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CREW ACTIVITY & MOTION EFFECTS

ON THE SPACE STATION

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ABSTRACT

CREW ACTIVITY & MOTION EFFECTS ON THE SPACE STATION

Among the significant sources of internal disturbances that must be considered in the design of Space Station vibration control systems are the loads induced on the structure from various crew activities. Flight experiment T013, flown on the second manned mission of Skylab, measured force and moment time histories for a range of preplanned crew motions and activities. This experiment has proved itself invaluable as a source of on-orbit crew induced loads that has allowed a Space Station forcing function data base to be built.

This will enable forced response such as accelerations and deflections, attributable to crew activity, to be calculated.
The flight experiment, resultant database and structural model pre-processor, analysis examples and areas of continued research shall be described.

I. Introduction

Since the early sixties, crew activity/motion (CA/M) has been a concern and important parameter in the areas of space vehicle stability, attitude and control during its on-orbit operation. Initially, the impact of CA/M on the pointing accuracies and control of spacecraft carried the most concern. More recently, however, the on-orbit 'micro-g' environments of the Space Shuttle and the forthcoming Space Station have provided the motivation for further crew disturbance studies.

Various ground simulations and one flight experiment have been conducted through the years, yielding sufficient amounts of data to promote an understanding of the potential impact man has on his spacecraft's on-orbit quiescent environment. For analysis purposes, modeling can yield only part of the CA/M disturbance spectrum; stochastic modeling techniques can be used for low-level restrained activities. Flight data can be used to build a forcing function database and a structural model pre-processor can be generated to yield the remainder of the CA/M disturbance spectrum; the deterministic or discrete high-level restrained and translational activities.

The following is dedicated to describing the evolution of a CA/M forcing function database and preprocessor, 'CREW', developed by Lockheed-EMSCO for the Loads & Dynamics Branch of the Structures & Mechanics Division at NASA/JSC. The description of this evolution will include: background discussion of early studies and ground simulations; a description of the only flight experiment conducted to date; modeling techniques; features of 'CREW' and the T-013 CA/M forcing function database; analysis examples and plans for continued work in this area.

II. Background & Evolution of Skylab Experiment T-013

To demonstrate the potential impact man has on his spacecraft, the following 'real world' examples of CA/M disturbances can be cited. On the manned Skylab missions, the astronauts found that they had a 'jogging' track at their disposal. At the top of the Orbital Workshop (OWS), a bank of lockers around the perimeter of that compartment were used by the astronauts to 'run' on. In doing so, they were able to achieve centripedal acceleration equivalent to the moon's gravity, and more importantly, the induced loads started to precess the entire spacecraft. Needless to say, ground controllers had the crew discontinue this activity because the Skylab Attitude and Pointing Control System (APCS) was not able to maintain control of the spacecraft, and the Apollo Telescope Mount Experiment Pointing Control System (ATM EPCS) pointing accuracy, required by the solar experiments, was threatened (refs. 1 and 2).

More recently, aboard the shuttle, various forms of CA/M disturbances have been examined. During STS-9, after the Spacelab 1 module had been powered up and run through a systems checkout, the crew was asked to participate in the Spacelab Environment Verification Flight Test (ref. 3). The activities investigated were coughing and soaring. Peak response in the module was measured as 0.007 g. In the Shuttle's crew cabin middeck, a treadmill is provided for the crew to satisfy their exercise requirement while on-orbit. On recent missions, NASA/LaRC's ACIP/HIRAP accelerometer package has measured peak accelerations that exceed 0.0001 g's (nominal treadmill operation aboard a 220,000 lb Orbiter).

Thus the effect of CA/M on a spacecraft's on-orbit environment can be a dramatic one. Consideration of this potential impact is especially important for a spacecraft such as the Space Station, which is dedicated to providing a pure micro-g environment for its payloads and experiments.

During the development of early long duration spacecraft, other investigators (refs. 4, 5) demonstrated that CA/M disturbances would exceed other sources such as gravity-gradient and aero drag effects using point-mass representations of man in the spacecraft equations of motion. In 1966, Fuhrmeister and Fowler (ref. 6) reported that the crew would have to be isolated to ensure fine pointing accuracies for their MDAC Manned Orbital Research Laboratory (MORL). In 1969 Goodman and Middleton of MDAC conducted a 60 day crew locomotion study in their Space Cabin Simulator (ref. 7). Using applied force data (measured in the 1966 MORL ground simulation) to drive a computer simulation of their spacecraft dynamics, they confirmed the Fuhrmeister and Fowler conclusion and added that basic attitude control would also be compromised by frequent crew motion over a long time interval.

The lack of flight data and the need to verify simulation results culminated in the proposal of a dedicated experiment to be conducted on what was to be called Skylab. In addition, the experiment would test the design of a control/isolation system which would be used to ensure pointing accuracies of the Skylab's Apollo Telescope Mount (ATM). In 1967, Martin Marietta, under contract to MSFC, began the development of experiment T-013; in parallel they began conducting detailed ground simulations using their 6 DOF servo-driven simulator and a predecessor of the T-013 force measurement system (refs. 8, 9).

Reinforcement to the need for experiment T-013 can be found in understanding the limitations of ground simulation and, consequently, the questionable applicability of the resultant data. Several techniques of simulating the zero-g environment of a manned spacecraft and their advantages/disadvantages with respect to a crew-motion experiment are listed in Table 1.

Table 1: CREW ACTIVITY SIMULATION METHODS

METHOD	ADVANTAGES	DISADVANTAGES
FMU	engineering design and computer program to reduce instrumentation already developed; can measure effectof similar limb motions in both the horizontal and vertical plane and thus obtain comparisons with and without gravity	presence of gravity can affect manner in which motions are performed
Three DOF air bearing simulator at JSC	provides good approximation to zero-gravity limb motion effects in two translational and one rotational DOF (horizontal plane); low cost because air bearing floor and other hardware already exist at JSC	additional instrumentation of current simulator configurations may be required; computer program must be written to reduce data from instrumentation system; torque & force from air & instrumentation wires are negligible except for all but smallest limb motions; cannot measure effect of limb motions in vertical plane
air bearing simulation	provides good low-g or zero-g effect in two dimensions (horizontal plane)	implementation of force measuring techniques difficult; requires extremely fine balance and CG shift compensation; must counteract gravity in many motions; mounting harnesses, etc., too restrictive; susceptible to ambient air movement
underwater neutral buoyancy	approx. actual zero-g for unsuited subject	drag excessive for all but slowest motions, breathing equipment restrictive
servo-drive simulation	can be tied together with computer simulation of spacecraft dynamics	must counteract gravity in many motions; mounting harnesses too restrictive
cable suspension	relatively low cost	degrees of freedom limited; pendulum effects present; support apparatus restrictive
zero-g aircraft	actual zero-g environment	short run times; unnatural positive g forces interspersed between zero-g runs

III. Skylab Experiment T-013

Skylab experiment T-013 was proposed to determine the characteristics of CA/M disturbances and to evaluate the performance of a dedicated isolation system that would ensure the pointing accuracies of the ATM's solar experiment package.

The principal investigator, Mr. Bruce Conway, outlines the development and design of experiment T-013 in reference 10. Two categories of CA/M would be explored; restrained activities including respiration exercises, limb motion, gross torso motion and simulated console operations; and translation activities including various levels of soaring.

The restrained activities would be conducted with the test subject attached to a force measurement unit (FMU) with foot restraints and the translation activities would have the test subject pushing off from one FMU, soaring across the Skylab Orbital Workshop and landing on another FMU; see Figures 1 and 2.

The forces and frequency content of the disturbances produced by the T-013 subject were generally, and notably higher than those measured in ground simulations. For the respiration exercises (breathing, coughing, sneezing), only coughing had the same force levels in flight as obtained in simulation. Sneezing produced up to twice the force and deep breathing resulted in over 25 times as much force. A lack of 1-g restraint on the subject's viscereal mass, allowing more acceleration and motion of this mass, appears to provide reasonable explanation for the larger on-orbit forces. The experiment was performed approximately three weeks into the Skylab 3 mission (second manned mision) and it is assumed that the crew had become well adapted to their zero-g environment.

The crew's zero-g adaptation may also explain why the preflight zero-g aircraft soaring data was not as high as the T-013 flight levels. Figure 3 is a plot of the zero-g aircraft data and Figure 4 is a plot of representative T-013 data. In addition to the force time histories, these plots include a trace of the cumulative absolute force impulse. In comparison, the T-013 data indicates forces two times greater and an impulse value five times greater than the zero-g aircraft data. It should be noted that Figure 3 represents only the force normal to the 'wall' and with the addition of the other components of the total force, as measured in experiment T-013, there is a significant increase in the energy imparted to the spacecraft.

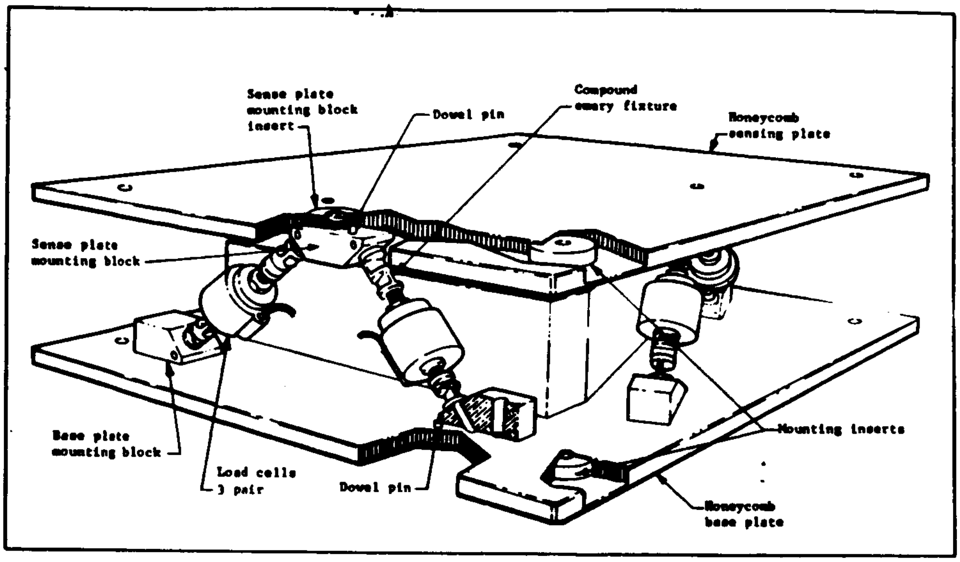


Figure 1 - Force Measurement Unit (FMU)

