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Group 23N, Apollo Project Memo

To: Distribution
From: W. Tanner, Ann Hathaway
Date: 11 February 1970
Subject: Performance of Landing Radar during powered descent of Apollo 12.

The Apollo 12 Lunar Module touched down 125 km south-east of the Lansberg Crater near the Surveyor III landing site. The approach to the landing site was from ESE in an orbital plane that was inclined relative to the lunar equatorial plane by 14^{o}. Landing Radar data were downlinked just after the Lunar Module had passed the crest of the Fra Mauro Rima Parry I, about 900 meters above the landing site. Velocity relative to the terrain was 3655 ft/sec and the altitude was 41000 ft. (above landing site = ALS). Radar data continued to be received up to touch-down, except for two drop-outs of 23 and 8 seconds just prior to touch-down. Touch-down occurred at 397957 sec LGC elapsed time or at 6:54:39.5 GMT on November 19, 1969.

This memo discusses the quality of the velocity data which the Landing Radar provided to the primary guidance system. A comparison is made between radar data and the velocity of the LM relative to the terrain as computed from the on-board state vector. Since the state vector is updated by radar information its velocity components will eventually represent a smoothed value of radar velocity. The equivalent smoothing time is about 60 seconds. Right after touch-down the true terrain velocity equals zero. The state vector derived velocity at that time represents the velocity bias of the navigation system and with it the bias of the radar sensor. A velocity error build up at some time after touch-down can be interpreted in terms of misalignment of the inertial platform.

The post-flight data analysis has led to the following conclusions:

1. Radar data were in general excellent, but there was a small number of erratic errors of up to 2.5% in the high velocity regime and one erratic error of 6 ft/sec shortly before flare-out.
2. During the manual descent (P-66) there were two drop-outs of radar data for 23 and 8 seconds. The drop-outs were caused by velocities of less than 0.6 ft/sec along the axis of radar beam #1. Just before the first drop-out a large error of 5.8 ft/s was recorded. Reacquisition after the drop-outs was good.
3. As on the Apollo 11 flight the radar produced erroneous data just before touch-down. At an altitude of less than 10 ft the radar started to track lunar dust which was agitated by the DPS engine. The radar recorded velocity errors up to 14 ft/s. Such large error data are excluded by the reasonableness test. However the smaller errors can contaminate the vehicle's state vector. Exclusion of radar data at low altitudes is therefore needed. On Apollo 13 radar data will not be accepted below 50 ft of altitude.
4. The spacecraft touched down with a vertical velocity of 2.3 ft/sec. After touch-down the navigation system recorded bias errors of -0.48, +0.18, -1.01 for the three components of velocity. These bias's are caused by equivalent errors of the radar sensor. The overall performance of the system was excellent and well within specification limits.

5. After touch-down the state vector was observed to change in agreement with the rotation rate of the moon. The drift of the velocity components of the state vector over a 30 second interval amounted to -0.01, -0.12, -0.19 ft/s. These figures are excellent; they represent a platform misalignment* after landing of 1.5 mr or 0.08°.

* Misalignment relative to true local vertical resulting from all error contributions.

The enclosed plots show radar data and ground velocity of the vehicle in the coordinate system of the radar antenna. This presentation was chosen because the updating of the state vector is performed sequentially for each component of the measured velocity vector. An individual radar update will show up only on the plot which contains the radar measurement. The time scale is marked at each end with the LM elapsed time minus 110 hours. State vector derived ground velocity is marked by the stair-like solid line. The height of each step corresponds to the velocity update. Time of the update is on the left hand side of the step. Radar data are marked by crosses (x).

Radar data were downlinked, starting at 110:24:06 GFT. The crew enabled the incorporation of data 18 seconds later. Since the altitude at this time was 39800 ft, the slant range data were used for updating of the state vector with a weighting factor of 0.07. The weighting would later increase inversely with altitude to 0.35 at touch-down. Velocity data incorporation began at 110:26:26 GET with a constant weight of 0.1 after the total velocity had been reduced to 2000 ft/s. Relatively large errors of -1.5% can be seen for the Y-component at 110:24:12 and 110:25:18 GET. These errors of -55 and -43 ft/sec appear to be falling outside of otherwise very narrow error distribution, but they are within radar specifications. At 110:26:38 an erratic error of 2.5% of the Z-component can be observed.

After incorporation of radar velocity data one can usually observe the gradual convergence of state vector derived velocity to the mean of the radar data. On this flight the two sets of data were in agreement right from the beginning to within a small fraction of the radar's random deviations. This indicates excellent performance of the inertial and radar sensors and accurate angular alignment of the radar antenna.

High gate (end of P-63) was reached at 110:29:30 and the lowering of the radar antenna into position "2" started at that time. Immediate accurate radar reacquisition can be observed 10 seconds later. For the remaining part of the automatically guided descent the radar errors are less than 1 ft/sec for x and z components and less than 2.5 ft/sec for the y-component. There is one exception, an erratic y-component error of 6 ft/sec or 4.4% at 110:30:28. The error coincides with the use of the manual attitude control while in program P-64.

At 110:30:45 the guidance system was switched into program P-66 by crew take over of horizontal velocity control at an altitude of about 400 ft. At 110:31:15 drop-out of radar data occurred because of the low velocities of less than 0.6 ft/sec along the radar's rear beam axes (see enclosed graph). Just prior to drop-out the radar errors are usually large. In this case there is a 5.9 ft/sec error in the Z-component. A second drop-out, starting at 110:31:57 did not cause any erroneous data.

The only significant disturbance of radar data took place just before touch-down as mentioned in the summary under item 3. Moving dust trapped the radar's frequency trackers at an indicated altitude of 26 ft. Height of the landing gear above the landing site was about 10 ft. The trapping of the frequency trackers occurred at 110:32:30 when the velocity and slant range outputs of the radar were affected. Velocity errors were +8, -3, +14 ft/sec for the three components. Radar slant range jumped from 26 to 49 ft. The two larger velocity errors were excluded from data incorporation by the computer's reasonableness test. The single error of -3 ft/sec in the Y-channel caused an erroneous up-date of -0.3 ft/sec.

The expanded plot of the last 30 seconds and the plot of beam velocities show at the time of engine cut-off an increase in vertical velocity to -2.3 ft/sec at the moment of touch-down. Lateral and forward velocities at touch-down were below 0.6 ft/sec, an achievement that must be credited to the commander-astronaut. The performance of the navigation system which has already been quoted is due to low radar bias errors, exceptional inertial platform stability and the sophisticated testing and weighting of the radar data by the computer.

The data which have been used in this report are available upon request in form of a computer print-out. A sample page of the print-out which shows the input and output variables is enclosed.

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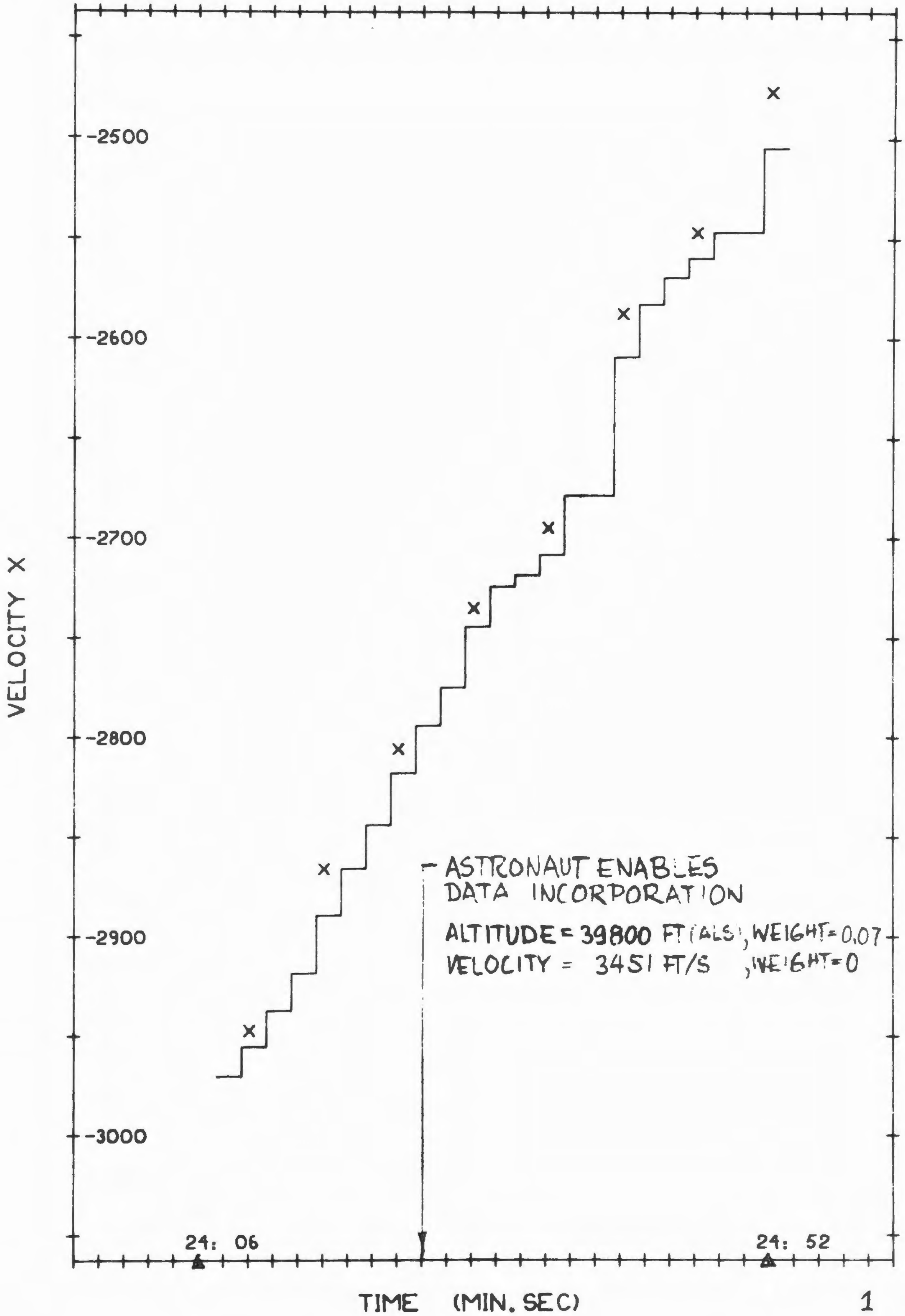
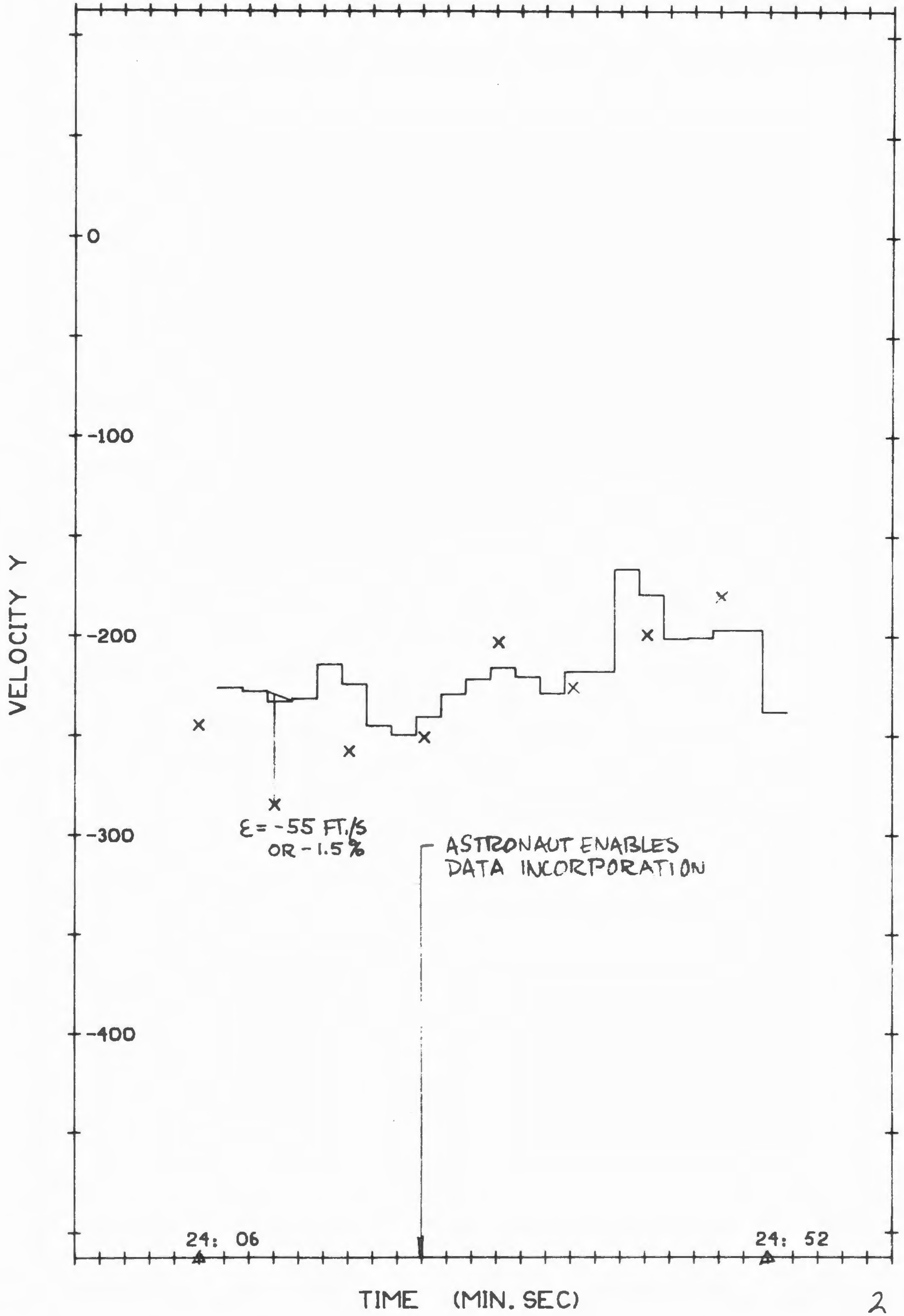
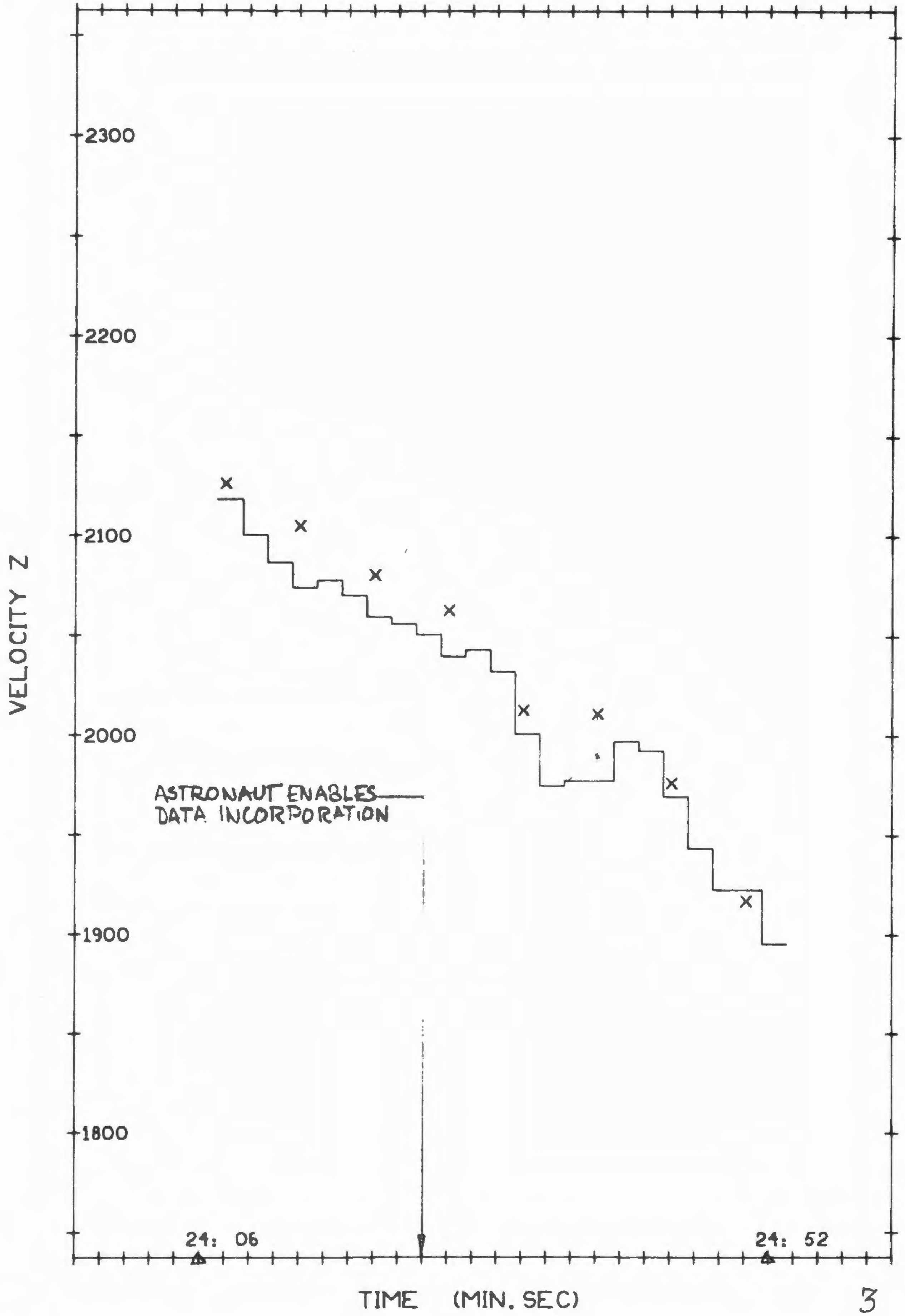


