80-FM-12

JSC-16425

MAY 19 1980

Retrieval Techniques

LVLH and Inertially Stabilized Payloads

(NASA-TM-81099) RETRIEVAL TECHNIQUES: LVLH AND INERTIALLY STABILIZED PAYLOADS (NASA) 42 p HC A03/MF A01 CSCL 22E

N80-27416

Unclas

G3/16 25916

Mission Planning and Analysis Division

May 1980

National Aeronautics and Space Administration

Lyndon B. Johnson Space Center
Houston, Texas

80FM12

80-FM-12 JSC-16425

SHUTTLE PROGRAM

Retrieval Techniques

LVLH and Inertially Stabilized Payloads

By J. A. Yglesias
McDonnell Douglas Technical Services Company

JSC Task Monitor: Michael E. Donahoo
Flight Planning Branch

Approved: Harold D. Beck
Edgar C. Lineberry, Chief
Flight Planning Branch

Approved: Edgar C. Lineberry
for Ronald L. Berry, Chief
Mission Planning and Analysis Division

Mission Planning and Analysis Division

National Aeronautics and Space Administration

Lyndon B. Johnson Space Center

Houston, Texas

May 1980

CONTENTS

TABLES

FIGURES

ACRONYMS

COAS	crew optical alinement sight
DAP	digital autopilot
GF	grapple fixture
LDEF	long duration exposure facility
LVLH	local vertical/local horizontal
MMS	multimission modular spacecraft
POPIS	proximity operations/plume impingement simulation
PRCS	primary reaction control system
RHC	rotational hand controller
RCS	reaction control system
RMS	remote manipulator system
SMM	solar maximum mission
STV	stabilized television camera
SVDS	space vehicle dynamics simulation
THC	translational hand controller
TPM	terminal phase maneuver
TRS	teleoperator retrieval system
UPP	universal pointing processor

1.0 SUMMARY

This document discusses procedures and techniques for retrieving payloads that are inertially or local vertical/local horizontal (LVLH) stabilized. Selection of the retrieval profile to be used depends on several factors:

a. Control authority of the payload

b. Payload sensitivity to primary reaction control system (PRCS) plumes

c. Whether the payload is inertially or LVLH stabilized

d. Location of the grapple fixture

e. Orbiter propellant consumption

The following general retrieval profiles are recommended:

a. V-bar approach for payloads that are LVLH or gravity-gradient stabilized

b. V-bar approach with one- or two-phase flyaround for inertially stabilized payloads

Once the general type of profile has been selected, the detailed retrieval profile and timeline should consider the various guidelines, groundrules, and constraints associated with a particular payload or flight.

Reaction control system (RCS) propellant requirements for the recommended profiles range from 200 to 1500 pounds, depending on such factors as braking techniques, flyaround maneuvers (if necessary), and stationkeeping operations. The time required to perform a retrieval (starting from 1000 feet) varies from 20 to 130 minutes, depending on the complexity of the profile.

The goals of this project are to develop a profile which ensures mission success; to make the retrieval profiles simple; and to keep the pilot workload to a minimum by making use of the automatic features of the Orbiter flight software whenever possible.

2.0 INTRODUCTION

Over the past few years, retrieval operations have been studied in detail for several specific payloads: multimission modular spacecraft/solar maximum mission (MMS/SMM), long duration exposure facility (LDEF), SPAS-01, stabilized television camera (STV), Skylab, and teleoperator retrieval system (TRS) (fig. 1 and 2). These studies have involved different retrieval techniques and operational procedures. As a result, several things have been learned about retrievals. This document contains a summary of the retrieval analyses and simulations that have been performed for inertially and LVLH stabilized payloads. During retrieval, the remote manipulator system (RMS) is used in the final stages for grappling and stowing. Because of the size and difficulty in maneuvering the RMS, it is desirable to achieve a final payload/Orbiter relative configuration, which minimizes the RMS maneuvering required prior to capture. This places a practical limit on the acceptable payload/Orbiter configurations and, therefore, the most desirable final relative orientations must be defined. Figure 3 shows the desired configuration for the solar maximum mission observatory (ref.1). Because it is easier and safer to manipulate the RMS than to maneuver the Orbiter when in close proximity (30 to 50 feet) to the payload, the final approach profile (from 1000 feet to grapple range) is designed so that on completion, the Orbiter will be in an acceptable position/orientation for the grappling operation.

2.1 PURPOSE

One goal is to develop standard retrieval procedures so that preflight crew training can be minimized. Because of the variability of payload size and shape, grapple fixture placement, and control system type, it is impossible to develop a single retrieval profile that will always work. General profiles have been developed for retrieving both inertially stabilized and LVLH stabilized payloads. Minor profile variations will occur within the two types of retrieval techniques, depending on payload-specific requirements.

In the remainder of this section, proximity operations terms are introduced and defined. Section 3.0 contains a description of the tools and techniques used to perform the analyses, a discussion of the potential problems associated with different types of payloads, a list of assumptions, and a description of the profiles selected. Simulation results are presented in section 4.0. Conclusions and recommendations are made in section 5.0, and references are provided in section 6.0.

2.2 PROXIMITY OPERATIONS TERMINOLOGY

2.2.1 Proximity Operations

Proximity operations officially begin with the terminal phase maneuver (TPM); however, for the purpose of this document, proximity operations will refer to those activities occurring within 1000 feet of the payload. This includes all pregrappling activities such as stationkeeping and final approach.

2.2.2 Local Vertical/Local Horizontal Coordinate System

The LVLH system has its origin at the vehicle center of mass; Z_{LVLH} lies along the geocentric radius vector to the vehicle positive toward the center of the Earth, X_{LVLH} is alined with the velocity vector, and Y_{LVLH} completes the right-hand system (fig. 4).

2.2.3 Approach Techniques

In this study three basic Orbiter approaches were analyzed. They are R-bar, V-bar, and inertial.

For the R-bar approach, the Orbiter approaches along the Z_{LVLH} axis of the payload (radius vector). The primary advantage of this method is that "natural braking" due to gravity greatly reduces the amount of active braking (upfiring PRCS jet activity) necessary to null the range rate between the Orbiter and payload. However, some of the propellant savings from natural braking are offset by increased X jet firings to keep the Orbiter on the Z_{LVLH} axis.

For the V-bar approach, the Orbiter approaches along the X_{LVLH} axis of the payload (velocity vector). For this technique, very little propellant is required to keep the Orbiter on the X_{LVLH} axis; however, since there is no "natural braking", considerable active braking is required to null the range rate between the two vehicles. Active braking results in increased PRCS plume impingement on the payload.

For the inertial approach, the Orbiter approaches the payload along a vector fixed in inertial space. Although this technique is clear-cut, maintaining a range versus range-rate schedule can be difficult because of orbital mechanics effects.

2.2.4 Braking Techniques

The methods used to control the range rate of the Orbiter with respect to the payload greatly affect the amount of plume impingement imparted to the payload. The two techniques considered, normal-Z braking and low-Z braking, are shown in figure 5.

For normal Z-braking, three upfiring PRCS jets (one forward and two aft) are fired simultaneously. The combined 2600 pounds-force thrust results in an acceleration of about 0.4 fps^2 for a 200 000-pound Orbiter. This is the fastest and most efficient way to null the relative rates, but at ranges less than 500 feet, plume impingement on the payload is a potential problem.

For low-Z braking, the upfiring Z jets are inhibited, and braking comes from firing four X jets (two forward and two aft) simultaneously. Because of canting and scarfing effects, these X-jet thrust vectors are tilted 8° to 10° up from the $\pm X$ axes of the Orbiter. This gives a total thrust in the Z direction of about 500 pounds-force, resulting in an acceleration of 0.08 fps^2 for a 200 000-pound Orbiter. This is the least efficient braking technique in terms of propellant consumption, but it is needed for payloads that have little control authority or that are contamination sensitive.

2.2.5 Sun and Roll Angles

The Sun angle (β angle) is the angle between the orbital plane and the Sun-line (from Sun to the center of Earth). For nominal missions, the Sun angle can range from $\beta = 0^{\circ}$ (Sun in the orbital plane) to a maximum of $\beta = 52^{\circ}$ (inclination of 28.5°, plus 23.5° angle between the ecliptic and equatorial planes). The roll angle is best illustrated with an example. SMM points its +X axis at the Sun and since SMM has limited control (ref. 2), it is free to rotate about the solar vector (+X-axis). The roll angle refers to the rotation about the X axis which, practically speaking, will not be known but is useful in establishing flyaround procedures.

2.2.6 Onorbit Digital Autopilot

The onorbit digital autopilot (DAP) commands the RCS jet firing activity during the onorbit flight phase. In the manual DAP mode, the system is driven with rotational and translational hand controller (THC) inputs. The THC has two modes of operation: acceleration mode and pulse mode. In the automatic DAP mode, several submodes are available, including a tracking mode and an Orbiter attitude-hold option. In the analyses both the manual and automatic capabilities of the DAP are used.

2.2.7 Universal Pointing Processor

The universal pointing processor (UPP) can be used to supply inputs to the onorbit DAP to perform three basic pointing maneuvers. The three available options are LVLH hold, rotation, and maneuver. Under the LVLH option, the software will command a maneuver to point a vector fixed in Orbiter body axes at the center of the Earth. Under the rotation option, the Orbiter is rotated at a constant rate about a vector fixed in Orbiter body axes and in inertial space. Under the maneuver option the Orbiter maneuvers to a specified attitude. In these analyses all three options are used.

3.0 DISCUSSION

This section contains a detailed discussion of the retrieval studies, including a list of assumptions and potential problems and an explanation of the profiles. The section also describes the tools and techniques used in designing the profiles.

3.1 ASSUMPTIONS AND POTENTIAL PROBLEMS

In developing profiles, the following assumptions were made.

a. Payloads do not have translational capabilities

b. Full Orbiter DAP and UPP capabilities will be available for retrieving payloads

c. $\pm$X-braking will be available

d. Ground communications constraints can be met by going to the most stable orientation and waiting for proper ground coverage

e. Grapple fixture (GF) location varies considerably from payload to payload as a function of size, shape, and control system. (Figures 1 and 2 show several different payloads and GF locations)

Potential problems that may result in violating a payload constraint during retrieval are as follows:

a. Disturbing the payload attitude with plume impingement

b. Contaminating sensitive payload surfaces

Potential problems which may complicate the retrieval operation are as follows:

a. Restricted access to the GF because of its location or obstruction by payload structures (e.g., on SMM the solar panels severely restrict access to the GF)

b. Retrieval of payloads that are rate-damped about their axis of symmetry. (This results in uncertainty about the roll axis.)

c. The effects of orbital mechanics that may cause the Orbiter to accelerate towards or away from the payload, resulting in increased jet activity

d. Payloads with large solar panels (such as SMM and TRS) that may enhance the effects of plume disturbance

e. Large gravity gradient stabilized payloads (such as LDEF and Space Telescope) whose control systems are extremely plume sensitive

All of the factors listed above have been considered in developing the proposed profiles. Other factors such as pilot workload (demands made on the pilot, mission specialist, and RMS operator) and propellant consumption must be taken into consideration. The goal has been to develop profiles that minimize the adverse effects of the potential problems, make realistic demands on the crew, and optimize propellant consumption.

3.2 METHODOLOGY

The tools and techniques used in the retrieval study are discussed in the next few paragraphs. The Orbiter mass properties used are given in table I.

Although the standard orbit has an inclination of 28.5°, several other angles were used as well. Also, the simulations were run for various beta angles. All of the simulations began at a range of 1000 feet and ended at a range of 30 to 40 feet.

The basic tool is the proximity operations/plume impingement simulation (POPIS), that integrates the plume impingement and paper-pilot models with the space vehicle dynamics simulation (SVDS) program (ref. 3). This tool gives a two-vehicle, twelve-degree-of-freedom digital simulation of onorbit proximity operations. (For a detailed explanation of the tools and capabilities see reference 4). The primary purpose of these simulations is to generate payload disturbance data (forces and torques) and Orbiter PRCS propellant consumption data that are used in assessing the feasibility of the proximity operations segment of the mission.

The basic logic for the paper pilot models is shown in figure 6. This logic is used for all approach types (R-bar, V-bar, inertial) discussed earlier. The cross-axis logic will keep the payload centered in the crew optical alinement sight (COAS) field of view, while the approach-axis logic will keep the Orbiter moving away from or towards the payload at the desired rate. The desired rates are input by the user, as are the limits of the COAS field of view and the frequencies at which each type of logic is executed.

