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78-FM-16

JSC-13913

APR 6 1978

Orbiter Payload Proximity Operations SES Postsim Report

Lateral Approach and Other Techniques

Mission Planning and Analysis Division

March 1978

(NASA-TM-79450) ORBITER/PAYLOAD PROXIMITY OPERATIONS SES POSTSIM REPORT. LATERAL APPROACH AND OTHER TECHNIQUES (NASA) 112 p HC A06/MF A01 CSCL 22A

N78-24271

Unclas

G3/16 21268

NASA

National Aeronautics and Space Administration

Lyndon B. Johnson Space Center
Houston, Texas

78-FM-16 JSC-13913

SHUTTLE PROGRAM

ORBITER/PAYLOAD PROXIMITY OPERATIONS SES POSTSIM REPORT

LATERAL APPROACH AND OTHER TECHNIQUES

By Oscar Olszewski
Mathematical Physics Branch

Approved:
Edgar C. Lineberry, Chief
Flight Planning Branch

Approved:
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

March 1978

ACKNOWLEDGMENT

The author gratefully acknowledges the assistance of the following persons in the planning, conduction, and preparation of this report: Mickey Donahoo/FM2, for his overall assistance and coordination of the SES LAT simulations; Sam Wilson/TRW, for his crew procedure suggestion for the tailfirst approach and generation of V-overlays; Brian Sumner and Juanita Dennis/MDTSCO, for the generation of plots from RCS jet firings data on magnetic tapes provided by LEC-SES personnel; and last, but certainly not least, the overall patience, dedication, and professionalism of the SES and flight crews without whose support this analysis would not have been possible.

CONTENTS

TABLES

FIGURES

Figure | Page

ORBITER/PAYLOAD PROXIMITY OPERATIONS
SES POSTSIM REPORT

LATERAL APPROACH AND OTHER TECHNIQUES

By Oscar Olszewski
Mathematical Physics Branch

1.0 SUMMARY

Various approach and stationkeeping simulations (proximity operations) were conducted in the Shuttle engineering simulator (SES) at JSC in the July through September 1977 time frame. This simulator is the first to dynamically include the Orbiter reaction control system (RCS) plume effects on a payload being recovered after rendezvous operations.

Simulation results indicate that standard, Apollo-type braking maneuvers will create severe plume forces on a passive large duration exposure facility (LDEF) payload and cause it to tumble and thus, prevent its recovery. Payloads with small attitude-control systems might have similar problems with this type of direct approach.

A procedure for braking, using the simultaneous firing of both the +X and -X jets, was evaluated and found very useful for proximity operations. However, this procedure is very inefficient in the RCS usage and requires modifications to the digital autopilot (DAP) software.

The final velocity vector proximity approach ($\bar{V}$) and radius vector proximity approach (R) procedures developed in earlier simulations were found adequate for payload recovery if complemented with $\pm$X jet braking. Without $\pm$X jet braking, recovery with V is zero percent and with $\bar{R} \approx 50$ percent.

A new final approach, the lateral approach technique (LAT), or the momentum vector proximity approach ($\bar{H}$), was also evaluated in the simulations. When complemented with $\pm$X jets, the LAT was found to be adequate from a plume effects point of view. The LAT, which included a tailfirst approach for braking, was evaluated successfully with both inertial and gravity stabilized payloads. No simulations were conducted on the LAT without $\pm$X jet braking capability.

2.0 INTRODUCTION

Various approach and stationkeeping simulations (tables 1, 2, 3, and 4) were conducted in the SES in building 16 in the July through September 1977 time frame. The SES is the first man-in-the-loop high fidelity simulator where RCS plume impingement effects on the payload, an area of great concern during proximity operations, are incorporated in the close proximity environment.

A hybrid simulator with very sophisticated color scene generation equipment, the SES includes a high fidelity simulation of the Orbiter's attitude-control system including the DAP, main and vernier RCS systems, and the interacting dynamics of the Orbiter vehicle. The simulator's equations of motion for rotation and translation included the perturbative effects of various other models. These include drag, RCS plume fields and effects, gravity and gravity-gradient torques, rendezvous radar error models, closed circuit television (CCTV) cameras with realistic out-the-window scenes, and other models for adequate payload operations from the aft crew station cockpit. The SES does not presently have onboard computer/DSKY/CRT capability.

The overall objectives of the approach and stationkeeping simulations were to evaluate the RCS plume effects on the direct $\bar{V}$ and $\bar{R}$ approach schemes and to bring LAT ($\bar{\text{or}}$ H), which had been proposed as an additional candidate approach technique, up to the same level of maturity as the other candidate techniques. This new technique consisted of approach from an out-of-plane direction. Other objectives were: (1) feasibility of crew techniques proposed, (2) propellant usage of RCS, (3) potential time line impacts, and (4) Orbiter hardware and software modifications resulting from the viable techniques of the SES simulations.

3.0 ACRONYMS

ADI	attitude direction indicator
CCC	cross-coupling compensation (RCS)
CCTV	closed circuit television
CG	center of gravity
C/O	contamination/overpressure
COAS	crew optical alinement sight
DA	direct approach
DAP	digital autopilot
FAI	final approach initiation
fx, fy, fz	continuous force or thrust along the X_{LH}, Y_{LH}, or Z_{LH} axis

H	altitude, feet or n. mi.
$\bar{H}$	momentum vector (LAT) proximity approach
ΔH	delta altitude, feet
HP	Hewlett Packard
LAT	lateral approach technique
LDEF	long duration exposure facility
MPAD	Mission Planning and Analysis Division
OMS	orbital maneuvering system
PDRS	payload deployment retrieval system
PRCS	primary reaction control system
PYR	pitch, yaw, roll - degrees
q,r,p	pitch, yaw, roll rates - deg/sec
R	range, ft
$\dot{R}$	range rate, fps
$\bar{R}$	radius (LVLH) vector-proximity approach
RCS	reaction control system
Re	Earth radius, feet
RHC	rotation hand controller
RMS	remote manipulator system
SES	Shuttle engineering simulator
SK	stationkeeping
THC	thrust hand controller
$\bar{V}$	velocity (LVLH) vector-proximity approach
W	orbital rate, rad/sec
X_B, Y_B, Z_B $\dot{X}_B$, $\dot{Y}_B$, $\dot{Z}_B$	Shuttle body referenced state vector (ft/fps)

X_{LH}, Y_{LH}, Z_{LH} $\dot{X}_{LH}$, $\dot{Y}_{LH}$, $\dot{Z}_{LH}$	relative, rotating, right handed state vector centered at the target CG. X_{LH} points towards the local horizontal plane in the direction of motion; Z_{LH} points to Earth's center; Y_{LH} completes triad (ft/fps)
X_{LHO}, Y_{LHO}, Z_{LHO}	initial value of X_{LH}, Y_{LH}, Z_{LH}
X_T, Y_T, Z_T	desired target vector (LVLH) at time = t

4.0 ANALYSIS RESULTS

4.1 LAT - GENERAL

As stated before, the LAT was run in the SES environment for the first time in the third payload deployment/retrieval system (PDRS III) simulations. Several simulator problems peculiar to out-of-plane operations had to be corrected initially before a LAT simulation would be considered satisfactory. The two main problems were the ADI (attitude direction indicator) or "8-ball" and its singularity at yaw = 90 degrees Euler angle and intermittent scene roll problems for the payload. A working ADI was required for pitchover maneuvers. The scene roll problem, which was never completely fixed but improved to make it tolerable, consisted of an intermittent, unpredictable, and dynamically fictitious (but optically real) roll of the long duration exposure facility (LDEF) payload. This created a problem for stationkeeping operations in that the grapple fixture (spike) features, which were monitored by the CCTV camera, would appear to move because of the payload fictitious roll. Therefore, the LAT stationkeeping data should be used with caution.

4.1.1 LAT Procedure

The type A procedure was initialized after pitchover. The types B and C LAT cases were initialized approximately 6 minutes after final approach initiation (FAI) (refs. 1 and 2). Because three approach velocities were investigated, three basic initial conditions with typical and expected FAI dispersions were used. The dispersed type B case represents a typical case where the midcourse was not executed and the crew elected to manually continue the trajectory from then on.

The tailfirst manual phase was simulated in two parts. The first procedure was initiated after pitchover (type A) with the Shuttle Orbiter already at the proper attitude and the crew controlling the spacecraft using the V-overlays in the CCTV and starboard aft window (figs. 11 to 14) plus the thrust hand controller (THC) for translation control. These simulations are classified as type A on column 5 of table 5. The quick summary for the type A runs are listed in table 6 as the "tailfirst only" data. The second part, or type B simulation, of column 5 in table 5 (also see fig. 1) consisted of a type A case plus a crew optical alinement sight (COAS) phase where the crew corrected the dispersions using the COAS reference and pitched over to the tailfirst attitude by a crew controlled manual pitchover maneuver. The quick summary data in table 6 also includes the most important parameters that characterize the approach procedure; i.e., time to execute the approach phase simulated, RCS pounds used including forward/total, torque impulse on payload, tail-miss distance (if applicable) and final payload attitude to determine dynamic disturbances induced by the RCS plumes during the case in question.

Type C is not a tailfirst approach. Instead of pitching over after removing the dispersions, the Orbiter line of sight (LOS) to the target was controlled from the -Z COAS optical reference by the crew as a $\overline{V}$ approach. At a safe distance, the Orbiter was braked by the simultaneous firings of the $\pm X$ jets. Even though the resulting stationkeeping position from a type C case is not theoretically as stable as a type A or B tailfirst case, it was determined in the SES that stationkeeping after a type C approach is not difficult for 15 minutes or less. The type C results for plume impingement seem to be somewhat better than a comparable $\pm X$ jet $\overline{V}$ approach. This is probably because of the relative attitude differences of both configurations and the less demands on RCS firings for a LAT type C as opposed to $\overline{V}$ because of orbital mechanics.

For the type B tailfirst procedure, the Orbiter was initialized at FAI + 6 minutes at the COAS phase relative attitude. The crew was told to remove the trajectory dispersions, if any, and pitchover 83 degrees to the tailfirst attitude. The sense switch was changed from -Z to -X and the remaining payload dispersions were removed using the THC and the V-overlays on the CCTV and starboard aft window. The "fly to" spacecraft procedure was used. Because the rendezvous radar is not available after pitchover and because it was known that $+\dot{Z}_b$ translations with the downfiring jets would cross-couple heavily into $+X_b$ and reduce the Orbiter's closing range rate, $\dot{R}$ ($\dot{Y}_{LV}$), the crew was told to enter a $-X_b$ pulse for every $+Z_b$ pulse entered to manually compensate and maintain the desired closing rate (fig. 2). Failure to do this manual compensation would result (and did in fact result) in the approach velocity ($\dot{R}$) being reduced to almost half its normal value.

After pitchover the crew again removed the remaining trajectory dispersions using the THC and V-overlays (the CCTV was tilted 14 degrees and zoomed until the two horizontal scribe marks were exactly over the tail tip and orbital maneuvering system (OMS) pod tip line). The CCTV was now considered calibrated (see fig. 1) and the crew was told that when they approximately reached the first "goalpost" (an H-mark on the V-overlay), as signified by the payload width matching the width of the H-mark, they should be alined fairly close to the middle or reference dashed V-line and tracking it at the right slope. At this point, the payload would be about 100 feet behind the tail and about 200 feet from the braking point. A crewmember then informed the SES operator that he was at the goalpost and the operator set some external switches that disabled the upfiring jets and enabled the $\pm X$ jet braking for $-\dot{Z}_b$ translations by the THC. At this point, all translation control was terminated (except emergencies) and the payload was monitored in the V-overlays as it drifted over the Orbiter's tail into the braking zone. See figures 3(a) through 3(l) for the relative motion in this phase.

As the payload moved between the first and second goalpost, the crew monitored the payload motion (or drift) and for the few cases that resulted in near-misses or collisions, they elected to continue the drift to get a feel for the collision potential (see fig. 4). However, it should be pointed out that in a real flight these approaches would have been aborted. When the payload appears over the overhead window the sense switch was changed back from -X to -Z and Dapload B was selected with X translation set to "normal" with Y and Z remaining at "pulse" in preparation for the +X braking. After the braking was accomplished, all residual velocities were nulled (X back to "pulse") with the aid of the aft CCTV camera that zoomed in and focused on the steel spikes of the grapple fixture - an obvious two-man operation at this point. When the velocities were nulled the crew entered into stationkeeping. For those cases where stationkeeping data were required, an RCS propellant check was done (temporary stopping of the simulation to print RCS propellant data and relative state vector end conditions) prior to continuing with the stationkeeping. These data can be compared with cases in reference 3. The stationkeeping simulation was then continued as long as required.

It was observed in all cases for which RES jet firing tape data is available (fig. 5) that the crew had no problem in removing the payload position dispersions with the aid of the COAS before pitchover or the V-overlays after pitchover. In fact, the 30 to 60-foot position dispersions were removed in 2 to 5 minutes and the payload was brought to the nominal dashed V-line. This can best be observed in the complete relative motion plots (figs. 5(a) through 5(t)) for several typical LAT cases. Residual velocities at distances greater than 400 feet were apparently more difficult to ascertain and position overshoots resulted. At closer distances the residual velocities were easier to pick up by the crew and were nulled. At the first goalpost velocity residuals were easy to track (as shown in table 5, columns 28 to 33), which gives the relative state vectors (both position and velocity) for the first and second goalpost plus the final stationkeeping end condition. Table 5, column 29 shows that the velocity residuals for state vectors $\dot{X}_{LH}$ and $\dot{Z}_{LH}$ were usually less than 0.1 fps, which would normally result in a safe, noncollision trajectory. In column 29 $\dot{Y}_{LH}$ should be -1.0, -2.0, or -3.0 fps, depending on the desired final velocity. The ideal relative state vectors at the first goalpost, second goalpost, and final stationkeeping position for the V-overlays used in the SES would be as follows:

First goalpost		Second goalpost	
Column 28	Column 29	Column 30	Column 31
X = -52	$\dot{X}$ = 0	X = -52	$\dot{X}$ = 0
Y = 150	$\dot{Y}$ = -1, -2, [a]-3	Y = 50	$\dot{Y}$ = -1, -2, [a]-3
Z = 0	$\dot{Z}$ = 0	Z = 0	$\dot{Z}$ = 0

[a]$\dot{Y}$ should be -1.0, -2.0, or -3.0, as desired.

Final stationkeeping	
Column 32	Column 33
X = -52	$\dot{X} = 0$
Y = -30 to -40	$\dot{Y} = 0$
Z = 0	$\dot{Z} = 0$

[a]Y should be -1.0, -2.0, or -3.0, as desired.

Table 5, columns 29 and 31 shows that $\dot{Y}_{LH}$ was frequently much less than desired. In fact, table 5, columns 20 and 21 gives exactly the final velocity desired and the actual velocity. In some cases, the actual velocity is less than one half the desired velocity. The reason for this is $+\dot{Z}_b$ pulses cross-coupled into $+\dot{X}_b$ when dispersions were taken out by the crew and no $-\dot{X}_b$ pulses (to compensate for this RCS cross-coupling effect) were entered by the crew. As a net result, the closing velocity was reduced substantially and, in fact, for some of the slower approach velocities, the Orbiter "stalled out" to almost a standstill (case 35H (sequence 216)) until the crew added some $-\dot{X}_b$ pulses to continue the approach. This essentially proved that if no manual compensation is added and if the desired closing rate is less than 1 fps, trajectory deviations will occur with undesirable and dangerous drifts towards the tail and there is a collision potential.

Other interesting data columns in table 5 are columns 34, 35, and 36. Column 34 gives the height change in feet from the first goalpost to the second goalpost (where the payload is essentially over the Orbiter's tail). A negative number denotes a height drop. Columns 35 and 36 denote the miss distances for the tail and cockpit, respectively. This same data is more vividly displayed in figures 3 and 4. Only one tail collision (case 13H (sequence 192)) occurred for a stalled 1 fps approach. Three cockpit collisions occurred: case 13H (sequence 192), case 15H (sequence 195), and case 34H (sequence 215). The first two collisions were also 1 fps approaches; the latter was a 3 fps familiarization approach where apparently a large closing residual velocity of 0.475 fps for $\dot{X}$ was not nulled by the pilot at the first goalpost and even though it cleared the tail satisfactorily, it nevertheless crashed into the cockpit because of procedure limitation (see section 3.2, case 34H). Near-misses (less than 7 feet, which is the lower V-control line and the SES overlay) occurred three times (case 15H (sequence 195)) and later collided with the cockpit (case 21H (sequence 201) and case 32H (sequence 213)). All collisions and near-misses could have been avoided by using V-overlays that would give greater tail clearances than those used in this SES simulation. (See proposal in section 6.0 and also see figures 10, 13, and 14.)

Other important parameters in table 5 are column 17 - RCS used for total = T, forward = F, and aft = A; column 18 - torque impulse in ft-lb-sec imparted to payload from RCS plumes; columns 22 to 25 - payload attitude and rates, both initial and final, to determine dynamic effects on payload because of plumes. It can be seen in column 23 that, with two exceptions, all LAT cases resulted in payload attitude changes of less than 1 degree. The exceptions were:

a. In the inertial cases (case 19H (sequence 199), case 30H (sequence 211), case 41H (sequence 223), and case 42H (sequence 224)), where both vehicles were at an inertial attitude, the pitch, yaw, roll (PYR) angles (given in the SES printout as columns 22 and 23 of table 1) must be transformed to determine the Δ attitude deviation during the approach created by the RCS plumes. When determined, the relative attitude changes for these cases were also less than 1 degree.

b. In case 40H (sequence 222), which was a procedural error caused by voice communication problems, the upfiring jets were never disabled and inadvertently the crew flew an "all-jet enabled braking" case. Surprisingly, the payload attitude was only about 4 degrees off in this case and, rotating at about 7 deg/min relative to the Orbiter, was almost retrievable. The Δ attitude rates imparted by the Orbiter RCS plumes on the payload were less than 0.01 deg/sec except for case 40H (sequence 222) where the induced rate was approximately 0.1 deg/sec, which is probably too high.

For specific analysis of LAT cases, the reader is referred to all the LAT data summarized in tables 1, 2, 3, 5, and 6 plus figures 3(a) through 3(l) and figures 5 (a) through 5 (t). Highlights for each specific case (sequence number) are given in the following section.

4.2 LAT ANALYSIS - CASE BY CASE HIGHLIGHTS

Case 1H (sequence 170) was a 2 fps, type A (tailfirst only after pitchover) approach simulation with no dispersions in the IC (initial condition). The important thing to note here is that no pilot action is required (except for braking) if there are no position or velocity errors. Approaches $\overline{V}$ and $\overline{R}$, even if alined perfectly, require periodic corrections because of orbital mechanics effects, which naturally result in heavier RCS propellant consumption. The RCS used was 72 pounds, which is slightly higher than expected because of a slight overshoot at braking. The torque impulse on the payload caused by RCS plumes was a negligible 0.04 ft/lb/sec. The relative height change from the first goalpost to the second goalpost was zero for an almost perfect approach with a 13-foot tail-miss distance (see figs. 3(a) and 5(a)).

Sequence 171 was not tabulated in the data tables because the run was aborted after 4 minutes when it was discovered that the upfiring minus-Z (-Z) jets were disabled throughout the run because of a simulator reconfiguration error. However, figure 5(b) shows an interesting point worth noting about this sequence. Because this was a repeat of case 1H (sequence 170) (i.e., no dispersions), within 2 minutes an $\dot{X}_{LH}$ rate of 0.1 fps had built up because of the net $-\dot{Z}_b$ translation created by the DAP in its control of attitude (an 8-foot dispersion had built up by then). This clearly confirms what has long been suspected - if the upfiring jets are disabled, the DAP will generate a net $-\dot{Z}_b$ translation for some attitude control commands. This net effect is used very advantageously and indirectly in some of the $\bar{R}$ approaches discussed later in this report. Case 2H (sequence 172) was a repeat of case 1H with very similar results. Use of RCS was slightly less than case 1H, 47 pounds versus 72 pounds, and torque impulse on payload was zero, which indicates that it is possible to reduce the plume effect in LAT approaches to almost negligible values if the state vector errors at the first goalpost are minimum. See figures 3(a) and 5(c).

Case 3H (sequence 173) was similar to the first two except that it included dispersions in the IC (fig. 5(d)). Within 30 seconds, the crew began removing the dispersions and had removed them 2 minutes later with velocity errors nulled to very low values (i.e., less than 0.1 fps at a range of 600 feet). However, no manual compensations were executed by the crew and the closing rate $\dot{Y}_{LH}$ or $\dot{R}$ (as per fig. 2) was reduced about 0.4 fps by the dispersion removal effort of the crew. Braking was uneventful (fig. 3(c)) but trimming the residuals generated some minor torques on the payload and consumed a little too much propellant because of overshoots and the use of $\pm X$ jets for nulling the closing rates. A total of 373 pounds (about 200 pounds postbraking) of RCS were used and torque impulse was about 5.8 ft/lb/sec (fig. 5(d)). Stationkeeping was then conducted for over 7 minutes uneventfully and, as shown in figure 6(a) and table 5, column 14, an additional 145 pounds of RCS were used and 1.66 ft/lb/sec of torque impulse imparted on the payload. The payload had an attitude of 91.8, 1.1, and 0.3 degrees (PYR) at the end of stationkeeping for a total attitude delta of 1.8, 1.1, and 0.3 degrees; the final attitude ratios were -0.063, 0.002, and 0 deg/sec. Data can be compared with table 5, columns 22 to 25 and it can be seen that the dynamic disturbances, though minor, were mainly caused by stationkeeping pulsing of the RCS.

Case 4H (sequence 174) was a repeat of case 3H (sequence 173) without stationkeeping. Results were significantly better because RCS propellant consumption was reduced 50 percent to 188 pounds (fig. 5(e) and 3(c)) and torque impulse 80 percent to 0.9 ft/lb/sec. Payload dynamic disturbance was essentially zero. Again, no manual translation compensation for the closing rate was made by the crew.

Case 5H (sequence 175) was basically the same as cases 3H and 4H except the IC dispersions were larger. Dynamic results were equivalent. The consumed RCS was about 293 pounds, torque impulse was 0.74 ft/lb/sec and dynamic effects on payload were negligible. Some minor overshoots in correcting the dispersions (fig. 5(f)) account for the heavier RCS usage plus the fact that again because no manual RCS translation compensation for $-\dot{Z}_b$ was done, the range rate ($\dot{R}$) was reduced to almost half and the final closing velocity (table 5, columns 20 and 21) instead of being -2.0 fps was -1.10 fps. This caused the time between the first goalpost and braking to be doubled from 90 seconds to approximately 200 seconds (fig. 3(c)). Because of the slower closing rate, the crew had a tendency to pulse the THC more frequently to ensure a safe trajectory but with the higher RCS consumption.

Case 6H (sequence 176) was identical to cases 1H and 2H (sequences 170 and 172) (i.e., no dispersions) except with another pilot. Results were basically the same. See figure 3(a).
Case 7H (sequence 180) was basically the same case as 5H (sequence 175) but a different pilot. Use of RCS was slightly lower (200 pounds versus 293 pounds)

and torque impulse on payload was slightly larger (1.99 versus 0.74 ft/lb/sec). Other parametric results were basically the same. See figure 3(d).

Case 8H (sequence 183) was a repeat of case 5H (sequence 175) for the same pilot. Results were basically the same for this tailfirst only (type A) run except that RCS use was down to 165 pounds from 293 pounds. See figures 3(d) and 5(g). Again, dynamic effects on payload were practically nil. Six minutes of stationkeeping followed braking. Only 37 pounds of RCS and 0.35 ft/lb/sec torque impulse resulted here because of low residuals after braking. See figure 6(b).

Case 9H (sequence 184) was a complete manual approach (type B) starting at FAI + 6 minutes where dispersions were taken out and pitchover initiated into the tailfirst attitude for final control as in previously discussed cases. See figure 3(d). One hundred ninety pounds of RCS were used in the COAS phase to remove dispersions and 0.22 ft/lb/sec torque impulse on the payload. (There were some overshoots in removing the dispersions by the crew, which accounts for the heavy RCS use.) Pitchover was done at 1 deg/sec and because the velocity residuals were somewhat light at maneuver start ($\dot{X}_{LH}$ = 0.35, $\dot{Z}_{LH}$ = 0.10 at R = 1150), position errors had built up again substantially and had to be removed again. As in previous cases, no manual compensation into $-\dot{X}_b$ because of $-\dot{Z}_b$ pulsing was done by the crew and the closing rate $\dot{R}$ ($\dot{Y}_{LH}$) was reduced somewhat. Approximately 173 pounds of RCS were used for the pitchover and tailfirst and braking maneuvers and 0.05 ft/lb/sec torque impulse applied to payload for a total of 363 pounds and 0.27 ft/lb/sec. Overall dynamic effects on payload were minimal. Observing the THC time history, it appears that with more crew training the RCS use can probably be reduced about 100 pounds for this type of tailfirst approach.

Case 10H (sequence 185) was the first type C approach. In this case, the spacecraft was initialized in the COAS mode but was substantially closer than a type B run (674 feet versus 1451 feet) (fig. 5(h)). This implied a 1 fps closing rate rather than 2 fps for previous cases. The pilot was asked to remove dispersions using the COAS for a reference and when in close proximity to brake using the simultaneous $\pm X$ jet firing mode. Because there were no pitchover maneuvers, columns 28 to 31 in table 5 are not applicable. Plume impingement on payload (table 5, column 18) was very low but, as expected, RCS use was substantially higher than the tailfirst approach (661 pounds). According to the crew, however, the procedure is definitely simpler for this type C approach compared to the tailfirst (type A) approach. Again, RCS cross-coupling affected $\dot{R}$ to cause the vehicle to almost stall because of the pulsing of the $+X_b$ or $-X_b$ jets for dispersion corrections (at this attitude, the $-Z_b$ jets are disabled but a net $+Z_b$ translation is produced by either the $+\dot{X}_b$ or $-X_b$ jets, which at this attitude reduces the closing ($\dot{Y}_{LH}$) range rate ($\dot{R}$). This cross-coupling from $\pm\dot{X}_b$ into $+\dot{Z}_b$, though not as severe as the $-\dot{Z}_b$ into $+\dot{X}_b$ for the tailfirst approaches, does affect it sufficiently enough to tend to create a stall condition. The crew noted that $\dot{R}$ was being affected and added some downfiring pulses ($-\dot{Z}_b$ thrust) to maintain a closing rate. Unfortunately, because the baseline radar was being used to drive the cockpit displays (3σ error of 1 fps noise for the $\dot{R}$ measurement), an overcompensation resulted and at a range of approximately 400 feet, $\dot{R}$ was increased to -1.0 fps instead of the desired -0.8 fps. This required more RCS propellant to be used to brake with the $\pm X$ jets, which are too inefficient to begin with (an approximate ratio of 10 to 1 or 300 pounds to null 1 fps closing rate). Nevertheless, the procedure was conducted easily by the crew with minimum plume or dynamic disturbances on the payload. Five minutes of stationkeeping followed this approach and consumed 40 pounds of RCS and negligible (0.2 ft/lb/sec) plumes dynamic effects on payload. See figure 6(c).

Case 11H (sequence 188) was a 1 fps, tailfirst only (type A) approach with no dispersions. Results are similar to the cases noted. See figure 3(h). Seven minutes of stationkeeping after braking consumed 102 pounds of RCS and imported a torque impulse of 2.57 ft/lb/sec on the payload.

Case 12H (sequence 190) was another 1 fps, tailfirst only (type A) with some dispersions (figure 3(h)). At the first goalpost the payload was 1 foot from the nominal trajectory but it had a closing $\dot{Z}_b$ ($\dot{X}_{LH}$) rate of 0.1 fps. This caused the payload to drop 7 feet from the first goalpost (150 feet behind the Orbiter) to the second goalpost (payload over the Orbiter's tail) and it cleared the tail by 7 feet, which is considered a near-miss (distance less than 10 feet). Nevertheless, braking was nominal. Torque impulse on the payload was 3.49 ft/lb/sec. This is a little high but dynamic effects on payload were negligible.

Case 13H (sequence 192) was another 1 fps, type A (tailfirst only) simulation with dispersions. Because of heavy RCS cross-coupling while removing the dispersions, the closing rate was reduced to about 0.5 fps at the first goalpost, which meant that approximately 200 seconds of drift occurred between the first and second goalpost. Because a residual $\dot{Z}_b$ of 0.07 fps (had not been removed by the pilot at the first goalpost, the payload dropped 18 feet and collided with the Orbiter's tail. Of course, in real life the pilot would not have allowed the collision to occur. By observing the relative motion in the V-overlay, the pilot could determine the possibility of collision and abort the approach by firing the upfiring jets. See figure 3(h) for the first to second goalpost relative motion.

Case 14H (sequence 193) was another 1 fps case with dispersions but initialized before pitchover (type B). In this run, the crew did notice that the closing rate was slowing down after pitchover and did fire $-\dot{X}_b$ to speed up the approach. Pitchover rate was 0.55 deg/sec. Use of RCS was 279 pounds and plume on payload was 1.13 ft/lb/sec with almost no dynamic effects on it. This case proves that even 1 fps cases can be successful with experience and procedures. See figure 3(i).

Case 15H (sequence 195) was another 1 fps, type B (tailfirst before pitchover) approach with dispersion. This was a curious case in that it missed the tail by 5 feet and yet collided into the aft window area of the cockpit. An RCS fuel check after pitchover indicates that 149 pounds of RCS were used for the first 8 minutes of the approach and almost 300 pounds for the rest of the approach. Again, the approach was stalled by RCS cross-coupling and the pilot had to enter $-\dot{X}_b$ pulses to increase the range rate ($\dot{R}$). The approach was fairly good to the 150-foot range (first goalpost) but because the payload was opening slightly at this distance (-0.086 fps), the pilot, at a distance of 106 feet (classified as first goalpost), overcorrected for this rate and changed the rate from -0.086

to +0.208 and closing as shown in table 5, column 29. The low plume disturbance at 106 feet indicates that first goalpost distance is not critical and can probably be reduced to significantly less than the present 150 feet. When the payload was over the tail (second goalpost), it did clear the tail by 5 feet, but because of the closing rate it did have a cockpit collision as shown in table 5, column 36. This collision could have been avoided, but apparently the pilot wanted to see the effects of free drift made with those closing rates (fig. 3(i)). Braking was nominal but the closing rate of the payload towards the Orbiter, easily seen with the aft bay CCTV camera, was never taken out and eventually resulted in the collision. The relatively high torque impulse on payload (19.28 ft/lb/sec) is due to DAP yaw attitude firings just a few seconds before collision. Dynamic effets on payload (irrelevant after a collision) were nevertheless negligible.

Case 16H (sequence 196) was a type C or non-tailfirst approach with dispersions. Braking was done by the simultaneous firing of ±X jets. The pilot overcompensated for reaction control system (RCS) cross-coupling and increased range rate ($\dot{R}$) to -1.6 fps at a range of 340 feet instead of the desired -0.6 fps. This caused an extra 200 pounds of RCS to be required for the ±X jet braking totaling 587 pounds for the approach. Nevertheless, the RCS plumes and dynamic effects on the payload were negligible. Braking was commenced at 50 feet. Columns 28 through 31 in table 5 are left blank for this approach, as they are not applicable.

Case 17H (sequence 197) was a repeat of case 16H with identical results by the same pilot.

Case 18H (sequence 198) was a 2 fps, tailfirst approach (type A) with dispersions. Results were typical with total RCS used being 155 pounds. No manual compensation for cross-coupling was done so the closing rate was 1.28 instead of 2.0 fps. This case can be considered a good, typical case for the LAT. Payload disturbance was minimal. See figure 3(e).

Case 19H (sequence 199) was another 2 fps, type A approach (tailfirst phase only) with dispersions and 14 minutes of stationkeeping after braking. This was the first case where the payload was at an inertial attitude throughout the approach. The procedure was identical for the Orbiter approach except the Orbiter was also set to inertial-attitude hold during the approach. Because the attitudes were inertial and the attitude angles in the printout are with respect to a local vertical-local horizontal (LVLH) rotating frame, the dynamic disturbances on the payload were more difficult to assess. In addition, it was noted that gravity-gradient torques were erroneously left on, and masked further the effects of RCS plumes. Nevertheless, because the approach was only 10 minutes long, no significant errors by gravity torques were induced and it was determined that the results were valid through braking. Observing the jet-firing strip charts output from the SES, it was noted that the upfiring -Z jets were not disabled until after the payload cleared the tail and hence, DAP attitude firings increased the torque impulse in table 5 (column 18) to 28.6 ft/lb/sec, which is significantly high but, nevertheless, of little effect on dynamic attitude of the payload since it moved less than 2 degrees overall. The stationkeeping data must be viewed with double caution because of the earlier simulation problem mentioned (payload rolled intermittently) plus the attitude rates induced by gravity-gradient torques inadvertently left on and the rates induced by the upfiring jets left enabled until just before braking. For 14 minutes of stationkeeping with an inertial payload, 38 pounds of RCS were used and 9.22 ft/lb/sec of impulse imparted on the payload. It became obvious though that the relative attitude changes of both inertial vehicles would create retrieval difficulties if the operation was not done quickly. No attempt to revolve about the payload was made - only a very passive form of stationkeeping procedure was provided.

Case 20H (sequence 200) was another typical 2 fps tailfirst only (type A) run with dispersions. The RCS was a modest 183 pounds with a torque impulse of 0.07 ft/lb/sec and dynamic effects on payload negligible. No manual compensation for RCS cross-coupling was done and $\dot{R}$ was therefore reduced from -2.0 to -1.25 fps with a comfortable tail-miss distance of 15 feet. See figure 3(e).

Case 21H (sequence 201) was a type A (tailfirst only), 1 fps approach with dispersions. Some RCS pulsing was done up to a range of 135 feet and left a closing rate ($\dot{Z}_b$ or $-\dot{X}_{LH}$) of -0.06 fps. Because the payload was at -48 instead of the nominal -52 and $\dot{R}$ was -0.75 instead of -1.0 fps, the payload came within 3 feet of the tail for a near-miss. The rest of the RCS and plume data was fairly nominal. The pilot commented that in a real flight the procedure would be changed to move away or at least abort the approach. See figure 3(i).

Case 22H (sequence 202) was basically another 1 fps, type A approach with a different dispersion. The pilot did compensate for some of the RCS cross-coupling effects and at the first goalpost, 135 feet away, entered a $-\dot{Z}_b$ pulse ($-\dot{X}_{LH}$) to cause the opening rate to increase from -0.02 to -0.05 ($-\dot{Z}_b$), which ensured a good tail clearance in spite of the slow $\dot{R}$ (-0.66 versus -1.0). The payload, which was 2 feet higher than nominal (-54 feet), continued to rise until at braking it was -63 feet and was easily retrieved. The RCS and torque impulse were fairly nominal; dynamic disturbance on payload was negligible. This case did show that even a stalled 1 fps approach could be made safe by crew action. See figure 3(j).

Case 23H (sequence 203) was a 1 fps, type A (tailfirst only) with no dispersions. Results are similar to previous cases. Slightly higher RCS use is attributed to RCS pulsing by the crew that confused Orbiter attitude deadbanding with payload residual velocities. This indicates that for distances greater than 300 feet it may be difficult to distinguish between payload relative rates and Orbiter attitude deadband effects. The net result of this difficulty is extra RCS usage. Again, the pilot entered an upfiring RCS pulse at the first goalpost to ensure an opening rate, which it did, and braking was nominal. See figure 3(j).

Case 24H (sequence 204) was the first 3 fps, type A (tailfirst only) simulation run. Dispersions were quickly taken out by the pilot and a slightly high (-61) but good relative state vector was achieved at the first goalpost. The closing rate of +0.06 fps did not affect the approach at all and a tail-miss distance of 21 feet occurred. Braking for 3 fps created no particular problems but the crew did say that the approach was too fast. Use of RCS was 163 pounds total and torque impulse only 0.32 ft/lb/sec with no dynamic effects on payload attitude. See figure 3(l).

Case 25H (sequence 206) was a dispersed, 2 fps, type B (COAS phase, pitchover, and tailfirst) simulation. Plumewise it was very nominal with negligible dynamic effects on payload. However, it was rather expensive in RCS at 558 pounds total. Pitchover was started 4 minutes into the run at 0.92 deg/sec. An analysis of the SES printout and strip charts shows that 276 pounds of RCS were used through pitchover. The majority of the propellant was spent by inefficiently removing the dispersions (i.e., excessive number of overshoots at high relative velocities). Because this was the first data run of this type, it seems obvious that experience was an important factor. The RCS propellant use after pitchover was somewhat better after pitchover, obviously because of closer range and better visibility. However, since the payload ended above the remote manipulator system (RMS) reach envelope, the pilot, after braking, moved the Orbiter closer and stopped his final motion with the inefficient ±X jet braking to account for the total 557 pounds of RCS used. See figure 3(b).

Case 26H (sequence 207) was a repeat of case 25H except with a different pilot. One hundred five pounds of RCS were used for dispersion removal the first 5 minutes and 60 pounds for the pitchover (with overshoots) for a total of 165 pounds before tailfirst control. A total of 270 pounds were used for the tailfirst control for a grand total of 435 pounds of RCS. This compares favorably with the 558 pounds used for case 25H but not as good as the identical case 44H (sequence 226) where only 316 pounds were used. This indicates that experience and pilot technique will affect the RCS use considerably and the potential for lower use is there. Plume impingement and dynamic effects on payload were minor. See figure 3(e).

Case 27H (sequence 208) was a 2 fps case with no dispersions (i.e., a perfect trajectory). It used a total of 138 pounds of RCS (35 pounds before pitchover and 50 pounds during pitchover at 0.62 deg/sec). Plume impingement and payload dynamics were negligible. This can probably be considered the best manual approach possible for the LAT using the tailfirst option. See figures 3(b) and 5(i).

Case 28H (sequence 209) was a dispersed, fps, type B (COAS phase, pitchover, and tailfirst) approach. This case is a prime example of stalling caused by RCS cross-coupling. The Orbiter was not only halted in its approach before pitchover, it was actually halted and caused to move away from the payload until the pilot realized the situation and corrected it. Other than the confusion and subsequent heavy RCS use, the approach continued with no significant problems. Total fuel was 535 pounds with minor plume effects. See figure 3(j) and 5(j).

Case 29H (sequence 210) was a dispersed, type C (±X jet braking, no tailfirst) approach. Probably because of the stallout in the previous case, the pilot "poured on the coals" and increased the range rate from less than 0.8 fps to 2.8 fps. Because the ±X jets were used for braking and it costs 300 lb/1 fps of braking, the total RCS used was 1214 pounds, which is considered too excessive and nontypical. Plume effects on payload were minimal. Stationkeeping continued easily for 13 minutes at an additional cost of 103 pounds of RCS and

0.5 ft/lb/sec of torque impulse on the payload. The pilot continued on a berthing procedure. See figures 5(k) and 6(d).

Case 30H (sequence 211) was another 2 fps, dispersed, type B (prepitchover type) exercise. However, the payload was at an inertial attitude; but, gravity-gradient torques were not removed from the SES model as required and began to interact with the drifting payload. The run was terminated before the first goalpost was reached. The high RCS usage was caused by the overcorrections in removing the dispersions. Plume effects were minor throughout the run. See figure 5(l).

Case 31H (sequence 212) was a 2 fps, type A (tailfirst only) with no dispersions. Results were basically the same as for cases 1H, 2H, and 6H - low RCS use and minimum plumes. See figure 3(b).

Case 32H (sequence 213) was a dispersed, 2 fps, type A (tailfirst only) familiarization approach for pilots new to the LAT technique (fig. 3(f)). The upfiring jets were not disabled until the payload was at 40 instead of 100 feet behind the tail and, yet, plume effects at this point were minimal. As expected for a familiarization run, there was a heavy RCS usage caused by overcontrolling in the procedure. The $\dot{Z}_b$ rate at the first goalpost was 0.151 fps, which created a near-miss with the tail (cleared by 4 feet). At braking, the payload was off to one side (not centered with the COAS), which created some torques on the payload caused by firings of $-Y_b$ jets commanded by the pilot for stationkeeping correction plus yaw attitude firings commanded by the DAP. This indicates that the payload must be alined side-to-side fairly symmetrically before braking if attitude firings are not to disturb it. Nevertheless, the plume effects on the payload were minor yet considerably higher than previous cases (i.e., 10.2 ft/lb/sec of torque impulse versus less than 1 ft/lb/sec). Yet, payload attitude changed less than 1 degree during the whole approach/braking, and payload retrieval was successful.

Case 33H (sequence 214) was a dispersed, 1 fps, type A (tailfirst only) familiarization approach for the third pilot. The first goalpost was not announced by the pilot until the payload was 30 feet behind the Orbiter's tail. Thus, some upfiring jets were commanded, which impinged on the payload and caused the torque impulse measurement to be slightly higher than normal (9.6 ft/lb/sec); however, the payload dynamics effect was relatively minor. The rest of the parameters were fairly nominal for a successful retrieval. See figure 3(k).

Case 34H (sequence 215) was a dispersed, 3 fps, type A (tailfirst only) approach. Unexpectedly, the pilot kept the DAP mode panel in the "normal" acceleration mode rather than in the "pulse" mode while removing dispersions. This gave faster controllability at a larger RCS cost. It also created some overcontrolling, causing the pilot to delay announcing the first goalpost until the payload was at 87 feet (37 feet behind the tail instead of 100 feet). Because the payload was coming a little high (-57 versus -52 feet), the crew entered a closing rate at that point of 0.47 fps, which is extremely high going into the drift mode. Nevertheless, the tail was safely cleared by 12 feet (caused by the high approach velocity 3 fps). However, at braking time the payload was only 12 feet above the cockpit and at closing, 0.5 fps. The crew executed the braking perfectly by going to the "normal" mode for all three axes (X,Y,Z) and commanding correctly and simultaneously a +X and -Z translation. The +X was applied promptly but the -Z (which had the ±X jet-braking mode enabled) translation was ignored until the +X command was removed and -Z placed in detent. When -Z was again commanded (with no +X commanded), the ±X jet braking was commenced, but it was too late because the payload collided with the cockpit a few seconds later. This seems to be a simulator or DAP limitation, which should be evaluated thoroughly if the ±X jet option is installed in the DAP software. See figure 3(l).

Case 35H (sequence 216) was a dispersed, type B, 2 fps (COAS, pitchover, tailfirst) approach. Apparently, the sense switch was initialized in the wrong position and it was not until 4 minutes into the run that the problem was noted. Some RCS was wasted because of this problem. The position dispersions were fairly well under control at the start of pitchover; however, the residual velocities were not quite nulled (0.15 and -0.25 fps at a range of 700 feet), which caused the position errors to grow during the pitchover maneuver (0.6 deg/sec). Therefore, position errors had to be taken out again. After pitchover 253 pounds of RCS had been used. Because range had decreased to 400 feet after pitchover, the pilot elected to remove the errors quickly. Cross-coupling of RCS caused the range rate ($\dot{R}$) to be reduced significantly, so instead of a desired -2 fps approach velocity, the actual velocity was down to -0.5 fps (table 1, columns 20 and 21) which is an almost stalled condition. Nevertheless, the approach was adequate. Total RCS use was 433 pounds and plume effects on payload were minor. See figure 3(f).