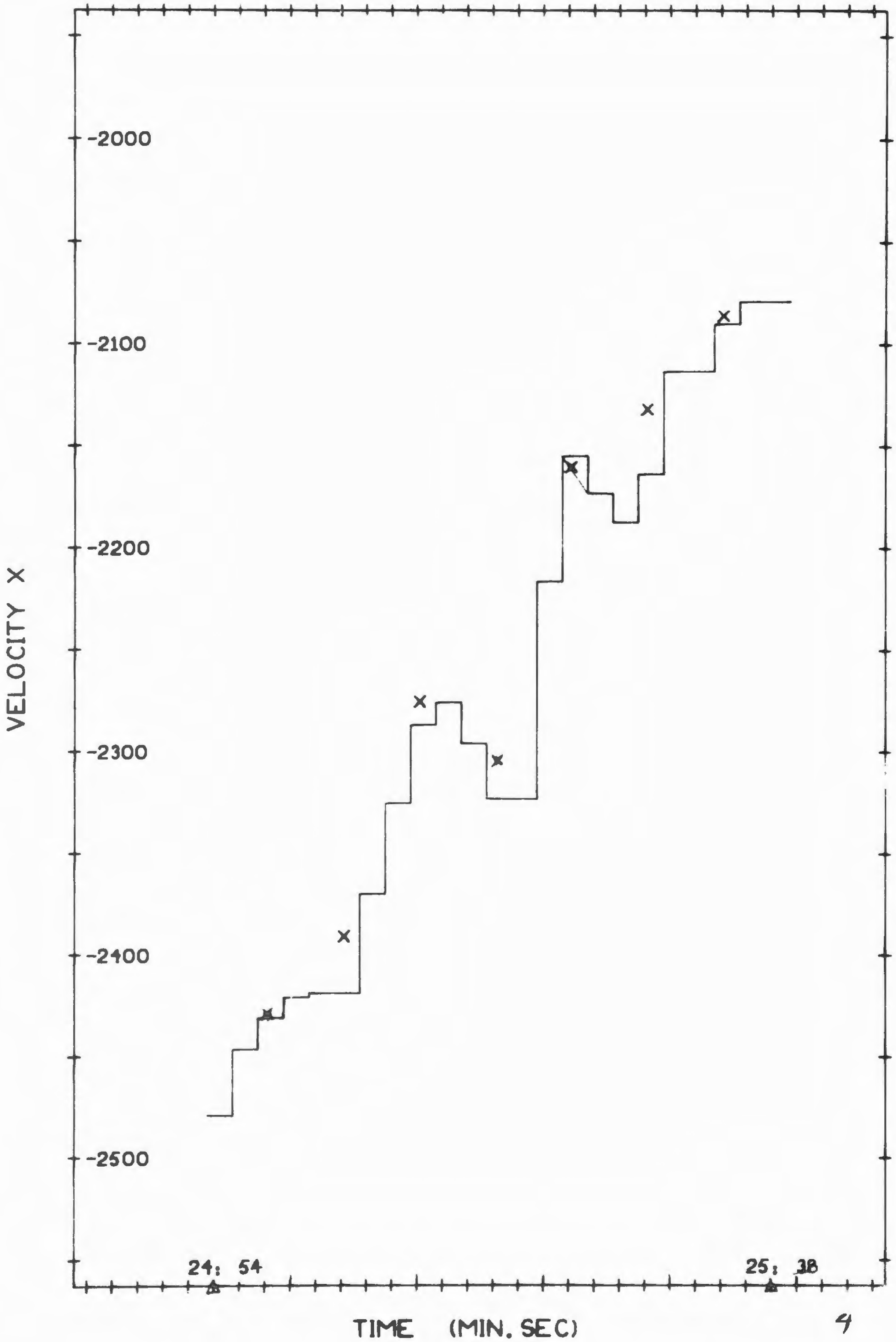
-2500
-2600
-2700
-2800
-2900
-3000
VELOCITY X
ASTRONAUT ENABLES
DATA INCORPORATION
ALTITUDE = 39800 FT (ALS), WEIGHT = 0.07
VELOCITY = 3451 FT/S , WEIGHT = 0
24: 06
24: 52
TIME (MIN. SEC)


VELOCITY Y
0
-100
-200
-300
-400
ε = -55 FT./S
OR -1.5%
ASTRONAUT ENABLES
DATA INCORPORATION
24: 06
24: 52
TIME (MIN. SEC)

FRAME ØØ2

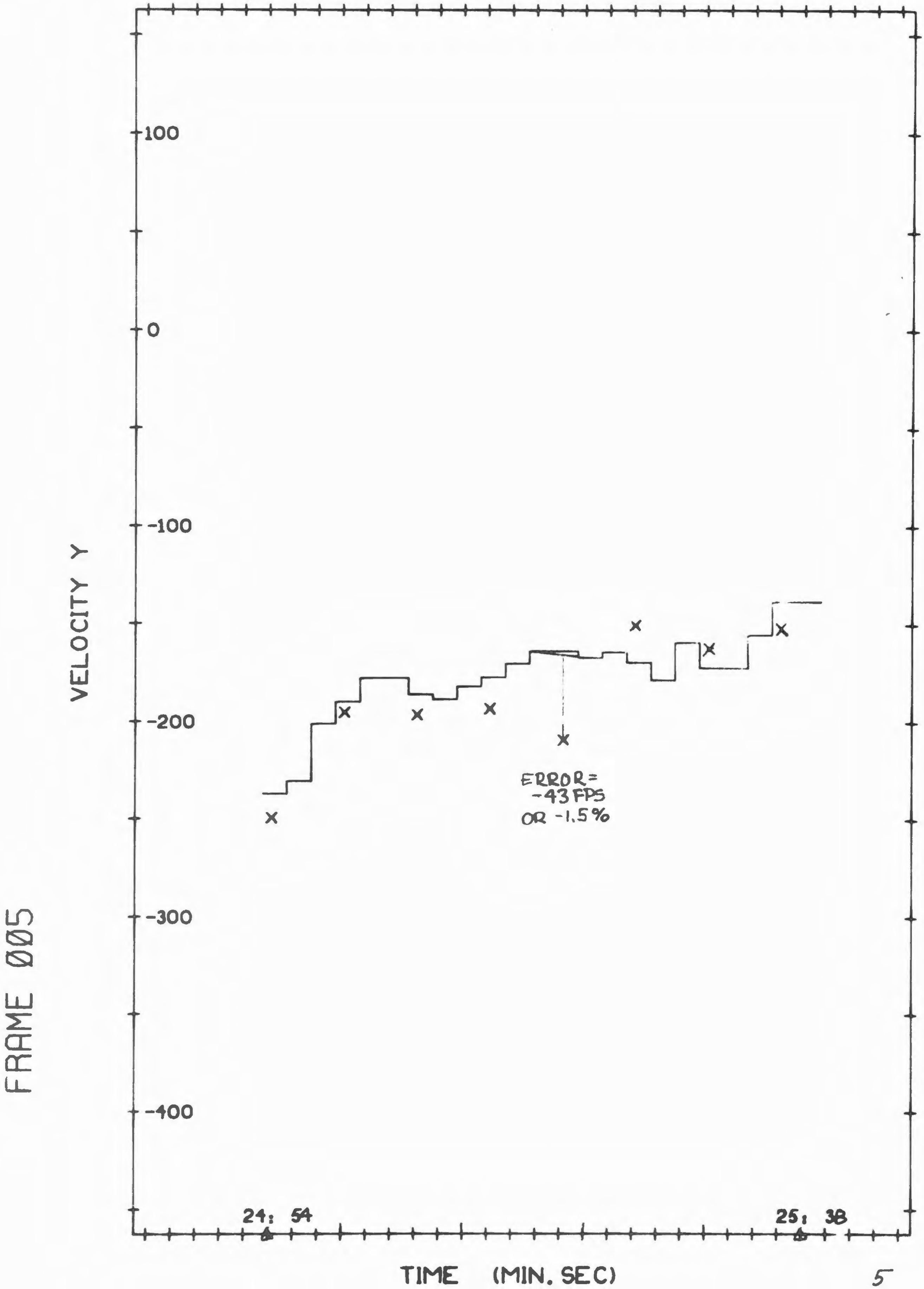

2300
2200
2100
2000
1900
1800
VELOCITY Z
ASTRONAUT ENABLES DATA INCORPORATION
24: 06
24: 52
TIME (MIN. SEC)

