SECTION 3
TOOLS FOR RENDEZVOUS

Performance of orbital RNDZ and PROX OPS is enabled by numerous hardware and software tools on the Orbiter. This section is a summary of their capabilities and basic operational characteristics relevant to RNDZ and PROX OPS usage. Discussion is intended to be more detailed than in other available literature, but also more narrowly focused. Subsequent sections will discuss specific applications of these tools to real RNDZ and PROX OPS profiles.

The material in this section, both tool descriptions and general procedures for use of those tools, can be considered "subroutines" for sections 4 and 5, which consist of specific procedures rationale narratives for RNDZ operations (section 4) and PROX OPS (section 5).

3.1 ATTITUDE DETERMINATION/CONTROL

For determination and control of Orbiter attitude, the crew uses the OPS 201 display (Universal Pointing), along with the attitude direction indicator (ADI) and the hand controllers.

3.1.1 Universal Pointing (UNIV PTG, or UP) (OPS 201)

UNIV PTG (fig. 3-1) is the MM 201 display and provides the crew with four mutually-exclusive options for automatic (AUTO) attitude control with respect to the forward (+X) ADI reference frame. Three options are universal

```
 2011/   /          UNIV PTG       XX X DDD/HH:MM:SS
   CUR MNVR COMPL XX:XX:XX              DDD/HH:MM:SS
 1 START TIME XXX/XX:XX:XX
                                 CUR FUT
MNVR OPTION      START MNVR 18 X    X
 5 R XXX.XX            TRK  19 X    X
 6 P XXX.XX            ROT  20 X    X
 7 Y XXX.XX           CNCL  21

TRK/ROT OPTIONS       ATT MON
 8 TGT ID XXX          22 MON AXIS X XX
                       ERR TOT 23X
 9  RA    XXX.XXX      ERR DAP 24X
 10 DEC   ±XX.XXX
 11 LAT   ±XX.XXX             ROLL     PITCH      YAW
 12 LON  ±XXX.XXX     CUR    XXX.XX   XXX.XX   XXX.XX
 13 ALT ±XXXXX.X      REQD   XXX.XX   XXX.XX   XXX.XX
                      ERR   ±XXX.XX  ±XXX.XX  ±XXX.XX
 14 BODY VECT X       RATE  ±XX.XXX  ±XX.XXX  ±XX.XXX

 15 P  XXX.XX
 16 Y  XXX.XX
 17 OM XXX.XX

                                                 (XX)
```

Figure 3-1.- The UNIV PTG (OPS 201) display.

in that they are defined by data inputs made by the crew. The other option is a cancel option that holds the inertial attitude that is current at the time the option is selected. It terminates any other current or future AUTO option. These options are accomplished automatically only if the digital autopilot (DAP) is in AUTO.

The first option is the maneuver (MNVR) option. It allows the crew to maneuver the Orbiter to a specified inertial attitude at a specified start time.

The second option is the tracking (TRK) option. It allows the crew to orient the Orbiter to point a specified body vector at another orbiting vehicle, an Earth target, center of Earth (for local vertical local horizontal (LVLH) hold), center of Sun, or a celestial target (specified coordinates or target navigation star number) at a specified start time.

The third option is the rotation (ROT) option. It allows the crew to rotate (always clockwise) the Orbiter inertially about a specified body vector at the DAP selected rate, beginning at a specified start time.

The fourth option is the cancel (CNCL) option. It allows the crew to deselect any other option and hold attitude automatically about the existing inertial attitude at the time the cancel option is selected.

Also provided is the capability to monitor vehicle attitude parameters in roll, pitch, and yaw body coordinates.

3.1.1.1 Options

For detailed explanation of the general capabilities of UNIV PTG, see the Attitude/Pointing Flight Procedures Handbook (JSC-10511). The following discussion is concentrated on the specific use of UP in RNDZ and PROX OPS.

a. <u>CUR MNVR COMPL</u> - The current maneuver completion (CUR MNVR COMPL) time is shown in hrs:mins:secs when a maneuver (MNVR or TRK) is in progress until the attitude is within 1° of desired, at which time it is frozen. The time is also frozen if a maneuver is in progress and the DAP LVLH mode is selected. Time is reset to zero if a maneuver is in progress and CANCEL is selected. The completion time remains unchanged if a maneuver is not in progress and the DAP MAN or LVLH, or ROT option, or CANCEL is selected.

b. <u>START TIME</u> (items 1 through 4) is designated in days/hrs:mins:secs mission elapsed time (MET) for the selected control option. Display is initialized with the time at zero.

c. <u>TRK/ROT OPTIONS</u> - Item 8 selects the TGT identification for the TRK option. "Orbiting Vehicle" is ID number 1 and center of Earth is number 2; the LOS is determined from the SV's of the Orbiter and the TGT vehicle. Item 14 selects the body vector (BODY VECT) which is pointed along the LOS for the TRK options. The BODY VECT identifiers are as follows:

1 is +X ;
2 is -X ;
3 is -Z ;
4 is PTC (passive thermal control), about 2° below +X;
5 is Selectable, using items 15 and 16 to define the BODY VECTOR. (P and Y must be positive.)

NOTE: In practice +X is used for PTC ROT's, instead of PTC axis.

Any attempt to load other identifiers will result in an illegal entry message. The identifier will be initially loaded with 1 (one).

Item 17 selects the omicron angle desired for the TRK option. With this item, the user can specify the attitude orientation of the Orbiter about the selected body pointing vector used in the TRK attitude option. A precise definition of "omicron" is found in the Attitude/Pointing Flight Procedures Handbook.

The omicron item is blanked when a new TGT ID is entered. If the item is still blank when the TRK attitude option (item 19) is selected, two-axis TRK will be implemented. In this mode, the Orbiter-selected body-pointing vector is aligned with the TGT LOS with a minimum attitude change in which the maneuver transfer angle (often called "eigenangle") is minimized. This means that the Orbiter will track the TGT with the specified TRK body vector, but that the Orbiter orientation about that body pointing vector (omicron) will not be fixed. Instead, it will vary such that the total required rotation is minimized. If an omicron-angle restraint is input in item 17 and the TRK option is selected, three-axis TRK will be used. In this mode, both the pointing requirement and the omicron-angle constraint are imposed in making computations.

If omicron is not blank, entering a body vector ID in item 14 initiates the flashing of omicron. The flashing is terminated when a value of omicron is entered or when an attitude option is selected.

The allowable range for omicron is 0° to 359.99°. User input outside this range results in an ILLEGAL ENTRY message. The value of omicron is initialized to zero, and three-axis TRK is selected.

d. <u>START MNVR, TRK, ROT (items 18, 19, 20)</u> provide selection of the MNVR, TRK, or ROT control option. Initiation of a control option depends on the START TIME entered in items 1 through 4. If the START TIME is zero, current (CUR), or in the past and DAP is AUTO, the control option is initiated upon selection, a "*" appears in the CUR column next to the selected option, and any other option is deselected (no "*"). If the START TIME is in the future, the selected control option is initiated at that time and in the interim a "*" appears in the future (FUT) column next to the selected option. The selected option in progress ("*" in the CUR column) drives the REQD attitude, ERR, and the ADI error needles.

Control option initiation must be preceded by DAP AUTO. If a future start time is within 30 seconds of current time and AUTO has not been selected, a class 3 alert and "SEL AUTO" message is generated. Data may be entered for a single future control option during execution of the current option.

When the START TIME entered for the future option equals current time, the "*" in the FUT column is blanked and "*" displayed in CUR column. If the previous control option is active, it is deselected (no "*"). If a future option has been selected and then data are changed prior to the future start time via keyboard inputs, the future option will be deselected (no "*"), and CANCEL (CNCL) will be automatically selected. The crew must repeat selection of the desired future option.

The three control options are terminated/inhibited by: (a) selection of MNVR (item 27) on the MM 202 ORBIT MNVR EXEC display (which maneuvers to the specified burn attitude); (b) selection of LVLH or MAN pushbutton (pb); (c) moving an RHC out of detent; (d) selection of the CANCEL option, or (e) OMS/RCS ignition. Providing that CANCEL has not been executed, a control option is reinitiated by: (a) exiting MM 202 (ORBIT MNVR EXEC) back to MM 201 (which is the only legal transition) or (b) selecting the AUTO DAP pb.

e. CANCEL (item 21) deselects both current and future control options and initiates inertial attitude hold at the current attitude. The display is initialized with item 21 selected. When in DAP AUTO and CNCL is selected, attitude errors are displayed with respect to the current attitude when the CNCL option was executed. This attitude reference is maintained in a subsequent selection of a MAN MNVR and return to AUTO DAP. Reselection of the CNCL option zeroes these attitude errors. Then errors are displayed with respect to the current attitude regardless of DAP configuration.

   Even in MM 202, selecting LVLH on the orbital DAP control panel reinitiates the LVLH processing done by UNIV PTG processor, but does not reinitiate any other AUTO MNVR mode.

   After a transition from MM 201 to MM 202 or OPS 8 and a subsequent transition back to MM 201, the item select status that existed prior to cancellation is shown on the UNIV PTG display. The UNIV PTG display is initialized only when OPS 2 is entered from an OPS other than OPS 8.

   Selecting the LVLH attitude mode via pushbutton inhibits the cyclic processing of the selected AUTO attitude option (item 18-20) until the LVLH attitude mode is deselected.

3.1.1.2 Attitude Monitor

Select ERR TOT (Item 23) or ERR DAP (Item 24) at crew option. DAP errors show effects of attitude deadbanding (ATT DB), and allow crew to anticipate RCS firings to maintain attitude; TOT errors allow monitoring how far the Orbiter is out of a desired attitude (e.g., a track attitude, such as used to maintain V-BAR). When the ADI error needles are displaying TOTAL ERROR, they display DAP ERROR by simply selecting ITEM 24 on UNIV PTG. No cycling of the DAP is required to make the ITEM 24 take effect.

3.1.1.3 Enhanced Universal Pointing

For software release OI 12 with the new general purpose computers (GPC's), there will be a major upgrade of UP/DAP capabilities. Their applications to RNDZ are as yet undefined, but are likely to be extensive. The following description is intended for future users so they will have a proper understanding of Orbiter capabilities after the UP/DAP modification. Closer to the operational date of this new capability, this entire section will be replaced with a new section.

The UP upgrade is via CR 79879. It is a companion to CR 79862.

In the upgraded UP, up to 25 future AUTO MNVR's will be contained in a "maneuver table" (each entry can be loaded, edited, or canceled). Each maneuver will have its own ID number, start time, and DAP/jet selection (currently only a single "future option" can be stored, and DAP/jet select can be made from pb's only for the maneuver (designated "MNVR"). A second DAP load and jet selection are entered in the maneuver definition to specify the configuration to be used when the the desired attitude has been reached or tracking hold has been established (designated "HOLD"). For the ROT option, which never "ends," no such entry is made. If a current maneuver is canceled, the DAP/jet select reverts to those last loaded prior to the beginning of that current maneuver.

The future maneuver stack can be enabled or inhibited by item entry. As entries are made/edited in this table, it is automatically put in chronological order. In another upgrade, DAP's can be called up by number (e.g., DAP "ALL") rather than making individual entries on SPEC 20. These future AUTO maneuver's will be loadable by I-load (activated upon entry into OPS 2 from any legal OPS except OPS 8), uplink, as well as by keyboard (at present, only keyboard loads are possible); they can be downlisted (one maneuver per UP cycle) for verification.

Once a maneuver becomes "current", it can only be manipulated in certain restricted ways. It can only be canceled by crew input, not by uplink.

Another major upgrade involves maneuver options. A "tracking/rotation" (TRK/ROT) option is added, which allows rotation (at a constant rate) to be performed about the pointing vector during TRK operations. LVLH reference frame becomes available (in addition to inertial frame as currently) for output angles (attitude and attitude error and rates) and for attitude/

rotation maneuvers. That is, rotation about a body axis in LVLH frame will be possible. Lastly, rotation direction (now always clockwise (CW)) becomes selectable, CW or counterclockwise (CCW).

A new OPS 201 display has been designed to allow control and monitoring of these new capabilities. The current maneuver (if any) and the next 11 maneuvers (if any) from the table are displayed. New messages have been created to alert crew if a new maneuver is loaded into the table whose start time is in conflict with an existing maneuver. When a maneuver is within 30 seconds of beginning, but the crew has not enabled the AUTO processing by selecting DAP AUTO, the message "SEL AUTO" will appear on the message line.

The data defining each maneuver is similar to the data defining the current single future maneuver. To illustrate this, the following list of parameters in the 25-deep maneuver table is given:

1.	GMTS	Maneuver start time in GMT, dd/hh/mm/ss
2.	LC_FLAG	Load/cancel flag (1 = loaded, 0 = cancelled)
3.	UL_FLAG	Maneuver uplink flag (1 = loaded, 0 = cancelled)
4.	M_DAP	Maneuver DAPLOAD (1-15 = A1-A15, 16-30 = B1-15)
5.	H_DAP	Hold DAPLOAD (same as 4)
6.	M_JETS	Maneuver jet selection (1 = primary, 0 = vernier)
7.	H_JETS	Hold jet selection (1 = primary, 0 = vernier)
8.	OPT_FUT	maneuver type (1 = att, 2 = TRK, 3 = ROT)
9.	FRAME	If #8 = 1 or 3, Frame Indicator (1 = inertial, 0 = LVLH)
	THREE AXIS	If #8 = 2, Three axis TRK flag (1 = 3 axis, 0 = 2 axis)
10.	OMICRON	Only if #8 = 2 (TRK) and #9 = 1 (3 axis), Omicron angle for 3-axis TRK MNVR, degrees "+" = CW, "-" = CCW
11.	TGT_ID	Target ID for track (#8 must be 2)
12.	BODV-ID	Body Vector ID (#8 must be 2 or 3)
13.	TGT_RA	If #8 = 2 and #11 = 5, MED, star right ascension, deg
	TGT_LON	3, MED, surface target longitude, deg
14.	TGT_DEC	If #8 = 2 and #11 = 5, MED, star declination, deg
	TGT_ALT	3, MED, surface target altitude, NM
15.	TGT_LAT	If #8 = 2 and #11 = 3, MED, surface target latitude, deg
	ROLL1	If #8 = 1, roll euler angle (frame is given in #9)
16.	PITCH1	If #8 = 1, pitch euler angle (frame is given in #9)
	PITCH	If #8 = 2 or 3 and #12 = 5, body vector pitch euler angle for MED input, deg
17.	YAW1	If #8 = 1, yaw euler angle (frame is given in #9)
	YAW	If #8 = 2 or 3 and #12 = 5, body vector yaw euler angle for MED input, deg

The individual keystrokes on the new OPS 201 display will be defined in detail in a future edition of this ~~target~~ handbook.

3.1.2 Rotational Hand Controller and Translational Hand Controller

The rotational hand controller (RHC) and THC (aft station, panels A7U and A8) are used to provide input commands to the DAP, which then (depending on DAP configuration) outputs appropriate RCS jet fire commands. The THC outputs single commands when deflected; the RHC has a soft stop and hard stop feature that outputs separate signals which can be interpreted differently depending on DAP mode (fig. 3-2).

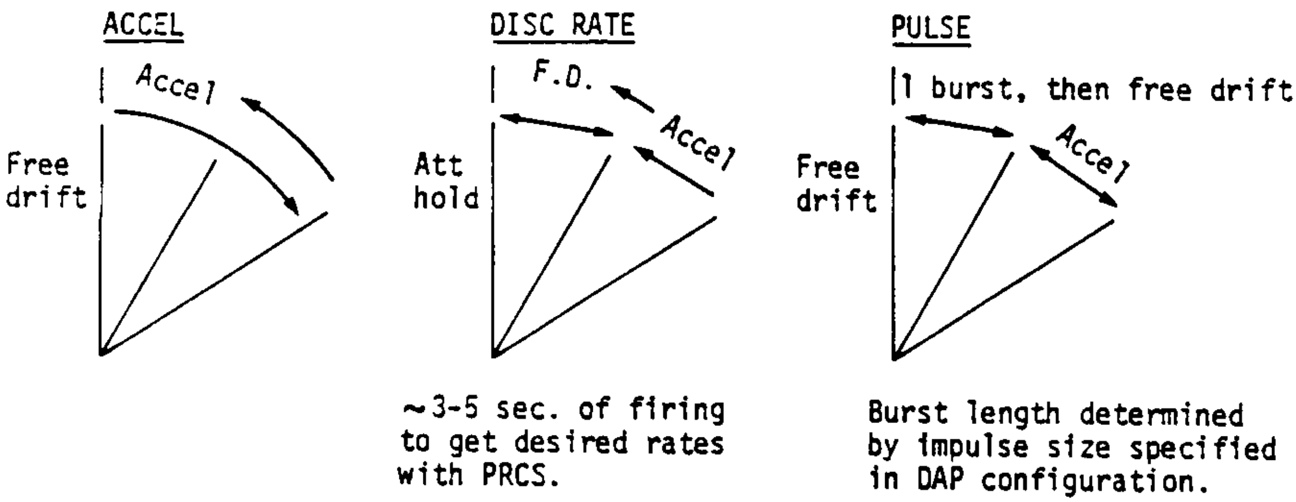


Figure 3-2.- RHC soft/hard stop logic.
F.D. is FREE DRIFT

Detailed descriptions of the functioning of the RHC and THC can be found in the Attitude/Pointing Flight Procedures Handbook and the Controllers Workbook.

Visualizing THC/RHC control modes in the two aft sense options can be facilitated by imagining an Orbiter being grasped by the hand on the RHC/THC, where the gross deflections of the RHC/THC are duplicated in same-sense motions of the actual Orbiter. The "sense" is down the crewmember's arm: -X has the Orbiter tail pointing down the arm and its top up; -Z has the Orbiter top pointing down the arm with its nose up. This is directly analogous to the forward RHC/THC +X sense mode.

3.1.3 SENSE Switch Options

The SENSE switch (panel A6U) allows the RHC and THC to command relative to the current control axis, either -X or -Z depending on whether the crewmember (at the aft crew station) is viewing through the payload bay PLB windows or the overhead windows (fig. 3-3). The vehicle motions induced by RHC and THC deflections are relative to the desired control axis as selected by the SENSE switch position (figs. 3-4A and 3-4B).

For RNDZ/PROX OPS applications, the proper setting of this switch is -Z. This is true especially for post-Ti through grapple, and for separation as well. The crew may also select this at any other time. The only proper use of -X sense is as a backup to the forward THC for translation, particularly for burn completion. Or in extreme cases to maintain +Z redundancy against multiple THC contact failures.

3.1.4 See page 3-12

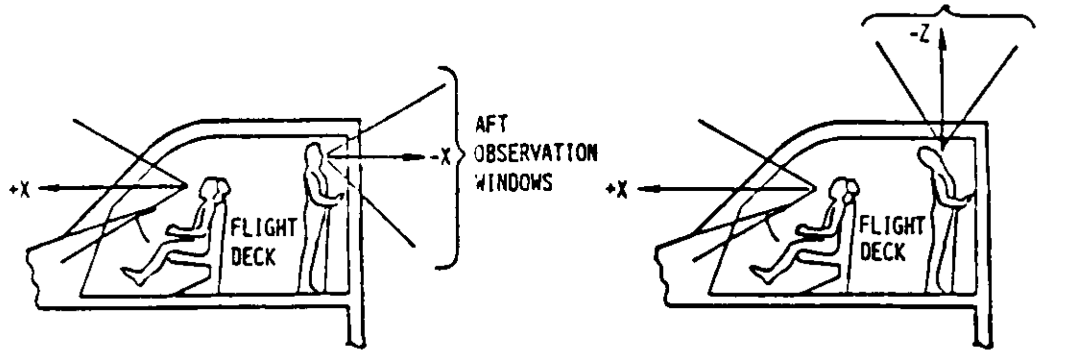
3.1.5 "FWD Tank Constraint" issues [written 5/18/1988]

A significant consideration in Orbiter attitude control is the DAP implementation of old constraints on the maximum number of forward RCS jets which can fire simultaneously. Too high a number was once thought to create the possibility of helium ingestion in the FRCS tanks, so a high limit of 3 FRCS jets was apparently implemented in FSW. Later, flight experience and hardware analysis relaxed this concern, and so CR 69781 was approved to remove this constraint. However, this limit's implementation in FSW and in simulators was clouded in the return-to-flight era (1987-1988) since proper paper trails could not be followed. Close coordination with DM43 specialists is required for an up-to-date appreciation of the real status of this issue. Analysis of FSW code was incomplete as of publication date.

Impact on proximity operations procedures (particularly separation sequences from large payloads) can be significant and surprising. For example, while in low Z mode (NORM-NORM-NORM) a prolonged -Z translation (2 +X jets and 2 -X jets) can create a pitch down which soon exceeds the deadband and thus commands a pitch up using two forward down-firing jets. To satisfy the constraint, the DAP cuts off one of the -X jets for the duration of this pitch up firing (several seconds), but leaves the two +X jets on, causing an X-axis imbalence and a consequent +X small translation. So instead of a nearly pure -Z translation (as commanded) this THC input results in a departure vector tilted forward about 30 degrees, possibly leading to RMS/PL contact. NOTE: Performing such a separation in PULSE mode avoids this difficulty.

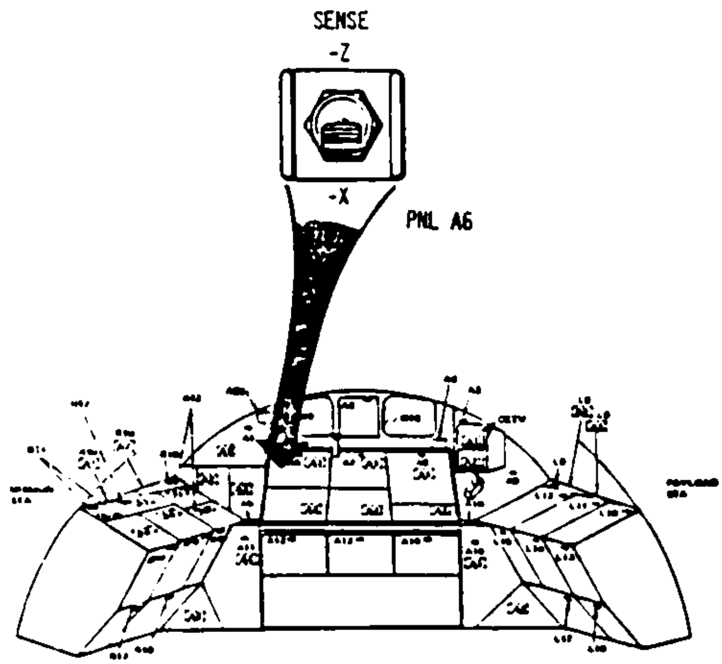
should this be +Z?

AFT STATION CONTROL



- TWO SETS OF WINDOWS-AFT (-X) AND OVERHEAD (-Z)
- ONE SET OF AFT STATION CONTROLS (RHC & THC)
- MUST ESTABLISH A VISUAL CONTROL REFERENCE BASED ON THE LINE OF SIGHT
- DONE WITH THE AFT SENSE SWITCH

AFT SENSE SWITCH



AFT STATION

-Z SELECTS THE CONTROLLER & ADI REFERENCE ABOUT THE -Z AXIS, IE, OVERHEAD LINE-OF-SIGHT REFERENCE.

-X SELECTS THE CONTROLLER & ADI REFERENCE ABOUT THE -X AXIS, IE, AFT LINE-OF-SIGHT REFERENCE.

Figure 3-3.- Aft station control, sense switch.

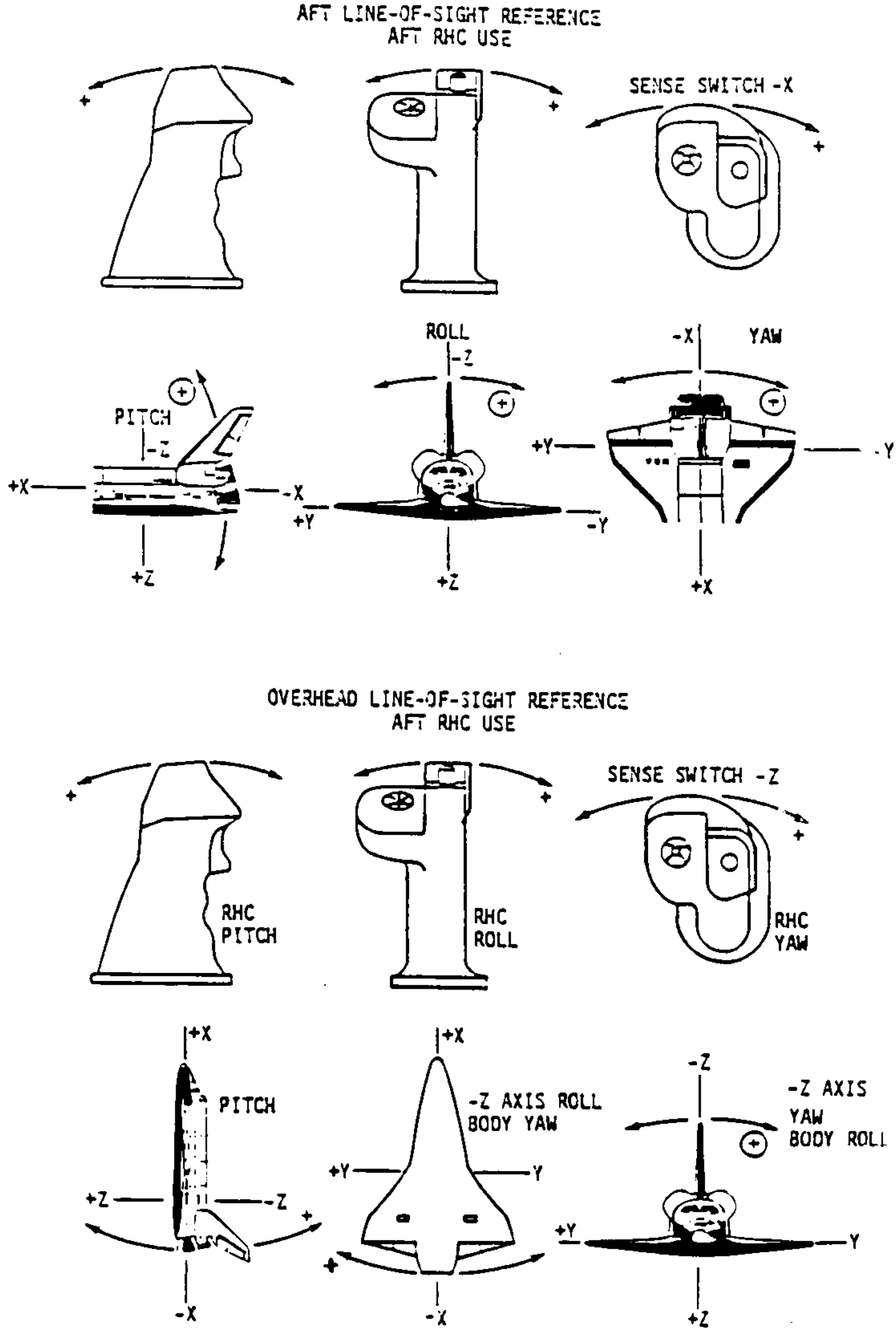


Figure 3-4A.- Aft and overhead line-of sight references, aft RHC use.

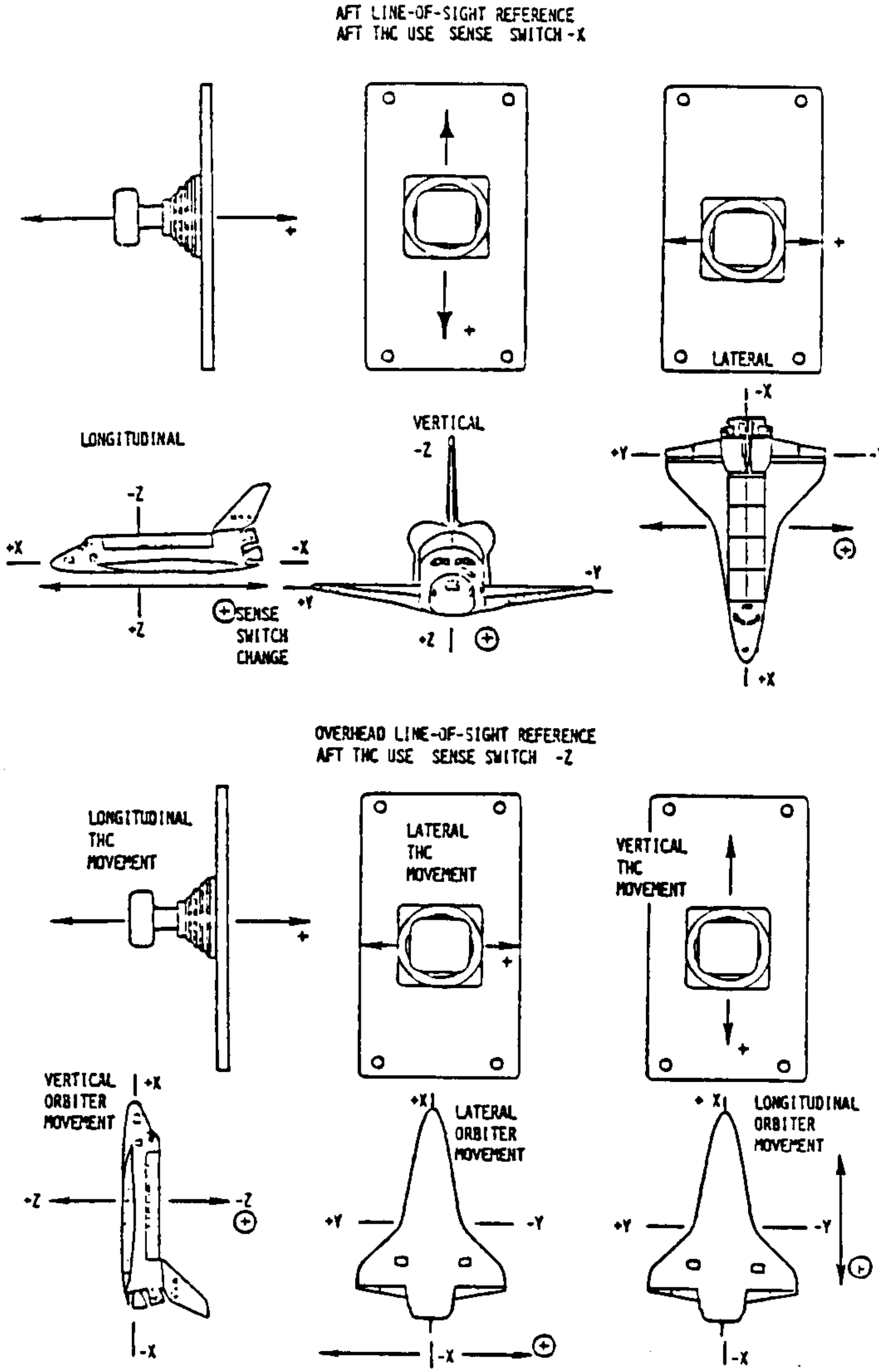


Figure 3-4B.- Aft and overhead line-of sight references, aft THC use.

3.1.4 Attitude Direction Indicator (ADI)

The ADI is a crew-observed hardware instrument that provides indications of the Orbiter pitch, yaw, and roll attitude via a gimballed ball (fig. 3-5).

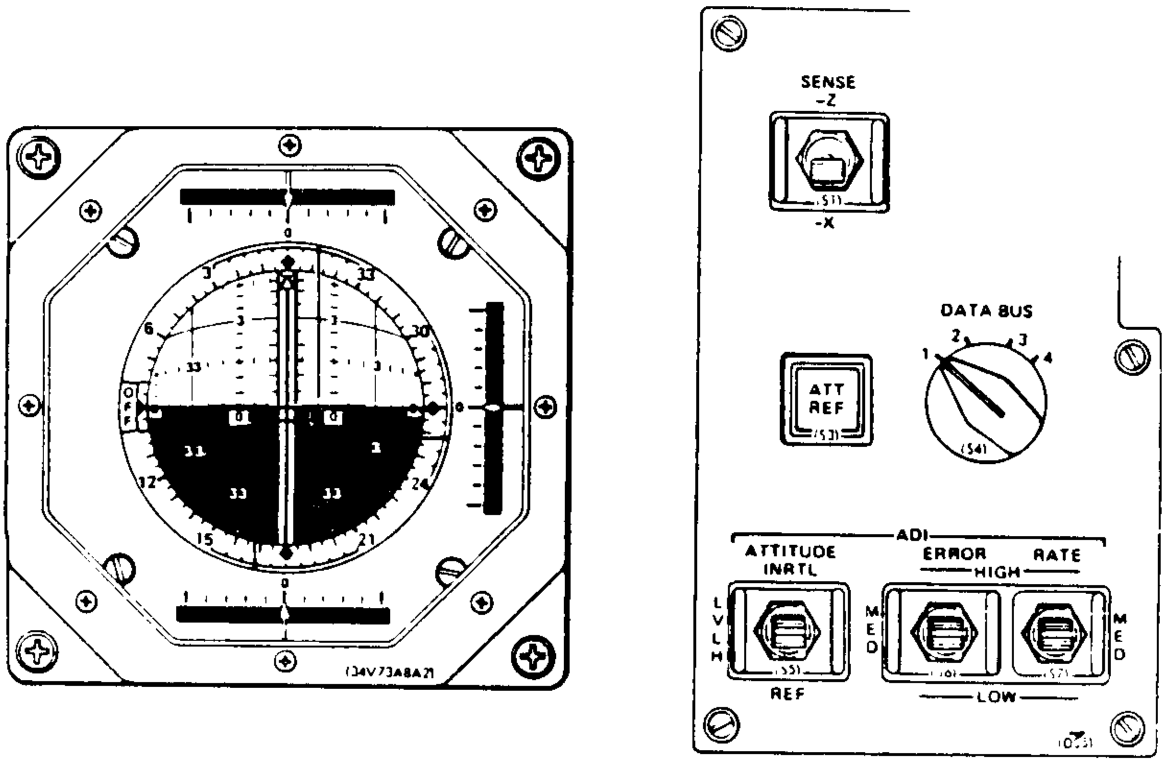


Figure 3-5.- Aft station ADI displays and controls.

Attitude errors are shown by three metered position needles; attitude rates are indicated by three metered position pointers. Top is roll, right side is pitch, bottom is yaw. The scale for each of the three ADI's is controlled by the ADI scale switches; the aft switch is on panel A6U. Each ADI can be set to an error level of high, medium, or low (10, 5, or 1, with the units "degrees" (error) or "deg/s" (error rate)); RNDZ procedures call for selection of "MED." When change from AUTO to MAN is made on the DAP, the ADI error needles will reflect the desired tracking or MNVR attitude loaded on UNIV PTG. See section 3.1.1.2 for the effect of ERR TOT/DAP selection.

The ADI error needles change when the DAP is moded to LVLH. The error needles go to zero. When the LVLH pushbutton is pressed, the current Orbiter attitude is defined as the reference LVLH ADI attitude, making the attitude error zero.

The ADI attitude switch selects the ADI reference frame desired for display on the ADI. The switch selections are INRTL, LVLH, and REF. The INRTL and REF reference frames are defined by I-loaded RELMAT's (inertial system is M50). The crew can also set up their present attitude as the REF reference frame for future reference by pressing the ATT REF pb on panel A6U.

The SENSE switch allows the aft ADI angles to indicate the orientation of either a -X sense axis system or a -Z sense axis system depending on whether the crewmember is viewing through the payload bay (-X) windows or the overhead (-Z) window. These sense-axes systems (-X, -Z) are fixed in the body, and the ADI displays the pitch, yaw, and roll of the sense system axes with respect to the ADI reference frame as defined by the RELMAT. More details on the use of the SENSE switch are in section 3.1.3.

A more detailed discussion of the ADI can be found in the Attitude/Pointing Flight Procedures Handbook.

3.2 DIGITAL AUTO PILOT (DAP)

The Orbiter DAP is controlled by the crew via the DAP CONFIG (SPEC 20) display and the DAP pushbuttons. Different values of attitude/rate deadbands (DB's) and translation/rotation pulse sizes are selected during different mission phases in order to best accommodate the often-conflicting requirements for MNVR timelines, pointing accuracy, and propellant economy.

In practical terms for this application, the major differences between DAP A and DAP B are pulse size for the PROX OPS DAP's and pulse plus rotation maneuver size in the RNDZ DAP's. While in the RNDZ DAP's, when DAP B is called for, it is because a higher maneuver rate is required. That is, DAP A will be used for attitude control with vernier jets and DAP B will be used for attitude maneuver with normal jets. DAP A also has a translational pulse size that is twice as large as DAP B.

3.2.1 DAP Management

The first requirement for RNDZ-specific DAP values is to minimize differences between the standard A1/B1 values and the values for RNDZ (called A9/B6) and for PROX OPS (called A10/B7). Specific differences are justified by phase-unique and payload-unique features (e.g., see section 4.1.66)

For translation pulse, DAP A is traditionally larger than DAP B. For RNDZ, they are 0.1 and 0.05 ft/s; for PROX OPS, they are 0.05 and 0.01 ft/s (the 0.01 value results in the smallest possible pulse size, 80 milliseconds).

For rotation during RNDZ, there is the need for occasional fast maneuvers. The DAP B has a 0.5 deg/s NORM discrete rate. During PROX OPS and most attitude maneuvers during the RNDZ, a slow rotation rate (0.2 deg/s) is used for both DAP's A and B, both NORM and VERN. Occasionally there is a need to maneuver at the higher 0.5 deg/s rate (e.g., post-Ti if radar fails, the crew needs to get back to -Z target track fast to get STRK NAV marks).

For DB's, the large values for A1/B1 are reduced to values which have proven suitable in flight and in ground simulations. For RNDZ and PROX OPS, the values are 2° (NORM) and 1° (VERN) for both DAP's A and B (the standard values are 5/1 and 3/1). The values of these DAP's are shown in figure 3-6.

During the RNDZ, in general DAP A is selected. DAP B is used for higher rotational precision (such as during COAS marks), finer translational control (V-BAR approach), or higher attitude rates (such as during maneuver to/from Ti burn attitude). Jet selection is nominally VERN, with NORM for translation or 0.5 deg/s maneuvers; AUTO is nominally selected, to allow UP control for TGT track or for maneuvering to attitude; MAN is selected to execute burns or for INRTL ATT hold; LVLH is seldom used.

During the PROX OPS phase, in general DAP B is selected for stable periods or where fine translational control is required. DAP A is selected during dynamic operations because of the greater control authority defined by RCS pulse/discrete values. The VERN/NORM and AUTO/MAN selections are the same as during the RNDZ phase. See section 5.1.1.1 for operational details.

For heavy payloads such as Long Duration Exposure Facility (LDEF), the CNTL ACCEL values are set to zero during rendezvous and PROX OPS.

Note: The upper and lower limits on selectable DB parameters are as follows for NORM (VERN) jets:

attitude hold (deg)	0.10 (0.01)	to 40 (40)
discrete rate (deg/s)	0.05 (0.002)	to 2 (1)
rot pulse (deg/s)	0.04 (0.001)	to 1 (0.5)
trans pulse (ft/s)	0.01	to 5

	RENDEZVOUS		PROX OPS		SPEC 20 ITEM NO	
DAP	A9	B6	A10	B7	A	B
TRANSLATION						
PULSE FT/SEC	0.10	0.05	0.05	.01	1	15
ROTATION						
DISC RT NORM	0.200	0.500	0.200	0.200	2	16
DISC RT VERN	0.200	0.200	0.200	0.200	3	17
PULSE NORM	0.10	0.04	0.10	0.04	4	18
PULSE VERN	0.010	0.002	0.010	0.002	5	19
DEADBAND						
ATT NORM	2.00	2.00	2.00	2.00	8	22
ATT VERN	1.000	1.000	1.000	1.000	9	23
RATE NORM	0.20	0.20	0.20	0.20	10	24
RATE VERN	.020	.020	.020	.020	11	25

Figure 3-6.- DAP configurations for rendezvous/PROX OPS.

The tail-only/nose-only option is not currently planned for use. However, multiple jet failures, vernier reaction control system (VRCS) failures, or forward prop being critically low, may lead to such a configuration.

3.2.2 DAP Configuration (SPEC 20)

DAP CONFIG (fig. 3-7) is a GNC specialist function available in OPS 2. Among other things, it allows the crew to specify the size of attitude and rate DB's and the magnitude of discrete/pulse RCS attitude/translation maneuver's.

Two sets of numbers are maintained (designated "A" and "B") and can be readily changed during a flight. In practice, the primary difference between DAP A and DAP B will be the translation pulse size, with DAP A having the larger. Selection of "A" and "B" is via console pb (section 3.2.3.).