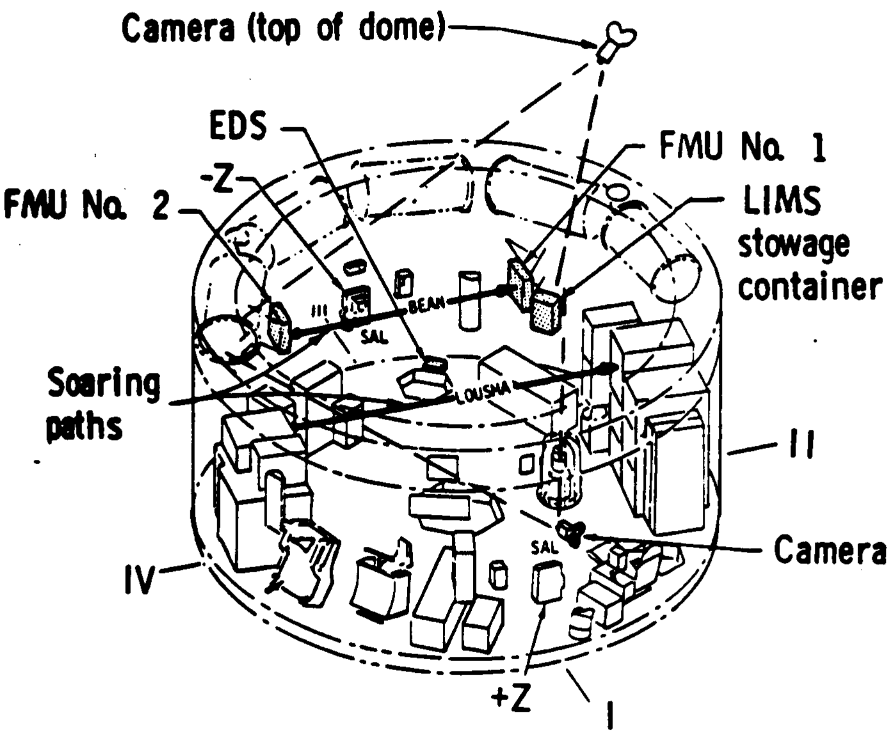


Figure 2 - T013 operations area of OWS
indicating soaring paths

FIGURE 3 - ZERO G AIRCRAFT WALL PUSHOFF & LANDING

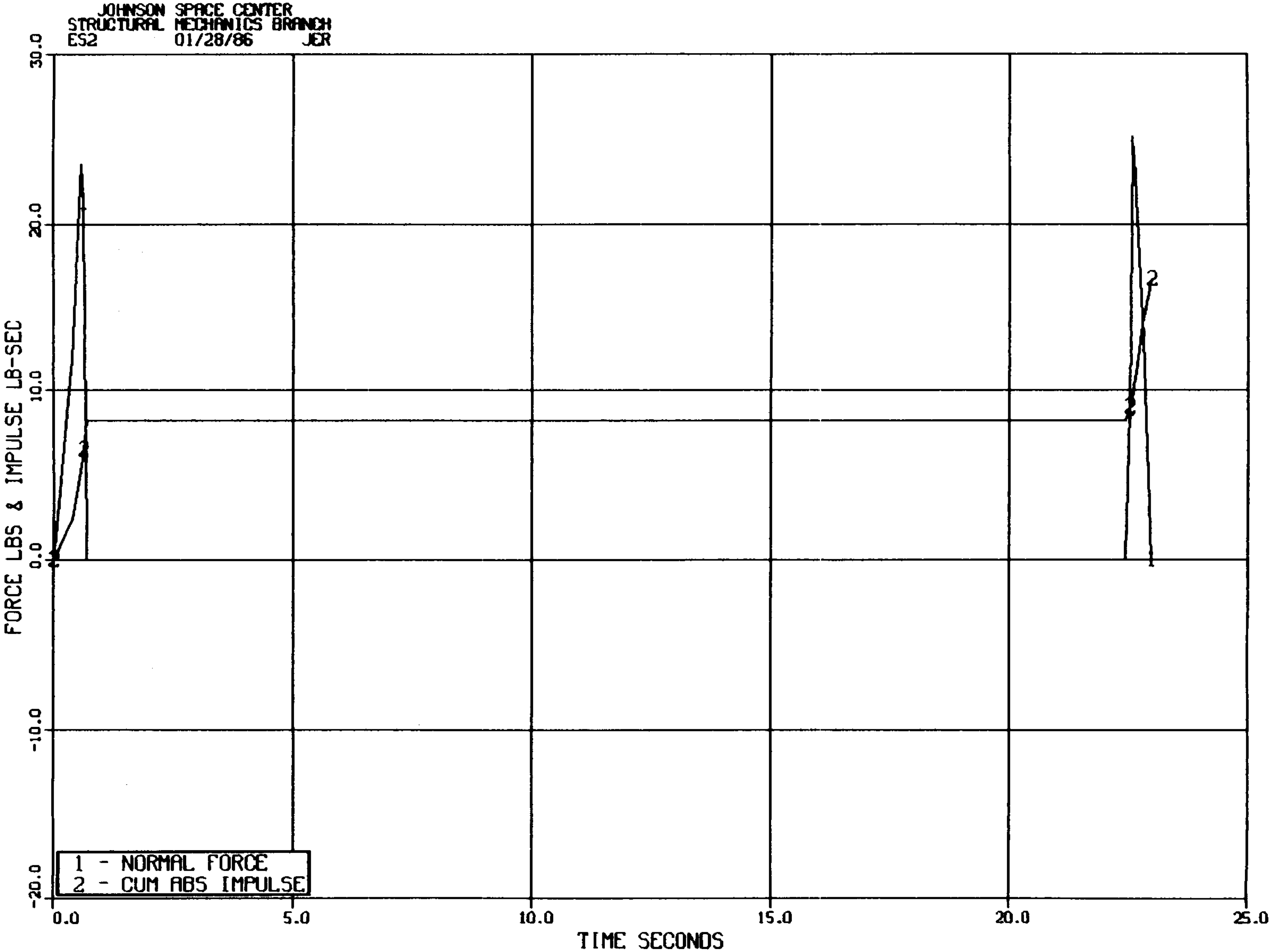
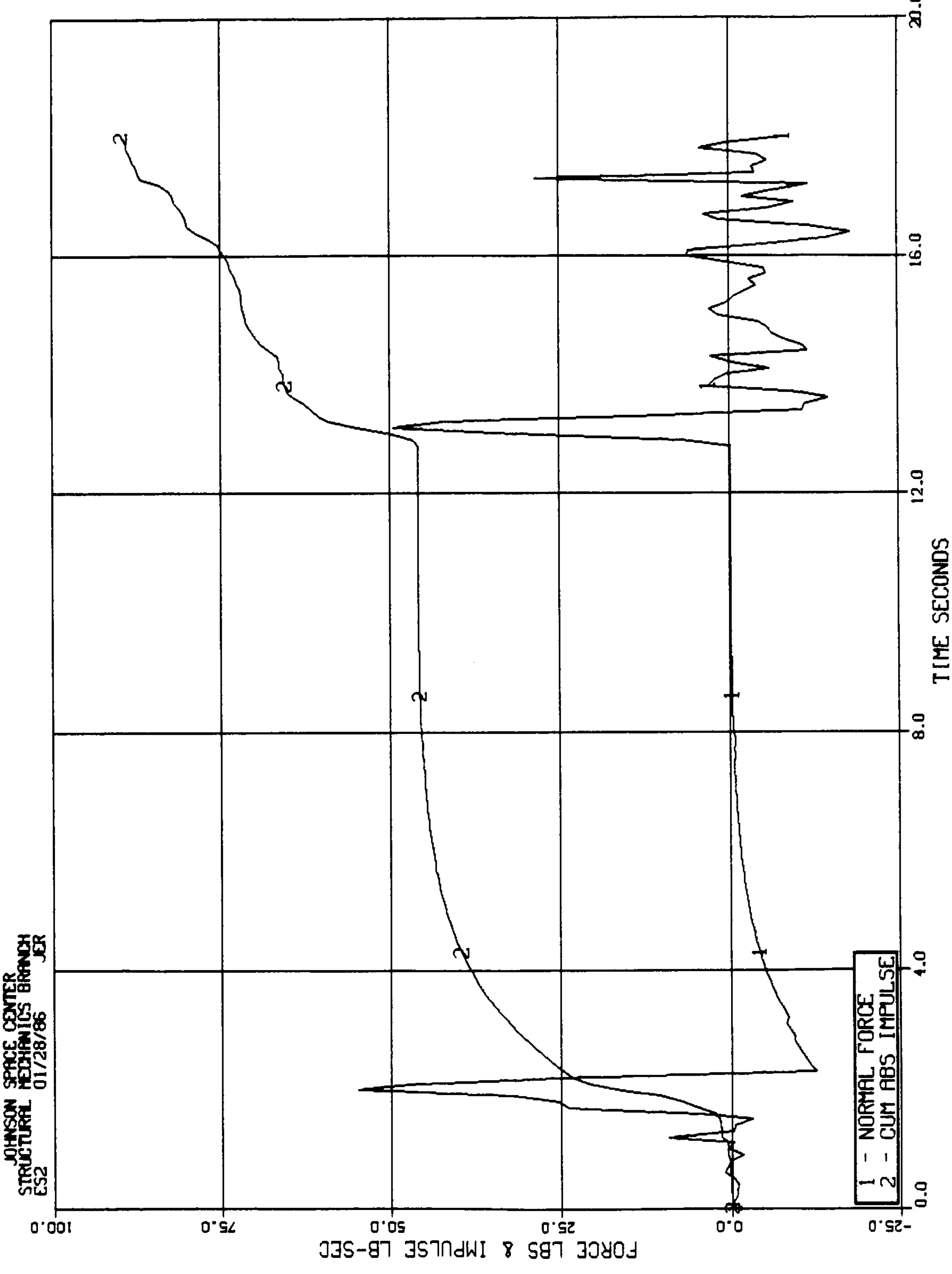


FIGURE 4 - TYPICAL EXPERIMENT T-013 WALL PUSHOFF & LANDING



Thus it appears that short periods of zero-g interspersed with periods of greater than 1g would seem to preclude a complete adaptation and development of the large translation capabilities evidenced in Skylab. Those activities associated with gross body motion (subject restrained) and translation, simulated by Murrish and Smith, indicated poor correlation with T-013 results. The on-orbit force levels exceeded the simulated force levels by at least a factor of two. Analysis by Conway (ref. 11) showed that the discrepancy arises from the increased limb and torso velocities attained by the subjects during on-orbit activities (Conway noted that T-013 translation velocities were as much as two times the velocities measured during the ground simulations, and that limb motions showed a 35 percent increase compared to ground simulation predictions).

Console operations, as expected, produced the lowest forces and agreement with ground simulation data was very good. Hendricks and Johnson (ref. 12), Murrish and Smith conducted stochastic (deep breathing, console operations, coughing and sneezing) activity simulations using an FMU similar to that used in T-013. In brief, most of the low-level restrained motions were performed on mockups for console activities or hygiene functions, and after careful comparison of their results with the results collected from T-013, excellent correlation was evidenced. Thus motions necessary to personal hygiene, meal preparation, and console operations are considered stochastic and Kullas (ref. 13) feels that they are aptly represented using stochastic models. However, Conway noted that use of the T-013 flight data would be a more accurate 'model'.

Table 2 lists the peak forces for various activities collected from the MDAC MORL ground simulation, the pre T-013 ground simulations and the T-013 flight experiment. Table 3 lists summary data for all of the T-013 activities investigated. General conclusions derived from experiment T-013 by the principal investigator follow:

1) The Skylab APCS experienced significant disturbance inputs as a result of the T-013 activities.

2) In general, the forces generated were higher than those predicted from pre-flight ground simulations.

Table 2: CREW ACTIVITY & MOTION PEAK FORCES (LBS)

	MDAC/MORL	GROUND SIM (PRE T-013)	T-013
CONSOLE OPERATIONS	13.0	4.0	9.4
RESPIRATION EXERCISES	N/A	20.0	48.6
ARM MOTION	4.0	1.5	35.3
LEG MOTION	7.6	10.0	28.2
ARM FLAPPING	N/A	8.0	82.4
FORCEFUL THRUST	110.0	N/A	99.7
SOARING	350.0	10.0	77.3

TABLE #3
EXPERIMENT T-013 SUMMARY DATA
MAXIMUM VALUES

ACTIVITY	FORCE (lbs)			MOMENT (ft-lb)			PSD (lb^2 /htz)			PSD (lb^2 ft^2 /htz)		
	Fx	Fy	Fz	Mx	My	Mz	Fx	Fy	Fz	Mx	My	Mz
Respiration Exercises	12.73	47.81	8.95	9.35	7.92	13.74	0.11	2.54	0.16	2.74	0.07	0.51
Console Operations	7.54	7.26	3.03	11.32	5.21	10.02	0.79	0.32	0.54	8.89	0.51	4.10
Normal Body Exer:												
Arm Motion	5.80	33.56	12.02	8.20	7.74	6.20	0.19	5.21	0.83	0.99	0.65	0.38
Leg Motion	23.05	24.63	13.25	6.93	6.02	11.12	6.35	5.56	2.54	1.81	0.51	1.61
Bowing	17.73	52.12	8.68	19.04	9.36	6.51	1.21	155.58	3.94	34.19	0.55	1.71
Swaying	12.12	27.50	27.54	32.57	32.57	25.14	0.67	16.51	21.59	68.38	5.13	31.45
Gross Body Exer:												
Arm Flapping	14.71	88.96	28.18	21.64	8.97	11.55	0.41	165.11	10.16	5.81	0.24	1.16
Forceful Thrust	29.33	99.70	14.55	22.82	18.84	8.48	5.14	190.51	7.46	30.77	2.05	2.74
Oneman Soaring:												
Normal	18.53	69.51	27.42	23.18	11.86	19.37	2.86	34.93	2.06	11.62	1.30	5.47
Forceful	16.04	65.25	15.30	19.38	10.92	16.94	2.54	39.69	2.00	11.62	0.75	5.13
Twoman Soaring:												
Normal	13.54	64.03	14.17	19.73	11.26	16.21	1.17	50.80	2.16	19.49	0.62	4.79
Forceful	30.57	77.12	35.13	25.40	16.09	30.78	6.99	47.63	4.13	14.36	1.71	21.88

TABLE #3 (con't)
EXPERIMENT T-013 SUMMARY DATA
MAXIMUM VALUES

ACTIVITY	FREQUENCY (htz) @MAX PSD			FREQUENCY (htz) @ MAX PSD		
	Fx	Fy	Fz	Mx	My	Mz
Respiration Exercises	0.32	1.91	1.91	0.16	0.40	0.27
Console Operations	0.19	0.32	0.16	0.16	0.32	0.19
Normal Body Exer:						
Arm Motion	0.40	1.59	1.59	0.16	0.70	0.32
Leg Motion	0.92	1.40	0.92	0.40	0.51	1.40
Bowing	1.11	0.72	1.11	0.38	0.32	1.11
Swaying	0.16	0.32	0.32	0.13	0.13	0.16
Gross Body Exer:						
Arm Flapping	0.80	1.64	1.64	1.27	0.80	0.67
Forceful Thrust	0.80	0.99	0.37	0.37	0.95	0.32
Oneman Soaring:						
Normal	0.40	0.32	0.40	0.32	0.40	0.32
Forceful	0.51	0.80	0.70	0.19	0.32	0.40
Twoman Soaring:						
Normal	0.40	0.48	0.48	0.19	0.32	0.32
Forceful	0.32	0.38	0.32	0.19	0.32	0.32

3) The lack of 1-g restraint is the primary reason for the higher forces and velocities experienced.

4) Pre-flight locomotion capability study predictions were conservative.

5) The ATM EPCS provided adequate isolation from T-013 activities.

6) Use of the T-013 data is feasible for future multi-man crew spacecraft disturbance analyses.

7) Use of the T-013 data to develop a family of flight-verified CA/M models could prove useful for future spacecraft ACS design and analysis.

IV. CA/M Modeling Techniques

Prior to Experiment T-013, it had been realized that many of the low-level CA/M disturbances are stochastic in nature. The types of CA/M considered to be stochastic, or stationary random processes, are console operations, respiration, personal hygiene, etc. Realization of the above CA/M's stochastic nature came as a result of a search by investigators for a more convenient technique of incorporating CA/M forcing function data into a spacecraft dynmamic simulation. The lack of convenience was found to be in the necessity of recording the data from a physical simulation on analog or digital tape and then continuously feeding the data from the tapes into the spacecraft dynamic simulation programs, along with the inherent tape handling problems associated with computers of that era.

After Murrish and Smith had demonstrated the stationarity of their ground simulated console operations data, Hendricks and Johnson generated PSD curves of the data and set about synthesizing the digital filters to approximate the calculated PSD curves. Once the filter parameters were synthesized, they used a random number generator to drive the filter and generated PSD curves that were close approximations to the actual curves generated from the simulation data. They noted that because their approximation was made in the frequency domain, that one should not expect to see a similar forcing function generated for the time domain, once the inverse Fourier transform is completed.

For deterministic, or discrete, CA/M forcing function data, the sound approach is to use actual flight data, if it exists, as suggested by Conway and Kullas. If the analysis has a 'first-cut' flavor, then the investigator can employ a 'first order' model, which is an approximation of the actual time domain data, taking care to use peak force values.