FRAME ØØ3

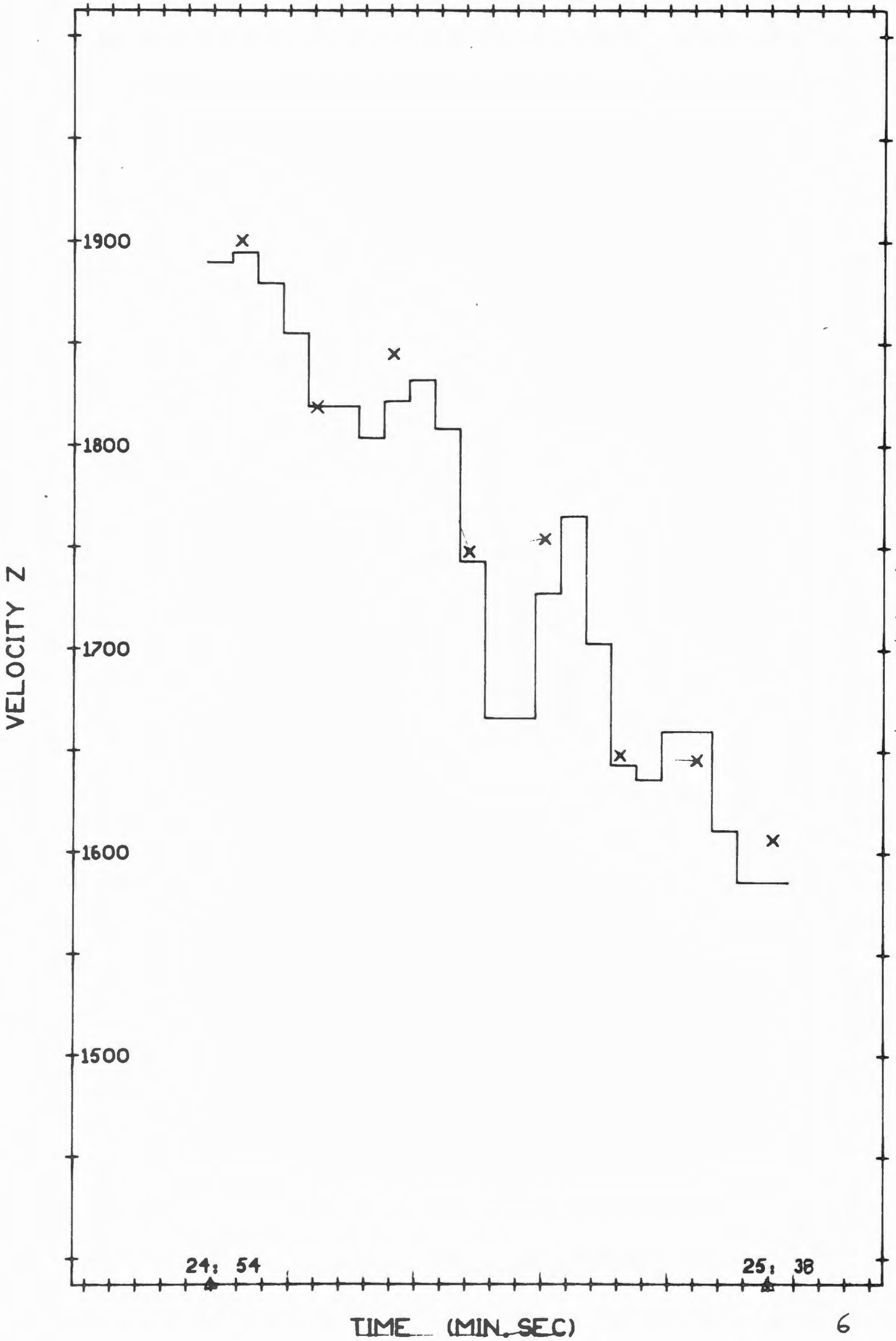


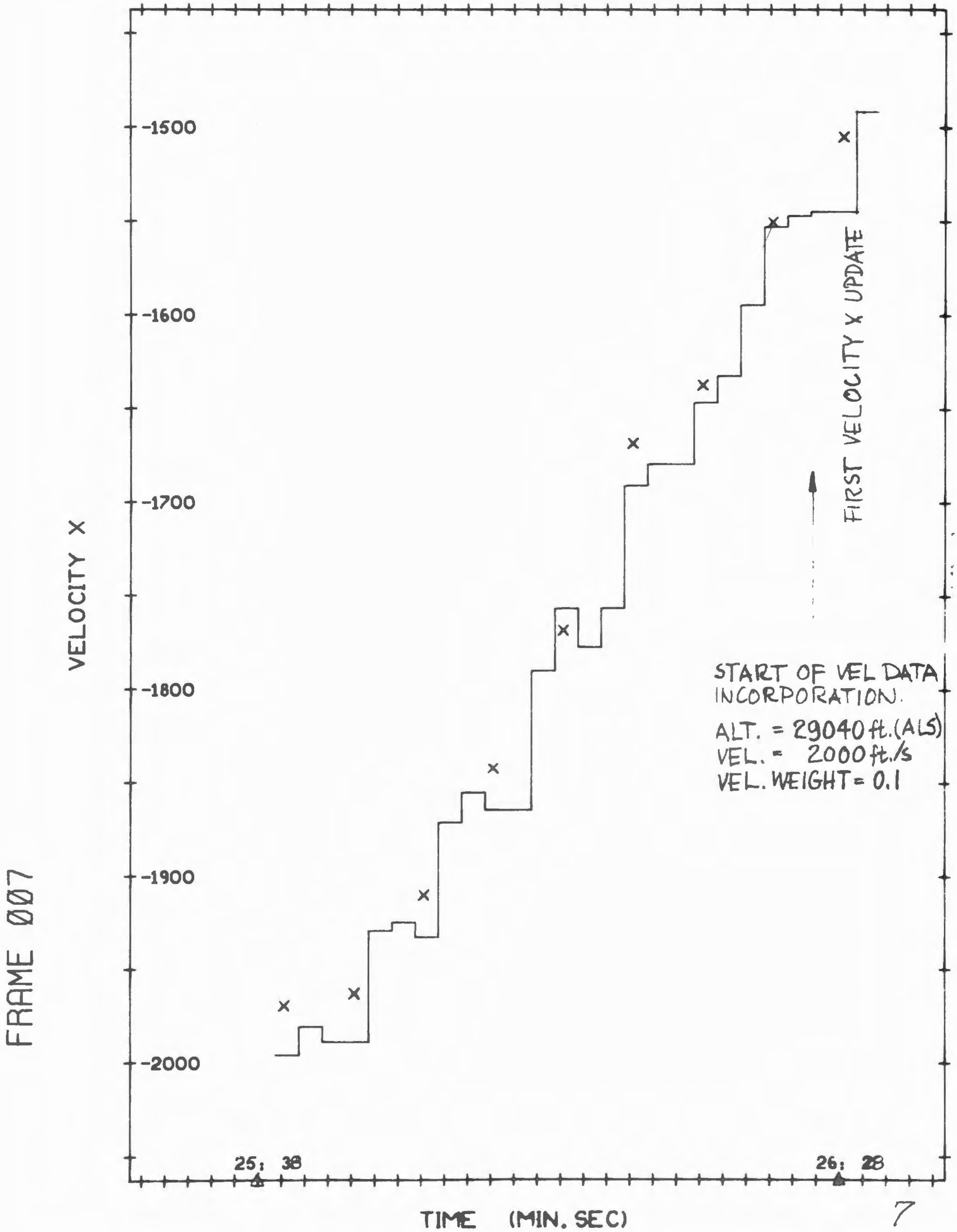
VELOCITY X
-2000
-2100
-2200
-2300
-2400
-2500
24: 54
25: 38
TIME (MIN. SEC)

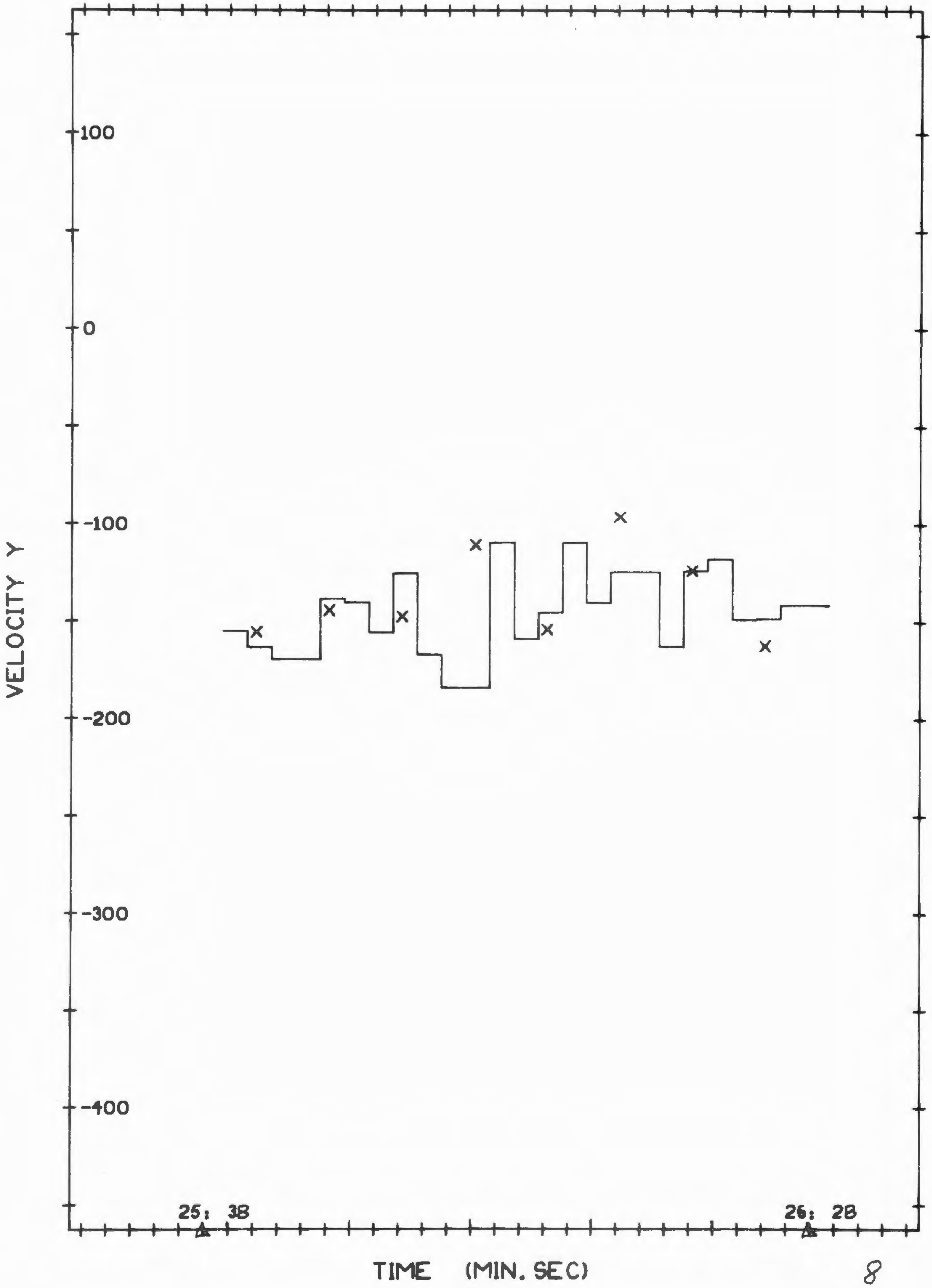
FRAME ØØ4


FRAME ØØ5
VELOCITY Y
100
0
-100
-200
-300
-400
ERROR=
-43 FPS
OR -1.5%
24: 54
25: 38
TIME (MIN. SEC)

FRAME ØØ6

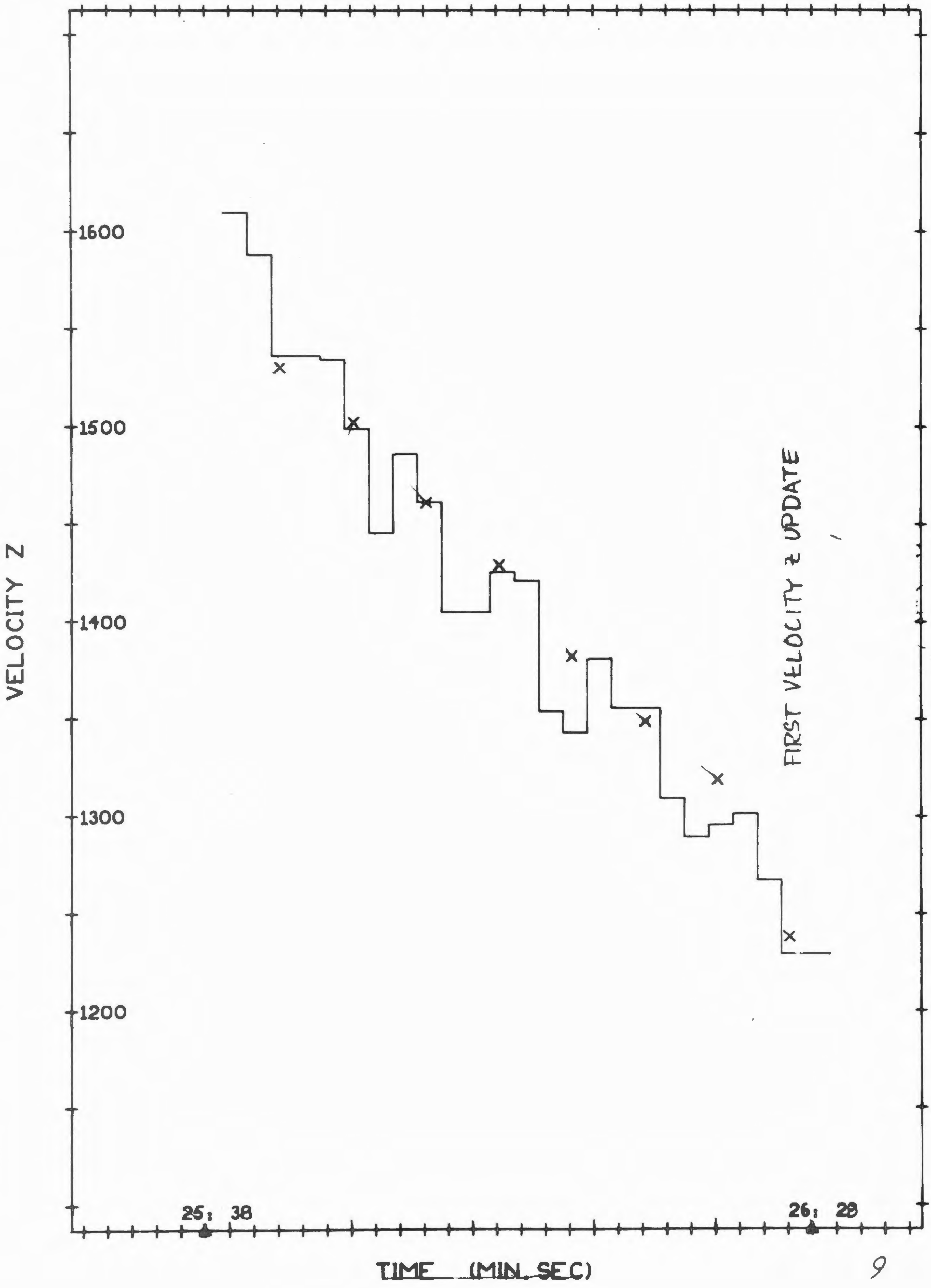



FRAME 007
VELOCITY X
-1500
-1600
-1700
-1800
-1900
-2000
FIRST VELOCITY X UPDATE
START OF VEL DATA INCORPORATION.
ALT. = 29040 ft. (ALS)
VEL. = 2000 ft./s
VEL. WEIGHT = 0.1
25: 38
26: 28
TIME (MIN. SEC)