The significance of the DAP A(B) item entries is as follows:

- 1(15) is PULSE, a means of specifying the desired ΔV (ft/s) resulting from a single THC deflection. Multiple deflections are additive.

```
XXXX/020/            DAP  CONFIG        XX X DDD/HH:MM:SS
                                             DDD/HH:MM:SS
TRANSLATION               A             B
 PULSE              1   X.XX   15     X.XX

ROTATION
 DISC RATE NORM     2  X.XXX   16    X.XXX
           VERN     3  X.XXX   17    X.XXX
 PULSE     NORM     4   X.XX   18     X.XX    INERTIAS
           VERN     5  X.XXX   19    X.XXX   29 IX X.XXX
 COMP      NORM     6    .XX   20      .XX   30 IY X.XXX
           VERN     7   .XXX   21     .XXX   31 IZ X.XXX

DEADBAND
 ATT       NORM     8  XX.XX   22    XX.XX
           VERN     9 XX.XXX   23   XX.XXX

 RATE      NORM    10   X.XX   24     X.XX
           VERN    11   .XXX   25     .XXX

JET OPT       P    12      X   26        X
              Y    13      X   27        X

CNTL ACCEL         14      X   28        X
                                                      (XX)
```

Figure 3-7.- The DAP CONFIG (SPEC 20) display.

- 2(16) and 3(17) are DISC RATE for primary and vernier jets respectively; they are used to specify the desired rotational rate (deg/sec) to be achieved for a discrete rate manual command (MAN or MAN LVLH), or for an AUTO MNVR, AUTO MNVR to TRK attitude, and for AUTO ROT.

- 4(18)/5(19) are PULSE, or the primary/vernier values used to specify the rotational rate (deg/s) resulting from each single manual RHC pulse command. Multiple deflections are additive.

- 6(20)/7(21) are COMP, used to specify the threshold ROT rate (deg/s) for a given axis resulting from a rate command about another axis. When that threshold is reached, the DAP will command jets to reduce the rate. Note that an entry of zero implies that the DAP will attempt to compensate for all cross-coupling, but it actually disables ROT compensation. Minimum entry to enable ROT COMP is 0.113 deg/s primary RCS (PRCS) and 0.003 deg/s (VRCS).

  At the present time, ROT COMP is not used nominally, due to high fuel use and incompatibility with any DAP mode other than free drift. Instead, normal DAP attitude hold is used to minimize undesired cross-coupling effects.

- 8(22)/9(23) is attitude (ATT), used to specify the attitude DB's (degrees) for primary/vernier jets.

- 10(24)/11(25) is RATE, used to specify the rate DB's (deg/s) for primary/vernier jets.

In addition, various jet options can be selected (for primary jets only). The options are "normal" (1), "nose only" (2), and "tail only" (3). For pitch, one can choose the option with item 12(26); for yaw, the choice of option is via item 13(27); there is no option for roll, since it is always tail only, PRCS. Translations are always "normal"; control is always "normal" anytime VRCS is selected.

3.2.3 DAP Pushbuttons

The DAP pb's on panel A6 (fig. 3-8) allow selection of various control modes in the Orbiter response to RHC/THC input commands from a crewmember or AUTO commands from the DAP. An identical set of pb's is on panel C3. Note that the specific DAP lights illuminated on the forward and aft panels will not necessarily be identical. In particular, since the forward RPY indicators are always in the +X sense while the aft RPY indicators can be in -X sense or -Z sense, any mixed configuration (e.g., DISC-PULSE-DISC) may not look the same on both panels. Thought must be given to which axis in which sense is being specified by each light.

The on-orbit DAP functions are DAP A or B with AUTO, MAN, or LVLH rotation modes selected, and a choice of NORM or VERN jets. There is also a choice of DISC RATE, ACCEL, or PULSE manual (MAN) ROT submodes selectable by axis. With NORM jets selected, the following translational submodes are available: PULSE and NORM (ACCEL) in all axes, HIGH Z (high ACCEL), NORM Z, and LOW Z (upfiring jets inhibited always) for +Z translations.

DAP's A and B each represent different sets of control parameters for the DAP. These parameters can be seen on the DAP CONFIG specialist function (SPEC 20), and can also be changed through keyboard item entries on this display (section 3.2.2). These changes are invoked after the item execution, if the parameter changed is applicable to the currently selected DAP (A or B and NORM or VERN). The following modes and submodes are available for DAP on-orbit operation.

3.2.3.1 AUTO/MAN Selection

AUTO enables execution by the DAP of AUTO maneuvers commanded by use of the UNIV PTG display (section 3.1.1); MAN enables execution of the selected ROT submodes manually commanded through the RHC.

Note: Any input from an RHC causes automatic downmode from AUTO to MAN.

3.2.3.2 LVLH

With DISC RATE selected in all three axes and with the LVLH mode selected, the LVLH attitude that existed at the time of selection of LVLH will be held fixed within the LVLH frame until changed by use of the RHC. The RHC can be used with LVLH selected to change the LVLH attitude. While out of detent, the Orbiter maneuvers at DISC RATE. When the RHC returns to detent in any axis, the LVLH attitude in that axis is held fixed again. This mode would be used manually for precise PROX OPS attitude control in the near vicinity of a target, an example being flyaround (section 5.2) of an LVLH-stabilized target.

Note: For LVLH mode to work, at least one ADI must be in LVLH mode. Otherwise, required computations will not be performed and resulting attitude will be unpredictable.

3.2.3.3 NORM/VERN Jet Select

Primary RCS (PRCS or NORM) and vernier RCS (VRCS or VERN) jets can be used for attitude hold and maneuvers. NORM jets must be selected for translation maneuvers. With primaries selected, there is a choice through the DAP CONFIG display (SPEC 20) via the JET OPT for tail jets only, or nose jets only to be used for pitch/yaw control (in VRCS rotation is always a combined tail/nose function).

3.2.3.4 Translation Submodes (NORM Jets Required; MAN, MAN LVLH, and AUTO)

- PULSE X, Y, or Z - With this submode selected, each deflection of the THC will result in a change in velocity of the magnitude specified for TRANSLATION PULSE on the DAP CONFIG display for the selected DAP (A or B) in the axis and direction (+ or -) of the THC deflection.

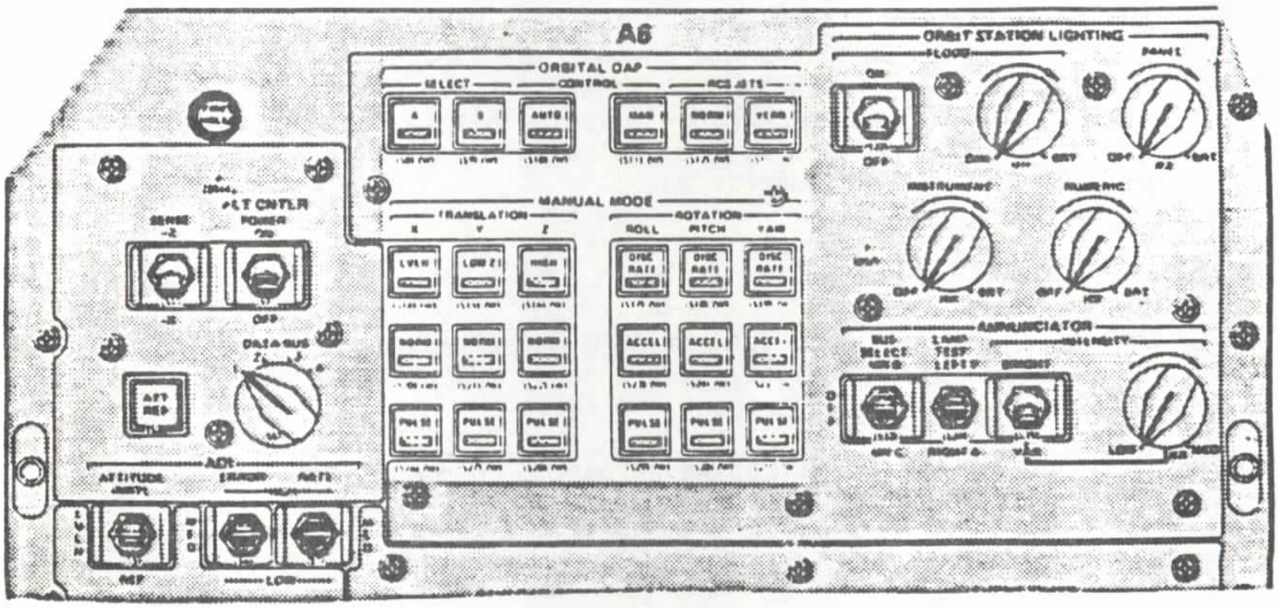


Figure 3-8.- Panel A6.

- NORM, X, Y, or Z - With one of these submodes selected, continuous acceleration will occur at whatever level is available with the commanded jets for the axis and direction (+ or -) of the THC deflection as long as the THC is deflected.

- HIGH Z - An ACCEL submode that is available for +Z translation only. Selection of this submode fires more jets than are fired for the NORM =Z command. This option is currently not used.

- LOW Z - Low Z is a submode that takes advantage of some +Z thrust components that exist for both the +X and -X translational jets. To get the +Z translation, the +X and -X translational jets are fired simultaneously so that the jets nearly cancel the X components of each other and combine the small +Z components. The result is a small +Z velocity change at about 10 times the normal prop usage. See section 3.2.4 for applications. The RCS plume overpressures for low Z MODE versus NORMAL Z MODE are shown in figure 3-9. Low Z translations also affect pitch and roll, since upfiring jets are inhibited. This results in significant -Z translational cross-coupling (see section ~~6.2.1~~ 3.8.1), but reduces the duty cycle for attitude maintenance.

huh?

3.2.3.5 Manual Rotational Submodes

- DISC RATE - ROLL, PITCH, or YAW - With the DAP mode MAN and the submode DISC RATE, when the RHC is deflected out of the detent (but not past the soft stop) in an axis, jets are fired until an angular rate is achieved in that axis equal to DISC RATE specified in the DAP CONFIG display for the selected DAP (A or B) and selected jet option (NORM or VERN). When the rate is achieved, the jets are turned off until the RHC is returned to detent in that axis unless the jets are momentarily required to maintain attitude or rates within the DB's. When the RHC is returned to detent in an axis, the attitude in that axis is snapshotted and jets are fired to stop the rate in that axis and to begin holding the snapshotted attitude.

  If the RHC is deflected beyond the soft stop while in DISC RATE (and any DAP mode/submode), jets are fired continuously, giving a constant angular acceleration (in the axis and sense of the RHC deflection) until the RHC is backed out of the soft stop, at which time the jets are turned off. When the RHC is returned to detent, the attitude is snapshotted and jets are turned on to stop the angular rates and initiate hold about the snapshotted attitude. In effect, this provides an ACCEL mode if the RHC is deflected past the soft stop, and a free drift mode when returning the RHC from the soft stop while between the soft stop and detent. See figure 3-2 in section 3.1.2.

- ACCEL - ROLL, PITCH, or YAW - When the DAP mode is MAN/ACCEL and the RHC is deflected out of detent, a fixed number of jets is fired to provide constant angular acceleration as long as the RHC is out of detent in the axis and sense of the deflection. When the RHC is returned to detent, the jets are turned off, but the angular rates continue. The result is a free mode since the attitude is uncontrolled when the RHC is in detent (free drift at the existing angular rates).

- PULSE - ROLL, PITCH, or YAW - When the DAP mode is MAN/PULSE and the RHC is deflected out of detent, jets are fired just long enough to achieve the angular rate change specified on the DAP CONFIG display for rotation pulse for the axis and sense of the RHC deflection. PULSE is also a free drift mode.

3.2.3.6 Applications

These DAP options can be used as follows:

For free drift, select MAN PLS/PLS/PLS. See section 5.4.1.5 for example.

For inertial attitude hold, select MAN DISC/DISC/DISC. See section 4.1.61 for example.

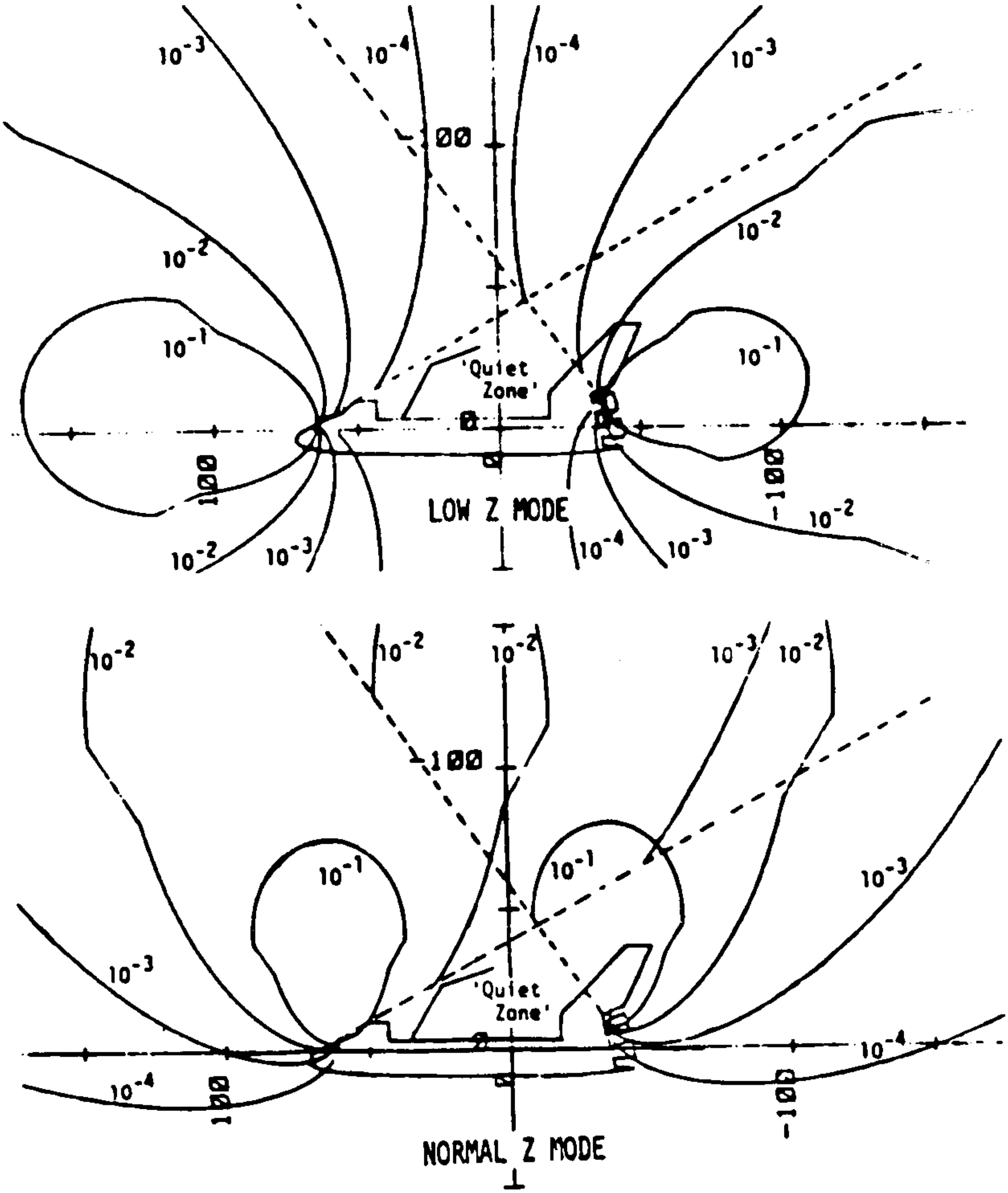


Figure 3-9.- RCS plume overpressure for LOW Z and NORMAL Z mode (lb/ft^2).

3.2.4 Low Z Operations

3.2.4.1 Plume Impingement (PI) Issues

Within about 1000 feet, attention should be given to effects of RCS jet firings. One effect is contamination by combustion products and/or unburned propellants; the other effect is disturbance of the target attitude and position by the plume overpressure. Choice of low Z mode (and the expense associated with it) is made based on those factors. Due to shadowing by Orbiter structure, a target close above the PLB may be out of the RCS plumes, and normal Z mode may be resumed while the target remains in this zone (see fig. 3-9). A full discussion of propellant plume issues is found in section 3.8.2.

3.2.4.2 Low Z Operations

The low Z DAP mode (mentioned in section 3.2.3.4 and described and illustrated in section 5.3.1.2) was designed to minimize both types of RCS PI on targets. A given technique that offers acceptable PI effects in one of these areas may or may not satisfy acceptable limits in the other. Low Z does minimize PI effects at a direct cost of about 10-12 times the NORM Z fuel usage. However, the penalty of low Z operations is not limited to this increase in fuel usage. Due to cross-coupling effects (see section 6.2.1) 3.8.1 resulting from braking, -X translations, and VRCS attitude control, only about one-half of a given commanded braking pulse is actually received. Further, there is a tendency for rapid buildup of a closing rate during stationkeeping or precisely scheduled range/range-rate V-BAR approaches, due in large part to cross-coupling from +/- Y translations. These rates can reach 0.2 ft/s or more, requiring more braking, resulting in a vicious circle. These effects can be particularly serious when trying to establish V-BAR stationkeeping following the manual phase of the RNDZ, either while in low Z mode, or especially if the low Z mode is selected prematurely. Prop usage rates of 8 to 12 pounds per minute are not unheard of (4-6 pounds per minute is more common), much higher than the 1 to 1.5 pounds per minute for normal stationkeeping. Usage can be controlled to 2 pounds per minute or less by taking great care in stabilizing on the V-BAR at the precise position required for the desired range (see PROX OPS cue card, section 4.3.5) prior to selecting low Z. Stabilizing on the V-BAR following a RNDZ in the low Z mode is not recommended. 6

Flight experience has revealed several common mistakes involving use of low Z mode. First, during approach, some crews have exited low Z mode using loss of radar lock (80 to 90 feet) as the cue, when in fact the target is not yet in the Orbiter body "shadow" (less than 50 to 60 feet range, directly over the PLB). Second, during PROX OPS, the low Z mode select pb may be pushed repeatedly, leaving the DAP back in low Z when the pilot believed it was in NORM Z. Great care must be exercised since propellant consumption can be critical and, under marginal conditions, be cause for calling a PROX OPS BREAKOUT if usage is excessive.

3.3 RENDEZVOUS/PROX OPS SENSORS

Prior to the day of RNDZ, on-board NAV sensors are not required since the ground is targeting all MNVR's and the relative separation of the Orbiter and TGT is sufficiently large. On the day of RNDZ, with no functioning NAV sensors, flight rules specify to proceed to Ti (this is done in the hope of acquiring sensor data or visual acquisition) and then breakout post-Ti if no acquisition.

3.3.1 Star Tracker

The two star trackers (STRK or S TRK) (-Y and -Z) are nominally used to take sightings on stars so as to align the IMU's. They also can track TGT satellites and provide angular data for use in onboard relative NAV. Their nominal TGT brightness range is from +3 to -8 stellar magnitude (brightness is monitored in the MCC, but is not displayed on board).

During RNDZ operations, the purpose of the star trackers is to provide Orbiter body-axis measurements of the TGT LOS. This is called "target track mode."

Lighting constraints limit STRK operations to conditions when the TGT is illuminated. For a standard RNDZ profile from behind and below, this occurs during the period between orbital noon and sunset. This period could be extended if the TGT has appropriate artificial lighting systems. Such extensions should help reduce dispersions in a radar fail case.

3.3.1.1 Control Switches

The STRK control switches are found on panel O6 (fig. 3-10) and involve power and door control. Door position is shown on talkbacks.

3.3.1.2 Capabilities

Each STRK has a 10° x 10° square FOV. There is a bright object sensor (BOS) which closes a protective shutter (or door) over the STRK optics when the STRK is pointing within 16° to 19° of the sunlit Earth limb, or 30° of the Sun or 8° of any other magnitude -12 object, (e.g., the Moon).

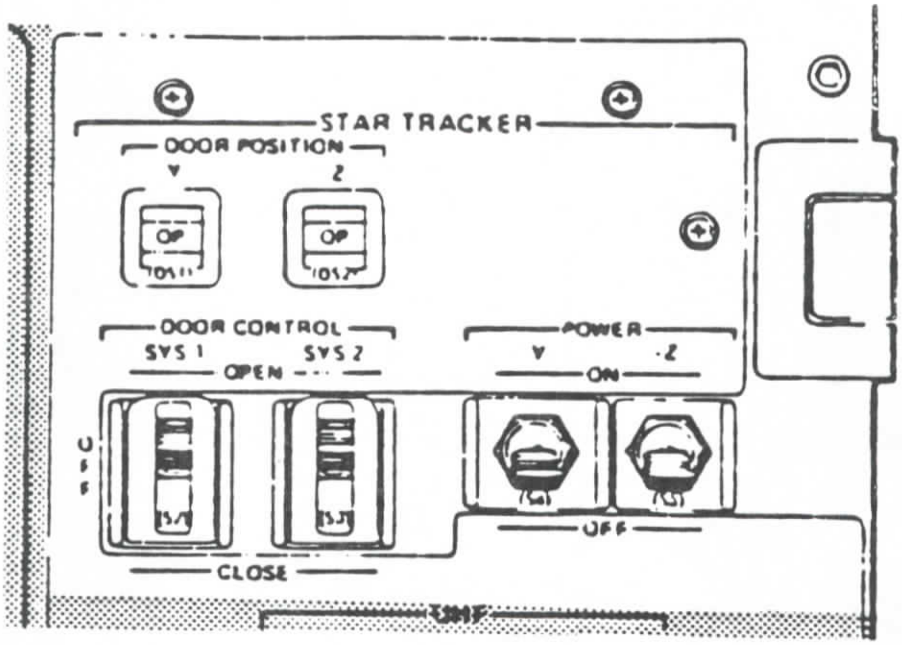


Figure 3-10.- Panel 06.

Newer data?

On STS-8, STRK tests were conducted near the sunlit Earth limb. The lowest +3 magnitude star angle above horizon at acquisition was 13°, when the boresight angle was 12°. Background noise and false tracks increased dramatically after this last track. Lower angles might be possible by offsetting the boresight to above the target, or by use of STRK thresholding (ITEM 13, 14) for brighter TGT's (this option is not currently utilized). Angles below 5°-7° are considered impossible due to the horizon in the FOV. All baselined RNDZ profiles involve targets 20°-30° above the limb.

When the shutter is closed, the crew gets a closed indication, but cannot tell if it was due to the TGT suppress (TS) or BOS. The hardware fix for this included raising the TS spec limit from -8 magnitude to -12 magnitude, and setting the TS to 1 magnitude brighter than the BOS. The TS range for OV 102 and 099 (-8 magnitude) was 1.7 n. mi. for Solar Maximum Mission (SMM) and 1.4 n. mi. for integrated rendezvous target (IRT), and in fact on STS 41-C the shutter did close during RNDZ at a range of about 1 n. mi.

When commanded to track a TGT, the STRK will center on coordinates provided by NAV and will search a 1° by 1° square. If after 4 seconds the TGT is not acquired, the STRK will search its entire FOV for 20 seconds, at which time a warning message is displayed to the crew if the TGT was not found. If the TGT is acquired, the STRK scans a 12-arc second cruciform track centered on the TGT every 42 milliseconds. The TGT will be tracked until it leaves the FOV or the STRK is commanded to stop.

Once locked on, tracking continues across the FOV at up to 0.2 deg/s with guaranteed accuracy and up to 0.5 deg/s with reduced accuracy.

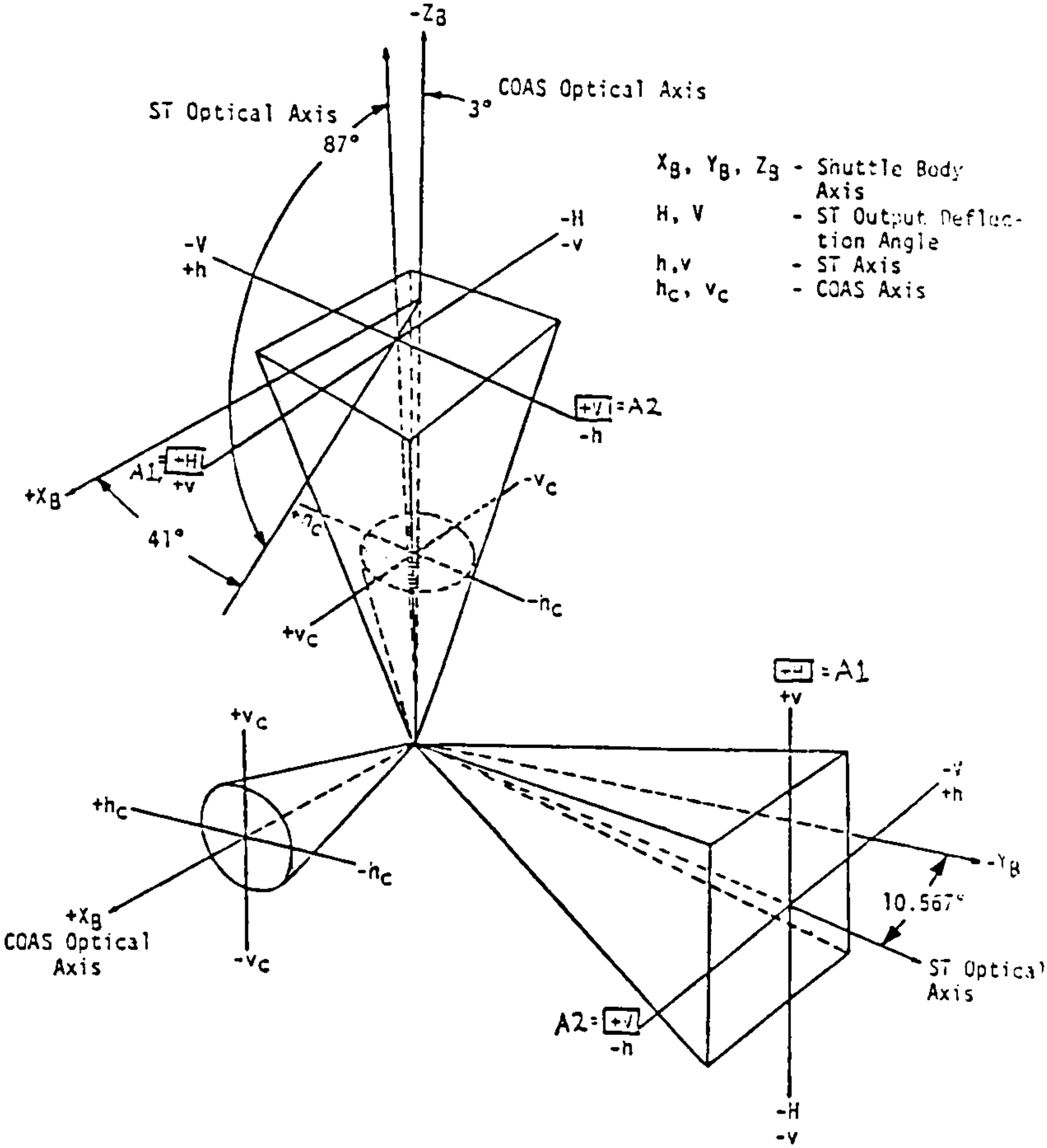


Figure 3-11.- STRK/COAS geometry.

If the TGT passes within 1/4° of a bright star, the lock may jump over to that star. The filter will recognize this if it has already processed enough data; the remedial action is to break track and search again.

There is a potential problem with Orbiter-related trash (or ice), which could remain in range for a few REV's. The Y STRK is particularly susceptible to picking up ice shaken loose from a previous water dump.

Star sighting data from the first seven STS missions indicated a total star sighting one-sigma error of 0.016°. This includes STRK bias and noise, as well as IMU structural and resolver errors. The error is far less than the specification value. Newer?

3.3.1.3 Lines of sight

The orientation and coordinate systems of the STRK are shown in figure 3-11. The optical axes of the STS are slightly offset from the Orbiter axes. For -Z, it is inclined 3° in a plane rotated 41° from the Orbiter +X axis toward the -Y axis; for -Y, it is in the Orbiter X-Y plane and is rotated 10.567° from the Orbiter -Y axis into the +X axis. For precise Orbiter pointing, therefore, the boresighted trackers are:

	P	Y	OM
-Y	0	280.6	90
-Z	87.7	358	0

Note: For the -Z STRK, for procedural convenience, pointing is usually done along the pure -Z axis, which introduces several degrees offset from the precise boresight. If the combination of SV pointing error and attitude deadbanding is large enough and in the appropriate (or inappropriate, from the Orbiter point of view) direction, the TGT could be out of the FOV. For this reason, small attitude DB's (0.5°) are recommended for target acquisition. Pointing the exact -Z STRK boresight may slightly improve this problem as well.

3.3.2 S TRK/COAS CNTL (SPEC 22)

S TRK/COAS CNTL (fig. 3-12) provides a means of monitoring and controlling STRK operation. It also provides data and controls for COAS operation and calibration, as well as supporting data for IMU alignments.

The STRK can be placed in the TGT track mode via Items 5 and 6 (OPS 2 only). These are mutually exclusive: putting the second STRK in TGT TRK will automatically downmode the first one to TERM/IDLE. For each STRK, TGT TRK and STAR TRK are mutually exclusive; however, one STRK can be in TGT TRK while the other is in STAR TRK. Normally the -Z STRK will be selected. Angle data from the STRK is treated in the REL NAV display (section 3.4).

```
XXXX/022/        S TRK/COAS CNTL   XX X DDD/HH:MM:SS
                                        DDD/HH:MM:SS
 S TRK CNTL -Y   -Z      S TABLE     1       2      3
SELF-TEST   1X   2X     TRK ID      XXX     XXX    XXX
STAR TRK    3X   4X     Δ MIN       XXX     XXX    XXX
TGT TRK     5X   6X     ANG DIF   XXX.X   XXX.X  XXX.X
BREAK TRK   7    8          ERR   XX.XX   XX.XX  XX.XX
TERM/IDLE   9X  10X     SEL         17X     18X    19X
                        S TABLE CLR 20

 S TRK         -Y          -Z         COAS
REQD ID     11 XXX      12 XXX      REQD ID       21  XXX
TRK ID         XXX         XXX      ΔDEG X           ±X.X
S PRES           X           X           Y           ±X.X
ΔANG         ±X.XX       ±X.XX      SIGHT MODE    22X
THOLD       13   X      14   X      ACCEPT        23
SHUTTER         XX          XX      CAL MODE      24X
  MAN OP    15X         16x         DES           25X
STATUS      XXXXXXXXX XXXXXXXXX     POS    +X 26X   -Z 27X
            XXXX        XXXX        ΔBIAS    X.XX      X.XX
                                    UPDATE   28        29

                                                     (XX)
```

Figure 3-12.- The S TRK/COAS CNTL display.

The "S PRES" (STAR PRESENT) indicator signifies that lock-on (and closed-loop tracking) has begun.

The shutter for the -Y (-Z) STRK can be locked open by selecting ITEM 15 (16). This should be done only after the crewmember has made a visual check out the appropriate window to confirm that no bright object is within 30° of the tracker LOS. The shutter control should be placed in the AUTO mode as soon as possible because direct exposure to a bright source could cause a tracker to fail.

Note: In flight, on rare occasion the crew has had to perform ITEM 15 to manually open the shutter.

3.3.2.1 STRK Target Acquisition

This step occurs during RNDZ operations, as shown in section 4.1.11 and 4.1.21. The steps are shown in figure 3-13; steps dealing with REL NAV are discussed in section 4.1.13.

3321' IMU DES One of the orbiter IMU's is deselected if the Orbiter is currently operating at the three-IMU level. This is done to force IMU redundancy management (RM) to remain locked onto a single IMU (the lowest numbered one) for

```
        GNC 21 IMU ALIGN
CRT     IMU DES - ITEM 7 (8,9) EXEC (*)
        (per PAD)

        GNC 22 S TRK/COAS CNTL
CRT     -Z(-Y) TGT TRK - ITEM 6(5) EXEC (*)
            √STATUS    - blank
            √SHUTTER   - OP
            √S PRES    - *

        GNC 33 REL NAV
CRT     √INH Angles, ITEM 24 - (*)
        √S TRK, ITEM 12 - (*)
        √SV SEL, ITEM 4 - PROP                      [1]

Record  ~~Monitor RESID V and H each NAV cycle~~

        If RESID V and H change < 0.05 for
          four consecutive NAV cycles (~31 Sec),
          If RATIO < 1.0,
             AUTO Angles - ITEM 23 EXEC (*)        [2] Record POS u/D
          If RATIO > 1.0,                          [3]
             FORCE 3 Angle Marks
          If RATIO > 1.0,
             call MCC >>
        If RESID V or H changes by > 0.05,

        GNC 22 S TRK/COAS CNTL

          -Z(-Y) BREAK TRK - ITEM 8(7) EXEC

        When SV UPDATE POS < 1.0                    [1]
         and MARK ACPT Angles > 9,                  [1]
         SV SEL - ITEM 4 EXEC (FLTR)                [1]

                      ~~NOTE~~
        If FLTR minus PROP changes by more than
        40K ft within a S TRK pass, then
        SV SEL - ITEM 4 EXEC (PROP)
        INH Angles - ITEM 24 EXEC (*)
        PROP TO FLTR transfer - ITEM 9 EXEC

        GNC 22 S TRK/COAS CNTL

        -Z(-Y) BREAK TRK - ITEM 8(7) EXEC
        Repeat S TRK TARGET ACQ
```

Figure 3-13.- S TRK TARGET ACQ procedure.

Notes:

[1] Omitted on subsequent acquisitions
[2] Subsequently, always precede with: FLTR to PROP - ITEM 8 EXEC
[3] Subsequently, there are three stages for recovery (4.1.22)

attitude data throughout the STRK pass (see section 3.9.4 ~~6.3.4~~). The reason for this is as follows. At the three line replaceable unit (LRU) level, RM midvalue selects IMU data for use as attitude reference. Under normal operations all three IMU's are closely aligned and RM cycles between the units. Although the slight amount of misalignment between the units is not enough to affect most Orbiter operations, it is enough so that when applied to the STRK data in NAV it adds unnecessary noise to the SV calculations.

Note that the attitude deltas between IMU's is very small and is of concern because the STRK's are extremely accurate pointing instruments, and the slight attitude reference deltas show up as SV updates. When operating using RR or COAS as the source of angular data on the TGT, the IMU deselection is not required due to the granularity of RR and COAS angle data.

33212 Measurement incorporation will be inhibited prior to sensor acquisition. This allows the crew to assess the quality of the data prior to its incorporation into the filter.

33213 The STRK's are commanded to the TGT track mode. This configures the data path such that the STRK software gets its pointing designate information from the NAV function for initial TGT lock-on. The STRK status is also verified satisfactory with no error messages, an open shutter, and an indication of TGT sighting. The informational displays for each tracker (REQD ID through STATUS) work the same way for a TGT as they do for a star.

During its search, the STRK first covers a 1° by 1° cruciform pattern centered about the designated pointing offsets. If a TGT acquisition is not accomplished during the offset scan, the STRK scans the entire 10° by 10° field of view in a raster scan pattern (see fig. 3-14). The offset scan is accomplished in approximately 4 seconds, and the full field scan takes 20 seconds. At the end of this time, if the STRK has still not acquired the target, the STRK waits in idle until it receives another search command. The STRK software issues the search command every 60 seconds.

The "no target" status is displayed after one search has failed, until the next search is commanded.

A bad STRK can be distinguished from a bad NAV state by using the COAS. At STRK acquisition, the crew sights the TGT through the COAS. If the TGT is centered while the residuals and ratios are high, the NAV state is good and the tracker is bad. If the TGT is not centered, the NAV state may be off and the tracker may (or may not) be bad.

33214 To determine if the tracker has locked on to something other than the TGT, the crew must watch the STRK RESID V and H values on the REL NAV display. If the values change by more than 0.05 every NAV cycle, then the tracker has locked on to something other than the TGT. For example, the residuals would change approximately 4° per minute, if the tracker were locked on to an inertially stable object (a star). To force the tracker to resume looking for the TGT, a BREAK TRK should be executed for that STRK. Flight experience has shown that occasional star lock-ons can be expected.

33215 Variation

The second STRK acquisition is somewhat modified (see section 4.1.20 and 4.1.22). Procedures for STRK fail cases are discussed in section 4.4.1.

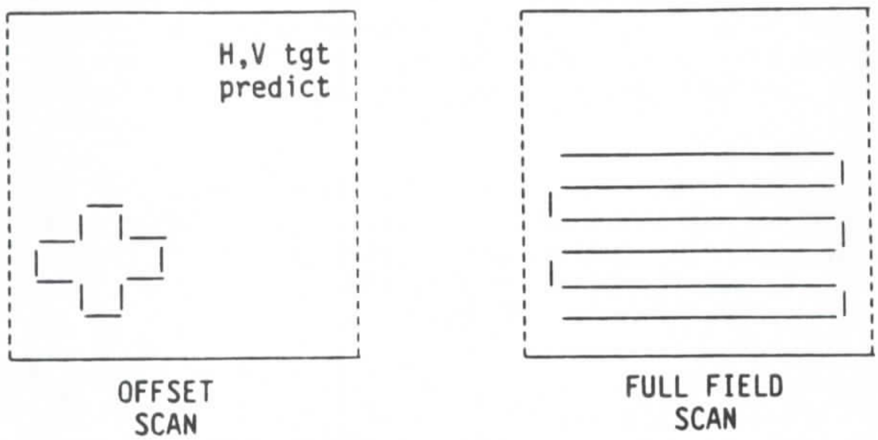


Figure 3-14.- STRK search pattern.

3.3.2.2 End STRK NAV PASS

This procedure is shown in fig. 3-15; it is called out from sections 4.1.16 and 4.1.25 in the RNDZ procedure narrative.

The crew inhibits the sensor data path to the NAV filter in order to be sure that no erroneous data gets incorporated into the SV calculations. The most likely false lock-on would be to a star, and this is quite likely to happen after sunset.

The crew places the STRK's in the terminate/idle (TERM/IDLE) mode to eliminate the cyclic displaying of NO TARGET to the crew while the target is not sufficiently illuminated to support acquisition.

Finally, the crew reconfigures to the nominal on-orbit three-IMU set after the STRK pass is complete.

CRT	GNC 33 REL NAV
	INH Angles - ITEM 24 EXEC (•)
	GNC 22 S TRK/COAS CNTL
	-Z(-Y) TERM/IDLE - ITEM 10(9) EXEC (•)
	GNC 21 IMU ALIGN
	IMU DES - ITEM 7 (8,9) EXEC (no •)

Figure 3-15.- END S TRK NAV procedure. ✓ ok

✓

3.3.3 Crew Optical Alignment Sight (COAS)

The COAS is a sighting unit that can show TGT position relative to either Orbiter -Z or +X axes. The unit bolts into position either on panel 01 in front of window W3 (for +X view, from commander (CDR) seat), or on panel 019 below the aft overhead starboard window W7 (for -Z view, from the aft flight deck). The aft overhead window is the standard COAS position for PROX OPS and RNDZ.

During RNDZ operations, the COAS allows the crew to determine Orbiter body-axis angle measurements of the LOS to the TGT. These angle marks can be input to REL NAV if needed (nominal procedures do not use them). TGT LOS angles observed through the COAS are also crucial to manual control after the final midcourse MNVR (section 4.1.61).

The crew uses the COAS to monitor angular position of the TGT relative to the -Z Orbiter axis. If the Orbiter attitude is maintained fixed relative to the TGT inertial or LVLH frame, the Orbiter position relative to that frame can be determined from these angles (e.g., above or below or off to side of desired LOS). Appropriate translation MNVR's can then be made to correct this position.

Proper determination of desired TGT depression angle during PROX OPS is discussed in section 4.3.6.

3.3.3.1 System Characteristics

There is a 5° radius circle of hatch marks in the middle of the COAS FOV. The entire COAS FOV has a radius of 20° (fig. 3-16). The COAS coordinate system is designated "X, Y" which corresponds to vehicle body coordinates. That is, at the aft crew station, crewmember facing aft, +X is "up" in the COAS (and forward along the Orbiter X axis) and +Y is "left" in the COAS (and to the right along the Orbiter Y axis, facing forward).

The -Z axis is not precisely at 0,0 in the COAS FOV (on 099, for example, it was at -0.562, -0.159 at 15 psi). Cabin pressure levels also have measurable effect on COAS alignment, as the crew compartment ceiling flexes. The crew must perform COAS pointing direction calibration for current pressure level, before NAV use.

3.3.3.2 Position Verification

Observation of the TGT position in the COAS can provide a confidence check on the convergence of onboard NAV (the TGT will get closer and closer to the -Z point, slightly offset from 0,0 in the COAS when the Orbiter is in TGT track mode with -Z axis selected.). Also, troubleshooting problems with the -Z STRK involves looking at the target through the COAS to see if some gross NAV error is mispointing the STRK.

