SECTION 4
RNDZ PROCEDURE SEQUENCES

This section is the heart of the flight procedures rationale narrative, and is an entry point into the entire book. As each step is listed, described, and explained, in depth citations are given to specific background sections in chapter 3.

A standard last few REV's of the on-orbit rendezvous profile is narrated in section 4.1, where all the operations in the FDF Rendezvous book are described and explained. Differences with other rendezvous sequences are discussed, and in section 4.2 the features of rendezvous variations are described.

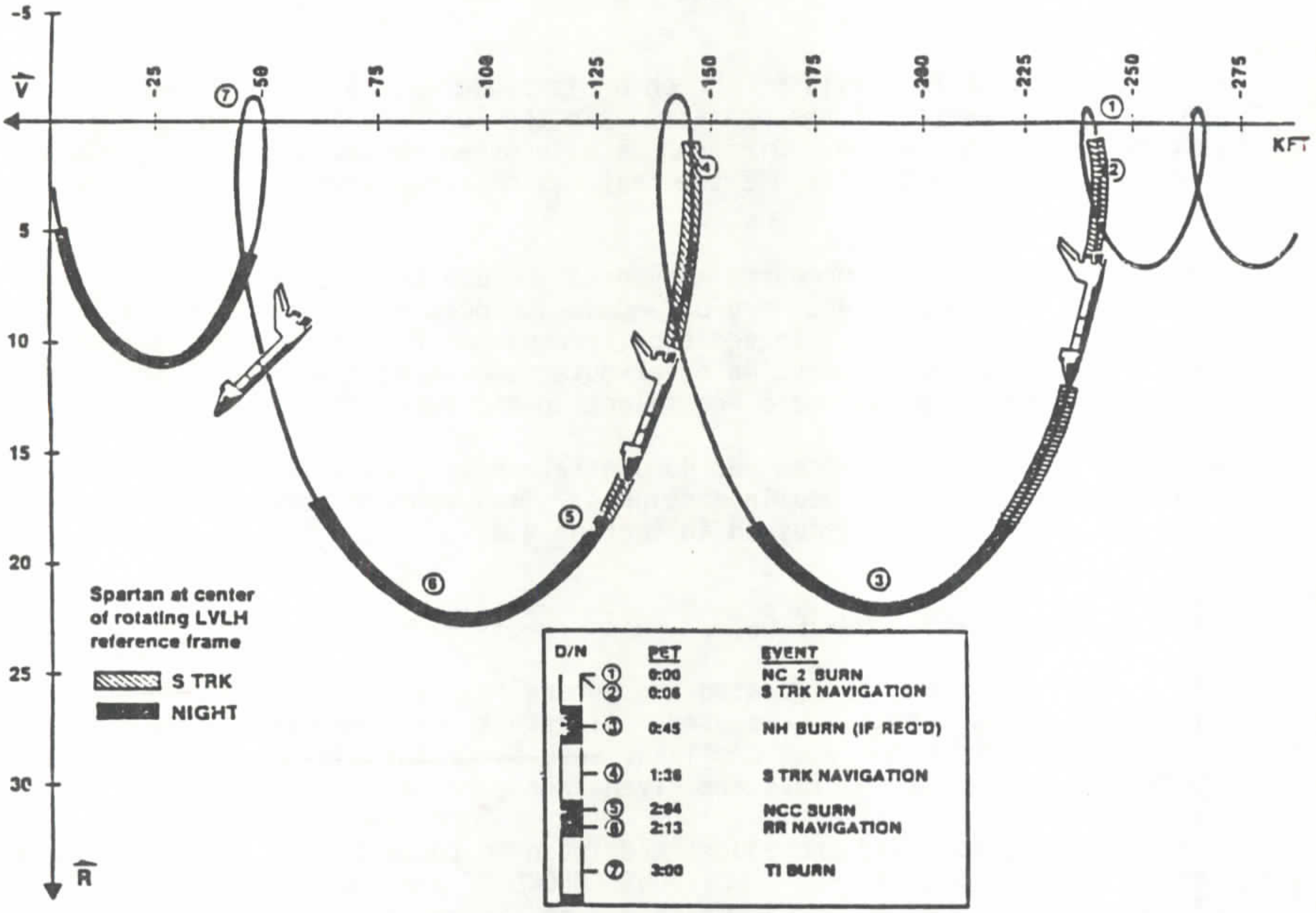
Specific rendezvous procedures sequences include both cue cards (described and explained in sec. 4.3) and off-nominal procedures (described and explained in sec. 4.4). In addition, procedures for post-rendezvous back-out (sec. 4.5) and for anytime break-outs (sec. 4.6) are referenced, with attention given to rationale for selection and execution.

Lastly, questions of procedures documentation are addressed. Relative motion plots are described in section 4.7, and generic documentation rationale for FDF is discussed in section 4.8.

4.1 STANDARD OPERATIONS FLOW

As a model for RNDZ, the updated and generalized version of the C RNDZ ~~STS 51-L (Spartan-Halley) checklist~~ is used. All steps are consistent with other current standard rendezvous profiles, ~~such as in the Contingency Rendezvous book~~. Relative motion plots are given in figures 4-1, 4-2, and 4-3.

The following specific procedures are intended to be strung along the pages of the flight-specific FDF RENDEZVOUS CHECKLIST and thus comprise the "contents" referred to in paragraph 4.8 on FDF management. This book is entered from an explicit call-out in the CAP Flight Plan. Every 30-minute period is portrayed on a right-hand page and consists of a timeline with AOS, SR/SS, and DAP information, line by line action specifications or numbered block call-outs, and specific blocks themselves, each containing an integrated procedure; left-hand pages may contain burn pads or more numbered blocks referenced from right-hand pages or other blocks, or they may be marked "This Page Intentionally Left Blank". Also included on the 30-minute pages should be entries for expected MCC uplinks (e.g., voiced-up PAD's, MNVR CMD loads, COVAR MATRIX loads, etc.) and periodic notations of nominal range (kft) and range rate (ft/s) to target. The book's timeline ends with an explicit directive to return to a specific point in the ~~CAP~~ Flight Plan.



D/N	PET	EVENT
①	0:00	NC 2 BURN
②	0:06	S TRK NAVIGATION
③	0:45	NH BURN (IF REQ'D)
④	1:36	S TRK NAVIGATION
⑤	2:04	NCC BURN
⑥	2:13	RR NAVIGATION
⑦	3:00	TI BURN

Figure 4-1.- ~~Spartan rendezvous profile~~.
CRNDZ

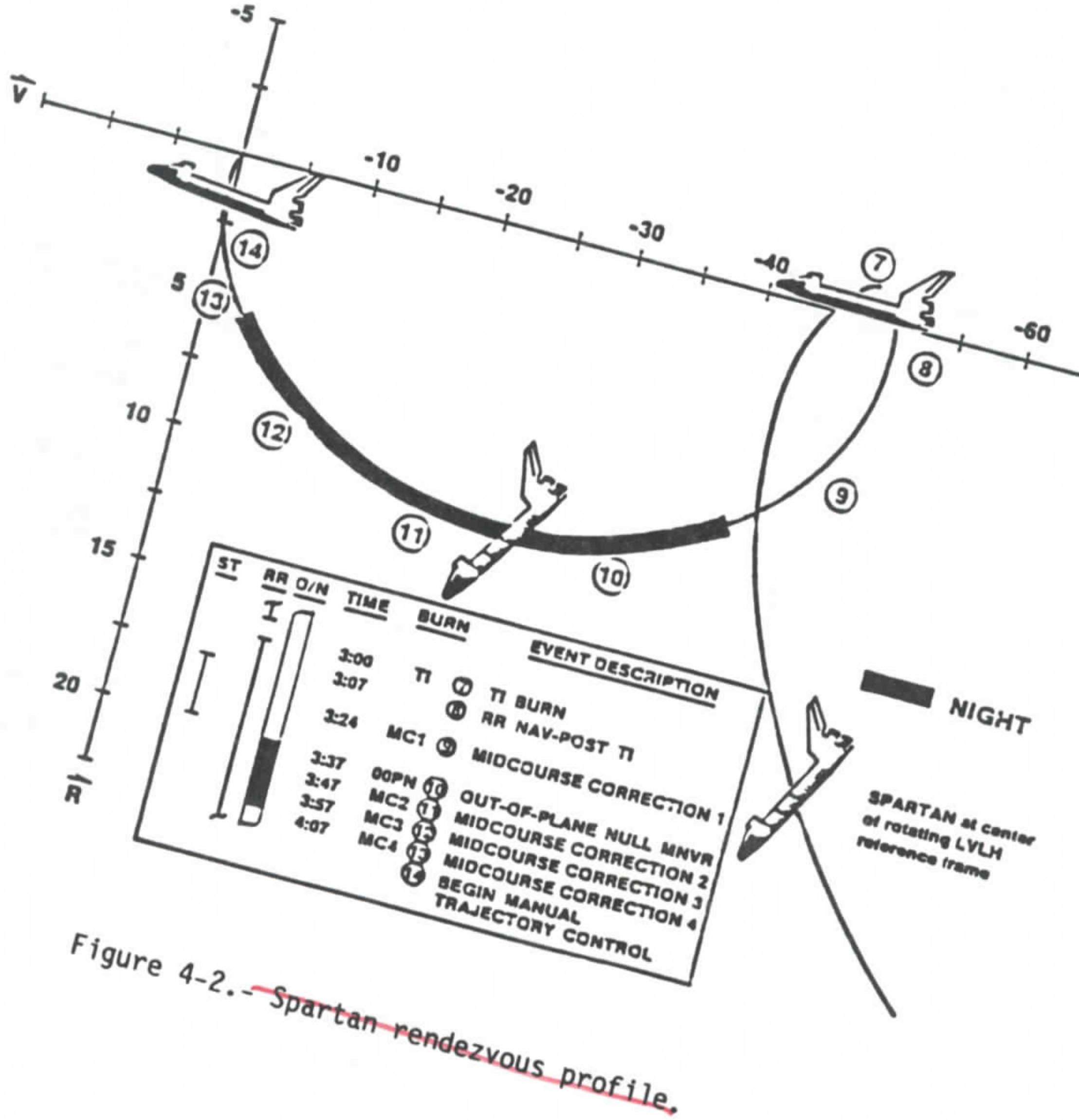


Figure 4-2.- Spartan rendezvous profile.

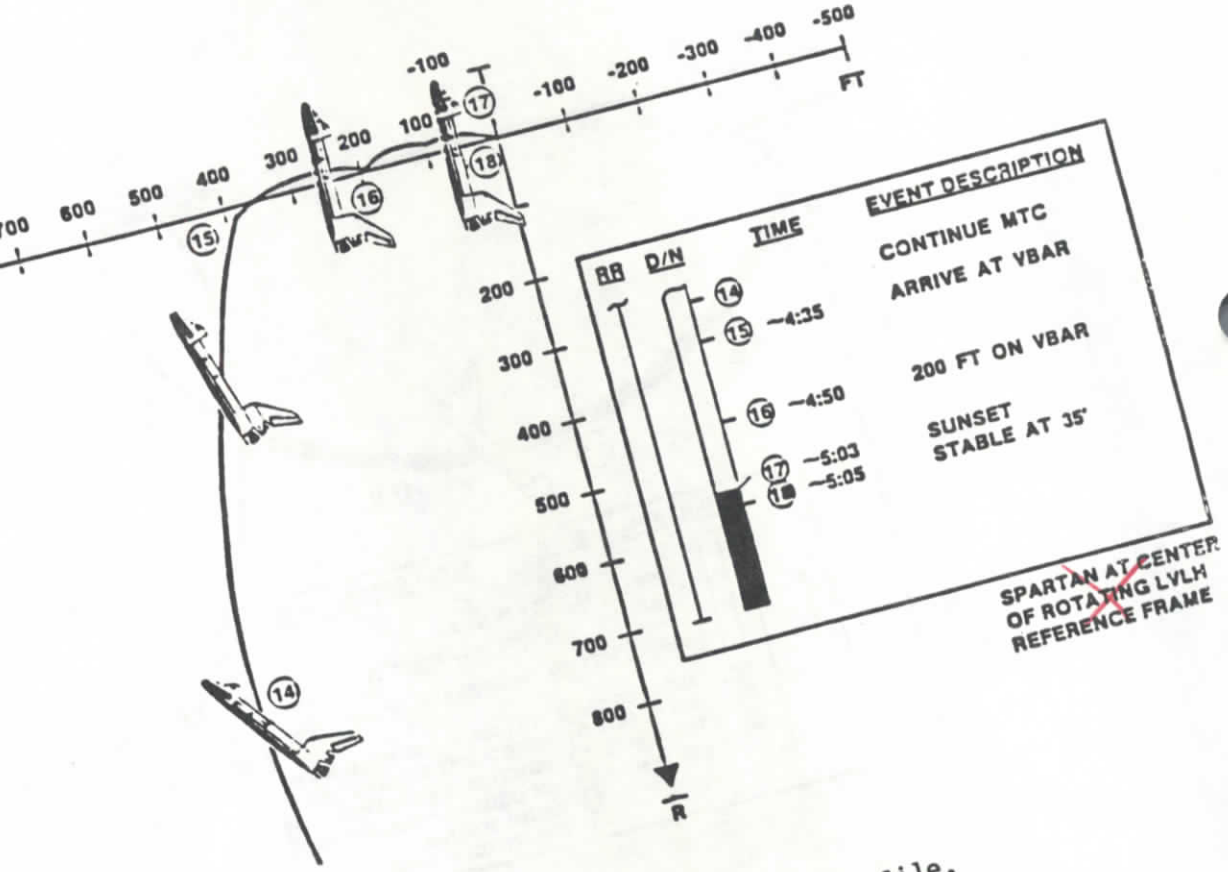


Figure 4-3.- Spartan ~~rendezvous profile.~~

CRNDZ

4.1.1 Configure DPS

(See section ~~6.1.1~~ 3.7.1.)

SPEC 2 PRO
ITEM 2 EXEC (MET)
ITEM 17 + D + H + M + S
ITEM 12
RESUME

4.1.2 Set SM Timer

SM 2 TIME:

The crew performs the step: "Set SM TIMER counting ~~up~~ to Ti TIG per BURN PAD ~~NC TIG (SPEC 2~~)."

The events that make up a RNDZ are not scheduled as individual items during an STS mission. The various procedures are timelined in specific sequences relative to each other, to lighting conditions, or to target-referenced apogee/perigee occurrences. As such, the RNDZ timeline can, and should, be moved as a complete entity during a mission, if the need arises. To be as flexible as possible in supporting preflight mission planning and real-time mission operations, the RNDZ timeline was developed on a phase elapsed time (PET) scale. The reference time (00:00 = HH:MM) is ~~usually~~ defined as occurring at the ~~NC~~ Ti burn. The crew utilizes the SM CRT timer in order to have an onboard timer set up as a reference for the RNDZ PET. The GNC computer timer is not used because one of the outcomes of targeting an onboard RNDZ burn using ORB TGT is that the GNC timer is automatically reset to count down to the burn ignition and would therefore overwrite the PET reference.

(which is also the BASE TIME = 0 for maneuver targeting

4.1.3 Configure Aft Flight Station

This block is shown in figure 4-4; this configuration can be done as the very first RNDZ action, ahead of the preceding two sections. The aft ADI is configured with its attitude coordinate system reference set to the LVLH coordinate reference. This reference is selected to support crew monitoring of Orbiter attitude and relative motion profile. The error and rate switches are set so that the crew has the most accurate display of data without truncating data. In these settings the error display is to ± 5° and the rate to ± 1 deg/s. The sense switch is set to the -Z position since this is the axis parallel with the crew LOS as they monitor the TGT out the overhead windows and through the COAS.

