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SIMULATION OF THE MOTION OF THE CENTER OF MASS OF AN OCCUPANT UNDER EJECTION ACCELERATIONS

Louis A. D'Aulerio
Aircraft and Crew Systems Technology Directorate
NAVAL AIR DEVELOPMENT CENTER
Warminster, Pennsylvania 18974

and

Georg D. Frisch
Naval Biodynamics Laboratory
New Orleans, Louisiana 70189

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The development of higly sophisticated and complex ejection seats to provide safe egress from aircraft during low altitude, high speed and adverse attitude ejections addresses the need for a reliable computer simulation capability to determine the trajectory of the seat and occupant under these conditions. The occupant response to increasingly severe acceleration profiles must, therefore, be addressed if the simulation model is to be able to evaluate the behavior of the seat/occupant system. Traditionally, the seat and occupant have been treated in combination as a rigid body for purposes of trajectory analysis.

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Louis A. D'Aulerio
Aircraft and Crew Systems Technology Directorate
Naval Air Development Center
Warminster, PA 18974

Georg D. Frisch
Naval Biodynamics Laboratory
New Orleans, LA 70189

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However, experience with ejection seat tests has demonstrated a considerable amount of relative motion between the occupant (typically an anthropomorphic dummy) and the seat itself. This report presents a lumped mass, spring-damper mathematical computer model to simulate the motion of the occupant's C.G. with respect to the seat under a dynamic ejection environment. The analysis of anthropomorphic dummy results and of computer generated biodynamic simulation data used in the evaluation of the model will be discussed.

ABSTRACT

The development of highly sophisticated and complex ejection seats to provide safe egress from aircraft during low altitude, high speed and adverse attitude ejections addresses the need for a reliable computer simulation capability to determine the trajectory of the seat and occupant under these conditions. The occupant response to increasingly severe accelerations profiles must, therefore, be addressed if the simulation model is to be able to evaluate the behavior of the seat/occupant system. Traditionally, the seat and occupant have been treated in combination as a rigid body for purposes of trajectory analysis. However, experience with ejection seat tests has demonstrated a considerable amount of relative motion between the occupant (typically an anthropomorphic dummy) and the seat itself. This paper presents a lumped mass, spring damper mathematical model to simulate the motion of the occupant's C.G. with respect to the seat under a dynamic ejection environment. The analysis of anthropomorphic dummy results and of computer generated biodynamic simulation data used in the evaluation of the model will be discussed.

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INTRODUCTION

The relationship between the seat/occupant center of mass and the rocket thrust line has been of great concern in the ejection seat community ever since the introduction of the booster rocket. This relationship is critical in determining the motion of the seat/occupant during rocket thrusting, and ultimately strongly affects the trajectory achieved during ejection. The determination of the seat/occupant's C.G. under static or 1 G conditions is a relatively simple procedure and the variation in C.G. location for different anthropomorphic and human occupants is well documented (1,2). However, experience with ejection seat tests with both anthropomorphic dummy and human occupants has demonstrated a considerable amount of motion between the occupant and the seat itself, and attempts have been made to quantify and describe the resulting C.G. shift (2,3).

Computer simulations of ejection seats can be used effectively to evaluate the trajectories of the seat and occupant during low altitude, high speed and adverse attitude ejections for which actual track tests are not feasible. The motion of the occupant's center of mass and the resulting seat/occupant C.G. shift caused by these increasingly severe ejection conditions must be taken into account in order for the simulation model to effectively evaluate the behavior of the seat/occupant system.

This paper describes the investigation undertaken to develop and evaluate a mathematical model for the motion of the center of mass of an occupant under ejection accelerations. Since the vast majority of ejection seat tests use anthropomorphic dummies, the investigation first addressed dummy C.G. motion and a mathematical Dynamic C.G. Model was developed and evaluated. The model was then exercised using human biodynamic simulation data in order to assess its effectiveness in replicating the motion of the center of mass of simulated human occupants. Finally, the model was incorporated into an existing 6 Degrees-of-Freedom trajectory simulation computer program which is presently being employed to conduct trajectory analysis for the Escapac Replacement Program.

METHODOLOGY

Ejection Tower Tests

The standard scientific paradigm was used in this investigation: collect data, analyze data, form hypothesis, and test hypothesis. No tests were actually conducted, but rather the data base from all the previous tests conducted on the Ejection Tower at NADC was used. The only criteria used to select tests from this data base for further investigation were that the occupant had to be an anthropomorphic dummy, and both seat and dummy vertical accelerations had to have been measured and the oscillograph records were available. These criteria resulted in 52 candidate tests (see Table 1). For each of these tests, the seat and dummy vertical accelerations were digitized and stored on tape. The two accelerations were then subtracted and double integrated (figure 1). The quantity "d" shown in figure 1 represents the relative displacement between the seat and the center of mass of the dummy, and is in fact the quantity that is being modeled. There are some serious problems with the accuracy of this calculated relative displacement. First, the seat and dummy accelerations are very similar, so that the subtraction removes a large part of the signal and leaves the noise and error to constitute a more major portion of what remains. Secondly, double integration greatly magnifies small errors, and is particularly sensitive to zero biases such as can occur during digitizing. The form of the resulting error is a function which grows with time: either parabolic or cubic. This type of error is evident in a number of the 52 tests but it is not easy to correct, especially since the tests are not recent and it is not possible to go back and recalibrate the accelerometers, for instance. Another problem with the data is that it is possible that the dummy did not remain perfectly vertical and parallel to the seat back throughout the test, and so the two accelerometers being compared do not point in exactly the same direction. Despite all these inaccuracies in the data, information can still be extracted. For any given test one can never be sure that certain features of the data are real or artifacts of the errors, but when all 52 tests are examined together certain facts show through.

By visual inspection of the C.G. displacement curves it was possible to extract a general pattern (figure 1) and certain parameters were identified as potentially significant and these were collected in Table 1. To characterize this shape, the times and displacements at the first and second turns for all 52 tests were recorded, along with other parameters which conceivably might determine or at least influence the shape of the displacement curve; these parameters were entered into the computer for plotting and statistical analysis. Figures 2 and 3 show scatter diagrams of the displacements at the first and second turns of the standard displacement curve. It must be noted that the displacement at the first turn is quite consistent across tests, but that the second turn is much more variable. This agrees with the preceding error analysis, which pointed out that the error should increase rapidly with time. It should be noted also that the two displacements are very nearly the same, which indicates that the paradigm should be trapezoidal. Figure 4 shows the times of the two turns. The time of the first turn is rather constant, but the second turn seems to vary with the test conditions: it is not constant over all tests and its variations do not appear random. The hypothesis that the displacements at the two turns are more or less the same is tested in figure 5. If the displacements at the two turns were in fact equal, the points would fall on the straight line in the figure. The data is not inconsistent with the hypothesis that the displacements at the two turns are nearly equal, but it certainly doesn't confirm the hypothesis either. The displacement at the first turn is then plotted in terms of the peak seat acceleration and the maximum seat velocity in an attempt to discover controlling factors for the displacement curve (figures 6 and 7). The figures show no pattern at all, indicating that the magnitude of the displacement is indipendent (within the small range examined) of the strength of the input acceleration. Figures 8 and 9 test the hypothesis that the second displacement turn is caused by a release of force. The release of force was represented by the time of thrust end (which was sometimes difficult to mearure) (figure 8), and the time of maximum seat velocity (i.e., the time when the acceleration crosses zero and goes negative) (figure 9). In both cases, and particularly in figure 8, there is a strong correlation.

From the preceding analysis, the following shape for the dynamic C.G. displacement can be hypothesized: initially the center of mass of the dummy moves down about 1.25" in approximately 90 msec, then levels off or rebounds slightly as the thrust remains on. When the thrust ends, the dummy's center of mass returns to its initial position. This final turn takes place at about 150 msec, when the displacement is roughly 1". It appears that the initial movement of the C.G. corresponds to the crushing of the cushion and the rubber buttocks of the dummy. The displacement then levels off, or "bottoms out", when the materials have been completely crushed. Finally, when the thrust ends, the dummy rebounds and the C.G. returns to its neutral position.

Human Biodynamic Simulations

The next step in the development of the model was to analyze human response data in a manner similar to the dummy Tower Test data in an attempt to extend the model for human occupants. Because of the paucity of human test data that would lend itself to this type of analysis, and because of the extreme difficulty in obtaining this type of data, a different approach to the problem was deemed necessary. Rather than relying on actual human tests to provide the necessary data, it was felt that a biodynamic gross motion simulation program could provide the time history of the center of mass of a human occupant against which the C.G. Model could be evaluated. It must be kept in mind that when ejection seat tests are conducted with human subjects, medical and physiological considerations insure that the tests are conducted under ideal conditions: the subjects are extremely well restrained and the accelerations imposed are moderate. The simulation program permits the relaxation of these restrictions so that the motion of the center mass of the occupant can be investigated for conditions with a loose restraint system, higher acceleration profiles, and different occupant initial positions. The computer program used to provide the dynamic response of various occupants subjected to a number of different acceleration profiles was the Calspan Simulator (4), which has been the subject of several validation efforts (5,6,7). The formulation of the human occupant model has been previously described (5). Briefly, the occupant was modeled via 16 segments and 15 joints (figure 21); the segment masses and inertial properties, as well as the joint locations, were estimated from various sources (8,9,10). The Calspan

Simulator generates the complete linear and angular time history of the center of mass of each segment used and that information, along with the segment masses, allows the easy calculation of the center of mass of the entire occupant. By subtracting the instantaneous location of the occupant's C.G. from its initial position, the C.G. displacement curve is then easily obtained. As was the case with the Tower Test data, there are also some problems with this type of analysis. First of all, the data in question is not human test data but only human simulation data and, because of that, it is limited by the restrictions imposed by the simulation model that generated it. The 16 segments representation of the occupant may be inadequate to accurately represent the C.G. of the entire occupant because the C.G. locations of the individual segments were mere estimates, and errors in their locations will alter the position of the occupant's center of mass. In addition, the simulation program does not allow for segment deformation, nor does it take into account the displacement of internal organs. Finally, assumptions had to be made about the elongation characteristics of the restraint system and about the deformation properties of the seat cushion. In spite of all these assumptions and restrictions, useful information could still be extracted when the results from a number of simulation runs were analyzed together.

RESULTS

Model Definition

Having defined the general shape of the C.G. displacement curve, the next step was to derive a model that would exhibit the same behavior. A simple lumped-mass, spring damper model was chosen to represent the occupant and its relationship to the seat (figure 10). It was felt that this simple spring-damper model could cover the entire motion of the occupant's center of mass if the spring constant "k" (see equations in figure 10) was made non-linear, as shown in figure 11. The first slope, k1, represents the seat cushion and the dummy's rubber buttocks and remains in effect until the C.G. bottoms out. The second slope, k2, represents the stiffness of the seat pan and the seat structure; this constant comes into play after the C.G. displacement has bottomed out. For simplicity, the same damping coefficient was used for both phases.

Tower Test Data Analysis

To test out this model, 9 of the best tower tests were selected for parameter fitting. Figures 12 through 20 show the seat acceleration input, the measured C.G. displacement, the best fit with a linear spring-damper model, and the best fit with a two piece non-linear model for these 9 tests. The figures indicate that the two piece non-linear spring constant model is more accurate than the single slope, linear constant model, and the fit obtained with the non-linear model is quite accurate. The parameters used to obtain these curves are shown in Table 2. It should be noted that the heavier dummy requires a smaller bottoming distance for an accurate fit. This is reasonable since the heavier dummy will crush the seat cushion and rubber bottocks to a greater degree prior to ejection.

Human Biodynamic Simulation Data Analysis

The Calspan Simulator was exercised numerous times to simulate the response of human occupants of different sizes when ejected from several of the presently operational Navy aircraft. The results from four representative runs, along with the best linear and non-linear fit, are shown in figures 22 through 25. The parameters used to obtain these curves are shown in Table 2.

As is evident from the shape of the C.G. displacement curves shown in figures 22 through 25, the behavior of the center of mass of the simulated human occupant differs from that of the dummies tested on the NADC Tower. The displacement curves do not exhibit the characteristic trapezoidal shape of the dummy C.G. displacement, but seem to be much more linear. This observation is further substantiated by the close agreement between the linear and non-linear fit. The values of the parameters used to generate the curves (Table 2) also show that, whereas the dummies required a coefficient of .3 of critical damping, the simulated human occupant required a coefficient of .95 of critical damping. This is reasonable since the dummies, being composed largely of metal, are much "stiffer" than humans and consequently should exhibit a less damped behavior.

DISCUSSION

The model presented clearly shows that it is possible to obtain a close approximation for the displacement of the C.G. of an ejection seat occupant during a typical ejection. Because of limitation in the available data the model presented is only applicable in the vertical or Z direction, but the methodology outlined in this paper makes it possible to evaluate the model in other directions of interest, and in particular the forward or X direction. Though one of the primary reasons for undertaking this investigation was to develop an analytical tool to improve the trajectory simulation capability of the Navy, the model should prove valuable in the design of rocket systems for ejection seats.

REFERENCES

1. J.M. Peters, "Static Center-of-Gravity and Inertial Properties Measurements of Selected USAF Ejection Seats." Technical Memorandum AFFDL-TM-71-2-FER, Wright Patterson AFB, Ohio, 1971.

2. J.W. Chaffee, "Change in Human Center of Gravity Produced by Change in Direction of Acceleration." Aerospace Division, Boeing Company, Seattle, Washington, May 1962.

3. R.R. Yeager, "Transient Deviations of the Human Body's Center of Mass." Report No. TI00320-70-1, Technology Incorporated. Prepared for the Aerospace Crew Equipment Laboratory, Philadelphia, PA, under Contract No. N00156-69-C-2077, April 1970.

4. J.T. Fleck, F.E. Butler, S.C. Volgel, "An Improved Three Dimensional Computer Simulation of Crash Victims." Volumes 1-4. Final Report for Contract No. DOT-HS-053-2-485, DOT Report No. DOT-HS-801-507 through 510, NHTSA, 1975.

5. G.D. Frisch, J. O'Rourke, L.A. D'Aulerio, "The Effectiveness of Mathematical Models as a Human Analog." Paper No. 760774, Society of Automotive Engineers, 1976.

6. G.D. Frisch, L.A. D'Aulerio, J. O'Rourke, "The Mechanism of Head and Neck Response to -Gx Impact Acceleration. A Math Modeling Approach." Aviation Space and Environmental Medicine, 48:223-230, 1977.