RR AUTO TRACK ACQ

A1U KU - AUTO TRK
SLEW ELEV - as reqd to EL = 0
(or to EL as seen in COAS)
SLEW AZIMUTH reqd to AZ = 0
(or to AZ as seen in COAS)
✓KU TRACK tb - gray
If KU TRACK tb - bp,
KU SEARCH - SEARCH (tb-gray)
If no lock-on within one min,
KU-GPC

COAS NAVIGATION

CRT GNC 22 S TRK/COAS CNTL
COAS: SIGHT MODE - ITEM 22 EXEC
REQD ID - ITEM 21 +1 EXEC
GNC 33 REL NAV
INH Angles - ITEM 24 EXEC (*)
If TGT in COAS FOV,
FLTR TO PROP - ITEM 8 EXEC
COAS - ITEM 14 EXEC (*)
A6U FLT CNTLR PWR - ON
DAP ROT: DISC/PULSE/PULSE
DAP: as reqd
RHC: Center TGT in COAS
ATT REF pb - push
If mark acceptable,
CRT FORCE Angles - ITEM 25 EXEC
Repeat COAS marks as reqd

When COAS marks complete,
A6U DAP: A/AUTO/VERN
DAP ROT: DISC/DISC/DISC
FLT CNTLR PWR - OFF

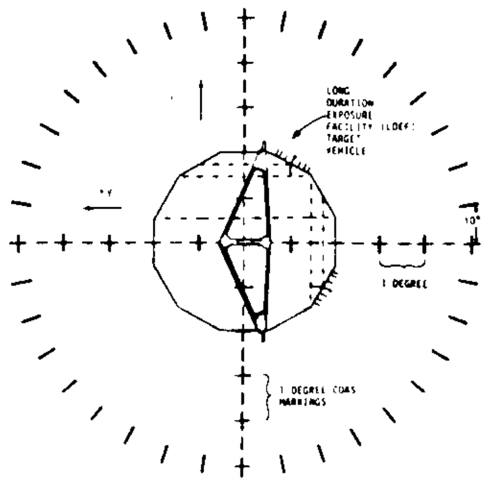


Figure 3-16.- The COAS reticle pattern (-Z view from aft crew station).

3.3.3.3 RNDZ NAV Marks

In a multiple failure case, the COAS can be used to take NAV marks. Since this involves pointing the entire Orbiter (and hitting the ATT REF pb when the TGT reaches the crosshairs), it can be very fuel-expensive and tedious. Generally, one crewmember takes the marks and a second crewmember forces them on REL NAV. The accuracy of this technique remains uncertain.

The operational use of the COAS for NAV is described in section 4.3.3.

3.3.4 Rendezvous Radar (RR)

During RNDZ operations, the RR is GNC's only direct source of R/R-DOT measurements and a secondary source of target LOS angles (STRK angles are more accurate at longer ranges). The RR can also provide angle rate data but when TGT angular size is greater than radar beamwidth (1.6° at 3 dB), beam wandering across the TGT can generate spurious angle rates.

Techniques to enhance radar trackability of the TGT are discussed in section 3.3.10.

The RR shares the steerable 3-foot diameter dish antenna with the Ku-band link to the TDRS. It is a 50-watt pulse system operating around 13.883 GHz, employing frequency agility (cycles through five frequencies to enhance TGT detection and tracking), designed to acquire and track a TGT (with a radar cross section of at least 1 square meter) at a range of 10 miles.

Note: A TGT-mounted transponder could increase that range to 300 miles but no manifested TGT's have such equipment (onboard H/W and S/W could support it). RR hardware design limits skin track ranges to 80 feet minimum and 27.2 n. mi. maximum.

EL and AZ output from the RR are in a body aligned coordinate system centered at the antenna system. The coordinate system is shown in figure 3-17. SHAFT and TRUNNION are in the radar antenna system and RESIDS are computed in that coordinate system.

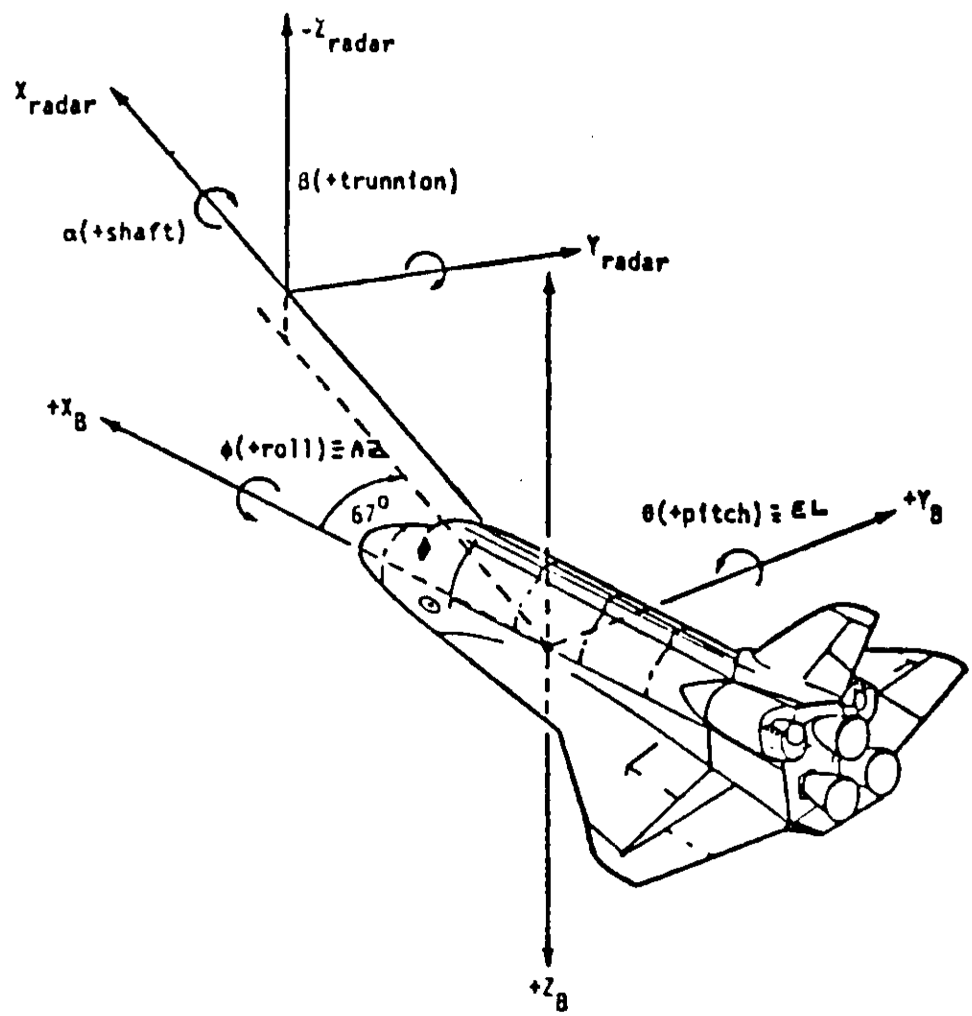


Figure 3-17.- Orbiter body coordinate system and RR coordinate system.

Although the radar can be used in any pointing region not obscured, it is generally assumed that the TGT lies near the -Z axis. In fact, at angles greater than about 30°, radar data becomes too inaccurate for use by RNDZ NAV.

3.3.4.1 Switches

The RR is controlled from panel A1U (fig. 3-18).

The following switch options are available:

- POWER - To go from OFF to STANDBY or ON, warmup takes about 3-1/2 minutes.
- MODE - RDR COOP: Assumes transponder on TGT ~~(see section 8.4.3.2)~~
  - RDR PASSIVE: Assumes skin track only
  - COMM: No RNDZ function

Note: The antenna pointing depends not on MODE (COMM or RDR) but on whether KU ANT ENA (ITEM 2 on REL NAV) is enabled. When ITEM 2 is enabled, the Ku-band antenna TGT-pointing data is shipped from GNC to the SM GPC. This allows SM to automatically point the Ku antenna at the TGT when the KU ANT switch is in the GPC or GPC DESIG position. This is true whether the MODE switch is in the RADAR or COMM position. When ITEM 2 is enabled, TDRS antenna pointing (ITEMS 12, 13, 14 on SM ANTENNA) via the KU ANT switch is inhibited. The TDRS state vector is still maintained by GNC and will be used when ITEM 2 is disabled. See section 3.4.1.3 for details on ITEM 2.

- RADAR OUTPUT - HIGH, MED, LOW: During SEARCH the RR will be cycled through all power levels at or below the switch setting, lower power first. Once lock-on occurs the power is set to the switch setting. If the RR breaks lock and the system is in GPC, 20 seconds later the search begins again automatically, but power level does not cycle unless the designated range is less than 2550 feet; if the switch is in AUTO TRACK, a new SEARCH must be manually initiated, and power level will cycle. When tracking a TGT at a range of 640 feet or less the power level automatically drops from the switch setting level to bypass mode. Automatic downmoding is required only to protect the receiver, and will not necessarily protect the TGT if track is broken or if a SEARCH is initiated. To protect the TGT, the manual downmoding must be used.

  Therefore, in practice, during an approach it is advised to manually switch from high to medium power and from medium to low power at appropriate ranges (2 n. mi. and 1 n. mi. have been proposed for a 1-square meter radar cross section (RCS) TGT, but in practice a signal strength check ~~will~~ be included). This will keep field strength below 20 V/m on the TGT. This is payload dependent, and usually they want low power inside 800 feet.

could ( )

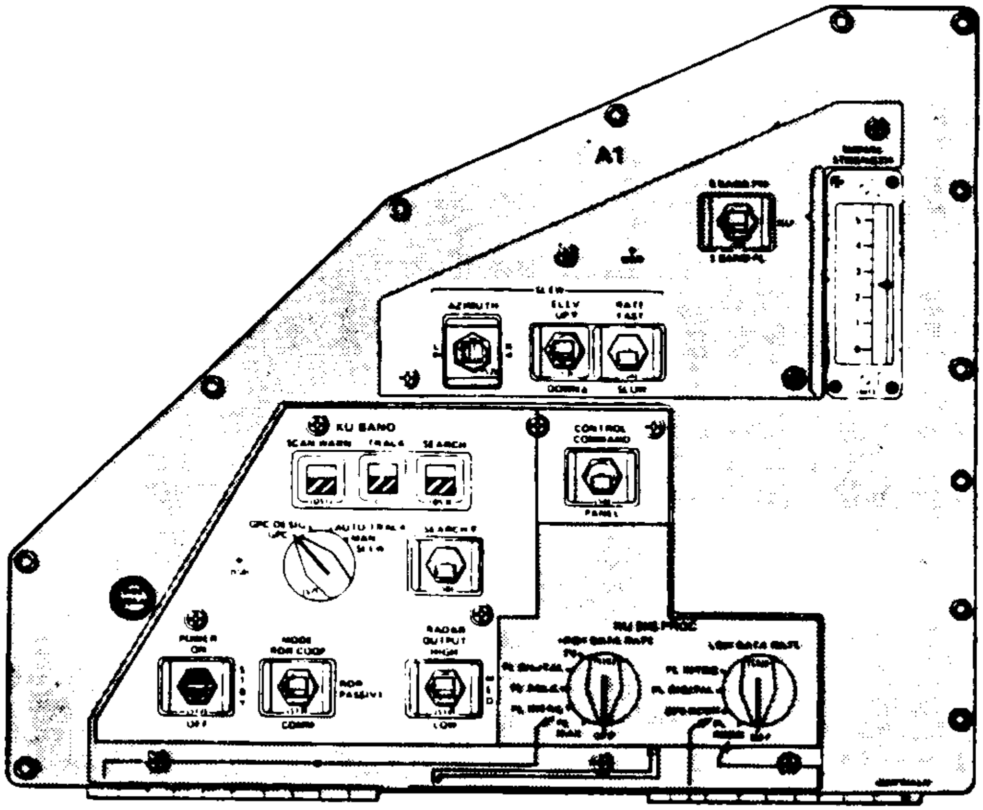


Figure 3-18.- Panel A1U.

- Antenna steering rotary switch (fig. 3-18). These modes and their application to RNDZ are summarized in figure 3-19.

  - GPC: This is "GPC acquisition." The antenna will point to the SM GPC-commanded AZ and EL, and will perform range and closed-loop angle TRK once the TGT is acquired. If the TGT is not acquired, the antenna is automatically commanded to search (in a spiral scan) around the designated point. The angle of search depends on expected range: it is $\pm 30°$ at 8 miles, $\pm 20°$ at 12 miles, $\pm 5°$ at 300 miles.

  - GPC DESIG: The GNC GPC provides a TGT position vector which the SM GPC uses to aim the radar. There is no search pattern initiated. Range/rate data are provided if the SV estimate was close enough and a strong enough signal is returned. No closed-loop angle TRK is provided in this mode, but the designated angles are updated every 2 seconds.

Note: The Ku-band GPC DESIG position should not be selected when the antenna is in the obscuration zone. When the antenna tracks a TGT into the obscuration zone, the GPC reorients the antenna so it can pick up the TGT as it clears the other side of the zone. When GPC DESIG is selected with the TGT in the obscuration zone, the GPC doesn't have any history from which to make a reemergence prediction, so the antenna may rotate around endlessly. This is why the procedures call for RR-AUTO TRK when this situation occurs.

- AUTO TRACK: This begins with manual antenna pointing control, followed by a manually initiated search. The antenna does a spiral scan about the pointing direction at the time search is initiated, at all ranges, to a width of ±30°. Once the TGT is detected, automatic angle and range TRK is provided. Note: The antenna can be manually slewed in this mode. → until TRACK indicator is set

- MAN SLEW: The RR is pointed manually; there is no scan, but all ranges are searched within the 1.6° full-angle (for 3dB) cone of the radar beam. If a TGT is acquired, standard range/rate data are provided. To break track on a TGT, go to MAN SLEW, then slew the antenna away a few degrees until the TRACK talkback (tb) goes barber pole (bp).

  Note: Valid RR angle data is available only in GPC or AUTO TRK modes and if the antenna is free to slew.

- SEARCH (momentary contact) - This command only works if the rotary switch is in AUTO TRACK and no TGT is currently being tracked. The antenna will then begin a spiral search pattern.

- CONTROL - PANEL: The panel switches have absolute control.

  - COMMAND: The only functions which can be commanded from the ground via the ground control interface logic (GCIL) unit despite the current position of the power and mode switches are: COMM power ON/STANDBY/OFF.

Note: Regardless of the control switch position, the ground can uplink six command loads to the SM GPC which will configure the Ku-band system via the serial input/output (SIO): KU/serial I/O enable, range estimate AUTO/MIN, radar self test ON/OFF, antenna inertial stabilization ON/OFF (GPC designate mode only), obscuration mask ON/OFF, and traveling wave tube (TWT) amplifier ON/OFF. There are no current plans to utilize this capability.

- SLEW - These switches allow manual slewing of the antenna. Two rates are allowed: low (0.4 deg/s) and high (20 deg/s). Elevation and azimuth are defined in an Orbiter body frame (see figure 2-16) along the -Z axis, with elevation corresponding to Orbiter pitch (+ is toward the nose) and azimuth corresponding to Orbiter body roll (+ is toward the right looking out OH window; i.e., the port wing).

In man and auto track (pre detect) only

	Uses TGT SV for ant EL, AZ	If not pointed at target*	Angles good to NAV and ADI LOS needles	Perform closed-loop tracking	Rendezvous/ PROX OPS phase usage
GPC ACQ	Yes	Search angle dependent on expected range	Yes	Yes	Normally, always on approach
GPC DES	Yes	No search	No	No	Never (TDRS COMM only)
AUTO TRACK	No	Search to ±30° angle	Yes	Yes	Backup mode to GPC ACQ. Likely to be needed post deploy, then switch to GPC ACQ after NAV converged
MAN SLEW	No	No search	No	No	Possibly for space station at R ≤ 2-3n.mi.

* If pointed at target, RR locks on in all modes.

Figure 3-19.- RR steering modes.

see ONAV cons H/B p. 9-3 (WRTL hold)

- SIGNAL STRENGTH meter - This shows how much power is being reflected back from the target and is a function of range, transmitted power, and radar cross section. discuss units

- TALKBACKS - TRACK is gray if tracking, bp otherwise.

  - SCAN WARN is gray if the beam is within about 5° of the Orbiter body, bp otherwise. When SCAN WARN is on, RF transmission is disabled, but this has been overridden. So for RR OPS the indicator is a NO OP.

  - SEARCH is gray if searching, bp otherwise. After 1 minute maximum, SEARCH automatically times out. It will repeat in GPC acquisition mode about new designate angles after a 20-second delay.

3.3.4.2 Parameters

Range, range rate, azimuth, and elevation are measured along the LOS to the TGT (The RR directly measures relative range rate via Doppler tracking of the TGT). The values are displayed on the REL NAV SPEC function (section 3.4.1) and on an aft crew station dedicated display meter (select R/R-DOT or EL/AZ).

The RR data are displayed on panel A2 (fig. 3-20) with a pair of LED digital displays which represent either range (in kft) and range rate (in ft/s) or (depending on position of the DIGI-DIS SELECT switch) elevation and azimuth angles (degrees, Orbiter -Z reference). The elevation and azimuth inertial LOS TGT angle rates (in mr/sec) are always displayed on a two-D meter (scale is selectable, X1 or X10); the mr (milliradians) unit is useful because multiplying mr/s by range (in kft) gives normal to line of sight (NLOS) rate in ft/s, with respect to an inertial frame centered on TGT. The elevation and azimuth angles and rates allow maintenance of Orbiter position on the TGT V-BAR, even in darkness when the COAS is not usable (see section 4.3.6 for desired c.g.-offset depression angles).

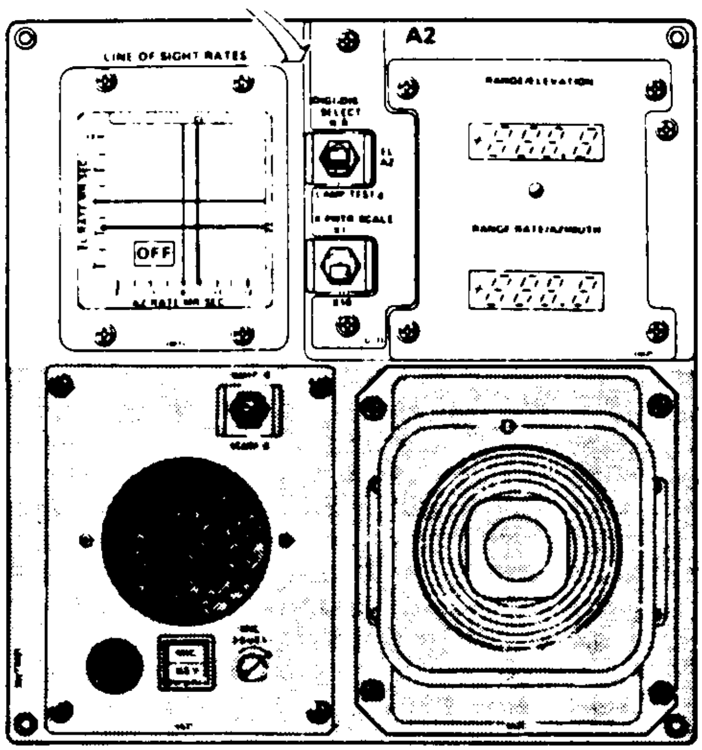


Figure 3-20.- Panel A2.

The elevation and azimuth inertial LOS angle rates provide information on relative position rates normal to the LOS to the TGT and are independent of Orbiter body attitude as they are referenced to the radar gyro (inertial reference) frame. Once close to the TGT, they become unusable due to beam wandering and random relative motion. In fact, flight experience indicates that, at all ranges, LOS rates as displayed on panel A2 jitter far too much to be useful as procedures criteria. Proper filtering may improve this.

A "detect" flag is set (but not displayed onboard) when a return signal is first received. Once the return passes a Ku-band electronic assembly internal validity check, "DATA GOOD" flags are set and closed-loop tracking can begin. The data can now be used in REL NAV.

Performance ~~at~~ in Extremes

1 Max range
2 Min range
3 Max RDOT
4 Min sig strength
5 Large TGT angular size
6 Fast spin tgt

3.3

The ...):

... o the TGT
... from TGT
... line of
... ing is
... close range.

Th ... low clutter
en ... OPS
pr ... t was later
fixed in hardware, ... convenient
software scrub.

update w/ POST-32 insights ?

3.3.4.4 Self-Test

The Ku-band system is put through a self-test of its circuitry early in the RNDZ phase. While the self-test in itself is not always an absolute indication of a failed or operational radar system, it does provide insight into the system should some anomaly become apparent later in the profile.

The system is configured to the RDR PASSIVE mode for self-test. The system can be tested in the COMM mode, but in the RDR PASSIVE mode the radar processor is tested as well as the electronics assembly and deploy mechanism. For self-test to pass, the radar system power output must be at HIGH.

The system control is put to MAN SLEW to keep the antenna from receiving gimbal commands to follow the TDRS at the completion of the test. One of the system peculiarities occurs when the system is placed into the communications mode while the TDRS is obscured by Orbiter body blockage. In this situation, the antenna could possibly begin oscillating from one gimbal stop to another until the TDRS exits blockage.

When the panel is properly configured, the system control is transferred from ground command to onboard by selecting CNTL - PNL.

The SIGNAL STRENGTH meter is set to register for Ku so the crew can monitor the progress of the self-test; range/range rate is selected on the digital display so the crew can tell if the system passed or failed self-test; and cross pointer scaling is set to its high resolution display so the crew can more accurately monitor LOS rates during PROX OPS. Self-test is initiated via the appropriate item entry on the SM ANTENNA display and lasts about 3 minutes. During the test, several simulated TGT inputs are sent through the system, and the crew will see the SCAN WARN, TRACK, and SEARCH panel talkbacks cycle to gray from barberpole. At test completion, a pass (888.8) or fail (333.3) indication will be given on the digital display (panel A2) and on the REL NAV display in the range slot.

At test conclusion, the crew cancels the self-test command (ITEM 7) and reconfigures the Ku system. Before going back to ground command, the mode switch is put back into COMM, but the antenna pointing is not reconfigured back to GPC from MAN SLEW to avoid gimbal oscillations. During the next ground acquisition of signal (AOS), the MCC will verify that the TDRS is not in blockage before configuring back to GPC pointing control of the antenna.

Flight experience has shown that the RR self-test has failed about half the time, but the RR has always performed properly for RNDZ and PROX OPS.

3.3.4.5 Configure for RNDZ Radar TGT Acquisition

This procedure is shown in figure 3-21A; it is called out in section 4.1.18 of the RNDZ procedures rationale narrative.

	GNC 33 REL NAV	
CRT	KU ANT ENA - ITEM 2 EXEC (*)	
	GNC. I/O RESET EXEC	
A1U	KU MODE	- RDR PASSIVE
	KU	- GPC
	✓KU RDR OUTPUT	- HI
	KU CNTL	- PNL
A2	DIGI-DIS SEL	- R/RDOT

Figure 3-21A.- configure for RR TARGET ACQ.

Because of the pulse repetition techniques used by ~~for~~ the RR, the maximum possible unambiguous range for TGT acquisition is just under 164 kft (27 n. mi.). To avoid acquiring confusing and inaccurate data at longer ranges, the system is configured to the radar mode after the Orbiter-to-TGT predicted range is less than 150 kft. ? range = ct

STS-32

No NAV until.

Speed of electromagnetic waves multiplied by pulse repetition frequency of the RR system while in long range track mode gives the total distance traveled by one RR pulse before the next pulse is sent. Dividing by 2 gives the one-way distance from Orbiter to TGT that allows a single RR pulse to be sent, reflected off the TGT, and returned to the Orbiter before another RR pulse is sent.

If the RR did acquire a TGT at longer ranges, a second RR pulse would have already been sent by the time the initial pulse was returned. In this case the RR would interpret the returning initial pulse as being a return of the second pulse off of a TGT close to the Orbiter. The interpreted TGT range would be approximately 164 kft less than the actual range to the TGT.

The radar is put into the RDR PASSIVE mode for TGT's without radar transponders on them (the RDR COOP mode for aided TGT's has not yet been validated on the STS). The KU switch is placed in the GPC position so that the radar can automatically receive pointing estimates for where to search for the TGT from the Orbiter GPC's. In the GPC mode of operation, the RR performs a spiral search for the TGT every 80 seconds until lock-on. The search pattern begins at the GPC designated gimbal angles and covers a 30° half angle cone. The spiral search takes 60 seconds to complete, after which the RR receives new designate angles, drives to those designates, and waits for the next search command. HIGH power on the RADAR OUTPUT switch is required to support TGT acquisition at maximum ranges. Once the panel has been properly set up, the control of the radar system is transferred from ground command (CMD) to onboard control panel (PNL) via the KU CNTL switch.

Interface software is set up for the Ku system to receive pointing designates from the GN&C software for the RNDZ TGT by executing KU ANT ENA. Without this item executed, the Ku designates come from the SM software and are for the TDRS satellite selected for communication. The GNC I/O RESET executed later initiates this interface processing.

NAV software is configured such that angle data will be input from the RR system instead of the STRK or COAS by executing ITEM 13 on the REL NAV display. Even if angles are still selected from STRK or COAS, the R and R-DOT are exclusively from the RR and are thus always selected (there is no choice).

The DIGI-DIS SEL is set to monitor range and range rate. Until lock-on, this value will be zero and will show data only after the TGT is detected. If the meter were configured to display AZ and EL, the crew would see the designated pointing angles displayed prior to acquisition and then actual angles after acquisition. Since designate angles should be close to actual, if the panel were set to angle data, it would not be obvious by viewing the meter if an acquisition had occurred or not.

Whenever either RR angle exceeds 30°, radar angle measurements will be inhibited by crew action. This is because angle data is considered valid only within a band plus or minus 30° from the line-of-sight of the RR. (Ref: Onboard Navigation Systems Characteristics, Dec. 1981, section 7; JSC-14675; 79-FM-5, Rev 1)

3.3.4.6 RR ~~Cue Card~~ AUTO TRACK

contingency procedure

A standard procedure for RR AUTO TRACK acquisition is shown on the RNDZ OPS ~~cue card~~ below (fig. 3-21B). The antenna is manually pointed towards where the TGT really should be; if lock-on still fails, return to GPC/ACQ mode (pointed by NAV), and the last hope is that target radar reflectivity characteristics (range and/or attitude) will improve enough to allow acquisition.

KU - AUTO TRK
Slew antenna to Elev 0, Az 0 see 39
(or Elev, Az as seen in COAS)
Ku TRACK tb - gray
If no TRK (Ku TRACK tb - bp)
KU SEARCH - SEARCH (tb-gray)
If no lock-on within one minute,
KU - GPC

Figure 3-21B.- RR AUTO TRACK ACQ.

3.3.4.7 Radar Effects on Target

The electromagnetic pulse from the Ku-band antenna must be powerful enough to allow a sufficiently strong echo to return off the TGT. Since inverse square law dissipation occurs on both the outbound and inbound legs, the total energy loss follows an inverse fourth power law. This feature suggests that a radar powerful enough for tracking an object several miles away could be powerful enough to damage its electronics when it gets to within several hundred feet. This is true, even with the option of reducing power during approach (see section 4.1.62 for a discussion of these procedures).

Figure 3-22 shows the induced electrical charge in volts/meter caused by the Ku-band radar at its four power settings, as a function of range.

When operating in any power mode, when the Ku-band system detects range < 640 feet it will automatically command "bypass power," which reduces power to 40 dB below high (there is no other way, either from onboard or MCC, to instigate this mode). If the system breaks lock it will jump to the power setting on the panel (HIGH, or MEDIUM [12 dB below HIGH], or LOW [24 dB below HIGH]) momentarily before detecting R < 640 and resuming "bypass mode".

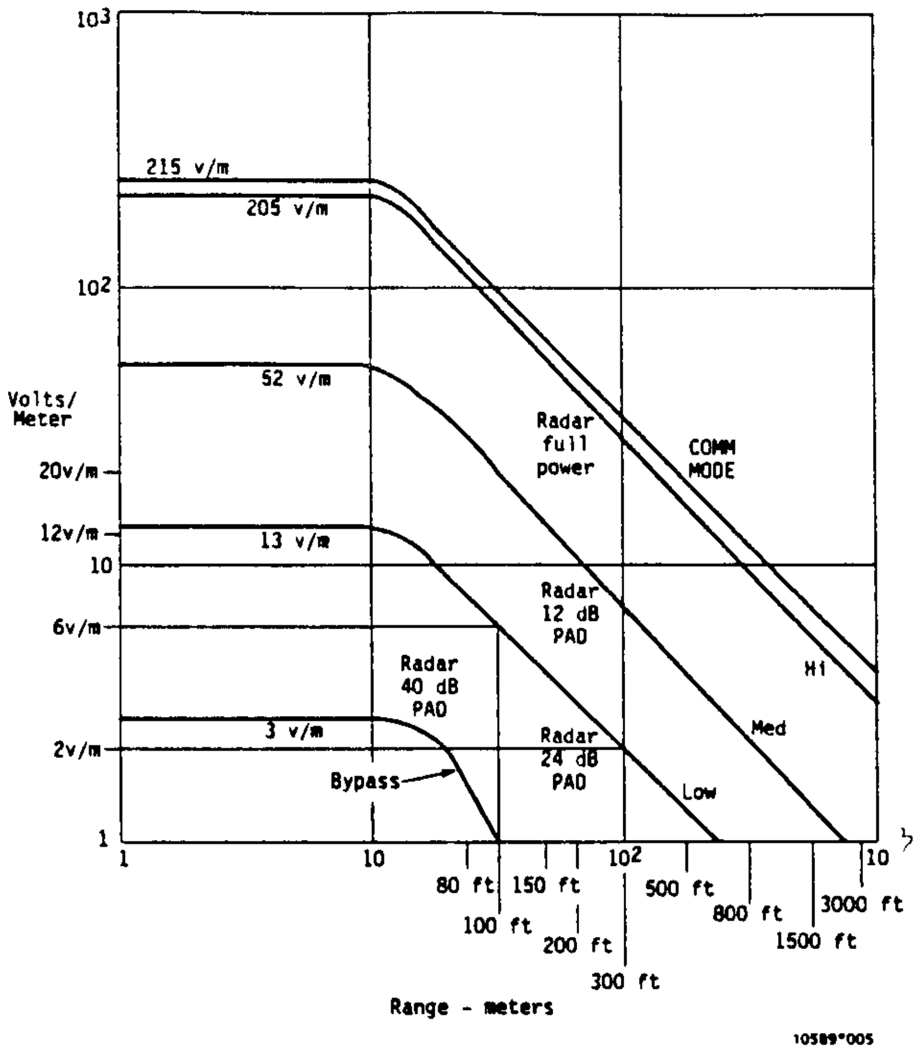


Figure 3-22.- Induced volts/meter on target.

3.3.5 Closed Circuit Television

Although installed for other purposes, the CCTV's are also used as important range/rate sensors.

The fields of view of the CCTV's are as follows:

There are normal lenses (usually on the PLB A, B, C, and D cameras and the RMS EE) with focal lengths of 18 mm to 108 mm (zoom of 6:1) and wide angle lenses (RMS elbow and sometimes per PL request on PLB B and C) with focal lengths of 8.2 mm to 25 mm (zoom of 3:1). The following values apply for focus set to far and underscan on, and they refer to the horizontal scale on the CCTV monitor, in degrees: normal-lenses zoom-out is 40.9, zoom-in 6.6; wide-angle lenses zoom-out is 83.3, zoom-in is 29.5.

Note: Adjusting the focus will affect the width of the normal lens FOV, with zoom-out FOV changing from 40.9 to 33 as the focus is changed from "far" to "near," and zoom-in FOV changing from 6.6 to 5.8 as the focus is changed from "far" to "near"; however, for rendezvous and PROX OPS, the focus will always be set to "far." With the wide lens, changing focus will hardly affect width of FOV at all.

3.3.5.1 Locations

There can be four bulkhead-mounted CCTV's in the PLB, designated A (forward port), B (aft port), C (aft starboard), and D (forward starboard); two RMS cameras (elbow and wrist); and possibly keel and pallet cameras. Selection and control of camera operations is made via panel A7U (fig. 3-23); the two monitors are on panel A3 (fig. 3-24). Camera pan and tilt angles are shown on the CCTV monitors in the monitor "data on" mode. These angles are not downlisted

3.3.5.2 Control/Display

On each of the two CCTV monitors, the camera ID, pan, tilt, and camera over-temperature can be displayed (selectable via the DATA SWITCH ON/OFF on the monitor). Crosshairs can also be displayed (selectable via the X HAIR ON/OFF toggle switch). Two camera scenes can be multiplexed onto one monitor, but in this case only camera ID information can be displayed; neither pan/tilt nor crosshairs can be displayed.

3.3.5.3 Triangulation Technique

Forward and aft bulkhead camera tilt angles are obtained by the crewmember after the TGT has been centered in the FOV (fig. 3-25). By use of triangulation (see chart, fig. 3-26), the range to the TGT can be determined (it is then biased by the distance from the forward camera to the roof of the crew compartment, to provide a pure "clearance" reading where "0" is contact). The error sensitivity of this technique is a function of tilt angle, and the range estimates become degraded at angles of greater than about 80° (ranges greater than 200 feet).

The CCTV cameras must be "zeroed" ahead of time and possibly during RNDZ phase if the tilt encoders are disturbed. This is done in the CCTV CONFIG block by pointing camera A at camera B (and vice versa) and hitting PAN/TILT-RESET switch for both; repeat for cameras C and D.

See section 4.3.6 for values of forward (FWD) PLB CCTV tilt angle on V-BAR, as function of range.

3.3.5.4 Keel/Pallet

For some payloads (e.g., LDEF or TSS), one or more of the bulkhead cameras may be remounted inside the PLB. A keel-mounted camera will look right up

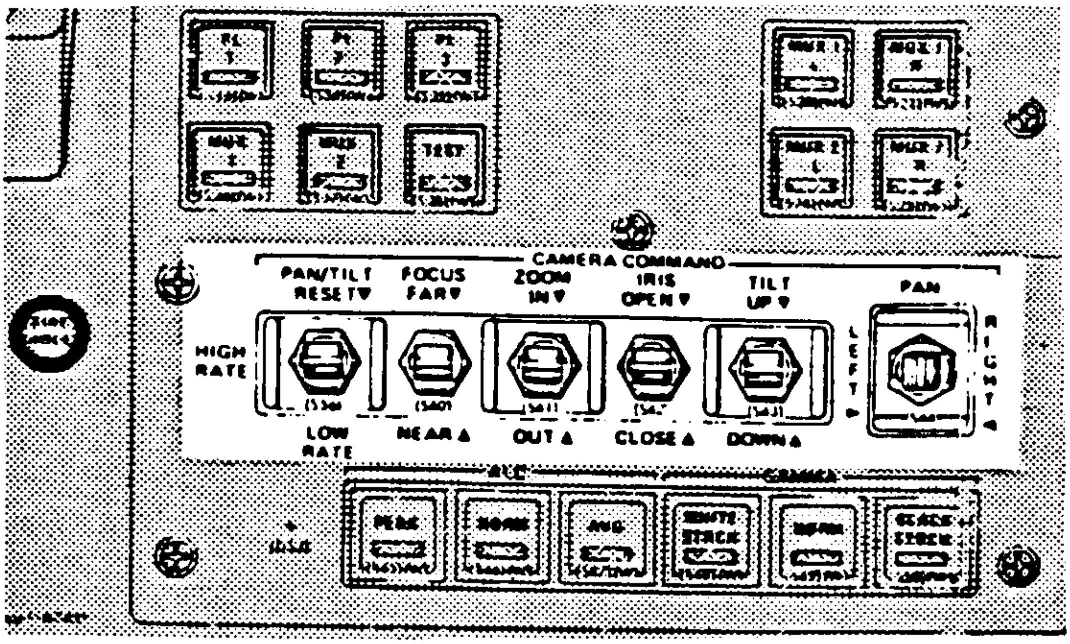


Figure 3-23.- Panel A7U. Camera command & video input/output.

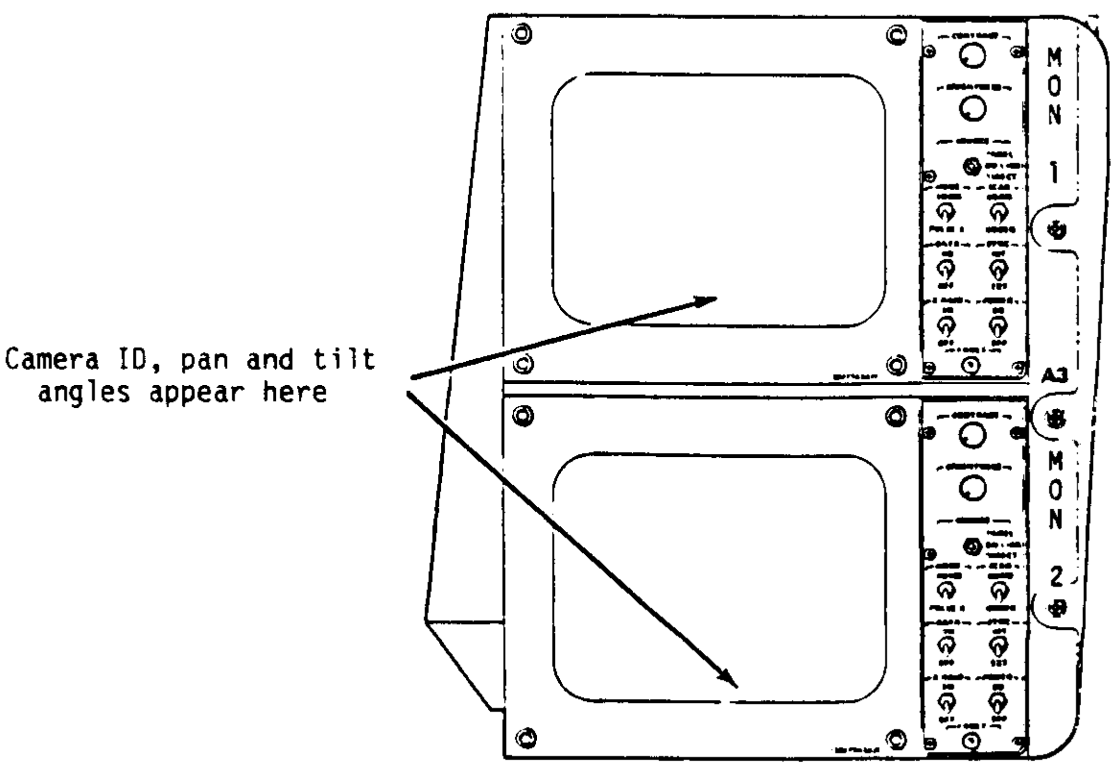


Figure 3-24.- Panel A3.

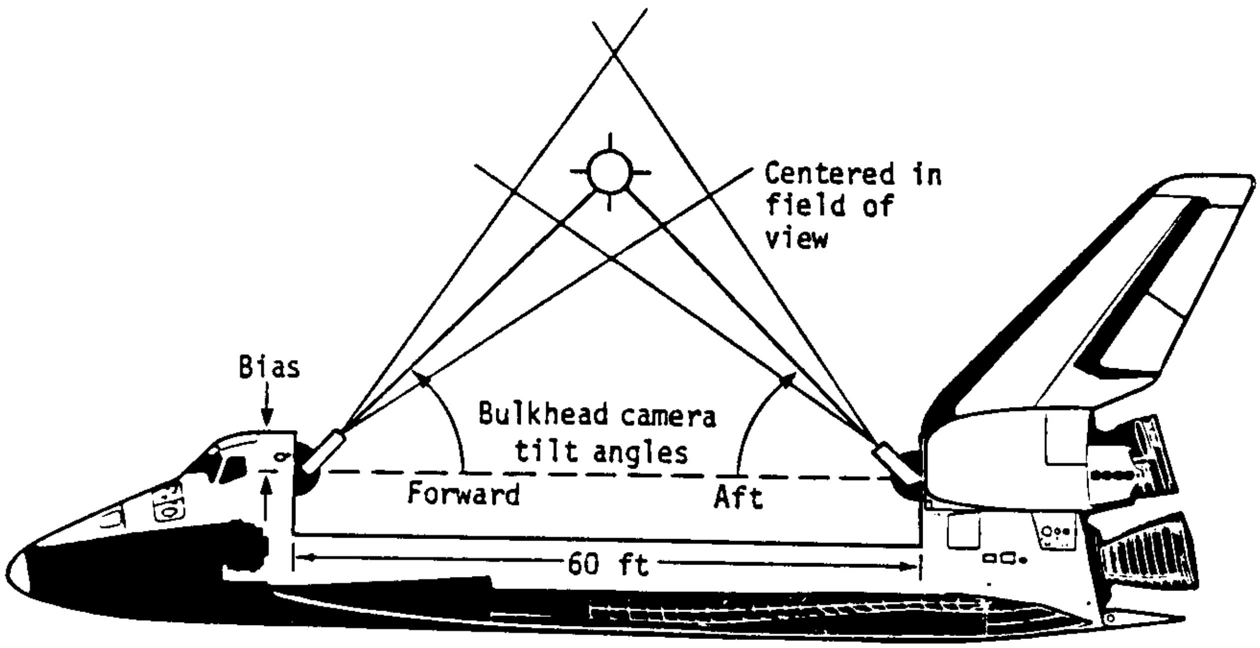


Figure 3-25.- Use of bulkhead cameras tilt angles to determine range.