Case 36H (sequence 217) was a 2 fps, type B approach with no dispersions except for some residual velocities. Pitchover was at 0.33 deg/sec. Use of RCS through pitchover was 51 pounds and 137 more pounds were used in the tailfirst control phase plus braking for a total of 188 pounds. Plume effects were minimal. Results were very similar to case 6H (sequence 176) described earlier. See figure 3(b).

Case 37H (sequence 218) was a 2 fps, dispersed, type A (tailfirst only) approach. As in most cases the position dispersions were removed within 5 minutes. In this case, at braking the payload was outside the RMS reach envelope and the Orbiter was maneuvered to bring it within reach, hence, the slightly high RCS usage value of 335 pounds was caused by ±X jet braking for 0.5 fps or 150 pounds. Plume effects were negligible. See figures 3(f) and 5(m).

Case 38H (sequence 219) was a 1 fps, dispersed, type A approach. The pilot did compensate manually for RCS cross-coupling for some of the $-Z_b$ pulsing. At the first goalpost the relative state vector was good (position and velocity) but the 230 seconds drift time to the braking point (caused by a 0.7 fps rather than 1.0 fps $\dot{R}$) caused 10 feet drift errors and a total 263 pounds of RCS use. Plume effects were almost negligible. See figures 3(k) and 5(n).

Case 39H (sequence 221) was a dispersed, 3 fps, type A approach. Several overshoots occurred in correcting for dispersions and apparently the higher $\dot{R}$ seems to make the pilot task more difficult because of the changing relative geometry. First goalpost was announced at 110 feet but plume effects were minor. However, an opening $-\dot{Z}_b$ of -0.28 fps caused braking to occur just slightly outside RMS reach and necessitated ±X jet-braking action of 0.4 fps and used 120 pounds of RCS propellant for a total of 380 pounds. See figure 3(l) and 5(O).

Case 40H (sequence 222) was a dispersed, 2 fps, type A (tailfirst only) approach. The real significant point of this case was that all jets were on by mistake for the entire run because of a communication problem between the pilot and SES operator. An attitude jet firing occurred when the payload was passing over the tail and 9 ft/lb/sec of torque impulse was applied to the payload. More significantly, the gravity-gradient payload's pitch rate (-3.90 deg/min or orbital rate) was changed to -4.38 deg/min. No other significant dynamic effects on payload were created until after braking when the pilot was nulling the rates to prepare for stationkeeping. There was a closing rate taken out by direct $-Z_b$ jet firings that increased the pitch rate to -8.2 deg/min and created a -3.2 deg/min yaw rate. See figure 5(p). By subsequent overcorrection, these rates were increased to -10.44 deg/min and -5.04 deg/min for pitch and yaw, respectively. The total torque impulse was 137.5 ft/lb/sec, which was certainly the highest number of LAT cases. It is quite clear that direct translation jet firings (in this case, upfiring nose jet number 7) towards the target during stationkeeping will not be tolerated by the LDEF because of the tumbling potential. The data from this run indicate that 0.1 fps worth of RCS translation plumes will cause approximately a 1 deg/min LDEF payload rate at normal RMS stationkeeping distances.

Case 41H (sequence 223) was a 2 fps, type A run for a true (gravity-gradient torques out) inertial target. The approach was nominal with minor plume effects on the payload. However, braking was late and extra $+\dot{X}_b$ was required to bring the payload back into the overhead window field of view. Inexplicably, the rates were not nulled and the payload drifted away. Dynamic effects on payload were negligible and the payload did stay inertial throughout the approach. The RCS propellant used was 202 pounds total, which can be considered nominal. See figure 5(q).

Case 42H (sequence 224) was a repeat of case 41H. Results were basically the same. A total of 208 pounds of RCS were used with negligible plume effects on payload (fig 5(r)). Stationkeeping followed for approximately 7 minutes and it consumed 178 pounds of RCS with negligible dynamic effects on the payload. It seems that stationkeeping with an inertial payload is more difficult for the crew to control and it consumes more RCS than stationkeeping with a gravity-gradient stabilized payload probably caused primarily by the translation requirements, using the $\pm X$ jet capability for $+Z_b$ translation.

Case 43H (sequence 225) was a dispersed, 2 fps, type B (COAS, pitchover, and tailfirst) case for a gravity-gradient payload. For this case the pilot elected to pitchover immediately at 2 deg/sec before removing dispersions, which provides a good data point for this interesting variation in the procedure. A total of 88 pounds of RCS were used for pitchover because of an undershoot. At the end of pitchover the position errors were 60 and 90 feet, respectively, for downrange and radial errors. Ten minutes later the dispersions had been removed and the residual errors were monitored for nulling. First goalpost was announced when payload was at 105 feet (55 feet behind the Orbiter's tail) with no deleterious effects after a $\dot{Y}_b$ pulse. Braking was nominal. Use of RCS was 406 pounds total and plume effects were negligible. Though RCS use was better than most type B cases, there were several overshoots in removing dispersions, thus indicating that this figure can be reduced further with more crew experience and technique enhancement. See figures 3(g) and 5(s).

Case 44H (sequence 226) was the last LAT case run in the SES. It was a repeat of the previous case 43H except the dispersions were slightly different. The RCS use was significantly lower at 316 pounds total, probably because of slower correction rates used to take out dispersions (i.e., 0.2 fps or less versus approximately 0.5 fps in the previous case). Plume effects were found to be negligible also. See figure 3(g).

4.3 DIRECT APPROACHES

Case 2 DA (sequence 20) was an all-jet Apollo-type braking to a target or payload. Twenty-eight minutes into the run the payload was disturbed by RCS plumes sufficiently enough to change its attitude (P,Y,R) from 90, 0, 0 degrees to 82.5, -0.1, 2.2 degrees and its attitude rates from -0.066, 0, 0 deg/sec to -0.078, 0, 0 degrees. At the end of the run (8 minutes later) the payload attitude was 258, 0.9, 1.8 degrees (PYR) and the rates were 0.063, 0, -0.002 deg/sec with a torque impulse of 714.4 ft/lb/sec. It was clear that the tumbling payload was not recoverable. Other data for this case is available in table 7. See figures 7(a), (b), and (c) for typical relative-motion plots.

Case 2 DA (sequence 21) was a ±X jet direct approach to a range of 1000 feet where the range rate ($\dot{R}$) was reduced to -4.0 fps closing. At that point the upfiring jets were disabled and the ±X jet-braking capability was enabled. At 750 feet range the $\dot{R}$ was reduced to -3 fps with the ±X jets; similarly, at 500 feet the $\dot{R}$ was reduced to -2 fps, at 250 feet down to -1 fps and until at RMS distance the $\dot{R}$ was nulled. Total plume effect was minor on the payload. Payload attitude was changed from 90, 0, 0 degrees to 89.8, 0, 0 degrees at 24 minutes into the run or 8 minutes after initiating the ±X jet braking. Then the payload started pitching slowly the other way towards 91.4, 0, 0 degrees at the end of the run (T = 27). Total plume induced torque impulse was relatively minor at 11.35 ft/lb/sec. The only disadvantage noted in this procedure was the excessive RCS propellant consumed during the ±X jet activity. A total of 878 pounds were used to brake to 1000 feet and 1032 pounds from 1000 feet on in because of the inefficient ±X jet braking. In addition, the forward/AFT RCS use ratio increased from 34/66 to 52/48 from "pre-1000" to "post-1000" for an overall 44/56 ratio. The greatest advantage of this procedure is that no special procedure (V, R, or LAT) is required. If the $\dot{R}$ was reduced to -2 or -1 fps at 1000 feet, this procedure might be competitive with V, R, or LAT even in the RCS area and clearly superior in time line and other impacts.

Case 3 DA (sequence 33) and case 4 DA (sequence 35) were basically similar to case 1 DA with the same overall results; i.e., the payload tumbled because of the all-jet firings and resulting plume effects.

Case 5 DA (sequence 57) was an all-jet case like the previous ones except that no radar was used. Dynamic effects on payload were basically the same; i.e., the payload tumbled. In addition, the RCS use was four times as large - 4114 pounds versus about 1000 pounds. Clearly, a no-radar condition means an aborted mission, unless the payload is unaffected by RCS plumes.

Cases 6 DA, 7 DA, 8 DA, 10 DA, and 11 DA (sequences 60, 61, 62, 65, and 66, respectively) were basically repeats of cases 1 DA, 3 DA, and 4 DA with similar results; i.e., all-jet firings created similar results with dynamic disturbances on payload, which, if not causing the payload to tumble, it at least made recovery and retrieval a dangerous operation. Table 7 data can be studied for individual parameter effects.

Case 9 DA (sequence 63) was a repeat of case 2 DA (sequence 21). Again, the $\pm X$ jets were used for braking the last 1000 feet from -4 fps to a null and stationkeeping for RMS operations. Results were basically identical.

Case 12 DA (sequence 67) was a repeat of case 9 DA; i.e., $\pm X$ jet braking. However, the braking gate schedule was not followed by the pilot as he braked directly at a 400-foot range to -1.5 fps. This created some dynamic disturbance on the payload. When within RMS reach distance the payload had pitched 8 degrees from its normal attitude and its attitude rates changed significantly though still safe. It should be noted also that because the $\pm X$ jet braking was used to remove 1.5 instead of 4 fps, the RCS used for this part of the procedure was reduced from 1000 to 456 pounds.

Case 13 DA (sequence 68) was basically an end-to-end simulation. However, no rendezvous radar data were used by the pilot, therefore, RCS consumption was prohibitive. The pilot braked to a 2000-foot sphere radius and started to manually transition to the $\overline{V}$ position (3000 feet downrange) where a $\overline{V}$ approach was initiated with no $\overline{V}$ stationkeeping. The case proved that the procedure is possible even if radar is not available but that RCS propellant consumption will be prohibitive.

Case 14 DA (sequence 121) and 15 DA (sequence 122) were direct approaches to a 1000-foot distance from the target whose center of gravity was offset 3 feet. Results were basically the same for both cases. At 3000 feet some minor plume effects were received by the payload. These effects increased slightly at the closer ranges so that at 1000 feet the effects were definitely noticeable and more severe than the $\overline{R}$, or LAT final approaches. This indicates that at a 1000-foot range, plume effects may be significant. Therefore, consideration should be given to either increase the sphere range to 2000 or 3000 feet or ensure that the plumes from the last gates are not aimed directly at the target.

Case 16 DA (sequence 123) and 17 DA (sequence 127) were direct approaches to a target using all jets and with the payload CG offset by 3 feet. Results were basically similar to nonoffset cases; i.e., the payload tumbled and could not be recovered or approached safely. It can probably be said that the CG offset effect on the payload, if any, was masked by the irreversible plume effect.

Case 17 DA (sequence 124) and 19 DA (sequence 119) were direct approaches to a 1000-foot sphere where all rates were nulled. In case 17 DA the pilot then transitioned manually to the $\overline{R}$ position and the case was terminated. In case 19 DA, the transition was to the $\overline{V}$ position instead. See figure 7(a) for a typical plot of case 19 DA. Plume effects were basically the same for both cases. Approximately 160 pounds more of RCS were used in the transition to R than to the V, as expected, because of orbital mechanics.

In summary, it can be said that all jet direct approaches were unsuccessful in that they caused the payload to tumble. Modifications to this approach, where braking for the final 1000 feet was done with the ±X jet procedure, appears to be successful from a plume effects point-of-view but expensive in RCS. This procedure, however, could be modified further to use less RCS and still make it attractive for plume effects (see section 6.0).

4.4 $\overline{V}$ APPROACHES

Observing the data in table 8, it can be seen that $\overline{V}$ approaches, using all jets (i.e., Primary Reaction Control System (PRCS) in column 4), have the following characteristics:

a. Low RCS propellant (less than 200 pounds total)

b. High torque impulse (greater than 10 ft/lb/sec)

c. Substantial deviations in payload attitude/rates from initial-to-final condition.

From the attitude rate excursions in (c) of the preceding paragraph, it can be seen that the payload was, in effect, tumbling and thus, nonrecoverable. It can also be seen that different radar models used (as per table 8, column 5) has no effect on the final outcome. All cases tabulated except 4V, 8V, and 12V (sequences 32, 73 and 118) are all-jet PRCS approaches with similar results. Case 10V (sequence 97) was probably the most successful PRCS case in that payload disturbance was the least at 126 ft/lb/sec and pitch attitude/rate delta was only 22 degrees and 0.03 deg/sec. This payload was almost recoverable. However, the case was never duplicated again. Other cases were hopeless. See figure 8 for typical relative motions.

Cases 4V, 8V, and 12V (sequences 32, 73, and 118) used the ±X jet technique for braking. Results were nearly the opposite of PRCS cases. RCS use more than doubled (400 pounds), plume effects were negligible for both torque impulse (less than 10 ft/lb/sec), and payload attitude and attitude rate changed. Overall recovery was considered safe. These were considered the only good V cases.

Only two cases of stationkeeping after $\overline{V}$ were done - cases 4V and 10V. Both were successful for 15 and 9 minutes with 82 and 36 pounds of RCS required.

4.5 $\overline{R}$ APPROACHES

All cases tabulated in table 9 except cases 19 and 22 are final approaches from 1000 feet below the payload to less than 50 feet below and within RMS grappling distance. Cases 19 and 22 are essentially end-to-end cases that include an $\bar{R}$ approach at the end and are discussed separately.

There are essentially two types of approaches for $\bar{R}$:

a. With all PRCS jets enabled. See figures 9(a) and (b).

b. With $\pm$X jet braking and Orbiter upfiring jets disabled.

All cases run with method (b); i.e., $\pm$X jet braking were considered successful in that plume effects on payload were minimal and the payload was approached sufficiently close to retrieve it with the RMS. In addition, the results were repeatable.

For cases run with method (a), the success ratio was approximately 60 percent. Plume-induced payload rates in the other 40 percent were sufficiently high to say that a safe payload retrieval was probably not possible. The main criteria for making this statement was a comparison of the payload attitude rates at the beginning and end of the simulation; i.e., t = 0 and $t = t_f$. If the payload p, q, r rates changed more than 0.01 deg/sec or 6 deg/min, the payload retrieval was considered unsafe.

Observing table 9, it can be seen that cases 1R, 8R, 12R, 13R, 15R, and 16R (sequences 23, 51, 104, 105, 112, and 113, respectively) are the PRCS (column 4) cases that are considered successful. The torque impulse for these cases ranged from 8.66 (1R) to 28.20 (8R); the run time varied from 24 minutes (13R) to 56 minutes (8R); the pitch angle delta, from beginning to end, varied from 0.2 degrees (13R) to 3.3 degrees (16R); the pitch rate delta varied from a nominal -0.066 deg/sec nominal to -0.063 deg/sec minimum (15R) to -0.074 deg/sec maximum (13R); the RCS consumed varied from 192 pounds (13R) to 376 pounds (8R).

The other PRCS cases that were unsuccessful were 3R, 4R, 6R, 7R, and 14R (sequences 38, 39, 43, 50, and 111). The parameters that changed drastically were torque impulse (23 $\rightarrow$ 70) and pitch rate (-0.012 $\rightarrow$ -0.046). Thus, it can be said that all-jet $\bar{R}$ approaches, though feasible, are probably not practical or repeatable because of the sensitivity of the approach.

The $\bar{R}$ approaches using $\pm$X jet braking, on the other hand, are very repeatable and were successful in all cases. The worst that can happen is a pilot error; i.e., overshoot will result in a heavier RCS usage. For these cases, torque impulse was down to 0.065 ft/lb/sec or less; pitch angle changed less than 0.2 degree; pitch rate change was less than 0.001 deg/sec; run time ranged from 21 to 39 minutes; RCS usage varied from 255 to 477 pounds. Case 17R (sequence 114) was a familiarization run and a bad case and is not included as a successful simulation.

Case 19R (sequence 120) was an end-to-end run starting at the braking IC number 5 (table 4) to a range of 1000 where the rates were nulled and a pitch rate (twice orbital rate) was manually entered by the crew. By centering the target on the COAS using the THC and maintaining a constant range of 1000 feet, the Orbiter transitioned to the $\bar{R}$ IC postion. A standard $\bar{R}$ approach followed to RMS distance for retrieval. Table 9 indicates the parameters of interest: run time = 57 minutes, RCS = 1771 pounds, torque impulse = 20.88 ft/lb/sec, pitch = 90 → 78 → 96 degrees, pitch rate = 0.066 → -0.083 → -0.073 → -0.49 deg/sec. In general, it can be said that the total procedure is feasible but a lot more data are needed to determine the expected performance.

Case 22R (sequence 88) was similar to 19R in that it also was end-to-end. However, the approach was to 3000 feet where transition to V was initiated. After stationkeeping at V for 15 minutes, transition to R at 3000 feet above was executed followed by an R from 3000 feet above. Total RCS propellant used was an excessive 3963 pounds and torque impulse was 1273 ft/lb/sec for the 2-hour and 19-minute run. Needless to say, the payload attitude was disturbed significantly. Probably the most important parameter to be observed here is that an R from 3000 feet used over 2000 pounds of RCS, which is five to seven times more fuel than from 1000 feet.

5.0 CONCLUSIONS

5.1 GENERAL

a. The approach and stationkeeping simulation conducted in the SES indicate that standard braking techniques cannot be used for retrieval of payloads without attitude-control stabilization. With no exceptions, the RCS plumes dynamically affected the gravity-gradient stabilized payload (a Goddard Space Flight Center (GSFC) LDEF) by inducing attitude rates that would make retrieval a hazardous and questionable operation. In addition, it is felt that payloads with an attitude-control system are in jeopardy of being tumbled by RCS plumes if its attitude-control authority is designed with no considerations for a Shuttle RCS plume environment.

b. Other special approaches developed in earlier SES simulations; i.e., $\overline{V}$ and $\overline{R}$ were found adequate in the plume environment only if the ±X jet-braking technique is used to complement them. The LAT or out-of-plane technique was initially evaluated in this simulation and was also found adequate when complemented with the ±X jet technique.

c. Without the ±X jet technique, only the $\overline{R}$ approaches showed promise of retrieval, and less than 50 percent of the cases were considered successful. In addition, without the ±X jet capability, the RCS propellant requirements increase and performance requirements on the radar and CCTV camera become more severe. The LAT was not evaluated without ±X jet capability but indirect information indicates that it does offer some potential and probably should be evaluated in future SES simulations.

d. The ±X jet braking technique is not baselined. Modifications to the DAP software and possibly cockpit hardware switches must be accomplished to provide this desirable capability. In addition, RCS tests are required to confirm if this theoretical braking capability will exist or not in the Orbiter vehicle.

e. Table 10 gives a brief comparison of all the approaches evaluated in the SES. For detailed data, the analysis section of this report should be consulted.

5.2 LAT (OR $\overline{H}$)

The lateral approach simulations recently completed in the SES indicate that out-of-plane approaches are not only feasible but have many desirable features for approaches to payloads sensitive to RCS plumes. See tables 5 and 6.

Only the final or manual phase of the LAT was simulated in the SES. However, both manual control options listed in reference 1 were successfully demonstrated; the tailfirst option with +X braking and the COAS option with simultaneous $\pm$X jet braking. Advantages and disadvantages of both LAT manual options are listed in table 11.

However, the tailfirst approach as presently designed may not be acceptable from an operational standpoint. Subsequent analysis shows that the 7-14-21-foot V-control lines in the CCTV and aft window overlays should probably be changed to 20-30-40 feet, respectively, to allow for a safer trajectory (fig. 10). The RCS cost for this redesign is not known at this time but digital simulations indicate that it should be minor. Comparison of LAT cases in the SES with digital simulations in MPAD's HP9825 desktop simulator gives approximately the same results. This indicates that the LAT manual trajectory can be redesigned and tried out first in the HP9825 environment before future SES simulations. Principal LAT findings are as follows:

a. Basic LAT objective for SES simulations - to determine the feasibility and practicality of LAT - has been sufficiently demonstrated.

b. There is relatively minor RCS plume impingement on payload for LAT. Payload attitude changed less than 1 degree in all cases except where a procedure error was made; i.e., in two cases up-firing jets were not turned off, as required. Payload attitude rate was disturbed less than 0.02 deg/sec.

c. LAT approach is identical for gravity-gradient or inertially stabilized targets. No inertial targets were simulated for V and R.

d. LAT final approach procedure is probably the least demanding to the crew for all manual approach procedures.

e. Time for LAT final approach is fairly uniform from the IC selected (i.e., FAI + 6) and compares favorably with V and R; i.e., 22 $\pm$ 3 minutes. Indications are that the LAT trajectory can be redesigned for other time-lines if desired.

f. Average RCS propellant used for the final approach phase indicates that LAT is less expensive than R and V for nondispersed cases:

LAT = 160 lb $\overline{R}$ = 320 lb $\overline{V}$ = 410 lb

For dispersed cases (no data are available for $\overline{V}$ and $\overline{R}$):

LAT = 430 lb

Additionally, the FWD/AFT RCS ratios (a critical parameter) are:

LAT = 36/64% $\overline{R}$ = 42/58% $\overline{V}$ = 45/55%

g. The LAT approach using ±X jet for braking, though simpler to execute, is relatively expensive in RCS propellant used; i.e., 630 pounds for dispersed cases and about 350 pounds for nondispersed cases (estimated). Note that the tailfirst approach does use the ±X jet mode to null any closing residual velocity after +X braking.

h. The two main concerns on LAT expressed by the flight crews (ref. 4) are: (1) How do you get to the LAT starting point? and (2) potential collision with the Orbiter's vertical stabilizer because of termination of translation pulsing at the first goalpost (payload 100 feet behind Orbiter tail) and subsequent relative-motion drift in the last 200 feet of the trajectory.

Concern (1) was beyond the scope of PDRS III simulations and will be investigated and documented elsewhere. Concern (2) is certainly within scope and can be minimized by LAT trajectory profile redesign (fig. 10) and crew procedures refinement.

i. Two overlays (for the aft window and the forward bay CCTV) were used to control the approach (fig. 11 and 12). Either one will work, but the CCTV with tilt and zoom capability seems to be the preferred (and easiest) one to use. Approaches without overlays, though feasible, are not recommended because of the collision danger plus the excessive RCS use required for contingencies.

j. Three different LAT closing velocities at braking time were investigated: (1) 3 fps - considered too fast by crews because not enough time is allowed to safely take out trajectory dispersions, (2) 2 fps - probably the best compromise speed, and (3) 1 fps - too slow where there is a dangerously long time-gap (1.5 to 3 minutes long) from the first goalpost to the second goalpost. Payload can drift into the Orbiter tail if residual velocities at the first goalpost are not sufficiently reduced or nulled; i.e., $Z_B \leq$ 0.05fps - for present CCTV overlay control lines of 7-14-21 feet.

k. Stationkeeping after LAT and in preparation for RMS unrigidizing and payload retrieval is no problem if RCS pulsing is allowed in either the tailfirst or +X jet approaches for targets stabilized by gravity gradient; i.e., payload at orbital rate. The stationkeeping RCS cost varied from 3 to 25 lb/min, depending on residual rates present at the stationkeeping IC. Stationkeeping with inertial targets for short time intervals (5 minutes) seems feasible. However, extended (i.e., greater than 5 minutes) stationkeeping with inertial payloads will be extremely difficult for all approaches, including LAT. The only reasonable alternative for inertial targets is a quick payload capture by the RMS. The aft CCTV camera was used for RMS stationkeeping.

5.3 DIRECT APPROACHES

a. All standard braking approaches resulted in unsuccessful retrievals caused by excessive payload attitude deviations or rates created by RCS plume impingment, which would make the payload recovery an unduly hazardous operation, if possible. See table 7.

b. A successful variation of the standard braking consisted of nominal braking gates until a range of 1000 feet was reached where the range rate had been reduced to 4 fps (closing). At that distance the upfiring $-Z_B$ jets (for $+Z_B$ translation) were disabled and braking was subsequently done by simultaneous firing of $\pm X$ jets ($\pm X$ jet braking). This technique, though successful in terms of plume effects on payload, is extremely wasteful in the RCS propellant consumed (i.e., about 2000 pounds for the total procedure of which 1000 is for $\pm X$ jet braking).

c. Approaches with no radar are extremely costly in RCS propellant - three to four times the average value and, even though attempts were made to minimize the RCS plumes to the payload, it tumbled.

d. No significant changes noted in the direct approach scenario to payloads whose CG was slightly offset (6 inches).

e. The RCS plume effects on an LDEF payload during a standard direct approach type braking are: (1) no plumes detected from standard braking burns at ranges greater than 1 mile, (2) minor, and probably insignificant, plume effects at ranges between 0.5 and 1 mile, and (3) for some direct approaches, significant plume effects were noted at ranges less than 3000 feet. It appears that braking gates might have to be redesigned so that most of the braking be done prior to 0.5 mile or with plumes directed perpendicular to the target line of sight (LOS). This includes those approaches to a 1000-foot contamination sphere or those direct approaches where $\pm X$ jet braking will be used.

f. The direct approaches attempted with $\pm X$ jet braking, though too wasteful of RCS, should probably be reconsidered. If the $\dot{R}$ is reduced to 2 fps closing at 1000 feet instead of 4 fps and successful approach results, about 500 pounds of extra RCS over a standard braking will result. This is comparable with the extra fuel penalty required for transitions and final approaches from $\bar{V}$, $\bar{R}$, or LAT. In addition, time line impacts and crew procedures would be significantly reduced.

g. Standard all-jet braking for direct approaches from the same IC used 900 to 1100 pounds of RCS of which one-third came from the forward tank. The $\pm X$ jet braking used a total of 2000 pounds of RCS of which 1000 was for the $\pm X$ activity with 44 percent coming from the forward tank. However, dispersed IC's will increase these numbers.

h. Manual transition from a 1000-foot sphere to $\bar{V}$ used about 100 pounds of RCS; manual transition from a 1000-foot sphere to $\bar{R}$ used about 250 pounds. Both cases were attempted after standard braking to the 1000-foot sphere.

i. Direct approaches to a 1000-foot sphere used about 850 to 900 pounds of RCS (slightly less than in (f)).

5.4 $\overline{V}$ APPROACHES

a. The only successful $\overline{V}$ approaches; i.e., those that did not cause the payload to tumble due to RCS plumes, were those that used $\pm$X jet braking. See table 8.

b. The $\overline{V}$ approaches using $\pm$X jet for braking used 370 to 410 pounds of RCS of which 45 percent came from the forward tank. For all-jet cases, the average RCS used was 179 pounds, although for these cases the target was tumbled.

c. The $\overline{V}$ approaches applying $\pm$X jets use about 20 minutes for a 1000-foot range.

d. Radar measurement error model does not appear to have any significant effect on V or any other type of final approaches; target size effects or radar operations are TBD.

e. Plume impingement effects on a payload were considerable for all-jet V approaches. With $\pm$X jet braking, plume impingement on payload was acceptable though substantially more than R approaches or slightly more than LAT.

f. The $\overline{V}$ crew procedure is relatively straightforward.

g. Effects of IC dispersions to the RCS used are unknown for $\overline{V}$.

h. All $\overline{V}$ approaches were initialized from the same IC with no position dispersions.

5.5 $\overline{R}$ APPROACHES

a. Successful payload retrieval on all $\pm$X jet braking cases was noted in R final approaches. See table 9.

b. About 50 percent of all jet-braking cases were retrieved successfully for R final approaches. The rest tumbled because of RCS plume impingement forces on payload. See table 9.

c. The SES data shows that plume impingement for $\overline{R}$ approaches with $\pm$X jets is probably the best of all approaches attempted, including the LAT. The reason is probably due to making the complete approach with upfiring RCS jets disabled and the small surface area of the payload seen by the

Orbiter RCS plume during the approach.

d. The average RCS used for ±X jet $\bar{R}$ cases was about 320 pounds; for all jets propellant used was 337 pounds average.

e. Average time to complete an $\bar{R}$ approach with ±X jet was 33 minutes (variations were ±6 minutes).

f. As in all approaches, the aft CCTV camera was used very effectively to null the residual rates at RMS distances and for close-in stationkeeping. Without this camera, the pilot task and RCS usage would probably increase.

g. No inertially stabilized targets were approached in the $\bar{R}$ (or $\bar{V}$) technique.

h. All $\bar{R}$ cases were initialized from the same IC. Dispersion effects are TBD.

6.0 RECOMMENDATIONS

a. Tests on the RCS hardware should be conducted to determine if ±X jet simultaneous firings do indeed give a -Z braking capability.

b. If simultaneous firing of ±X jets do indeed provide a braking capability, modifications to the DAP software should be considered. It is also suggested that a switch be added to the aft crew station. When set by the crew, this switch would inform the DAP that the up-firing jets should be disabled and ±X jet braking be enabled. Subsequent -Z translation commands from the THC will result in simultaneous firings of the ±X jets for -Z translation. In addition, the switch will also inform the DAP that translation cross-coupling compensation constants will be disabled, if previously enabled. Both Dapload A and B would have ±X jet braking capability.

c. More direct approach simulations should be scheduled to optimize the braking gates so that the plume is minimized before reaching the 1000-foot contamination sphere. In addition, at 1000 feet the R (range rate) should be reduced to 2 fps or less and ±X jet braking enabled for tests on the rest of the direct approach.

d. Dispersed trajectory cases should be run for future $\bar{R}$ and $\bar{V}$ cases with ±X jet braking to determine dispersion effects on RCS usage.

e. The $\bar{V}$ and $\bar{R}$ SES simulations, again with ±X jet braking, should be run from distances of 2000 and 3000 feet. No data for these distances exist.

f. The SES simulations to obtain RCS data for transition from $\bar{V}$ to $\bar{R}$ and $\bar{R}$ to $\bar{V}$ for transition angles from 10 to 90 degrees should be obtained for ranges of 1000 and 2000 feet.

g. The manual phase of the LAT should be simulated again in the SES, but this time without the $\pm X$ jet braking and/or inhibiting the upfiring jets so as to determine if this approach mode is feasible. Data indicate that the LAT and $\bar{R}$ may be the only two candidates available if $\pm X$ jet braking is not feasible.

h. The 7-14-21-foot V-line overlays used in the SES simulations should be replaced by 20-30-40-foot V-overlays or some other suitable distances to allow greater tail clearance and safety for these approaches. The SES simulations should be conducted to determine the feasibility and effects on RCS plumes and propellant usage of the new V-control lines. See figures 11 through 14 for V-overlays in various payload sizes.

i. Consideration should be given to optimize certain aspects of the tailfirst manual phase in the SES; i.e., pitchover maneuver rate versus dispersions propagation effects, remove dispersions before pitchover versus after pitchover and tradeoffs, time allotted to remove dispersions, evaluate different V-overlays for crew workload, and RCS use impacts and tradeoffs.

j. A COAS-type device should be installed in the starboard aft window and should be equipped to handle LAT V-overlays like the CCTV.

k. The Orbiter CCTV screen should be designed to accept LAT V-overlays with appropriate scribe marks for overlay positioning.

l. Consideration should be given to add a second forward bay CCTV camera in the starboard side. Then, either camera would be used for control. (It should have "tilt" and "zoom" capability.) The recommendation (j) on COAS would not be needed if this camera was provided.

m. Tests on the SES environment should be done to determine plume effects of moving the LAT first goalpost closer than 150 feet (CG to CG), possibly 120 feet.

n. The SES simulations with 10 and 60 foot payloads should be conducted to determine effect of payload size on the various procedures.

o. The $\bar{V}$, using the tailfirst approach, should be evaluated in the SES to determine if they offer an alternative to the $\pm X$ jet braking $\bar{V}$ approach.

p. The tailfirst approach is not recommended for $\bar{R}$ approaches because the forward tanks would be used exclusively for the required closing rate pulses plus there is no radar capability at tailfirst attitude and fairly accurate range/range rate is needed for $\bar{R}$ operation.

q. $\bar{V}$ and $\bar{R}$ should be run against inertial targets. Only gravity gradients have been approached with this technique so far.

r. More RMS stationkeeping data with inertial targets is needed; i.e., for V, $\bar{R}$, and LAT.

7.0 REFERENCES

1. Orbiter/Payload Proximity Operations - Lateral Technique. JSC IN 77-FM-47, Sept. 1977.

2. Wilson, S.W.: A Proposed Terminal Approach Strategy for Shuttle Payload Retrieval. TRW Report 28415-H005-R0-00, May 31, 1977.

3. Jones, Capt. H.L.: Preliminary Analysis of the Onorbit Stationkeeping Simulations on the Shuttle Engineering Simulator. JSC Memorandum FM32 (76-114), June 1976.

4. Lenoir, W.B.: PDRS III Proximity Operations Simulation - Pilot Comments. CB-Le-32, Oct. 20, 1977.

TABLE 1.- MPAD IC MATRIX FOR OUT-OF-PLANE LATERAL APPROACH TECHNIQUE

(a) PDRS III

	Orbiter												
IC no.	X_{REL}, ft	Y_{REL}, ft	Z_{REL}, ft	$\dot{X}_{REL}$, fps	$\dot{Y}_{REL}$, fps	$\dot{Z}_{REL}$, fps	Pitch θ_{LVLH}, deg	Yaw ψ_{LVLH}, deg	Roll ϕ_{LVLH},	p, deg/sec	q, deg/sec	r, deg/sec	Inert/ grav. grad.
701	-52	780	0	0	-1.791	0	0	83	-90	0.0	-.07	0.0	GG
702	-52	376	0	0	-0.904	0	0	83	-90	0.0	-.07	0.0	GG
703	-52	174	0	0	-0.460	0	0	83	-90	0.0	-.07	0.0	GG
704	-52	1184	0	0	-2.678	0	0	83	-90	0.0	-.07	0.0	GG
705	-52	780	0	0	-1.791	0	0	83	-90	0.0	.01	0.0	I
706	-32	780	-20	-.10	-1.791	-.15	0	83	-90	0.0	-.07	0.0	GG
707	-92	780	40	.15	-1.791	-.10	0	83	-90	0.0	-.07	0.0	GG
708	-32	376	-20	-.10	-0.904	-.15	0	83	-90	0.0	-.07	0.0	GG
709	-92	376	40	.15	-0.904	-.10	0	83	-90	0.0	-.07	0.0	GG
710	-52	1061	0	0	-1.69	0	0	0	-90	0.0	-.07	0.0	GG
711	-52	518	0	0	-0.81	0	0	0	-90	0.0	-.07	0.0	GG
712	-52	1451	0	0	-0.97	0	0	0	-90	0.0	-.07	0.0	GG
713	-52	674	0	0	-0.51	0	0	0	-90	0.0	-.07	0.0	GG
714	8	1451	-60	.10	-0.97	-.20	0	0	-90	0.0	-.07	0.0	GG
715	-112	1451	60	-.10	-0.97	-.20	0	0	-90	0.0	-.07	0.0	GG
716	8	674	-60	.10	-0.51	-.20	0	0	-90	0.0	-.07	0.0	GG
717	-112	674	60	-.10	-0.51	.20	0	0	-90	0.0	-.07	0.0	GG
718	-112	1451	60	-.10	-0.97	.20	0	0	-90	0.0	-.07	0.0	GG
719	-32	1184	-20	-.10	-2.678	-.15	38.20	71.56	-126.74	0.0	-0.7	0.0	GG

TABLE 1.- MPAD IC MATRIX FOR OUT-OF-PLANE LATERAL APPROACH TECHNIQUE - Continued

(a) PDRS III - Concluded

	Target				Orbiter							
IC No.	Pitch θLVLH,deg	Yaw ψLVLH,deg	Roll φ LVLH,deg	I/GG	FDAI I/GG	FDAI roll actual,deg	Pitch actual,deg	Yaw actual,deg	FDAI roll desired,deg	Pitch desired,deg	Yaw desired,deg	DAP config.[a]
701	90	0	0	GG	GG	0	0	0	0	0	0	1
702	90	0	0	GG	GG	0	0	0	0	0	0	1
703	90	0	0	GG	GG	0	0	0	0	0	0	1
704	90	0	0	GG	GG	0	0	0	0	0	0	1
705	90	0	0	I	I	0	0	0	0	0	0	1
706	90	0	0	GG	GG	0	0	0	0	0	0	1
707	90	0	0	GG	GG	0	0	0	0	0	0	1
708	90	0	0	GG	GG	0	0	0	0	0	0	1
709	90	0	0	GG	GG	0	0	0	0	0	0	1
710	90	0	0	GG	GG	0	0	0	0	-83	0	1
711	90	0	0	GG	GG	0	0	0	0	-83	0	1
712	90	0	0	GG	GG	0	0	0	0	-83	0	1
713	90	0	0	GG	GG	0	0	0	0	-83	0	1
714	90	0	0	GG	GG	0	0	0	0	-83	0	1
715	90	0	0	GG	GG	0	0	0	0	-83	0	1
716	90	0	0	GG	GG	0	0	0	0	-83	0	1
717	90	0	0	GG	GG	0	0	0	0	-83	0	1
718	90	0	0	GG	GG	0	0	0	0	-83	0	2
719	90	0	0	CG	CG	0	0	0	0	0	0	1

[a]See DAP configuration table page 3 of 3.

TABLE 1.- MPAD IC MATRIX FOR OUT-OF-PLANE LATERAL APPROACH TECHNIQUE - Concluded

(b) PDRS III - DAP Configuration

Dapload variables	Configuration [a]1		Configuration 2	
	Dapload B	Dapload A	Dapload B	Dapload A
NORM RCS MAN RATES	.5	2.0	.5	2.0
VERN RCS MAN RATES	.5	2.0	.5	2.0
DEADBANDS ROLL	.2	.2	.2	.2
PITCH	.2	.2	.2	.2
YAW	.2	.2	.2	.2
ROT RW (CYC) RPY	1 1 1	5 5 5	1 1 1	5 5 5
TRNS PW (CYC) XYZ	2 2 2	10 10 10	2 2 2	10 10 10
ROT COMPENSATION	.0 .0 .0	.0 .0 .0	.00087 .00087 .00087	.00087 .00087 .00087
TRNS COMPENSATION	.0 .0 .0	.0 .0 .0	.03 .03 .03	.03 .03 .03

[a]In Dapload B, the upfiring jets are disabled and when -Z translation is commanded, both +X and -X jets are fired simultaneously.

TABLE 2.- LATERAL APPROACH TECHNIQUE RUN MATRIX - PDRS III

Run no.	IC no.	Run time, min.	Total runs	Total mins.	Pilot 1 seq. nos.	Pilot 2 seq. no.	Pilot 3 seq. no.	Pilot 4 seq. no.	Case dispersion	Final approach velocity, fps	Other comments
7201	701	15	2	30	170,172		a212F		Reference	2	Final ϕ, tail first
7202	706	15	2	30	b173S,174, 200	222F	a213F	198	Moderate	2	Final ϕ, tail first
7203	707	15	2	30	b175,183S	218			Large	2	Final ϕ, tail first
7204	702	15	1	15	203			b188S	Reference	1	Final ϕ, tail first
7205	708	15	1	15	201	219	a214F	190	Moderate	1	Final ϕ, tail first
7206	709	15	1	15	202			192	Large	1	Final ϕ, tail first
7207	714	20	1	20	184	225	a216F	208	Moderate	2	COAS, pitch-over, & final ϕ-tail first
7208	715	20	1	20	206	226	a217F	207	Moderate	2	COAS, pitch-over, & final ϕ-tail first
7209	716	20	1	20	209			195	Moderate	1	COAS, pitch-over, & final ϕ-tail first
7210	716	20	2	40	b185,210S			196,197	Moderate	1	COAS, pitch-over and $\pm$ X braking
7211	717	20	1	20				193	Moderate	1	COAS, pitch-over & final ϕ-tail first
7212	705	15	1	15					Reference	2	Inertial TGT, final ϕ-tail first
7213	706 X	15	1	15		b224S		b199S	Moderate	2	Inertial TGT, final ϕ-tail first

[a]S denotes Stationkeeping after braking for this case.
[b]F denotes Familiarization case for pilot.

TABLE 2.- LATERAL APPROACH TECHNIQUE RUN MATRIX - PDRS III - Concluded

Run no.	IC no.	Run time, min.	Total runs	Total mins.	Pilot 1 seq. nos.	Pilot 2 seq. no.	Pilot 3 seq. no.	Pilot 4 seq. no.	Case dispersion	Final approach velocity, fps	Other comments
7214	714 X	20	1	20	211				Large	2	Inertial TGT, COAS, pitch-over, tail-first
7215	719	15	1	15	204	221	[a]215F		Moderate	3	Final ϕ, tail-first

[a]F denotes Familiarization case for pilot.

