ANALYSIS OF DAISY TRACK HUMAN TOLERANCE TESTS

Final Report Draft

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February 10, 1971

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16. Abstract

This report contains the results of an analysis of film and transducer records from a series of impact tests on human volunteers conducted by the 6571st Aeromedical Research Laboratories at Holloman Air Force Base, New Mexico. The purpose of the test program was to compare lap belt versus lap belt plus air cushion restraint systems. The analyses indicated that the lap belt plus a rapidly inflated air cushion performed significantly better than the lap belt alone by reducing head motion, linear head acceleration, shoulder motion and resultant neck and head injury.

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INTRODUCTION

This report contains the results of an analysis of film and transducer records from a series of impact tests on human volunteers conducted by the 6571st Aeromedical Research Laboratory at Holloman Air Force Base, New Mexico. The purpose of the test program was to compare and evaluate lap belt versus lap belt plus air cushion restraints. Particular reference should be given to the final report on the test program entitled "Department of Transportation Daisy Track Human Tolerance Tests," by Charles D. Bendixen, Capt., USAF. The following description of the test method has been abstracted from that report.

TEST METHODS

Six male human volunteers were subjected to increasingly severe impacts in each of the two restraint configurations being compared until in the subject's (subjective tolerance) or the medical monitor's opinion the testing should be terminated. Testing with the other restraint was to be continued until a similar level was reached.

The volunteers were seated on the Daisy Decelerator impact sled using each of the restraint systems being tested. The seat used on the sled during all of these tests was one designed for other ARL human impact tests and contained instrumentation capable of measuring all forces transmitted to it by the subject during impact. The seat pan was horizontal and the seat back was angled backwards 13° from vertical. (See Figure 3). All tests were conducted with a 0-0-0 seat orientation.

The Type I lap belt restraint used consisted of a 1 3/4 inch-wide webbed dacron belt rated at 6000 lbs. The belt angle at its attach point approximated 50° to the horizontal at the initiation of the run.

In order to assure that a subject would not contact the rigid airbag supporting structure and simulated windshield in the event of an airbag failure during impact, this structure was mounted so as to provide a 6-inch clearance from the maximum excursion envelope of the subject's head. This necessitated use of a bag of larger dimensions than would be found in a standard automobile. The airbag was enlarged enough to fill the space between the subject and simulated windshield structure. The change in bag volume also necessitated larger blow-out ports to allow the increased volume of gas to escape following bag deployment.

A second modification of the airbag test series which was initially specified by the ARL medical monitor specified use of a pre-inflated bag. Its purpose was to eliminate any possibility of bag deployment failure and subsequent injury during an airbag test at a level exceeding the injury level for the lap belt alone.

After the first series of runs using the pre-inflated airbag, it was seen that the pre-inflated bag was too soft and did not provide comparable support for the subject as a rapidly inflating bag. This resulted in the development by Eaton, Yale and Towne engineers of a "hybrid airbag" consisting of a pre-inflated bag into which additional gas was discharged during impact. It provided a "stiffer" bag response, more closely duplicating the rapidly inflating bag.

When films of the "hybrid bag" tests were reviewed, an excessive amount of rebound accompanied by hyperextension of the neck was noted and the medical monitor decided to cancel further tests with this system.

At this point it appeared obvious that a pre-inflated bag did not simulate an actual operational bag. Therefore, the 6571st ARL made the decision to use a rapidly inflating bag since previous tests showed less likelihood of injury in the event of bag failure than was originally anticipated.

The first series of human tests was conducted at a peak deceleration of 9 g's. The five runs conducted at this level included two with lap belt only restraints and three with lap belt plus pre-inflated airbag restraints. Although subjective reports from all riders indicated that each system was tolerable, a decision was made not to proceed to higher "g" levels with the pre-inflated bag because it was found to react too softly and poorly simulated a rapidly inflating airbag. To continue would have produced data of questionable value.

The test series was resumed using the "hybrid" airbag at the 12 g level since it had already been shown that 9 g's had not reached the tolerance level for the lap belt series. Six subjects were impacted at approximately 12 g's with each restraint, lap belt only and lap belt plus "hybrid" airbag. Subjective reports indicated that each system was tolerable at this level and all subjects were willing to proceed to the 15 g level. Review of test run films and seat back loadings, however, indicated an amount of rebound with the hybrid bag which was considered potentially hazardous with the rigid seat used on the test sled. Further increases in "g" levels using the hybrid bag were therefore cancelled by the project medical monitor.

While the decision of further airbag runs was re-evaluated, lap belt only runs were conducted at the 15 g level. At this level, more complaints of post-run neck and pelvis pains were being reported by the subjects although none felt that they had reached their tolerance limit with this system. Following analysis of impact data, however, several items were noted by the medical monitor. First, there was a marked increase in severity of post-run neck and hip pain complaints and second, the mean lap belt load peak had risen from 760 lbs at 12 g's to 975 at 15 g's with one subject's belt loading as high as 1163 lbs. Assuming a linear

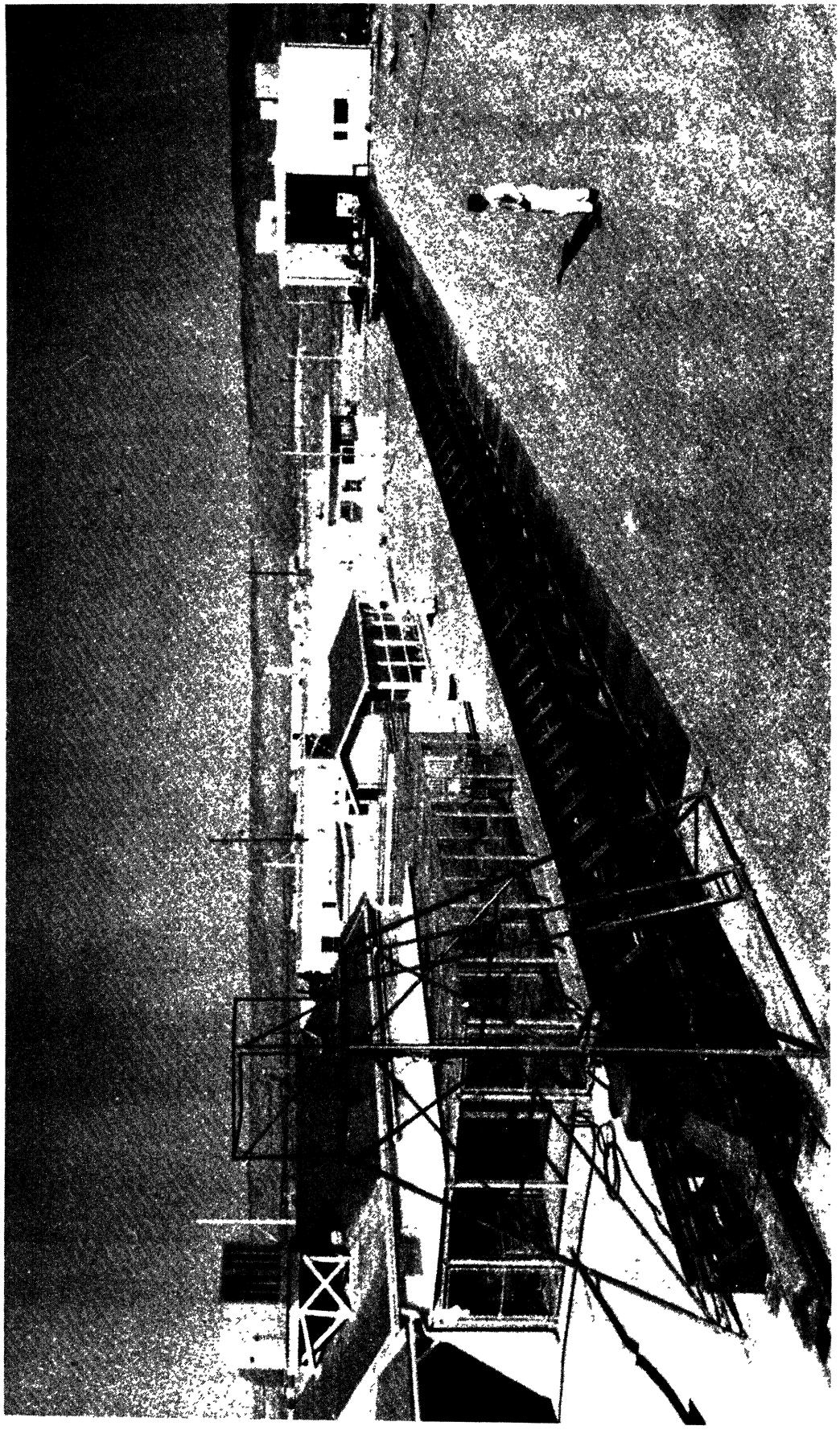


Figure 1. OVERALL VIEW of DAISY DECELERATOR

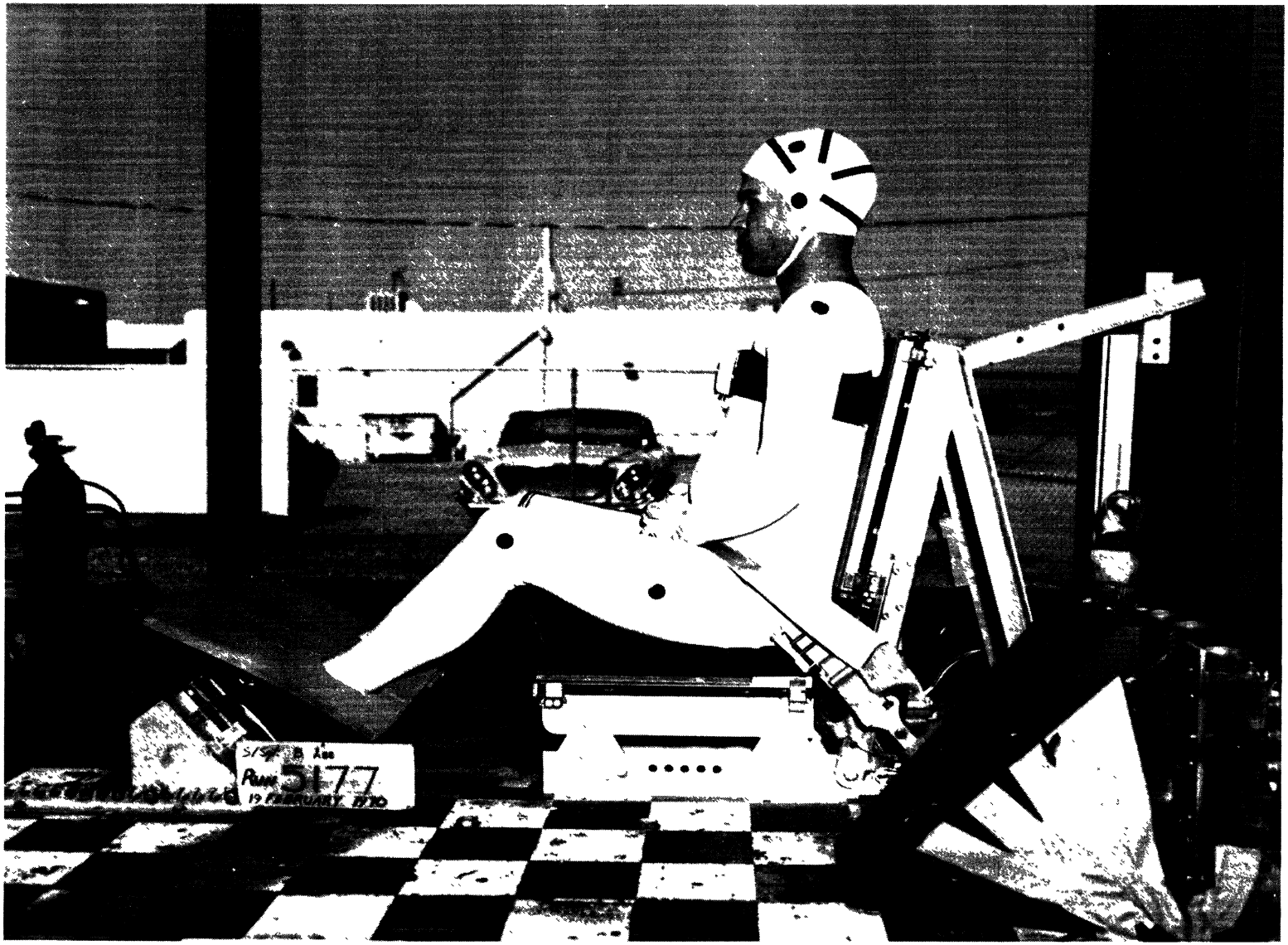
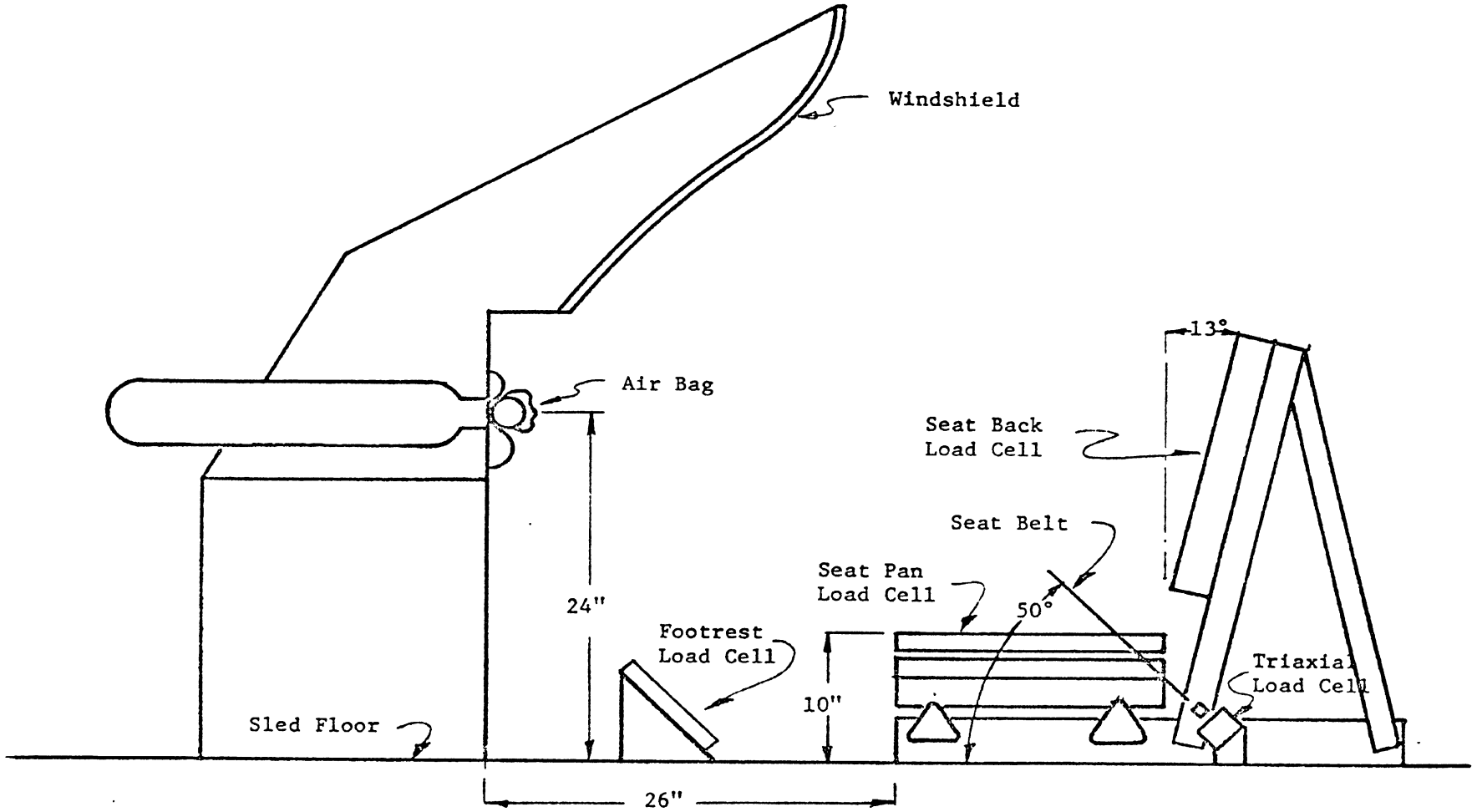


FIGURE 2. TYPICAL LAP BELT TEST SETUP



Human Air Bag Configuration

Figure 3.

Figure 4. VanGuard Analyser

extrapolation to a 18 g level, it was felt that a proper safety factor of belt strength to belt load could not be maintained. The combination of these two items led the medical monitor to limit further increases in the lap belt only test levels.

The 6571st ARL then decided to proceed with a rapidly inflating airbag. Six tests were conducted at the 12 g level utilizing this system.

ANALYSIS METHODS

A careful and detailed photometric analysis was performed on the high speed movie film of the tests previously described. The basic measuring device used in this work was the Van Guard film analyser model M-160 W (Fig. 4). Four-place accuracy in linear and angular measurements is obtainable with this instrument. The linear and angular displacements of the target points on the head, shoulder, hip and thigh were measured frame by frame. The film analyser was coupled to an IBM 29 card punch unit and computer cards were automatically punched with the displacement data. Several computer programs have been developed to analyze photometric data at HSRI, including routines to compute linear and angular velocities and accelerations with appropriate smoothing and filtering operations. The digitized displacement data was analyzed using these programs and the linear and angular head target velocities and acceleration computed.

RESULTS

The results of these analyses are presented in two ways. There are sets of curves showing the time history of the appropriate motion parameter and tables listing peak values and statistical data.

A typical set of these curves is presented in Figures 5, 6, 7 and 8. Figure 5 shows the head motion in x and y coordinates relative to a horizontal and vertical set of axes fixed in the sled. Figures 6 and 7 show the linear velocity and

acceleration of the head relative to a coordinate system fixed to the earth. Figure 8 gives the angular displacement, velocity and acceleration of the head relative to a fixed set of axes in the earth. Since the sled does not rotate with respect to the earth, these are also relative to the sled. Because of difficulties in camera coverage and targeting it was not possible to measure the angular displacement of the head relative to the torso and this must be kept in mind in interpreting the angular head motion curves.

Appendix 1 contains these curves for the runs in this test series. A problem that occurred with most of the airbag runs, was the disappearance of the head target as the head moved into the bag. This problem was overcome by using the back of the head as a target, by interpolating the displacement curves through those frames where the head was completely obscured and by analyzing the film from the diagonally placed camera.

Table I presents the peak values of the various test parameters as measured during the test or determined from the film analysis. Only three of the test configurations are directly comparable. These are the 12 g (nominal) runs with the lap belt only, the lap belt plus hybrid airbag and the lap belt plus rapidly inflating airbag restraint systems. Table II presents a statistical comparison of these three restraint systems. In determining a weighted index for the neck and pelvis pain observations the value 1 was assigned for "no reported symptom," 2 for "immediate symptom only," 3 for "persisting symptom 24 hours," and 4 for "persisting symptom 48 hours." A comparison of the mean values that takes into account the number of observations and the standard deviation was made utilizing a paired data "t" test at the 5% level of significance. In view of the limited number of tests, this significance level was considered appropriate. Thus, the column T_1 compares the lap belt only tests with the other two test series and the

T_2 column compares the hybrid bag with the rapidly inflating bag. A no in either the T_1 or T_2 columns indicates that there was no significant difference between the test parameter for the two series being compared. A yes indicates that there was a significant difference at the 5% level.

ERROR ESTIMATION

For several years HSRI has been developing methods and analyses for photometric data reduction. Included in this work has been a detailed error analysis. Figure 9 shows a calibration curve that was developed for the HSRI photometric measuring system. This curve includes consideration of the effect of measurement errors, round-off errors, standard differentiation routines and smoothing operations. The division or frame per pulse is the basic variable. From this number and the smoothing routine used, the error in estimating the pulse peak value can be estimated.

SUMMARY

The analyses described above indicate that the lap belt plus a rapidly inflating bag performed significantly better than the lap belt alone in the following ways:

1. reduced head motion both linear and angular
2. reduced linear head acceleration
3. reduced shoulder motion
4. reduced neck pain

There were, however, no significant differences in

1. angular acceleration of the head
2. chest linear acceleration
3. lap belt load
4. pelvis pain

5. foot pan load

6. seat back rebound load

It should be emphasized that the statistical indicators used here imply significance on a necessary basis only not on a "necessary and sufficient" basis. Thus if more tests of comparable types are performed it may well happen that some of the non-significantly different mean comparisons would move to the significant category but it would be highly improbable that significantly different mean comparisons would move into the non-significant category.

Restraint System	Run No.	Subject No.	Weight #	Height cm.	Pulse g's	Lap Belt #	Foot Pan #	Seat Back Rebound #	Neck Pain	Pelvis Pain	Chest g's	Head									Shoulder		Knee		Thigh		
												Δx in	Δy in	$\Delta\theta$ degrees	$\Delta^{\circ}x$ ft/sec	$\Delta\dot{y}$ ft/sec	$\Delta\dot{\theta}$ rad/sec	$\Delta^{\circ}\ddot{x}$ g's	$\Delta^{\circ}\ddot{y}$ g's	$\Delta\ddot{\theta}$ rad/sec^2	Δx in	Δy in	Δx in	Δy in	Δx in	Δy in	$\Delta\theta$ degrees
Lap Belt Only	4795	144	158	169	8.3	240	717	594	-	-	7.0	13	9	47	29	10	8	11	5	200	7	2	1	1	1	1	5
	4796	146	199	176	9.8	563	384	975	+++	-	8.8	18	18	75	34	31	29	13	14	800	15	6	3	3	3	1	12
Pre-Inflated Bag	4800	151	178	177	9.4	683	131	140	-	-	9.6	18	5	65	29	6	22	10	4	1100	11	2	0	1	2	1	21
Lap Belt Only	5082	118	136	180	11.6	666	150	410	-	-	10.5	25	27	108	37	41	33	18	16	400	21	13	4	4	4	3	11
	5081	128	155	171	12.4	949	245	163	++	-	18.3	28	27	127	39	46	45	24	18	1600	19	8	5	5	4	2	20
	5077	144	158	169	12.6	687	445	673	+++	-	12.6	21	16	110	32	16	16	11	8	500	14	3	1	2	1	1	6
	5078	127	177	185	11.5	703	340	551	++	-	8.5	17	12	85	32	20	24	11	8	500	14	5	1	2	1	1	10
	5079	151	178	177	11.4	1030	282	760	++	+	22.1	19	16	100	37	28	45	17	18	1700	16	6	1	3	1	1	16
	5080	146	199	176	10.1	530	605	949	+++	-	17.3	15	14	72	31	23	24	11	10	400	11	6	1	2	1	1	9
Lap Belt Plus Hybrid Airbag	5095	118	136	180	11.0	603	101	240	+	-	15.2	13	1	20	36	3	14	25	3	550	1	1	1	1	1	1	8
	5094	128	155	171	11.9	147	283	880	-	-	15.0	11	2	62	36	5	31	19	5	1000	4	1	1	2	1	1	14
	5097	144	158	169	12.4	500	920	808	++	+	16.2	17	6	100	44	16	43	22	14	1200	1	1	1	1	1	1	7
	5096	127	177	185	13.0	990	262	980	++	-	17.2	15	6	70	41	13	30	20	14	700	3	1	1	1	1	1	6
	5099	151	178	177	12.1	1126	122	430	-	+	14.8	9	2	27	9	34	17	18	8	250	4	2	1	1	1	1	29
	5100	146	199	176	10.0	500	590	1348	-	+	17.2	8	3	19	33	8	26	32	10	1000	0	0	3	3	3	1	14
Lap Belt Only	5179	118	136	180	14.6	800	540	360	++	-	11.4	18	20	13	33	29	36	13	10	550	15	13	0	4	1	2	12
	5175	128	155	171	15.3	903	404	500	++	-	16.4	25	27	138	38	41	36	19	11	700	15	11	1	3	0	1	13
	5177	144	158	169	15.4	808	755	440	-	+	14.6	22	18	122	36	24	25	13	12	1050	16	7	0	3	0	2	9
	5174	127	177	185	16.8	1050	474	640	++	++	15.9	25	25	128	36	36	35	17	13	900	16	10	1	3	0	2	12
	5178	151	178	177	15.0	1163	370	860	++	-	18.3	18	18	23	33	29	41	14	11	650	18	9	0	3	1	2	16
	5176	146	199	176	15.4	1120	714	760	-	+++	23.4	23	22	102	31	29	39	13	10	1500	19	11	1	4	1	2	13
Lap Belt Plus Rapidly Inflating Airbag	5225	118	136	180	11.6	600	301	N/A	-	-	12.1	7	3	40	30	5	26	12	10	1100	3	1	1	5	2	1	15
	5224	128	155	171	11.3	780	560	N/A	+	-	12.1	7	4	38	30	8	27	8	4	480	8	2	0	2	0	1	12
	5226	144	158	169	11.8	510	686	N/A	-	-	11.6	10	3	76	34	6	22	8	5	600	6	1	1	2	0	1	3
	5227	127	177	185	11.8	600	368	N/A	+	-	11.6	7	1	43	32	3	14	10	4	600	4	2	2	1	2	1	6°
	5228	151	178	177	11.8	890	144	N/A	+	-	16.2	7	3	61	27	10	20	9	14	600	3	2	0	3	1	1	10

- = No reported symptoms

+ = Immediate Symptoms Only

++ = Persisting symptoms 24 hours

+++ = Persisting symptoms 48 hours

TABLE II. STATISTICAL COMPARISON OF VARIOUS RESTRAINT SYSTEMS

Parameter	Lap Belt Only		Lap Belt Plus Hybrid Bag			Lap Belt Plus Rapidly Inflating Bag			
	Mean	Standard Deviation	Mean	Standard Deviation	T_1	Mean	Standard Deviation	T_1	T_2
Pulse g's	11.6	0.81	11.7	0.93	No	11.7	0.20	No	No
Lap Belt #	761	173	644	327	No	676	138	No	No
Foot Pan #	345	147	380	290	No	412	429	No	No
Seat Back #	584	252	781	362	No	N/A	N/A	-	-
Chest g's	14.9	4.7	15.9	1.0	No	12.7	1.8	No	Yes
Head Δx in.	20.8	4.5	12.2	3.2	Yes	7.6	1.2	Yes	Yes
Head Δy in.	18.6	6.0	3.3	2.0	Yes	2.8	1.0	Yes	No
Head $\Delta\theta$ degrees	100.3	17.8	49.7	30.0	Yes	51.6	14.7	Yes	No
Head $\dot{\Delta x}$ ft/sec	34.7	3.1	33	11.4	No	27.0	7.8	No	No
Head $\dot{\Delta y}$ ft/sec	29.0	11.0	13.2	10.3	Yes	6.4	2.4	Yes	Yes
Head $\dot{\Delta\theta}$ rad/sec	31.1	11.0	26.8	9.6	No	21.8	4.7	No	No
Head $\ddot{\Delta x}$ g's	15.3	4.9	22.7	4.7	Yes	9.4	1.5	Yes	Yes
Head $\ddot{\Delta y}$ g's	13.0	4.4	9.0	4.2	No	7.4	4.0	Yes	No
Head $\ddot{\Delta\theta}$ rad/sec^2	850	567	783	319	No	676	218	No	No
Shoulder Δx in.	15.8	3.3	2.2	1.6	Yes	4.8	1.9	Yes	Yes
Shoulder Δy in.	6.8	3.1	1.0	0.6	Yes	1.6	1.5	Yes	No
Knee Δx in.	2.2	1.7	1.3	0.7	No	0.8	0.7	No	No
Knee Δy in.	3.0	1.2	1.5	0.8	Yes	2.6	1.4	No	No
Thigh Δx in.	2.0	1.4	1.3	0.7	No	1.0	0.9	No	No
Thigh Δy in.	1.5	0.8	1.0	0.0	No	1.0	0.0	No	No
Thigh $\Delta\theta$ degrees	12.0	4.7	13.0	7.8	No	10.4	3.0	No	No
Neck Pain	3.0	1.0	1.8	0.9	No	1.6	0.5	Yes	No
Pelvis Pain	1.2	0.4	1.5	0.5	No	1.0	0.0	No	No

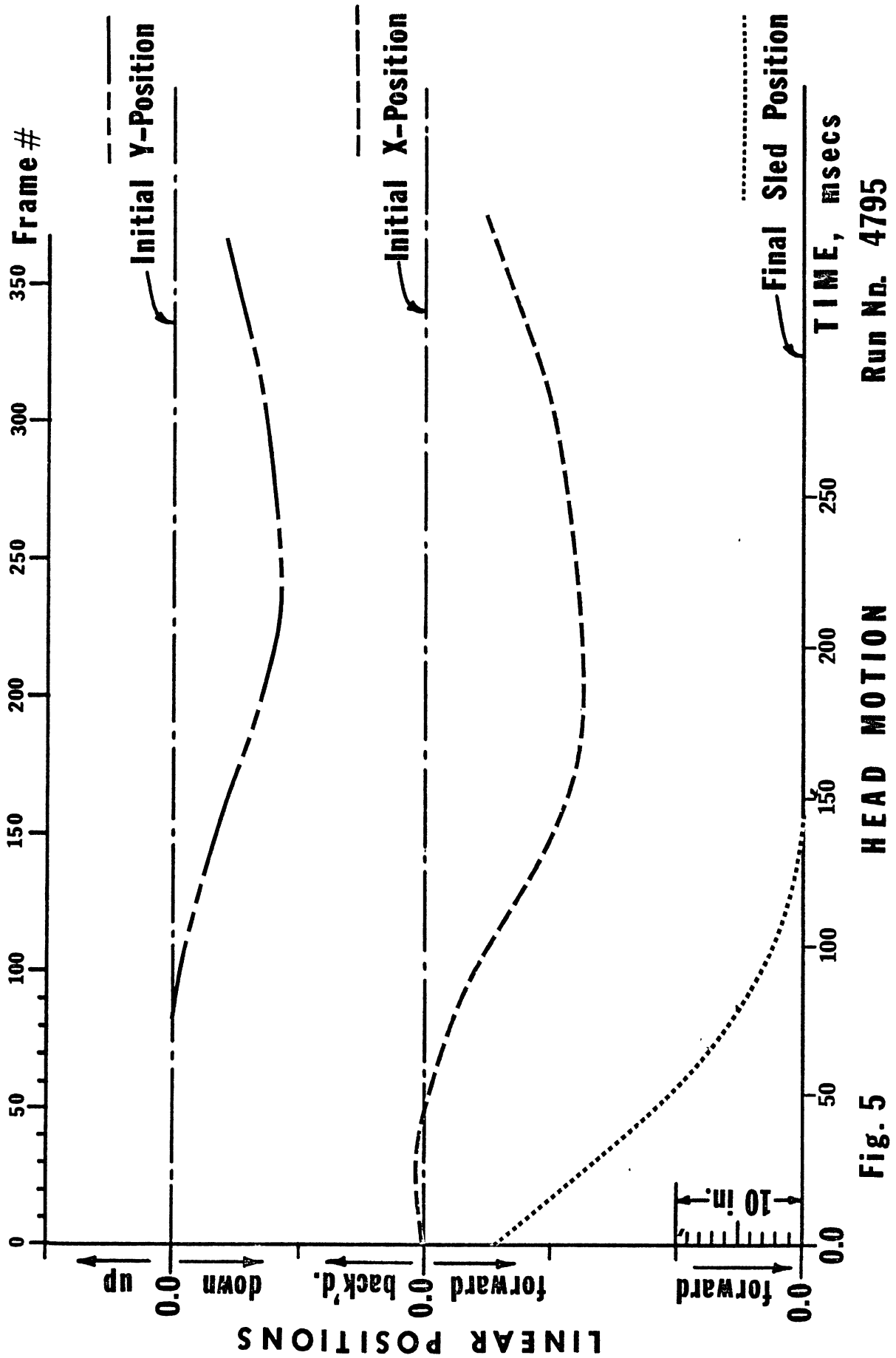

Frame #
0
50
100
150
200
250
300
350
Initial Y-Position
Initial X-Position
Final Sled Position
TIME, msecs
0.0
50
100
150
200
250
HEAD MOTION
Run No. 4795
LINEAR POSITIONS
up
down
0.0
back'd.
forward
0.0
10 in.
forward
0.0

Fig. 5

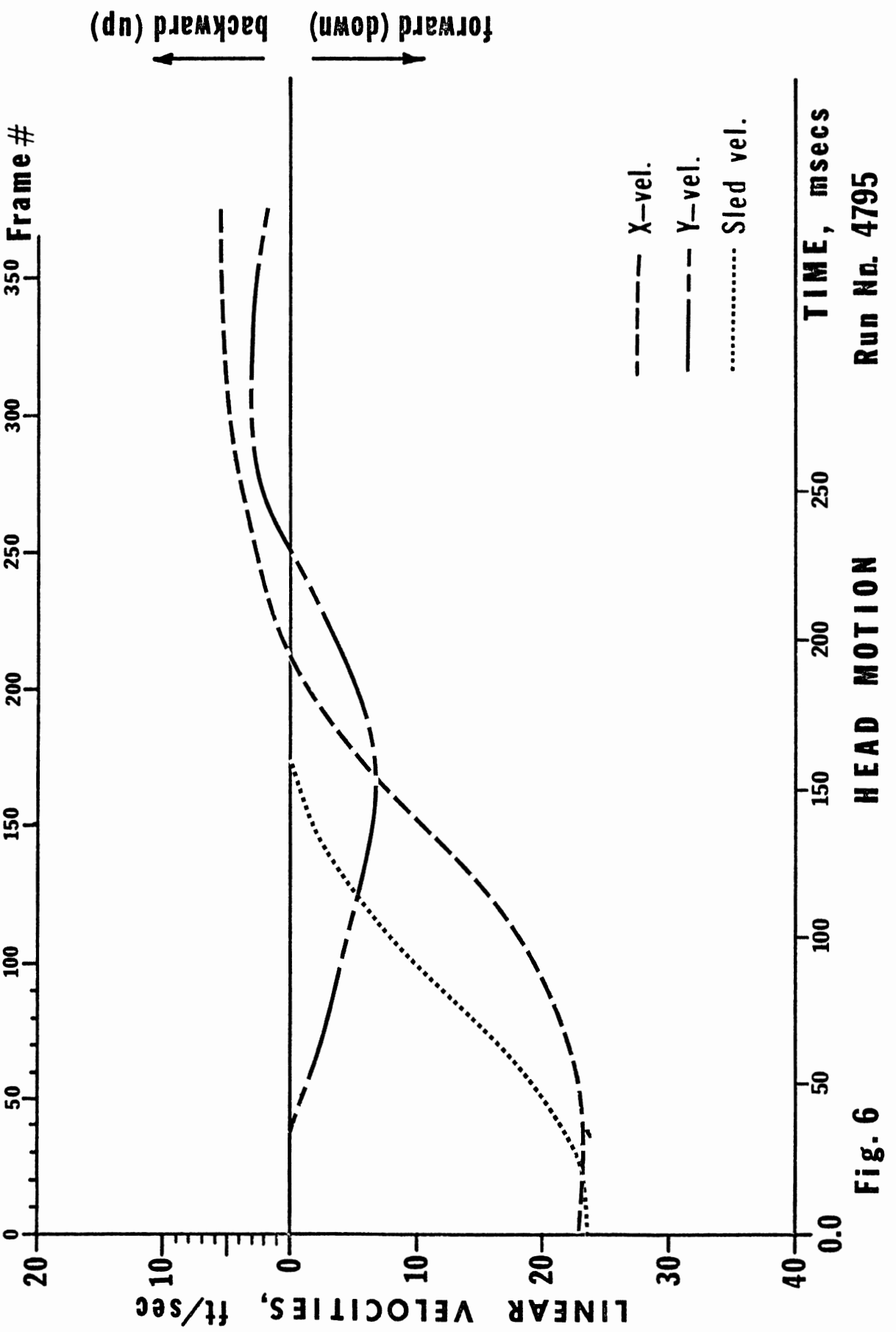

forward (down)
backward (up)
LINEAR VELOCITIES, ft/sec
20
10
0
10
20
30
40
0.0
50
100
150
200
250
TIME, msecs
0
50
100
150
200
250
300
350
Frame #
X-vel.
Y-vel.
Sled vel.
HEAD MOTION
Run No. 4795

Fig. 6

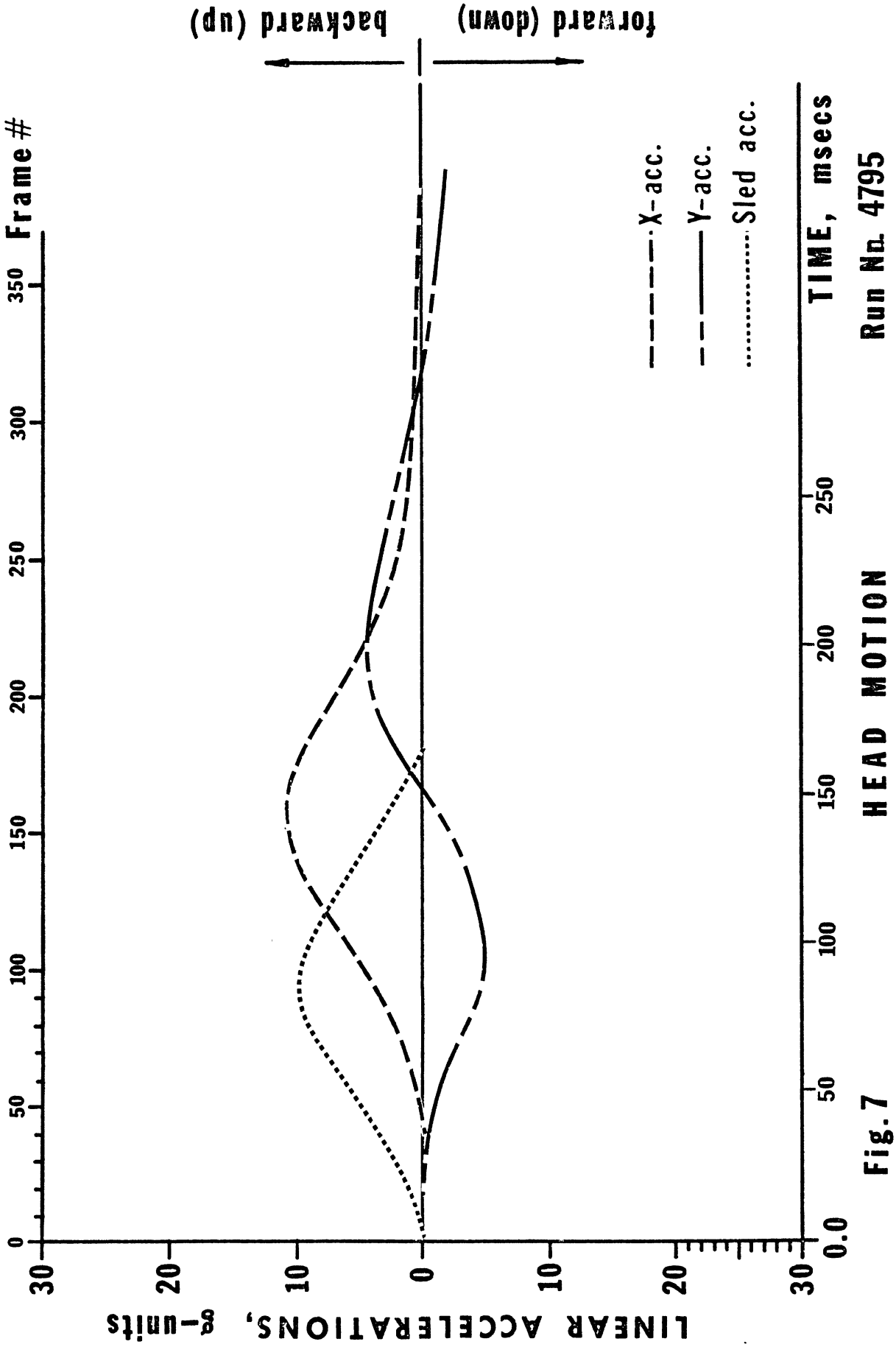

forward (down)
backward (up)
X-acc.
Y-acc.
Sled acc.
TIME, msecs
Run No. 4795
HEAD MOTION
LINEAR ACCELERATIONS, g-units
Frame #
0
50
100
150
200
250
300
350
0.0
30
20
10
0

Fig. 7

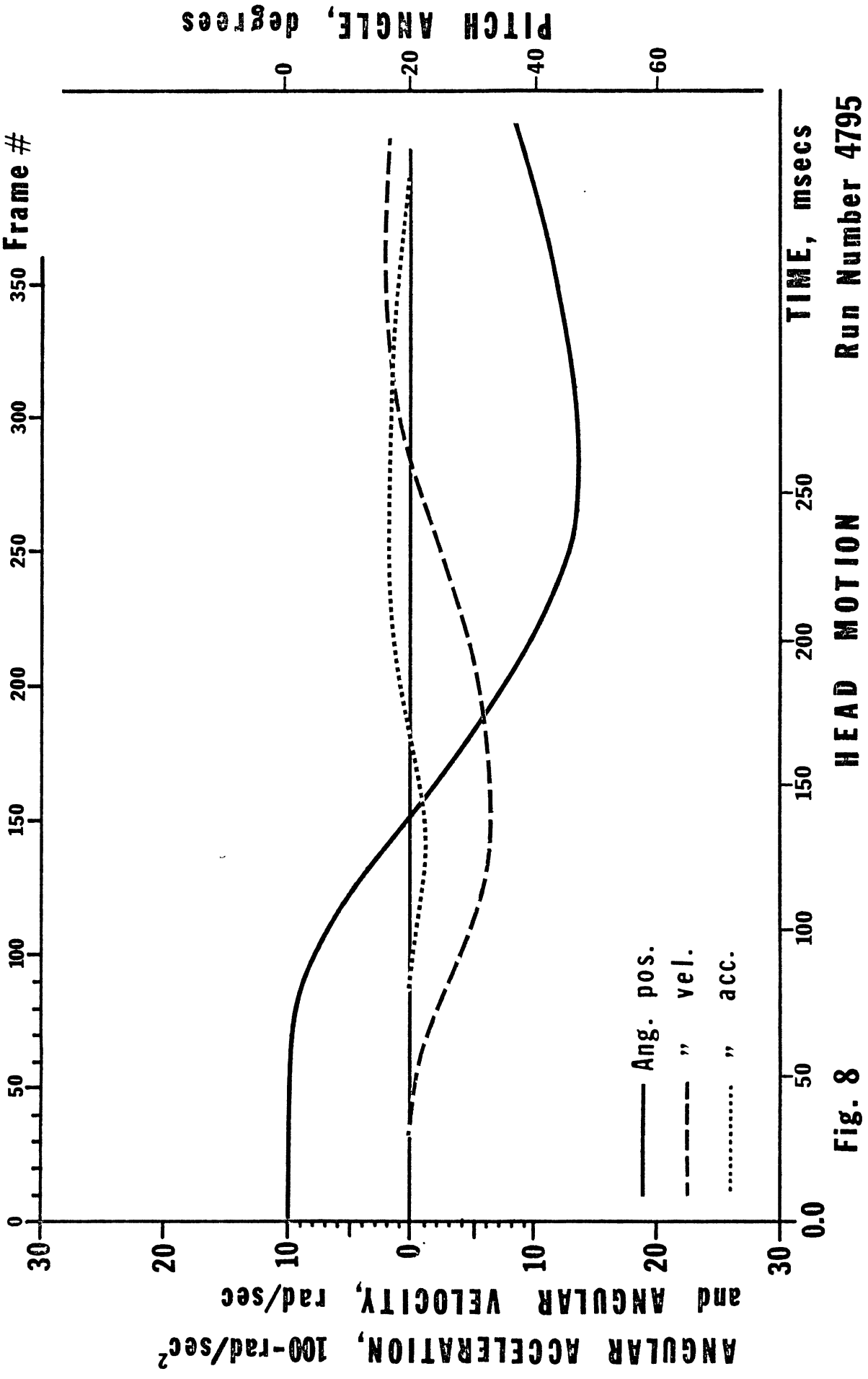

PITCH ANGLE, degrees
0
20
40
60
Frame #
0
50
100
150
200
250
300
350
TIME, msecs
0.0
50
100
150
200
250
HEAD MOTION
Run Number 4795
ANGULAR ACCELERATION, 100-rad/sec²
and ANGULAR VELOCITY, rad/sec
30
20
10
0
10
20
30
Ang. pos.
" vel.
" acc.

Fig. 8

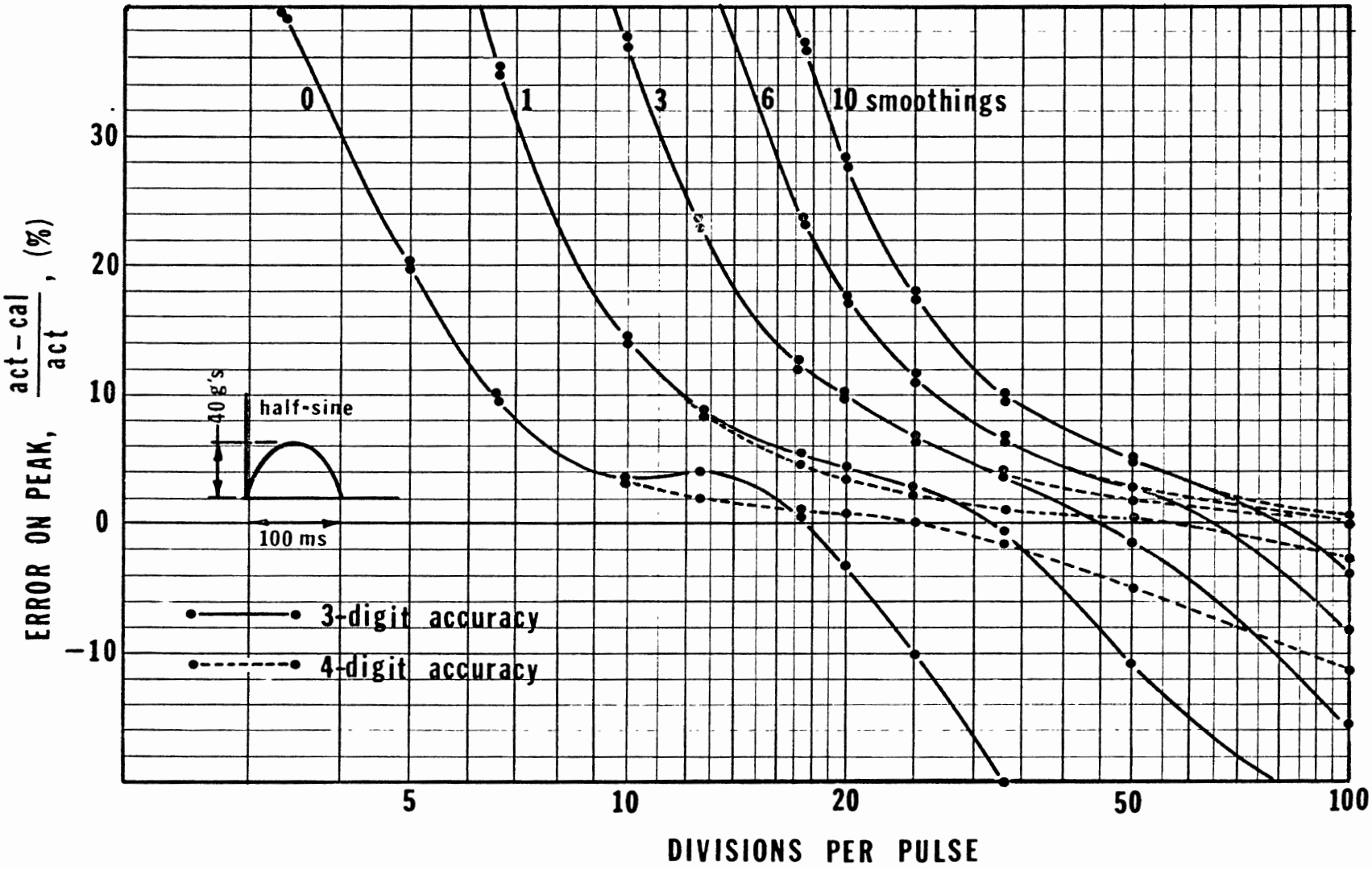


fig. 9 CALIBRATION CURVES FOR DOUBLE DIFFERENTIATION OF PHOTOMETRIC DATA

ACKNOWLEGEMENTS

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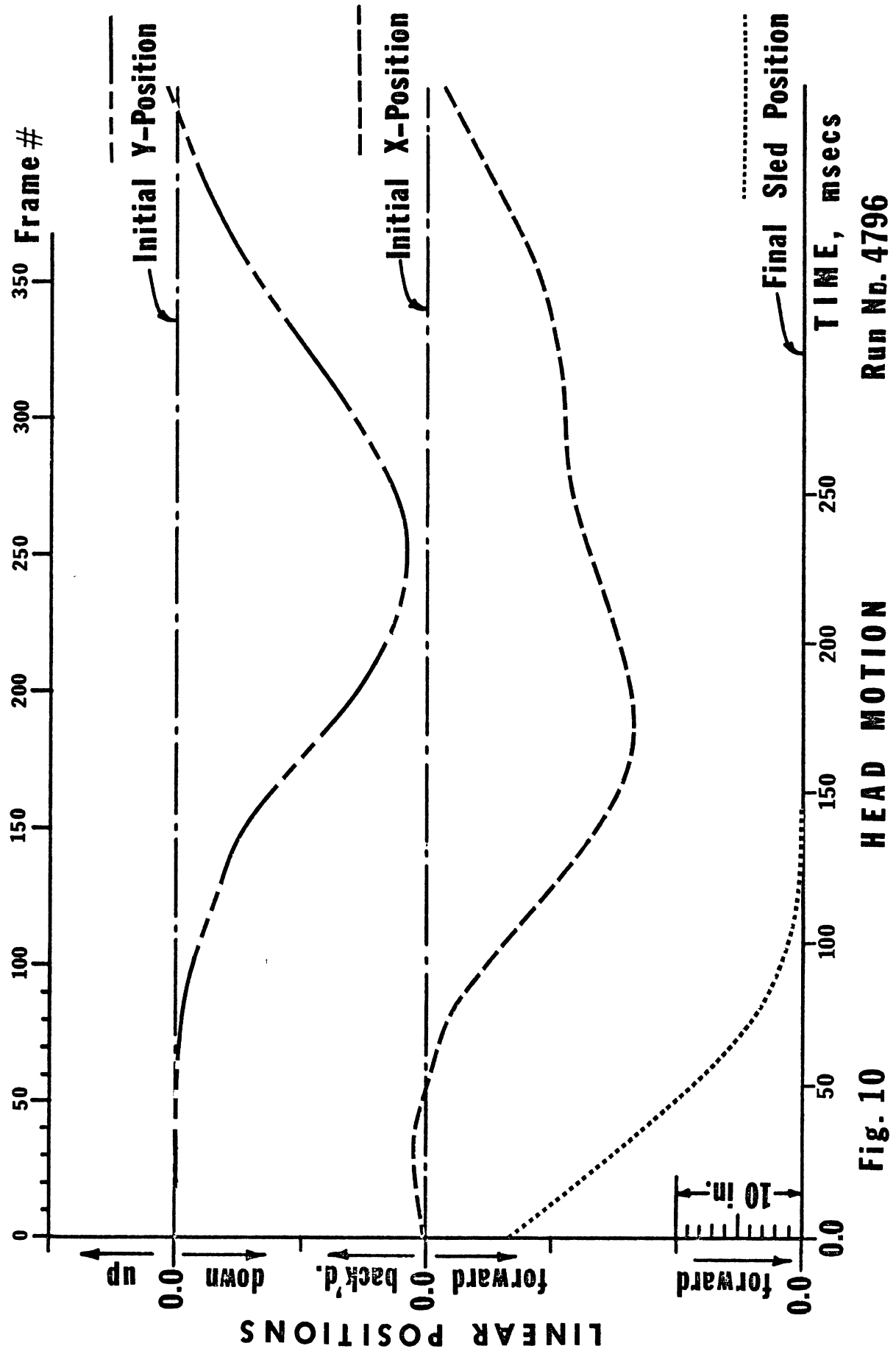
APPENDIX A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Initial X-Position
Final Sled Position
Frame #
0
50
100
150
200
250
300
350
TIME, msecs
0.0
50
100
150
200
250
LINEAR POSITIONS
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down
backward
0.0
forward
forward
0.0
10 in.
HEAD MOTION
Run No. 4796

Fig. 10

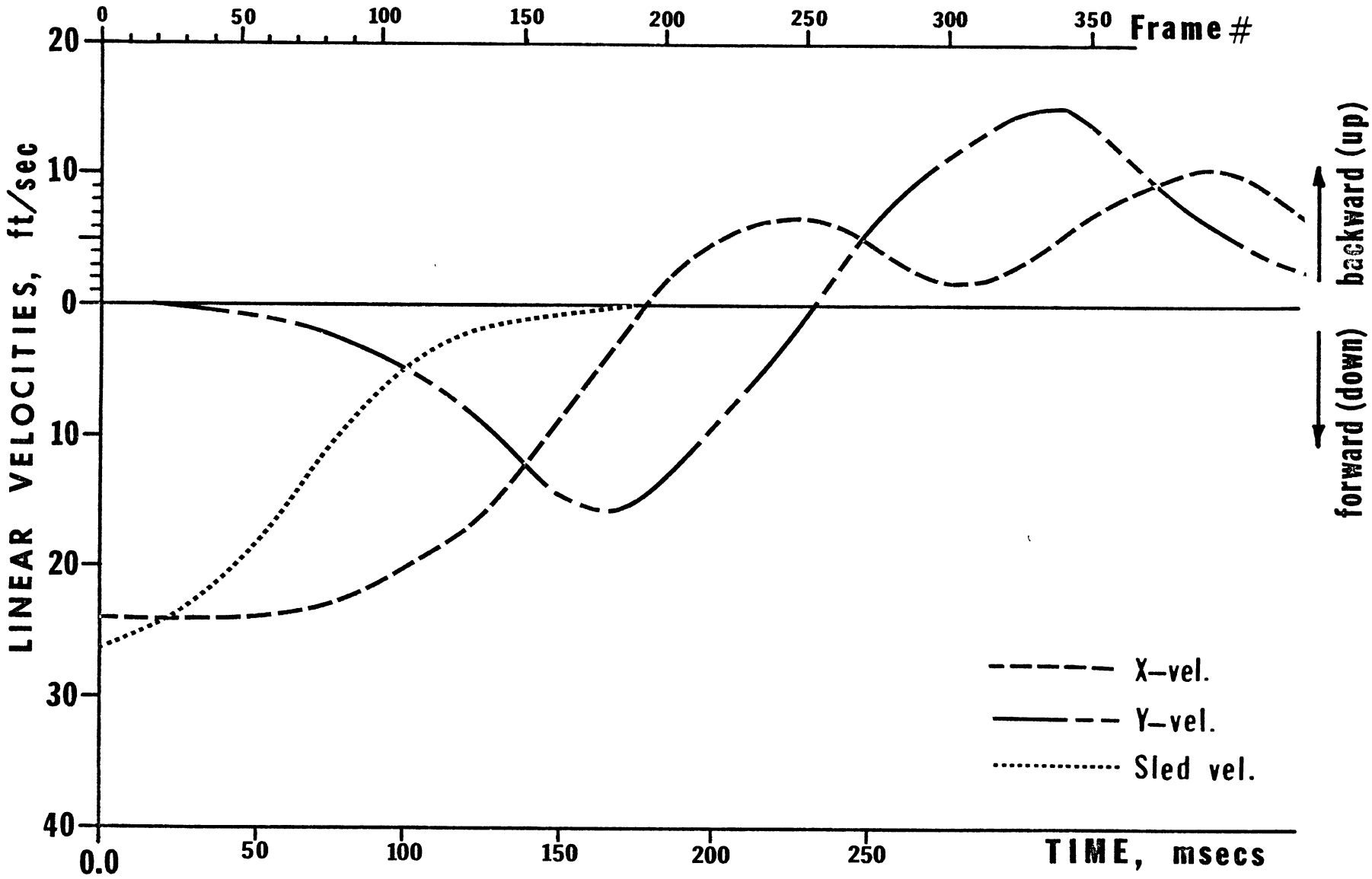


Fig. 11 HEAD MOTION Run No. 4796

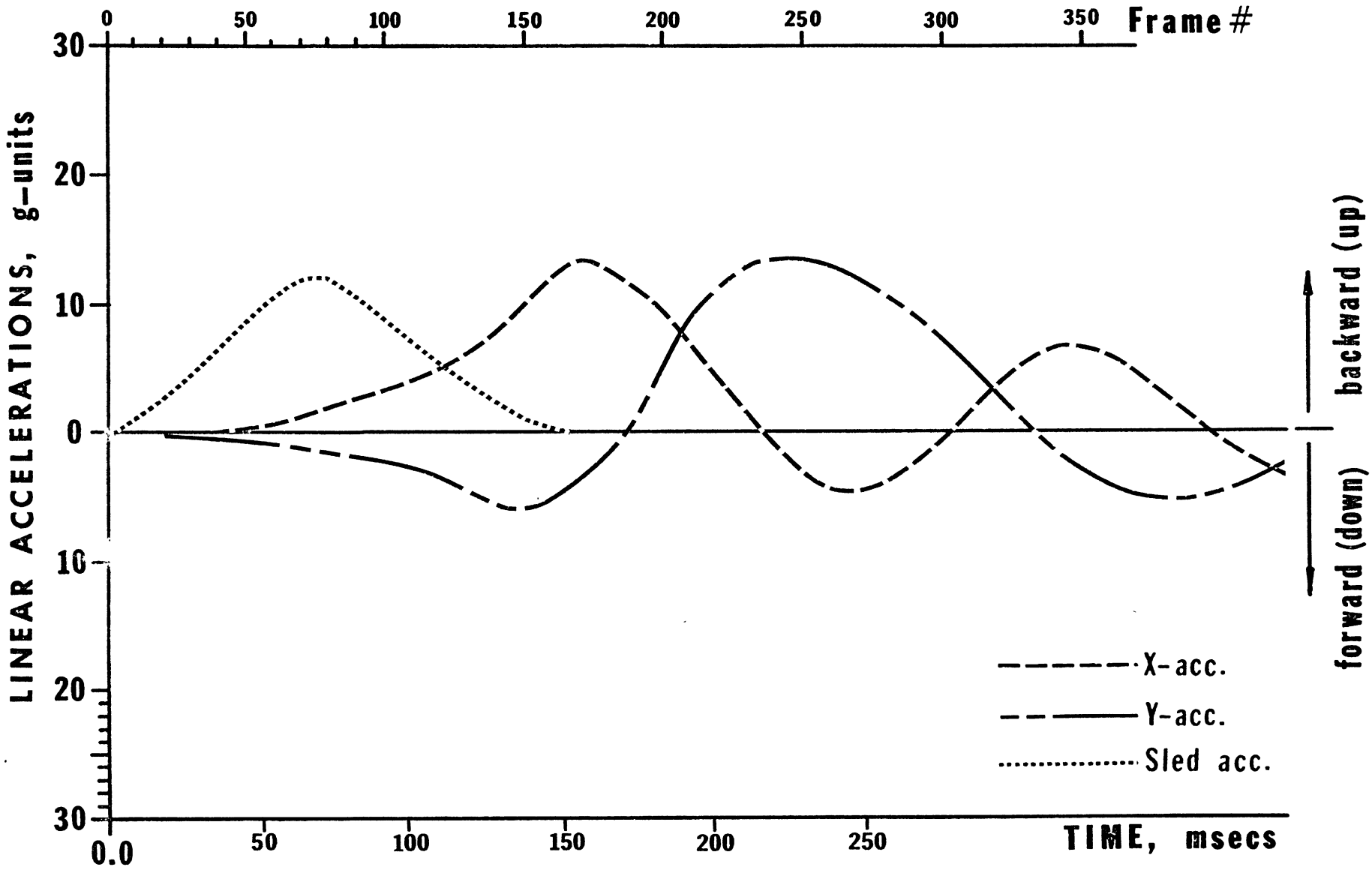


Fig. 12 HEAD MOTION Run Nr.4796

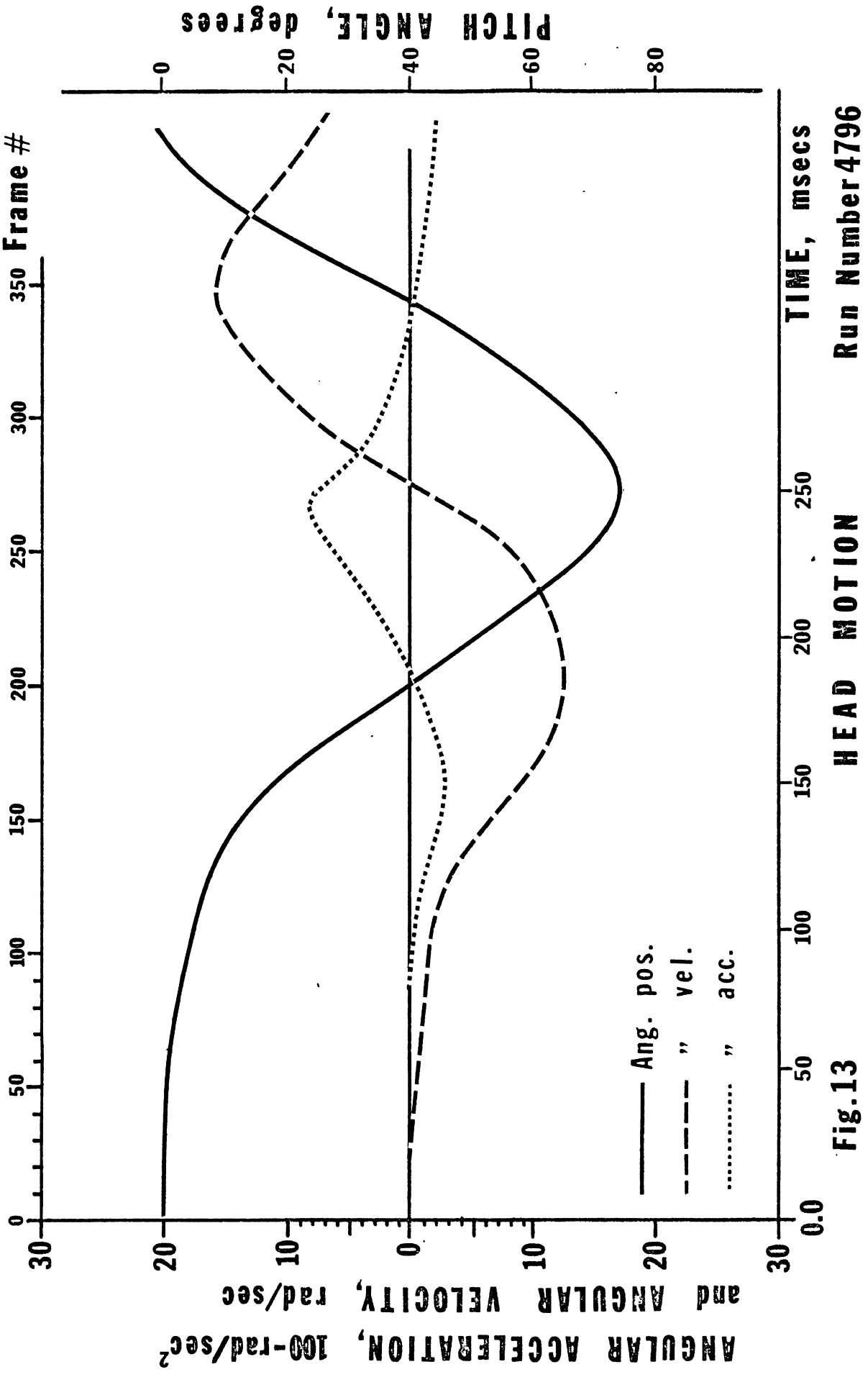

PITCH ANGLE, degrees
0
20
40
60
80
Frame #
0
50
100
150
200
250
300
350
TIME, msecs
0.0
50
100
150
200
250
HEAD MOTION
Run Number 4796
ANGULAR ACCELERATION, 100-rad/sec²
and ANGULAR VELOCITY, rad/sec
30
20
10
0
10
20
30
Ang. pos.
" vel.
" acc.