To prepare for subsequent operations the crew installs the COAS in the -Z (window 7) position and unstows and installs the cue cards needed for RNDZ.

A6U ADI ATT - LVLH
ERR - MED
RATE - LO
SENSE - -Z

R13L ✓KU ANT - GND
A1U ✓PWR - ON
KU MODE - RDR PASSIVE
RADAR OUTPUT - HIGH
- MAN SLEW
CNTL - PNL
SIG STRENGTH sel - KU
SLEW RATE - as reqd
A2 DIGI-DIS SEL - R/RDOT
X-PNTR SCALE - X1

CRT **SM ANTENNA**

SELF TEST - ITEM 7 EXEC (•)

NOTE
SELF TEST runs about 3 min

A1U ✓KU SCAN WARN tb - gray
✓TRACK tb - gray
✓SEARCH tb - gray
A2 ✓RANGE - 888.8
CRT SELF TEST - ITEM 7 EXEC (no •)
A2 DIGI-DIS SEL - EL/AZ

A1U KU MODE - COMM
✓KU - MAN SLEW
KU CNTL - CMD
Install -Z COAS
Install ~~RNDZ OPS~~ RCS BURN Cue Card ~~(two)~~
Install PROX OPS Cue Card

Figure 4-4.- Configure aft flight station for RNDZ.

4.1.4 Ku-Band Self Test

(See section 3.3.4.4.)

4.1.5 NSR burn (as required)

For reasons stated in section 2.9.1.3, an NSR burn sometimes is performed prior to the last NC burn. Although this profile did not have one, some ground-up rendezvouses will and all long-duration, on-orbit separation/rendezvous profiles probably will.

The burn is performed just like a standard RNDZ OMS BURN (fig. 3-54), except that postburn the RCS ENG SEL is not automatic, and the UP is selected to TRACK.

4.1.6 Enable RNDZ Navigation S/W

To begin the propagation of the various SV's required for RNDZ and to enable processing for onboard sensor data taking, the crew enables RNDZ NAV via an item entry (ITEM 1). The crew also verifies that SV SEL is PROP; that RNG, R-DOT, and angles are INH; and that S TRK (ITEM 12) is "*". See section 3.4.1.3 for background.

At this point, a software check is made to verify that the stored SV for the TGT has a time tag within 15 hours of the current time. If the check is passed, the TGT SV is propagated to current time using the SUPER G propagator, and the current Orbiter SV (stored as the FLTR SV) is automatically copied into the PROP SV location. If the TGT SV time tag is greater than 15 hours away from (before or after) current time, RNDZ NAV will not begin processing due to the excessive amount of time and inaccuracies involved in propagating the stored vector to current time. Also, if there is no TGT SV at all, RNDZ NAV will also not begin processing. No message or "*" is displayed.

The onboard Orbiter and TGT NAV states will be initialized by ground uplink prior to initiation of RNDZ NAV. ~~An onboard software restriction prohibits entering RNDZ NAV if the time tag of the TGT SV is older than 15 hours.~~ The target SV time tag I-load is normally zero; therefore, without a ground uplink of the TGT SV, RNDZ NAV cannot be enabled. It is ~~also~~ desirable for both ground and onboard to have the most accurate Orbiter and TGT SV's available, and hence the most accurate relative SV to initialize RNDZ NAV for the first onboard NAV sensor tracking interval. This allows the filter to rapidly determine the "true" relative state and prevents undesirable transients caused by large updates.

Once RNDZ NAV is enabled, the REL NAV display is verified to be in its initialized configuration.

4.1.7 Initialize ORB TGT

The ORBIT TGT function is initialized by loading in the base time for burn calculations. For clarity and non-ambiguity, the FDF wording is:

TGT NO - ITEM 1 + 1 EXEC

Set BASE TIME to Ti TIG (Ti Burn PAD, [page citation])

LOAD - ITEM 26 EXEC

This was chosen carefully based on actual checklist experience with a variety of wordings.

See section 3.5.2.8 for detailed rationale.

4.1.8 Establish RNDZ DAP

The DAP is configured for RNDZ usage by loading parameters as specified by DAP's coded A9 and B6. The primary items of interest for RNDZ are the translational pulse sizes, rotational discrete rates, ATT DB, and jet option selection.

Translational pulse size of 0.10 ft/s in DAP A gives the coarse control and 0.05 ft/s in DAP B gives the fine control necessary to effectively trim out the targeted translational burns, and also control the trajectory during the manual final phase corrections.

Rotational discrete rates are set to 0.2 deg/s (the standard Orbiter maneuver rate) except for DAP B primary RCS (NORM) which is set to 0.5 deg/s in order to maneuver quickly if necessary.

ATT DB sizes are based on several interrelationships. First, it is desirable to have the NORM ATT DB as large as possible because the primary RCS (PRCS) uses large amounts of propellant in tight ATT DB's. Secondly, to provide accurate pointing for sensor acquisition and crew monitoring, the ATT DB needs to be as small as is practical in all DAP configurations and for all jets. Lastly, in order to keep from constantly initiating small but costly attitude maneuvers back to attitude after performing PRCS translations, the NORM ATT DB should be no more than twice as large as the vernier ATT DB. This is due to the fact that the DAP phase plane logic initiates a DISC rate maneuver back to attitude when the Orbiter attitude errors exceed twice the specified ATT DB. In solving for the ATT DB values, a reasonable solution was a 1.0° VERN ATT DB and a 2.0° NORM ATT DB.

The jet option selection is set to 1 (full up nose and tail control) to provide coupled ROT's when on the PRCS. Either nose- or tail-only options introduce noticeable translational delta velocities when operating on the PRCS.

LOAD TARGET TRACK → use fig 4-5

4.1.9 Perform NC (Phasing) Burn

The NC burn is calculated to place Ti burn position 8 n. mi. (48,600 feet) trailing the TGT. To effectively move the downrange position of Ti without affecting its altitude, the NC burn is executed at an integral multiple of the orbital period prior to Ti.

NC is performed as a RCS BURN (with RNDZ OMS BURN if large enough)

~~A typical NC burn block is shown in figure 4-5.~~ The NC burn is performed using TIG and ΔV's that have been ground calculated and voiced to the crew (a command load is also sent up to MM202). NC TIG is usually one or two REV's prior to Ti.

In the case of a ground-up RNDZ, NC is usually posigrade, raising relative perigee and thereby decreasing the phasing rate. The major driver for temporal placement of the NC burn is the length of the crew workday on the day of RNDZ. Therefore, NC is usually done one REV before Ti to shorten the total time period required to perform the RNDZ.

For on-orbit rendezvous profiles, however, the NC burn usually is retrograde, lowering relative perigee and thereby increasing the Orbiter closing rate on the TGT. This is the case because the Orbiter is either drifting

~~**GNC UNIV PTG**~~

~~CNCL - ITEM 21 EXEC~~
~~OPS 202 PRO~~

~~**GNC ORBIT MNVR EXEC**~~

~~CRT Load TGT data per pad~~
~~LOAD - ITEM 22 EXEC~~
~~TIMER - ITEM 23 EXEC~~
~~✓ Burn data per pad~~
~~C3 ✓ DAP: A/AUTO/VERN~~
~~✓ DAP ROT: DISC/DISC/DISC~~
~~✓ DAP TRANS: As reqd~~
~~CRT MNVR - ITEM 27 EXEC (*)~~

~~TIG -2:00 **~~
~~Perform EXECUTE RCS BURN (Cue Card, RNDZ OPS)~~

Figure 4-5.- ~~Perform NC~~ load TARGET TRACK burn.

farther behind the TGT or just slowly closing. NC is usually done two REV's before Ti to reduce the ΔV (and therefore propellant) required, if time is available.

Depending on the total velocity to burn, the MNVR will be executed using either the RCS or the OMS. The OMS guidance system has been developed such that with 2 seconds remaining in an OPS 202 burn, a countdown mode is entered, and the software no longer iterates on the required remaining ΔV to burn, but rather calculates when to terminate the burn. This can result in substantial burn residuals that the crew needs to trim manually. In addition, the system configuration required for an OMS burn is more complicated than for an RCS burn and is only exercised when the velocity to be burned is large enough to warrant the extra system manipulation. ¶ for C RNDZ, use RCS. If the preflight analysis has shown the burn to require use of the OMS, the procedure will nominally be included in the RNDZ checklist. If in-flight trajectory dispersions result in (a planned/small) NC ~~being performed~~ requiring us~~ing~~ eq the OMS, the crew would use the RNDZ OMS BURN procedures (sec. **3.8.~~4.1~~** 5.2).

For either ~~translational control system~~ RCS or OMS, the initial onboard setup by the crew is the same.

~~Depending on the profile, the crew may cancel the UNIV PTG option in effect (via ITEM 21). This is done to prevent unnecessary attitude maneuvers after the completion of the burn operations. After the NC burn, the crew will need to maneuver the Orbiter to a TGT TRK attitude to support STRK acquisition of the TGT. Canceling the UNIV PTG option ensures that the Orbiter will not begin maneuvering to the pre-NC burn attitude, once the burn is complete and OPS 201 is reentered.~~

The crew transitions the GNC GPC's to OPS 202 for burn execution and enters the burn targeting data per the uplinked pad. The data is loaded and the GNC burn countdown timer is initiated. The onboard calculations for resulting burn duration, apogee, perigee, and attitude are verified by comparison

If the burn is to be +X,

with the uplinked data. The crew verifies that the DAP is configured as required for an attitude maneuver, and then initiates the maneuver via ITEM 27 execution.

The remainder of the burn procedures differ depending on the translational system to be used for the burn.

more often (+X)

RCS NC BURN: At 2 minutes prior to TIG, the crew begins the procedures specified for an RCS burn on the RNDZ OPS cue card (sec. **3.8.5.1**). It should be noted that the cue card procedure was written for an RCS burn which is performed in a random attitude, as is the case for the midcourse correction (MC) burns. Since the NC burn is done in single-axis burn attitude, several of the cue card steps are done early to allow time for the maneuver to attitude, so these steps need not be repeated at TIG-2:00.

OMS NC BURN: See section **3.8.5.2** for rationale.

~~Before returning to OPS 201 and continuing RNDZ operations, the DAP is configured to be under VRCS control so that subsequent attitude maneuvers are not begun by the PRCS.~~

4.1.10 Initiate -Z Target Tracking

see fig 4-6 (move to here)

After the NC burn is complete and the GPC's are back in OPS 201, the crew begins a maneuver to track the TGT with the -Z axis for -Z STRK TGT acquisition or with the -Y STRK, if the -Z STRK is known to be failed. Since NC was performed just prior to orbit noon, lighting conditions after the burn should be favorable for TGT acquisition (fig. 4-1). The maneuver to track attitude is done on PRCS in DAP B to utilize the 0.5 deg/s rate and arrive in track attitude as quickly as possible and begin taking sensor data; return to DAP A VERN when maneuver is completed.

4.1.11 First STRK Acquisition

(See section 3.3.2.1.)

4.1.12 Configure NAV for STRK data

The NAV software is verified to be in proper configuration for processing of STRK data. Initial setup ensures that the source of angle data to be incorporated is the STRK's, the uplinked propagated SV is selected as input to user parameter processor (UPP) while the filtered SV is being sent the initial sensor marks in case of erroneous or large updates, and that the angles are inhibited from AUTO incorporation in order to allow crewmembers to verify proper target lock-on.

4.1.13 STRK NAV Data Acceptance

The SV selection is made when the SV POS update is less than 1.0 K ft. At STRK acquisition ranges it is felt that the Orbiter body pointing vector will be locked on to the TGT within the Orbiter ATT DB at this point. Typical error is about 1000 feet at 30 miles. ~~Disregard SV U/D VEL.~~

The angle residual (RESID) value is a measure of the angular error between the predicted LOS to the target and the detected LOS. A star will have an angular rate of 0.5° per 8-second cycle, which is 10 times the threshold for rejection of marks. If the STRK has locked on to the TGT and Orbiter is in TGT track attitude hold, the RESID value need not be zero, but should remain constant. It is not important that the value of the RESID is less than 0.05, but that it remains at a constant value ± 0.05. A constant RESID value indicates that the predicted state for the target is slightly offset from the actual. Changing values indicate that the STRK has locked onto an object that has an angular rate with respect to the predicted target position, such as a star or debris in the vicinity of the Orbiter. The value of 0.05 was selected as the criteria for determination of lock-on based on estimations of system noise and granularity.

For the usual Orbiter attitude during this phase (nose to Earth), if the STRK locks on to a star, the affected residuals will depend on which STRK is active. For the Z STRK, the H RESID will change, and for the Y STRK, the V RESID will change. Such behavior by the residuals is positive proof that star lock-on has occurred.

If the 0.05 criteria is met for four NAV cycles (four to ensure repeatability) the target lock-on is assumed to be correct, and the software is set to automatically incorporate data marks into the NAV filter that update the Orbiter FLTR SV once the crew selects AUTO.

If the filtered minus-propagated SV changes by more than 40 kft during a single STRK pass, the STRK data is considered bad and has corrupted the filtered state. See section 4.1.15.

4.1.14 SV Selection

In order to have a consistent SV input to UPP during the TGT acquisition, the propagated SV remains selected until the filtered SV "settles down," and no large updates are seen. Once again, analysis has shown that for STRK NAV when the position updates to the SV are less than 1.0 kft, and more than nine marks have been accepted into the filter, the filtered SV has converged to the point where it can be selected as the source of Orbiter SV data in UPP.

The propagated SV will be selected for the UPP until the beginning of the first relative TRK interval. The filtered SV will be selected:

a. If 10 STRK measurements have been accepted with the last SV position update less than 1.0 kft

b. If 10 RR measurements have been accepted with the last SV position update less than 0.3 kft

c. If three COAS measurements have been accepted

Accepting 10 STRK or RR measurements prior to selecting the filtered SV for the UPP prevents filter vector transients from reaching the UPP. Also, if bad measurements are incorporated into the filtered SV (e.g., tracking a star with the STRK, tracking with a side lobe with the RR), this delay allows the crew to take appropriate action to prevent use of the corrupted state. Because COAS processing takes longer, only three marks are taken prior to selecting the filtered state vector. (Ref: Charles Stark Draper Lab Memo 10E-94-07, appendix A; Apr. 19, 1984.) Analysis shows that most pointing error has been removed after nine marks.

4.1.15 Off-Nominal SV

Analysis has shown that the initial SV data should not be in error by more than 40 kft and, therefore, if the updates to the SV exceed 40 kft in a single STRK data pass, lock-on was probably false and the data should be erased (another alternative is an IMU is failing). In this case, the propagated SV is reselected as the source of data to UPP. The sensor data is inhibited from being incorporated into NAV any further, and the filtered SV is overwritten with the unpolluted propagated SV. The STRK is then commanded to break lock with the TGT it has been tracking, and the acquisition process is begun again.

4.1.16 End STRK Pass

(See section 3.3.2.2.)