TABLE 3.- NON-LAT PDRS III RUN MATRIX

Title	IC no.	Braking technique	RR 3σ, fps	Pilot 1	Pilot 2	Pilot 3
Direct	5	PRCS	1.0	20	60	65
	5	PRCS	.3	127, 124	123, 122	121
	5	PRCS	.1	35	62	
	5	+X jets	.3	21	63	67
		$\overline{X}$ axis (+X and +Z jets)	.3			
		TBD	No RR	57	68	
		TBD		114		
$\overline{V}$	4	PRCS	1.0	28	95	71
	4	PRCS	.3	29	97	72
	4	PRCS	.1	30	100	
	4	+X jets	.3	32	68	73
		$\overline{X}$ axis (+X and +Z jets)				
		TBD (PRCS)	1.0	52		
	1	TBD (V end to end)	No RR	68		
$\overline{R}$	2	PRCS no CCTV	1.0	43		
	2	PRCS	.3	51	104	113
	2	PRCS	.1	50	105	112
	2	PRCS (use aft CCTV)	1.0	23		
	2	PRCS (use aft CCTV)	.3			
	2	PRCS (use aft CCTV)	.1	39		
	2	+X jets (no CCTV)	.1	42	102	126
	2	+X jets (use aft CCTV)	.1	56	103	125
	2	+X jets (use aft CCTV)	1.0	24		
		$\overline{X}$ axis (+X and +Z jets)				
	2	$\overline{DA} \rightarrow 1K \rightarrow \overline{R} \rightarrow$ RMS		120	88	
$\overline{H}$		See LAT RUN MATRIX TABLE				

TABLE 4.- NON-LAT PDRS III IC MATRIX

IC no.	Orbiter: Rel. state, ft	Orbiter: Vector, fps	Orbiter: Attitude, deg	Target: Att. rates, deg/sec	Target: Attitude, deg	Target: Att. rates, deg/sec
	X_{REL}	$\dot{X}_{REL}$	Pitch	p	Pitch	p
	Y_{REL}	$\dot{Y}_{REL}$	Yaw	q	Yaw	q
	Z_{REL}	$\dot{Z}_{REL}$	Roll	r	Roll	r
2 for $\overline{R}$	-45	.1	0	.02	90	-.066
	0	.1	0	.02	0	0
	1000	.4	0	.02	0	0
4 for $\overline{V}$	1000	.2	90	0	90	-.066
	0	.1	0	.02	0	0
	45	.1	0	0	-180	0
5 for direct approaches	-12389.	45.	-24.4	.02	90	-.066
	1061.	1.18	0	.02	0	0
	27286.	-37.7	-2.0	.02	0	0

DAPLOAD FOR IC 2, 4, 5

	B	A
Norm man rates	.5	2.0
Vern man rates	.5	2.0
Deadbands roll	.2	.2
Deadbands pitch	.2	.2
Deadbands yaw	.2	.2
Rot PW	1 1 1	5 5 5
Tran PW	2 2 2	10 10 10
Rot comp	0,0,0	0,0,0
Tran comp	0,0,0	0,0,0

TABLE 5.- LAT OR H DATA SHEET

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Case no.	Seq. no.	Run no.	IC no.	Type	Pilot	IC dispersion	Run time, min	Collision	Station-keeping and time, min	Pitchover rate, deg/sec and time, min	Payload attitude mode	Orbiter attitude mode	Stationkeeping torque impulse and RCS lbs
1H	170	7201	701	A	1	None	9	No	No	None	Orb. rate	Orb. rate	None
2H	172	7201	701	A	1	None	8	No	No	None	Orb. rate	Orb. rate	None
3H	173	7202	706	A	1	1 ,moderate	12	No	Yes-7 min	None	Orb. rate	Orb. rate	1.66 - 145#
4H	174	7202	706	A	1	1 ,moderate	10	No	No	None	Orb. rate	Orb. rate	None
5H	175	7203	707	A	1	2 ,large	13	No	No	None	Orb. rate	Orb. rate	None
6H	176	7201	701	A	2	None	8	No	No	None	Orb. rate	Orb. rate	None
7H	180	7203	707	A	2	2 ,large	9	No	No	None	Orb. rate	Orb. rate	None
8H	183	7203	707	A	1	2 ,large	9	No	Yes-6 min	None	Orb. rate	Orb. rate	0.35 - 37#
9H	184	7207	714	B	1	2 ,large	18	No	No	1.0@5	Orb. rate	Orb. rate	None
10H	185	7210	716	C	1	2 ,large	21	No	Yes-5 min	None	Orb. rate	Orb. rate	0.13 - 40#
11H	188	7204	702	A	4	None	9	No	Yes-7 min	None	Orb. rate	Orb. rate	2.57 - 102#
12H	190	7205	708	A	4	1 ,moderate	9	No	No	None	Orb. rate	Orb. rate	None
13H	192	7206	709	A	4	2 ,large	11	Yes	No	None	Orb. rate	Orb. rate	None
14H	193	7211	717	B	4	2 ,large	22	No	No	0.55@5	Orb. rate	Orb. rate	None
15H	195	7209	716	B	4	2 ,large	21	Yes	No	0.62@5	Orb. rate	Orb. rate	None
16H	196	7210	716	C	4	2 ,large	17	No	No	None	Orb. rate	Orb. rate	None
17H	197	7210	716	C	4	2 ,large	11	No	No	None	Orb. rate	Orb. rate	None
18H	198	7202	706	A	4	1 ,moderate	9	No	No	None	Orb. rate	Orb. rate	None
19H	199	7213	706	A	4	1 ,moderate	10	No	Yes-14 min	None	Inertial	Inertial	0.22 - 38#
20H	200	7202	706	A	1	1 ,moderate	10	No	No	None	Orb. rate	Orb. rate	None
21H	201	7205	708	A	1	1 ,moderate	11	No	No	None	Orb. rate	Orb. rate	None
22H	202	7206	709	A	1	2 ,large	11	No	No	None	Orb. rate	Orb. rate	None
23H	203	7204	702	A	1	None	8	No	No	None	Orb. rate	Orb. rate	None
24H	204	7215	719	A	1	1 ,moderate	8	No	No	None	Orb. rate	Orb. rate	None
25H	206	7208	715	B	1	2 ,large	24	No	No	0.92@4	Orb. rate	Orb. rate	None
26H	207	7208	715	B	4	2 ,large	22	No	No	0.76@6	Orb. rate	Orb. rate	None
27H	208	7207	714	B	4	None	19	No	No	0.62@6	Orb. rate	Orb. rate	None
28H	209	7209	716	B	1	2 ,large	22	No	No	1.03@2	Orb. rate	Orb. rate	None
29H	210	7210	716	C	1	2 ,large	11	No	Yes-13 min	None	Orb. rate	Orb. rate	0.50 - 103#
30H	211	7214	714	B	1	2 ,large	22	No	No	1.56@3	Inertial[a]	Inertial	None
31H	212	7201	701	A	3	None	9	No	No	None	Orb. rate	Orb. rate	None
32H	213	7202	706	A	3	1 ,moderate	12	No	No	None	Orb. rate	Orb. rate	None
33H	214	7205	708	A	3	1 ,moderate	10	No	No	None	Orb. rate	Orb. rate	None
34H	215	7215	719	A	3	1 ,moderate	10	Yes	No	None	Orb. rate	Orb. rate	None
35H	216	7207	714	B	3	2 ,large	27	No	No	0.69@9	Orb. rate	Orb. rate	None
36H	217	7208	715	B	3	None	16	No	No	0.33@3	Orb. rate	Orb. rate	None
37H	218	7203	707	A	2	2 ,large	9	No	No	None	Orb. rate	Orb. rate	None
38H	219	7205	708	A	2	1 ,moderate	10	No	No	None	Orb. rate	Orb. rate	None
39H	221	7215	719	A	2	1 ,moderate	10	No	No	None	Orb. rate	Orb. rate	None
40H	222	7202	706	A	2	1 ,moderate	9	No	No	None	Orb. rate	Orb. rate	None
41H	223	7213	706	A	2	1 ,moderate	14	No	No	None	Inertial	Inertial	None
42H	224	7213	706	A	2	1 ,moderate	15	No	Yes-7 min	None	Inertial	Inertial	15.2 - 178#
43H	225	7207	714	B	2	2 ,large	20	No	No	2.0@1	Orb. rate	Orb. rate	None
44H	226	7208	715	B	2	1 ,moderate	22	No	No	2.0@1	Orb. rate	Orb. rate	None

[a]Bad SES configuration - payload not truly inertial, grav. grad. forces in.

TABLE 5.- LAT OR $\overline{H}$ DATA SHEET - Continued

15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
		RCS prop. lbs. used-	Torque imp on pay-load, ft-lb-sec	Final range shlder joint to PL CG	Final Velocity		Payload att. P,Y,R		Payload att. q,r,p		Orbiter att. P,Y,R		First goal-post rel. state vector-		Second goal-post rel. state vector		Final station-keeping rel. state vector		GP1 to GP2 ht chg, ft	Tail miss dist, ft	Cock-pit miss dist, ft
Case no.	Seq. no.	T,F,A			Desired	Actual	Initial	Final	Initial	Final	Initial	Final	x,y,z	$\dot{x},\dot{y},\dot{z}$	x,y,z	$\dot{x},\dot{y},\dot{z}$	x,y,z	$\dot{x},\dot{y},\dot{z}$			
1H	170	T=72 F=14 A=58	0.04	51	-2.0	-1.95	P=90.0 Y= 0.0 R= 0.0	90.0 0.0 0.0	q=-.066 r=0.0 p=0.0	-.066 0.0 0.0	P=0.0 Y=83.0 R=-90.0	0.8 83.0 -91.0	x=-51 y=149 z= 0	.011 -1.95 -.015	x=-51 y=51 z=1	.013 -1.95 -.018	x=-56 y=-31 z=-4	-.060 .033 -.012	0	13	40
2H	172	T=47 F=3 A=44	0.00	52	-2.0	-1.96	P=90.0 Y=0.0 R=0.0	90.0 0.0 0.0	q=-.066 r=0.0 p=0.0	-.066 0.0 0.0	P=0.0 Y=83.0 R=-89.1	359.2 83.1 -89.1	x=-54 y=149 z=0	-.007 -1.957 -.009	x=-54 y=51 z=0	-.005 -1.96 -.010	x=-56 y=38 z=-1	-.065 -.031 -.002	0	16	40
3H	173	T=373 F=157 A=216	5.48	28	-2.0	-1.46	P=90.0 Y=0.0 R=0.0	90.3 0.2 0.0	q=-.066 r=0.0 p=0.0	-.062 .003 0.0	P=0.0 Y=83.0 R=-90.0	358.5 83.2 -88.4	x=-53 y=150 z=1	.089 -1.47 -.055	x=-45 y=51 z=-2	.135 -1.46 -.052	x=-30 y=-43 z=0	.135 -.069 .053	-8	7	12
4H	174	T=188 F=58 A=130	0.90	32	-2.0	-.138	P=90.0 Y=0.0 R=0.0	90.0 0.0 0.0	q=-.066 r=0.0 p=0.0	-.065 0.0 0.0	P=0.0 Y=83.0 R=-90.0	0.6 83.1 -90.7	x=-53 y=150 z=0	.007 -1.395 -.060	x=-50 y=51 z=-2	.082 -1.378 .021	x=-36 y=-41 z=-4	.113 -.052 .015	-3	12	20
5H	175	T=293 F=99 A=194	0.74	37	-2.0	-1.10	P=90.0 Y=0.0 R=0.0	90.1 .1 0.0	q=-.066 r=0.0 p=0.0	-.065 0.0 0.0	P=0.0 Y=83.0 R=-90.0	359.1 82.8 -89.1	x=-54 y=150 z=0	.076 -1.099 .001	x=-52 y=51 z=-2	.076 -1.06 -.002	x=-41 y=-42 z=-4	-.027 -.029 -.002	-2	14	22
6H	176	T=64 F=11 A=53	0.02	47	-2.0	-1.95	P=90.0 Y=0.0 R=0.0	90.0 0.0 0.0	q=-.066 r=0.0 p=0.0	-.066 0.0 0.0	P=0.0 Y=83.0 R=-90.0	1.5 82.8 -91.8	x=-53 y=149 z=2	.005 -1.95 .008	x=-53 y=52 z=2	.024 -1.95 .009	x=-51 y=-35 z=3	.122 -.114 .001	0	15	33
7H	180	T=220 F=83 A=137	1.99	25	-2.0	-1.77	P=90.0 Y=0.0 R=0.0	90.0 0.1 0.0	q=-.066 r=0.0 p=0.0	-.066 0.0 0.0	P=0.0 Y=83.0 R=-90.0	0.9 83.1 -90.4	x=-56 y=149 z=-3	-.105 -1.85 .085	x=-49 y=50 z=3	.126 -1.77 .069	x=-30 y=-37 z=-3	-.004 -.072 -.047	-7	11	12
8H	183	T=165 F=48 A=117	0.19	44	-2.0	-1.60	P=90.0 Y=0.0 R=0.0	90.0 0.0 0.0	q=-.066 r=0.0 p=0.0	-.066 0.0 0.0	P=0.0 Y=83.0 R=-90.0	1.7 83.0 -91.4	x=-56 y=148 z=-1	.025 -1.61 -.018	x=-54 y=52 z=-1	.058 -1.60 -.002	x=-48 y=-41 z=-2	.058 -.073 -.018	-2	16	30
9H	184	T=359 F=127 A=232	0.27	52	-2.0	-1.60	P=90.0 Y=0.0 R=0.0	90.1 0.2 0.1	q=-.066 r=0.0 p=0.0	-.065 0.0 0.0	P=0.0 Y= 0.0 R=-90.0	357.7 83.0 -87.4	x=-50 y=150 z=0	-.044 -1.61 .002	x=-52 y=50 z=0	-.032 -1.60 .002	x=-56 y=-40 z=1	-.043 -.032 .017	+2	14	39
10H	185	T=661 F=328 A=33	0.13	41	-1.0	-1.32	P=90.0 Y=0.0 R=0.0	90.1 0.5 0.3	q=-.066 r=0.0 p=0.0	-.066 0.0 0.0	P=0.0 Y= 0.0 R=-90.0	359.9 -.2 -90.1	NOT	APP.	N.	A.	x=-48 y=44 z=-4	.015 .075 .034	NA	NA	27
11H	188	T=41 F=9 A=32	0.09	35	-1.0	-.924	P=90.0 Y=0.0 R=0.0	90.0 0.0 0.0	q=-.066 r=0.0 p=0.0	-.065 0.0 0.0	P=0.0 Y=83.0 R=-90.0	359.8 82.9 -89.6	x=-53 y=149 z=0	-.010 -.93 -.011	x=-53 y=50 z=-1	.032 -.934 -.011	x=-46 y=-40 z=-6	.015 .021 -.035	0	15	29

TABLE 5.- LAT OR $\overline{H}$ DATA SHEET - Continued

15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
					Final Velocity		Payload att. P,Y,R		Payload att. q,r,p		Orbiter att. P,Y,R		First goal-post rel. state vector -		Second goal-post rel state vector		Final station-keeping rel. state vector				
Case no.	Seq. no.	RCS prop. lbs used- T,F,A	Torque imp on pay-load, ft-lb-sec	Final range shlder joint to PL CG	Desired	Actual	Initial	Final	Initial	Final	Initial	Final	x,y,z	ẋ,ẏ,ż	x,y,z	ẋ,ẏ,ż	x,y,z	ẋ,ẏ,ż	GP1 to GP2 ht chg, ft	Tail miss Dist., ft	Cock-pit miss Dist. ft
12H	190	T=107 F=37 A=70	3.49	35	-1.0	-.723	P=90.0 Y=0.0 R=0.0	90.1 .1 0.0	q=-.066 r=0.0 p=0.0	-.063 .002 0.0	P=0.0 Y=83.0 R=-90.0	1.8 82.8 -91.6	x=-51 y=149 z=1	.103 -.732 -.031	x=-45 y=50 z=-7	.045 -.732 -.067	x=-40 y=-39 z=-16	-.011 -.024 .012	7	7	22
13H	192	[a]T=101 F=34 A=67	0.21	7	-1.0	-.53	P=90.0 Y=0.0 R=0.0	90.0 0.0 0.0	q=-.066 r=0.0 p=0.0	-.065 0.0 0.0	P=0.0 Y=83.0 R=-90.0	359.1 83.2 -89.0	x=-51 y=150 z=0	.067 -.559 -.034	x=-33 y=50 z=-10	.111 -.568 -.081	x=-8 y=-37 z=-27	.232 -.532 -.152	-18	Collide (-5)	Col- lide (-9)
14H	193	T=279 F=103 A=176	1.13	59	-1.0	-.738	P=90.0 Y=0.0 R=0.0	90.1 .5 .5	q=-.066 r=0.0 p=0.0	-.066 0.0 0.0	P=0.0 Y= 0.0 R=-90.0	.2 83.0 -90.1	x=-51 y=150 z=-1	-.086 -.732 -.001	x=-60 y=50 z=1	-.044 -.738 .019	x=-64 y=-38 z=5	-.023 .003 .028	+9	22	47
15H	195	T=447 F=180 A=267	19.28	18	-1.0	-1.07	P=90.0 Y=0.0 R=0.0	90.5 1.1 0.4	q=-.066 r=0.0 p=0.0	-.054 .016 0.0	P=0.0 Y= 0.0 R=-90.0	.5 82.8 -89.9	x=-56 y=106 z=-1	.208 -1.07 .020	x=-43 y=50 z=-1	.249 -1.07 -.012	x=-6 y=-51 z=-9	.224 .010 .097	-13	5	Col- lide
16H	196	T=587 F=307 A=280	0.09	38	-1.01	-1.67	P=90.0 Y=0.0 R=0.0	90.0 0.0 0.0	q=-.066 r=0.0 p=0.0	-.066 0.0 0.0	P=0.0 Y= 0.0 R=-90.0	.2 .1 -89.8	NOT	APP.	NOT	APP.	x=-43 y=-41 z=-1	-.025 .066 .066	NA	NA	31
17H	197	T=638 F=333 A=335	0.57	37	-1.0	-1.70	P=90.0 Y=0.0 R=0.0	90.0 -0.1 0.0	q=-.066 r=0.0 p=0.0	-.065 0.0 0.0	P=0.0 Y= 0.0 R=-90.0	1.0 -.4 -89.9	NOT	APP.	NOT	APP.			NA	NA	29
18H	198	T=155 F=42 A=113	0.43	37	-2.0	-1.28	P=90.0 Y=0.0 R=0.0	90.0 0.0 0.0	q=-.066 r=0.0 p=0.0	-.066 0.0 0.0	P=0.0 Y=-83.0 R=-90.0	2.1 -82.7 -91.5	x=-55 y=143 z=-4	.007 -1.307 -.140	x=-55 y=49 z=-2	.022 -1.276 .034	x=-52 y=-38 z=1	.012 .002 .032	0	17	28
19H	199	T=216 F=65 A=151	[b]28.61	43	-2.0	-0.95	P=90.0 Y=0.0 R=0.0	126.6 1.5 0.0	q=0.0 r=0.0 p=0.0	-.017 .010 .000	P=0.0 Y=83.0 R=-90.0	36.8 83.1 -88.8	x=-48 y=150 z=23	[c].069 -1.15 .138	x=-45 y=50 z=26	.077 -.952 0.0	x=-45 y=-40 z=28	.033 .003 .036	-3	12	27
20H	200	T=183 F=52 A=131	0.07	48	-2.0	-1.25	P=90.0 Y=0.0 R=0.0	90.0 0.0 0.0	q=-.066 r=0.0 p=0.0	-.066 0.0 0.0	P=0.0 =83.0 R=-90.0	1.5 82.9 -91.2	x=-52 y=149 z=-1	-.018 -1.26 -.016	x=-53 y=51 z=-1	+.014 -1.25 0.0	x=-51 y=-40 z=-2	.003 -.114 -.006	+1	15	34
21H	201	T=173 F=63 A=110	0.34	24	-1.0	-.77	P=90.0 Y=0.0 R=0.0	90.0 0.0 0.0	q=-.066 r=0.0 p=0.0	.065 0.0 0.0	P=0.0 Y=83.0 R=-90.0	1.3 83.1 -91.4	x=-49 y=141 z=-2	.064 -.774 -.015	x=-41 y=50 z=1	.080 -.773 .018	x=-26 y=-43 z=0	-.025 -.024 -.018	-8	3	9
22H	202	T=188 F=62 A=126	0.20	60	-1.0	-.665	P=90.0 Y=0.0 R=0.0	90.0 0.0 0.0	q=-.066 r=0.0 p=0.0	-.065 0.0 0.0	P=0.0 Y=83.0 R=-90.0	1.7 83.0 -91.4	x=-54 y=135 z=-2	-.051 -.654 .005	x=-60 y=50 z=0	-.042 -.665 .019	x=-64 y=-40 z=4	-.007 -.061 .013	+6	22	47

[a]No Braking.
[b]Jets were not turned off until braking/inertial PL but gravity in by error.
[c]Rel. state vector for inertial cases must be converted for comparison with GG cases.

TABLE 5.- LAT OR $\overline{H}$ DATA SHEET - Continued

15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
		RCS prop. lbs.	Torque imp on pay-load,	Final range shlder joint	Final Velocity		Payload att. P,Y,R		Payload att. q,r,p		Orbiter att. P,Y,R		First goal-post rel. state vector		Second goal-post rel. state vector		Final station-keeping rel. state vector		GP1 to GP2 ht	Tail miss	Cock-pit miss
Case no.	Seq. no.	used-T,F,A	ft-lb-sec	to PL CG	Desired	Actual	Initial	Final	Initial	Final	Initial	Final	x,y,z	$\dot{x},\dot{y},\dot{z}$	x,y,z	$\dot{x},\dot{y},\dot{z}$	x,y,z	$\dot{x},\dot{y},\dot{z}$	chg, ft	dist, ft	dist, ft
23H	203	T=93 F=31 A=62	0.06	62	-1.0	-.980	P=90.0 Y=0.0 R=0.0	90.0 0.0 0.0	q=-.066 r=0.0 p=0.0	-.066 0.0 0.0	P=0.0 Y=83.0 R=-90.0	4.4 82.8 -92.2	x=-53 y=151 z=1	-.091 -.971 .009	x=-61 y=50 z=3	-.067 -.980 .028	x=-67 y=-38 z=7	-.033 -.171 .037	+8	23	50
24H	204	T=163 F=39 A=124	0.32	55	-3.0	-2.897	P=90.0 Y=0.0 R=0.0	90.0 0.0 0.0	q=-.066 r=0.0 p=0.0	-.066 0.0 0.0	P=0.0 Y=83.0 R=-90.0	1.6 83.0 -91.4	x=-61 y=148 z=0	.058 -2.895 .017	x=-59 y=50 z=1	.058 -2.897 .011	x=-58 y=-43 z=2	-.023 .011 .020	-2	21	41
25H	206	T=558 F=201 A=357	0.14	55	-2.0	-1.18	P=90.0 Y=0.0 R=0.0	90.1 .2 .2	q=-.066 r=0.0 p=0.0	-.066 0.0 0.0	P=0.0 Y=0.0 R=-90.0	358.4 83.1 -92.7	x=-53 y=149 z=2	-.145 -1.182 .012	x=-65 y=50 z=3	-.130 1.184 .019	x=-56 y=-29 z=6	.161 .122 -.040	+12	27	39
26H	207	T=435 F=165 A=270	0.12	36	-2.0	-1.24	P=90.0 Y=0.0 R=0.0	90.1 .1 .1	q=-.066 r=0.0 p=0.0	-.066 0.0 0.0	P=0.0 Y=0.0 R=-90.0	358.0 83.3 -87.5	x=-60 y=151 z=1	.124 -1.24 .074	x=-50 y=50 z=5	.134 -1.24 .030	x=-37 y=-39 z=7	.001 -.007 .005	-10	12	22
27H	208	T=138 F=38 A=100	0.17	39	-2.0	-1.48	P=90.0 Y=0.0 R=0.0	90.1 .1 0.0	q=-.066 r=0.0 p=0.0	-.065 0.0 0.0	P=0.0 Y=0.0 R=90.0	3.5 81.8 -92.1	x=-50 y=138 z=0	-.012 -1.48 -.053	x=-49 y=50 z=-3	.034 -1.48 -.062	x=-47 y=-44 z=-10	.010 .016 -.071	-1	11	30
28H	209	T=534 F=204 A=330	1.42	42	-1.0	-.677	P=90.0 Y=0.0 R=0.0	90.1 .5 .6	q=-.066 r=0.0 p=0.0	-.066 0.0 0.0	P=0 Y=0 R=90.0	.7 83.2 -89.8	x=-52 y=134 z=0	-.054 -.713 -.052	x=-54 y=49 z=-2	.052 -.677 -.016	x=-46 y=-40 z=-7	.036 -.058 -.037	+2	16	29
29H	210	T=1213 F=620 A=593	0.25	52	-1.0	-2.98	P=90.0 Y=0.0 R=0.0	90.0 0.0 0.0	q=-.066 r=0.0 p=0.0	-.066 0.0 0.0	P=0 Y=0 R=-90	.5 .2 -89.2	NOT	APP.	NOT	APP.	-52 -53 1	.052 .087 -.031	NA	NA	36
30H	211	T=512 F=192 A=320	0.34	NA	-2.0	-1.07	P=90.0 Y=0.0 R=0.0	141. .3 .1	q=0.0 r=0.0 p=0.0	-.065 0.0 0.0	P=0.0 Y=0 R=-90.0	88 83 -91.9		Not applicable Run terminated due to PL Went to grav. grad. by error					NA	NA	
31H	212	T=57 F=8 A=49	1.89	38	-2.0	-1.95	P=90.0 Y=.0 R=0.0	90.0 0.0 0.0	q=-.066 r=.0 p=0.0	-.066 0.0 0.0	P=0.0 Y=3 R=-90.0	3.3 82.7 -92.6	x=-53 y=49 z=2	-.004 -1.95 .008	x=-54 y=8 z=3	-.010 -1.95 .009	x=-42 y=42 z=3	.153 -.081 -.022	+2	16	25
32H	213	T=334 F=127 A=207	10.22	33	-2.0	-0.98	P=90.0 Y=0.0 R=0.0	90.5 .7 0.0	q=-.066 r=0.0 p=0.0	-.059 .008 0.0	P=0.0 Y=83.0 R=-90.0	1.3 83.0 -91.3	x=-48 y=93 z=-2	.152 -.977 -.081	x=-42 y=50 z=-6	.146 -.98 -.10	x=-35 y=-39 z=-8	-.156 .020 .097	-6	4	18
33H	214	T=120 F=40 A=80	9.87	45	-1.0	-.616	P=90.0 Y=0.0 R=0.0	90.7 .8 .1	q=-.066 r=0.0 p=0.0	-.064 .002 0.0	P=0.0 Y=83.0 R=-90.0	1.1 83 -91.3	x=-54 y=0 z=-1	-.031 -.627 .012	x=-55 y=0 z=-1	.006 -.616 .013	x=-46 y=43 z=2	.103 .043 -.007	+1	17	29

TABLE 5.- LAT OR $\overline{H}$ DATA SHEET - Concluded

15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
		RCS prop. lbs. used-	Torque imp on pay-load,	Final range shlder joint	Final Velocity		Payload att. P,Y,R		Payload att. q,r,p		Orbiter att. P,Y,R		First goal post rel. state vector		Second goal-post rel. state vector		Final station-keeping rel. state vector		GP1 to GP2 ht chg,	Tail miss dist,	Cock-pit miss dist,
Case no.	Seq. no.	T,F,A	ft-lb-sec	to PL CG	Desired	Actual	Initial	Final	Initial	Final	Initial	Final	x,y,z	$\dot{x},\dot{y},\dot{z}$	x,y,z	$\dot{x},\dot{y},\dot{z}$	x,y,z	$\dot{x},\dot{y},\dot{z}$	ft[a]	ft	ft
34H	215	T=314 F=109 A=215	5.18	15	-3.0	-2.63	P=90.0 Y=0.0 R=0.0	90.5 .6 .1	q=-.066 r=0.0 p=0.0	-.062 .003 0.0	P=0.0 Y=83.0 R=-90.0	.3 83.1 -90.0	x=-57 y=87 z=-1	.475 -2.64 -.059	x=-50 y=50 z=-2	.473 -2.63 -.073	x=-13 y=-40 z=-17	.151 .112 -.162	-7	12	Col- lide (-4)
35H	216	T=433 F=156 A=277	0.62	48	-2.0	-0.49	P=90.0 Y=0.0 R=0.0	90.2 .5 .4	q=-.066 r=0.0 p=0.0	-.065 0.0 0.0	P=0 Y=0 R=-90.0	357.6 81.5 -87.1	x=-49 y=140 z=-1	-.029 -.486 -.006	x=-55 y=50 z=-1	-.019 -.493 .004	x=-53 y=-29 z=1	.015 .014 .005	+6	17	36
36H	217	T=189 F=55 A=134	0.03	31	-2.0	-1.68	P=90.0 Y=0.0 R=0.0	90.0 0.1 0.0	q=-.066 r=0.0 p=0.0	-.066 0.0 0.0	P=0 Y=0 R=-90	359.6 81.5 -88.7	x=-50 y=134 z=-1	-.001 -1.68 -.067	x=-50 y=50 z=5	.022 -1.69 -.07	x=-48 y=-37 z=-12	-.001 -.033 -.067	0	12	31
37H	218	T=335 F=139 A=196	0.94	38	-2.0	-1.79	P=90 Y=0 R=0	90.0 0.0 0.0	q=-.066 r=0 p=0	-.066 0 0	P=0 Y=83 R=-90	1.5 83. -90.6	x=-59 y=149 z=1	-.145 -1.79 .166	x=-66 y=51 z=10	-.117 -1.79 .184	x=-44 y=-33 z=-4	.085 .005 0	+7	28	27
38H	219	T=262 F=195 A=157	2.49	28	-1.0	-.75	P=90 Y=0 R=0	90.1 .1 0	q=-.066 r=0 p=0	-.064 .001 0	P=0 Y=83 R=-90	1.7 83.1 -91.5	x=-53 y=146 z=1	.045 -.739 -.027	x=-47 y=51 z=-4	.063 -.75 -.045	x=-38 y=-35 z=0	.154 -.018 .042	-6	9	21
39H	221	T=380 F=140 A=240	2.79	38	-3.0	-2.35	P=90 Y=0 R=0	90 0 0	q=-.066 r=0 p=0	-.066 0 0	P=0 Y=83 R=-90	.9 83.1 -90.4	x=-50 y=105 z=-1	-.280 -2.36 .007	x=-56 y=48 z=-1	-.255 -2.35 .021	x=-41 y=-40 z=-3	.010 -.048 -.076	+6	18	24
40H	222	T=176 F=54 A=122	[a]137.54	41	-2.0	-1.85	P=90 Y=0 R=0	86.6 -1.9 -.1	q=-.066 r=0 p=0	-.174 -.084 .001	P=0 Y=83 R=90	1.5 82.8 -91.1	x=-58 y=145 z=1	.075 -1.85 -.022	x=-55 y=49 z=2	.069 -1.85 -.029	x=-47 y=-33 z=-4	.071 .110 .011	-3	17	30
41H	223	T=202 F=55 A=147	4.15	15	-2.0	-1.71	P=90 Y=0 R=0	[b]123.2 .1 0	q=0.0 r=0.0 p=0.0	.003 .002 .000	P=0 Y=83 R=-90	36.2 82.8 -92.7	x=-52 y=131 z=24	.013 -1.80 -.113	x=-41 y=50 z=19	.288 -1.11 -.150	x=-17 y=-28 z=2	.159 .985 -.148	-9	7	10
42H	224	T=208 F=67 A=141	0.42	25	-2.0	-1.80	P=90 Y=0 R=0	[b]121.2 0 0	q=0 r=0 p=0	.000 .000 .000	P=0 Y=83 R=-90	34.6 83.0 -93.1	x=-51 y=147 z=21	.14 -1.80 .114	x=-43 y= 49 z=27	.157 -1.81 .101	x=-32 y=-35 z=30	.163 .282 -.321	-9	13	15
43H	225	T=406 F=149 A=257	1.80	40	-2.0	-1.44	P=90 Y=0 R=0	89.9 -.1 0	q=-.066 r=0 p=0	-.066 -.001 0	P=0 Y=0 R=-90	354.5 81.4 -83.1	x=-51 y=105 z=1	.014 -1.44 .031	x=-50 y=50 z=2	.027 -1.44 .029	x=-45 y=-37 z=4	.072 -.065 0	-1	12	31
44H	226	T=316 F=100 A=216	0.31	51	-2.0	-1.38	P=90 Y=0 R=0	90.1 .1 .1	q=-.066 r=0 p=0	-.065 0 0	P=0 Y=0 R=-90	341.5 82.9 -70.9	x=-52 y=116 z=1	.056 -1.38 -.122	x=-50 y=50 z=5	.047 -1.38 -.128	x=-50 y=-51 z=-21	-.028 -.226 -.093	-2	12	36

[a]GP1 = First goalpost and GP2 = Second goalpost.
[b]All jets on by error.
[c]PL/inertial attitude.

TABLE 6.- LAT OR $\bar{H}$ - QUICK SUMMARY TABLE

Sequence no.	Type/dispersion/ velocity (a,b)	Time	RCS lbs TOT-FWD	Torque	Tail miss	Final payload attitude (c)
			TYPE A - Tailfirst only			
170	AR2	9	72-14	.04	13	90.0,0.0,0.0
172	AR2	8	47-3	.00	16	90.0,0.0,0.0
173	AM2	12	373-157	5.48	7	90.3,0.2,0.0
174	AM2	10	188-58	.90	12	90.0,0,0
175	AL2	13	293-99	.74	14	90.1,.1,0
176	AR2	8	64-11	.02	15	90,0,0
180	AL2	9	220-83	1.99	11	90,0.1,0
183	AL2	9	165-48	.19	16	90,0,0
188	AR1	9	41-9	.09	15	90,0,0
190	AM1	9	107-37	3.49	7	90.1,.1,0
192	AL1	11	101-34	.21	-5	90,0,0
198	AM2	9	155-42	.43	17	90,0,0
199	AM2	10	216-55	[a]28.61	12	89.7,1.4,0
200	AM2	10	183-52	.07	15	90,0,0
201	AM1	11	173-63	.34	3	90,0,0
202	AL1	11	188-62	.20	22	90,0,0
203	AR1	8	93-31	.06	23	90,0,0
204	AM3	8	163-39	.32	21	90,0,0
212	AR2	9	57-8	1.89	16	90,0,0
213	AM2	12	334-127	10.22	4	90.5,.7,0
214	AM1	10	120-40	9.87	17	90.7,.8,.1
215	AM3	10	314-109	5.18	12	90.5,.6,.1
218	AL2	9	335-139	.94	28	90,0,0
219	AM1	10	262-105	2.49	9	90.1,.1,0
221	AM3	10	380-140	2.79	18	90,0,0
222	AM2	9	176-54	[d]137.54	17	86.6,-1.9,-.1
223	AM2	14	202-55	4.15	7	- - -
224	AM2	15	208-67	.42	13	- - -
Average		10	186-62	1.98		
			TYPE B - COAS phase + pitchover + tailfirst			
184	BL2	18	359-127	.27	14	90.1,.2,.1
193	BL1	22	279-103	1.13	22	90.1,.5,.5
195	BL1	25	447-180	19.28	5	90.5,1.1,0.4

[a]All jets on by error, not included in average.
[b]R = Reference, M = Moderate, L = Large, 2 = 2 fps, etc.
[c]Payload initial attitude always 90,0,0.
[d]All jets on till braking, not included in average.

TABLE 6.- LAT OR $\bar{H}$ - QUICK SUMMARY TABLE - Concluded

Sequence no.	Type/dispersion/ velocity (a)	Time	RCS lbs TOT-FWD	Torque	Tail miss	Final payload attitude (b)
TYPE B -COAS phase + pitchover + tailfirst - concluded						
206	BL2	24	558-201	.14	27	90.1,.2,.2
207	BL2	22	435-165	.12	12	90.1,.1,1
208	BR2	19	138-38	.17	11	90.1,.1,0
209	BL2	22	534-204	1.42	16	90.1,.5,.6
211	BL2	22	512-192	.34	NA	-
216	BL2	27	433-156	.62	17	90.2,.5,.4
217	BR2	16	189-55	.03	12	90.0,.1,0
225	BL2	20	406-149	1.80	12	89.9,-.1,0
226	BM2	22	316-100	.31	12	90.1,.1,.1
Average		22	383-139	2.13		
TYPE C - COAS phase with X jet braking						
185	CL1	21	661-328	.13	NA	90.1,.5,.3
196	CL1	17	587-307	.09	NA	90,0,0
197	CL1	11	638-333	.57	NA	90,-.1,0
210	CL1	11	[d]1213-620	.25	NA	90,0,0
Average		16	628-322	.26		

[a]All jets on by error, not included in average.
[b]Payload initial attitude always 90,0,0.
[d]Improper closing velocity - not included in average.

TABLE 7.- DIRECT APPROACHES DATA

Case no.	Seq. no.	IC no.	Type braking	Radar model	Pilot	IC dis- persion	Run time, min	RCS prop. lbs used- TOT,FWD,AFT (a)	Torque impulse ft-lb-sec	Final range shoulder joint to PL CG	Payload attitude, P,Y,R: deg (b) Init	max	fin	Payload attitude rates q,r,p; deg/sec (c) Init	max	fin	Stationkeeping time/RCS lbs
1 DA	20	5	PRCS	1.0	1	None	36	T=975	714.4	51	t=0	t=28	t=36	t=0	t=28	t=36	None
											P=90	82.5	258	q=-.066	-.078	.603	
								F=320			Y=0	-.1	.9	r=0	.003	0	
								A=655			R=0	2.2	1.8	p=0	0	-.002	
2 DA	21	5	±X JETS	1.0	1	None	27	T=16,27	11.35	47	t=0	t=24	t=27	t=0	t=24	t=27	None
								T=878,1910			P=90	89.8	91.4	q=-.066	-.065	-.056	
								F=302,840			Y=0	0	0	r=0	0	0	
								A=576,1070			R=0	0	0	p=0	0	0	
3 DA	33	5	PRCS	.3	1	None	34	T=1013	673.1	53	t=0	t=25	t=34	t=0	t=25	t=34	None
											P=90	86.0	156.	q=-.066	-.071	.568	
								F=349			Y=0	.4	.7	r=0	0	.007	
								A=664			R=0	.1	.1	p=0	0	.002	
4 DA	35	5	PRCS	.1	1	None	25	T=1023	416.2		t=0	t=23.	t=25	t=0	t=23	t=25	None
											P=90.0	66.7	85.2	q=-.066	-.161	.141	
								F=340			Y=0	2.7	4.5	r=0	.021	.010	
								A=683			R=0	.6	.2	p=0	.001	-.001	
5 DA	57	5	PRCS	NO	1	None	47	T=4114	688.9	63	t=0	t=47	t=47	t=0	t=47	t=47	None
				RADAR							P=90.0	307	307	q=-.066	-.323	-.323	
								F=1595			Y=0	-34	-34	r=0	-.790	-.790	
								A=3020			R=0	-100	-100	p=0	.058	.058	
6 DA	60	5	PRCS	1.0	2	None	24	T=1105	198.1	35	t=0	t=24	t=24	t=0	t=24	t=24	None
											P=90	69.5	69.5	q=-.066	-.030	-.030	
								F=366			Y=0	3.7	3.7	r=0	.013	.013	
								A=739			R=0	.8	.8	p=0	-.001	-.001	
7 DA	61	5	PRCS	.3	2	None	25	T=1214	101.2	37	t=0	t=21	t=25	t=0	t=21	t=25	None
											P=90	89.2	92.7	q=-.066	-.091	-.026	
								F=426			Y=0	.1	-.3	r=0	.002	-.005	
								A=788			R=0	0	0	p=0	0	0	
8 DA	62	5	PRCS	.1	2	None	27	T=1095	897.9	41	t=0	t=21	t=27	t=0	t=21	t=27	None
											P=90	89	322	q=-.066	-.073	.802	
								F=387			Y=0	.1	2	r=0	.001	.004	
								A=708			R=0	0	-.3	p=0	0	-.004	

aT = total, F = FWD, and A = AFT.
bP = pitch, Y = yaw, and R = roll.
cq = pitch rate, r = yaw rate, and p = roll rate.

TABLE 7.- DIRECT APPROACHES DATA - Continued

Case no.	Seq. no.	IC no.	Type braking	Radar model	Pilot	IC dis- persion	Run time, min	RCS prop. lbs used- TOT,FWD,AFT (a)	Torque impulse ft-lb-sec	Final range shoulder joint to PL CG	Payload attitude, P,Y,R; deg (b) Init	max	fin	Payload attitude rates q,r,p; deg/sec (c) Init	max	fin	Stationkeeping time/RCS lbs
9 DA	63	5	±X JET	.3	2	None	29	T=,1996 F=,860 A=,1136	3.35	49	t=0 P=90 Y=0 R=0	t=29 90.1 0 0	t=29 90.1 0 0	t=0 q=-.066 r=0 p=0	t=29 -.063 0 0	t=29 -.063 0 0	None
10 DA	65	5	PRCS	1.0	3	None	24	T=1261 F=580 A=681	338.9	48	t=0 P=90 Y=0 R=0	t=21 83.4 .8 .1	t=24 102 .6 0	t=0 q=-.066 r=0 p=0	t=21 -.102 .004 0	t=24 .186 -.006 0	None
11 DA	66	5	PRCS	.3	3	None	25	T=1112 F=392 A=720	311	50	t=0 P=90 Y=0 R=0	t=22 80 1.2 .2	t=25 89.1 1.5 .1	t=0 q=-.066 r=0 p=0	t=22 -.105 .007 0	t=25 .169 -.005 0	None
12 DA	67	5	±X JET	.3		None	22	t=15,22 T=869,1325 F=340,575 A=530,750	24.77	12	t=0 P=90 Y=0 R=0	t=15 89.7 .1 0	t=22 82.9 2 0	t=0 q=-.066 r=0 p=0	t=15 -.085 .003 0	t=22 -.078 .007 0	None
13 DA → 2K → $\frac{T}{V}$ V_3K ÷	68	5	±X JET	NO RADAR	1	None	84	t=71,84 T=3258,3738 F=1157,1398 A=2100,2336	11.1		t=0 P=90 Y=0 R=0	t=71 90.4 -.6 -.6	t=84 90.5 -.5 -.8	t=0 q=-.066 r=0 p=0	t=71 -.066 0 0	t=84 -.055 0 0	None
14 DA - 1K	121	5	PRCS -CG offset	.3	4	None	21	T=996 F=329 A=667	14.3	NA	t=0 P=90 Y=0 R=0	t=21 88.2 .1 0	t=21 88.2 .1 0	t=0 q=-.066 r=0 p=0	t=21 -.078 .001 0	t=21 -.078 .001 0	None
15 DA - 1K	122	5	PRCS - CG offset	.3	4	None	22	T=1017 F=348 A=669	16.3	NA	t=0 P=90 Y=0 R=0	t=22 88.3 .1 0	t=22 88.3 .1 0	t=0 q=-.066 r=0 p=0	t=22 -.080 .001 0	t=22 -.080 .001 0	None
16 DA	123	5	PRCS - CG offset	.3	4	None	23	T=1028 F=358 A=669	505.4	35	t=0 P=90 Y=0 R=0	t=21 82.1 .5 .1	t=23 44.3 2.1 1.1	t=0 q=-.066 r=0 p=0	t=21 -.112 .003 0	t=23 -.261 .01 -.002	None
17 DA - 1K $\frac{\_}{R}$ TRANS.	124	5	PRCS - CG offset	.3	5	None	33	T=1152 F=420 A=731	14.94	NA	t=0 P=90 Y=0 R=0	t=21 87.7 .3 .1	t=33 81.4 .9 .6	t=0 q=-.066 r=0 p=0	t=21 -.078 .002 0	t=33 -.069 0 0	None

[a]T = total, F = FWD, and A = AFT.
[b]P = pitch, Y = yaw, and R = roll.
[c]q = pitch rate, r = yaw rate, and p = roll rate.

TABLE 7.- DIRECT APPROACHES DATA - Continued

Case no.	Seq. no.	IC no.	Type braking	Radar model	Pilot	IC dis-persion	Run time, min	RCS prop. lbs used-TOT,FWD,AFT (a)	Torque impulse ft-lb-sec	Final range shoulder joint to PL CG	Payload attitude, P,Y,R; deg (b) Init	max	fin	Payload attitude rates q,r,p; deg/sec (c) Init	max	fin	Stationkeeping time/RCS lbs
18 DA	127	5	PRCS	.3	4	None	23	T=1016	821.86	60	t=0	t=21	t=23	t=0	t=21	t=23	None
			- CG								P=90	71.1	82.9	q=-.066	-.211	.398	
			offset					F=360			Y=0	.9	.7	r=0	.001	-.010	
								A=656			R=0	.1	.1	p=0	0	-.001	
19 DA	119	5	PRCS	.3	4	None	30	T=991	19.93	NA	t=	t=22	t=30	t=0	t=22	t=30	None
1K			- CG								P=90	86.5	80.6	q=-.066	-.079	-.075	
TRANS.			offset					F=339			Y=0	.2	.4	r=0	.001	0	
V								A=652			R=0	0	.2	p=0	0	0	

[a]T = total, F = FWD, and A = AFT.
[b]P = pitch, Y = yaw, and R = roll.
[c]q = pitch rate, r = yaw rate, and p = roll rate.