Fig.13

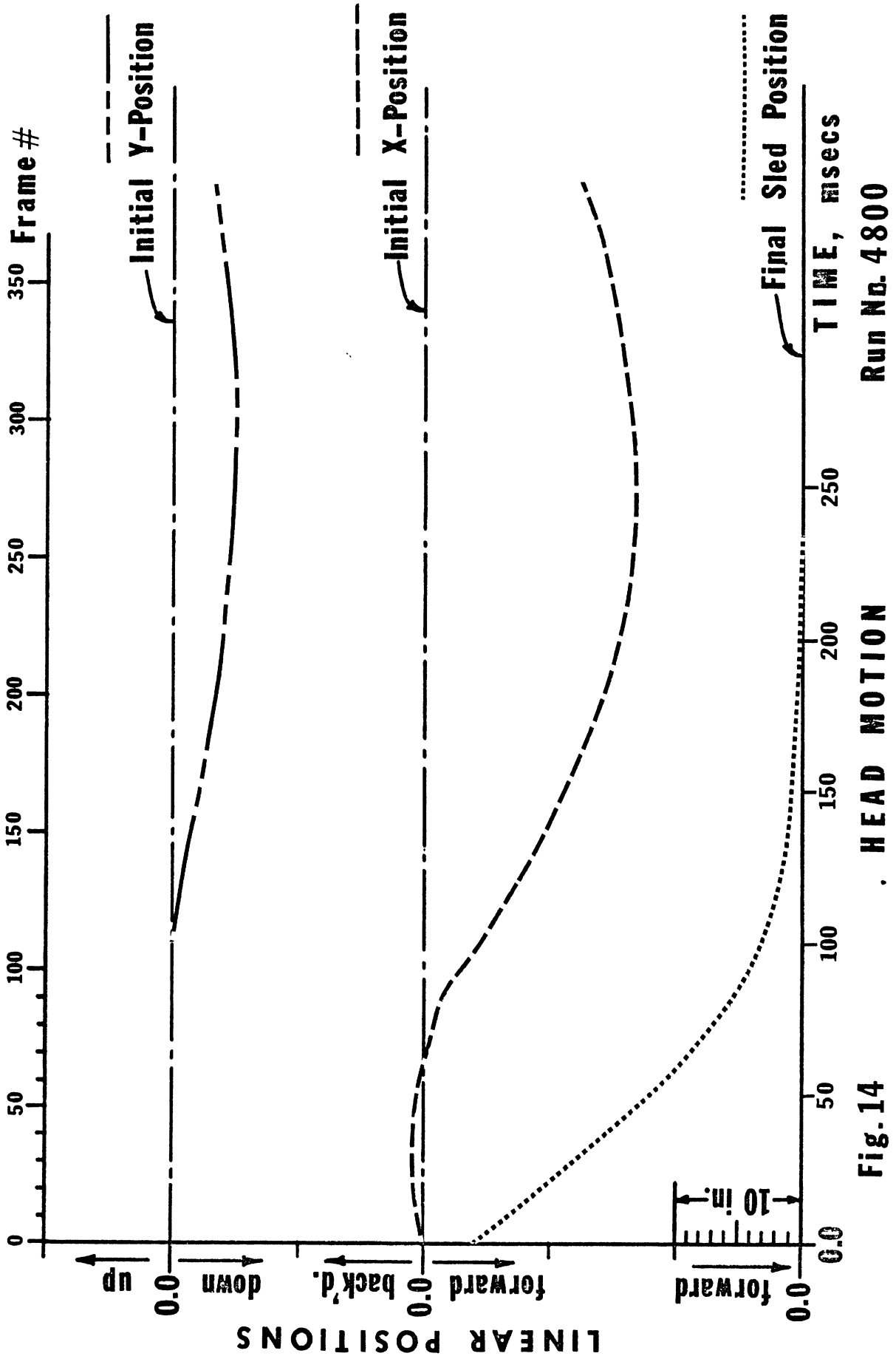


Fig. 14 . HEAD MOTION

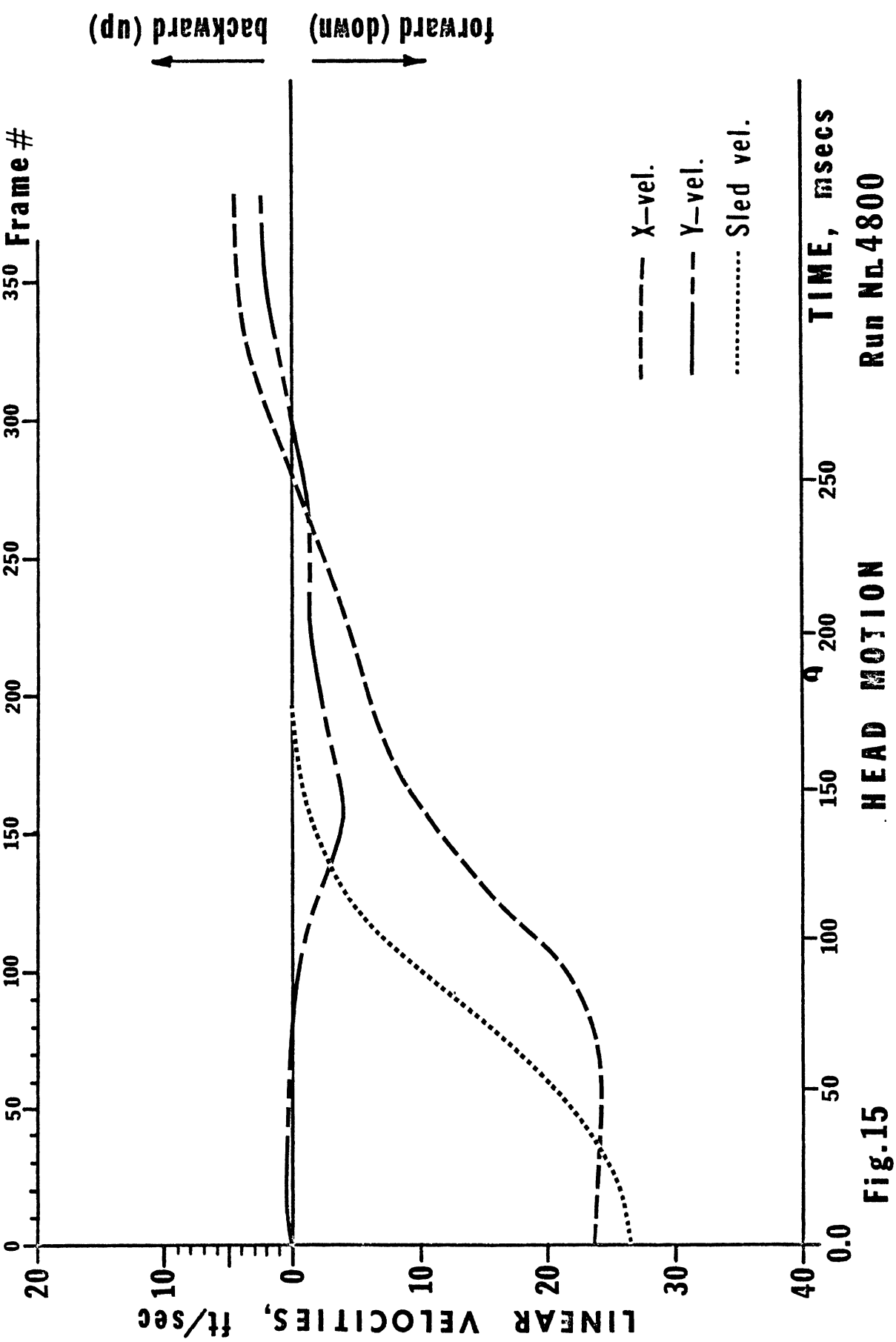
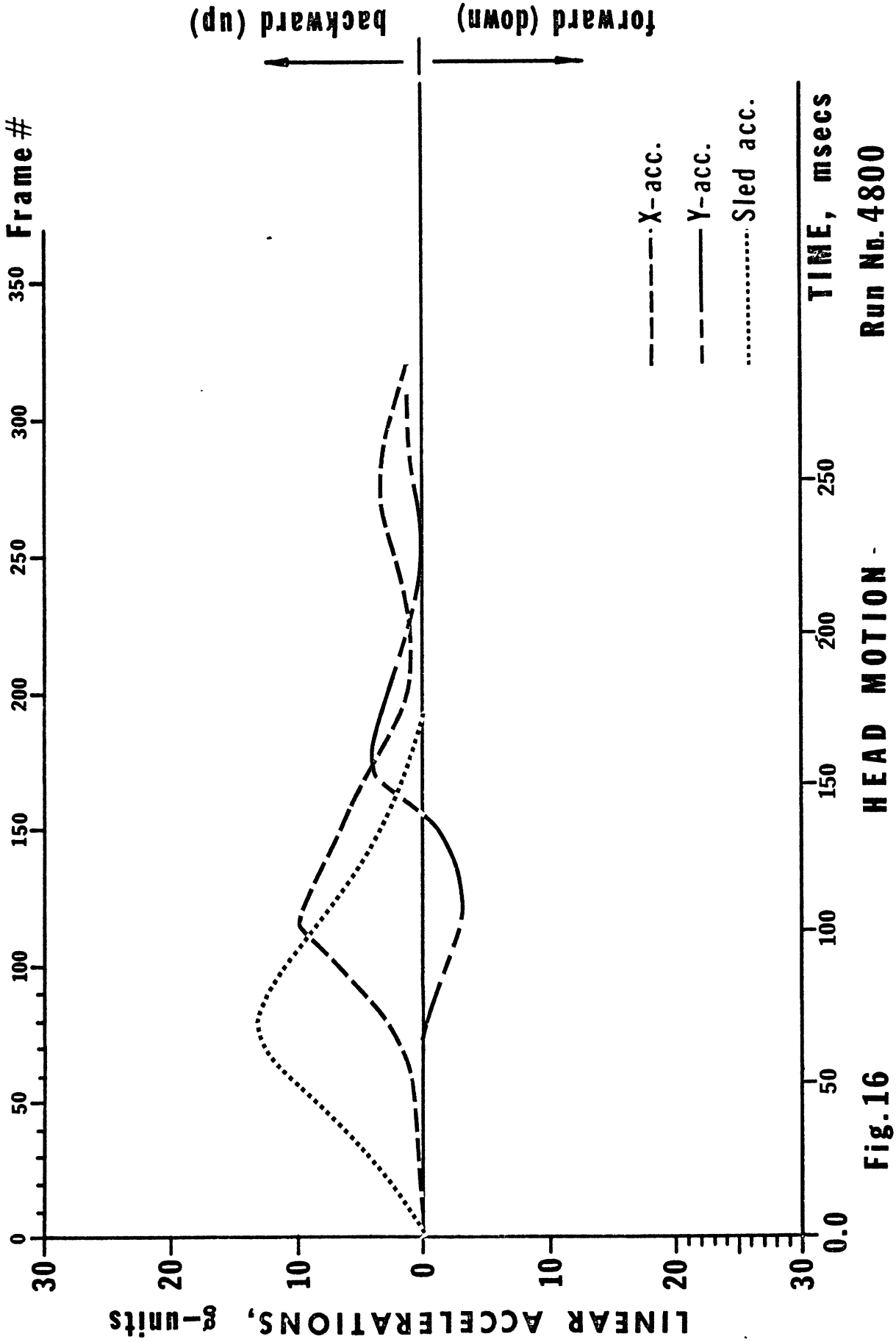

forward (down)
backward (up)
LINEAR VELOCITIES, ft/sec
20
10
0
10
20
30
40
0.0
50
100
150
200
250
TIME, msecs
0
50
100
150
200
250
300
350
Frame #
X-vel.
Y-vel.
Sled vel.
HEAD MOTION
Run No.4800

Fig.15



HEAD MOTION -

Fig.16

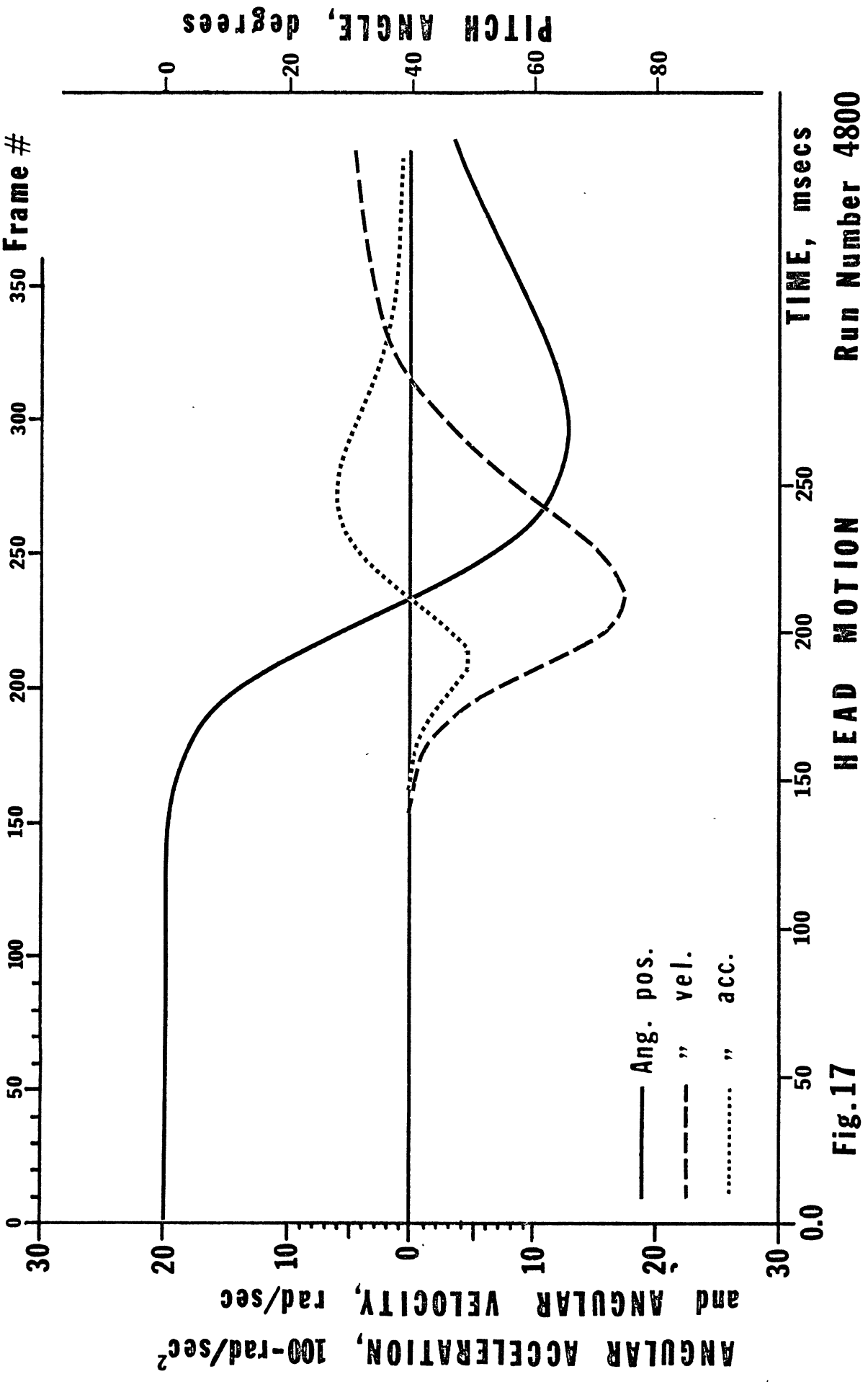

PITCH ANGLE, degrees
0
20
40
60
80
Frame #
0
50
100
150
200
250
300
350
ANGULAR ACCELERATION, 100-rad/sec²
and ANGULAR VELOCITY, rad/sec
30
20
10
0
10
20
30
Ang. pos.
" vel.
" acc.
0.0
50
100
150
200
250
TIME, msecs
HEAD MOTION
Run Number 4800

Fig.17

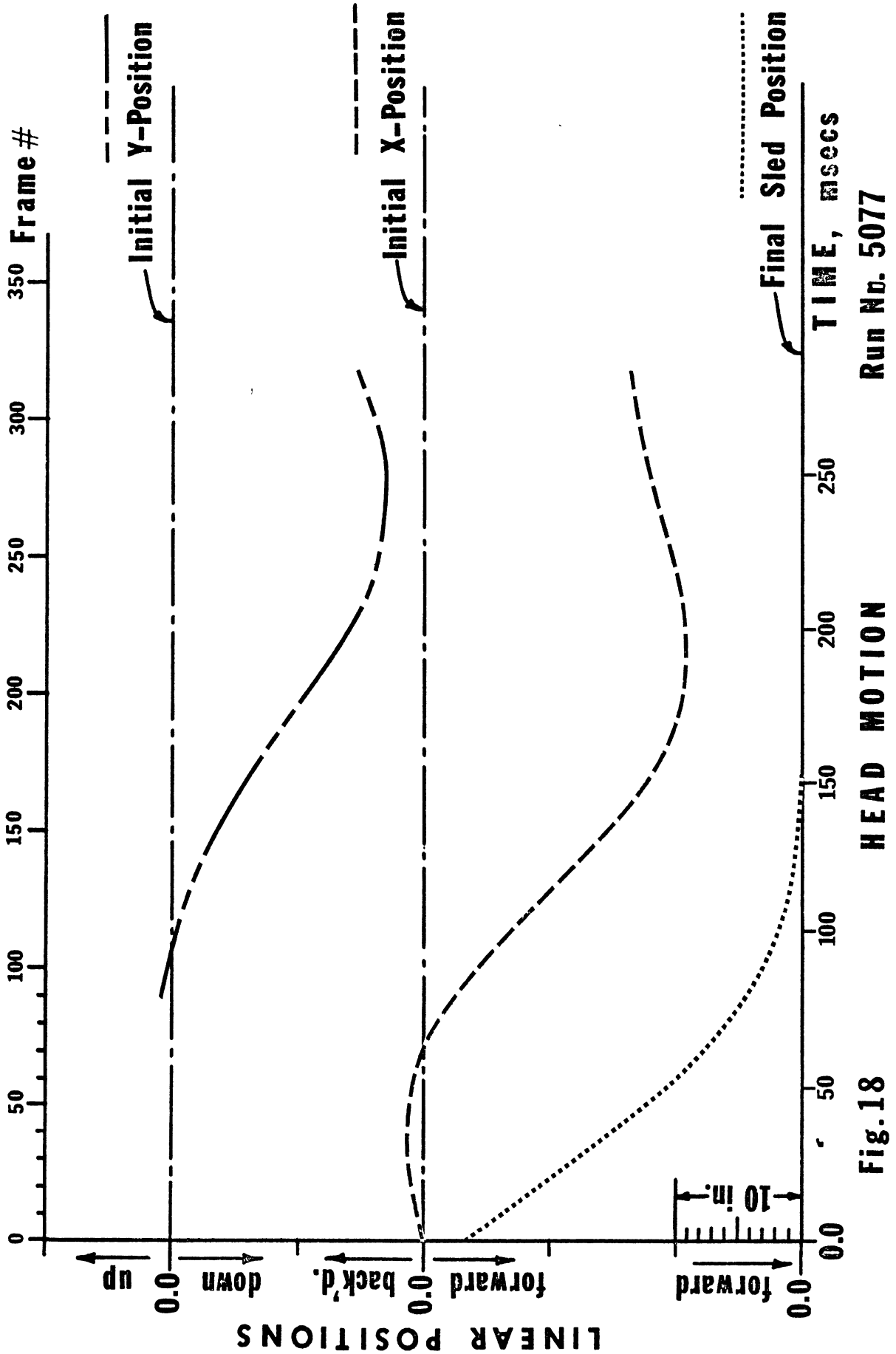

Initial Y-Position
Initial X-Position
Final Sled Position
Frame #
TIME, msecs
Run No. 5077
HEAD MOTION
LINEAR POSITIONS
up
down
0.0
back'd.
forward
0.0
forward
0.0
10 in.
0
50
100
150
200
250
300
350
0.0
50
100
150
200
250

Fig. 18

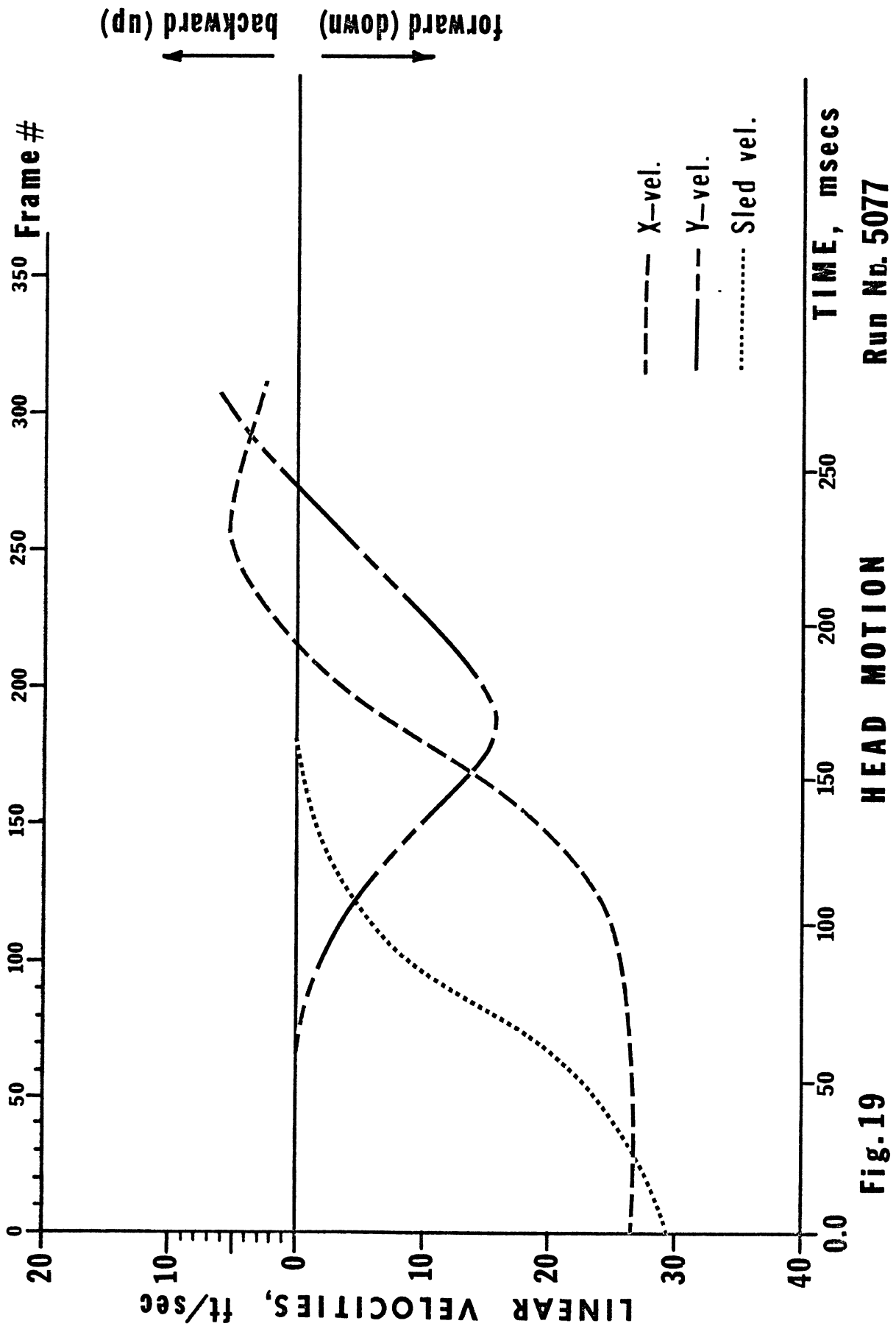

forward (down)
backward (up)
LINEAR VELOCITIES, ft/sec
20
10
0
10
20
30
40
0.0
50
100
150
200
250
300
350
Frame #
0
50
100
150
200
250
TIME, msecs
X-vel.
Y-vel.
Sled vel.
HEAD MOTION
Run No. 5077

Fig. 19

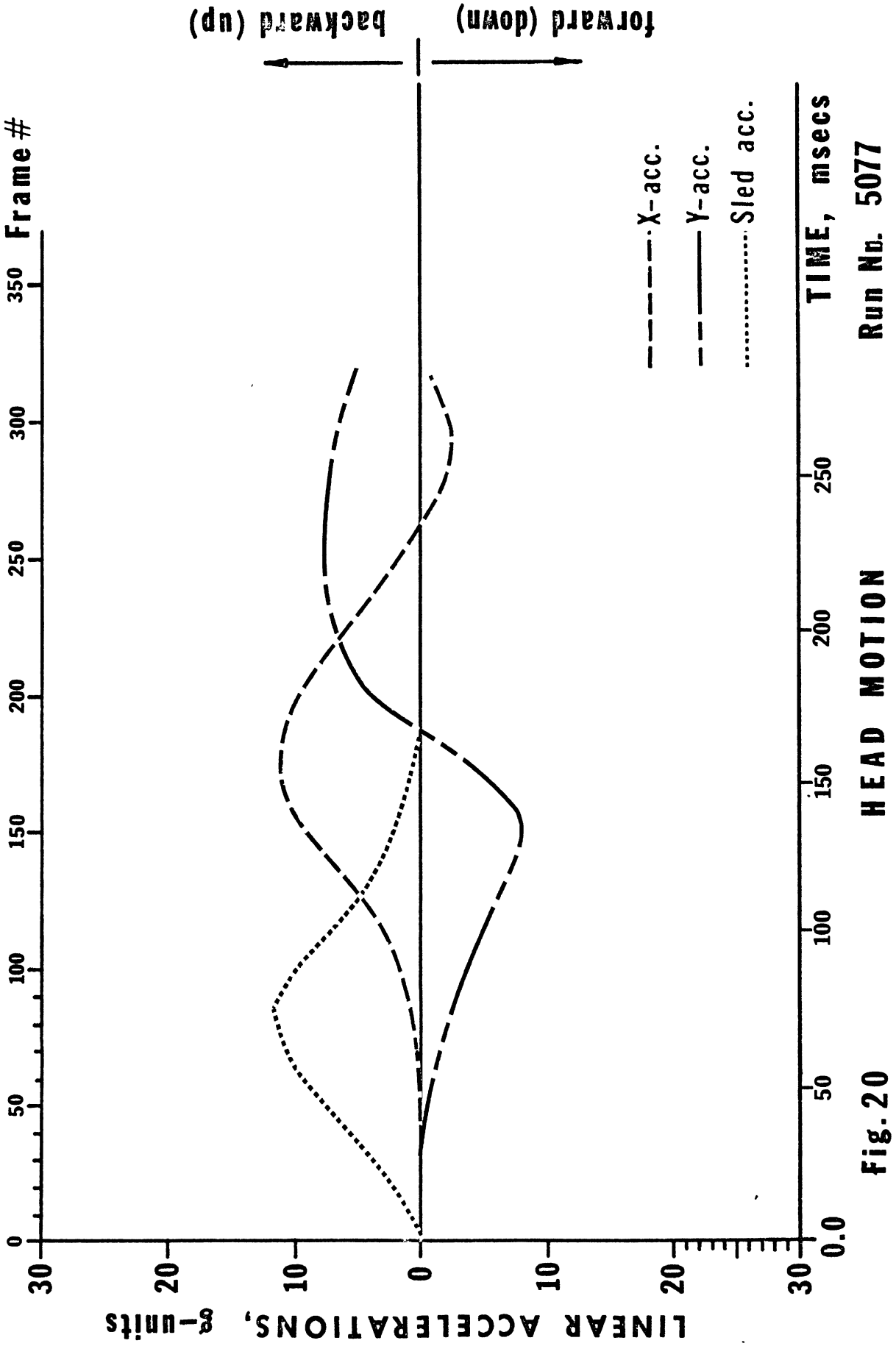

forward (down)
backward (up)
X-acc.
Y-acc.
Sled acc.
TIME, msecs
Run No. 5077
HEAD MOTION
LINEAR ACCELERATIONS, g-units
Frame #
0.0
50
100
150
200
250
300
350
30
20
10
0
10
20
30

Fig. 20

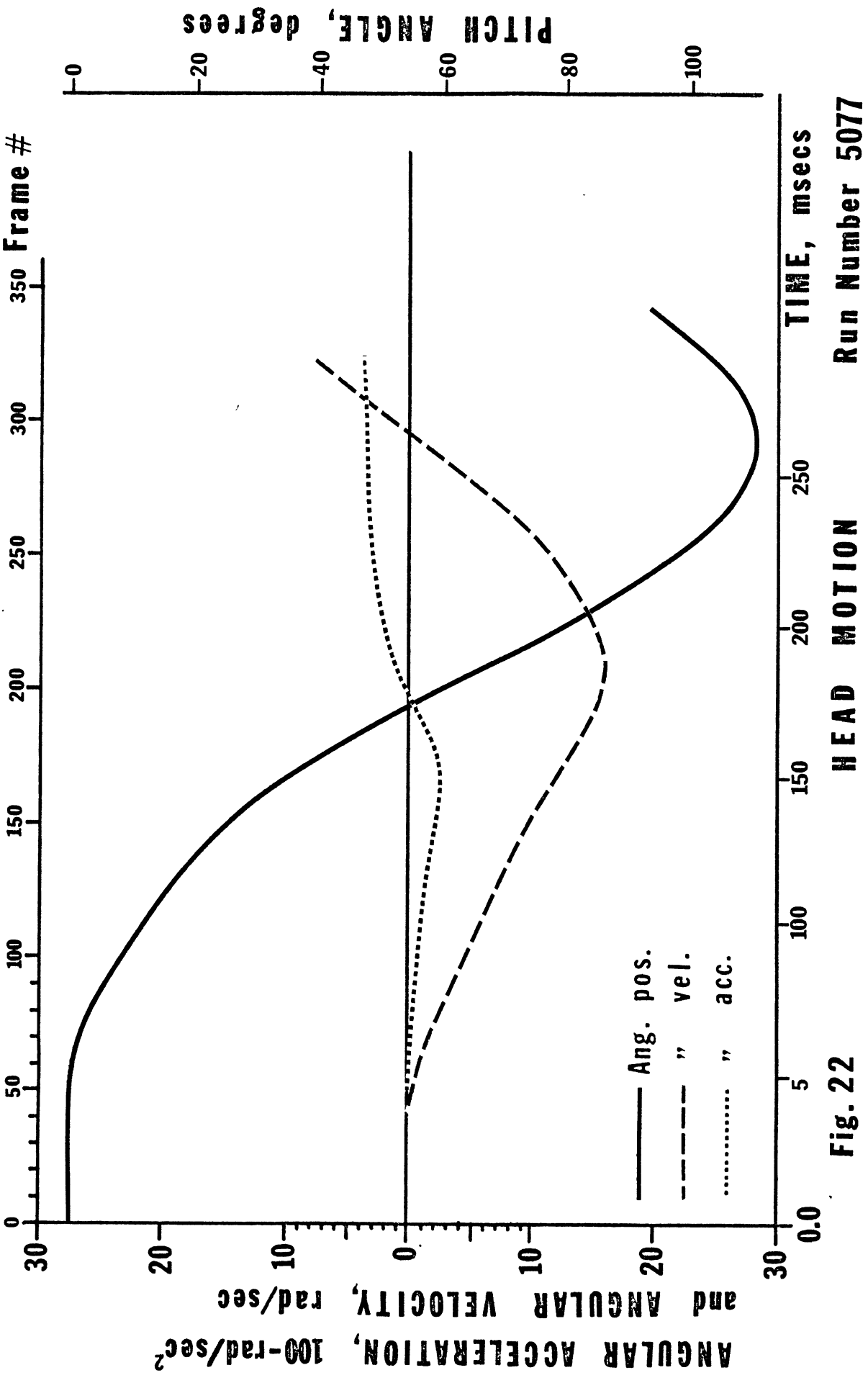

ANGULAR ACCELERATION, 100-rad/sec²
and ANGULAR VELOCITY, rad/sec
PITCH ANGLE, degrees
Frame #
TIME, msecs
Ang. pos.
" vel.
" acc.
HEAD MOTION
Run Number 5077

Fig. 22

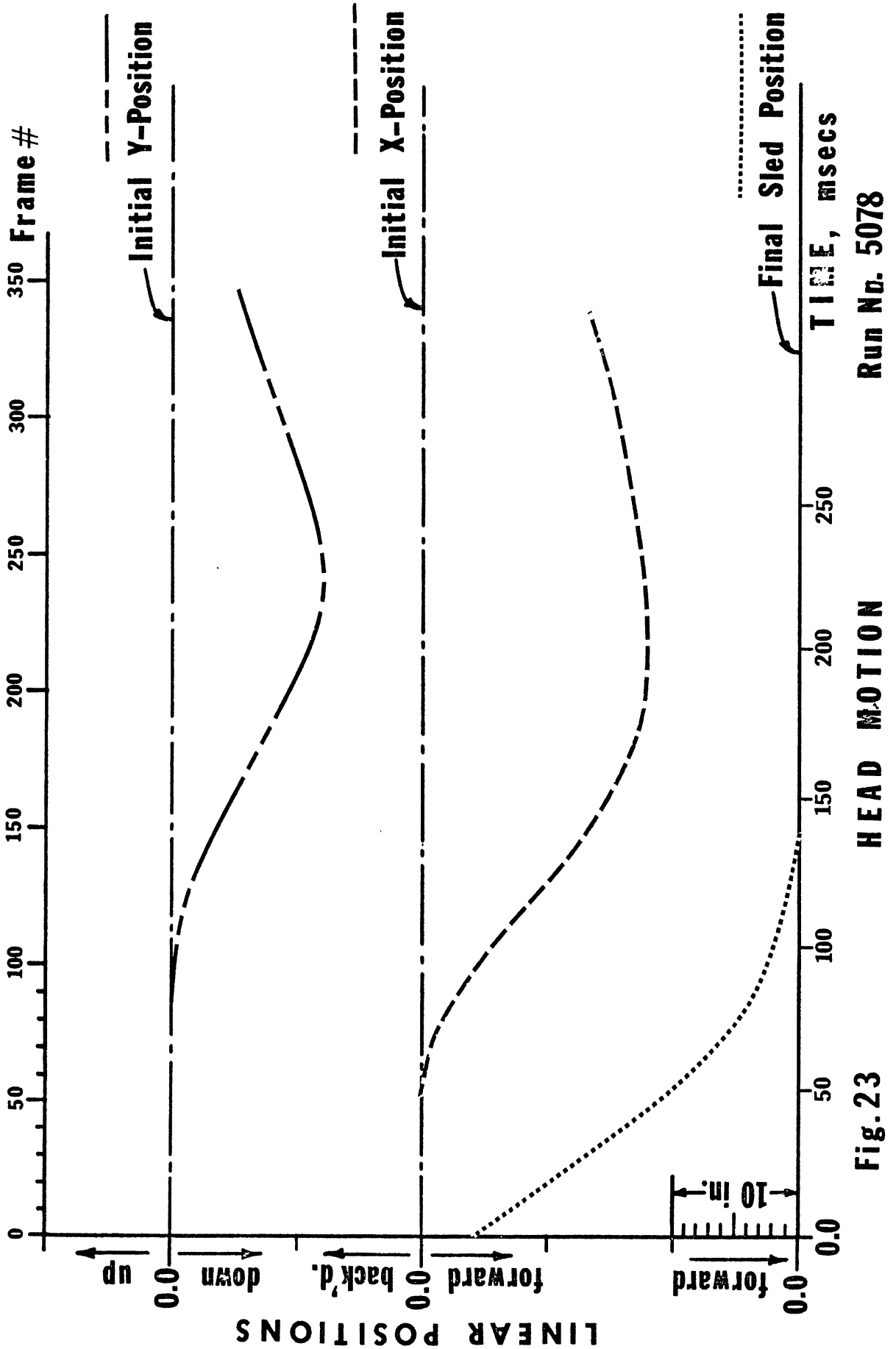

Frame #
0
50
100
150
200
250
300
350
Initial Y-Position
Initial X-Position
Final Sled Position
TIME, msecs
0.0
0.0
0.0
up
down
back'd.
forward
forward
10 in.
LINEAR POSITIONS
HEAD MOTION
Run No. 5078

Fig. 23

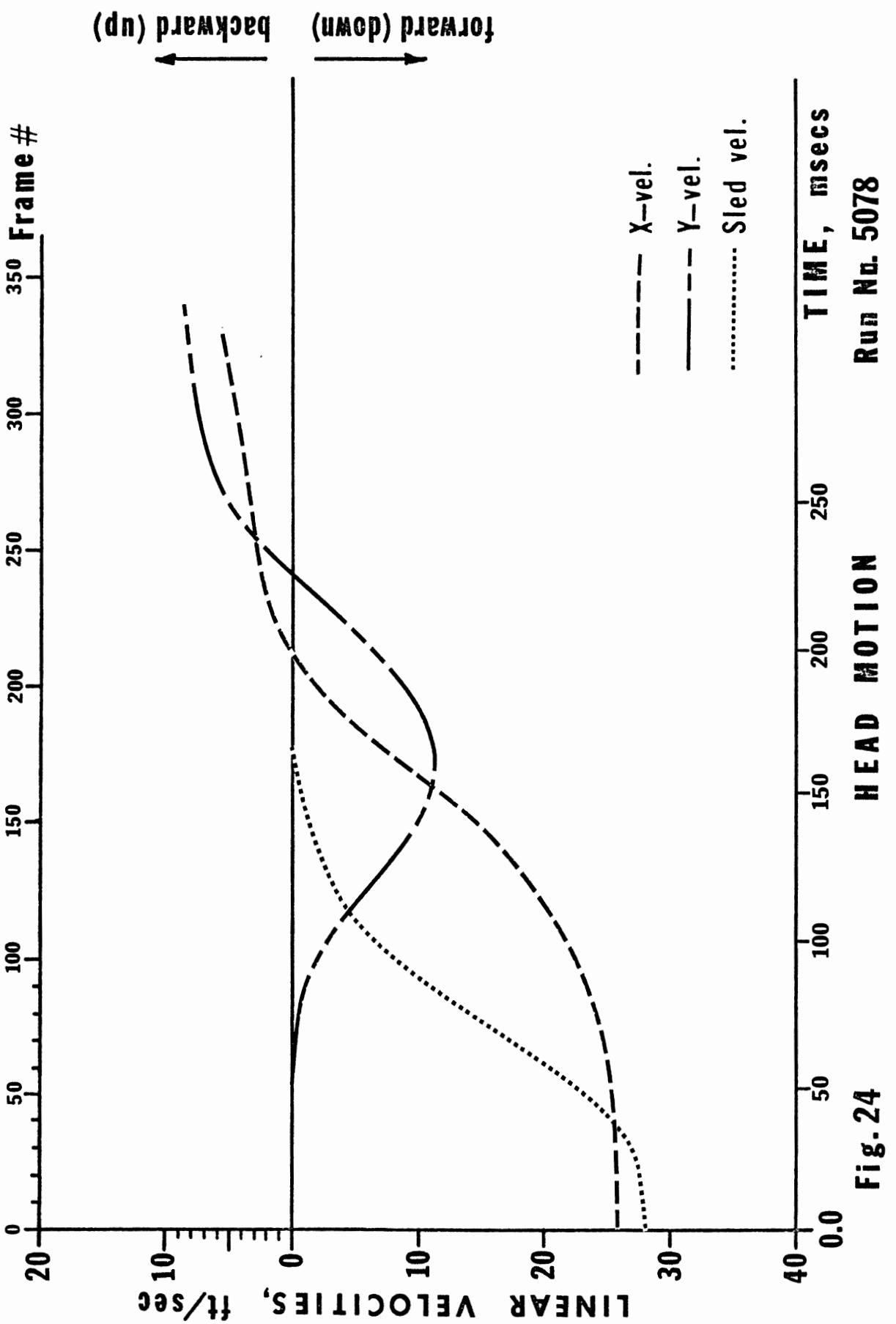
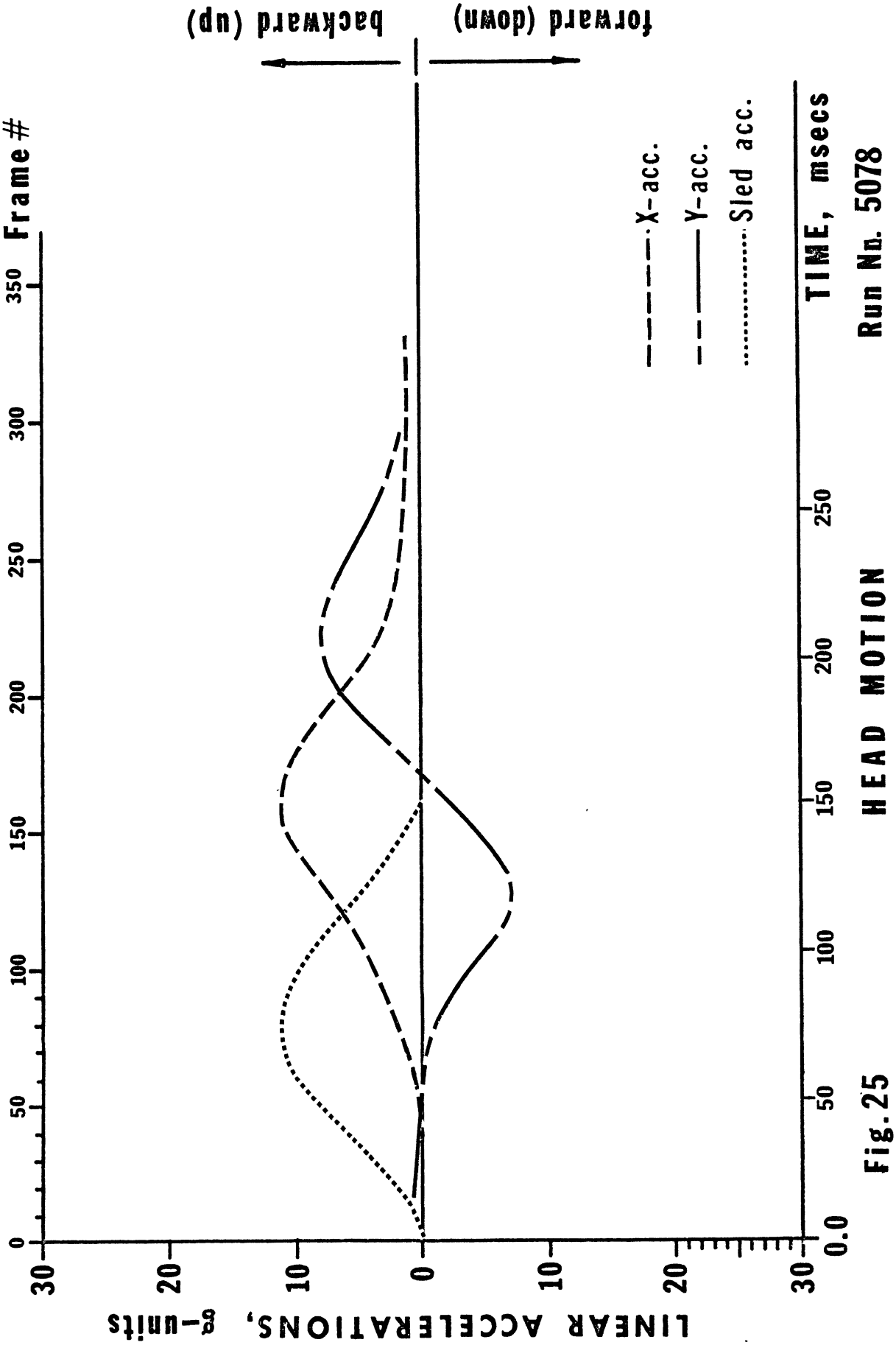

forward (down)
backward (up)
Frame #
0
50
100
150
200
250
300
350
20
10
0
10
20
30
40
0.0
50
100
150
200
250
LINEAR VELOCITIES, ft/sec
TIME, msecs
X-vel.
Y-vel.
Sled vel.
HEAD MOTION
Run No. 5078

Fig. 24



Run No. 5078

HEAD MOTION

Fig. 25

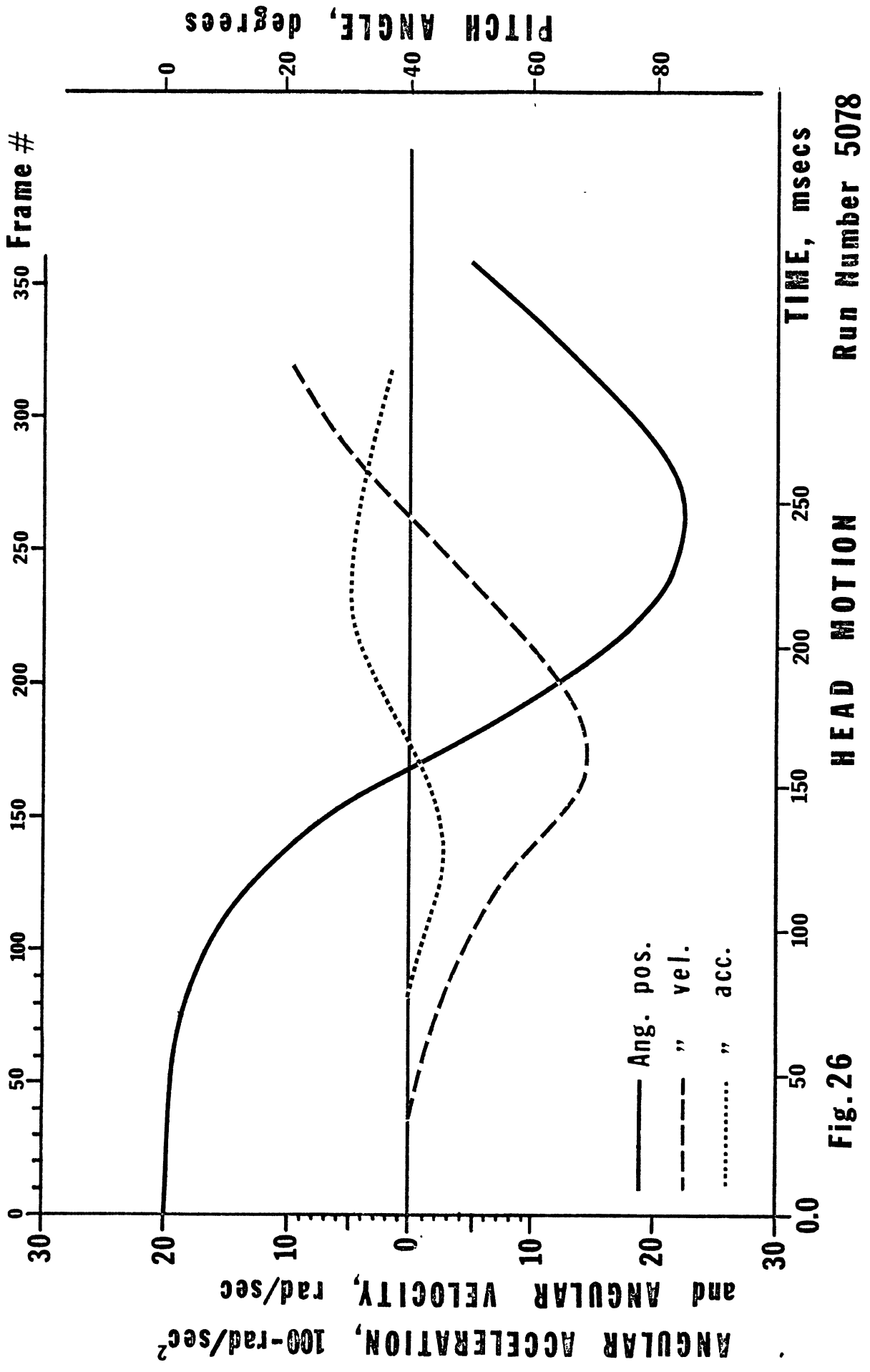

ANGULAR ACCELERATION, 100-rad/sec²
and ANGULAR VELOCITY, rad/sec
PITCH ANGLE, degrees
Frame #
TIME, msecs
HEAD MOTION
Run Number 5078
Ang. pos.
" vel.
" acc.
30
20
10
0
10
20
30
0
50
100
150
200
250
300
350
0.0
50
100
150
200
250
0
20
40
60
80