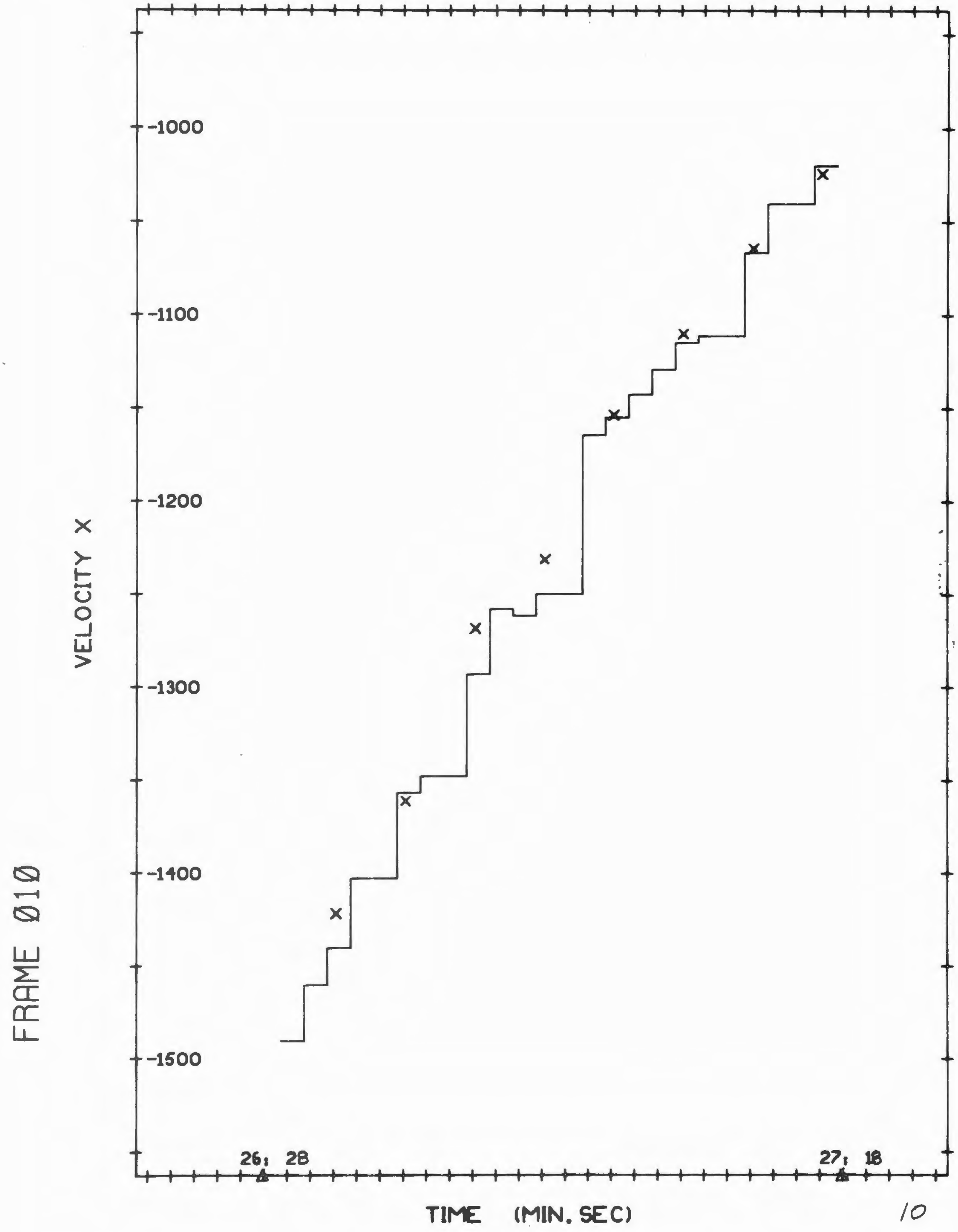


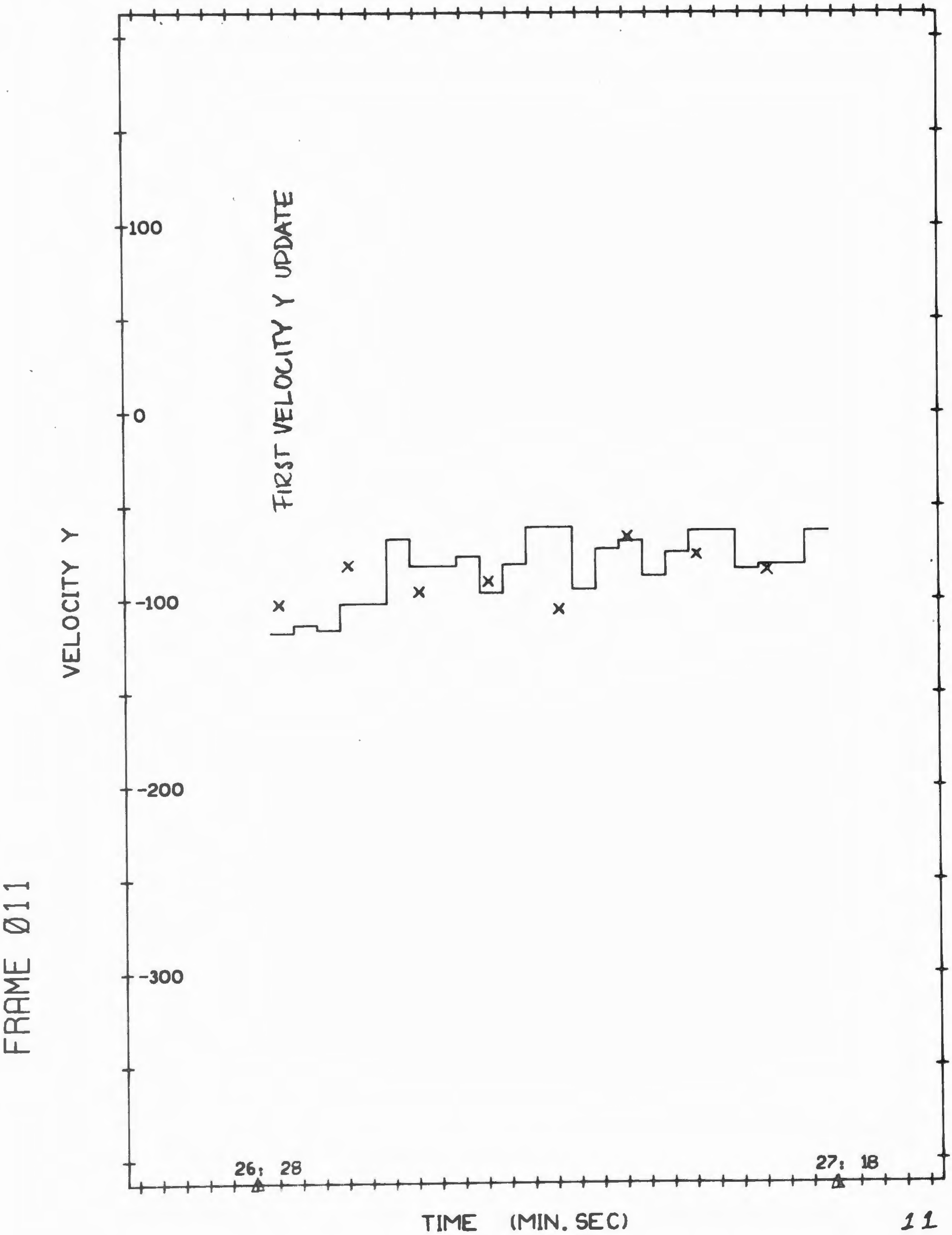
FRAME ØØ8

FRAME ØØ9

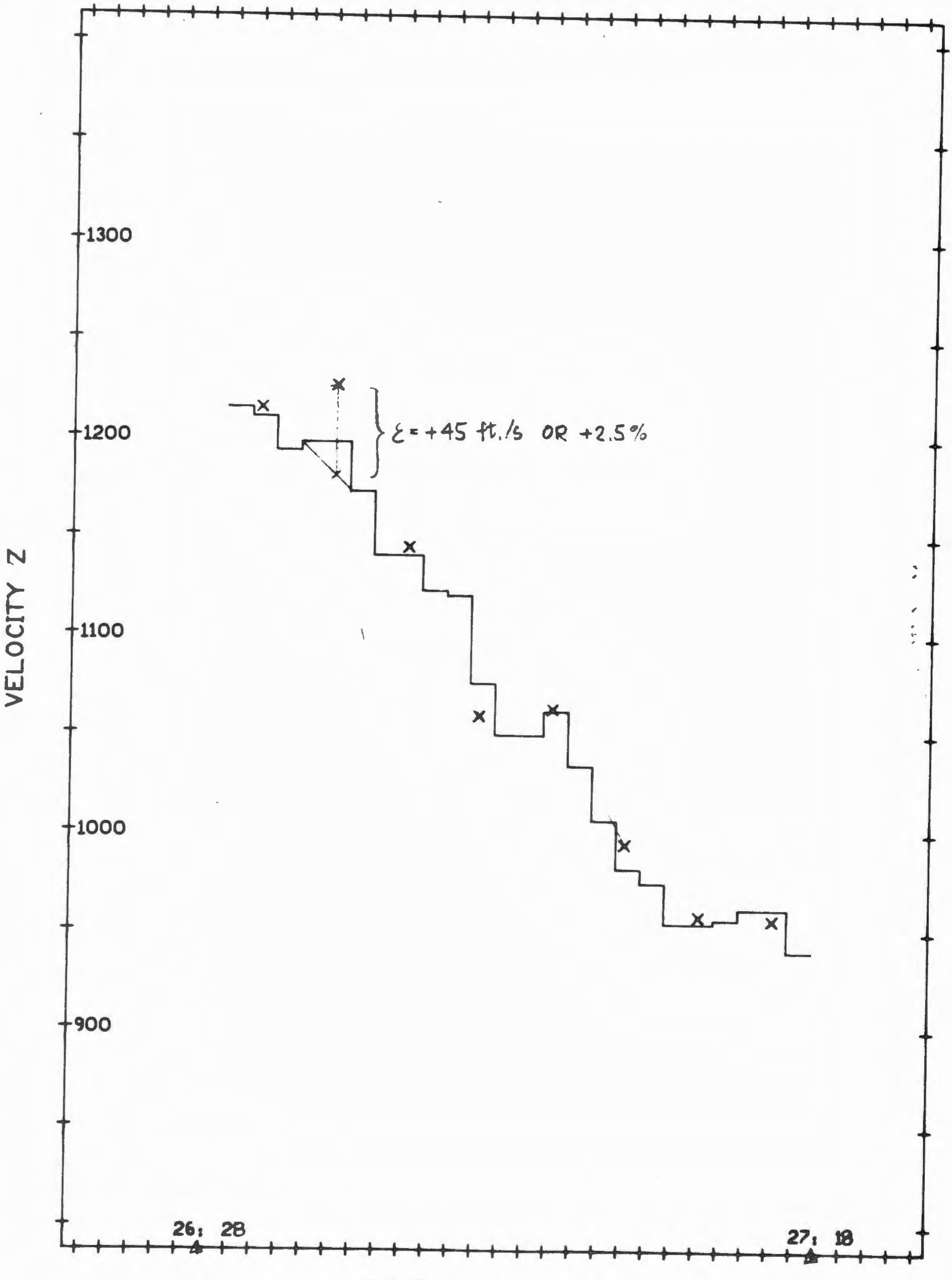


VELOCITY Z
1600
1500
1400
1300
1200
FIRST VELOCITY Z UPDATE
25: 38
26: 28
TIME (MIN.SEC)


FRAME Ø10
VELOCITY X
-1000
-1100
-1200
-1300
-1400
-1500
26: 28
27: 18
TIME (MIN. SEC)