CAMERA ANGLES AND RADAR ANGLES RANGING CHART

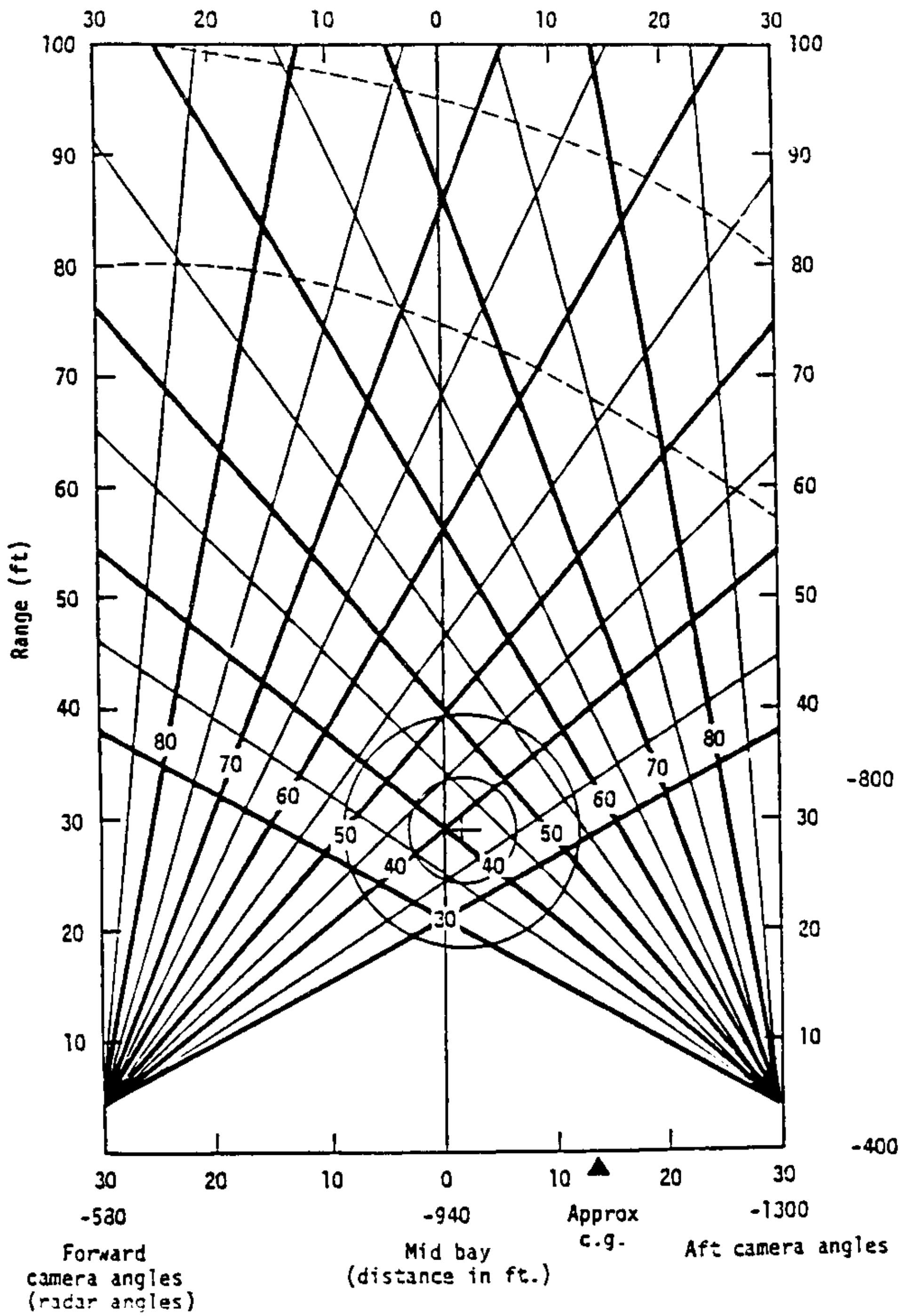


Figure 3-26.- Triangulation chart.

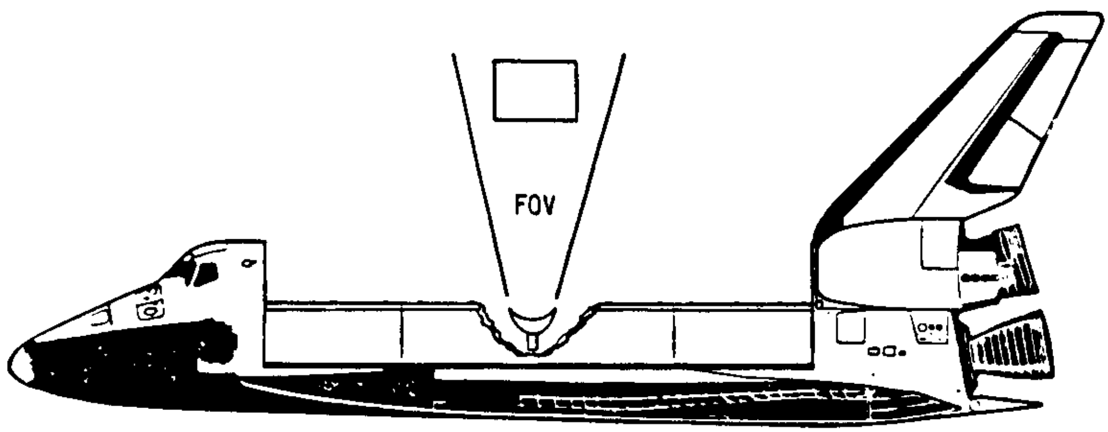
(Note: RMS EE coordinates also provided here.)

the -Z axis; it will have no tilt/pan control. Both Orbiter X and Y axis deviations can readily be detected and controlled using such a view. (See fig. 3-27.)

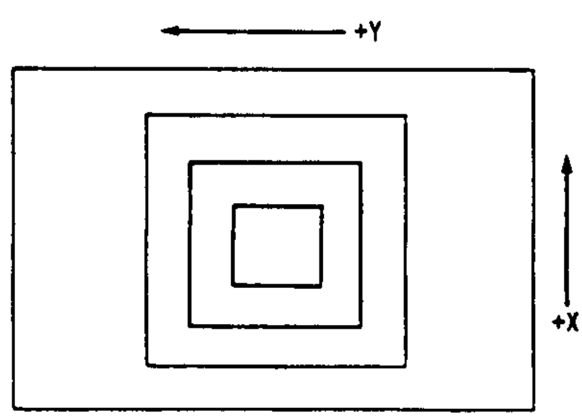
3.3.5.5 RMS Wrist

With the RMS in grapple position, the wrist camera FOV is normal to the -Z axis. Motion of the payload in this view is the prime indicator of fine closing rates just prior to final stationkeeping and grappling (fig. 3-28a). Rates along Orbiter X axis are also monitored here.

The RMS elbow camera (if installed) could be used as a backup to the RMS wrist camera. Pan/tilt orientation for this camera must be manually adjusted. In such a case, it might be preferable to perform grapple over the COAS, using aft bay CCTV's for rate measurement. See section 4.4.6 for failure recovery discussion.



Plain view



Monitor view

Figure 3-27.- Keel camera.

As an aid to visualizing Orbiter-relative motion of an object being observed in the EE CCTV, a transparent overlay (fig. 3-28B) is included in Flight Data File (FDF) for installation over the appropriate CCTV monitor.

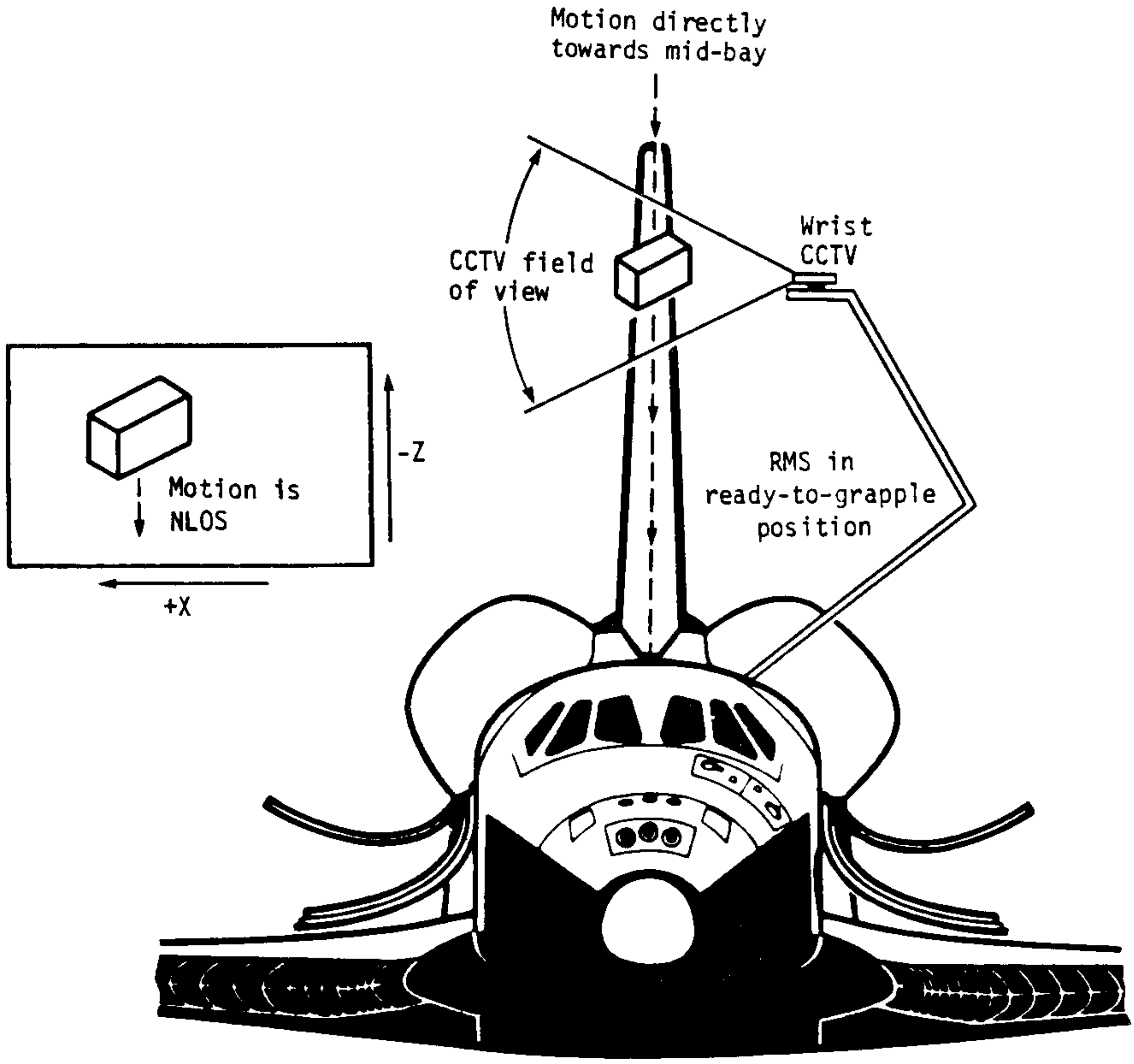


Figure 3-28A.- Use of RMS wrist camera to determine range rate.

3.3.5.6 Other PLB cameras

Depending on mission cargo mix, there may be other CCTV's in the PLB viewing up the -Z axis (e.g., Earth observation systems). Their utility to RNDZ and PROX OPS must be determined on a mission-by-mission basis.

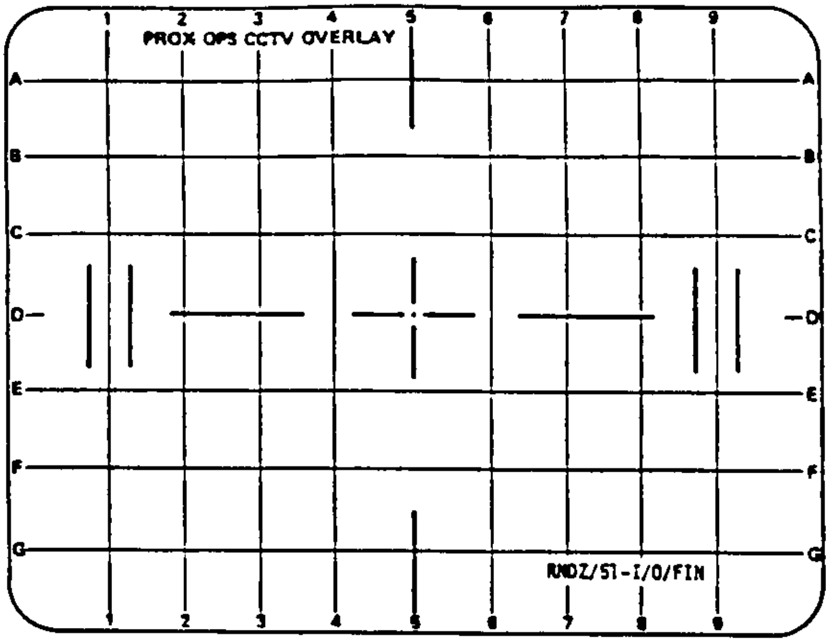


Figure 3-28B.- EE CCTV object motion overlay.

3.3.6 CCTV/Overlay

A variety of methods exist to estimate distance to a TGT in the event of radar failure. Within 200 feet, CCTV elevation angle is used, and COAS subtended angle can be used out to about 1000 feet, depending on the size of the TGT. A crewmember's binocular vision can provide excellent ranging estimates out to 60 to 80 feet; judgements based on TGT angular size are probably good to 200 to 400 feet, depending on TGT size. A combination of hardware, geometry, and human factors limitations degrade the accuracy of these methods as range increases. The most reliable technique is use of TGT angular size on CCTV screens.

In current practice, if the radar is failed, there is only one method of determining range at distances much beyond 1000 feet with reasonable accuracy. For payloads the size of Solar Maximum Mission (SMM) or long-duration exposure facility (LDEF), range can be estimated from about 40 to 6000 feet, with a mean error (based on SES experience) of about 3 percent to 4 percent. Procedurally, the crew configures the CCTV cameras for either full or no zoom. The TGT is approximately centered, then the bottom line of the applicable range ruler (fig. 3-29) is placed atop the screen image of one end of the optimum axis. Range is read where the other end of the axis falls. A gross estimate of range rate may also be obtained using the rulers and a stopwatch or HP41CV program, although SES experience shows that range rate accuracy is poor (mean error of 50 percent). Essentially, the rulers can only be relied upon to provide a "sense" of the range rate; e.g., opening or closing; fast or slow. In practice, it is best to wait until two or three ruler hacks are taken that give consistent R-DOT, before performing translation to adjust R-DOT. However, it may not be possible to wait that long.

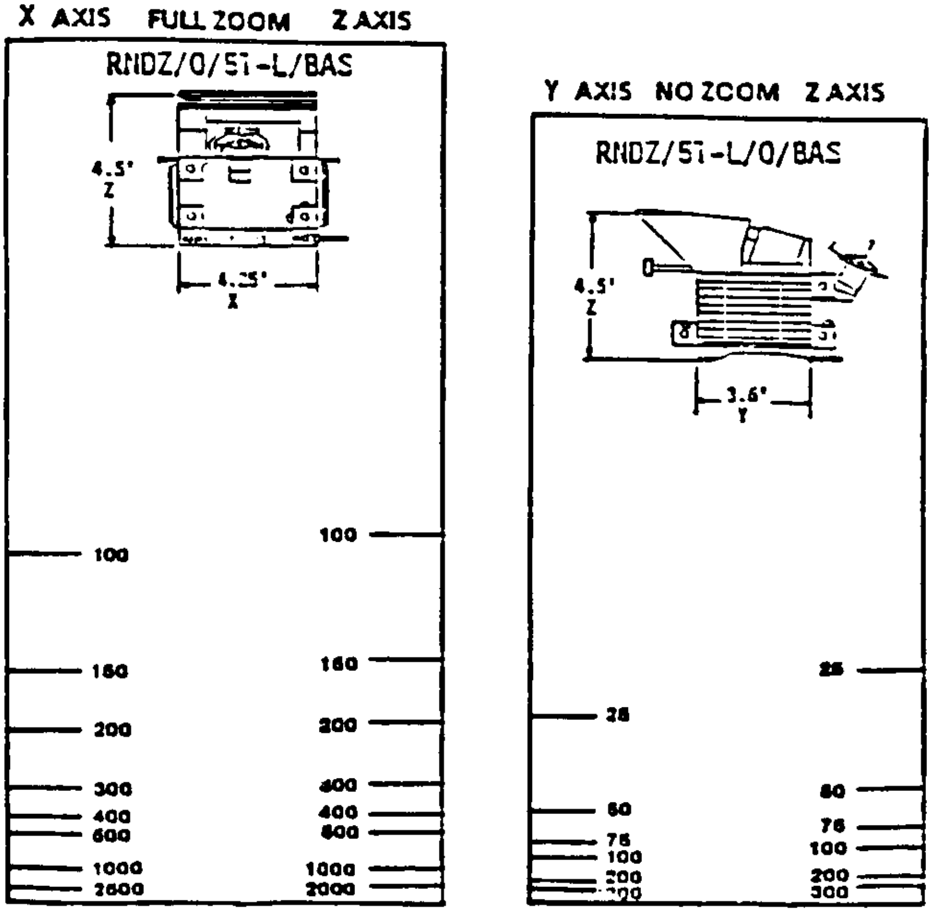


Figure 3-29.- Typical ranging overlay.

Flight experience has shown that image blooming caused by overbrightness from Sun reflections off the TGT can seriously degrade the utility of this procedure. The displayed CCTV image can be rendered useless during these phases. Current CCTV H/W improvements may help with this problem; manual camera iris control is also useful.

Note: Underscan should be selected on the CCTV's when using the ranging rulers. The rulers can be made either way, but are made up for underscan because DOD requirements for downlist TV preclude the use of operating without underscan. Underscan (switch selectable) creates a blank border around the CCTV monitor image, which insures that no edge overlap scenes are being downlinked. However, it also results in a 6 percent reduction in image size on the CCTV monitor.

3.3.7 Other Ranging Devices

3.3.7.1 Laser Rangefinder

A laser rangefinder was operated on early RNDZ missions. Originally conceived as part of an AUTO-focusing system for the CCTV system, it was mounted on a PLB TV camera, and range and range rate readouts were displayed on a CCTV screen. The device was effective out to a range of perhaps 400 feet. Experience was unsatisfactory and this particular device was not used subsequently.

In principle, such devices (with improvements) can be very useful as close range sensors for space station docking. With ranges of up to several miles, such devices make terminal phase much easier, especially when range and rate data can be fed directly into NAV. Hardware development is underway on such a device.

3.3.7.2 Stadimetric Binoculars

This optional equipment, first flown on STS 51-A and highly recommended by the crew, consists of 8X binoculars with tick-marked reticle (5-milliradian increments). In conjunction with an HP41C program for angle-to-range conversion, it provided an accurate and easy-to-use backup ranging device.

3.3.7.3 Global Positioning System

Use of the global positioning system (GPS) for relative NAV may someday be feasible. Equipment on both Orbiter and TGT process GPS data and then difference the pseudorange data for relative motion NAV. This technique would allow GPS systematic biases to cancel out. For a single user, expected accuracy is to within 35 feet in position, and 1 ft/s in rates; however, relative positions would be accurate to within 3 to 10 feet. Use of this technique would require new NAV software in the Orbiter, and to date this has not been approved.

3.3.7.4 Other

Other NAV technologies have been proposed for determining the SV of the Orbiter. These include "TACAN NAV" and "TDRS NAV." Neither has been implemented or scheduled, and thus they have no relevance to current or planned RNDZ operations. Advanced systems for space station RNDZ NAV are discussed in chapter 8.

3.3.8 Orbiter Lights

For nighttime viewing of TGT's through the COAS along the -Z axis, a spotlight is mounted on the forward PLB bulkhead and projects a 10° beam (half intensity at edges). The light is a 230-watt metal halide device providing about 1200 candlepower. Brightness is sufficient to determine TGT attitude at 700 feet, where the beam width is about 100 feet. The light is controlled from a switch on panel A1.

The six PLB lights already installed do provide some nighttime TGT illumination capability, but the overhead docking light increases intensity in its beam by about 30 percent. At low light levels this is quite significant.

There is also another light atop the CCTV on the RMS wrist. Note that for PL's in the bay, some or all of the PLB lights may have to be kept off for PL thermal constraints.

A specialized portable xenon light (called the "streamlight") is available as an optional item for night stationkeeping. It throws a lot more light (one million candlepower) than regular Orbiter lights, and crews (the first was 51-A) highly recommend it. The light is fastened on a camera bracket at one overhead window and plugs into utility power; stowed, it and its own power converter take up one full middeck locker. It is a big power user and gives off a lot of heat. In-cabin use is constrained by window transmissivity.

3.3.9 Target-Mounted Sensors

Some TGT's have their own attitude sensors and make such data readily available for display onboard the Orbiter and on the ground. Where such attitude data exists or can be derived, every effort should be made to make it available to the crew during PROX OPS.

3.3.10 Target-Mounted Tracking Aids

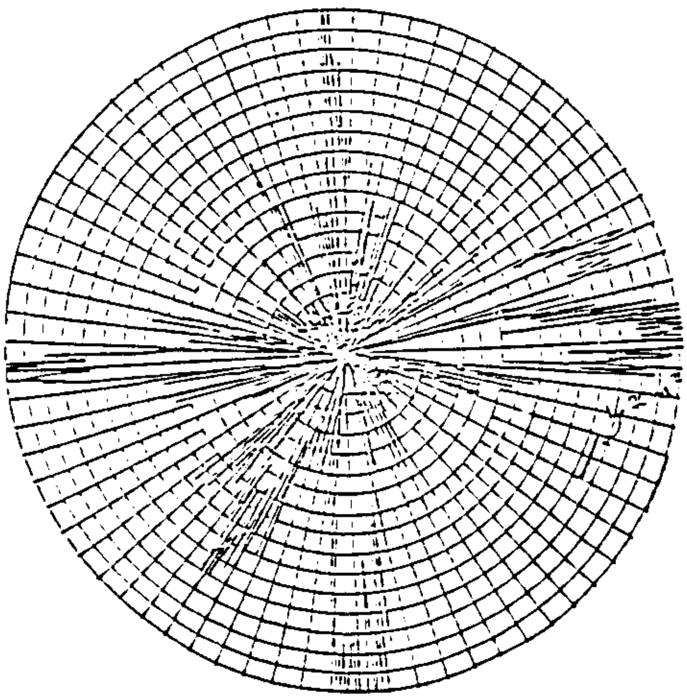
Various TGT characteristics are desirable for enhancing the ability of the Orbiter crewmember to determine TGT range and attitude.

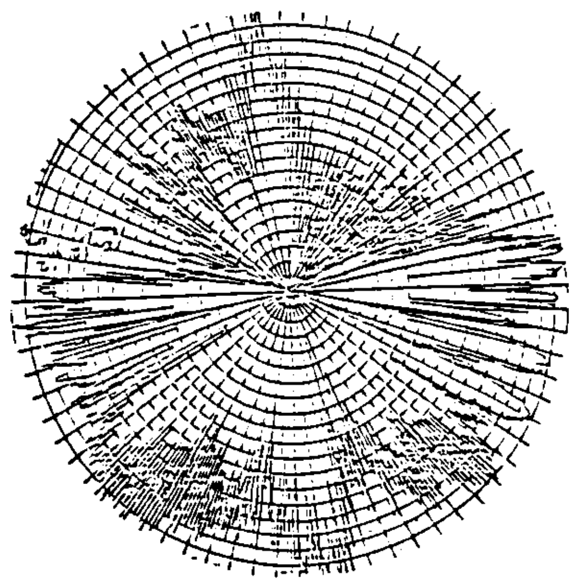
In terms of visual tracking, it is desirable that the TGT not have high-gloss surfaces which can cause specular reflections of sunlight (flat white paint is a good scheme). Furthermore, ranging through the COAS can be facilitated if some visible features of the TGT (either structures or markings) are sized appropriately so as to subtend angles of 2° at 100 feet and at 30 feet (that's a true linear dimension of 3.5 feet and 1 foot, respectively); this is a desirable, but not required, feature.

Reflection characteristics of the TGT can be enhanced by use of reflective tape. Visibility out to 500 feet can be achieved.

Spartan radar cross section measurements

without corner reflectors





Spartan radar cross section measurements

with corner reflectors

Figure 3-30.- Effect of corner reflectors on radar cross section.

In terms of lighting, if the reflection of the TGT characteristics or Orbiter pointing is inadequate to provide visual cues at night (regarding TGT relative position, orientation, and grapple fixture location), then running lights are highly desirable, with the following characteristics:

- Capability exists for flight-crew on-off commanding.
- Lights are steady-state with intensity of 1.0 candlepower on the beam cone centerline, decreasing to 10 percent of maximum at ±80°.
- If flashing lights are required (due to power limitations), the rate should be more than once per second.
- The optimum number of lights is eight (of equal brightness), located orthogonally with respect to target coordinate frame, with color coding as follows: port - red (two), starboard - green (two), and bottom - yellow (four).
- A minimum of two lights should be provided on spin-stabilized TGT's.

Radar reflectivity can be enhanced through the use of simple corner reflectors (fig. 3-30), which significantly increase the radar cross section of the target.

In terms of close-in radar TRK, a radar enhancement device (RED) can be used to prevent beam wandering over a TGT of large angular extent; this can reduce noise in the range and range rate measurements. At long ranges a RED can be expected to provide more distant radar tracking capability.

3.4 NAVIGATION

The task of NAV is to find out where one object is located and is moving, relative to a reference frame or another moving object. This section describes the use of the REL NAV SPEC, the theory of Orbiter SV management, and the stages through which onboard sensor data pass into SV knowledge.

3.4.1 REL NAV (SPEC 033)

Relative navigation (REL NAV) (fig. 3-31) is available in OPS 2. It provides the crew with relative state information and translational thrust monitor capability for the RNDZ, PROX OPS, and PL deployment/retrieval phases of the mission. It also provides data and controls for RNDZ NAV operations using the STRK, RR, and COAS. NAV filter controls are provided to allow manual control of NAV data from the STRK, RR, or COAS, depending on which are being used.

```
                                                      DDD/HH:MM:SS
RNDZ NAV ENA 1X    SV UPDATE
KU ANT   ENA 2X     POS XX.XX                   AVG G ON      5X
MEAS     ENA 3X     VEL XX.XX                  ΔVX         ±XX.XX
       NAV                                     ΔVY         ±XX.XX
SV SEL 4 XXXX         RR XXXX                  ΔVZ         ±XX.XX
RNG    XXXX.XXX   RNG   XXXX.XXXS              ΔVTOT        XXX.XX
Ṙ     ±XXXXX.XX   Ṙ    ±XXXXX.XXS               RESET COMPNT 6
θ        XXX.XX   EL       ±XXX.XS                          TOT 7
Y       ±XX.XX    AZ       ±XXX.XS             SV TRANSFER
Ẏ       ±XXX.X    ωP        ±XX.XS             FLTR MINUS PROP
NODE XX:XX:XX     ωR        ±XX.XS              POS          XX.XX
            FILTER                              VEL          XX.XX
S TRK 12X     RR 13X     COAS 14X              FLTR TO PROP    8X
STAT XXXXXXXXX   OFFSET X ±X.X                 PROP TO FLTR    9X
     XXXX                Y ±X.X                ORB  TO TGT    10X
SLOW RATE      15X                             TGT  TO ORB    11X
COVAR REINIT 16X         MARK HIST                EDIT OVRD
           RESID   RATIO ACPT  REJ              AUT   INH   FOR
RNG       ±XX.XX    X.X  XXX  XXXS              17X   18X   19X
Ṙ         ±XX.XX    X.X  XXX  XXXS              20X   21X   22X
V/EL/Y    ±X.XX     X.X  XXX  XXXS              23X   24X   25X
H/AZ/X    ±X.XX     X.X  XXX  XXXS
```

Figure 3-31 - The REL NAV (SPEC 033) display.

Interaction with Orbiter DPS actions can affect REL NAV's processing, as specified in section 3.7.

The NAV data is used to update the Orbiter SV. However, FSW can conceivably be changed so sensor data would improve the TGT state instead of the Orbiter state, but not through a simple ITEM entry on the REL NAV display. The present design has an I-loaded flag that determines which state will be updated by the Kalman filter. This flag could only be changed in I-load, or by a G-MEM via crew input or by uplink.

Note: Although FLTR is the SPEC abbreviation of "FILTER," use of the abbreviation "FILT" is ~~widespread~~ in documentation with identical meaning. occasionally found

3.4.1.1 Parameters

The RR determined relative state information includes the following (compare to generic RNDZ parameters in section 2.5 and RR-specific parameters in section 3.3.4):

- RNG: Line of sight range (kft) between the vehicles.*

- R-DOT: Range rate (ft/s); sign convention is positive opening, negative closing.*
  Note: Both raw radar and NAV values are displayed for RNG and R-DOT.

- EL: Pitch position (elevation) of the radar antenna gimbal relative to its -Z null position (±90°); positive sense - antenna motion toward the +X Orbiter axis.*

- AZ: Roll position (azimuth) of the radar antenna gimbal relative to its -Z null position (±180°); positive sense - antenna motion toward -Y Orbiter axis.*

- ωP or EL-DOT: Pitch inertial angle rate (± mr/sec); positive sense - antenna motion toward the +X Orbiter axis (mr = milliradians).*

- ωR or AZ-DOT: Roll inertial angle rate (± mr/sec); positive sense - antenna motion toward the -Y Orbiter axis.*

*This radar information will be displayed whether or not RNDZ NAV is enabled, as long as there is a data path through FF3. The same data can also be seen on crew station panel A2. After the radar locks on to the TGT, there are still down arrows on the REL NAV display for a short period of time. This happens because the software is conducting a data good check on the radar data and until the discrete becomes GOOD the down arrows will remain. RR data may still be good enough for manual phase.

- θ - (Theta): The angle between the Orbiter V-bar and the UNIV PTG body vector (ignoring effects of deadbanding). If UNIV PTG is tracking the TGT with the -Z axis, θ is the elevation angle of the TGT with respect to the chaser V-bar.

- Y - The out-of-plane distance (kft). Positive sense is along negative angular momentum vector of the TGT, or to the right when heads up, facing forward. For posigrade orbits, this is south.

- Y-DOT - The out-of-plane rate (ft/s), same sense as Y.

- NODE - The MET time hh:mm:ss of the next nodal crossing between TGT and Orbiter. This is generally unusable with current flight software precisions since the Orbiter and TGT are always so close to being co-planar.

3.4.1.2 Processing

RNDZ NAV processes sensor data to update the SV and covariance matrix in OPS 2 under the following conditions:

a. NAV is on a measurement processing cycle, which occurs every other 3.84-second cycle. This is, marks are incorporated every 8 seconds (two NAV processing cycles).

b. Sensed acceleration (CONT ACC) for this cycle is < 20,000 μg (i.e., no OMS burn in progress, since a single OMS burn gives about 34,000 μg).

c. Data are flagged good.

d. Auto/Inhibit/Force (AIF) switch is not set to INH.

e. Data residual passes the NAV residual edit test.

f. If in MM 202, MEAS ENA is on.

Note: Even though both radar and STRK output data at a rate faster than it can be used by software, RNDZ NAV simply snapshots the data when it is needed; it does not average the values.

3.4.1.3 REL NAV SPEC Manipulation

All item entries may require up to 8 seconds for response to appear.

3.4.1.3.1 RNDZ NAV enable (Item 1).- This item is used to transition between the basic orbit NAV and RNDZ NAV. It is a flip-flop item and is inhibited on initial display call-up whenever entering OPS 2. An asterisk will appear when RNDZ NAV is enabled.

The PROP SV is created as a copy of the FLTR SV, and the FLTR SV is enabled for sensor data incorporation. During RNDZ NAV, the TGT SV and the Orbiter/TGT covariance matrix are also maintained (in addition to two Orbiter SV's) using preloaded acceleration models and external sensor data (STRK, RR, COAS), if available. In non-RNDZ NAV, only the Orbiter FLTR SV is maintained; the TGT SV is not propagated and no external sensor data are used to update the Orbiter SV. If RNDZ NAV is not enabled, the following parameters are blanked: RNG, R-DOT, θ, Y, and Y-DOT.

When RNDZ NAV is enabled, the COVAR MATRIX is also initialized along with the mark accept/reject counters. Enabling RNDZ NAV does not change previous values of the AIF flags, the sensor selected as angle source, and the KU ANT enable flag. See sections 4.1.6 and 3.7.3 for operational use of this feature.

Note: A TGT SV must be ~~less than~~ within 15 hours ~~old~~ of current time to allow enabling of RNDZ NAV.

3.4.1.3.2 Ku-band antenna enable function (Item 2).- Execution of Item 2 results in the GNC GPC's passing the ~~GNC~~ relative state, which is necessary for Ku-band antenna management, to the SM GPC. SM commands the antenna through MDM PL1. This tells the radar where to point to acquire the TGT. Recall that the RR is part of the Ku-band antenna system, and that this function is controlled by the SM OPS 2 GPC. Prior to RR acquisition of a TGT, this item must be enabled and a GNC I/O reset performed. When this item is selected, the antenna is pointed at the target, no matter what the RR MODE switch says. See section 3.3.4.1.

20

3.4.1.3.3 Sensor measurement enable (Item 3).- This item, MEAS ENA, is used to enable the RNDZ NAV software to use onboard sensor data (RR, STRK, COAS) to update the filtered SV in MM 202. Even with the AIF's (EDIT OVRD selection) set to AUTO (items 1, 17, 21, 23 selected), onboard sensor data are not utilized in MM 202 unless the MEAS ENA item is selected. Even then, external sensor measurements can only be incorporated in MM 202 NAV if the total sensed acceleration is less than a threshold value (currently 20,000 μg). When that threshold is reached, such as during an OMS burn, only the IMU data are used to update the Orbiter SV. This item is not applicable in MM 201, and an attempt to use it in MM 201 will result in an ILLEGAL ENTRY message. In MM 202, execution of Item 3 will cause an "*" to appear when the capability is enabled in the software. This may take up to 8 seconds to be initiated. Upon return to MM 201, MEAS ENA will be automatically disabled and the "*" will disappear.

Current (mid-1987) thinking is to leave MEAS ENA off when in MM 202, since presumably enough RR data has been obtained in the period leading up to MM 202 transition (approximately 8 minutes prior to Ti TIG) for a good TGT'ing solution. If MEAS ENA were set "on," additional RR marks would be taken during this period and would presumably be improving knowledge of the Orbiter-to-target relative state. However, the Orbiter is moving to a BURN ATT, which was computed when the MNVR was loaded (Item 22) on ORBIT MNVR EXEC. Lambert guidance takes over just prior to the time of ignition (TIG -15 seconds) and computes a "new improved" BURN ATT (based on these recent RR marks) which may significantly differ from the one issued earlier if the maneuver is small. The problem is that the crew has no way of quickly (in several seconds) determining if this BURN ATT update truly reflects a genuinely improved knowledge of the SV, or is due to some guidance or tracking anomaly.

If RR acquisition occurs sufficiently in advance of the pre-Ti MM 202 transition, the small additional improvement potentially generated by more RR marks during maneuver to BURN ATT is considered to be insufficient justification for risking the dilemma of a sudden "surprise" at TIG -15 seconds. If RR lock-on is late and only a few marks are available for Ti targeting, the issue is more debatable. One possible way out is to then have MEAS ENA on during the maneuver to attitude and then reload the MNVR in ORBIT MNVR EXEC. Any change to BURN ATT will then show up with 1 to 2 minutes for decision, rather than 5 to 10 seconds. This issue is still ~~being worked~~ unresolved and final discussions will be reflected in specific mission RNDZ books.

3.4.1.3.4 State vector select (Item 4).- Item 4 allows the crew to control the source of the Orbiter SV for use in relative state data being displayed on REL NAV, and being sent to UNIV PTG, targeting, on-orbit guidance, and downlink to the MCC real-time monitoring. Item 4 is a flip-flop that alternately selects "filtered" or "propagated" Orbiter SV data. Upon execution, the word "FLTR" or "PROP," as applicable, will be displayed to the right of the item number. This item is initialized in "PROP." The filtered SV is an SV that incorporates RNDZ NAV filter data derived from RR, STRK, or COAS measurements. The propagated SV is a separate Orbiter SV which is not updated by RNDZ NAV filter inputs. The philosophy for practical SV management is described in section 3.4.2, plus in 4.1.14 and 4.1.22.

3.4.1.3.5 State vector update.- This section of the display shows the filtered SV correction in position (POS) and velocity (VEL) resulting from use of sensor data from the previous cycle. This is used to evaluate convergence of the filtered NAV state, particularly early in a sensor pass.

3.4.1.3.6 Powered flight NAV controls and displays (Items 5, 6, 7).- The upper right-hand portion of the display includes displays and controls useful during powered flight. In particular, item 5 is used to enable/disable the interface between Orbiter NAV and IMU-accumulated sensed-velocity data; nominal condition is interface enabled. In the nominal modes the NAV software continuously monitors the IMU accumulated sensed-velocity data and incorporates it if the observed ΔV exceeds a threshold value. AVG G comes up "on" in MM 201, but it may be toggled with ITEM 5 EXEC; AVG G is always "on" in MM 202 and ITEM 5 EXEC will result in an ILLEGAL entry message.

When AVG G is off, IMU-sensed velocities are not used in updating the Orbiter SV. With this type of modeling, RCS translations or rotations made manually by a crewmember with the THC or RHC will not be accounted for in the navigational model until observed with the on-board NAV sensors. Thus, before any such MNVR is made in MM 201, AVG G should be on.

In the upper right-hand portion of the display, a translation thrust monitor capability is possible when AVG G is enabled. The velocity gained along each of the X, Y, and Z body component axis, as well as the total velocity gained, will be displayed. The individual velocity component registers will increment or decrement according to the sense of the velocity change, whereas the total velocity will increment due to the absolute magnitude of any velocity change. An item number is provided (Item 6) to reset all of the component registers to zero, and another item number (Item 7) is used to reset the total velocity register to zero. The first time in OPS 2 that this display is called, these values will be zeroed. Thereafter, they will reflect the values which were available the last time the display was terminated (that is, the values become static when AVG G is OFF).

Current planning is for the AVG G switch to always be on. Experience has shown that the displayed velocity deltas are not particularly useful over a long period of time because of IMU noise accumulation. The only known reason to turn AVG G off would be if a new GPC IPL is required and GNC has been unable to uplink IMU accel compensations. The AVG G switch would be set to off until GNC has had a chance to do the IMU uplinks. There are no other known situations.

Note: There is currently a question of what the AVG G threshold value should be. The problem is to have a value high enough to eliminate accelerometer bias from being accepted by NAV, yet low enough to include all the uncoupled ROT maneuvers which affect the SV. It appears (minutes of Rendezvous Flight Techniques Panel 5, Sept. 9, 1983) that a threshold of less than 0.1 ft/s will be needed to detect 0.2 deg/s vernier RCS MNVR's which cause translation cross-coupling. The current IMU accelerometer 1-sigma bias is 50 μg's (0.0016 ft/s/sec) corresponding to 0.01 ft/s over one NAV cycle (7.3 sec). This question is still being worked. Current limit is set to 0.06, a

1990 status ?

"best compromise." IMU LSB allows pulses as low as 0.0345 ft/s to be measured.

3.4.1.3.7 State vector transfer (Items 8, 9, 10, 11).- Four item controls are provided for the transfer of SV's. Item 8 transfers the filtered Orbiter SV to the propagated Orbiter SV slots, and item 9 transfers the propagated Orbiter SV to the filtered Orbiter SV slots (this is called "FLTR RESTART"). FLTR to PROP occurs for several different rationales which are explained in detail in section 3.4.2.2.

Item 10 transfers the Orbiter FLTR SV to the TGT SV slots, and item 11 transfers the TGT SV to the Orbiter FLTR SV slot.