Fig. 26

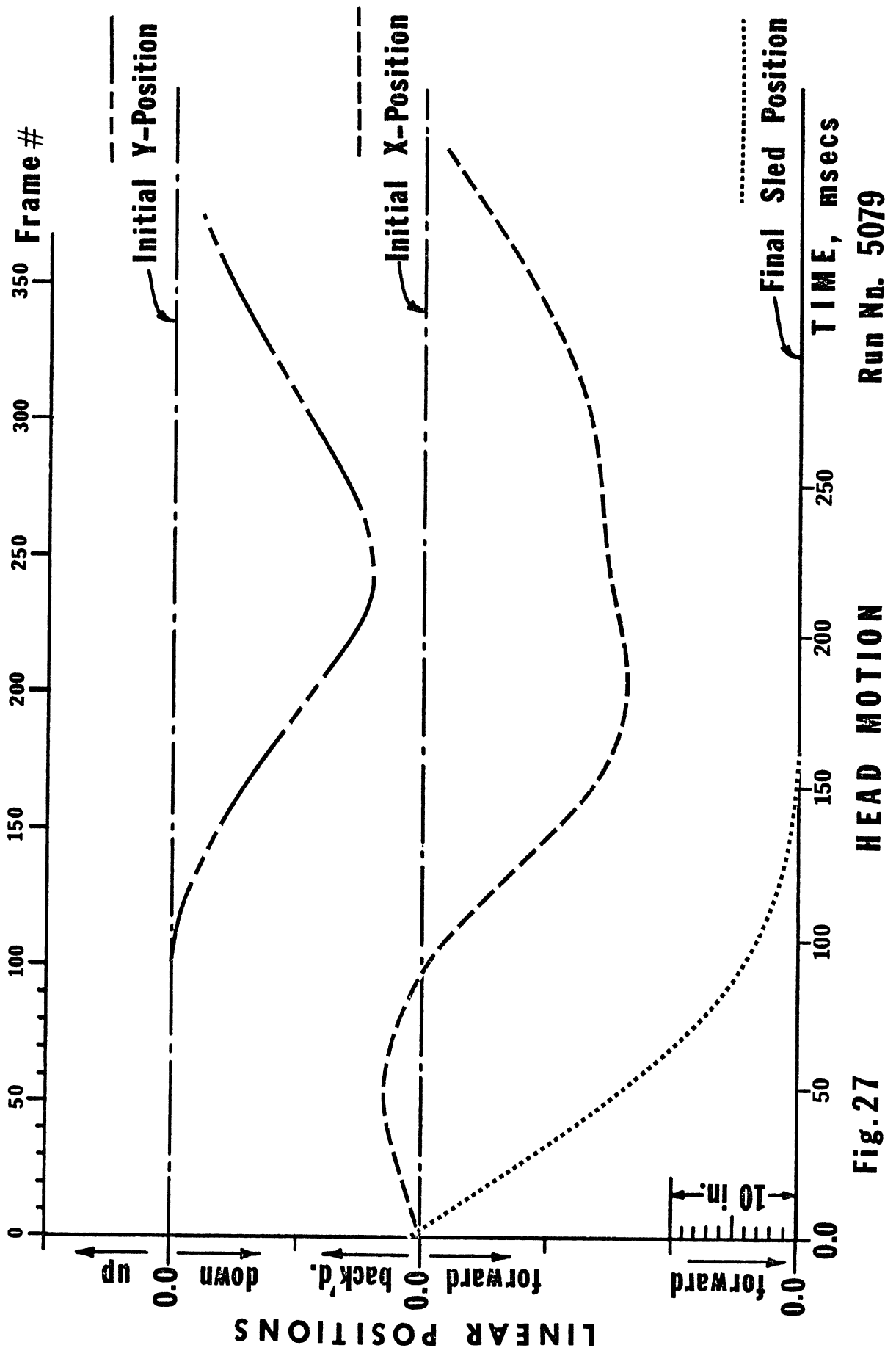

Frame #
0
50
100
150
200
250
300
350
Initial Y-Position
Initial X-Position
Final Sled Position
TIME, msecs
Run No. 5079
HEAD MOTION
LINEAR POSITIONS
up
down
0.0
forward
back'd.
0.0
forward
10 in.
0.0
0.0
0
50
100
150
200
250

Fig. 27

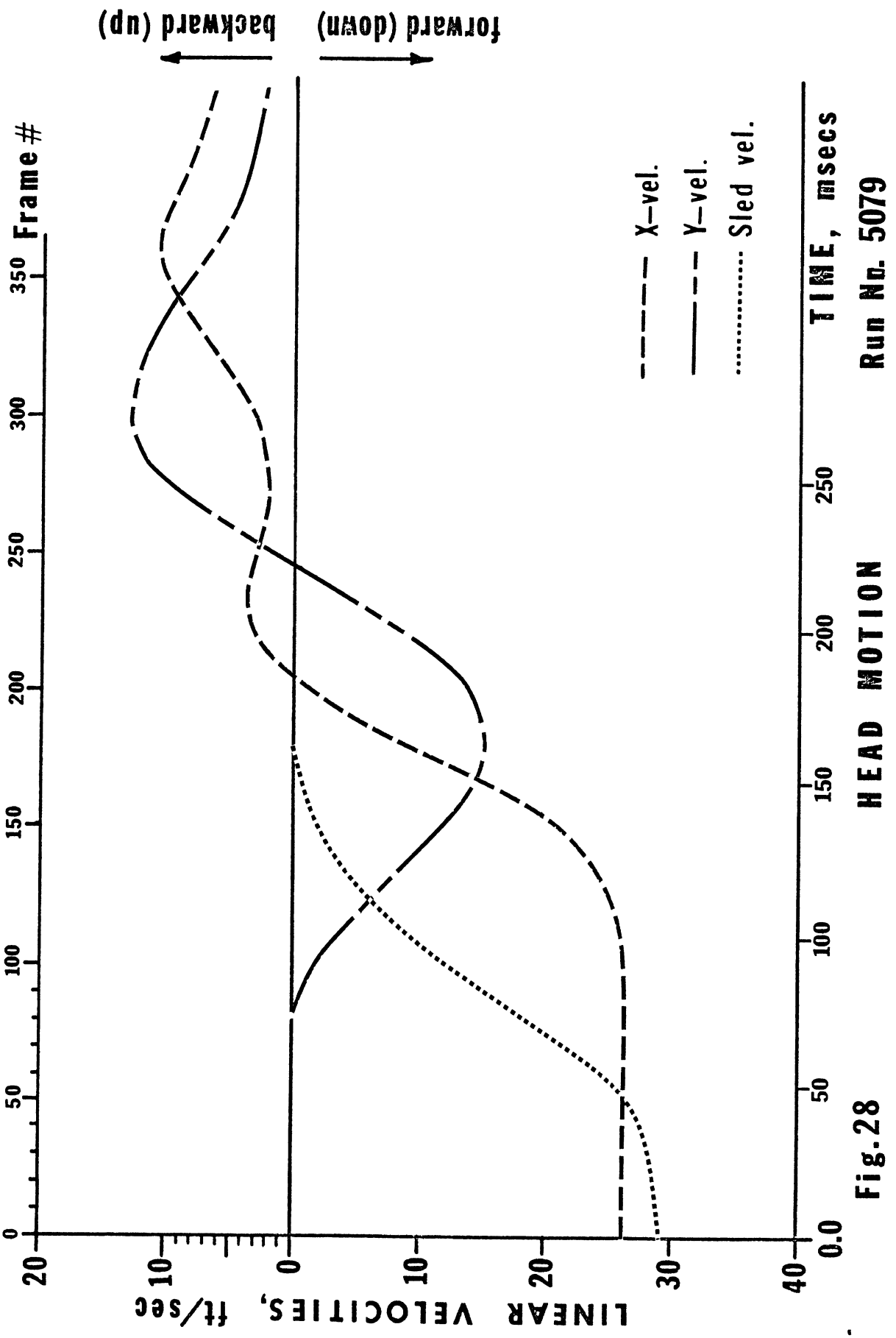

forward (down)
backward (up)
LINEAR VELOCITIES, ft/sec
20
10
0
10
20
30
40
0.0
50
100
150
200
250
300
350
Frame #
0
50
100
150
200
250
TIME, msecs
X-vel.
Y-vel.
Sled vel.
HEAD MOTION
Run No. 5079

Fig.28

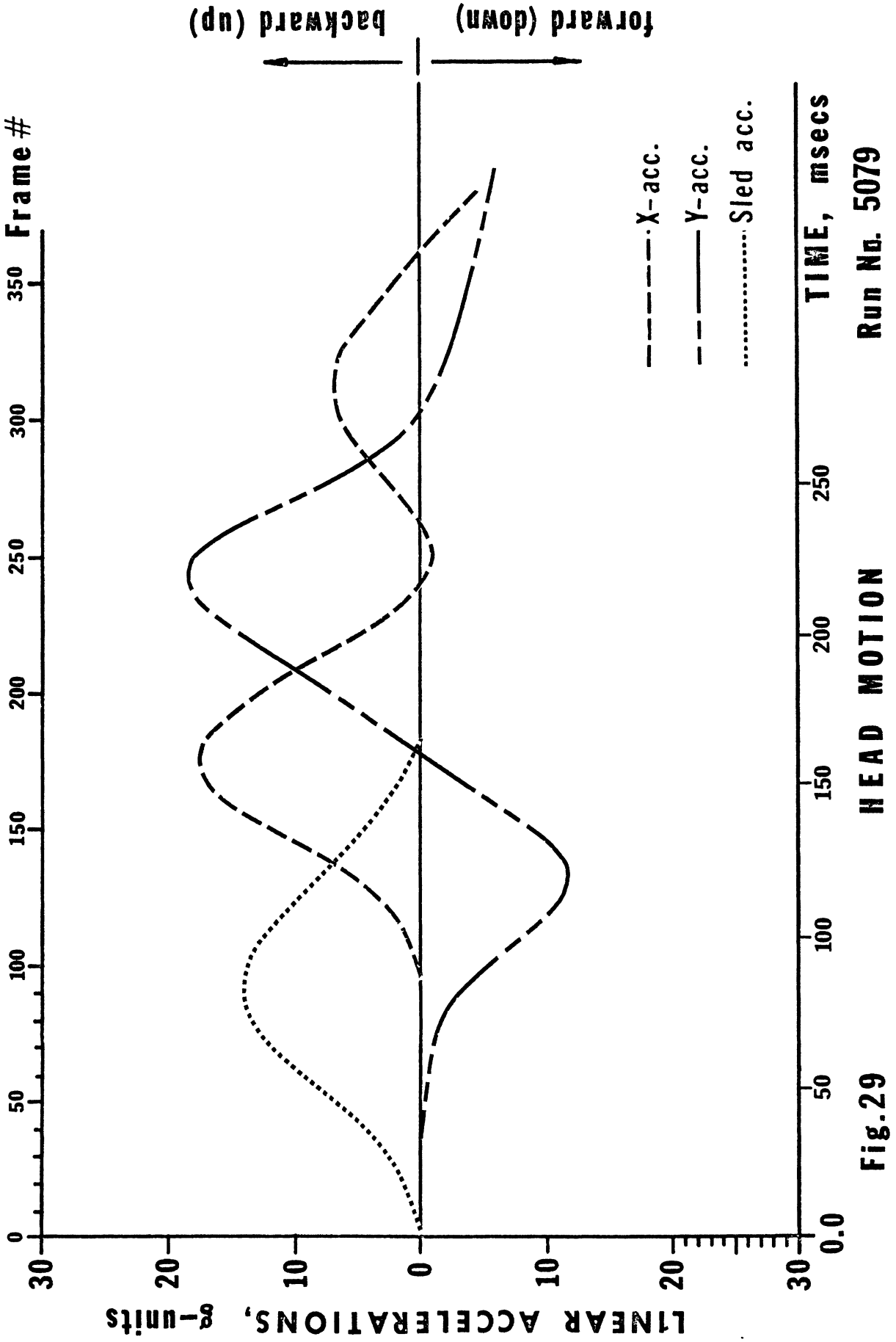

forward (down)
backward (up)
LINEAR ACCELERATIONS, g-units
30
20
10
0
10
20
30
0.0
50
100
150
200
250
TIME, msecs
0
50
100
150
200
250
300
350
Frame #
X-acc.
Y-acc.
Sled acc.
Run No. 5079
HEAD MOTION

Fig.29

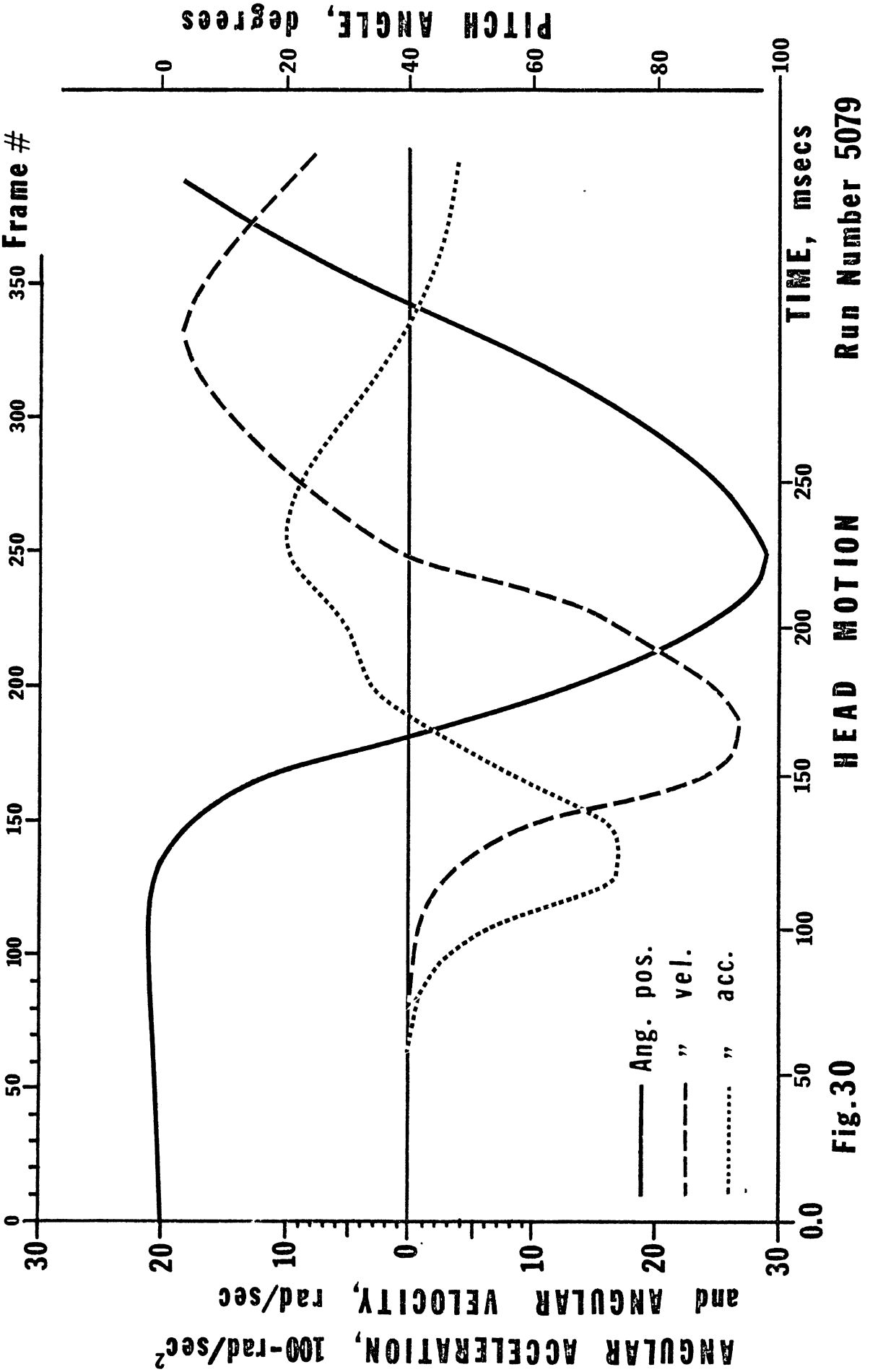

ANGULAR ACCELERATION, 100-rad/sec²
and ANGULAR VELOCITY, rad/sec
PITCH ANGLE, degrees
TIME, msecs
Frame #
Ang. pos.
" vel.
" acc.
HEAD MOTION
Run Number 5079

Fig.30

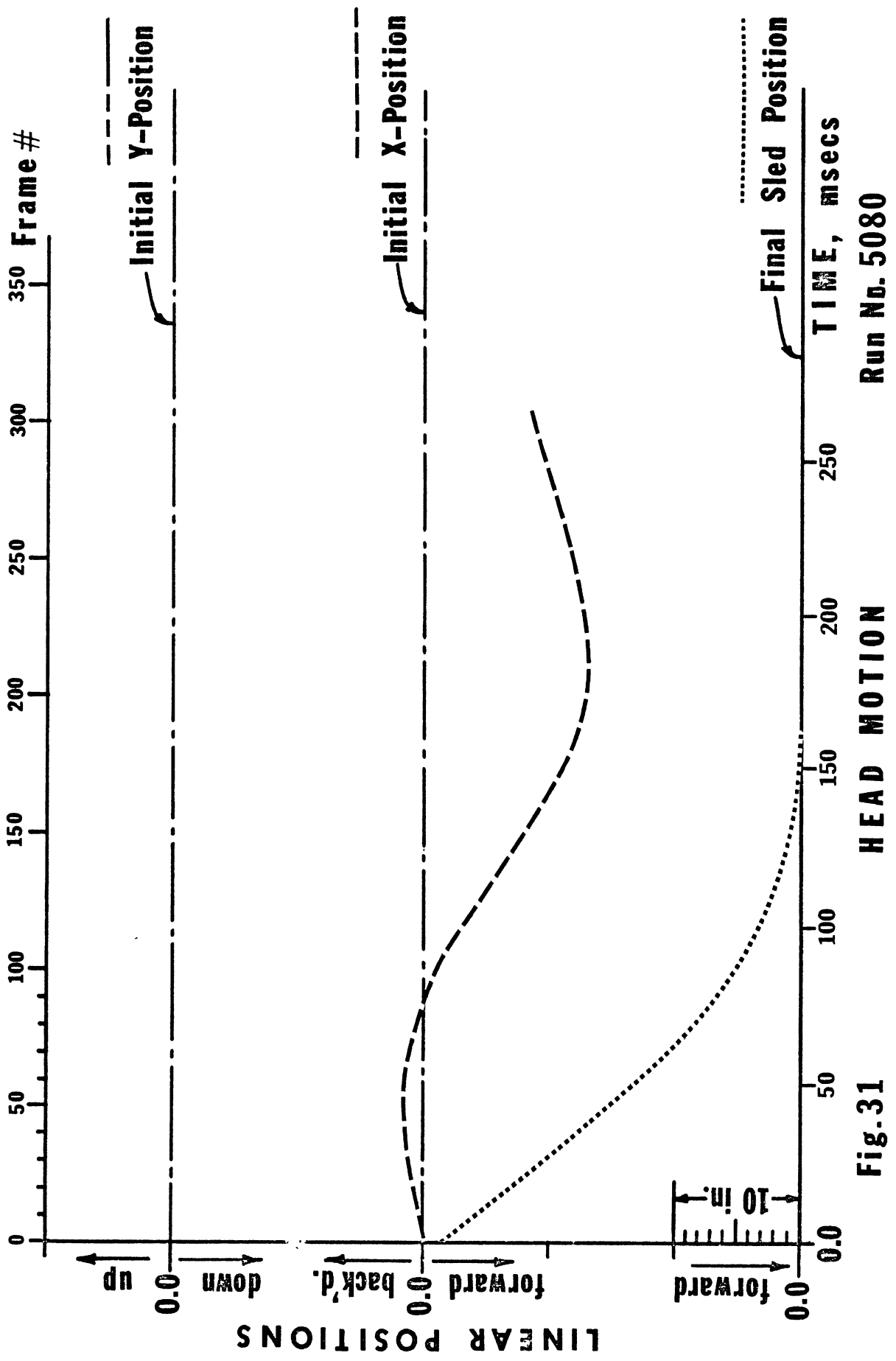

Frame #
0
50
100
150
200
250
300
350
Initial Y-Position
Initial X-Position
Final Sled Position
TIME, msecs
0.0
50
100
150
200
250
Run No. 5080
HEAD MOTION
LINEAR POSITIONS
up
down
0.0
forward
back'd.
0.0
forward
10 in.
0.0

Fig. 31

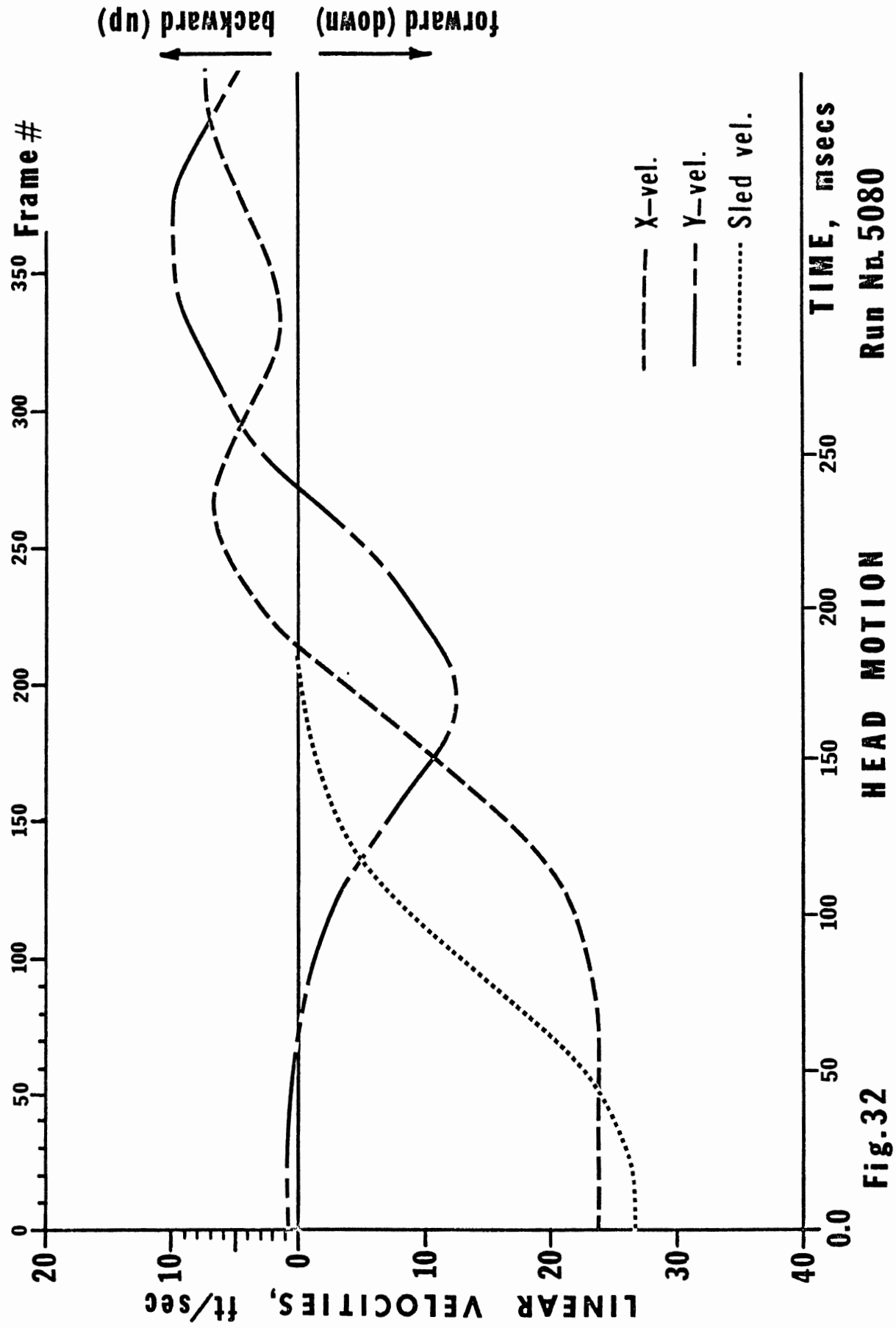

forward (down)
backward (up)
LINEAR VELOCITIES, ft/sec
20
10
0
10
20
30
40
0.0
50
100
150
200
250
TIME, msecs
0
50
100
150
200
250
300
350
Frame #
X-vel.
Y-vel.
Sled vel.
HEAD MOTION
Run No. 5080

Fig.32

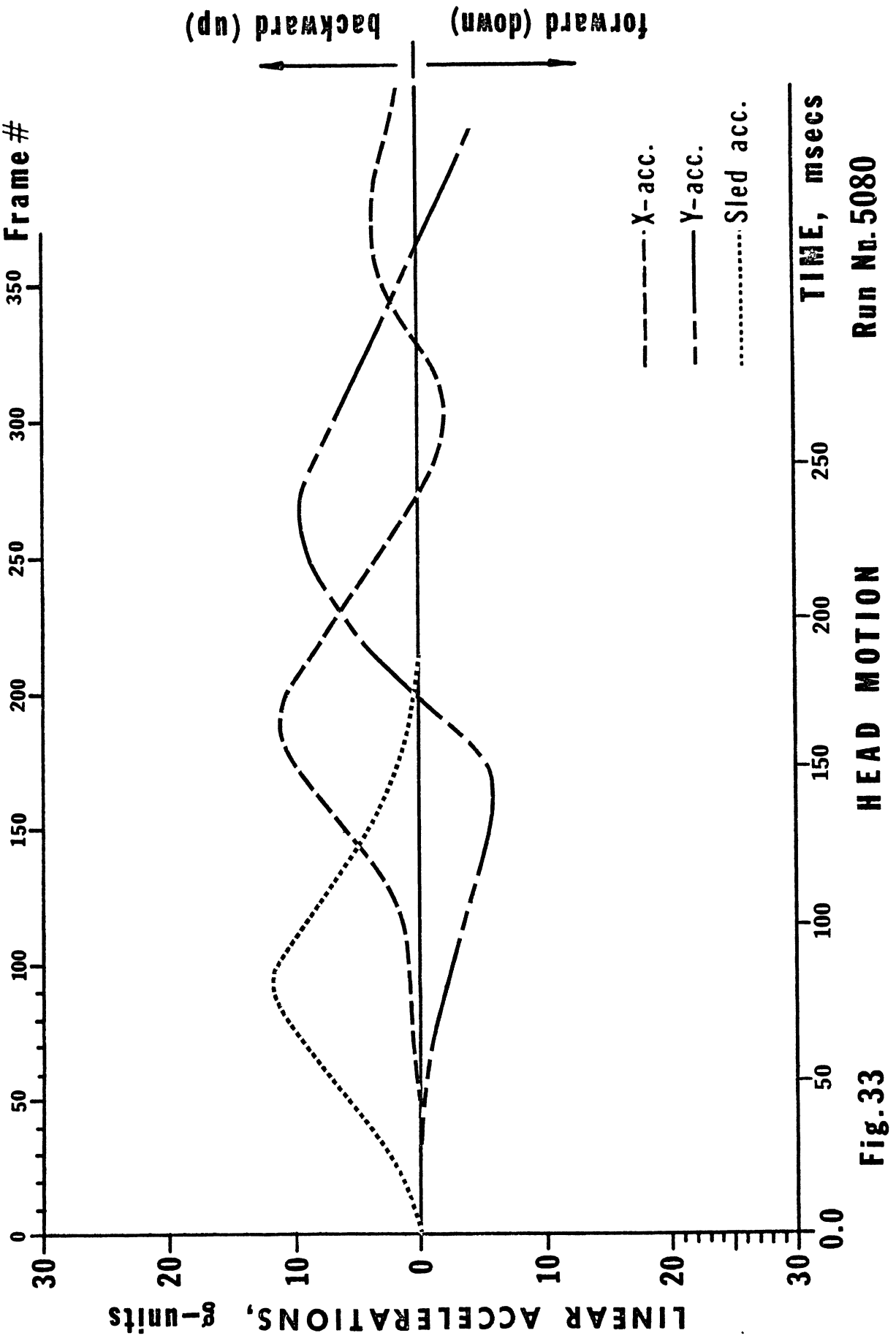

forward (down)
backward (up)
LINEAR ACCELERATIONS, g-units
30
20
10
0
10
20
30
0.0
50
100
150
200
250
TIME, msecs
Run No. 5080
HEAD MOTION
X-acc.
Y-acc.
Sled acc.
0
50
100
150
200
250
300
350
Frame #

Fig. 33

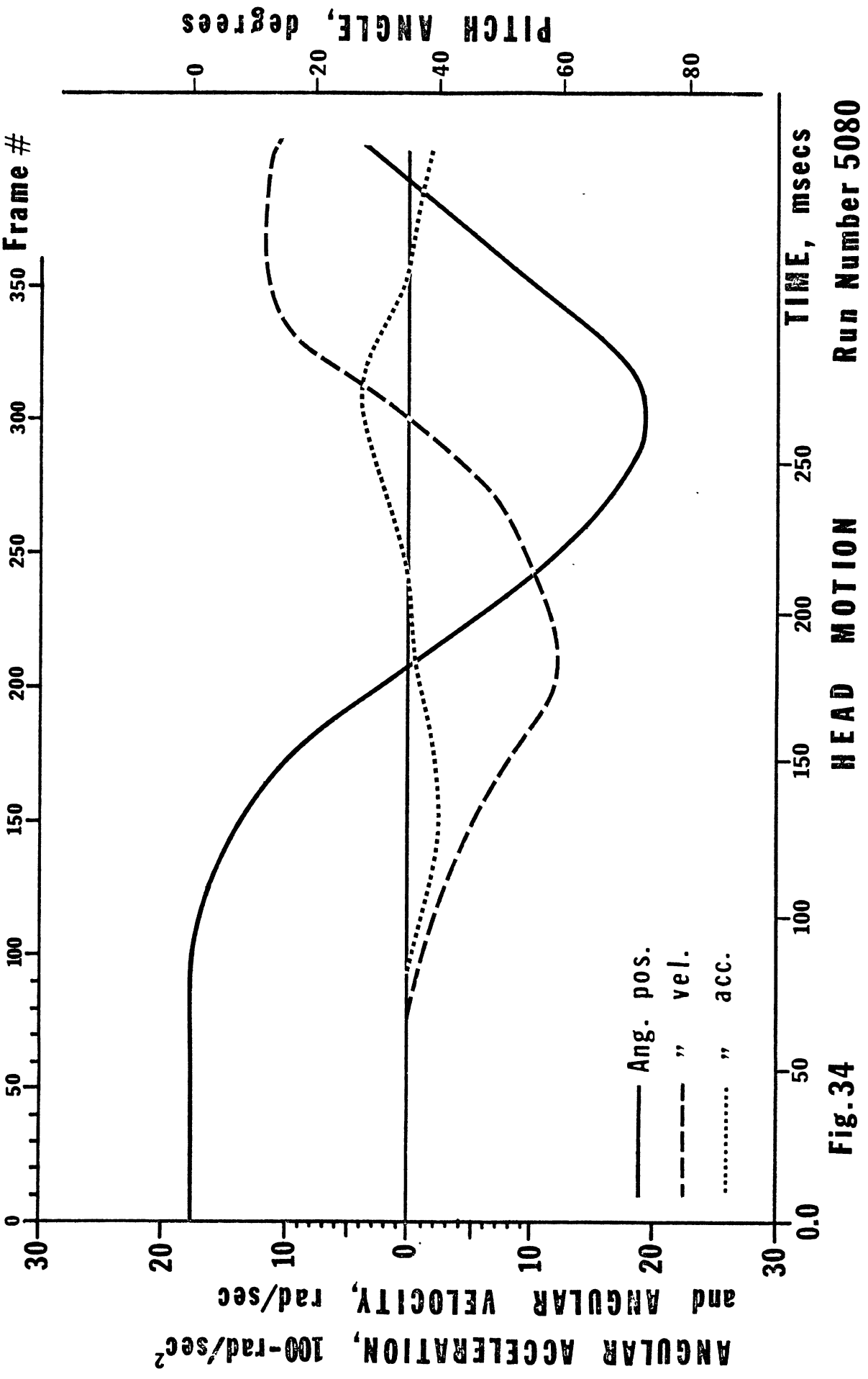

PITCH ANGLE, degrees
0
20
40
60
80
Frame #
0
50
100
150
200
250
300
350
TIME, msecs
0.0
50
100
150
200
250
HEAD MOTION
Run Number 5080
ANGULAR ACCELERATION, 100-rad/sec²
and ANGULAR VELOCITY, rad/sec
30
20
10
0
10
20
30
Ang. pos.
" vel.
" acc.

Fig.34

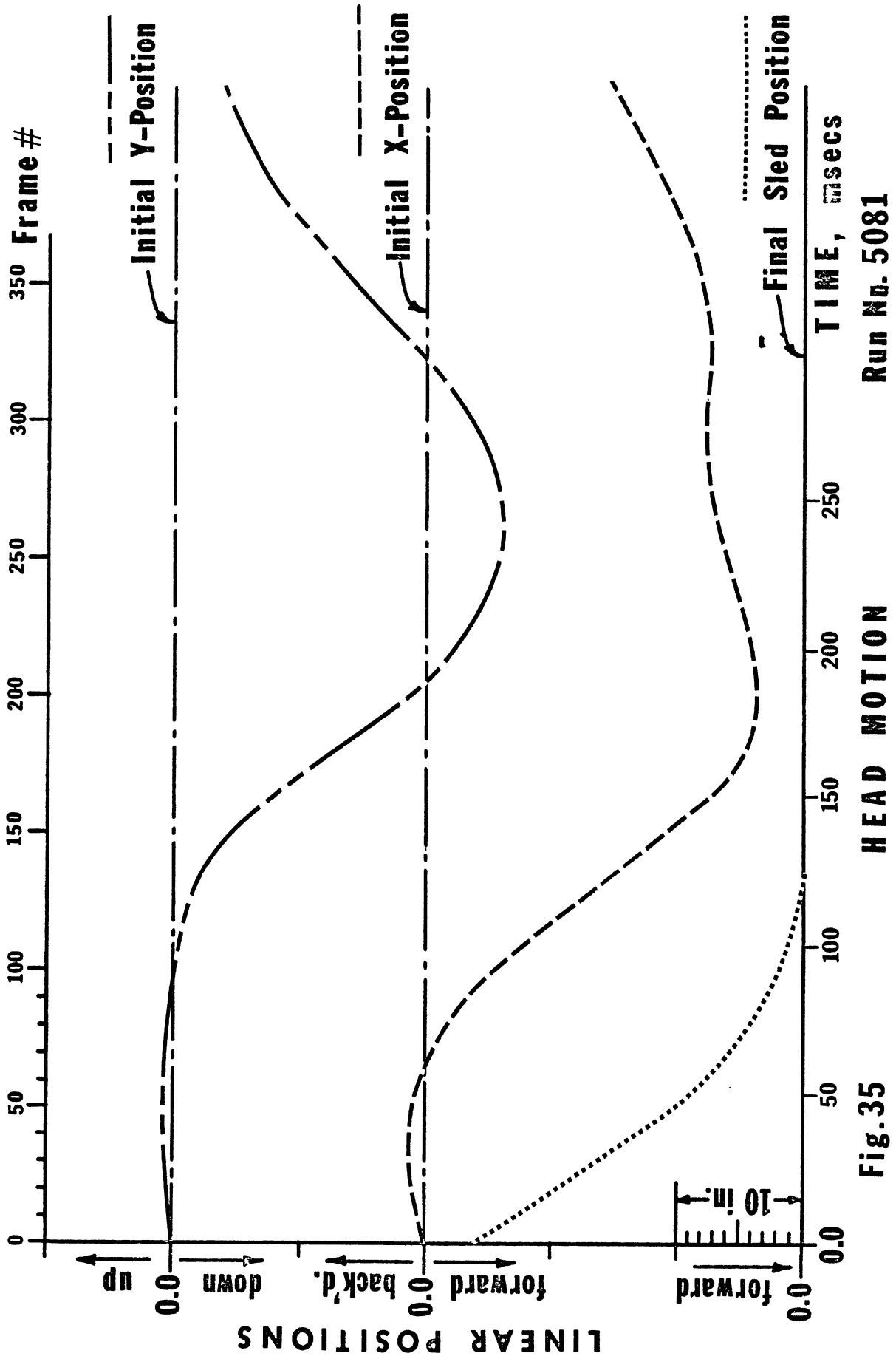

Frame #
0
50
100
150
200
250
300
350
Initial Y-Position
Initial X-Position
Final Sled Position
TIME, msecs
Run No. 5081
HEAD MOTION
LINEAR POSITIONS
up
down
0.0
forward
back'd.
0.0
forward
10 in.
0.0

Fig. 35

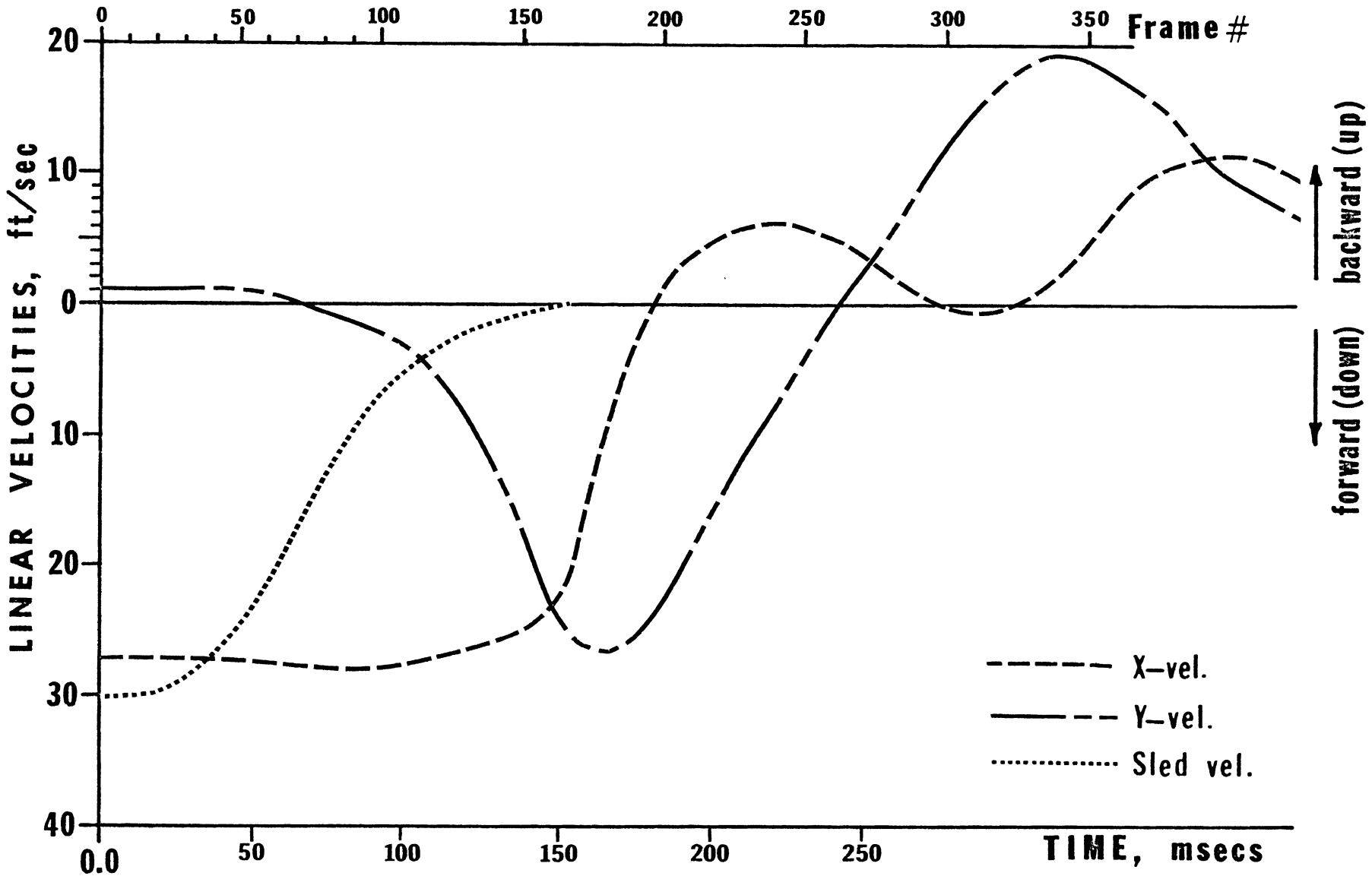


Fig. 36 HEAD MOTION Run Nn. 5081

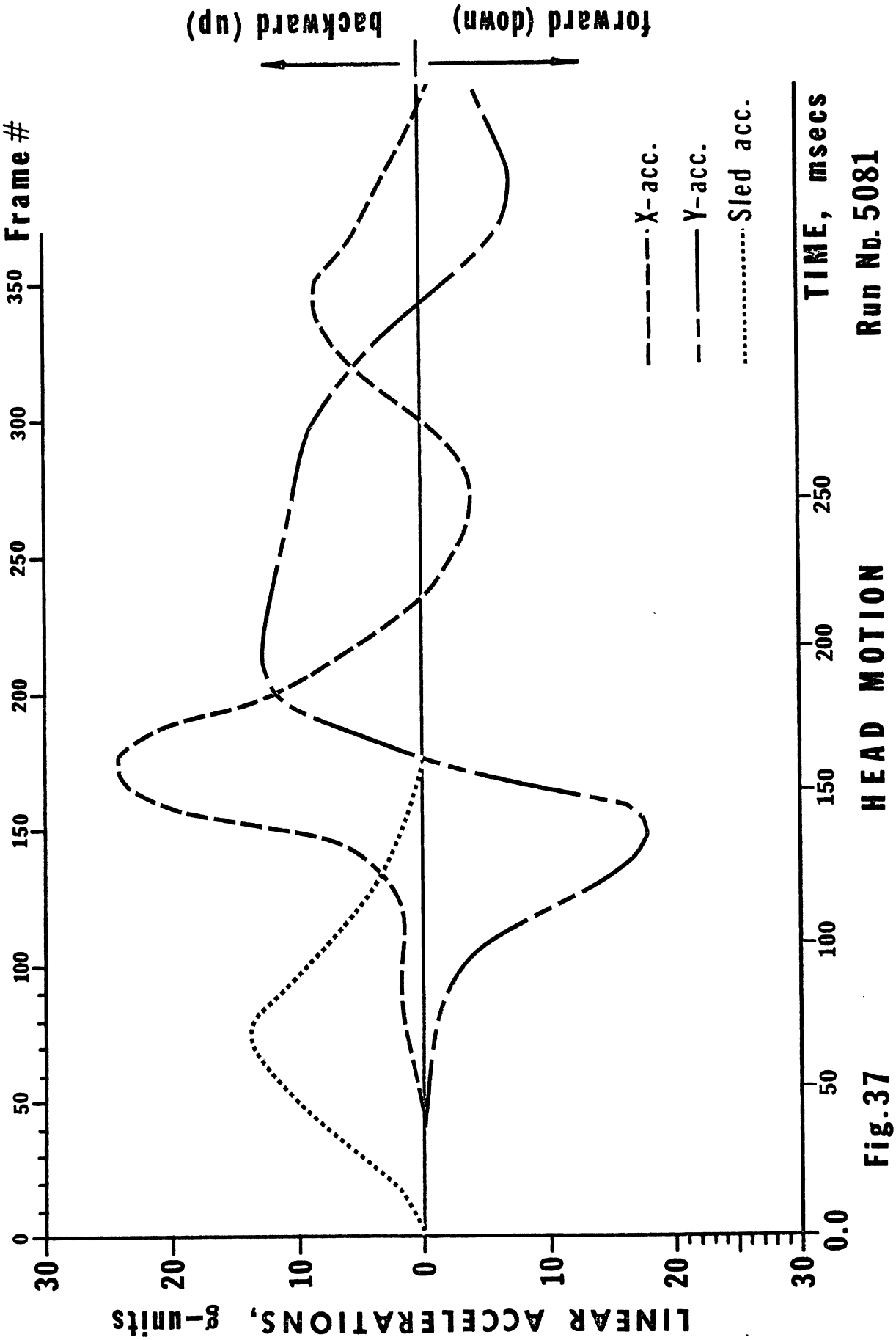

forward (down)
backward (up)
X-acc.
Y-acc.
Sled acc.
TIME, msecs
Run No. 5081
HEAD MOTION
LINEAR ACCELERATIONS, g-units
Frame #
0.0
50
100
150
200
250
300
350
30
20
10
0
10
20
30

Fig.37

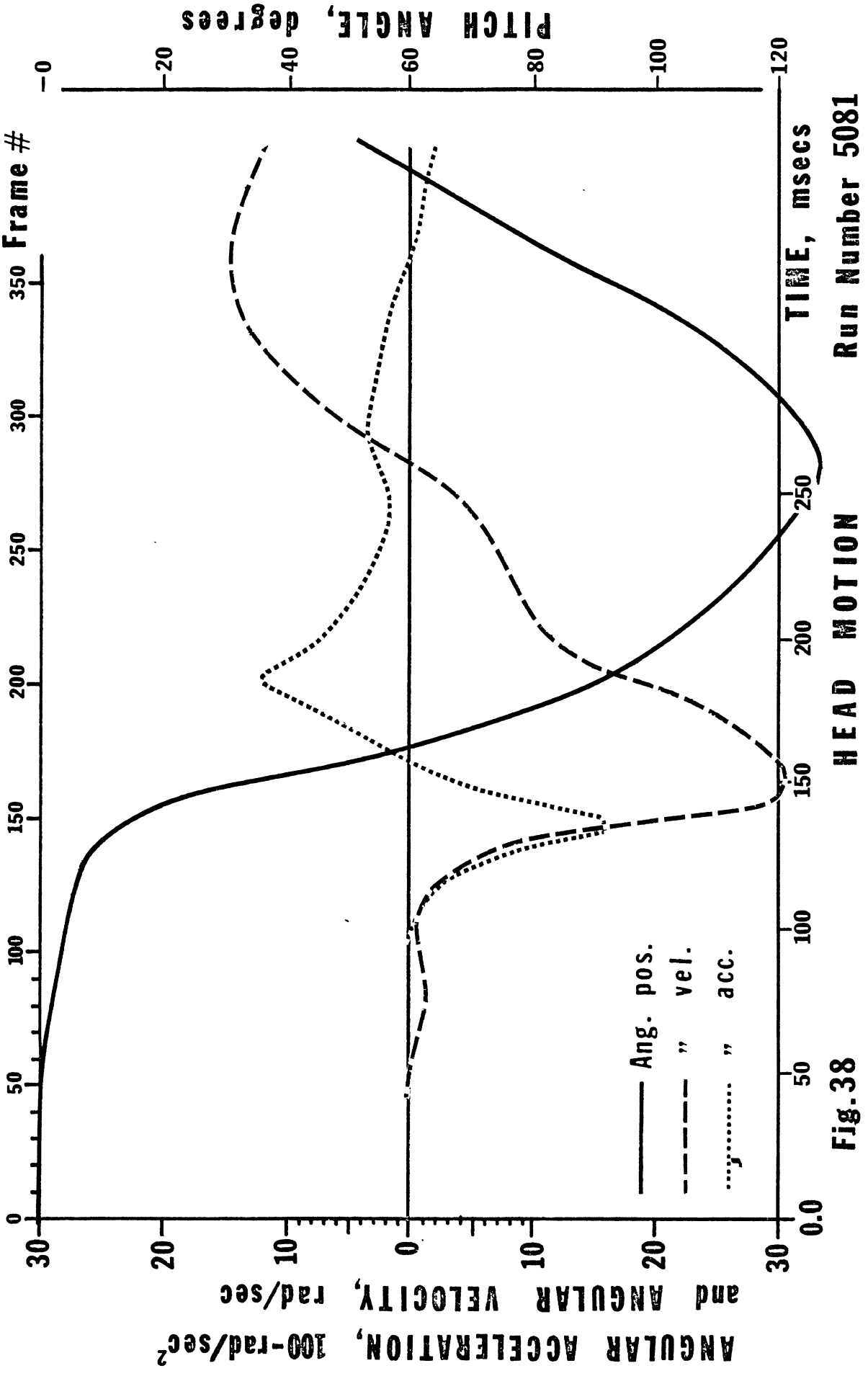

PITCH ANGLE, degrees
0
20
40
60
80
100
120
Frame #
0
50
100
150
200
250
300
350
TIME, msecs
0.0
50
100
150
200
250
HEAD MOTION
Run Number 5081
ANGULAR ACCELERATION, 100-rad/sec²
and ANGULAR VELOCITY, rad/sec
30
20
10
0
10
20
30
Ang. pos.
" vel.
" acc.

Fig.38

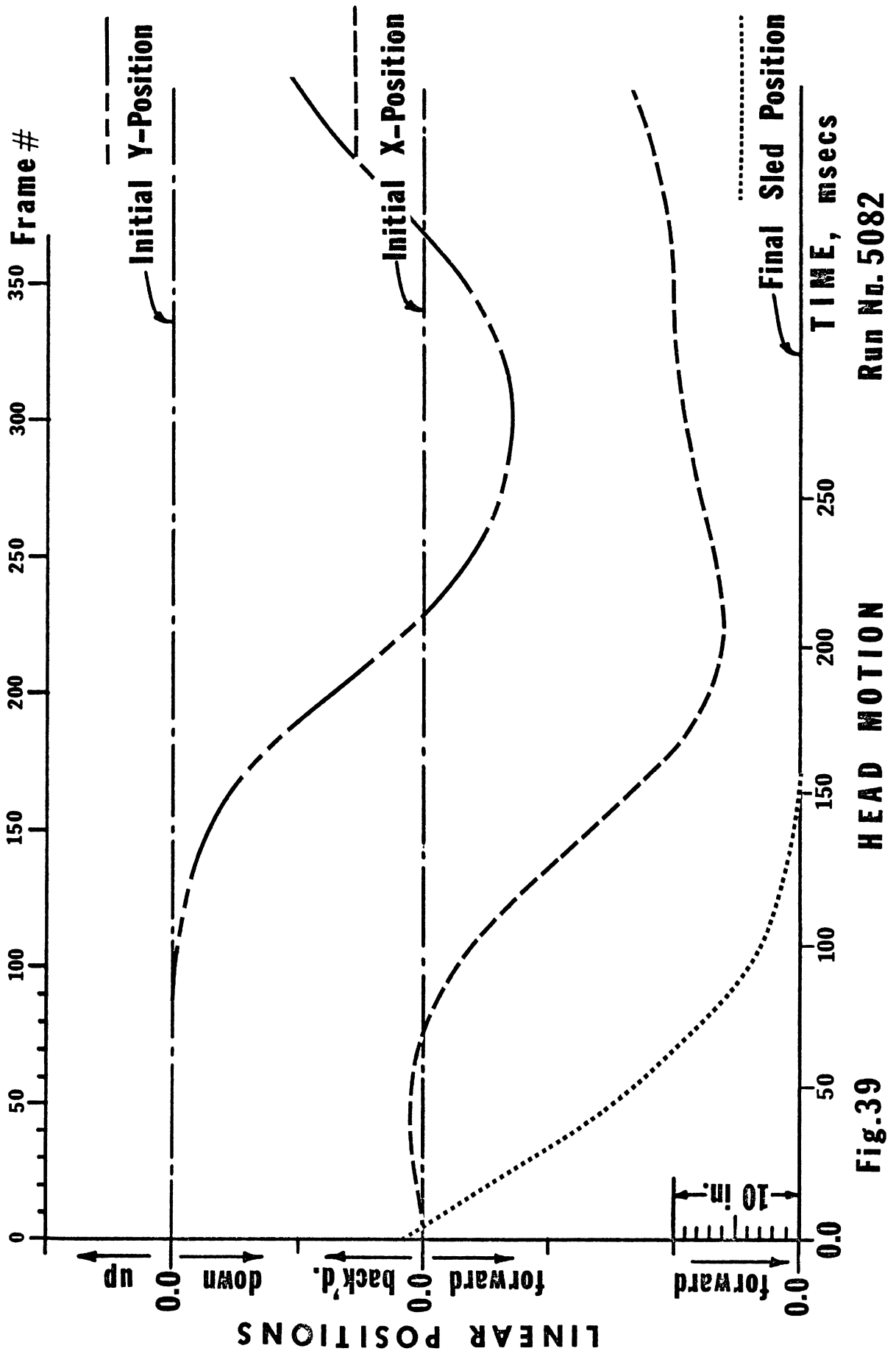

Initial Y-Position
Initial X-Position
Final Sled Position
Frame #
0
50
100
150
200
250
300
350
TIME, msecs
0.0
50
100
150
200
250
HEAD MOTION
Run No. 5082
LINEAR POSITIONS
up
down
0.0
back'd.
forward
0.0
forward
0.0
10 in.