7. G.D. Frisch, C. Cooper, "Mathematical Modeling of the Head and Neck Response to -Gx Impact Acceleration - Minimum Articulation Requirements." Aviation Space and Environmental Medicine, 49:196-204, 1978.

8. W.T. Dempster, "Space Requirements of the Seated Operator." Report 55-159, Wright Air Development Center, Air Research and Development Command, Wright Patterson AFB, Ohio, 1955.

9. L.B. Walker, E.H. Harris, U.R. Pontius, "Mass, Volume, Center of Mass, and Mass Moment of Inertia of Head and Neck of Human Body." Paper No. 730985, Society of Automotive Engineers, 1973.

10. E.B. Becker, "Preliminary Discussion of an Approach to Modeling Human Head and Neck to -Gx Impact Acceleration." Human Impact Response, Plenum Publishing Corp., 1973, pp. 321-328.

Index	TEST NUMBER	TIME OF 1st DISP. TURN (sec)	DISP. AT 1st TURN (in)	TIME OF 2nd DISP. TURN (sec)	DISP. AT 2nd TURN (in)	TIME OF THRUST END (sec)	PEAK SEAT ACCEL. (G's)	MAX SEAT VEL. (ft/sec)	TIME OF MAX SEAT VEL. (sec)
1	4448	0.091	-1.37	0.206	-2.85	0.213	10.30	43.80	0.202
2	4449	0.093	-1.04	0.205	0.89	0.203	10.00	35.00	0.201
3	4450	0.081	-1.63	0.175	-0.59	0.175	13.40	40.08	0.174
4	4451	0.090	-1.13	0.181	-0.63	0.173	15.80	40.18	0.178
5	4452	0.080	-1.00	0.170	-0.68	0.165	17.70	41.00	0.166
6	4453	0.090	-1.20	0.174	-0.84	0.171	16.80	40.11	0.173
7	4455	0.090	-1.61	0.171	-1.46	0.167	17.95	40.03	0.168
8	4456	0.090	-1.13	0.191	-0.79	0.186	12.30	37.09	0.190
9	4457	0.102	-1.47	0.200	-2.38	0.192	12.60	37.33	0.198
10	4458	0.103	-1.38	0.200	-1.62	0.192	12.90	38.19	0.195
11	4459	0.108	-1.18	0.210	-1.20	0.202	13.10	36.22	0.203
12	4460	0.083	-1.40	0.170	-1.57	0.167	18.45	39.90	0.166
13	4461	0.099	-1.44	0.188	-1.72	0.180	14.90	39.66	0.185
14	4462	0.091	-1.09	0.177	-0.96	0.174	16.10	38.95	0.174
15	4463	0.107	-0.78	0.201	-0.39	0.197	11.50	36.84	0.201
16	4464	0.086	-1.73	0.176	-1.10	0.176	13.10	39.57	0.173
17	4465	0.087	-1.18	0.187	-1.42	0.171	17.50	41.27	0.181
18	4467	0.100	-1.04	0.180	-0.77	0.184	15.80	39.58	0.186
19	4468	0.089	-0.96	0.186	-0.79	0.173	16.00	39.30	0.177
20	4489	0.100	-1.20	0.200	-0.28	0.200	10.40	34.24	0.198
21	4490	0.112	-1.18	0.216	-0.77	0.211	9.90	35.01	0.214
22	4492	0.100	-1.31	0.195	0.04	0.201	10.35	34.55	0.197
23	4493	0.109	-1.50	0.198	-1.18	0.200	10.74	34.60	0.198
24	4877	0.098	-2.20	0.170	-3.48	0.182	17.72	49.48	0.171
25	487[illegible]	0.072	-1.89	0.160	-3.60	0.168	19.10	53.48	0.161
26	4887	0.076	-0.93	0.194	-3.83	0.187	14.40	48.00	0.190
27	48[illegible]8	0.075	-0.98	0.189	-3.62	0.185	16.40	50.00	0.220
28	4889	0.091	-1.46	0.172	-2.72	0.183	15.90	49.00	0.185
29	4890	0.086	-1.18	0.188	-2.82	0.193	14.20	47.61	0.192
30	4998	0.064	-1.93	0.128	-2.66	0.147	22.90	58.58	0.144
31	5083	0.080	-1.61	0.164	-1.02	0.194	10.50	30.92	0.190
32	5084	0.103	-0.55	0.209	-0.77	0.265	6.76	32.00	0.263
33	5085	0.125	-1.04	0.249	-3.22	0.238	10.56	39.74	0.249
34	5086	0.093	-1.10	0.153	-1.52	0.211	12.90	43.80	0.210
35	5087	0.086	-1.18	0.191	-2.44	0.194	15.50	49.37	0.194
36	5089	0.075	-0.87	0.116	-0.79	0.176	17.20	38.30	0.139
37	5090	0.119	-0.56	0.165	-0.45	0.237	10.16	30.91	0.193
38	5091	0.098	-1.20	0.209	-2.90	0.207	13.50	44.68	0.206
39	5092	0.083	-1.12	0.124	-1.34	0.178	17.30	52.90	0.170
40	5093	0.073	-0.88	0.110	-0.59	0.165	18.80	52.89	0.170
41	5106	0.049	-1.05	0.069	0.00	0.147	23.11	54.01	0.130
42	5364	0.067	-1.42	0.148	-2.80	0.165	17.40	51.89	0.165
43	5840	0.069	-0.88	0.107	-0.28	0.187	10.85	29.07	0.150
44	5841	0.072	-1.35	0.110	-0.79	0.173	13.80	36.60	0.147
45	5842	0.073	-1.36	0.111	-1.02	0.182	13.20	36.34	0.149
46	5843	0.078	-1.47	0.107	-0.94	0.169	15.50	45.50	0.170
47	5844	0.081	-1.50	0.116	-1.10	0.169	15.80	42.27	0.151
48	5845	0.079	-1.09	0.106	-0.83	0.190	10.80	29.18	0.150
49	5846	0.079	-1.07	0.102	-0.93	0.189	10.90	29.85	0.151
50	5847	0.069	-1.35	0.101	-1.14	0.164	15.20	40.63	0.151
51	5849	0.071	-1.34	0.111	-1.02	0.169	12.50	35.20	0.145
52	5850	0.079	-1.48	0.098	-1.46	0.172	13.40	37.72	0.154

TABLE 1 - Selected Ejection Tower Tests and Significant Parameters

	Occupant Weight (Lbs)	Linear Model K (Lbs/in)	Linear Model C	Non-Linear Model K1 (Lbs/in)	Non-Linear Model K2 (Lbs/in)	Non-Linear Model Dbot (in)	Non-Linear Model C
Tower Tests							
5841	145	1500	.30	1000	2000	1.25	.30
5842	145	1500	.30	1000	2000	1.25	.30
5843	145	1500	.30	1000	2000	1.25	.30
5844	145	1500	.30	1000	2000	1.25	.30
5845	212	1500	.30	1000	2250	0.75	.30
5846	212	1500	.30	1000	2250	0.75	.30
5847	212	1500	.30	1000	2250	0.75	.30
5849	212	1500	.30	1000	2250	0.75	.30
5850	212	1500	.30	1000	2250	0.75	.30
Simulation Runs							
F18ECQK	175	1000	.95	1000	1150	1.25	.95
AV8BEWL	225	1150	.75	1000	1250	1.00	.95
F14KDJF	225	1000	.95	750	1000	1.00	.95
A4KPAQD	225	1000	.95	750	1000	0.75	.95

TABLE 2 - Results of C.G. Model Parameter Fit

$$d = \iint \left[A_d(t) - A_s(t) \right] dt$$

$A_d(t) \cong$ MEASURED DUMMY ACCELERATION

$A_s(t) \cong$ MEASURED SEAT ACCELERATION

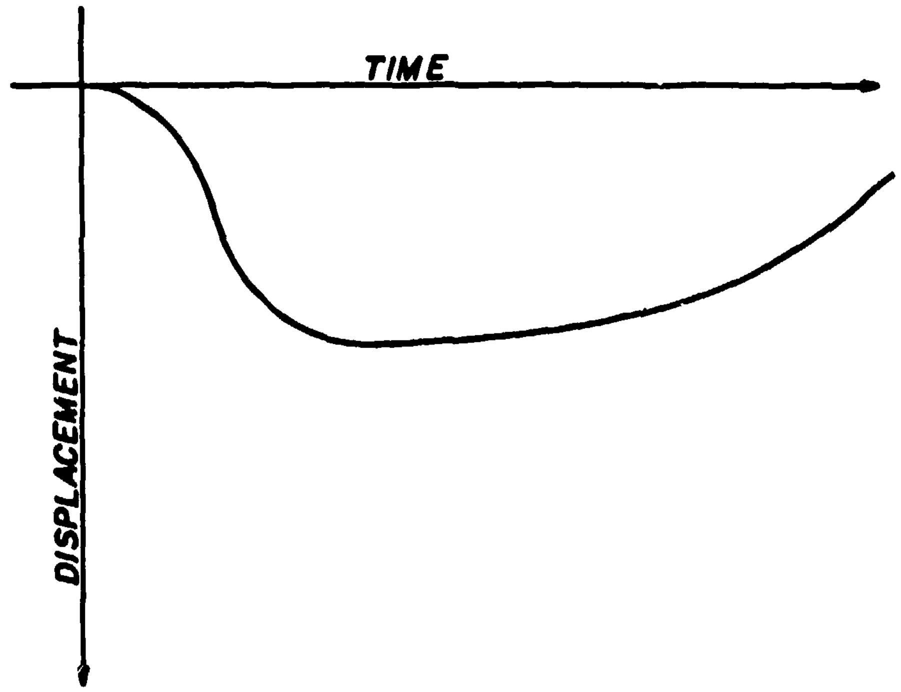


FIGURE 1 - Double Integration of Relative Acceleration and Typical C.G. Displacement Curve