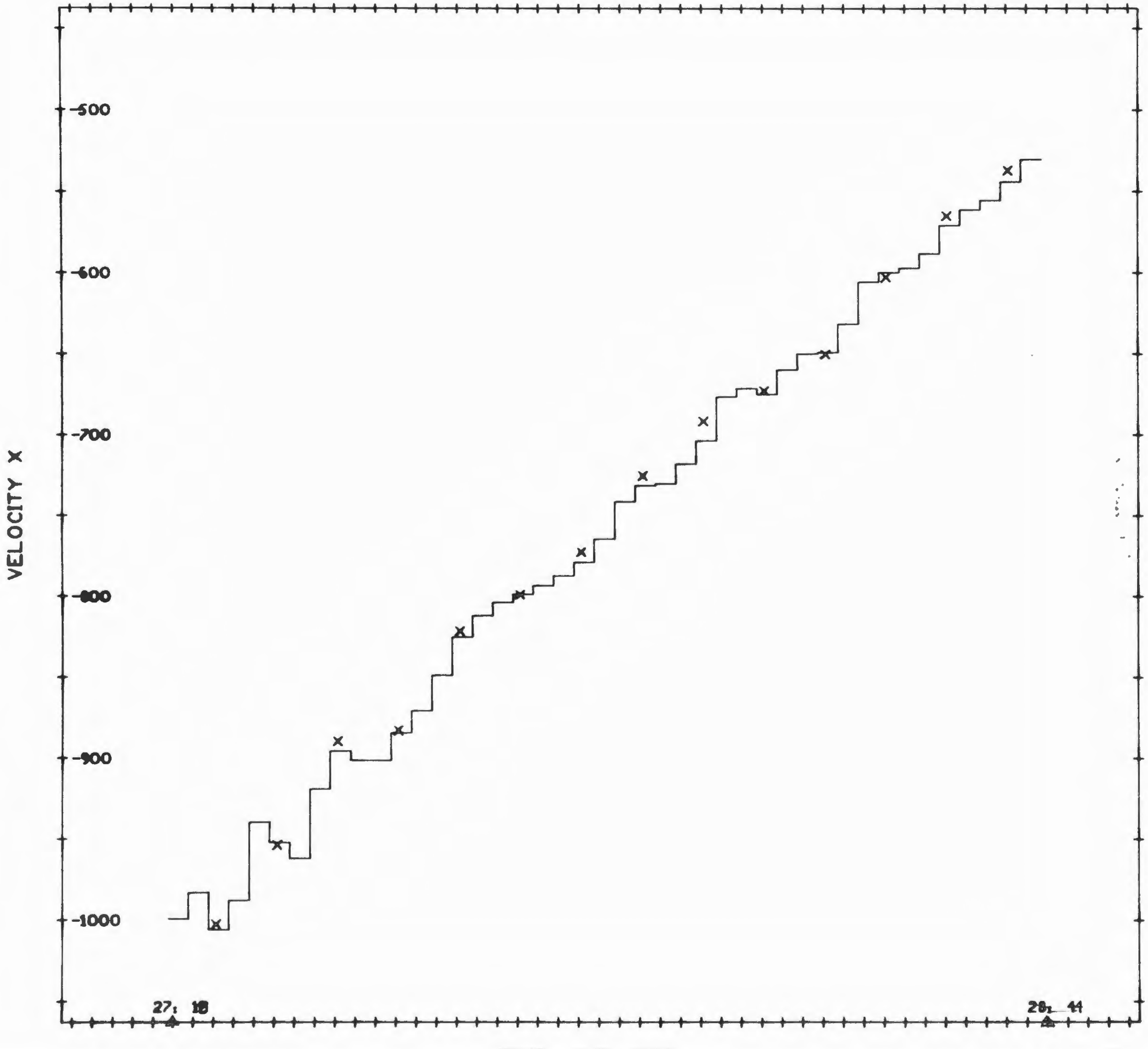

FRAME Ø11
VELOCITY Y
FIRST VELOCITY Y UPDATE
100
0
-100
-200
-300
26: 28
27: 18
TIME (MIN. SEC)

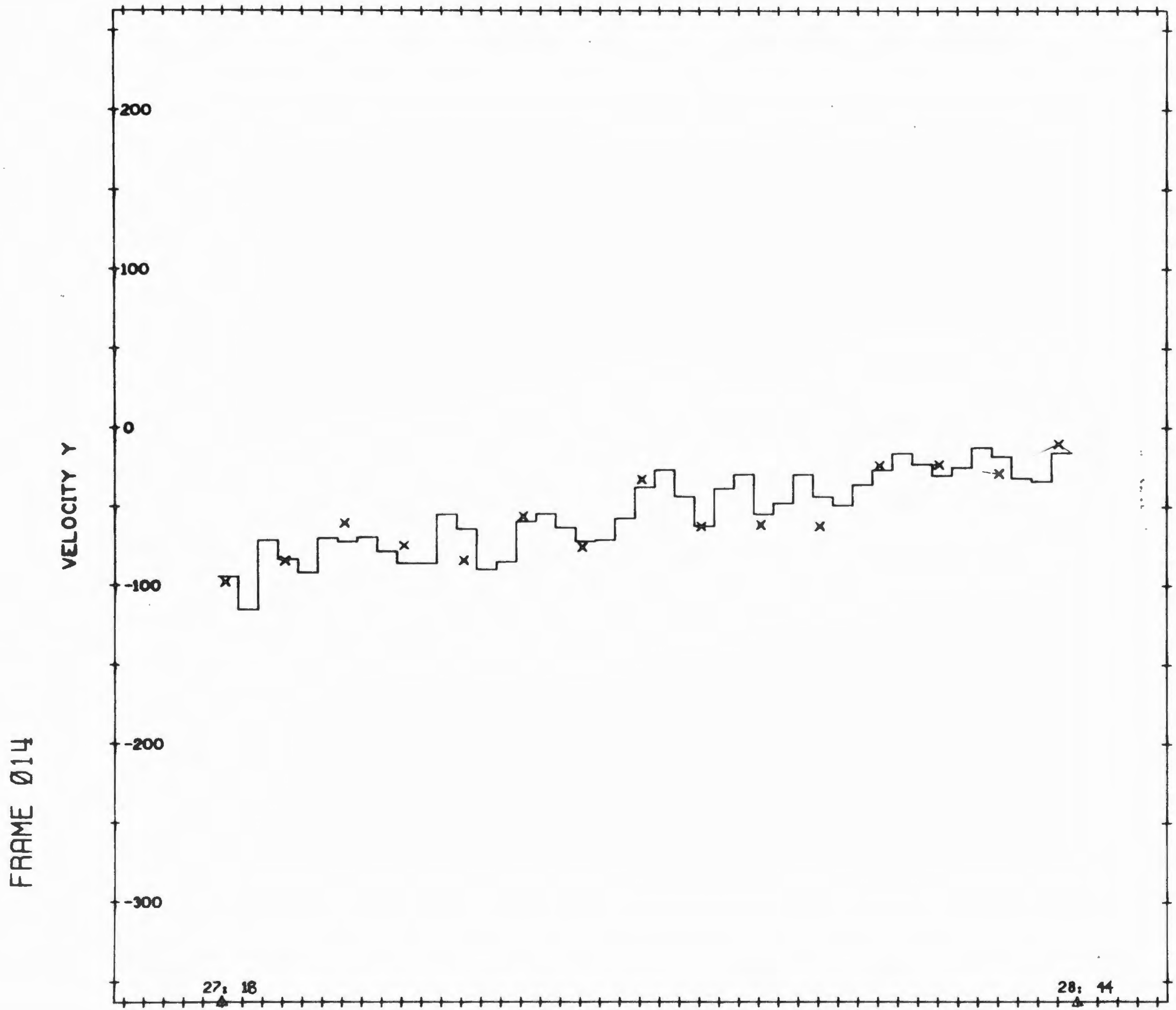
FRAME Ø12

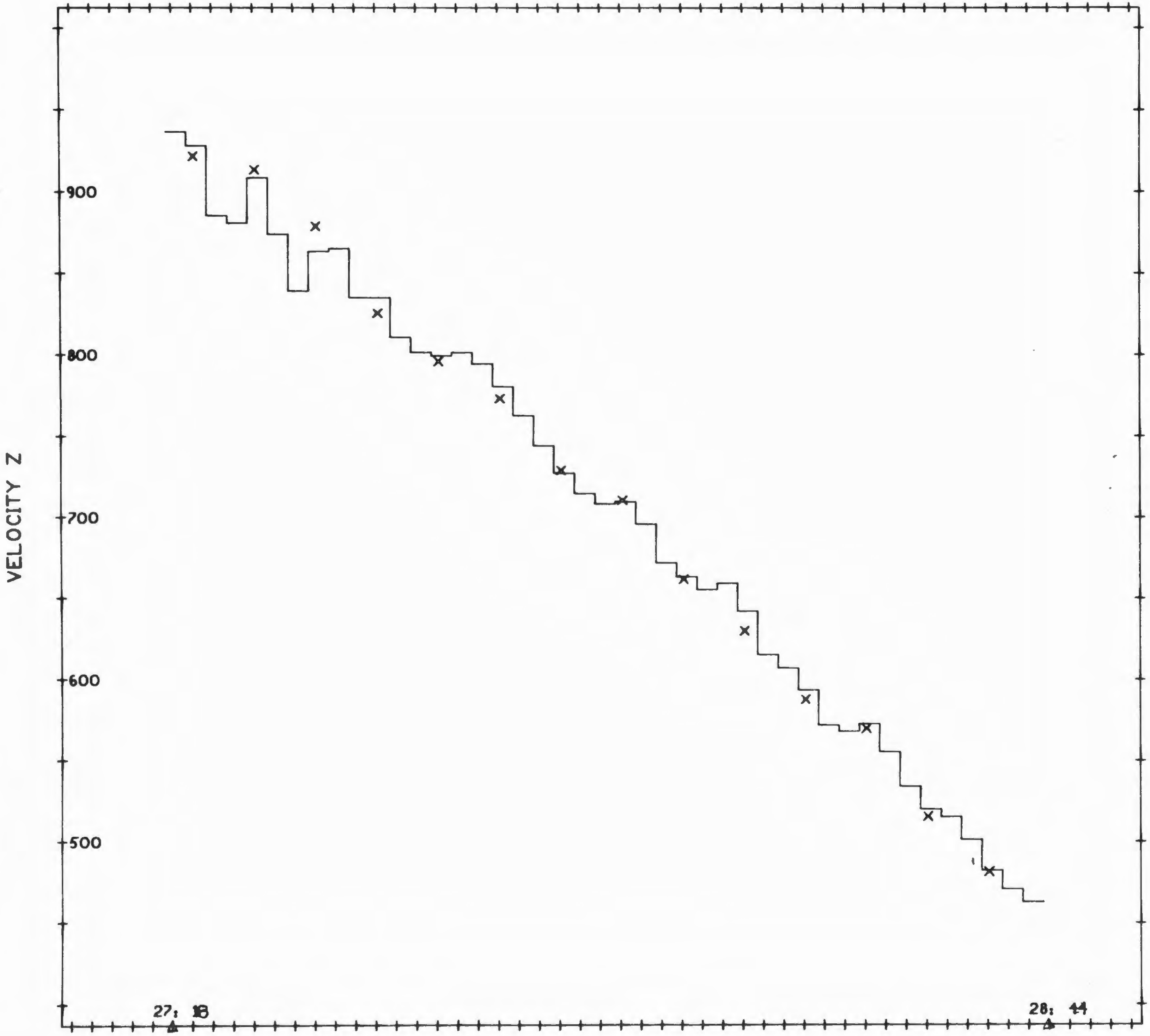


VELOCITY Z
1300
1200
1100
1000
900
ε = +45 ft./s OR +2.5%
26: 28
27: 18
TIME (MIN. SEC)