3.3 CANDIDATE FINAL APPROACH PROFILES

The various types of profiles can be divided into two categories: in-plane and out-of-plane profiles. These two types differ only in how the GF of a payload is visually acquired when the Orbiter is about 200 feet from the payload. To fly an in-plane profile, the Orbiter stays in the orbital plane and "waits" for the payload to rotate until the GF is in view. For an out-of-plane profile, the Orbiter flies out of the orbital plane and "finds" the GF.

Figure 7 shows five in-plane candidate profiles in a target centered LVLH coordinate system. Because the LVLH system rotates at orb rate, inertial approaches (which would appear as straight lines in an inertial frame) appear as curved lines. These profiles are discussed in more detail in section 3.3.1.

Figure 8 shows the basic out-of-plane candidate profile as seen in the X-Y plane of the target-centered LVLH frame. A zero beta angle is used in order to simplify the drawing. (For nonzero beta, the view in figure 8 would be of the plane perpendicular to the sunline). The profiles simulated differ in whether they are performed in one or two phases, which depends upon how much is initially known about the payload roll attitude (the details will be discussed in section 3.2.2). Some work was done on R-bar/out-of-plane approaches, and although they are straightforward for small beta angles, the V-bar/out-of-plane profiles are better in this particular case. In general, in-plane approaches are recommended for LVLH stabilized payloads, and out-of-plane approaches are recommended for inertially stabilized payloads.

3.3.1 In-Plane Profile

3.3.1.1 GF Visible

For an LVLH stabilized payload, the first phase of an in-plane profile is to approach from 1000 feet with the Orbiter in LVLH hold, stopping at a range of about 200 feet from the payload. If the GF is in sight and the payload is favorably oriented with respect to the Orbiter, the pilot would continue the approach along the line-of-sight vector to the GF. Thus, the final 200 feet would be flown as an LVLH approach in the X-Z LVLH plane (profile 1 of fig. 7). For an inertially stabilized payload, the first phase would be the same, and at 200 feet the Orbiter would go into an inertial hold if the GF was in view and favorably oriented (profile 2, fig. 7).

3.3.1.2 GF Not Visible

For an inertially stabilized payload, on reaching 200 feet, if the GF is not in sight or if the payload/Orbiter alinement is not correct for grappling, it may be possible for the Orbiter to stationkeep and wait until conditions are favorable for beginning the final approach. This technique can work because the Orbiter is in LVLH hold and the payload is in an inertial hold, rotating relative to the LVLH frame. If the Orbiter could stationkeep and wait "long enough" (given the time and propellant constraints), the GF may rotate around and come into view. At this point, the pilot would switch to inertial hold and continue the approach along the line-of-sight vector to the payload. The problem with this method is that it is difficult to know how long it will take for the GF to come into view; indeed, for some orientations it will never come into view. For this reason, in-plane approaches are not generally recommended for retrieving inertially stabilized payloads.

For an LVLH stabilized payload, the position of the GF in the LVLH frame will be known. Furthermore, at 200 feet the payload is not rotating relative to the Orbiter because both are LVLH stabilized. Under these conditions, it is usually possible to perform a simple Orbiter in-plane maneuver that will favorably orient the GF for payload retrieval. For example, if the GF is in the orbital plane (or close to it) the pilot could switch DAP modes and initiate a pitch maneuver to fly around the payload in the orbital plane until the GF is visible (fig. 9).

In previous simulations, in-plane profiles have always worked for LVLH stabilized payloads. While in-plane techniques are not completely satisfactory for inertially stabilized payloads, the following methods result in a clear view of the GF and proper alinement before moving from 200 to 30 feet.

3.3.2 <u>Out-of-Plane Profile</u>

Out-of-plane techniques are designed specifically for inertially stabilized payloads. The initial and final phases of the approach profile are identical to the in-plane techniques. That is, the V-bar approach is started at 1000 feet and stops at 200 feet; when the two vehicles are properly alined (GF in sight), the Orbiter DAP is switched into inertial hold and the approach continues along the line-of-sight vector, stopping at 30 feet. The differences are in the methods used to aline the two vehicles and visually acquire the GF. The technique proposed in this document is shown in figure 10.

The first step occurs at 200 feet and consists of alining the +X-axes of the Orbiter and payload so that they are parallel. Because the beta angle will be known at the time of the flight, this maneuver can be done automatically. The DAP/UPP inputs can be either precomputed and stored or uplinked in real time so that they will be available when needed. Because the maneuver rate is also a

DAP/UPP input, the time it will take to execute the maneuver will vary. The maneuver has been simulated at 0.2 to 0.4 deg/sec, and it takes 2 to 3 minutes to aline the X-axes of the two vehicles for a maximum beta of 52°. Alining is basically a yaw-pitch maneuver for the Orbiter; during this operation the pilot keeps the payload centered in the COAS via THC deflections (also simulated).

After the X-axes are alined, the pilot initiates the second step by commanding a constant rate (0.2 to 0.4 deg/sec) rotation maneuver about the Orbiter X-axis. (Whether a positive or negative roll is required is determined prior to the maneuver.) Once again, this is an automatic maneuver that requires that the pilot switch DAP modes. The direction of the Orbiter X-axis will be held fixed in inertial space, keeping the payload and Orbiter +X-axes parallel. As the Orbiter rolls, the payload will tend to move out of the COAS field of view; the pilot will command Y-axis translations to keep the payload centered in the COAS. The net result is an out-of-plane flyaround (fig. 11).

At most, the pilot should have to fly around 180° to bring the GF into the desired position, which means that this could take as long as 15 minutes. The alinement/flyaround phase could take as long as 18 minutes. As before, the pilot would then switch to inertial attitude hold and complete his approach.

If the payload roll angle is known, the proper DAP/UPP inputs can be made and the two-step method described earlier can be accomplished in one step in no more that 15 minutes. The X-axes are not necessarily alined at the start, but the pilot commands a constant rate rotation that terminates with the GF in sight and the vehicles alined (fig. 12) before initiating the final approach.

3.4. COMPARISONS

The major advantage of out-of-plane flyaround techniques over the in-plane techniques is that they work for any beta or for any roll angle. However, this is significant only when the payload is inertially stable or if it does not have three-axis attitude control. Because there is no extended stationkeeping in the out-of-plane techniques, there could be a propellant savings over the in-plane methods. Both techniques are semiautomatic maneuvers (automatic attitude control and manual translation). The maneuver rates and times are variable for all the techniques. Both rely on optical ranging and both are performed at ranges of 200 feet ± 20 feet. All techniques have been simulated on digital computers; however, none have been analyzed in man-in-loop simulations. In general, the in-plane approach is recommended for LVLH stabilized payloads, and out-of-plane profiles are recommended for inertially stabilized payloads.

3.5 DAP/UPP INPUTS

For completeness, the onorbit DAP and UPP inputs and loads for our recommended retrieval operations are given in table II. The variables are described below.

a. IUPP - flag indicating that a new universal pointing processor option is going to be selected

b. IUPO - mode select switch for the universal pointing processor

c. IAAO - submode selector for automatic mode

d. BODVP - pitch coordinate of body vector (for LVLH and rotation tasks)

e. BODVY - yaw coordinate of body vector (for LVLH and rotation tasks)

f. OMCRON - constraint angle about body vector (for LVLH task)

g. RMMAG - desired magnitude of discrete maneuver rate about eigenaxis for the AUTO-MNVR-TRACK module

h. ROTRA - desired rate of rotation about body vector in rotation mode

4.0. SIMULATION RESULTS

The results are divided into two parts: inplane and out of plane. Generally speaking, it was found that the 0.2 to 0.4 deg/sec maneuver rate was acceptable for all techniques requiring a flyaround and that plume impingement disturbances are acceptable if the low-Z braking mode is used. The simulation times given do not include actual grappling or any time between phases (such as stationkeeping while waiting for the GF to rotate into view).

4.1 IN-PLANE RESULTS

Table III contains propellant and impingement data for SMM retrieval analyses. Note that only low-Z braking results in acceptable impingement disturbances (including gravity gradient torques) and that both R-bar and V-bar approaches are feasible in the low-Z mode. Stationkeeping on V-bar expends less propellant than stationkeeping on R-bar because less cross-axis jet activity is required to keep the payload centered in the COAS, again because of orbital mechanics. However, since there is no "natural braking" on V-bar, all the delta-V used to approach the payload must be taken out by firing jets in the direction of the SMM (either +Z or $\pm$X). The $\pm$X jets provide about one-fifth as much braking as the +Z jets so the $\pm$X jets must be fired five times as long to null out the same amount of delta-V, thus increasing propellant requirements for the low-Z approaches. The inertial flyaround maneuvers require about the same amount of propellant regardless of whether they are initiated on R-bar or V-bar. The complete R-bar profiles use about the same amount of propellant as the complete V-bar profiles. Because there are operational advantages to V-bar approaches (easier for pilots to fly), the V-bar profiles are preferred.

Inertial approaches initiated at 1000 feet rather than 200 feet are slightly more expensive, more difficult, and not necessary. Switching to an inertial approach at 200 feet does not pose a problem (in the simulations discussed in this document) but is a little more difficult than a pure V-bar profile.

Table IV contains similar data for other payloads.

4.2 OUT-OF-PLANE RESULTS

Because V-bar approaches are preferred from a flight operations point of view, the out-of-plane simulations were initiated on V-bar. Table V contains the results of the one-phase and two-phase flyaround techniques for SMM retrieval analyses. Although the one-phase flyaround uses less propellant and less time, it relies on having data about the SMM orientation prior to the maneuver; if the data were wrong, the GF might not be favorably oriented at the end of the operation. Simulations indicate that the two-phase flyaround will work even with no knowledge of the SMM roll angle. It will also work for any beta angle. This method is general enough to be used for retrieving all inertially stabilized payloads.

Table VI contains similar data for other payloads.

4.3 SIMULATION PLOTS

The data in figures 13 and 15 are from the same in-plane approach profile, consisting of a V-bar approach from 1000 feet to 200 feet followed by an inertial approach from 200 feet to grapple range. Figures 16 to 19 present similar data for an out-of-plane profile: a V-bar approach from 1000 feet to 200 feet, a two-phase flyaround and finally an inertial approach from 200 feet to 30 feet. Both profiles used the low-Z braking mode.

Figures 13 and 16 are plots of range versus closing rate of the Orbiter relative to the target. In figure 13 the braking gates are clear at 600 feet, 300 feet, and 35 feet. In figure 16 the activity at 200 feet indicates that the Orbiter is no longer approaching the payload (this is where the flyaround occurs).

A torque history chart (fig. 14 and 17) shows the cumulative torque impulse on the payload caused by plume impingement, aerodynamic drag, and gravity gradient effects. The "smooth" contours of figure 14 indicate that most of the torque is caused by gravity gradient and aerodynamic drag effects, whereas the "steps" in figure 17 correspond to plume disturbance because of Orbiter braking.

Figures 15 and 18 give the time history of the propellant usage for each profile. The sudden vertical rises correspond to braking maneuvers. The high propellant consumption is due to $\pm X$ braking. By looking at figure 18 and knowing that the flyaround occurred from 18 to 36 minutes into the simulation, it can be determined that 700 pounds-mass of propellant are used. "FWD" and "AFT" refer to the forward and aft RCS tanks.

Figure 19 gives a "third-person" view looking down on the X-Y LVLH plane and clearly shows the out-of-plane flyaround.

5.0 RECOMMENDATIONS AND CONCLUSIONS

For an LVLH stabilized payload the following profile is recommended:

a. V-bar approach from 1000 to 200 feet with Orbiter in LVLH hold

b. In-plane maneuver to visually acquire GF (if necessary)

c. Final approach from 200 to 30 feet along line of sight to GF with Orbiter in LVLH hold

For an inertially stabilized payload the following profile is recommended:

a. V-bar approach from 1000 feet to 200 feet with Orbiter in LVLH hold

b. Two-phase flyaround to visually acquire the GF (if necessary)

c. Final approach from 200 feet to 30 feet along line of sight to GF with Orbiter in inertial hold

Although the simulation data for this document indicate that these techniques will work, man-in-loop simulation data are still needed, especially for the flyarounds. Finally, it is recommended that studies be initiated to look at potential problems involving maneuvering the Orbiter with an unstowed RMS. The maximum translational rates achieved are as high as 0.7 fps for the proposed maneuvers, and it is necessary to know if the arm can tolerate the resulting loads.