After reviewing the above discussion, it seems logical and practical to employ the flight experiment forcing function data directly as input for time domain analysis routines where possible. Stochastic modeling techniques were desirable and convenient because of the logistics involved in handling large amounts of data, via magnetic tape on relatively 'weak' computers. However, with database management techniques used on computers capable of handling large amounts of I/O it seems prudent to use the actual flight data for both the stochastic and discrete CA/M disturbances.

V. Development of 'CREW'

The forcing function database was formed from all of the activities investigated during the flight experiment T-013, once the data tapes were acquired from NASA/GSFC. The experiment was conducted in a continuous manner, and after ground processing, all results were stored in one stream, requiring a breakdown of each event. The data from the tapes was broken down into the selected activities by following a chronological list of events for DOY 228 of the Skylab 3 mission. The data was seperated for each activity at its given start and stop time, as instructed by Conway.

For use with the pre-processor, the activities in the database are divided by physical description into three categories. The three categories are: 1 - respiration exercises (subject restrained), 2 - body movements (subject restrained), and 3 - soaring events.

The soaring portion of the experiment covered a larger time span, requiring breakdown into individual soaring events. Each of the four types of soaring were broken down into separate pairs involving a kickoff and the following landing (It should be noted that during experiment T-013, FMU #2 experienced a failure during a 'vigorous landing' by the test subject, thus the soaring data pairs were formed from FMU #1 data only). A section of the database contains the entire time span of each soaring category as one element for future use. One kickoff and landing pair was selected from each type of soaring as a representative example for analysis purposes.

The forcing function data is stored at a frequency of 10 Hz (unchanged from the original NASA/MSFC post-flight T-013 reduction effort) with six measurements pertaining to the three forces and three moments. An explanation of the data breakdown and force and moment plots for all T-013 CA/M activities are available in the 'CREW' User's Guide (ref. 14).

The major purpose of the menu-driven pre-processor is to build forcing function input files in the necessary format for dynamic analysis of a particular structural model. The program can output forcing function input formats for the following analysis routines: 1 - TRAP (Transient Response Analysis Program developed and used by JSC ES4), 2 - FRISBE (also developed and used by JSC/ES4), and 3 - NASTRAN. All three formats require similar user inputs which are: length of time for forcing function output file, requested activities (the number of selections is currently limited to five but can be increased), starting time, model node point (location), scaling values, and forcing function directions for each activity. The entire time span of an activity must be used, reduced time ranges are not available and the amount of data for the forcing function output file is limited to 250 seconds at this time. The output is available in both Fortran V and Fortran 77 while the program itself is written in Fortran 77. Output capabilities are discussed in further detail in the 'CREW' User's Guide along with examples.

There are three other options available from the 'CREW' pre-processor which complement the forcing function output routines. A helpful option is FORPLT, a plotting routine allowing the user to see the TRAP or FRISBE output graphically. The entire time span can be seen at once or in smaller time slices to improve clarity. The maximum and minimum force values are provided with the plot as an aid, and the model node point numbers for each forcing function activity are listed in a legend.

The two remaining options pertain to the individual activities of the database. The program allows the user to plot an individual activity, in its entirety, or selected time slices without building an output file. It also allows the user to dump the raw data from the database into a file for observation. Both options are discussed in detail in the User's Guide.

VI. CA/M Disturbance Analysis Example

The following analysis example has a dual purpose: (1) to demonstrate the use of 'CREW', and (2) to demonstrate the potential impact of CA/M on the Space Station microgravity environment. The results presented are preliminary and by no means represent the worst case for CA/M effects on the Station.

One of the expected disturbance sources of CA/M on the Space Station is that of a crew person undertaking a module to module transfer. A logical method for this crew translation would be to 'soar' from one node to another. Because of the fact that the laboratory modules will contain 'micro-g' sensitive payloads and/or experiments, it will be required to determine the vibration environment in those modules induced by CA/M such as a module to module transfer. Other areas of concern, in terms of Station vibration response to this type of CA/M will be the upper and lower booms, radiators, and the solar panels.

For comparison purposes, Station transient response induced by a crew person 'soaring' was generated from the following four different forcing function representations of an astronaut 'soaring':

1) Zero-g aircraft wall pushoff (ref. 11)
2) A first order soaring model used for preliminary CA/M analysis by the Space Station Program "Skunk Works" (ref. 15)
3) Soaring data from 'CREW'; normal force only
4) Soaring data from 'CREW'; all six components

For this analysis, a NASTRAN "stick" model of an early Dual Keel Space Station Configuration was used. The nine-foot deployable truss box-beam structure was represented by single NASTRAN CBAR elements with equivalent section properties (employing the so-called 'continuum' modeling philosophy often used for repeating truss structures). Radiators and solar panels were modeled as massless beams with concentrated masses located at each grid point. The modules and nodes were modeled by distributing one half of the mass in CBAR elements and concentrating the remaining mass at the geometric center of the module or node such that the given inertia properties were replicated.

For economy's sake, all of the NASTRAN runs utilized General Dynamic Reduction (Modified Givens) and modal methods ; extraction of normal modes for a frequency range of 0 to 2 Hz was selected based on an assumption that the error terms associated for the modal superposition method would not be dramatic (frequency content of the induced loads was 0.5 to 1.0 Hz). The analysis proceeded as follows:

1) Normal modes run (NASTRAN SOL 3)

2) Modal transient response (NASTRAN SOL 31), with 1% modal damping, from each type of soaring forcing function

3) Modal frequency response (NASTRAN SOL 30), again assuming 1% modal damping, using normalized force versus frequency from the T-013 normal force PSD (ref. 13) as excitation

From the normal modes run, 72 modes were extracted between 0.0 and 2.0 Hz. (with 51 between 0.0 and 1.0 Hz.). The lowest mode had a frequency of 0.14 Hz. and can be characterized, as expected, as a solar panel mast 'dominated' mode, as shown in Figure 5.

For each of the modal transient response runs, the soaring kickoff and landing were assumed to occur at grids 801002 and 800002, respectively; representing a module to module 'tunnel' transfer between habitation modules 1 and 2; see Figure 6. The kickoff and landing forcing functions are displayed in figures 7 through 9 for each type of soaring investigated. It should be noted that Figure 9 was generated by the program 'CREW', to serve as an example of its preprocessing capabilities.

Table 4 contains maximum acceleration values, in micro-g's, for each of the soaring types at various locations of the Dual Keel stick model; refer to Figures 6 and 10 for the grid point locations. Reviewing the tabulated values leads to the observation that both the zero-g aircraft and the first order model soaring representations yield response levels at least two times smaller in the Y axis direction than the T-013 representation, due to the fact that the peak and peak to peak values for the forcing functions exhibit the

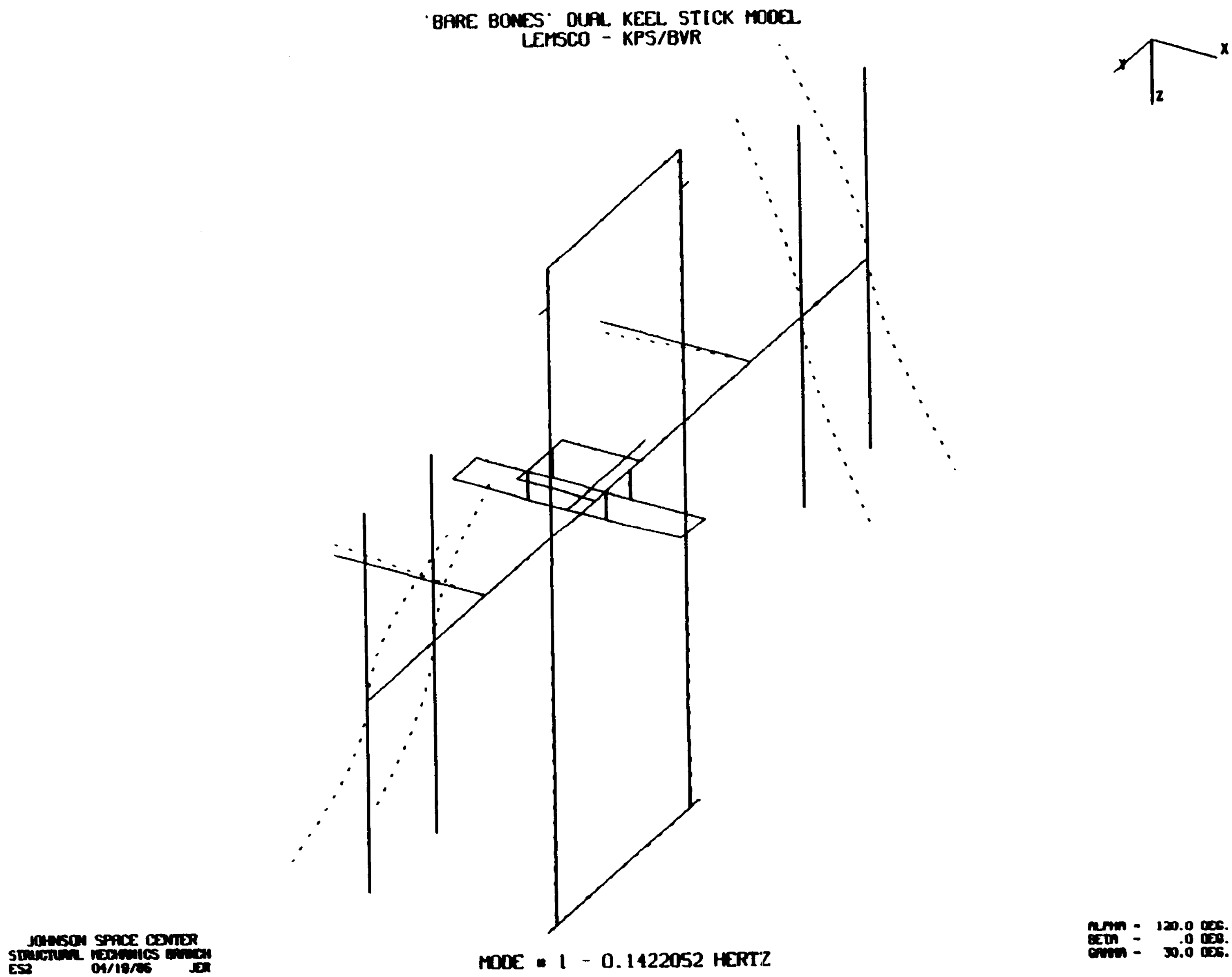

'BARE BONES' DUAL KEEL STICK MODEL
LEMSCO - KPS/BVR
X
Y
Z
JOHNSON SPACE CENTER
STRUCTURAL MECHANICS BRANCH
ES2 04/19/86 JER
MODE # 1 - 0.1422052 HERTZ
ALPHA - 120.0 DEG.
BETA - .0 DEG.
GAMMA - 30.0 DEG.