TABLE 8.- $\bar{V}$ APPROACHES DATA

Case no.	Seq. no.	IC no.	Type braking	Radar model[a]	Pilot	IC dis-persion	Run time, min	RCS prop. lbs used-TOT,FWD,AFT	Torque impulse ft-lb-sec	Final range shoulder joint to PL CG, ft	Payload attitude, P,Y,R; deg Init	max	fin	Payload attitude rates q,r,p; deg/sec Init	max	fin	Stationkeeping time/RCS lbs
1V	28	4	PRCS	1.0	1	None	25	T=151 F=36 A=115	373.8	40	t=0 P=90 Y=0 R=180	t=21 89.1 0 180	t=25 144 -3.4 -179	t=0 q=.066 r=0 p=0	t=21 .065 0 0	t=25 -.290 .041 -.002	None
2V	29	4	PRCS	.3	1	None	25	T=139 F=32 A=107	186.4	35	t=0 P=90 Y=0 R=-180	t=20 89.4 0 180	t=25 105.5 -.6 -180	t=0 q=.066 r=0 p=0	t=20 .067 0 0	t=25 -.110 .010 0	None
3V	30	4	PRCS	.1	1	None	42	T=196 F=50 A=146	143.4	52	t=0 P=90 Y=0 R=-180	t=21 89.4 0 -180	t=42 141.8 -1.1 -179.9	t=0 q=.066 r=0 p=0	t=21 .068 0 0	t=42 -.030 .002 0	None
4V	32	4	±X JETS	.3	1	None	16	T=407 F=184 A=223	2.33	42	t=0 P=90 Y=0 R=-180	t=13 90.0 0 -180	t=16 90.3 0 -180	t=0 q=.066 r=0 p=0	t=13 .066 0 0	t=16 .063 0 0	15-82#
5V	52	4	PRCS	1.0	1	None	26	T=148 F=36 A=112	395.6	40	t=0 P=90 Y=0 R=-180	t=22 89.6 0 -180	t=6 148.7 -8.2 -177.5	q=.066 r=0 p=0	t=22 .062 0 0	-.315 .108 -.006	None
6V	71	4	PRCS	1.0	3	None	33	T=NA F=NA A=NA	538.0	20	t=0 P=90 Y=0 R=-180	t=29 87.3 0 -180	t=33 125 -2.6 -179	q=.066 r=0 p=0	t=29 .071 0 0	t=33 -.45 .059 -.002	None
7V	72	4	PRCS	.3	3	None	22	T=176 F=45 A=131	92[illegible].8	20	t=0 P=90 Y=0 R=-180	t=20 87.5 0 -180	t=22 144 -3.4 -179	q=.066 r=0 p=0	t=20 .064 0 0	t=22 -.840 .117 -.006	None
8V	73	4	±X JET	.3	3	None	20	T=417 F=188 A=229	3.09	31	t=0 P=90 Y=0 R=-180	t=17 90.1 0 -180	t=20 90.5 0 -180	q=.066 r=0 p=0	t=17 .065 0 0	t=20 .063 0 0	None
9V	95	4	PRCS	1.0	2	None	24	T=217 F=62 A=155	124.5	54	t=0 P=90 Y=0 R=-180	t=20 88.4 0 -180	t=24 93.4 0 -180	q=.066 r=0 p=0	t=20 .072 0 0	t=24 -.043 0 0	None

[a]Denotes $\dot{R}_{noise}, 3\sigma = 1.0$ fps, etc.

TABLE 8.- $\overline{V}$ APPROACHES DATA - Concluded

Case no.	Seq. no.	IC no.	Type braking	Radar model[a]	Pilot	IC dis-persion	Run time, min	RCS prop. lbs used-TOT,FWD,AFT	Torque impulse ft-lb-sec	Final range shoulder joint to PL CG, ft	Payload attitude, P,Y,R; deg Init	max	fin	Payload attitude rates q,r,p; deg/sec Init	max	fin	Stationkeeping time/RCS lbs
10V	97	4	PRCS	.3	2	None	26	T=190	126.5	46	t=0	t=11	t=25	t=0	t=11	t=26	9-36#
											P=90	88.2	67.3	q=.066	.071	.069	
								F=45			Y=0	0	-0.1	r=0	0	.001	
								A=145			R=-180	-180	-180	p=0	0	0	
11V	100	4	PRCS	.3	2	None	36	T=216	297.3	39	t=0	t=23	t=36	t=0	t=23	t=36	None
											P=90	79.1	211.	q=.066	.092	-.114	
								F=60			Y=0	.3	-4.	r=0	-.001	.008	
								A=156			R=-180	-180	-177	p=0	0	-.002	
12V	118	4	±X JET - CG	.3	4	None	23	T=372	1.32	42	t=0	t=21	t=23	t=0	t=21	t=23	None
											P=90	90	90.1	q=.066	.066	.064	
			offset					F=165			Y=0	0	0	r=0	0	0	
								A=207			R=-180	-180	-180	p=0	0	0	

[a]Denotes $\dot{R}_{noise}$, 3σ = 1.0 fps, etc.

TABLE 9.- $\bar{R}$ APPROACHES DATA

Case no.	Seq. no.	IC no.	Type braking	Radar model	Pilot	IC dispersion	Run time, min	RCS prop. no. used- TOT,FWD,AFT	Torque impulse ft-lb-sec	Final range shoulder joint to PL CG	Payload attitude, P,Y,R; deg Init	max	fin	Payload attitude rates q,r,p; deg/sec Init	max	fin	Stationkeeping time/RCS lbs
1R	23	2	PRCS	1.0	1	None	32	T=260 F=90 A=170	8.66	41	t=0 P=90 Y=0 R=0	t=29 90.1 0 0	t=32 90.7 -.1 0	t=0 q=-.066 r=0 p=0	t=29 -.066 0 0	t=32 -.061 0 0	None
2R	24	2	±X JET	1.0	1	None	39	T=290 F=119 A=171	0.01	35	t=0 P=90 Y=0 R=0	t=39 P=90.0 0 0	t=39 P=90.0 0 0	t=0 q=-.066 r=0 p=0	t-39 q=-.066 0 0	t=39 q=-.066 0 0	None
3R	38	2	PRCS	.3	1	None	67	T=440 F=158 A=	51.7	42	t=0 P=90 Y=0 R=0	t=55 91.0 .1 0	t=67 97.6 .3 .3	t=0 q=-.066 r=0 p=0	t=55 -.065 .001 0	t=67 -.036 -.003 0	None
4R	39	2	PRCS	.1	1	None	54	T=303 F=104 A=199	42.70	40	t=0 P=90 Y=0 R=0	t=41 90.6 0 0	t=54 99.7 -1.4 -.3	t=0 q=-.066 r=0 p=0	t=41 -.065 0 0	t=54 -.041 0 0	None
5R	42	2	±X JET	.1	1	None	39	T=310 F=132 A=178	.12	32	t=0 P=90 Y=0 R=0	t=39 90.1 0 0	t=39 90.1 0 0	t=0 q=-.066 r=0 p=0	t=39 -.066 0 0	t=39 -.066 0 0	4-29#
6R	43	2	PRCS NOCCTV	1.0	1	None	50	T=385 F=145 A=240	45.09	41	t=0 P=90 Y=0 R=0	t=47 90.6 0 0	t=50 94.2 -.5 0	t=0 q=-.066 r=0 p=0	t=47 -.065 0 0	t=50 -.026 -.006 0	None
7R	50	2	PRCS	.1	1	None	53	T=354 F=131 A=223	70.49	34	t=0 P=90 Y=0 R=0	t=51 91.3 .1 0	t=53 98.5 -.4 0	t=0 q=-.066 r=0 p=0	t=51 -.064 .001 0	t=53 -.012 -.007 0	None
8R	51	2	PRCS	.3	1	None	56	T=376 F=136 A=240	28.20	31	t=0 P=90 Y=0 R=0	t=45 90.5 0 0	t=56 93.3 .6 .2	t=0 q=-.066 r=0 p=0	t=45 -.065 0 0	t=56 -.063 .001 0	None
9R	56	2	±X JET	.1	1	None	31	T=339 F=147 A=192	.05	40	t=0 P=90 Y=0 R=0	t=31 90.1 0 0	t=31 90.1 0 0	t=0 q=.066 r=0 p=0	t=31 -.066 0 0	t=31 -.066 0 0	

TABLE 9.- $\bar{R}$ APPROACHES DATA - Continued

Case no.	Seq. no.	IC no.	Type braking	Radar model	Pilot	IC dis-persion	Run time, min	RCS prop. no. used-TGT,FWD,AFT	Torque impulse ft-lb-sec	Final range shoulder joint to PL CG	Payload attitude, P,Y,R; deg Init	max	fin	Payload attitude rates q,r,p; deg/sec Init	max	fin	Stationkeeping time/RCS lbs
10R	102	2	±X JET	1.0	4	None	36	T=255 F=103 A=152	0.02	39	t=0 P=90 Y=0 R=0	t=36 90.1 0 0	t=36 90.1 0 0	t=0 q=-.066 r=0 p=0	t=36 -.066 0 0	t=36 -.066 0 0	None
11R	103	2	±X JET	1.0	4	None	36	T=267 F=108 A=159	0.03	30	t=0 P=90 Y=0 R=0	t=36 90.1 0 0	t=36 90.1 0 0	t=0 q=-.066 r=0 p=0	t=36 -.066 0 0	t=36 -.066 0 0	None
12R	104	2	PRCS	.3	3	None	35	T=293 F=98 A=195	12.97	37	t=0 P=90 Y=0 R=0	t=34 90.4 0 0	t=35 90.9 0 0	t=0 q=-.066 r=0 p=0	t=34 -.065 0 0	t=35 -.056 0 0	None
13R	105	2	PRCS	.3	3	None	24	T=192 F=62 A=130	12.36	39	t=0 P=90 Y=0 R=0	t=21 90.4 0 0	t=24 90.2 0 0	t=0 q=-.066 r=0 p=0	t=21 -.065 0 0	t=24 -.074 .001 0	None
14R	111	2	PRCS - NO CCTV	.3	2	None	46	T=455 F=171 A=284	22.78	52	t=0 P=90 Y=0 R=0	t=44 91.1 0 0	t=46 92.4 -.3 0	t=0 q=-.066 r=0 p=0	t=44 -.065 0 0	t=46 -.046 .004 0	None
15R	112	2	PRCS	.1	2	None	37	T=319 F=115 A=204	11.59	39	t=0 P=90 Y=0 R=0	t=26 90.4 0 0	t=37 91.4 0 0	t=0 q=-.066 r=0 p=0	t=26 -.065 0 0	t=37 -.063 0 0	None
16R	113	2	PRCS - CG off-set	.3	2	None	50	T=328 F=123 A=205	18.92	36	t=0 P=90 Y=0 R=0	t=37 90.8 0 0	t=50 93.3 -.1 0	t=0 q=-.066 r=0 p=0	t=37 -.064 0 0	t=50 -.072 .001 0	None
17R	114	2	±X JET	1.0	2	None	20	T=917 F=450 A=467	0.83	34	t=0 P=90 Y=0 R=0		t=0 90.3 -.1 0	t=0 q=-.066 r=0 p=0		t=0 -.065 0 0	None
18R	116	2	±X JET	.3	2	None	26	T=477 F=215 A=262	0.065	49	t=0 P=90 Y=0 R=0	t=22 90.1 0 0	t=26 90.0 0 0	t=0 q=-.066 r=0 p=0	t=22 -.065 0 0	t=26 -.066 0 0	None

TABLE 9.- $\overline{R}$ APPROACHES DATA - Concluded

Case no.	Seq. no.	IC no.	Type braking	Radar model	Pilot	IC dis-persion	Run time, min	RCS prop. no. used-TOT,FWD,AFT	Torque impulse ft-lb-sec	Final range shoulder joint to PL CG	Payload attitude P,Y,R degree Init	Inter	Inter	Fin	Payload attitude rates q,r,p, deg/sec Init	Inter	Inter	Fin	Station keeping time/RCS lbs
19R	120	5	±X JET	.3	4	None	57	T=1771	20.88	37	t=0	t=18	t=29	t=57	t=0	t=18	t=29	t=57	None
DA→IK			CG off-								P=90	88.2	78.4	96.3	q=-.066	-.083	-.073	-.049	
T→$\overline{R}$			set								Y=0	.1	.5	-.5	r=0	.001	0	0	
$\overline{R}$→RMS											R=0	0	.2	.1	p=0	0	0	0	
								F=689											
								A=1082											
20R	125	2	±X JET	.3	5	None	36	T=306	0.05	40	t=0	t=36		t=36	t=0	t=36		t=36	None
											P=90	90.1		90.1	q=-.066	-.066		-.066	
								F=129			Y=0	0		0	r=0	0		0	
								A=177			R=0	0		0	p=0	0		0	
21R	126	2	±X JET	.3	5	None	21	T=588	0.02	40	t=0	t=21		t=21	t=0	t=21		t=21	None
											P=90	90.1		90.1	q=-.066	-.066		-.066	
								F=277			Y=0	0		0	r=0	0		0	
								A=311			R=0	0		0	p=0	0		0	
22R									107.3	50		3K		$\overline{V}$		3K		$\overline{V}$	
end-	88	5	±X JET	1.0	4	None	139		148.0		t=0	t=23		t=31	t=0	t=23		t=31	15@$\overline{V}$;89#
to-									161.7		P=90	73.2		70.8	q=-.066	-.073		-.061	
end								T F A	196.7		Y=0	4.4		3.5	r=0	-.023		-.022	
DA→3K							t=23	1071 320 751	1273.0		R=0	-17.3		-16.5	p=0	.002		-.005	
T→$\overline{V}$							t=31	1272 445 827											
SK_V15min							t=46	1361 478 883			$\overline{V}$	$\overline{T}$R3K		$\overline{R}$	$\overline{V}$	$\overline{T}$R3K		$\overline{R}$	
T→-$\overline{R}$							t=70	1905 783 1122											
							t=139	3963 1750 2213			t=46	t=70		t=139	t=46	t=70		t=139	
											P=81.1	84.8		70.4	q=-.046	-.074		-.179	
-$\overline{R}$@3K→RMS											Y=.5	5.1		.8	r=-.018	-.030		-.018	
											R=-20.0	-23.6		-9.6	p=-.005	-.004		.001	

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TABLE 10 - COMPARISONS OF LAT, $\overline{V}$, $\overline{R}$, AND DIRECT APPROACH

	LAT	V	R	Direct approach
1. Inertial or grow gradient targets	Can approach either	GG evaluated only	GG evaluated only	GG evaluated only
2. Plume effects (dynamical)	Good for tailfirst; good for -Z	Fair for ±X jet; unsat for all jet	Good to excellent for ±X jet; unsatisfactory to fair for all jet	Fair for ±X jet unsatisfactory for all jet
3. RCS used (no dispersion); average of runs	160 lb-tailfirst; 350 lb-Z (est)	410 lb for ±X; unsatisfactory for all jet	320 lb for ±X jet 330 lb for all jet	1000 lb for ±X jet;[a] none for all jet
4. RCS used (w/dispersions); average of runs	430 lb tailfirst 630 lb -Z	Not tested but probably substantial	Not tested but probably substantial	[a]Not tested but probably minor
5. Time of final approach; average	22±3 min tailfirst 16±4 min -Z	20±3 min	33±6 min	None-part of braking[a]
6. Transition requirements (RCS + time)	Required with moderate cost	Required with lowest cost	Required with substantial cost	None required
7. Crew aids other than CCTV and ±X jet braking	Aft window and CCTV overlays for tailfirst; none for -Z	None	None	None
8. Controllability of LOS	Fair to good for tailfirst; excellent for -Z	Excellent	Excellent	Excellent

[a]RCS and time listed pertains only to last 1000 ft of braking with ±X jets. In addition, standard braking cost is required.

TABLE 11. - PRINCIPAL FINDINGS IN SES FOR EACH LAT MANUAL OPTION

	Advantages	Disadvantages
Tailfirst option with ±X Braking	1. Potential for lowest RCS usage 2. Approach is hands-off after dispersions are taken out and residual velocities nulled. 3. Identical procedure for both inertial and gravity gradient targets. 4. Approach from either side enhances lighting (4 sides), and flexibility for grapple fixture location. 5. No rendezvous radar required so target size effects are irrelevant.	1. Requires different aft window and CCTV overlays for each payload size and view. 2. Potential collision path with tail because of drift if residual velocities at first goalpost not nulled properly for present V-overlays. 3. Crew reluctance to procedure because of non-LOS approach. 4. Susceptible to sense switch errors by crew
-Z approach with ±X	1. Optimum LOS approach backed by radar. Excellent optical view. 2. Approach is hands-off after dispersions are taken out. Velocity residuals not critical. 3. Identical procedure for both inertial and GG targets. 4. Approach from either side enhances lighting. 5. No aft window or CCTV overlays needed.	1. Substantially higher RCS use than tailfirst because of ±X jet braking.

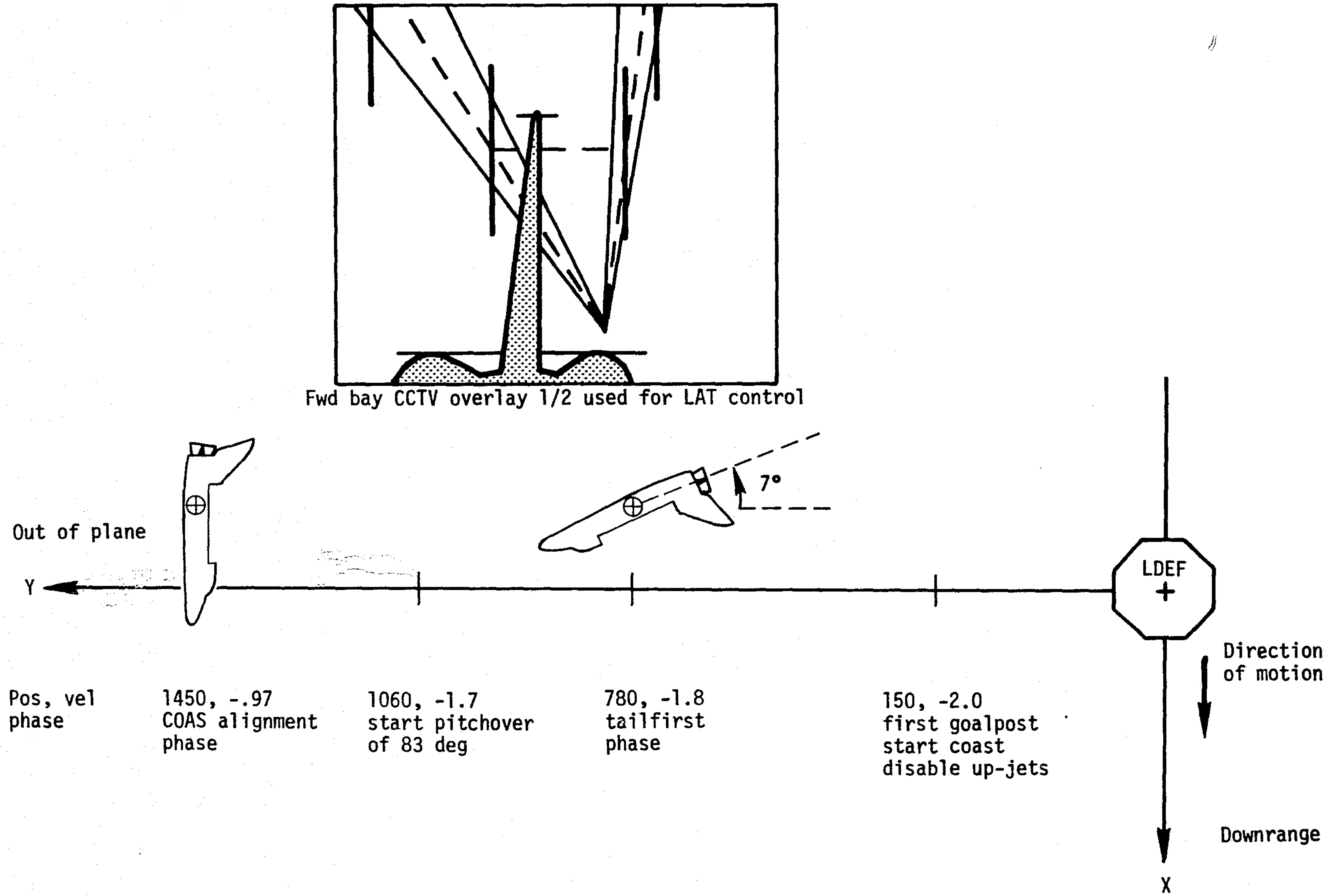


Figure 1.- Typical scenario for a tailfirst out-of-plane LAT approach (not drawn to scale).

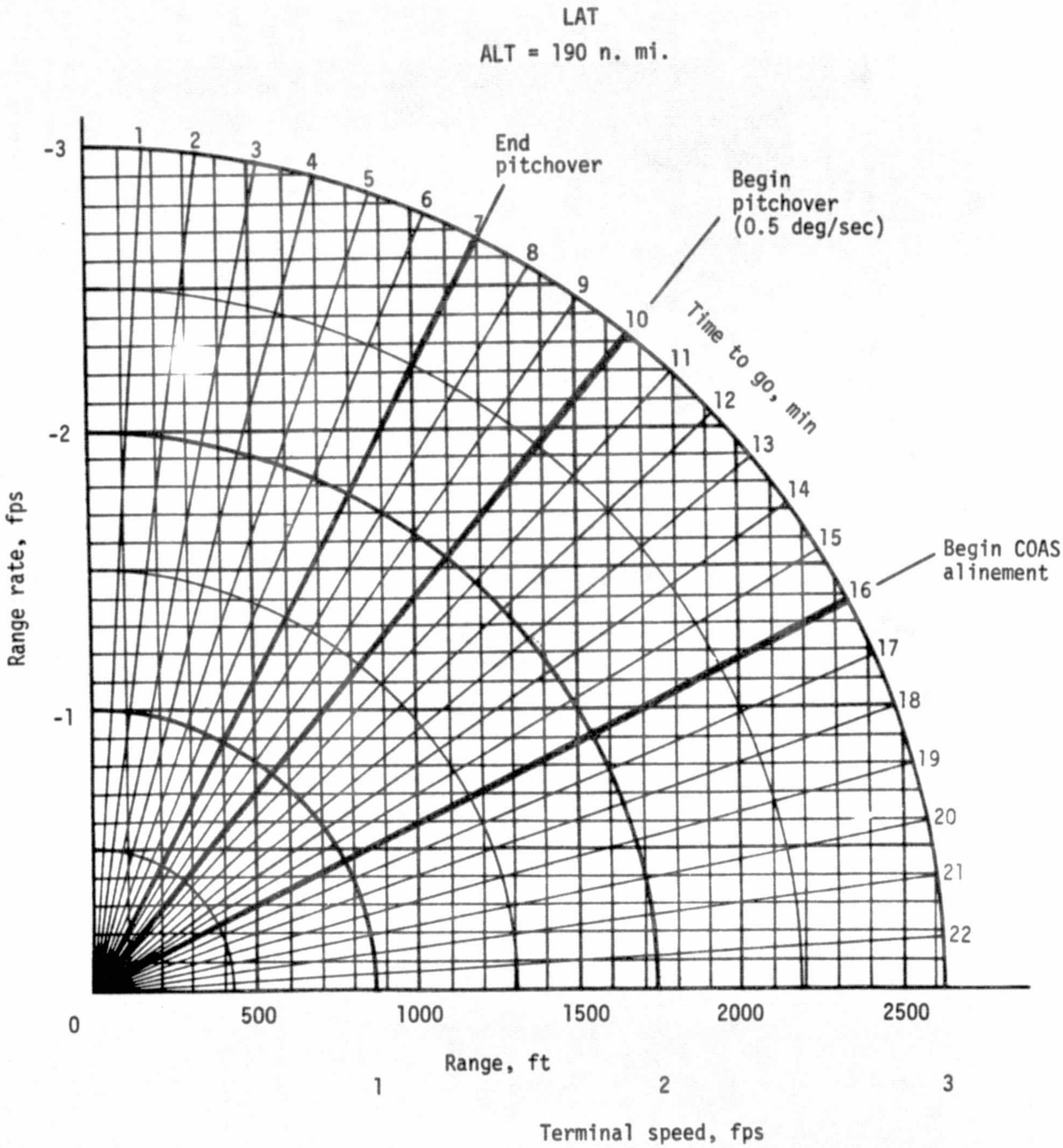
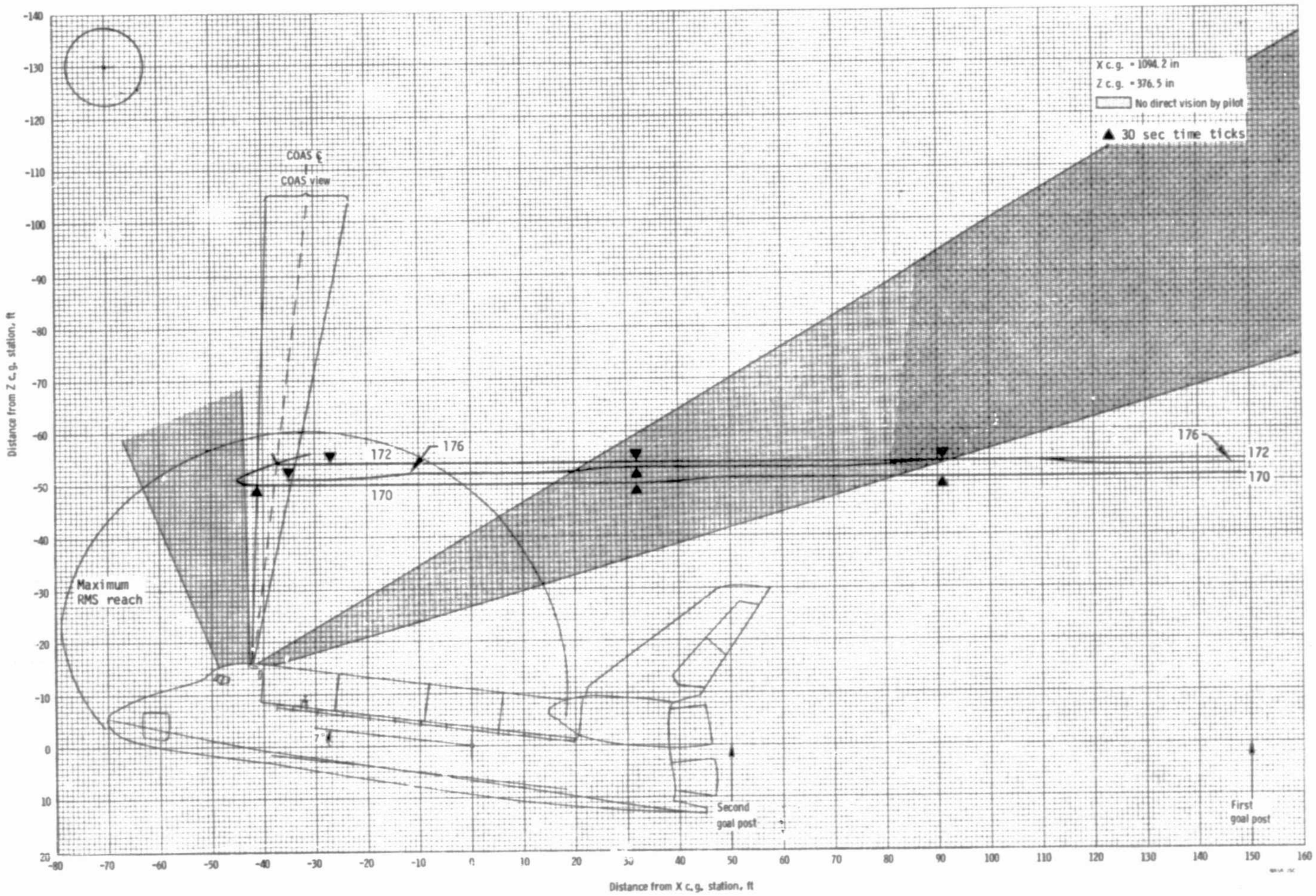
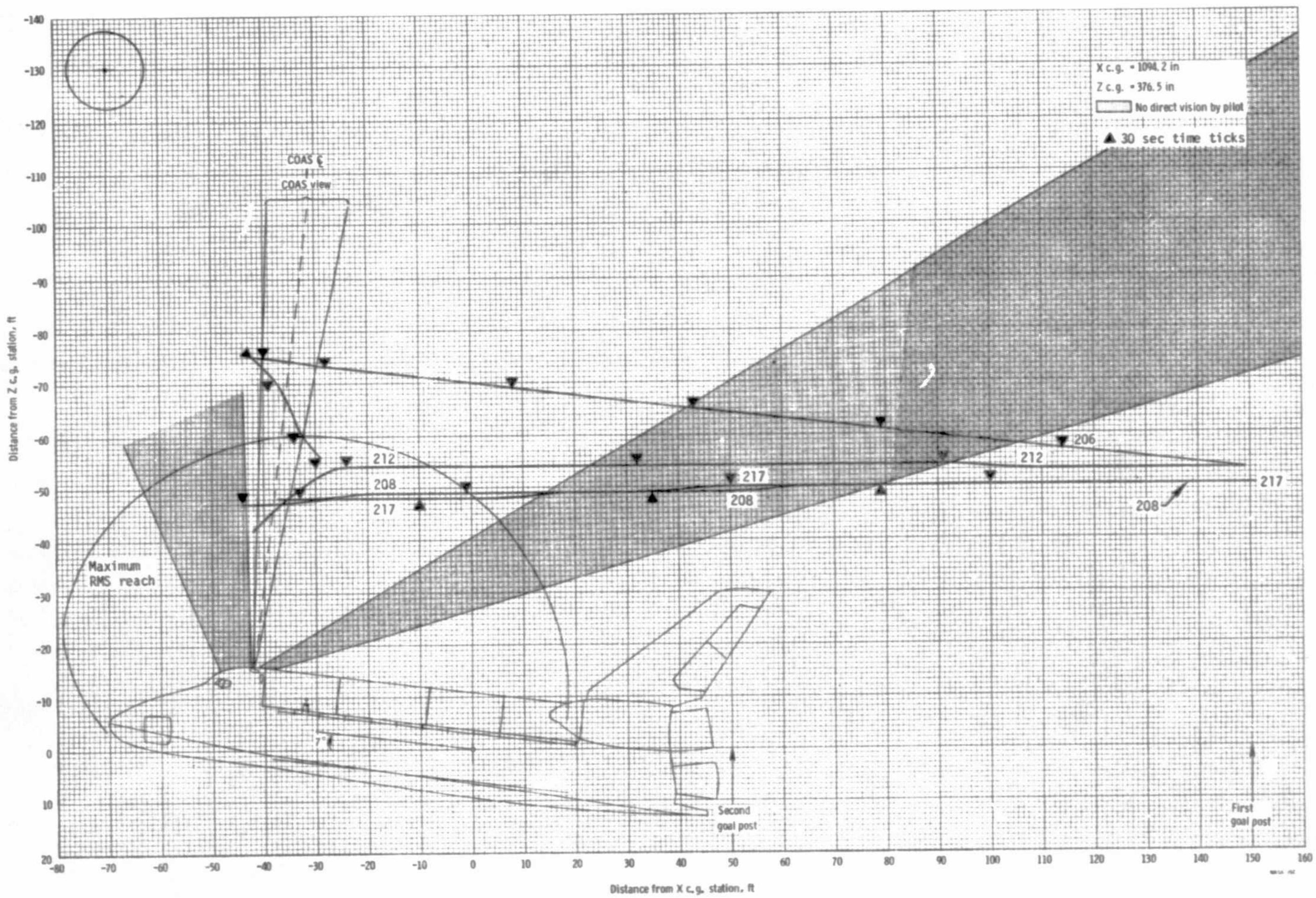


Figure 2.- LAT range versus range rate chart.



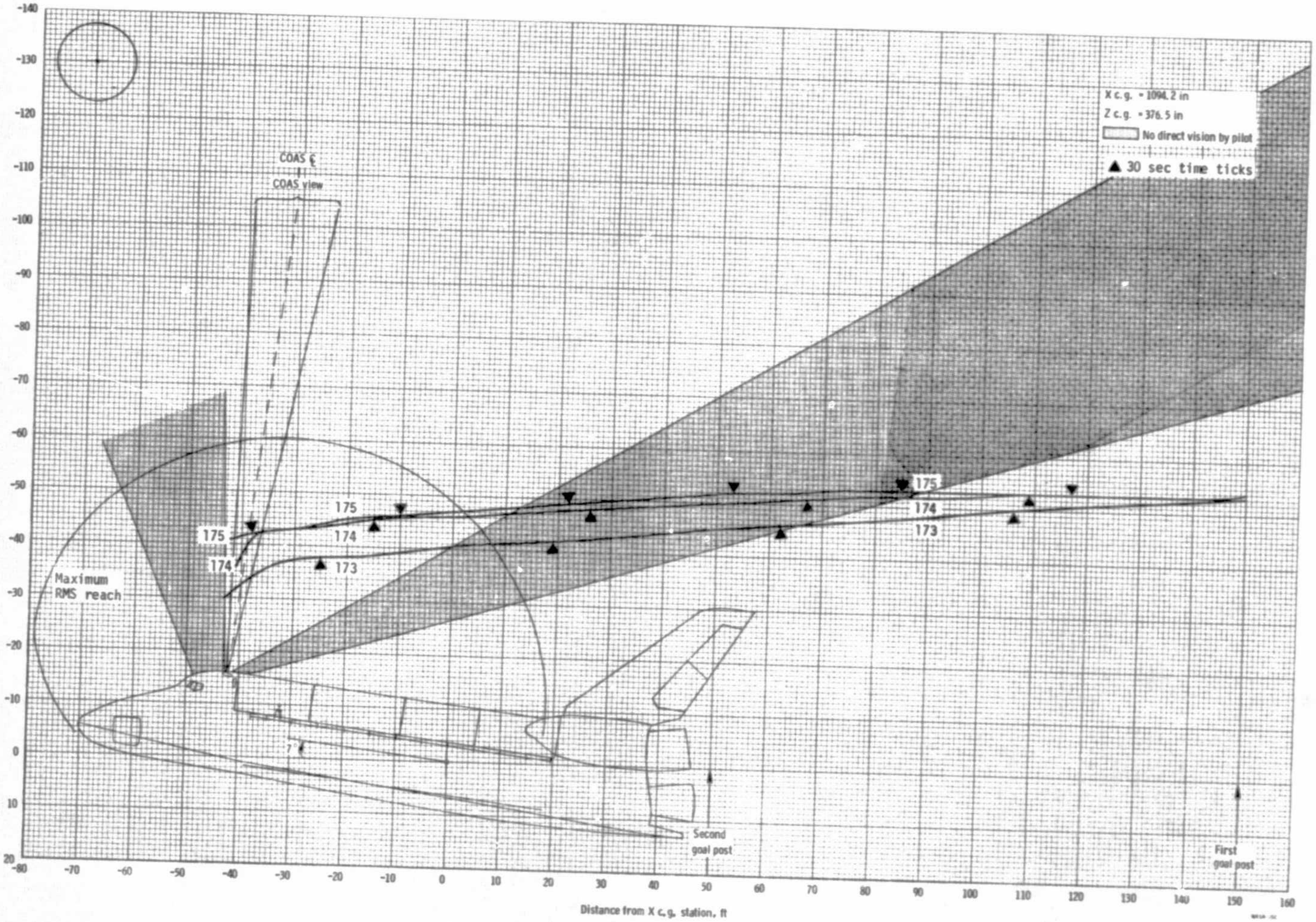
(a) Sequences 170, 172, 176 for 2 fps approach velocity.

Figure 3.- LAT relative-motion from first goalpost to stationkeeping.



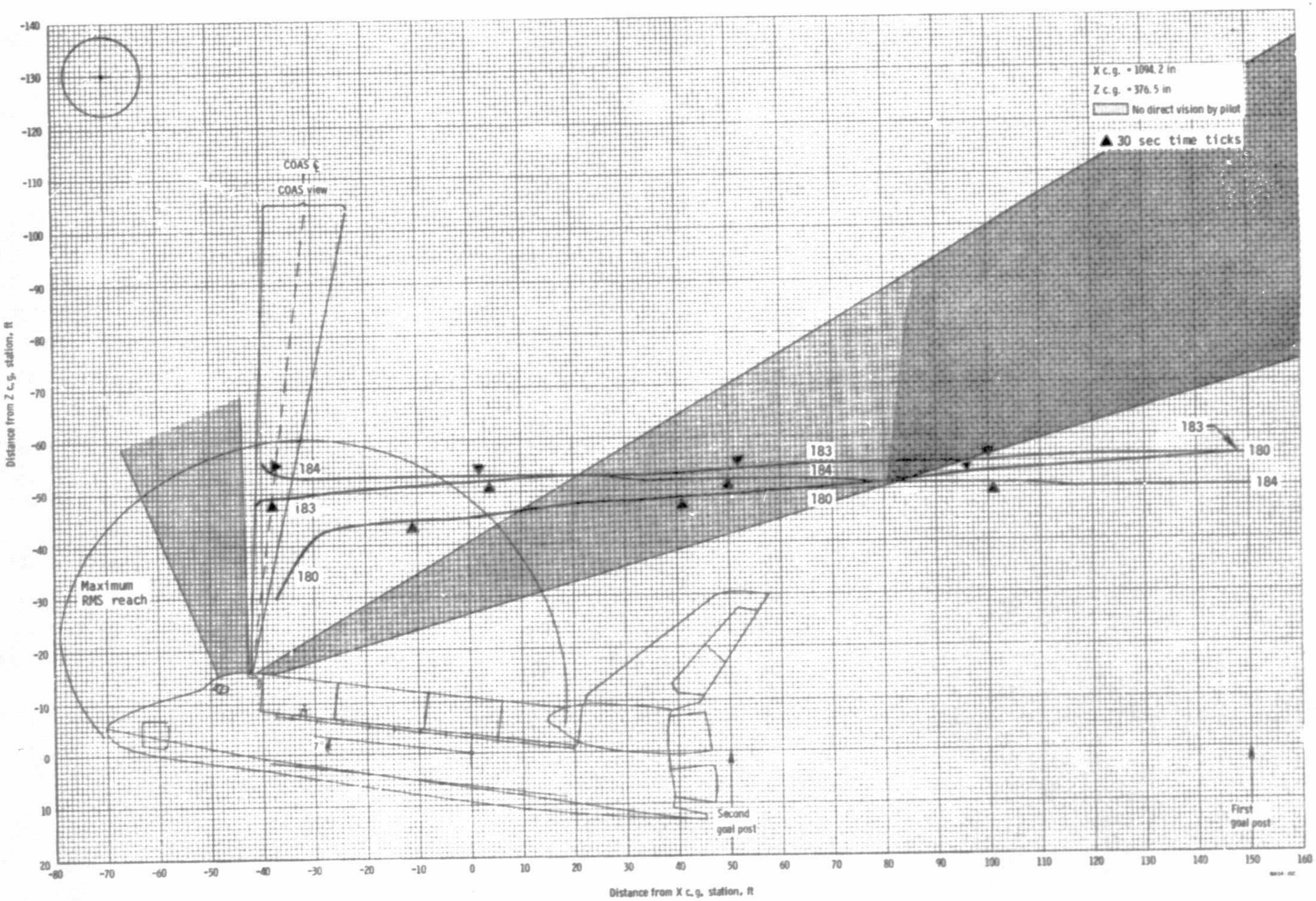
(b) Sequences 206, 208, 212, 217 for 2 fps approach velocity.

Figure 3.- Continued.



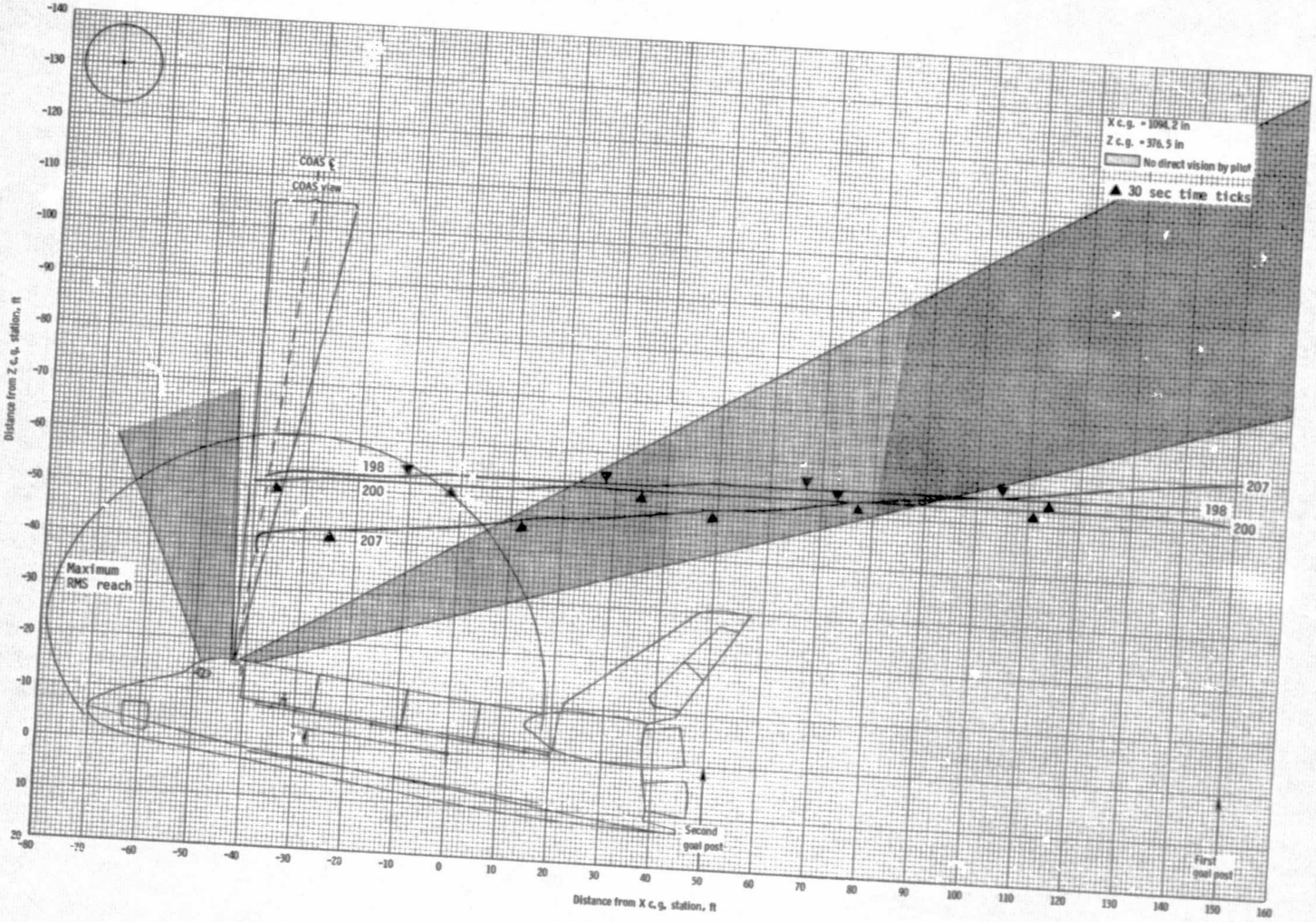
(c) Sequences 173, 174, 175 for 2 fps approach velocity.