If a TGT TO ORB SV transfer (which replaces the FLTR SV) were done inadvertently, an easy, though not perfect, recovery would be to do a PROP TO FLTR SV transfer. The problem arises when an inadvertent ORB TO TGT state transfer is executed. Supposedly, the MCC plans to have a TGT SV ready for uplink at every AOS just in case something like this happens. The only other alternative is to keep repeating a COVAR REINIT followed by a few forced marks until data is accepted automatically.

Whenever any of the four transfer items are executed, an asterisk (*) will be displayed next to the appropriate item number while the selected transfer is in progress. The appearance and removal of the asterisk (*) will have a time delay depending on the NAV processing rate (the asterisk is displayed for only one NAV cycle). Items 8, 9, 10, and 11 are mutually exclusive; execution of any of these items while a transfer is in progress will be illegal. In addition, these four items are legal only while RNDZ NAV is enabled ("*" displayed by Item 1).

FLTR→PROP (Item 8) is nominally performed just after the beginning of each sensor acquisition period, and is a means of providing an up-to-date backup SV if for some reason the FLTR state wanders off (e.g., lock onto a star or debris). It is performed at this time because it appears that the Orbiter FLTR SV is good enough to attain acquisition.

PROP→FLTR (Item 9) is for contingency use, presumably in a situation such as just described where the FLTR state diverges and a FLTR SV restart is required.

ORB→TGT (Item 10) is primarily designed to provide an SV for deployed payloads, particularly nonimpulsive deployments such as via RMS (see section 5.4.1.4). TGT→ORB (Item 11) is provided for use after RNDZ completion. At that time it is quite possible that the TGT state will be more accurately known than the ORB state (currently, there is no planned utilization of this option). Note that items 9, 10, and 11 also cause a COVAR REINIT (see item 16).

Two parameters, FLTR MINUS PROP POS and VEL, indicate the difference between the propagated and filtered SV's. The FLTR MINUS PROP position value (in kft) can be used to evaluate how much the Orbiter FLTR SV has changed during a sensor pass. This assessment is particularly meaningful if data problems were observed during the sensor pass. The POS and VEL values can be used to verify a successful FLTR TO PROP SV transfer; they should drop to zero. The VEL value is computed incorrectly and should be disregarded.

3.4.1.3.8 RNDZ NAV FILTER (Items 12 to 25).- Data from the RR, STRK, or COAS must pass a NAV filter residual edit test before it can be used to update NAV (the Orbiter SV and target/Orbiter covariance matrix). In the bottom third of this display, the results of this filter test and some crew controls are located. This allows the crew to monitor the condition of the filter and the external sensor measurements. In particular, the RR range and range rate residual edit test results are displayed, as well as the results for the selected sensor angle data (STRK-V/H; RR-EL/AZ; COAS-Y/X).

3.4.1.3.9 RNDZ angle sensor data selection (Items 12, 13, 14).- While RNDZ NAV is enabled with Item 1, the following external sensor data may be processed: RR elevation, azimuth, range and range rate, STRK horizontal and vertical angles, and COAS horizontal and vertical angles. The RR range and range rate are always processed by NAV as long as the RR DATA GOOD flag indicates valid data. However, only one of STRK, RR, or COAS will be used as a source of angle data as selected by the crew via items 12, 13, or 14, respectively. These are mutually exclusive items. Once again, a DATA GOOD flag for the selected external sensor must be "on" and residual edit test must be passed in order to be used in NAV. Also, the sensor must be in the appropriate mode. In particular, the RR must not be in a self-test mode, the STRK must be in the TGT track mode, and the COAS data (with COAS sight mode selected) must not have been previously processed and must not be stale (age exceeding 2 minutes) to be usable.

The display is initialized with STRK angle data selected (Item 12). When a new angle source is selected, a delay of up to 8 seconds will be experienced before the asterisk switches to the new source.

Note: When taking radar, STRK, or COAS marks, the software does not always take into account the sensor location relative to the Orbiter c.g. It does so only for the radar. Although data displayed on the CRT and LED's is based on position relative to the radar dish, they are converted to an Orbiter c.g. reference frame before being incorporated into the FLTR state. Thus, radar residuals and ratios are displayed based on the c.g. frame. On the other hand, STRK and COAS residuals and ratios are based on the location of the sensor; data is not converted to the c.g. reference frame before updating the FLTR state.

Also included in the RNDZ angle sensor select section is information used to monitor STRK operation. The STRK/COAS CNTL display is used to select which STRK (-Y or -Z) is to be in the TGT track mode. The status of the selected STRK will be displayed below Item 12, and can be one of the following: (blank), STRK FAIL, STRK PASS, NO TARGET, OUT FOV, or HI RATE (FALSE TRK was called for in the original design, but was not implemented). Below this status, a BITE indication can be driven when a failure has been detected for the selected STRK.

If the -Z STRK is being used, the offset angles (see section 3.3.3 for an explanation of COAS angles X and Y coordinate system) that represent the displacement of the TGT being tracked (by the -Z STRK) in the -Z COAS field of view will appear. These offset angles allow the crewman to locate the TGT that the -Z STRK is TRK in the COAS. This field is driven whenever there is a star present in the -Z STRK and the STRK is in target track or star track mode. It is updated every 1 second; the values are static when the STRK is searching.

3.4.1.3.10 NAV rates (SLOW RATE, Item 15).- The SV is updated in NAV at one of two rates. Current I-loads for slow and fast rate have been set identical, at 8 seconds per cycle, the fastest rate at which NAV can process STRK marks. Item 15 is a flip-flop item which can be used to select the desired rate, if future I-loads are no longer set to the same value. The first time the display is called in OPS 2, the asterisk will be present. If RNDZ NAV is not enabled, execution of this item is illegal.

3.4.1.3.11 COVAR REINIT (Item 16).- This will reinitialize the covariance matrix to preset I-load values or, if one or more covariance uplinks has been executed in the MCC, to the latest set of uplinked values. When the covariance matrix reinitializes, it resets differently depending on which angle sensor is selected, because it has different biases for each sensor. An "*" is displayed next to this item while the reinitialization is occurring. If RNDZ NAV is not enabled, this is an illegal entry. This is executed only as a contingency operation.

not any more

A covariance matrix is uplinked from the MCC, once before RNDZ phase and then again post-Ti with narrower limits (if acquisition by RR has occurred). There are six other ways the covariance matrix can be reinitialized besides this manual item entry, and they are listed in the "Mark History" paragraph, below.

COVAR REINIT is used when a sensor is apparently locked on to the TGT, but ratios are >1.0 so the marks won't get into the filter. Performing an "ITEM 16" will reopen up the filter (assuming that previous sensor marks have been taken; in cases when no sensor data has been taken in a long time, the matrix may actually get smaller) and reduce the ratios (if this does not work, the next step is to force a few marks). See section 3.4.1.3.13 for an explanation of edit ratios.

COVAR REINIT can be used to assist data incorporation when the Orbiter and target SV's are incorrect. Suppose the crew accidentally executes an ITEM 10 (ORB TO TGT transfer). If the Orbiter is less than a couple of miles from the TGT, the covariance matrix will accept radar data and converge on a fairly accurate relative Orbiter and TGT state even though the Orbiter SV will be wrong. Once converged, Lambert targeting (SPEC 34) could be used to compute a burn solution. At large separation distances, a COVAR REINIT may not be enough, so 1 or 2 marks may have to be forced until RATIO < 1.0 is satisfied and marks can be taken automatically.

3.4.1.3.12 Residuals.- A residual is calculated by taking the difference between the NAV computed estimate of the relative position of the Orbiter and TGT, and the observed measurement using sensor data (STRK, RR, COAS). If RNDZ NAV is enabled and sensor(s) are correctly configured and are tracking the TGT, the residuals are computed and displayed for RR range and range rate, and for the selected sensor angle data (V/EL/Y, H/AZ/X). These data are blanked when RNDZ NAV is inhibited; if data are missing or invalid, the data remains static.

Angle residuals are monitored by the crew for approximately 30 seconds at the beginning of each TGT acquisition to ensure that the sensor is not locked onto a star or debris. The sensor is left in INH until the stability criteria is met.

The coordinate system of the angle residuals displayed in the V/EL/Y and H/AZ/X lines is confusing. The three labels are intended to correspond to the three angle sensors (STRK, RR, COAS respectively) and their inconsistent coordinate system references make it difficult to associate the residuals with any reference. See figure 3-11. In practice it is not necessary for the crew to appreciate the distinction between the two angles.

On the -Z STRK: the V/EL/Y line is "V" and means "azimuth" (related to the slightly tilted -Z STRK boresight), positive V toward the -Y wing; the H/AZ/X is "H," corresponding to elevation angle, positive H towards the nose (+X). In <u>this</u> sense the X and Y designations in the same line do actually closely correspond to the X, Y offset coordinates of the COAS (+X toward nose, +Y to left when facing aft, matching Orbiter body axes). It is important to note that the sign of the V (or azimuth) residual and the Y offset coordinate are opposite.

For the -Y STRK, V/EL/Y is "azimuth" from the -Y STRK boresight (approximately 11° toward nose from pure -Y), positive toward +X axis (nose), and H/AZ/X is "elevation" from out the -Y STRK boresight to the -Z axis (positive) or +Z axis (negative).

The COAS offset angles will be displayed any time the -Z tracker star present discrete is set. This discrete will be driven by a star or the TGT when the tracker is in STAR TRK or TGT TRK.

For RR, EL and AZ (or "roll and pitch") are <u>not</u> body axis elevation and azimuth (which is what EL and AZ mean in the RR section of the display in the upper center area). They correspond instead to physical antenna pointing angles, the trunnion (beta) and shaft (alpha) angle residuals (see fig. 3-15). As such they are hard to relate to the real body axes (to convert body axis frame to antenna frame, rotate the X axis about the Z axis to the right (+X into +Y) by 67°).

For the -Z COAS NAV data source option, EL and AZ are reverse of what they seemed for the STRK (see fig. 3-14). V/EL/Y is elevation in the COAS (in the COAS frame this is the X coordinate) and H/AZ/X is the azimuth (in the COAS frame this is the Y coordinate). The Y and X in the display text were originally named because the measurements are rotations about the Y and X axes.

For X COAS angles the residual V/EL/Y is measured in the XZ body plane with a positive measurement from +X towards +Z (an angle of depression). The residual H/AZ/X would actually correspond to a residual of azimuth angles since positive is measured from +X to +Y (nose to right wing). Thus if a perfect mark was taken and the COAS was perfectly aligned with the +X body axis then a positive V/EL/Y residual would indicate the TGT estimated LOS is above the true LOS and a positive H/AZ/X would indicate the estimated LOS is to the left wing side of the true LOS. If the radar is locked on simultaneously with X COAS tracking, then EL = 23° ± E and AZ = -90° ± S where E and S are functions of noise and bias in the radar system.

3.4.1.3.13 <u>Residual edit ratio</u>.- The residual edit ratio is the ratio of the magnitude of the actual measurement residual divided by a multiple of the expected residual based on the current covariance matrix. The residual edit ratio is computed for use in the data edit test inside NAV. A data measurement is edited if its residual ratio is greater than 1. The ratios update on the display in an 8-second cycle. See also 3.4.1.3.11.

In calculating a RATIO on the REL NAV display, the RNDZ NAV filter uses a value that is 6 times the expected error (covariance matrix and filter weighting). For example, the current covariance (which contains 1-sigma NAV uncertainties) starts at 20 kft in X. After a COVAR REINIT, a RATIO of 1.0 would reflect an error of 120 kft.

3.4.1.3.14 <u>Mark history, accept/reject</u>.- The number of NAV marks of each type (range, range rate, angle 1, angle 2) that have been accepted or rejected by the RNDZ NAV filter will be displayed.

These ACC/REJ counters are all reset to zero under the following conditions:

a. After a burn (probably OMS) of more than 20,000 μg

b. After covariance matrix reinitialization, either by execution of item 16 or by other actions as follows:

    (1) Entering RNDZ phase (RNDZ NAV set to "*")

    (2) Orbiter SV uplink during RNDZ phase

    (3) Target SV uplink during RNDZ phase

    (4) PROP → FLTR SV transfer

    (5) ORB → TGT SV transfer

    (6) TGT → ORB SV transfer

c. When the angles input data source (STRK, RR, COAS) is changed (angle counters only)

When more than a K-loaded number (currently 3) of sequential marks are rejected, a down arrow will be driven in the status column of that measurement type, an alert message ("NAV EDIT") will appear and a tone will be heard.

This down arrow is removed when the data are manually forced and the ratio test is passed for one mark, or when more than a K-loaded number (currently 2) of sequential acceptable marks occur.

3.4.1.3.15 AIF switch (EDIT OVRD - AUT/INH/FOR, Items 17-25).- The displayed residuals, ratios, accept, and reject counters serve as the basis for the crew decision as to how external measurement data are to be processed by the NAV filter. Three mutually exclusive options are available to the crew for each of the range (Items 17, 18, 19), range rate (Items 20, 21, 22), and selected sensor angle data (Items 23, 24, 25). These are as follows:

a. AUTO: Valid sensor data passing the residual edit test are to be automatically used to update the SV and covariance matrix.

b. INHIBIT: Valid sensor data are to be used for computing residual and ratio values but are not to be used to update the SV and covariance matrix. Thus, when in INHIBIT, the ACCEPT/REJECT counters will not be incremented.

c. FORCE: The edit test criterion is relaxed, since the maximum allowable residual ratio used in the NAV filter edit test is increased to a higher value (currently last mark + 0.2). Valid data will be used to update the SV and covariance matrix only if the new edit criterion is met on the next residual edit test. These new test criteria are in effect for only one NAV cycle. The control then reverts to the previously selected option (AUT or INH). An "*" appears beside the FORCE item only while the control is in effect. For angles from COAS, the force option is the nominal mode for processing the data. The force input applies to the last COAS mark taken within the previous 2 minutes. However, NAV does not necessarily incorporate the COAS mark since it still could fail the ratio test, but this is not likely.

   Note: When forcing COAS marks on the REL NAV display, the threshold (last RATIO value plus 0.2) is applied to the last forced and accepted mark, not to the last mark taken by pushing the ATT REF button.

When the display is first called in OPS 2, the INHIBIT items will be selected. These items are applicable both when RNDZ NAV is enabled in MM 201, and also in MM 202 when the MEAS ENA item is selected.

For all tracking passes, measurement incorporation will be inhibited prior to sensor acquisition. Inhibiting data prior to sensor acquisition allows the crew to assess the quality of the sensor data prior to its incorporation into the filter.

Note that the documented error message FALSE TRK will never appear on the display. The discrete that drives the message is used to update the reject counter instead of displaying the message FALSE TRK. A problem incident report DR was written against the software, but instead of fixing the descrepancy, the requirement has been waived.

3.4.1.4 Editing Contingencies

The AIF switches on REL NAV are used to control flow of data from sensors into NAV. For all sensor acquisition intervals, measurement processing will be inhibited until the crew determines that the sensor acquisition was successful. At that time the crew will select AUTO, and NAV will begin to process the sensor data to update the Orbiter SV.

3.4.1.4.1 STRK Marks.- For STRK acquisition, there is a ~~same~~ small risk that the STRK will lock-on to a star instead of the target, so the crew must monitor residuals and residual ratios for at least four consecutive NAV cycles. They should then select AUTO when residual growth is less than 0.05° for four measurement processing cycles and residual ratios are less than 1. If the residuals indicate TGT lock-on, but the ratios remain greater than 1, perform the following steps sequentially until the ratio drops below 1, then proceed with the timeline.

a. Break track and reacquire TGT. If residual editing continuously occurs, most likely the STRK has either locked onto a star, or has a malfunction, or very large relative state errors are present. To prevent bad measurements from being incorporated into the filter, breaking lock and reacquiring the TGT is the desirable first step because it does not update anything in the relative navigation state.

b. Reinitialize covariance matrix. If the covariance matrix has been reduced by measurement incorporation, reinitializing the covariance will expand it and allow larger updates to be incorporated into the filter (i.e., it enlarges the acceptance criteria). Incorporating these larger updates should correct the relative SV, which will stop the residual editing.

c. Force up to three measurements (select AIF = FORCE for three marks). If covariance reinitialization is not sufficient to prevent residual editing, data can be forced into the filter (this enlarges the acceptance criteria still further). Three consecutive measurements should correct the relative SV sufficiently to stop the residual editing. If measurements continue to be edited, a generic problem may exist and, most likely, forcing more measurements will not improve the situation.

d. Filter restart (propagated to filtered SV transfer). This assumes an unusable totally ruined FLTR SV. An SV restart eliminates all data incorporated into the filtered SV since the last filtered-to-propagated SV transfer. This is a last-resort procedure to correct the RNDZ NAV relative state.

At the end of the STRK pass, and before sunset, it is required that the STRK angles be set to INH in REL NAV to prevent the corruption of the FLTR SV if the STRK locks on to a star.

3.4.1.4.2 RR Marks.- For RR acquisition, the crew must monitor the radar data flags to verify no down arrows and verify that ratios are less than 1. Under these conditions, they would select AUTO. If after repeated RR acquisitions the ratios remain greater than 1, the following steps should be performed sequentially until the ratio drops below 1 (at that point, proceed with the timeline).

a. Reinitialize covariance matrix. (See b. above.)

b. Perform FLTR-to-PROP SV transfer. By this point the NCC burn has been performed, based on multiple STRK passes. If the onboard-targeted ΔV was within 3 sigma of the ground solution, this should validate the FLTR SV and it should be saved.

c. Either select AIF = FORCE three times (to force three marks), which is the primary method, or wait for STRK data post-Ti to help resolve the impasse. If the FLTR SV has given a reasonable targeting solution for the NCC burn, perform FORCE. If FORCE is unsuccessful in that the RR data cause the FLTR SV to diverge, execute a filter restart (PROP TO FLTR) and then wait for the post-Ti STRK data.

3.4.1.4.3 RR/STRK Marks.- Post-Ti the crew will have both STRK and RR data available. Approaching Ti, the following procedure is used:

a. Initial condition is ANG SELECT = RADAR and all AIF = AUTO.

b. To perform Ti, go to MM 202, select ANG AIF = INH, perform burn, return to MM 201, when back in attitude select ANG AIF = AUTO.

3.4.1.4.4 COAS Marks.- A discussion of COAS marks is found in sections 3.3.3.3, 4.1.14, and 4.3.3.

3.4.1.5 Defining The Stages of Relative Navigation

The process of acquiring and utilizing onboard sensor data consists of several distinct events and criteria, each of which have been discussed individually elsewhere. A summary review of these events in proper sequence can allow an appreciation of their interrelationships, and can provide a view of the precise stages through which relative navigation progresses. The precise meaning of each of these stages is summarized below.

3.4.1.5.1 Search.- The STRK and/or RR sensors perform their programmed search patterns, or the crewmember looks through the COAS or on the CCTV monitor.

3.4.1.5.2 Detection.- The presence of the target is reflected by sensor monitoring software, but "DATA GOOD" flags are not yet set. Alternately, the target is spotted visually or on CCTV.

3.4.1.5.3 Acquisition.- "Data Good" flags are set on the RR parameters by the Ku-band hardware, and these are displayed; "S PRES" is displayed for the STRK. For STRK, see section 3.3.2.1; for RR, see section 3.3.4.5 and 4.1.30. For COAS, the equivalent phase is performed manually, with the crewmember noting the LOS angles.

3.4.1.5.4 Lock-on.- This implies that the sensor is performing closed-loop tracking with sensor data, aiming the sensor or the Orbiter based on this data. Only the RR and STRK are capable of "lock-on", and nominally they lock on as soon as they acquire.

There are RR configurations in which acquisition is not followed by lock-on but in which range and range rate marks may be used by relative navigation. Angle data should remain inhibited.

The COAS inherently cannot perform "lock-on", although with man-in-the-loop operation this function can be approximated.

3.4.1.5.5 Data into REL NAV.- This happens as soon as RR "DATA GOOD" flags are set, as long as the data path from sensor to GN&C GPC's is good. Sensor data is being processed by SPEC 33 for display purposes only, and RESID's and RATIO's (defined in 3.4.1.3.12 and 13) are being computed and displayed/downlinked.

3.4.1.5.6 Data meets "accept" criteria.- Data as displayed on REL NAV passes the RATIO/RESID editing criteria, as defined in navigation blocks in RNDZ BOOK. For STRK, see section 4.1.13; for RR, see sections 4.1.31 and 4.1.32.

3.4.1.5.7 AIF to "AUTO" (or "FORCE").- The crew manually modes AIF flags to "AUTO" (section 3.4.1.3.15) for incorporating sensor data into the GN&C navigation FSW computations to improve the FLTR SV. The ACC/REJ counters increment. Edit checking begins.

For COAS NAV, the marks are taken with the ADI REF pb, have their RESID/RATIO's displayed, and are then always individually incorporated into REL NAV by use of the AIF "FORCE" option.

3.4.1.5.8 Marks pass edit check.- The RESID's of each parameter meet edit criteria as defined by COVAR matrix (section 3.4.1.3.11). RR marks are converted from a sensor-centered to an Orbiter-cg-centered frame; STRK and COAS marks are not converted. They then are used to shrink the COVAR matrix and to improve the FLTR SV.

The commonly-used phrases "RR NAV" and "STRK NAV" refer to this stage. The "Sensor data" criterion used in Flight Rules also is best defined by this stage.

3.4.1.5.9 NAV converged (operationally).- In practice, for STRK, 40 marks will give "operational convergence". Other criteria include the SV POS update being less than 0.5 kft for the last four marks, or in general "SV POS/VEL updates small and stable".

This situation means that the FLTR SV is "good enough" for performing targeting: "good enough" is defined by the predictable errors being less than dispersions to be expected from other sources such as IMU errors or burn trim uncertainties. The FLTR solution will normally be better than either the PROP solution or the ground solution.

3.4.1.5.10 NAV converged (mathematically).- Additional marks continue to improve the FLTR SV and the accuracy of the FLTR solution, up to a point. After this point, the scatter of the NAV marks is such that no improvement in SV knowledge is made by incorporating further marks. For STRK, this occurs at about 120 marks.

3.4.1.5.11 End of tracking pass.- The sensor may be unable to continue taking marks (for STRK or COAS, at sunset; for RR, beyond a certain range or with a changed target attitude reducing its radar cross section). Generally, however, the tracking pass can end when the FLTR SV has fully profited from the marks and there is no advantage to taking more marks. At this point, the FLTR SV should be superior to the PROP SV. In practice, the sensor may be left locked-on to the target as long as feasible, but relative navigation is not the driver on this.

3.4.1.6 Improved REL NAV

Based on actual RNDZ mission experience, improvements to the REL NAV SPEC function have been developed and documented in CR 79735. These improvements may be implemented in the near future, once the new GPC's are installed on the Orbiter fleet. For the sake of future users, the following descriptive material outlines the expected new capabilities of REL NAV once the proposed improvements are in force. At that point, this entire section will be updated by a PCN to this book.

As outlined on the CR, the display changes include:

a. Add arm/fire logic to RNDZ NAV ENA function. The "ITEM 1" will be the "ARM", and "ITEM 2" will cause execution of the RNDZ NAV state flip-flop. This will insulate the crew from inadvertently turning off RNDZ NAV and thus losing the current propagated state, which is serving as a backup SV. An inadvertent drop of RNDZ NAV complicates SV management plans.

b. Modify thrust monitor computations of displayed ΔV's. This will prevent incorporation of IMU noise, especially absolute values of same.

c. Add display of PET (HH:MM:SS) and PROP SV (HH:MM:SS) age. The MET base time for the PET clock is entered on the TIME SPEC. The SV age clock is reset whenever the PROP SV is updated by uplink or item entry transfer.

This eases the crew mental timekeeping computation/comparison workload, allowing straightforward references to the FDF RNDZ Book and standard separation profiles.

d. Add ARM/FIRE logic to SV transfer items. A special "ITEM 13" toggle is set prior to executing an ITEM 9, 10, 11, or 12 for all SV transfers. This will prevent inadvertent loss of one SV when the other is copied over it.

e. Add accept/reject counter reset ITEM. This is ITEM 41 (RESET CNTR). It will give a quick count of marks during the current sensor pass, which is used as a cue to decide on "convergence."

f. Add navigated elevation angle display. This is displayed both for FLTR-PROP and for currently-used SV (the angle between the projection of a line joining the Orbiter and the TGT into the orbit plane, and the Orbiter local horizontal plane, 0° to 360°). In addition, the angle between the projection of the Orbiter tracking body vector (selected on UP) into the orbit plane and the local horizontal (0° to 360°) is also displayed. This replaces a laborious manual crew task and aids in the plotting of Orbiter trajectory on "Relative Motion Plots" (section 4.7), which is valuable to alert crew to off-nominal dispersion trends.

g. Change time OF nodal crossing (in MET) to time TO nodal crossing (countdown in MM:SS). This is used as alert for imminent performance of out-of-plane-null burn post MC1, and relieves the crew from the requirement for constant monitoring and mentally estimating trends of Y and Y-DOT.

h. Add STRK TGT present indicators. This is an easier feedback of status, and relieves crew of need to call up STRK/COAS SPEC repeatedly.

i. Add COAS offset angles for RR. This allows visual observation through COAS of object being tracked by RR, especially if object is dim against star background.

j. Modify display to show only the coordinate system for the RNDZ sensor which is supplying angle data. This enhances readability and reduces potential crew confusion.

k. Delete filter slow-rate item. This is never used; originally it was intended to use STRK only every 16 seconds, to keep CPU time down.

m. Add FLTR-PROP angle data. See "f", above.

n. Expand RR status text field. This enhances readability and reduces potential of crew confusion.

o. Blank residuals and ratios when data-good flag from sensor is off. This enhances readability and reduces distractions.

Further, the CR makes some changes to other displays. On the TIME DISPLAY, it adds PET SET controls and PET ALARM SET controls. On ORB TGT, it adds PET clock. On IMU ALIGN display, it provides crew control for updating the ΔV threshold as part of the thrust monitoring update to the REL NAV display.

3.4.2 State Vector Management

Three SV's are maintained aboard the Orbiter: The TGT SV, a filtered (sensor data) Orbiter SV (called FLTR), and a propagated Orbiter SV (called PROP) using IMU ΔV's only. The management philosophy for the Orbiter SV has undergone considerable evolution due to SES experience, NAV analysis, RNDZ mission profile documentation development, and actual flight experience.

The crew is required to manage these SV's during various RNDZ mission phases by performing appropriate SV selection, transfers, and editing (AIF switches) via item entries on the REL NAV display (section 3.4.1).

3.4.2.1 State Vector Select

Upon entry into RNDZ phase (sections 4.1.6 and 4.1.14), the STATE VECTOR SELECT option is initialized to PROP. The setting will be manually changed to FLTR after 10 marks have been accepted by the filter for each measurement type appropriate for the active sensor, and when SV UPDATE POSITION is less than the following convergence criteria: for STRK, 1000 feet; for RR, 300 feet.

RNDZ burns are done using the most accurate SV. This will be the PROP state until the first good NAV sensor pass, then it will be the FLTR state. The PROP state then becomes a "backup" state, to be used if the FLTR state somehow becomes corrupted by bad data. See section 4.1.27 on "Solution Selection."

3.4.2.2 FLTR-TO-PROP Transfer

The crew will exercise a FLTR-TO-PROP SV transfer at the beginning of each new sensor tracking interval (excluding the first), to update the PROP SV with the up-to-date FLTR SV. The PROP vector will then be a better SV for any required future FLTR restart. The FLTR-TO-PROP transfer will not be exercised until after successful acquisition of the target with the tracking sensor (since if the acquisition is not successful, an independent Orbiter SV - the PROP SV - will be available to attempt acquisition again). Successful acquisition is regarded as confirmation of the goodness of the FLTR SV. Following acquisition, the crew will monitor the residuals, residual ratios, and sensor data-good for at least four NAV cycles (approximately 30 seconds) before executing the FLTR-TO-PROP transfer.

These FLTR-TO-PROP SV transfers will usually be conducted at the following times:

a. After STRK acquisition (second pass), but prior to enabling the STRK data into the filter. Criteria are growth in residuals less than 0.05° over successive NAV cycles (every 8 seconds) and residual ratios less than 1. This is to save the current best estimate SV before putting sensor data into it, on the chance that the sensor data may subsequently degrade rather than improve the SV. A good practice is to keep a "proven SV" in the PROP slot for fall back in the event of FLTR SV problems (see section 4.1.22).

b. After RR acquisition pre-Ti, but prior to enabling the radar data into the filter. Criteria are radar data flags good (no down arrow) and residual ratios less than 1 (see 4.1.31).

c. Post-Ti, after the STRK or RR acquisition, but prior to enabling the data into the filter (section 4.1.45). Criteria are STRK angle residuals growth over about 30 seconds is less than 0.05° and all measurement residual ratios less than 1.

   Caution: A FLTR-TO-PROP is generally not performed in the middle of a sensor pass because there is no positive test to determine if the FLTR SV is good.

3.5 TARGETING (SPEC 034)

Targeting is defined as the computation of the necessary MNVR required to transfer the Orbiter to a desired state or position at a desired time.

Rendezvous targeting begins with launch. During ascent the Orbiter is steered to the proper insertion orbital plane. This depends on the target's orbital plane and the phase angle at MECO. OMS2 is the first on-orbit rendezvous maneuver: it is a phasing maneuver targeted with the MCC rendezvous targeting processor (RTP). The MCC performs all rendezvous targeting until the range to the target decreases to about ~~200~~ 40 n. mi., at which time onboard relative NAV sensors begin to measure the relative state more precisely than ground tracking of both vehicles.

Even within the last 200 miles, several maneuvers for phasing, altitude, and planar adjustment are targeted only on the ground. This is due to STS FSW algorithm limitations which were imposed in 1978 during a software scrub to make room for higher priority FSW. Only two-impulse rendezvous targeting software survived that scrub.

Before the 1978 scrub there were two separate onboard software packages which were expected to be incorporated into the FSW. One was a scrubbed-down version of the RTP which had Lambert 2-impulse maneuvers and coelliptic maneuvers; it also allowed a maneuver to be scheduled at geometric elevation angles, while transfer times between maneuvers could be scheduled in fractions of orbital periods or in minutes. The other package was the Prox

Ops Specialist Function which would perform CW targeting for terminal phase rendezvous (ranges < 5 n. mi.) since it was at that time just becoming evident that the Orbiter's FRCS was not large enough to support manual braking with the proposed double-coelliptic profile with a differential altitude of 10 n. mi.

During the scrub effort, essentially the Lambert 2-impulse scheme was extracted from the "onboard RTP" and placed into the Prox Ops Specialist Function, and the combination was renamed "ORBIT TARGETING" (SPEC 34). About 5 years later, the double coelliptic profile concept was dropped in favor of the stable orbit rendezvous (SOR) technique which solved the FRCS limitations.

While the "targeting" for PROX OPS is normally a manual function, performed by the crew with the aid of procedures which use raw sensor data and rules-of-thumb, most RNDZ translation MNVR's use Orbit targeting with AUTO maneuver execution (e.g., see sections 4.1.9 and 4.1.38).

The ORBIT TGT display is SPEC 34 and is available in GN&C OPS 2. (See figure 3-32.) This display and the associated orbit targeting software give the crew the capability to generate a software targeted two-MNVR set. The first MNVR is targeted to move the Orbiter from a predicted position to a desired TGT relative position in a given amount of time (ΔT). The second MNVR is targeted to null the Orbiter velocity relative to the TGT. The targeted MNVR outputs of this software are displayed to the crew on the ORBIT TGT SPEC are also available as inputs to the MNVR execution software and CRT display, ORBIT MNVR EXEC in MM 202. The ORBIT TGT display is divided into three sections: inputs, controls, and maneuvers.

One warning on MCC monitoring of onboard targeting activities: of all the parameters on the targeting SPEC, only "TGT ID" is currently downlisted. If the crew modifies a TGT set (deliberately or inadvertently), the MCC cannot see it. The MCC does not see PRED MATCH or BASE TIME.

3.5.1 General Description

In general, a sequence of RNDZ, braking, stationkeeping, or transition MNVR's can be performed by selecting the appropriate TGT set and executing the computation with the ORBIT TGT display, then executing the MNVR with the aid of the ORBIT MNVR EXEC display in MM 202 and repeating that procedure for each remaining MNVR in the sequence.

3.5.1.1 Target Sets

One of 40 targeting sets can be chosen by the crew via Item 1 on the ORBIT TGT display. The possible TGT sets are part of the I-load and may be changed by ground uplink or by crew manual input. In most cases, each TGT set has a nominal time (T1) associated with it when the first MNVR should occur and the desired position, with respect to the target (ΔX, ΔY, ΔZ) where the Orbiter should be a given amount of time (ΔT) later. In this case, the elevation of the TGT with respect to the Orbiter local horizontal is not usually used to determine T1. (Item 6 is zero.)

When the target set ID is entered in Item 1, the following will appear with data: Items 2-6, 17, 18, 19, 20.

These parameters are used by the targeting software to compute the first burn of the specified two-impulse MNVR sets. This computation is not made until a COMPUTE T1, Item 27, is executed. When the COMPUTE T1 item is executed, the other Items (7-12, 13-16) in the input list will be computed and displayed. Items 7-12 (ΔX/DNRNG, ΔY, ΔZ/ΔH, ΔẊ, ΔẎ, ΔŻ) show the Orbiter relative position (kft) and velocity (ft/s) with respect to the TGT-centered rotating curvilinear reference frame, at the input-time T1 based on current onboard NAV information. Items 13-16 (T2 TIG) represent the time of the second MNVR of the two-impulse set and are computed based on the T1 and TIG time and the given ΔT.

As will be described later, the computed ΔV's (ΔVX, ΔVY, ΔVZ, total ΔVT) necessary for the first burn will appear in the MNVR section of the display and will also be passed to the on-orbit guidance software (MM 202). The burn is not executed, however, until it is subsequently loaded with the ORBIT MNVR EXEC display. The burn is then executed (section 3.6.2) either automatically (OMS only) following a crew entry to the ORBIT MNVR EXEC display, or manually by the crewmember using the THC (RCS only).

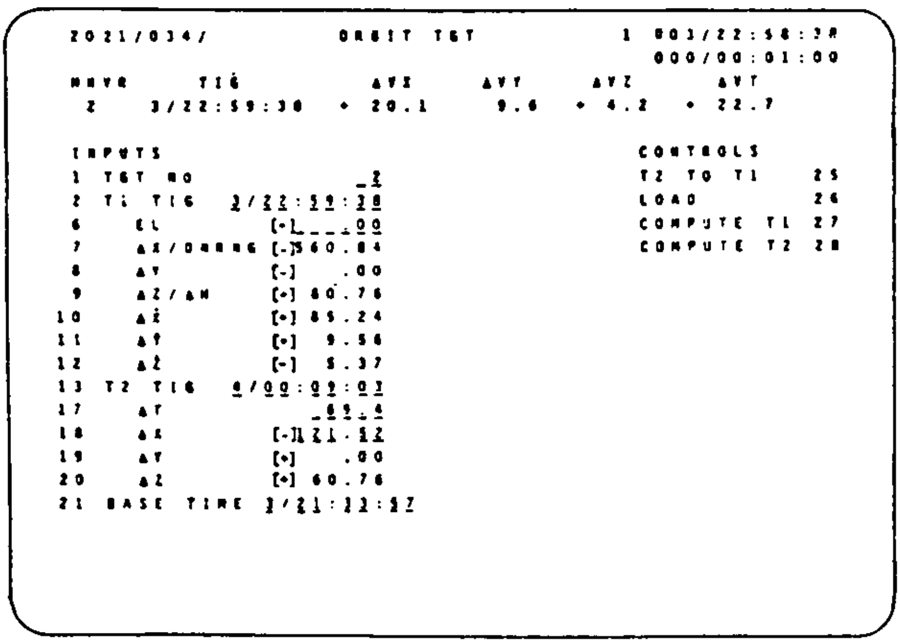


Figure 3-32.- ORB TGT display.

Other options are available using this display. For example, with the elevation option, the T1 time is determined onboard and is the time when the TGT LOS is the specified number of degrees (Item 6) from the Orbiter local horizontal axis. This also resets the base time. As an example of another user option, if the input ΔT time (Item 17) is negative, a flag is set in the S/W such that a new T2 time will be computed with an algorithm which ensures that the second burn is accomplished in a direction orthogonal to the TGT LOS. This could be used in orthogonal braking. Current procedures do not use this option.

Another option includes user input of a T2-TIG in Items 13 to 16, with ΔT (ITEM 17) set equal to zero. Then the software will compute ΔT for the user. Finally, the user may input what he feels is the true relative state of T1 via Items 7 to 12. After these are subsequently loaded via Item 26, the software will utilize the "required relative state" to determine the ΔV maneuver when Item 27 is requested. As an example, if the crew used alternate ranging devices (e.g., ranging rulers) while stationkeeping on the V-BAR when the Ku-band radar has failed, they could load the resulting range into Item 7 and set Items 8 to 12 to zero. They could then compute a maneuver to transfer to the -R-BAR or some other point in some transfer time ΔT.

Current planning includes a midcourse burn (MC2, section 4.2.4.4) targeted on elevation, but no use of orthogonal braking (possibly with space station).

3.5.1.2 Targeting Computation Techniques

A detailed discussion of Lambert targeting versus Clohessy-Wiltshire (C-W) targeting is found in Appendix B of the Rendezvous/Proximity Operations workbook (February 1985). In practical terms, the following brief treatment explains the different procedural options available to the crew.

In MM 202, burns may be executed with either Lambert iterative guidance or with constant or external ΔV targets. The former must be targeted onboard, using the Lambert computation technique; the latter may be targeted onboard using the C-W computation technique, <u>or</u> the ΔV's may be manually entered from written pads (see section 3.6.1). The choice of Lambert vs C-W targeting is specified in the MNVR table defined by I-load.

Computations for Lambert targeting were once expected to take much longer to solve, but that disadvantage never materialized and targeting now typically takes 10 to 30 seconds. Its advantages include dynamic retargeting in the event of a TIG slip. The only practical advantage of the C-W technique is its ability to handle multi-REV targeting, and that advantage is not needed for current RNDZ strategies. Hence the current policy is to perform all onboard targeting using Lambert guidance, while doing ground-targeted burns in "external ΔV" (PEG 7) mode.

3.5.2 Inputs to ORB Targeting

3.5.2.1 Target Number (Item 1)

As stated earlier, the capability exists to load 40 predefined MNVR's in the I-load preflight. These MNVR's may be changed through ground G-MEM writes, or by the crew through Items 2-20 and execution of a LOAD item (Item 26) on this display. For each TGT set there is a flag internal to the software which is set to identify whether Lambert targeting or the closed form Clohessy-Wiltshire equations will be used in the targeting. These flags are part of the I-load and can be changed by the ground or by the crew via GPC memory modification using the GPC MEMORY SPEC (There is no known reason for wanting to do this). The number entered with Item 1 will retrieve the necessary targeting inputs for that MNVR set from memory and display them in the appropriate locations on the display. An example of the projected TGT sets is given in figure 3-33. Other target sets are either blank C-W or blank Lambert, so they can be called up and filled in as specified by the MCC for off-nominal situations. Note that transitions out of OPS 2 will result in the reinitialization of the original I-loads upon subsequent return into OPS 2. In the following sections, assume that a TGT number has been entered in Item 1.

Target set ID	MNVR to be computed
9	NCC
10	Ti
11	MC1
12	MC2
13	MC3
14	MC4
19	MC2 on TIME

Figure 3-33.- Projected TGT sets.

3.5.2.2 T1 TIG (Item 2-5)

These items specify the time (days, hours, minutes, seconds) in MET of the first burn, in the 2-impulse pair. If the COMPUTE T1 item (Item 27) is executed when the T1 TIG is in the past (as may happen, if a burn is missed, or if it is recomputed due to high velocity residuals following the first execution of the burn), or is less than an I-loaded interval (currently 1 minute) in the future, a new T1 TIG will automatically be computed as the current time plus the predefined I-loaded interval (currently 1 minute) and the transfer time will be decremented accordingly. Also this will cause software to ignore any inputs in Items 7-12, and instead, the software will use the onboard navigated state at that new T1 TIG time. It is also possible to change the T1 TIG through a keyboard entry to Items 2-5. In this case, the word LOAD will flash next to Item 26, and after the input values are verified, they will be loaded into the I-loaded slots for the T1 TIG for that TGT set after execution of Item 26.

The I-loaded T1 TIG times are actually loaded in the software as times referenced to the "base time" (Items 21-14). (See section 3.5.2.8). This was done to make it easy to slip a full RNDZ plan: just change the BASE TIME and all T1-TIG's will be adjusted accordingly.

3.5.2.3 Elevation Angle (EL-Item 6)

This item refers to the elevation angle, positive up, to the TGT. If the EL = 0, the elevation angle option is ignored and the input T1 TIG and associated values will be used. However, for certain MNVR's such as MC2, an elevation angle ≠ 0 (such as 28°) will be loaded. When this is the case, the T1 TIG time is determined by the onboard software as the time nearest the T1 TIG time at which the elevation angle is equal to value given in Item 6.