4.1.17 Perform NH Burn (if Required)

To control the differential altitude between the Orbiter and the TGT on the day of RNDZ, an NH MNVR may be included in the RNDZ sequence (fig. 4-6). Often, the differential altitude between the Orbiter and the TGT has been properly adjusted prior to entering the RNDZ procedures and an NH burn is not required. If, however, the projected Ti relative altitude differs significantly from premission design, the NH burn will be performed. Should an adjustment be required, the rationale and procedures for burn execution are the same as for the NC burn.

In the extremely unlikely event that ΔVT > 6 ft/s, perform NH using the RNDZ OMS BURN cue card. If the ground solution shows >2 ft/sec from the FRCS, a +X RCS burn will be performed.

Done via RCS cue card

```
         OPS 202 PRO
        ┌───────────────────┐
        │ GNC ORBIT MNVR EXEC │
        └───────────────────┘
CRT      Load TGT data per pad
         LOAD - ITEM 22 EXEC
         TIMER - ITEM 23 EXEC
        ✓Burn data per pad

TIG -2:00 **
         Perform EXECUTE RCS BURN (Cue Card, RNDZ OPS)
```

Figure 4-6.- ~~Perform NH~~ burn. Delete

4.1.18 Configure for Radar Target Acquisition

(See section 3.3.4.5)

4.1.19 Target NCC Burn (Preliminary)

The NCC burn (fig. 4-7) is aimed at the Ti point, 48.6 kft behind and 1.2 kft above the target, and in plane. The trailing distance is chosen based on expected trajectory dispersions and RR acquisition limits. The delta height is chosen empirically to reduce MC2 TIG slips and thus maintain manual phase lighting. Being in plane with the target at Ti allows the planar error to be nulled in a propellant-efficient manner.

Establishing a 225° transfer from NCC to Ti was based on several factors. With Lambert targeting, 360° transfers will not control delta altitude or out-of-plane errors, and 180° transfers will not control planar errors. Waiting as long as possible (typically until orbital sunset) allows maximum time for relative NAV to incorporate sensor data. A compromise of 225° was selected because it controls phase, delta altitude, and out-of-plane errors; it is close to orbital sunset to allow sufficient STRK data to be incorporated; and it is large enough to be propellant efficient.

The theoretical basis for out-of-plane control is described in section 2.9.2.

Prior to the beginning of the second STRK data pass, a preliminary calculation of the NCC burn is performed using the onboard Orbiter targeting software. As is the case for the preliminary solution for all the onboard calculated burns, this initial targeting exercise serves two purposes: it gives a very early indication of the onboard estimate of burn ΔV's, and it begins the GNC GPC timer counting down to the burn TIG.

..Final Solution............
. OPS 202 PRO
.✓ENGINE SELECTION CORRECT . ← CRT GNC ORBIT MNVR EXEC
....
CRT ✓SV SEL correct

GNC 34 ORBIT TGT

TGT NO - ITEM 1 +9 EXEC
✓TGT Set data:
T1 TIG = BASE TIME - 0/00:56:18
EL +0
ΔT +56.3
ΔX -48.60
ΔY +0
ΔZ -1.20
COMPUTE T1 - ITEM 27 EXEC

Record ~~Note~~ solution in pad

Final solution

....
. If > 40 marks in current sensor pass and .
. SV UPDATE POS < 0.5, Burn FLTR soln .
. If FLTR within ground solution limits, Burn .
. FLTR soln .
. If PROP within ground solution limits, Burn .
. PROP soln .
. If none of the above, Burn ground soln EXT ΔVs .
....

for the last 4 marks

Figure 4-7.- Target NCC burn.

ΔT value is typical only

Before performing the targeting, the crew verifies that the SV source for the calculations is as expected. Nominally the FLTR SV will be selected, but depending on the circumstances (mainly, sensor failures time history), the PROP SV may still be the prime source of the UPP state data. The crew and ground need to be aware of the source of the burn solution.

The TGT set for the NCC burn is called up by entering the appropriate TGT number, and then the I-loaded data for the TGT set is verified. The TIG displayed in MET is verified to be equal to the base time as loaded earlier (see 4.1.7) plus the relative time stored as part of the TGT set. The elevation (EL) in degrees, the delta time in minutes, and the targeted offset position in k/ft are all verified to be the correct values. The crew then computes (ITEM 27) the burn solution. If any of the data displayed is not as expected, the crew overwrites the affected data entry, loads (ITEM 26) the new value into memory for that TGT set, and recalls that TGT set to confirm the proper data was saved before computing a solution. This is done because the burn calculation is based on the data stored in memory for the displayed TGT set, not on the displayed data itself. For informational purposes the crew notes the burn solution in their checklist.

Because the REL NAV systems of the Orbiter can provide the most accurate and current states for the Orbiter and TGT, orbit targeting (SPEC 34) is utilized to compute MNVR's on the day of RNDZ, beginning with the first MNVR (NCC). Orbit targeting is designed to schedule MNVR's relative to a specified base time. By doing so, the entire maneuver plan can be shifted in time by updating just one I-load rather than every MNVR target set. Typically, the initial base time is set to Ti TIG near orbital noon. Since orbit targeting has no lighting software and the GRID/SPOC computer currently cannot support this computation, the ground will provide the initial base time.

4.1.20 Second Star Tracker Target Acquisition

The procedures used in the first STRK acquisition (sec. 3.3.2.1) are slightly different from all subsequent acquisitions due to the fact that the first acquisition had no history of sensor data taking. In the initial acquisition, the covariance matrix was configured with wide data acceptance criteria and the propagated and filtered SV's were identical. In subsequent acquisitions, the covariance and the filtered SV have been updated based on sensor data. Analysis of valid TGT lock-ons can therefore utilize more sources of data to determine accurate and valid TGT acquisition. Special procedures are also needed if the -Y STRK is being used. Note also that on entering this box, the SV SEL (ITEM 4) is now FLTR, not PROP, so that check statement (fig. 3-13) is eliminated.

The STRK procedures in sections 4.1.20, 4.1.21, and 4.1.22 are essentially identical to the STRK procedures for RR fail post-Ti, as described in section 4.4.2.

4,1.21 STRK Configuration

All of the configuration setups are the same as for the first STRK pass (sec. 3.3.2.1).

4.1.22 REL NAV Management

Because the filtered SV now has some incorporated sensor data, the filtered SV and the propagated SV now differ and the covariance has been shaped based on the data acquired. The procedures for acceptance of subsequent sensor data utilize these differences in the determination of valid lock-on condition.

If the RESID values pass the 0.05 test as in the first acquisition, the data is not immediately assumed to be valid as in the first acquisition. If the RATIO is confirmed to be less than 1.0, the data being accumulated by the sensor is within error boundaries as defined by the covariance and is assumed good. The FLTR SV which was used as the initial estimate for TGT lock-on has been proven to be correct since a valid lock-on occurred (see section 3.4.2.2) and it is then "saved" away in the PROP SV location (via a "FLTR TO PROP - ITEM 8 EXEC" line). This is done to provide a proven backup SV should the subsequent sensor data corrupt the FLTR SV. After the SV transfer, the NAV filter is configured to automatically accept STRK angle measurements.

If, however, the RATIO value is greater than 1.0, the crew now has several actions to take. The first assumes that the covariance has inappropriately tightened its data acceptance criteria thereby causing the data to result in a RATIO greater than 1.0. By reinitializing the covariance to the last uplinked values (usually those sent for the beginning of the RNDZ), the acceptance criteria is opened up. This is done via a "COVAR REINIT - ITEM 16 EXEC" line.

At this point, the crew begins their data analysis again by verifying RESID V and H VALUES, as well as rechecking the RATIO to verify it as now less then 1.0. If it is, they perform a FLTR TO PROP transfer and begin AUTO data collection as is called out in the first part of the "If" statement. If not, perform the "problems" steps specified in section 3.4.1.~~7~~ 4.1 (on the checklist this will now be items 2 and 3, "FORCE 3 Angle Marks" and "PROP TO FLTR - ITEM 9 EXEC").

4.1.23 State Vector Management

(See section 4.1.15)

4.1.24 Target NCC Burn (Intermediate)

After approximately 70 data marks (about 10 minutes, when SV updates are small and stable) of STRK data, the NAV filter should "settle down" and the subsequent updates to the FLTR SV should be small. At this point, the crew calculates an intermediate solution for the NCC burn to get an early indication of the impact the new STRK data is having on the FLTR SV, and therefore on the burn solution. To calculate a valid burn solution, the crew must first recall the TGT set, even though the TGT set data still appears on the screen from the preliminary targeting. If a burn solution is requested and the displayed relative state values (ITEM's 6 to 12) are non-zero, orbit-targeting software will calculate a new solution, but will assume that the displayed relative state values currently in memory are still correct. Recalling the TGT set blanks out the previous values so that a new solution for the burn is computed.

If at this time the total ΔV to be burned appears to be approaching or greater than 6 ft/s, the crew should perform another burn calculation early enough to support a maneuver-to-burn attitude and OMS system configuring. If the crew waited until TIG-4:00 to do their final burn solution as in the standard timeline, it would be too late to maneuver to attitude and still get NCC performed in time.

4.1.25 End STRK NAV

(See section 3.3.2.2)

4.1.26 Target NCC Burn (Final)

At 4 minutes prior to TIG, the final solution for the NCC burn is calculated (fig. 4-7). If the total ΔV to be burned was estimated at greater than 6 ft/s during the intermediate solution, the final burn calculation should be accomplished earlier (approximately TIG -10:00) in order to allow time enough to maneuver to OMS burn attitude.

Before executing the final onboard calculation, the crew transitions the GPC's to OPS 202. This halts data collection and ensures that the SV used for calculating the final burn solution will not be updating from the time the final solution is calculated until the burn is executed. This is important for the NCC and Ti burns because ΔV comparison is part of the decision process that the crew goes through in determining whether or not to burn the onboard solution. Remember that even though the software is configured for AUTO (ITEMS 17, 20, or 23) in OPS 202, sensor data is not incorporated into the FLTR SV unless an ITEM 3 (MEAS ENA) has been executed. The ITEM 3 is only valid in 202; it is an ILL ENTRY in 201.

The crew recalls the TGT set and calculates the final burn solution. At this point the crew has several independent NCC burn solutions and must decide which solution is the best to execute.

Note that all onboard MNVR's will be targeted at least twice: once soon after the previous maneuver, then again shortly before TIG (as late in the NAV pass as possible).

The intent in choosing 4 minutes before TIG (as opposed to 6, 8, or 10 minutes) as the time to do the final targeting solution was to have a time as close as possible to the burn (more sensor marks are taken to improve the state), but far enough away so that the crew doesn't have to rush to get the burn off.

Note that verification of RCS engine selection should have been done prior to entering this box (i.e., before leaving MM 202 after the last burn). If ORB TGT'ing has already been executed, a change on the left side of ORB MNVR EXEC causes a Lambert burn to downmode to external ΔV. If this occurs, the crew can recall and recompute the TGT set on ORB TGT'ing. If not, the crew can proceed with the axis-by-axis burn with any engine selected. In that case, since the VGO's will be correct and that's all the crew is "flying to," the only real difference is that for an OMS selection the EXEC will flash (it can be ignored) and the TGO and burn attitude will be wrong (they should be be ignored also).

4.1.27 Solution Selection

The hierarchy of priority for burn solutions has the FLTR SV solution as the most desirable source of burn calculation, followed by the onboard PROP SV solution and the ground calculated burn delta velocities. If the onboard FLTR SV has had greater than 40 STRK data marks incorporated during the pass just completed, and if the updates to SV position are less than 0.5 kft for the last 4 marks, the FLTR SV has operationally converged and is the best source of relative state data, so it is therefore used for the NCC burn execution. After 40 STRK marks, the major transients in SV convergence are over and the filtered result is more accurate than the SV used for TGT acquisition. During the first 40 marks, filter performance can actually result in SV divergence leading to degraded burn solutions. The marks are specified to have occurred during the sensor pass just completed, rather than the earlier STRK pass to ensure that the data is current, and to serve as a rough order of magnitude data validation.

Note: Four consecutive marks with SV position errors less than 0.5 kft was added to this criterion to eliminate transient effects and to ensure the filter state was stable. (Ref: Charles Stark Draper Lab Memo 10E-84-03, STS-13 Rendezvous Nav Study)

Obtaining and incorporating COAS NAV marks is a time consuming manual task. Forty marks in a single COAS pass is unrealistic. Furthermore, statistical studies show that after the first few COAS marks, updates to the filtered state are somewhat random and do not significantly contribute to the improvement of the relative state. Therefore, since the COAS can never meet this criterion of sufficient NAV data, this rule does not apply to it.

If these criteria are not met, the burn solution based on the FLTR SV is compared with the ground computed ΔV's. If FLTR SV and ground solutions agree on an axis-by-axis basis to within ± the LIMITS values given in the NCC BURN SOLUTION pad, the burn is executed using the FLTR SV calculations. These limits are the root-sum-squared differences of the premission-calculated 3-sigma values for the ground and onboard NCC burn ΔV's solutions.

The onboard filtered solution, even without sufficient relative NAV data, will be as good or better than the propagated or ground solutions because it may have some REL NAV data incorporated plus any IMU sensed ΔV's since the ground initialization SV. Agreement with the ground solution serves as a gross quality check for the onboard solution and, therefore, only needs to fall within the 3-sigma comparison limits.

Next in priority for usage is the onboard PROP SV solution. If the FLTR SV solution passes neither of the above criteria, the PROP SV solution is compared to the ground solution and is executed if it agrees within the limits.

The onboard propagated solution will be better than the ground solution because it has been computed on either the ground initialization state vector plus any IMU sensed ΔV's, or a filtered SV containing REL NAV data from a previous sensor pass that had been saved via a FLTR to PROP transfer. Agreement with the ground solution serves as a gross quality check for the onboard solution and, therefore, only needs to fall within the 3-sigma comparison limits.

As a last resort, if none of the above criteria are met, the crew manually loads and executes the ground solution for the NCC ΔV's.

Perform

4.1.28 ~~Execute~~ NCC Burn

perform

Unless the NCC burn velocity has increased to the point where an OMS burn is required, the crew ~~executes~~ the burn using the PRCS and trimming out the required ΔV's while staying in the TGT TRK attitude. The detailed procedures for burn execution are included on the "~~Execute~~ RCS Burn" cue card (see sec. 4.3.1).
[illegible]

4.1.29 Maneuver To -Z Track Attitude From -Y STRK (Off-Nominal)

If the -Y STRK has been in use for TGT data taking, the Orbiter will be in TGT track attitude with the -Y STRK pointing at the TGT. Since the next sensor to acquire the TGT in the profile sequence is the RR, and since its boresight axis is along the -Z axis, the Orbiter will need to be maneuvered to a -Z axis TGT tracking attitude. Although use of the -Y STRK was terminated earlier, the maneuver is not initiated until the NCC burn execution is complete to avoid complication during the burn (the burn normally occurs just after sunset).