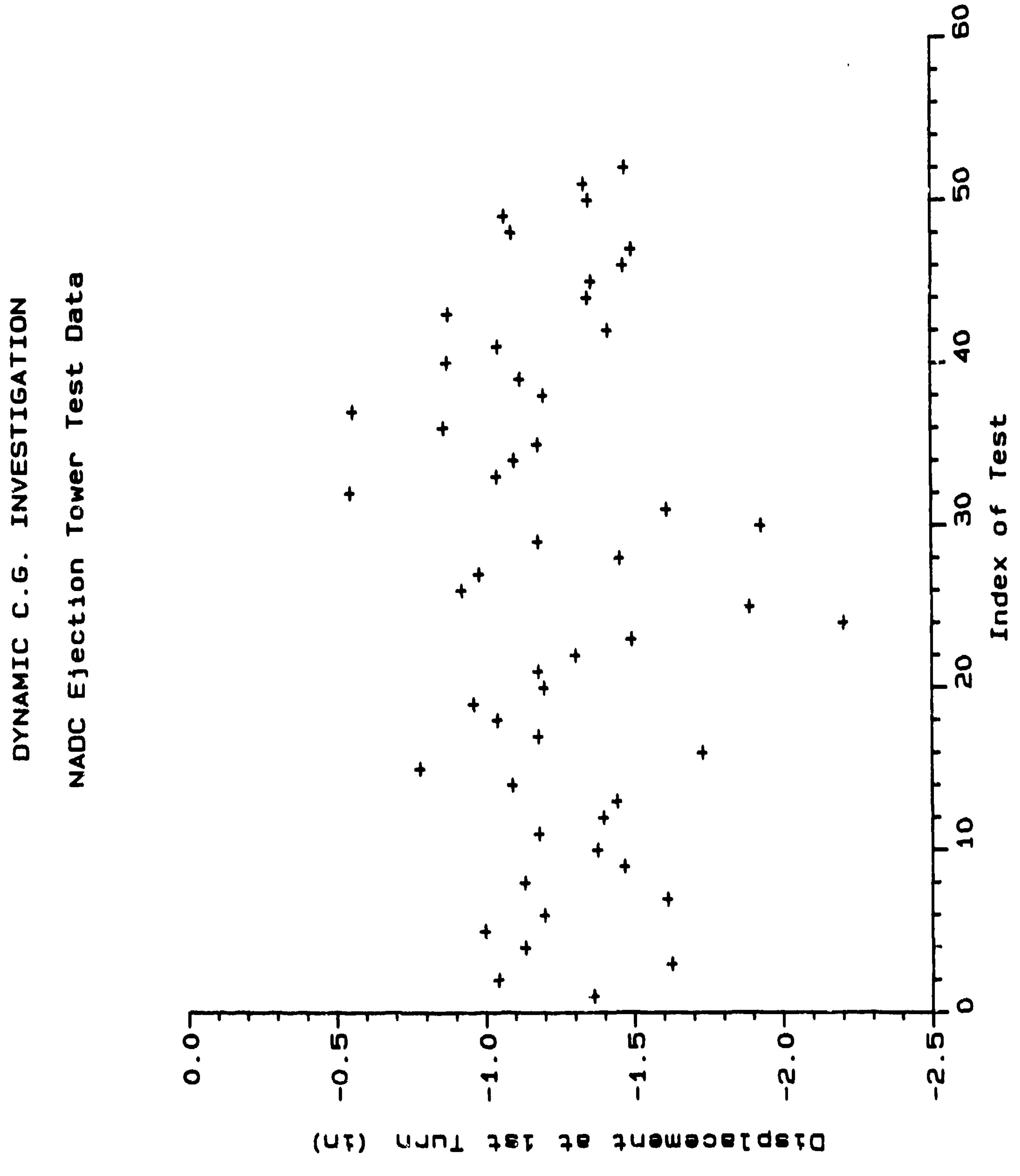


FIGURE 2 - Displacement at the 1st Turn for all 52 Ejection Tower Tests

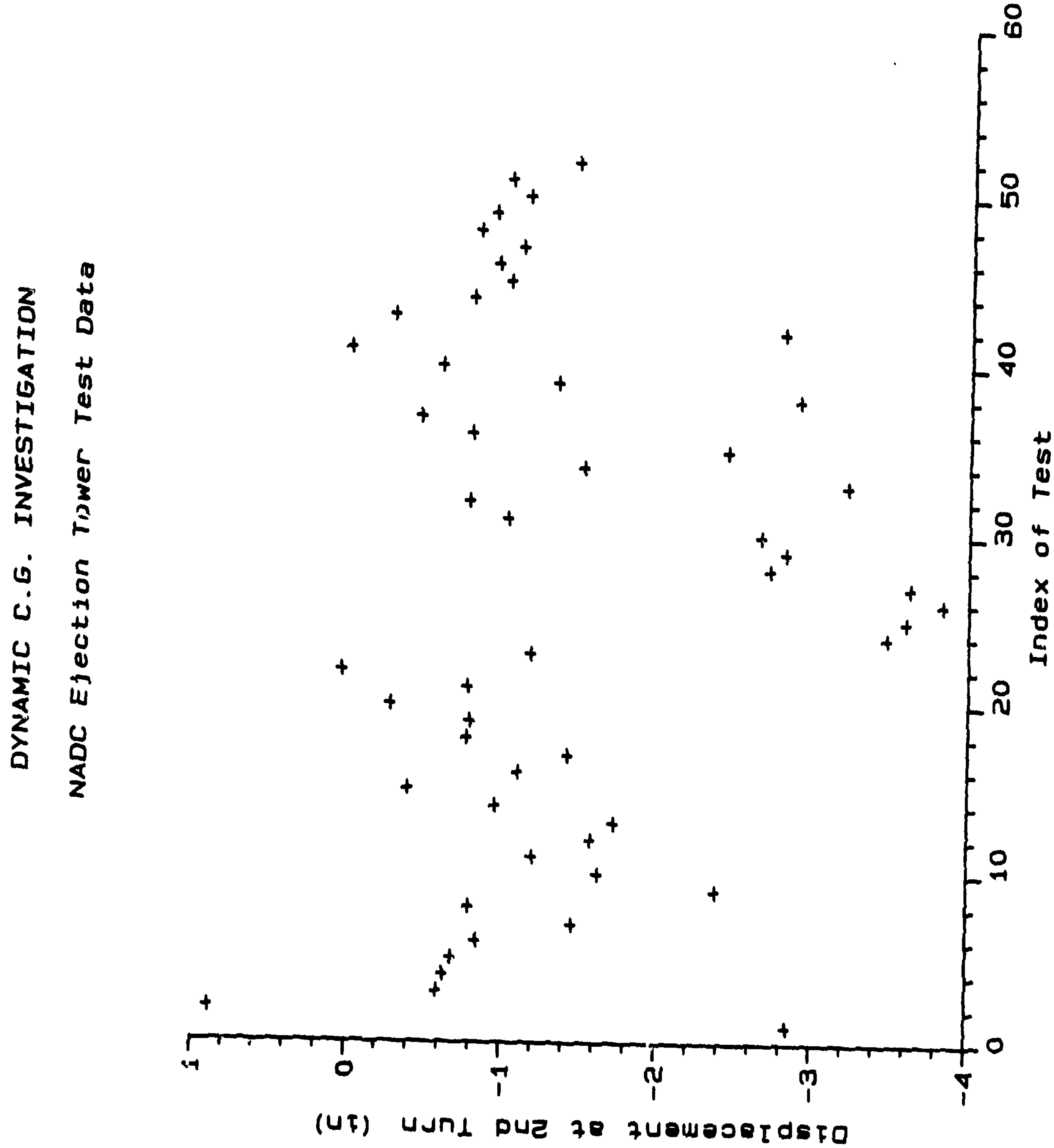


FIGURE 3 - Displacement at the 2nd Turn for all 52 Ejection Tower Tests

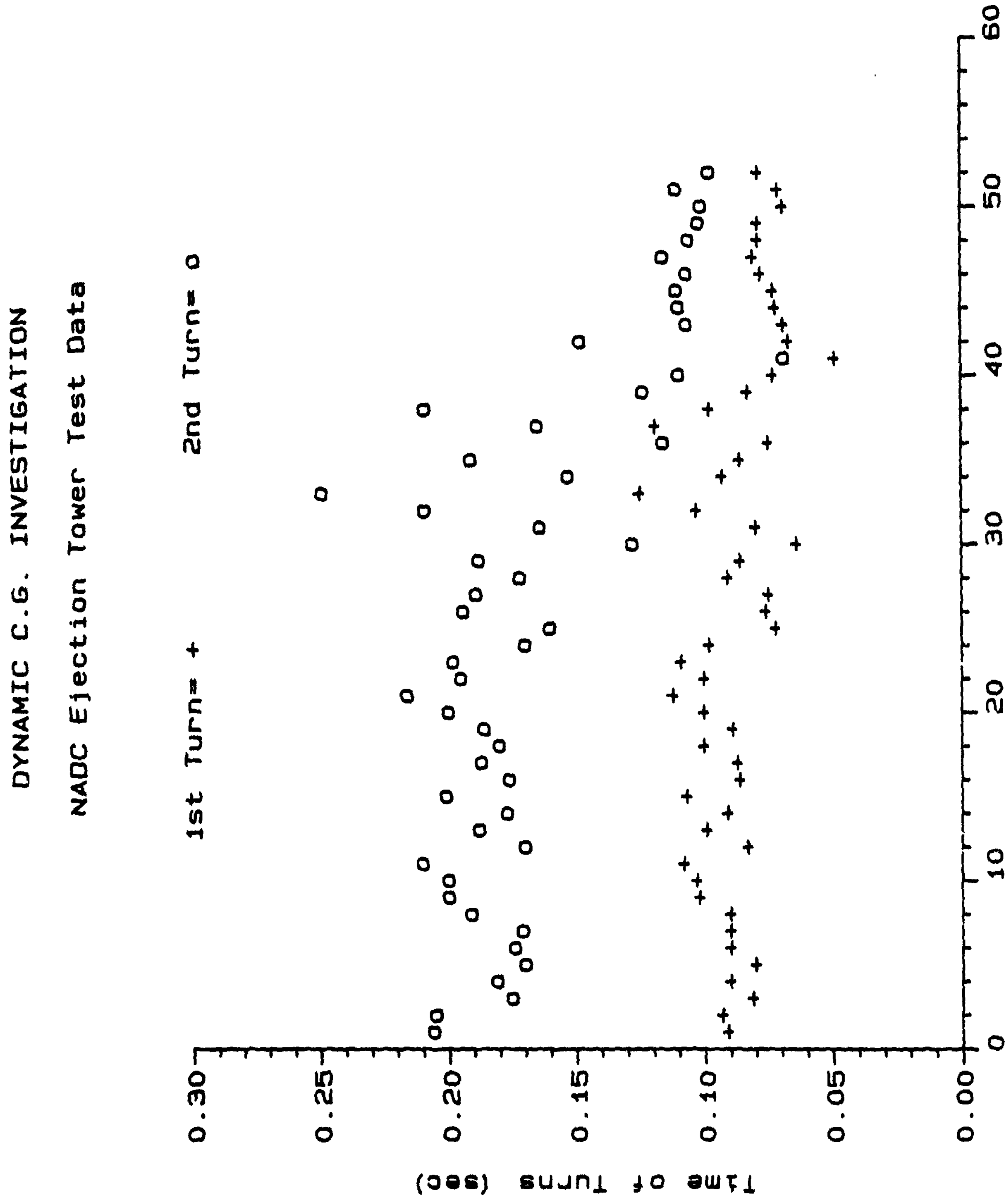


FIGURE 4 - Time of the Two Turns for all 52 Ejection Tower Tests

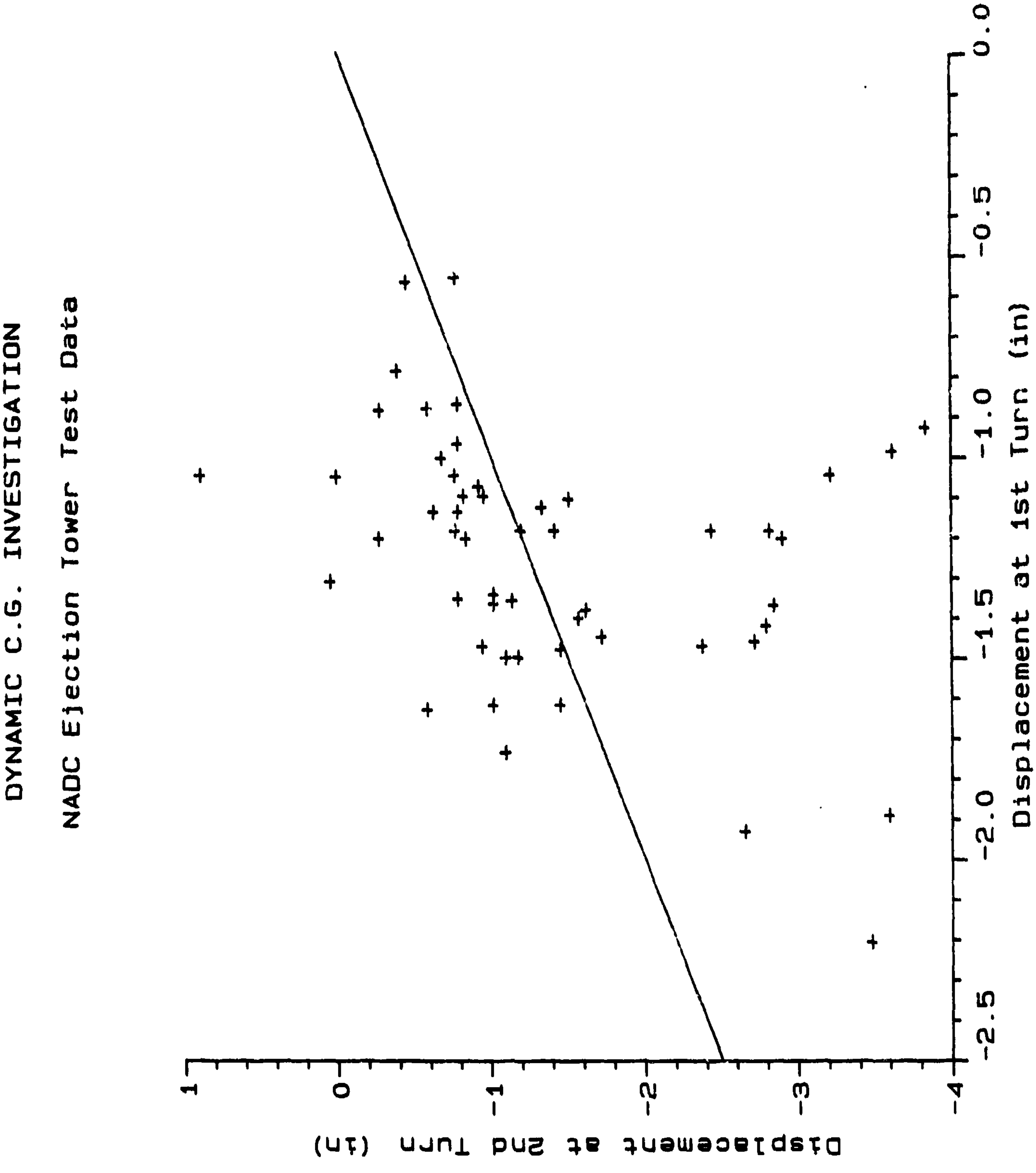


FIGURE 5 - Comparison of the Displacements at the two Turns for all 52 Ejection Tower Tests

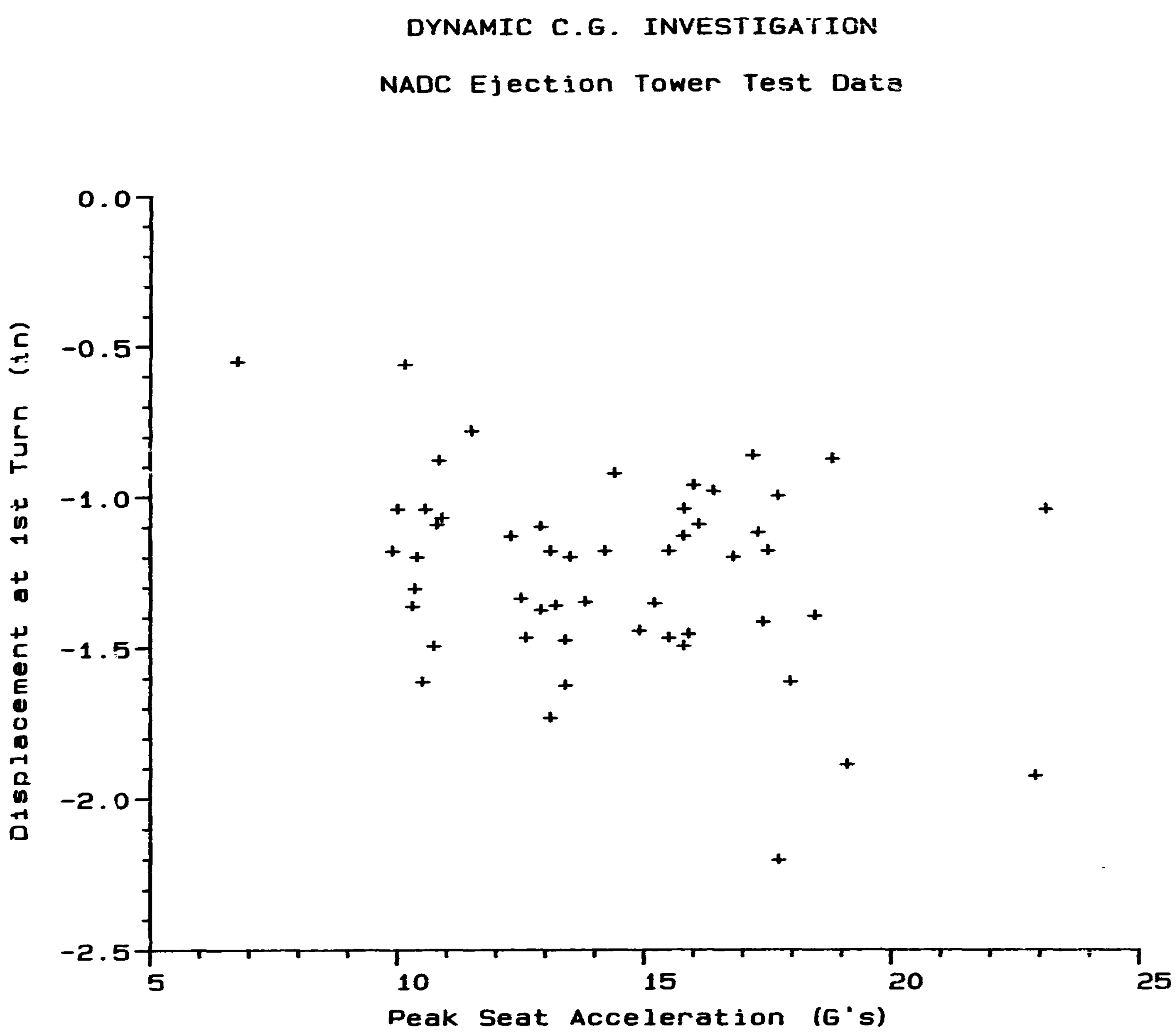


FIGURE 6 - Displacement at the 1st Turn vs Peak Seat Acceleration for all 52 Ejection Tower Tests