Figure 3.- Continued.



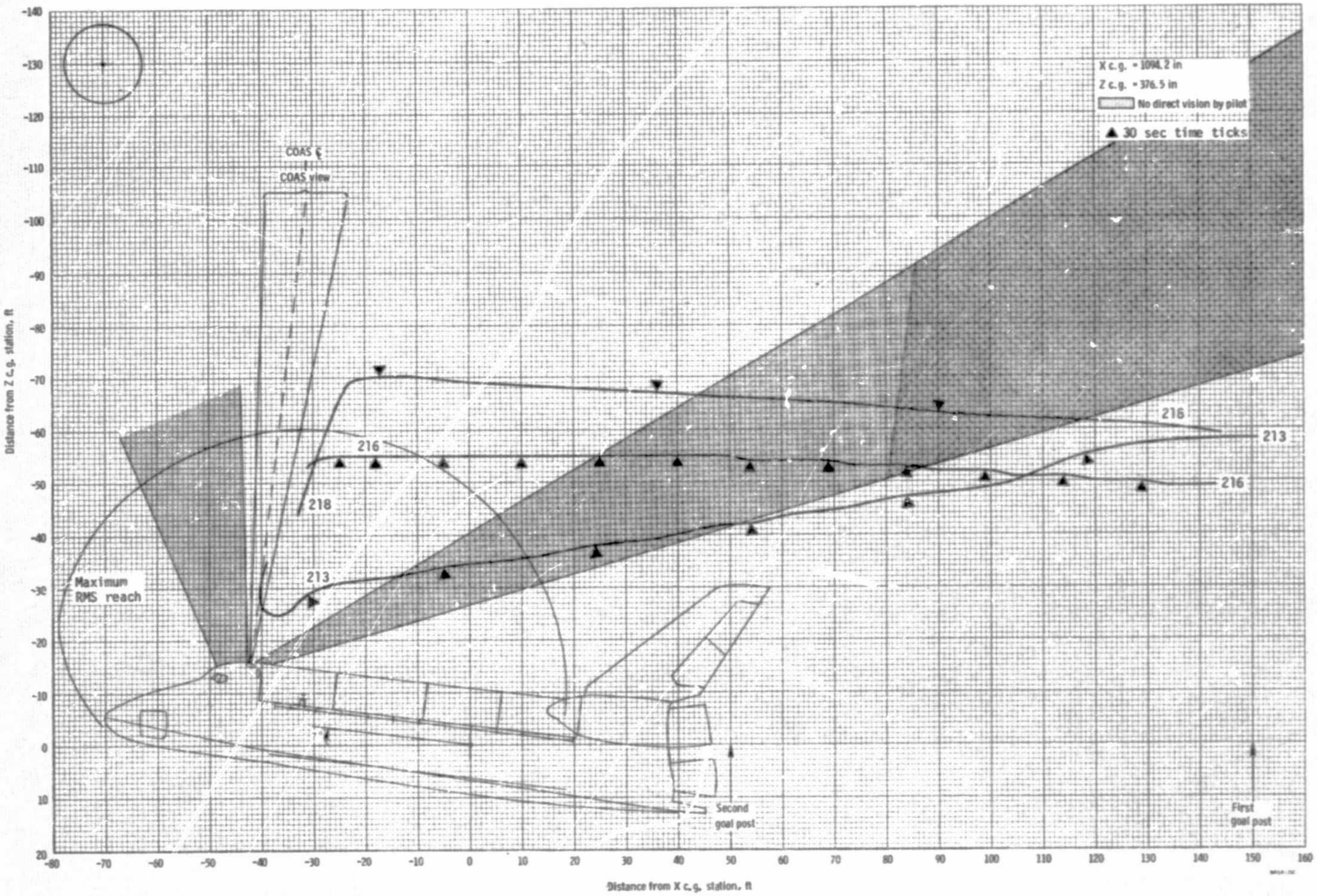
(d) Sequences 180, 183, 184 for 2 fps approach velocity.

Figure 3.- Continued.



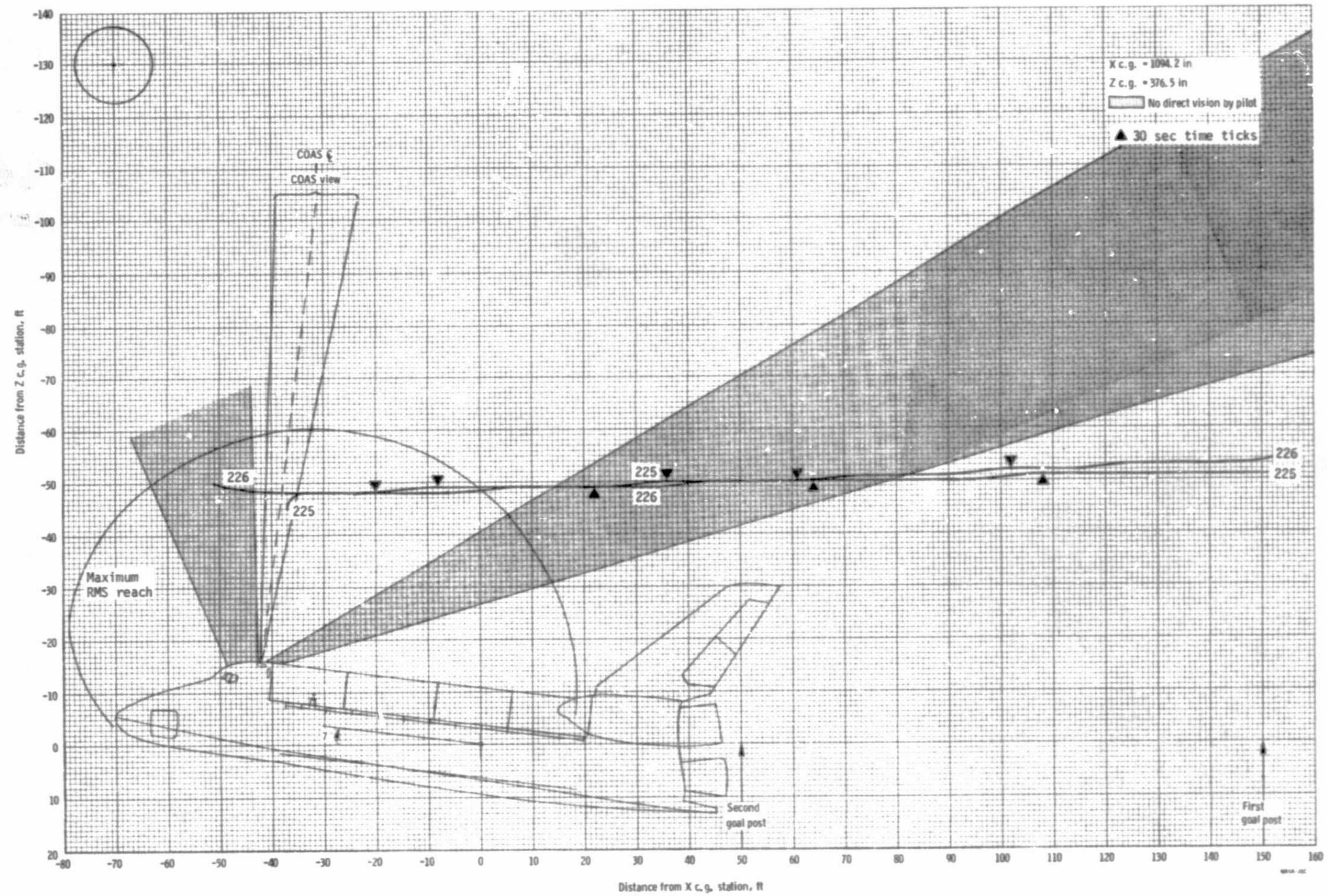
(e) Sequences 198, 200, 207 for 2 fps approach velocity.

Figure 3.- Continued.



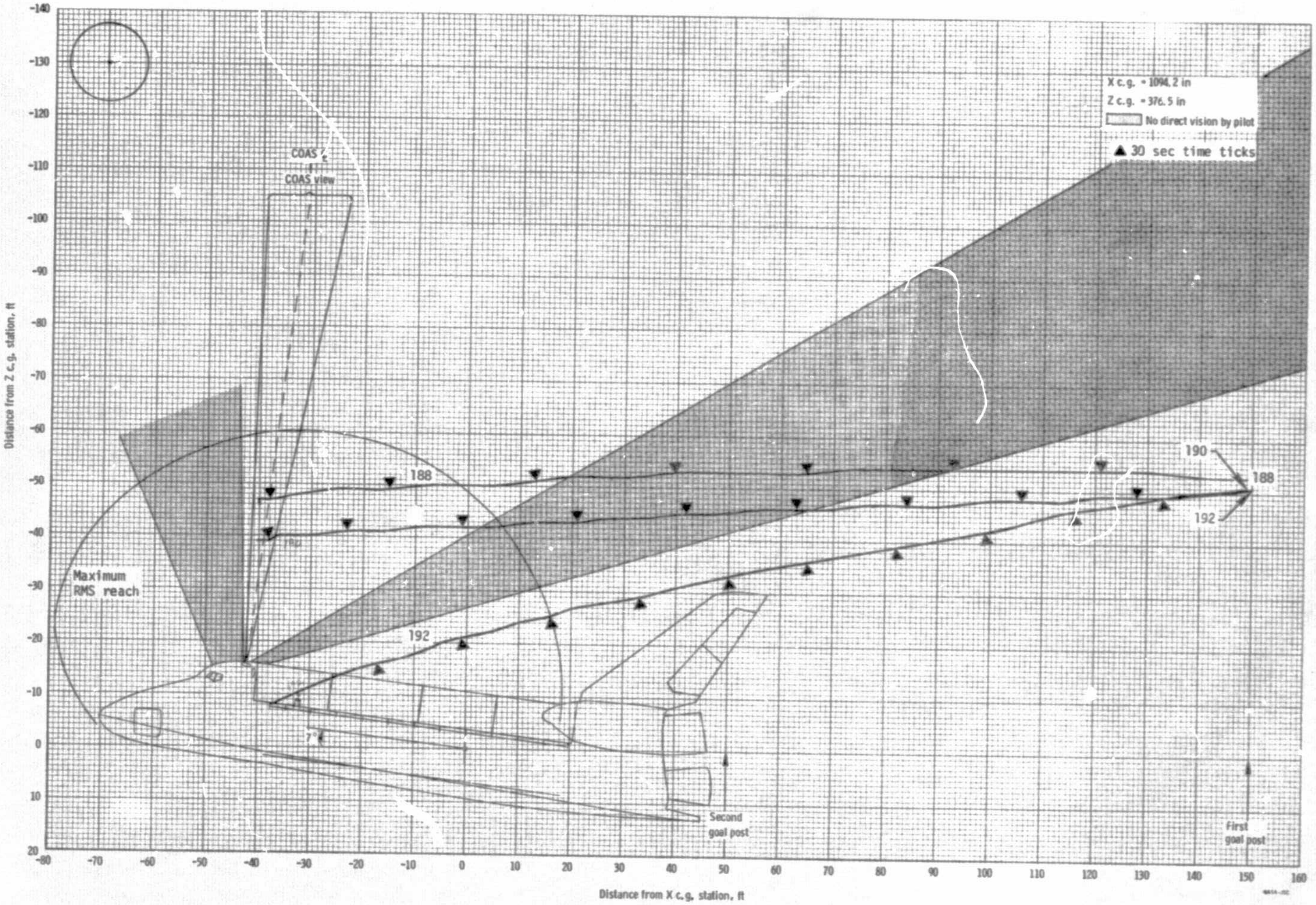
(f) Sequences 213, 216, 218 for 2 fps approach velocity.

Figure 3.- Continued.



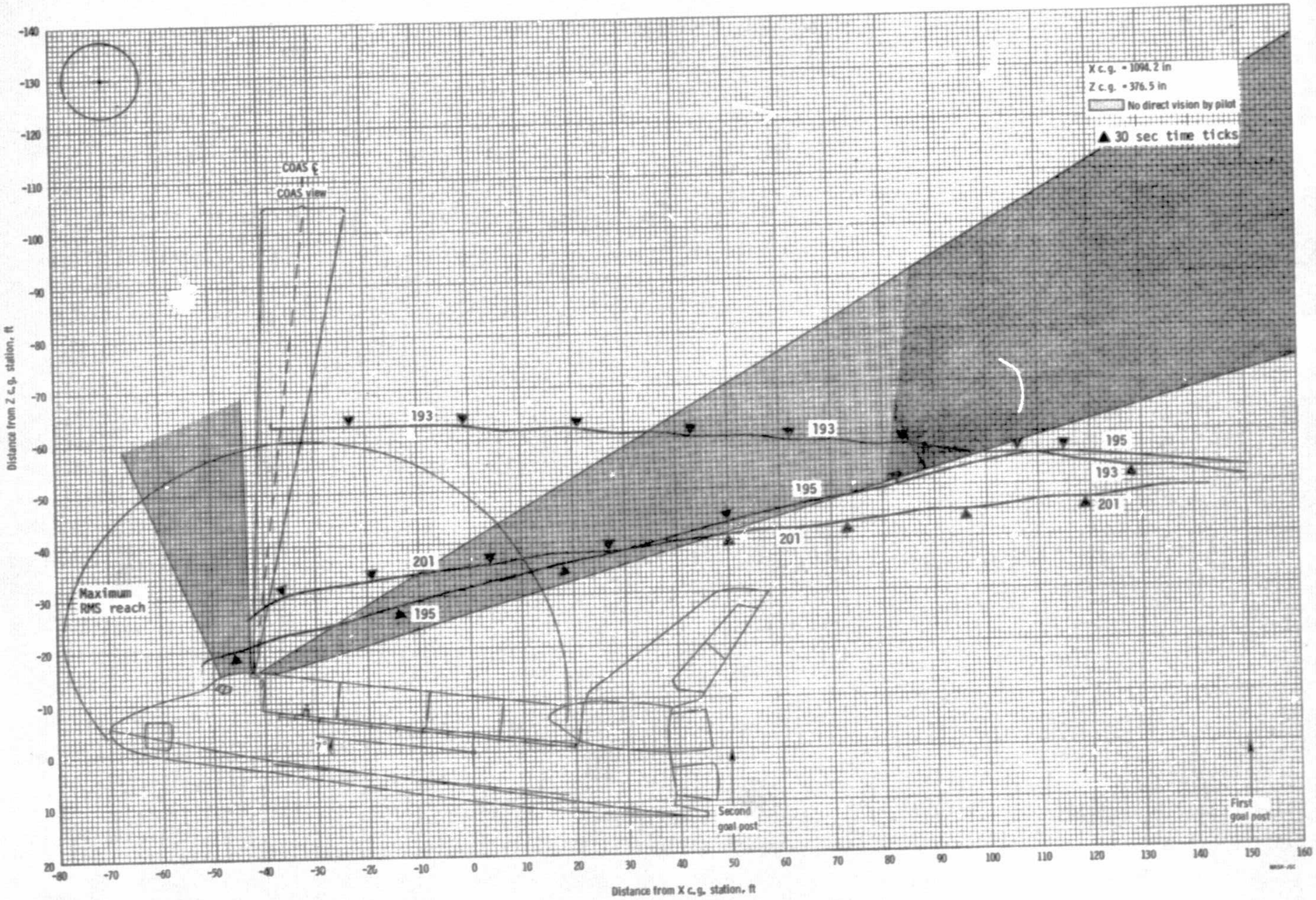
(g) Sequences 225, 226 for 2 fps approach velocity.

Figure 3.- Continued.



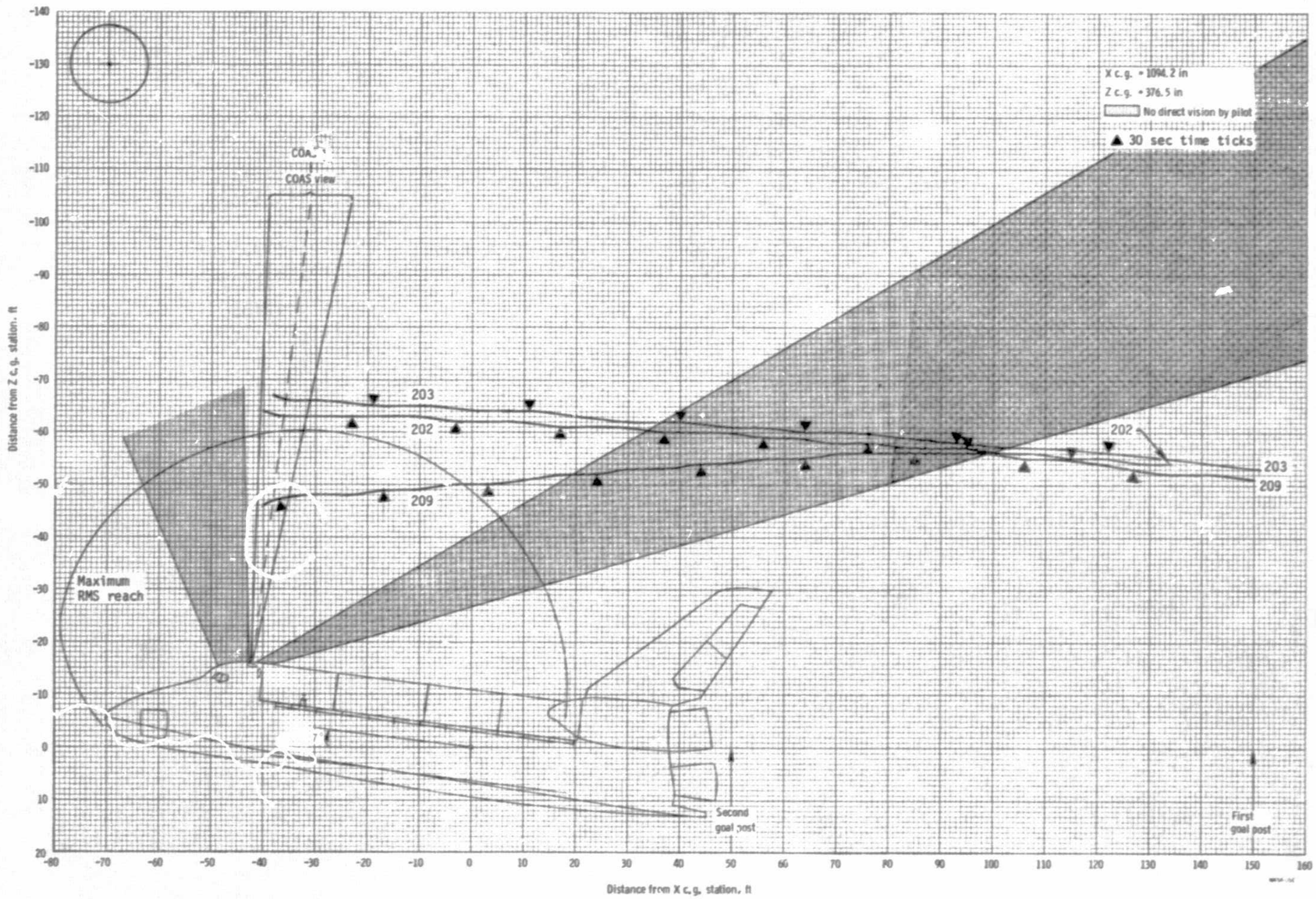
(h) Sequences 188, 190, 192 for 1 fps approach velocity.

Figure 3.- Continued.



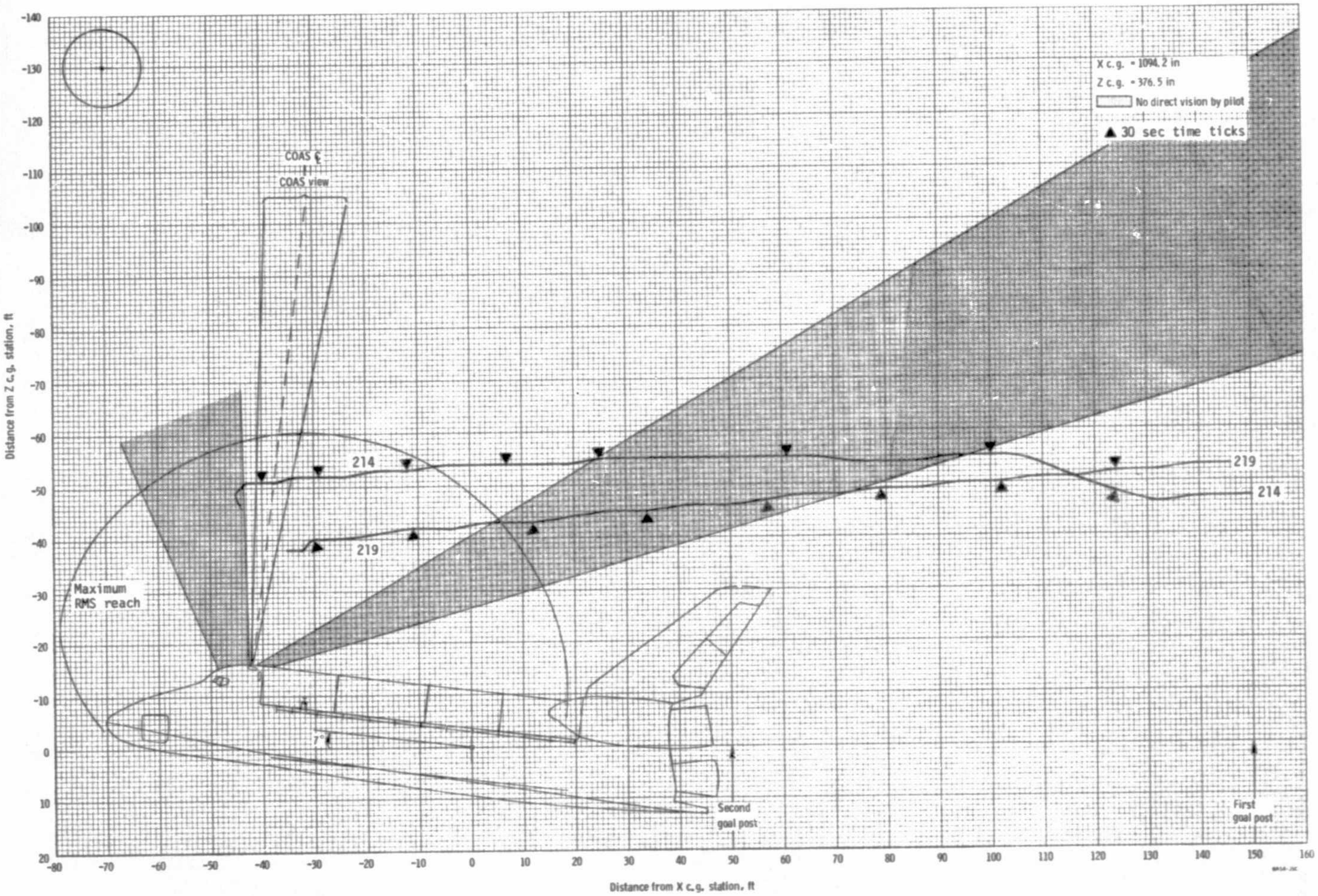
(i) Sequences 193, 195, 201 for 1 fps approach velocity.

Figure 3.- Continued.



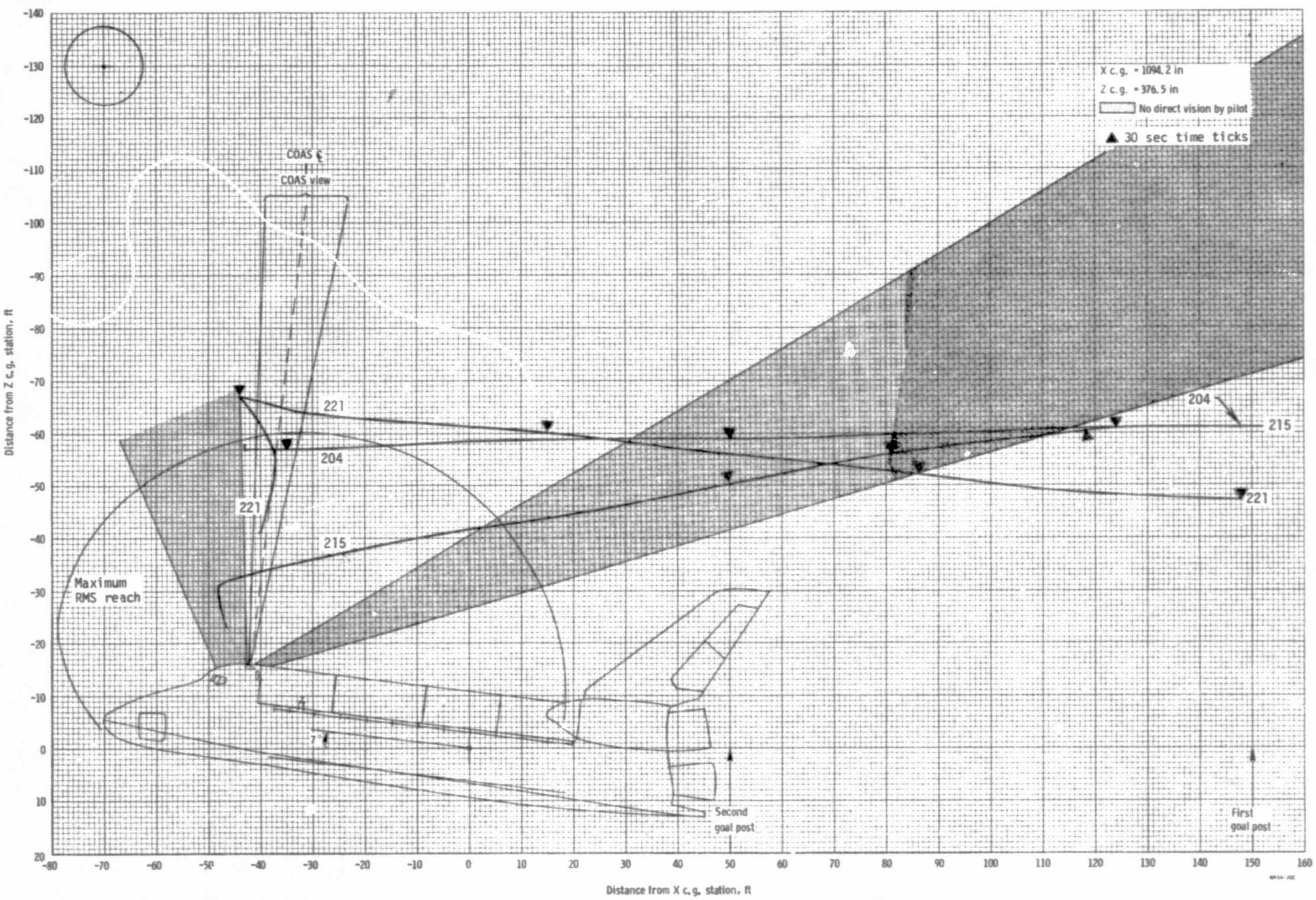
(j) Sequences 202, 203, 209 for 1 fps approach velocity.

Figure 3.- Continued.



(k) Sequences 214, 219 for 1 fps approach velocity.

Figure 3.- Continued.



(l) Sequences 204, 215, 221 for 3 fps approach velocity.

Figure 3.- Concluded.

Segment number	Pilot	Crash	Miss distance, ft		Velocity at brake
			Tail	Cockpit	
173	1	No	7	12	1.46
190	4	No	7	22	.72
192	4	Yes, tail	-5	-9	.53
195	4	Yes, cockpit	5	-10	1.07
201	1	No	3	9	.77
213	3	No	4	18	.98
215	3	Yes, cockpit(FAM)	12	-4	2.63
219	2	No	9	21	.75

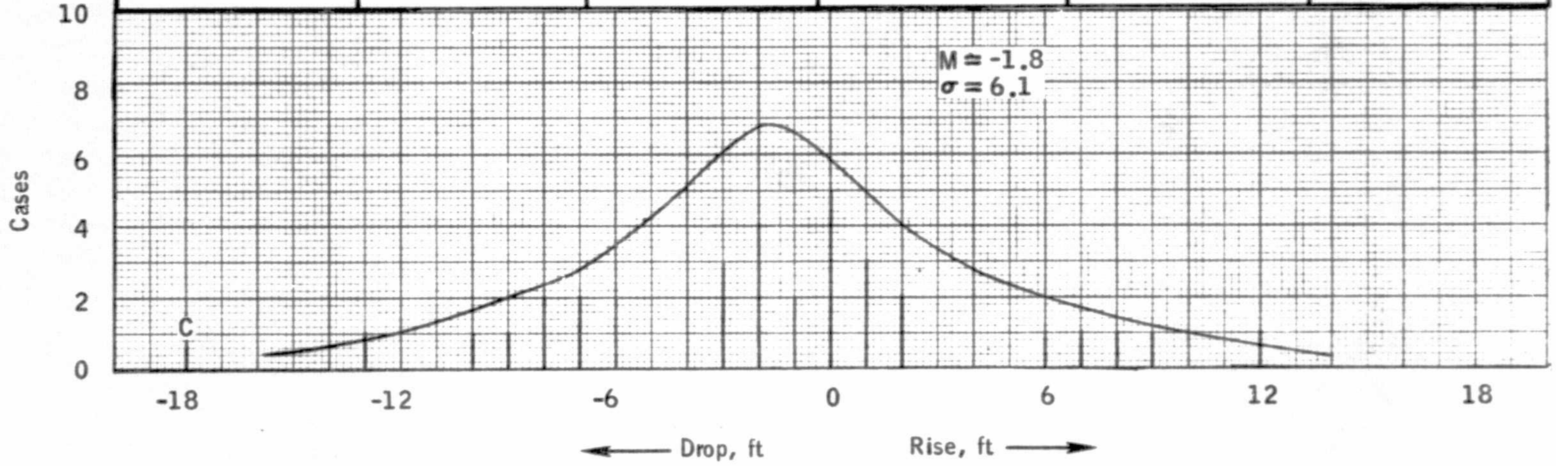
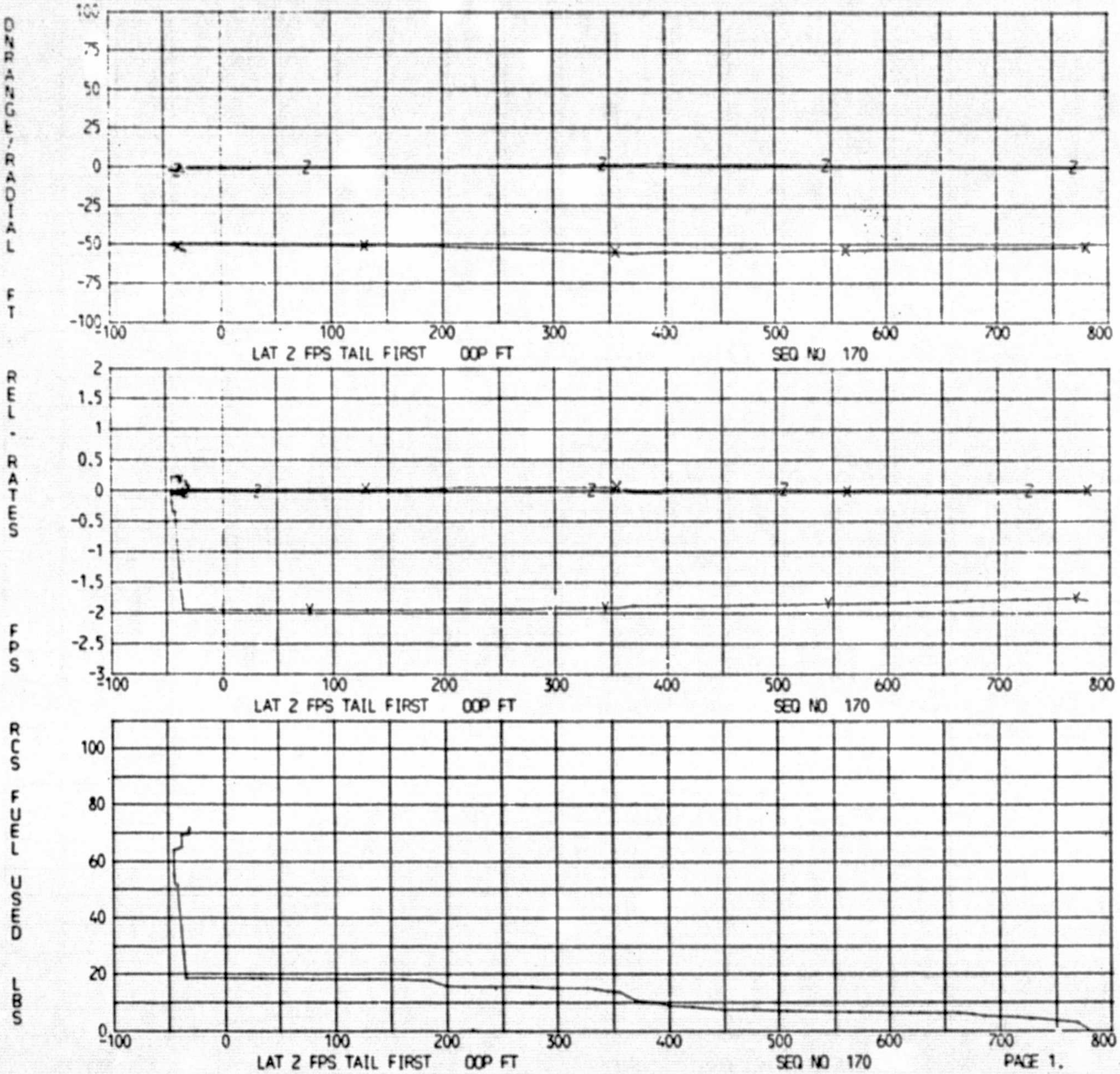


Figure 4.- SES LAT collision or near-miss summary and cumulative distribution of height change between first goalpost and second goalpost.



(a) Sequence 170.

Figure 5.- LAT approach.

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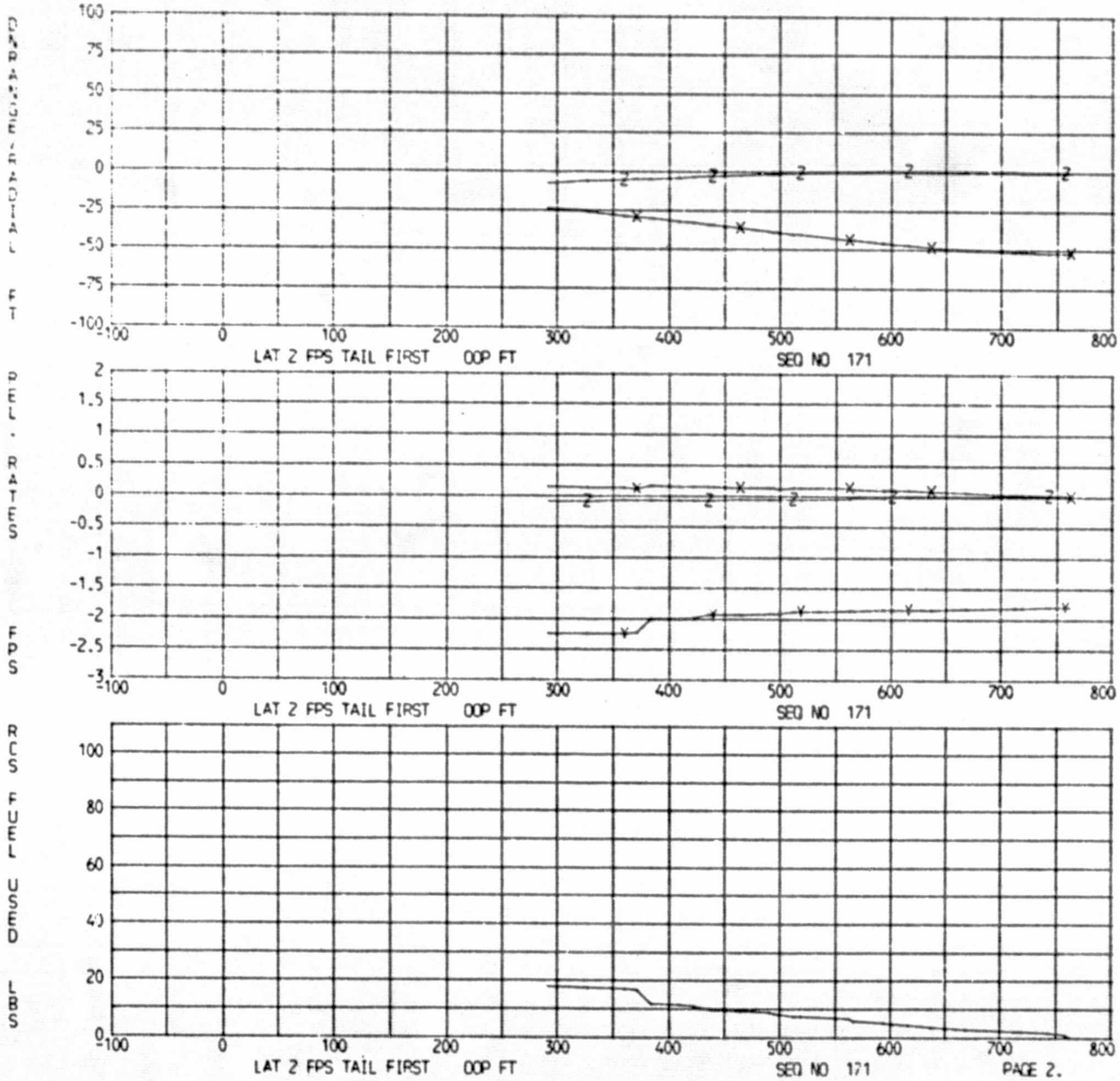
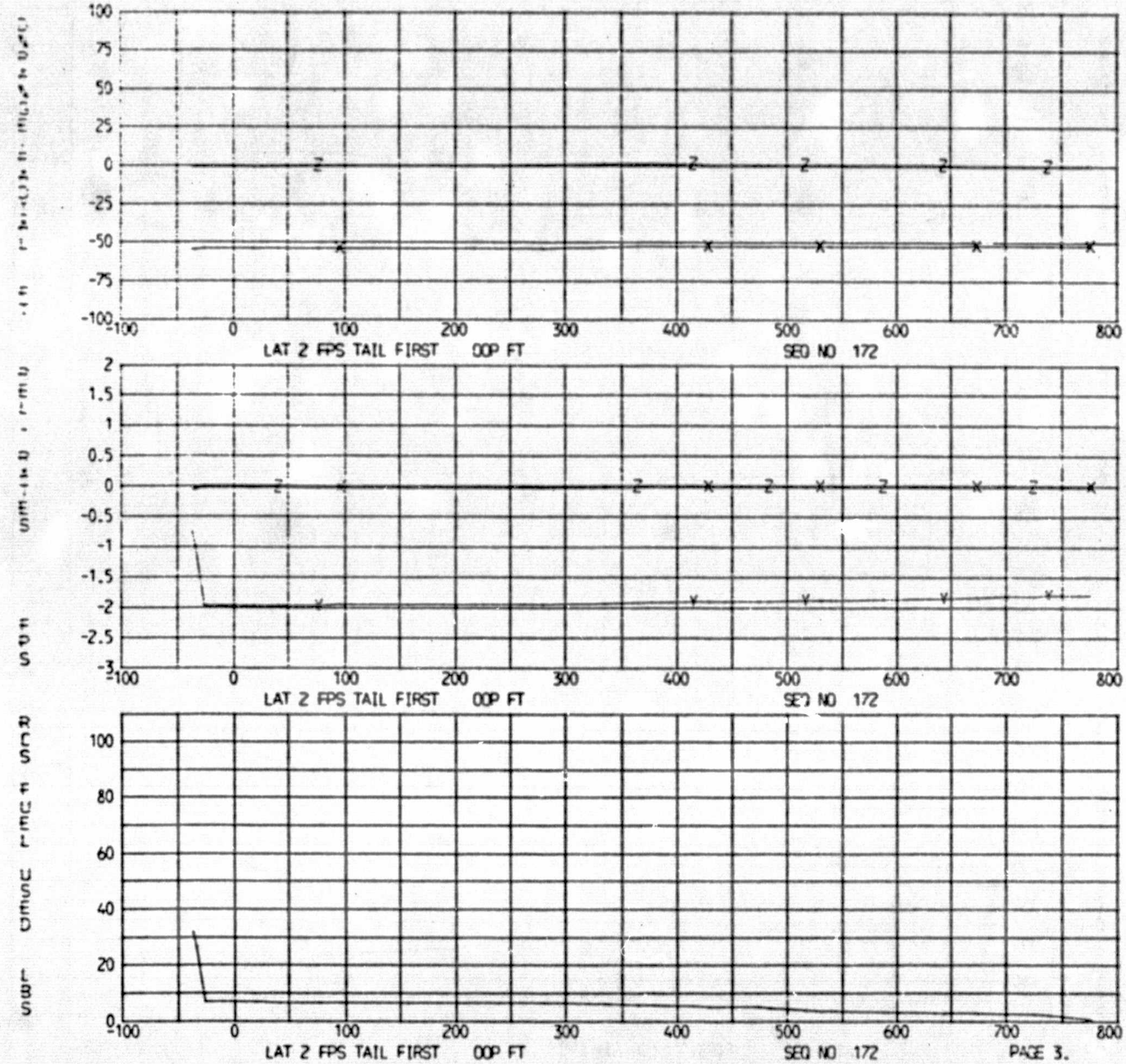


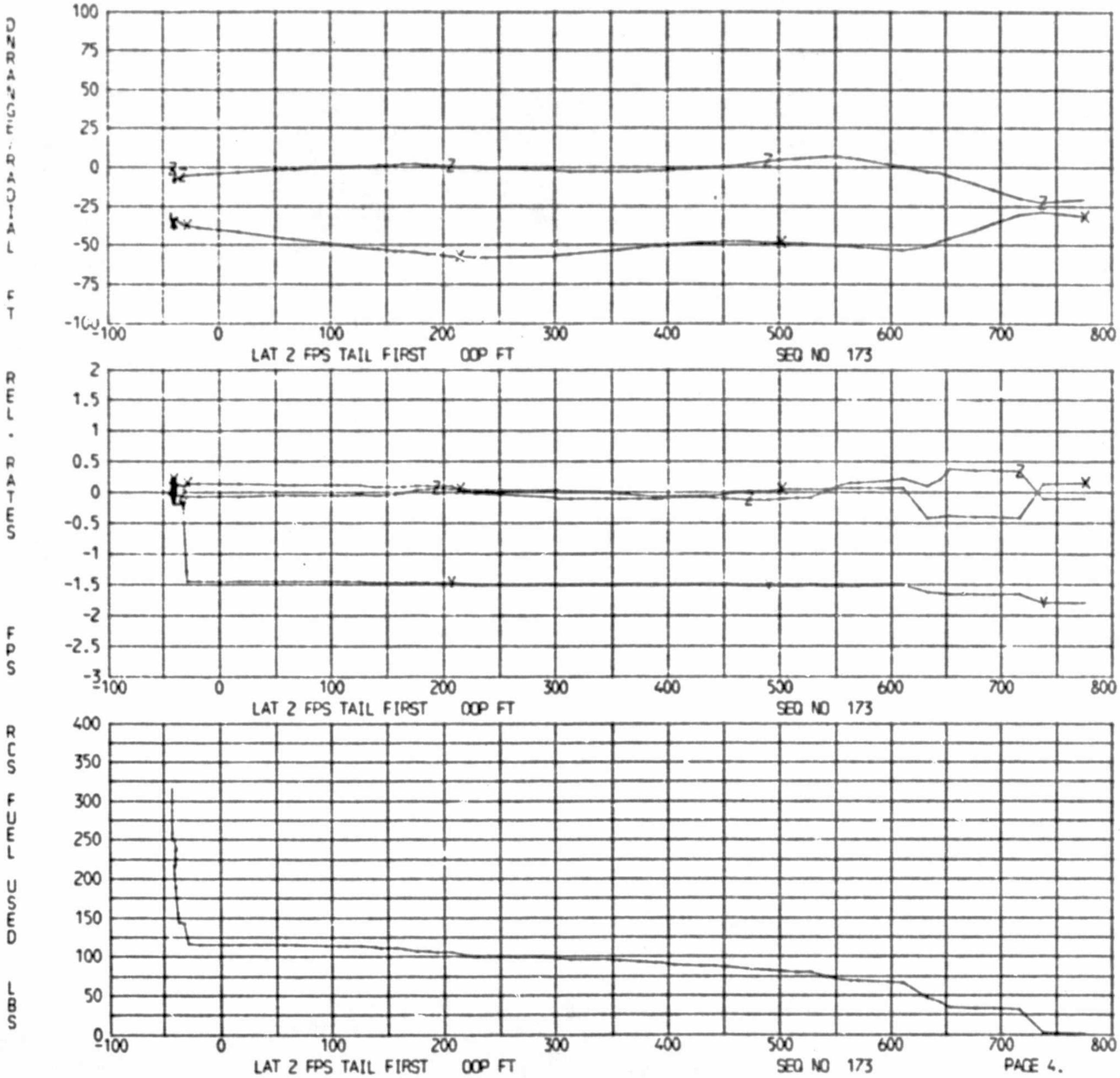
(b) Sequence 171.