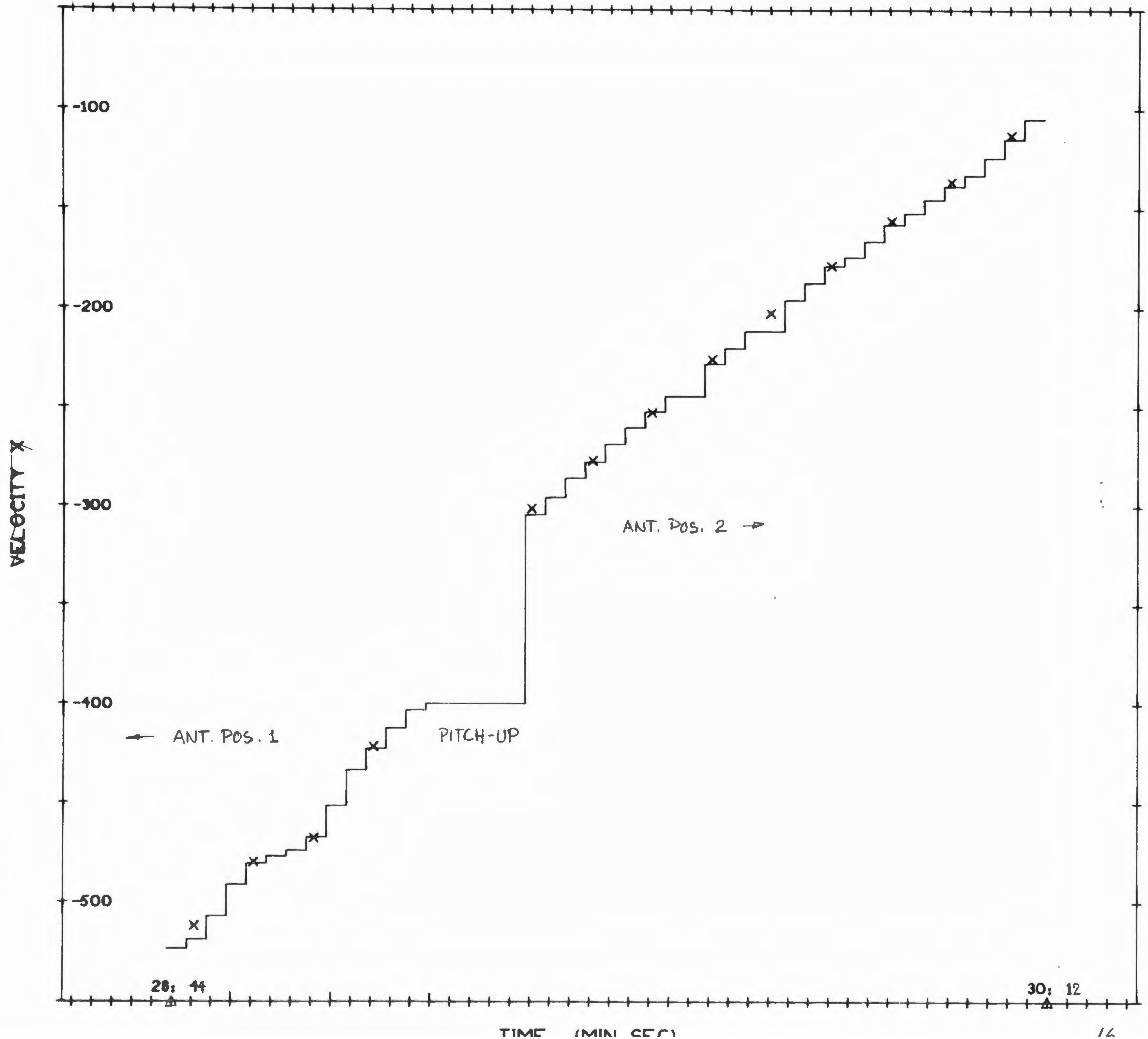
FRAME Ø13




200
100
0
VELOCITY Y
-100
-200
-300
27: 18
28: 44
FRAME Ø14

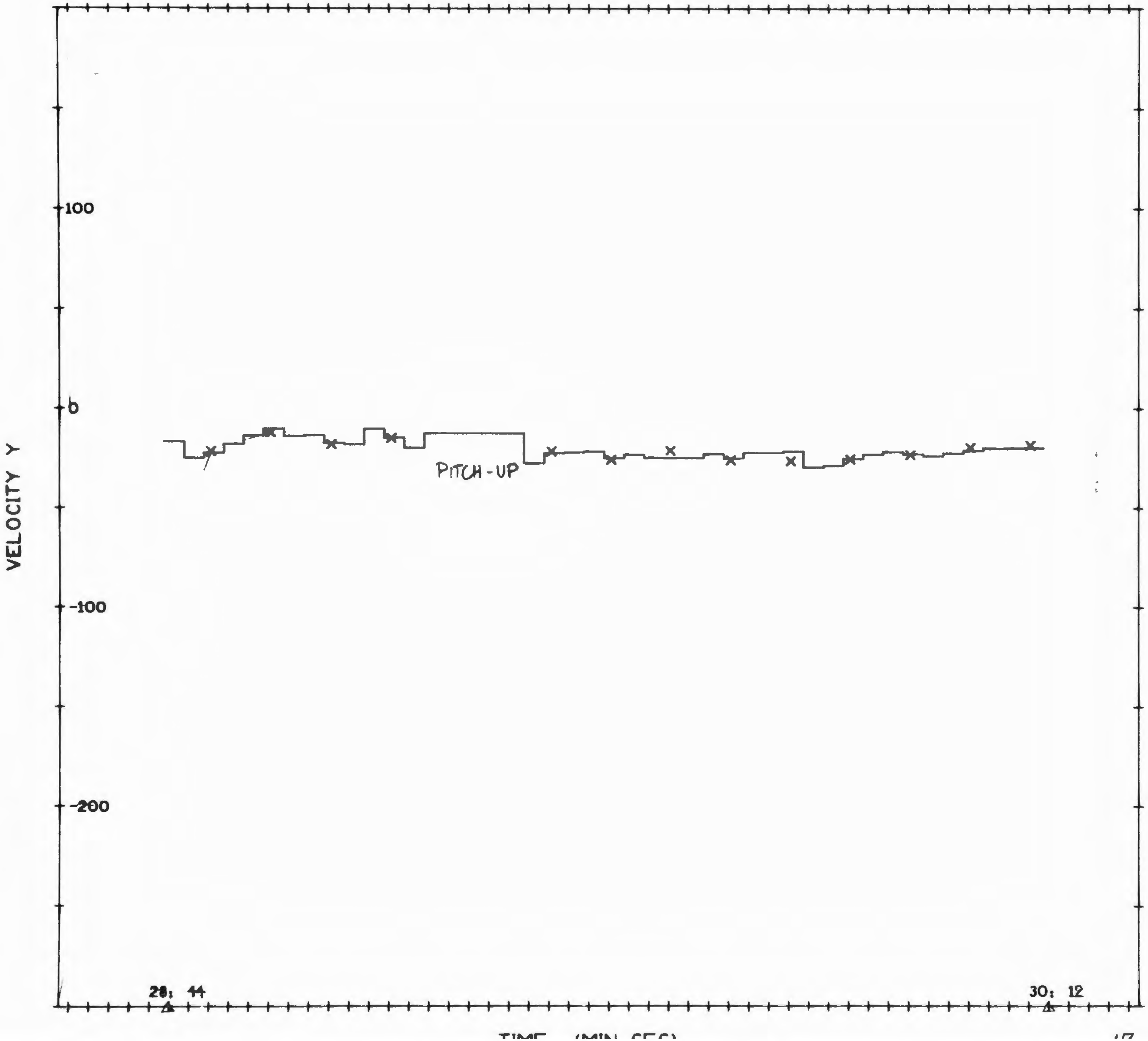


FRAME Ø15

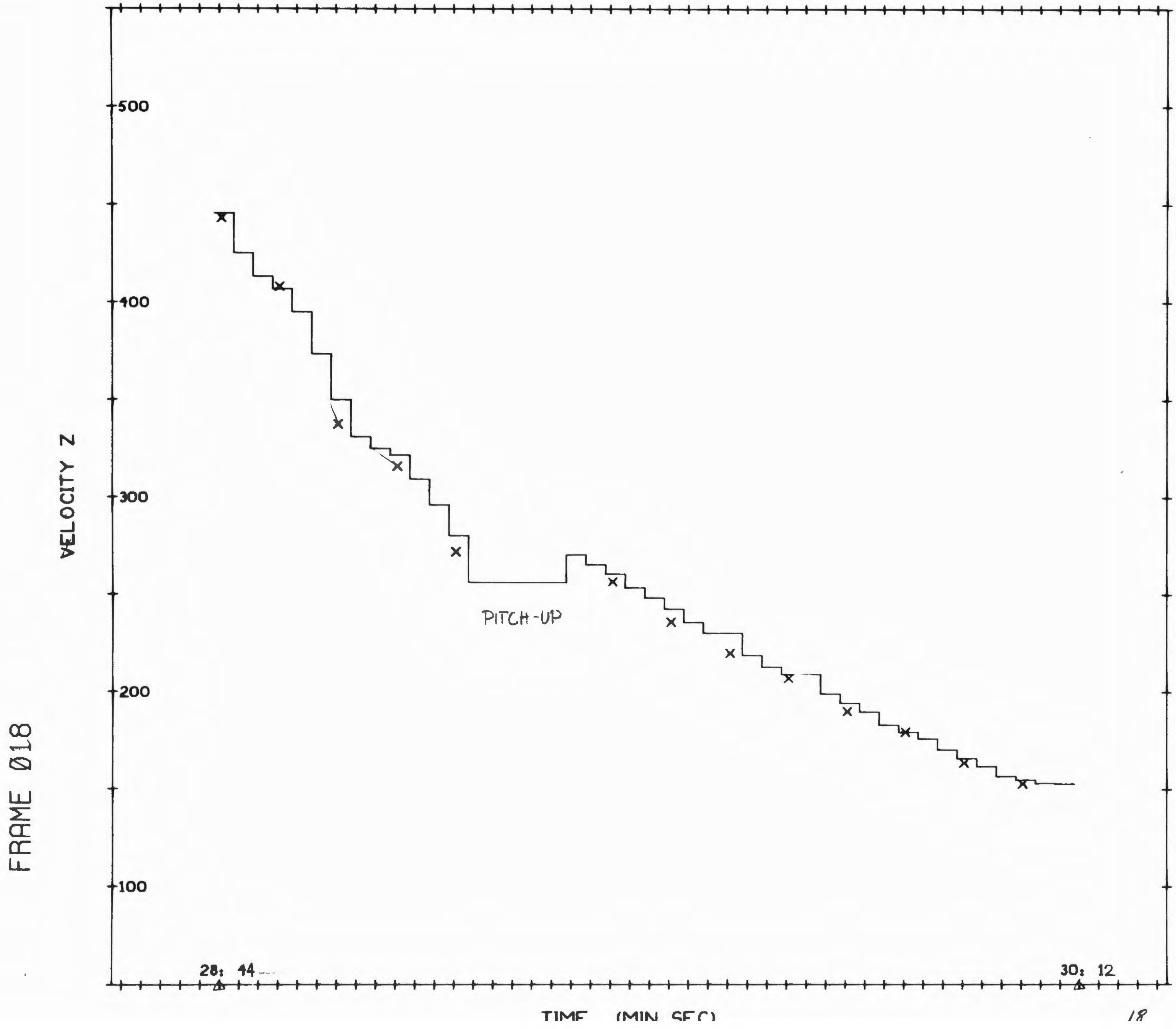


-100
-200
-300
-400
-500
VELOCITY X
ANT. POS. 2
ANT. POS. 1
PITCH-UP
28: 44
30: 12
TIME (MIN SEC)