4.1.30 Perform Radar Lock-on

During the radar acquisition (fig. 4-8), the Orbiter attitude is such that the -Z body axis is pointing at the estimated TGT position. Since the RR system boresight (AZ = EL = 0) is fairly closely aligned with the Orbiter -Z, the RR AZ and EL angles should be nearly zero if the main beam has acquired the desired TGT. If this is not the case, the RR may have acquired via one of the beam side lobes, and the crew should break track and allow the system to reacquire. If no lock-on has occurred by R = 60 kft, the crew performs the RR AUTO TRACK ACQ ~~cue card~~ (sec. 4.3.2).
procedure

4.1.31 Initiate RR NAV

After the RR hardware has indicated a TGT lock-on, the compatibility of the data with the NAV state is confirmed by monitoring the RATIO. Unlike with the STRK, in a typical RNDZ environment, it is highly improbable that the RR could be locked on to anything other than the desired RNDZ TGT. Therefore, it is not a question of determining a valid acquisition, but rather of data compatibility. See figure 4-8.

```
RR NAVIGATION

        GNC 33 REL NAV

CRT     RR - ITEM 13 EXEC (*)
       ✓Elev, Az approx 0

   ..............If RATIO > 1.0.........................
   .                                                   .
   .    If no previous S TRK,                          .
   .    |   FORCE 3 marks                  ✓           .
   .    |     If RATIO still > 1.0, ~~Call~~ MCC          .
   .    |                                              .
   .    If previous S TRK,                             .
   .        COVAR REINIT - ITEM 16 EXEC                .
   .          If RATIO still > 1.0 and NCC burned      .
   .          | on FLTR vector,                        .
   .          | FLTR TO PROP - ITEM 8 EXEC, then       .
   .          |    FORCE 3 marks                       .
   .          |  If RATIO still > 1.0,                 .
   .          |     PROP TO FLTR - ITEM 9 EXEC         .
   .          |   ✓~~Contact~~ MCC when time permits       .
   .          |     ~~Meantime,~~ proceed as if RR failed. >> .
   .                                                   .
   .          If RATIO still > 1.0 and NCC not         .
   .            burned on FLTR vector,                 .
   .            PROP TO FLTR - ITEM 9 EXEC             .
   .            If RATIO still > 1.0,                  .
   .               FORCE 3 marks            ✓          .
   .               If RATIO still > 1.0, ~~Call~~ MCC >>  .
   .....................................................
        Record Init Range Resid ______
        When RATIO < 1.0 for four NAV cycles (~31 sec).
        FLTR TO PROP - ITEM 8  EXEC
        AUTO RNG     - ITEM 17 EXEC
             RDOT    - ITEM 20 EXEC
            Angles   - ITEM 23 EXEC
        Record 1st POS update ______
             ..........If SV SEL = PROP...........
             .                                   .
             .   When SV UPDATE POS < 0.3        .
             .     and MARK ACPT > 9,            .
             .   SV SEL - ITEM 4 EXEC (FLTR)     .
             .....................................
```

Figure 4-8.- RR navigation.

If the RATIO is less than 1.0 for range, range rate, and angles, the crew saves the FLTR vector used for acquisition by copying it to the PROP location before beginning to accept RR data into the NAV filter (see 3.4.2.2). Unlike with the optical devices, radar provides range and range rate information as well as angles, and each of these parameters must be individually accepted into the SV processing. At this point, if the PROP SV is still selected as input to UPP, the crew monitors FLTR SV convergence and selects it for UPP usage when greater than nine marks in each of range, range rate, and angle are collected, and the SV position updates are down to less than 0.3 kft.

Several consecutive measurement cycles allow transients to settle and the crew to assess the quality of the data. Stable measurements are an indirect indication that the radar sensor is locked onto the TGT with the main lobe instead of a side lobe. Residual ratios less than one indicate that the measurements, if accepted by selecting AUTO, will not be edited by the NAV filter.

Recall that in the condition where RATIO > 1.0, performance of the specified steps is continued until the condition fails, then return to top of the conditional statement, where RATIO < 1.0 is performed and procedure is continued. Do <u>not</u> perform <u>all</u> the steps by rote, but exit as soon as one of the steps has forced RATIO $\leq$ 1. See next section.

4.1.32 <u>Off-Nominal RR NAV</u>

If the RATIO happens to be greater than 1.0, there are two cases to consider. In the first, there has been a valid STRK acquisition previously in the RNDZ, and in the second, the RR data is the first onboard sensor data to be acquired.

If previous STRK data has been incorporated into the FLTR, the high RATIO value may be the result of the covariance having converged too tightly; therefore, the first crew action is to do a COVAR REINIT. If the RATIO is still too high, the crew questions the validity of the FLTR SV by looking at the past usage of that state. If the NCC burn was performed using ΔV's calculated using the FLTR SV (see 4.1.27), the SV is assumed good. The FLTR SV is copied into the PROP SV, and three marks are forced into whichever parameter(s) has the high RATIO value. If the RATIO remains above 1.0 for any of the three radar parameters or if the FLTR SV was not used for NCC, the FLTR SV is overwritten with the PROP SV and acquisition is attempted again.

With no previous STRK data in the FLTR SV, the covariance is already open and the FLTR and PROP SV's are the same. Therefore, the only alternative to try to bring down the RATIO is to force three data points into the NAV filter.

The above discussions for RATIO greater than 1.0 apply easily when all three radar parameters have high RATIO values. If one or two parameters only are above the 1.0 limit, the related crew action is based on the overall complexion of the RNDZ. Have there been radar hardware problems/glitches? Was there a lot of noise in the STRK data? Are the RATIO's for two of the parameters near zero while one parameter fluctuates?

For example, if two parameters have near zero RATIO's while one parameter has greater than 1.0, it may be prudent to do a FLTR TO PROP transfer and configure the two "good" parameters to AUTO incorporation into NAV and see if their impact on the FLTR SV causes the ratio of the third parameter to drop below 1.0. For noisy data that sometimes has RATIO values greater than 1.0, that procedure may also be advisable, although on MCC call it may be possible to put all three parameters into AUTO and allow the NAV software to reject the out-of-limit data takes while filtering the remainder of the data. The Kalman filter and the sizing of the covariance should keep damaging data out of the FLTR SV. These conditions have never been observed in flight.

4.1.33 Target Ti Burn (Preliminary)

A preliminary solution for the Ti burn is calculated (fig. 4-9). The Ti TGT set is I-loaded as TGT set no. 10. Since the Ti TIG was selected as the reference time for orbit targeting, the T1 TIG time displayed should equal base time. The transfer time is equal to 320° of orbital travel and the ~~target~~ aim point is a ~~TGT~~ target intercept.

```
           GNC 34 ORBIT TGT

CRT        TGT NO - ITEM 1 +1 0 EXEC
          ✓TGT Set data:
             T1 TIG = BASE TIME
             EL       +0
             ΔT       +80.1
             ΔX       +0
             ΔY       +0
             ΔZ       +0
           COMPUTE T1 - ITEM 27 EXEC

           Note solution in pad.
```

Figure 4-9.- Target Ti burn.

Ti TIG is chosen so that MC4 occurs 3 minutes after orbital sunrise. Typically, this equates to 3 minutes prior to orbital noon for Ti TIG.

The 320° transfer to intercept is a byproduct of placing orbital sunrise 3 minutes prior to MC4, protecting an STRK pass post-Ti, and requiring zero inertial line-of-sight rates at manual control initiation.

By performing Ti above the V-BAR, MC2 time slips are decreased because the expected dispersion ellipse begins to line up, or "point," to the TGT.

Ti is targeted to intercept, rather than any offset point (e.g., 1000 ft down the TGT V-BAR), because this allows the selection of a trajectory which has the crucial quality of near constant inertial LOS rates to TGT for terminal phase. This characteristic provides a "fly-to" target (especially for radar fail) and this is deemed a mandatory piloting aid.

The ground solution limits referred to in the Ti BURN PAD are the RSS of the preflight predicted ground solution errors and the predicted 3-sigma onboard solution errors, and represent the maximum expected difference between the final onboard solution and the in-flight ground solution. If, for some reason, the onboard solution is suspect, the limits will be used to evaluate the agreement between solutions.

4.1.34 Target Ti Burn (Intermediate)

After the NAV filter has converged (>40 marks accepted and SV position updates <500 ft), an intermediate solution for Ti is calculated. Remember that the target set must be recalled in order to get a valid burn solution. As with earlier burns, if the total ΔV to be burned is large enough, the crew may be instructed to execute the Ti burn using the OMS. Additionally, if the burn is less than 4 ft/s, the crew may be instructed to perform the burn by burning out the velocities axis by axis while maintaining the TGT TRK attitude. The 4-ft/s value was selected to minimize the amount of forward reaction control system (FRCS) propellant used. As a groundrule, if performing a burn axis by axis will result in greater than 2 ft/s being burned out of the FRCS, the burn should be replanned to be a +X RCS burn. Due to the Orbiter attitude at Ti, and based on the nominal burn ΔV's, a multiaxis Ti execution can be estimated to be 50 percent FRCS and 50 percent ARCS. A 4-ft/s burn, therefore, would probably result in a 2-ft/s FRCS usage and is the upper limit for multiaxis execution.

4.1.35 Perform RR Auto Track Acquisition (Off-Nominal)

If the RR has not acquired the TGT by the time the range to the TGT has decreased to less than 60 kft, the crew attempts an acquisition using the AUTO track mode of RR operation. At approximately 60 kft, the probability of acquiring a TGT with a 0.5-square-meter radar cross section approaches 100 percent. The detailed AUTO track acquisition procedure~~s are on the RNDZ OPS cue card and are~~ is explained in sections 3.3.4.6 and 4.3.2.

4.1.36 Target Ti Burn (Final)

Before targeting the final solution for the Ti burn, the crew transitions the GNC GPC's to OPS 202. As for the NCC burn, this is done to terminate sensor data processing into the FLTR SV so that burn solution comparisons are done based on nonchanging state data. If the Ti burn is to be executed using the OMS or the +X PRCS, the proper engine selection needs to be made on the MNVR EXEC display as well as the desired thrust vector roll (TVR) angle, Orbiter weight, and the engine gimbal trim angles. After being correctly loaded into the display, the data is then loaded (ITEM 22) into software in order to put the data onto the downlist for MCC visibility. On the REL NAV display the crew verifies that the source of SV data is correctly configured and then (if burn is +X) inhibits the incorporation of angle data into the NAV state. Since the GNC GPC's are already in OPS 202, this has no immediate effect. The inhibit is done to preclude the acceptance of inaccurate RR angle data into the filter immediately after the Ti burn is complete and the crew transitions back into OPS 201. The data would be inaccurate because the Orbiter will be maneuvered out of -Z axis TGT tracking attitude for the burn and RR gimbal angle measurement accuracies decrease as the antenna is pointed away from its -Z boresight.

The RENDEZVOUS ~~OMS/RC~~S PRPLT PAD should be checked at this point (sec. 4.3.4) and then periodically afterwards for the remainder of the rendezvous operations.

4.1.37 Solution Selection

The same rationale as in 4.1.27 (NCC) is used for this burn. The values of the comparison LIMITS are different since trajectory dispersions at Ti differ from those that can be expected at NCC.

4.1.38 Perform ~~Execute~~ Ti Burn

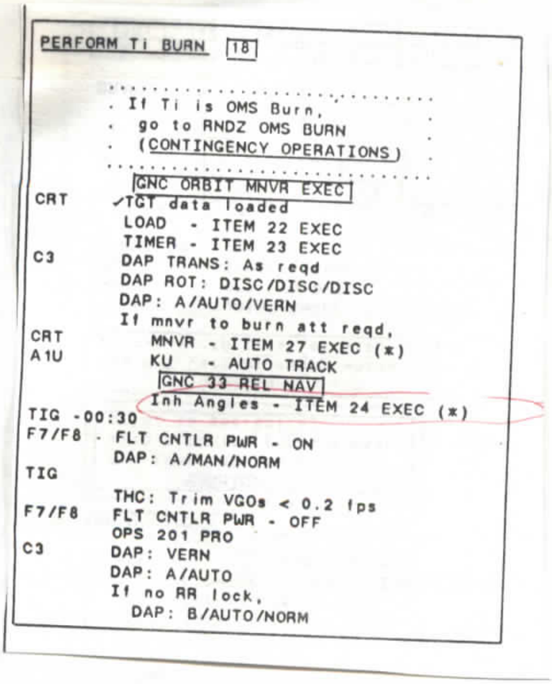
The FDF block for this action is shown in figure 4-10. This is a mission-critical burn which sets up an intercept with the target. It is generally posigrade with some radial component. It is very time critical and cannot be slipped more than a few minutes.

OR just RCS burn →

Due to possible vehicle blockage of radar LOS to TGT, the Ku-band pointing mode is set to prevent the antenna from thrashing around in case of loss of track. If the burn is performed in LOMS (as is usual), vehicle angles should allow RR track to be maintained. Burns in ROMS, both OMS's, or +X RCS can result in RR break track. In that case, DAP B is used to get back to track attitude ASAP.

4.1.39 Ti As Multiaxis RCS Burn

See section 3.6.3 for discussion of this variation. A major driver for this decision may be a requirement for as much target tracking as possible. Propellant savings may also be a consideration.



```
PERFORM Ti BURN  [18]

           ...................................
           . If Ti is OMS Burn,              .
           .   go to RNDZ OMS BURN           .
           .   (CONTINGENCY OPERATIONS)      .
           ...................................
              [GNC ORBIT MNVR EXEC]
CRT        ✓TGT data loaded
             LOAD  - ITEM 22 EXEC
             TIMER - ITEM 23 EXEC
C3           DAP TRANS: As reqd
             DAP ROT: DISC/DISC/DISC
             DAP: A/AUTO/VERN
             If mnvr to burn att reqd,
CRT             MNVR - ITEM 27 EXEC (*)
A1U             KU   - AUTO TRACK
                 [GNC 33 REL NAV]
                Inh Angles - ITEM 24 EXEC (*)
TIG -00:30
F7/F8 .    FLT CNTLR PWR - ON
           DAP: A/MAN/NORM
TIG

           THC: Trim VGOs < 0.2 fps
F7/F8      FLT CNTLR PWR - OFF
           OPS 201 PRO
C3         DAP: VERN
           DAP: A/AUTO
           If no RR lock,
             DAP: B/AUTO/NORM
```

4.1.40 Load/Execute Delay Burn (Off-Nominal)

Should a situation arise prior to execution of the Ti burn that requires a delay in the completion of the RNDZ, performing the RNDZ DELAY burn places the Orbiter in a safe trajectory relative to the TGT. This allows the crew and ground to assess the status of the problem and decide whether or not to continue with the RNDZ. See figure 4-11. Skip to section 4.1.47 for subsequent crew activity.

For short delays (one or two REV's), the ground will compute a phasing MNVR to return to the Ti position based on the most current onboard relative state, and will voice the MNVR target sets to the crew during the RNDZ sequence (see sec. 3.6.1.3). Desirable lighting conditions will be maintained as long as there is an integral number of REV's between the original and new Ti MNVR's. The crew has expressed an interest in remaining at least 6 n. mi. from the target when Ti is positioned at 8 n. mi.; the ground can easily accommodate this desire. Typically, a short delay will always be executed prior to a long delay.