Figure 5.- Continued.



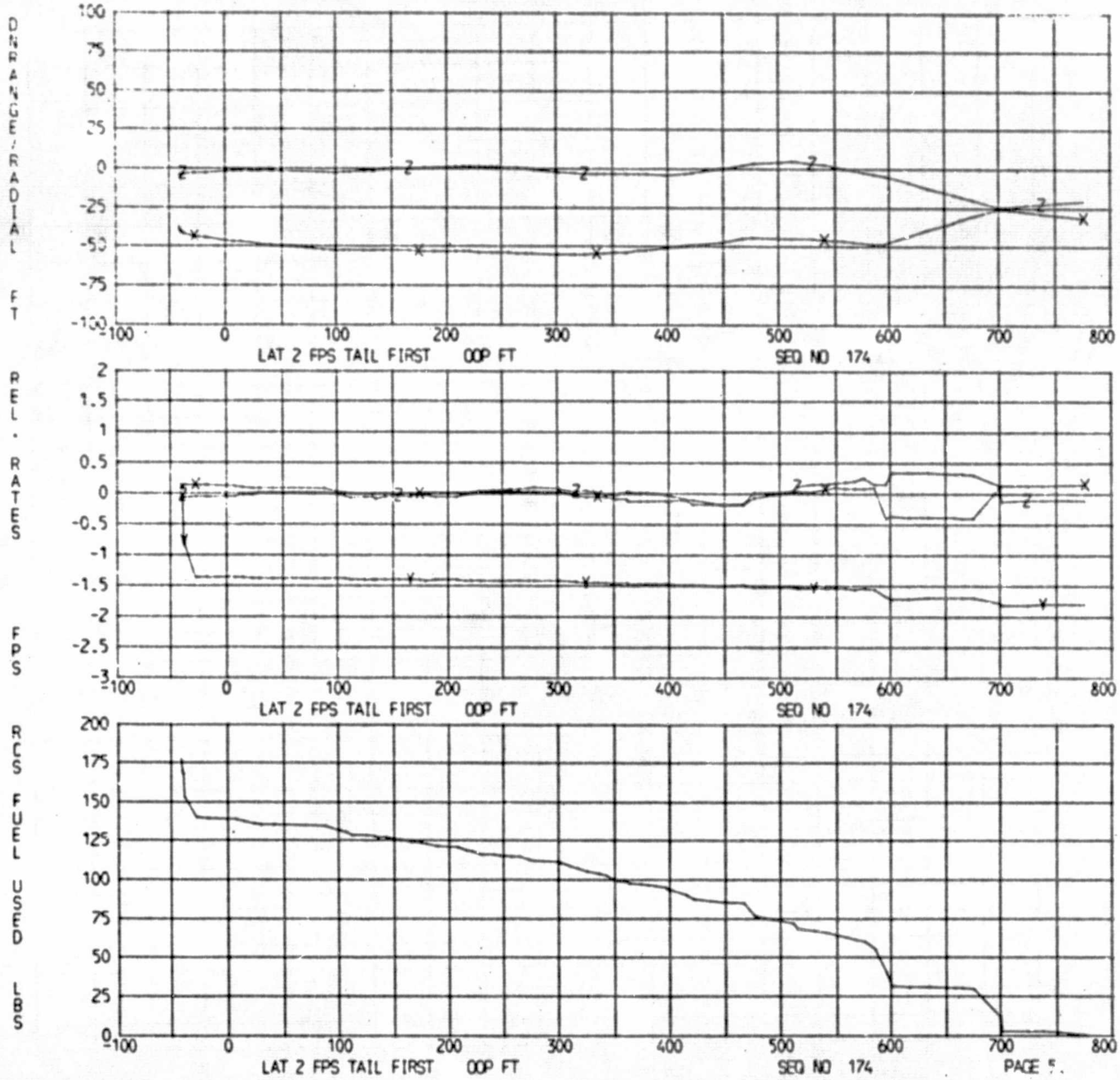
(c) Sequence 172.

Figure 5.- Continued.



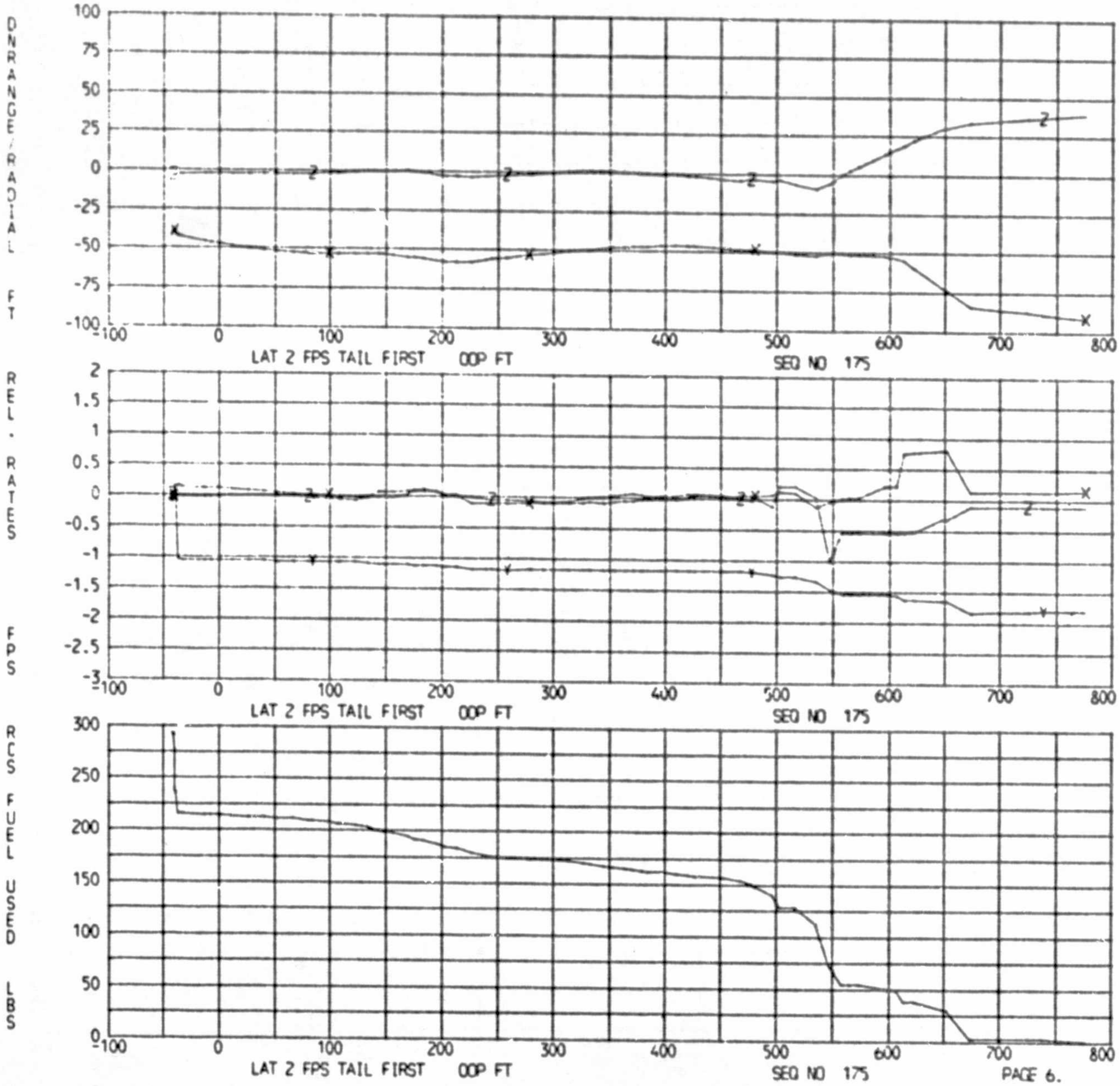
(d) Sequence 173.

Figure 5.- Continued.



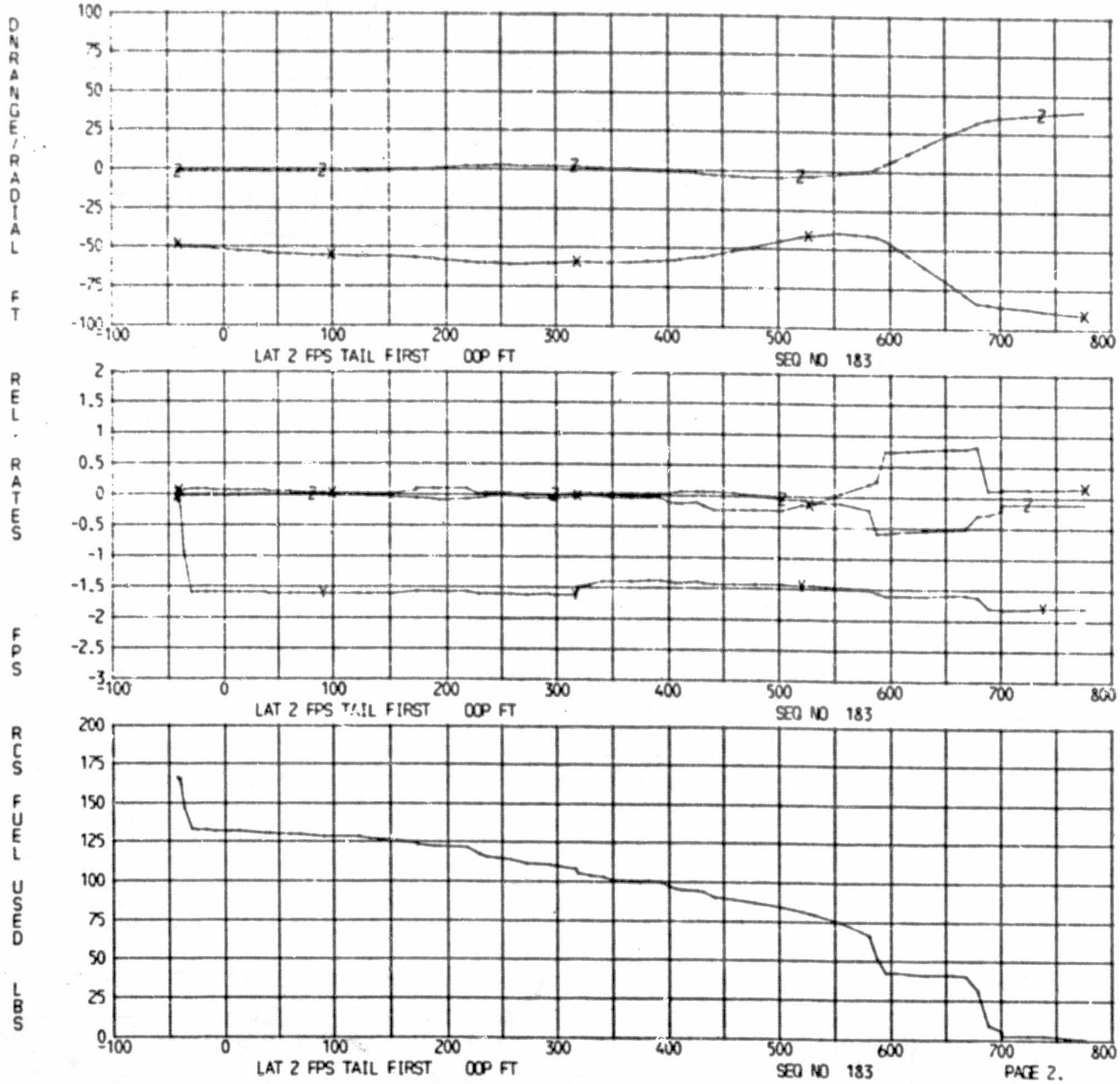
(e) Sequence 174.

Figure 5.- Continued.



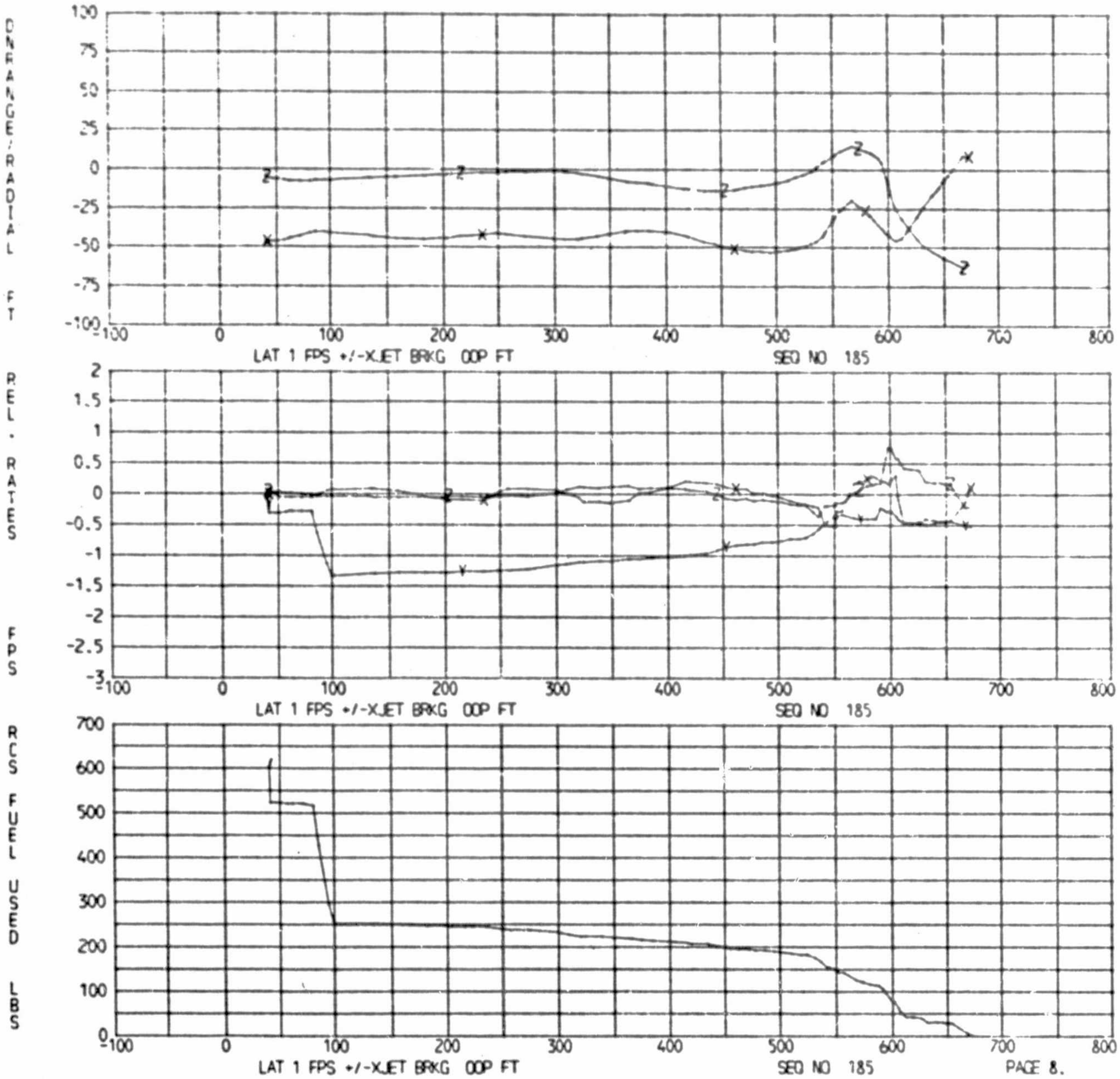
(f) Sequence 175.

Figure 5.- Continued.



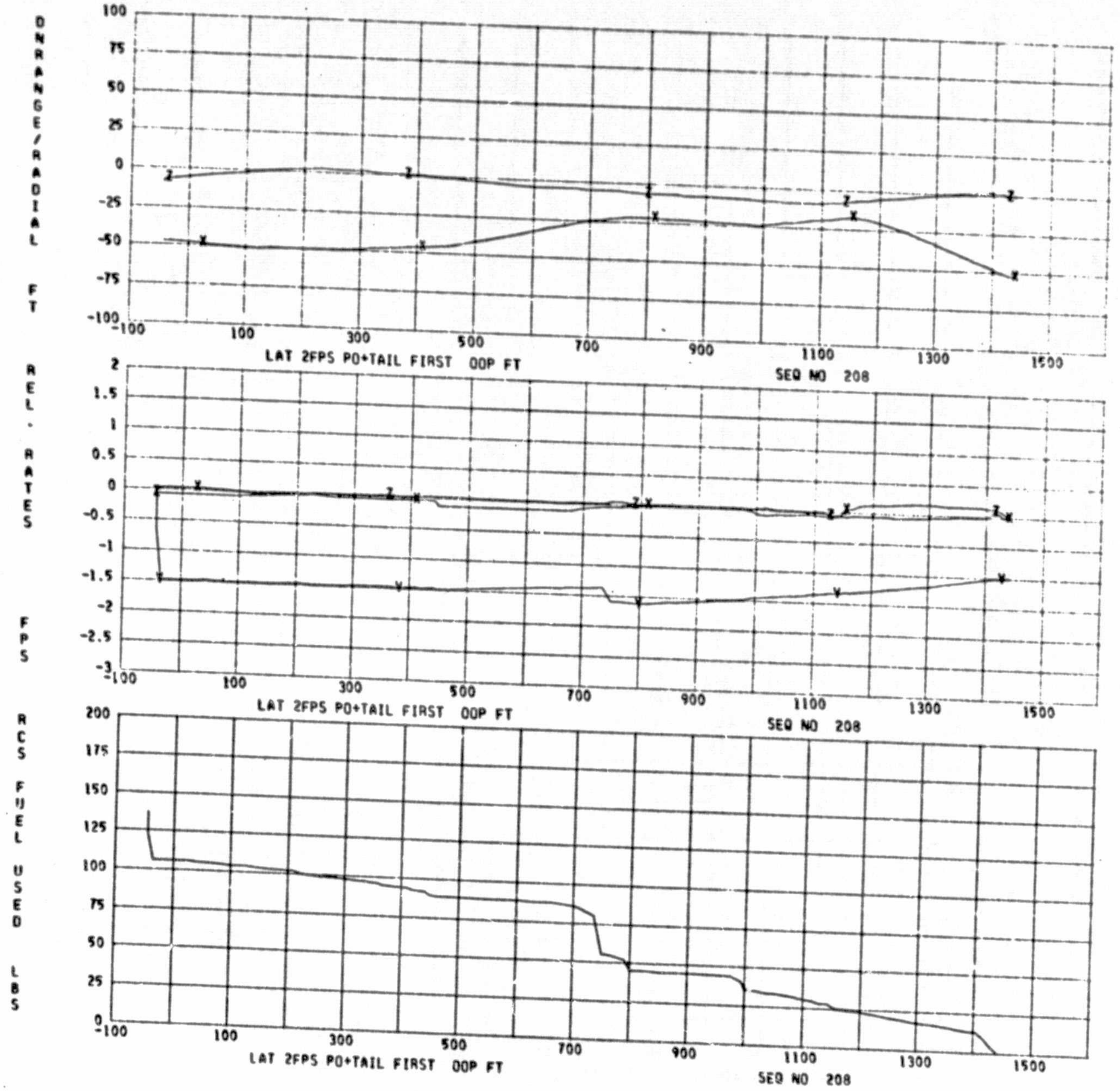
(g) Sequence 183.

Figure 5.- Continued.



(h) Sequence 185.

Figure 5.- Continued.



(i) Sequence 208.

Figure 5.- Continued.

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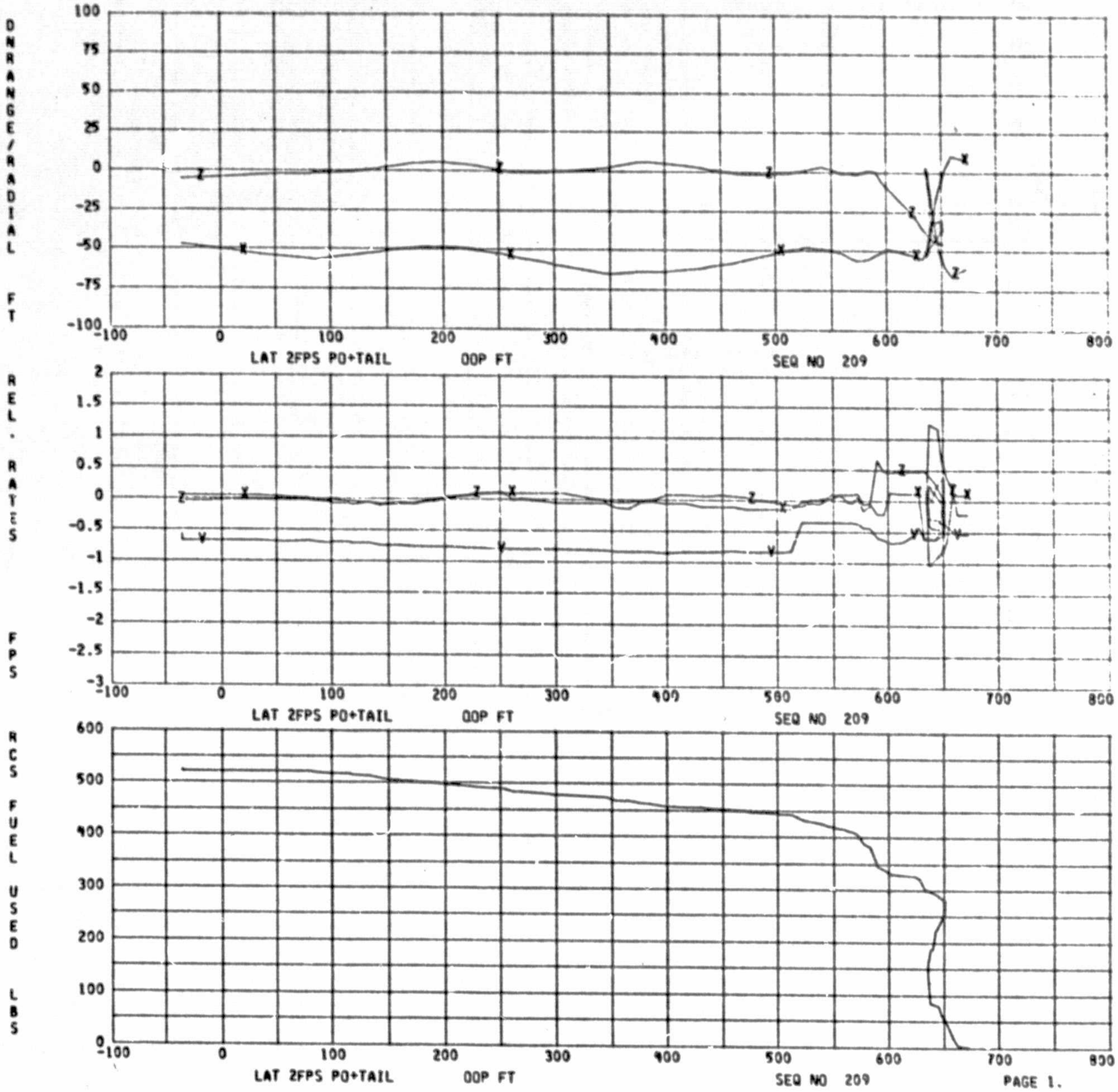
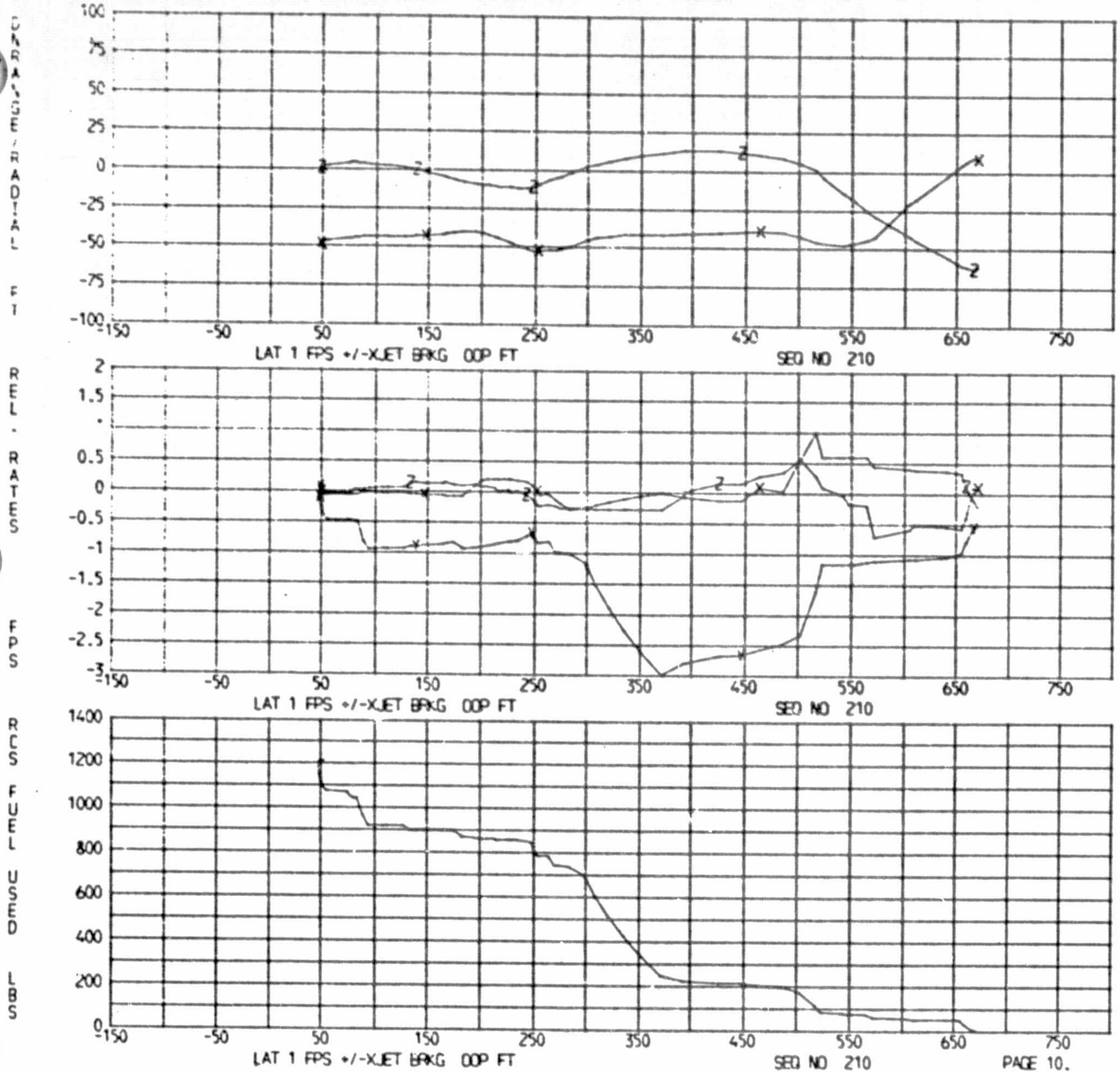


(j) Sequence 209.

Figure 5.- Continued.



(k) Sequence 210.

Figure 5.- Continued.

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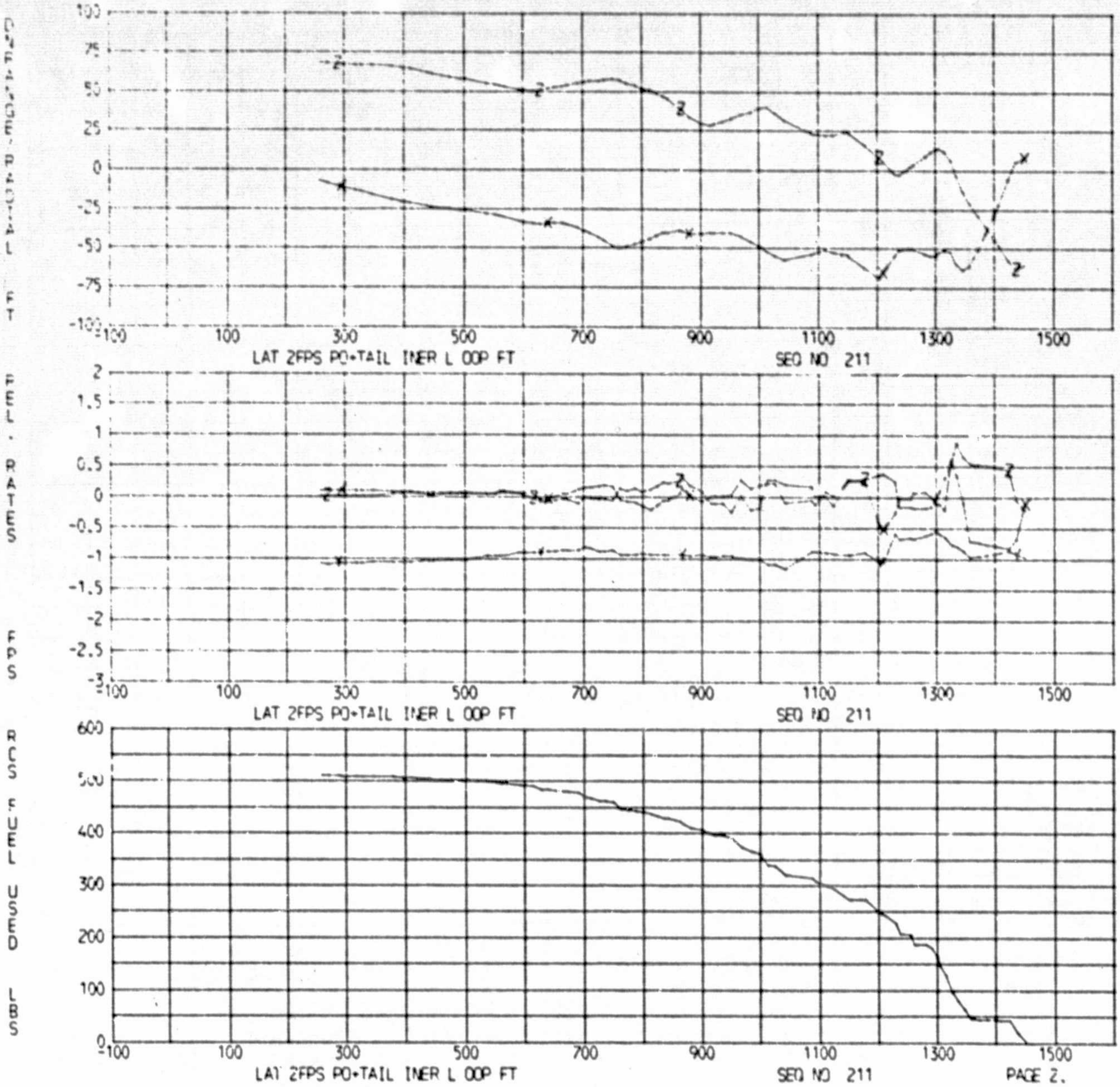
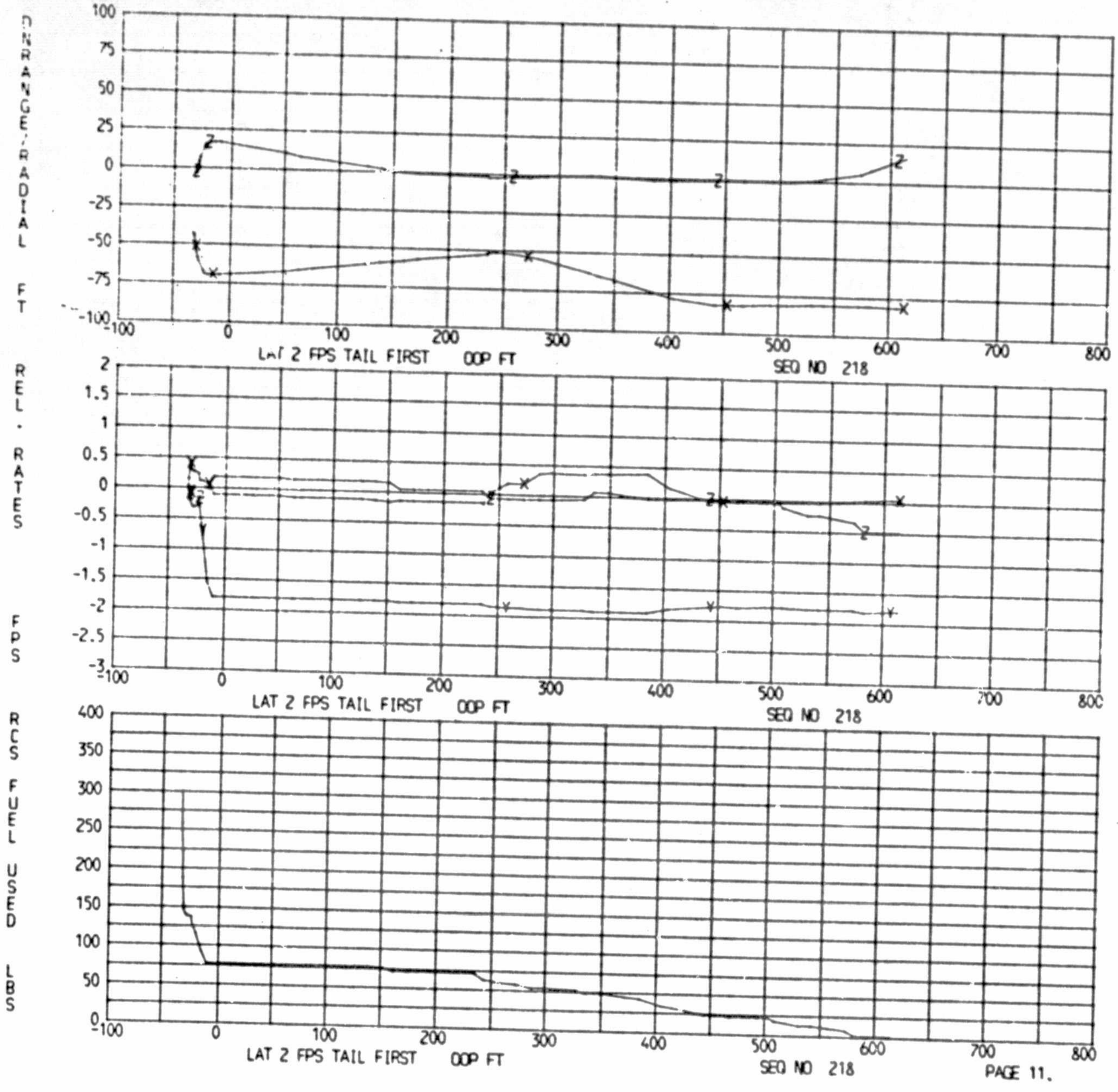


(1) Sequence 211.

Figure 5.- Continued.



(m) Sequence 218.

Figure 5.- Continued.

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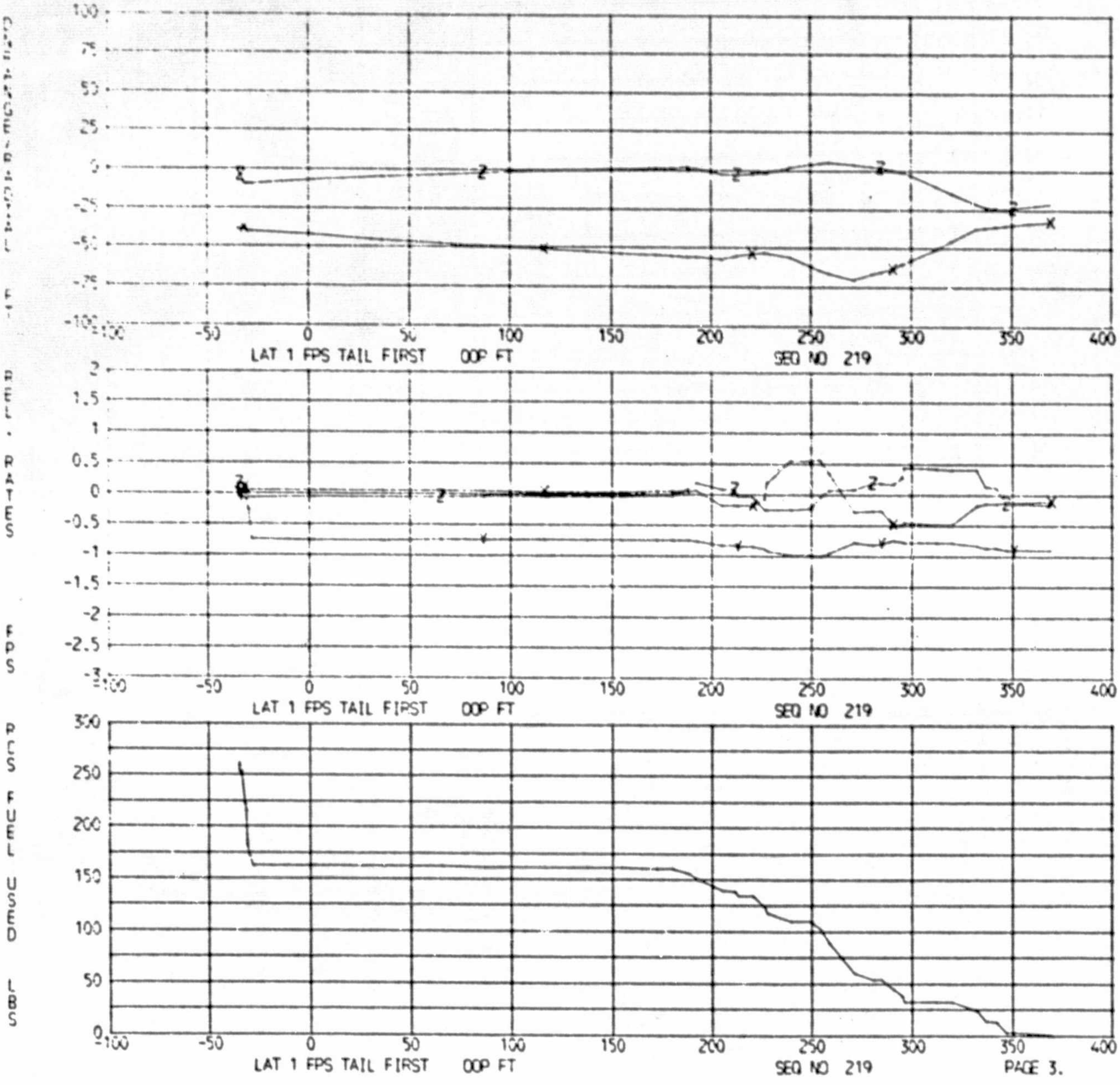

(n) Sequence 219.