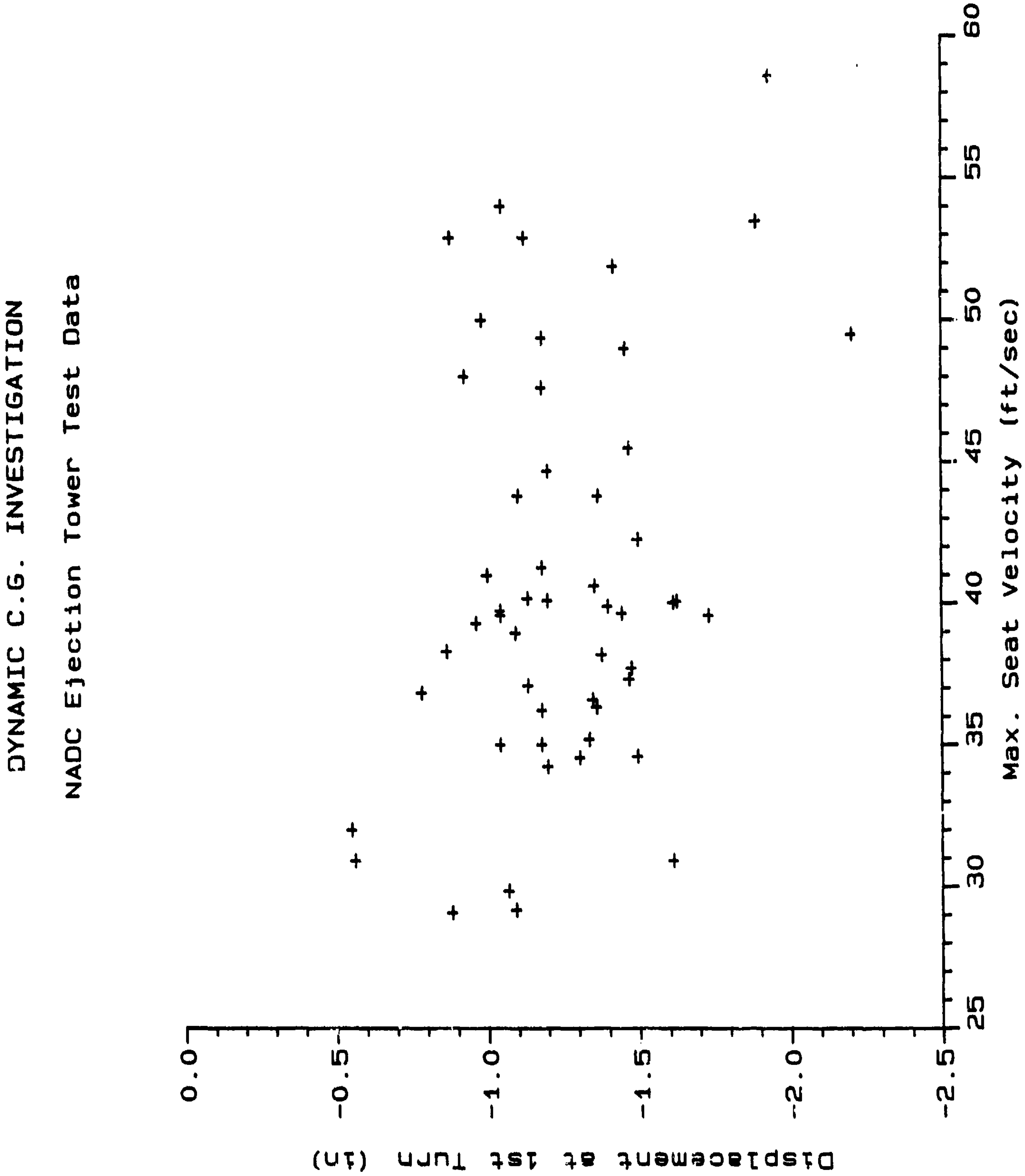


FIGURE 7 - Displacement at the 1st Turn vs Maximum Seat Velocity for all 52 Ejection Tower Tests

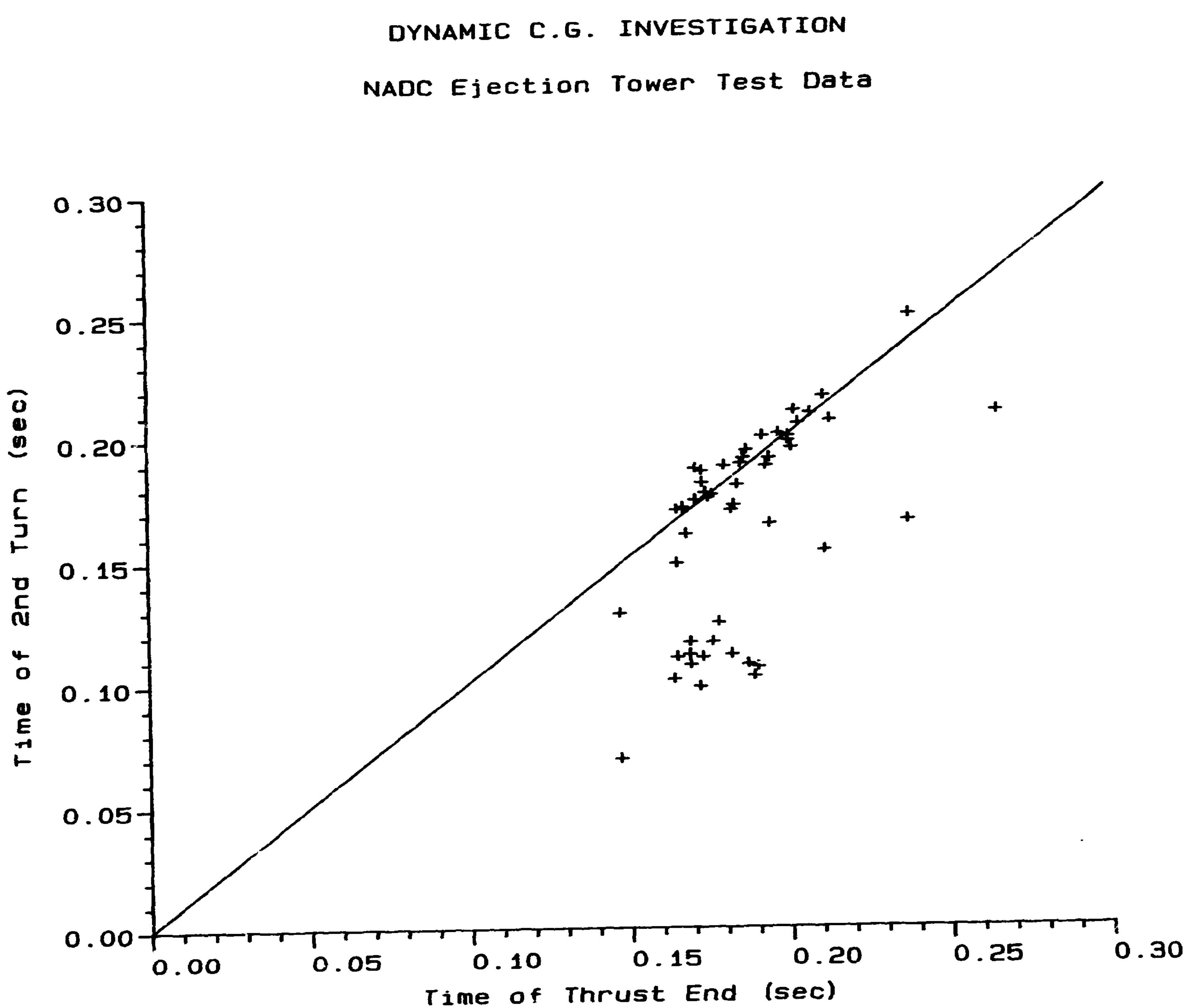


FIGURE 8 - Time of 2nd Turn vs Time of Thrust End for all 52 Ejection Tower Tests

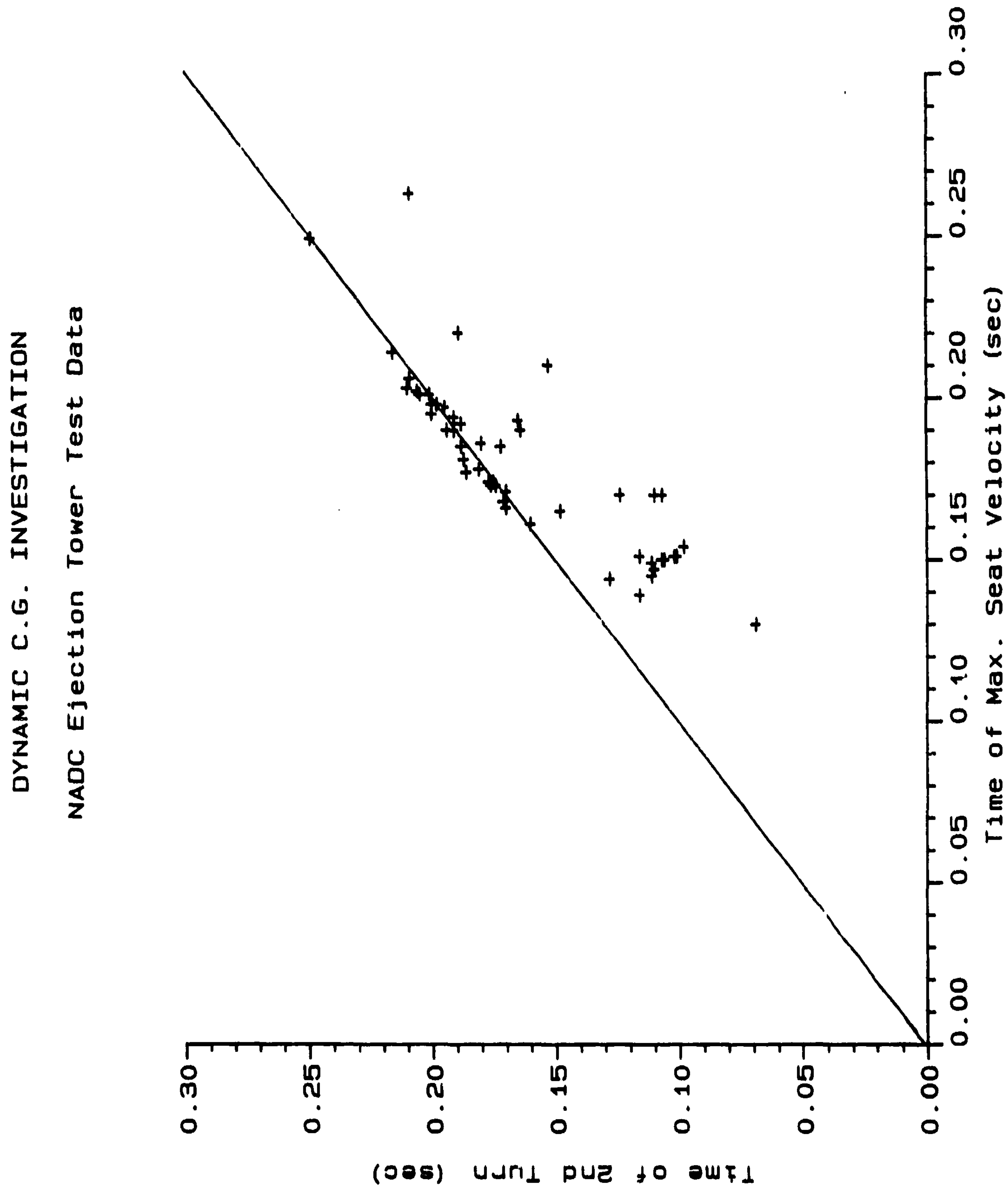
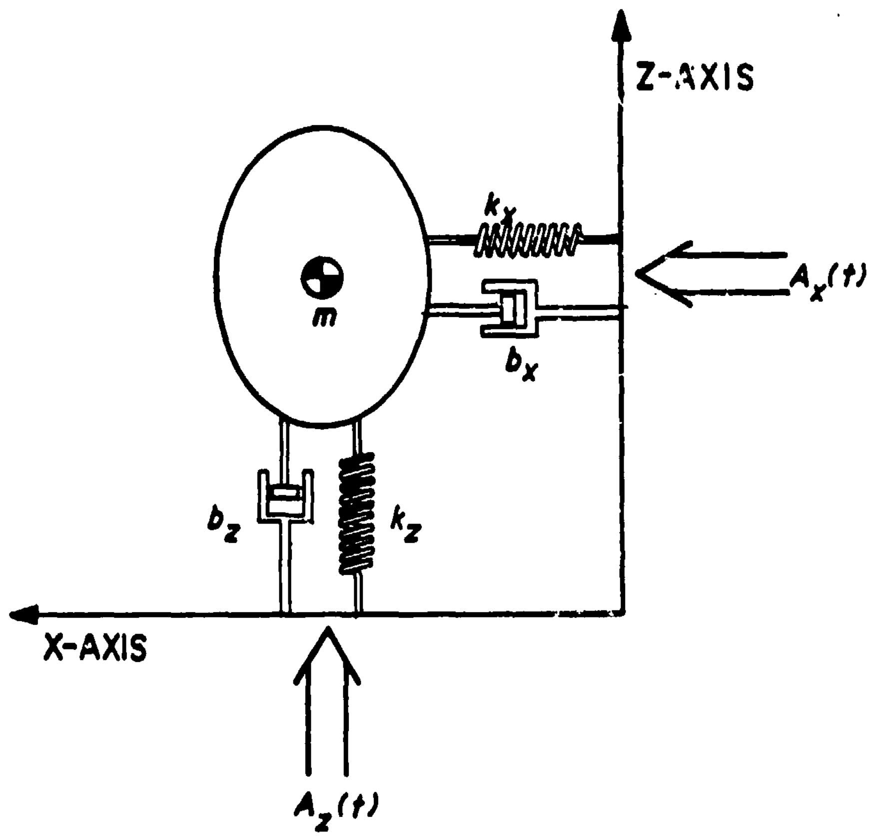


FIGURE 9 - Time of 2nd Turn vs Time of Maximum Seat Velocity for all 52 Ejection Tower Tests

DYNAMIC C.G. MODEL



EQUATION OF MOTION:

$$\ddot{\delta} + \frac{b}{m}\dot{\delta} + \frac{k}{m}\delta = A(t)$$

or $$\ddot{\delta} + 2\gamma\dot{\delta} + \omega_o^2\delta = A(t)$$

where $$\gamma = \frac{b}{2m} \qquad \omega_o^2 = \frac{k}{m}$$

SOLUTION GENERATES 3 CASES:

(a) $\gamma < \omega_o$ (b) $\gamma = \omega_o$ (c) $\gamma > \omega_o$

or $\gamma = c\omega_o$ *where* $c<1$ *for (a),* $c=1$ *for (b) and* $c>1$ *for (c)*

therefore $$\ddot{\delta} + 2c\omega_o\dot{\delta} + \omega_o^2\delta = A(t)$$

FIGURE 10 - Dynamic C.G. Model and Equations of Motion

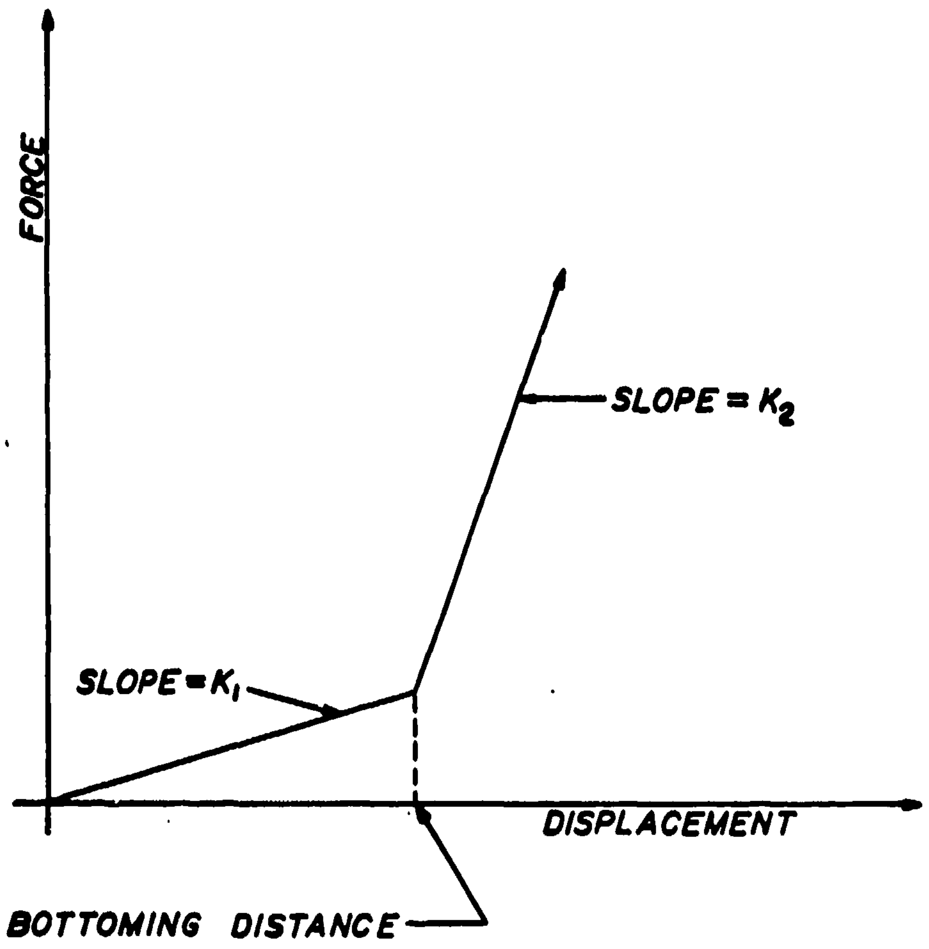


FIGURE 11 - Two Piece Non-Linear Spring Constant

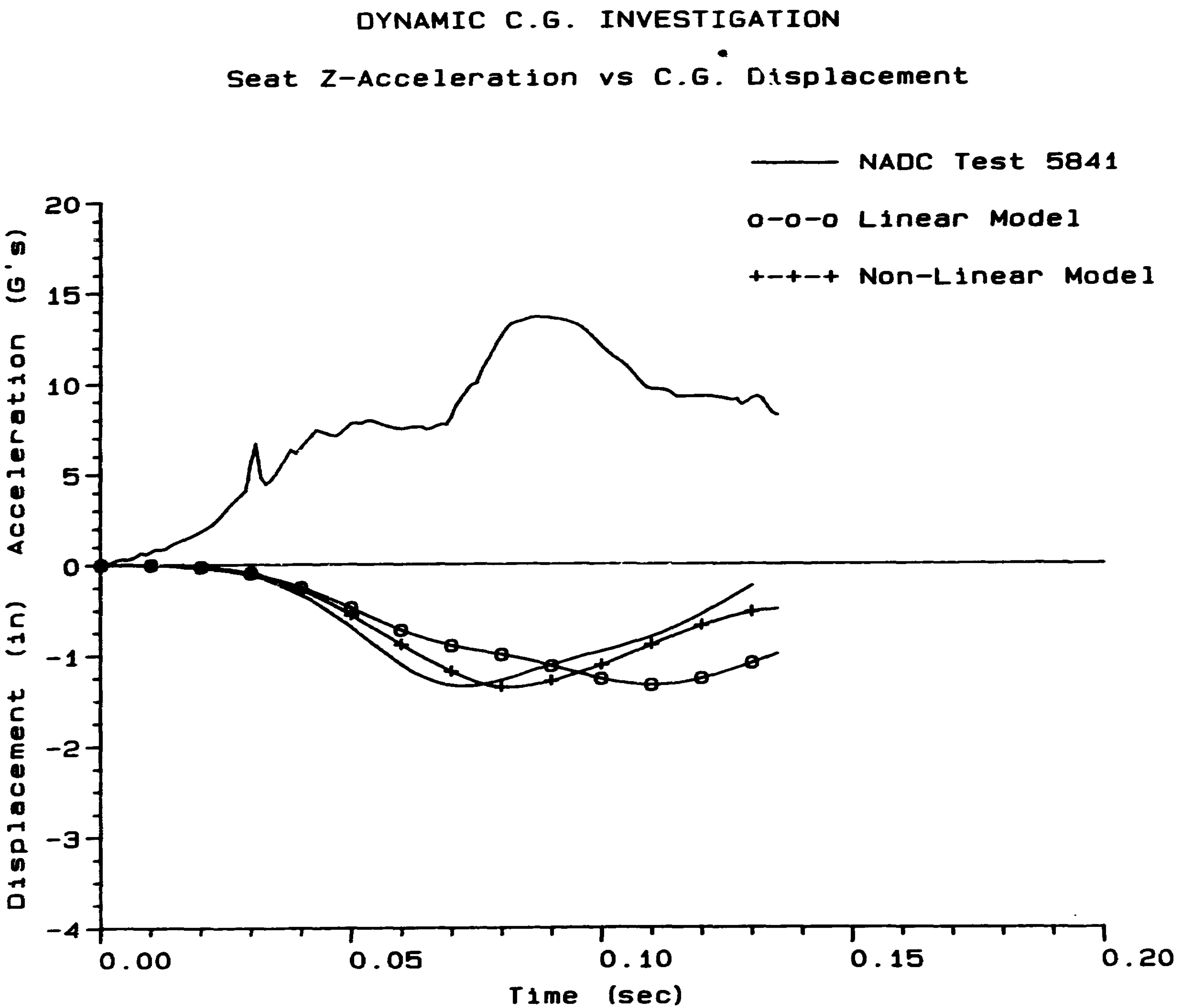


FIGURE 12 - Monitored Seat Acceleration and Resulting C.G. Displacement for Tower Test No. 5841

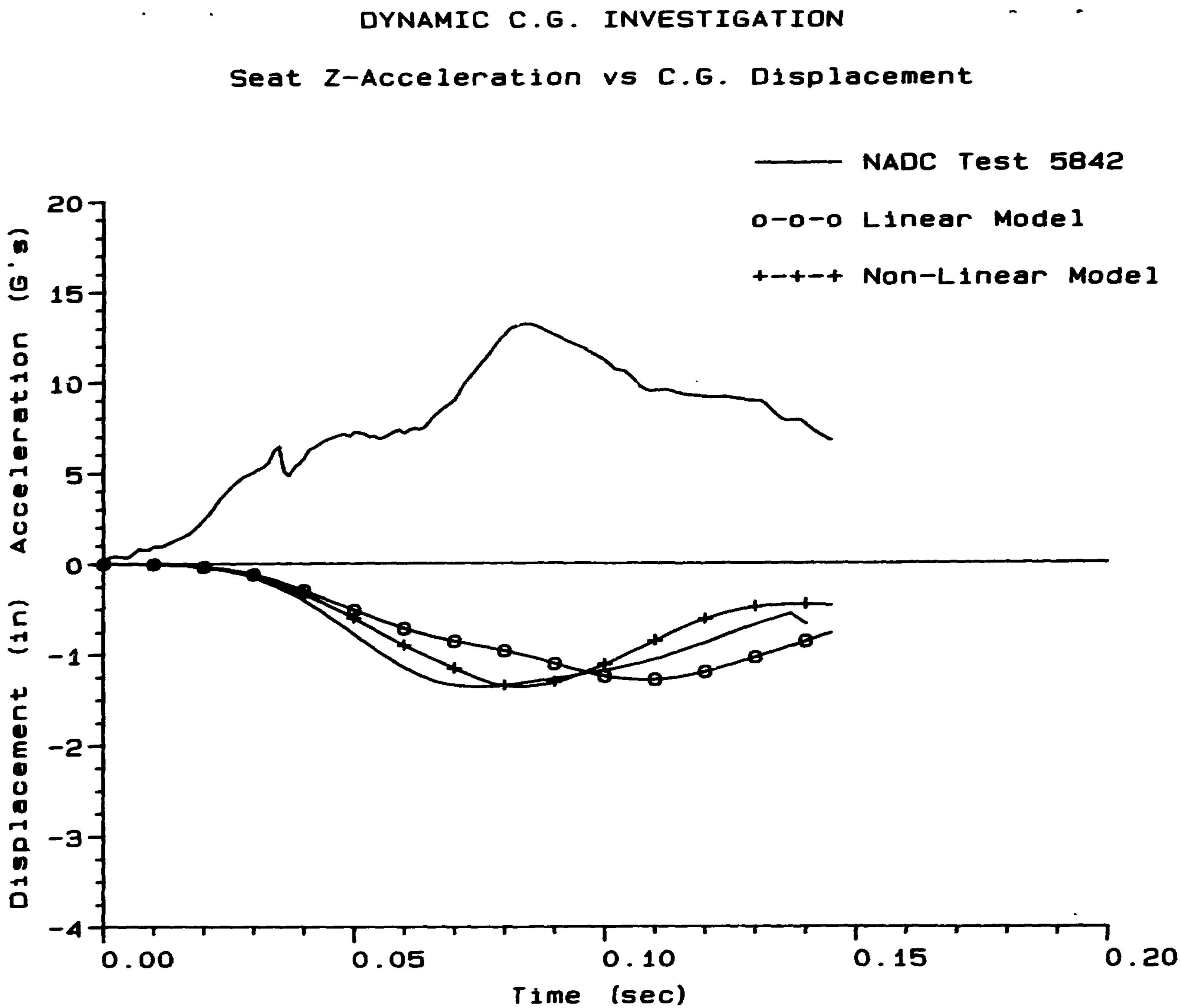


FIGURE 13 - Monitored Seat Acceleration and Resulting C.G. Displacement for Tower Test No. 5842

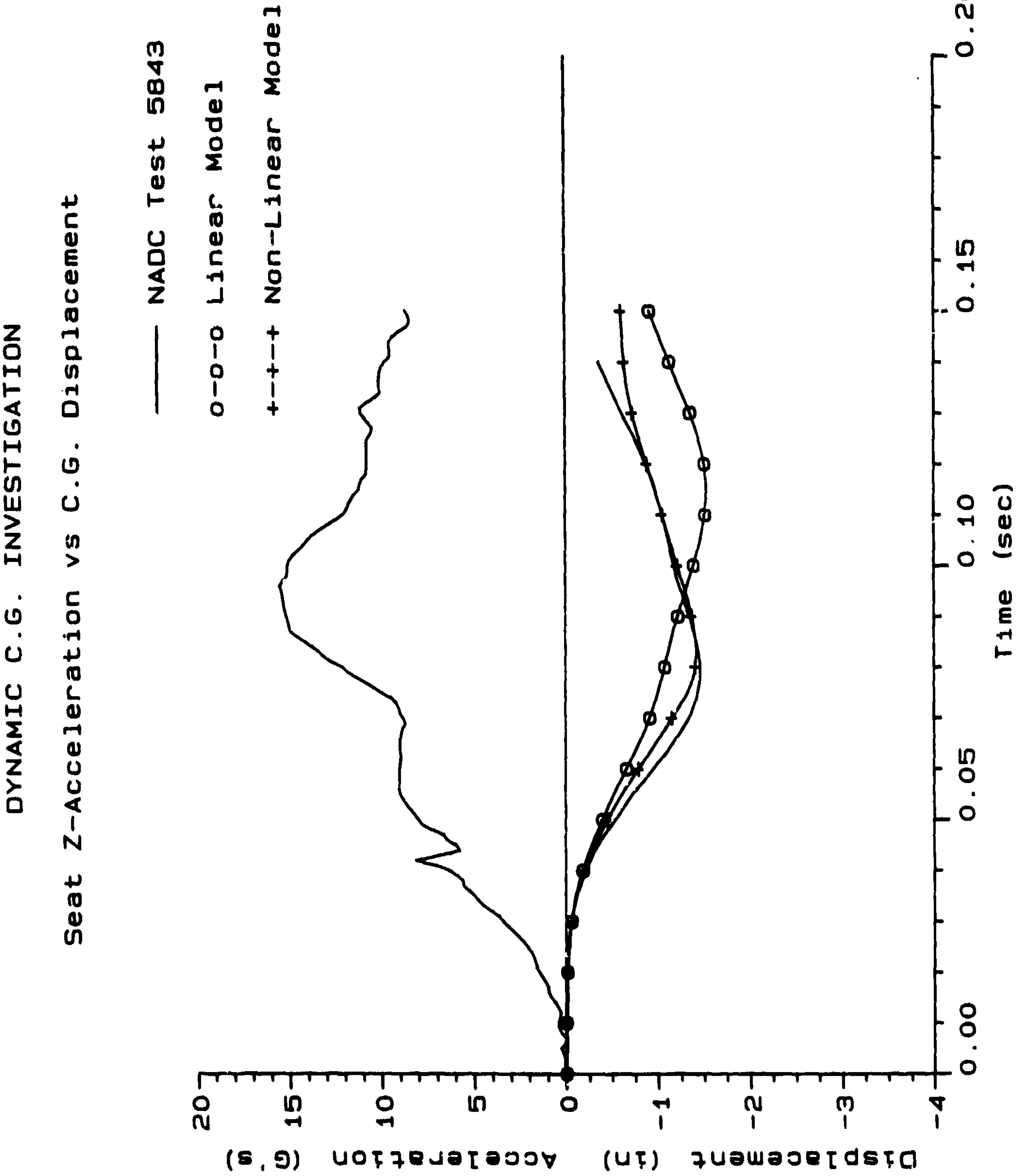


FIGURE 14 - Monitored Seat Acceleration and Resulting C.G. Displacement for Tower Test No. 5843