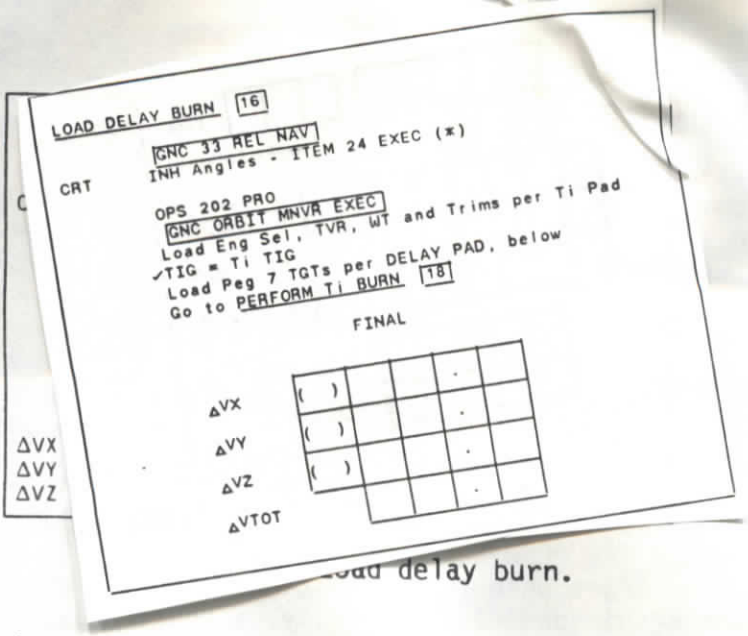
A long delay (greater than two REV's) requires an opening rate to eliminate the need for the crew to continuously monitor the target. Long delays usually involve at least one crew sleep cycle. A 1-n. mi./orbit opening rate corresponds to a 0.3-ft/s MNVR assuming the current closing rate has been nulled. Typically, if propellant is available, the delay MNVR would be targeted to the point where the final phasing MNVR was executed (≈40 n. mi. trailing); this corresponds to an opening rate of 2.7 n. mi. per REV. Doing a larger than 1-n. mi./orbit opening rate MNVR reduces the probability of waking the crew to execute an additional opening rate MNVR. Also, the second RNDZ trajectory would be similar to the original trajectory.

Unfortunately, there is a propellant penalty for executing a Ti delay (see table 4-1). The magnitude of this penalty is dependent on the specific delay scenario. The table assumes a one-REV return to Ti.

TABLE 4-1.- PROPELLANT PENALTY

Scenario	Approximate penalty
1 or 2-REV delay	6 ft/s
24-hour delay Minimum phasing (23 n. mi.)	11 ft/s
24-hour delay Nominal phasing (40 n. mi.)	25 ft/s

In a loss of COMM case, the crew can target a rough Ti delay burn by targeting the T2 burn after NCC; this is supposed to be a burn which nulls Orbiter motion with respect to the TGT at Ti. This is not a verified procedure.



LOAD DELAY BURN 16

CRT

GNC 33 REL NAV
INH Angles - ITEM 24 EXEC (*)

OPS 202 PRO
GNC ORBIT MNVR EXEC
Load Eng Sel, TVR, WT and Trims per Ti Pad
✓TIG = Ti TIG
Load Peg 7 TGTs per DELAY PAD, below
Go to PERFORM Ti BURN 18

FINAL

ΔVX	( )			.	
ΔVY	( )			.	
ΔVZ	( )			.	
ΔVTOT				.	

oad delay burn.

4.1.41 RMS Operations

As discussed in section 3.3.5.5, the RMS wrist CCTV camera is a critical, close-in PROX OPS sensor. Also, problems with the RMS will impact plans for final approach (sec.3.9.2). ¶The RMS cannot be deployed pre-Ti. This is because it could be an OMS burn and there would be too much stress on the brakes. RMS POWERUP and RMS MNVR TO POISE FOR PROX OPS follow Ti.

4.1.42 Target MC1 Burn (Preliminary)

The midcourse burns are targeted to intercept. Their BURN PADS are described in section 3.6.1.4 and they are burned axis by axis (sec. 3.6.3). The targeting terminology is:

T1 TIG = BASETIME +__/__:__:__

MC1 (target set no.11) occurs about 8 minutes before sunset. Waiting until then allows most of the post-Ti REL NAV data to be incorporated into the MC1 computation while still being executed early enough to be propellant efficient. Also, orbital sunset minus 8 minutes leaves enough time between MC1 and MC2 for the manual out-of-plane (OOP) null.

Note: The MC burns may be done even with the tail-only RCS option, since tail-only mode is ignored by translations, so axis-by-axis translations can be done. If the intention is to make sure that all of the propellant comes out the aft RCS, however, the Orbiter must maneuver to +X burn attitude. This is not recommended for use.

Onboard solutions will be selected for all midcourse correction MNVR's. This is because the ground has no capability to improve the relative state information between the Orbiter and target for the midcourse correction MNVR computations. This is due to ground tracking uncertainties and the relatively close proximity of the two vehicles. Hence, the Orbiter solution for these MNVR's will always be selected.

In general, midcourse correction MNVR's, except MC2, will not be executed unless additional target sensor data has been obtained since the previous MNVR. This logic is subject to further analysis.

The rationale for this is as follows: Midcourse correction MNVR's are designed to correct the Orbiter intercept trajectory based on the most current relative state information. Since no additional relative state information is available, these MNVR's will only correct for trim errors or attitude maneuver effects. However, the onboard navigated state used to compute the MNVR could be in error by an amount as large as the computed MNVR. Hence, there is no real benefit to executing these MNVR's and they can be deleted to save propellant.

MC2 (sec. 4.1.51) is currently an exception to this rule. It is executed on an elevation angle to ensure the manual control trajectory is "standard." Also, MC2 must be targeted at least once so orbit targeting can automatically redefine its base time (MC2 TIG) for the MC3 and MC4 computations. Otherwise, the ground would have to supply the new base time and the crew would have to manually load it.

4.1.43 ~~Verify Target Track~~ Post-Ti NAV

fig 4-11B
POST-Ti NAV
block

Before trying to configure for TGT acquisition, the crew verifies that the Orbiter is in proper TGT TRK attitude, usually -Z towards the TGT, and that the DAP is properly configured. The Ku system is placed back into its GPC mode so if a break-lock occurs on the TGT, the software will use GPC-supplied angle designates to automatically command a search pattern to reacquire the TGT.

Even though STRK angles are more accurate than radar angles, STRK marks are not preferred past Ti. The STRK's can define angles to a greater accuracy than the radar, but the accuracy decreases as the distance to the TGT decreases because the TGT is no longer a point source, and also because the angle data is not converted to the Orbiter c.g. frame. From Ti on in, the sensors are roughly equivalent, but the radar is more convenient to use. Also, of course, STRK is lighting-dependent, and optical tracking may be affected by target geometry and orientation.

If at this point it is known that the RR is inoperable, the crew attempts to use the STRK or COAS to collect REL NAV data on the TGT.

4.1.44 STRK Target Acquisition Post-Ti With Confirmed Radar System Failure

In the event of RR failure post-Ti, the crew is directed to a contingency block titled "STRK TARGET ACQ - RR FAIL." This contingency is described in detail in section 4.4.2, and is summarized as follows:

The hierarchy of sensor desirability is based on the accuracy of the resulting SV. The crew first attempts to perform a -Z STRK acquisition. This gives high accuracy while maintaining the -Z track attitude. This attitude allows the crew to monitor the TGT in the COAS, and also eliminates the need for another attitude maneuver later in the profile to prepare for manual phase. Should the -Z STRK not be operable, however, the procedures call for the crew to give up TGT viewing and attitude continuity by attempting to acquire the TGT in the -Y STRK (as long as there is sufficient time to get to attitude before sunset). The -Z COAS is used only if no other sensors are functioning because the COAS data is less accurate than that of the STRK's, and because COAS data taking is a manual pointing operation resulting in higher fuel usage and fewer data points.

An IMU is deselected to stop IMU RM from changing the reference IMU during data taking (see sec. **3.9.4**), and the DAP is verified to be configured for a 1° attitude deadband (DAP select A) and on the vernier control jets.

With the Orbiter operating on a 1° ATT DB and in a -Z target track attitude, the TGT should be within approximately 1° of the COAS centerline, assuming that the COAS misalignment with the body -Z axis is small. If the TGT is off COAS center by greater than 1°, it may be due to TGT SV inaccuracies in calculating the pointing direction toward the TGT. In this case, if the -Z STRK has not already acquired the TGT, it may be necessary to use the COAS to update the SV so that STRK has an initial pointing designate accurate enough to support TGT acquisition. With a valid -Z STRK acquisition the COAS data is not required. If COAS data is required, the crew takes marks on the TGT and incorporates data into the SV until the angular RESID's are less than 0.5°. At this point the SV pointing designate information should be accurate enough for the STRK to acquire the TGT in the 1° offset scan mode. The crew should then attempt to perform an STRK TGT acquisition instead of continuing to use up time and propellant pursuing further COAS data takes.

The following is a desperate last-ditch measure.

If only the -Y STRK is functional at this point (i.e., if the RR and the -Z STRK are known to be hard-fail permanently), the crew begins a rapid attitude maneuver to point the -Y STRK boresite at the predicted TGT position. For the maneuver, DAP select B and the primary RCS (NORM) are used to implement a rotational rate of 0.5 deg/s. After the maneuver is completed (approximately 3 minutes, unless the faster DAP B is selected), attitude control is reconfigured back to the vernier RCS to take advantage of the smaller ATT DB and vehicle rates possible when using these jets.

System configuration and data acceptance criteria are the same as for previous STRK data passes.

If after 5 minutes of attempted TGT acquisition the STRK still cannot lock on to the TGT, the crew is instructed to return to -Z target track attitude, if not already there, and begin taking COAS NAV marks. Five minutes allows the STRK to perform several 60-second field-of-view searches. With the short amount of time available for gathering optical data on the TGT, and with the upcoming trajectory correction maneuvers, it is important for the crew to take COAS marks often and for as long as possible to provide the best possible SV data. The best procedure is to take five marks early in the pass and five marks late in the pass, and to take advantage of changing relative geometry.

4.1.45 SV Management

If valid RR track is established, the crew performs a FLTR TO PROP transfer to save the pre-Ti data (sec. 3.4.2.2), and then configures the RR angles back to the AUTO incorporation mode.

4.1.46 Off-Nominal Radar OPS

If the RR has not yet attained a TGT lock-on, but is not known to be failed, the crew attempts to acquire a lock-on by utilizing the AUTO TRACK mode of operation (see "cue cards" in sec. 3.3.4.6). If there is still no acquisition, the crew assumes that the Orbiter-to-TGT range may be the reason. The Orbiter is maintained in the -Z-to-TGT attitude in hopes that the RR will lock on as the Orbiter approaches the TGT. The crew inhibits range, range rate, and angle data acceptance into the NAV filter. If the -Z STRK is functioning, the crew performs an STRK acquisition. Otherwise they perform COAS data takes. If at any time during the STRK or COAS data taking should the RR acquire the TGT, the NAV inputs are reconfigured to use the RR data because of the increased SV accuracy obtained through the use of range and range rate data.

4.1.47 If Delay Burn Was Performed (Off-Nominal)

If Ti Delay has been performed, a number of activities will occupy this extra 90 minutes.

First, retargeting Ti with the new base time received from the MCC will restart the counter. As a first approximation, add 90 minutes to the old base time.

Second, since the TIG is near orbital noon, an STRK pass can begin soon afterwards. Take STRK marks until near sunset; continue to take RR marks.

Essentially, the checklist is reentered at Ti TIG -1:30 (without doing NCC again!). Another STRK pass is performed (see sec. 4.1.20), and Ti is approached again. If there is good RR tracking, the MCC may advise the crew to not perform the STRK pass.

4.1.48 Target MC1 Burn (Intermediate/Final)

With the advantage of an SV improved by post-Ti tracking, the MC1 burn is targeted twice more.

4.1.49 Perform ~~Execute~~ MC1 Burn

Except in highly unusual circumstances (e.g., badly executed Ti burn), this will be a small axis-by-axis RCS burn. It is possible that the burn TGT's will be less than the desired trim limits; in that case there is no need to execute the burn.

An explanation of the direction of midcourse burns is found in section 2.8.7.

4.1.50 End STRK Navigation for Post-Ti Data Pass (Off-Nominal)

This procedure is utilized if the STRK is used to gather target data post-Ti due to a failed RR, or if STRK angle data is desired over RR data.

At sunset, the angle input to NAV is inhibited so that erroneous STRK data is not incorporated should the STRK lock onto another light source. Since the only possible sensor data for the remainder of the RNDZ is radar data, the software is set up to accept RR angles should they become available.

The STRK's are placed in their TERM/IDLE mode and the shutter doors are confirmed to not be latched open.

At the end of each STRK pass, the IMU's are reselected to configure back to the three-LRU level.

If radar data becomes available as the Orbiter closes on the TGT, the crew is instructed to monitor and accept the data, using criteria laid out in the RR NAVIGATION block (see 4.1.30, 4.1.31, 4.1.32).

Mention
ST →
Maning
if RR?

4.1.51 Target MC2 (Preliminary/Intermediate)

The second midcourse burn differs from others in that the TIG is tied to an Orbiter-target LOS elevation angle rather than a preset clock time. The preliminary targeting block is shown in figure 4-12.

CRT	✓	SV SEL correct
		GNC 34 ORBIT TGT
		TGT NO - ITEM 1 + 1 2 EXEC
	✓	TGT Set data: T1 TIG = BASE TIME +0/00:47:00 EL +26.6 ΔT +33.1 ΔX +0 ΔY +0 ΔZ +0
		Note Nominal T1 TIG in pad
		COMPUTE T1 - ITEM 27 EXEC
		Note solution in pad and inform MCC

Figure 4-12.- Target MC2 (preliminary solution).

The use of an elevation angle as a cue for MNVR execute forces a standardized final approach profile to the TGT and maintains lighting conditions. Such a profile has a known LOS rate regardless of the range dispersions prior to MC2. It involves essentially zero inertial line-of-sight rates during the crucial final minutes of the approach. This allows straightforward, out-the-window monitoring to give crewmembers cues for any off-nominal trajectory and to define direct "fly-to" corrective MNVR's. This burn shapes the intercept to occur in 125° (32 minutes) of orbit travel. It is cued to occur when the elevation angle of the TGT is about 28°. This occurs near orbital midnight.

In general, if the Ti point was long, then MC2 will be delayed, and if the Ti point was short, MC2 will be early. Flight experience has been that Ti tends to be long (late MC2 also equals early orbital sunrise relative to manual takeouver).

Note: The terms "long" and "short" as applied to Ti (and any other RNDZ MNVR locations) refer explicitly to range from TGT, not to range from previous MNVR point. Thus, Ti is "long" if the TIG location is farther than expected from the TGT; however, from the point of view of earlier burns, the same result could be viewed as having fallen "short" of the aim point, as in artillery terminology. To avoid ambiguity, always refer "long" and "short" to the range-to-TGT, not range-from-starting-point. See figure 4-13.