Figure 5

DUAL KEEL STICK MODEL
SOARING TRANSIENT RESPONSE
MODULE GRID LOCATIONS

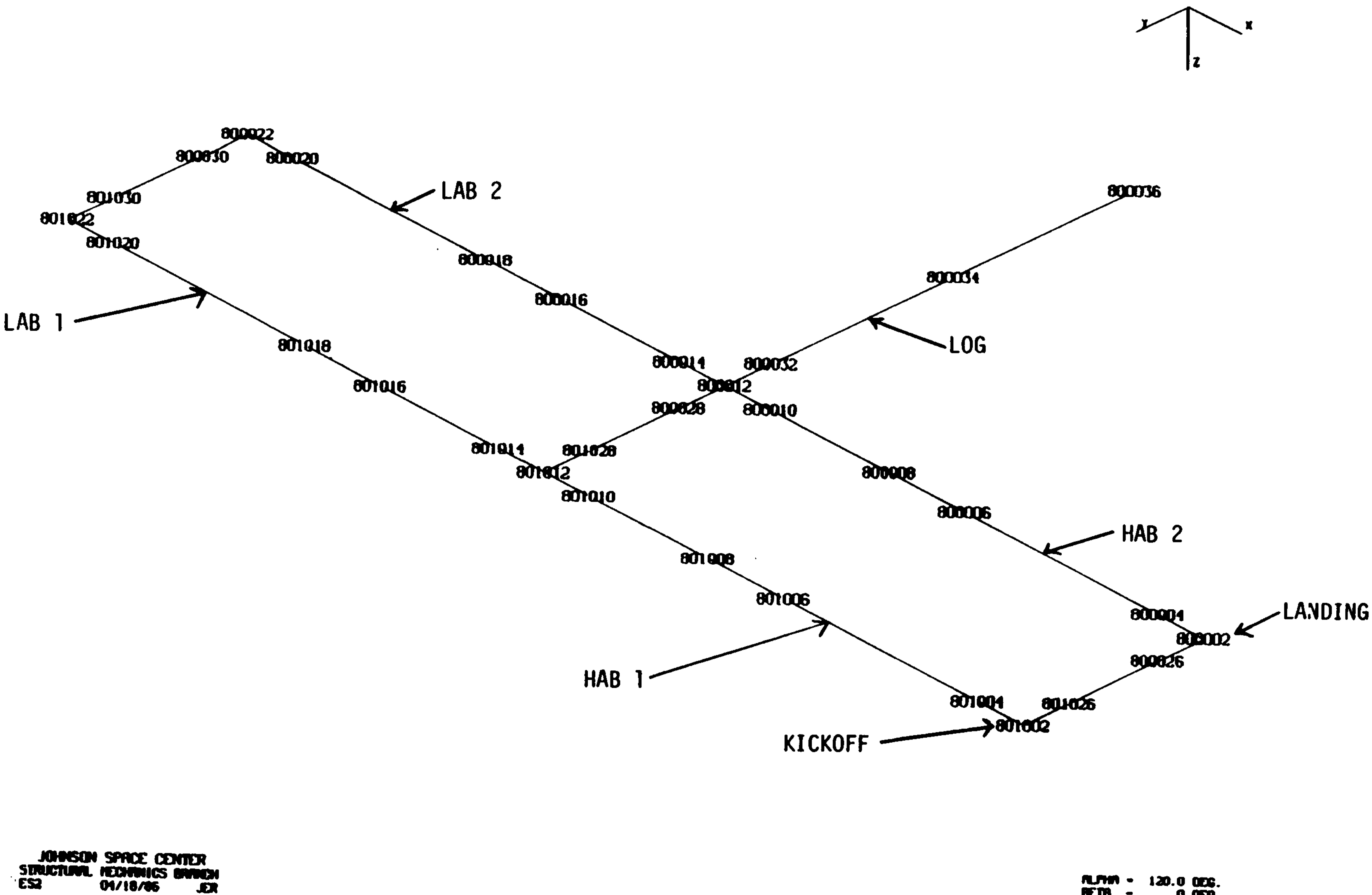


Figure 6

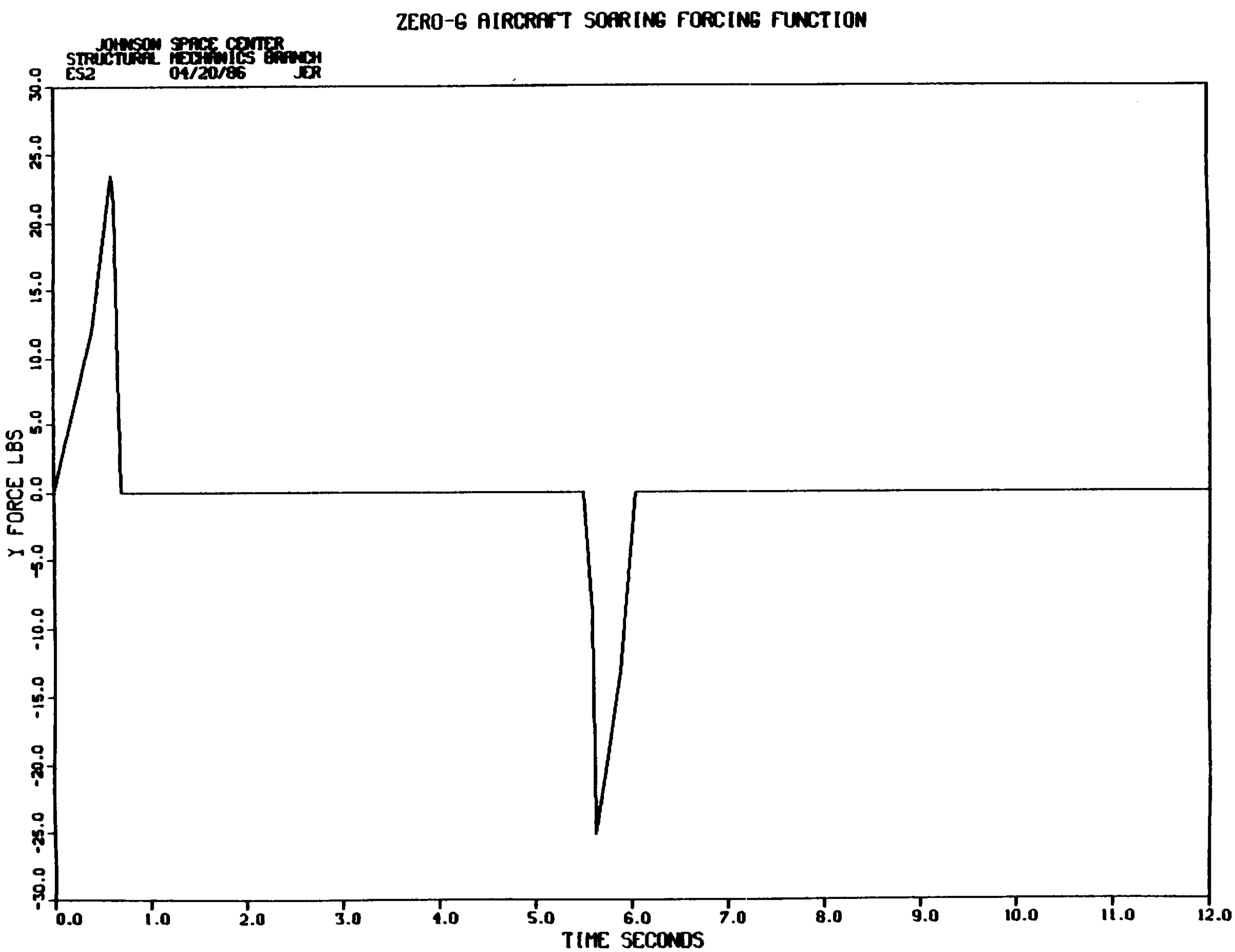

ZERO-G AIRCRAFT SOARING FORCING FUNCTION
JOHNSON SPACE CENTER
STRUCTURAL MECHANICS BRANCH
ES2 04/20/86 JER
Y FORCE LBS
30.0
25.0
20.0
15.0
10.0
5.0
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
TIME SECONDS

Figure 7

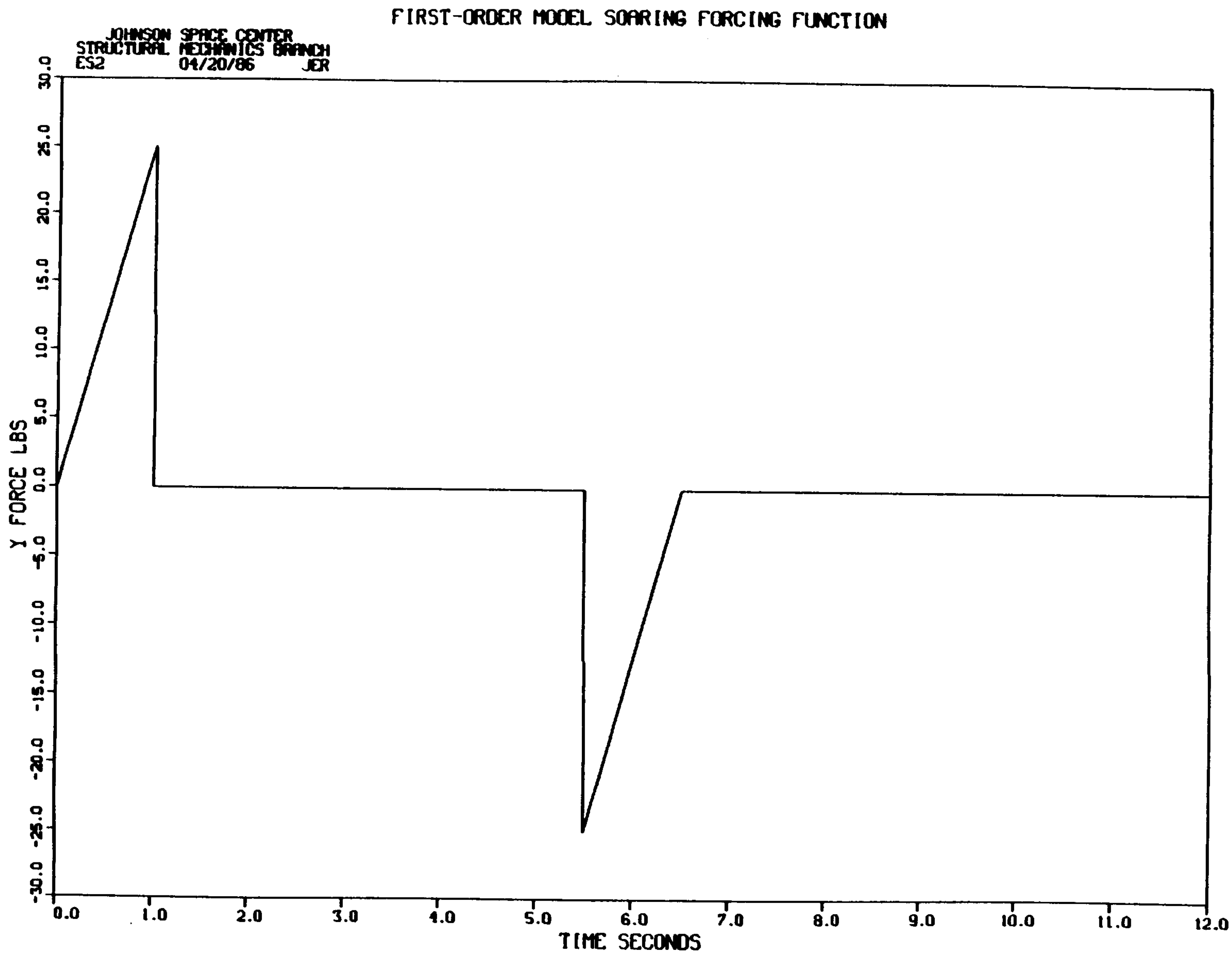
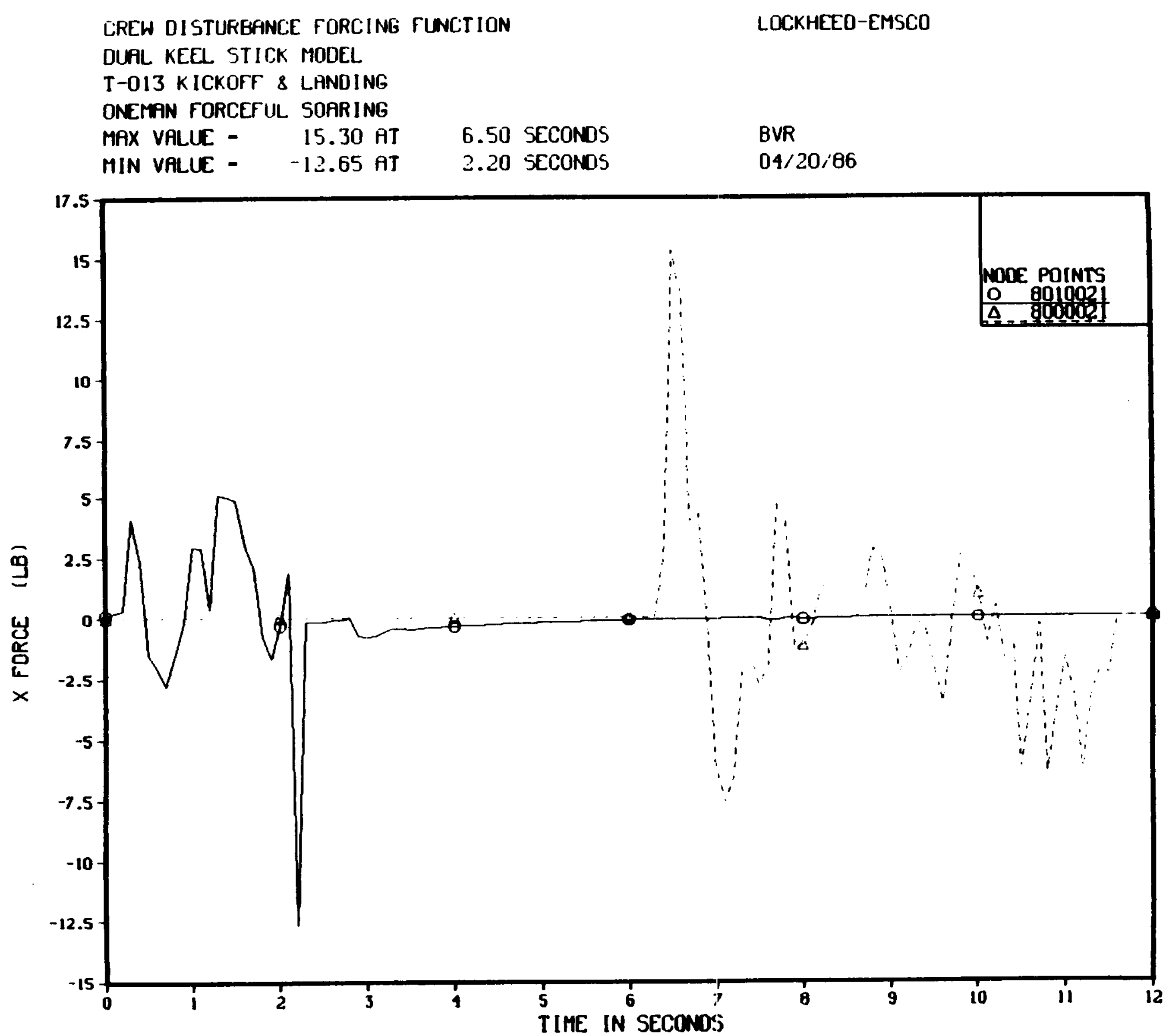

FIRST-ORDER MODEL SOARING FORCING FUNCTION
JOHNSON SPACE CENTER
STRUCTURAL MECHANICS BRANCH
ES2 04/20/86 JER
Y FORCE LBS
30.0
25.0
20.0
15.0
10.0
5.0
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
TIME SECONDS

Figure 8



CREW DISTURBANCE FORCING FUNCTION
DUAL KEEL STICK MODEL
T-013 KICKOFF & LANDING
ONEMAN FORCEFUL SOARING
MAX VALUE - 15.30 AT 6.50 SECONDS
MIN VALUE - -12.65 AT 2.20 SECONDS
LOCKHEED-EMSCO
BVR
04/20/86
NODE POINTS
O 8010021
Δ 8000021
X FORCE (LB)
TIME IN SECONDS
17.5
15
12.5
10
7.5
5
2.5
0
-2.5
-5
-7.5
-10
-12.5
-15
0
1
2
3
4
5
6
7
8
9
10
11
12

