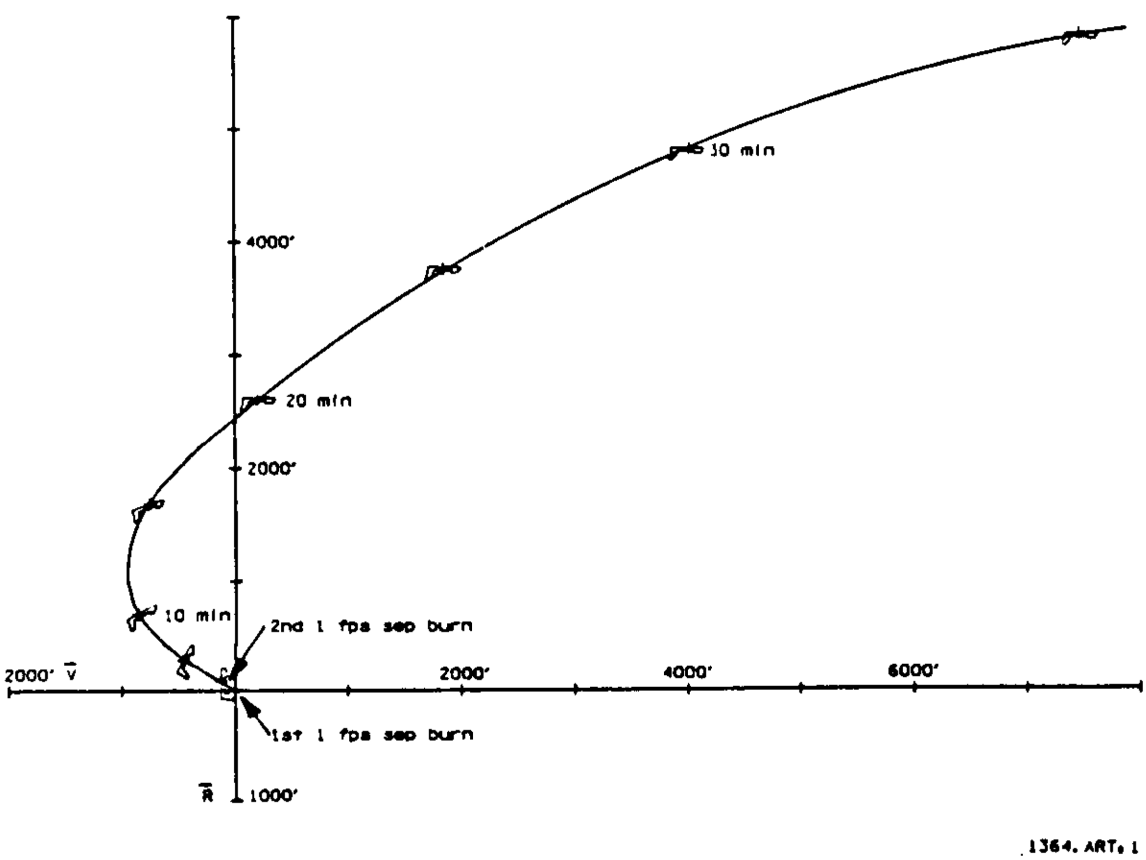


Figure 5-48.- Orbiter separation trajectory following jettison.

5.4.3.4 Inadvertent/Immediate Release

Although inadvertent/immediate release is generally considered to be highly unlikely, it is a sufficiently serious situation to require some attention. The major difficulty with an inadvertent/immediate release is that in general it can happen with the Orbiter in any LVLH attitude, so simply backing away from the body is not the answer. If the back-off maneuver happens to be out of plane, a recontact situation may occur half a REV later. If the back-off were radial, recontact could occur one REV later. A procedure which can handle the general case is the generic "1-2-3 burn" described in 5.4.2, especially beginning in step 5. See figure 5-49.

This procedure does not necessarily provide for crew visibility of the other body throughout the SEP sequence, but is an efficient and relatively simple procedure, minimizing crew training.

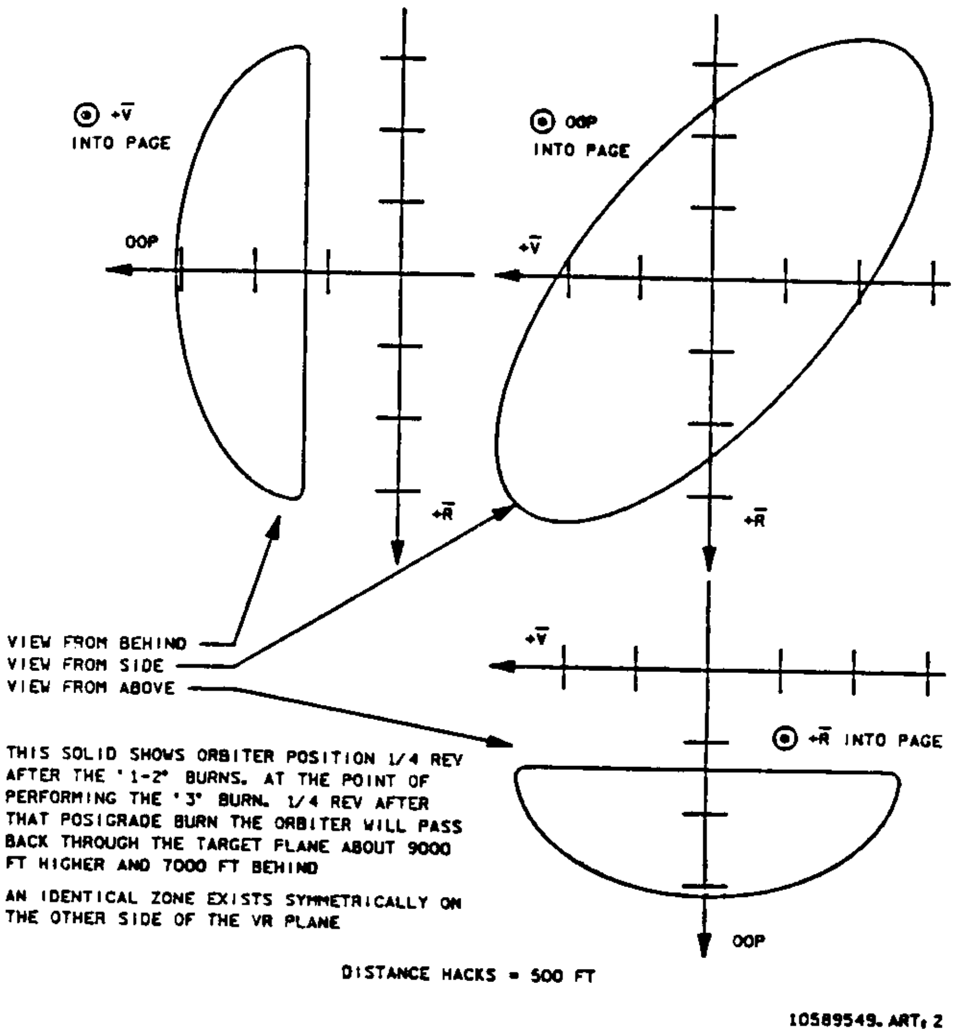


Figure 5-49.- Generic ("1-2-3") Separation