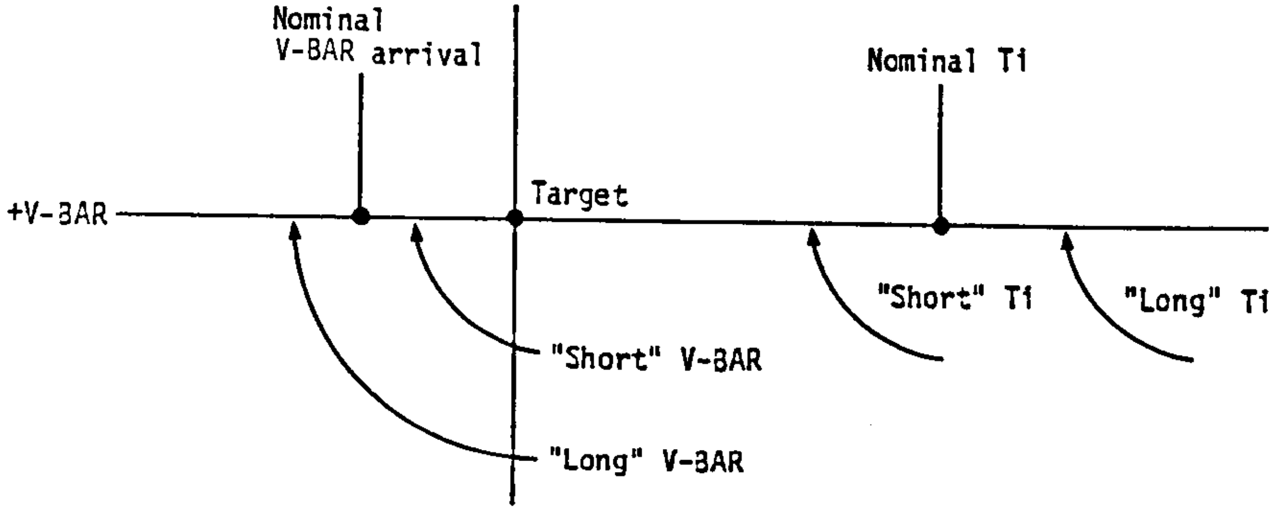


Figure 4-13.- Long/short terminology.

At some point, lighting can no longer be sacrificed to maintain a "standard" manual control trajectory. That limit was chosen to be minus 3 ("early") to plus 7 ("late") minutes from the nominal TIG. This will maintain sunrise between MC3 and MC4 and ensure a lighted manual control initiation at MC4 plus 2 minutes.

See section 4.1.42 for a discussion of rationale for sensor fail MC2 targeting.

See section 3.5.5.3 for discussion of possible ORB TGT alarm "TGT EL ANG."

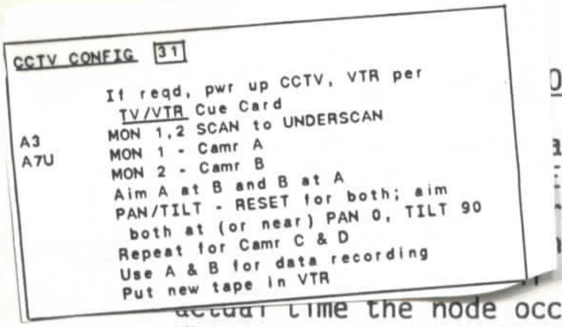
Acquisition of additional tracking data may result in significant changes to the MC2 TIG (several minutes) for the intermediate targeting. Each new TIG should be read down to the MCC since the solutions are not downlisted.

4.1.52 Execute RNDZ Breakout If No Sensor Data Or If No Filter Convergence (Off-Nominal)

See section 4.6 for discussion. The ~~OMS/RCS~~ RENDEZVOUS PRPLT PAD (sec. 4.3.4) may also be the cause of a BREAKOUT call near this point.

4.1.53 CCTV Configuration

If required, power up CCTV and VTR per cue card, set SCAN to UNDERSCAN, perform PAN/TILT and load new tapes in VTR's.



CCTV CONFIG 31

If reqd, pwr up CCTV, VTR per
TV/VTR Cue Card
MON 1,2 SCAN to UNDERSCAN
A3 MON 1 - Camr A
A7U MON 2 - Camr B
Aim A at B and B at A
PAN/TILT - RESET for both; aim
both at (or near) PAN 0, TILT 90
Repeat for Camr C & D
Use A & B for data recording
Put new tape in VTR

Out-of-Plane Null

axis-by-axis RCS burn (fig. 4-14) is performed based
L NAV. Ti had set up a 180° transfer from this
eful monitoring of the Y and Y-DOT parameters on REL
hough Ti is supposed to create a node (Orbiter/target
a REV prior to intercept (see sec. 3.5.7), the
actual time the node occurs can vary by up to 10 minutes due to NAV updates. When executed using Y thrusters, the burn drives Y-DOT to zero, so Y should not increase substantially afterwards.

If the burn is missed, the Y-DOT component should be nulled ASAP and the rest of the planar difference will have to be taken out manually during terminal phase. While this complicates that operation, it is certainly doable. See section 2.4.2.2 for a theoretical discussion of the orbital dynamics effects.

Flight experience has shown that the Ti burn is often successful in nulling out-of-plane rates to the point that the subsequent manual burn is not required. Generally the Y-DOT is a couple tenths of a foot per second.

```
                GNC 33 REL NAV

CRT             When Y = 0
F7              FLT CNTLR PWR - ON
C3              DAP:A/AUTO/NORM
                DAP TRANS: as reqd
                THC - null YDOT

                If -Z-AXIS TRACK,
                    +YDOT = FWD THC left
                            AFT THC right
                If -Y S TRK TRACK,
                   +YDOT = FWD THC down
                           AFT THC out

                DAP:A/AUTO/VERN
F7              FLT CNTLR PWR - OFF
```

Figure 4-14.- Manual out-of-plane null.

4.1.55 Target MC2 Burn (Final)

Once the last MC2 solution is computed (fig. 4-15), its TIG is compared to the preflight TIG, and the "TIG slip" is noted. Note that the "slip" can be in either direction, either ahead ("later") or back ("earlier").

```
          ✓ SV SEL correct

            GNC 34 ORBIT TGT

CRT       TGT NO - ITEM 1 +1 2 EXEC
          COMPUTE T1 - ITEM 27 EXEC
        ✓ TIG change between -3 and +7 min

          ..........If TIG Change <-3 OR >+7 min..............
          .                                                  .
          .   Set BASE TIME to (Nominal MC2 TIG -3,+7 min)   .
          .   as appropriate.                                .
          .   Load - ITEM 26 EXEC                            .
          .   TGT NO - ITEM 1 +1 9 EXEC                      .
          . ✓ TGT Set data                                   .
          .   T1 TIG = (BASE TIME)                           .
          .   EL       +0                                    .
          .   ΔT       +33.1                                 .
          .   ΔX       +0                                    .
          .   ΔY       +0                                    .
          .   ΔZ       +0                                    .
          .   COMPUTE T1 - ITEM 27 EXEC                      .
          ....................................................
          Set EVENT TIMER counting to MC 2 TIG
          Note solution and inform MCC
                      [illegible]
```

Figure 4-15.- Target MC2 (final solution).

A different TGT set (one based on time rather than elevation) is called up when TIG slips more than -3 or +7 minutes. The reason MC2 must be done within a particular time interval is that this burn will determine the lighting for the manual phase. A TIG slip greater then -3 or +7 minutes causes unacceptable orbital lighting conditions during manual terminal phase. (Sunrise must occur by MC4.) Changing BASE TIME prior to calling up the new target set allows the new BASE TIME to be changed by FSW in all sets. This saves keystrokes and simplifies crew procedures.

The reason for the new set is procedural. The new TGT set number is a quick indicator in the MCC that MC2 is being done on time rather than elevation angle. This is to avoid any possible confusion by seeing the old TGT set number selected.

4.1.56 Perform MC2

The burn is executed like any other axis-by-axis burn.

4.1.57 If in -Y STRK Track ATT, Return to -Z Axis Target Track (Off-Nominal)

If the -Y STRK had been used post-Ti, the Orbiter will still be in the -Y STRK TGT TRK attitude. In order to support the manual phase operations, it is necessary for the Orbiter to be aligned with its -Z axis pointing toward the TGT. The maneuver to the -Z axis TGT TRK attitude is delayed until after MC2 so that the approximately 8-minute-long attitude maneuver does not interfere with the execution of the OOP null or MC2. If the actual execution time of the OOP null and MC2 are such that it could be accomplished earlier, the crew has the option to execute the maneuver anytime after sunset.

4.1.58 Timeline Notes for No Radar Final Phase (Off-Nominal)

In the case of a failed RR, the crew will take over manual control of the trajectory at the earliest possible moment. This is done to keep the trajectory dispersions small in the manual phase.

The crew begins manual translational control at sunrise, based on out-of-the-window observation of the TGT.

A detailed discussion of this contingency is found in section 4.4.2.

4.1.59 Target and Perform MC3 Burn

This burn is scheduled to occur exactly 10 minutes after MC2. This has no significance other than correcting the trajectory so dispersions do not accumulate. It may be small enough to be skipped.

Post-Ti target acquisition can be accomplished through any one of four NAV sensors; the RR, the -Z or -Y STRK, or the COAS. All things considered, the RR is by far superior for RNDZ NAV purposes, but is also subject to the most single point failures, and is the most difficult to check out prior to the RNDZ activities (self-test pass or fail is not necessarily significant. See sec. 3.3.4.4). Either STRK is next in priority, since angle marks can be taken more accurately, more frequently, and with less propellant use than COAS marks. In addition, STRK's are typically used on a daily basis for IMU alignments, and so their operational status is known with a high degree of confidence prior to RNDZ initiation. The COAS is the last in priority, with no reasonable failure modes that would preclude its use.

In accordance with the relative usefulness of the sensors for NAV purposes, a hierarchy has been established for failure downmoding. A known RR failure is treated differently than a lack of TGT lock-on due to unknown causes. If the RR is known to be failed (mechanical problems with the Ku antenna, etc.), the first downmode is to the -Z STRK (see procedure in 4.1.44 in RNDZ rationale narrative). If the STRK is known to be failed, then the -Y STRK is the next choice. Before maneuvering, however, the COAS is used as a quality check on the NAV state. If necessary, COAS marks are taken to improve the NAV state accuracy and ensure that the target will be within the 1° small scan of the tracker, increasing the probability of acquisition. If the -Z STRK is thought to be working but fails to lock on, then NAV accuracy or TGT spectral characteristics (brightness, variability, etc.) are suspected to be the problem, so the -Y STRK is not anticipated to be an improvement. Thus, rather than wasting time in an attitude maneuver, COAS marks are taken, if possible. At the crew's discretion, -Z STRK acquisition can be reattempted.

Similarly, if the RR does not have a known failure, then lack of lock-on is assumed to be a result of NAV errors or insufficient signal return. To overcome NAV inaccuracy, manual slewing and acquisition with the RR are attempted first (sec. 3.3.4.6). Still failing to acquire, the downmode is to the -Z STRK. Even if the -Z STRK is known to be failed, in this situation the COAS will be used rather than the -Y STRK, since the -Y STRK acquisition attitude makes it impossible for the RR to lock on due to body blockage.

If no RR lock-on has been established by MC3, then at sunrise (usually ~7 minutes after MC3) a manual takeover is performed. MC3 and MC4 are not executed since no new sensor data has been incorporated since MC2, and also because it is considered imperative to establish proper LOS rates as early as possible. If visual acquisition is not available by MC4 + 5 minutes, a breakout MNVR must be performed ASAP. This MNVR is sized to ensure no recontact throughout the 3-sigma ellipse of dispersions.

The arrival of sunrise is a critical moment because at that point the TGT becomes visible and the procedure can begin. If the TGT is equipped with lights, the procedure can begin even earlier (the earlier the better).

When visual acquisition is accomplished, the Orbiter is pitched to bring the TGT to the COAS horizontal, and yawed until the LVLH yaw is zero. The pitch allows for determination of in-plane errors, and the yaw is performed to unmask any planar errors. Having accomplished the pitch, it is possible to determine the "theta angle," which is the in-plane angle from the Orbiter V-bar to the target line of sight. From the associated table (fig. 4-29), the dispersion region can be determined.

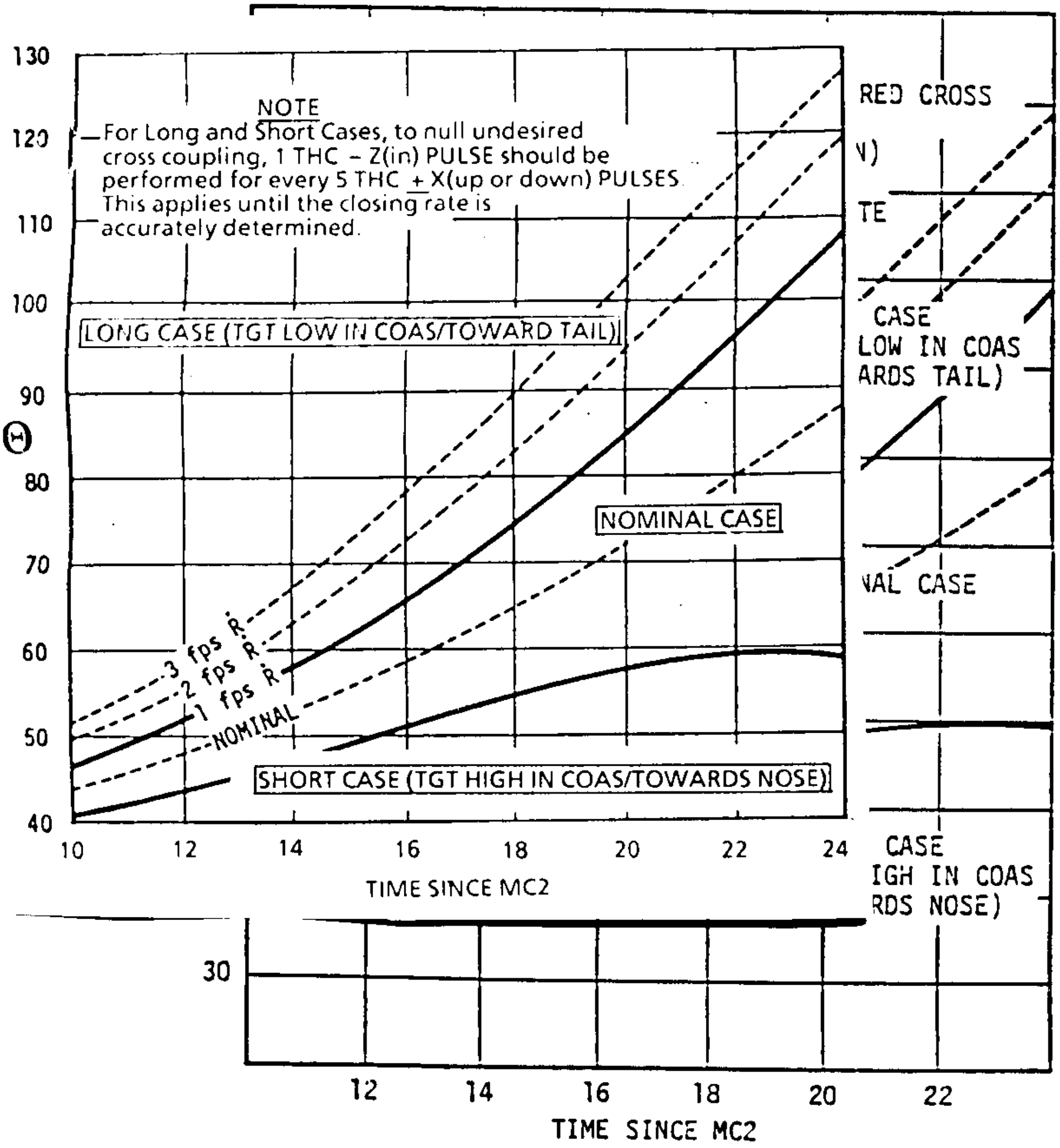


Figure 4-29.- Region determinator.

Note: The lines in figure 4-29 are empirically derived from analysis of a large number of ground simulations. They are valid for circular orbits only.