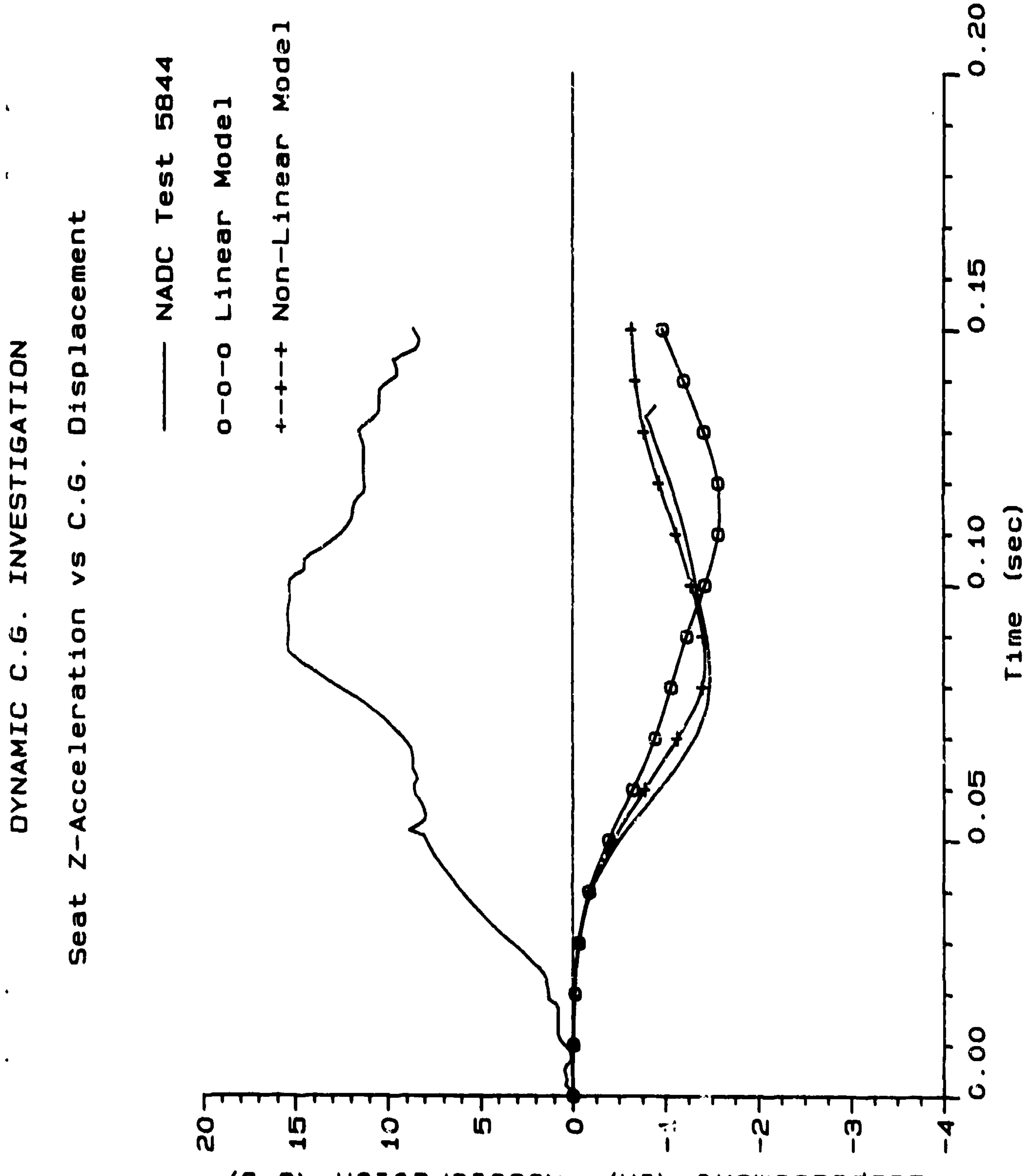


FIGURE 15 - Monitored Seat Acceleration and Resulting C.G. Displacement for Tower Test No. 5844

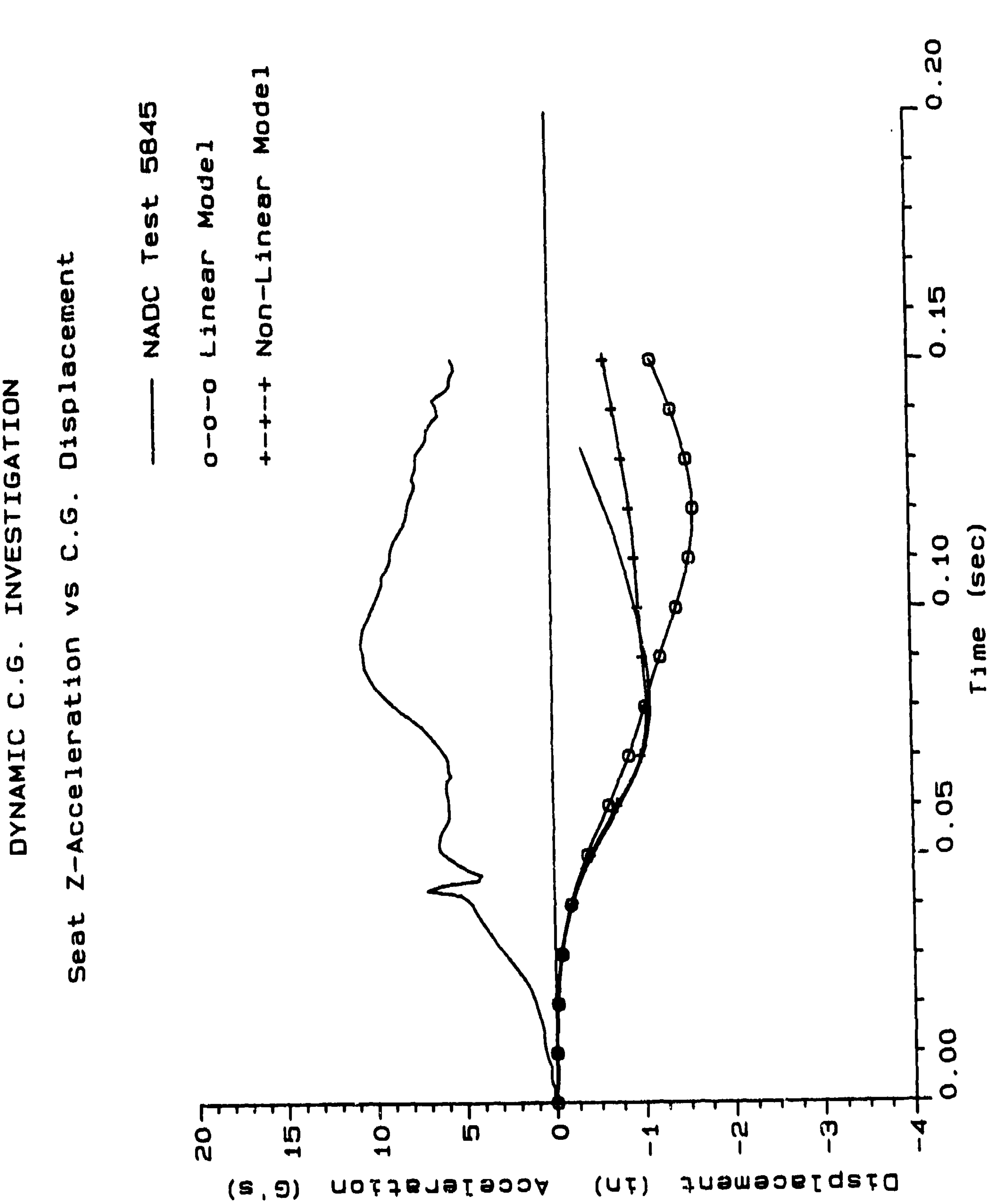


FIGURE 16 - Monitored Seat Acceleration and Resulting C.G. Displacement for Tower Test No. 5845

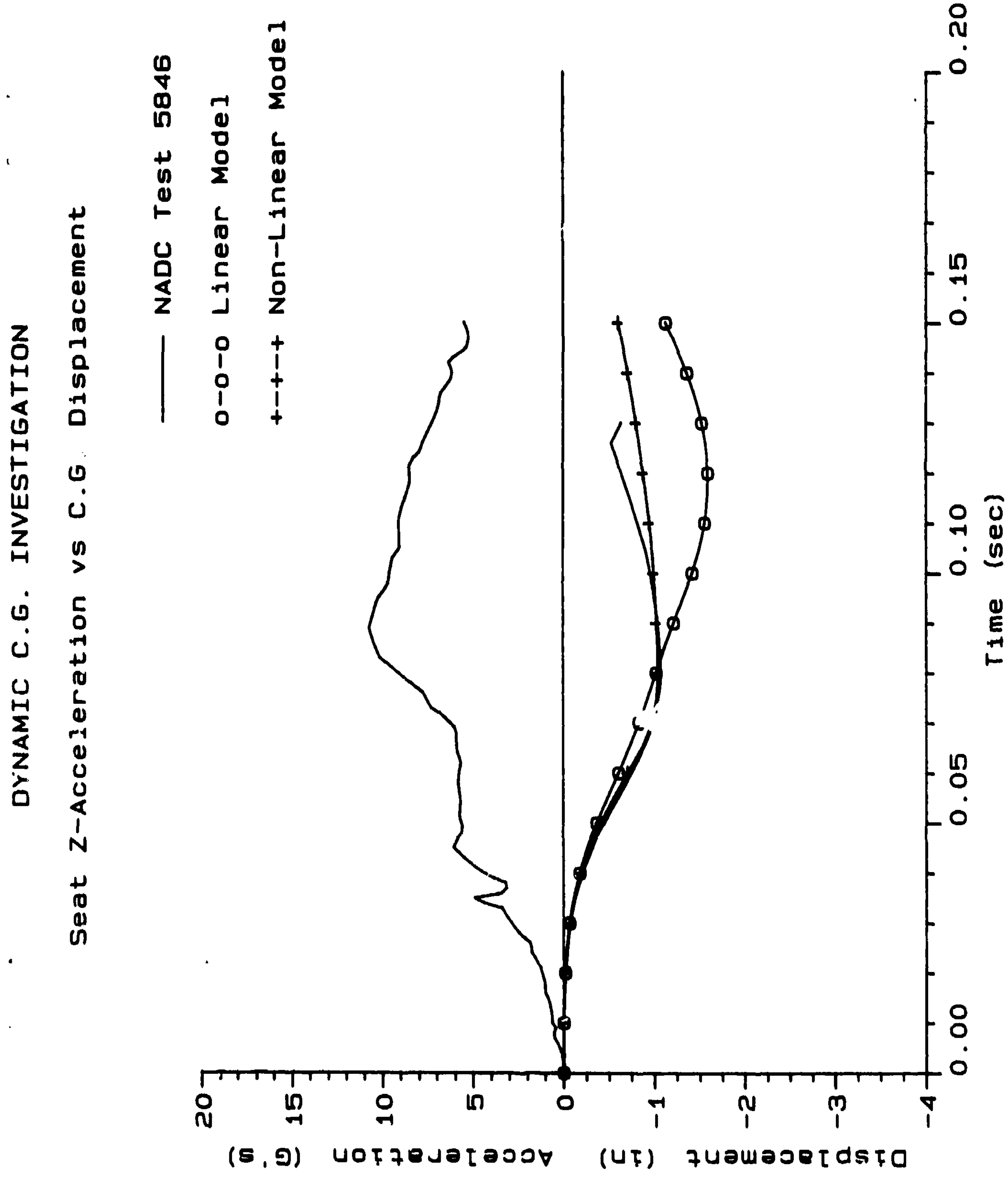


FIGURE 17 - Monitored Seat Acceleration and Resulting C.G. Displacement for Tower Test No. 5846

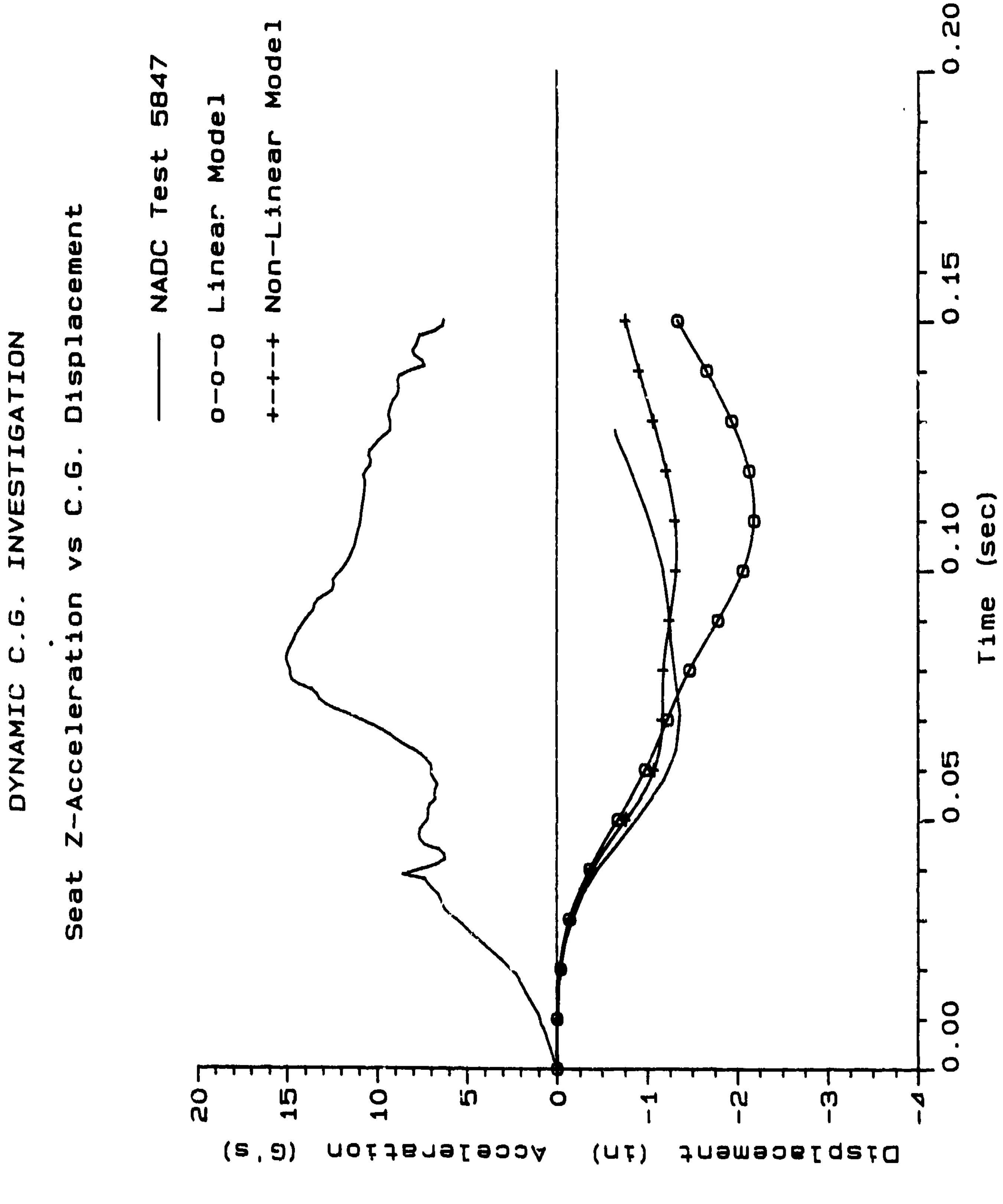


FIGURE 18 - Monitored Seat Acceleration and resulting C.G. Displacement for Tower Test No. 5847