Figure 9

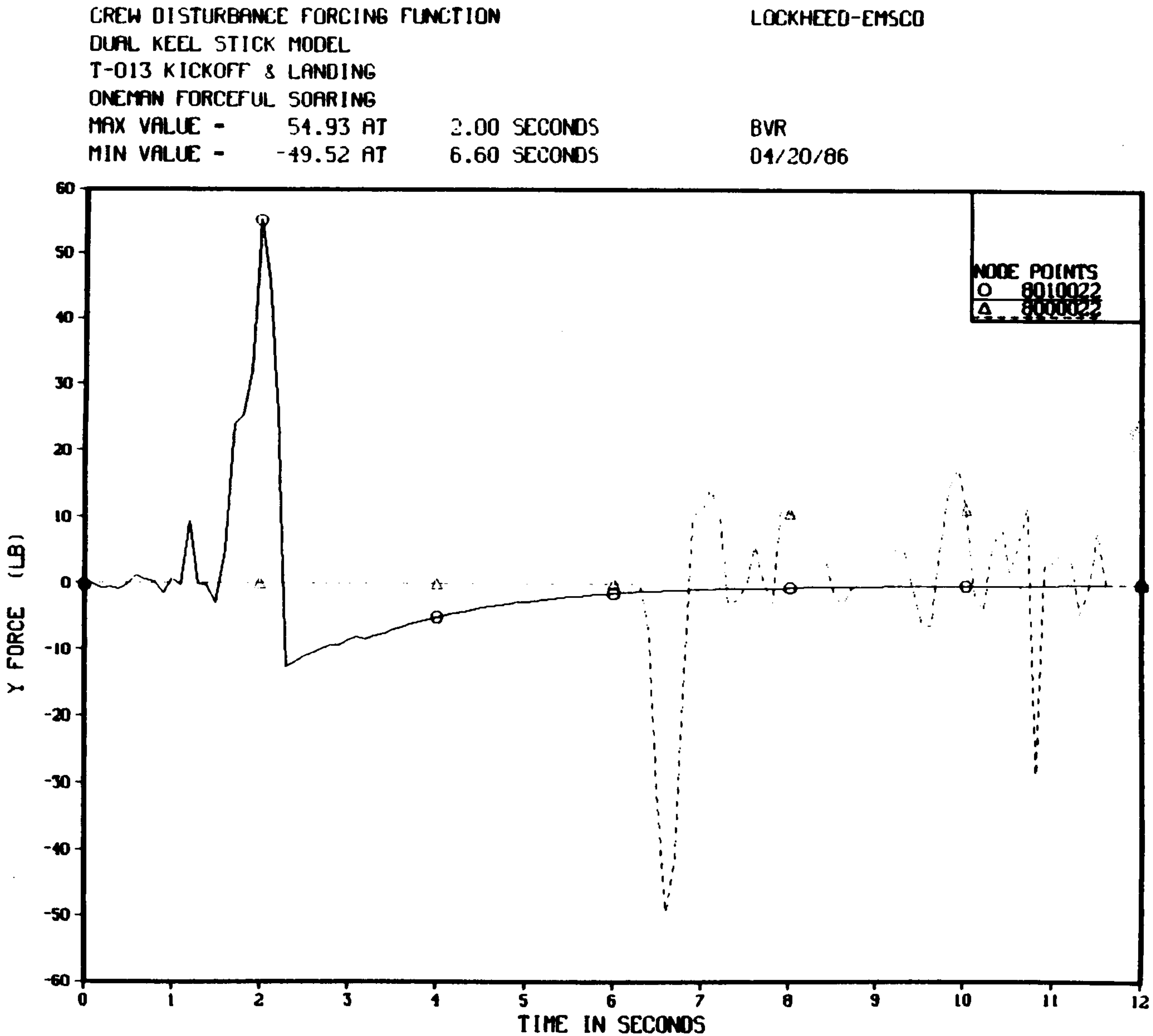


Figure 9 cont.

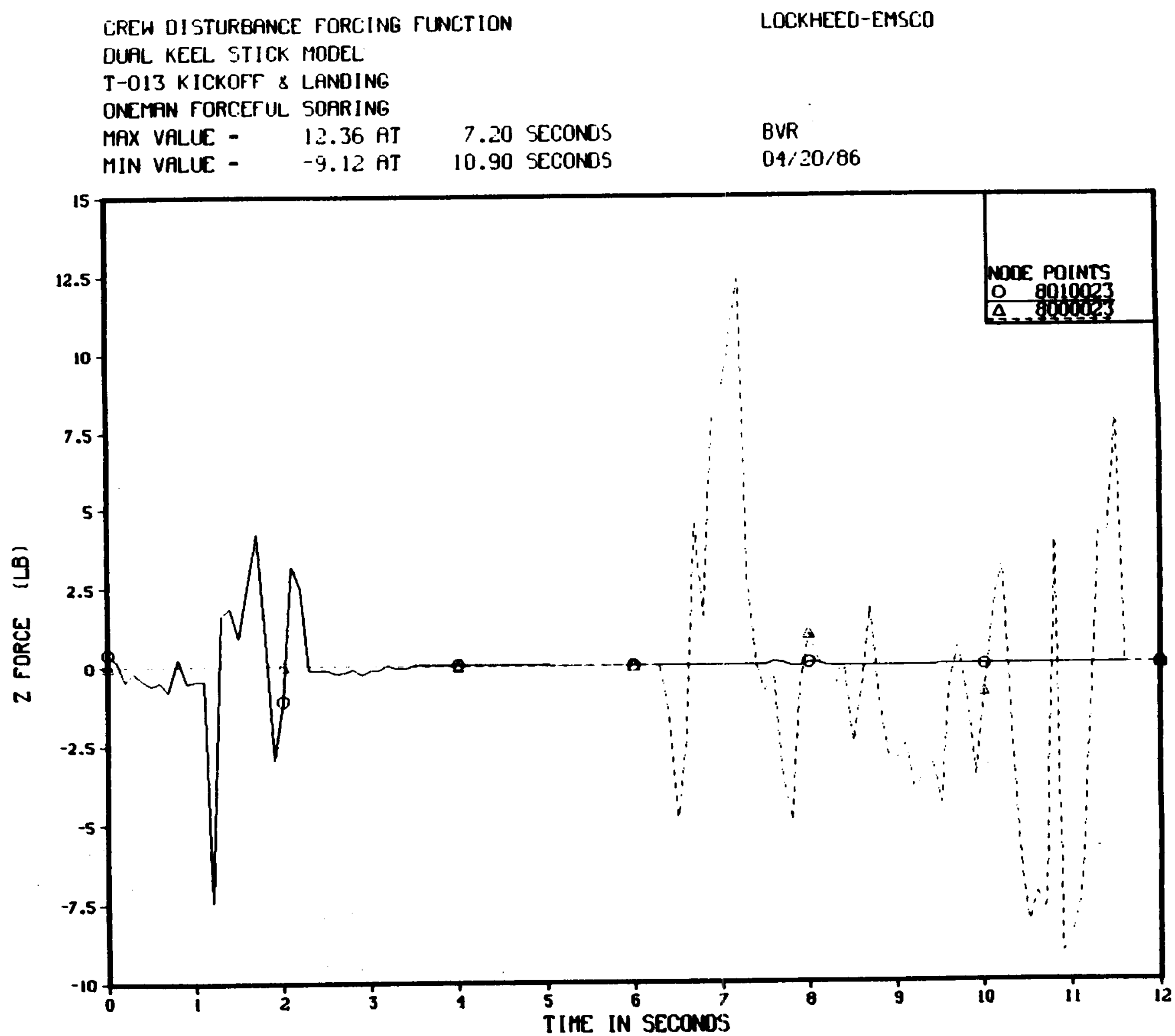


Figure 9 cont.

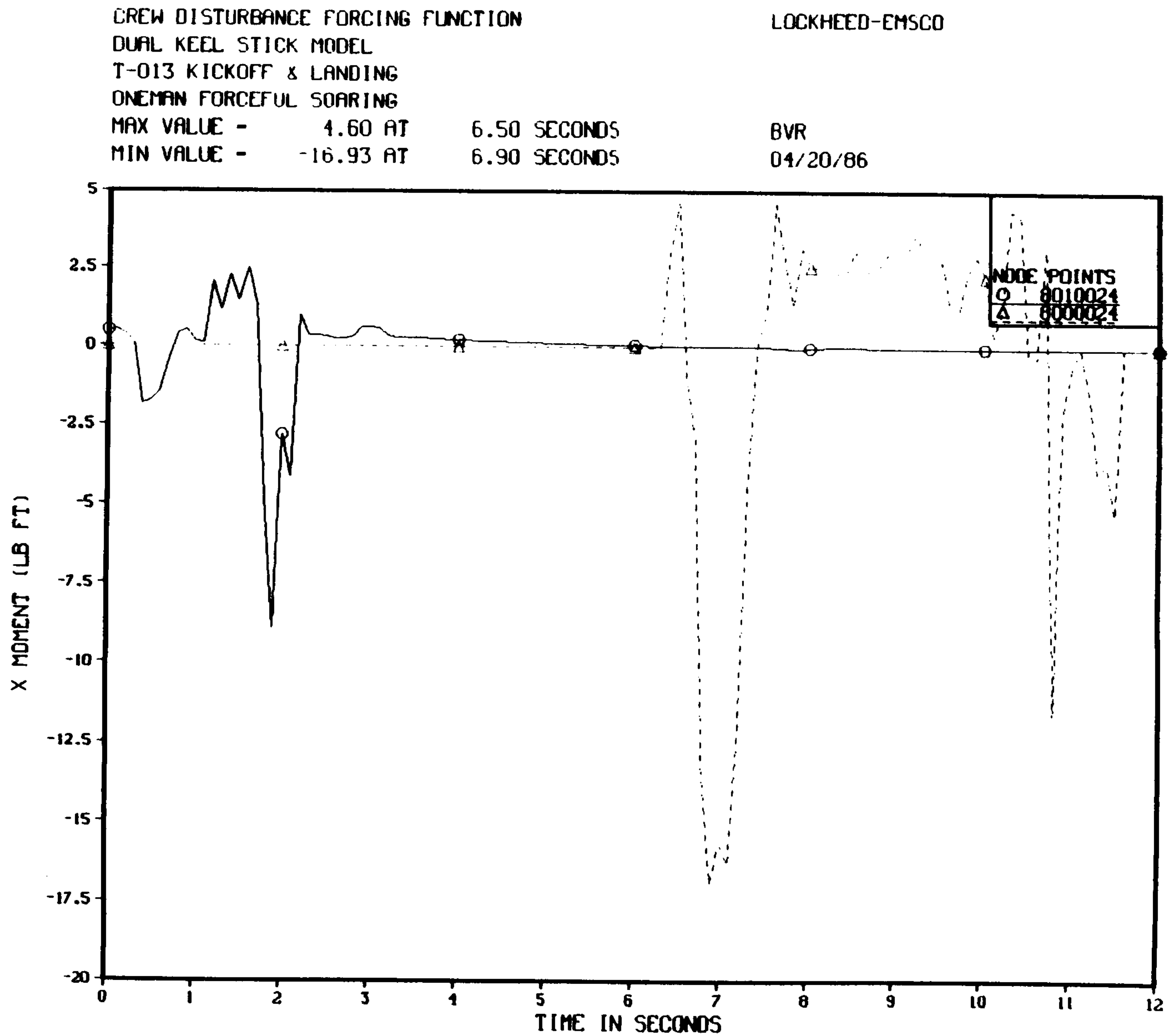


Figure 9 cont.

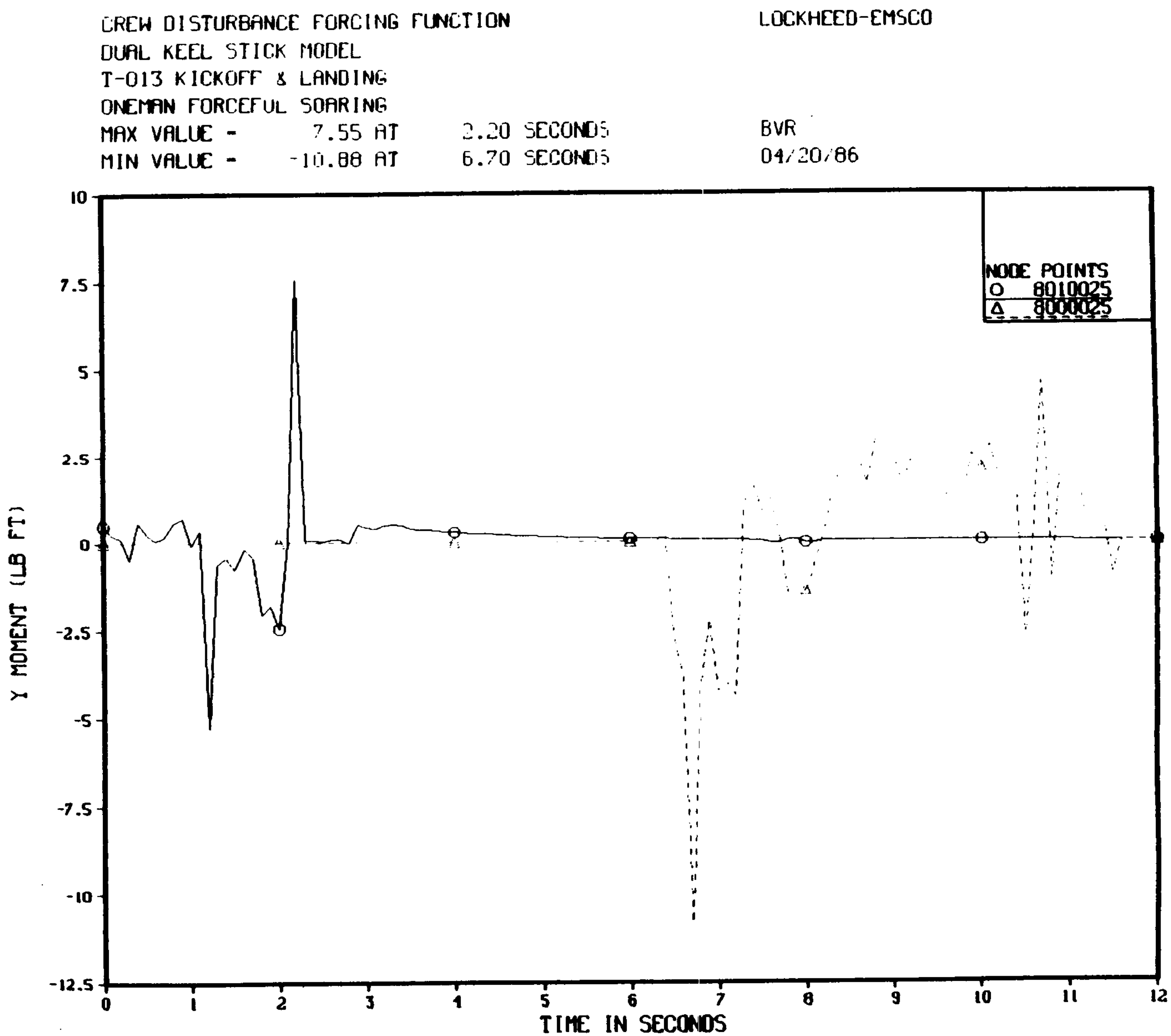


Figure 9 cont.