The logic behind the "theta" vs. "time since MC2" table (fig. 4-29) is as follows:

Prior to manual takeover the Orbiter attitude will follow a nominal time history, since without sensor data, NAV can only assume that a nominal trajectory is being flown. At sunrise, the NAV error will be suddenly exposed. As shown in figure 4-30, if the trajectory is short, the TGT will appear high in the COAS, and if the trajectory is long, the TGT will appear low. The great majority of cases will fall near enough to the nominal trajectory that nominal procedures can be followed. For sufficiently short or long trajectories, however, simulator experience has shown that nominal procedures will not result in a successful RNDZ, so special techniques must be used. The table delineates the boundaries of the "acceptably nominal" trajectories.

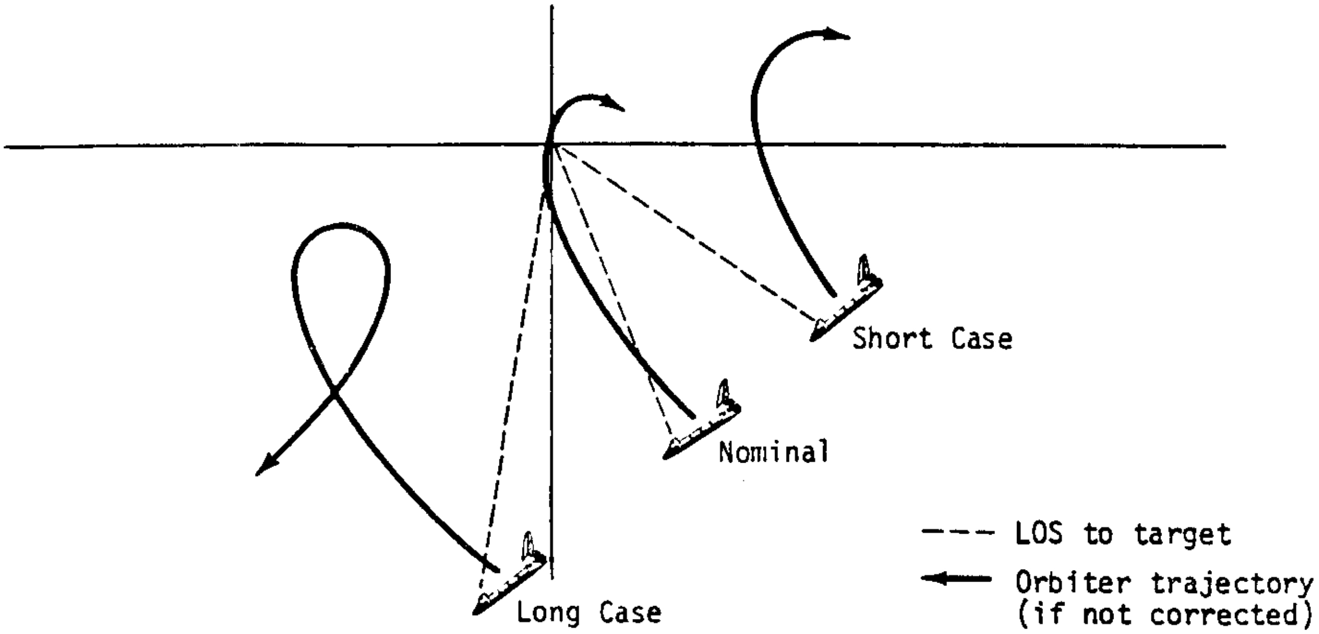


Figure 4-30.- Dispersed sunrise points.

For the family of trajectories that fall in the "short" category, it can be seen that many Orbiter +X corrections will be required to force the trajectory back towards the nominal path. Due to cross-coupling of X into +Z, this thrusting activity will tend to null the closing rate, and if not compensated for will turn a short case into a long case, as shown in figure 4-31. The final result of this is an unsuccessful RNDZ, since the change in range rate is difficult to detect with the RR failed, and the V-BAR arrival will be too far away to allow for closure within daylight. To compensate for this cross-coupling, the procedure calls for application of one Orbiter -Z pulse for every five ±X pulses (the theoretical background for this rule of thumb is found in sec.3.8.2). Note that it is very easy on short cases to initially overcorrect with +X, requiring subsequent -X; both contribute to +Z coupling. An important procedural point (that can only be driven home in the simulator) is that it is necessary to make the ±X corrections when visual cues suggest that they are required. Anticipating help from orbital mechanics effects, or thinking that error is "in the right direction," will usually result in an unsuccessful RNDZ. Many of these trajectories seem to "fall off the cliff," if errors are not corrected relatively quickly.

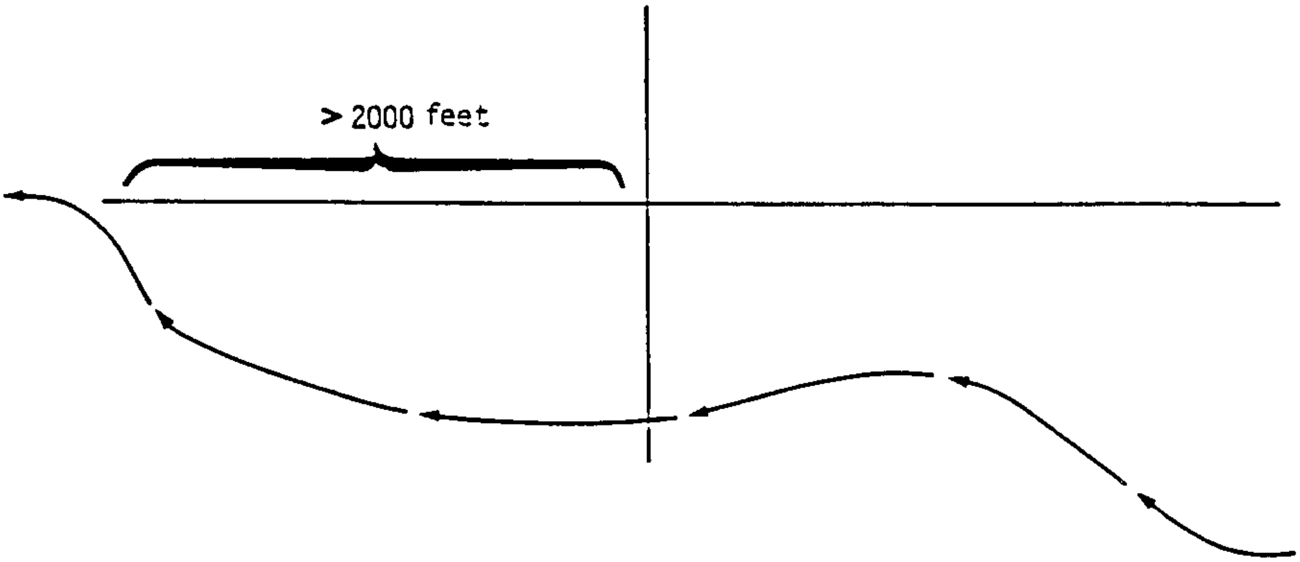


Figure 4-31.- Uncompensated coupling effects.

Pitch Rate	ωI deg/s	0.00	0.02	0.04	0.06	0.08	0.10	0.12	0.14	
	ωLVmrad/s	1.1	1.4	1.8	2.1	2.5	2.9	3.2	3.5	3.

Δv (ft/s) = ω_{LV}(mrad/s) x RANGE (kft)

Figure 4-32.- Calculation of -X ΔV (THC - down) required to stop on V-BAR.

The family of trajectories that falls in the "long" category, if no
specially handled, will also reach the V-BAR too far out to allow f
closure before sunset. To deal with these cases, two major changes
to the procedure. First, as soon as the theta error can be determine
adjustment to the closing rate is made, based on data from the chart.
because attempting to maintain inertial LOS rates at zero would tend t
the R-DOT correction, the Orbiter is pitched as required to keep the ta
centered in the COAS. However, allowing pitch rate to vary with the
trajectory makes it impossible to determine a priori when V-BAR arrival
occur, and, in fact, some trajectories may not reach the V-BAR, even wit
the R-DOT correction. Therefore, it is necessary to monitor the flyaroun
rate by monitoring the Orbiter pitch rate. If the pitch rate ever drops
down to zero prior to V-BAR arrival, it is necessary to put the Orbiter in
inertial attitude hold and perform +X THC corrections as required to drive
the trajectory to the V-BAR. Most of these cases, however, tend to reach
the V-BAR with a fairly large attitude rate, and require significant -X
thrusting to stabilize on the V-BAR (often 5 to 10 ft/s; see fig. 4-32). As
in short cases, this thrusting will couple into +Z, so the same "one -Z per
five ± X" rule of thumb applies.

Just as short case trajectories are sensitive to certain variations in pilot technique, this group of trajectories requires special attention to several points. First, the pitch rate can and should be carefully matched with the vernier RCS (VRCS). Allowing the TGT to drift up or down in the COAS can mask the effects of trajectory dispersions, and tend to make it difficult to anticipate the size of the -X correction needed at the V-BAR. Second, the -X correction at the V-BAR should be made aggressively, based on estimated range at the V-BAR arrival and knowledge of the flyaround rate. For example, using the table in figure 4-32, a pitch rate of 0.1 deg/s at a range of 500 feet will require -1.5 ft/s -X, and by the "1 per 5" rule, -0.3 ft/s -Z. Undercorrecting will result in a lofted trajectory that may or may not return to the V-BAR at an adequate range for comfortable, efficient stabilization. As in most problems of this nature, early correction of rate errors will reduce the required late corrections to a manageable level.

Notice that for a no-radar case there are not any real braking gates. A
braking gate is a desired closing velocity at a specific distance from the
TGT (a speed limit). In a no-radar case, range and range rate are foun

the change in TGT size over a period of time.
acy, braking gates are not used on a no-radar case,
e monitored to ensure reasonable closing rates.

ers

will call out the following procedure for loss of

Z DAP with TAIL ONLY CNTL from the beginning of the RNDZ
the NCC burn. Use NOSE and TAIL (full up) CNTL during and
burn.

entirely on OMS/RCS PROP consumption. If MCC decides
ntities have sufficient margins, this control mode (and the
t entails - see sec. ~~3.2.1~~ 3.8.1.1) can be waived and full control
be selected.

of Low Z Mode

Z mode the TGT will suffer less plume impingement effects. Loss of
impact expected TGT attitude and rates during final approach to
However, RNDZ and PROX OPS would probably continue on the nominal
e.

n payload separation MNVR's (e.g., Space Telescope) require use of low
contamination concerns. Unavailability of low Z mode may delay
yment until IFM restores capability or replanning can be accomplished.

.5 Loss of Aft THC,RHC

or RNDZ and possibly long-range stationkeeping, operations can be conducted
rom the forward THC/RHC's; close range flying is unacceptable. The only
reason to proceed with RNDZ/PROX OPS at all is if some IFM promises to
restore aft capability.

4.4.6 Loss of EE CCTV

Since the EE CCTV is a crucial PROX OPS sensor (see sec. 3.3.5.5), its failure will seriously impact procedures. The TGT must be moved up over the right rear window for better visibility by the RMS operator. Since it then is no longer in the plume shadow, DAP must be moded to low Z. Aft PLB CCTV's can be used to monitor Z axis sense motion.

Alternative procedures involving use of the RMS elbow CCTV have not been worked out.

Note: Loss of PDRS results in effective loss of EE CCTV, although it is conceivable that the elbow CCTV could still be used while the RMS is stowed.

4.5 BACKOUT

Certain systems failures, as specified in the flight rules, may disallow Orbiter operations within 200 feet of a TGT (e.g., loss of translation capability in any axis or loss of redundant +Z capability). Under such conditions the Orbiter will move out to the 200-foot point, go to normal Z control mode (usually), and begin stationkeeping while the problems are being resolved. From this point the Orbiter will either resume approach or perform PROX OPS breakout.

Caution: Once back out at 200 feet, use of RR may remain inhibited due to payload restrictions on induced electric field intensity. Even in low power, the antenna can induce high currents before automatically dropping to bypass mode.

4.6 BREAKOUT

The "breakout" MNVR is a separation MNVR performed at an unplanned point in the RNDZ sequence. Nominal separation MNVR's are described in section 5.4.2; breakout MNVR's, described in detail in section 5.4.3, must be quick, simple, and safe across a wide variety of initial conditions.

Note that choice of NORM Z or LOW Z for the separation is made on a payload-specific basis, mainly on the issue of whether the payload must be preserved for later return (on a subsequent rendezvous).

Two distinct types of breakout MNVR's have been defined and documented in the FDF RNDZ books, Rendezvous and PROX OPS. Once a "breakout" has been called, the choice must be made as to which available procedure is to be executed. These, or alternate procedures such as the nominal separation or no burn at all, are chosen by the MCC based on table 4-3.

TABLE 4-3.- BREAKOUT MANEUVER SELECTION

Time frame	Procedure	Usual key driver
Pre-Ti	Usually no burn (FDO defines maneuver)	Orbiter systems
Ti (RNDZ abort)	Usually no burn (FDO defines maneuver)	Orbiter systems
*Delay (1-2 REV's)	Per Ti Delay pad	Orbiter systems
*Delay (24 hr)	Follows Ti Delay (FDO defines maneuver)	Orbiter systems
Ti to sunset (ASAP at sunset)	RNDZ breakout (3 ft/s OOP, followed by 3 ft/s retro 15 min later)	Sensors
Sunset to MC2	RNDZ breakout (3 ft/s OOP, followed by 3 ft/s retro 15 min later)	Orbiter systems
MC2 to MC3	None	Orbiter systems
MC3 to V-bar	RNDZ breakout (3 ft/s OOP, followed by 3 ft/s retro 15 min later)	Propellant quantities
V-bar (or near)	PROX OPS breakout (2 ft/s posigrade)	Propellant quantities OR other flight rule (e.g., GNC redundancy)
Elsewhere	Flight specific OR Generic Sep, Orb OPS C/L (1 ft/s away, 2 ft/s OOP, 3 ft/s posigrade	Propellant quantities OR other flight rule (e.g., GNC redundancy)

4.6.1 Pre-Ti Breakout

Prior to Ti, a ground-computed breakout MNVR will be executed, if necessary, to guarantee a safe miss distance between the Orbiter and TGT. This is because prior to Ti, dispersions and the lack of a standard RNDZ profile prevent designing a "canned" breakout MNVR. The ground will compute a MNVR, if required, to ensure the Orbiter avoids the TGT by a safe distance. Typically, not executing a preplanned phasing MNVR will provide an acceptable miss distance.

4.6.2 Ti to V-BAR Breakout

Between Ti and V-BAR arrival, the breakout MNVR sequence will be a 3 ft/s out-of-plane MNVR (nominally Orbiter ±Y body axis) away from the TGT plane, followed 15 minutes later by a 3 ft/s retrograde MNVR (Orbiter +X body axis). This procedure is called "Rendezvous Breakout," and its rationale is found in section 5.4.3.1.

This breakout will be performed for the following reasons:

4.6.2.1 For Insufficient Propellant

For insufficient propellant or Orbiter system problems, the sequence will be initiated at orbital sunset, MC2, MC3, or ASAP if post-MC3. For reasons other than TGT sensor data, the breakout MNVR sequence should be initiated at the earliest acceptable point in the trajectory. Analysis indicates that orbital sunset to MC2, and at or post-MC3, are acceptable points in the trajectory to initiate the sequence. The earlier the sequence is initiated, the greater the TGT miss distance.