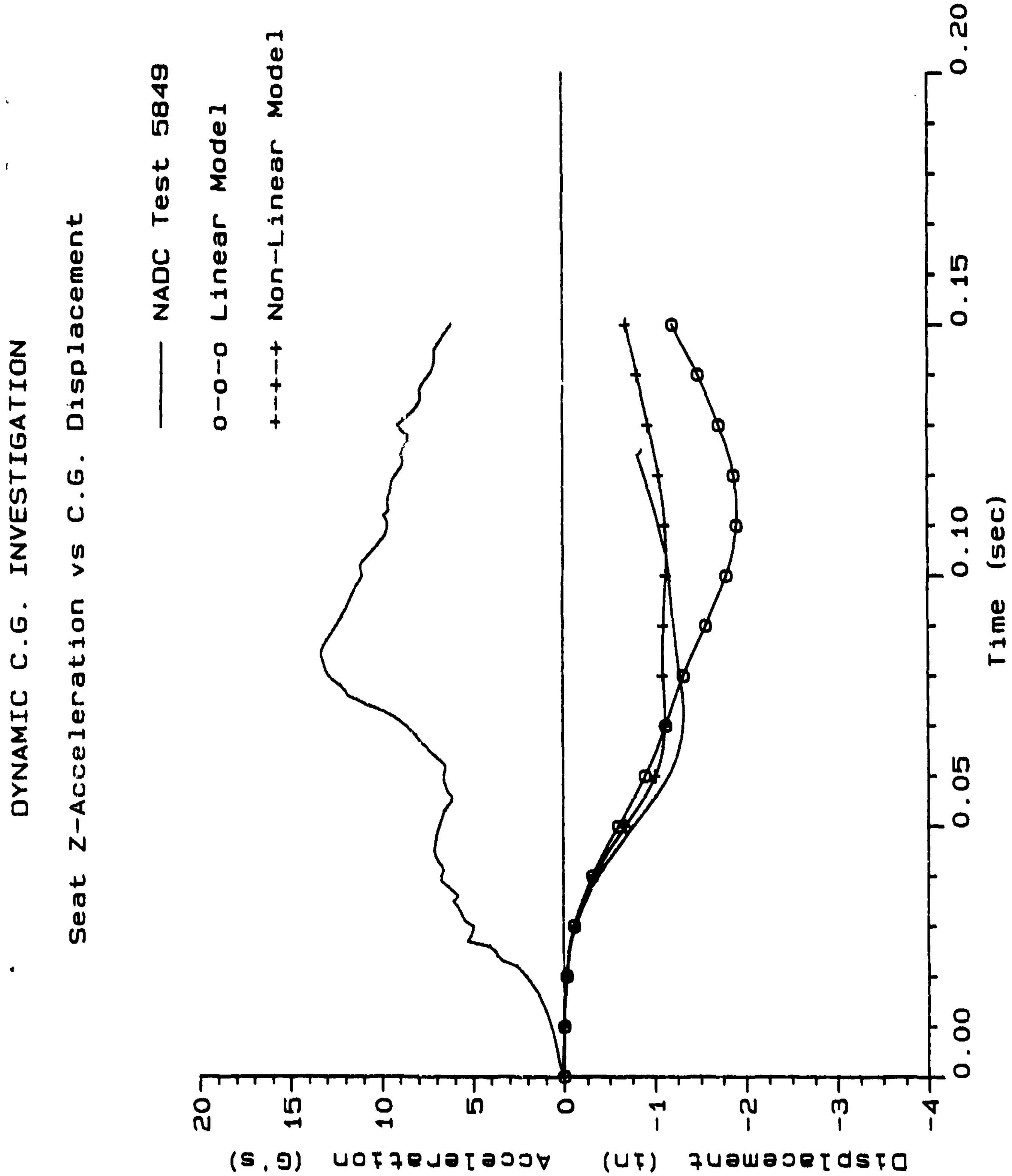


FIGURE 19 - Monitored Seat Acceleration and Resulting C.G. Displacement for Tower Test No. 5849

DYNAMIC C.G. INVESTIGATION

Seat Z-Acceleration vs C.G. Displacement

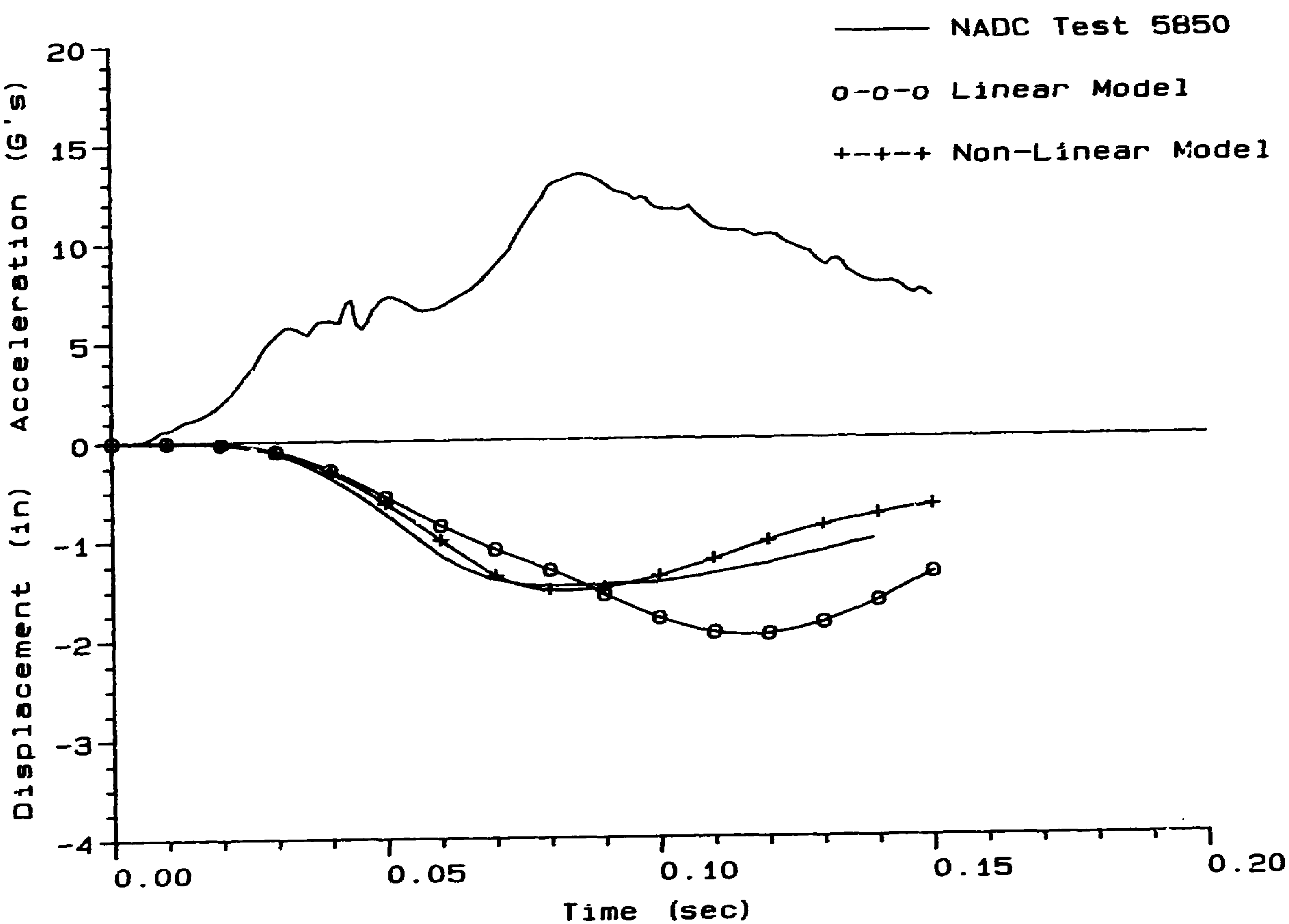


FIGURE 20 - Monitored Seat Acceleration and Resulting C.G. Displacement for Tower Test No. 5850