6.0 REFERENCES

1. Mosel, D. K.: SMM Rendezvous/Proximity Operations Status. July 1979.

2. Pandelides, J.: SMM System Design Specification. 409-2004-0002, January 1979.

3. Mission Planning and Analysis Division: Space Vehicle Dynamics Simulation (SVDS) Program. JSC-11157, October 1977.

4. Schoonmaker, P. B.: POPIS Overview Document. TM 1.4-MAB-310, April 1979.

TABLE I.- ORBITER MASS PROPERTIES

Parameter	Unit
Mass, lb	214 000
Control system deadbands, deg	1
Control system deadbands, deg/sec	0.2
Control	Auto attitude control
	Manual translation
Inertias, slug-ft^2	IXX = 790 900
	IYY = 6092 000
	IZZ = 6307 000
	IXY = -3 000
	IXZ = -134 000
	IYZ = -1 000

TABLE II.- DAP INPUTS

Function	DAP variables				
	IUPO	IAAO	BODVP	BODVY	OMCRON
LVLH hold on V-bar: -X axis towards Earth, +Z axis along velocity vector	1	3	-180	0	0
LVLH hold on R-bar: +Z axis towards Earth, +X axis along velocity vector	1	3	-90	0	0
Flyaround in X-Y plane, from ahead on V-bar to trailing on V-bar	1	3	-180	0	180
Flyaround in X-Z plane, from ahead to trailing on V-bar	1	3	0	0	0
Inertial hold	0	4	-	-	-

TABLE III.- IN-PLANE SIMULATION RESULTS FOR SMM

Profile no. Run no.	Profile	Orbiter braking mode	Time, min	SMM plume disturbance (abs. cum.): X,Y,Z lb-ft-sec	Orbiter RCS propellant, lb-mass
1, 39	V-bar	Normal-Z	30	6, [a]$\underline{18}$, $\underline{78}$	315
1, 34		Low-Z	28	1, 4, 8	635
2, 38	V-bar/inertial	Normal-Z	35	8, 12, $\underline{69}$	330
2, 35		Low-Z	28	1, 3, 8	705
2, 48[bc]		Low-Z	24	1, 1, 1	520
4, 3	R-bar	Normal-Z	33	8, $\underline{20}$, $\underline{65}$	350
4, 18		Low-Z	29	1, 2, 4	570
5, 17	R-bar/inertial	Normal-Z	37	5, 7, $\underline{32}$	350
5, 41[c]		Low-Z	29	1, 2, 5	530
3, 27[c]	Inertial	Low-Z	35	1, 1, 5	760

[a] Underlined numbers indicate SMM control authority exceeded.
[b] Run no. 48 is the same as run no. 35 except more efficient braking schedule and lower stationkeeping rates were used.
[c] Same braking schedule and stationkeeping rates.

TABLE IV.- IN-PLANE SIMULATION RESULTS

Run no.	Payload	Profile	Orbiter braking mode	Time, min	Plume disturbance (abs. cum.): X,Y,Z lb-ft-sec	Orbiter RCS propellant lb-mass fwd/aft/total
71	STV	V-bar SK at 150 feet ± 25 feet	Normal-Z	90	0.06, 0.54, 0.02	50/100/150
72	STV	V-bar retrieval from 1000 feet		26	0.51, 3.3, 0.97	118/243/361
81	SPAS-01		Low-Z	36	1.0, 1.0, 1.0	640/210/850
82	SPAS-01		Normal-Z	32	2.0, 46.0, 3.0	180/50/230
81	TRS	Direct approach along LOS from 6000 feet		29	1.8, 1.3, 10.1	267/662/929
66	MMS	Transition from R-bar to V-bar at 1000 feet		33	0, 1.1, 0.7	67/180/247
91	LDEF	V-bar retrieval from 1000 feet	Normal-Z	26	3, 43, 15	52/208/260
92	LDEF		Low-Z	28	0, 23, 1	250/283/533
93	LDEF	R-bar retrieval from 1000 feet	Normal-Z	29	—	116/360/476
94	LDEF		Low-Z	28	0.2, 1.0, 0.5	346/384/730

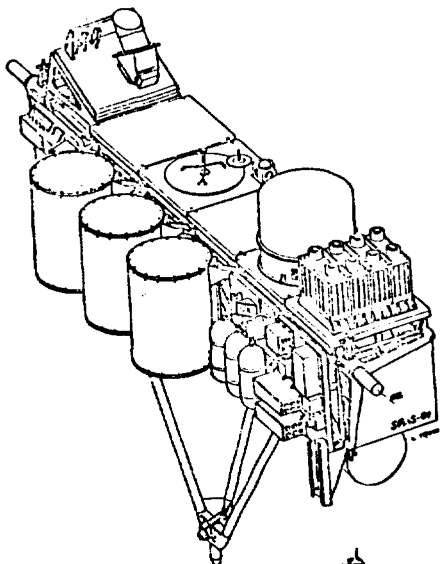
TABLE V.- OUT-OF-PLANE SIMULATION RESULTS FOR SMM

Run no.	Profile/flyaround type	Orbiter braking mode	Time, min	SMM Plume disturbance (abs. cum.): X,Y,Z lb-ft-sec	Orbiter RCS propellant, lb-mass
56	V-bar/2 phase (180°)	Low-Z	47	1,1,7	1 389
58[a]	V-bar/2 phase (180°)	Low-Z	45	1,1,6	1 129
61	V-bar/2 phase (90°)	Low-Z	38	1,1,4	803
59	V-bar/1 phase (180°)	Low-Z	44	1,1,7	1 601
63[b]	V-bar/1 phase (180°)	Low-Z	45	1,1,7	1 480

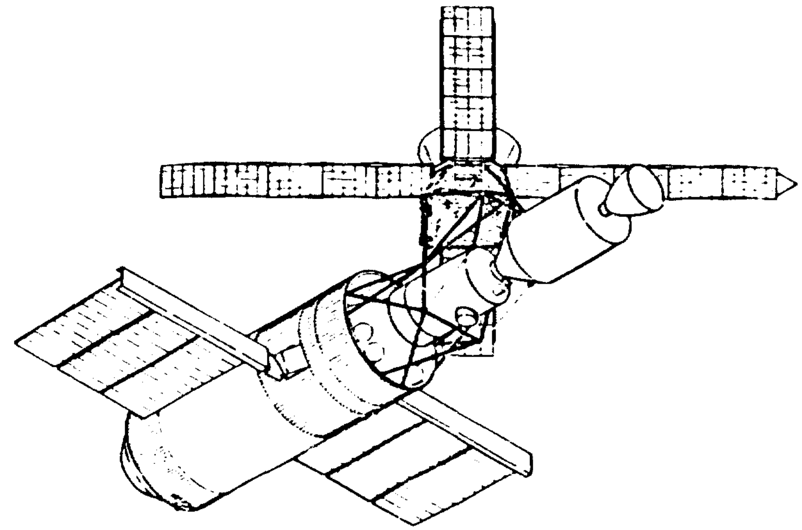
[a] Run no. 58 is the same as run no. 56 except that a more efficient braking schedule was used.
[b] Run no. 63 is the same as run no. 59 except that a more efficient braking schedule was used.

TABLE VI.- OUT-OF-PLANE SIMULATION RESULTS

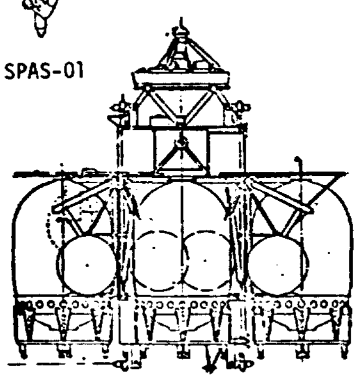
Run no.	Payload	Profile	Orbiter braking mode	Time, min	Plume disturbance (abs. cum.): X,Y,Z lb-ft-sec	Orbiter RCS propellant lb-mass
101	Space telescope	Retrieval from 1000 feet including 180° flyaround at 200 feet (plus 80 minutes of SK)	Normal-Z	133	78, 634, 207	134/420/554
102	Space telescope		Low-Z	129	36, 139, 27	742/803/1545



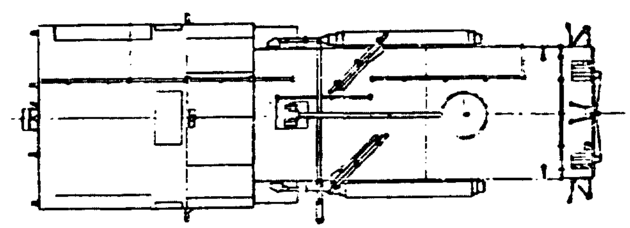
SPAS-01



Skylab



TRS



Space Telescope

Figure 1.- Typical payloads (1).

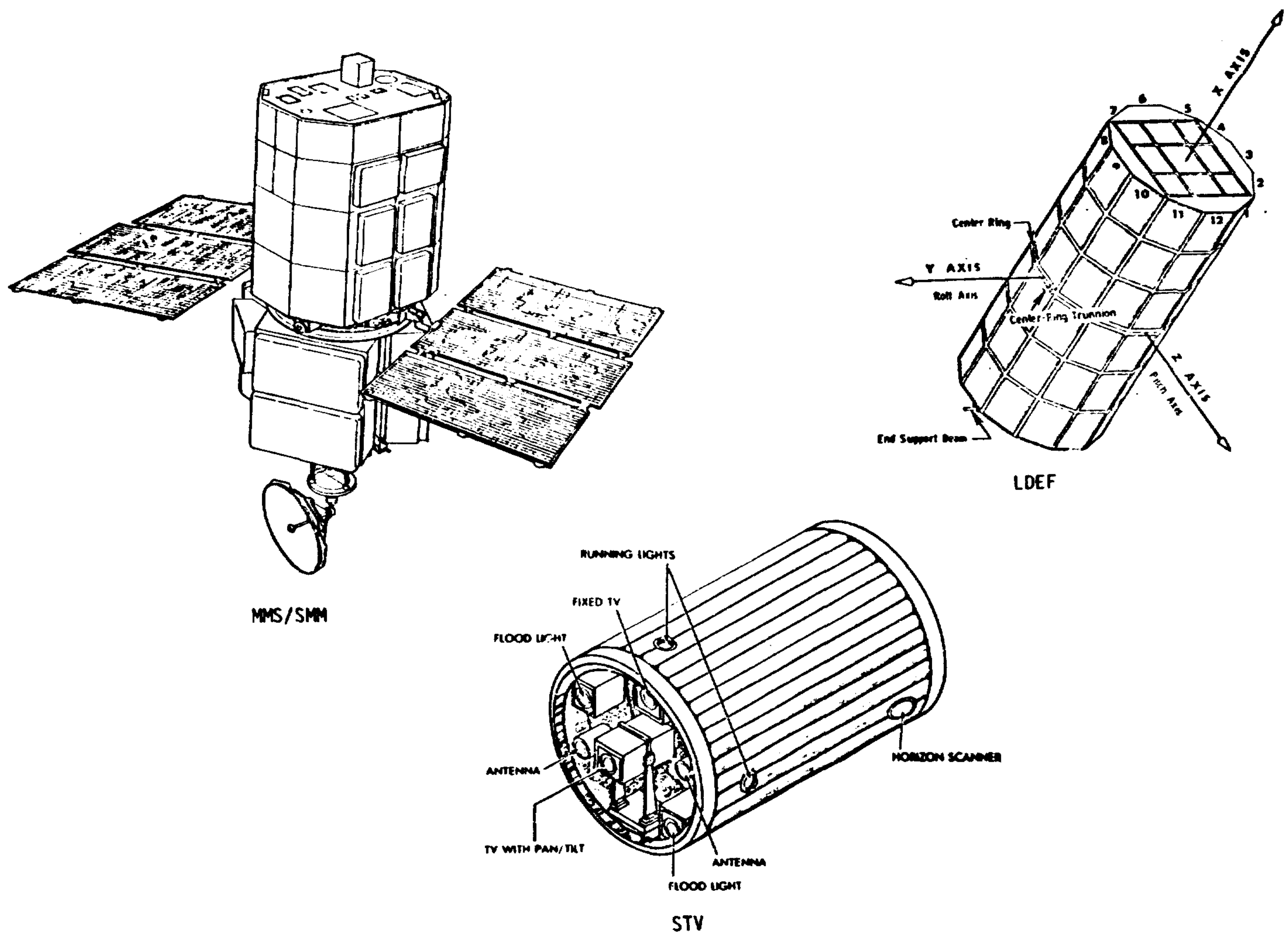


Figure 2.- Typical payloads (2).