Fig.39

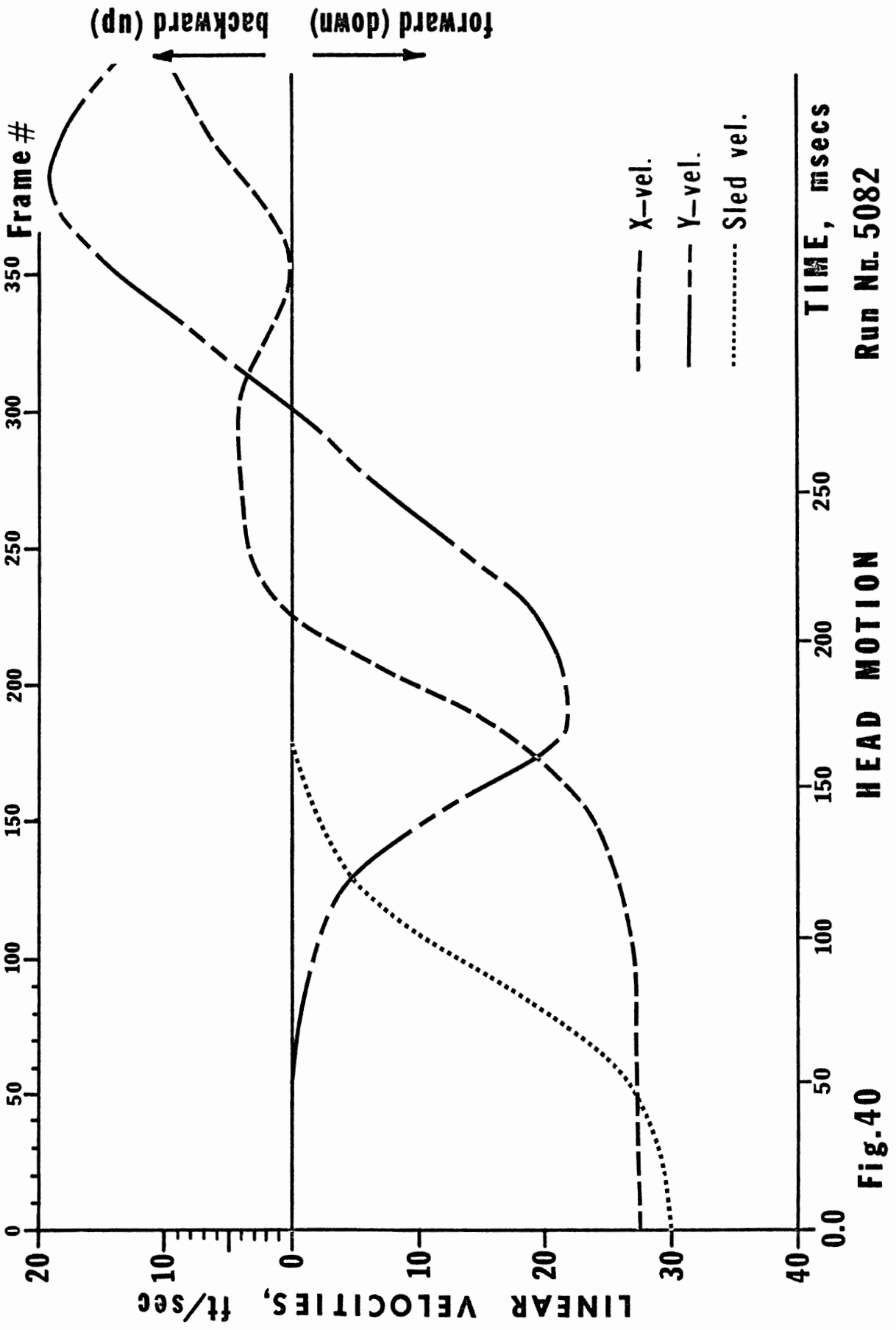

forward (down)
backward (up)
Frame #
0
50
100
150
200
250
300
350
LINEAR VELOCITIES, ft/sec
20
10
0
10
20
30
40
0.0
50
100
150
200
250
TIME, msecs
X-vel.
Y-vel.
Sled vel.
HEAD MOTION
Run No. 5082

Fig.40

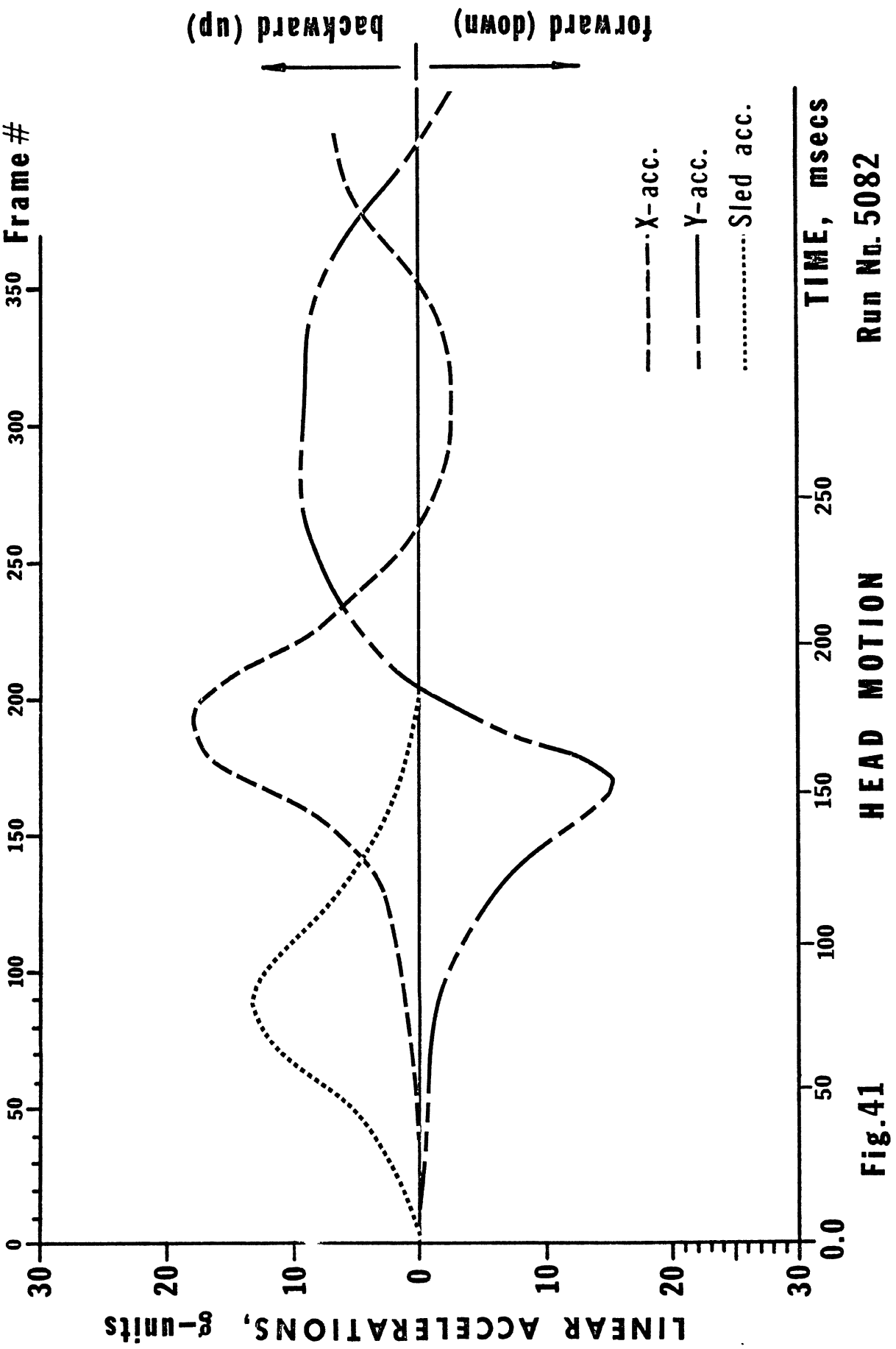

forward (down)
backward (up)
LINEAR ACCELERATIONS, g-units
30
20
10
0
10
20
30
0.0
50
100
150
200
250
TIME, msecs
0
50
100
150
200
250
300
350
Frame #
X-acc.
Y-acc.
Sled acc.
Run No. 5082
HEAD MOTION

Fig.41

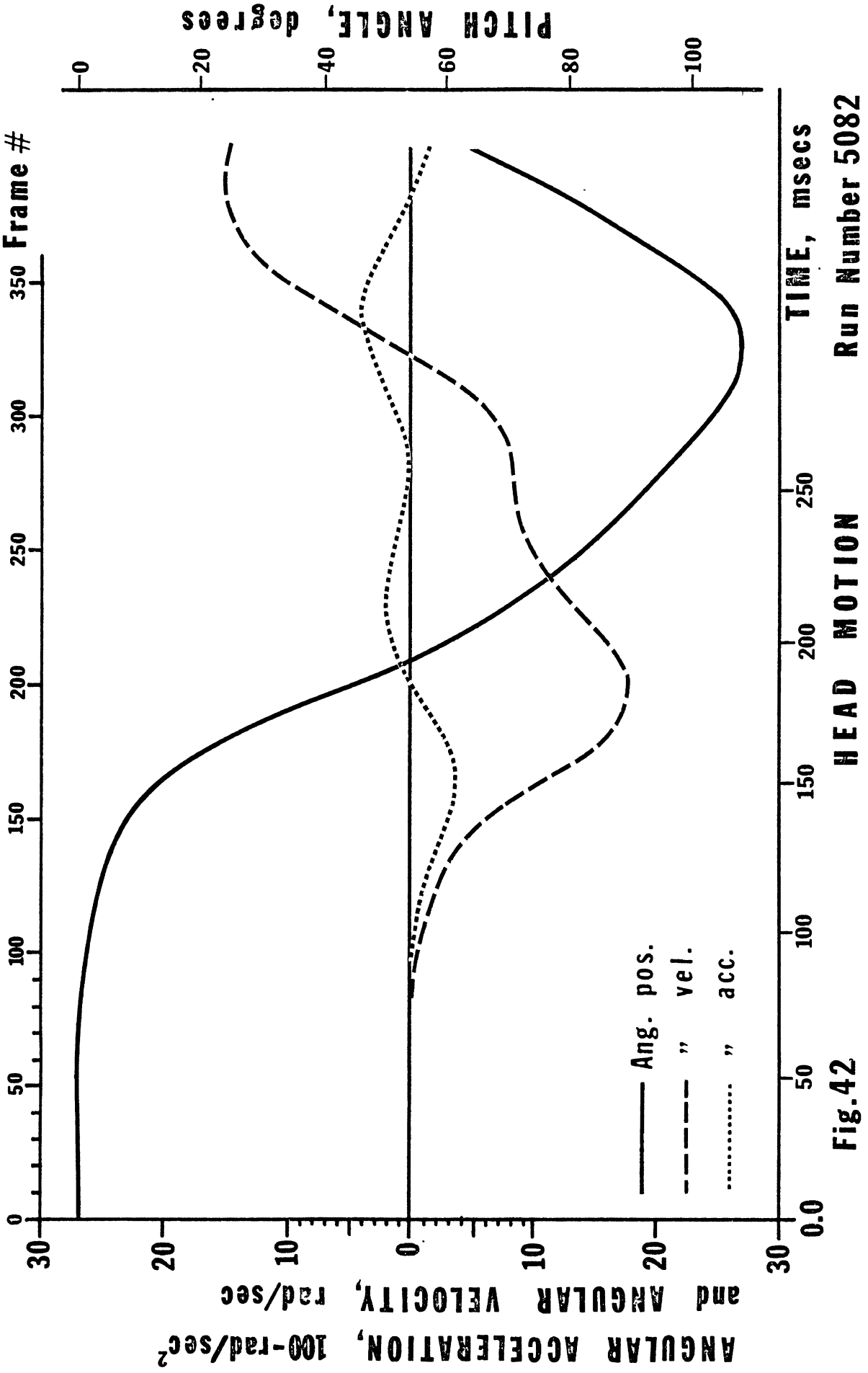

PITCH ANGLE, degrees
0
20
40
60
80
100
Frame #
0
50
100
150
200
250
300
350
TIME, msecs
0.0
50
100
150
200
250
ANGULAR ACCELERATION, 100-rad/sec²
and ANGULAR VELOCITY, rad/sec
30
20
10
0
10
20
30
Ang. pos.
" vel.
" acc.
HEAD MOTION
Run Number 5082

Fig.42

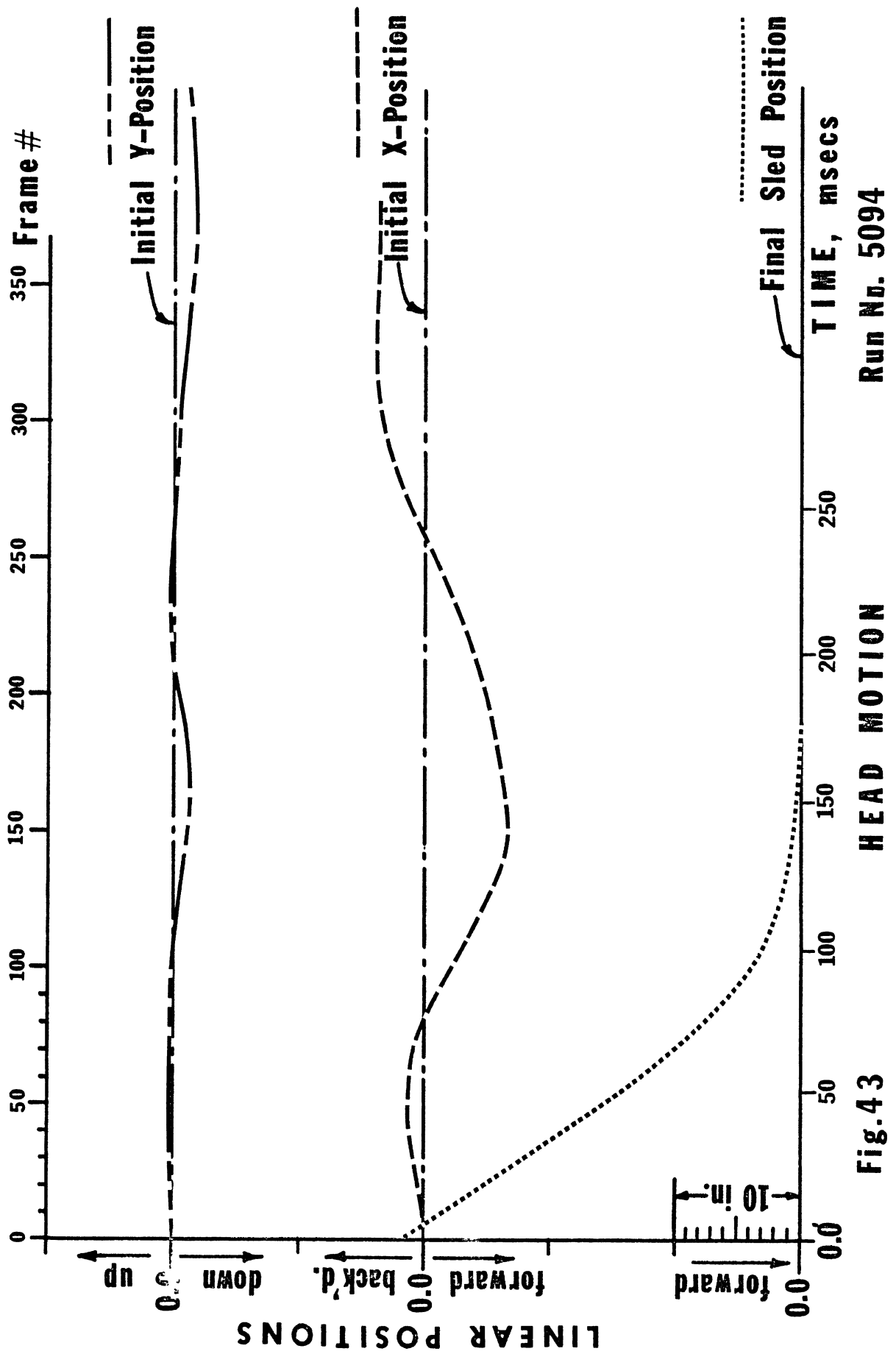


Fig. 43 HEAD MOTION

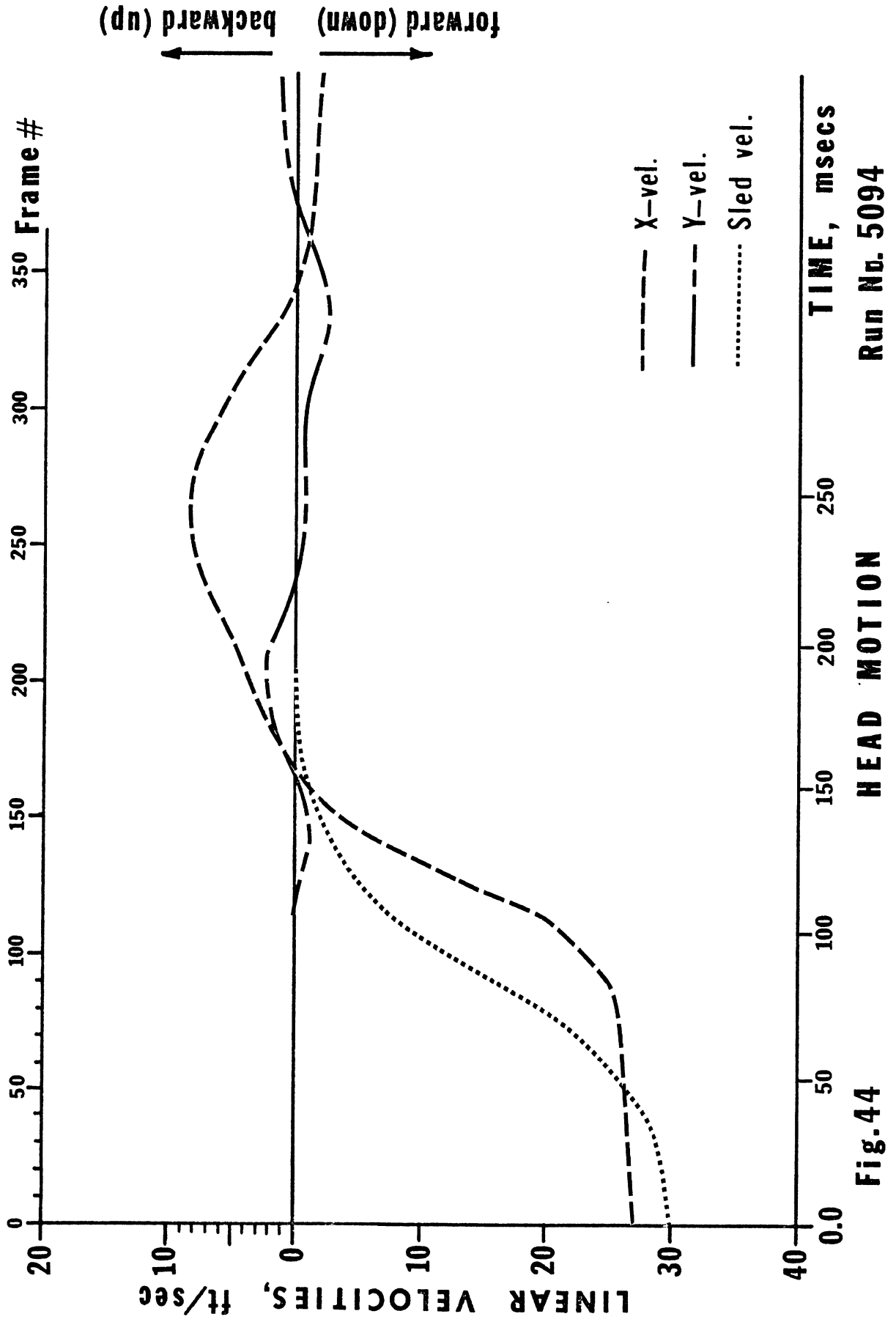

forward (down)
backward (up)
LINEAR VELOCITIES, ft/sec
20
10
0
10
20
30
40
0.0
50
100
150
200
250
TIME, msecs
0
50
100
150
200
250
300
350
Frame #
X-vel.
Y-vel.
Sled vel.
HEAD MOTION
Run No. 5094

Fig.44

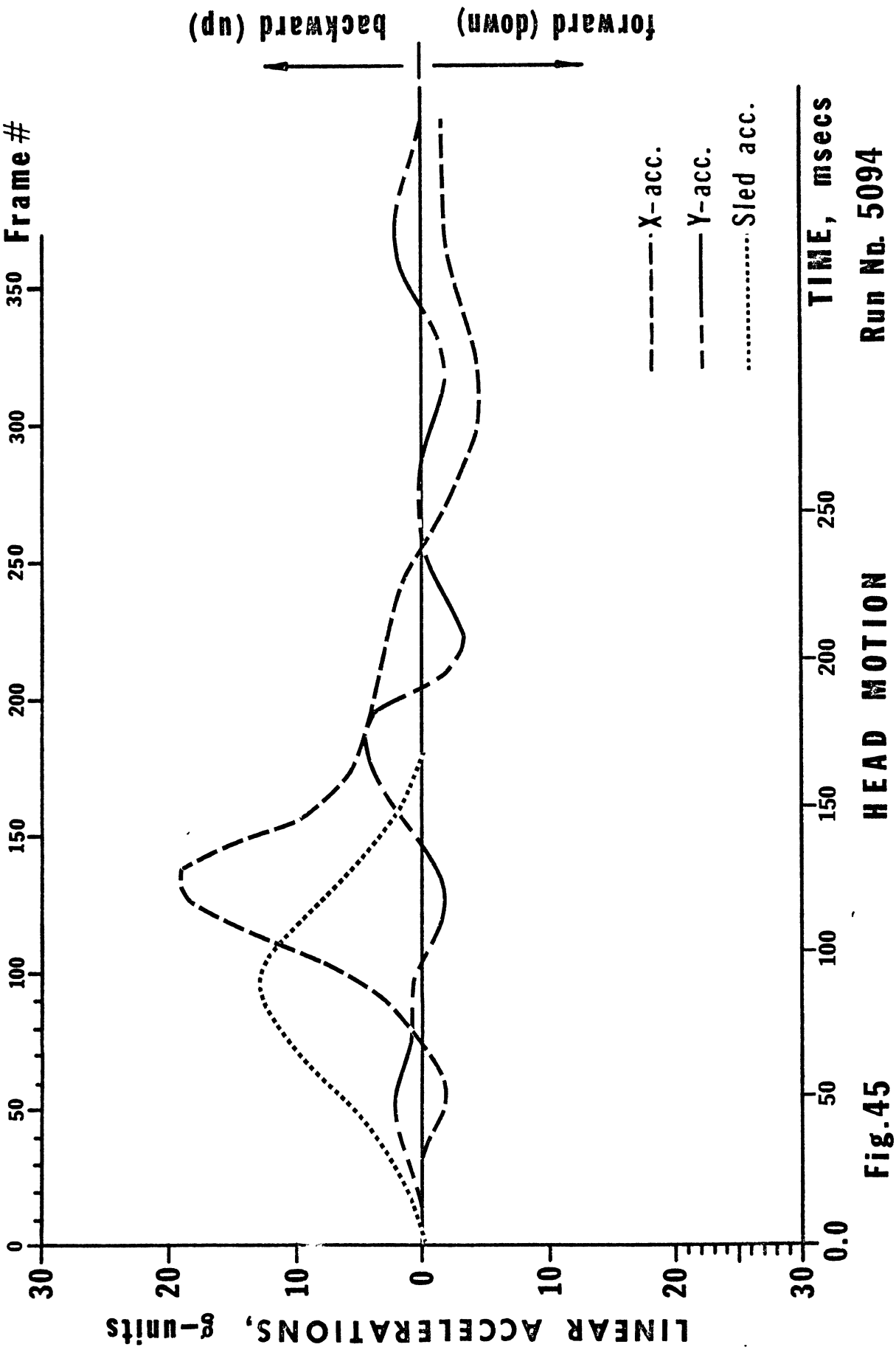

forward (down)
backward (up)
LINEAR ACCELERATIONS, g-units
30
20
10
0
10
20
30
0.0
50
100
150
200
250
TIME, msecs
Run No. 5094
HEAD MOTION
X-acc.
Y-acc.
Sled acc.
0
50
100
150
200
250
300
350
Frame #

Fig.45

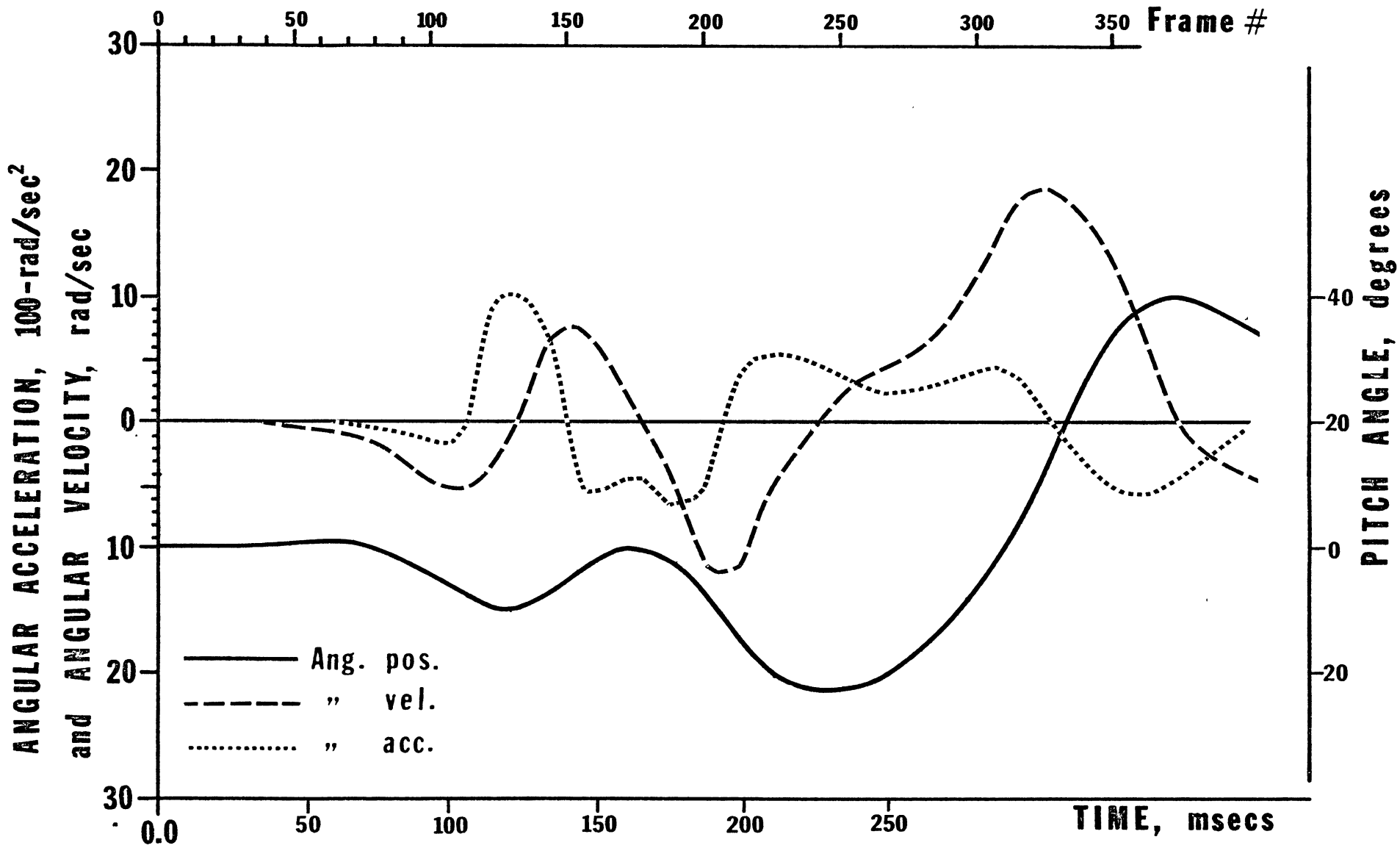


Fig.46 HEAD MOTION Run Number 5094

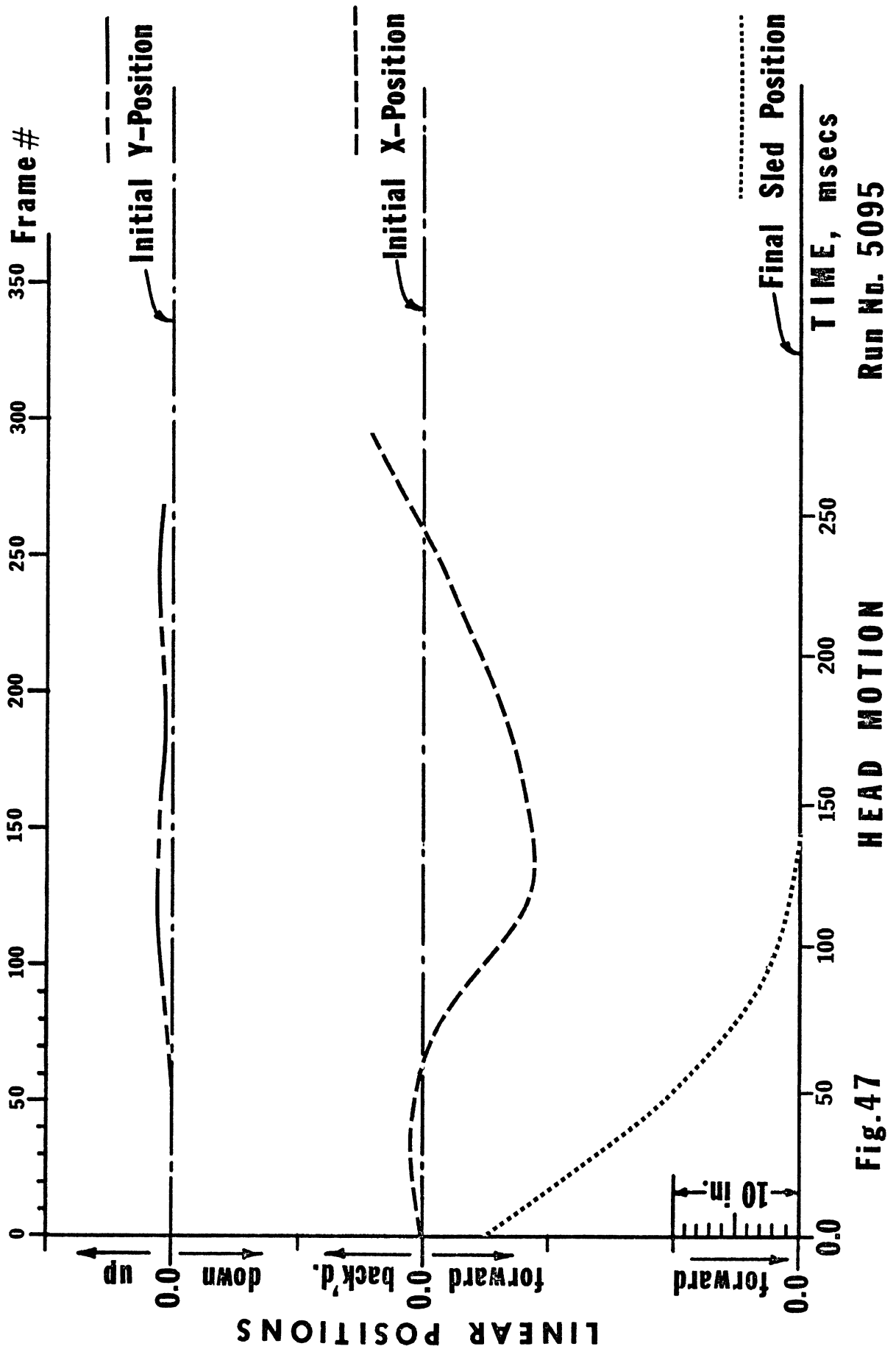

Frame #
0
50
100
150
200
250
300
350
Initial Y-Position
Initial X-Position
Final Sled Position
TIME, msecs
Run No. 5095
HEAD MOTION
LINEAR POSITIONS
up
down
0.0
back'd.
forward
0.0
forward
0.0
10 in.
0.0
50
100
150
200
250

Fig.47

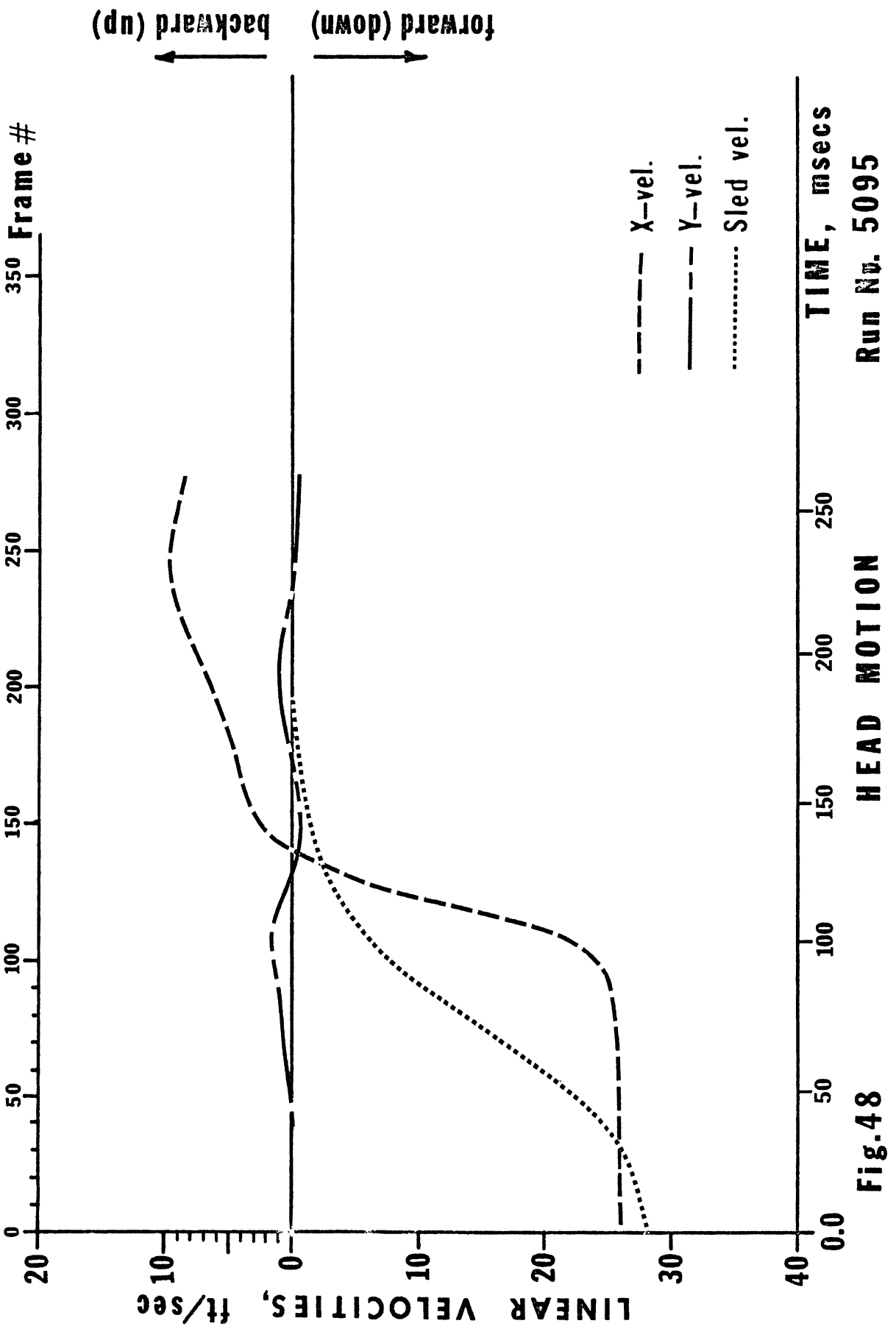

forward (down)
backward (up)
LINEAR VELOCITIES, ft/sec
20
10
0
10
20
30
40
0.0
50
100
150
200
250
300
350
Frame #
0
50
100
150
200
250
TIME, msecs
X-vel.
Y-vel.
Sled vel.
HEAD MOTION
Run No. 5095

Fig.48

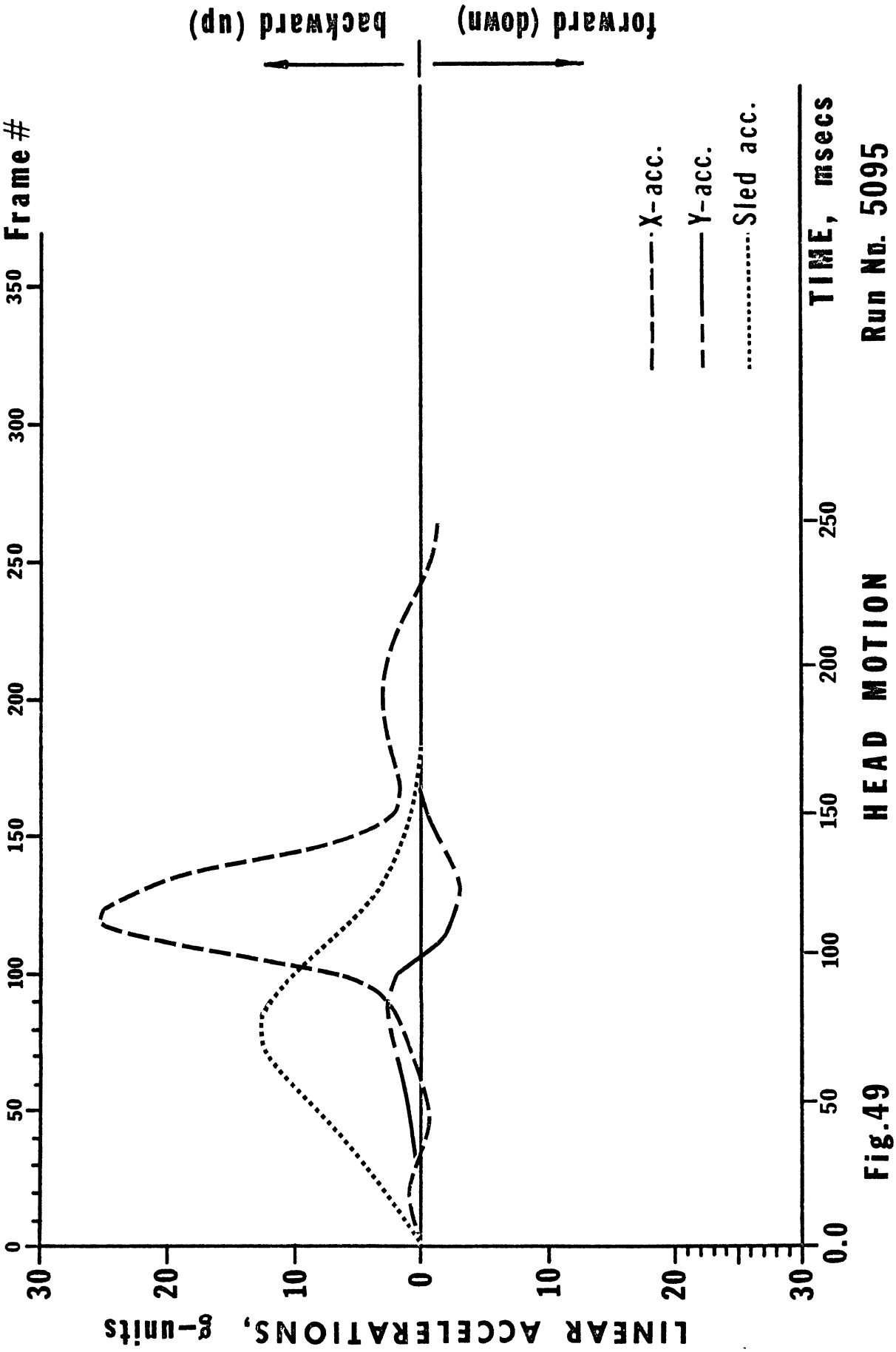

backward (up)
forward (down)
X-acc.
Y-acc.
Sled acc.
TIME, msecs
Frame #
LINEAR ACCELERATIONS, g-units
HEAD MOTION
Run No. 5095
0.0
50
100
150
200
250
300
350
0
50
100
150
200
250
30
20
10
0
10
20
30

Fig.49

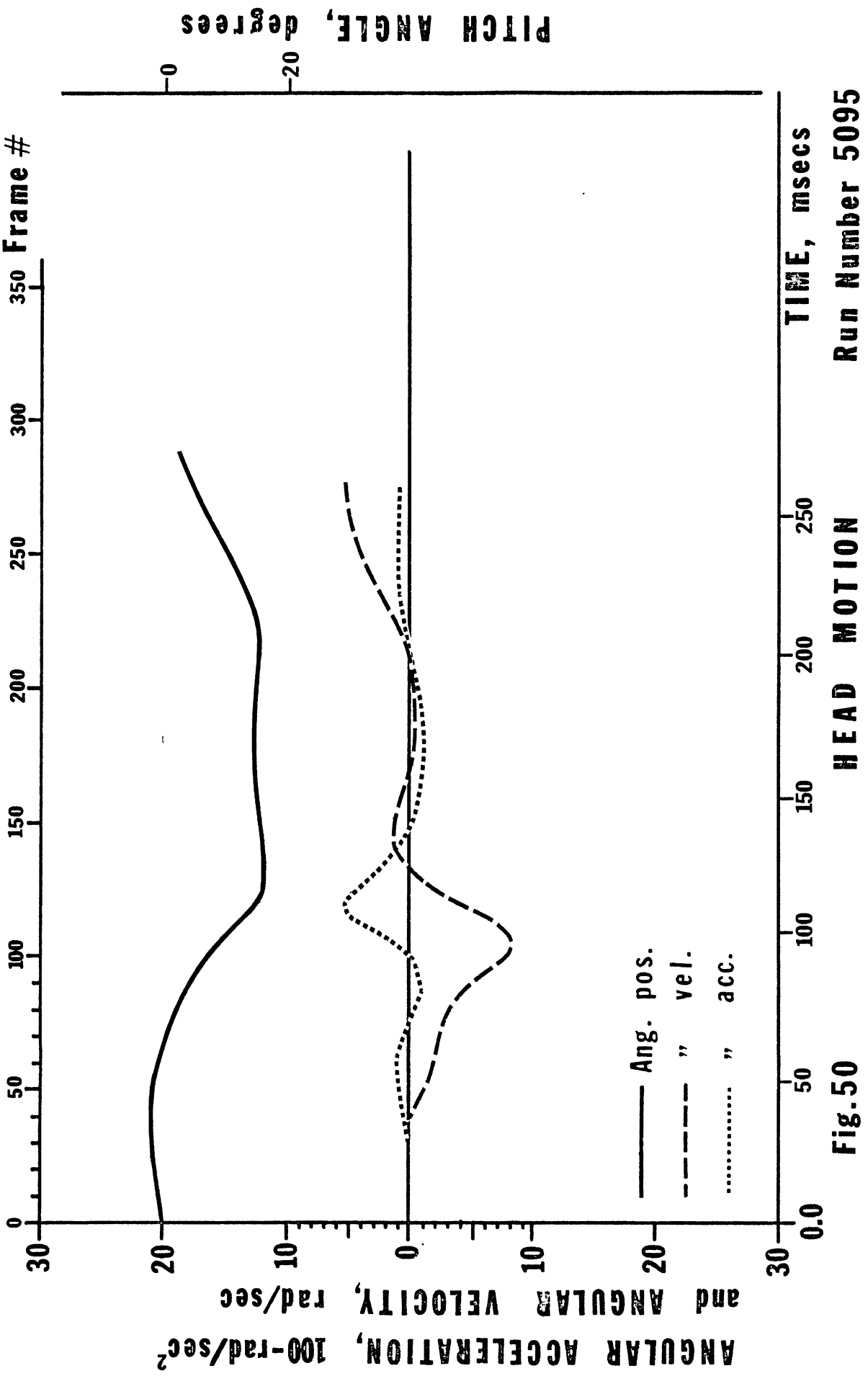

PITCH ANGLE, degrees
0
20
Frame #
0
50
100
150
200
250
300
350
TIME, msecs
0.0
50
100
150
200
250
HEAD MOTION
Run Number 5095
Ang. pos.
" vel.
" acc.
ANGULAR ACCELERATION, 100-rad/sec²
and ANGULAR VELOCITY, rad/sec
30
20
10
0
10
20
30

Fig.50

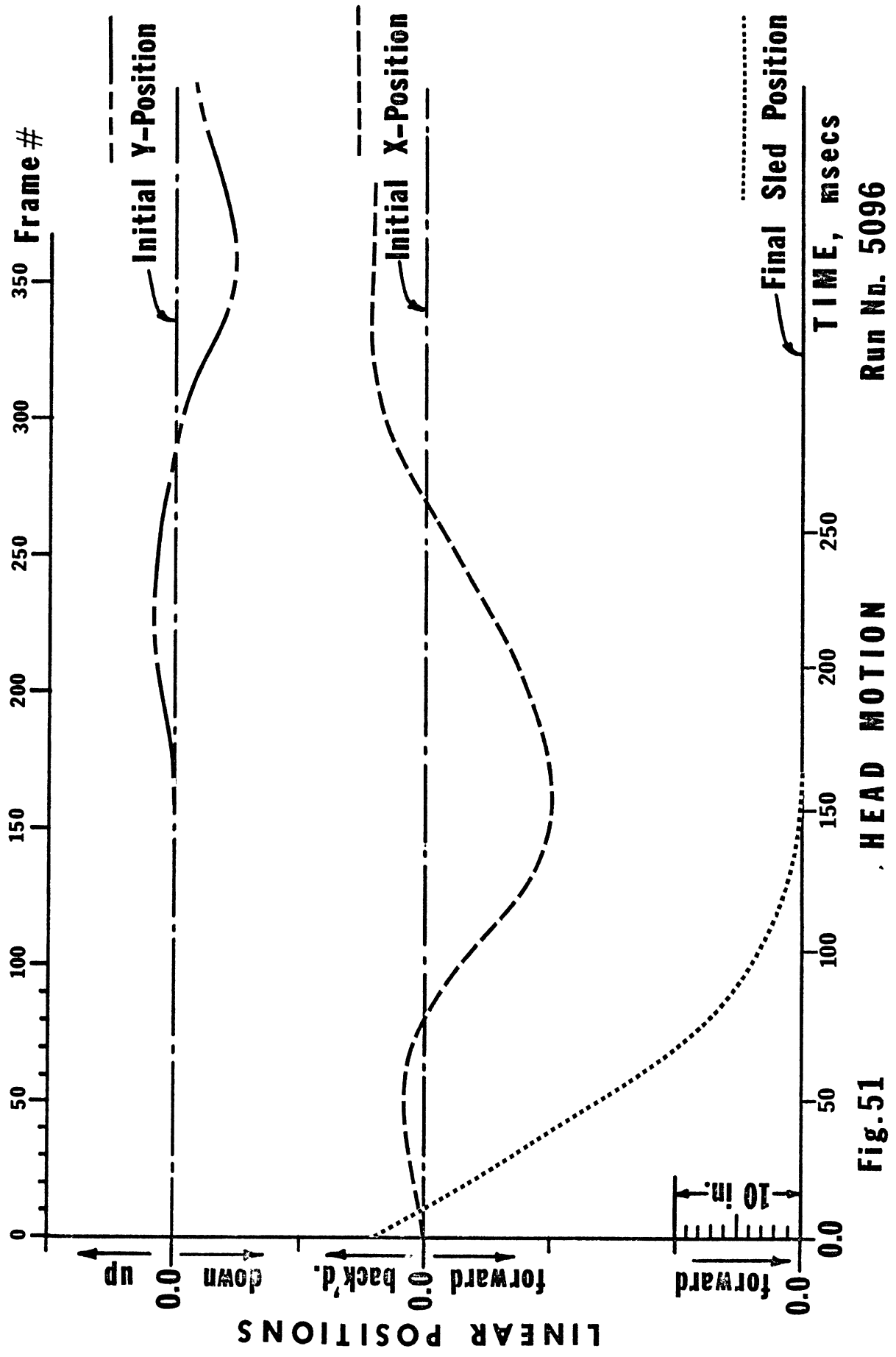

Initial Y-Position
Initial X-Position
Final Sled Position
Frame #
TIME, msecs
Run No. 5096
HEAD MOTION
LINEAR POSITIONS
up
down
forward
back'd.
forward
10 in.
0.0
0.0
0.0
0
50
100
150
200
250
300
350

Fig.51

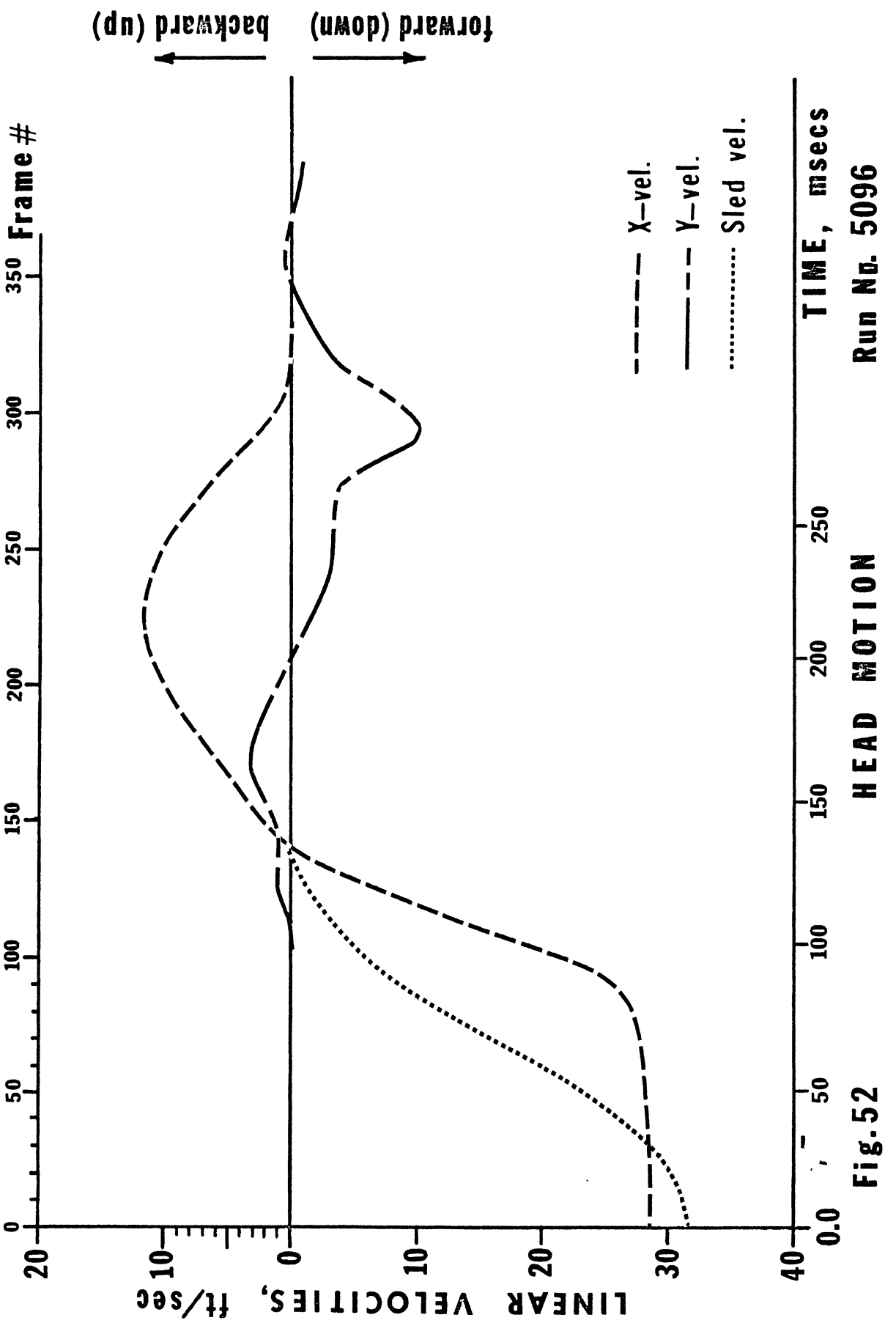

forward (down)
backward (up)
LINEAR VELOCITIES, ft/sec
20
10
0
10
20
30
40
0.0
50
100
150
200
250
300
350
Frame #
TIME, msecs
X-vel.
Y-vel.
Sled vel.
HEAD MOTION
Run No. 5096

Fig.52

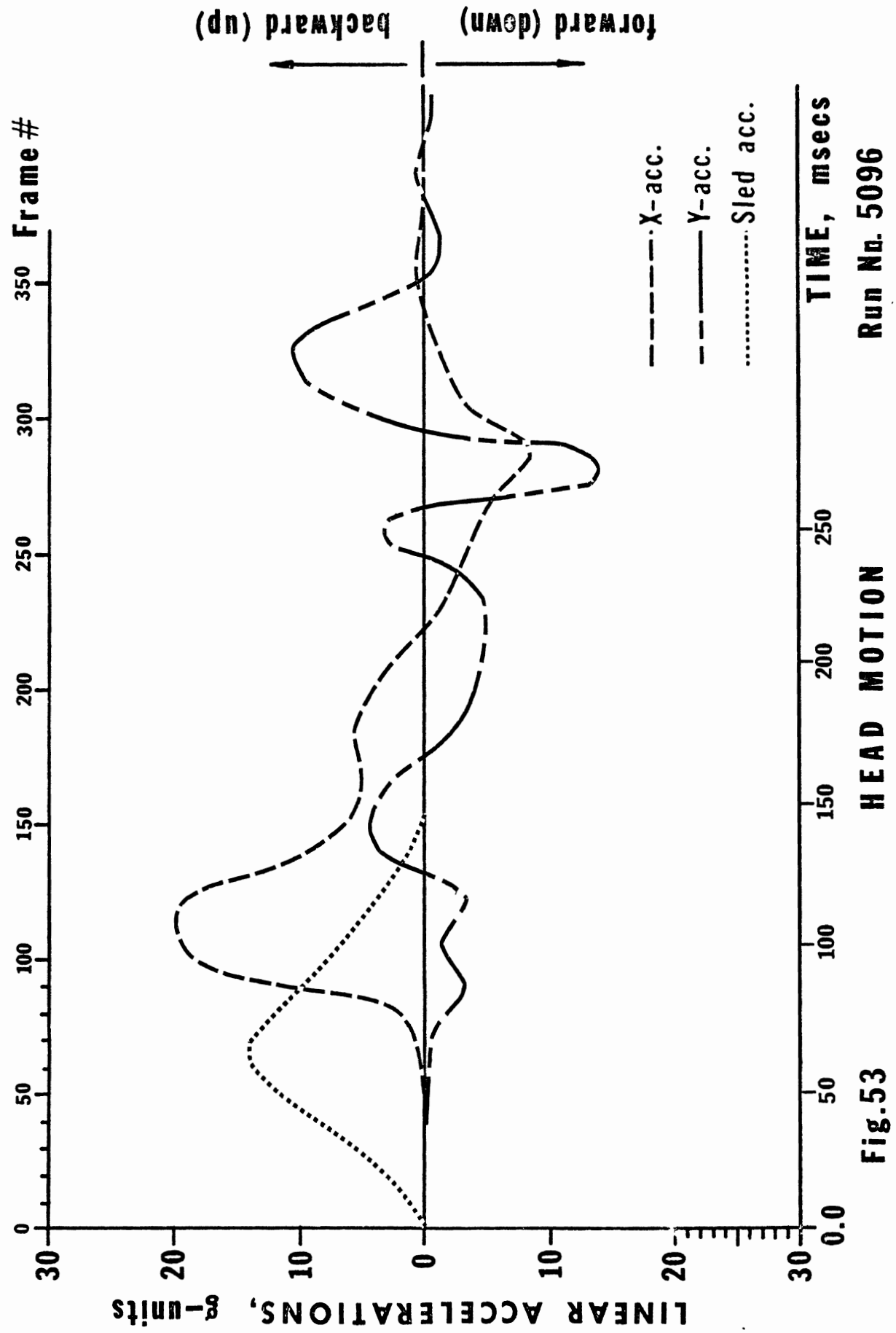

forward (down)
backward (up)
LINEAR ACCELERATIONS, g-units
30
20
10
0
10
20
30
0.0
50
100
150
200
250
TIME, msecs
0
50
100
150
200
250
300
350
Frame #
X-acc.
Y-acc.
Sled acc.
HEAD MOTION
Run No. 5096

Fig.53

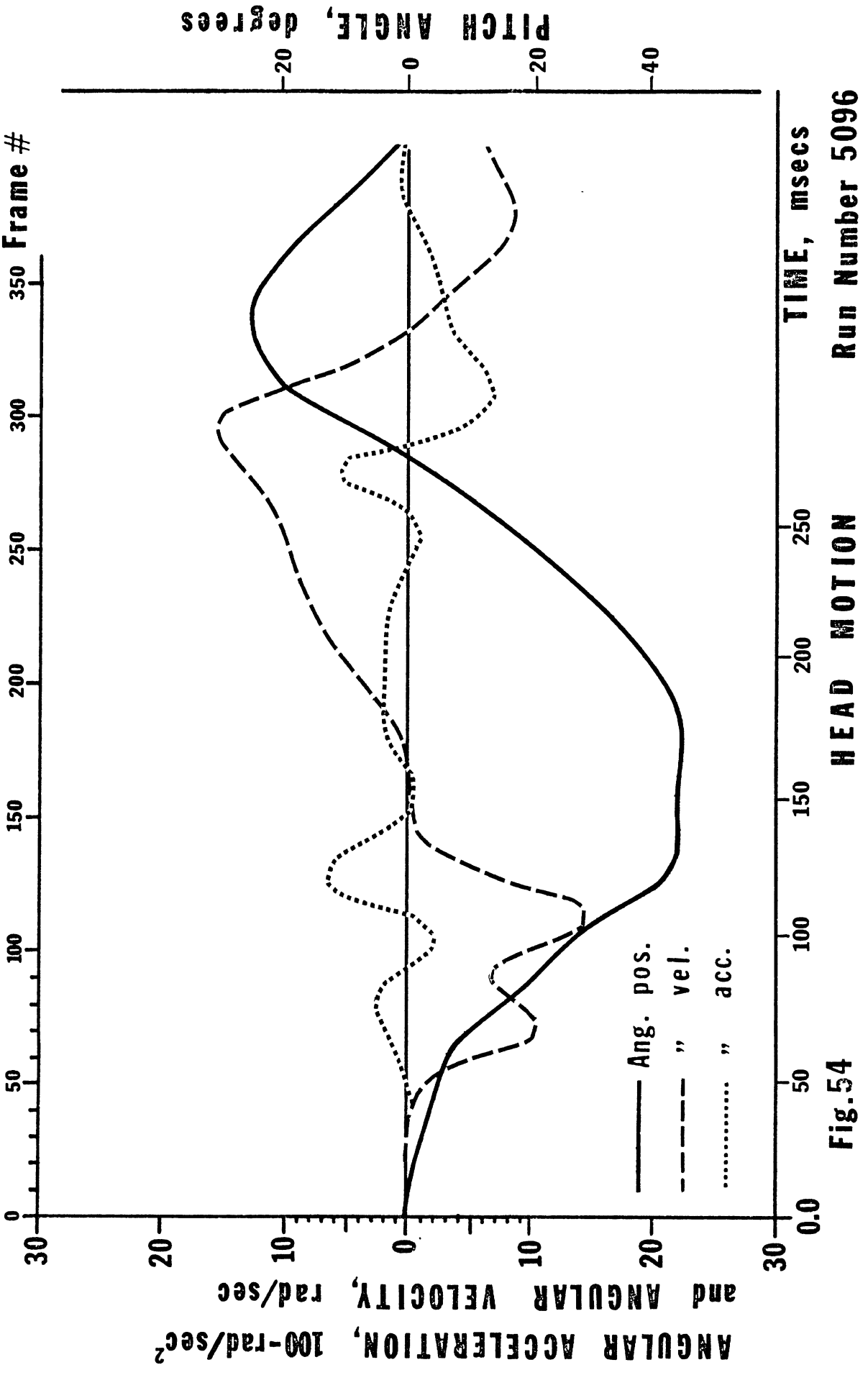

PITCH ANGLE, degrees
20
0
20
40
Frame #
0
50
100
150
200
250
300
350
TIME, msecs
0.0
50
100
150
200
250
HEAD MOTION
Run Number 5096
ANGULAR ACCELERATION, 100-rad/sec²
and ANGULAR VELOCITY, rad/sec
30
20
10
0
10
20
30
Ang. pos.
" vel.
" acc.