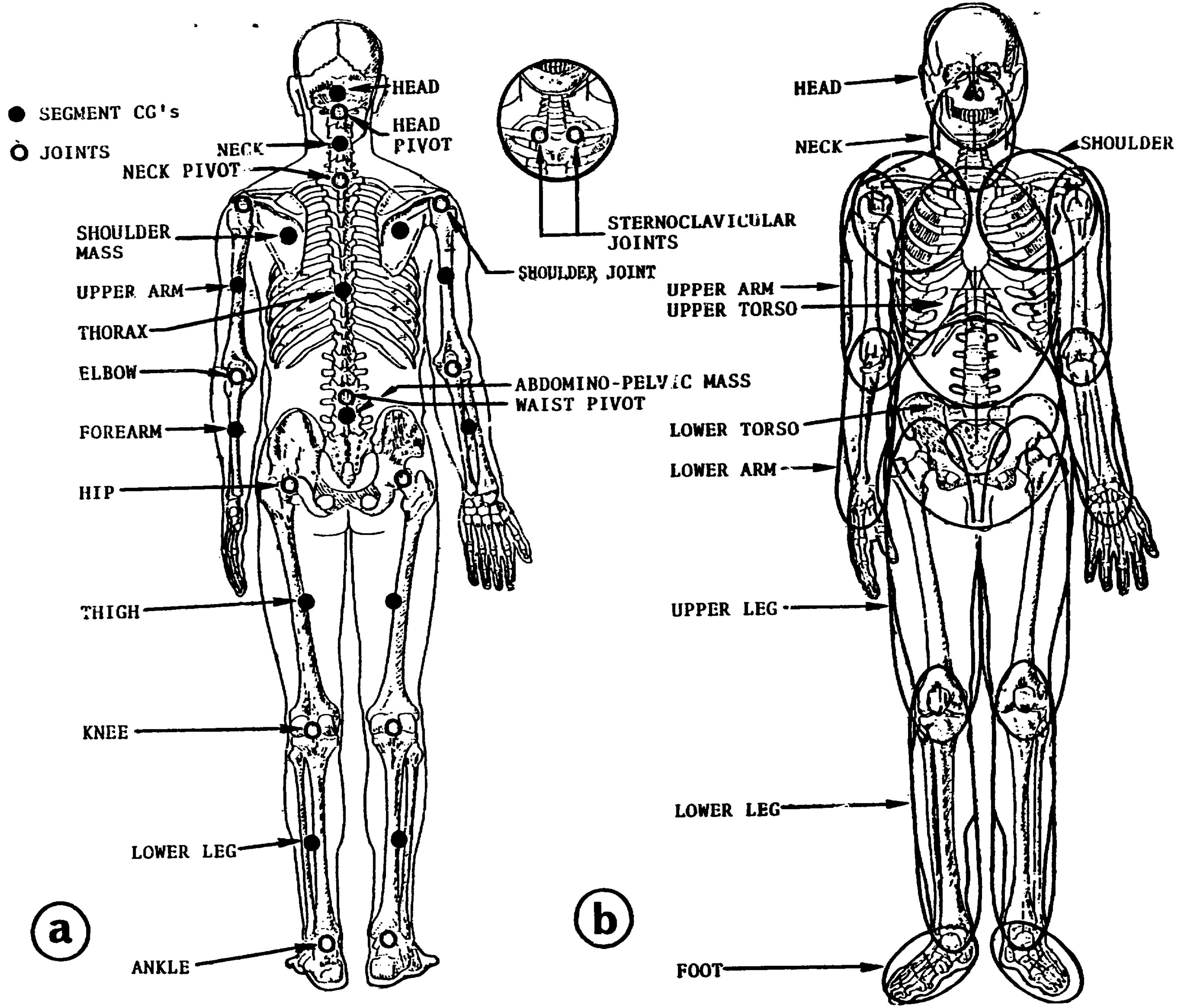


FIGURE 21 - 16 Segments, 15 Joints Representation of Human Occupant

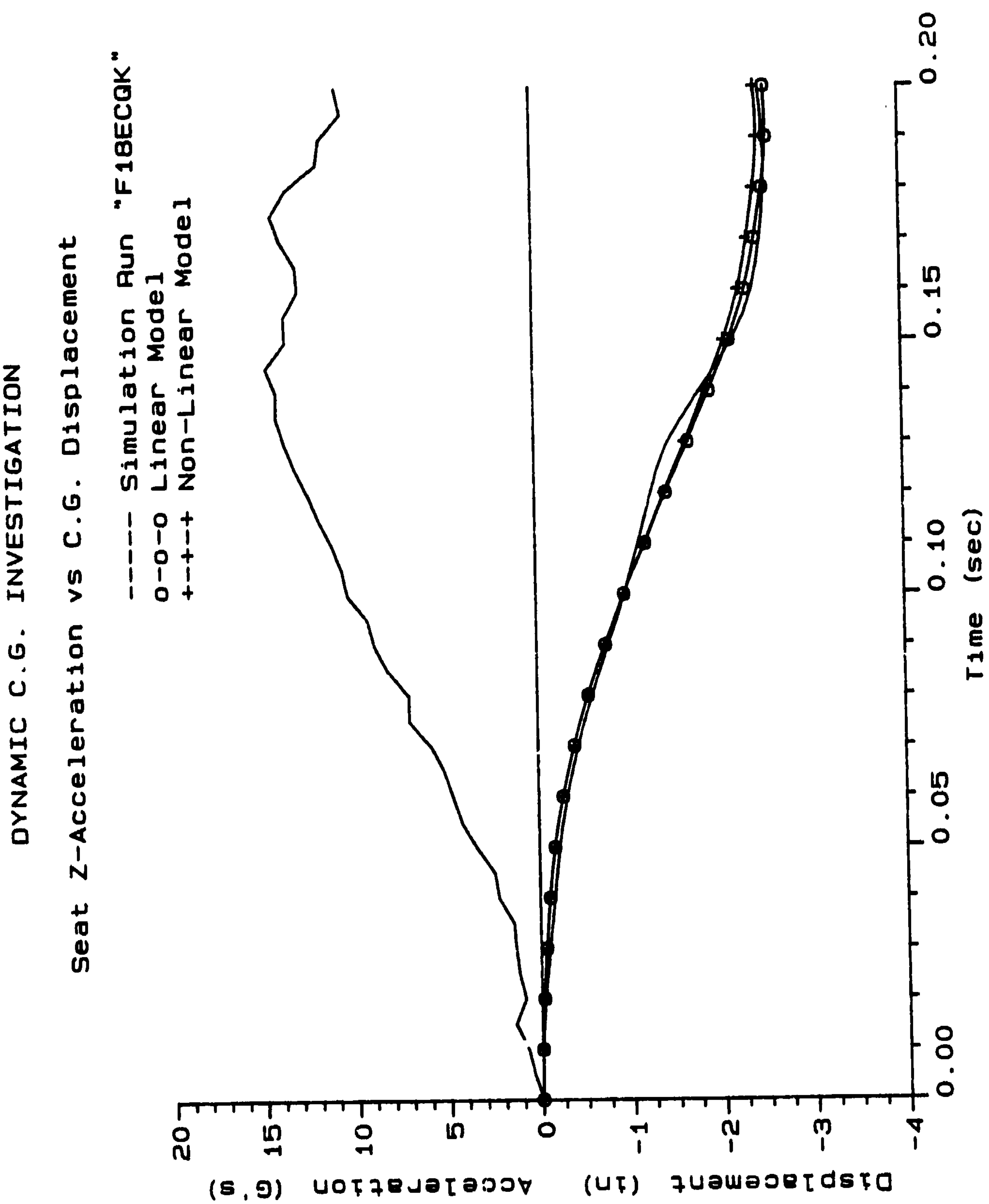


FIGURE 22 - Input Seat Acceleration and Resulting C.G. Displacement for Simulation Run F18ECQK

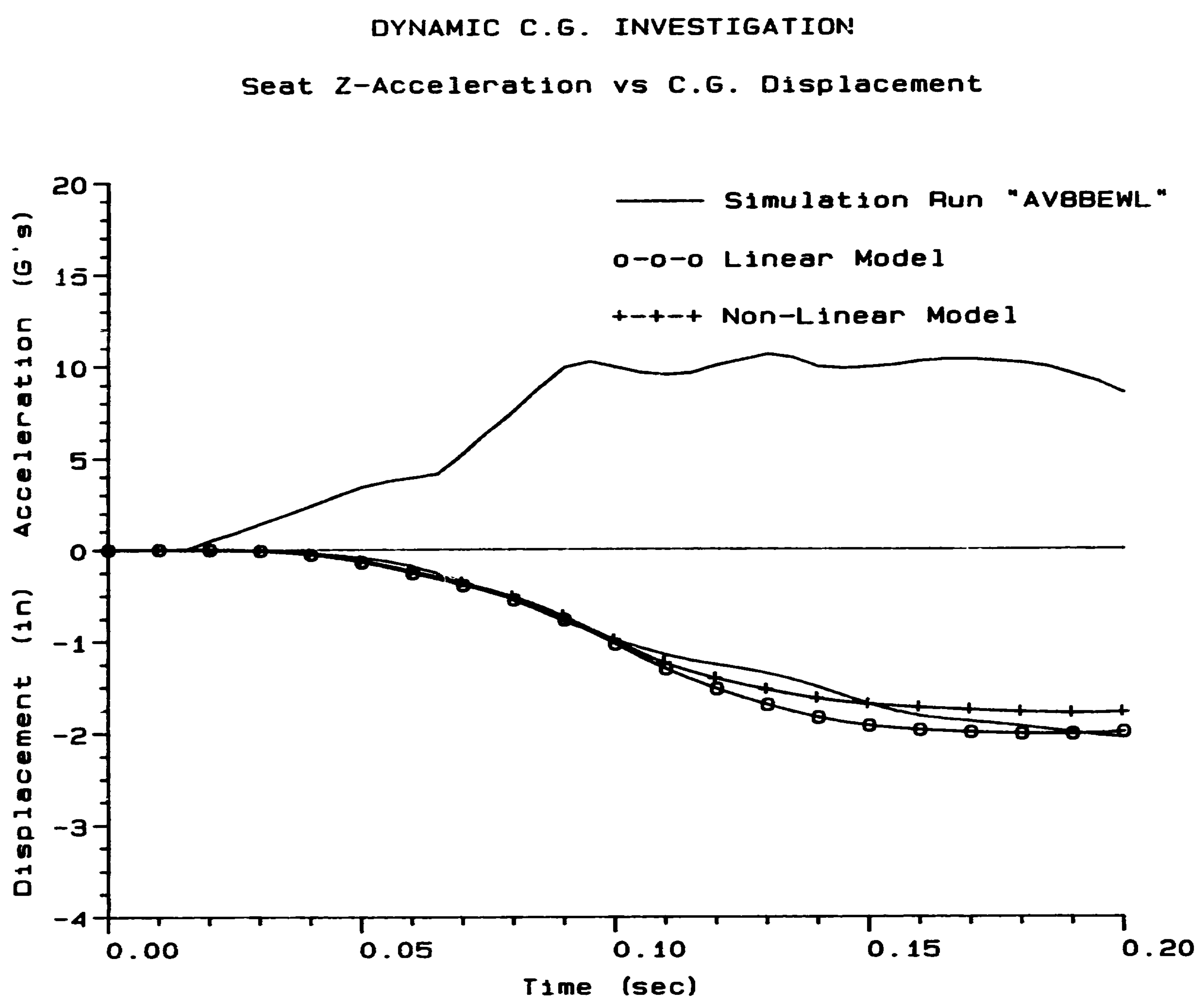


FIGURE 23 - Input Seat Acceleration and Resulting C.G. Displacement for Simulation Run AV8BEWL

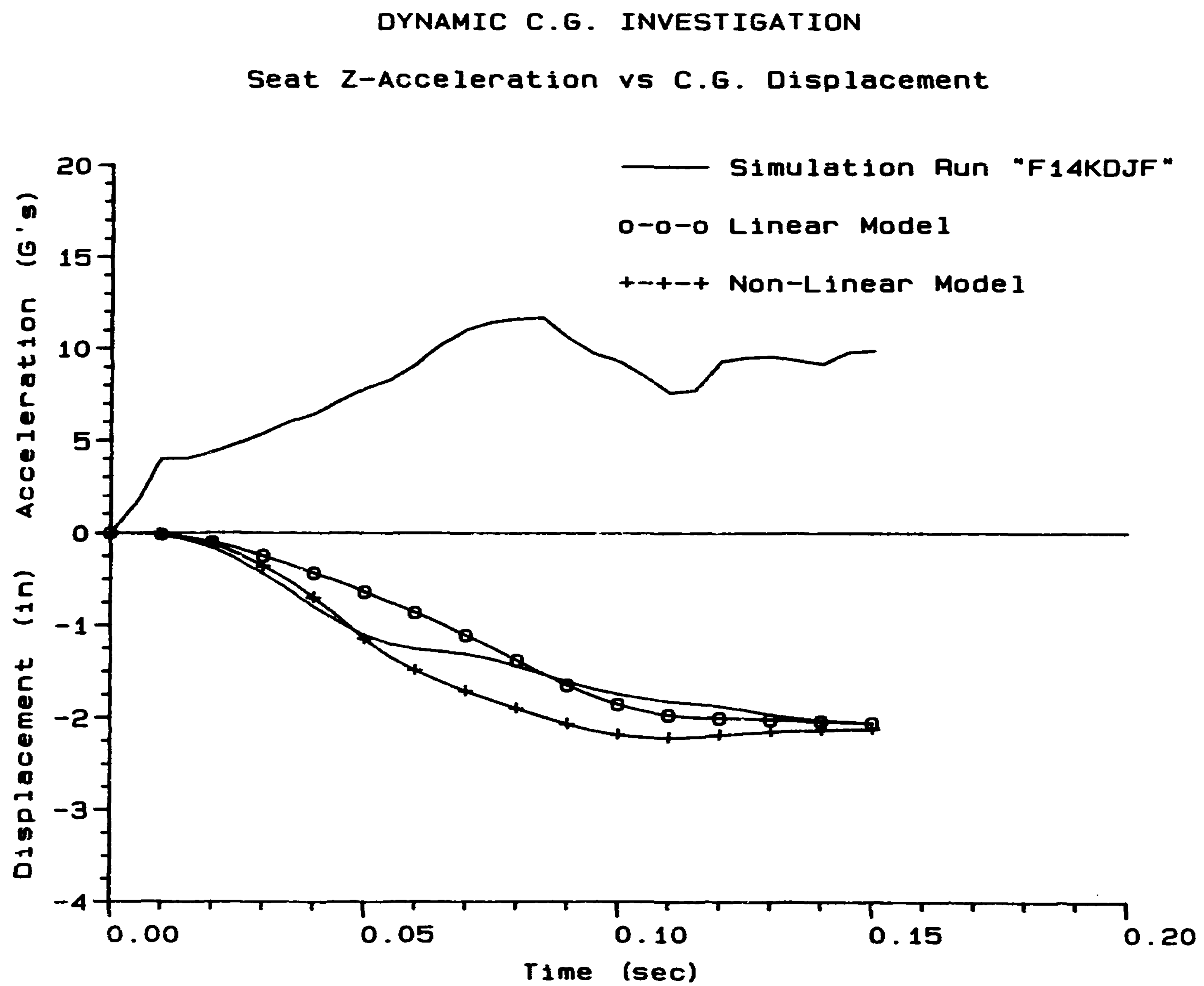


FIGURE 24 - Input Seat Acceleration and Resulting C.G. Displacement for Simulation Run F14KDJF

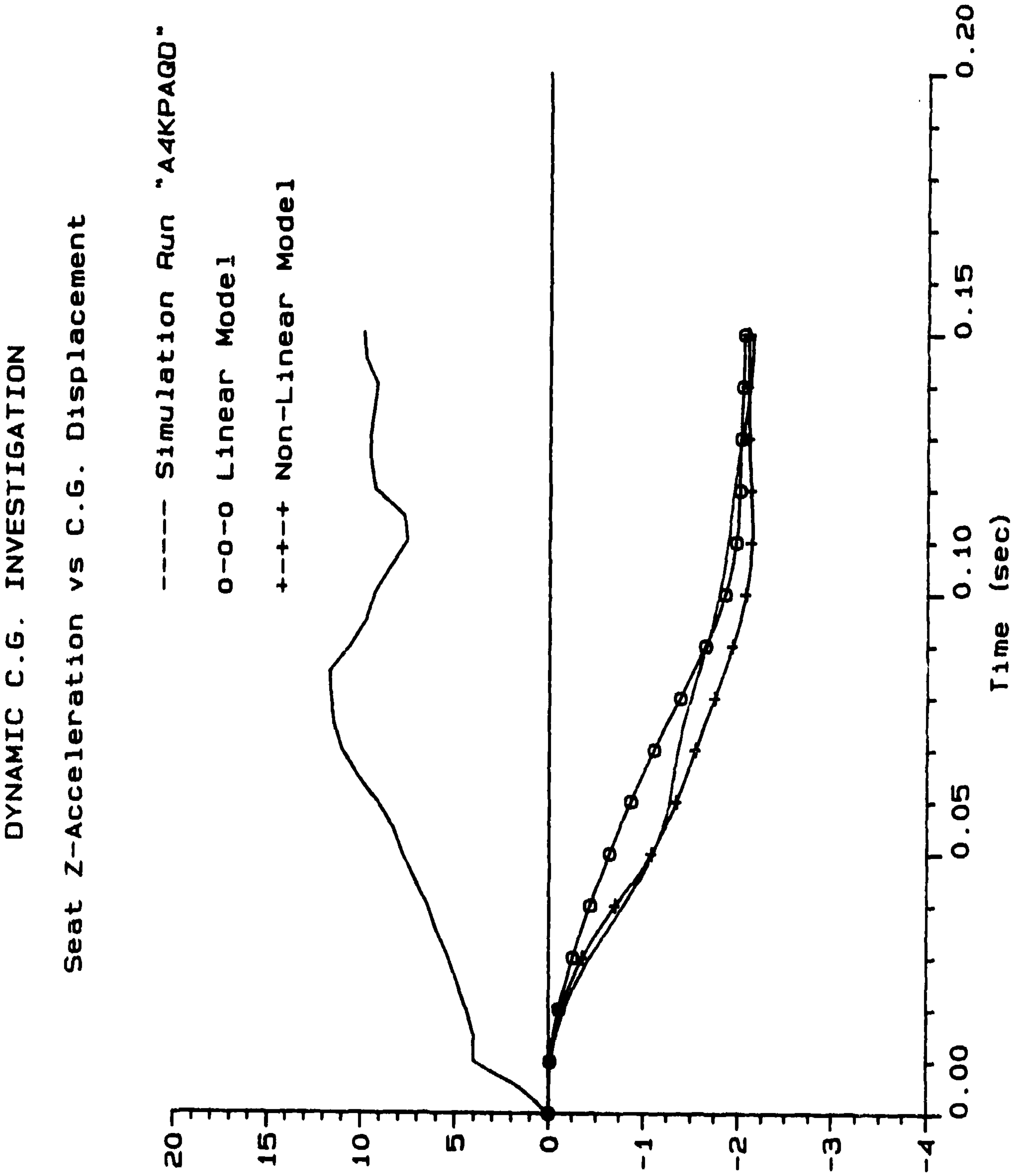


FIGURE 25 - Input Seat Acceleration and Resulting C.G. Displacement for Simulation Run A4KPAQD