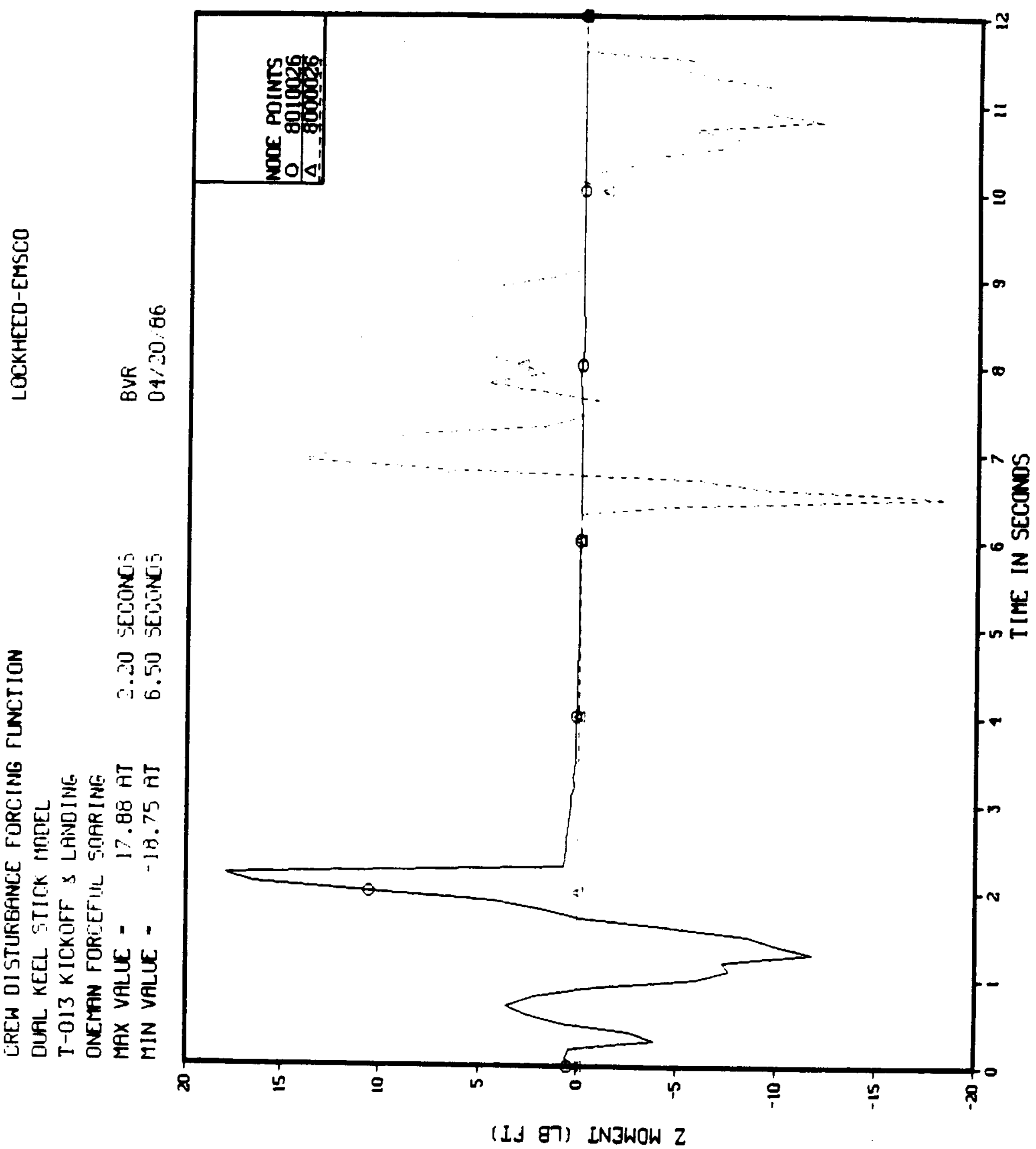


Figure 9 concluded

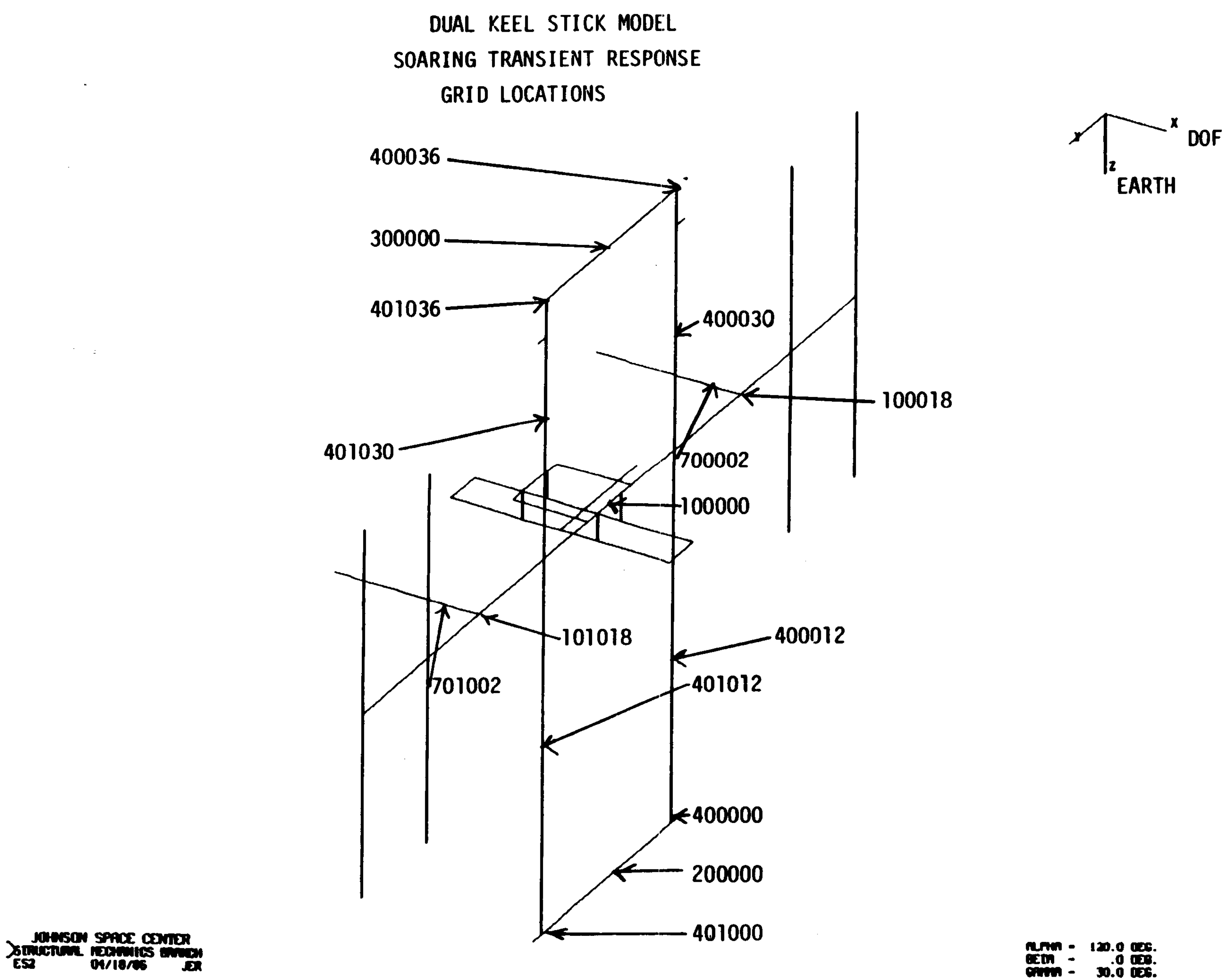

DUAL KEEL STICK MODEL
SOARING TRANSIENT RESPONSE
GRID LOCATIONS
400036
300000
401036
400030
100018
401030
700002
100000
101018
400012
701002
401012
400000
200000
401000
DOF
EARTH
x
y
z
JOHNSON SPACE CENTER
STRUCTURAL MECHANICS BRANCH
ES2 04/18/86 JER
ALPHA - 120.0 DEG.
BETA - .0 DEG.
GAMMA - 30.0 DEG.

Figure 10

TABLE#4
DUAL KEEL 'CREW KO/LAND' RESPONSE
(PRELIMINARY RESULTS)

MAX ACCELERATION (MICRO - G'S)

LOCATION/ GRID	T-013 (ALL)			T-013 (NORMAL ONLY)		
	X	Y	Z	X	Y	Z
TRANSVERSE BOOM						
100000	68.18	344.27	105.24	44.43	347.49	17.72
100018	625.89	343.16	163.96	666.29	346.56	137.72
101018	714.54	343.08	137.73	684.02	346.49	96.37
LOWER BOOM						
200000	538.63	973.83	94.14	52.81	948.27	19.76
400000	1047.21	973.56	125.48	756.63	947.95	58.38
401000	1239.69	973.59	106.44	830.98	947.98	84.99
UPPER BOOM						
300000	295.04	757.31	93.91	133.45	753.19	19.65
400036	1251.72	756.97	128.57	1131.05	752.84	63.62
401036	1134.10	756.87	112.47	1123.09	752.79	88.56
KEELS						
400012	526.93	561.87	127.05	406.40	555.47	60.37
401012	557.49	578.66	109.11	448.97	557.69	86.87
400030	1025.59	677.14	128.58	924.23	671.36	63.13
401030	919.05	672.80	112.32	942.48	669.29	88.60
RADIATOR MASTS						
700002	625.89	329.10	158.17	666.30	332.67	148.40
701002	714.54	336.00	125.67	684.03	335.92	100.86
LAB MODULES						
800014 (2)	66.26	173.83	47.47	60.95	173.28	21.07
801014 (1)	155.34	173.96	55.62	146.80	173.39	45.29
800022 (2)	66.28	495.34	101.49	60.97	488.77	32.00
801022 (1)	155.37	495.35	148.93	146.84	488.77	39.42
HAB MODULES						
800002 (2)	66.27	639.94	215.09	60.97	632.25	7.86
801002 (1)	155.37	639.94	207.95	146.83	632.25	55.06
800006 (2)	66.26	422.41	136.44	60.97	415.16	10.65
801006 (1)	155.36	422.13	134.54	146.82	414.96	48.38
LOGISTICS MODULE						
800032	111.10	213.62	72.30	114.73	212.00	36.99
800036	550.74	213.62	220.34	548.81	212.00	189.50

TABLE 4 (con't)
DUAL KEEL 'CREW KO/LAND' RESPONSE
(PRELIMINARY RESULTS)

MAX ACCELERATION (MICRO - G'S)

LOCATION/ GRID	ZERO-G AIRCRAFT			FIRST ORDER MODEL		
	X	Y	Z	X	Y	Z
TRANSVERSE BOOM						
100000	13.94	166.09	6.97	12.28	122.96	7.41
100018	165.15	164.64	57.56	252.88	122.97	56.29
101018	179.84	164.55	46.22	265.13	122.97	42.83
LOWER BOOM						
200000	17.04	259.01	8.78	22.12	387.00	9.50
400000	341.02	258.91	33.63	207.48	387.87	34.70
401000	368.03	258.92	36.43	220.87	387.88	45.25
UPPER BOOM						
300000	38.32	299.81	8.70	43.02	255.96	9.42
400036	363.19	299.68	35.79	362.68	255.82	37.80
401036	404.44	299.65	38.59	358.84	255.80	48.33
KEELS						
400012	163.55	148.37	34.23	99.29	198.97	35.91
401012	173.51	151.87	37.04	111.16	200.95	46.45
400030	292.24	266.30	35.58	301.06	217.22	37.65
401030	321.96	265.22	38.39	296.61	216.30	48.19
RADIATOR MASTS						
700002	165.15	136.21	63.44	252.88	99.80	50.04
701002	179.84	136.22	47.32	265.13	99.60	46.74
LAB MODULES						
800014 (2)	23.03	80.27	8.39	17.30	86.83	8.95
801014 (1)	51.56	80.39	17.96	41.68	86.91	19.09
800022 (2)	23.04	102.94	12.10	17.31	146.01	12.83
801022 (1)	51.57	102.94	16.82	41.69	146.01	18.09
HAB MODULES						
800002 (2)	23.04	300.00	3.28	17.31	215.59	4.05
801002 (1)	51.57	300.00	21.99	41.68	215.59	23.66
800006 (2)	23.03	199.92	3.56	17.31	156.58	5.53
801006 (1)	51.56	199.73	19.08	41.68	156.40	20.74
LOGISTICS MODULE						
800032	42.35	99.47	14.97	32.64	97.00	16.01
800036	197.63	99.48	79.93	157.26	97.00	86.03

same relationship. For the X znd Z axis directions, the T-013 soaring, with all six components, yields response at least three times greater than the zero-g aircraft and first order model representations. The response in the laboratory modules is assumed to have the highest priority, so Figures 11 through 14 display the transient acceleration response (in micro-g's) at laboratory module one (grid 801022) to each of the soaring types.

For the modal frequency response analysis, a normalized force versus frequency excitation was derived from a PSD of the T-013 one man forceful soaring normal (Y axis) forcing function data; see Figures 15 and 16. The modal acceleration response (normalized) to this excitation at laboratory module one is shown in Figure 17. The X and Y axis response is dominated by modes 16 and 26, while the Z axis response is dominated by modes 26, 27, 34, 35, 49, 54, and 63. These mode shapes are shown in figures 18 through 26, and for the most part are primary structure modes coupled with solar array motion.

In terms of 'accuracy of representation', for the CA/M disturbances, it is believed that the T-013 data is the best because of its 'exact' magnitude and frequency characteristics. Furthermore, the T-013 data should be employed simply because it represents a nominal CA/M disturbance case, whereas the other 'models' probably better represent the middle of the CA/M spectrum in terms of magnitude.