Fig.54

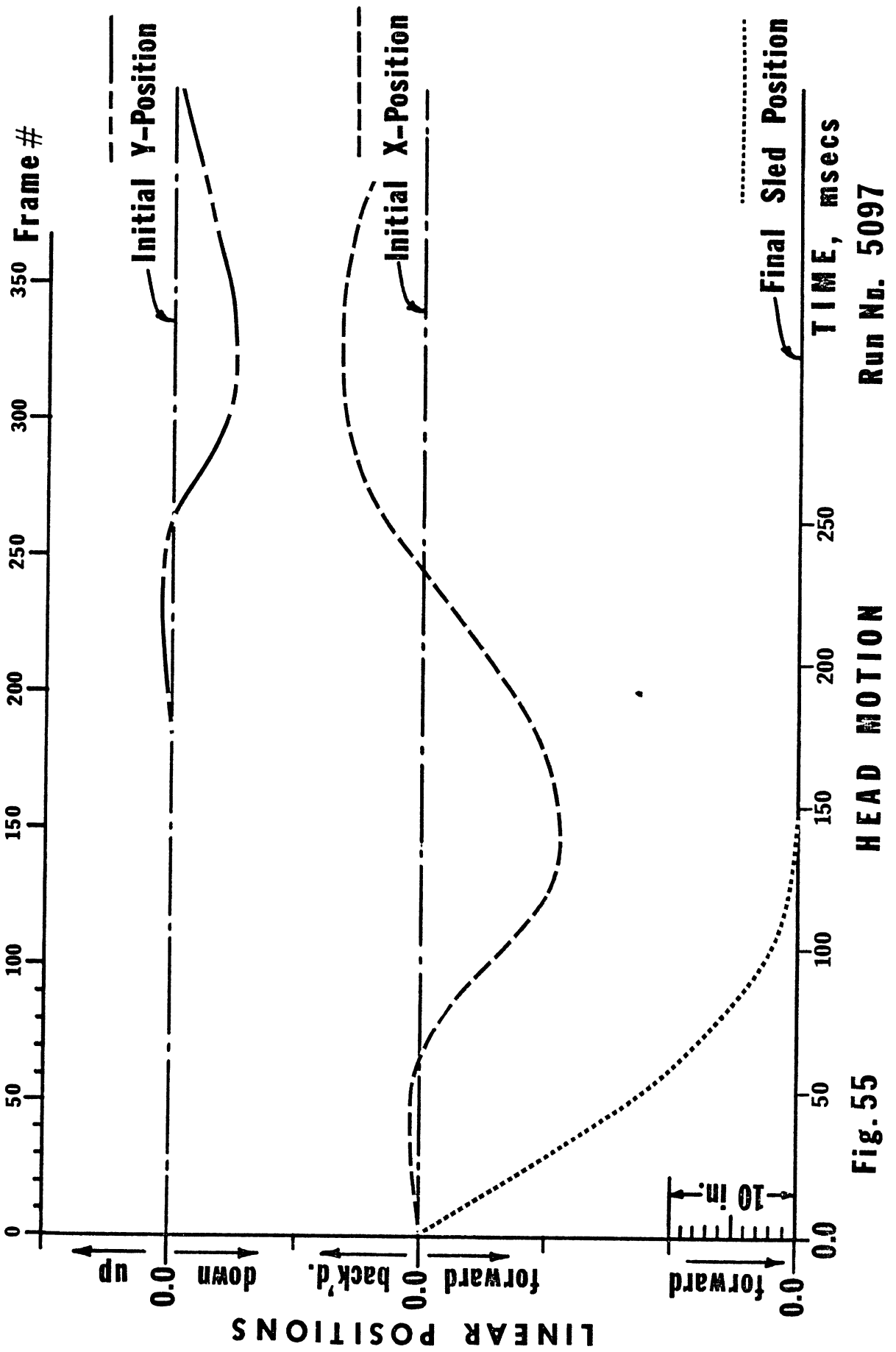

Frame #
0
50
100
150
200
250
300
350
Initial Y-Position
Initial X-Position
Final Sled Position
TIME, msecs
Run No. 5097
HEAD MOTION
LINEAR POSITIONS
up
0.0
down
forward
0.0
back'd.
forward
0.0
10 in.
0.0

Fig. 55

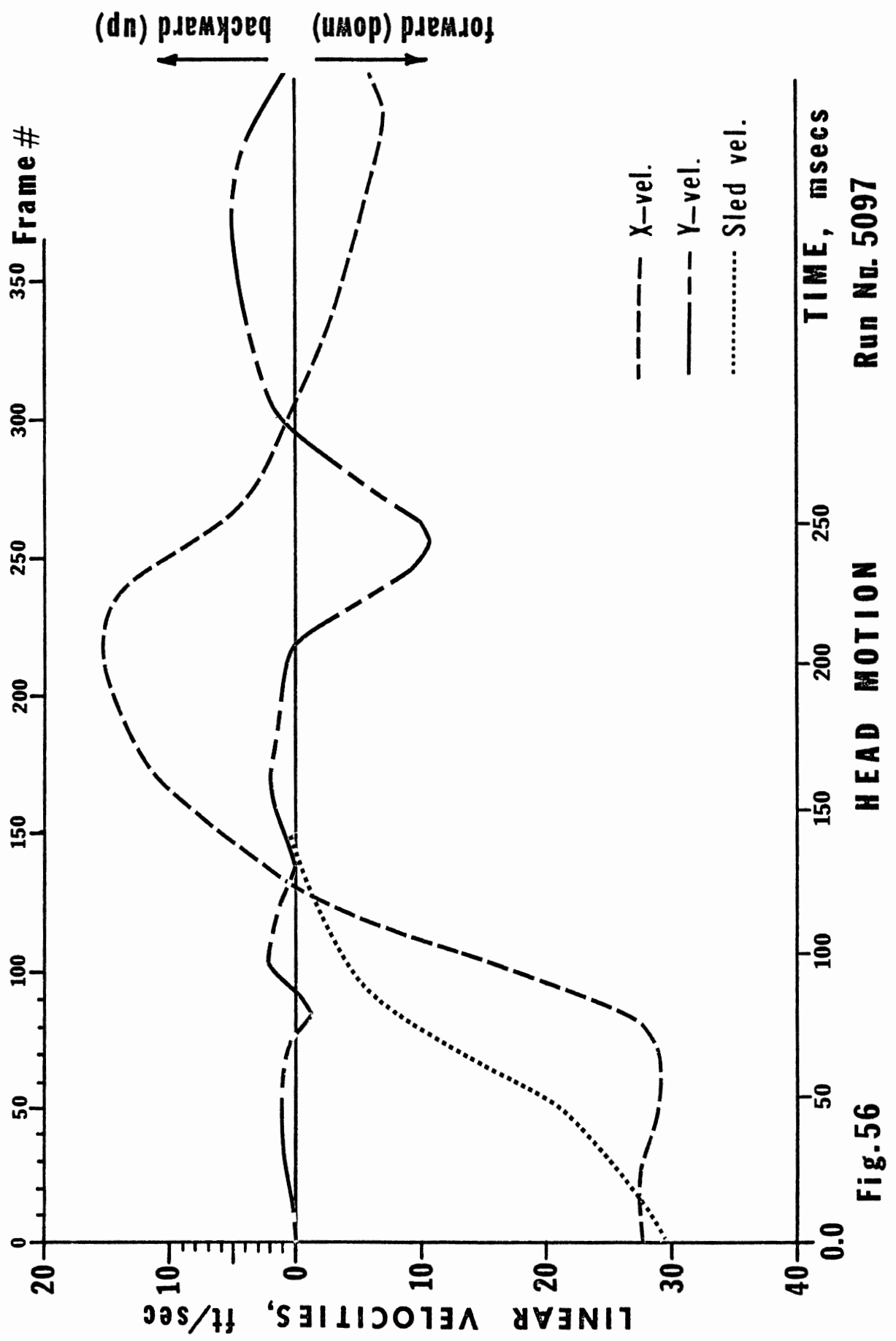

forward (down)
backward (up)
Frame #
0
50
100
150
200
250
300
350
LINEAR VELOCITIES, ft/sec
20
10
0
10
20
30
40
0.0
50
100
150
200
250
TIME, msecs
X-vel.
Y-vel.
Sled vel.
HEAD MOTION
Run No. 5097

Fig.56

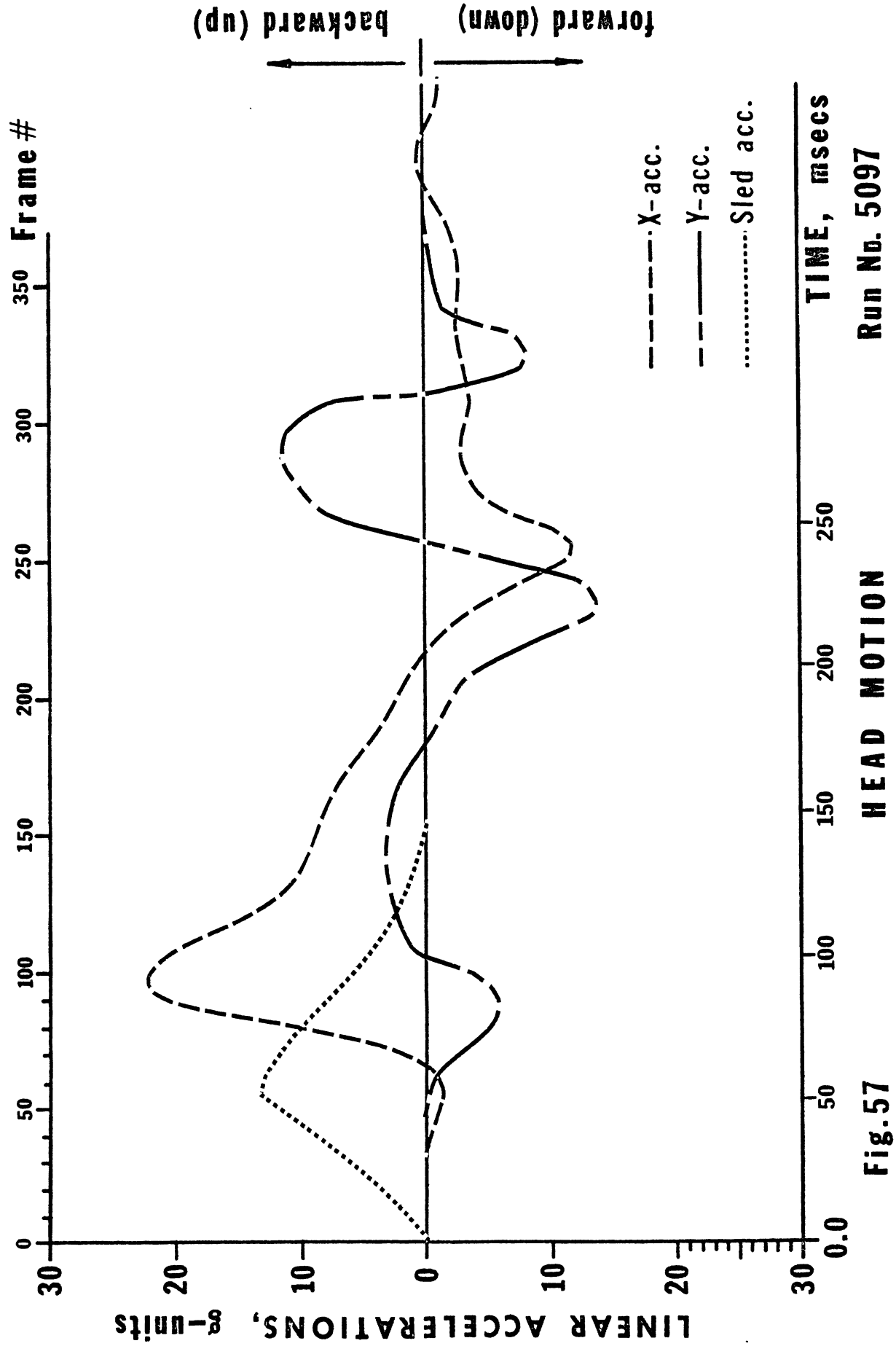

forward (down)
backward (up)
LINEAR ACCELERATIONS, g-units
30
20
10
0
10
20
30
0.0
50
100
150
200
250
TIME, msecs
0
50
100
150
200
250
300
350
Frame #
X-acc.
Y-acc.
Sled acc.
Run No. 5097
HEAD MOTION

Fig.57

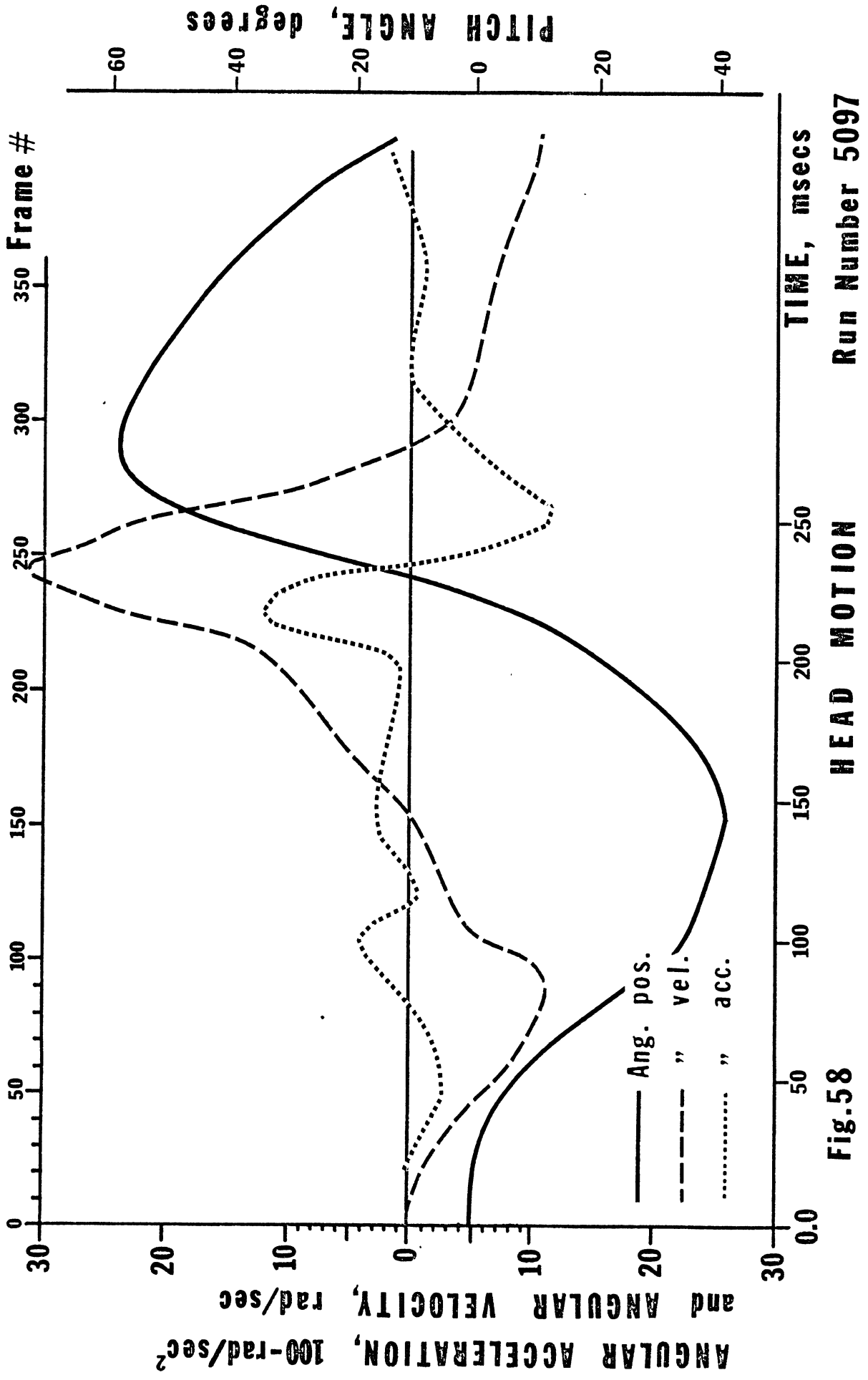

PITCH ANGLE, degrees
60
40
20
0
20
40
Frame #
0
50
100
150
200
250
300
350
TIME, msecs
0.0
50
100
150
200
250
HEAD MOTION
Run Number 5097
ANGULAR ACCELERATION, 100-rad/sec²
and ANGULAR VELOCITY, rad/sec
30
20
10
0
10
20
30
Ang. pos.
" vel.
" acc.

Fig.58

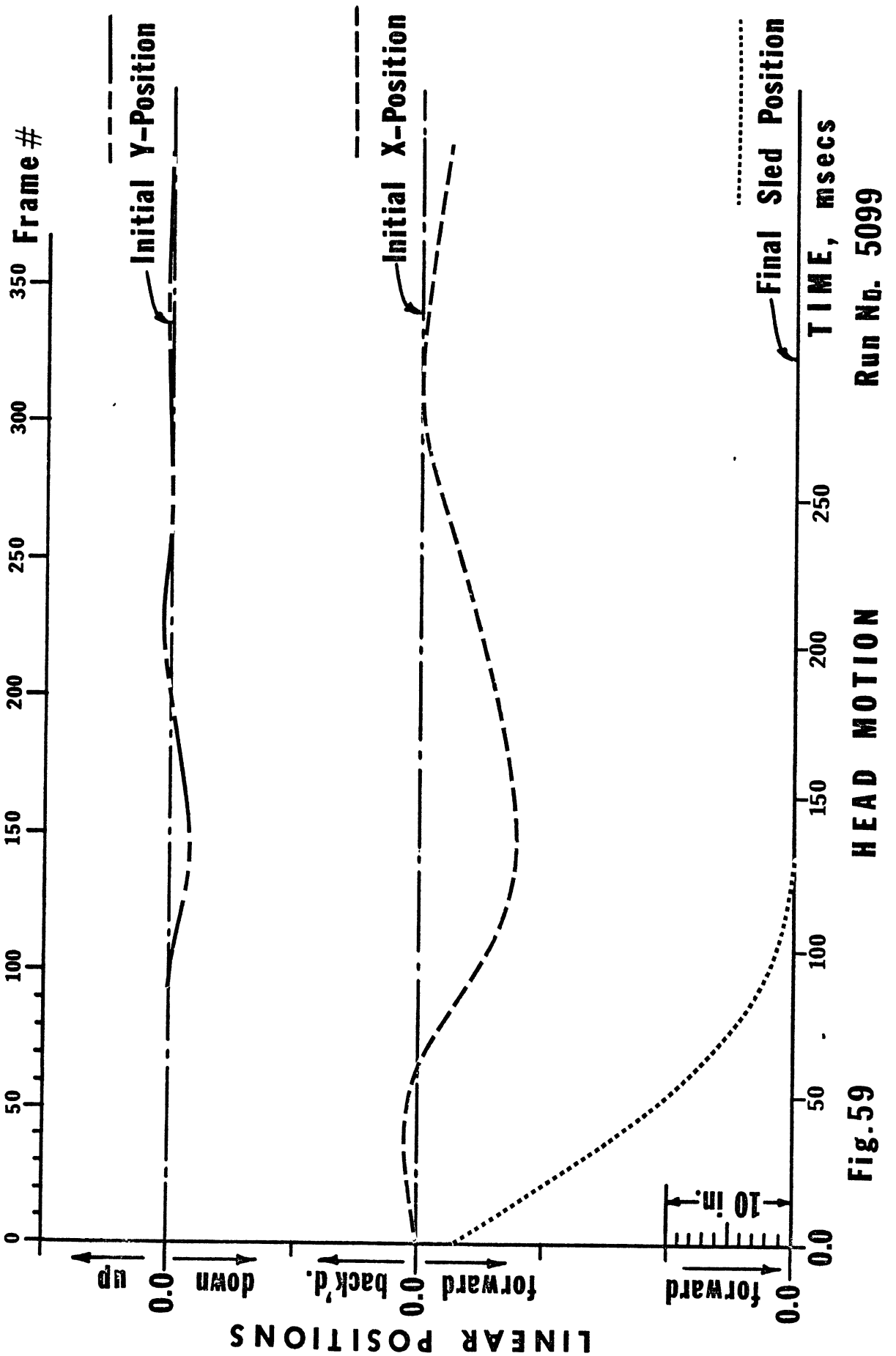

Frame #
0
50
100
150
200
250
300
350
Initial Y-Position
Initial X-Position
Final Sled Position
TIME, msecs
Run No. 5099
HEAD MOTION
LINEAR POSITIONS
up
down
0.0
back'd.
forward
0.0
forward
0.0
10 in.
0.0
50
100
150
200
250

Fig.59

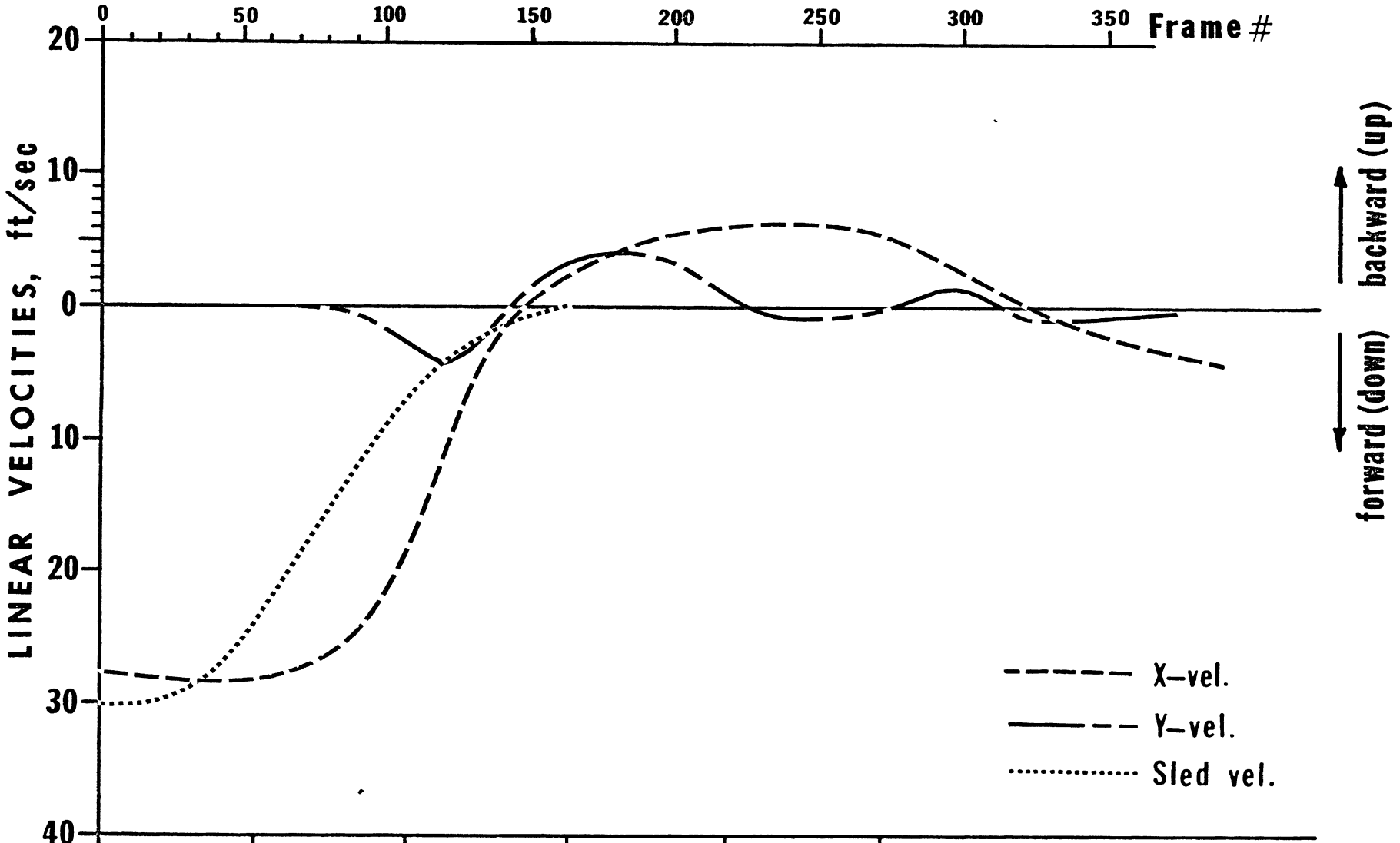


Fig.60 HEAD MOTION Run No. 5099

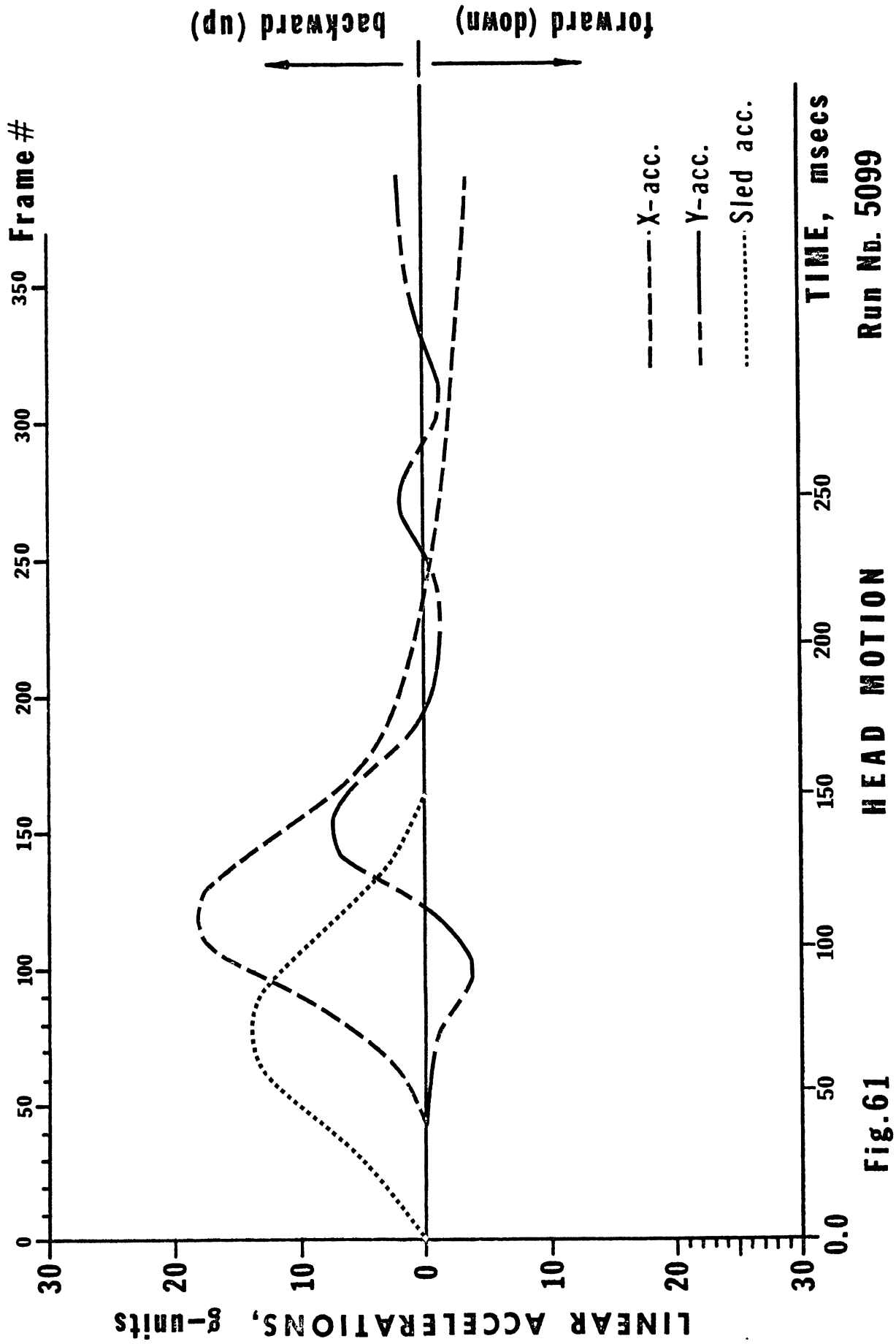

forward (down)
backward (up)
X-acc.
Y-acc.
Sled acc.
TIME, msecs
Frame #
LINEAR ACCELERATIONS, g-units
HEAD MOTION
Run No. 5099

Fig.61

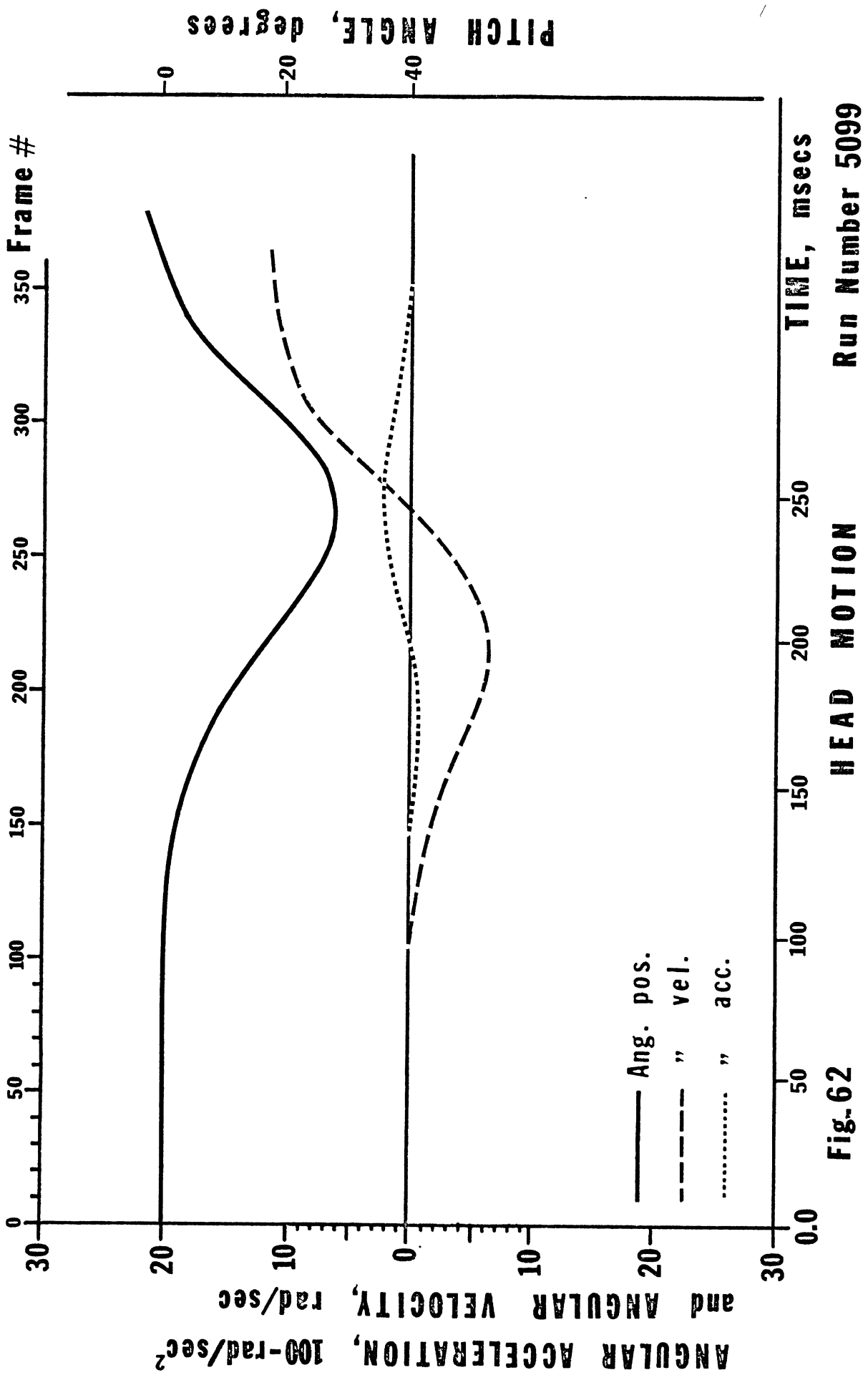

PITCH ANGLE, degrees
0
20
40
Frame #
0
50
100
150
200
250
300
350
TIME, msecs
0.0
50
100
150
200
250
HEAD MOTION
Run Number 5099
Ang. pos.
" vel.
" acc.
ANGULAR ACCELERATION, 100-rad/sec²
and ANGULAR VELOCITY, rad/sec
30
20
10
0
10
20
30

Fig.62

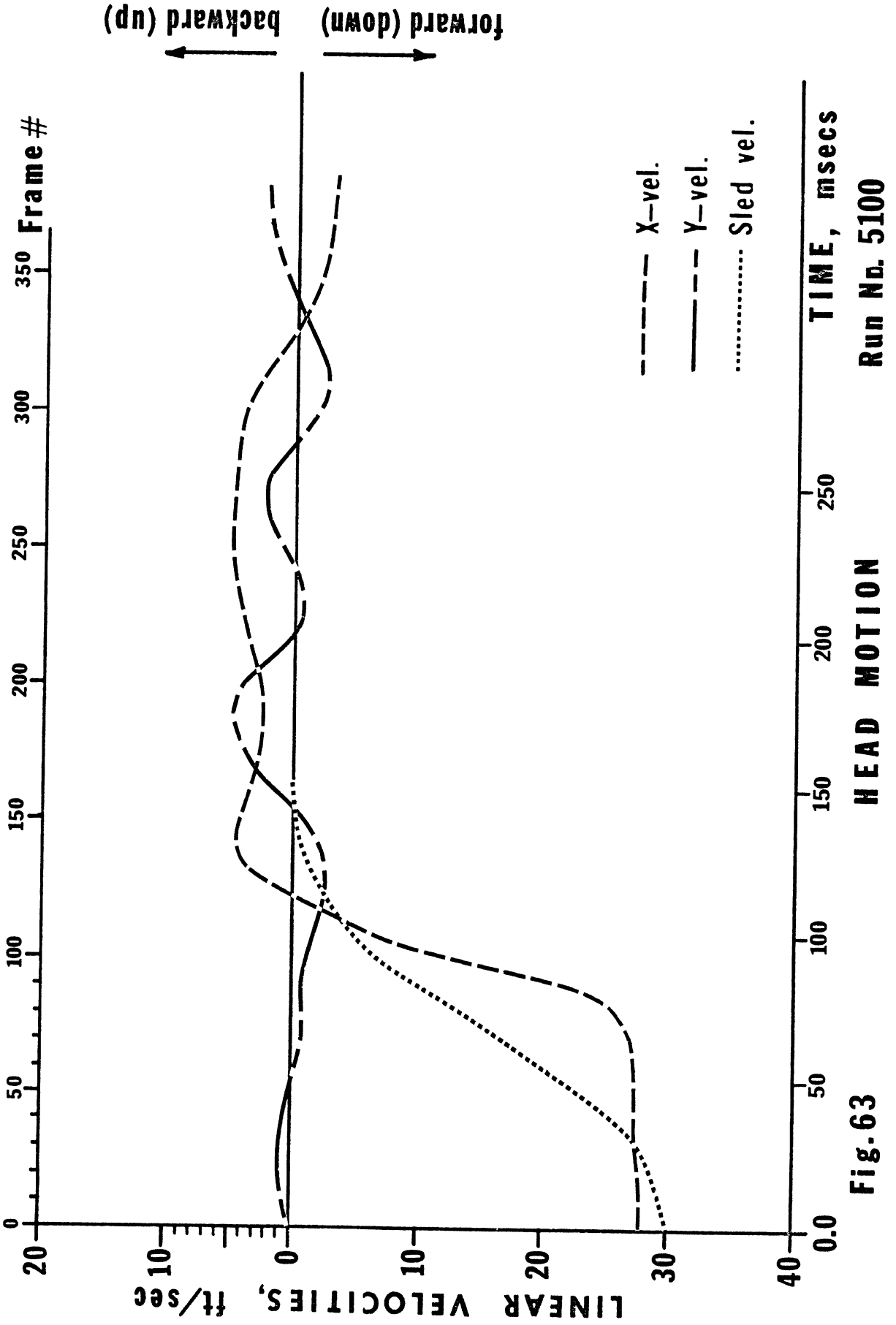

forward (down)
backward (up)
LINEAR VELOCITIES, ft/sec
20
10
0
10
20
30
40
0.0
50
100
150
200
250
300
350
Frame #
0
50
100
150
200
250
TIME, msecs
X-vel.
Y-vel.
Sled vel.
HEAD MOTION
Run No. 5100

Fig.63

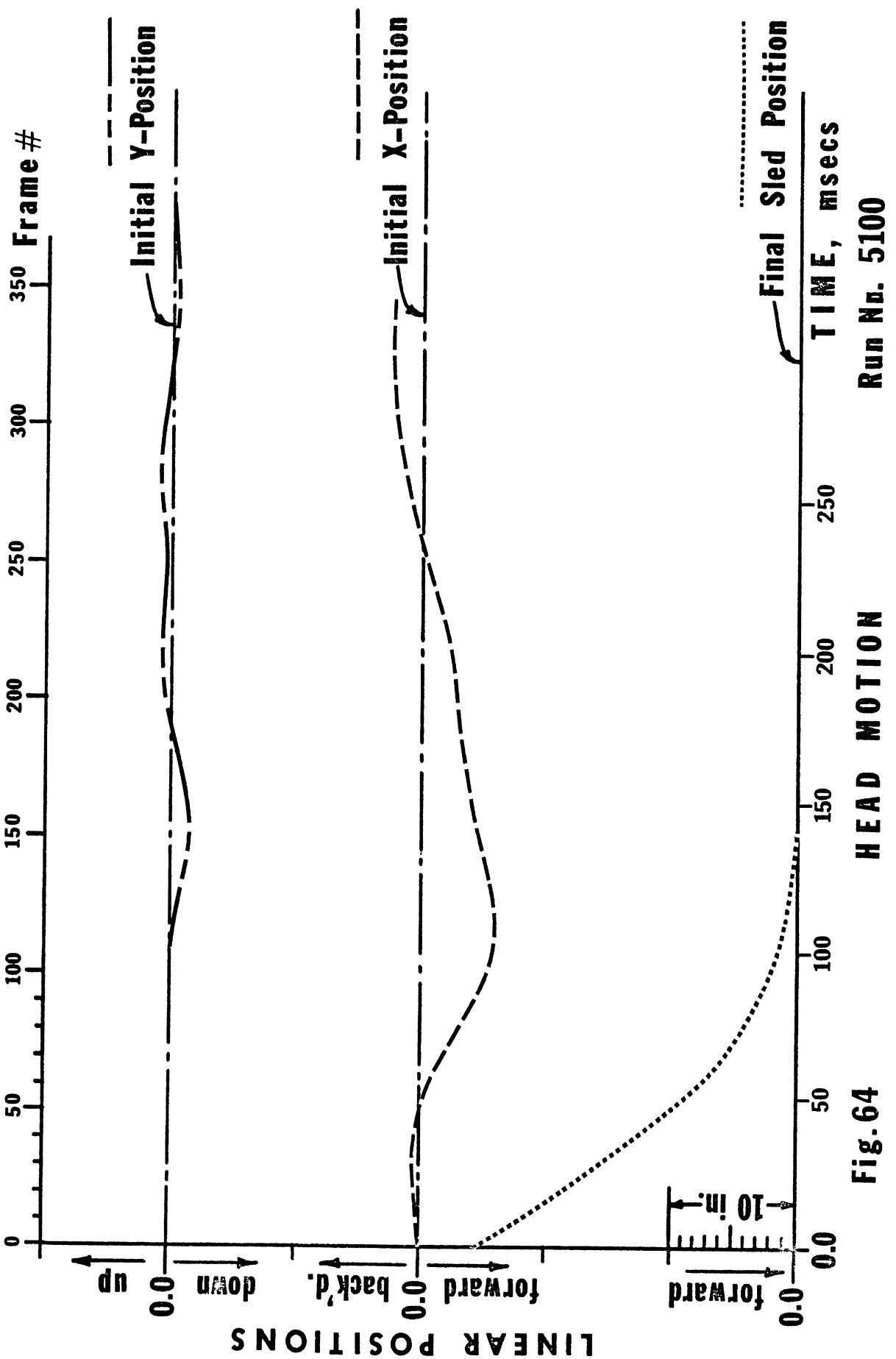

Initial Y-Position
Initial X-Position
Final Sled Position
Frame #
TIME, msecs
Run No. 5100
HEAD MOTION
LINEAR POSITIONS
up
down
back'd.
forward
forward
10 in.
0.0
0.0
0.0
0
50
100
150
200
250
300
350
0.0
50
100
150
200
250

Fig. 64

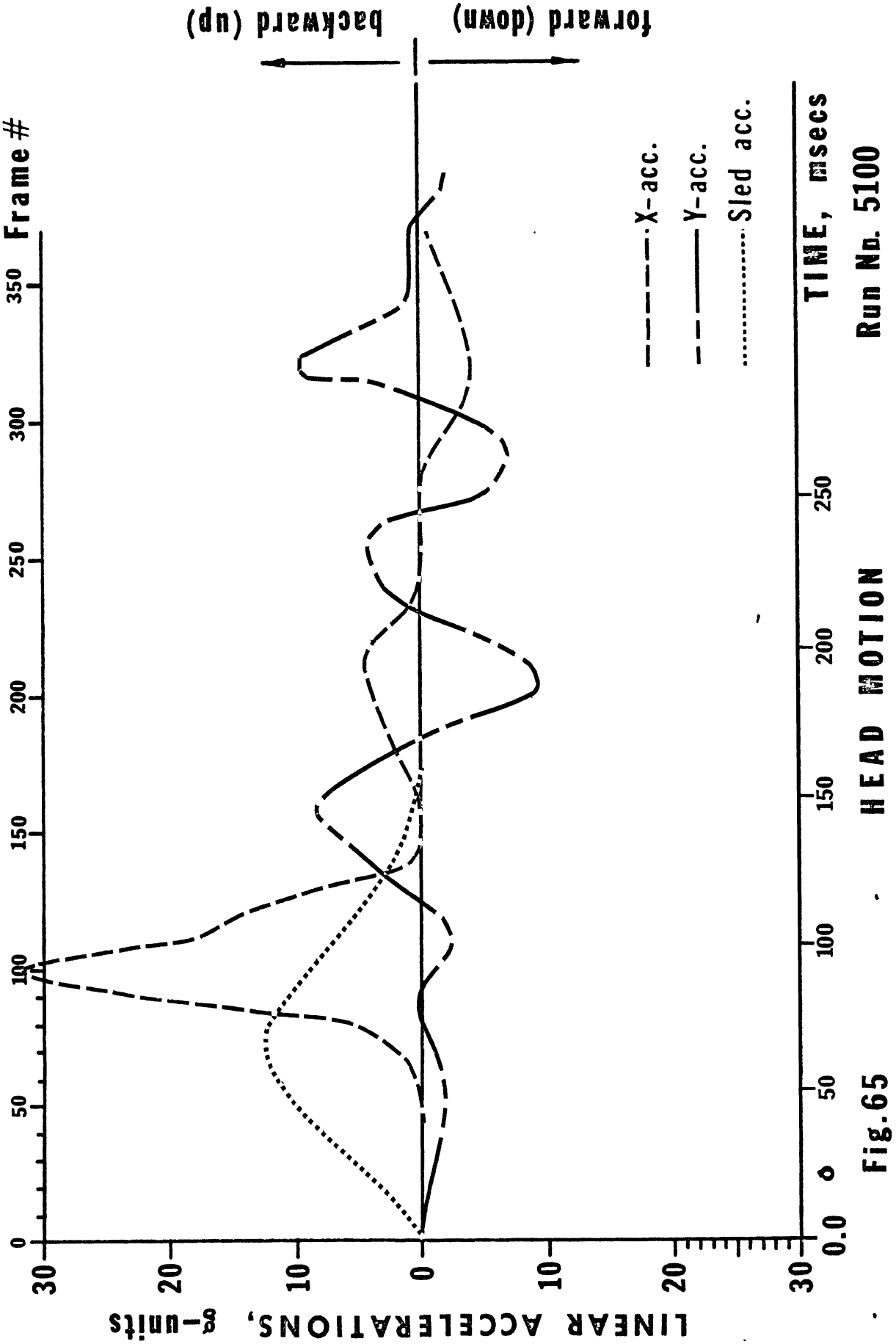

forward (down)
backward (up)
X-acc.
Y-acc.
Sled acc.
TIME, msecs
Frame #
LINEAR ACCELERATIONS, g-units
Run No. 5100
HEAD MOTION

Fig.65

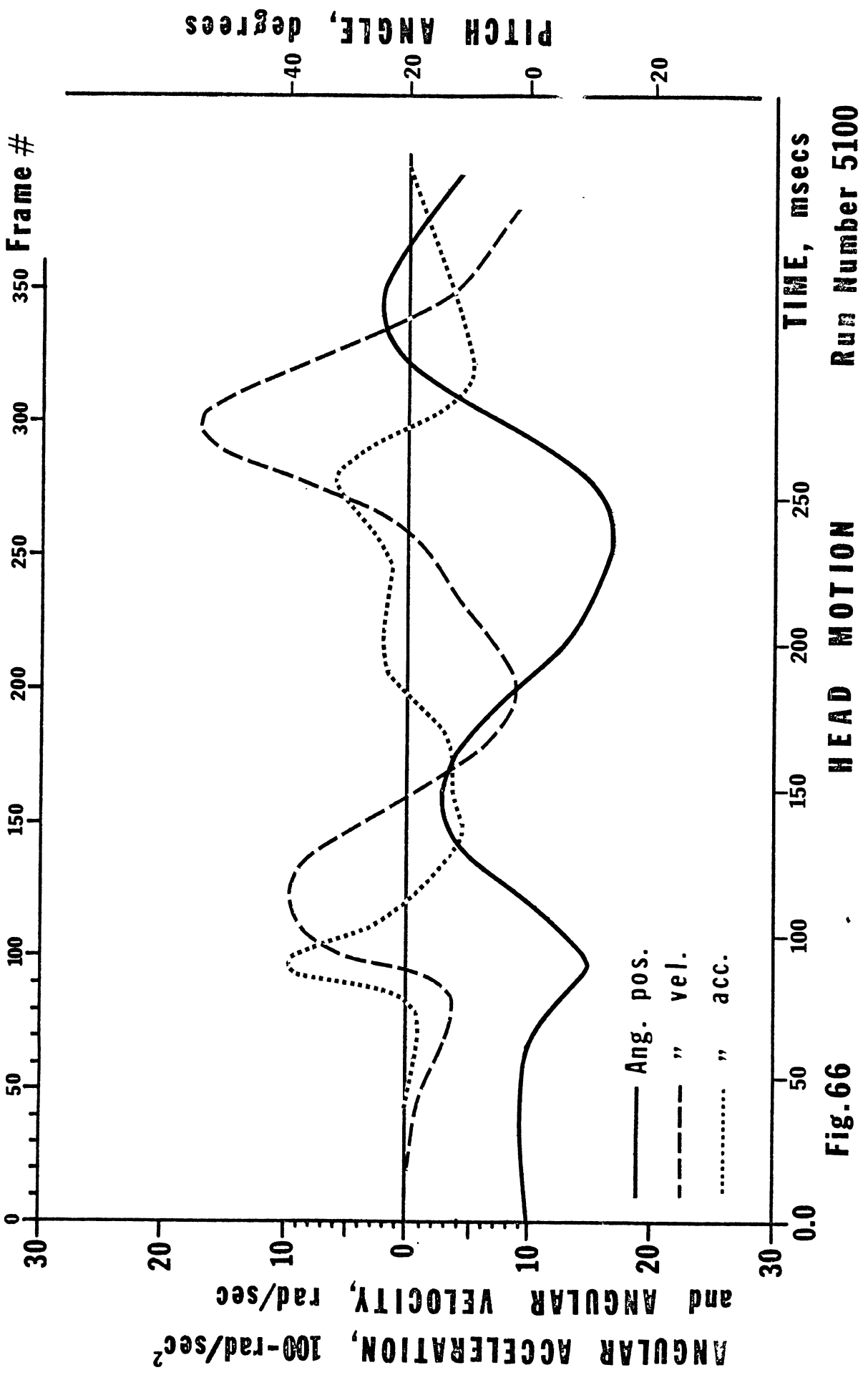

ANGULAR ACCELERATION, 100-rad/sec²
and ANGULAR VELOCITY, rad/sec
PITCH ANGLE, degrees
Frame #
TIME, msecs
HEAD MOTION
Run Number 5100
Ang. pos.
" vel.
" acc.