The angle tolerance is approximately 0.3°. If ORB TGT cannot satisfy this tolerance, an SM class 3 alarm (EL ANG) is issued (see section 3.5.5).

For current RNDZ profiles, the MC2 burn is targeted on elevation (see section 4.1.51).

Note that the crewmember can change a TGT set based on elevation angle to one based on the TIG time by reloading an elevation angle of zero. Loading zero does not force an elevation search for 0° so it will use the specified TIG.

It is possible for a burn based on elevation not to set the BASE TIME equal to the T1 TIG time. This can happen when the TGT set is computed with an initial displayed T1 TIG time in the past. When the TGT set is computed the elevation angle will be ignored, but not removed from the display. The TIG will be 1 minute in the future and the ΔT will be decremented accordingly.

3.5.2.4 Relative Position Items (T1 ΔX/DNRNG, ΔY, ΔZ/ΔH, ΔX-DOT, ΔY-DOT, ΔZ-DOT - Items 7-12)

These items show the Orbiter relative position (kft) and velocity (ft/s) with respect to the TGT at the T1 TIG time. If they are all zeros, or if the T1 TIG time is in the past, all of their values will be computed and displayed based on the onboard NAV information at the time a COMPUTE T1 (Item 27) is executed.

Alternately, values can be manually entered for Items 7-12 which will be used in the targeting algorithms as the assumed correct relative position and velocity of the Orbiter at the T1 TIG time regardless of the onboard NAV software. When one of Items 7-12 is entered, the LOAD item (Item 26) will flash until it is executed. Execution of this item actually loads the values in the INPUTS section of the display which are then used in the computations (relative state keyed in, but not loaded, is completely ignored). This provides a means for overriding the NAV state, although this is not used in any nominal procedures. The crew can get back to the onboard vector by calling a new TGT set.

3.5.2.5 T2 TIG (Items 13-16)

This item represents the time in MET of the second MNVR of the two-impulse set. If ΔT (Item 17) is not zero, a COMPUTE T1 (Item 27) will cause the T2 TIG to be calculated and displayed. If the T2 TIG is in the past when a COMPUTE T2 is done, it will be reset to current time plus a predefined ΔT, and the MNVR is computed using the NAV state vector at the new T2 TIG time. A "COMPUTE T2" does not update items 7-12.

NOTE: If a TGT set is computed (ITEM 27) with a T1 TIG in the past, targeting won't still attempt to get to the T2 point in the ΔT specified in the TGT set. When the TGT set is computed, the T1 TIG will be changed to the present time plus 1 min. The ΔT will also change an equal amount to reflect time elapsed since the original T1 TIG. The T2 TIG will remain the same.

Undesirable results may follow if the crewmember tries to compute a burn with a TIG in the past greater than the ΔT in the TGT set. Because the time change is greater than the ΔT, a negative time change is seen as a request for orthogonal braking and the S/W will try to compute a solution accordingly. This may result in an iteration alarm, a lengthy computation time, and an erroneous solution.

3.5.2.6 Delta-T (Item 17)

The transfer time in minutes between the first MNVR time (T1 TIG) and the second MNVR time (T2 TIG) is represented by ΔT. If ΔT is zero, it will be computed based on the T2 and T1 TIG times when a COMPUTE T1 is executed. If ΔT is negative on execution of a COMPUTE T1, both ΔT and T2 TIG will be computed based on an algorithm used in orthogonal braking and will be displayed. The algorithm computes the ΔT (and thus the new T2 TIG) necessary to ensure that the second burn of the two-burn MNVR set occurs normal to the LOS from the Orbiter to the TGT.

3.5.2.7 T2 Relative Position (ΔX, ΔY, ΔZ - Items 18-20)

These parameters represent the desired Orbiter relative position (kft) at the T2 time (ΔT after T1 TIG - Items 13-16). This is the TGT position for the first COMPUTE T1. If a COMPUTE T2 is done, a burn will be computed that will null the relative velocity between the Orbiter and TGT at the T2 TIG time, regardless of these values.

3.5.2.8 Base Time (Items 21-24)

This is the time from which subsequent MNVR's are calculated. As was stated earlier, each MNVR time in each MNVR set is stored as a ΔT added to a base time. Thus, in general, an entire RNDZ can be slipped without adjusting T1 TIG times. The base time is originally an I-loaded value. It automatically changes when the elevation angle search option is enabled for a Lambert-targeted MNVR. It is reset to be that MNVR's computed T1 TIG time. Thus, the base time is updated to the MC2 time when the MC2 MNVR is computed based on an elevation search (this is the only burn currently targeted on elevation). This forces subsequent MNVR's to occur at times relative to the elevation angle time.

This time is defined in MET and is used to anchor onboard calculations for burn execution to a specific instant during the mission. The I-loaded set of burn parameters for the Orbit-targeting software includes only a relative time tag for each translational burn and requires a mission timeline-specific MET anchor. By using this scheme, the entire RNDZ profile can be moved to various times in the mission, and only the base time needs to be updated. The base time for ORB TGT has been defined to be the ignition time of the Ti burn, although any time would work as long as the appropriate relative time tags were loaded as part of the I-loaded burn parameter set.

In loading the base time the crew calls up TGT set number 1 before entering the data, because loading the base time can alter the I-loaded data set, and TGT set no. 1 is an unused blank data set. Calling up an unused TGT set when they change BASE TIME is for protection. When ~~it~~ is first called up, it displays TGT set zero. Changing any item in that TGT set will write it into an unpredictable memory location not allocated to the 40 TGT sets. Subsequently, calling up TGT set zero will result in an ILLEGAL ENTRY.

Due to omission of a range check

ORBIT TGT

3.5.3 Controls

3.5.3.1 T2 to T1 (Item 25)

This item forces the T2 TIG time of the previous MNVR set to be transferred to the T1 TIG slot of the currently called MNVR set. This is useful, for example, in orthogonal braking where the ΔT and T2 TIG times for each MNVR are recomputed in order to ensure that the burn at T2 is normal to the TGT LOS. In this case, it is desirable to target the next two-impulse MNVR set with the new T1 MNVR TIG being at the previously defined T2 TIG. This is not currently used.

3.5.3.2 LOAD (Item 26)

Execution of this item loads item entry data values into the data slot for use by the targeting software. They actually overwrite the I-loaded values so that if that MNVR set is again requested via ITEM 1, the newly loaded values will appear. If any item entry (except TGT NO) in the INPUTS section is made, the word LOAD flashes until Item 26 is executed. After it is executed, it will remain static until a new item is entered in the INPUT section.

3.5.3.3 COMPUTE T1 (Item 27)

Execution of this item results in the software calculating the first MNVR of the specified two-MNVR set. The calculated results are displayed in the MNVR section of the display and are also output to guidance for display on the ORBIT MNVR EXEC display. Also, all of the items in the INPUTS section of the display will fill in. An "*" will be driven beside Item 27 until the calculations are complete (7-10 seconds for both Lambert targeting and for C-W targeting). As soon as the T1 computation is complete, the GN&C CRT timer will start counting down to the T1 TIG (it is stopped by a MM 202 transition or a LOAD on MNVR EXEC, and must then be restarted).

A targeting computation during a burn execution is not ignored, but is held and executed immediately when the burn is completed (i.e., when TGO = 0). Therefore, the crew must not initiate an orbit targeting computation during a burn, or the burnout velocity-to-go (VGO) residuals on the MNVR EXEC display will be lost.

There are no reasons why a preliminary TGT solution cannot be computed while the Orbiter is maneuvering to a new attitude after the maneuver. In fact, loading the TGT set early gives the advantage of having the CRT timer start counting down to the burn sooner (e.g., post Ti, the preliminary MC1 solution is called out to be calculated on the way back to track attitude).

3.5.3.4 COMPUTE T2 (Item 28)

This item is used to initiate the calculation of the second MNVR of the two-impulse set. This second MNVR is calculated to null the relative velocity at the T2 TIG. As stated earlier, if the T2 TIG is in the past, it will be updated to the current time plus a delta. An "*" is driven by Item 28 until the MNVR calculations are complete. When the calculations are complete, the required ΔV's are displayed in the MNVR section of the display and are passed to guidance awaiting execution. Also, the GN&C CRT timer will start counting down to the T2 TIG.

Note that execution of an Item 28 (COMPUTE T2) while the computation for Item 27 is still in progress, and vice versa, is illegal, and an ILLEGAL ENTRY message will be generated if that is attempted.

If the crewmember calls up a TGT set and does a COMPUTE T2 before doing a COMPUTE T1, the software will calculate the ΔV required to null rates at the last computed T2 time, which was saved internally during the last MNVR computation. Therefore, a COMPUTE T1 must always be performed before performing a COMPUTE T2.

If the crewmember executes a COMPUTE T2 with a T2 TIG in the past, the new T2 TIG will be the present time plus 1 min. All relative rates at the T2 ignition point will be nulled out.

This compute option not currently used.

3.5.4 Predictor Match (PRED MATCH)

Predictor match gives the distance (in feet) to which the onboard orbit predictor was matched in targeting. In other words, this is a readout of the GNC GPC selfcheck of how well the targeting logic can compute the given MNVR. The GPC's will make 3 to 10 iterations in calculating the burn solution, and will stop iterating when a solution has a predictor match ≤ 250 feet or for elevation angle ±0.30° (it will always make at least 3 iterations). There is a practical relationship between a small value of predictor match and the quality of the solution. Failure to achieve these tolerance limits in ten iterations results in a fault message.

As a result of precise PROX OPS flying requirements on 51-F, the predictor match was set to 2 feet for that flight, and points were hit to within 30 to 50 feet (with the time between the maneuver and arrival at the desired offset point being 7 minutes). This distance was larger than 2 feet primarily because of maneuver trim residuals and onboard computer precision limitations affecting Lambert guidance and their error effects propagating through the 7 minutes.

Note: To perform such precise flying, another targeting constant, eps-mu (a tolerance inside of a second iteration), must also be changed (from E-6 to E-7).

3.5.5 Alarms

There are three SM alerts which can appear while using ORB TGT display (see also their impacts in section 3.5.9, items "g", "i", "j", and "k"). They are:

3.5.5.1 TGT ΔT

This occurs when software tries to compute a solution whose ΔT results in a transfer angle near 180° or 360° ("near" as defined by an I-loaded value, currently about ±2 min or ± 8°), whose ΔT requires a parabolic transfer, around multirev transfer time singularities, or during an iteration failure in the orthogonal braking logic. The crew should check the transfer time and, if necessary, correct input errors. If using multirev capability, decrement ΔT by 10 minutes and retarget. If using orthogonal braking, override the option by reselecting the TGT set and removing the minus sign.

3.5.5.2 TGT-ITER

This can appear when using Lambert targeting. It can result when ORB TGT makes 10 iterations without reaching a solution. Crew should check PRED-MATCH and if it looks good, execute the MNVR anyway.

3.5.5.3 TGT EL ANG

This appears during Lambert targeting when the software exceeds the maximum number of iterations in planning a burn based on elevation angle, or when the desired elevation angle is not achievable. Targeting will indicate what angle the iteration stopped at by displaying it in ITEM 6. The ΔV's displayed on ORBIT TGT pertain to the displayed angle. Crew should check displayed angle and if it's good enough, execute the MNVR.

If the displayed value is near the desired value, then it is likely that the failure was due to maximum iterations; in this case, it is possible to recall the TGT set and retarget. The iterations will then begin from the end of the last set of iterations and continue for 10 more iterations. If value is highly divergent, the burn should not be executed; instead, the crewmember should remove elevation angle and use preflight T1 (TGT SET 19).

Note: Display of this message is considered highly unlikely and is not expected to occur, even with any anticipated trajectory dispersions.

3.5.6 Maneuvers

This section identifies parameters for one of either of the two-impulse MNVR's which has been computed. A MNVR using COMPUTE T1 is that required to intercept the desired position in a desired time, and a MNVR using COMPUTE T2 is that required at the intercept time to null relative motion (as observed in a target-centered rotating curvilinear reference frame). Quantities displayed in this section for each MNVR include:

a. XX - The target number on which the MNVR is based

b. X - An indicator (*) that the TIG is in the past

c. TIG - The impulsive ignition time (days, hours, minutes, seconds) in MET

d. VX - The LVLH X-component of the targeted ΔV (ft/s)

e. VY - The LVLH Y-component of the targeted ΔV (ft/s)

f. VZ - The LVLH Z-component of the targeted ΔV (ft/s)

g. VT - The magnitude of the targeted ΔV (ft/s)

Note that these solutions are not downlisted.

3.5.7 Out-Of-Plane Procedures

Out-of-plane dispersions are handled both by ORB TGT and later manually based on REL NAV. The ground-targeted NPC ("plane change") burn done early in the RNDZ phase removes out-of-plane dispersions observed via ground tracking. Onboard optical tracking pre-NCC provides additional relative orbital plane knowledge. This is used by ORB TGT for NCC targeting, to place Ti in plane. Subsequent Ti targeting (using post-NCC onboard radar tracking) places TGT intercept in plane, as well as can be done with these observations. In doing this, another node is created half a REV before intercept, and it is at this node that the RNDZ checklist calls for a manual plane correction to trim out all remaining out-of-plane error.

The theoretical background for out-of-plane control is given in section 2.9.2; the actual procedures are specified in 4.1.19 (Target NCC), 4.1.33 (Target Ti), and 4.1.54 (perform OOP null).

3.5.8 Operational Constraints

The orbit targeting software for flight software FSW version OI-7 still has several minor problems (see OI-7 Program Notes, JSC-19320, PN-OI7), as described below. The operational constraints they impose are as follows:

a. An elevation angle search for an elevation angle which cannot be obtained may take more than 15 minutes to complete. The long computation time results from an incompatible elevation angle which cannot arise in normal operations. A large relative SV update prior to an orbit targeting elevation angle search could produce this problem, for example. The inconsistency with the requirements will be resolved by CR #69491B, approved for OI-11.

b. An infinite software loop is possible when targeting Lambert MNVR's with a 180° transfer angle, but another coding error accidentally prevents the software from getting into the loop. A CR fix (#69133C) is approved for version OI-11. Such transfers are not planned for nominal RNDZ profiles.

c. A precision problem exists in the elevation angle computation. The problem occurs only for small phase angles. For a ΔH of 1 n.mi., the elevation angle computation breaks down around 50°. This is not really a limitation, since the baselined RNDZ profile operates at about 28° elevation angle at a ΔH of 2 n. mi. (see section 4.1.51). CR #69491B has been written to correct the problem, and has been approved for OI-11.

d. Upon initial call up of the ORB TGT display (SPEC 34) after entering OPS 2 from another OPS, the selected TGT set is initialized to 0. If a COMPUTE T1 (Item 27), or a LOAD (Item 26), or a COMPUTE T2 (Item 28) is then requested, undesirable results may occur. These include:

   1. Targeting may require several minutes to complete.

2. One or more GPC errors may occur.

3. Various targeting alarms may be annunciated.

Therefore, the crewmember should not request a COMPUTE T1 for TGT set 0 or when ΔT and T2 TIG are both zero. The crewmember must not request a LOAD for TGT set 0 (it could write zeroes into data locations not allocated to ORB TGTing). Any results displayed after performing any of these requests should be ignored. The orbit targeting protection CR #69491B adds protection to orbit targeting from operating on a non-existant (zero) TGT set; this CR has been written and approved for flight software version OI-11.

e. Orbit targeting allows the crewmember to define the Orbiter state (at T1 TIG) for a Lambert MNVR in terms of a TGT state and a keyboard input target centered relative state. The targeting algorithm will compute a MNVR based on the input relative state and transfer the MNVR information to the ORBIT MNVR display. When load is executed for the ORBIT MNVR EXEC display, neither the ORB MNVR display nor on-orbit guidance has knowledge that an input relative state was used. Consequently, an Orbiter state (at T1 TIG) is generated based on the current Orbiter state from on-orbit user parameter processing. This situation results in a targeted MNVR different from the intended MNVR. The degree of difference in the MNVR's may or may not be observable when comparing orbit targeting display data against ORBIT MNVR exec display data, but in either case the resultant MNVR will not yield the expected results.

Because the difference between the computed MNVR and the desired MNVR may not be readily observable, it is recommended that the relative offset state targeting technique not be used in PROX OPS. If it is desired to use the technique, either of the following workarounds is recommended:

1. Use the C-W targeting algorithm rather than Lambert (see section 3.5.12); or

2. Manually transfer the Lambert targeting data to the PEG 7 portion of the MNVR EXEC display and perform an external ΔV MNVR.

f. The value displayed for T1 TIG (Item 2 on the orbit targeting display, SPEC 34) may be 1 second less than the actual value of TIG used by guidance after the following sequence is performed:

1. The displayed TGT set data is stored into the predefined TGT set storage locations via an ORB TGT load (Item 26);

2. That same TGT set is evoked again, via item 1. Note that an intervening compute T1 (Item 27) or compute T2 (Item 28) makes no difference.

If a compute T1 is then done, the value displayed for T2 TIG (Item 13) may be 1 second less than the actual value used by guidance. The CRT timer will countdown to the correct TIG, and the correct value is used for computing the targeting and guidance solutions. The correct value of TIG will be displayed on the ORB MNVR EXEC display (MM 202 OPS display). The crewmember should refer to ORB MNVR EXEC display for the correct value of TIG if TGT set data is loaded and then used again.

g. When a compute T1 (Item 27) is requested for a Lambert TGT set, a transfer time alarm may be annunciated if targeting is unable to find a solution. This alarm produces the CRT message "TGT ΔT" (see section 3.5.5.1). Under some circumstances when this alarm is annunciated, the PRED MATCH field on the ORB TGT display is required to display a large value. As the large value required to be displayed has too many digits for the PRED MATCH field, a value of zero is displayed instead.

   The crewmember should not execute the resulting MNVR if the "TGT ΔT" message is annunciated for a Lambert TGT set and the PRED MATCH field displays zero.

   CR #69837A has been written and approved for FSW version OI-11. This CR changes the FSW such that when max iterations occur in the omega ΔT time computation, the alarm TGT ΔT is annunciated and PRED MATCH is set to 999999.

h. For a small Lambert MNVR of less than 5 ft/s, the VGO on the MNVR EXEC display incorrectly increases by an amount of 0.4 to 0.9 ft/s when the VGO corrector task is cycled at 10 to 15 seconds prior to TIG. The effect becomes less as TIG approaches and is correct at a time less than 4 seconds after TIG. This is due to the initiation of Lambert guidance prior to TIG and is negligible for MNVR's of larger ΔV's. This anomaly was predicted to occur in 1978, but was not fixed because of a crew desire to have a visual indication that guidance is cycling.

   The crewmember can avoid possibly inefficient maneuvering by not starting the trim of VGO's for axis-by-axis MNVR's until TIG.

   CR #69568A has been written and approved for FSW version OI-11 which will eliminate transient errors in ΔV total displayed on the ORBIT MNVR EXEC display before TIG when a small midcourse correction burn using Lambert guidance is executed.

i. If a load computation (Item 22 on ORBIT MNVR EXEC display) is requested for a Lambert guided burn and the "TGT ITER" or "TGT ΔT" alarm is annunciated during the computation, the following guidance parameters will be incorrect: VGO, TGO, total ΔV, burn attitude, TGT apogee, and TGT perigee. The data may appear reasonable, but they are incorrect.

   The crewmember should not execute the resultant MNVR. Reenter any portion of the TGT data to downmode from Lambert to external ΔV guidance, and recompute the solution.

j. If a burn is being executed using Lambert guidance and the "TGT ITER" or "TGT ΔT" alarm is annunciated, the following guidance parameters will be incorrect: VGO, TGO, total ΔV. The total ΔV will be in excess of 100 ft/s, with the VGO components and TGO correspondingly large. If the DAP is in AUTO mode, the Orbiter will maneuver to the incorrect burn attitude and maintain the incorrect body rates. Correct values for all of these parameters may be restored after four seconds.

The crewmember should terminate the burn immediately. If there is not enough time to set up and execute a corrective MNVR before the next scheduled MNVR, expect the next scheduled MNVR to be off nominal in order to correct for the aborted burn. If there is time to do a corrective MNVR, compute the corrective MNVR solution on the ORB TGT display using the same TGT set as for the aborted burn. To ensure successful execution of the corrective MNVR, the MNVR should be done using external ΔV guidance rather than Lambert guidance, although Lambert guidance may work. Beware of 180° and 360° transfer time singularities.

k. If a compute T1 (Item 27) is requested for a Lambert TGT set and the "TGT ITER" or the "TGT ΔT" alarm is annunciated during the computation, the resultant MNVR solution will probably be incorrect. The VGO's displayed on the orbit TGT display are expected to be grossly in error, but they may appear reasonable when they are really are not. The resultant MNVR-solution computed solution is required to verify this. In addition, the ground may see multiple GPC errors during the computation.

The crewmember should not execute the resultant MNVR unless comparison with the ground solution indicates the solution is good. Otherwise, check that the input data for the TGT set is reasonable. Especially ensure that the transfer time does not yield a 180° or 360° transfer angle. If the input data is correct, recomputing the MNVR may produce a successful solution. If recomputation fails and a ground-computed MNVR is available, enter the ground-computed MNVR on the ORBIT MNVR EXEC display and execute. If out of contact with the ground, manually transfer the data to a CW TGT set and compute the MNVR solution using C-W targeting. Note that if the MNVR uses orthogonal braking, TGT data must also be transferred for the next TGT set as well.

3.6 CONTROL

Once a desired change in orbit has been defined by targeting, it should be performed by "maneuver execution". This involves performing a propulsive burn to create a controlled ΔV.

3.6.1 PADS

Numerical data define MNVR's which can then be input to the MNVR EXECUTE display; this data is written on prepared forms called "BURN PADS", found in the RNDZ checklist. The burn data may be calculated several times (e.g., preflight, preliminary, intermediate, and/or final) and entered on the form each time. The preflight data is entered in the parenthesised fields; the multiple sets of "onboard solutions" is a unique feature of the Ti PAD.

3.6.1.1 Basic Information

The following information is needed for the performance of a burn (see fig. 3-34):

- Engine select
- Thrust vector roll, degrees
- Trim load (P, LY, RY)
- Vehicle weight, pounds
- TIG in MET
- PEG7 ΔV's (X, Y, Z) in LVLH, ft/s

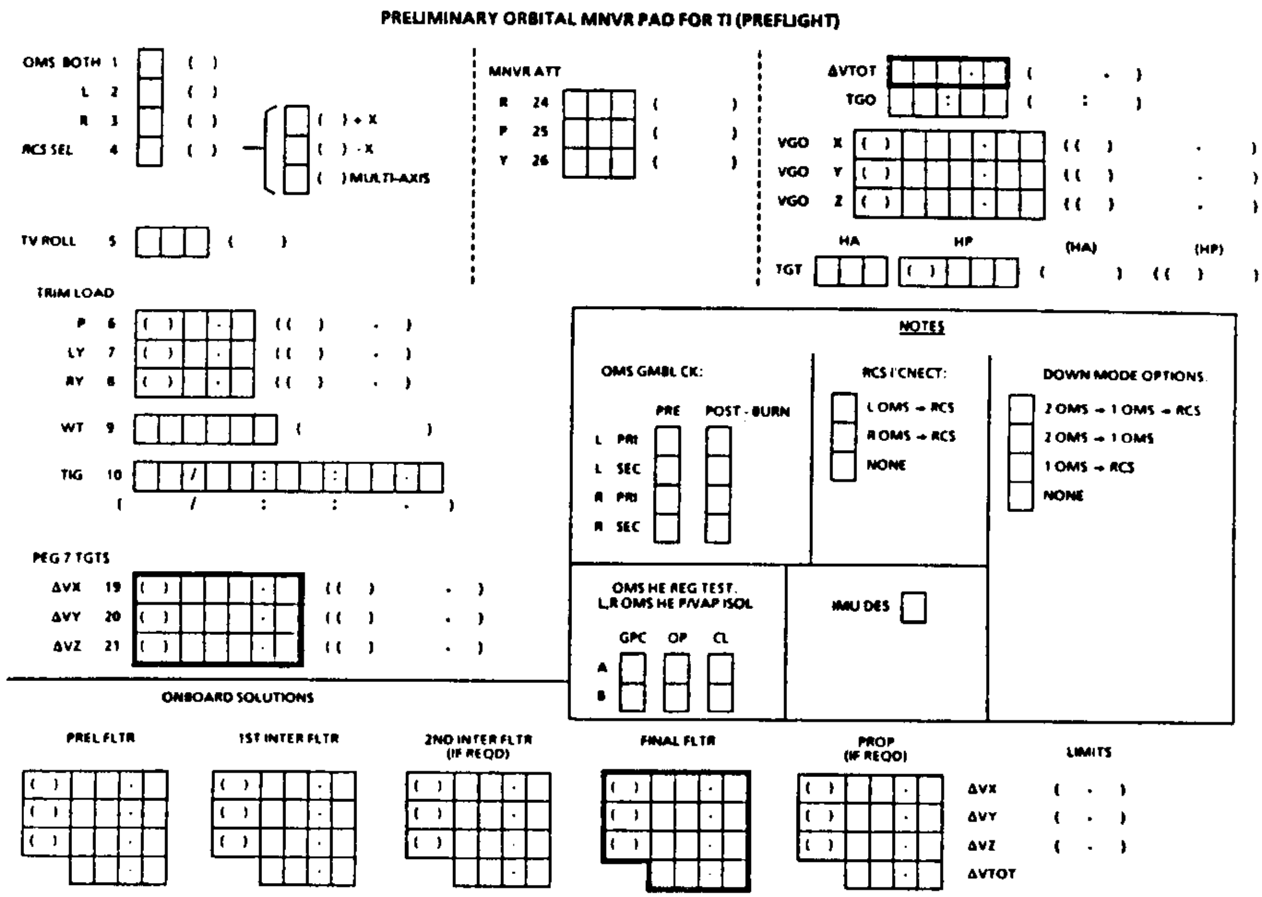


Figure 3-34.- Typical BURN PAD.

3.6.1.2 Other Systems Data

Performance of a burn may involve systems reconfiguration, which can be specified either on a cue card or on the burn pad. For example: OMS gimbal check (left/right, primary/secondary, pre/postburn) may be specified; OMS HE regulator (A,B), both sides, may be set to GPC/OP/CL; RCS interconnect may be altered. In addition, systems reconfigurations which are associated not with the burn but with some activity which closely follows the burn, may also be specified (e.g., IMU deselect, which actually is associated with the subsequent STRK pass. See sections 3.3.2.1 and 3.9.4).

3.6.1.3 Ti Delay PAD

The Ti burn is a convenient point to stop the RNDZ for one or more REVs, if needed. Instead of burning the nominal Ti pad, the crew loads a special pad read-up from the MCC (fig. 3-35). Use of this pad is discussed in section 4.1.40 in the RNDZ procedures rationale narrative.

ΔVX	( )			•		( )			•	
ΔVY	( )			•		( )			•	
ΔVZ	( )			•		( )			•	
ΔVT				•					•	

Figure 3-35.- Ti delay pad.

3.6.1.4 MC PADS

The post-Ti midcourse burns are usually small and are done axis-by-axis. Since there is no ground solution to check against, a "3-sigma variation" value is computed preflight for use as a confidence check (fig. 3-36).

The 3-sigma limits on the MC1 thru MC4 burns are for information only. They are the maximum expected value of the targeting solutions. The values are mission and burn dependent. If the limits are exceeded, the burn should still be executed, if REL NAV and the sensors being used look good.

MC 3 BURN SOLUTION

TIG 004 / 01 : 04 : 53

	PRELIMINARY	FINAL	3σ VARIATION
ΔVX	( ) _ _ • _	( ) _ _ • _	(0.8)
ΔVY	( ) _ _ • _	( ) _ _ • _	(0.8)
ΔVZ	( ) _ _ • _	( ) _ _ • _	(0.9)
ΔVT	_ _ • _	_ _ • _	(0.8)

Figure 3-36.- Typical MC PAD.

3.6.2 ORBIT MNVR EXEC (MM 202)

This is the OPS display in GNC MM 202. It provides the crew with a means for inputting and executing MNVR's, evaluating their effects on the trajectory, and adjusting parameters as necessary (fig. 3-37). It can be used during long-range stationkeeping and separation as well as RNDZ.

In general, this display provides the crew interface for monitoring and control of the functions contained in MM 202. These include the controls to maneuver the Orbiter to a burn attitude, and to monitor, guide, and control the vehicle while executing a translational MNVR, or while executing the burns used in the RNDZ mission phases. The same display is used during ascent, orbit, and entry, with the difference being the title (ASCENT/ORBIT/DEORBIT MNVR EXEC/COAST). Thus, there are some items on this display that are not used in OPS 2 (e.g., PEG 4 TGT's, Items 14-18; REI-range to entry interface status, Items 35-39).

RNDZ MNVR's will be trimmed to VGO less than 0.2 ft/s in each axis. Normally, on-orbit MNVR's are not considered delta-velocity critical for flight safety or mission success, and therefore, no strict trim requirements are set. However, RNDZ MNVR's are typically considered critical for mission success and should be trimmed more accurately. Based on flight experience, 0.2 ft/s in each axis is the smallest residual consistently achievable by crew input. This accuracy is required during RNDZ operations to keep deviations from the planned profile to a minimum.

```
 202/    /         ORBIT MNVR EXEC       XX X DDD/HH:MM:SS
OMS BOTH 1X                                   DDD/HH:MM:SS
        L 2XS       BURN ATT                          XXXX
        R 3XS        24 R XXX           ΔVTOT      XXXX.X
RCS SEL   4X         25 P XXX           TGO         XX:XX
5 TV ROLL XXX        26 Y XXX
TRIM LOAD           MNVR 27X            VGO X  ±XXXX.XX
 6 P  ±X.X                                  Y   ±XXX.XX
 7 LY ±X.X          REI   XXXX              Z   ±XXX.XX
 8 RY ±X.X          TXX XX:XX
9 WT XXXXXX               GMBL              HA     HP
10 TIG                   L      R         TGT XXX  ±XXX
  XXX/XX:XX:XX.X    P ±X.XS  ±X.XS      CUR XXX  ±XXX
TGT PEG 4           Y ±X.XS  ±X.XS
 14 C1      XXXXX
 15 C2   ±X.XXXX    PRI 28X   29X       35 ABORT TGT XX
 16 HT    XXX.XXX   SEC 30X   31X
 17 θT    XXX.XXX   OFF 32X   33X         FWD RCS
 18 PRPLT ±XXXXX                             ARM  36X
TGT PEG 7           GMBL CK   34X            DUMP 37X
 19 ΔVX  ±XXXX.X                             OFF  38X
 20 ΔVY   ±XXX.X    XXXXXXX                SURF DRIVE
 21 ΔVZ   ±XXX.X                             ON   39X
XXXX  22/TIMER 23                            OFF  40X
                                                  (XX)
```

Figure 3-37.- The ORBIT MNVR EXEC (MM 202) display.

Note that ORB MNVR EXEC would be used only to execute targeted translation MNVR's (via OMS or RCS). For other translation MNVR's, such as manual stationkeeping or V-BAR approach, the thrust monitor capability on REL NAV may be used to monitor manual translation command inputs from the THC, executed by RCS jets.

From flight experience, crews have suggested adding some features to OPS 202. These include the capability to perform RCS burns under GPC control and the display of time-to-go in current attitude maneuver (which is displayed in OPS 201). There are no current plans to implement these suggestions.

The RNDZ related functions of the display are described in this section. This is not a complete description of the functioning of the SPEC. For a detailed explanation of the entire display, see the DPS Dictionary or the GNC Display FSSR.

3.6.2.1 OMS BOTH/L/R, RCS SEL (Items 1-4)

These mutually exclusive items allow the user to select whether both OMS engines, or just the left or right one, or the RCS jets will be used in the upcoming MNVR. If an OMS failure is declared by fault detection, identification and reconfiguration (FDIR), a down arrow will appear in the status column next to item 2 or 3 (L or R OMS engine). The down arrow and FDI are reset if item 1 (BOTH) is subsequently selected. If item 4 is selected

(RCS SEL), the burn attitude and burn duration time computations for the targeted MNVR will be made, assuming that 2 +X RCS thrusters will be used to produce a +X acceleration. A required burn attitude will be computed to align the Orbiter +X effective thrust vector with the required thrust vector with the specified TV roll. These data will appear in Items 24-26.

3.6.2.2 Thrust Vector Roll (Item 5)

This item allows the crew to select the Orbiter orientation, in terms of roll, about the thrust vector during an OMS burn. Roll angles from 0° to 359° can be input, with 0° being heads up. It is initialized the first time to an I-loaded value (180° or heads down so the horizon is visible), and retains that value until user intervention. From then on, it comes up with the previously used value which can be changed by the user. TVR is valid only for a +X attitude burn (either +X RCS or OMS). The value of the TVR is determined by the right hand rule about the thrust vector, zero heads-up in LVLH.

3.6.2.3 Time of Ignition (Items 10-13)

These items represent the TIG in MET (DAYS/HR:MIN:SEC). A check is made by the software to ensure that a time entered in this item is realistic (within 5 minutes in the past, or 12 hours in the future). If it is not a realistic time, an illegal entry message will be generated.

3.6.2.4 PEG 7 (Items 19-21)

These items are used to input the three external ΔV's (ft/s) in the local vertical system at ignition. When COMPUTE is performed in ORB TGT SPEC, the results are automatically transferred here (ITEM 22 must then be executed to LOAD).

Note: The burn ΔV's may be different between the ORBIT MNVR EXEC display and the ORBIT TGT display for Lambert maneuvers. There are three reasons for this possible difference: Both displays use the current SV when computing the burn solution, but because they are used at different times some ΔV discrepancy results. If it is a Lambert targeted burn, Lambert will run through one iteration cycle when the targets are loaded on ORBIT MNVR EXEC, updating the previously computed targets for any sensed accelerations or NAV marks taken. Beginning at TIG-15 seconds, the ORBIT MNVR EXEC display starts receiving continuous updates from Lambert guidance, as compared to the ORBIT TGT display that computes the burn targets only once.

3.6.2.5 LOAD (Item 22)

The word LOAD will flash any time the display is called up in OPS 2. Once the LOAD item is executed, the word LOAD will cease flashing and the engine selection, trim, vehicle weight, and TGT data items will be sent to guidance. Also, certain display parameters will be computed, including burn attitude, total ΔV, targeted apogee/perigee, burn time, and required ΔV in body components. The CRT timer will stop and reset to zero.

Later, if the engine selection, trim, vehicle weight, or TGT data items are altered by crew input or by ground uplink prior to burn enable or after burn completion, the word LOAD will flash, and it will be necessary to retarget the MNVR to keep Lambert guidance. Such an entry will terminate all burn guidance computations and the load-dependent parameters will blank. Any change of these targeting or setup parameters while the burn is enabled, or prior to burn completion, will be treated as an illegal entry.

3.6.2.6 TIMER (Item 23)

The GNC CRT timer may be started to count down to TIG via this item. It may already have been counting since ORB TGTing targeted the burn, but moding to 202 or execution of LOAD stopped it.

3.6.2.7 Guidance Downmoding

The active guidance mode (Lambert or external ΔV) is displayed at the bottom of the middle column. Any changes to entries on the left-hand side of MNVR EXEC will cause an automatic downmoding from Lambert to external ΔV guidance mode. To return to Lambert guidance mode, the crew must call up ORB TGT, load and recompute targets, resume MNVR EXEC, and load results. Inadvertent guidance downmoding can cause trouble with procedures which are not executed in a crisp, careful fashion. Deliberate downmoding can be achieved by intentionally changing an entry on SPEC 34 or MM 202; there are currently no known reasons for doing this.

3.6.2.8 Burn Attitude (BURN ATT, Items 24-26)

The burn attitude at ignition in degrees, with respect to the FWD ADI inertial reference frame, will appear by these items after crew execution of the load ITEM (Recall that the roll orientation about the thrust vector was specified in Item 5.) The BURN ATT items may not be used for data entry in OPS 2. Such an attempt would result in an ILLEGAL ENTRY message. The burn attitude generates ADI attitude error such that the crew can maneuver to the desired attitude. In OPS 2, this maneuver may be done automatically with the next item.

3.6.2.9 MNVR execute (Item 27)

This item enables an AUTO DAP maneuver to the desired burn attitude (given in Items 24, 25, and 26). While the maneuver is in progress, an asterisk will appear next to Item 27. If ITEM 27 has not been selected, it will be enabled automatically 10 to 15 seconds before TIG with initiation of cyclic guidance. If it is not desired to maneuver to the burn attitude at TIG, the DAP must be placed in MAN or LVLH mode. If DAP is not in AUTO, the "*" will not appear. Note that in MM 202, the ADI error needles are referenced to BURN ATT when this item is executed.

3.6.2.10 Time to Next Apsis (TXX XX:XX)

A time is displayed (MIN:SEC) which is the time to next apsis. An alpha-numeric title next to the time will read TTA if apogee is the next apsis, TTP if perigee is the next apsis, or if apogee and perigee differ by less than 5 n. mi., the time will be blank and the title will read TTC ("C" for circularization).

3.6.2.11 Burn-related parameters

Several parameters used during a burn will be displayed in the upper right-hand corner of this display.

- EXEC: This is when OMS is selected only. At TIG -15 sec, the word EXEC will appear and will flash until a keyboard EXEC is performed, at which time the characters will disappear. Ignition is inhibited until this entry is made. If the EXEC entry is made after the specified TIG, the MNVR starts immediately following the EXEC entry. Releasing the display prior to enabling the MNVR (e.g., transitioning to MM 201, OPS 3, or OPS 8) cancels that MNVR.

- ΔV TOT: This parameter identifies the predicted total ΔV of the targeted MNVR.

- TGO: This parameter reflects the predicted burn length (MIN:SEC) before TIG occurs. After ignition, it reflects the remaining burn time.

- VGO X/Y/Z: These parameters show the velocity to go componentwise in ft/s with respect to the vehicle body axis system. These values can be used by the crewmember to manually execute the required RCS burn using the THC (see section 3.6.3).

- HA, HP TGT/CUR: These parameters reflect apogee (HA) and perigee (HP) information in nautical miles for the current orbit trajectory (CUR) and for the predicted postburn orbit (TGT).

3.6.2.12 Operational Constraints

The OI-7 Program Notes (JSC-19320) lists the following operational constraints on MM 202, "ORB MNVR EXEC." Constraints on SPEC 34 also will impact MM 202 operations, see section 3.5.9, items "e", "h", and "i."

8

a. Attitude maneuver to unknown attitude.

On the MNVR DISP, once an AUTO MNVR (Item 27) to a desired "BURN ATT" (Items 24 through 26) is initiated, an asterisk will appear next to Item 27 to indicate that the maneuver is in progress. Once this AUTO MNVR has been initiated, this asterisk remains next to Item 27 until:

(1) A new TGT Item is entered on the display (Items 1 through 21 except Item 18) and causes the values for "BURN ATT" to blank, but the vehicle continues to maneuver to the old "BURN ATT" (as indicated by the asterisk next to Item 27).

(2) If a new load Item (Item 22) is entered on display, this causes a new "BURN ATT" to be computed and displayed, but the vehicle continues maneuvering to the old "BURN ATT."

In response to this problem, the crew should do the following. If an AUTO MNVR to a desired "BURN ATT" is in progress (asterisk next to Item 27) and either of the above is performed, mode the DAP to manual and back to AUTO to avoid confusion regarding the attitude to which the vehicle is maneuvering.

b. Orbit DAP RCS burns while not at guidance attitude.

Problems arise in two cases if it is desired to execute an axis-by-axis guided RCS burn in manual mode while holding some attitude other than the guidance determined burn attitude:

(1) Without executing the MNVR Item on the ORBIT MNVR EXEC display: a maneuver to the burn attitude will begin if the AUTO mode is selected any time between TIG-15 and cutoff. Solution is to not select AUTO during this interval.

(2) Including execution of the MNVR Item: A maneuver to the burn attitude will begin if the AUTO mode is selected any time between execution of the MNVR Item and transition out of MM 202. Solution is to prevent the maneuver, by not selecting AUTO between execution of the MNVR Item and transition out of MM 202. To interrupt the maneuver, select manual, and then AUTO (does not work during burn).

c. OPS Transition with target track active.

When an OPS mode recall (with GPC TGT set change) or OPS 2 to 8 transition is executed with RNDZ NAV enabled, RNDZ NAV will be disabled afterwards and will not be propagating the TGT SV. If the UNIV PTG TGT track option (Item 19 on the UP display) was active at the time of the OPS mode recall or OPS transition, UNIV PTG will continue to track the last computed TGT state. This may cause undesirable RCS activity. After an OPS mode recall, UNIV PTG will continue the last computed relative state. After an OPS 2 to 8 transition, the relative state is lost, and multiple GPC errors will result from operations on zero vectors.