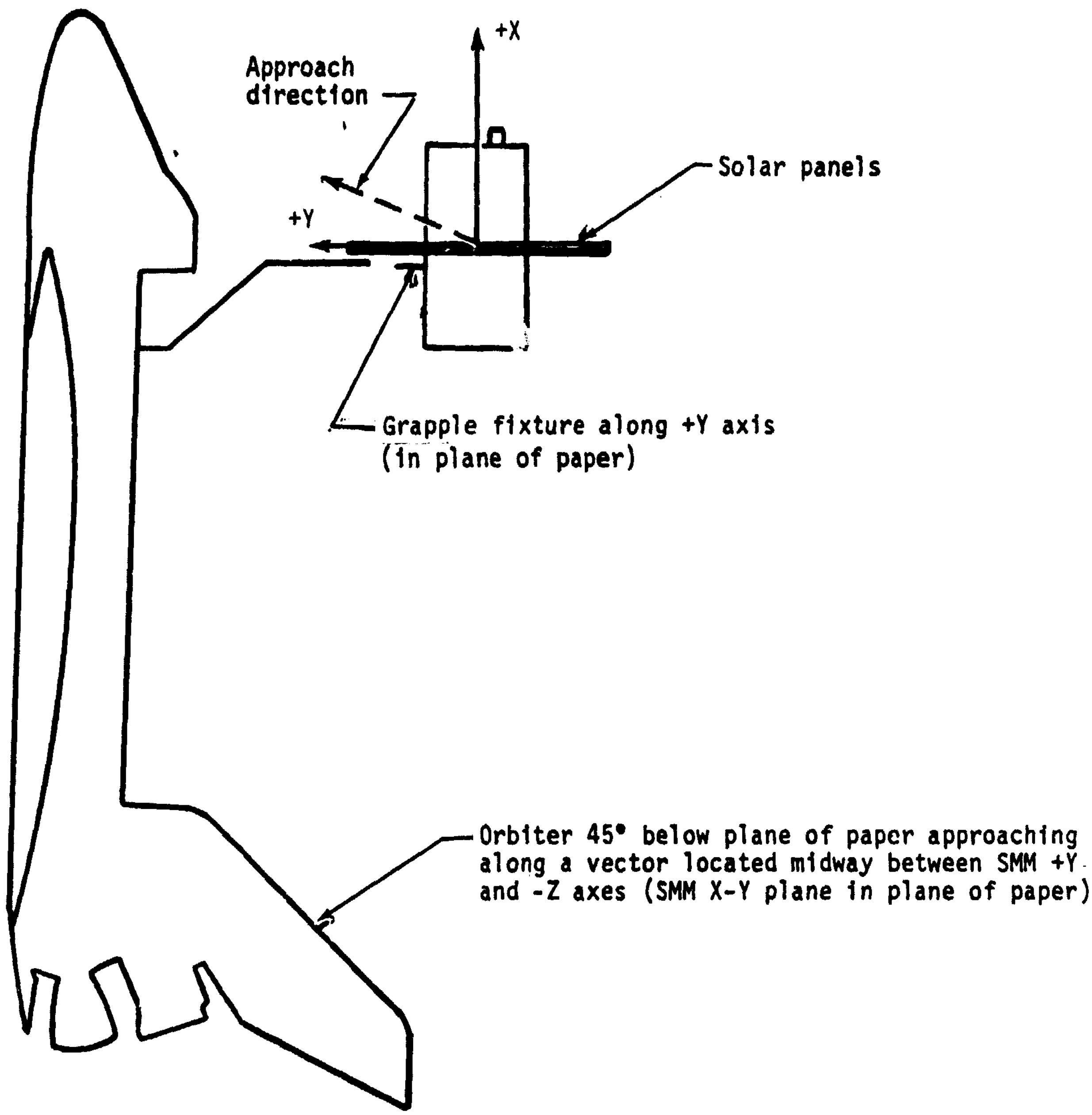


Figure 3.- Desired alinement prior to grapple.

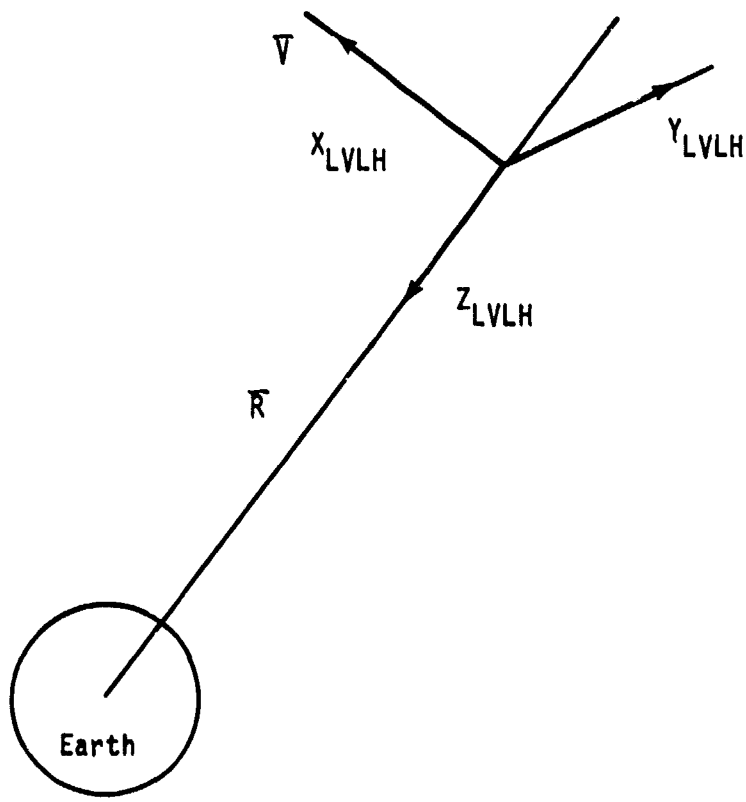


Figure 4.- Local vertical/local horizontal coordinate system.

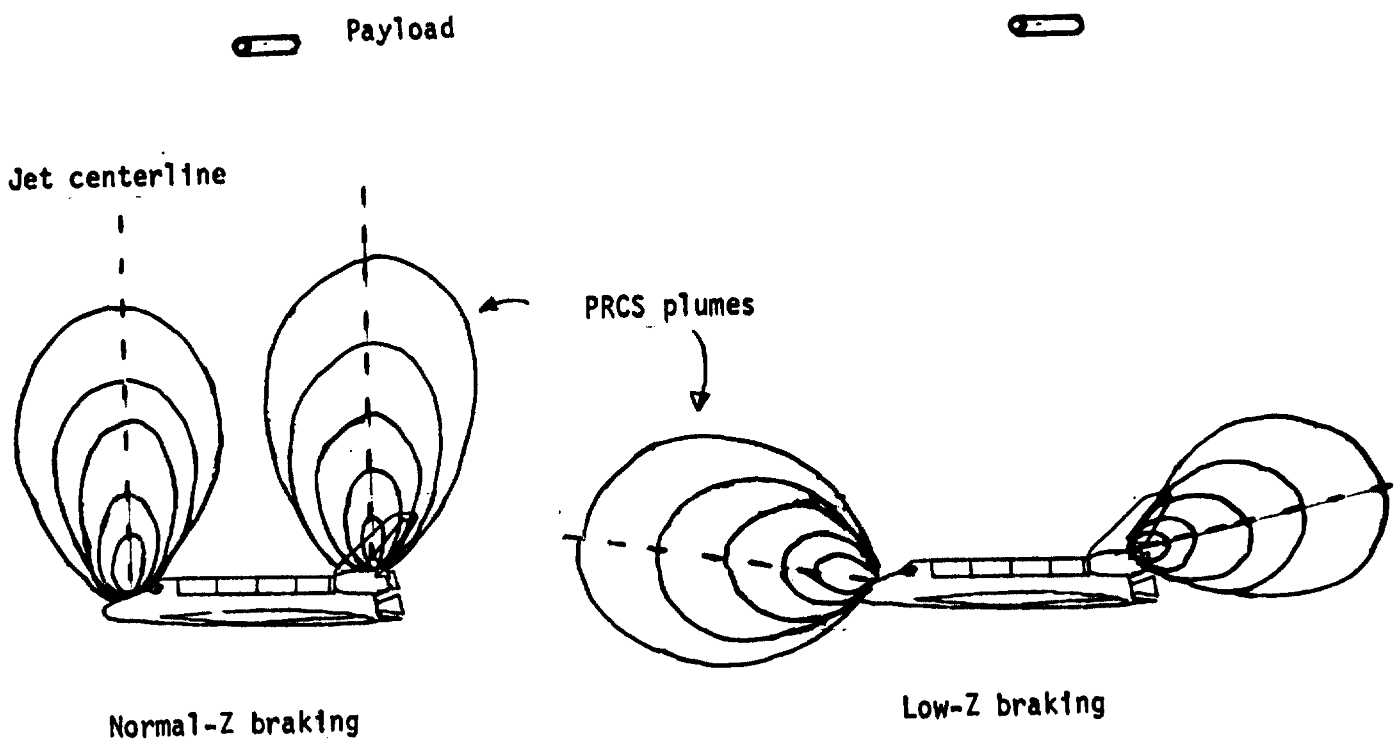
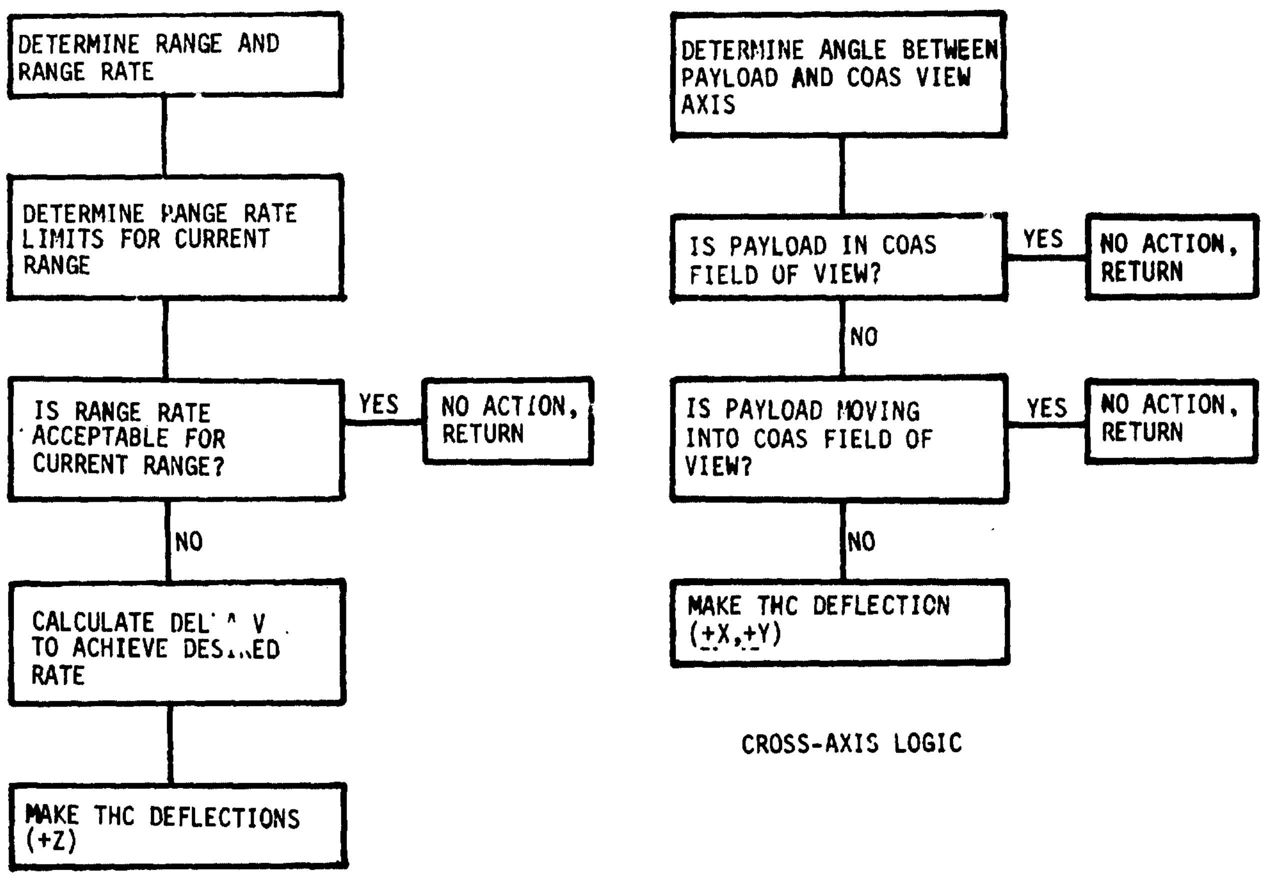


Figure 5.- Braking techniques.