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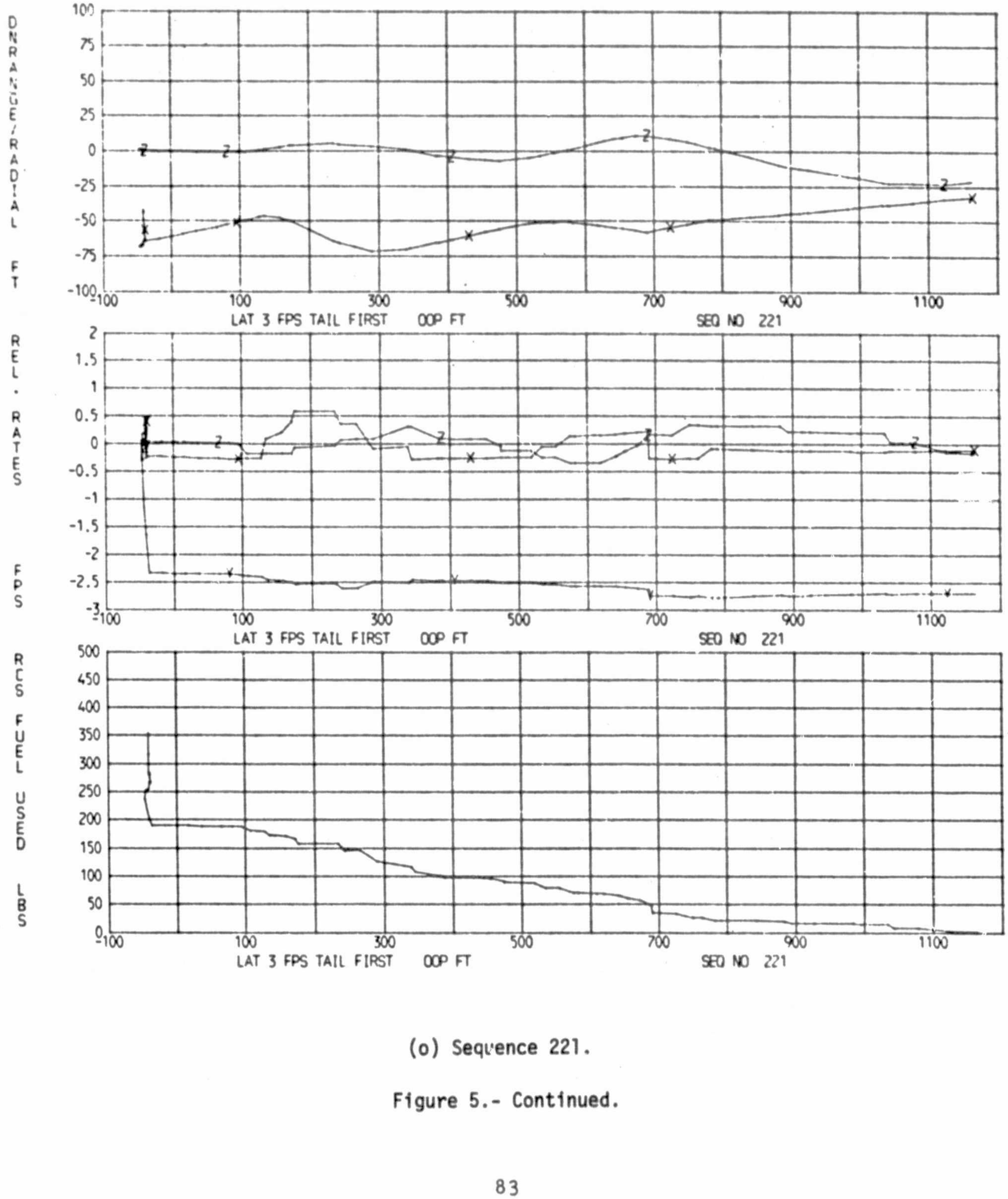
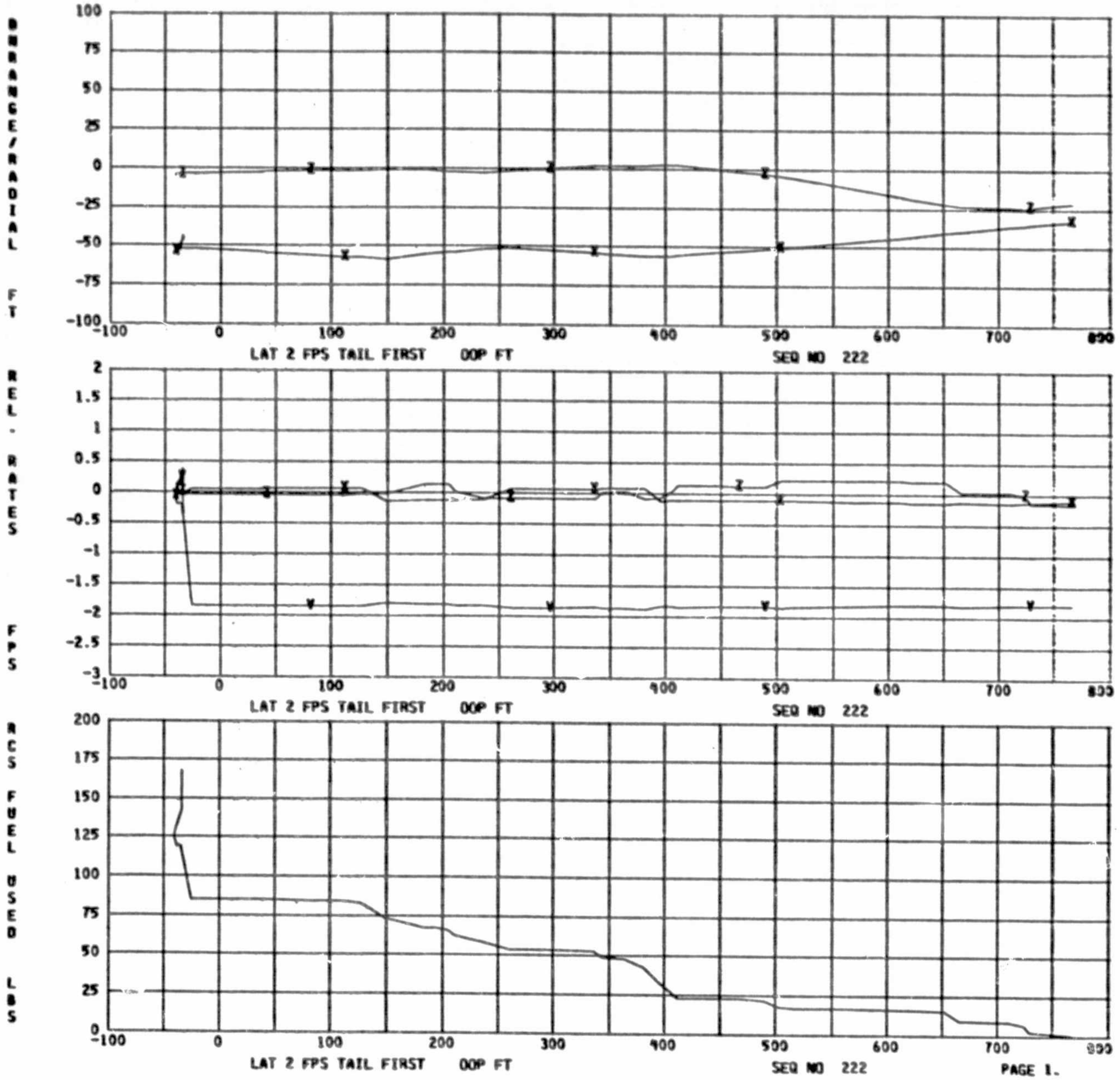


(o) Sequence 221.

Figure 5.- Continued.



(p) Sequence 222.

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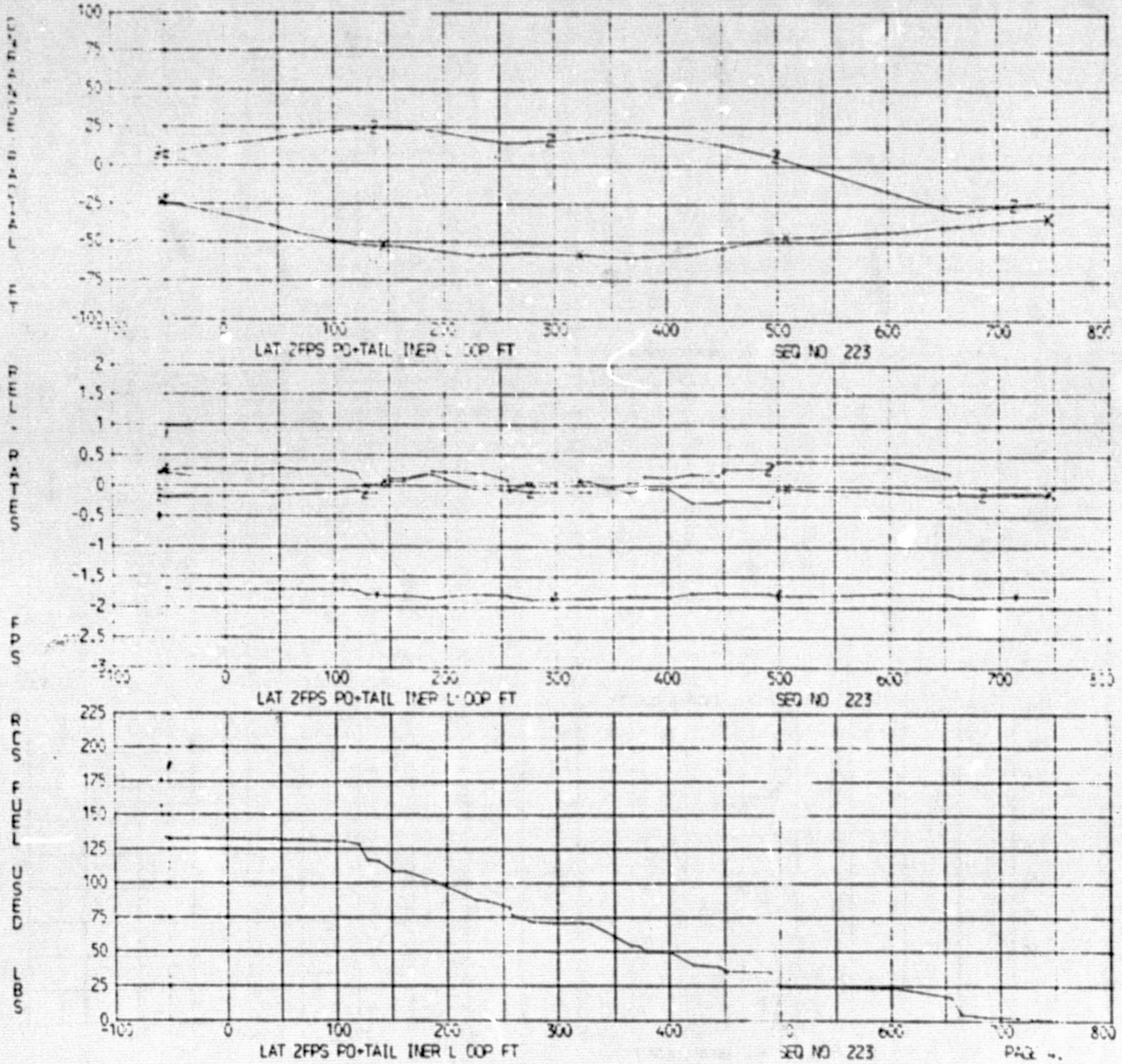
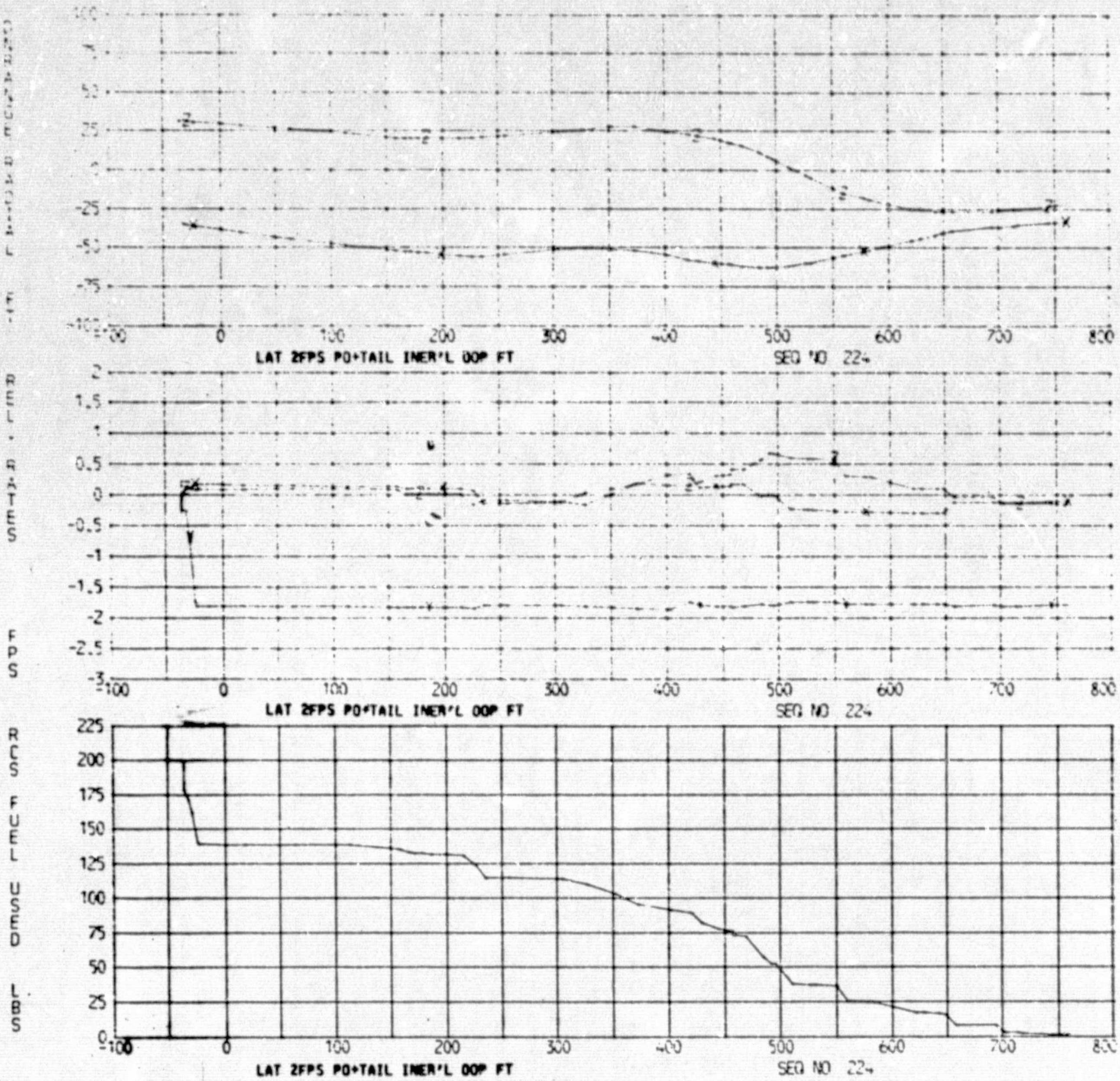


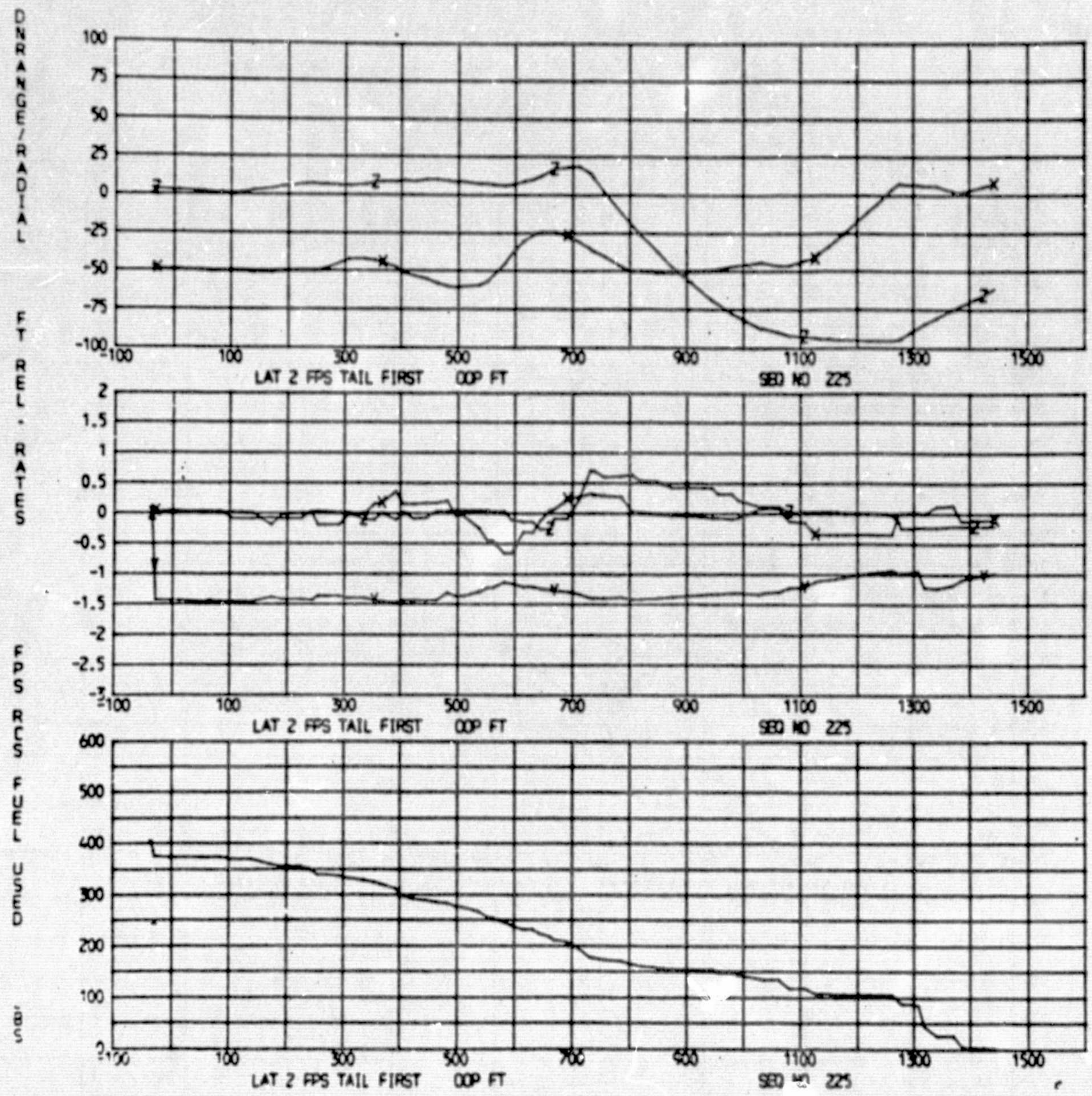
(q) Sequence 223.

Figure 5.- Continued.



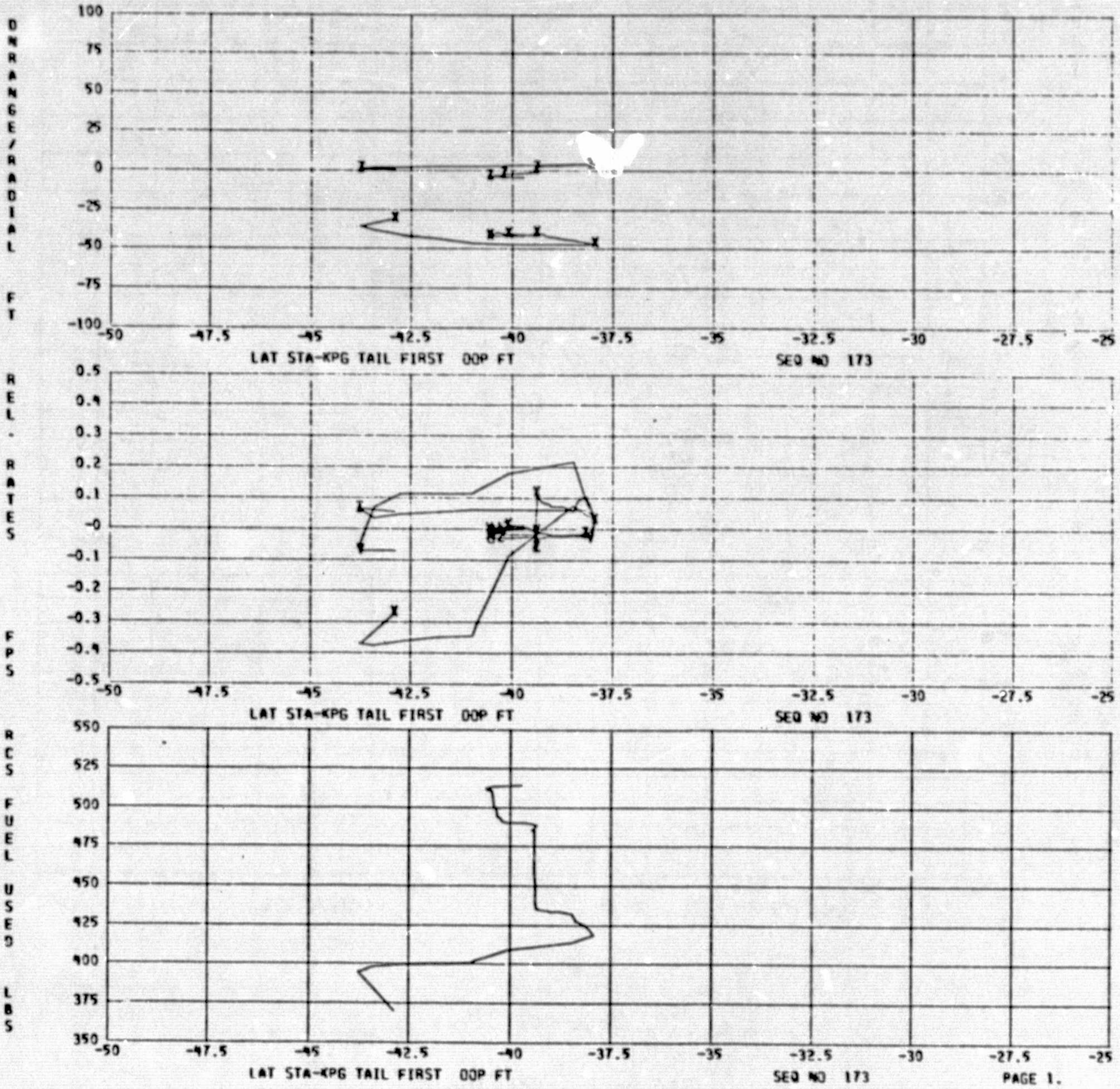
(r) Sequence 224.

Figure 5.- Continued.



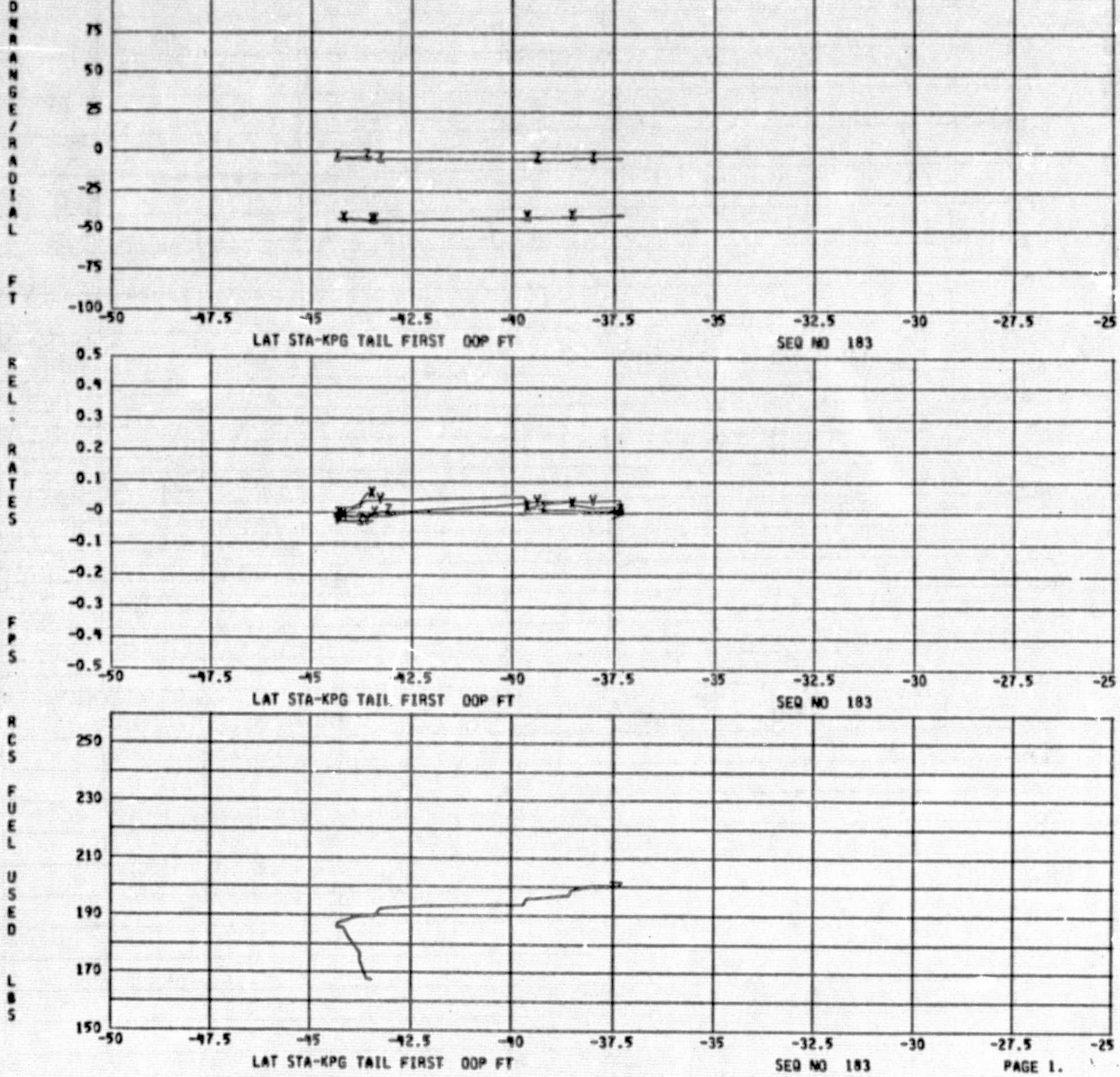
(t) Sequence 225.

Figure 5.- Concluded.



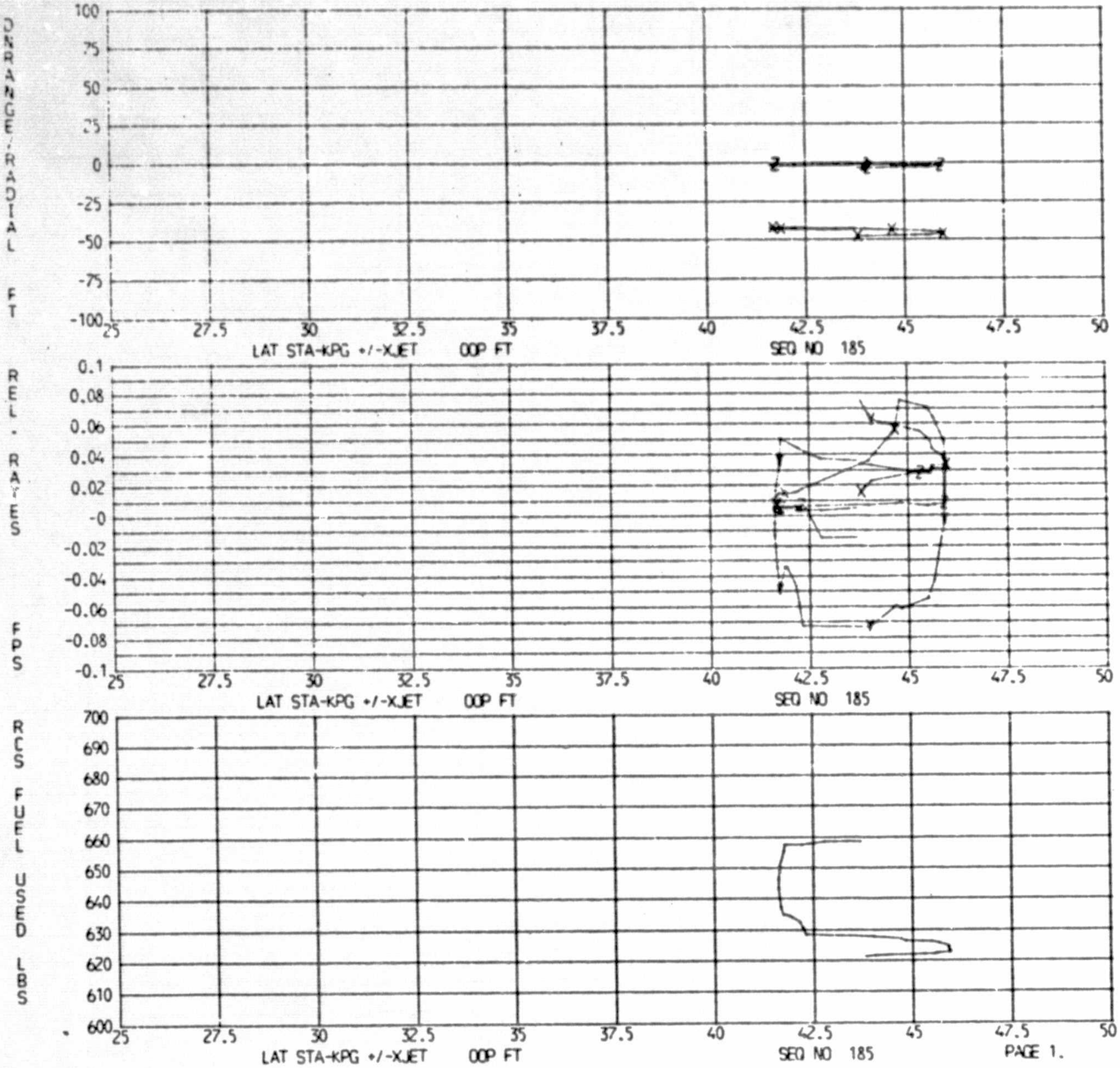
(a) Sequence 173.

Figure 6.- LAT stationkeeping.



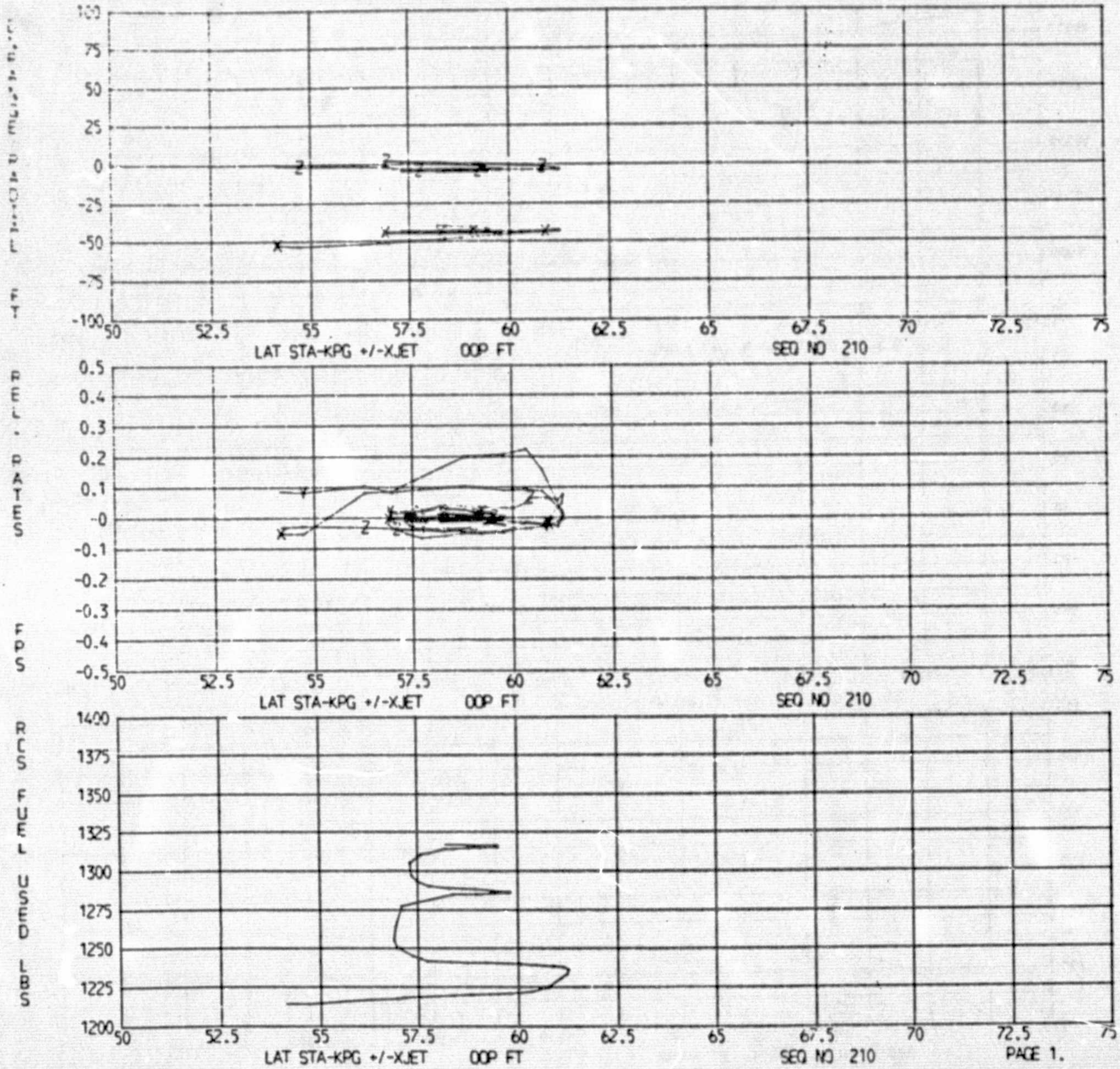
(b) Sequence 183.

Figure 6.- Continued.



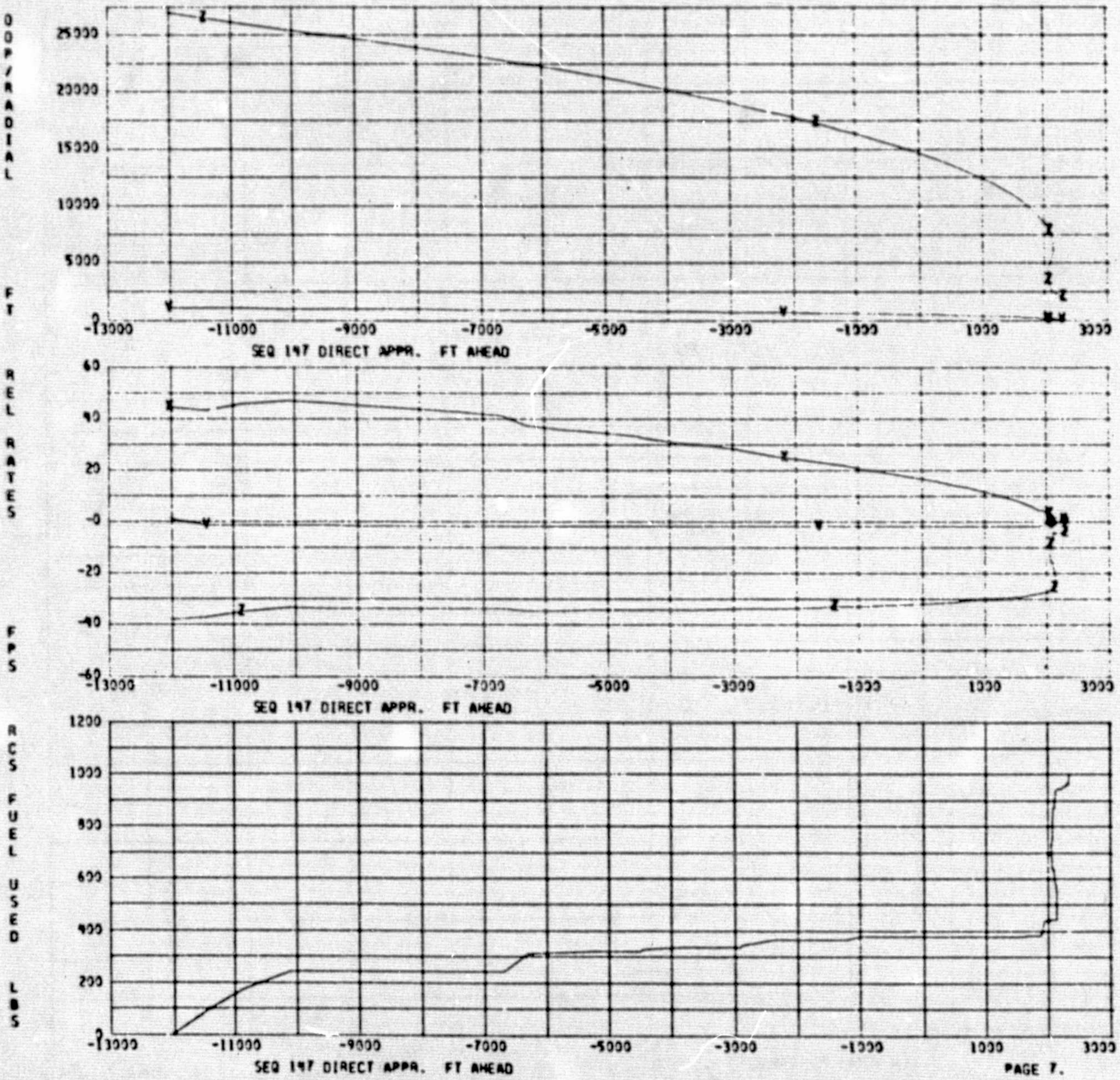
(c) Sequence 185.

Figure 6.- Continued.



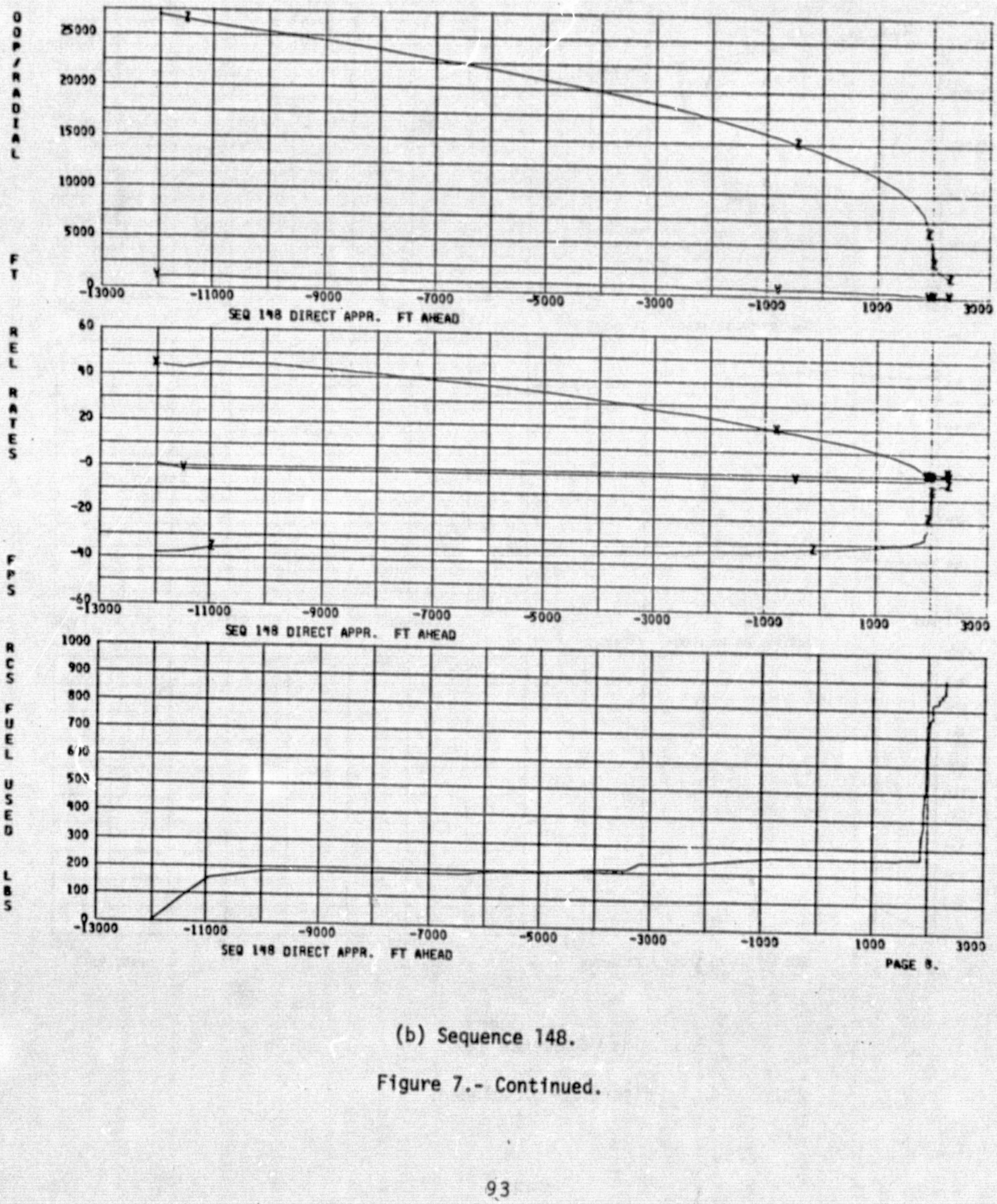
(d) Sequence 210.

Figure 6.- Concluded.



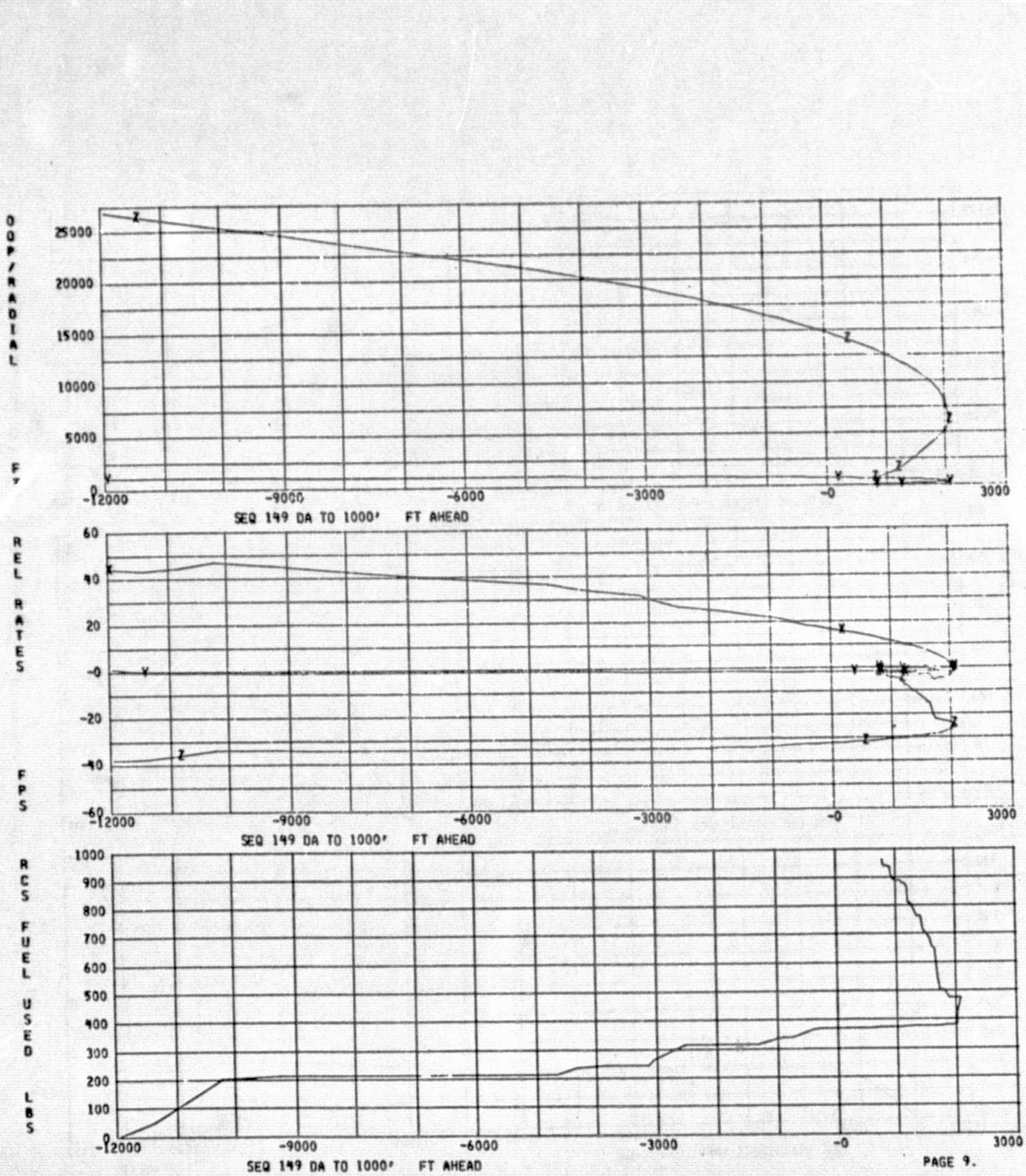
(a) Sequence 147.