Fig.66

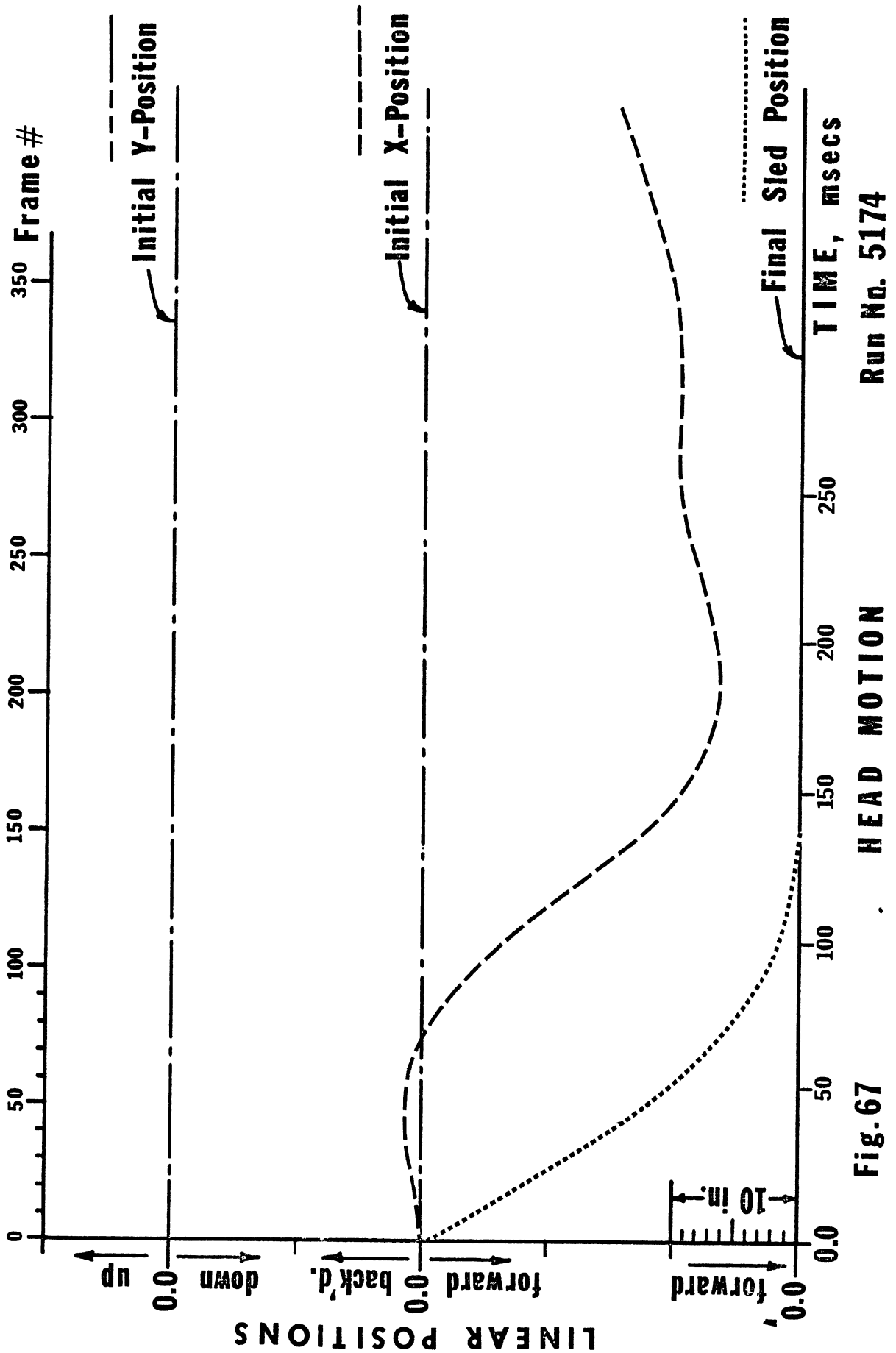

Frame #
0
50
100
150
200
250
300
350
Initial Y-Position
Initial X-Position
Final Sled Position
TIME, msecs
Run No. 5174
HEAD MOTION
LINEAR POSITIONS
up
down
0.0
back'd.
forward
0.0
forward
0.0
10 in.
0.0
50
100
150
200
250

Fig. 67

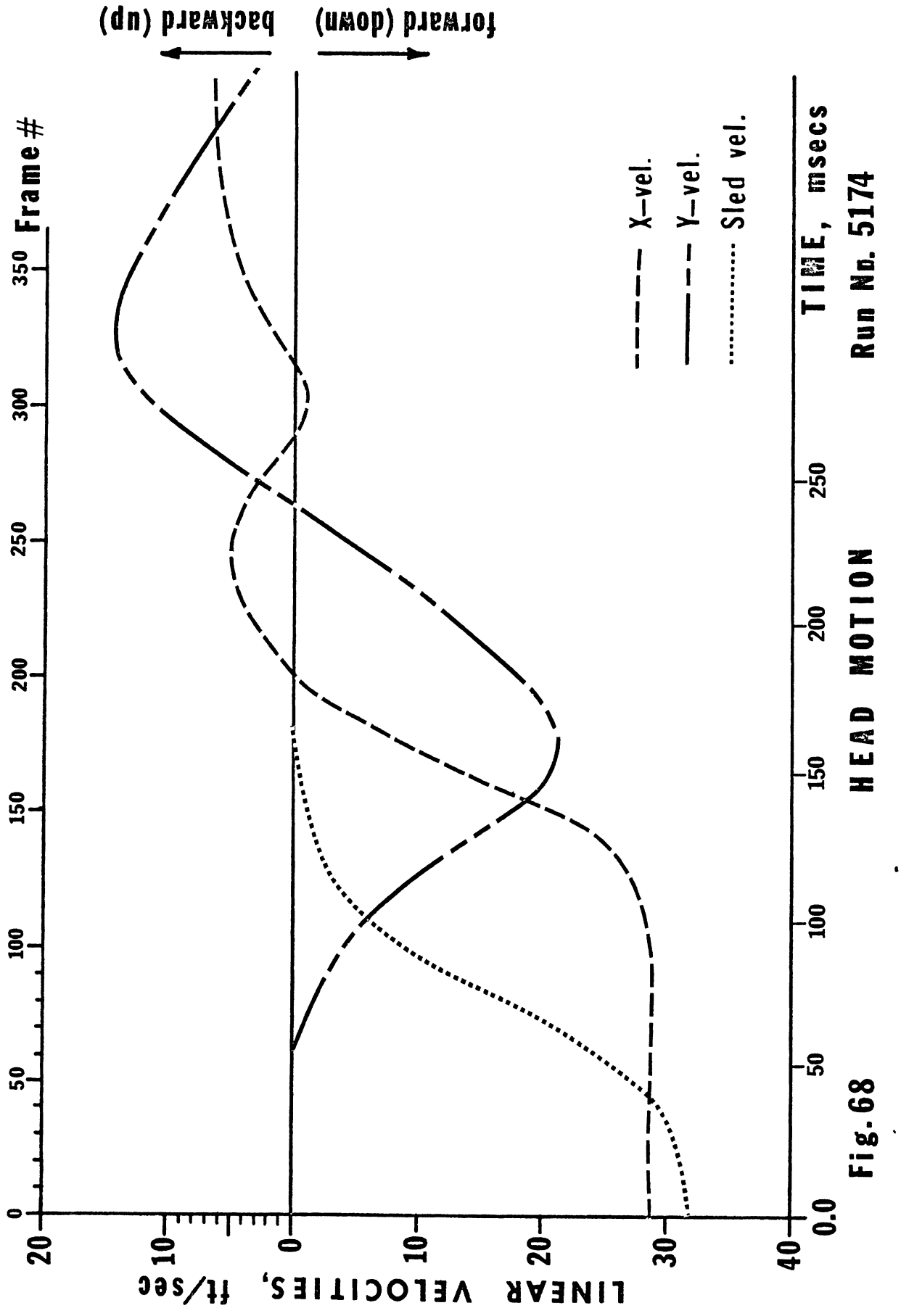

forward (down)
backward (up)
LINEAR VELOCITIES, ft/sec
20
10
0
10
20
30
40
0.0
50
100
150
200
250
TIME, msecs
0
50
100
150
200
250
300
350
Frame #
X-vel.
Y-vel.
Sled vel.
HEAD MOTION
Run No. 5174

Fig. 68

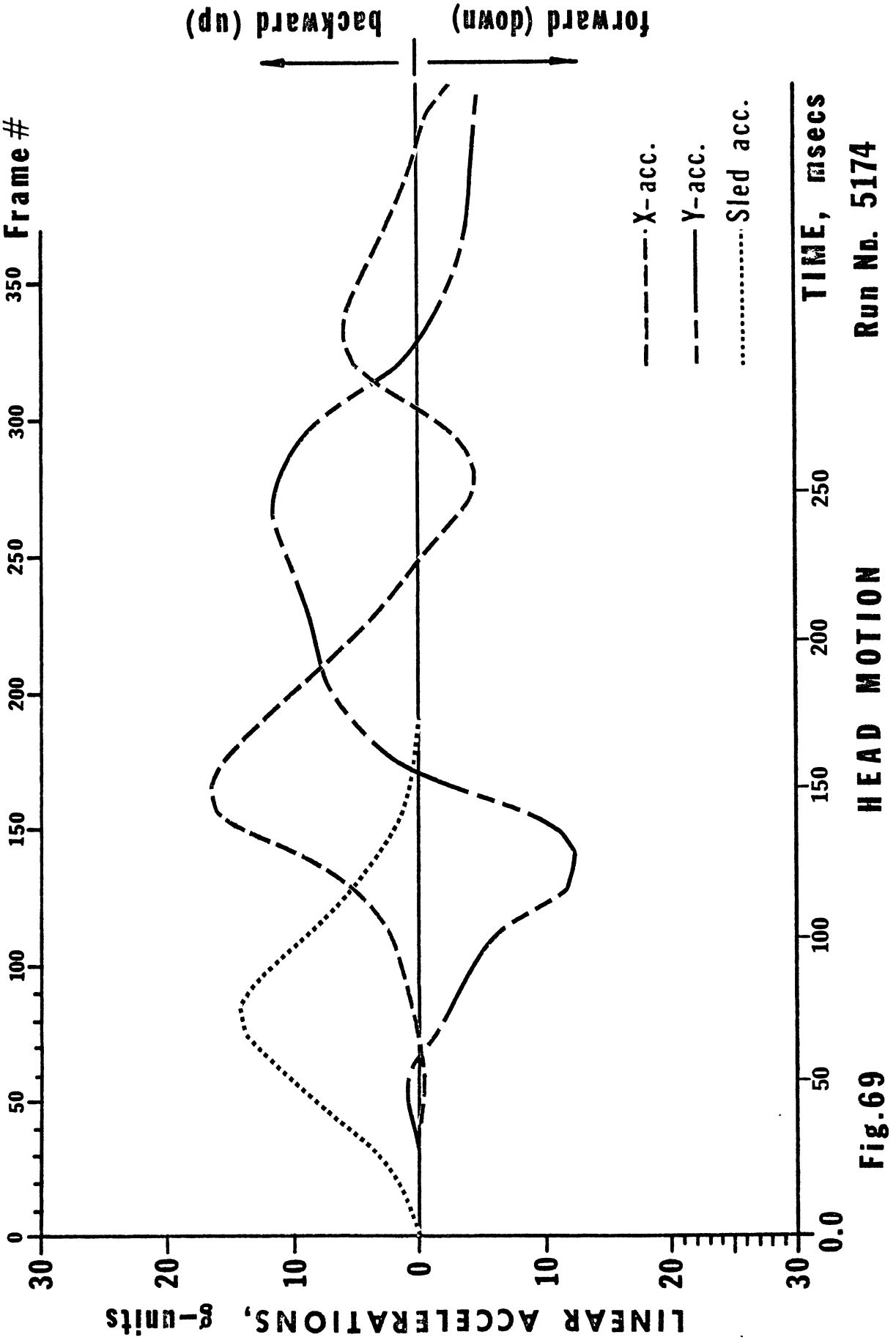

forward (down)
backward (up)
X-acc.
Y-acc.
Sled acc.
TIME, msecs
Run No. 5174
HEAD MOTION
LINEAR ACCELERATIONS, g-units
Frame#
0.0
50
100
150
200
250
300
350
30
20
10
0
10
20
30

Fig.69

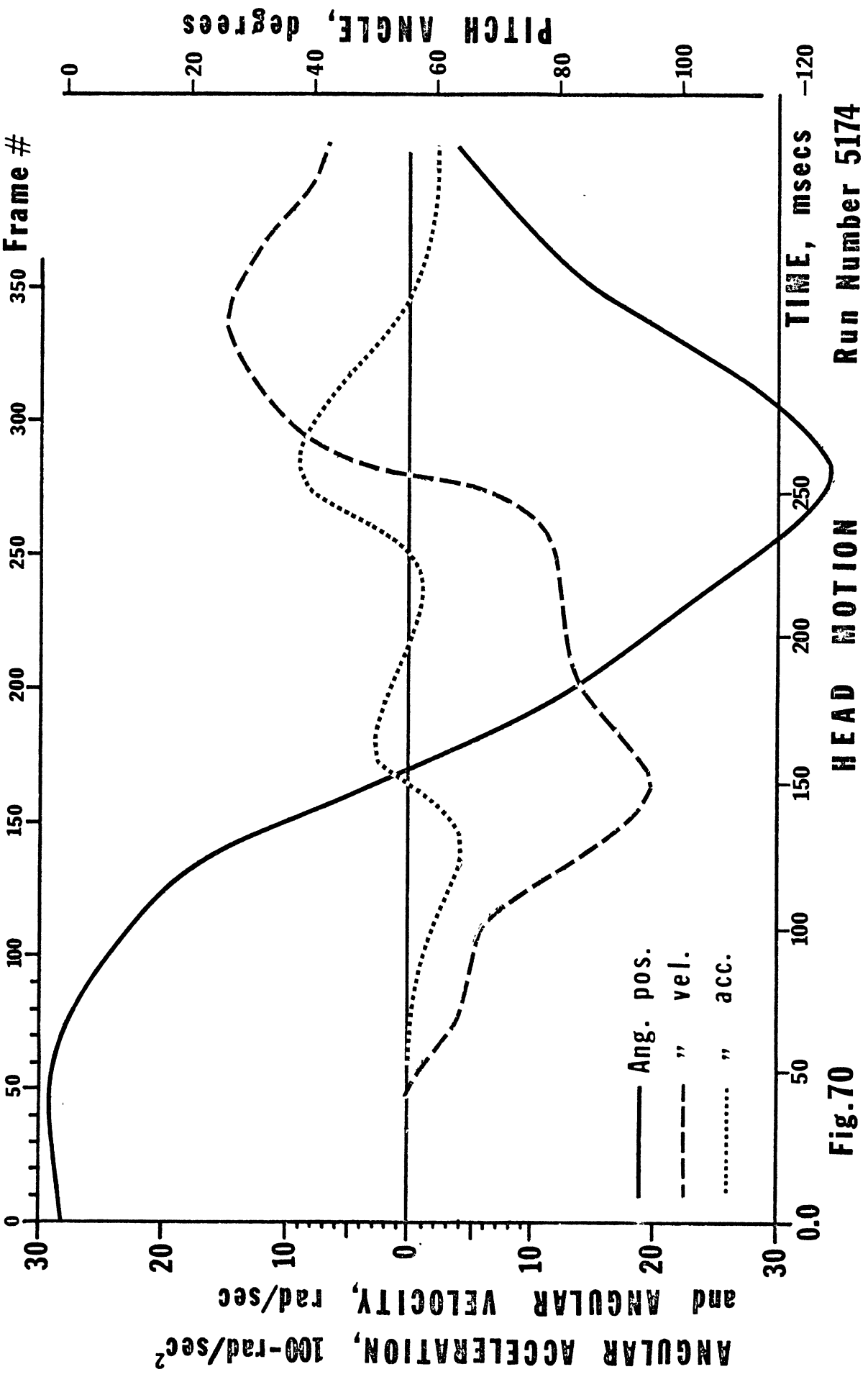

ANGULAR ACCELERATION, 100-rad/sec²
and ANGULAR VELOCITY, rad/sec
PITCH ANGLE, degrees
Frame #
TIME, msecs
Run Number 5174
HEAD MOTION
Ang. pos.
" vel.
" acc.
0
20
40
60
80
100
120
0
50
100
150
200
250
300
350
0.0
30
20
10
0
10
20
30

Fig.70

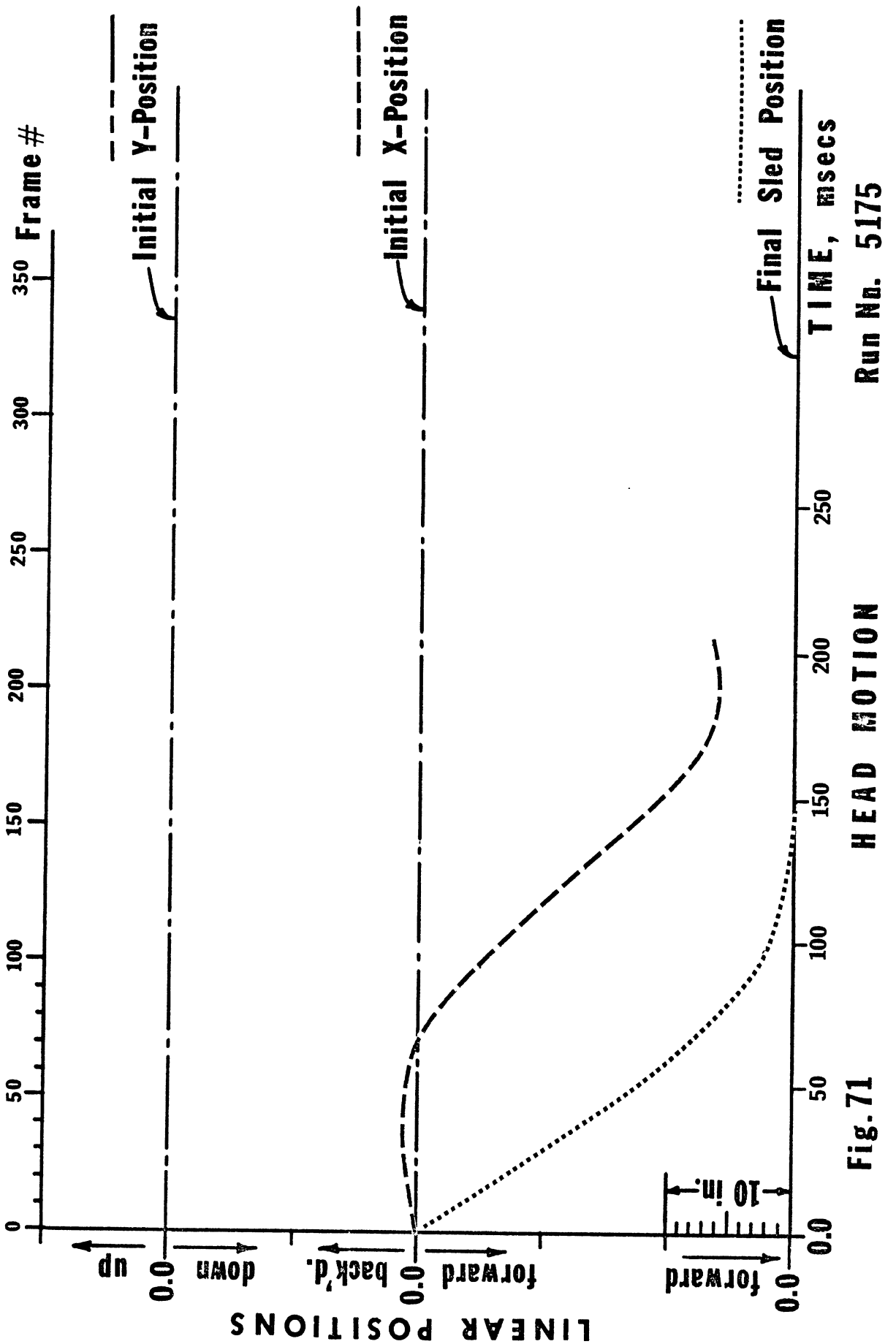

Frame #
0
50
100
150
200
250
300
350
Initial Y-Position
Initial X-Position
Final Sled Position
TIME, msecs
Run No. 5175
HEAD MOTION
LINEAR POSITIONS
up
0.0
down
back'd.
0.0
forward
forward
0.0
10 in.
0.0
50
100
150
200
250

Fig. 71

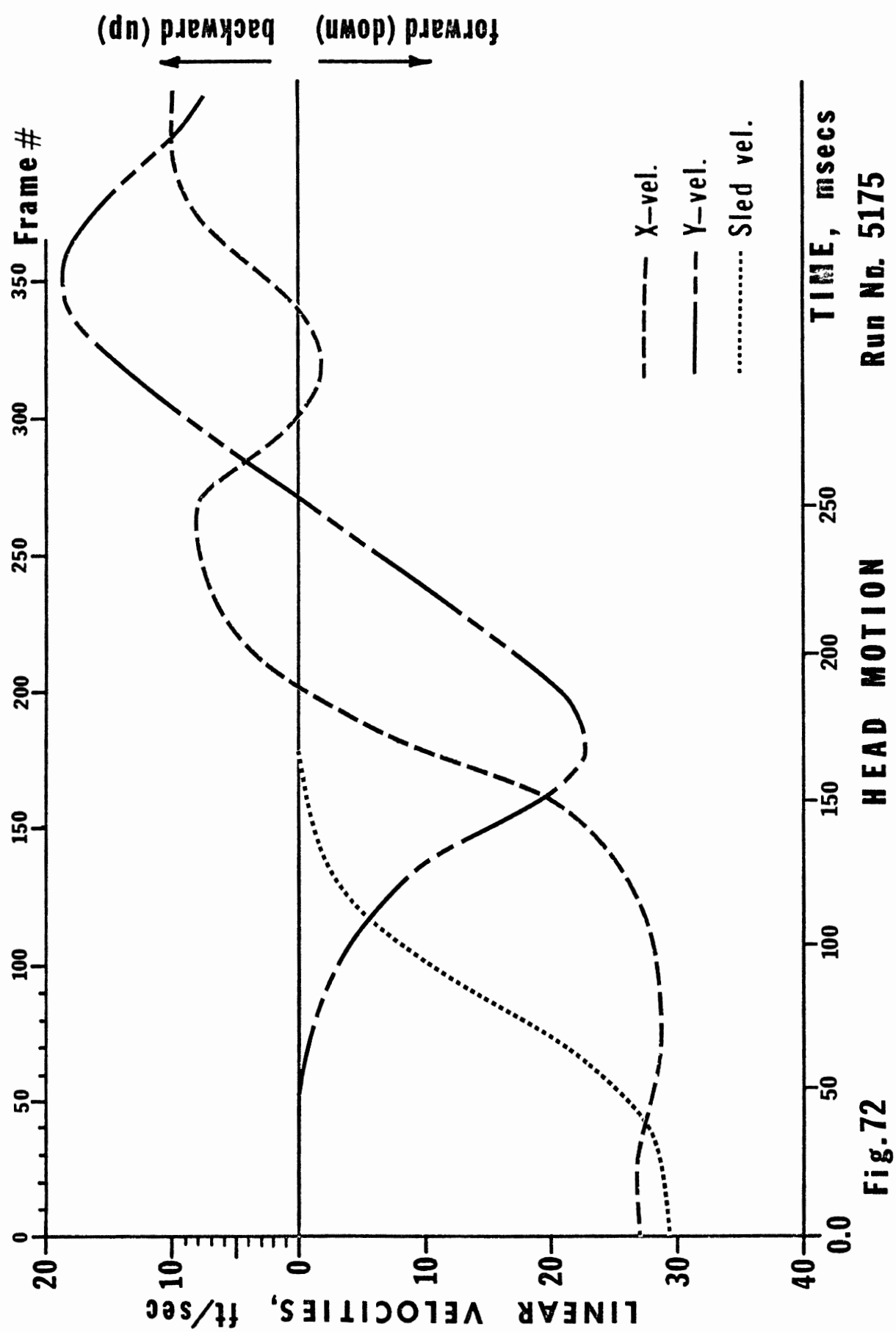

forward (down)
backward (up)
Frame #
0
50
100
150
200
250
300
350
LINEAR VELOCITIES, ft/sec
20
10
0
10
20
30
40
0.0
50
100
150
200
250
TIME, msecs
X-vel.
Y-vel.
Sled vel.
HEAD MOTION
Run No. 5175

Fig.72

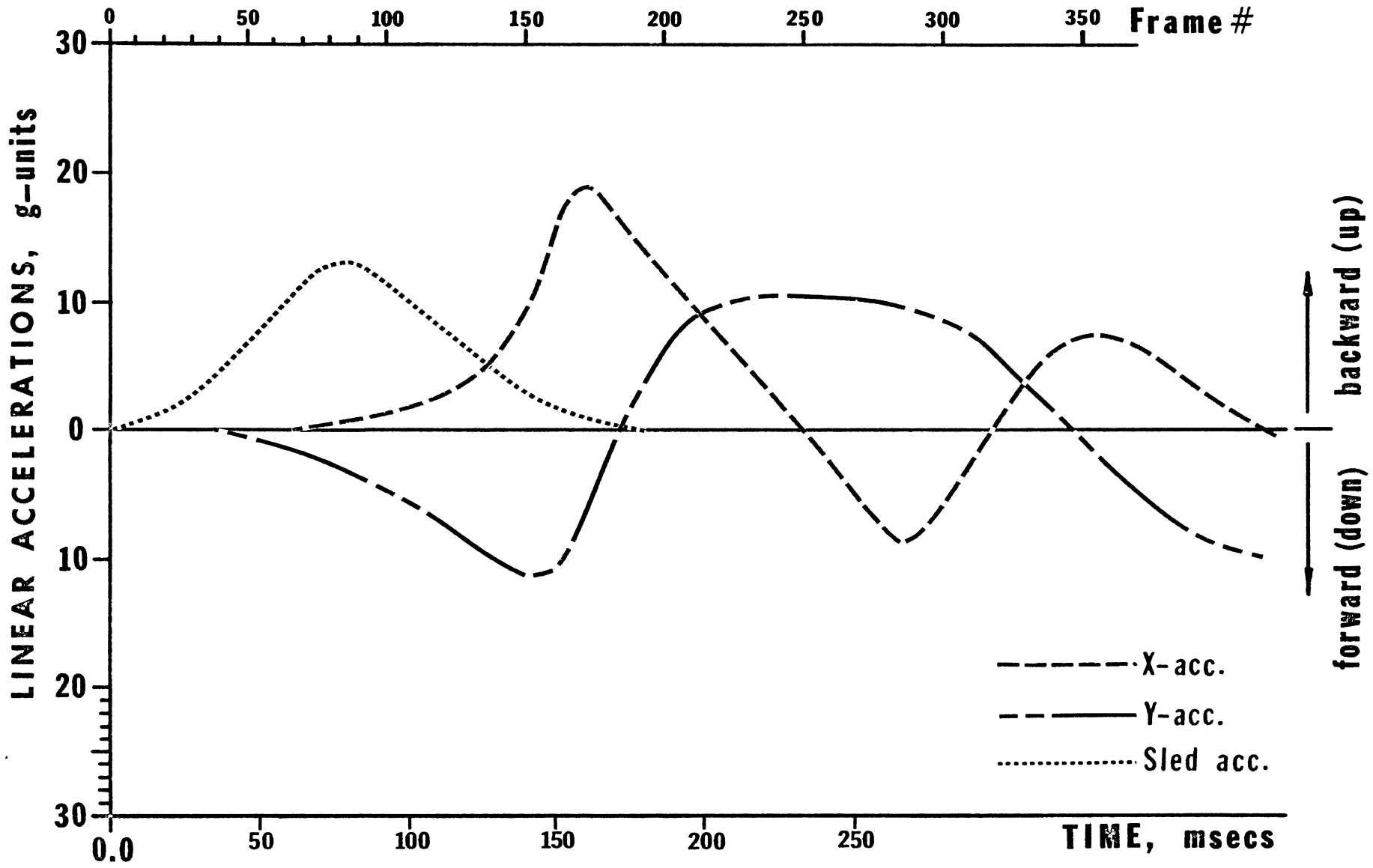


Fig.73 HEAD MOTION Run Nn. 5175

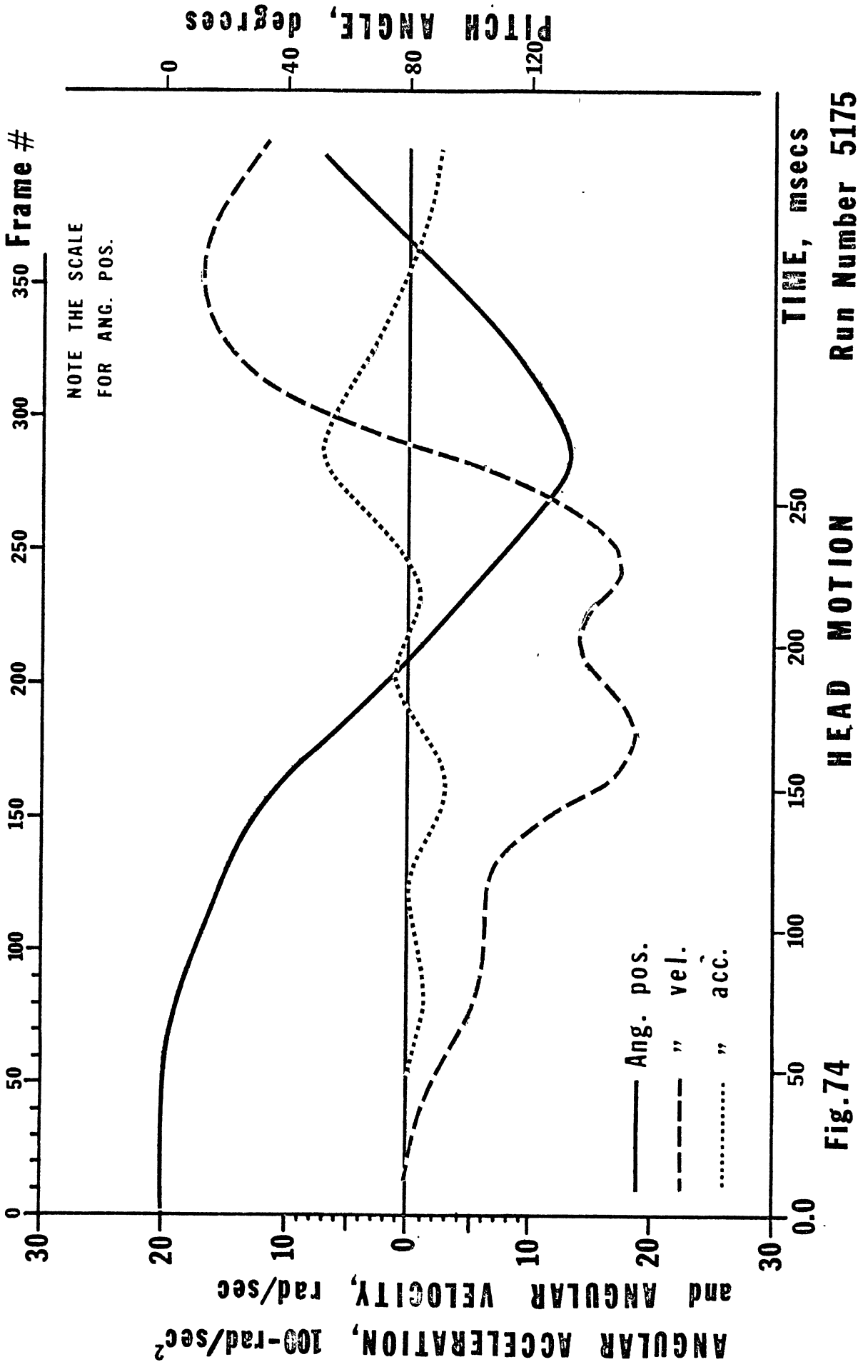

ANGULAR ACCELERATION, 100-rad/sec²
and ANGULAR VELOCITY, rad/sec
PITCH ANGLE, degrees
TIME, msecs
Frame #
NOTE THE SCALE
FOR ANG. POS.
Ang. pos.
" vel.
" acc.
HEAD MOTION
Run Number 5175

Fig.74

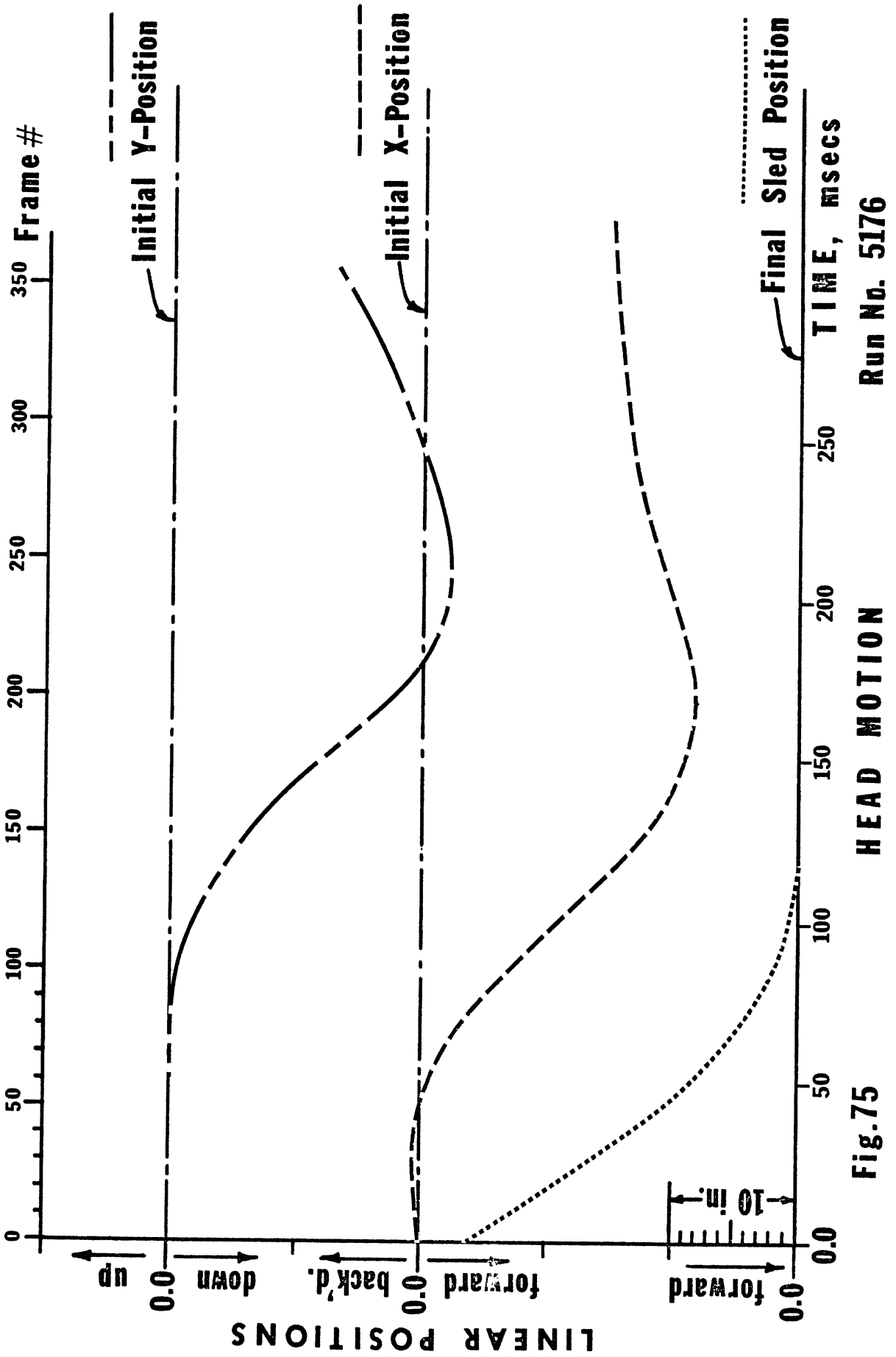

Initial Y-Position
Initial X-Position
Final Sled Position
Frame #
0
50
100
150
200
250
300
350
TIME, msecs
0.0
50
100
150
200
250
HEAD MOTION
Run No. 5176
LINEAR POSITIONS
up
0.0
down
back'd.
0.0
forward
forward
0.0
10 in.

Fig.75

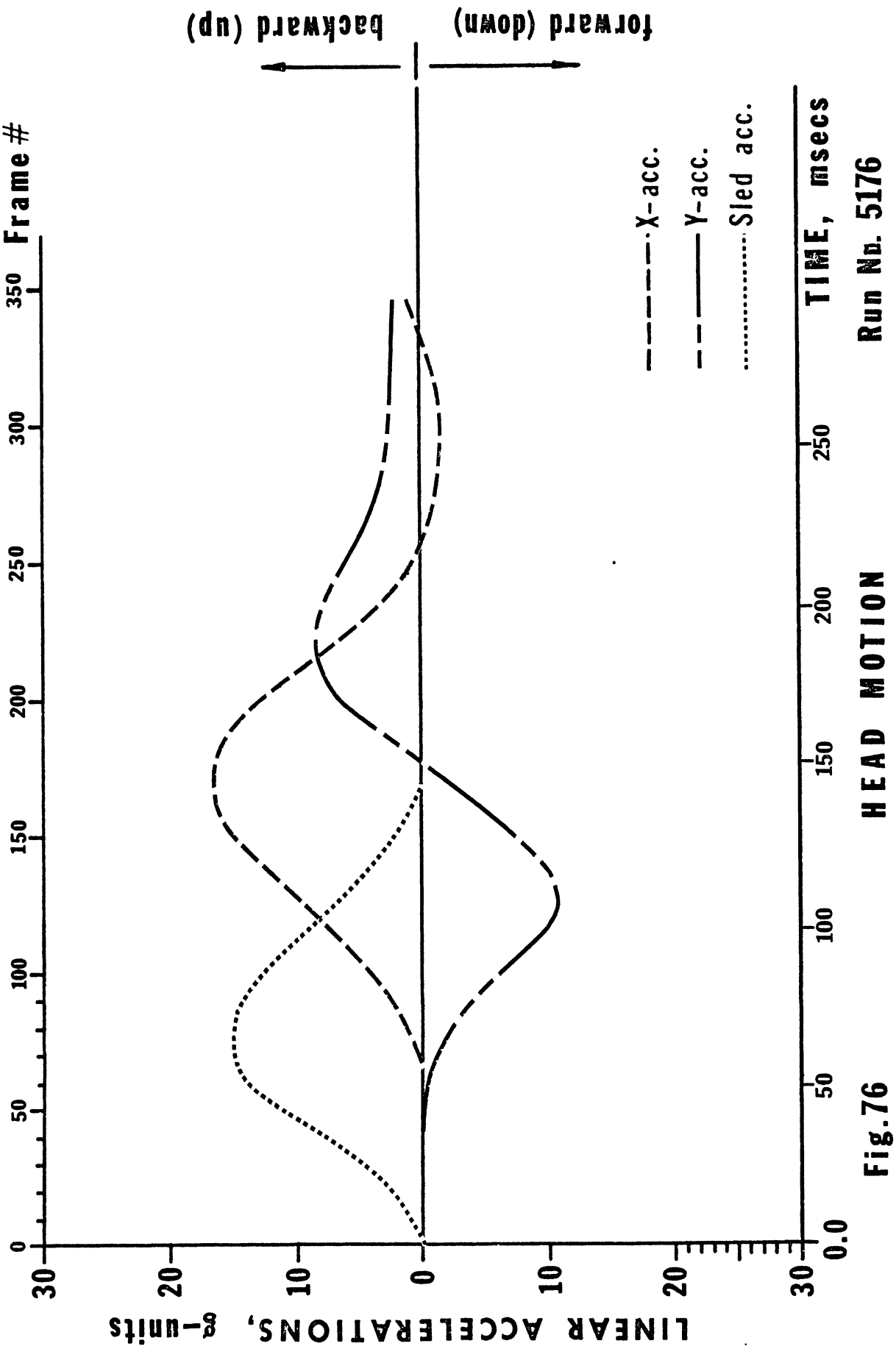

forward (down)
backward (up)
X-acc.
Y-acc.
Sled acc.
TIME, msecs
Run No. 5176
HEAD MOTION
LINEAR ACCELERATIONS, g-units
Frame #
0.0
50
100
150
200
250
300
350
30
20
10
0

Fig.76

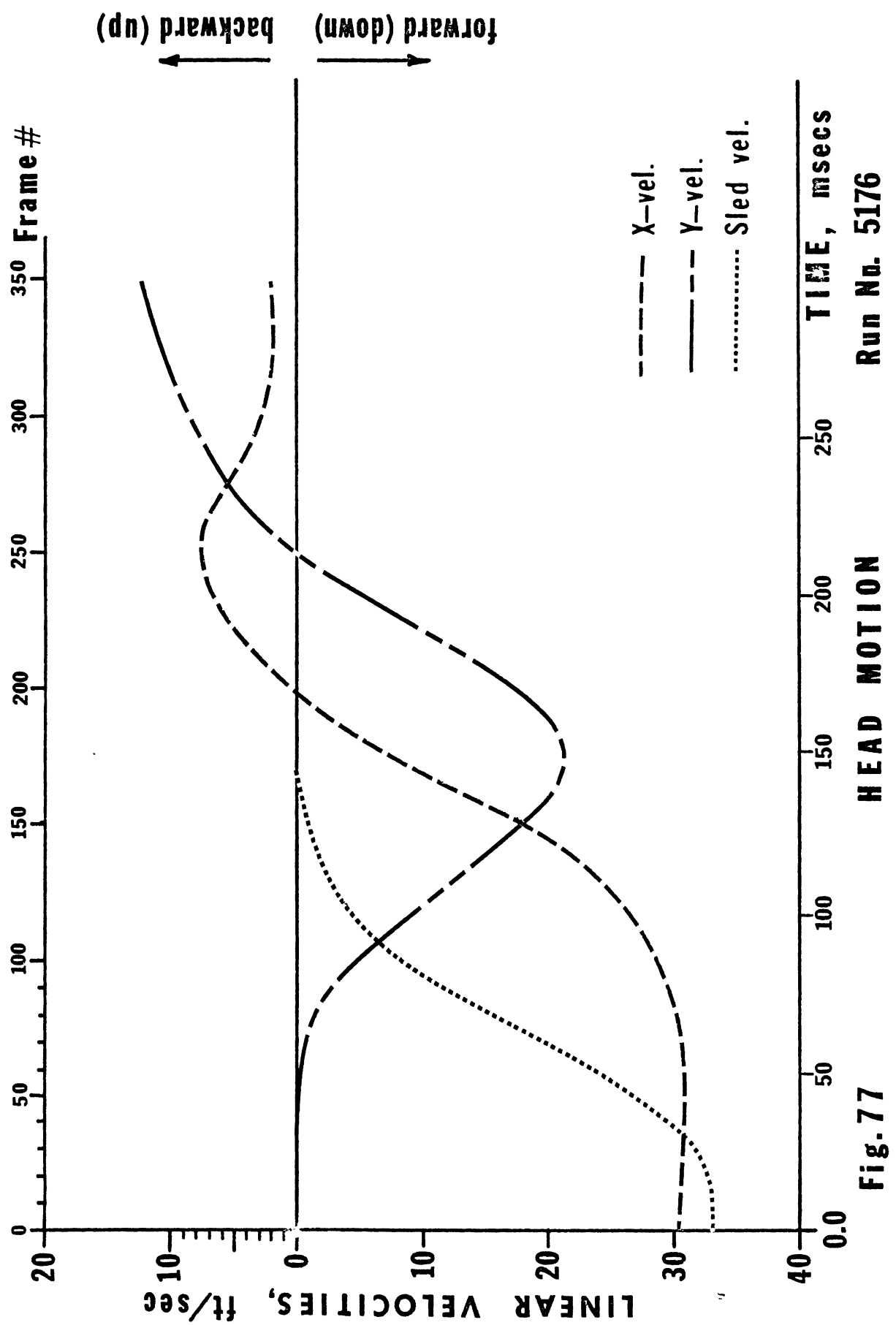

forward (down)
backward (up)
X-vel.
Y-vel.
Sled vel.
LINEAR VELOCITIES, ft/sec
TIME, msecs
Frame #
HEAD MOTION
Run No. 5176

Fig. 77

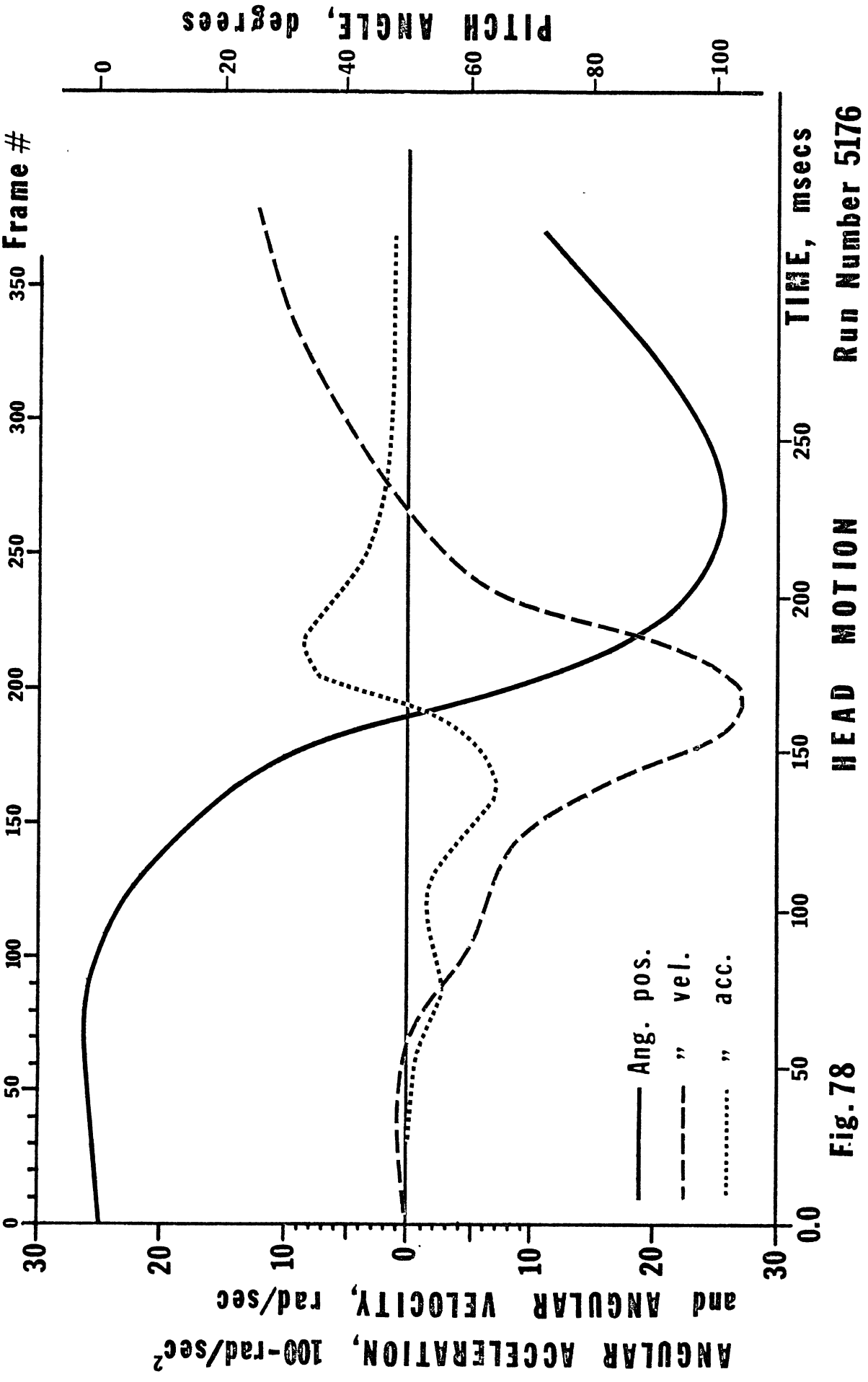

ANGULAR ACCELERATION, 100-rad/sec²
and ANGULAR VELOCITY, rad/sec
PITCH ANGLE, degrees
TIME, msecs
Frame #
Ang. pos.
" vel.
" acc.
HEAD MOTION
Run Number 5176

Fig. 78

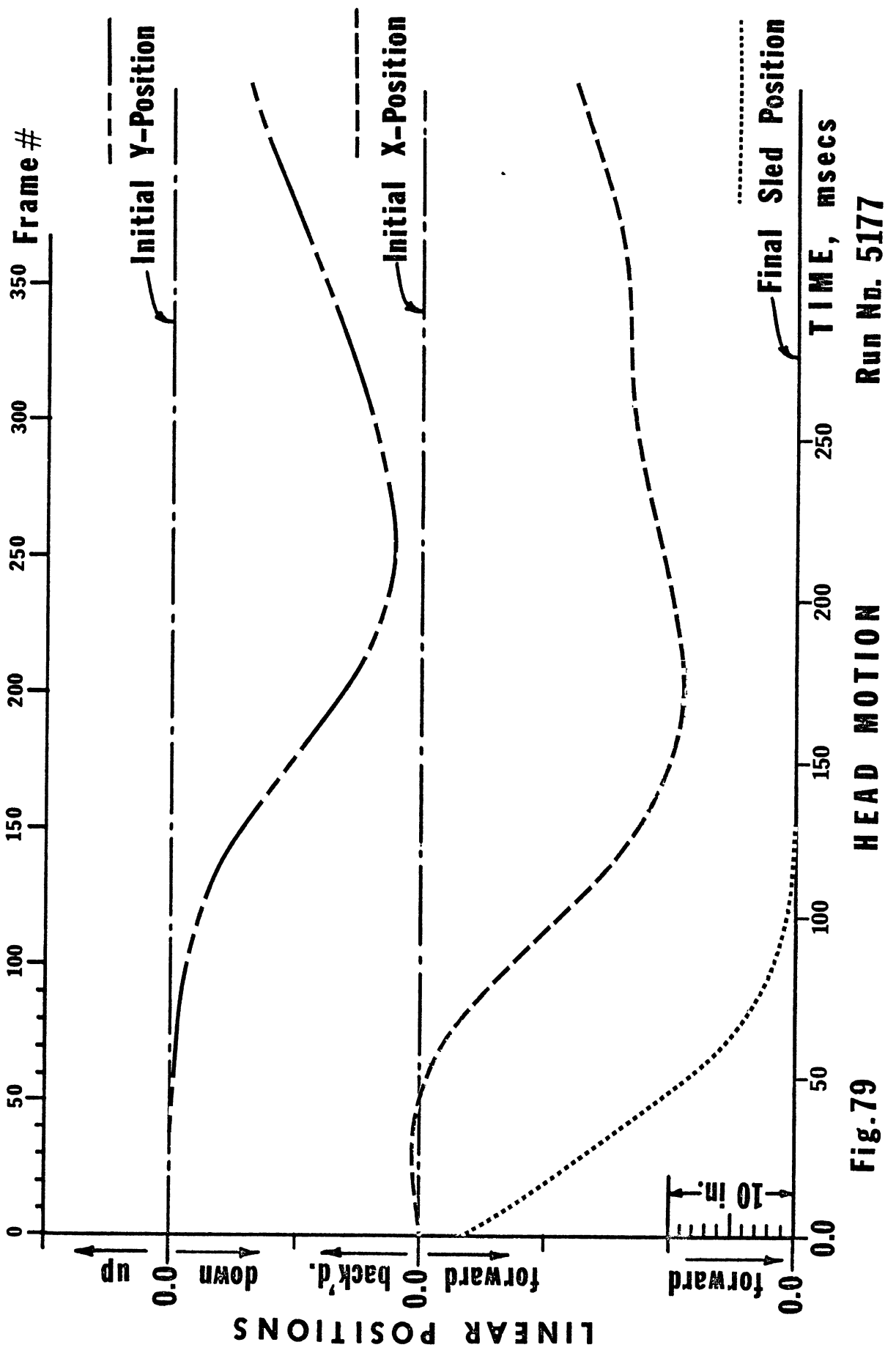

Initial Y-Position
Initial X-Position
Final Sled Position
Frame #
0
50
100
150
200
250
300
350
TIME, msecs
0.0
50
100
150
200
250
Run No. 5177
HEAD MOTION
LINEAR POSITIONS
up
down
0.0
back'd.
forward
0.0
forward
10 in.
0.0

Fig.79

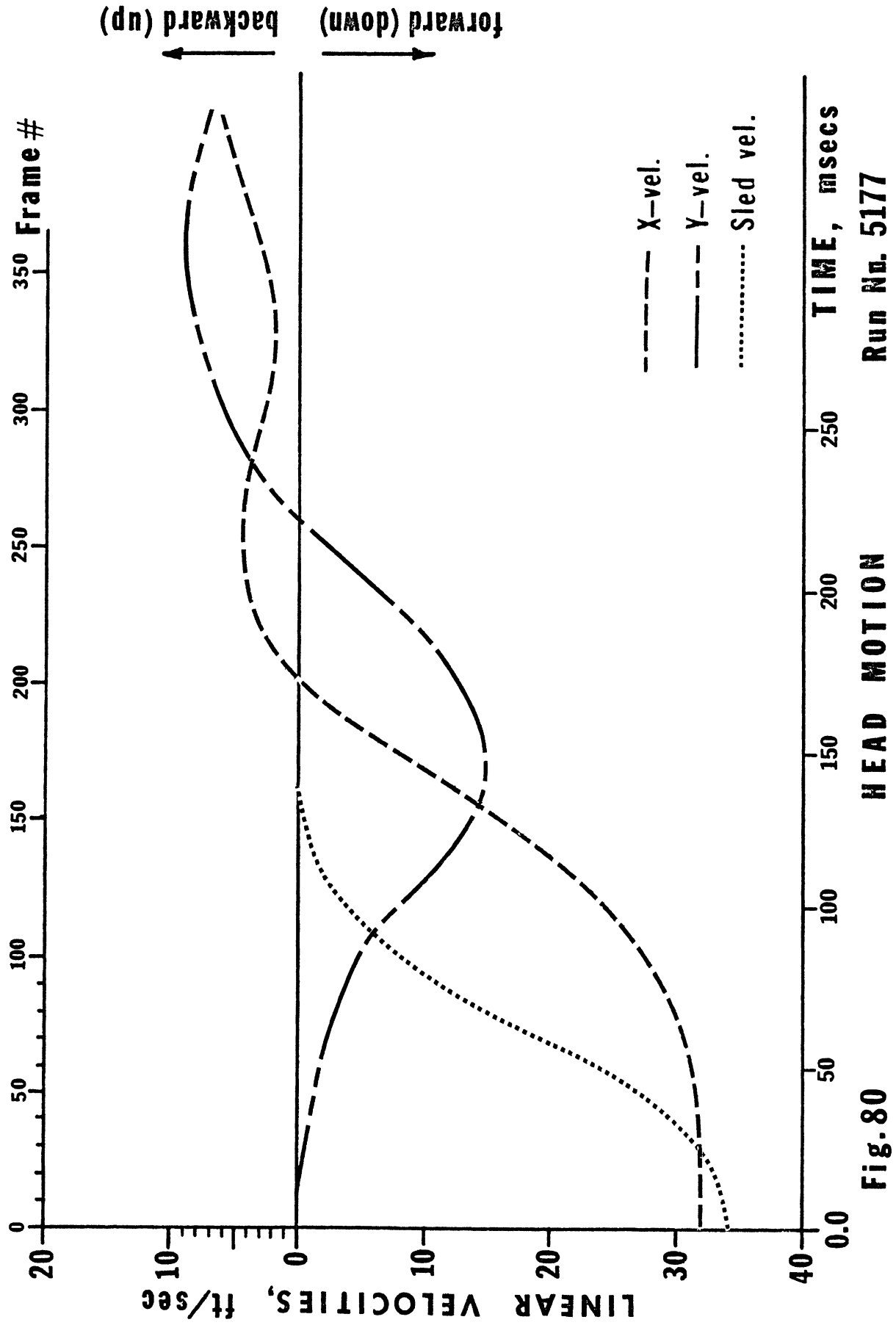

forward (down)
backward (up)
LINEAR VELOCITIES, ft/sec
20
10
0
10
20
30
40
0.0
50
100
150
200
250
TIME, msecs
Run No. 5177
HEAD MOTION
X-vel.
Y-vel.
Sled vel.
0
50
100
150
200
250
300
350
Frame #

Fig.80

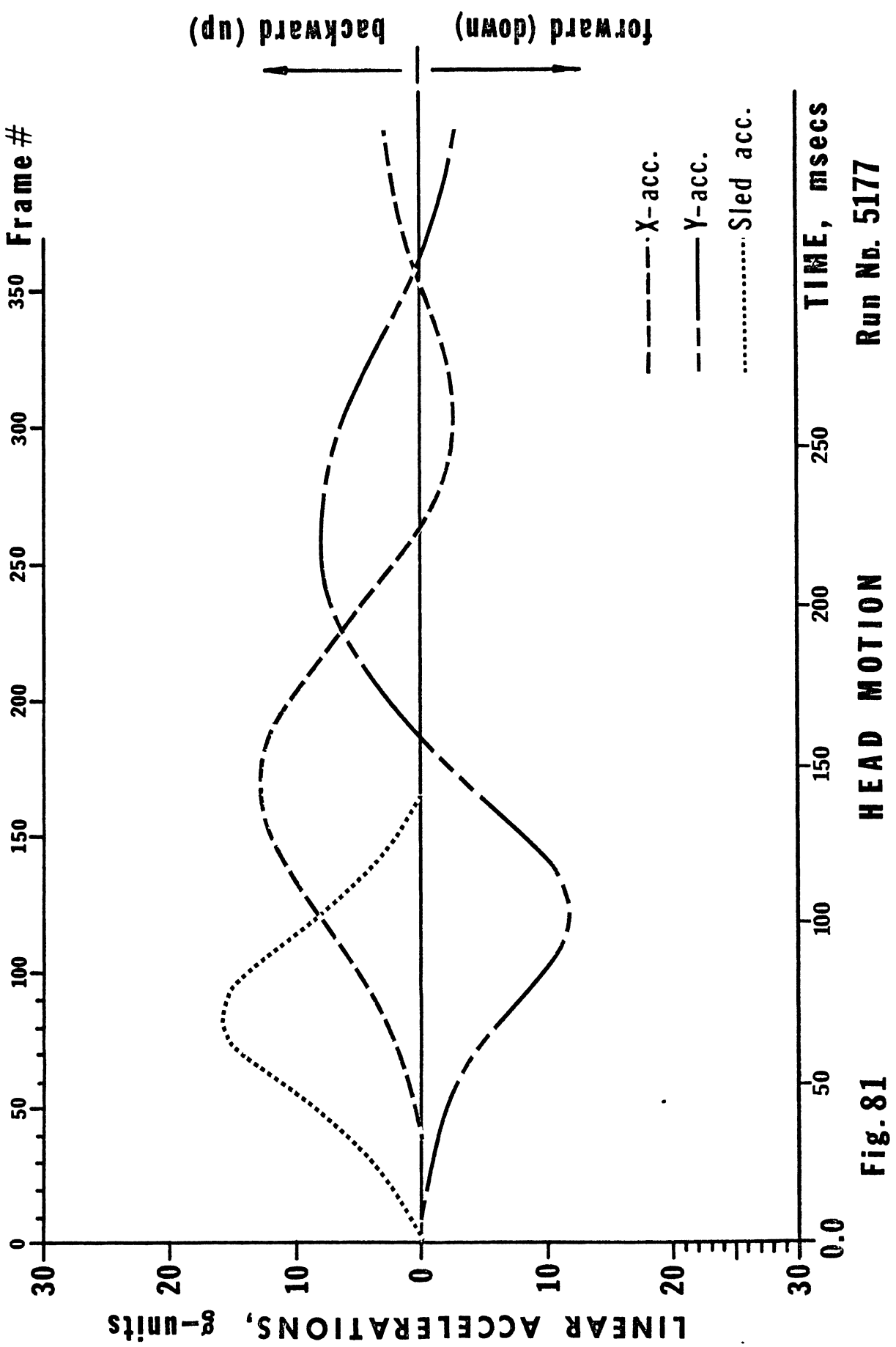

forward (down)
backward (up)
LINEAR ACCELERATIONS, g-units
30
20
10
0
10
20
30
0.0
50
100
150
200
250
TIME, msecs
Frame #
0
50
100
150
200
250
300
350
X-acc.
Y-acc.
Sled acc.
HEAD MOTION
Run No. 5177

Fig. 81

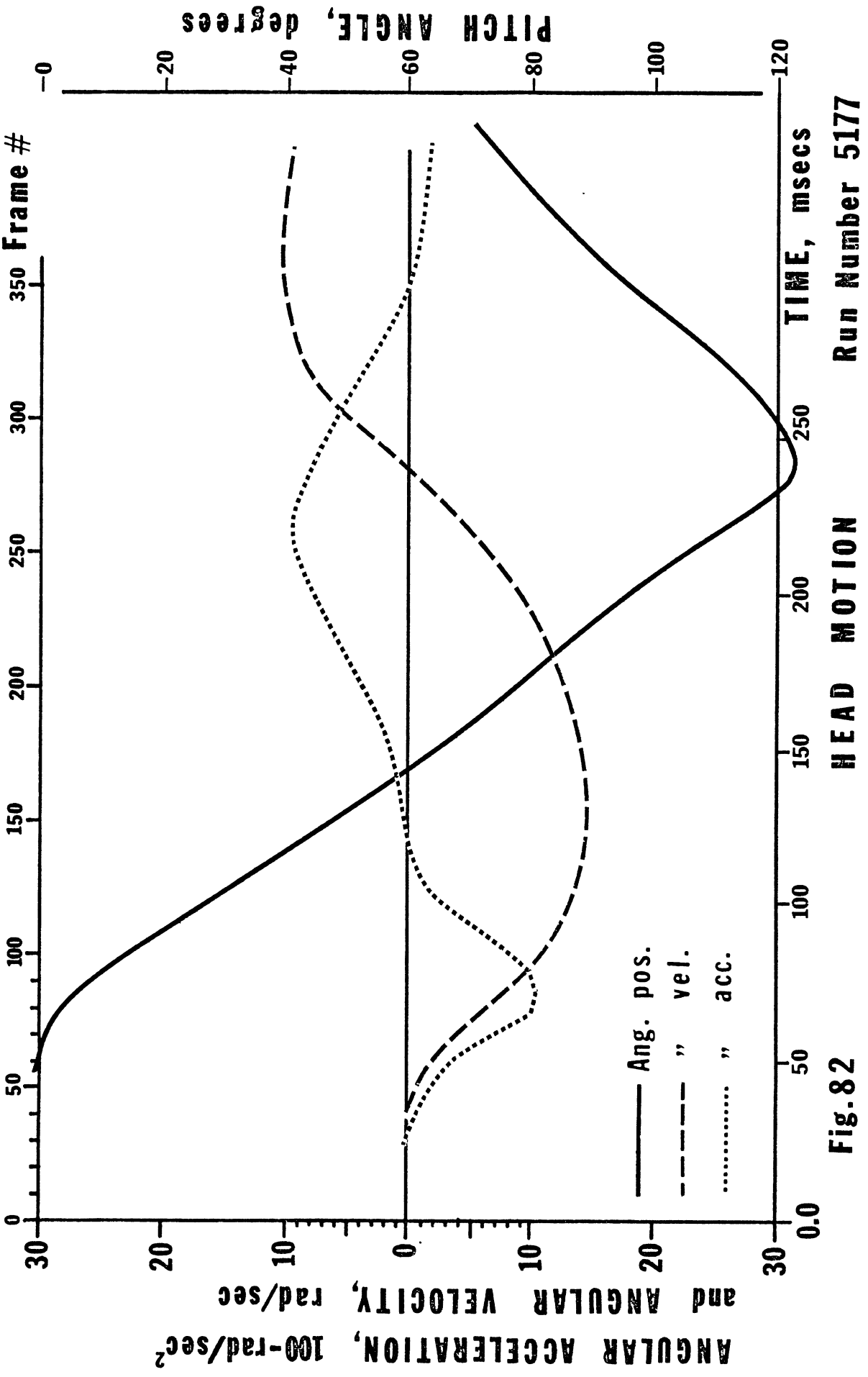

ANGULAR ACCELERATION, 100-rad/sec²
and ANGULAR VELOCITY, rad/sec
PITCH ANGLE, degrees
Frame #
TIME, msecs
Ang. pos.
" vel.
" acc.
HEAD MOTION
Run Number 5177