APPROACH-AXIS LOGIC

CROSS-AXIS LOGIC

Figure 6.- Paper pilot logic.

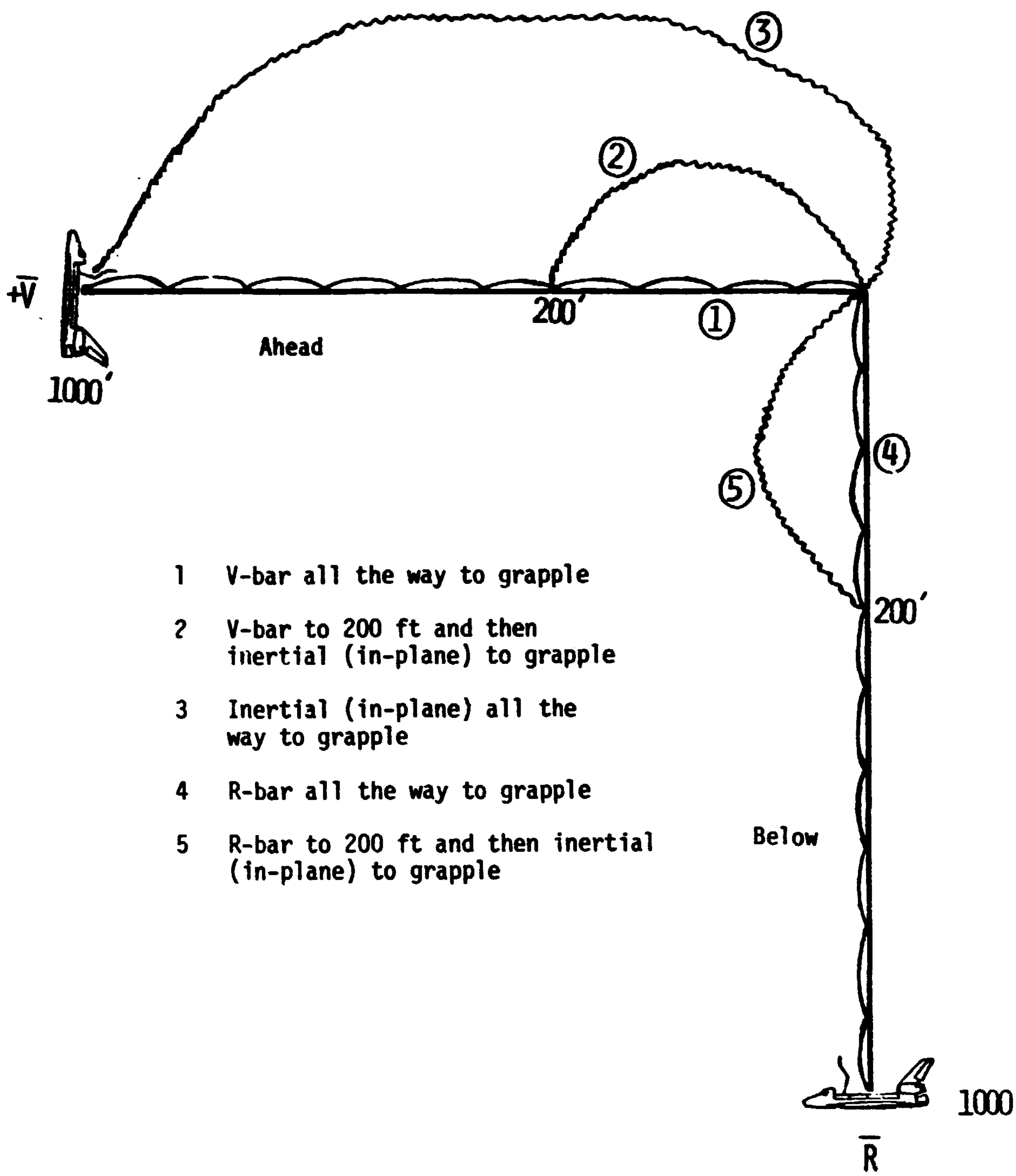


Figure 7.- In-plane approach profiles.

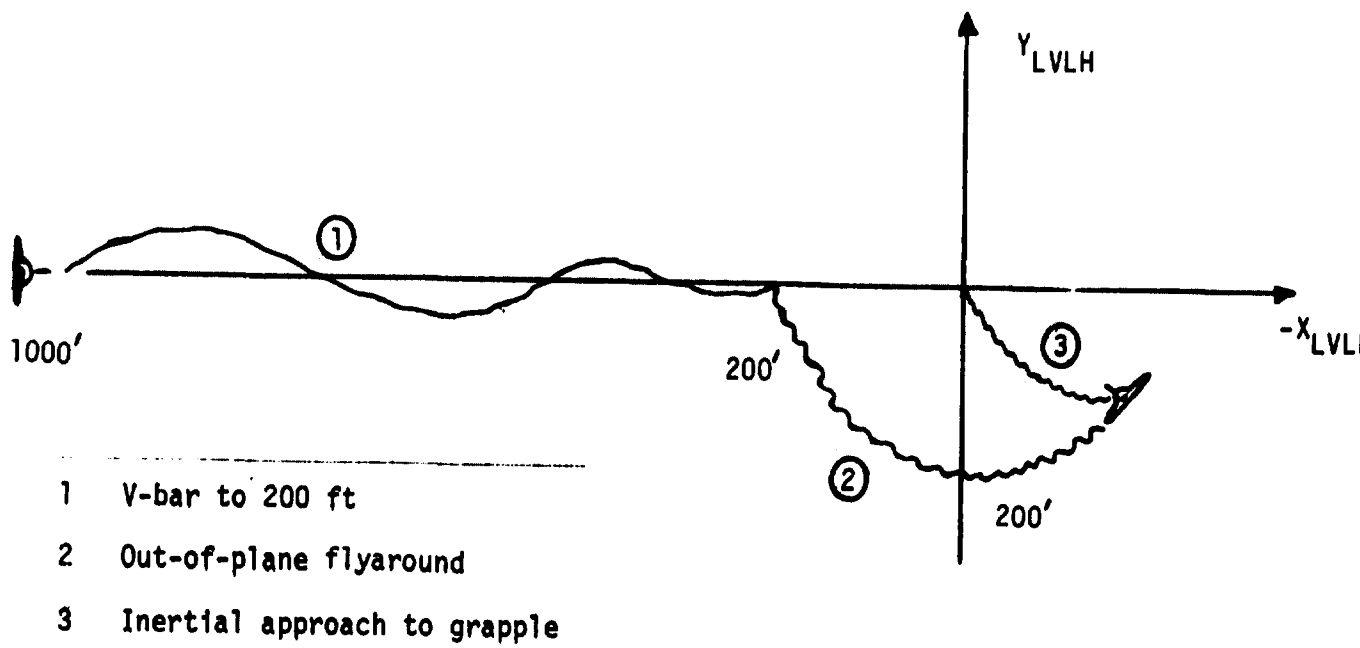
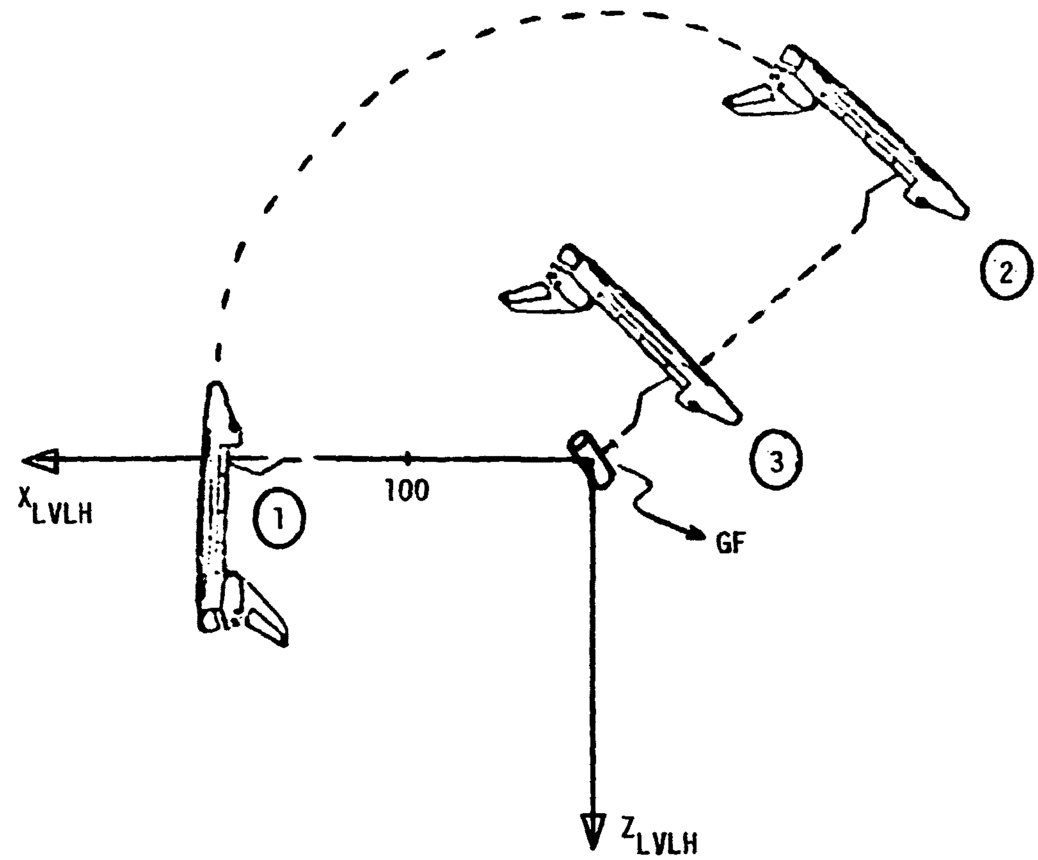


Figure 8.- Out-of-plane profiles.