FRAME Ø16

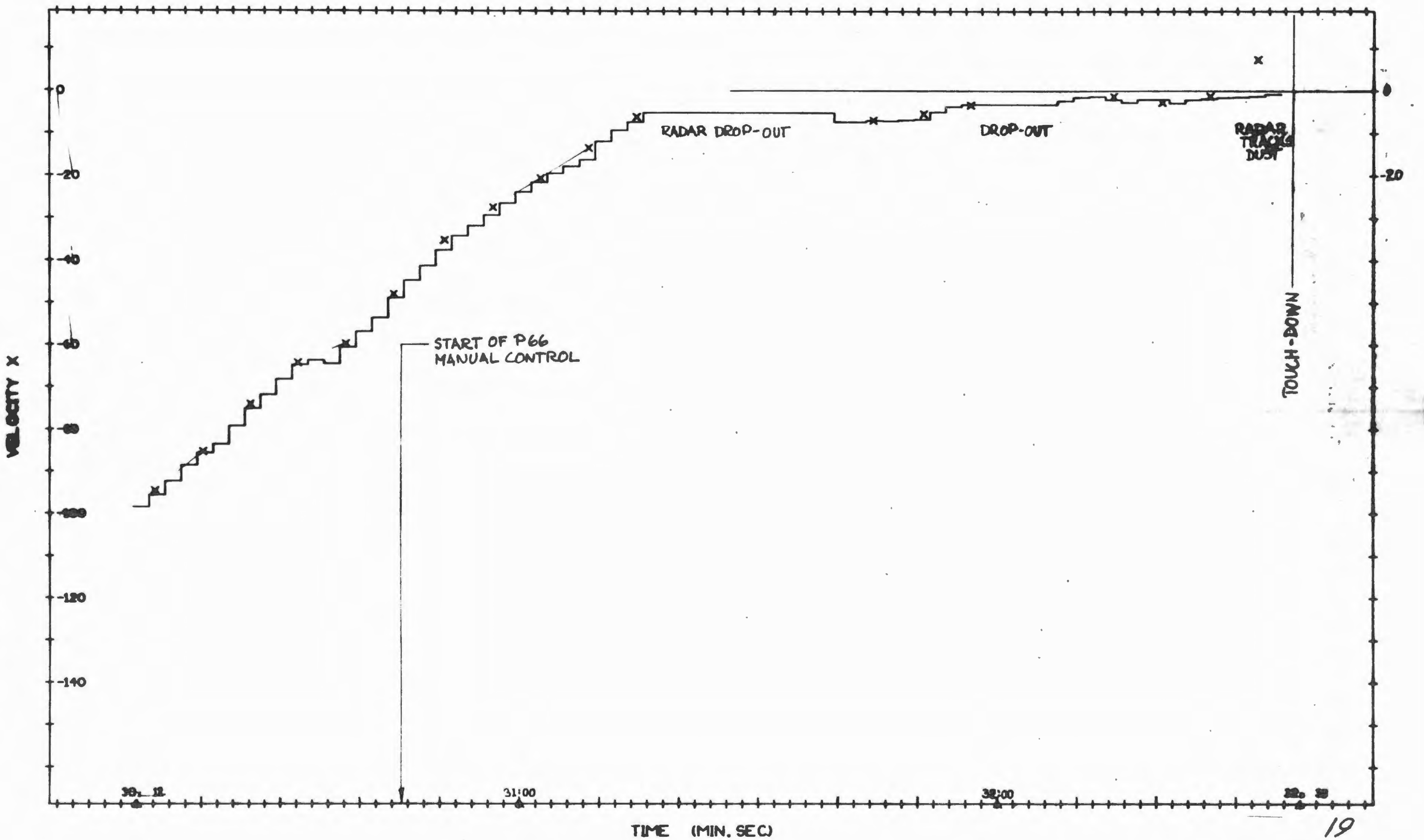


FRAME Ø17

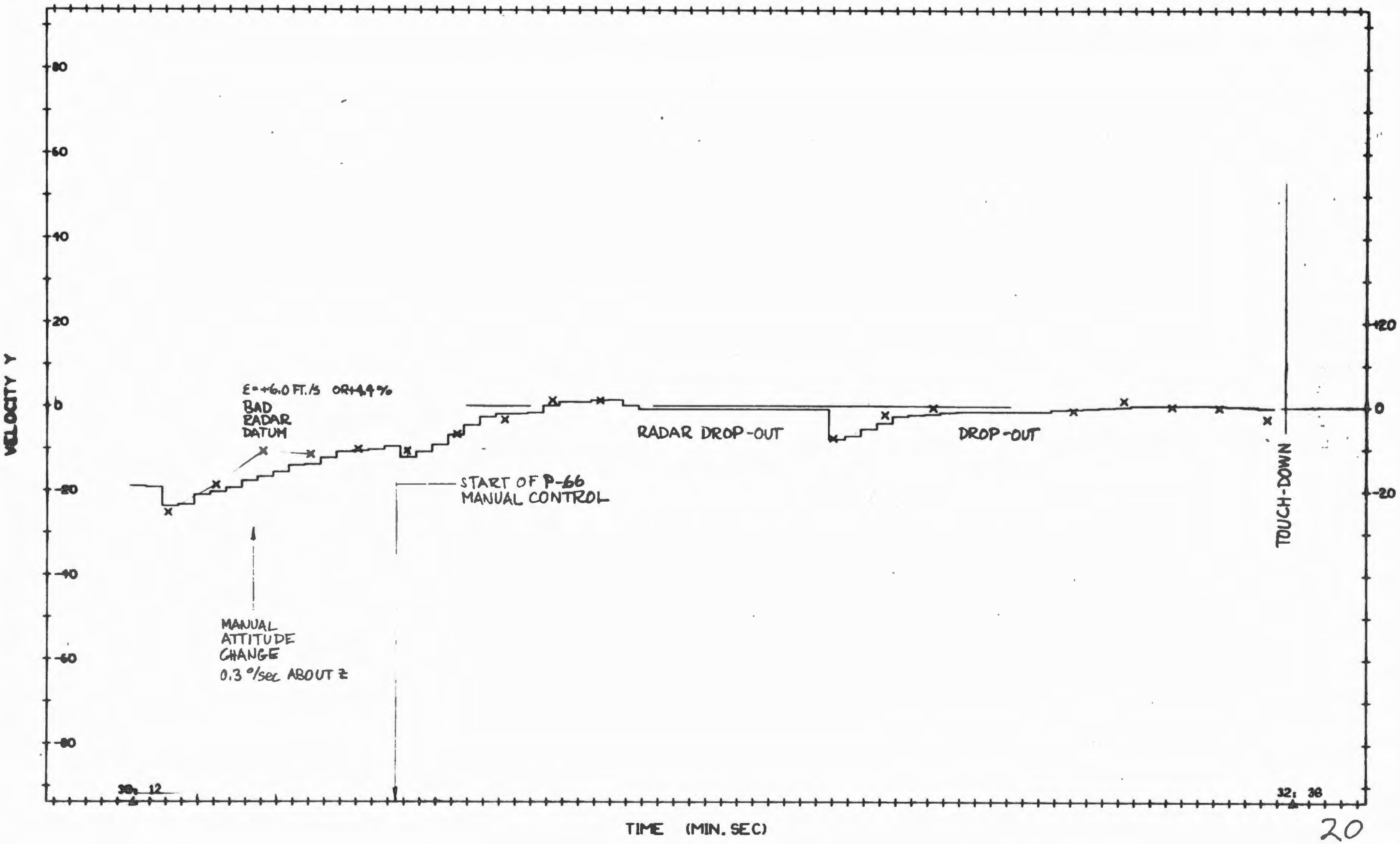


FRAME Ø18
VELOCITY Z
500
400
300
200
100
PITCH-UP
28: 44
30: 12
TIME (MIN SEC)

FRAME Ø19

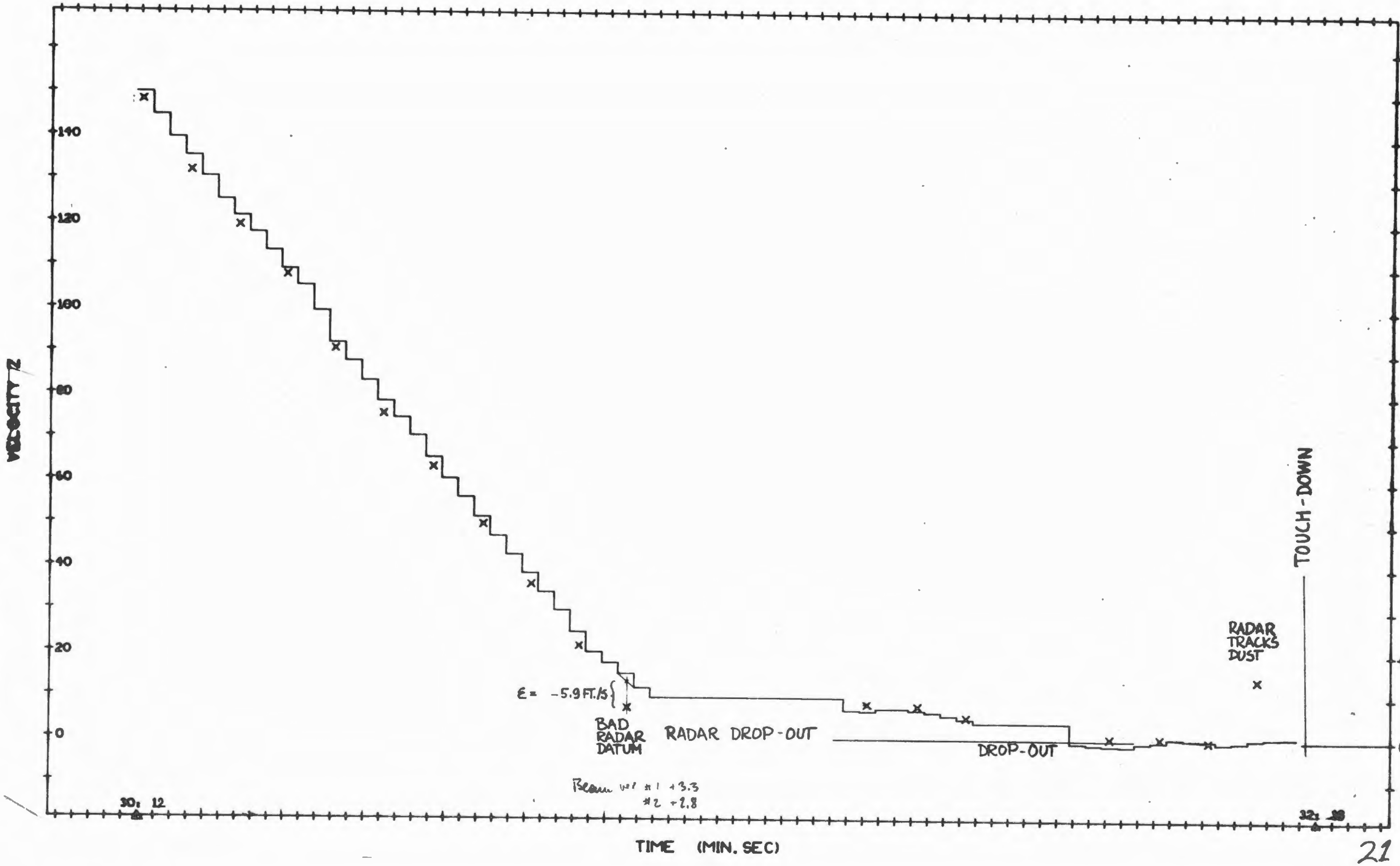


0
-20
-120
-140
VELOCITY X
RADAR DROP-OUT
DROP-OUT
RADAR TRACKS DUST
TOUCH-DOWN
START OF P66
MANUAL CONTROL
31:00
32:00
TIME (MIN. SEC)

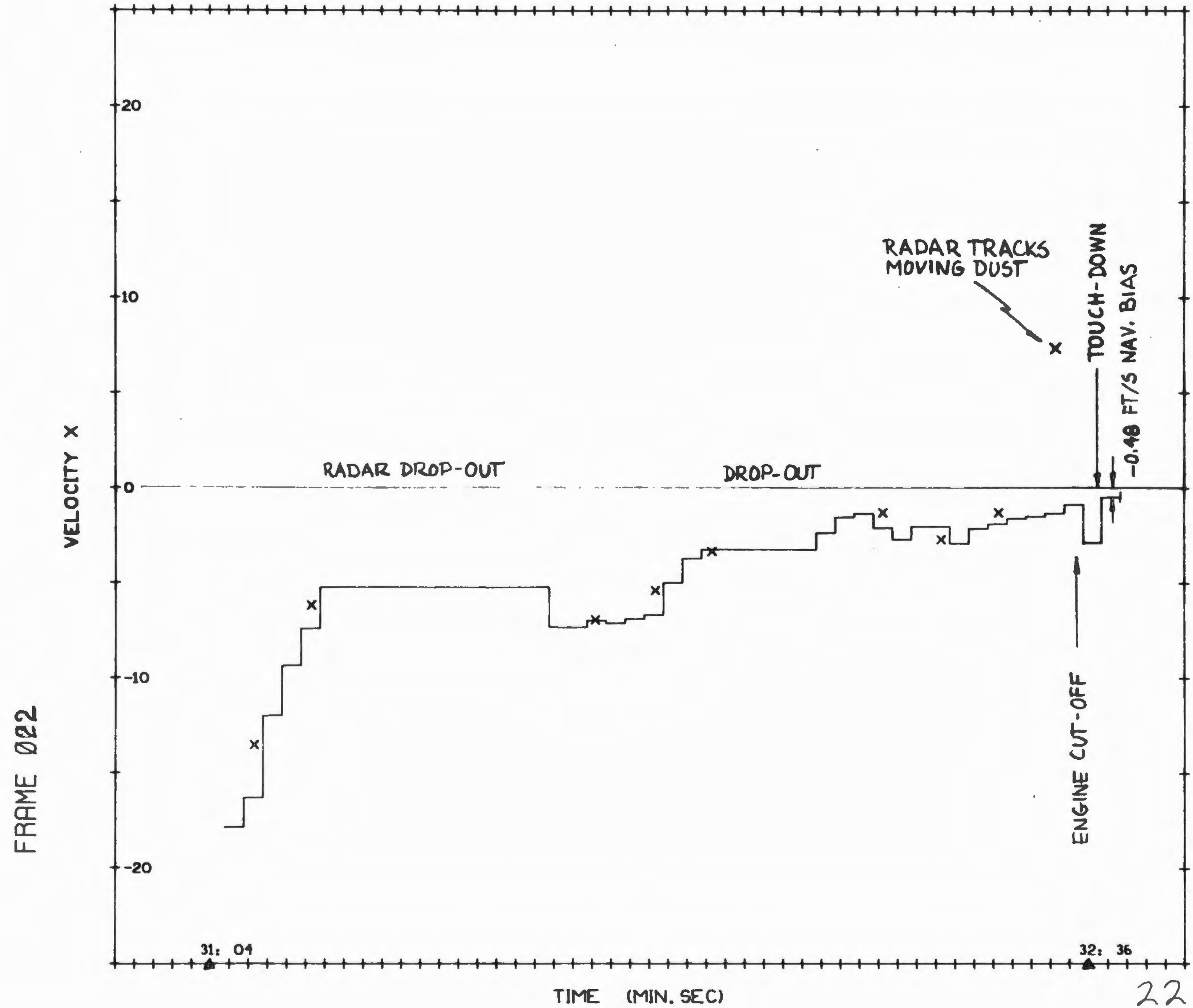

VELOCITY Y
80
60
40
20
0
-20
-40
-60
-80
20
0
-20
E=+6.0 FT./S
BAD RADAR DATUM
START OF P-66 MANUAL CONTROL
RADAR DROP-OUT
DROP-OUT
TOUCH-DOWN
MANUAL ATTITUDE CHANGE 0.3 °/sec ABOUT Z
32: 38
TIME (MIN. SEC)