This situation can be prevented by canceling the TGT TRK (Item 21 on the UNIV PTG display) before executing the OPS mode recall or transition. The jet firings can be stopped by moding the DAP to manual.

The GPC errors can be stopped by a PRO to MM 201 followed by canceling the TGT TRK.

If this situation occurs, a TGT state uplink is required to resume tracking. This is implemented in procedures discussed in section 6.1.3.1.

d. Stale SV after orbit OPS transition

On-orbit NAV does not execute and compute the Orbiter SV until between four and seven seconds after completion of an OPS mode recall with TGT set change or an OPS transition. During this period, the M50 to LVLH transformation quaternion will be stale and will cause the following anomalous behaviors:

(1) The attitude displayed on any ADI for which the LVLH reference is selected will be incorrect until the SV is recomputed on the next NAV cycle (4 seconds). The crew should be aware of this.

(2) If the DAP manual LVLH mode is initialized after the transition or recall, and before NAV runs, the commanded LVLH attitude will be based upon a stale SV. If NAV was inactive long enough during the transition or recall, and the Orbiter rates were high enough, a maneuver could result after NAV is reactivated. The crew should avoid the LVLH mode PBI during the transition or recall and for 7 seconds after resumption of GNC processing to preclude this RCS activity. Otherwise be aware of the problem.

(3) If the DAP manual LVLH mode or a UNIV PTG Earth-relative or center-of-Earth track option is activated prior to the transition or recall, the DAP will operate on an attitude error based in part on stale data. This could result intransient jet firings until the SV is updated. The crew should be aware of this.

This constraint is flagged in section 3.7.3.4.

e. IMU data loss during MM 202 preburn maneuver:

If all IMU data is lost for at least 960 ms during a MM 202 preburn altitude maneuver, the DAP will downmode to manual rotation (MAN ROT) pulse. This downmode normally terminates the maneuver.

However, two problems may occur, if the DAP was not in the AUTO mode at any time between the start of the maneuver and the time the IMU data was lost, and:

(1) If the IMU data is restored while in MM 202, the maneuver will re-activate immediately (Note: The DAP will remain in the MAN ROT pulse mode). Sequential transitions to MM 201 and back to MM 202 in between the loss and restoration of IMU data will not affect this situation. The crew response should be as follows.

If the IMU data is restored while in MM 202, and,

(a) It is desired to terminate the maneuver, execute a mode transition to MM 201, or cycle the DAP mode to AUTO, then MAN, then back to AUTO.

(b) It is desired to continue the maneuver, either:

- Use the RHC to manually maneuver the vehicle (in any desired rotational submode) according to the ADI, or
- Select the AUTO mode.

(2) If the IMU data is restored while in MM 201, the maneuver will reactivate immediately upon re-entry into MM 202, unless an OPS transition out of OPS 2 is executed before returning to MM 202. The crew response should be that if the data is restored while in MM 201, either

(a) Execute an OPS transition prior to the next entry into MM 202, or,

(b) Mode the DAP to the AUTO mode prior to the next transition into MM 202. Then, once in MM 202, cycle the DAP mode to MAN and then back to AUTO.

This constraint is flagged in section 3.7.3.4.

3.6.3 AXIS-BY-AXIS BURNS

Under certain circumstances the ΔV required is performed in OPS 202 while holding an arbitrary attitude. There could be some compelling reason to maintain that attitude (e.g., viewing requirement, Sun angle, etc.), or the burn might be small enough that the RCS cost in maneuvering to +X and back exceeds the efficiency loss in burning axis by axis. In this case, the EXEC command is not needed and the entire burn is manually executed the same way a +X burn is trimmed postguided cutoff.

The axes are trimmed in the sequence of X, then Y, then Z, unless Z is negative and thus is to be trimmed first. This sequence minimizes the impacts of translational coupling (section ~~6.2.1~~ 3.8.1.1).

This procedure is fully defined in section 3.8.5.1.

3.7 DPS

Proper processing and maintenance of RNDZ-related data is crucial to mission success. A variety of DPS activities can impact this processing, not always in obvious ways.

3.7.1 Configuration for Rendezvous

The GPC's are configured such that if either of the two computers fails during the RNDZ, vehicle attitude and translational control are maintained. This is especially important when the Orbiter is in close proximity to the TGT, and it is important for crew safety to be able to perform evasive MNVR's, should the need arise.

Stringing is accomplished to satisfy this requirement. Initially, strings 1 and 3 are on GPC 1, and 2 and 4 are on GPC 2 (NBAT is "1212").

3.7.2 Off-Nominal DPS Configurations

During actual rendezvous missions, a three-GPC redundant set has occasionally been established for redundancy reasons.

3.7.3 OPS Transition Effects

Performing OPS mode recalls or OPS transitions during the RNDZ phase can have significant impact on procedures. Where possible, such transitions should be delayed to the PROX OPS phase or later.

OPS mode recalls that are associated with the addition/deletion of a GPC to/from the GNC redundant set result in a number of undesirable secondary effects because of the momentary passage through OPS zero, particularly when rendezvous NAV is enabled. Among these are the disabling of RNDZ NAV, loss of the propagated NAV state, covariance matrix reinitialization, possible bad NAV measurements being incorporated into the filtered NAV state, an undesired attitude maneuver accompanied by the "pegging" of the ADI error needles, GPC errors, and increased propellant usage.

In addition, DPS OPS transitions are performed in accordance with several malfunction procedures. As a minimum, RNDZ NAV is disabled. In some cases, base time, target state vector, covariance matrix, and universal pointing can also be lost. GPC errors may also occur.

3.7.3.1 RNDZ NAV Termination

RNDZ NAV is terminated any time OPS 2 is left (see section 3.6.2.12, item "c"). This will happen when an OPS transition (OPS 2-X-2) is performed (for X = 8 or X = 3) or when a GPC is add/deleted to/from the set by performing an OPS/mode recall. RNDZ NAV is not terminated due to restringing.

In the ORB PKT C/L procedure for "PASS GNC GPC (1st FAIL)", there are steps which call out: (fig 3-38A)

IF RNDZ NAV Enabled:

~~Perform RNDZ NAV SAFING~~ DAP- free drift
$\boxed{\text{GNC UNIV PTG}}$
CNCL - ITEM 21 EXEC (no *)

and after the DPS manipulations

IF RNDZ NAV REQ'D:

Perform RNDZ NAV Recovery

The ~~two~~ procedure~~s~~, ~~for safing and~~ for recovery, ~~are~~ is found in figure~~s~~ ~~3-38 and~~ 3-39B. ~~Their~~ Specific uses and rationales are described below in three subsections.

a. The OPS 2-8-2 transition is necessary when starting an APU. The relevant procedures are located in the orbit operations checklist, "G2 to G8 Transition" and "G8 to G2 Transition." If RNDZ NAV is running and UP TGT ID=1, go to free drift and cancel UP tracking.

RNDZ NAV will be terminated on departure from OPS 2 since it is not supported in OPS 8. On return to OPS 2 the NAV software level, called "OPS overlay" (highest or last level), is read from the MMU. This means all NAV software at the "OPS overlay" level is in an I-loaded state. Target SV, covariance matrix, and base time are all lost. RNDZ NAV and KU ANT functions are terminated because they are not supported in OPS 8.

(Text continues on page 3-102.)

modification to

```
                    If OPS MODE recall (ADD/DELETE GPC
                       TO/FROM Redundant Set)

                       DAP:  FREE DRIFT
                      [GNC UNIV PTG]
                       CNCL - ITEM 21 EXEC (*)
                    If OPS TRANSITION (G2 to G8/G3)
                       Before OPS transition :
                    .........If MNVR for APU leak reqd.........
                    .  -Y FOR STRK   (+Y for RR)              .
                    . [GNC UNIV PTG]                          .
                    .  TGT ID    +1                           .
                    .  BODY VECT +5                           .
                    .  P         +0                           .
                    .  Y      +280.6  (+90)                   .
                    .  OM        +90  (+180)                  .
                    .  TRK - ITEM 19 EXEC (*)                 .
                    .  DAP:  B/AUTO/NORM,                     .
                    .    When in att, DAP:  A/AUTO/VERN       .
                    .  NOTE:  Do not take RR Angle data       .
                    .  while in +Y attitude                   .
                    ...........................................
CRT                [GNC 34 ORBIT TGT]
                    Record Base Time ___/___:___:___
```

Figure 3-38A.- RNDZ NAV safing in ORBIT PCL

After returning to OPS 2, the MCC uplinks a new TGT SV (RNDZ NAV cannot be enabled until this is done) and (if required) the PROX OPS COV MATRIX. The crew enables RNDZ NAV and KU ANT and returns to TGT TRK, then selects appropriate angle sensor (RR, STRK, or COAS, initiated as STRK) and incorporates sensor data into NAV when appropriate.

	If OPS MODE recall (add/delete GPC to/from redundant set)
CRT	GNC 33 REL NAV
	Inhibit RNG - ITEM 18 EXEC RDOT - ITEM 21 EXEC Angles - ITEM 24 EXEC
	[Note: * will not change until RNDZ NAV enabled]
	RNDZ NAV ENA - ITEM 1 EXEC (*) ~~✓KU ANT ENA - ITEM 2 as reqd~~ ~~GNC I/O reset - EXEC~~
CRT	GNC UNIV PTG
	~~✓TGT ID, BODY VECT, P, Y, OM~~ TRK - ITEM 19 EXEC (*) ~~DAP: A/AUTO/VERN~~
CRT	GNC 33 REL NAV
	Auto RNG - ITEM 17 as reqd RDOT - ITEM 20 as reqd Angles - ITEM 23 as reqd
	When SV UPDATE POS < 1.0 (0.3 if RR) and MARK ACCEPT>9, SV SEL - ITEM 4 EXEC (FLTR)
	(MORE)

Figure 3-39.- RNDZ NAV recovery.

RNDZ NAV RECOVERY

If Recovery from OPS MODE RECALL
(add/delete GPC to/from redundant set)

|GNC 33 REL NAV|
(Note: Asterisks will not change until RNDZ NAV is enabled)

CRT Inhibit RNG - ITEM 18 EXEC
RDOT - ITEM 21 EXEC
Angles - ITEM 24 EXEC
RNDZ NAV ENA - ITEM 1 EXEC (*)

|GNC UNIV PTG|
TRK - ITEM 19 EXEC (CUR - *)

If Recovery from OPS TRANSITION (G8/G3 to G2)

|GNC 34 ORBIT TGT|
TGT NO - ITEM 1 +1 EXEC
Set BASE TIME to Ti TIG (Ti Burn Pad, 2-20)
LOAD - ITEM 26 EXEC

|GNC 33 REL NAV|
Upon MCC uplink of TGT SV,
RNDZ NAV ENA - ITEM 1 EXEC (*)

NOTE
If RNDZ NAV not enabled (no *),
DO NOT PROCEED

Select appropriate target track attitude

|GNC UNIV PTG|

	-Z	-Y (STRK)	+Y (RR)
TGT ID	+1	+1	+1
BODY VECT	+3	+5	+5
P		+0	+0
Y		+280.6	+90
OM	+0	+90	+180

TRK - ITEM 19 EXEC (cur - *)

C3 DAP ROT: DISC/DISC/DISC
DAP: VERN
DAP: A/AUTO

If NAV sensor data available:
If STRK NAV

perform S TRK TARGET ACQ [6], 2-9 >>

If RR NAV

|GNC 33 REL NAV|
CRT KU ANT ENA - ITEM 2 (*)
GNC I/O RESET - EXEC
perform RR NAVIGATION [15], 2-19 >>

RNDZ NAV RECOVERY

RNDZ NAV RECOVERY

RNDZ NAV DPS impacts/remedies JEO Oct 10

function	RNDZ NAV enable	OPS Mode recall	G3/G8 transition	Available remedy
Angle Source	Keeps last	OK	= STRK	REL NAV (per C/L) ITEM 12,13 for ST,RR
KU ANT ENA	Keeps last	OK	off	REL NAV, ITEM 2 EXEC
AIF flags	Keeps last	Keeps last	INH	REL NAV item entries (C/L) ITEM 17,20,23 AUT R,Ṙ, ang
TGT SV	OK	OK	Gone	MCC uplink
BASE TIME	OK	OK	Gone	ORB TGT item entries (PAD)
UP options (incl TGT trk)	OK	OK	-XLV/ same	UP item entries, from C/L
UP track sel	OK	Cancel	Cancel	UP ITEM 19, per C/L
RNDZ NAV ENA	..	Gone	Gone	REL NAV, ITEM 1 EXEC
DV DISPs	OK	set to zero	set to zero	none
Mark counters	=0	=0	=0	none
FLTR, PROP values	FLTR ->PROP	FLTR ->PROP	FLTR ->PROP	none
SV sel	PROP	PROP	PROP	REL NAV, ITEM 4
STRK mode		Term/ idle	Term/ idle	S TRK/COAS CNTL (22), ITEM 5,6 for ST -Y,-Z
COV MX	Initial- ized	Initial- ized	I-load	none

	If OPS TRANSITION (G8/G3 to G2)
	~~After returning to OPS 2:~~
	After ground uplink of TGT SV~~, COV MATRIX,~~
CRT	GNC 33 REL NAV
	RNDZ NAV ENA - ITEM 1 EXEC (*) ✓KU ANT ENA - ITEM 2 as reqd GNC I/O reset - EXEC
CRT	GNC UNIV PTG
	✓TGT ID, BODY VECT, P, Y, OM TRK - ITEM 19 EXEC (*) DAP: A/AUTO/VERN
CRT	GNC 33 REL NAV
	S TRK (RR, COAS) - ITEM 12 (13, 14) EXEC (*)
	Auto RNG - ITEM 17 as reqd RDOT - ITEM 20 as reqd Angles - ITEM 23 as reqd
	When SV UPDATE POS< 1.0 (0.3 if RR) and MARK ACCEPT>9, SV SEL - ITEM 4 EXEC (FLTR)
CRT	GNC 34 ORBIT TGT
	TGT NO - ITEM 1 +1 EXEC Ti ~~TIG~~ (Ti BURN PAD) Set BASE TIME, ITEM 21 to ~~value as recorded above~~ LOAD - ITEM 26 EXEC
	(MORE)

Figure 3-39.- Continued.

copy page from CRNDZ

```
.........If MNVR for APU leak was reqd.........
.                                             .
.  After APU burn complete, mnvr to           .
.   reqd TGT TRK attitude:                    .
.                                             .
.  -Z TGT TRK     (-Y STRK)                   .
.  | GNC UNIV PTG |                           .
.  TGT ID     +1                              .
.  BODY VECT +3  (+5)                         .
.  P        +90  (+0)                         .
.  Y         +0  (+280.6)                     .
.  OM        +0  (+90)                        .
.  TRK - ITEM 19 EXEC (*)                     .
.  DAP:  B/AUTO/NORM,                         .
.  When in att, DAP:  A/AUTO/VERN             .
.                                             .
.  NOTE:  Do not take RR angle data           .
.         while in -Z TGT TRK att             .
.         (if appropriate)                    .
...............................................
```

MAL/ML/GEN A,9

Figure 3-39.- Concluded.

If an actual maneuver to APU burn attitude was required, the crew performs the steps shown in figure 3-39 as to resume target track.

b. The OPS 2-3-2 transition is used any time it is necessary to use the master X-feed switch (not available in OPS 2). It is also possibly used in RCS/OMS leak isolation. Another use is if both G2 GPC's fail. None of these uses has occurred in flight and none is expected.

check pages

The procedures are located in malfunction procedures: G2/G8 TO G3 TRANS (5-11~~9~~ 4); G3 TO G2/G8 TRANS (5-11~~9~~ 4); TWO GNC GPC FAIL (5-6~~2~~ 4).

The effect is similar to an OPS 2-8-2 transition, and the fix is the same as OPS 2-8-2 transition.

c. Adding a GPC to the redundant set (OPS/Mode recall) is an OPS transition, even though it is not readily obvious. Any time a GPC is brought into the set an OPS MODE RECALL is performed.

The procedure is located in the Orbit Pocket Checklist (PASS GNC GPC (1st FAIL)) 2 and in the malfunction procedures (PASS GNC GPC (1st FAIL) (5-6); SINGLE GPC FAIL (5-6~~0~~); DPS RECONFIG FOR LOSS OF AV BAY COOLING (5-8~~2~~ 3); GNC REASSIGNMENT (5-~~104~~ 99)). NO RN02 REF

The ITEM 21 (CNCL) is performed to prevent annunciation of GPC errors due to divide-by-zero, and pegging of ADI needles.

The effect of an OPS MODE RECALL is slightly different from an OPS TRANSITION. If a GPC is brought into the set, the crew will change the GPC TGT set in the NBAT and then perform an OPS/Mode recall (OPS XXX

PRO). This momentarily takes all GPC's in the set to OPS 0 to synchronize them and then returns them to the appropriate OPS (in this case OPS 2). RNDZ NAV is terminated upon leaving OPS 2 (RNDZ NAV is not supported in OPS-0). Upon return to OPS 2, the "OPS overlay" software is read from the G2 GPC, not the MMU. This means one comes back into OPS 2 in basically the same configuration in which one is left, except RNDZ NAV is not automatically reenabled. The target SV is not being propagated; when RNDZ NAV is reenabled, the TGT SV is propagated forward to the current time. Also, when RNDZ NAV is manually re-enabled, a FLTR to PROP and COVAR REINIT are automatically performed and the PROP SV is automatically selected.

A ~~table~~ list of all these impacts and remedies is in fig 3-39.

still exists but

3.7.3.2 ORB TGT'ing

Computation is terminated and must be manually restarted.

3.7.3.3 Attitude Control

Failure to go to free drift on transition to OPS 8 can have damaging effects. Since the TGT SV is frozen (it tracks where the TGT was when OPS 2 was left), the DAP can get confused if it hits a DB; multiple jet firings may result. There would also be a large attitude maneuver when OPS 2 is resumed.

3.7.3.4 Star Tracker

OPS transition (8 to 2 or 2/0/2 for set change) will cause STRK processing to go to TERM IDLE. The STRK acquisition procedure must be performed after returning to OPS 2.

3.7.3.5 Other Effects

The covariance matrix and NAV sensor mark counters are reset. Also, see section 3.6.2.12 for MM202 OPS constraints involving DPS transitions (especially items "d" and "e").

3.8 OMS/RCS ISSUES

3.8.1 RCS Cross-Coupling

Due to the awkwardly unsymmetric alignments of the physical arrangement of the RCS jets (fig. 3-41), commanded translation/rotation maneuvers in one axis tend to induce motion in other axes as well. This effect is called "cross-coupling." It can have significant impact on manual flying during RNDZ terminal phase and PROX OPS.

A complete description of Orbiter PRCS-induced acceleration is given in figure 3-42. To be useful for understanding the magnitude of the problem, however, a better representation would show the relative accelerations normalized (that is, the desired acceleration is set to "1," and the sizes of the other accelerations proportioned accordingly). Such a cross-coupling ratio table is given in figure 3-43 (normal and low-Z modes) and figure 3-44 (nose only and tail only modes), and should be taken only as an indicator of relative cross-coupling effects.

In order to make quantitative comparisons of rotation and translation cross-couplings, a proportionality constant had to be derived to allow unitless ratios to be computed. The scheme was developed to set this proportionality constant to the value that gave equal ratios of each type of motion cross-coupling to the primary commanded motion; that is, once properly adjusted, the ratio of commanded rotation rates to the undesired induced translation rates would be the same as the ratio of commanded translation rates to the undesired induced rotation rates. A satisfactory value was found to be approximately 3 times the translation rates in feet; in practice, this creates equivalence (1 deg = 3 feet) at a range of about 150 to 200 feet, where in fact much PROX OPS maneuvering occurs. Because this is an arbitrary scheme, the values in the proportional tables must be used properly and not misinterpreted. However, the tables do provide qualitative cross-coupling ratios which are entirely consistent with, and often explain some superficially puzzling dynamics aspects of, both simulations and flight experience.

In examining the translational impacts of specific RCS firings, one further step is necessary. Where any translation is directly induced, that is immediately added to the totals; where a rotation is induced, that rotation is nulled with a "perfect" opposite rotation command and the translational impacts of that theoretical maneuver are added to the totals. This computation algorithm continues until all rotational impacts have been nulled. This technique will provide useful results, but in the real world there may actually be overcorrection for the rotational cross-couplings, with consequently different total translational impact.

The "attitude hold" section for rotation maneuvers is computed by performing a unit rotation maneuver and then immediately nulling it with an opposite sense rotation maneuver, restoring rates to zero in that axis. The induced rates in other axes are then computed and nulled, and the resultant translational cross-couplings are summed.

Not surprisingly, the different DAP modes give markedly different amounts of translational cross-coupling from the same sized rotation maneuvers. These are shown in figure 3-40, where the roll-pitch-yaw coupling into Orbiter body X and Z axes are displayed (there is no significant coupling into the Y axis). DAP NORM is the lowest (the "cleanest") on this scale, and the TAIL-ONLY and NOSE-ONLY options are also both quite "clean." At the opposite extreme, vernier jets are the "dirtiest" in terms of translational cross-coupling from rotation maneuvers, especially in that such cross-coupling occurs exclusively in the -Z axis. DAP LOW Z is almost as bad, and since some DAP configurations call for larger rotation rates, the total cross-coupling magnitude will be greater.

DAP mode:	In X axis:	In Z axis:	Avg:
NORM (R,P,Y)	+0.26,+0.00,+0.26	+0.26,+0.02,+0.00	0.1
LOW Z (R,P,Y)	+0.50,+0.50,+0.00	-2.00,-2.00,-0.00	0.8
Tail Only (R,P,Y)	* ,+0.50,+0.00	* ,+0.00,+0.00	0.2
Nose Only (R,P,Y)	* ,+0.00,+0.00	* ,+0.00,+0.00	0.1
VERN (R,P,Y)	+0.00,+0.00,+0.00	-1.50,-2.00,-2.00	0.9

Figure 3-40.- DAP vs translational cross-coupling (unitless ratio value) * = same as NORM.

3.8.1.1 Translation Effects

The analysis generates some very useful insights into cross-coupling effects, and conforms to experience in flight and in simulators. The following effects should be specifically noted (assume Orbiter is on TGT V-BAR, tail-to-earth and bay-to-TGT):

NORM ROLL: This is clearly the "dirtiest" maneuver, with measurable cross-coupling in every other degree of freedom except yaw. This is far worse in low Z.

NORM +/-X: This induces significant +Z (braking) translations, and thus the closing rate needs to be put back in (see section 3.2.4.2 and 4.4.2). This is also true in low-Z +X, but it is not true in low-Z -X.

NORM -Z (closing): These pulses also induce significant +X ("up") translation. Same in low-Z.

LOW-Z +Z (braking): In free drift, this induces major negative pitch; in attitude hold, the translation pulse loses half its force in the subsequent counteraction of attitude deviation.

Low-Z +/-Y: When in attitude hold, these firings induce major -Z (closing) rates, more than half the size of the commanded Y-axis translation.

ROLL/PITCH deadbanding: In NORM, this generally induces a small +Z (away from TGT) force; in low-Z, however, this induces a major -Z (closing) force. In low-Z, minus pitch also produces a significant +X translation.

TAIL-ONLY: This off-nominal control mode has several unique cross-coupling characteristics. Pitch induces a powerful Z translation, and

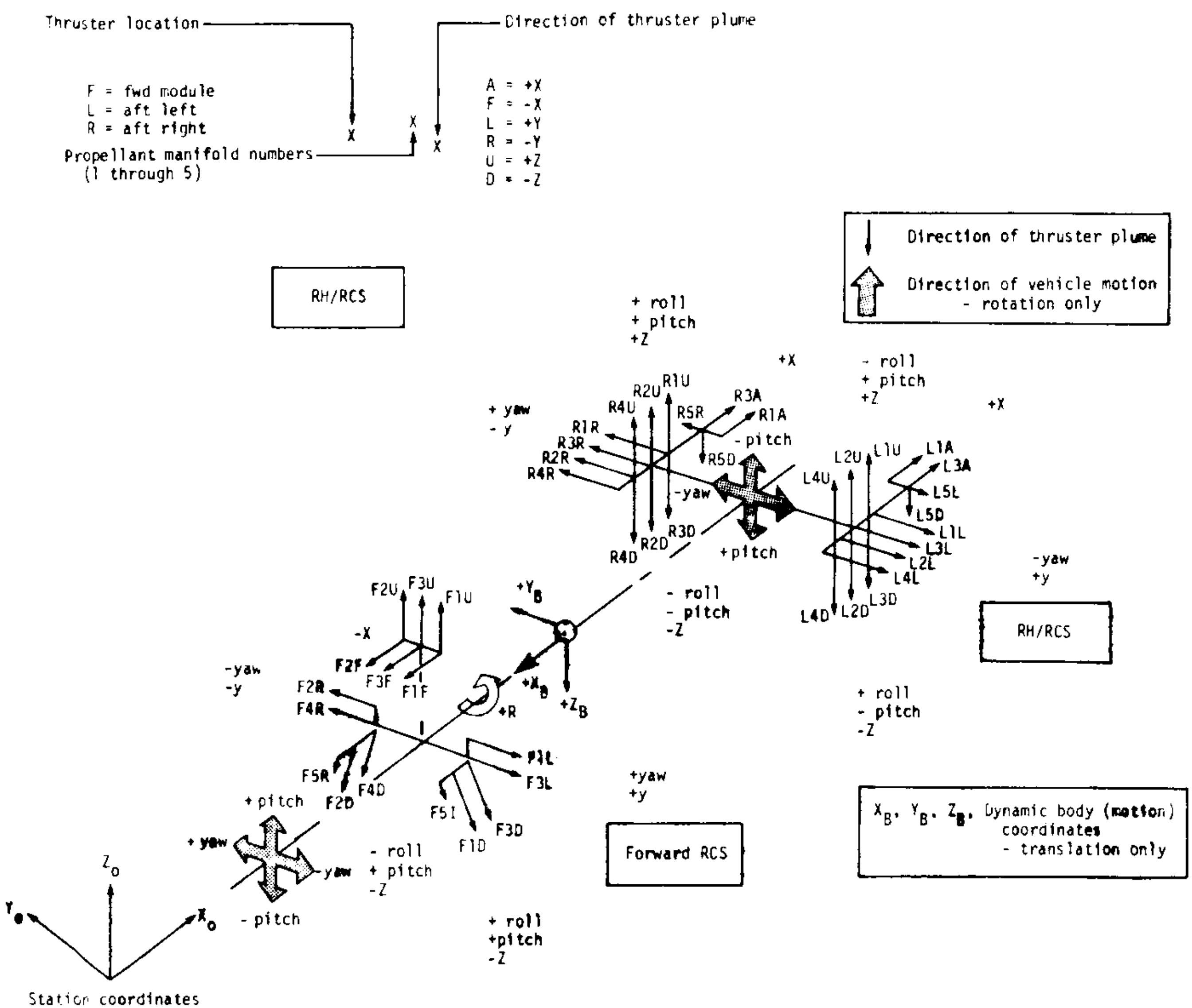


Figure 3-41.- RCS jets.

Orbiter's Acceleration Rates

Orbiter data for STS-7 PLBD closed (End of Mission)

Ixx,Iyy,Izz(S.FT.^{2})	924,014.1 ,	6,783,809.4 ,	7,084,860.2
Ixy,Ixz,Iyz(S.FT.^{2})	3,666.3 ,	196,815.6 ,	-710.1
Xcg,Ycg,Zcg(in.)	1,105.1 ,	-0.4 ,	376.2
Orbiter Weight (lbf)	214,046.4		

DAP Config	Jet Group	Jets Fired	rate in Xo (FT/S^2)	rate in Yo (FT/S^2)	rate in Zo (FT/S^2)	roll rate (Deg/S^2)	pitch rate (Deg/S^2)	yaw rate (Deg/S^2)
NORM	+roll	R1U,L3D	0.03170	0.03642	0.04468	0.87813	0.08571	-0.03082
NORM	-roll	L1U,R3D	0.03170	-0.03642	0.04456	-0.87521	0.08478	0.03054
NORM	+pitch	F4D,F3D,L1U,R1U	-0.00743	0.00000	0.07004	0.00566	1.21710	0.00005
NORM	-pitch	F3U,L3D,R3D	0.05856	0.00000	-0.04190	-0.00473	-0.82895	-0.00013
NORM	+yaw	F3L,R3R	-0.00266	0.00023	0.00080	-0.27265	-0.00116	0.68086
NORM	-yaw	F4R,L1L	-0.00268	-0.00023	0.00080	0.27093	-0.00094	-0.68853
NORM	+X	R3A,L3A	0.25778	0.00000	0.04546	0.00044	-0.02227	-0.00046
NORM	-X	F2F,F1F	-0.26458	0.00000	0.03607	0.00017	-0.11276	0.00049
NORM	+Y	F3L,L1L	-0.00266	0.26162	0.00080	0.31098	-0.00101	0.17908
NORM	-Y	F4R,R3R	-0.00266	-0.26162	0.00080	-0.31268	-0.00109	-0.18674
NORM	+Z	F3U,L1U,R1U,	-0.00477	0.00000	0.39382	0.00672	0.07387	0.00016
NORM	-Z	F4D,F3D,L3D,L2D,R3D,R2D	0.11926	0.00000	-0.53898	-0.00950	-0.03658	-0.00043
Low Z	+Z	F1F,F2F,R3A,L3A	-0.00680	0.00000	0.08154	0.00061	-0.13504	0.00004
Low Z	+roll	L3D	0.03168	0.04790	-0.08665	-0.38733	-0.18287	-0.06782
Low Z	-roll	R3D	0.03168	-0.04790	-0.08665	-0.39209	-0.18329	0.06764
Low Z	+pitch	F4D,F3D	-0.00746	0.00000	-0.19238	-0.00004	0.88045	-0.00006
Low Z	-pitch	L3D,R3D	0.06336	0.00000	-0.17330	-0.00478	-0.36616	-0.00019
Tail only	+pitch	L1U,R1U	0.00003	0.00000	0.26242	0.00568	0.63665	0.00010
Tail only	-pitch	L3D,R3D	0.06336	0.00000	-0.17330	-0.00476	-0.36616	-0.00019
Tail only	+yaw	R3R	0.00050	-0.13070	0.00072	-0.29287	-0.00063	0.24706
Tail only	-yaw	L1L	0.00050	0.13070	0.00072	0.29095	-0.00047	-0.25473
Nose only	+pitch	F4D,F3D	-0.00746	0.00000	-0.19238	-0.00004	0.88045	-0.00006
Nose only	-pitch	F3U	-0.00480	0.00000	0.13140	0.00004	-0.46278	0.00008
Nose only	+yaw	F3L	-0.00316	0.13092	0.00008	0.02002	-0.00053	0.43381
Nose only	-yaw	F4R	-0.00316	-0.13092	0.00008	-0.02002	-0.00046	-0.43380

Figure 3-42.- RCS axis cross-coupling values.

For cmded accels...			...The Orbiter also gets these: In free drift X	Y	Z	R	P	Y	Under attitude hold X	Y	Z
NORM-Z	ROLL	+	+1/9	+1/8	+1/7		+1/10	0	0.26	0	0.26
		-	+1/9	-1/8	+1/7		+1/10	0			
	PITCH	+	0	0	+1/6	0		0	0.20	0	0.02
		-	+1/5	0	-1/7	0		0			
	YAW	+	0	0	0	-1/2	0		0	0	0
		-	0	0	0	+1/2	0				
		+X		0	+1/6	0	0	0	+1.00	0	0.17
		-X		0	+1/7	0	-1/7	0	-1.00	0	0.17
		+Y	0		0	+1/3	0	+1/4	0.04	+0.95	-0.07
		-Y	0		0	-1/3	0	-1/4	0.04	-0.95	-0.07
		+Z	0	0		0	0	0	0	0	+1.00
		-Z	+1/5	0		0	0	0	+0.20	0	-1.00
LOW-Z	ROLL	+	+1/4	+1/3	-1/2		-1/2	-1/6	0.5	0	-2
		-	+1/4	-1/3	-1/2		-1/2	+1/6			
	PITCH	+	0	0	-1	0		0	0.5	0	-2
		-	+1/2	0	-1	0		0			
	YAW	±	same as NORM-Z						0 to .5	0	0 to -1
		+X	same as NORM-Z						+1.00	0	0.17
		-X	same as NORM-Z						-1.00	0	0
		±Y	same as NORM-Z						0.12	±0.83	-0.50
		+Z	-1/12	0		0	-1/2	0	0.08	0	0.50
		-Z	same as NORM-Z						+0.20	0	-1.00

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Figure 3-43.- PRCS cross-coupling ratios.

			Free drift						Attitude hold		
			X	Y	Z	R	P	Y	X	Y	Z
TAIL-ONLY	PITCH	+	0	0	+1	0		0	.5	0	0
		-	+1/2	0	-1	0		0		0	
	YAW	+	0	-2	0	-1	0		0	0	0
		-	0	2	0	+1	0		0	0	0
NOSE-ONLY	PITCH	+	0	0	-1	0		0	0	0	0
		-	0	0	+1	0		0	0	0	
	YAW	+	0	+1	0	0	0		0	0	0
		-	0	-1	0	0	0		0		

roll = same as nominal

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Figure 3-44.- PRCS off-nominal cross-coupling ratios.

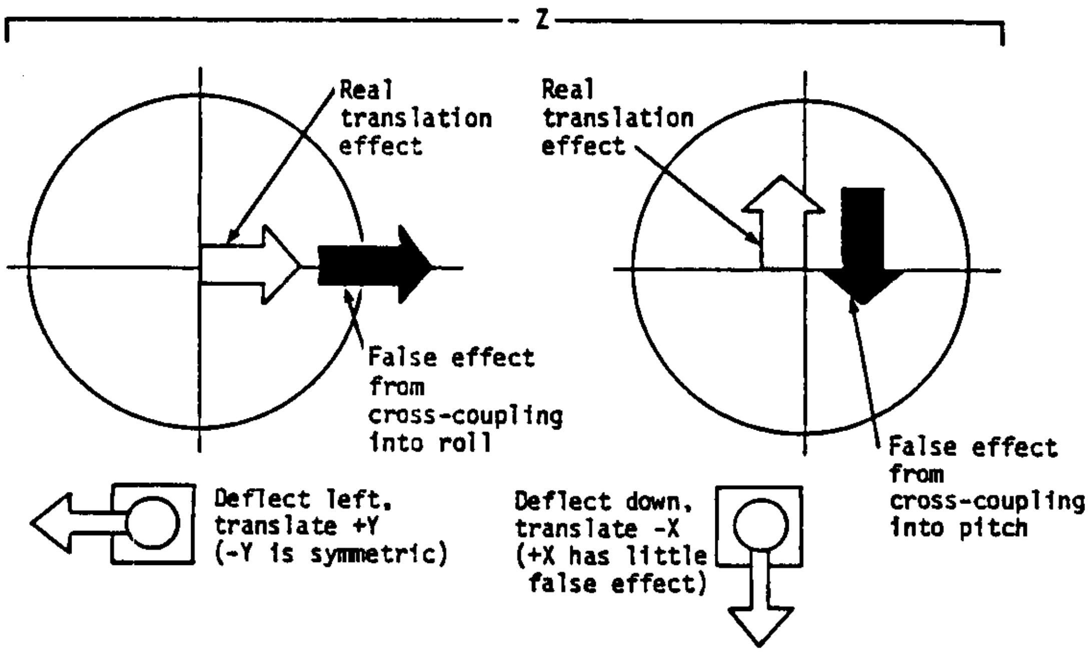

Figure 3-45.- TGT LOS cross coupling aft THC, -Z sense 200 foot range.

Motion shown is prior to hitting DB.

pitch also induces significant +X translation. Yaw induces an extremely powerful Y translation and noticeable X and Z translations as well. All other control modes are identical to normal control.

NOSE-ONLY: This off-nominal control mode also has its own peculiar cross-coupling characteristics. In pitch, translational effects are the mirror-image of tail-only control (but with no X effects); in yaw they are also the opposite sense to tail-only, but much reduced.

3.8.1.2 LOS Cross-Coupling Effects

When observing a target out the overhead window, the crewmember may command RCS translation maneuvers perpendicular to the LOS in order to control Orbiter/TGT relative position (in a "fly to" mode). Because of induced rotations, the initial LOS motion of the TGT may be momentarily misleading (see fig. 3-45). The following examples are based on a target at a range of 200 feet:

NORM/LOW-Z "+Y" translation: Commanding a +Y pulse (to the left, when facing aft) results in angular rates due both to translation and also momentarily to rotation (until a DB is hit). Both rates are to the right, but the momentary rotation-induced LOS motion is FOUR TIMES the size of the translation-induced LOS rate. The translation-induced rate only gets as large as the rotation-induced rate at a range of 50 feet.

NORM/LOW-Z "-Y" translation: Symmetric opposite to +Y.

NORM/LOW-Z "-X" translation: Commanding a -X pulse results in a translation-induced LOS motion upwards and a rotation-induced motion downwards (the Orbiter performs a minus pitch). At 200 feet, the translation-induced rate is slightly smaller than the rotation-induced rate, so the TGT will actually appear to move downwards, opposite to the desired (and commanded) sense, at least until a DB is hit. At 100 feet, the motion will clearly be in the proper direction, but only a fraction of the actual true LOS rate due to rotation-induced LOS motion, until deadbanding occurs.

NORM/LOW-Z "+X" translation: Rotational rates are very small.

These effects accentuate the need for the crewmember to be patient after performing translation pulses, to see the LOS motion after deadbanding, and not be misled by the initial LOS rates (which may contain deceptive rotation-induced components).

3.8.1.3 VRCS Effects

Vernier RCS jets induce their own cross-coupling, and although the jets are smaller than primary jets, their geometry is even more awkward. The accelerations are shown in figure 3-46 (both free drift and attitude hold,

RCS/DAP RESPONSE MATRIX
JET SELECT OPTION V, NO COMPENSATION
(FREE DRIFT)

	ACCELERATIONS					
	TRANSLATIONAL (FT/SEC/SEC)			ROTATIONAL (DEG/SEC/SEC)		
CMD	X	Y	Z	R	P	Y
+ROL	-0.00006	0.00699	-0.00483	0.02417	0.00557	0.00119
-ROL	-0.00006	-0.00699	-0.00483	-0.02418	0.00553	-0.00119
+PCH	0.00025	0.00000	-0.00544	0.00009	0.02060	0.00000
-PCH	0.00012	0.00000	-0.00404	-0.00009	-0.00909	-0.00000
+YAW	-0.00012	-0.00108	-0.00281	-0.00311	0.01009	0.01717
-YAW	-0.00012	0.00108	-0.00281	0.00319	0.01010	-0.01717

RCS/DAP RESPONSE MATRIX
JET SELECT OPTION V, ROT COMPENSATION
(ATTITUDE HOLD)

	ACCELERATIONS					
	TRANSLATIONAL (FT/SEC/SEC)			ROTATIONAL (DEG/SEC/SEC)		
CMD	X	Y	Z	R	P	Y
+ROL	0.00001	0.00707	-0.00781	0.02433	0.00000	0.00000
-ROL	0.00001	-0.00707	-0.00780	-0.02446	0.00000	0.00000
+PCH	-0.00025	-0.00003	-0.00545	0.00000	0.02063	0.00000
-PCH	0.00012	0.00003	-0.00406	0.00000	-0.00907	0.00000
+YAW	0.00002	-0.00015	-0.00827	0.00000	0.00000	0.01733
-YAW	-0.00002	0.00019	-0.00830	0.00000	0.00000	-0.01733

Figure 3-46.- VRCS Cross-Coupling.

where ALL attitude cross-coupling is taken out and converted into translation cross-coupling), and a normalized ratio table is given in figure 3-47.

The most striking observation is that ALL vernier firings wind up inducing translational cross-couplings of roughly equivalent size in the same body axis, the -Z direction. During the rendezvous phase, over a long period of time, such translational cross-coupling could induce significant downtrack errors in Orbiter position, despite the individually minute force of each single firing. The firings do not randomly cancel out; instead, they accumulate preferentially in one Orbiter body direction.

3.8.1.4 Cross-Coupling Examples

Several examples can illustrate the role that translational cross-coupling can play in rendezvous and PROX OPS trajectories. (See figure 3-47.)