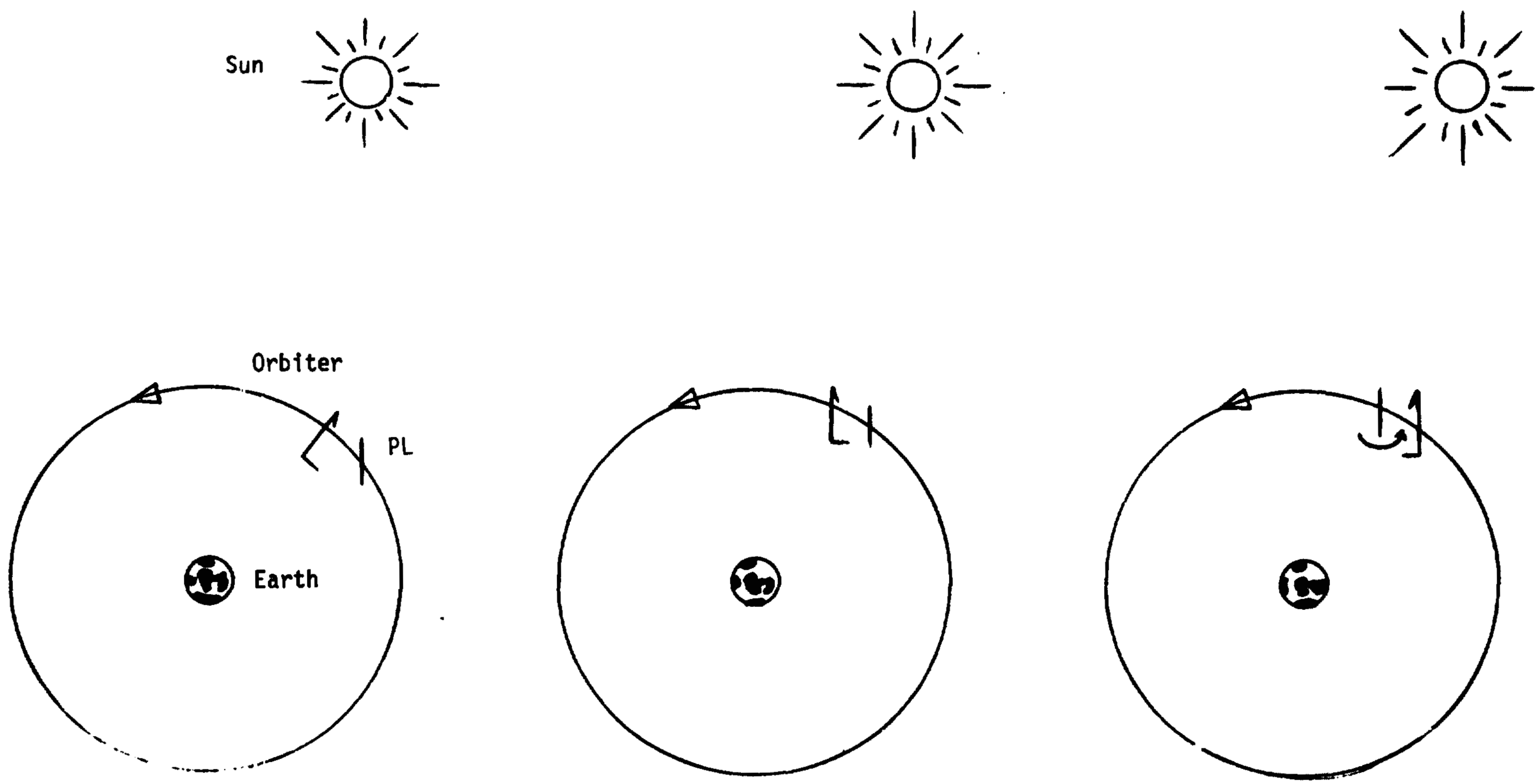


1 At 200 ft begin pitch maneuver to initiate flyaround

2 Visually acquire GF and aline Orbiter and SMM

3 Approach along line-of-sight to 30 ft

Figure 9.- Flyaround and final approach for GF in orbital plane.



Orbiter in LVLH hold with -X axis pointed at center of Earth; PL pointed at Sun.

Phase 1 - Aline +X-axis of Orbiter with +X-axis of PL

Phase 2 - Roll Orbiter and perform flyaround keeping Orbiter X-axis fixed in inertial space

Figure 10.- Two-phase flyaround.

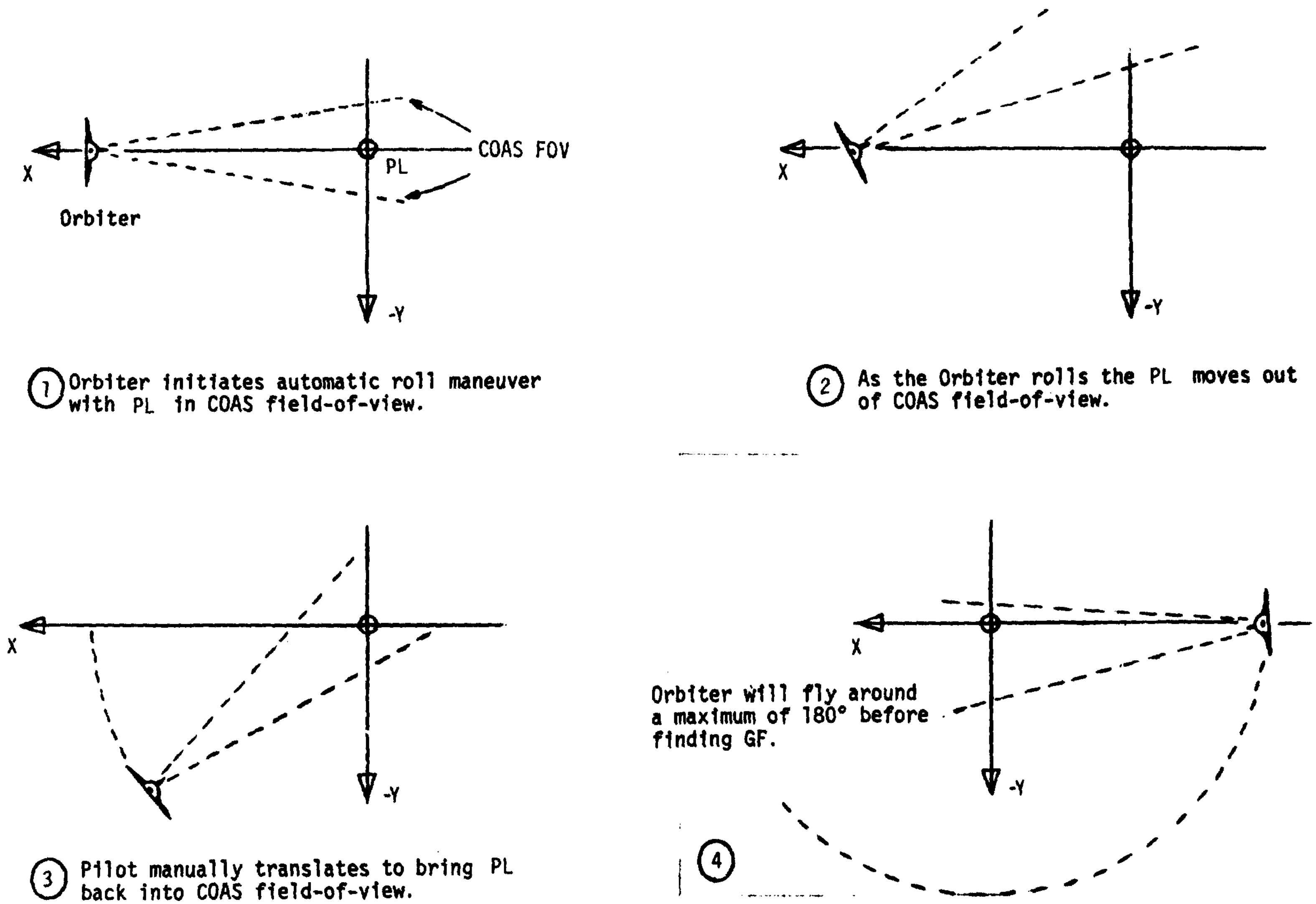
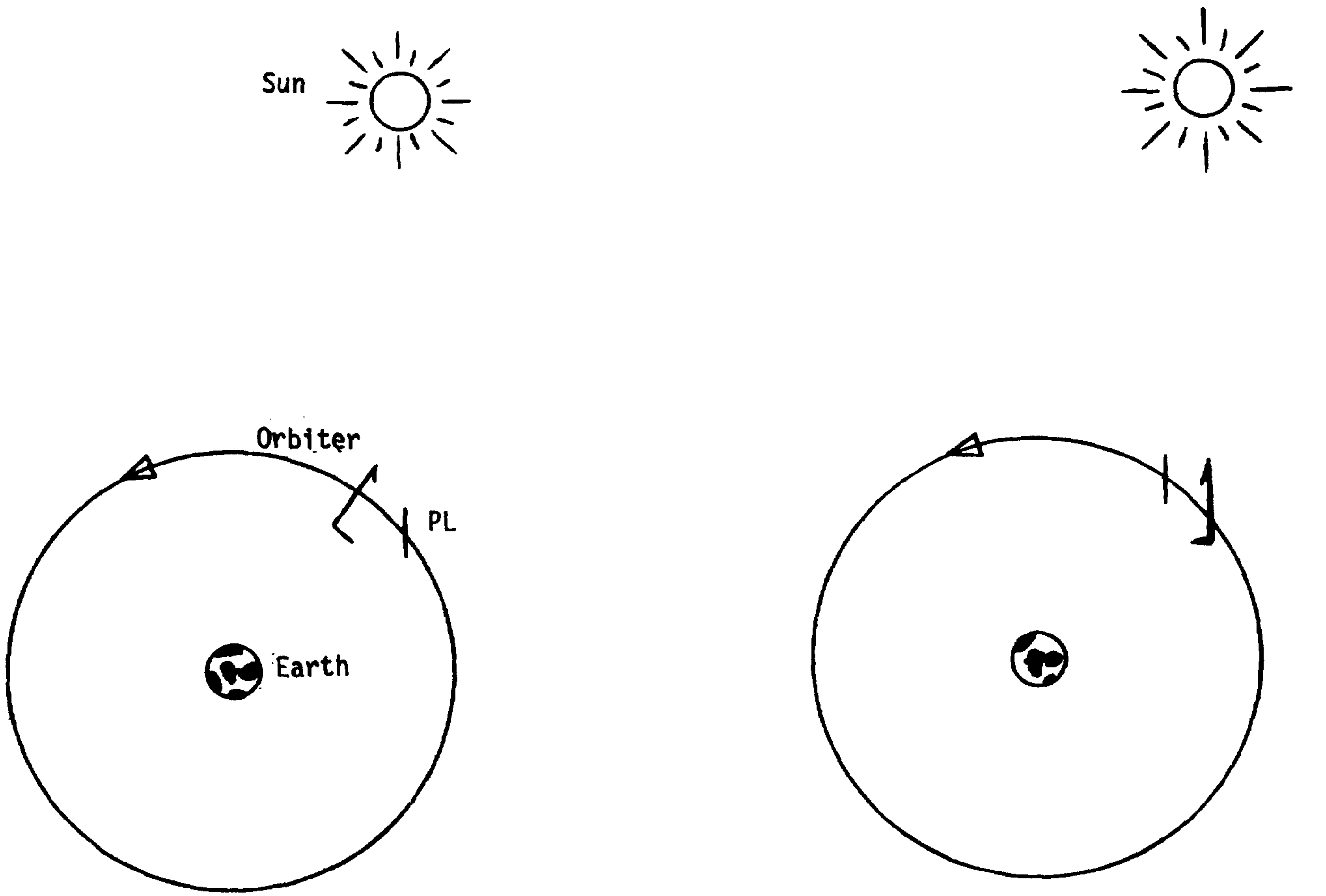


Figure 11.- Automatic roll and manually centering PL in COAS results in flyaround.



Initialize on V-bar with Orbiter in LVLH hold

Phase 1 - A single rotation will result alining X axes and flying around

Figure 12.- One-phase flyaround.

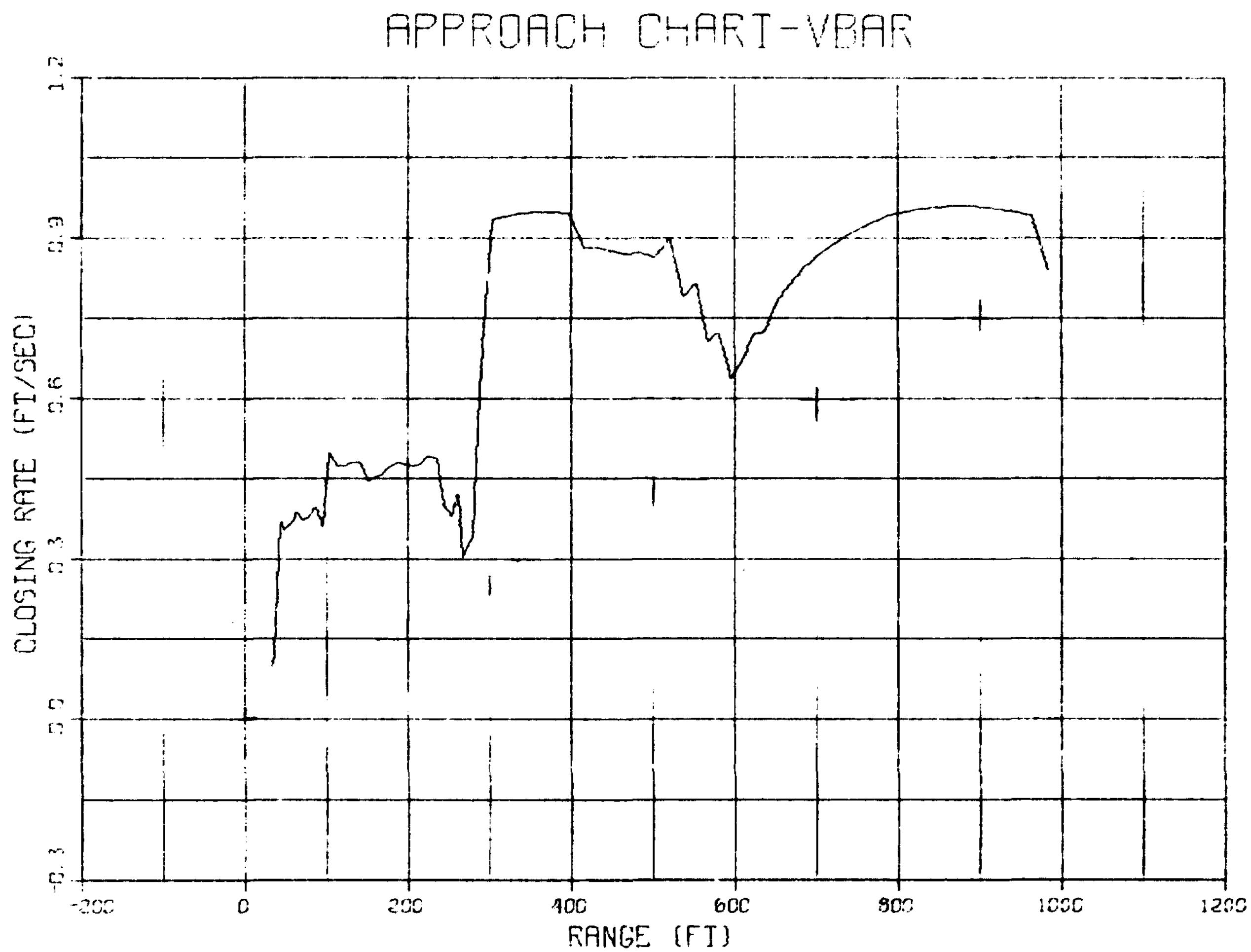


Figure 13.- Approach chart (in-plane profile).