Figure 7.- Direct approach (PRCS), relative motion, and RCS plots.



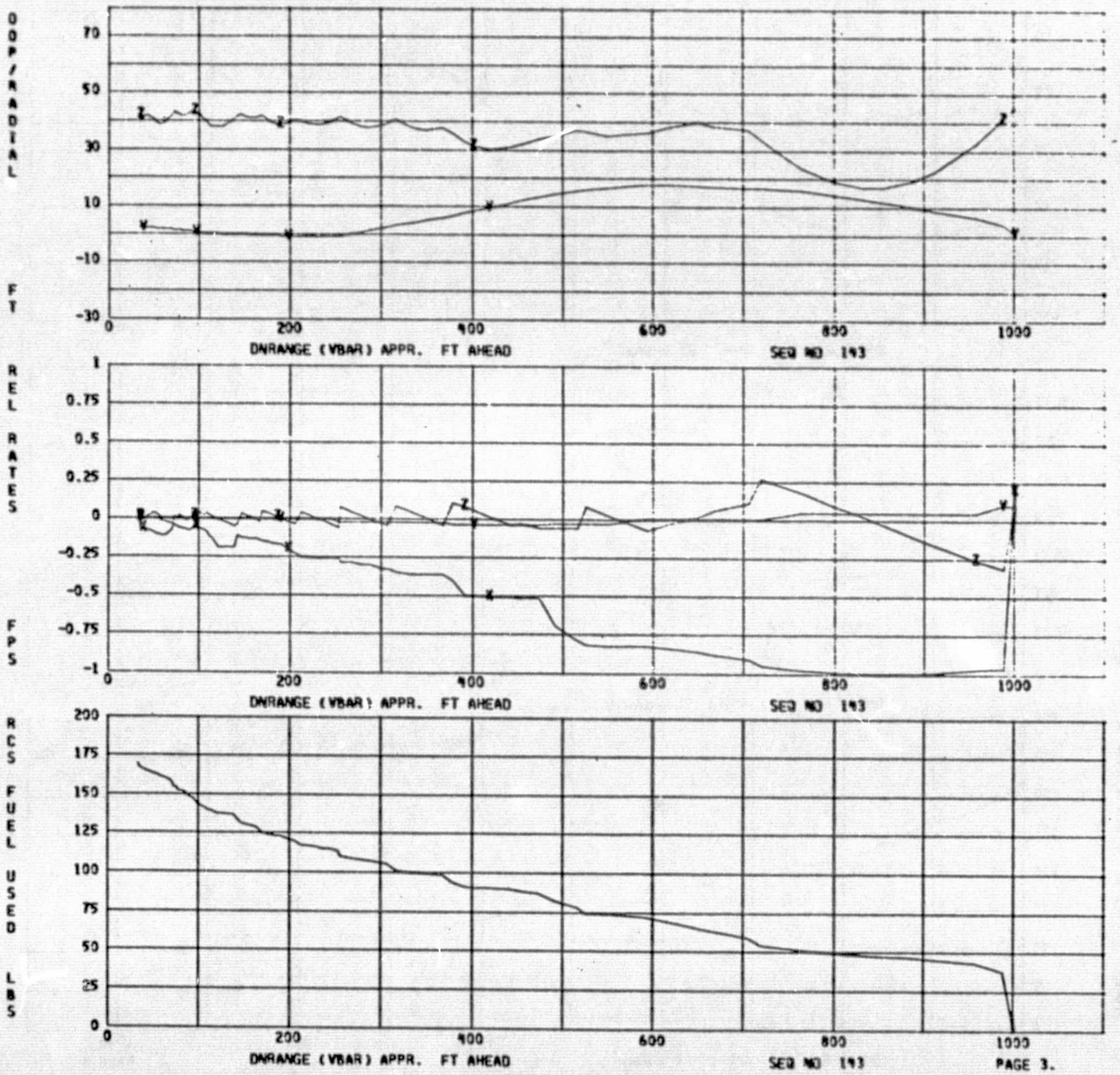
(b) Sequence 148.

Figure 7.- Continued.



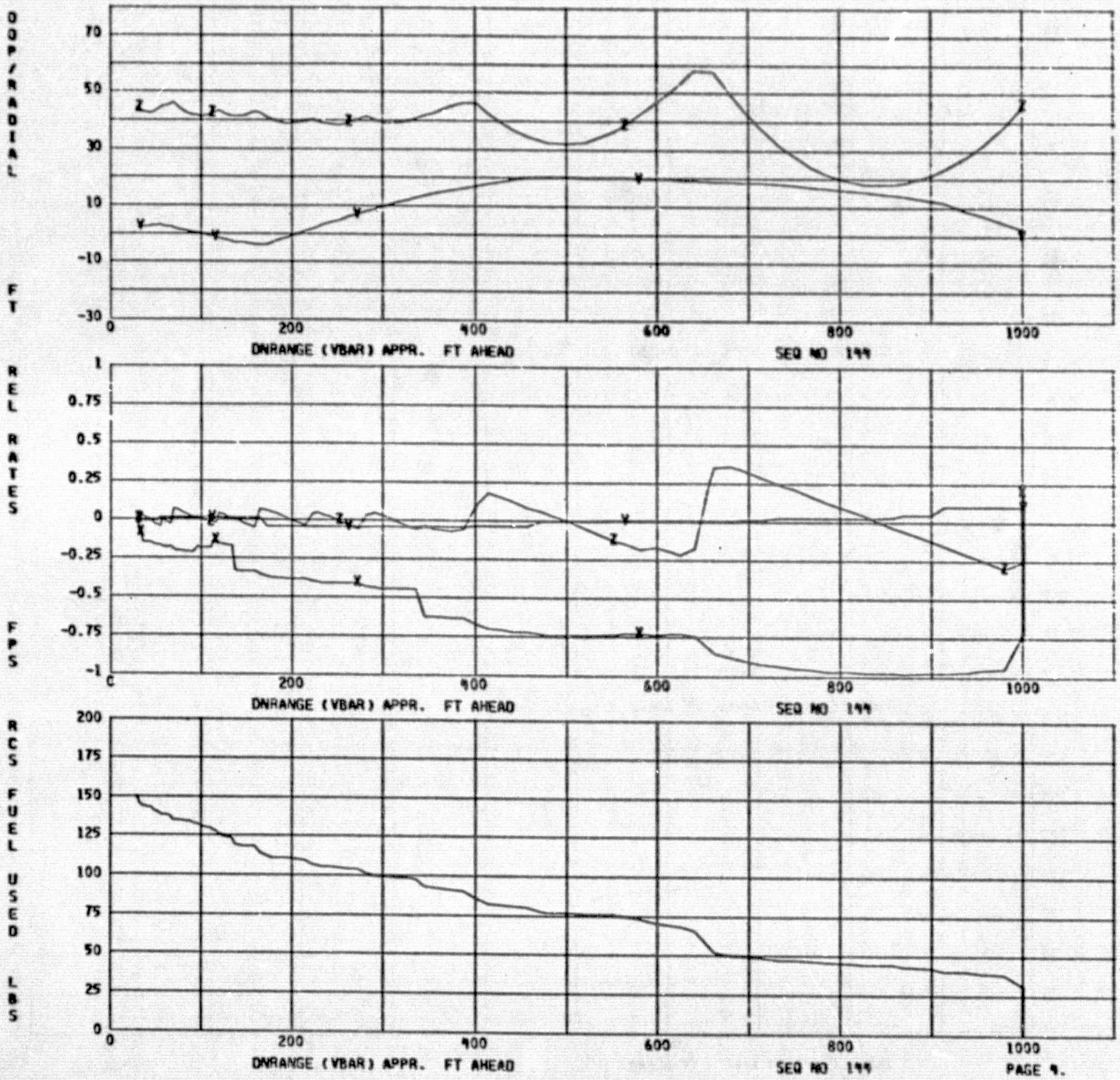
(c) Sequence 149.

Figure 7.- Concluded.



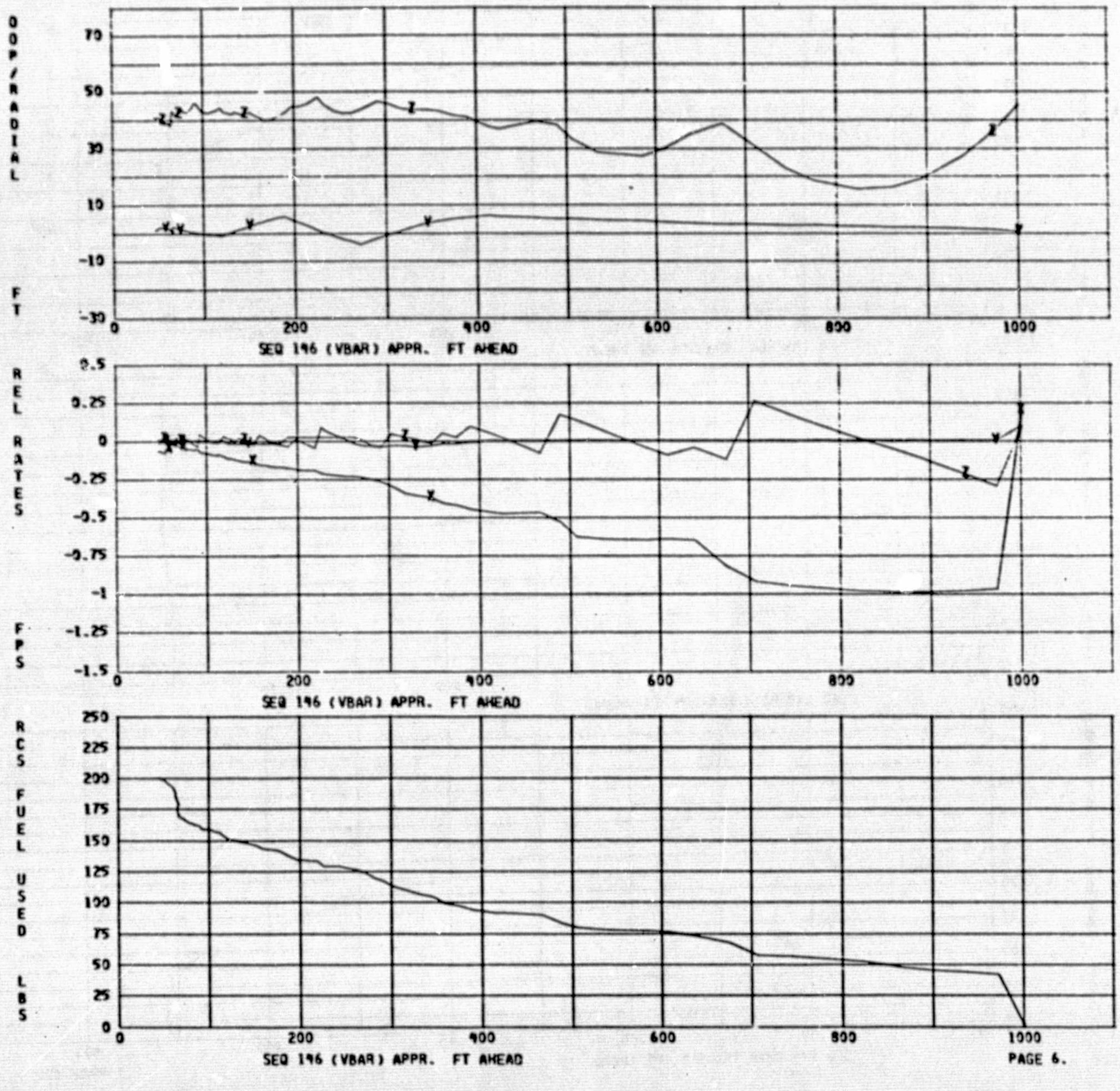
(a) Sequence 143.

Figure 8.- $\overline{V}$ approach (PRCS), relative motion, and RCS plots.



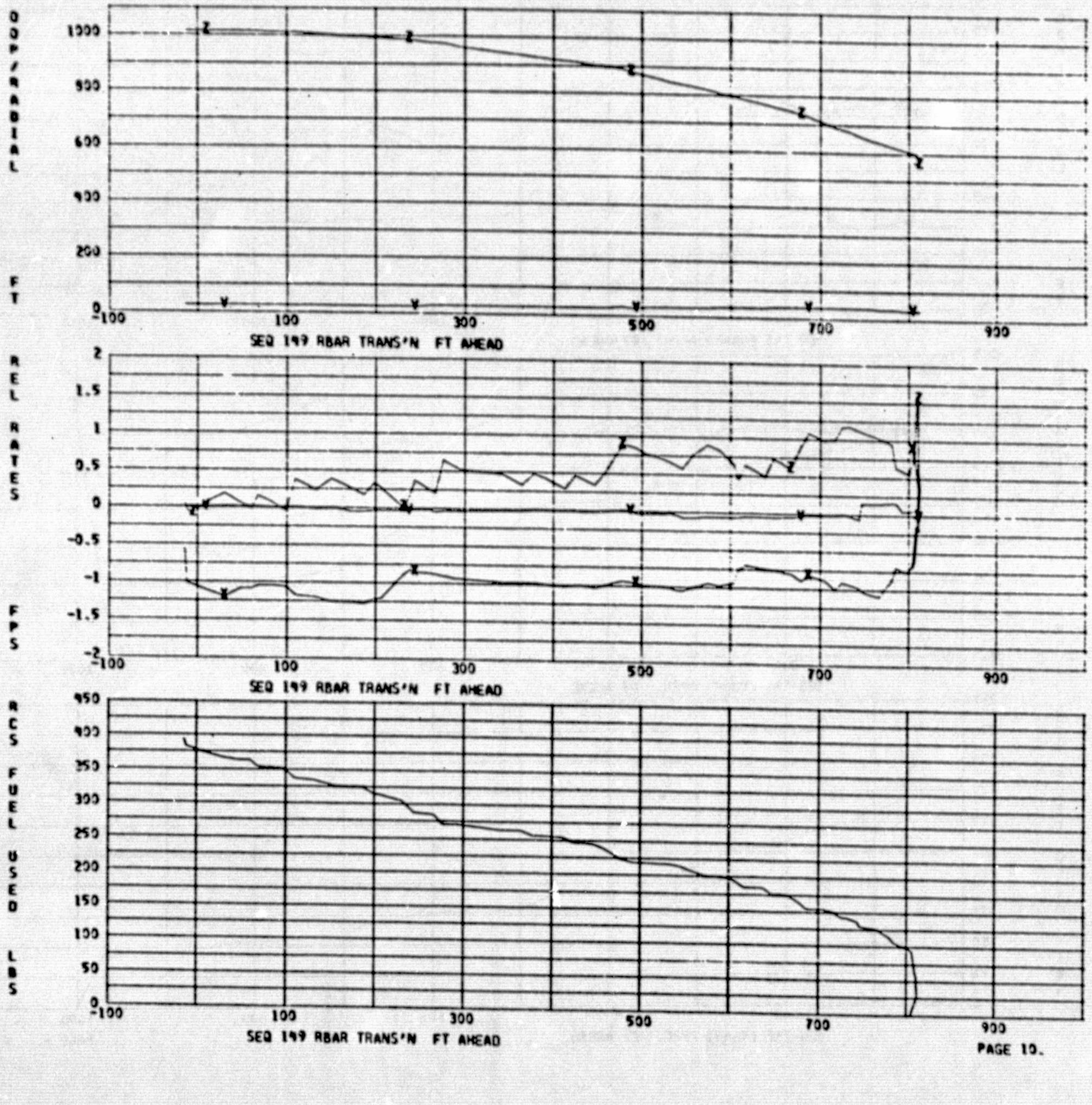
(b) Sequence 144.

Figure 8.- Continued.



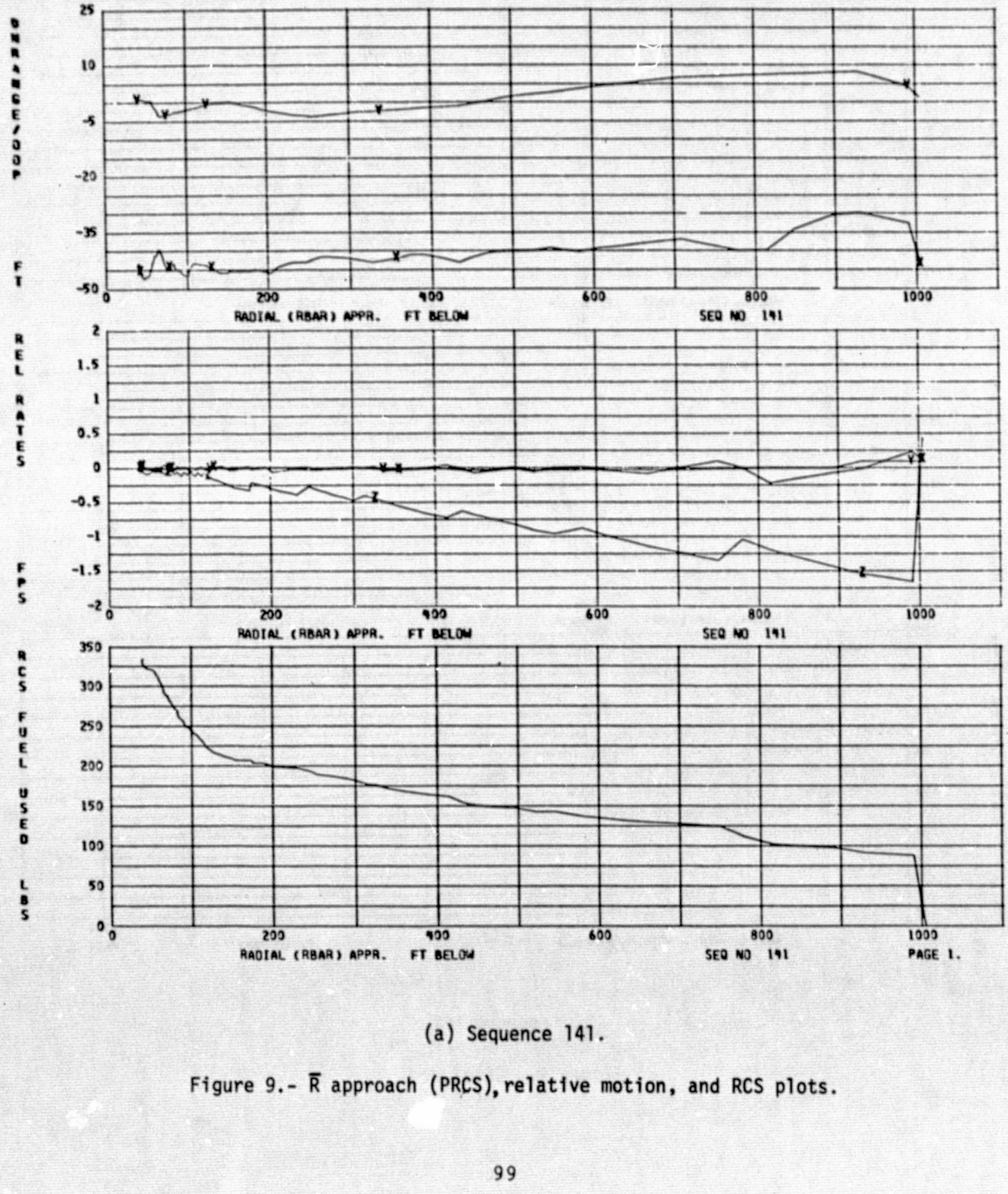
(c) Sequence 146.

Figure 8.- Continued.



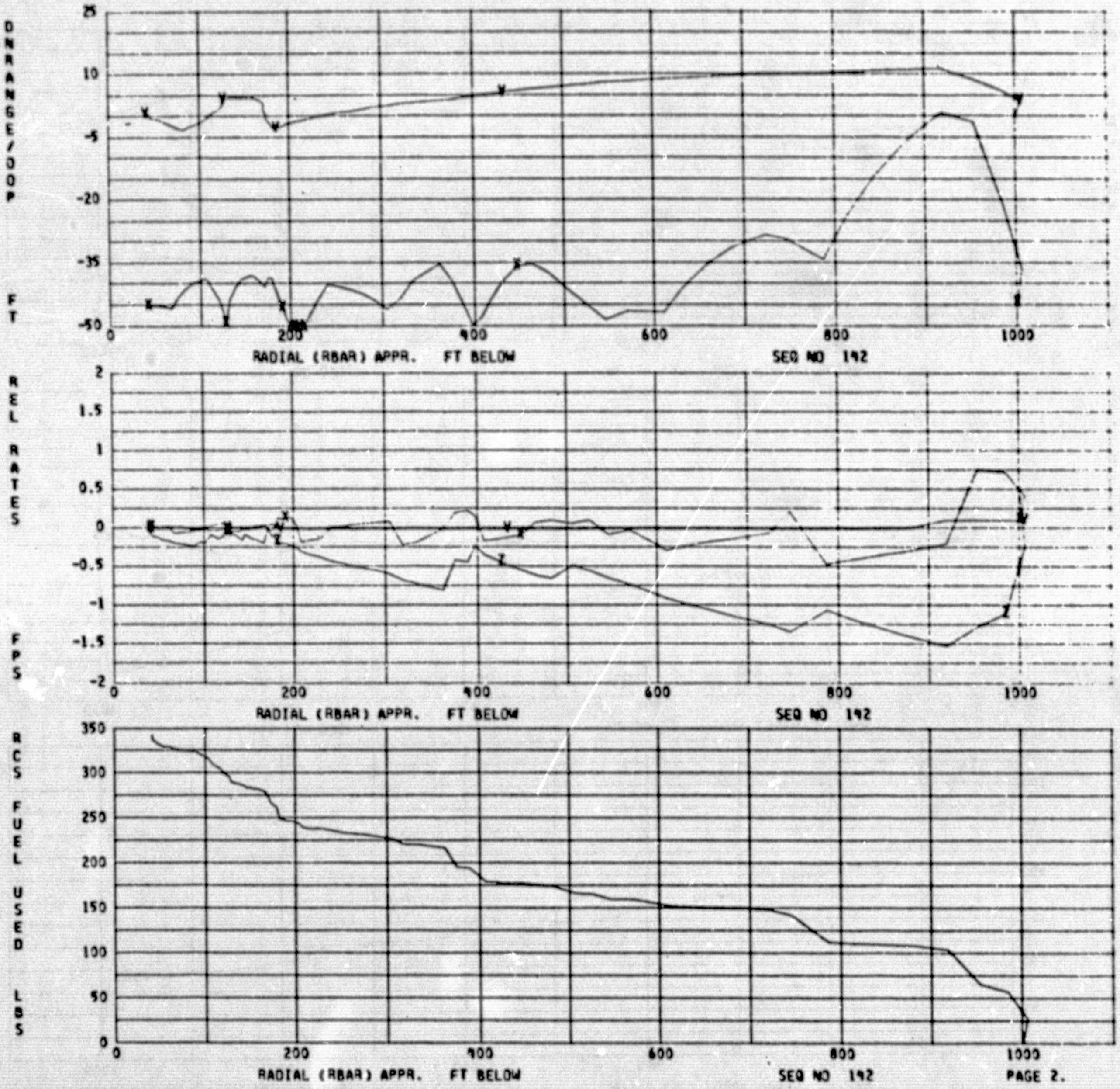
(d) Sequence 149.

Figure 8.- Concluded.



(a) Sequence 141.

Figure 9.- $\overline{R}$ approach (PRCS), relative motion, and RCS plots.



(b) Sequence 142.

Figure 9.- Concluded.

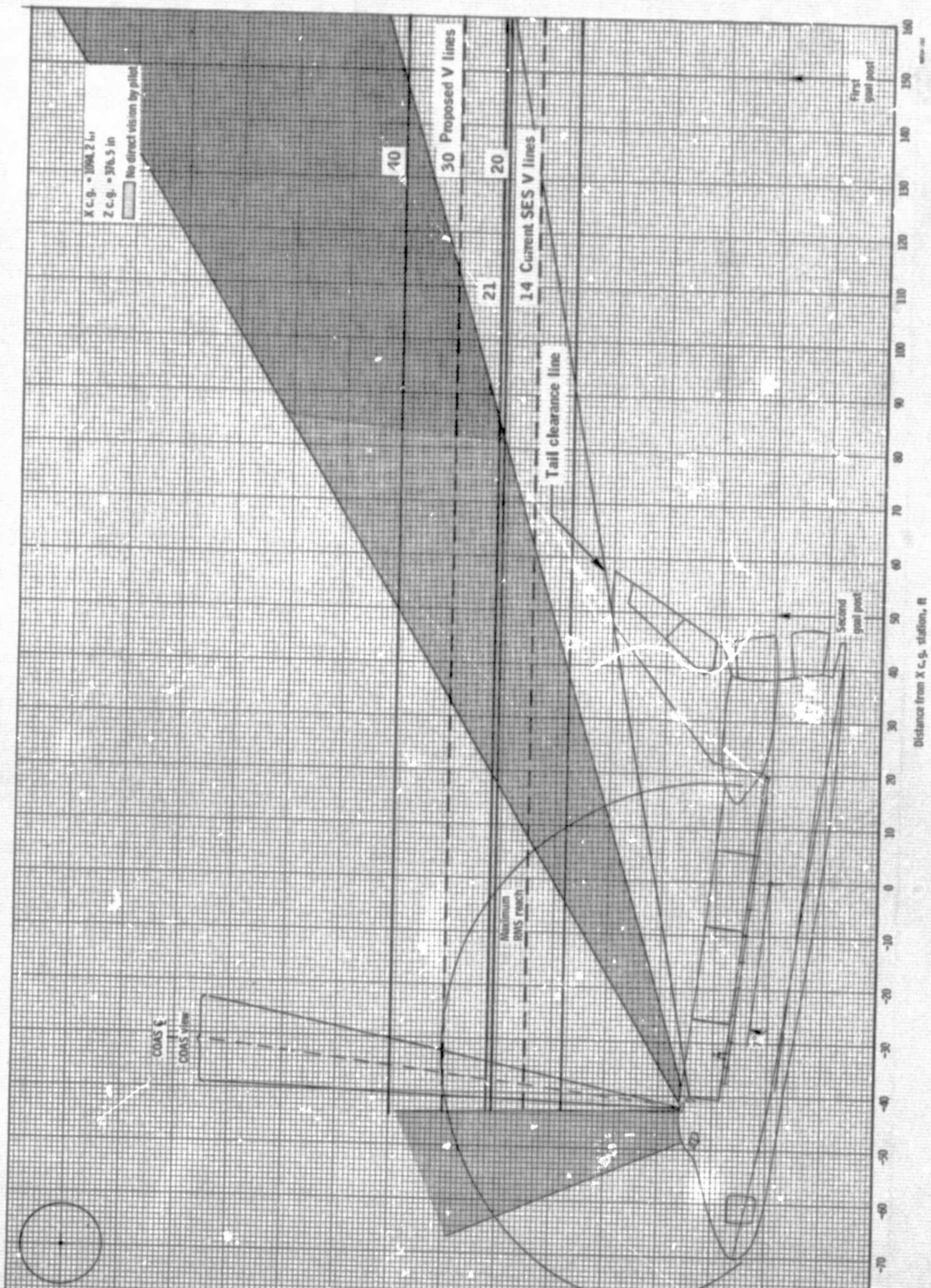


Figure 10.- SES V-overlay control lines current and new proposed V-overlay lines.

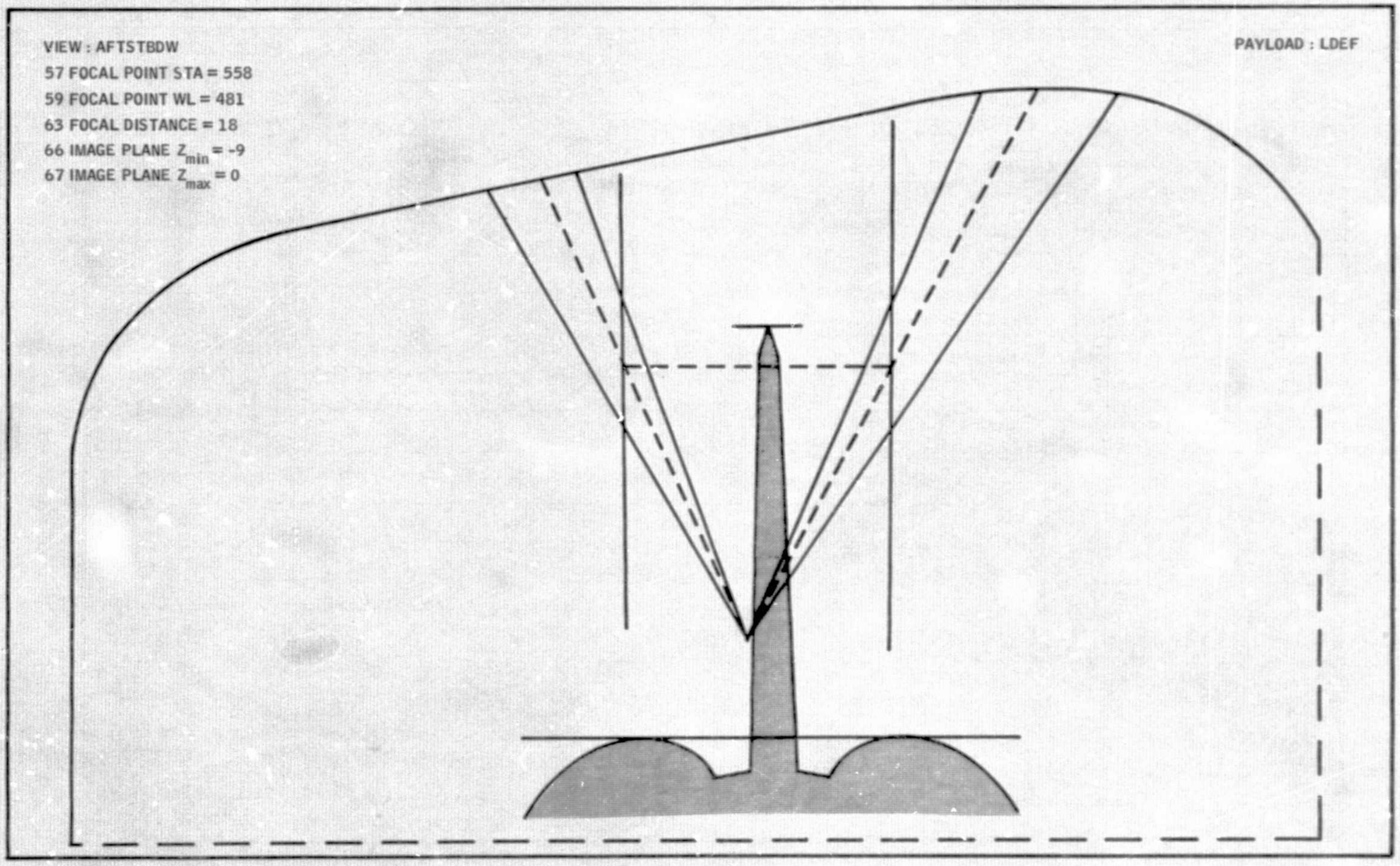


Figure 11.- Standard SES (7, 14, and 21 ft) V-overlay used for 30 ft (LDEF) payload in aft starboard window.

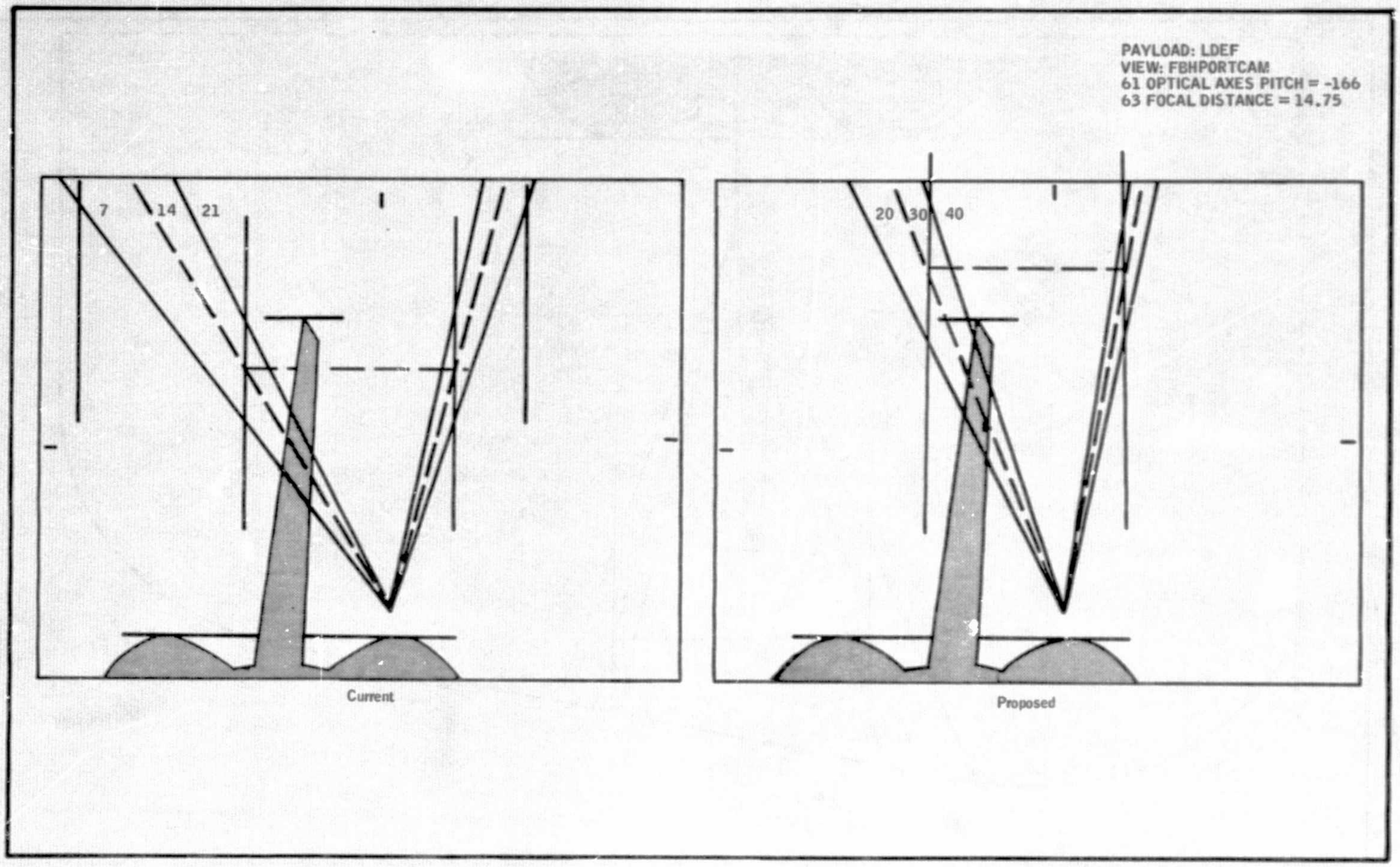


Figure 12.- Standard SES (7, 14, and 21 ft) and new proposed (20, 30, and 40 ft) CCTV V-overlay for LDEF (30 ft) payloads.

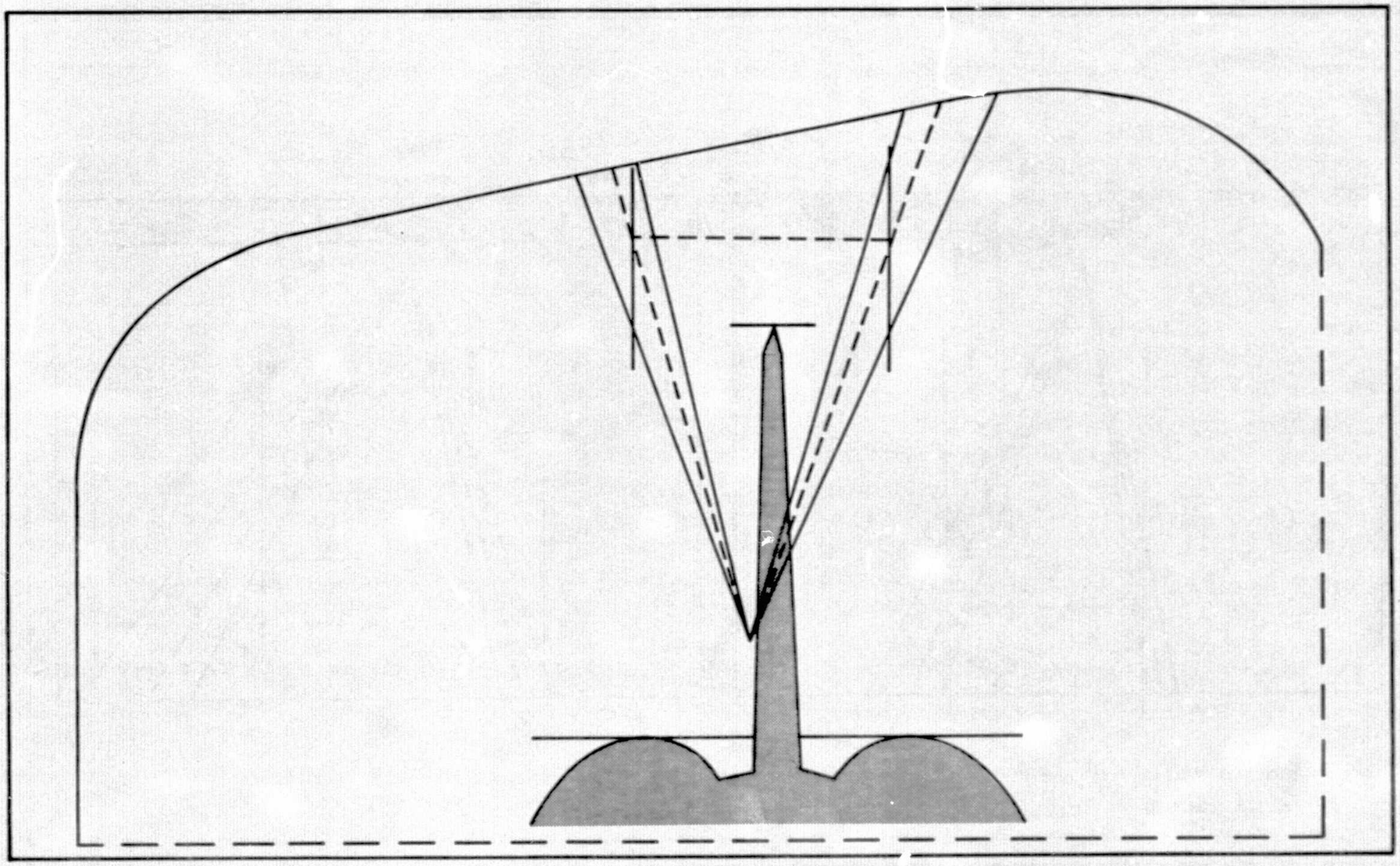


Figure 13.- Proposed new (20, 30, and 40 ft) V-overlay for 30 ft payloads for aft starboard window.

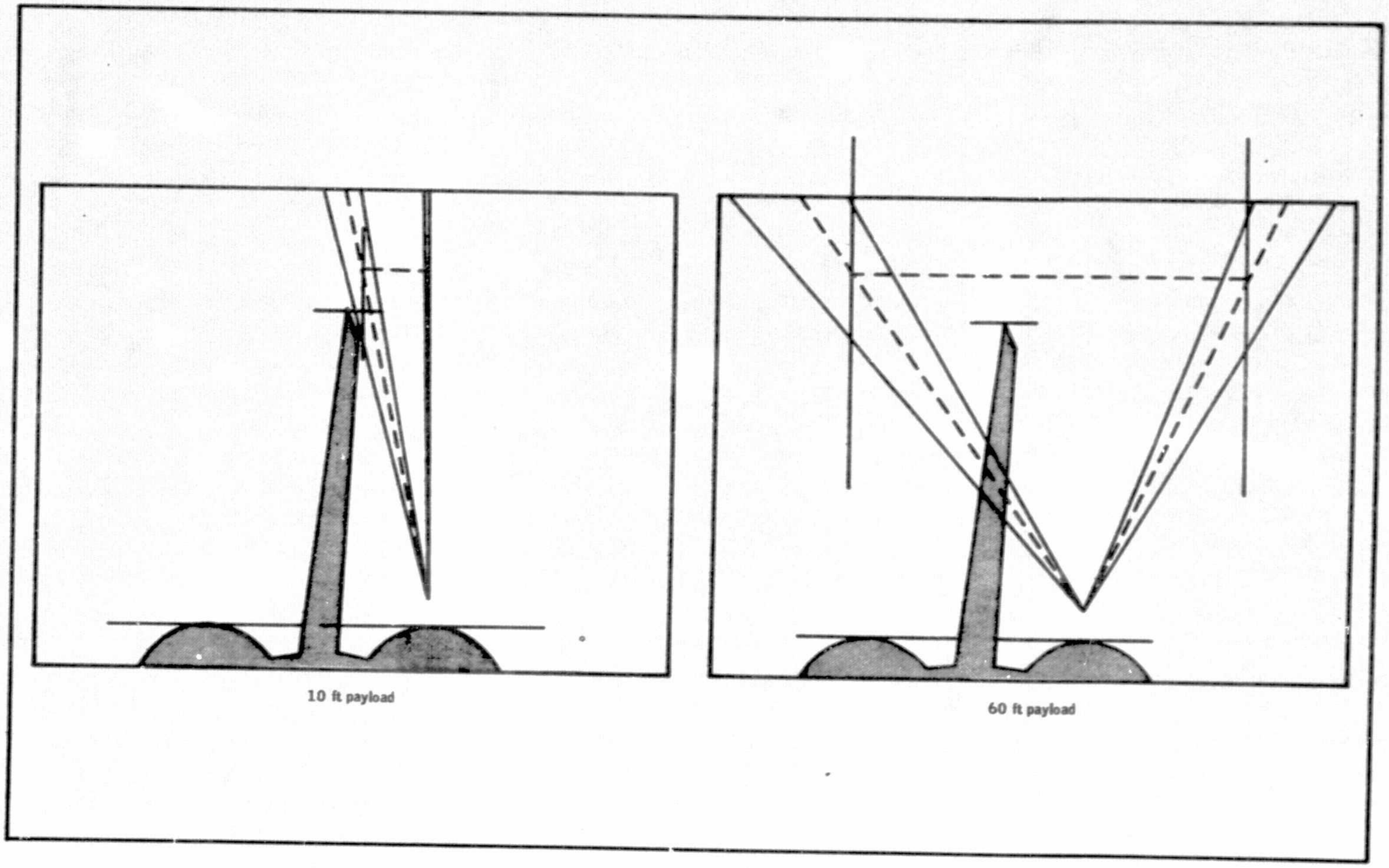


Figure 14.- Proposed CCTV V-overlays (20, 30, and 40 ft) for 10- and 60-foot payloads.

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