Finally, the preliminary results presented above (T-013 soaring response) are somewhat dramatic; implying that 'a conflict of interest' may exist for a manned Station requiring a pure micro-g environment (based on a 'bare bones' Space Station with the nine-foot truss and having a mass of approx. 300,000 lbs).

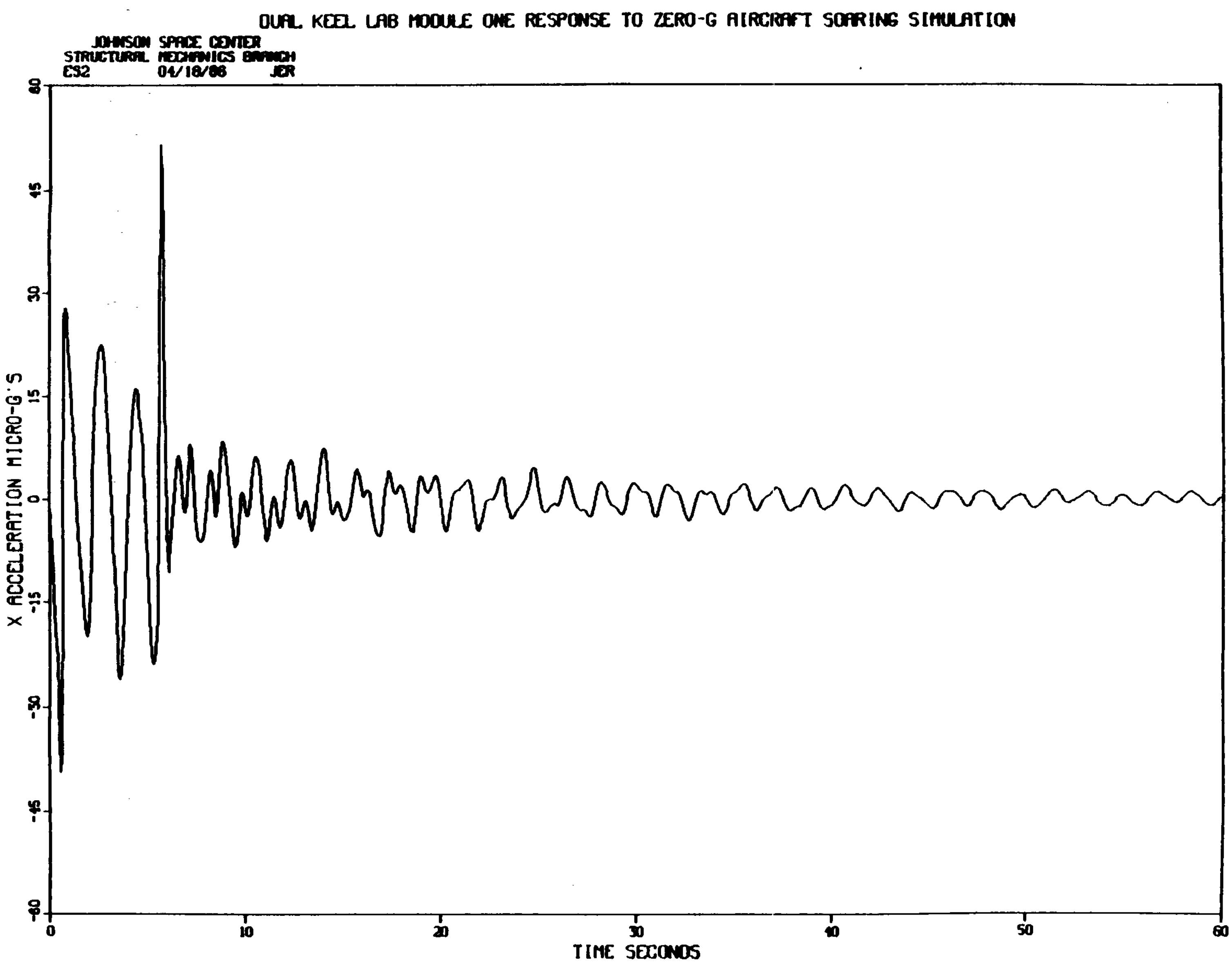

DUAL KEEL LAB MODULE ONE RESPONSE TO ZERO-G AIRCRAFT SOARING SIMULATION
JOHNSON SPACE CENTER
STRUCTURAL MECHANICS BRANCH
ES2 04/18/86 JER
X ACCELERATION MICRO-G'S
60
45
30
15
0
-15
-30
-45
-60
0
10
20
30
40
50
60
TIME SECONDS

Figure 11

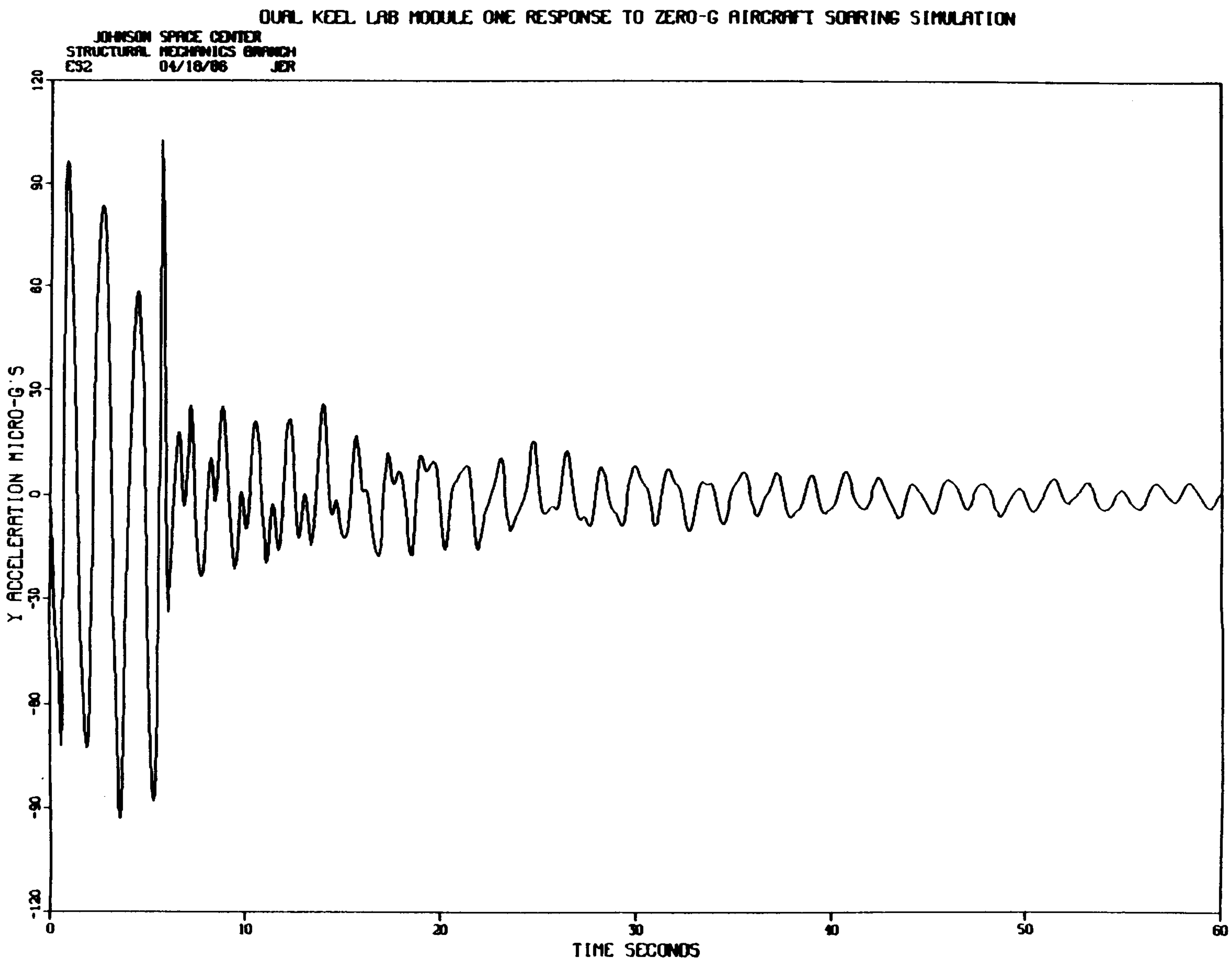


Figure 11 cont.