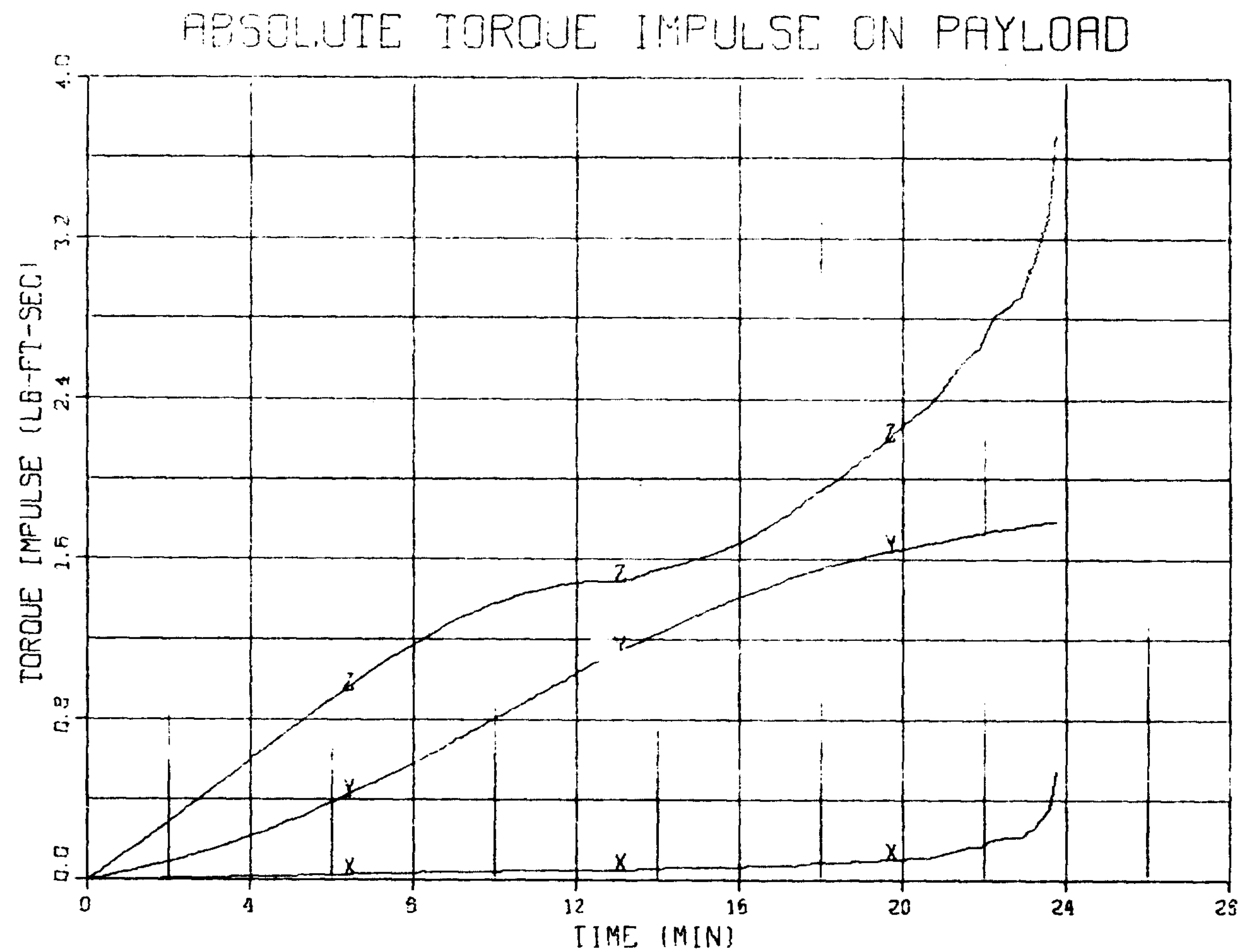


Figure 14.- Torque impulse history (in-plane profile).

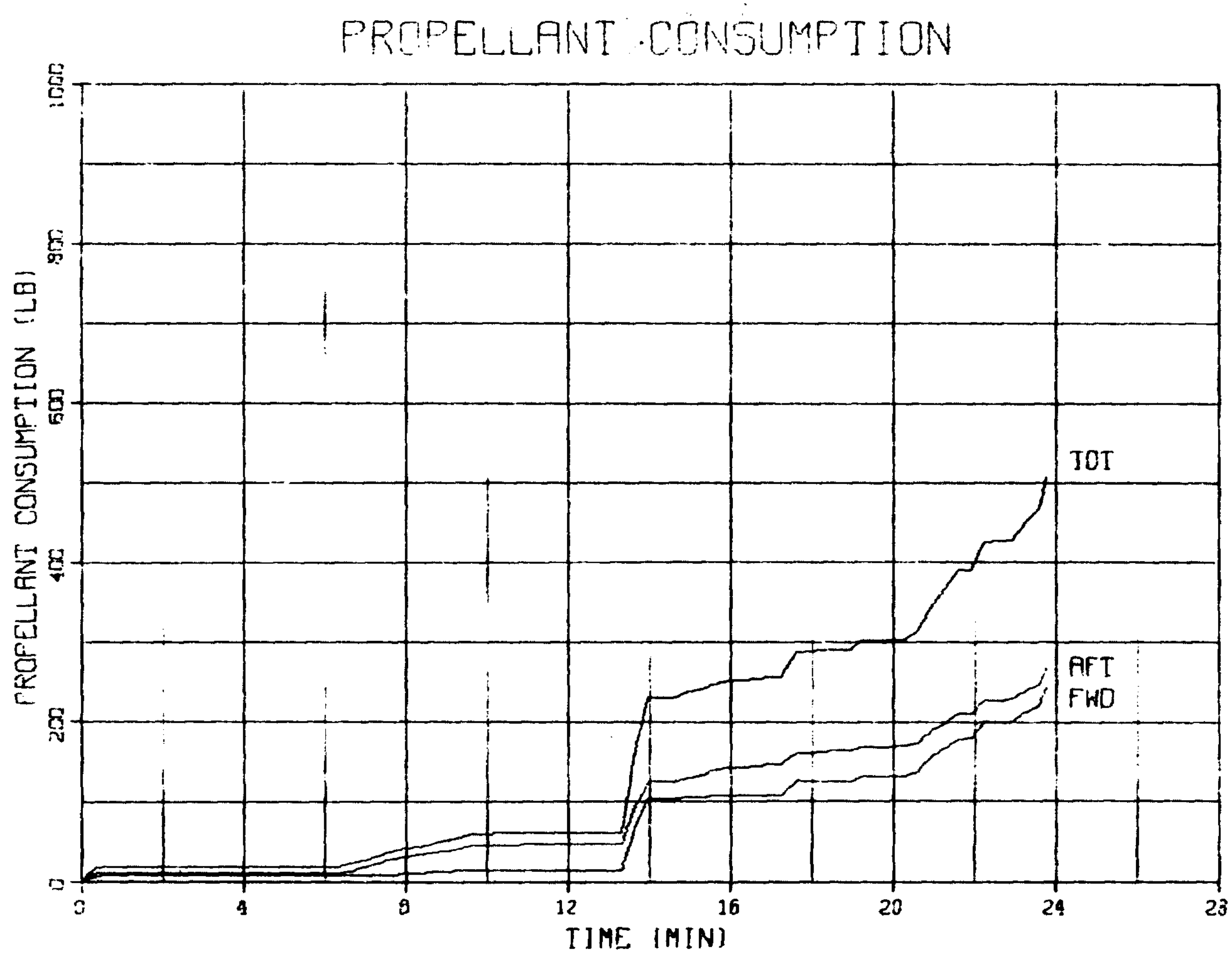


Figure 15.- Propellant consumption (in-plane profile).

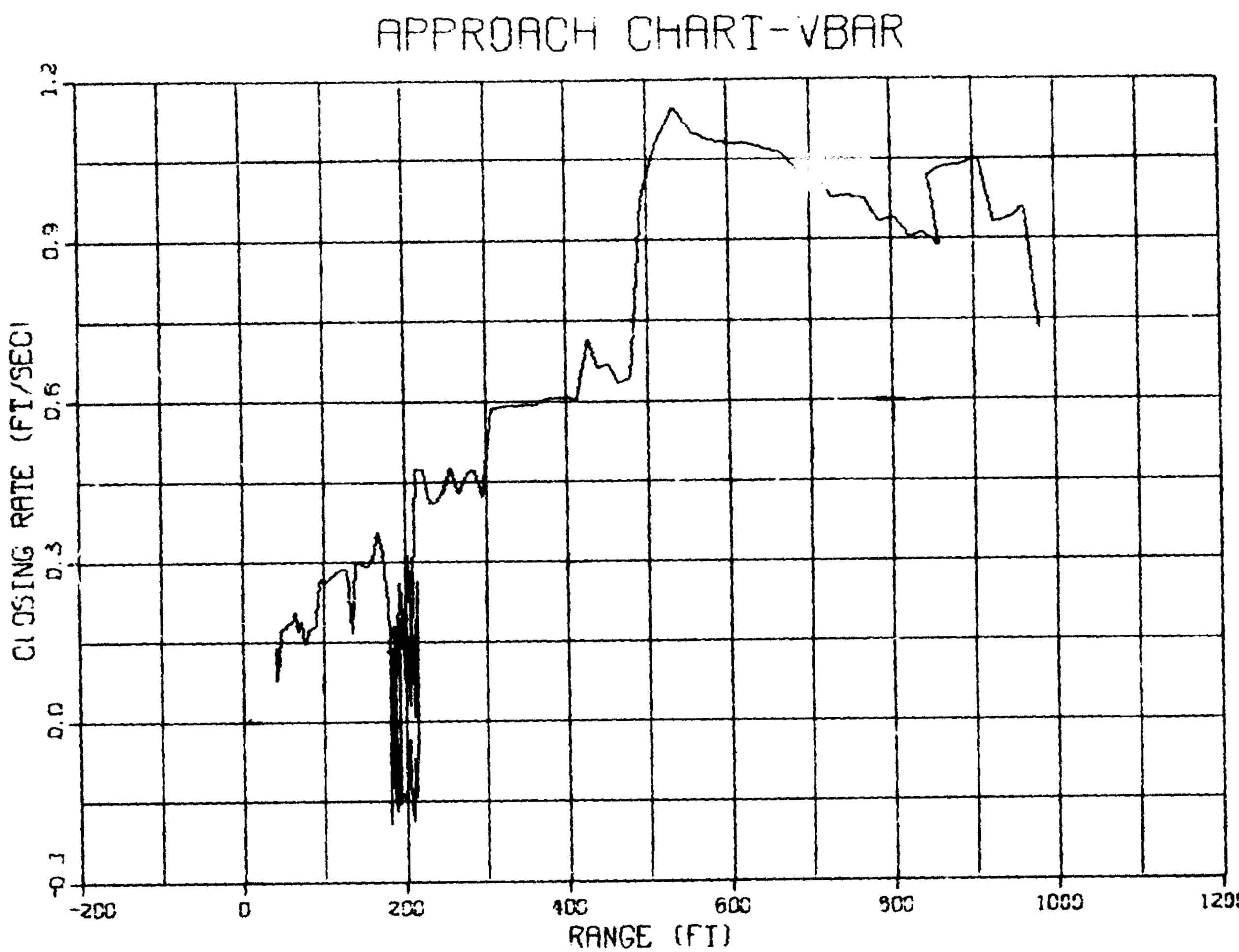


Figure 16.- Approach chart (out-of-plane profile).