Fig. 82

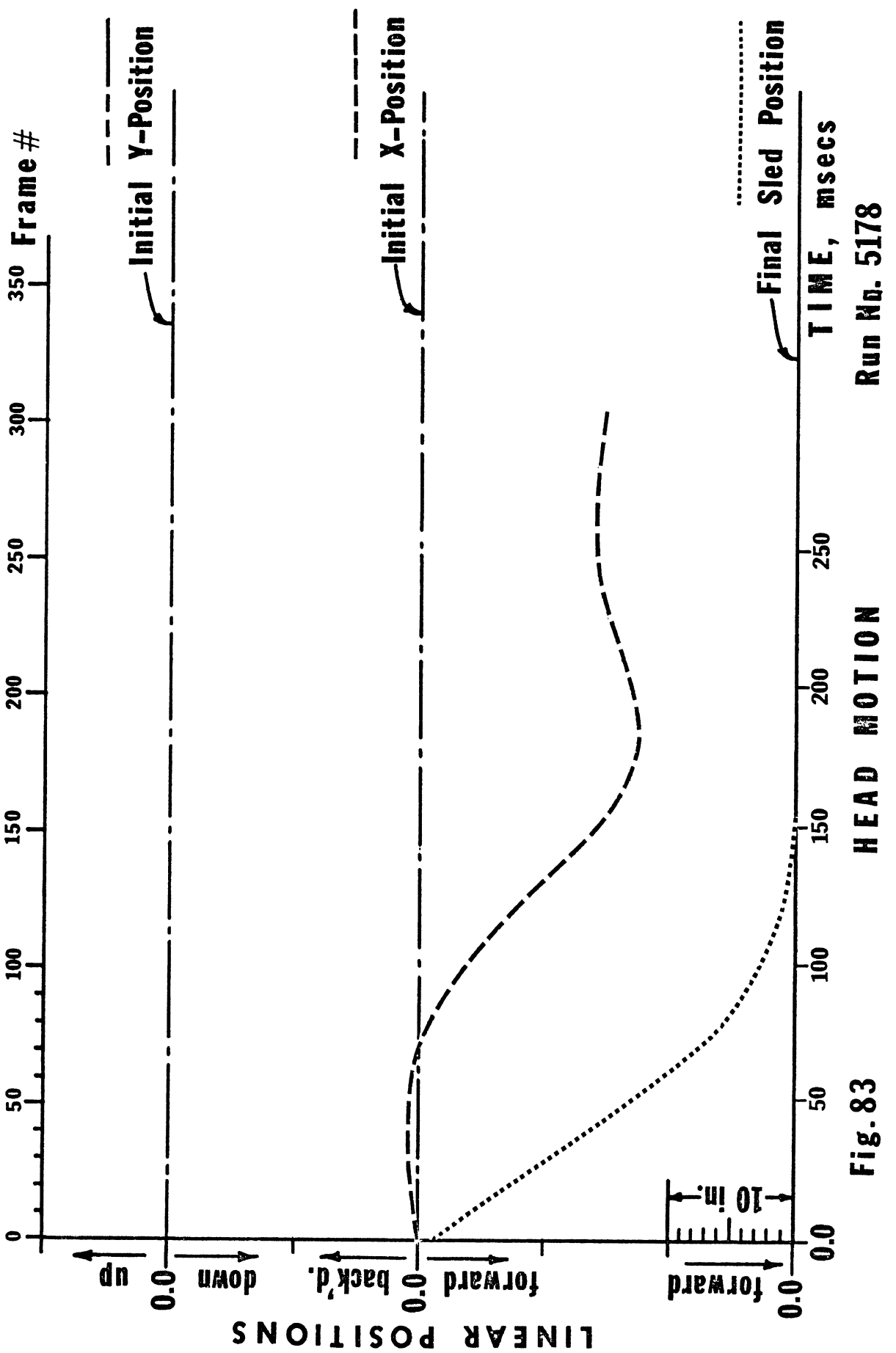

Frame #
0
50
100
150
200
250
300
350
Initial Y-Position
Initial X-Position
Final Sled Position
TIME, msecs
0.0
250
LINEAR POSITIONS
up
down
back'd.
forward
forward
0.0
0.0
0.0
10 in.
HEAD MOTION
Run No. 5178

Fig. 83

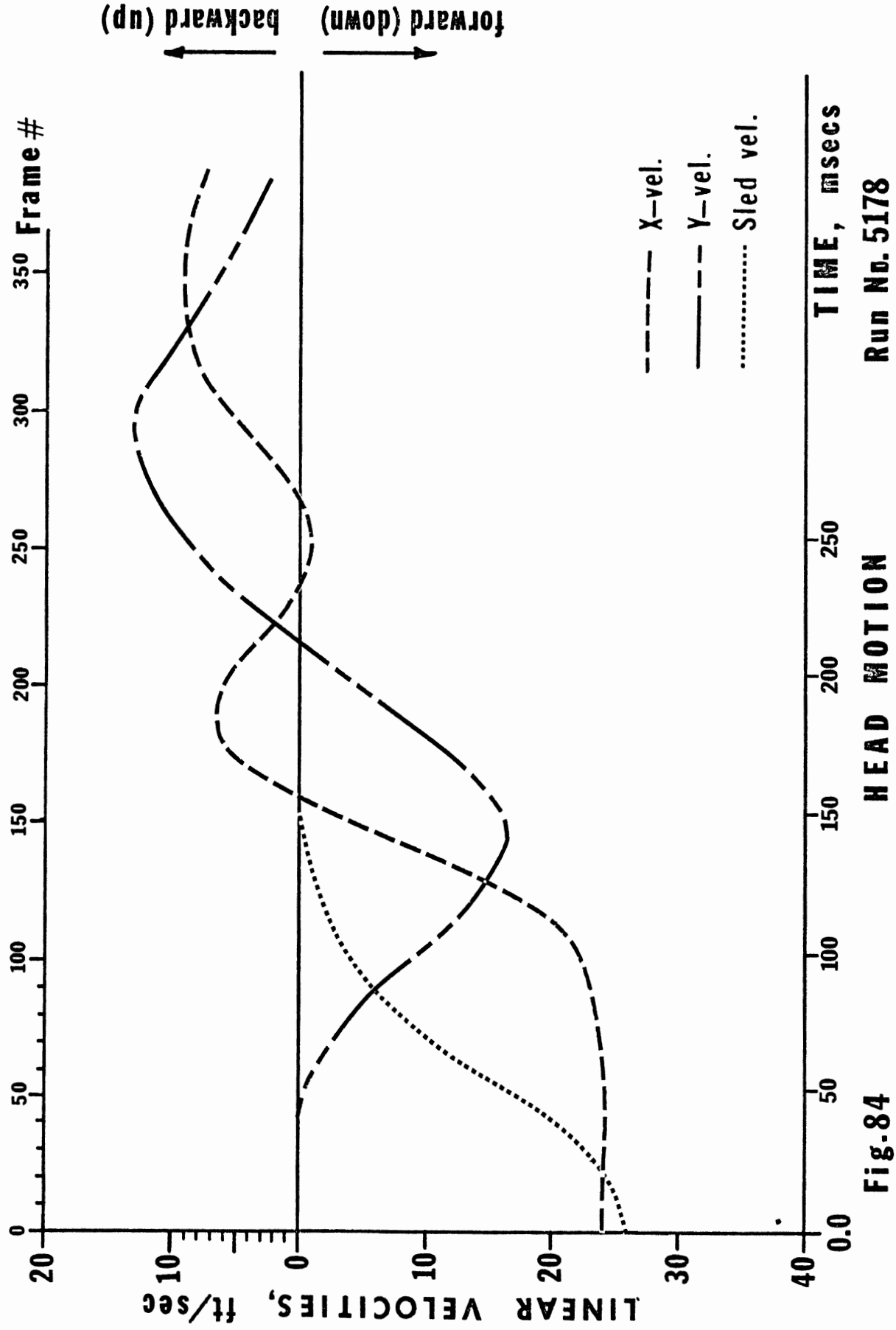

forward (down)
backward (up)
LINEAR VELOCITIES, ft/sec
20
10
0
10
20
30
40
0.0
50
100
150
200
250
300
350
Frame #
TIME, msecs
X-vel.
Y-vel.
Sled vel.
HEAD MOTION
Run No. 5178

Fig.84

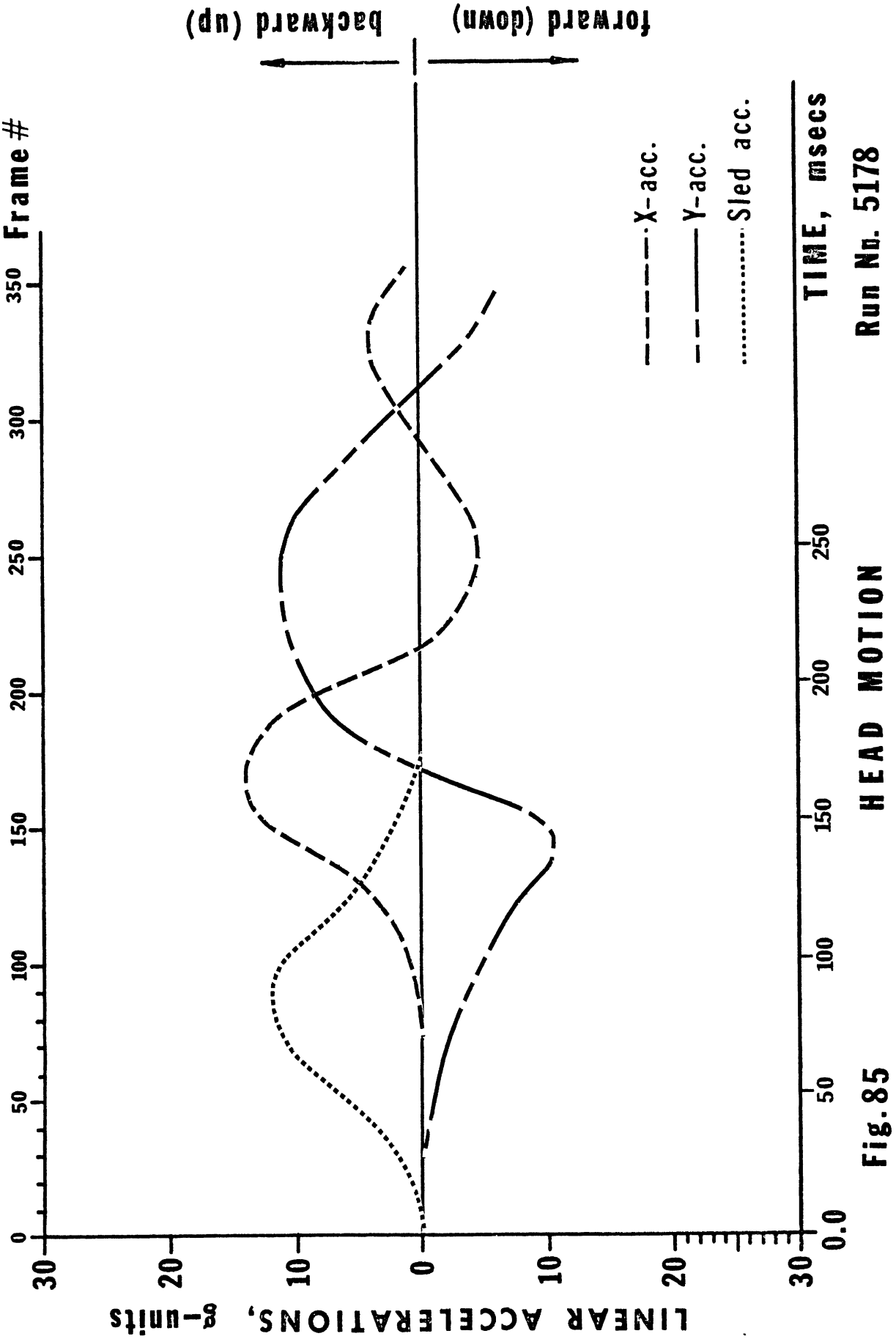

forward (down)
backward (up)
X-acc.
Y-acc.
Sled acc.
LINEAR ACCELERATIONS, g-units
30
20
10
0
10
20
30
0.0
50
100
150
200
250
TIME, msecs
0
50
100
150
200
250
300
350
Frame #
Run No. 5178
HEAD MOTION

Fig.85

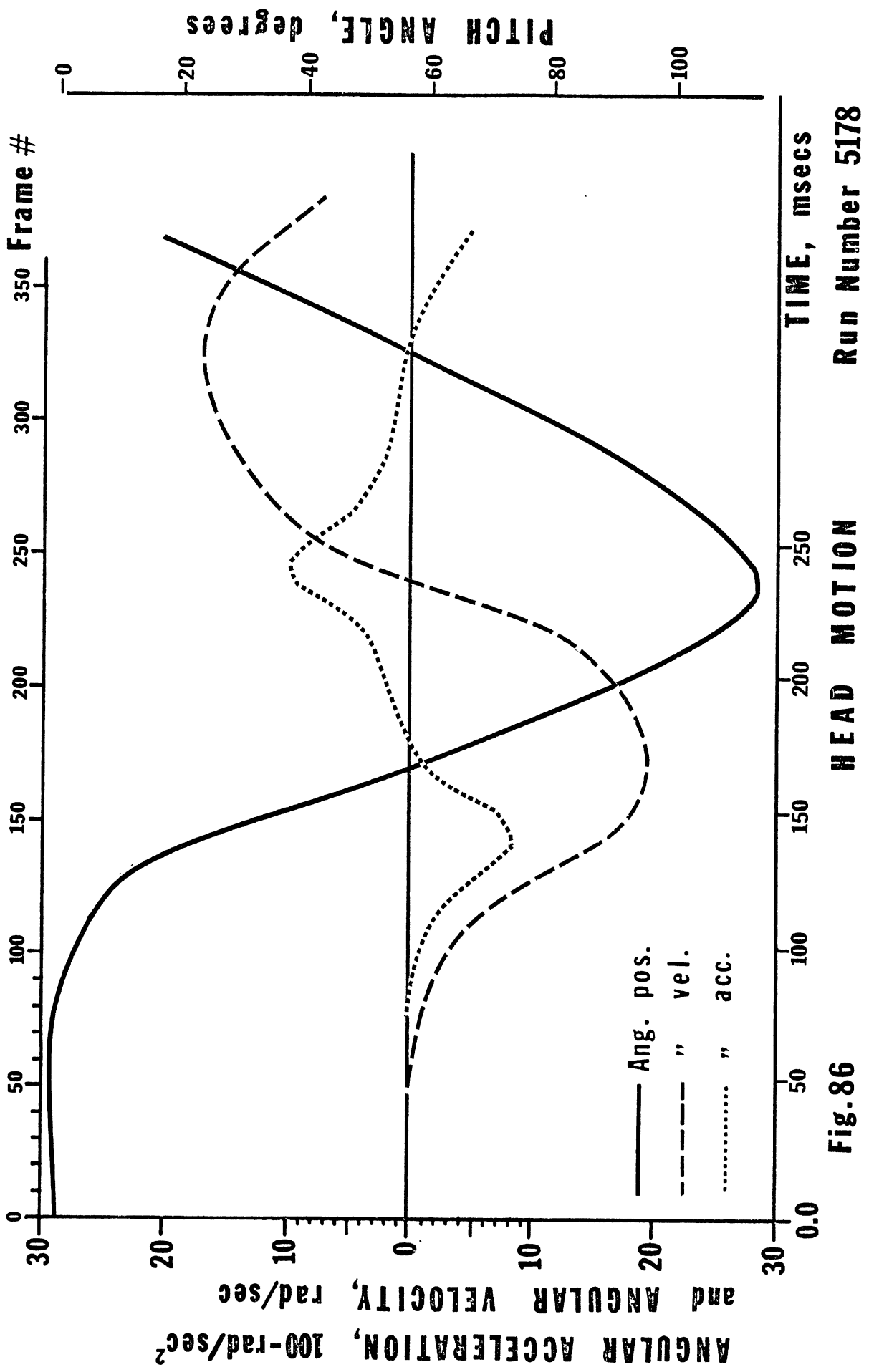

PITCH ANGLE, degrees
0
20
40
60
80
100
Frame #
0
50
100
150
200
250
300
350
TIME, msecs
0.0
50
100
150
200
250
ANGULAR ACCELERATION, 100-rad/sec²
and ANGULAR VELOCITY, rad/sec
30
20
10
0
10
20
30
Ang. pos.
" vel.
" acc.
HEAD MOTION
Run Number 5178

Fig.86

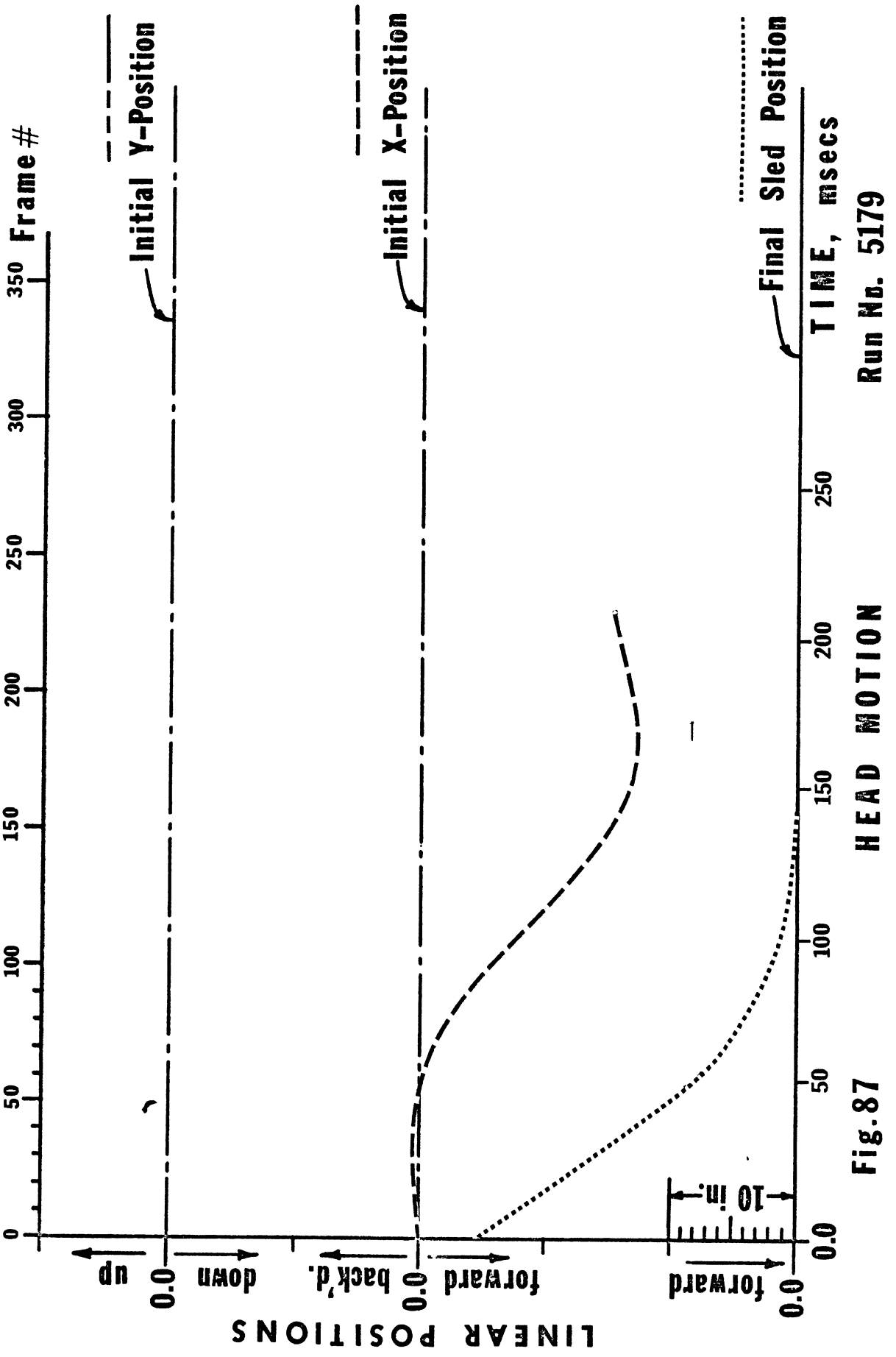

Frame #
0
50
100
150
200
250
300
350
Initial Y-Position
Initial X-Position
Final Sled Position
TIME, msecs
Run No. 5179
HEAD MOTION
LINEAR POSITIONS
up
down
0.0
back'd.
forward
0.0
forward
0.0
10 in.
0.0
50
100
150
200
250

Fig.87

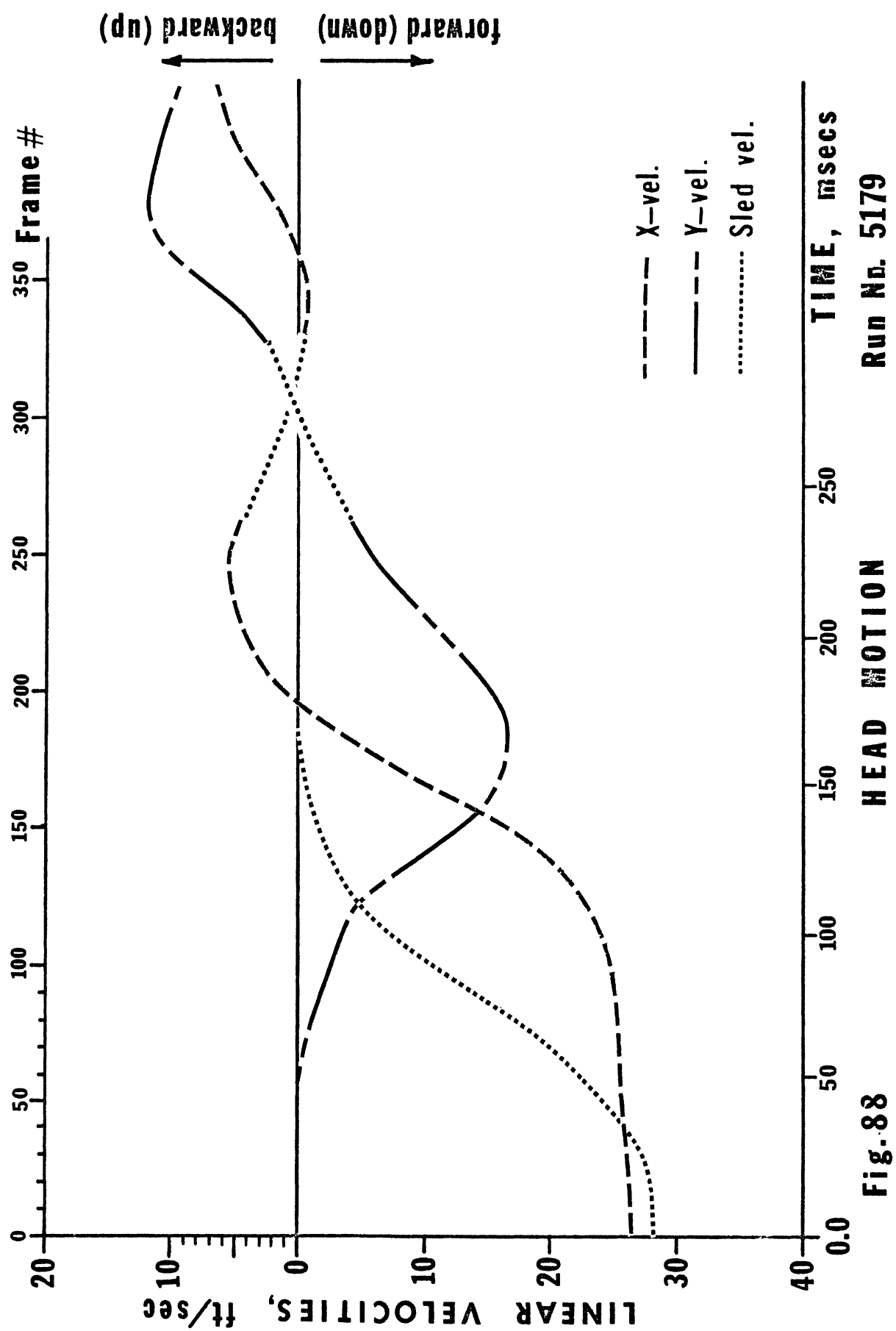

forward (down)
backward (up)
X-vel.
Y-vel.
Sled vel.
HEAD MOTION
Run No. 5179
LINEAR VELOCITIES, ft/sec
TIME, msecs
Frame #
20
10
0
10
20
30
40
0.0
50
100
150
200
250
300
350

Fig. 88

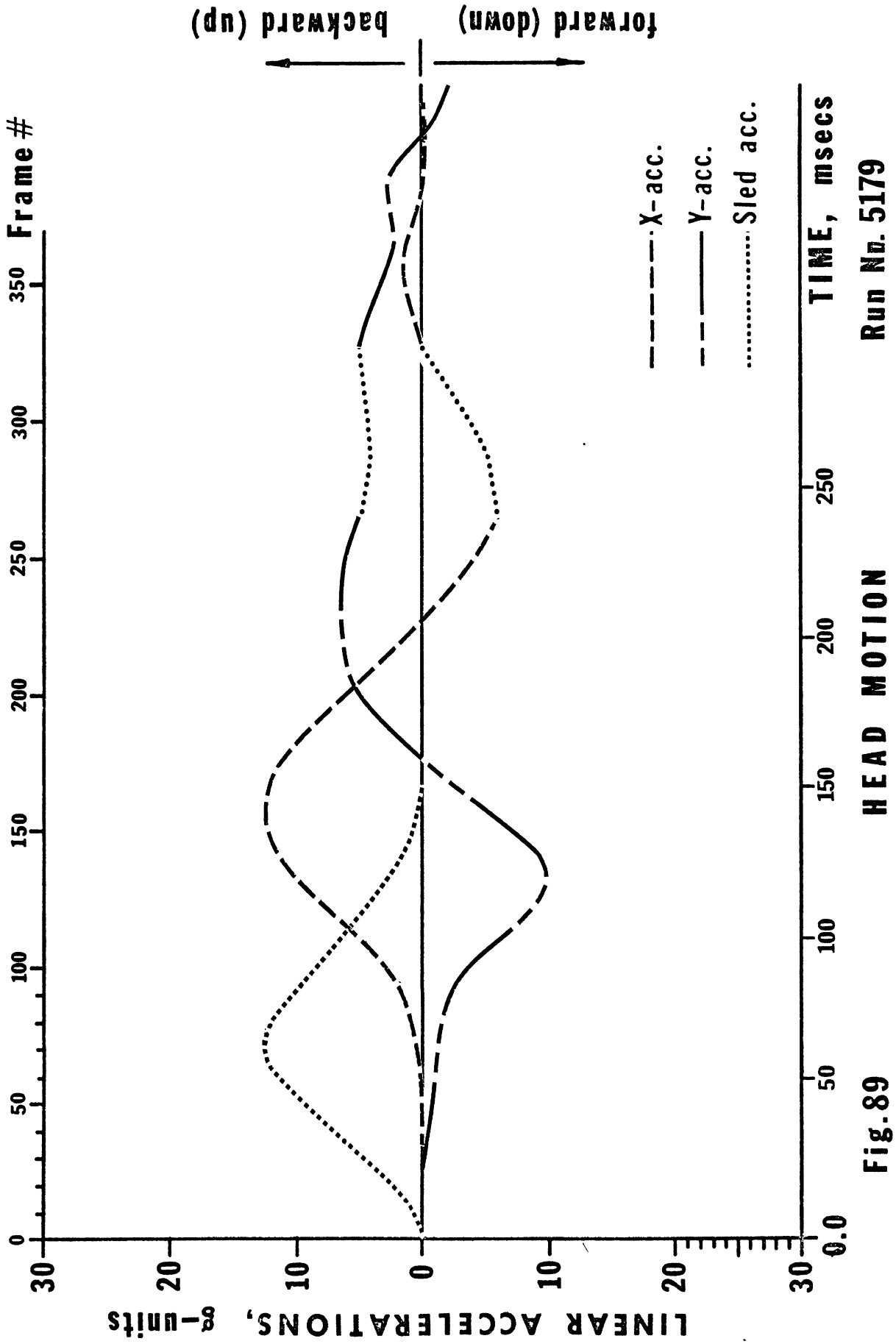


Fig.89 HEAD MOTION Run No. 5179

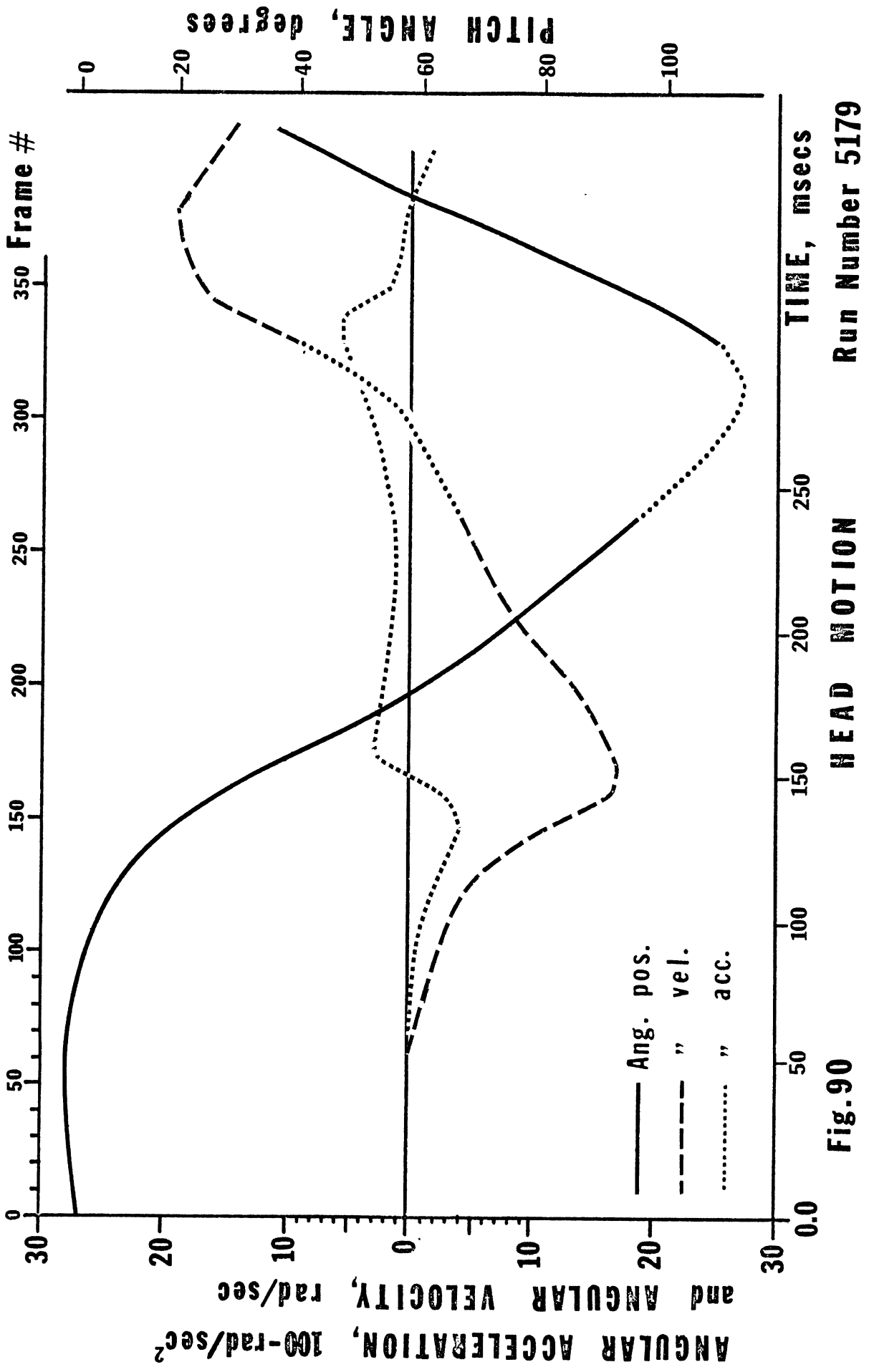

PITCH ANGLE, degrees
0
20
40
60
80
100
Frame #
0
50
100
150
200
250
300
350
TIME, msecs
0.0
50
100
150
200
250
Run Number 5179
HEAD MOTION
Ang. pos.
" vel.
" acc.
ANGULAR ACCELERATION, 100-rad/sec²
and ANGULAR VELOCITY, rad/sec
30
20
10
0
10
20
30

Fig.90

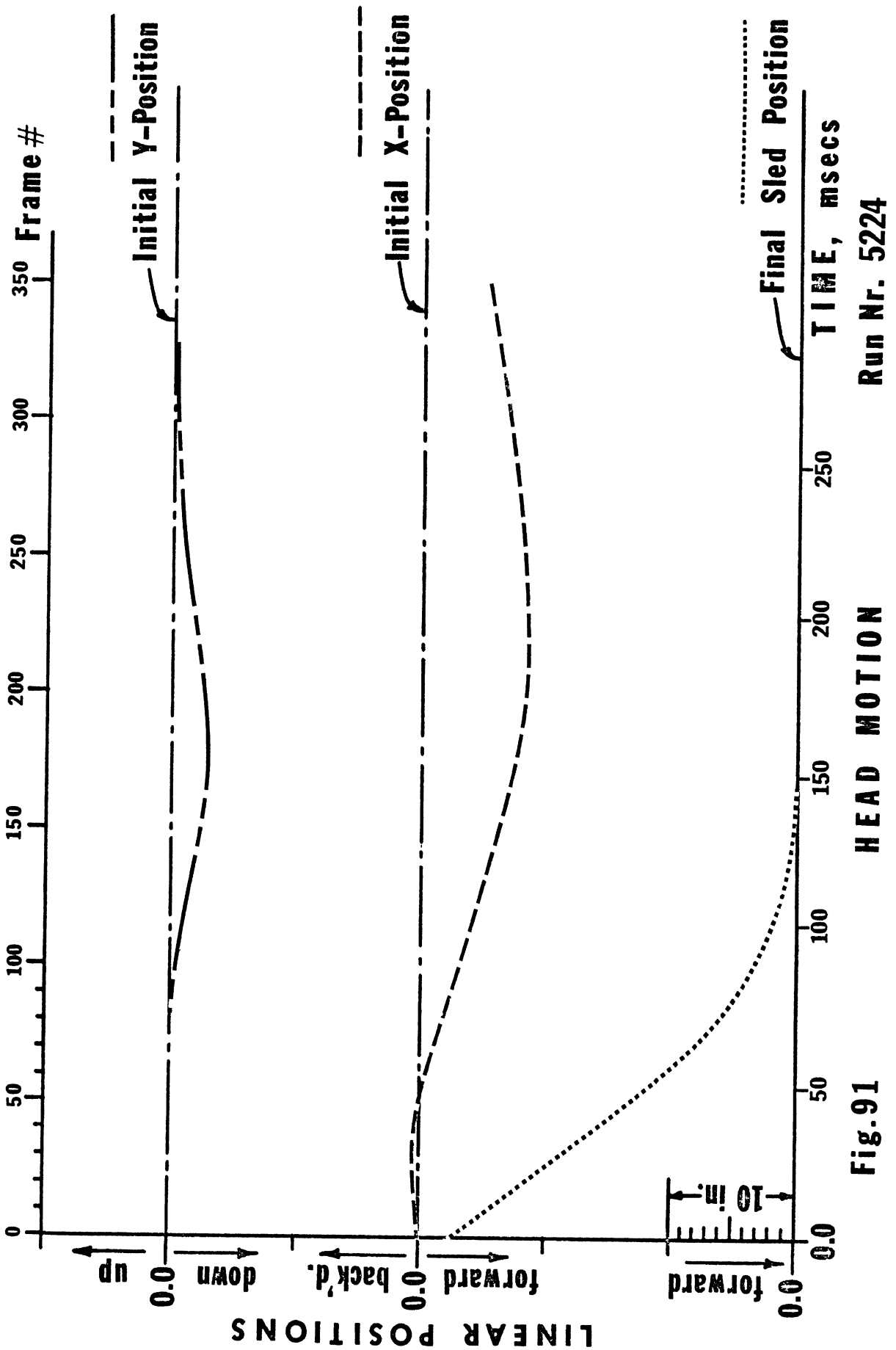

Frame #
0
50
100
150
200
250
300
350
Initial Y-Position
Initial X-Position
Final Sled Position
TIME, msecs
0.0
50
100
150
200
250
HEAD MOTION
Run Nr. 5224
LINEAR POSITIONS
up
down
0.0
back'd.
forward
0.0
10 in.
forward
0.0

Fig.91

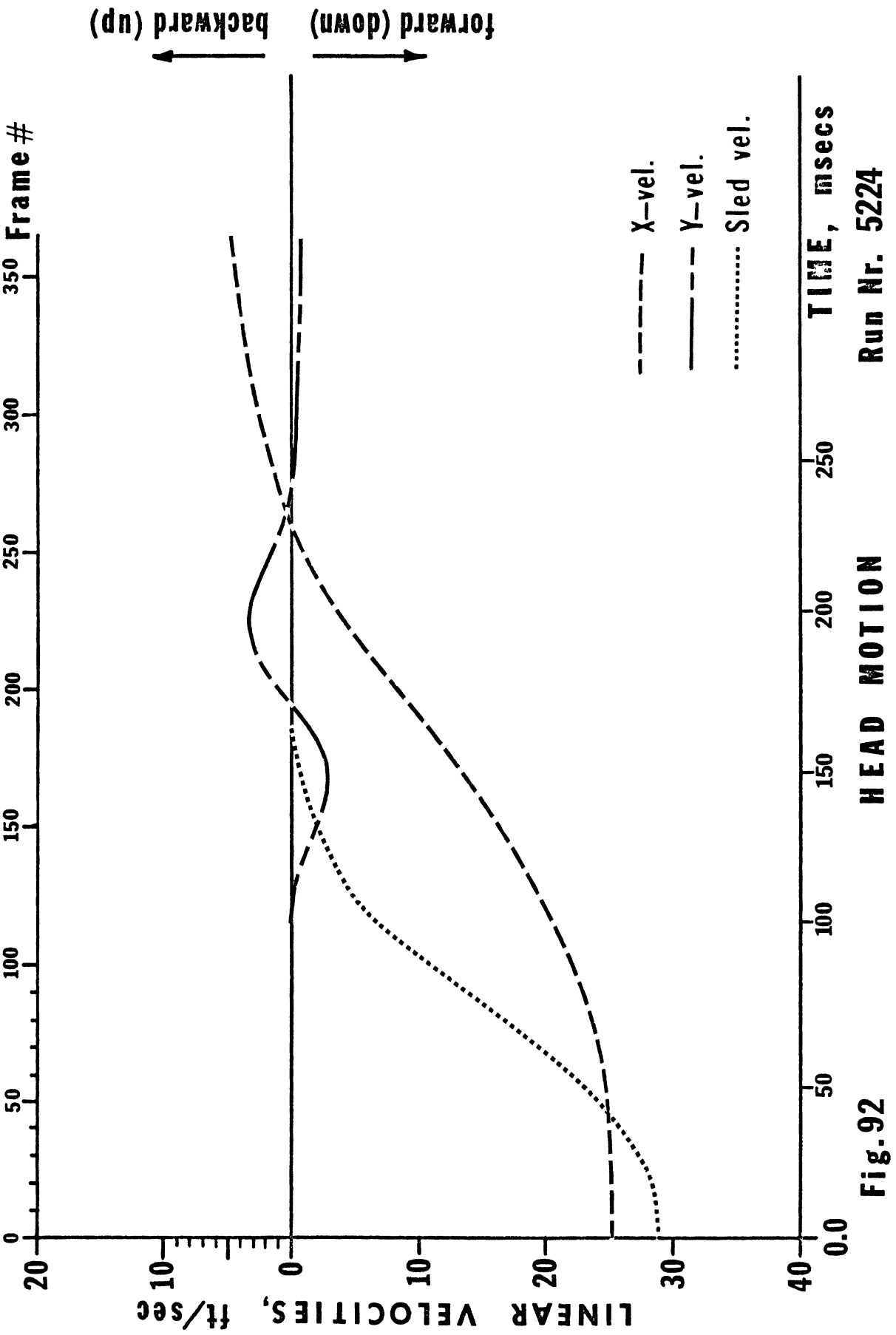

forward (down)
backward (up)
LINEAR VELOCITIES, ft/sec
20
10
0
10
20
30
40
0.0
50
100
150
200
250
300
350
Frame #
TIME, msecs
X-vel.
Y-vel.
Sled vel.
HEAD MOTION
Run Nr. 5224

Fig.92

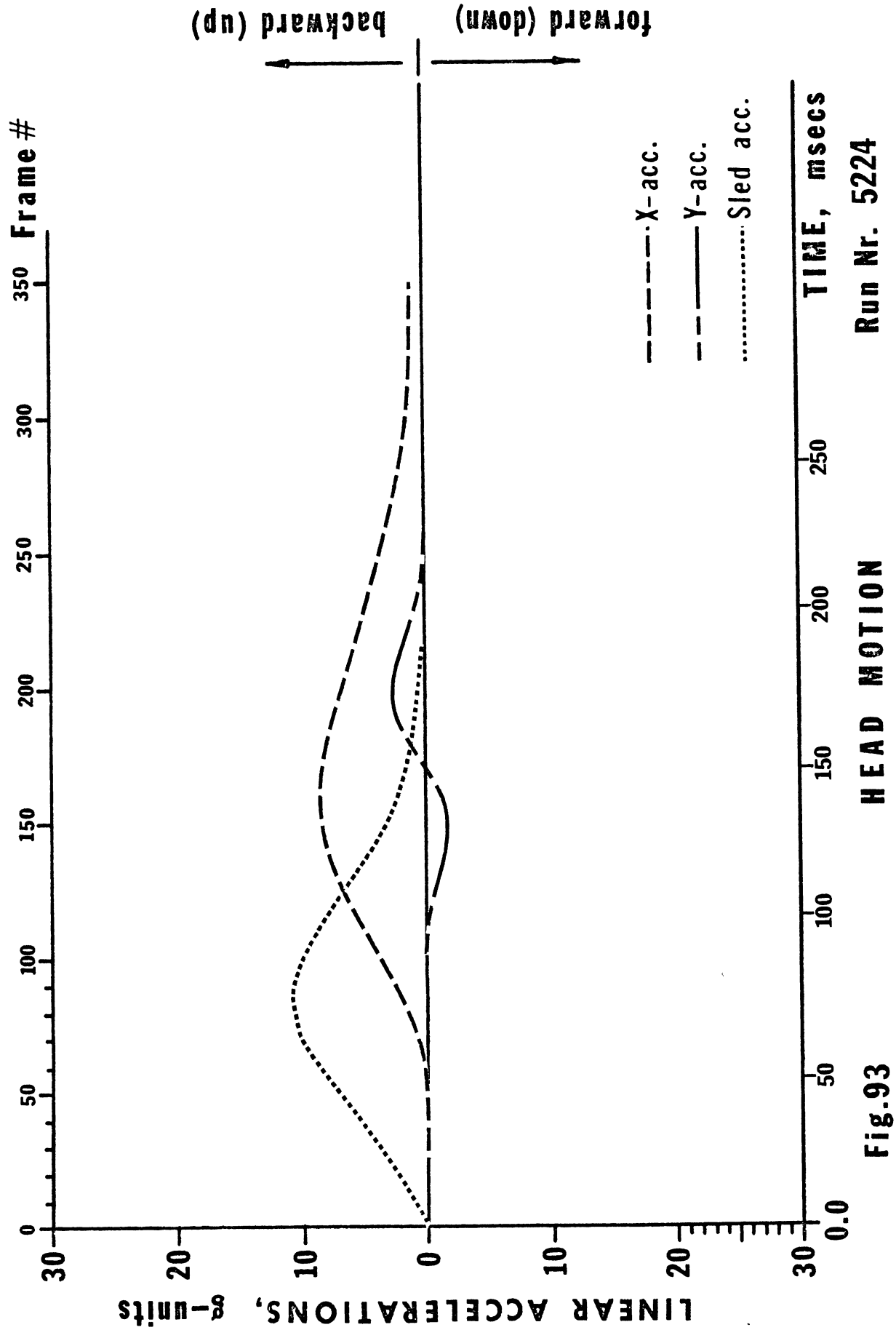

forward (down)
backward (up)
LINEAR ACCELERATIONS, g-units
30
20
10
0
10
20
30
0.0
50
100
150
200
250
TIME, msecs
Run Nr. 5224
HEAD MOTION
X-acc.
Y-acc.
Sled acc.
0
50
100
150
200
250
300
350
Frame #

Fig.93

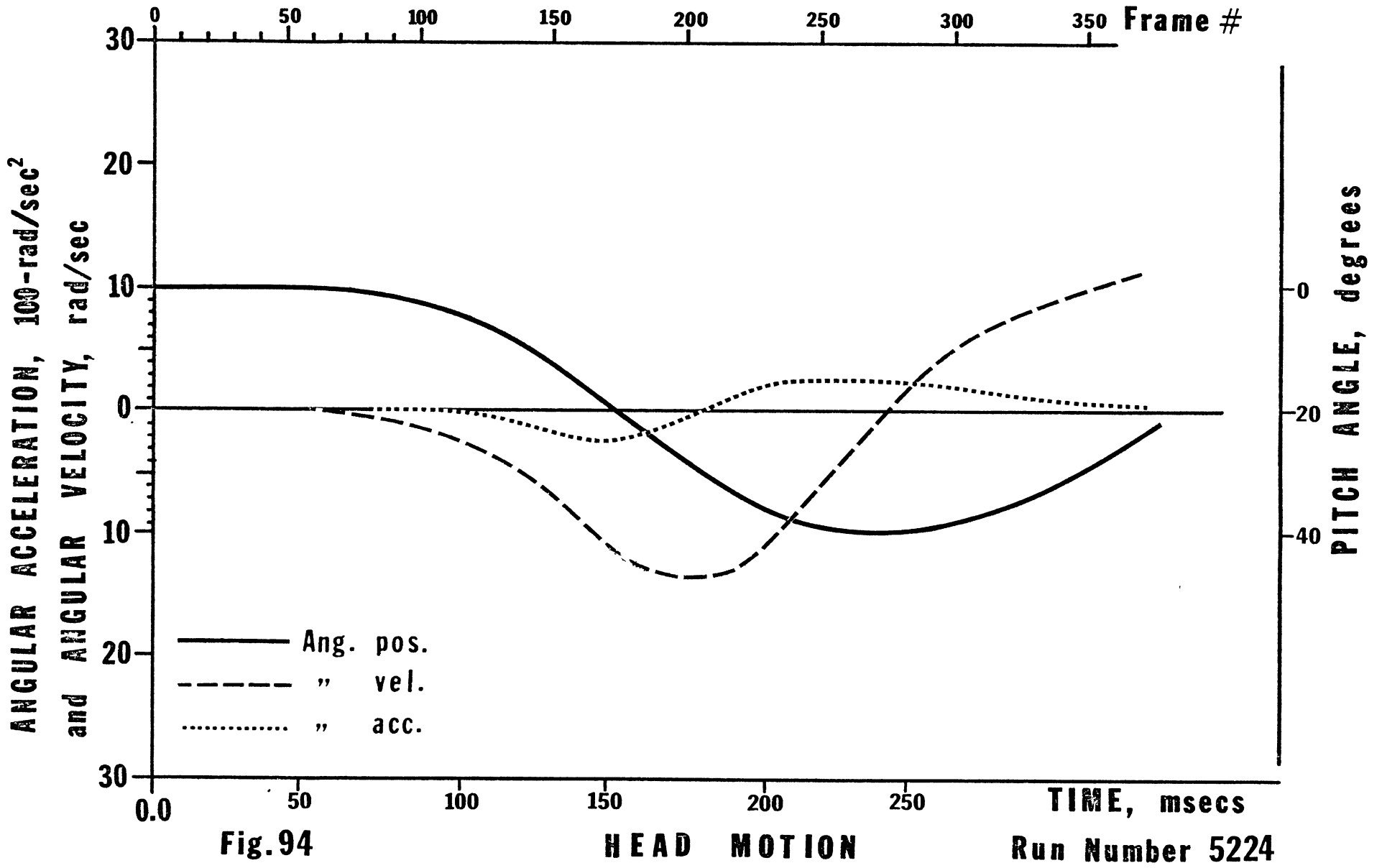


Fig.94 HEAD MOTION Run Number 5224

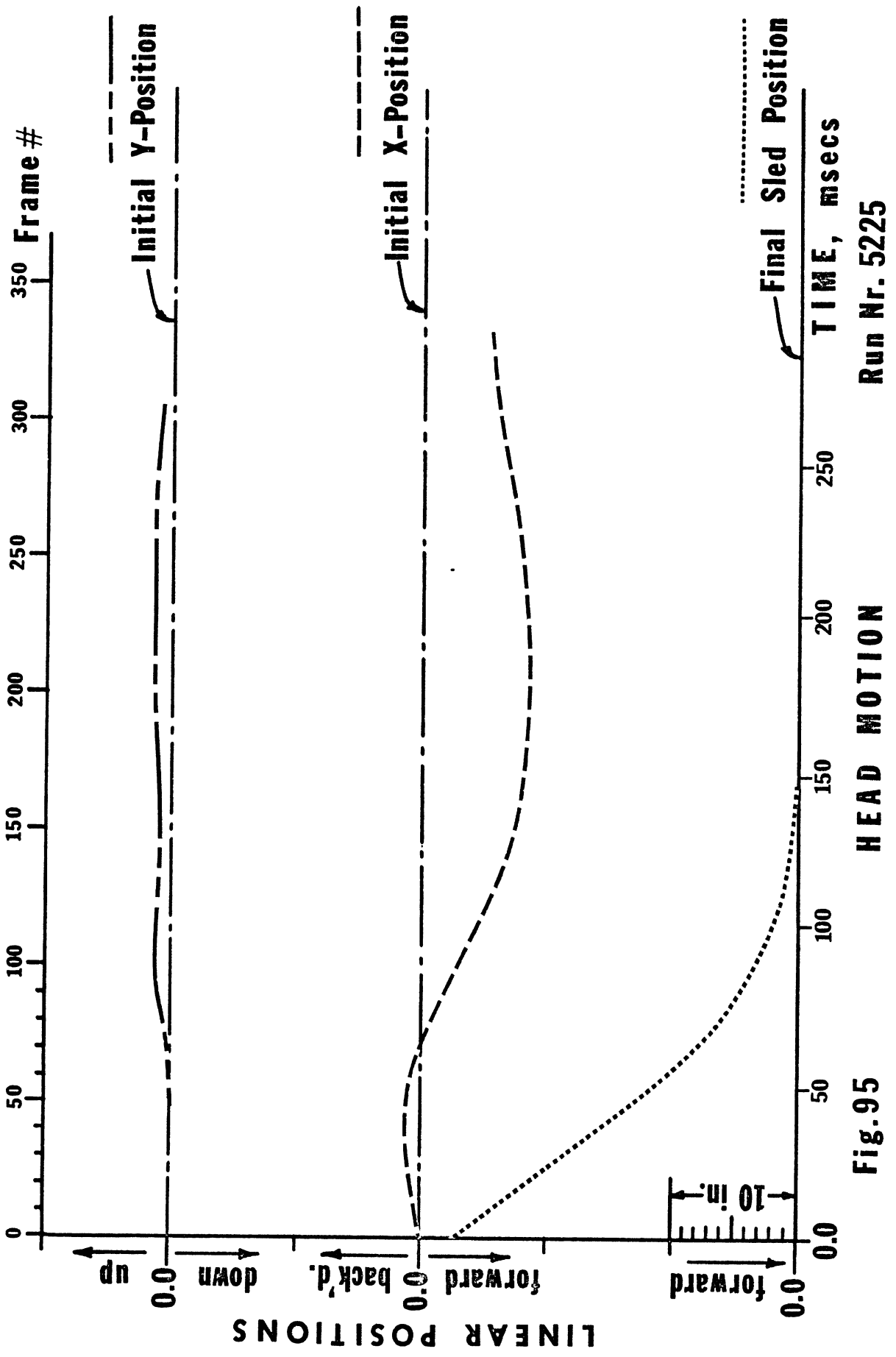

Frame #
0
50
100
150
200
250
300
350
Initial Y-Position
Initial X-Position
Final Sled Position
TIME, msecs
0
50
100
150
200
250
Run Nr. 5225
HEAD MOTION
LINEAR POSITIONS
up
0.0
down
back'd.
0.0
forward
forward
0.0
10 in.
0.0