FRAME Ø2Ø

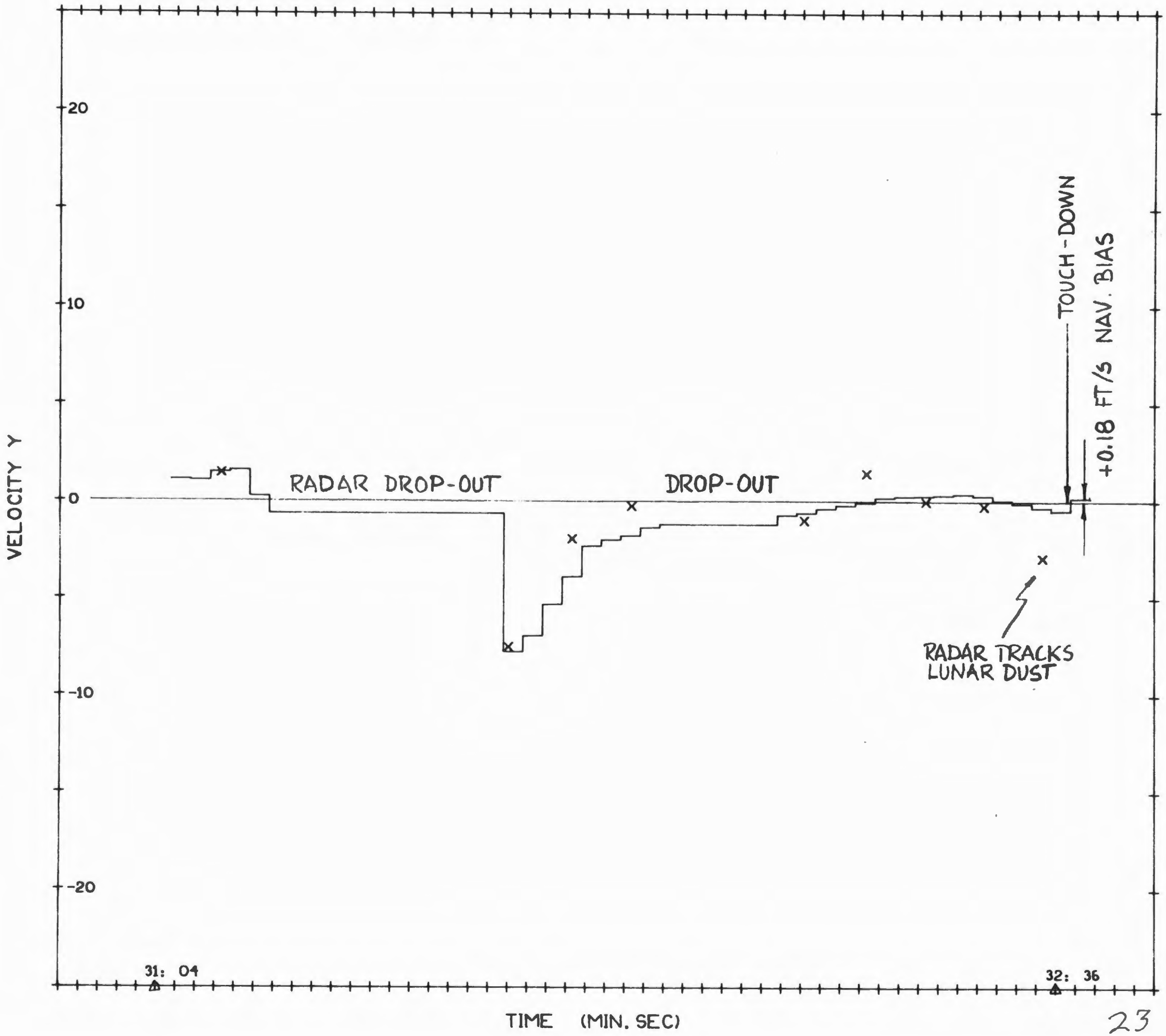
FRAME Ø21



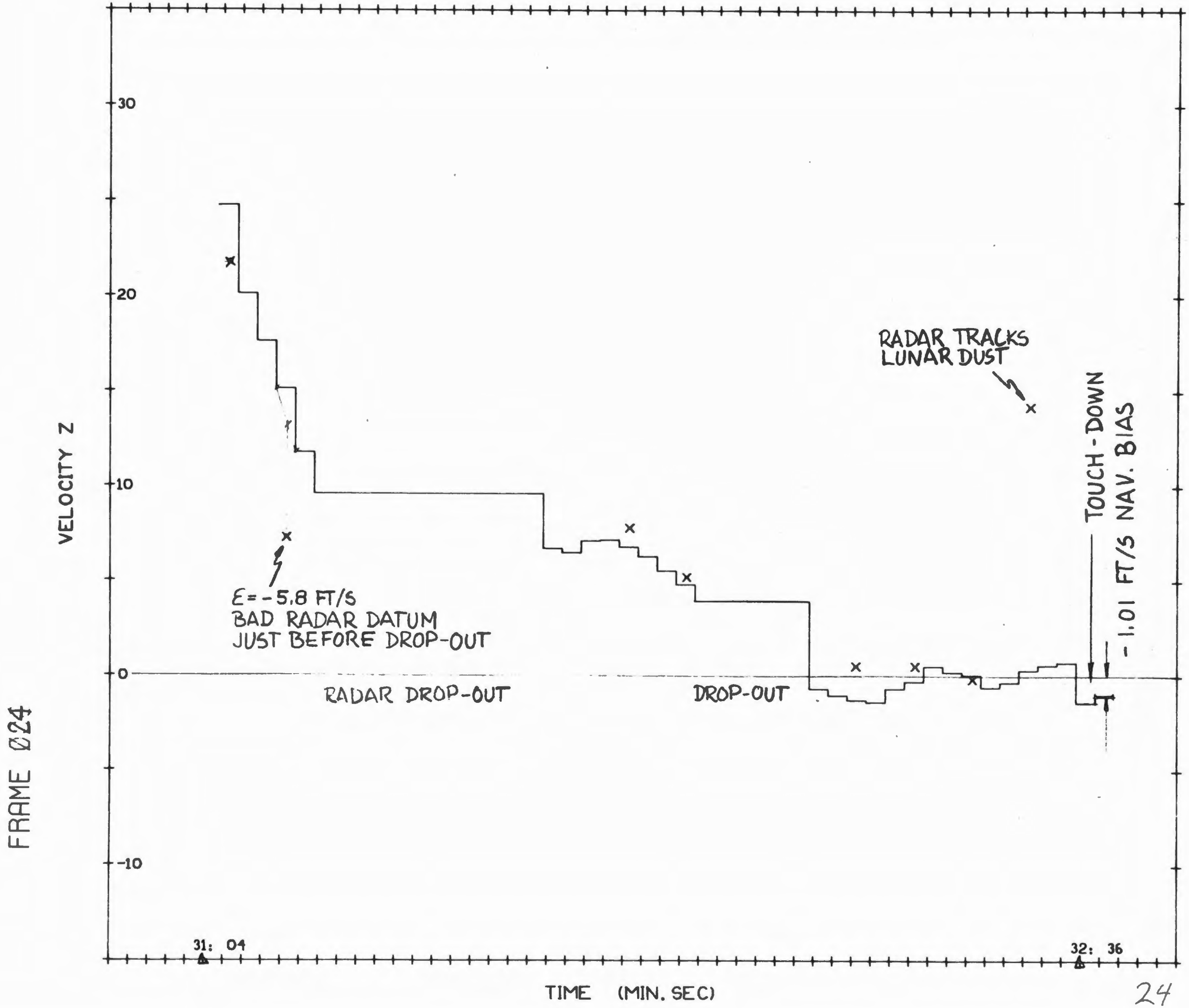
VELOCITY Z
140
120
100
80
60
40
20
0
+20
0
TOUCH-DOWN
RADAR
TRACKS
DUST
E = -5.9 FT./S
BAD
RADAR
DATUM
RADAR DROP-OUT
DROP-OUT
Beam
#1 +3.3
#2 +2.8
30: 12
32:
TIME (MIN. SEC)



VELOCITY X
20
10
0
-10
-20
RADAR DROP-OUT
DROP-OUT
RADAR TRACKS
MOVING DUST
TOUCH-DOWN
-0.48 FT/S NAV. BIAS
ENGINE CUT-OFF
31: 04
32: 36
TIME (MIN. SEC)
FRAME ØØ2


20
10
0
-10
-20
VELOCITY Y
RADAR DROP-OUT
DROP-OUT
TOUCH-DOWN
+0.18 FT/S NAV. BIAS
RADAR TRACKS
LUNAR DUST
31: 04
32: 36
TIME (MIN. SEC)

FRAME Ø23



FRAME Ø24
VELOCITY Z
30
20
10
0
-10
RADAR TRACKS LUNAR DUST
TOUCH - DOWN
- 1.01 FT/S NAV. BIAS
ε= - 5.8 FT/S
BAD RADAR DATUM
JUST BEFORE DROP-OUT
RADAR DROP-OUT
DROP-OUT
31: 04
32: 36
TIME (MIN. SEC)

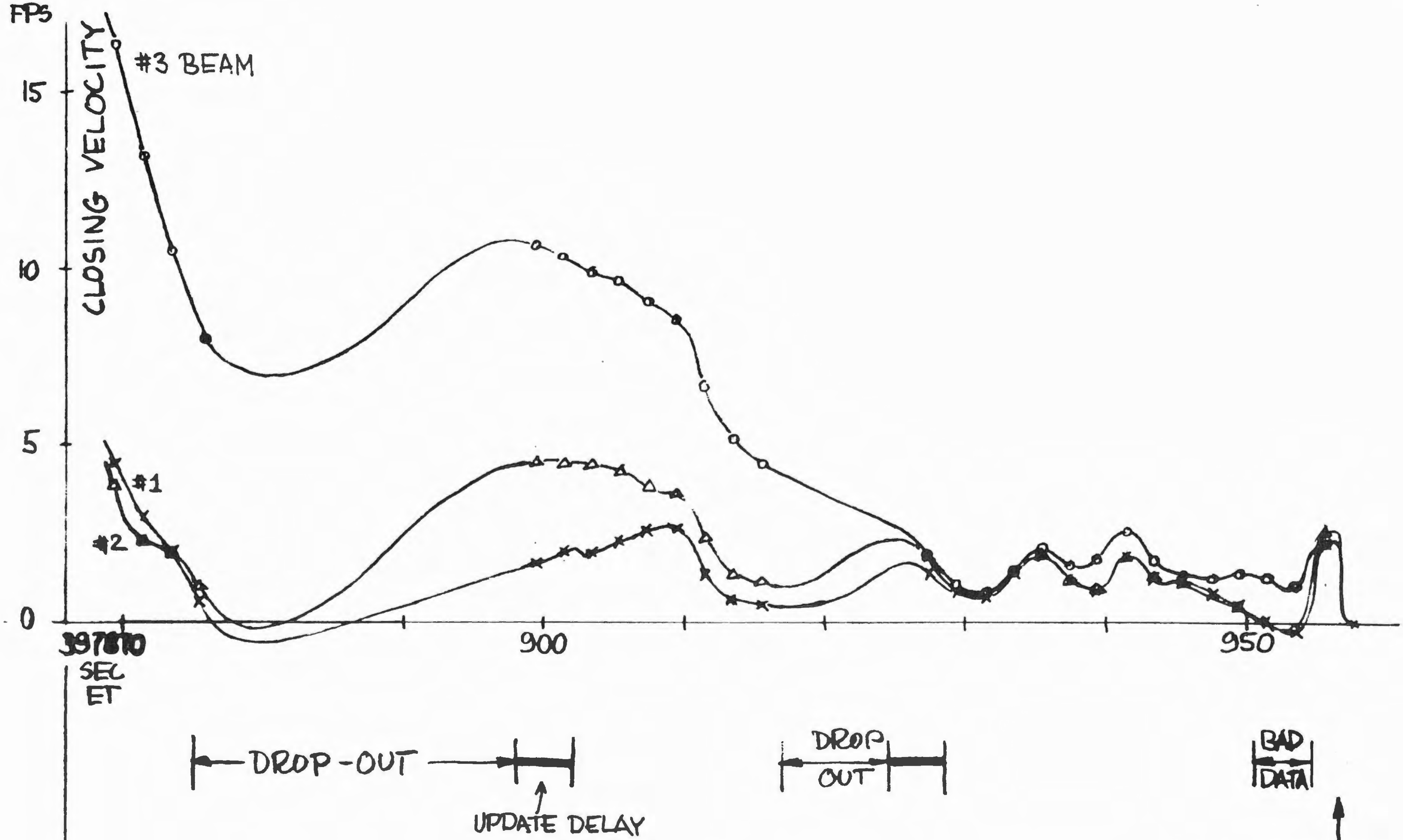


FIGURE 25

APOLLO 12 - LANDING
LR BEAM VELOCITIES
2-6-70 Tanner.

STATE VECTOR IN INERTIAL COORDINATES

INPUT

			X	Y	Z
GRND ELAPSED TIME	MSEC	3.9773784900 E 8			
LR VEL TIME	SEC	3.9773617968 E 5			
~~LR VELOCITY~~	~~FT/SEC~~				~~3.3753191757 E 2~~
LM STATE TIME	SEC	3.9773750781 E 5			
~~RANGE~~	~~FT~~		~~-5.0296915625 E 6~~	~~2.5863779375 E 6~~	~~7.4655510937 E 5~~
VELOCITY	FT/SEC	5.5876142120 E 2	3.8841952896 E 2	3.0893415451 E 2	2.5671829605 E 2
LR RANGE TIME	SEC	3.9773750781 E 5			
CDU	RAD		0.0000000000 E 0	1.0768545130 E 0	4.4485442848 E- 2

STATE VECTOR IN ANTENNA COORDINATES

OUTPUT

INCORP FLAG = 1					
~~LM STATE TIME~~	~~SEC~~	~~3.9773750781 E 5~~			
VELOCITY	FT/SEC	5.7284433368 E 2	-4.6749416878 E 2	-1.3583548144 E 1	3.3077986638 E 2
DELTA VEL	FT/SEC		6.7349980306 E 0	5.5154236578 E- 1	-1.8944182452 E 1
LR VEL TIME	SEC	3.9773617963 E 5			
LR VELOCITY	FT/SEC				3.3753191757 E 2
			#1	#2	#3
BEAM	FT/SEC	~~6.9888979286 E 2~~	3.1017288636 E 2	3.1674061339 E 2	5.4029157049 E 2

FIGURE 26. COMPUTER PRINTOUT