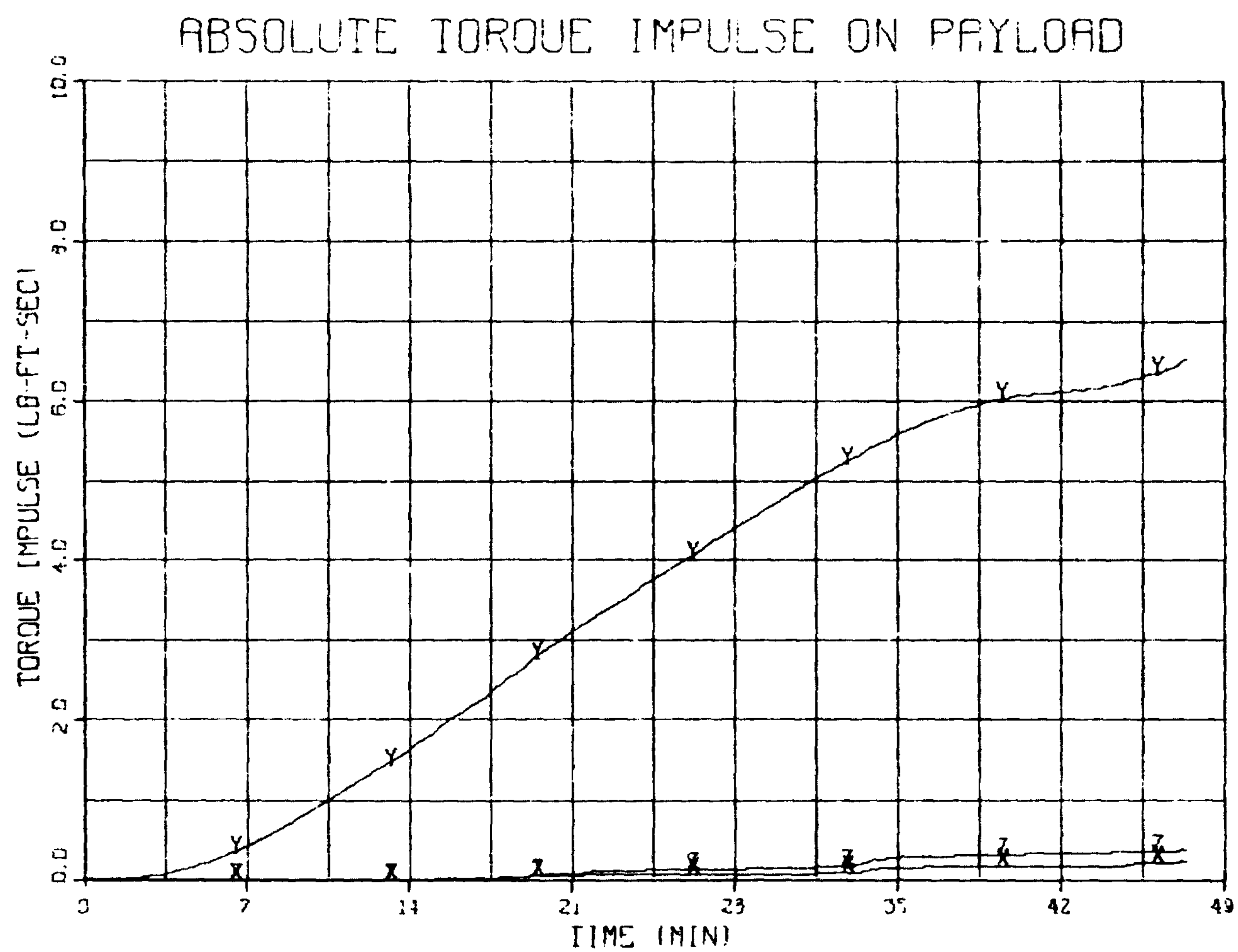


Figure 17.- Torque impulse history (out-of-plane profile).

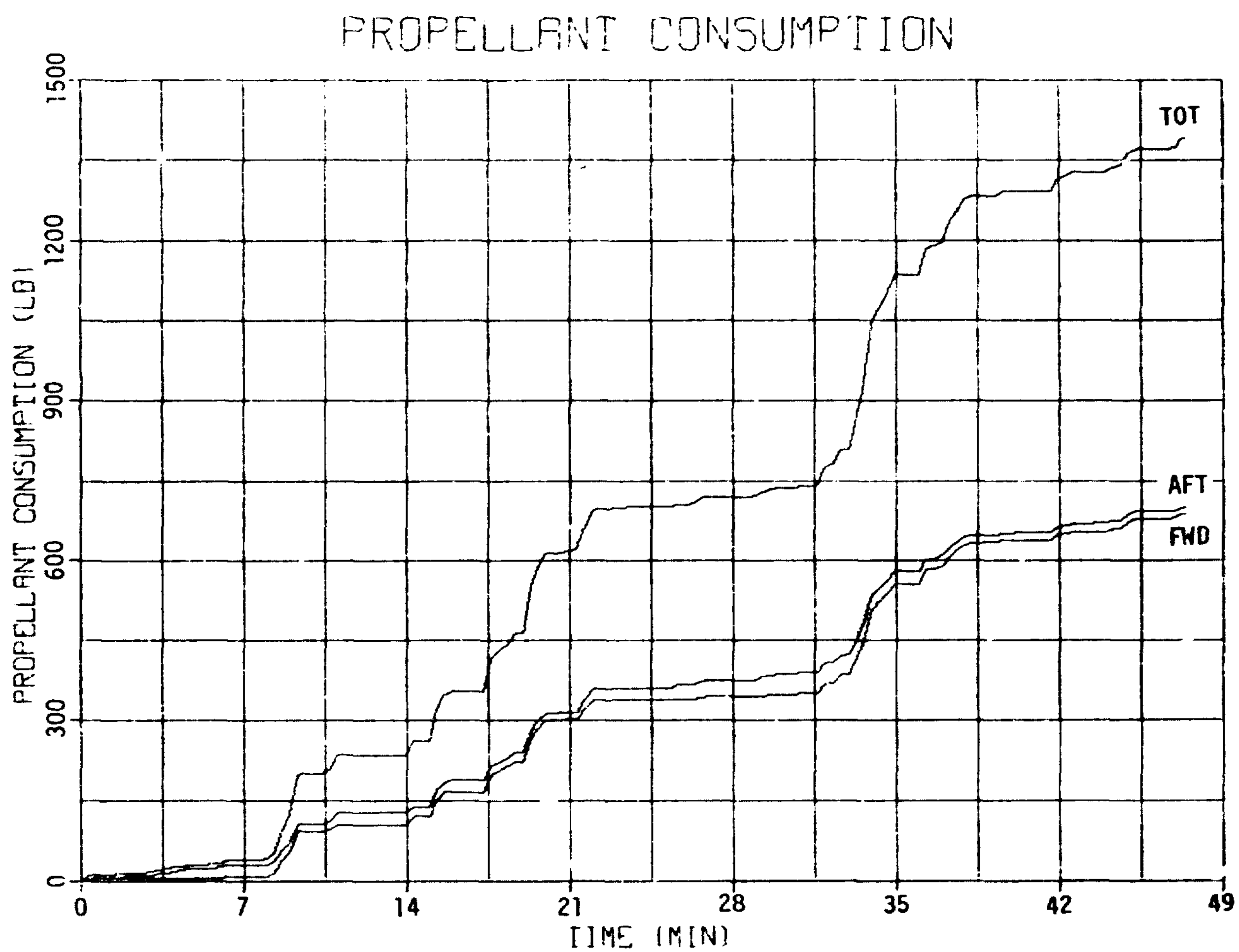


Figure 16.- Propellant consumption (out-of-plane profile).

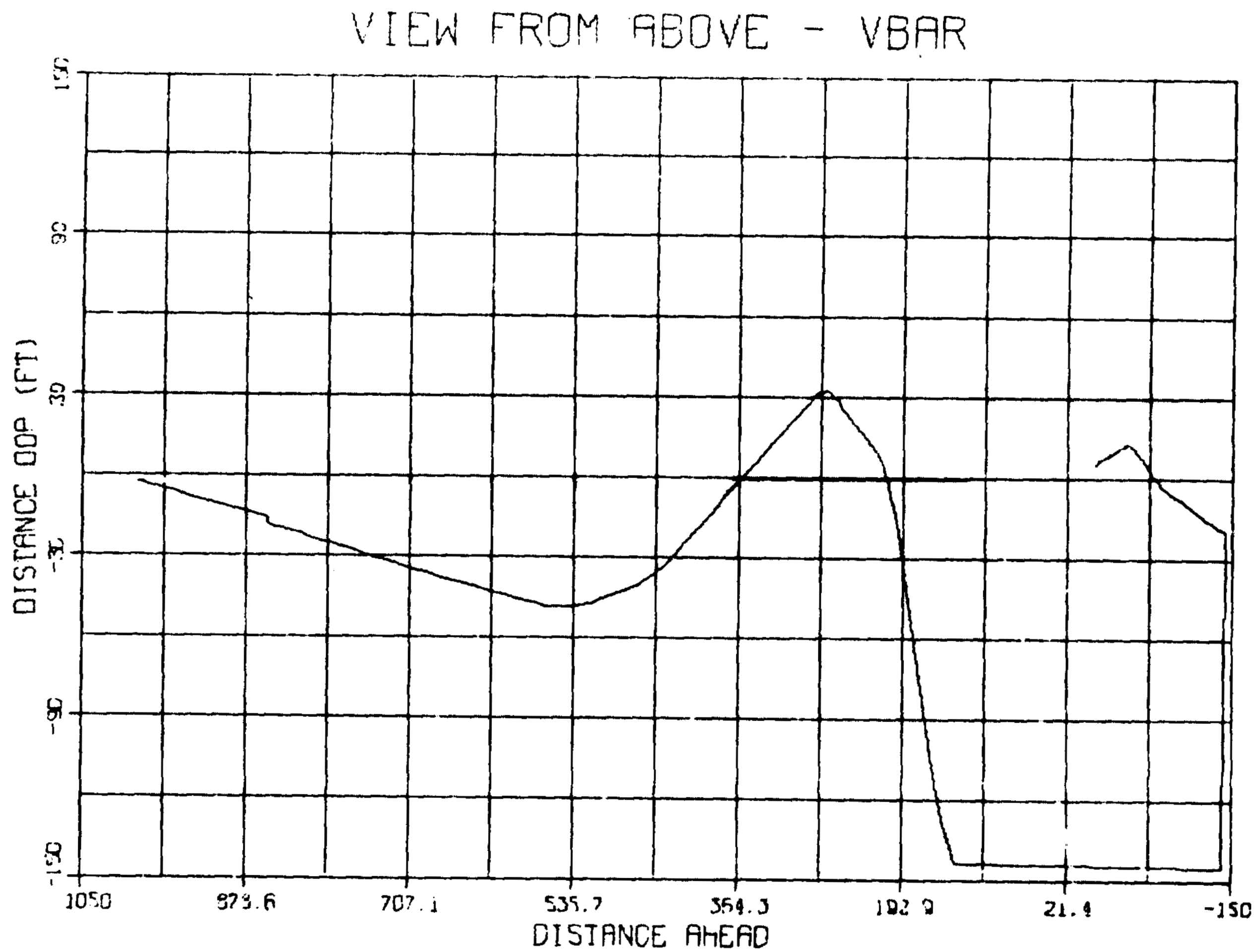


Figure 19.- Third-person view (out-of-plane profile).

U.S. GOVERNMENT PRINTING OFFICE: 1980—671-099/1213