Fig. 95

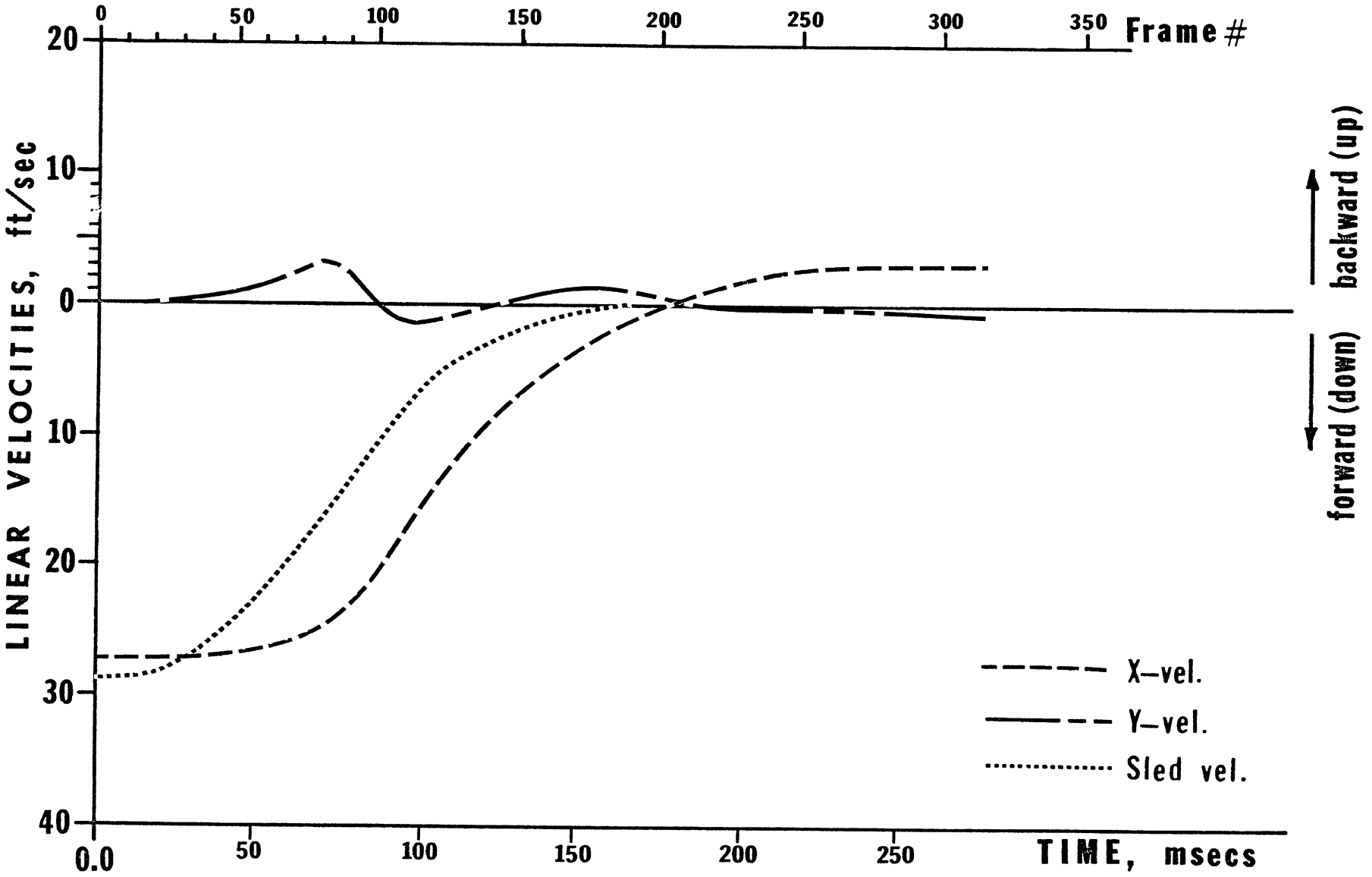


Fig.96 HEAD MOTION Run Nr. 5225

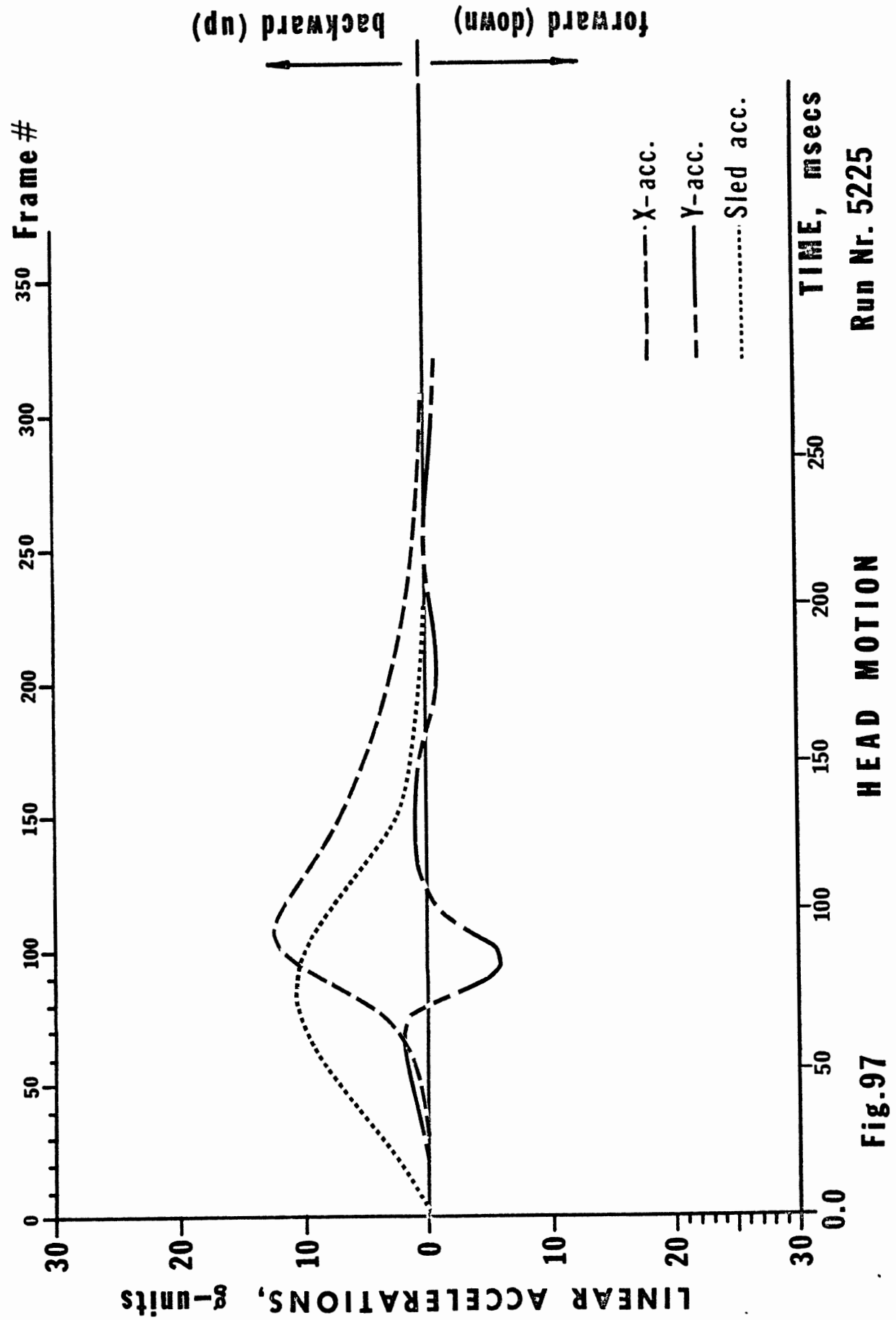

backward (up)
forward (down)
Frame #
0
50
100
150
200
250
300
350
30
20
10
0
10
20
30
LINEAR ACCELERATIONS, g-units
X-acc.
Y-acc.
Sled acc.
0.0
50
100
150
200
250
TIME, msecs
Run Nr. 5225
HEAD MOTION

Fig.97

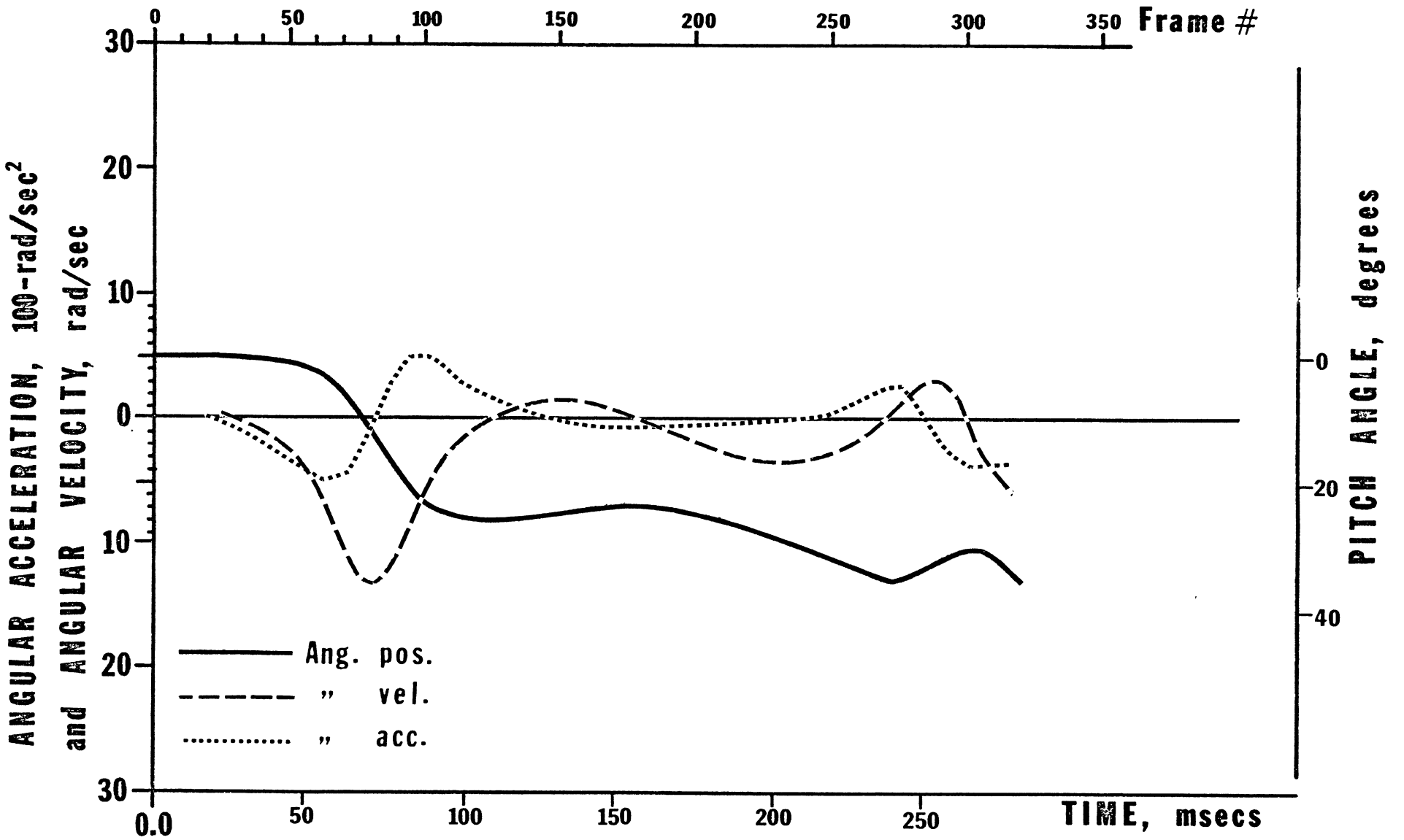


Fig.98 HEAD MOTION Run Number 5225

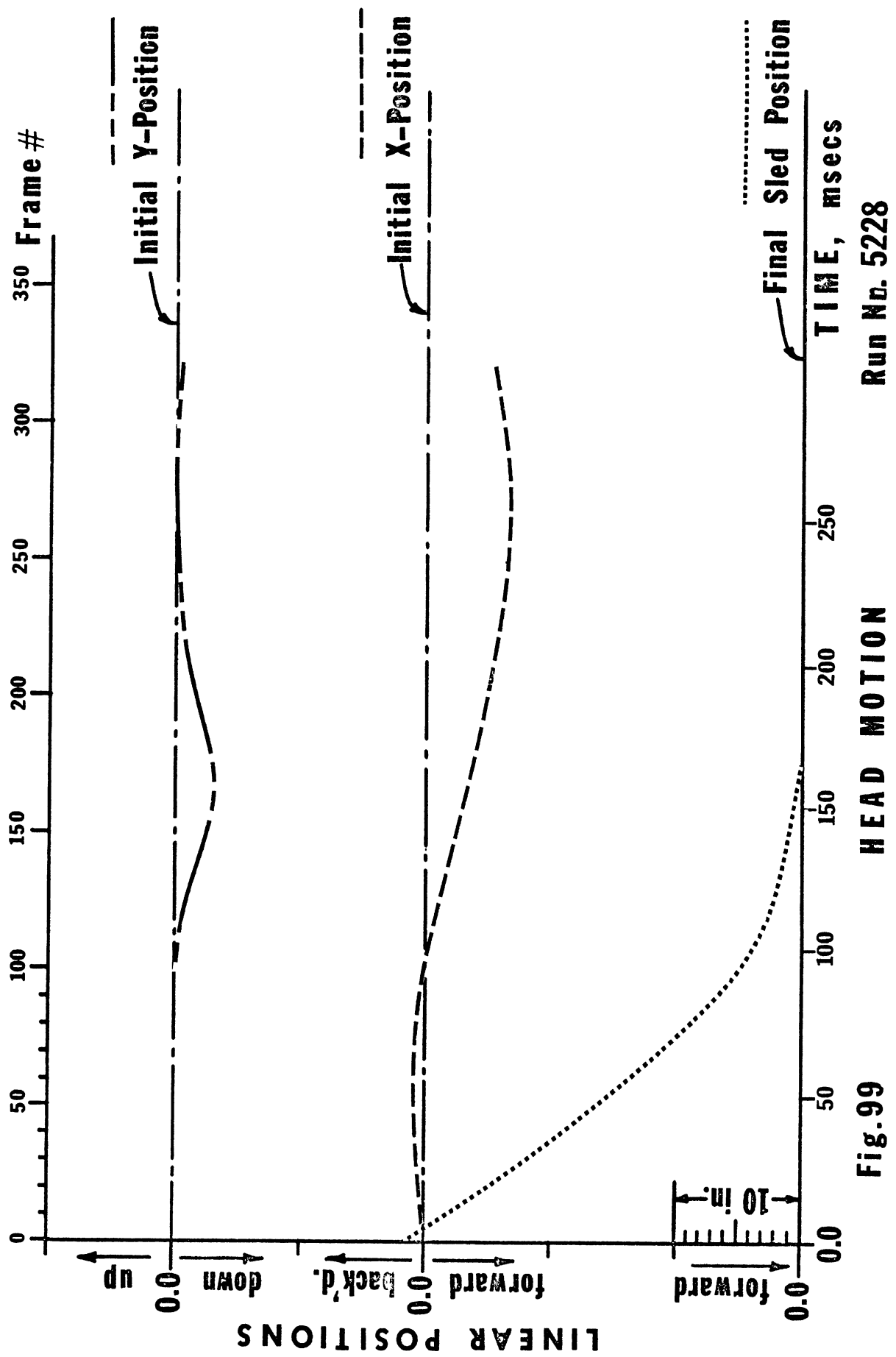

Initial Y-Position
Initial X-Position
Final Sled Position
Frame #
0
50
100
150
200
250
300
350
TIME, msecs
0.0
0.0
0.0
up
down
back'd.
forward
forward
10 in.
LINEAR POSITIONS
HEAD MOTION
Run No. 5228

Fig. 99

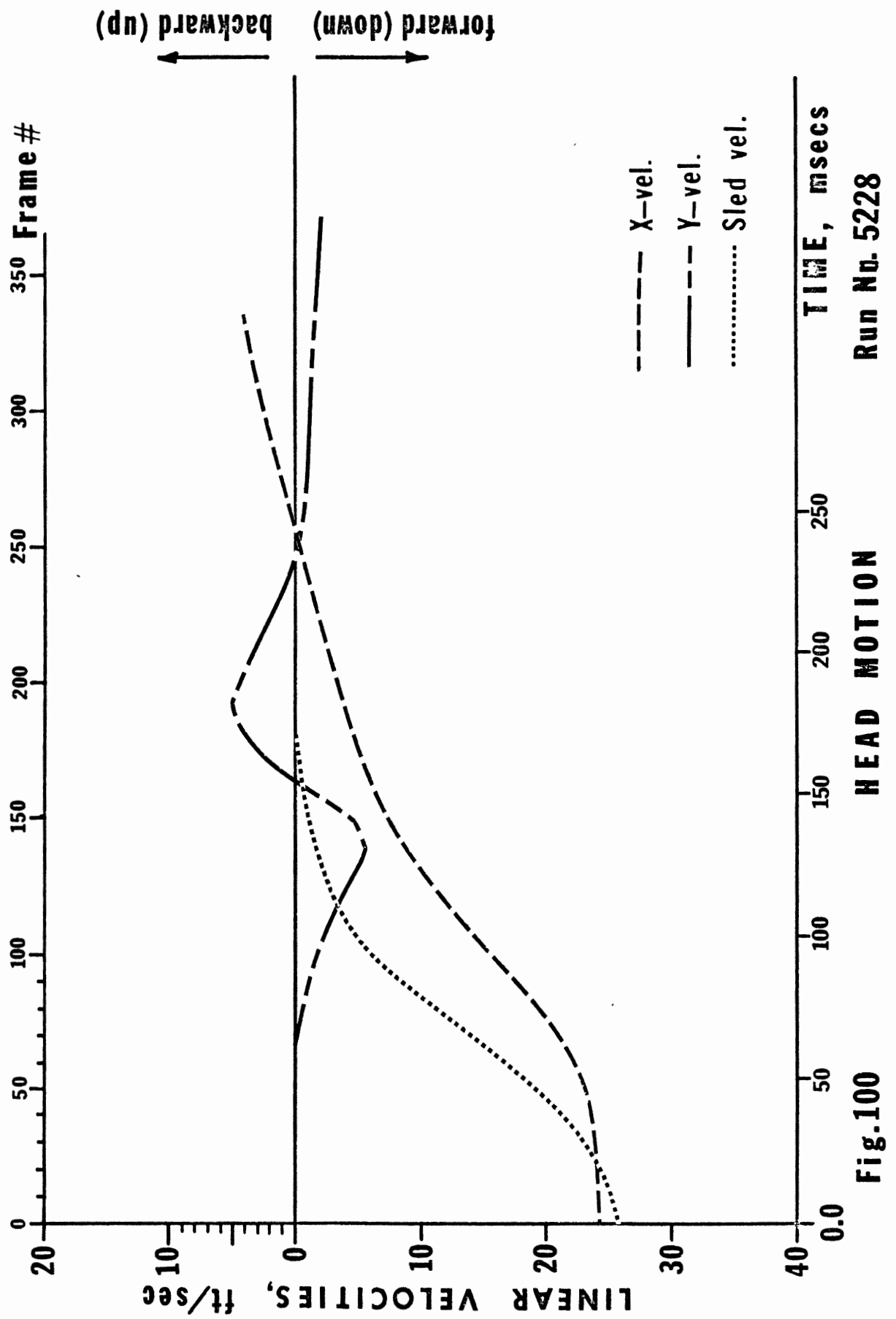

forward (down)
backward (up)
X-vel.
Y-vel.
Sled vel.
TIME, msecs
Frame #
LINEAR VELOCITIES, ft/sec
HEAD MOTION
Run No. 5228
0.0
50
100
150
200
250
300
350
40
30
20
10
0
10
20

Fig.100

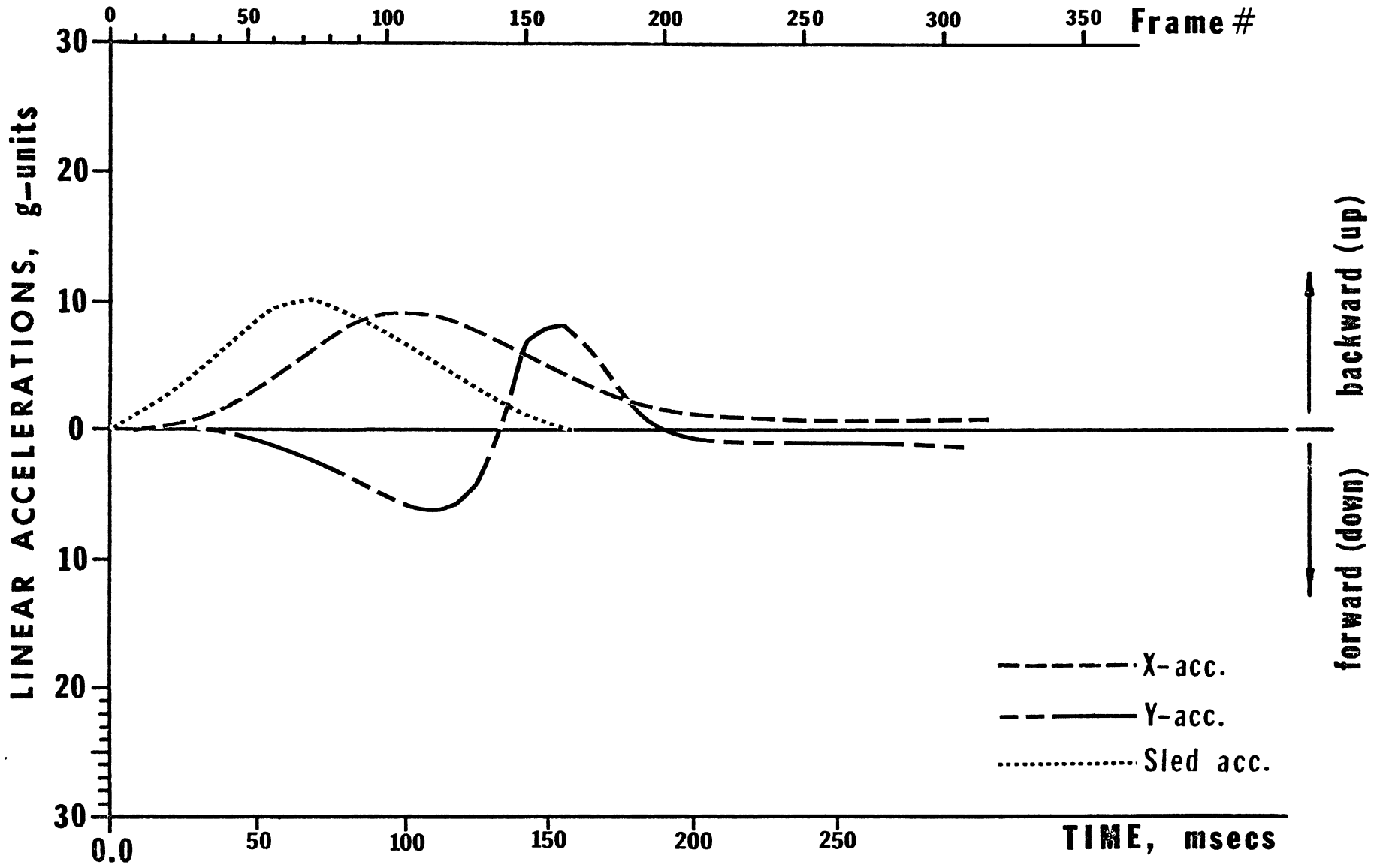


Fig.101 HEAD MOTION Run No. 5228

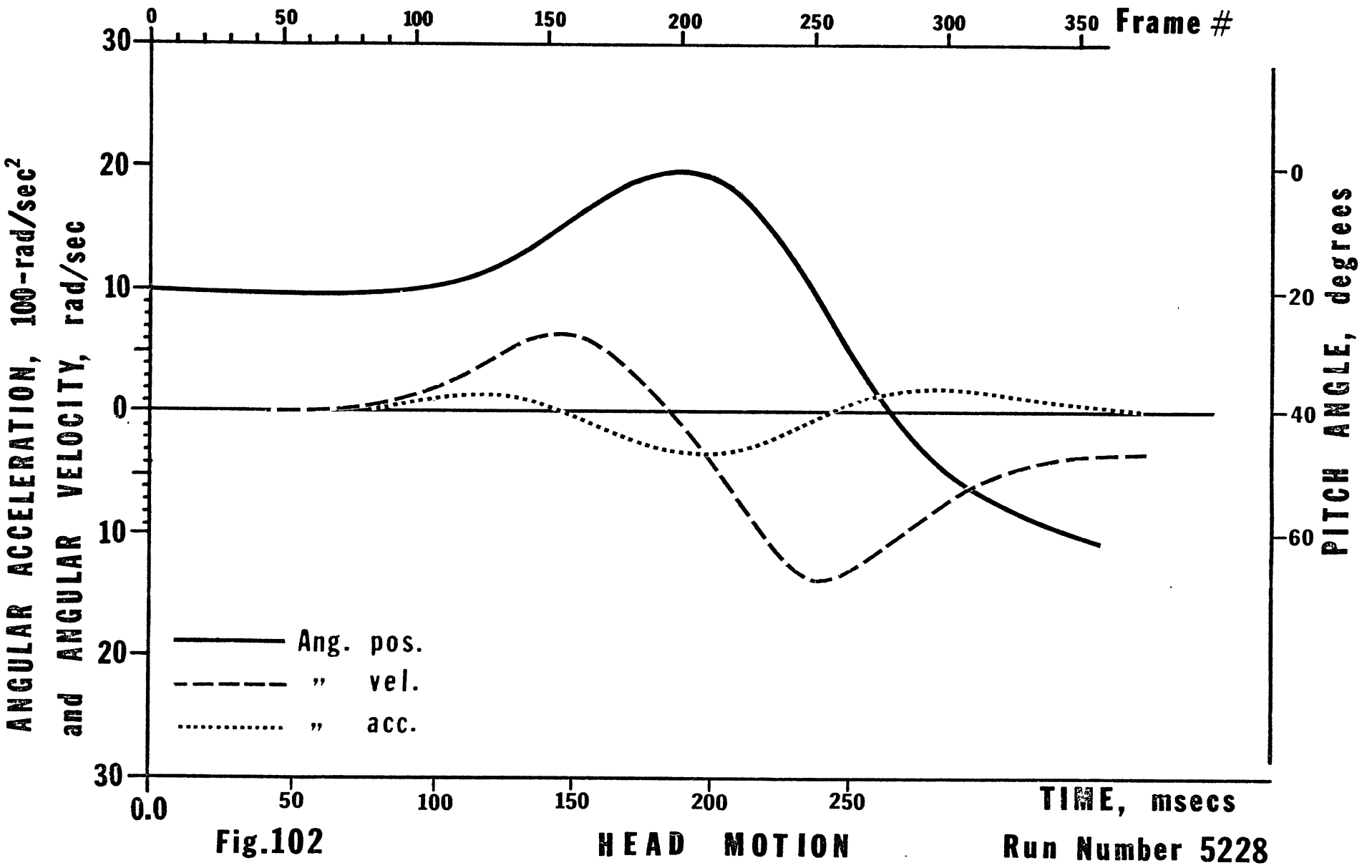


Fig.102 HEAD MOTION Run Number 5228

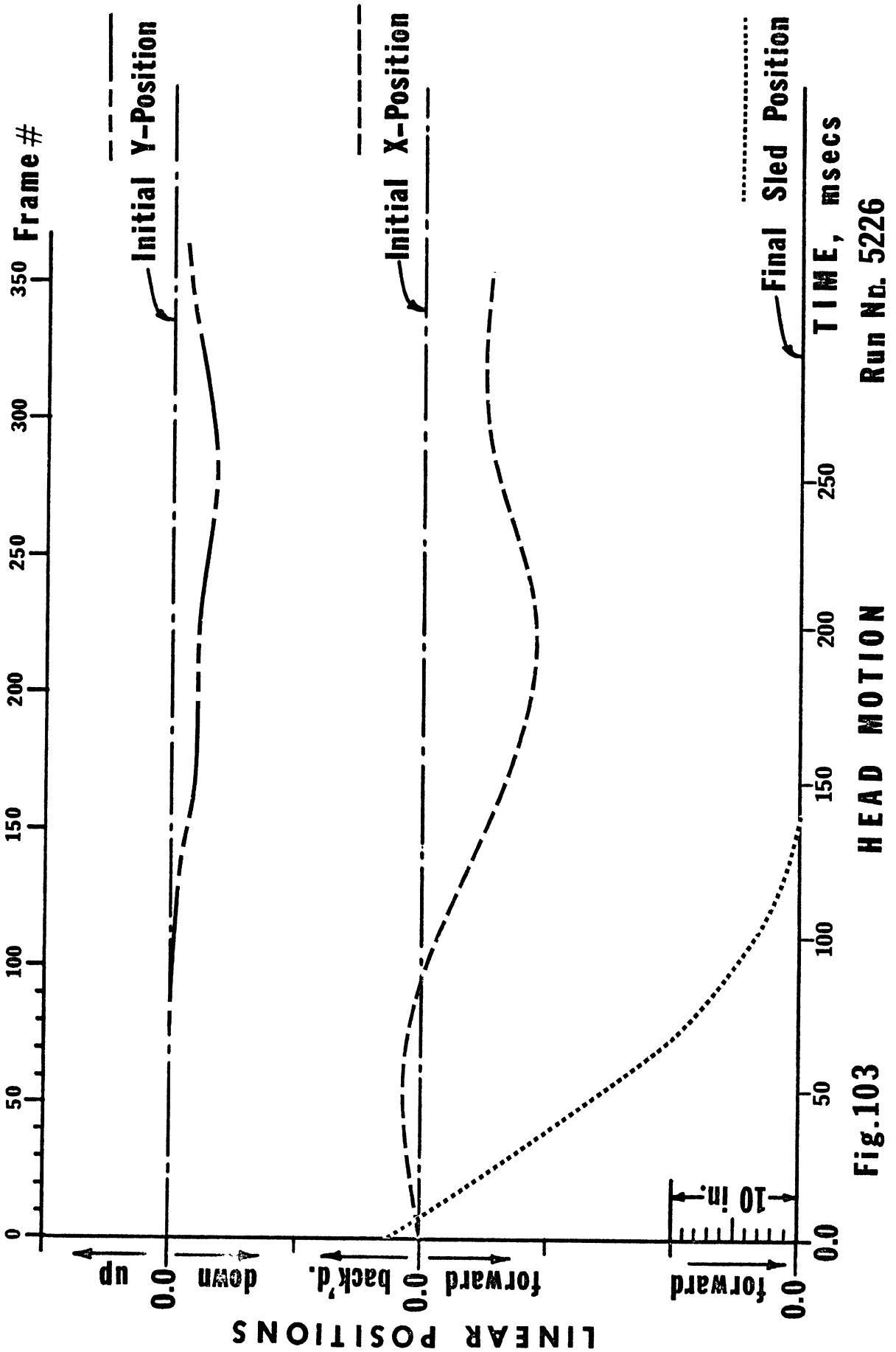

Initial Y-Position
Initial X-Position
Final Sled Position
Frame #
TIME, msecs
Run No. 5226
HEAD MOTION
LINEAR POSITIONS
up
down
back'd.
forward
forward
10 in.
0.0
0.0
0.0
0
50
100
150
200
250
300
350
50
100
150
200
250

Fig.103

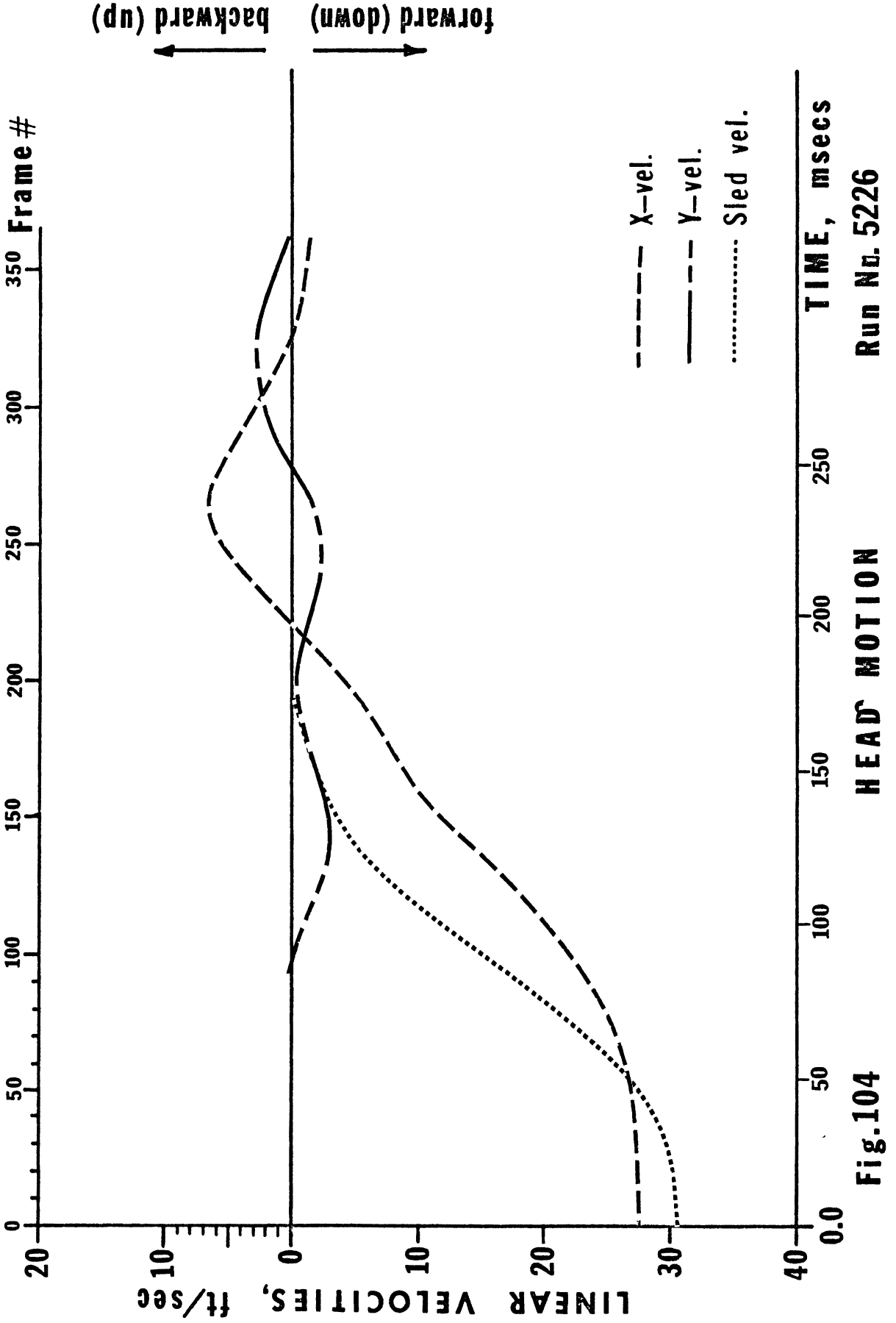

forward (down)
backward (up)
LINEAR VELOCITIES, ft/sec
20
10
0
10
20
30
40
0.0
50
100
150
200
250
300
350
Frame #
TIME, msecs
X-vel.
Y-vel.
Sled vel.
HEAD MOTION
Run No. 5226

Fig.104

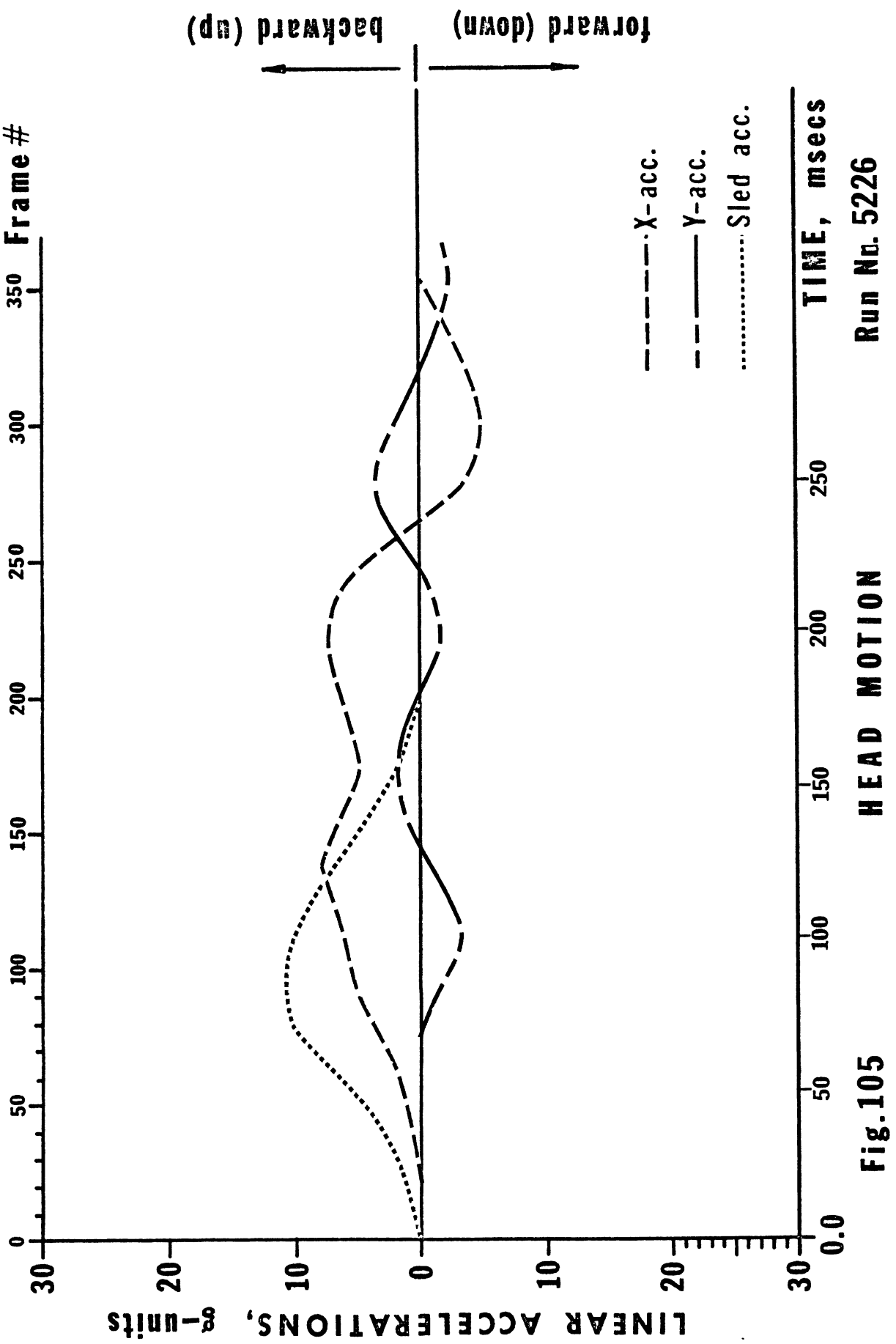

forward (down)
backward (up)
LINEAR ACCELERATIONS, g-units
30
20
10
0
10
20
30
0.0
50
100
150
200
250
TIME, msecs
X-acc.
Y-acc.
Sled acc.
0
50
100
150
200
250
300
350
Frame #
HEAD MOTION
Run No. 5226

Fig.105

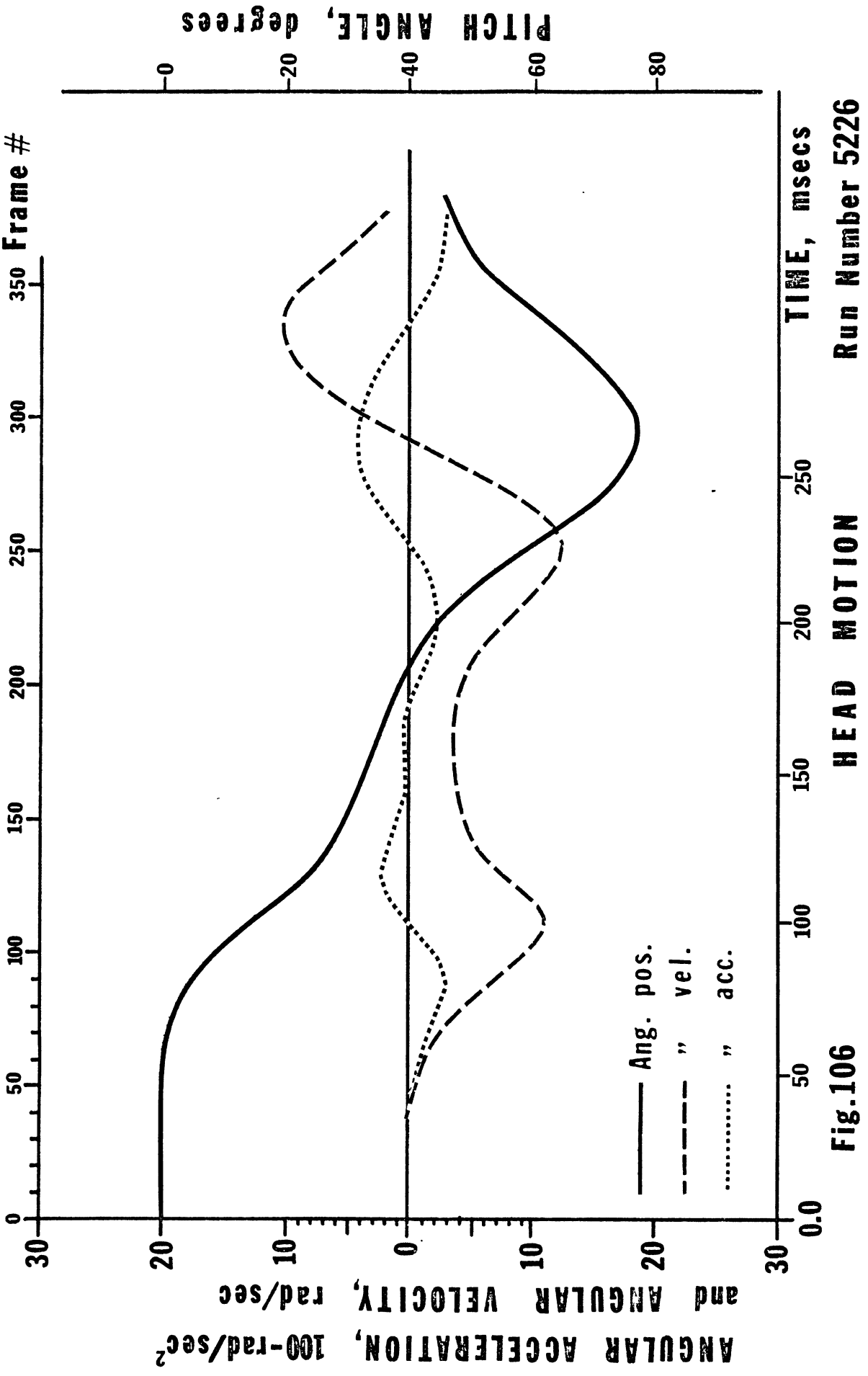

PITCH ANGLE, degrees
0
20
40
60
80
Frame #
0
50
100
150
200
250
300
350
TIME, msecs
0.0
50
100
150
200
250
ANGULAR ACCELERATION, 100-rad/sec²
and ANGULAR VELOCITY, rad/sec
30
20
10
0
10
20
30
Ang. pos.
" vel.
" acc.
HEAD MOTION
Run Number 5226

Fig.106

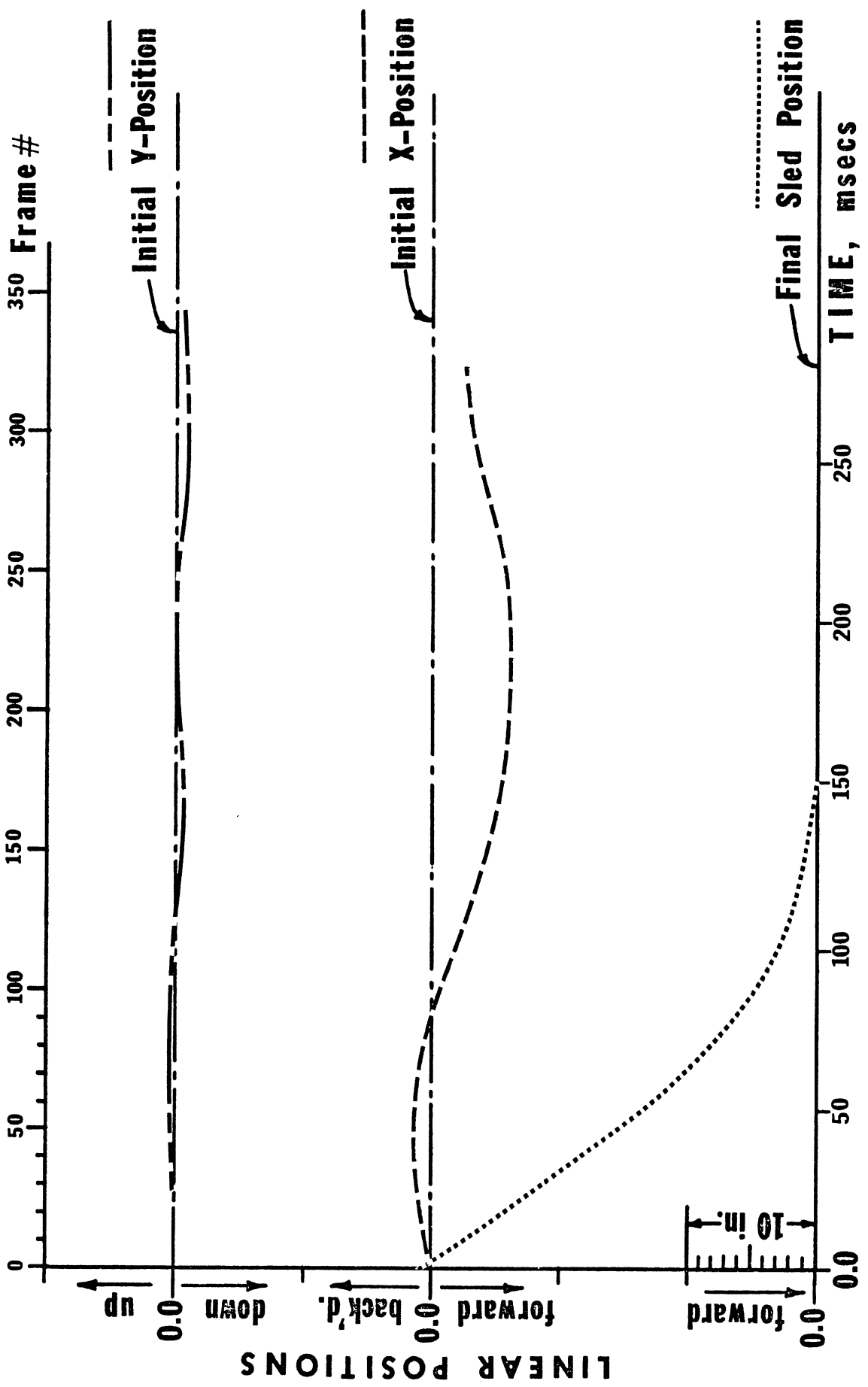

Frame #
0
50
100
150
200
250
300
350
Initial Y-Position
Initial X-Position
Final Sled Position
TIME, msecs
0.0
50
100
150
200
250
HEAD MOTION
Run No. 5227
LINEAR POSITIONS
up
0.0
down
forward
0.0
back'd.
forward
10 in.
0.0

Fig.107

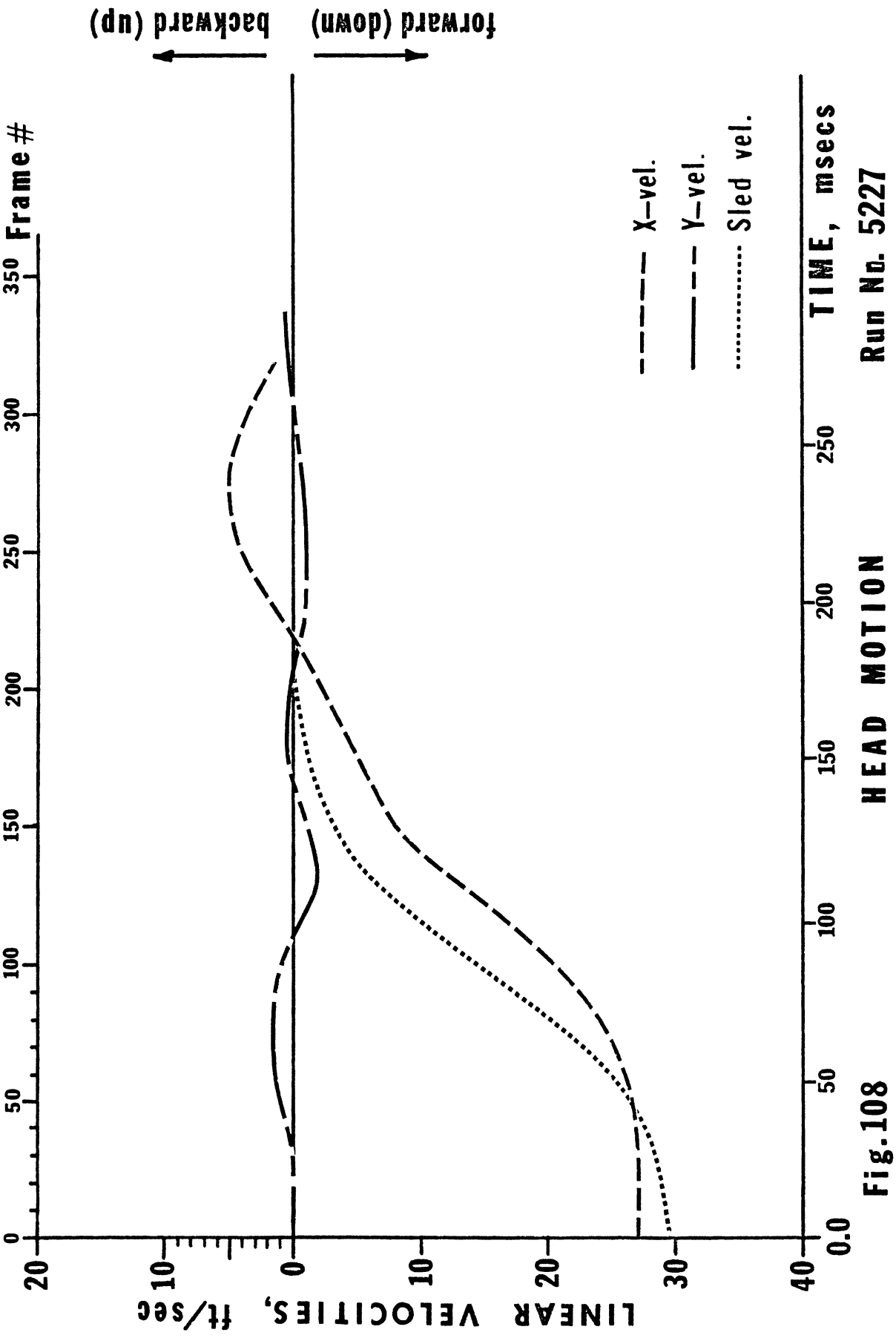
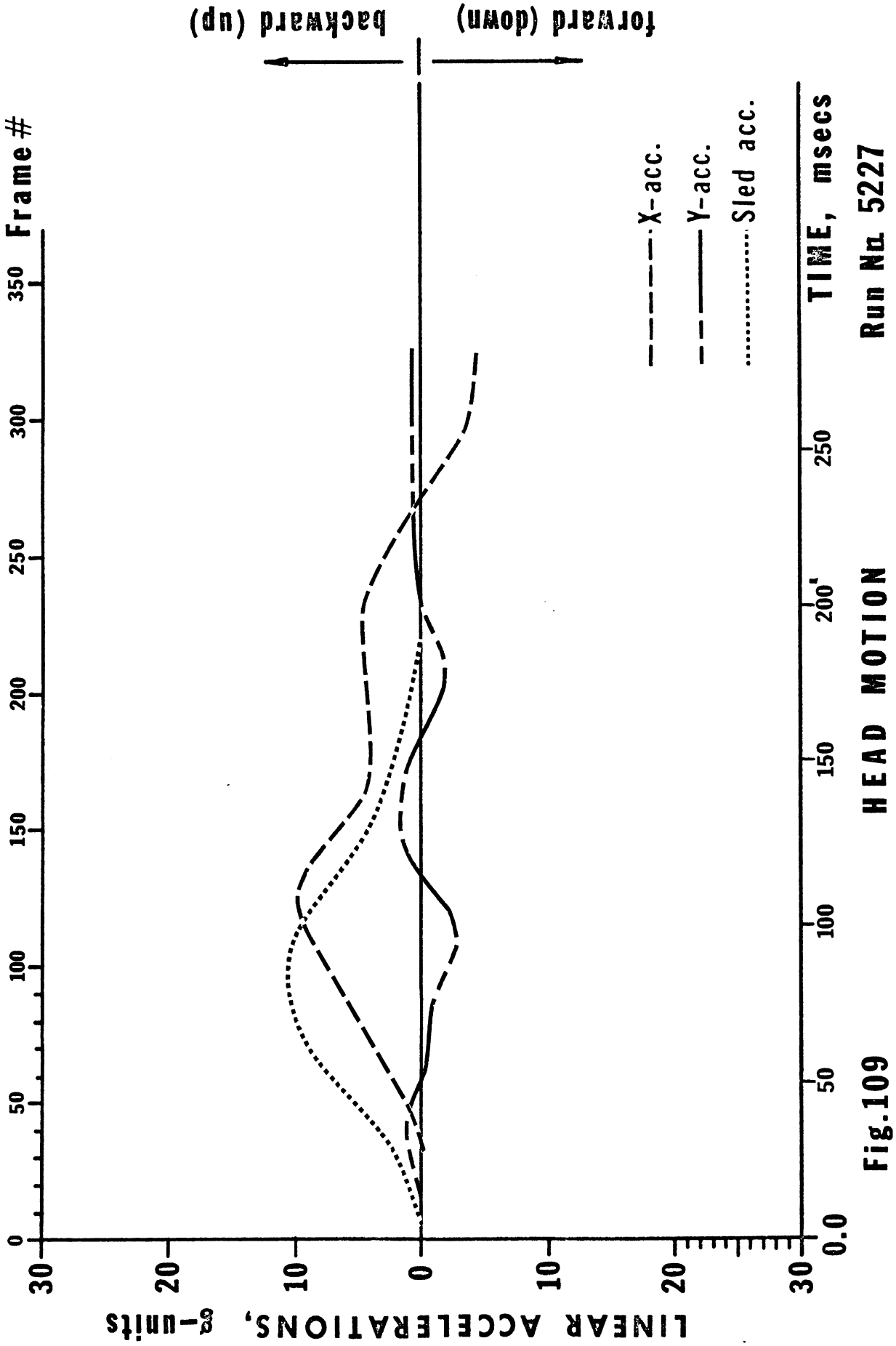

forward (down)
backward (up)
LINEAR VELOCITIES, ft/sec
20
10
0
10
20
30
40
0.0
50
100
150
200
250
300
350
Frame #
0
50
100
150
200
250
TIME, msecs
X-vel.
Y-vel.
Sled vel.
HEAD MOTION
Run No. 5227

Fig.108



HEAD MOTION

Fig.109

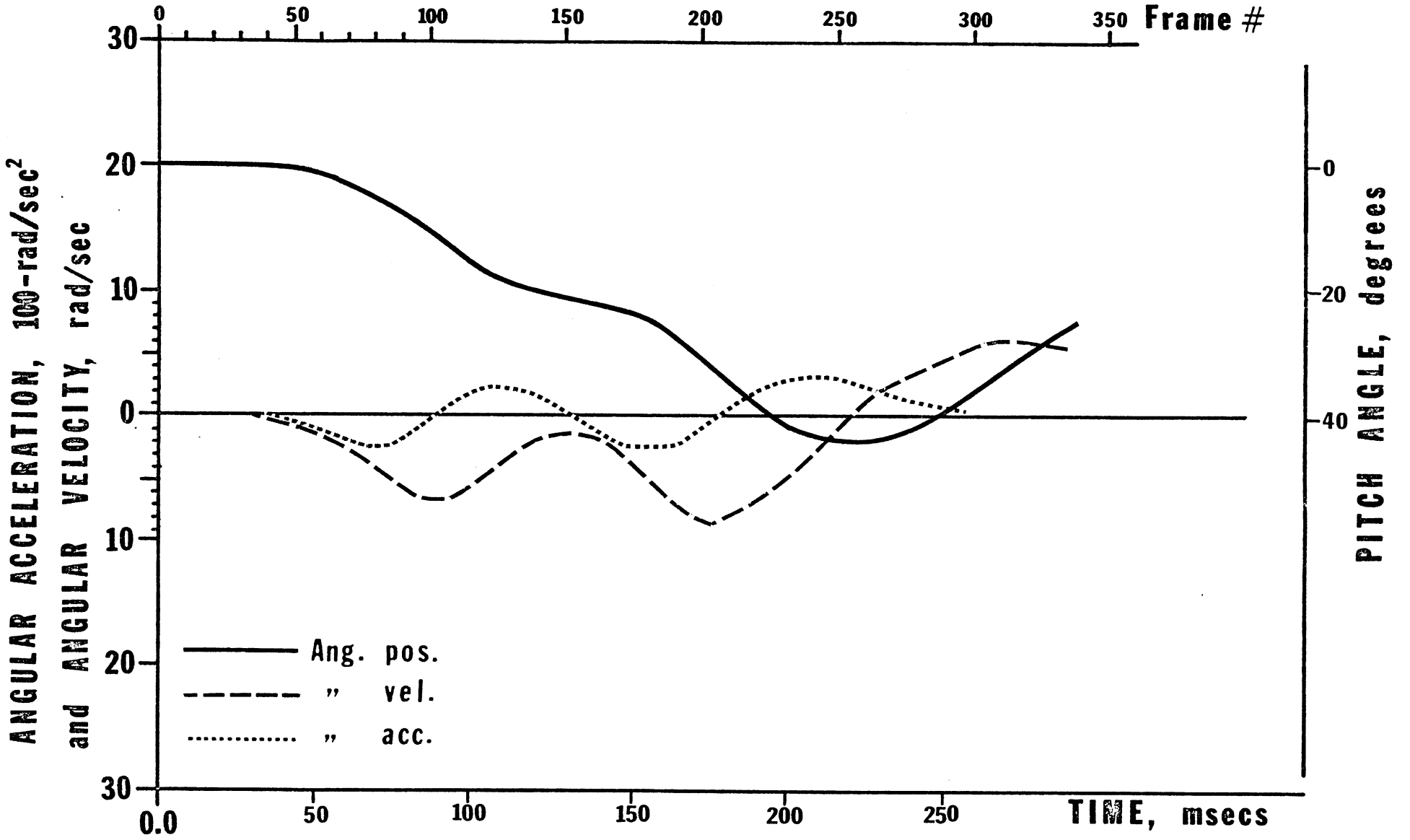


Fig.110 HEAD MOTION Run Number 5227