4.6.2.2 If No TGT Sensor Data

If no TGT sensor data (RR, STRK, COAS) has been obtained by orbital sunset, the sequence will be initiated at orbital sunset. With no TGT sensor data, the actual relative position between the Orbiter and TGT is not known with sufficient accuracy to complete the RNDZ. The sequence initiation was delayed until orbital sunset to allow maximum time for post-Ti sensors to obtain the TGT. The out-of-plane MNVR at sunset does not contribute to the TGT miss distance and could be deleted in real time as long as the retrograde MNVR is executed at orbital sunset plus 15 minutes.

4.6.2.3 If Only Pre-Ti TGT Sensor Data

If only pre-Ti TGT sensor data (RR,STRK, COAS) has been obtained, the sequence will be initiated no later than MC4 unless the TGT is acquired visually or with another sensor (RR is only current candidate). With pre-Ti TGT sensor data, trajectory dispersions are reduced. The sequence initiation can be delayed until MC4 and still provide an acceptable TGT miss distance. The retrograde MNVR does not contribute to the target miss distance and could be deleted in real time.

4.6.2.4 If Post-Ti TGT Sensor Data

If post-Ti TGT sensor data (RR, STRK, COAS) has been obtained, but is no longer available, the sequence will be initiated no later than MC4 plus 5 minutes unless the TGT is acquired visually or with another sensor (if all sensors are lost after this point, perform breakout immediately). With post-Ti TGT sensor data, the trajectory dispersions are reduced even more and the sequence initiation can be delayed until MC4 plus five minutes while still providing an acceptable miss distance (500 ft c.m. to c.m.). Again, the retrograde MNVR does not contribute to the TGT miss distance and could be deleted in real time.

4.6.2.5 To Continue the RNDZ Post-MC4

To continue the RNDZ post-MC4 plus 5 minutes, visual acquisition or RR is required. Subsequently, if both of these are lost, the sequence will be initiated ASAP. Without visual acquisition or RR data (the crew is electronically "seeing" the TGT), it is not possible to continue manual control. The entire breakout MNVR sequence is required once manual control has been initiated.

4.6.3 Post-V-BAR Arrival

Post-V-BAR arrival the breakout MNVR will be as described in section 5.4.3.2, PROX OPS Breakout, with its rationale. Motivation for PROX OPS BREAKOUT can include propellant limits, flight rules invocation, or serious target or Orbiter systems failures.

4.7 RELATIVE MOTION PLOTS

Included in the RNDZ checklist is a set of Orbiter/TGT relative motion plots in TGT-centered polar coordinates (fig. 4-33). These are designed to allow the crew to plot their progress through the RNDZ and note any course deviations.

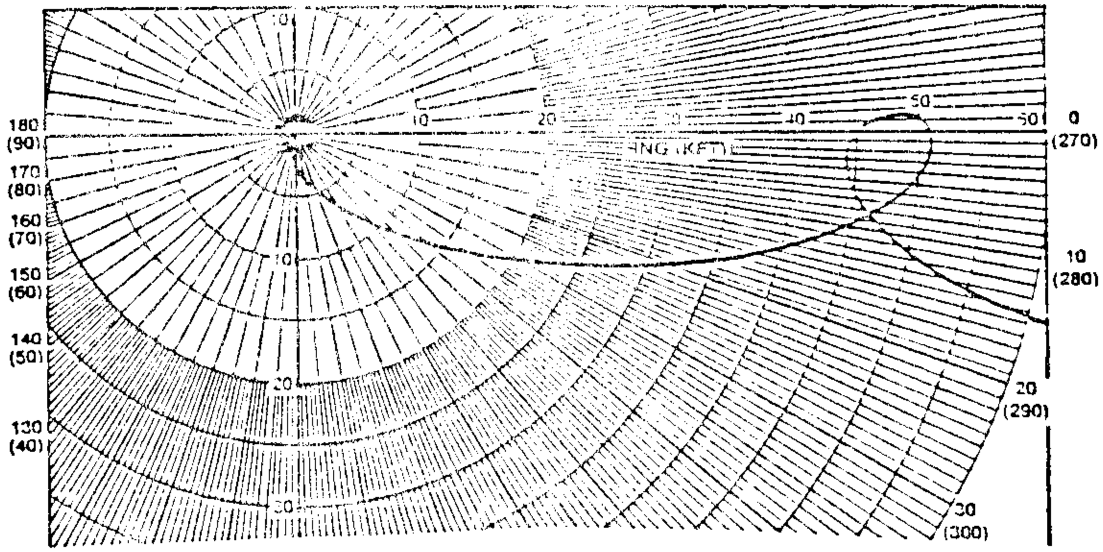
The specified angle assumes the Orbiter is in -Z axis TGT track. It can be read off the aft ADI; alternate values as seen on the forward ADI are also given.

4.8 FLIGHT DATA FILE DOCUMENTATION

A typical mission rendezvous or proximity operations book consists of a number of standard sections:

- Acronyms
- List of cue cards
- Contents
- Flight profile (charts)
- Detailed timelines (30 minutes per right-hand page) and pads

RELATIVE MOTION
FROM PRE TI



TERMINAL PHASE RELATIVE MOTION

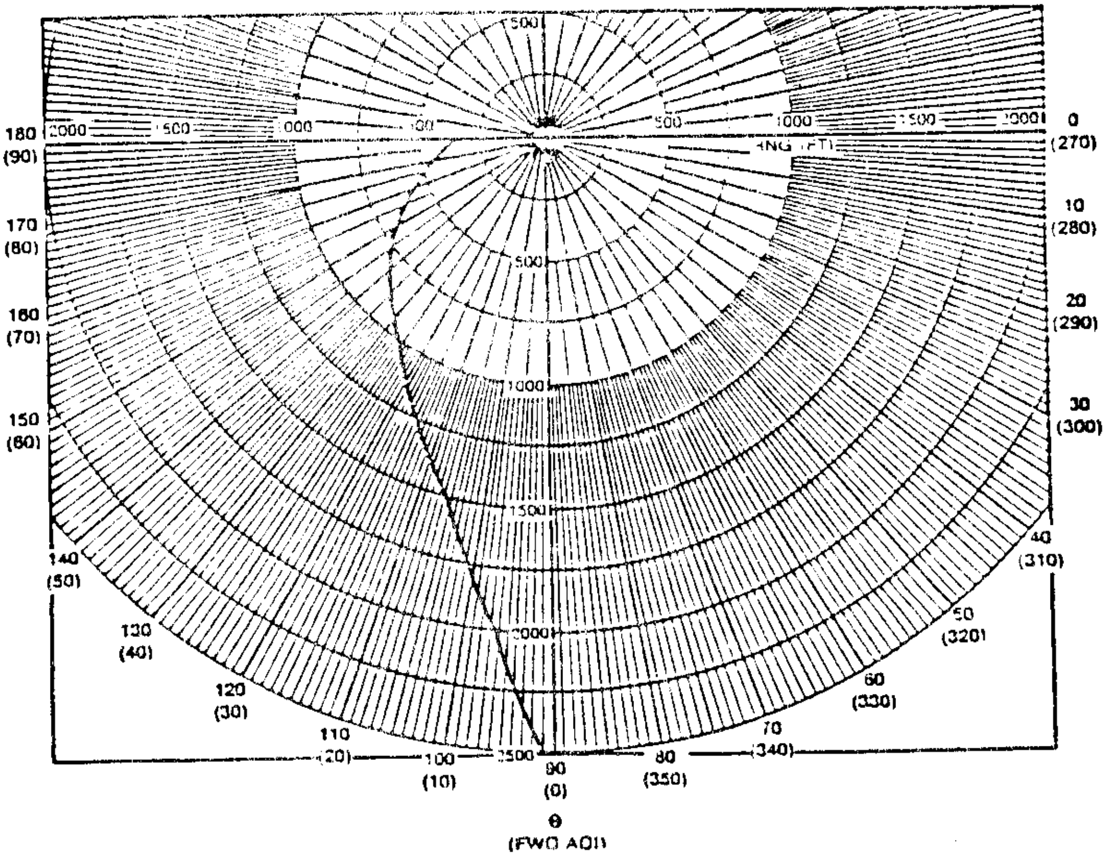


Figure 4-33.- Relative motion plots.

- Contingency operations (radar fail, loss of VRCS, DPS reconfiguration, RNDZ OMS burn, separations)

- Reference data (flight rules, targeting data, DAP configurations, relative motion plots, etc.)

- Ranging charts and rulers

- Cue cards (one set per text, one set with velcro layout)

- Notes (baseline trajectory and mission day)

The rationale for location and format of deploy/SEP/RNDZ procedures is given below. This philosophy applies to all missions where there is a scheduled nominal rendezvous or a planned contingency rendezvous. Examples of the former are STS 41-C (Solar Max repair) or STS 51-L (Spartan-Halley). An example of the latter is STS-30 (Hubble Space Telescope (HST)). Some missions (such as Spartan or the HST) involve deploy of a payload early in the mission, followed by either a nominal rendezvous (Spartan) or a planned contingency rendezvous (HST) 2 or 3 days later. For this type of mission (which may generically be referred to as "Spartan-type missions"), the predeploy, deploy, separation, postseparation, and rendezvous procedures should all be contained in the Rendezvous book. The exact point during predeploy operations at which the crew switches to the RNDZ book, and the level of detail of the predeploy procedures contained in the RNDZ book, will be determined for each flight depending on its unique requirements. In addition, for very complex missions requiring a high degree of crew coordination or procedural integration, nondeploy related payload or scientific operations can be included to varying levels of detail, such as on STS 51-F (Spacelab 2/Plasma Diagnostics Package (PDP)) proximity operations.

For Spartan-type missions, there are two main considerations, format and location. The Rendezvous book format has been a standardized format since the early Apollo days, containing an event timeline and detailed procedures, along with information concerning relative motion, GSTDN and TDRS coverage, day/night cycles, DAP settings, navigation schedules, and a variety of contingency procedures, cue cards, and supporting reference data. Unlike other checklists, it is compatible with DM43's Rendezvous and Proximity Operations Procedures Master Data Base (i.e., a radar acquisition procedure in the deploy section looks similar to that which the crew would see in the rendezvous section). As such, the format would be the same for pre- and postdeploy operations; it is used during crew and flight controller training, integrated sims, real-time support, and on-orbit operations.

Many payloads are very sensitive to contingencies during deploy, and most deploys are tied to specific times, lighting, or other trajectory events, such as particular beta angle or TDRS acquisition for a specified period of time pre- and/or postdeploy. Some deploy contingencies requiring special procedures are: unavailability of the low Z DAP mode; no-RMS deploy; single-joint RMS deploy; and late deploy. Sometimes these procedures are so different from the nominal, or are otherwise so complex or critical, that completely new contingency sections of the book need to be written. The rendezvous format easily accommodates these problems with a minimum of confusion and maximum crew coordination. Finally, the rendezvous format easily accommodates the integration of systems procedures (RMS, communications, OMS/RCS, payload systems, etc.).

From the preceding paragraphs it is possible to see many reasons why it is important that deploy and separation procedures be incorporated in the Rendezvous book for Spartan-type missions. There are, however, other reasons. It is highly desirable to have in one book all rendezvous-related procedures; i.e., those involving the integrated rendezvous GN&C hardware and software systems, especially when dealing with a two (or more) body problem. This provides the maximum continuity between deploy/separation and rendezvous procedures, especially during those critical moments just prior to and following the actual deploy when the minimum amount of confusion and the maximum possible level of crew and flight controller coordination is mandatory to ensure that the deploy is properly accomplished for both reasons of mission success and crew safety. Additionally, DM43 has means to establish a performance history of the sensors and navigation system. Also, it is easier for both the crew and flight controllers if all deploy and rendezvous maneuver pads are in one book, along with the propellant GO/NO GO pads and flight rules.

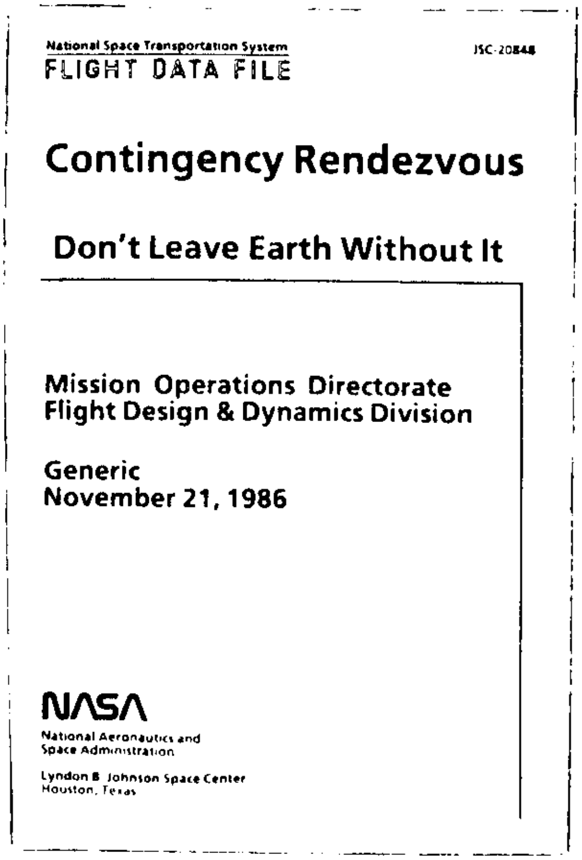
There is a need to check out the navigation sensors (radar and star tracker) at an early point in the mission (immediately following deploy), not only to satisfy the MCC that the sensor itself and the associated hardware and software are working properly, but also to get an idea of how the sensor interacts with the individual payload. In other words, was there any problem in acquiring the target, and did it stay locked on out to the expected range? Were there any problems in tracking the target, perhaps caused by its rotation, surface, or RF characteristics? These are among the target RF and optical characteristics and questions that can have an impact on the rendezvous timeline and procedures, and can be confirmed by using the sensors postdeploy. On some missions, there are nominally planned phasing burns, or other targeted maneuvers, designed to maintain the Orbiter within a desired area "near" (6 to 12 miles) the payload for a period of time up to several hours postdeploy. It is therefore critical to acquire the target and begin navigating immediately following deploy, and the best way to do this is to keep the crew in a checklist with the rendezvous format (preferably the Rendezvous book) throughout the entire procedure, thus ensuring maximum continuity and crew coordination.

In summary, by having a completely integrated checklist with all predeploy, deploy, separation, postseparation, and rendezvous procedures in one book as described above, the best possible level of mission support can be provided, both preflight and real time. This is a philosophy and methodology which has withstood the test of time and the test of actual on-orbit operations. It works well both for the people who develop techniques and provide real-time support, and for the people who use the procedures on orbit. But most importantly, it offers the best assurance of accomplishing the mission.

4.10 In-Flight C/L Utilization

Normally there will be three copies of the rendezvous checklist on board the Orbiter. They are stowed in a middeck locker for use after orbit operations begin. A sample cover sheet for such a checklist is shown in figure 4-34.

Crew handling of the checklist follows STS norms and standards. Cue cards are positioned at the disgression of the crewmembers using them. CCTV monitor overlays are on clear plastic with velcro tabs for affixing to the CCTV monitors. MCC calls will be made to the specific page number of the checklist. The crew will be familiar with this checklist from ground simulation activities.



National Space Transportation System
FLIGHT DATA FILE

JSC-20848

Contingency Rendezvous

Don't Leave Earth Without It

Mission Operations Directorate
Flight Design & Dynamics Division

Generic
November 21, 1986

NASA
National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
Houston, Texas

Figure 4-34.- FDF Rendezvous Checklist (Typical)