During quiescent periods of PROX OPS, even just simple pitch/yaw deadbanding in low Z mode or in verniers can quickly introduce a clear-cut -Z translation. Analysis (confirmed by SES simulations) indicates that a rule-of-thumb for this -Z translation is "35 to 40 pounds of propellant per -Z ft/s"; that is, the expenditure of 35 to 40 pounds of propellant through the RCS during attitude hold will result in a cross-coupling translation of 1 ft/s in the -Z direction. Use of propellant consumption to monitor this -Z buildup may be more reliable than watching AVG G on SPEC 33 (REL NAV) due to IMU noise accumulation and the fact that much of the cross-coupled -Z acceleration would be below the threshold of measurement by AVG G. The time period in which this -Z buildup occurs will vary depending on how stable the Orbiter attitude was when attitude hold was initiated. This -Z buildup effect is liable to be significant during close-range stationkeeping and especially during gentle separations; failure to monitor it could quickly lead to the appearance of uncomfortable closing rates. Note that in efficiency this result is not far different from a deliberate RCS axis-by-axis translation burn.

Maneuvering to attitude can induce trajectory dispersions whose severity depends on the DAP mode. Assuming an Orbiter in target track, nose to Earth, an 0.2 deg/s attitude maneuver to nose-forward heads-up for a +X burn and subsequent return to target track will induce translational cross-coupling. If the maneuver is performed in NORM, the total velocity deviation is about 0.022 ft/s, mainly in the -R-BAR (up) direction, and this can be safely disregarded since the burn itself is only trimmed to 0.200 ft/s. However, if both the attitude maneuvers are performed in VERN, the significant propellant savings are offset by a much higher velocity impact: the total deviation is about 0.213 ft/s, 10 times that with the NORM jets, and much of that (about 0.1 ft/s) is in the +V-BAR direction (25 times as much as with DAP NORM), which accumulates downtrack error. The result would be as serious as a sloppy trim of burn residuals, and this could definitely be apparent on subsequent navigation and targeting.

		Free drift						Attitude hold		
		X	Y	Z	R	P	Y	X	Y	Z
ROLL	+	0	+1	-1/2		+1/4	0	0	+1	-1.5
	-	0	-1	-1/2		+1/4	0	0	-1	
PITCH	+	0	0	-1	0		0	0	0	-2
	-	0	0	-1	0		0	0	0	
YAW	+	0	-1/5	-1/2	-1/5	+1/2		0	0	-2
	-	0	+1/5	-1/2	+1/5	+1/2		0	0	

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Figure 3-47.- VRCS cross-coupling ratios.

3.8.2 Plumes

Plumes from rocket engines are of concern due both to dynamic effects on payloads and to contamination. These concerns impact engine firing procedures, both for the Orbiter and for payloads.

3.8.2.1 RCS Plumes

The influence of RCS plume effects on PROX OPS flight techniques is discussed in section 3.2.4, Low Z Operations. The RCS plume overpressures near the Orbiter are shown in figure 3-~~10~~9.

The RCS plumes (both NORM Z and low Z) at greater ranges (out to 1400 feet) are shown in figures 3-48 and 3-49.

3.8.2.2 OMS Plume

The OMS plume for a single engine burn is shown in figure 3-50, out to about half a mile. See also figure 5-26 in section 5.4.1, Nominal Separation.

3.8.2.3 PL Plume

PROX OPS restrictions on payload thrusting are illustrated in figure 3-51. The source is the memo, Safe Distance for Firing of Liquid Propellant Engines, NS2/83-L167, from LA/Manager, NSTSPO, dated June 10, 1983.

3.8.3 Failure Modes

Various types of OMS/RCS failures can impact RNDZ and PROX OPS procedures.

3.8.3.1 Jet Fail On

The concern for a failed-on PRCS jet is a momentary disturbance to Orbiter attitude. Although opposing jets would automatically try to compensate (if in proper DAP mode), the initial perturbation could be significant in terms of translational velocity and attitude (e.g., instrument pointing or docking misalignment). If the opposing jets were able to overcome the failed-on jet, an attitude oscillation would occur as the vehicle was driven back to within the attitude/rate DB's. If the opposing jets were then turned off, this would allow the failed-on jet to again drive the Orbiter out of the DB resulting in more translation. A fail-on vernier jet would produce the same scenario, but attitude/rate offsets would be smaller.

There is a single-point failure which can cause this to occur, which involves the shorting out of either of two output transistors in the reaction jet driver. However, Rockwell has reported that the mean time between failures for these transistors is five billion hours (about half a million years).

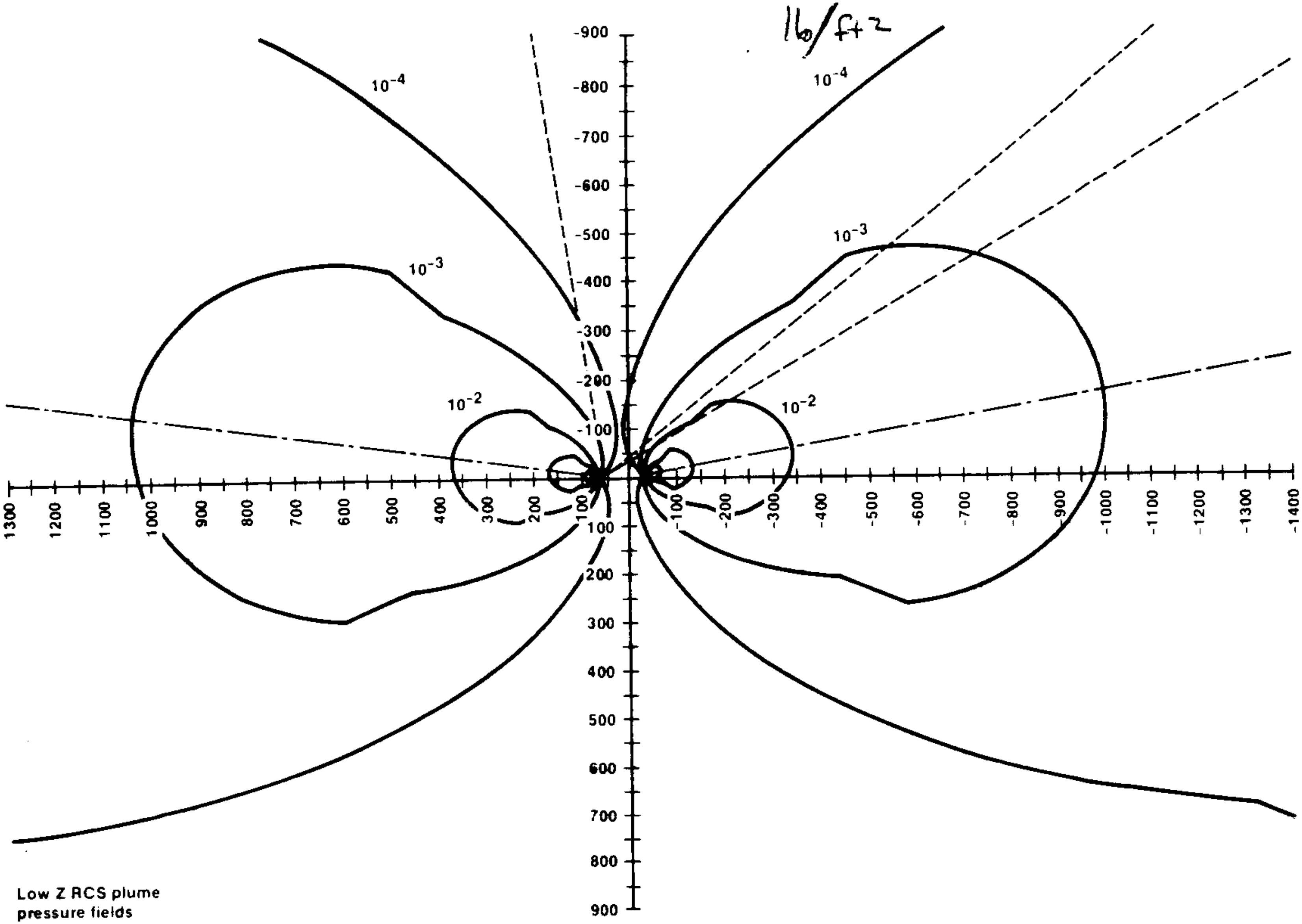

Figure 3-49.- Low Z RCS plume pressure fields.

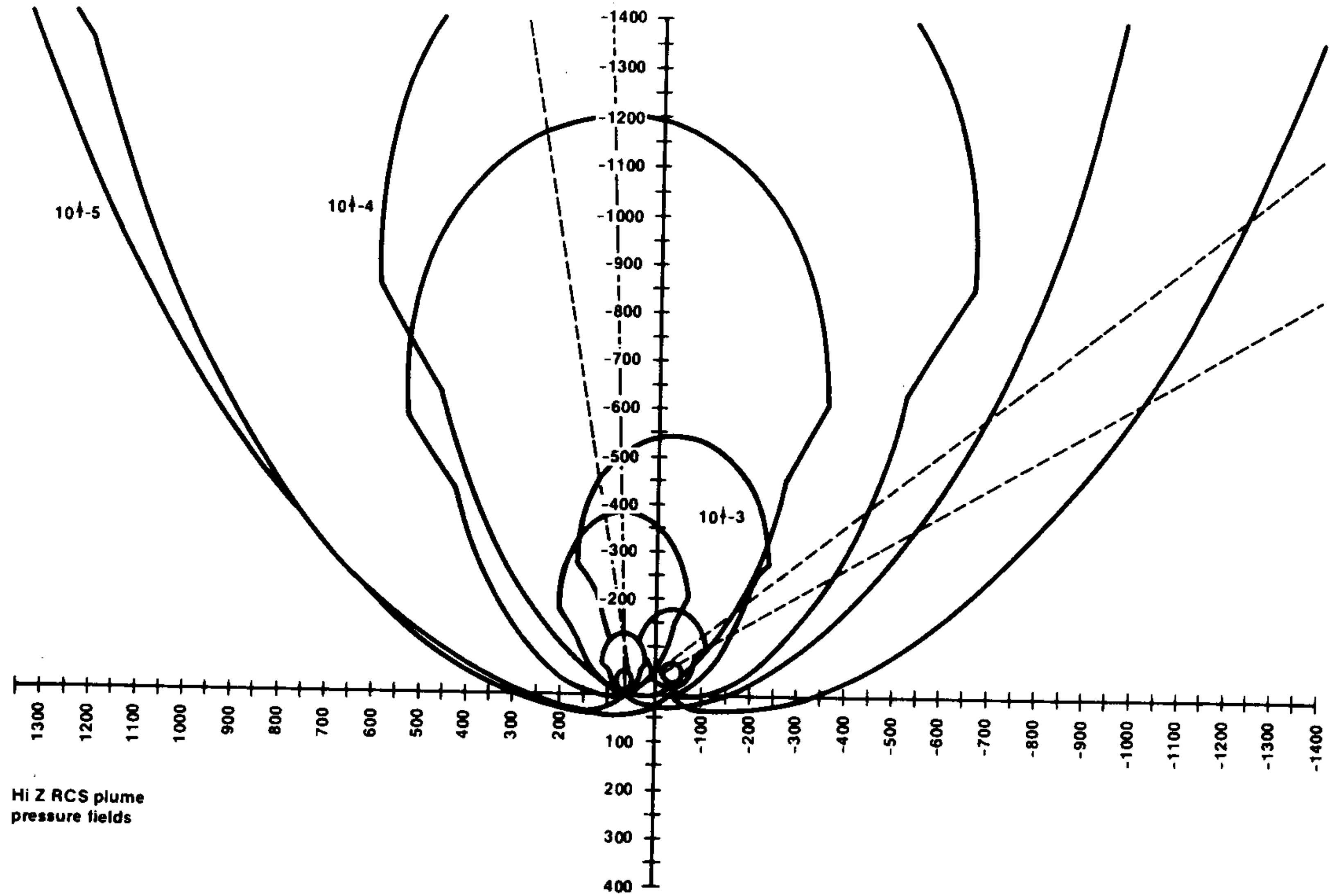

Figure 3-48.- Norm Z RCS plume pressure fields.

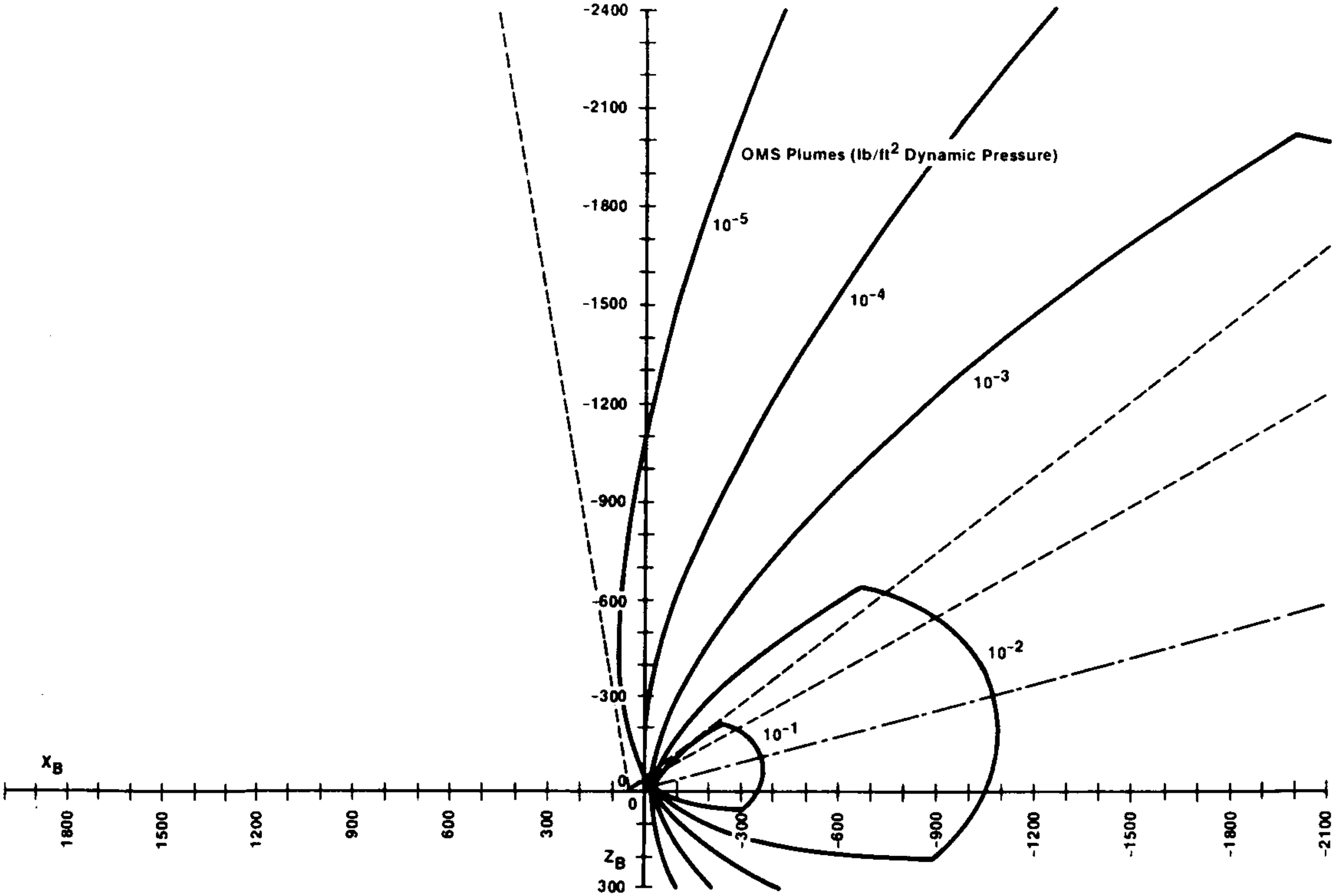

Figure 3-50.- OMS plume for single engine burn.

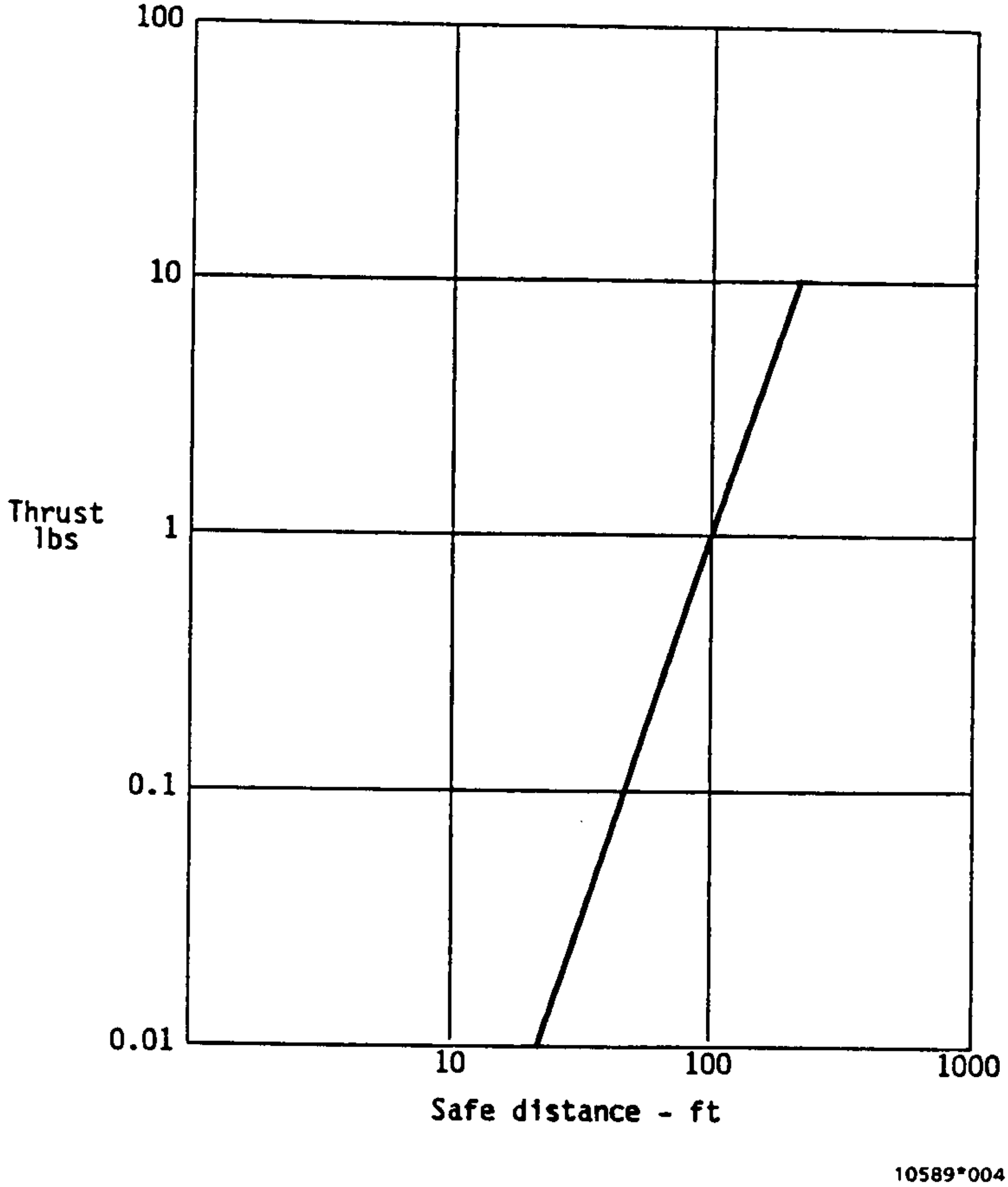

Figure 3-51.- Safe distance for firing liquid propulsion engines (paragraph 3.8.2.2).

In practice, the possibility of a failed-on jet has been handled informally by crews. On STS 51-F, during precise PROX OPS phases, the pilot was stationed in the forward cockpit with the responsibility of shutting off the proper manifold should a fail-on occur.

The current belief is that such a failure is highly unlikely and therefore does not require procedures to guard against it.

3.8.3.2 OMS Overburn

Failure to perform AUTO cutoff at VGO = 0 may occur due to a GPC failure during the burn if both valves have coil open commands strung together. In response, the crew manually takes ARM PRESS SW(s) to OFF. It is probably cheapest and safest to trim out the extra-high residuals immediately rather than waiting until the next scheduled burn; this is especially true at Ti. Flight experience has been that in the first 25 STS missions there have been 5 on-orbit GPC failures, none during OMS burns. Significant analysis has not been performed.

3.8.3.3 Loss of VRCS

See section 4.4.3.

3.8.3.4 Loss of Low Z Mode

See section 4.4.4.

3.8.4 Quantities

3.8.4.1 Rendezvous OMS/RCS PRPLT PAD

This pad (fig. 3-52) is used to reconfigure the OMS/RCS system due to low prop levels, and to abort the RNDZ, if required, due to low prop levels. Usage is defined in section 4.3.4. If breakout is performed, it provides a "disable RNDZ NAV" procedure.

RENDEZVOUS PRPLT PAD

When L or R RCS QTY < [1] :

ICNCT: L OMS to RCS (ORB PKT, RCS)

When [G23] L OMS/RCS QTY > [2] :

ICNCT TK SWITCH: From L to R OMS FEED (ORB PKT, RCS)

When [G23] R OMS/RCS QTY > [3] :

ICNCT RETURN (ORB PKT, RCS)

When L or R RCS QTY < [4] :

or when FRCS QTY < [5] :

DAP: NO LOW Z

When L or R RCS QTY < [6] :

or when FRCS QTY < [7] :

If prior to Ti,
Do not perform Ti

If after Ti, but prior to VBar arrival
Perform RNDZ BREAKOUT (Contingency Operations)

If post VBar arrival,
Perform PROX OPS BREAKOUT (Cue Card)

Figure 3-52.- Rendezvous OMS/RCS PRPLT PAD.

The first "bingo" quantity is the RCS level at which OMS interconnect is to be established. This is measured in RCS percent (1 percent RCS = 22 pounds of propellant), with the gauge (panel O3) counting down from 100 percent to 0 percent; typical interconnect bingo numbers are 50 to 60 percent. If the rendezvous phase is entered with an interconnect configuration already established, the value in this field is "N/A" for "not applicable."

The standard procedure is to interconnect first from the left OMS, with the total usage monitored on SPEC 23 (RCS), "OMS→RCS QTY" for "L." The units of this parameter are OMS percent (1 OMS percent = 129 pounds of propellant), counting up from 0 percent to a maximum interconnect of about 8.3 percent. Gauging is performed in the GPC by counting RCS jet pulses. Once the crew notices that a specified amount of L OMS propellant has been interconnected, they switch the interconnect to R OMS for another specified amount. Following that amount, the RCS system is manually returned to straight feed.

RCS quantities are then used to determine exit from DAP low Z mode; unlike the first set of RCS quantities (L or R only), this set includes FRCS as well as ARCS. Usually the ARCS values are the same as those provided in the first (top) RCS bingo specifications.

After an additional amount of RCS straight feed into NORM Z mode, the breakout bingo values are reached. Various options are available depending on where the crew is in the rendezvous profile.

The "post breakout reconfiguration" procedure performs the same essential steps as the standard post-rendezvous "disable rendezvous navigation" block, section 4.1.74 in the nominal rendezvous narrative.

3.8.4.2 Typical Propellant Consumption

The expected OMS/RCS consumption rates are provided in the CAP maneuver tables and consumables curves. Variations in preplanned operations will impact consumption and the following data is offered as an aid to estimating such impacts.

For propulsive maneuvers, the ΔV in ft/s converts to pounds of propellant via these equivalences: 1 ft/s costs about 22 lb through the OMS, 25 lb through the +X RCS, and about 35-40 lb through multiaxis RCS (about a third to a half out of the FRCS).

Once the final midcourse maneuvers are completed, the Orbiter begins manual phase, which involves nearly continuous thrusting.

The following propellant usages are derived from analysis of the 51-I and 51-L profiles:

	FWD(1σ)	AFT(1σ)	Total(1σ)
Manual Phase (MC4+2 to V-BAR)			
Nominal	88(35)	159(40)	242(70)
Radar Fail	241(71)	289(93)	530(130)
V-BAR Approach (400 ft - 35 ft)	35(20)	65(20)	100(35)
35 ft Stationkeeping (LB/MIN)			
+V-BAR	0.20(0.2)	0.6(0.6)	0.8(0.7)
INERTIAL	0.59(0.39)	1.00(0.59)	1.58(0.94)
+V-BAR (LOW Z)	0.5	1.5	2.0
Align Maneuver (Per Axis) (Usually two reqd)	22(7)	39(16)	61(21)

These values represent smooth, skilled flying after proper training, with all sensors operable (except as noted).

Note: MMU reserve from 35 feet, no low Z, uses about total 257 (127), with 101 (52) from forward

Precise predictions will be prepared as required by the MCC.

3.8.4.3 Propellant Saving Techniques

In propellant-limited situations, RNDZ and PROX OPS may continue with special care to the following guidelines:

- Stay in verniers as long and as often as possible.
- To conserve FRCS, use TAIL ONLY control mode.
- Stay out of low Z as much as possible. Get R-DOT and out-of-plane situation under control (0.1 - 0.2 ft/sec) before 200 feet so that no inputs need be made until NORM Z can be resumed.
- Performing translations based on overhead window LOS to TGT, carefully observe Orbiter DB's prior to THC inputs; only make inputs when near center of DB.
- In controlling out-of-plane dispersions, start as early as possible, wait for the NODE to put in the pulses, watch the deadbands, and do not fight orbital mechanics effects.

RCS BURN (+ X, -X, Multi-axis)

```
  OPS 202 PRO
  [GNC ORBIT MNVR EXEC]
 ✓RCS SEL, ITEM 4 - *
  Enter or verify TGT data
  LOAD - ITEM 22 EXEC
  TIMER - ITEM 23 EXEC
  If +X BURN,
    DAP: A/AUTO/VERN (B/NORM as reqd)
    MNVR - ITEM 27 EXEC (*)
    If radar ops,
      KU - AUTO TRK
      [GNC 33 REL NAV]
      INH Angles - ITEM 24 EXEC (*)

TIG-0:30
  FLT CNTLR PWR - ON
  DAP TRANS: as reqd
      ROT: DISC/DISC/DISC
  If Multi-axis,
    DAP: A/LVLH/NORM
  If +X OR -X,
    DAP: A/MAN/NORM

TIG
  If VGO Z is neg, Z,X,Y seq,
   otherwise, X,Y,Z

  THC: Trim VGOs < 0.2 fps

  FLT CNTLR PWR - OFF
  OPS 201 PRO
  DAP: VERN
  DAP: A/AUTO

  If radar ops, when in att,
    KU - GPC
   ✓KU TRACK tb - gray
    [GNC 33 REL NAV]
    AUT Angles - ITEM 23 EXEC (*)
```

CUE CARDS

3.8.5 Special Burns

RNDZ and PROX OPS require specialized applications of OMS/RCS propulsion capabilities.

3.8.5.1 RCS ~~Axis-by-Axis~~ BURN

For axis-by-axis burns (section 3.6.3), RCS is used to manually achieve the targeted ΔV's. The RCS BURN cue card is shown in figure 3-53, and specific call-outs of this procedure are defined in section 4.3.1.

```
TIG - 2:00
       OPS 202 PRO
      ┌─────────────────────────┐
      │ GNC ORBIT MNVR EXEC     │
      └─────────────────────────┘
      ✓TGT data loaded
       LOAD - ITEM 22 EXEC
       TIMER - ITEM 23 EXEC
TIG -0:30
       FLT CNTLR PWR - ON
       DAP TRANS:  as reqd
           ROT:  DISC/DISC/DISC
       DAP:  A/MAN/NORM
TIG
       THC - Trim VGO's < 0.2 ft/s

       If VGO Z is neg, Z,X,Y seq,
       otherwise, X,Y,Z

       OPS 201 PRO
       DAP:  A/AUTO/VERN
       FLT CNTLR PWR - OFF
```

Figure 3-53.- RCS BURN cue card.

This cue card may be entered from burn blocks where some operations (e.g., OPS 202 PRO item 22, 23 EXEC) may already have been executed. In that case do not repeat these steps.

The basis for this technique is described in section 3.6.3.

3.8.5.2 RNDZ OMS Burn

Specific call-outs of this procedure are defined in section 4.3.5. When performed for RNDZ maneuvers, the OMS burn (3-54) differs somewhat from the standard ORBIT OPS procedure. The KU antenna is moded to AUTO track if this is the Ti burn. Residuals trimming is specified to <0.2 ft/s. RCS engine select is explicitly selected as the default for the next burn. Resumption of UNIV PTG is explicitly called out. Nominal RNDZ DAP's are used.

RNDZ OMS BURN

	✓DAP A9, B6
	Install OMS 2/ORBIT OMS BURNS Cue Cards (two) and OMS BURN MONITOR Cue Cards (two) (F6,F8)
CRT	OPS 202 PRO
	GNC ORBIT MNVR EXEC
	GNC SYS SUMM 2
	Load TGT data per burn pad
	LOAD - ITEM 22 EXEC
	TIMER - ITEM 23 EXEC
	✓Burn data per burn pad
C3	DAP: B/AUTO/VERN,NORM as reqd
	DAP TRANS: as reqd
	DAP ROT: DISC/DISC/DISC
CRT	MNVR - ITEM 27 EXEC (*)
	If RR OPS,
A1U	KU - AUTO TRACK
	GNC 33 REL NAV
	Inh Angles - Item 24 EXEC (*)
	When mnvr to att complete,
C3	DAP: A/AUTO/VERN
O8	✓L,R OMS TK ISOL (four) - Per Pad
TIG -2:00	
F7/F8	FLT CNTLR PWR (two) - ON
	Perform OMS 2/ORBIT OMS BURNS Cue Card, then
	THC: Trim residuals < 0.2 fps
F7/F8	FLT CNTLR PWR (two) - OFF
O8	L,R OMS He PRESS/VAP ISOL (four) - CL
CRT	RCS SEL - ITEM 4 EXEC (*)
	Perform OMS GMBL CK per burn pad
	* If down arrow(s) or M(s), *
	* select good GMBL *
C3	DAP: B/MAN/NORM
CRT	OPS 201 PRO
C3	DAP: B/AUTO/NORM
	When in attitude,
	DAP: A/AUTO/VERN
A1U	If RR OPS,
	KU - GPC

Figure 3-54.- Perform RNDZ OMS Burn

HOOK VELCRO	OMS 2/ ORBIT OMS BURNS	HOOK VELCRO

ASC-2a/30/A,O/A

√MM105/202(302)
√BURN ATT (INRTL) then REF, pb - push
√ENG SEL CNTL PWR (two) - ON ··
√DAP - AUTO(PASS)/DISC √DAP TRANS - NORM
√GIMBAL TRIM
2 engine: P = +0.4 LY = -5.7 RY = +5.7
1 engine: P = +0.4 LY = +5.2 RY = -5.2
L,R OMS He PRESS/VAP ISOL A (two) - OP
wait 2 sec .... B (two) - GPC (OP for SE burn)

		GPC	OP	CL
ORB BURN	A			
	B			

TIG-2 SEL OMS ENG(s) - ARM/PRESS (√P VLVs OP)
If P VLV CL: Aff OMS ENG - OFF

WARNING
Do not burn affected engine if:
OMS N2 TK P < 470(564) (NONCRIT
He TK P < 640 BURN)
FU ENG IN P < 216(244)
OX ENG IN P < 151(244)

ΔVTOT: OMS XFEED RETURN (Planned Single Engine)

-:15 EXEC ··
If OMS ENG Pc MSG and non critical burn - Affected Eng - OFF
If Leaking OMS PROP burn RCS +X TIG -15 sec to OMS IGN + 1 sec

:00 TIG ·· (√Pc, ΔVTOT, ENG VLVs; start watch)

* **OMS PRPLT FAIL:**
* **HP <[85]** (CONTINUE BURN):
* Failed OMS ENG - OFF
* √XFEED (two) - CL
* TK ISOL (two) - CL
* He PRESS (two) - CL
* **HP >[85]** (STOP BURN):
* OMS ENG (two) - OFF
* √Failed OMS XFEED (two) - CL
* TK ISOL (two) - CL
* He PRESS (two) - CL
* **OMS ENG FAIL:**
* ASCENT or CRIT O/O (Continue Burn)
* Failed ENG - OFF
* OMS XFEED at → 1/2 ΔVTOT at FAIL [| |]
* **RCS COMPLETION:** (Hp <[85] or CRIT O/O)
* Interconnect to either OMS that was ENG FAIL
* THC +X (Hp = [85])
* Post burn, AFT RCS RECONFIG

CUTOFF ··
+:02 OMS ENG(s) - OFF
If Orbit Critical Burn,
| Trim all axes residuals < 0.2 fps
Otherwise
Trim all axes residuals < 2 fps

HOOK VELCRO | **OMS 2/ ORBIT OMS BURNS** | HOOK VELCRO

ASC/ALL/A,O/BAS A,9

✓MM 105/202(302)
✓BURN ATT (INRTL) then REF, pb - push
✓ENG SEL CNTL PWR (two) - ON ··
✓DAP - AUTO(PASS)/DISC ✓DAP TRANS - NORM
✓GIMBAL TRIM
2 engine: P = +0.4 LY = -5.7 RY = +5.7
1 engine: P = +0.4 LY = +5.2 RY = -5.2
L,R OMS He PRESS/VAP ISOL A (two) - OP, then GPC (OP for SE burn)
wait 2 sec .... B (two) - GPC (OP for SE burn)

		GPC	OP	CL
ORB BURN	A			
	B			

TIG-2 SEL OMS ENG(s) - ARM/PRESS (✓P VLVs OP)

WARNING
Do not burn affected engine if:
OMS N2 TK P < 470(523) (NONCRIT
He TK P < 640 BURN)
FU ENG IN P < 216(226)
OX ENG IN P < 151(238)

ΔVTOT: OMS XFEED (Planned Single Engine)

-:15 EXEC ··
If Leaking OMS PROP burn RCS +X TIG -15 sec to OMS IGN + 1 sec
:00 TIG ·· (✓Pc, PVTOT, ENG VLVs; start watch)

- **OMS PRPLT FAIL:**
  - **HP < 100** (CONTINUE BURN):
    - Failed OMS ENG - OFF
    - ✓XFEED (two) - CL
    - TK ISOL (two) - CL
    - He PRESS (two) - CL
  - **HP > 100** (STOP BURN):
    - OMS ENG (two) - OFF
    - ✓Failed OMS XFEED (two) - CL
    - TK ISOL (two) - CL
    - He PRESS (two) - CL
- **OMS ENG FAIL:**
  - ASCENT or CRIT O/O (Continue Burn)
  - Failed ENG - OFF
  - OMS XFEED at → 1/2 ΔVTOT at FAIL [| |]
- **RCS COMPLETION:** (Hp < 80 or CRIT O/O)
  - Interconnect to either OMS that was ENG FAIL
  - THC +X (Hp = 80)
  - Post burn, AFT RCS RECONFIG

CUTOFF ··
+:02 OMS ENG(s) - OFF
Trim inplane X,Z residuals < 2 fps

Figure 3-55.- OMS 2/Orbit OMS burns cue card.

After initiating the maneuver to burn attitude, the crew configures the propellant system pressurization valves. The OMS helium pressure/vapor isolation valves (A and B sides) are configured per instructions from the MCC. As part of the program to run on-orbit checks for redundant systems whenever possible, the A and B valves are configured so as to utilize the path with the least amount of flight usage. Most RNDZ OMS burns are classified as critical for mission success (the on-orbit NC2 burn is a crew safety maneuver because of potential for target impact if not performed) and therefore usually do require system redundancy during the burn. For a problem during execution, the crew completes the burn per downmoding instructions on the BURN PAD. At TIG-2:00 the crew powers on their flight control systems (the THC and RHC) and continues executing the burn. After exiting the cue card procedures, the crew uses the THC and manually trims out the residual ΔV's by selecting the PRCS and the manual translational mode he/she desires (PULSE or NORM), and then deflecting the THC until the displayed values of velocity to go (VGO) are less than 0.2 ft/s. The crew then powers down the flight controller systems and closes the helium pressurization valves. If required by the MCC, the crew performs an OMS thrust vector control (TVC) gimbal check on the appropriate gimbal system(s). This is also a part of the in-flight redundant system checkout program.

3.9 OTHER SYSTEMS

3.9.1 Auxiliary Power Unit (APU)

The need to burn a leaking APU at the wrong time during a RNDZ can seriously affect procedures. Over an hour period, the force of about 4 pounds in the +Z direction can introduce a ΔV of 2 ft/s, causing extremely serious NAV impacts and trajectory dispersions late in the RNDZ. To avoid this, such a burn (if absolutely unavoidable) should be performed out of plane to negate possible down-range errors; post-Ti, this cannot be done without impacting sensors, so the ΔV hit must be swallowed and taken out at the midcourse burns. Note that it is unlikely that an APU will be burned during a RNDZ because if the leak is tiny, burning the APU can be delayed, and if the leak is large, it can be expected that the RNDZ will be terminated with the appropriate breakout, followed by APU burn and deorbit prep.

The acceleration is well below the limit of detectability by the IMU accelerometers.

For more details, see "APU Venting Effects on the Rendezvous - Day Trajectory," W. R. Britz, RSOC, September 1987.

RNDZ C/L needs to include
A&L PORT RMS HTR A,B (two) - AUTO
one hour before powerup

3.9.2 PDRS

Track and capture training is normally conducted with translational rates up to 0.2 ft/sec and rotational rates of up to 0.3 deg/s simultaneously in all axes (pitch, yaw and roll). The training translational rate capability is generally considered to be unreasonable due to the potential hazards of attempting to grapple a translating target. In general, the translational rates would have been nulled by the Orbiter pilot during the terminal phases of the PROX OPS approach operations. The training rotational rates are considered to be reasonable. The flight specific rules governing any given flight will usually restrict these rates even further in order to prevent damage to the arm or the target.

RMS operations are mentioned in 4.1.41 in terms of use of the wrist CCTV. Problems which may frustrate PL recovery capability can be grounds for RNDZ delay, either at Ti or well before.

3.9.3 EVA

When an EVA and a RNDZ are occurring together, it is most important that the respective timelines be well coordinated. In particular, crewmembers may have to switch off tasks, since EVA normally involves two EVA crewmembers and one IVA crewmember and RNDZ (with or without RMS ops) involves two or three crewmembers.

The following items must be considered in preparing timelines:

a. The pre-breathe in EMU's needs to be started about the same time as Ti.

b. RMS is generally powered up immediately after Ti; it can be delayed, but should not be planned to occur prior to Ti.

c. Performance of the RR-FAIL procedures can get crowded by the EMU pre-breathe and/or the RMS powerup. Remember the RR-FAIL procedures take priority.

d. Depending on the history of the RNDZ, the post-Ti NAV can be very critical to the successful completion of the rendezvous; therefore, two crewmembers should be dedicated full-time to RNDZ OPS on the flight deck during this phase.

e. Selection of crewmember responsibilities (the flight crew does this) may require moving up or delaying activities from their nominal time slots.

Several other systems are impacted by joint RNDZ/EVA operations:

a. Extended use of the PLB cameras may lead to their overheating. Since maximum possible EVA coverage is highly desired, the cameras will remain powered up long after the completion of the rendezvous. To shorten the total interval of camera powering, do not plan to perform PLB camera operations earlier than Ti.

b. EMU problems can be a leading candidate for Ti delay.

3.9.4 IMU

The IMU is not used directly as a RNDZ sensor, but inertial attitude information from the IMU is processed by the RNDZ NAV software along with information from the RNDZ angle sensors. The three RNDZ sensors - radar, STRK, and COAS - measure angles in their respective coordinate systems, which are fixed with respect to the body coordinate system. The IMU supplies the necessary transformation from body coordinates to M50 coordinates. Therefore, any errors in the IMU attitude will result in errors in the incorporation of angular data into the RNDZ NAV filter. These IMU angular errors will appear to the filter as sensor measurement errors. IMU attitude errors as small as 0.01° will noticeably affect REL NAV.

An effort is made in the development of crew procedures to place an IMU alignment immediately before the beginning of the first navigation period (usually STRK) in a RNDZ profile. The need for an IMU alignment as close as possible to the beginning of the first STRK pass is due to the fact that IMU drift rate is large compared to STRK one-sigma expected bias.

A problem occurred on STS 41-C as a result of the way attitude processing is performed by the IMU redundancy management (RM) logic. With all three IMU's operating properly, the attitude RM logic should select the IMU with the smallest attitude error relative to the other two IMU's ("midvalue select"). If the errors between each of the three IMU's are nearly equal, then the RM may frequently change the selected IMU. This problem occurred on the first and second STRK passes of the first RNDZ of STS 41-C. This IMU switching appeared to the filter as a measurement noise of approximately 0.1° - much larger than expected from either the STRK or the IMU. Consequently, the filter believed the measurement and updated the Orbiter SV accordingly. Each time the selected IMU changed, a large update was made to the SV. To avoid these errors, one IMU is now deselected for the duration of each STRK pass, thus forcing RM to consistently send the lowest-numbered IMU's value to NAV.

This process is described in detail in section 3.3.2.1 on "STRK Target Acquisition".