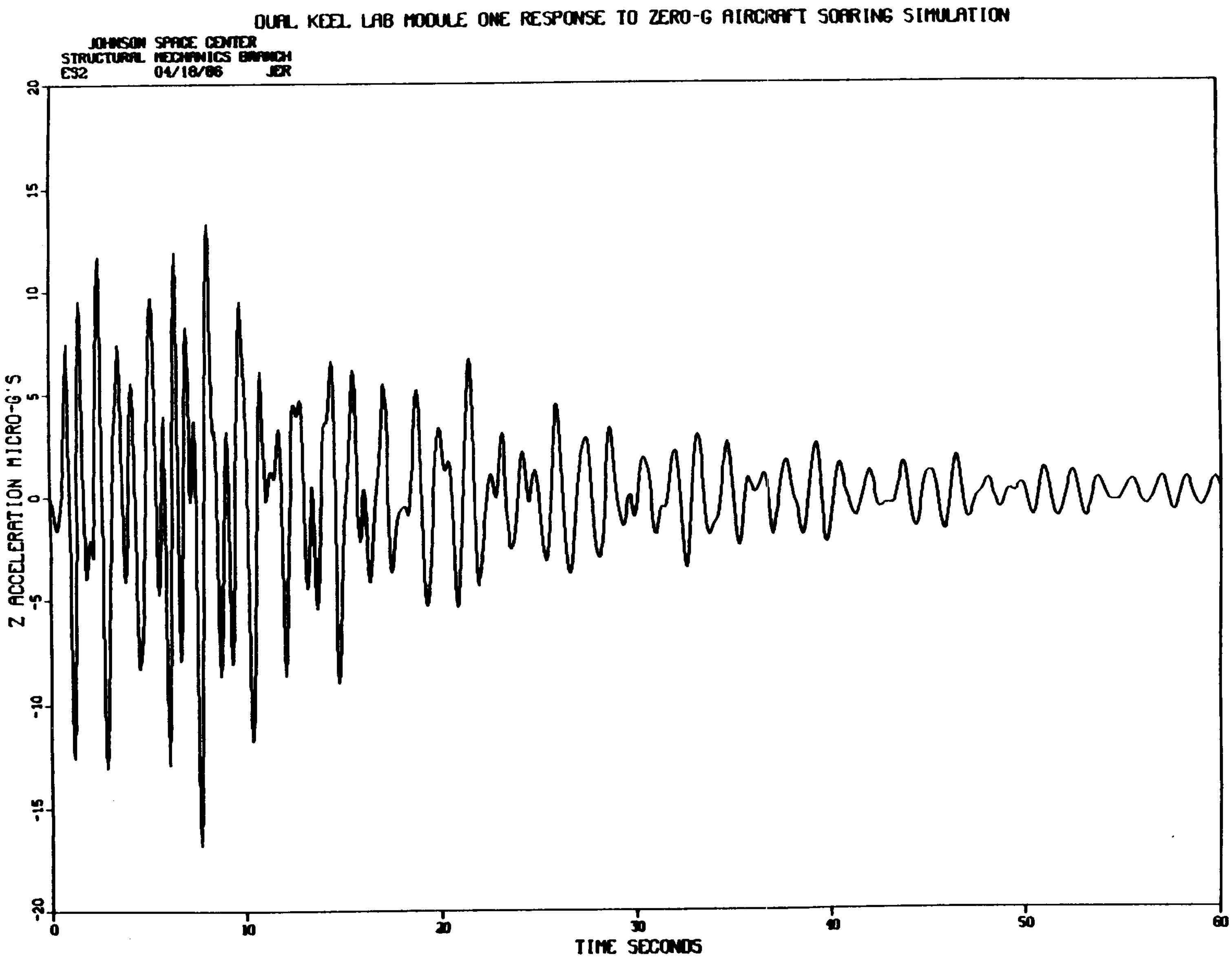


Figure 11 concluded

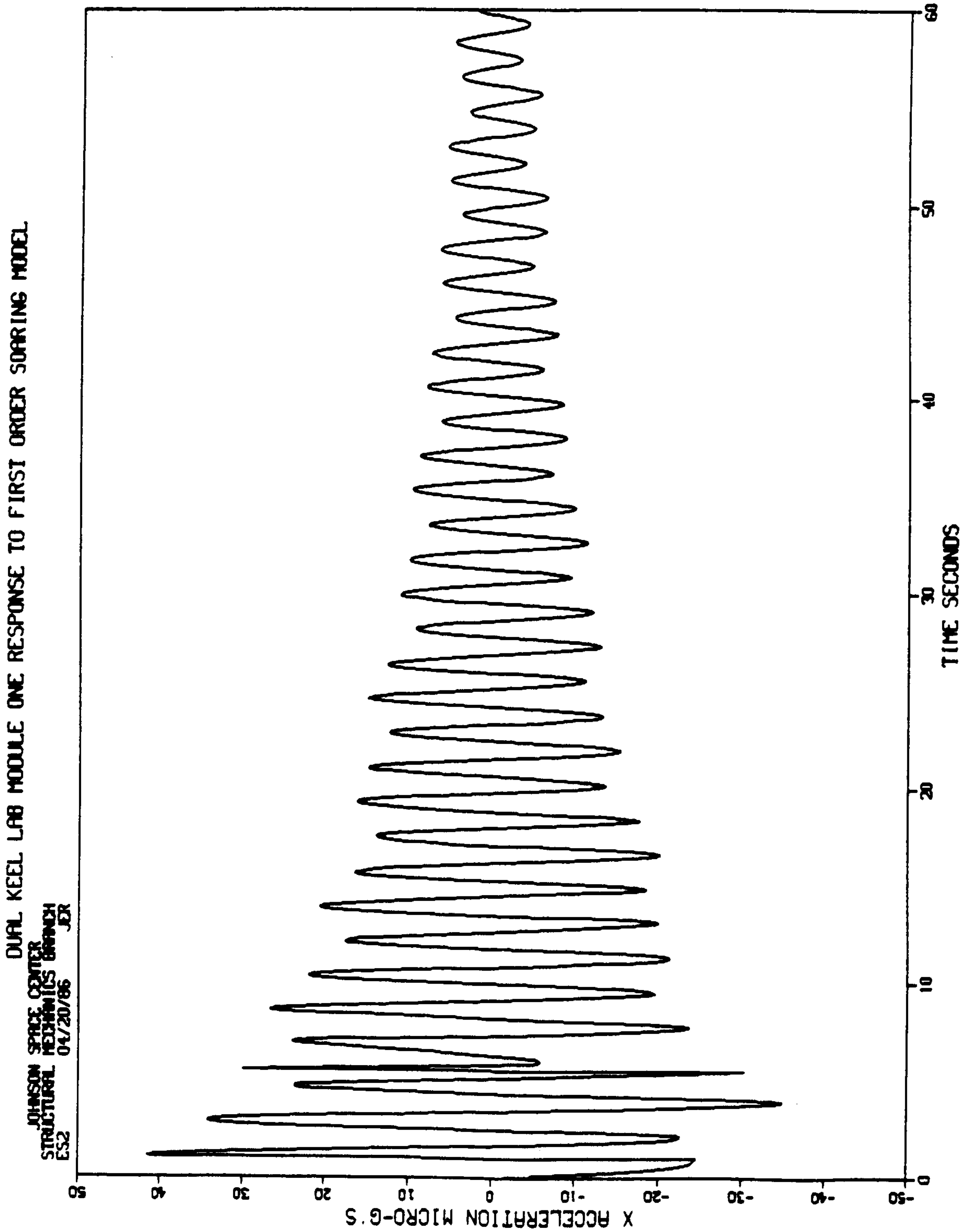

DUAL KEEL LAB MODULE ONE RESPONSE TO FIRST ORDER SOARING MODEL
JOHNSON SPACE CENTER
STRUCTURAL MECHANICS BRANCH
ES2 04/20/86 JER
X ACCELERATION MICRO-G'S
50
40
30
20
10
0
-10
-20
-30
-40
-50
TIME SECONDS
0
10
20
30
40
50
60

Figure 12

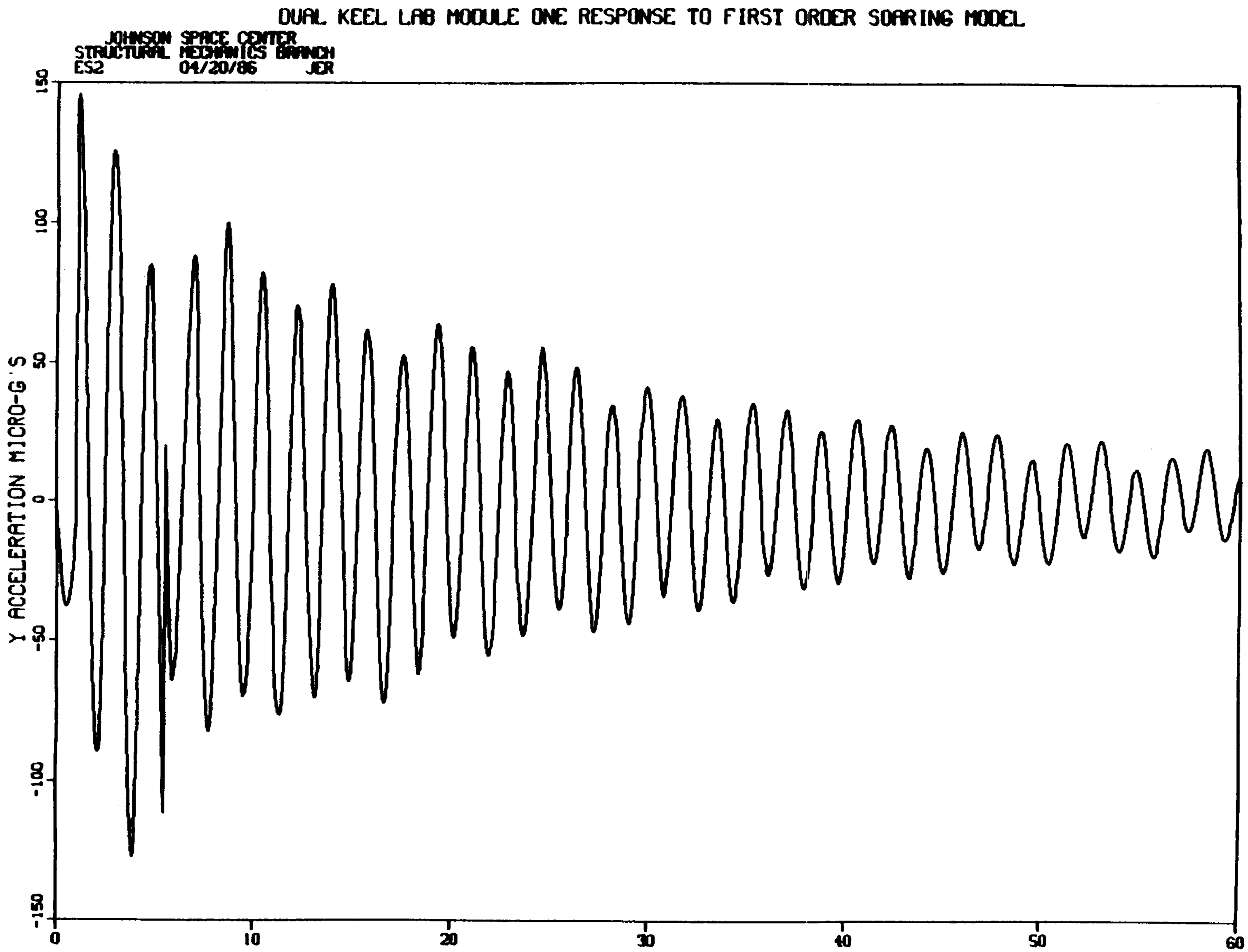


Figure 12 cont.

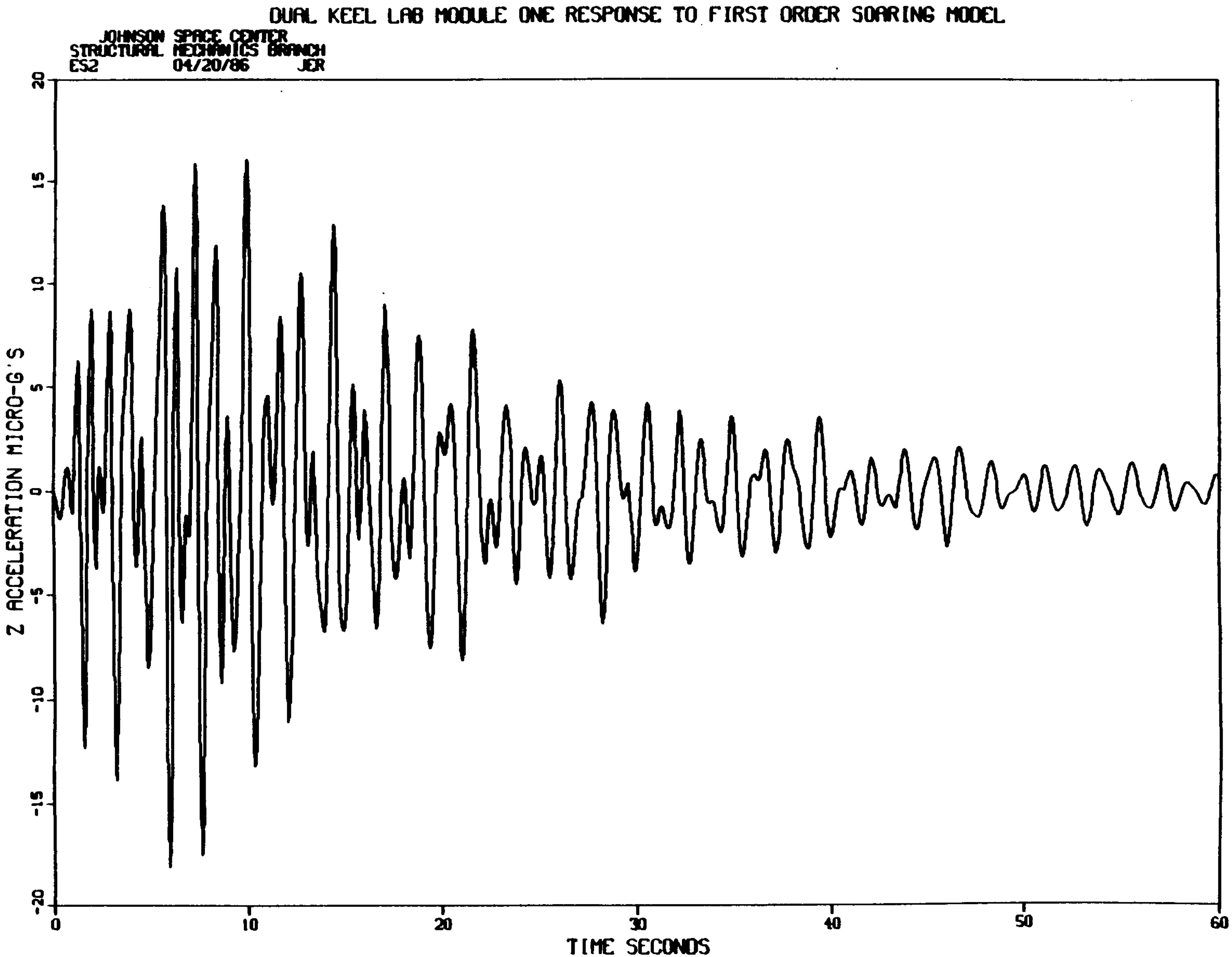


Figure 12 concluded

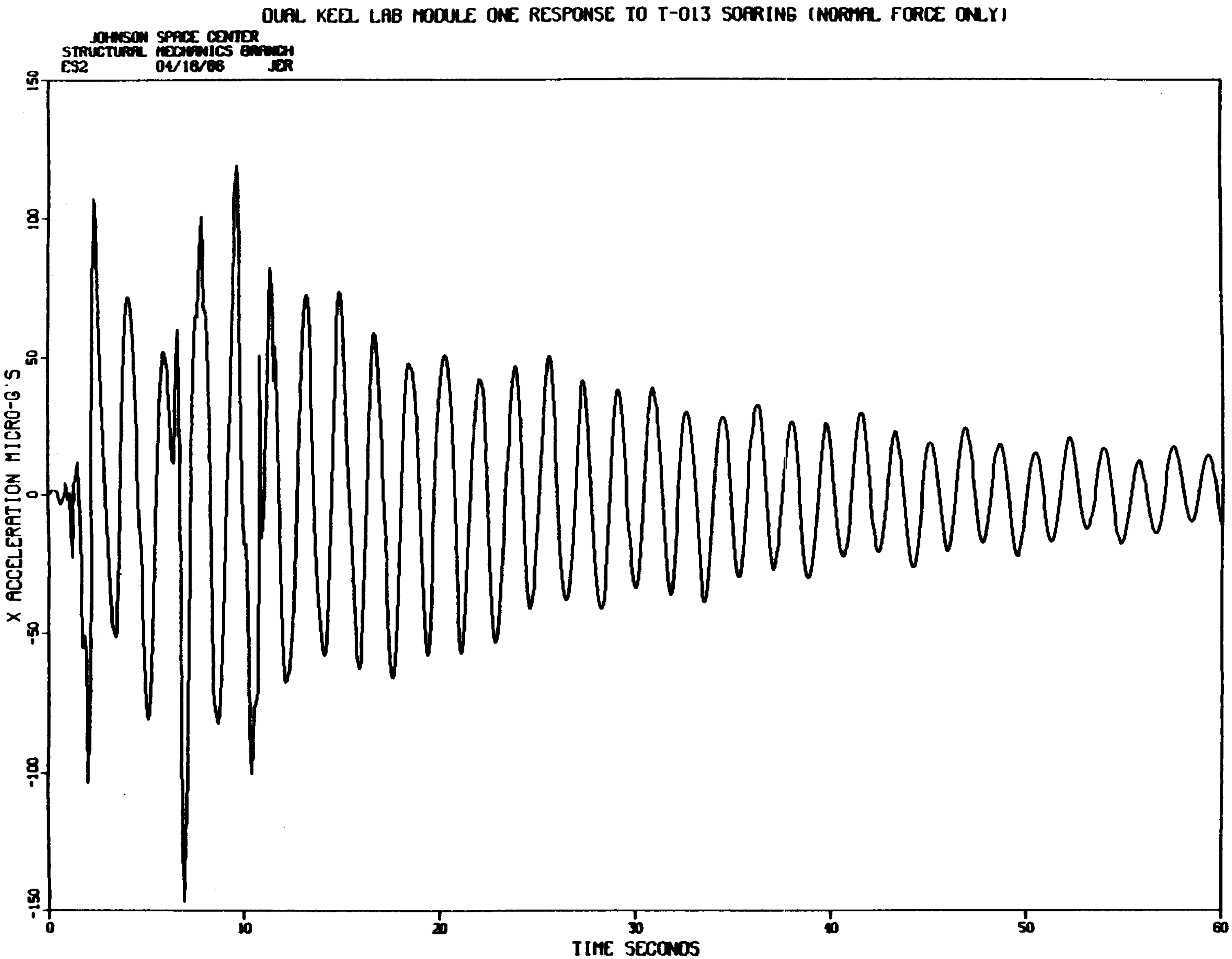

DUAL KEEL LAB MODULE ONE RESPONSE TO T-013 SOARING (NORMAL FORCE ONLY)
JOHNSON SPACE CENTER
STRUCTURAL MECHANICS BRANCH
ES2 04/18/86 JER
X ACCELERATION MICRO-G'S
150
100
50
0
-50
-100
-150
0
10
20
30
40
50
60
TIME SECONDS

Figure 13

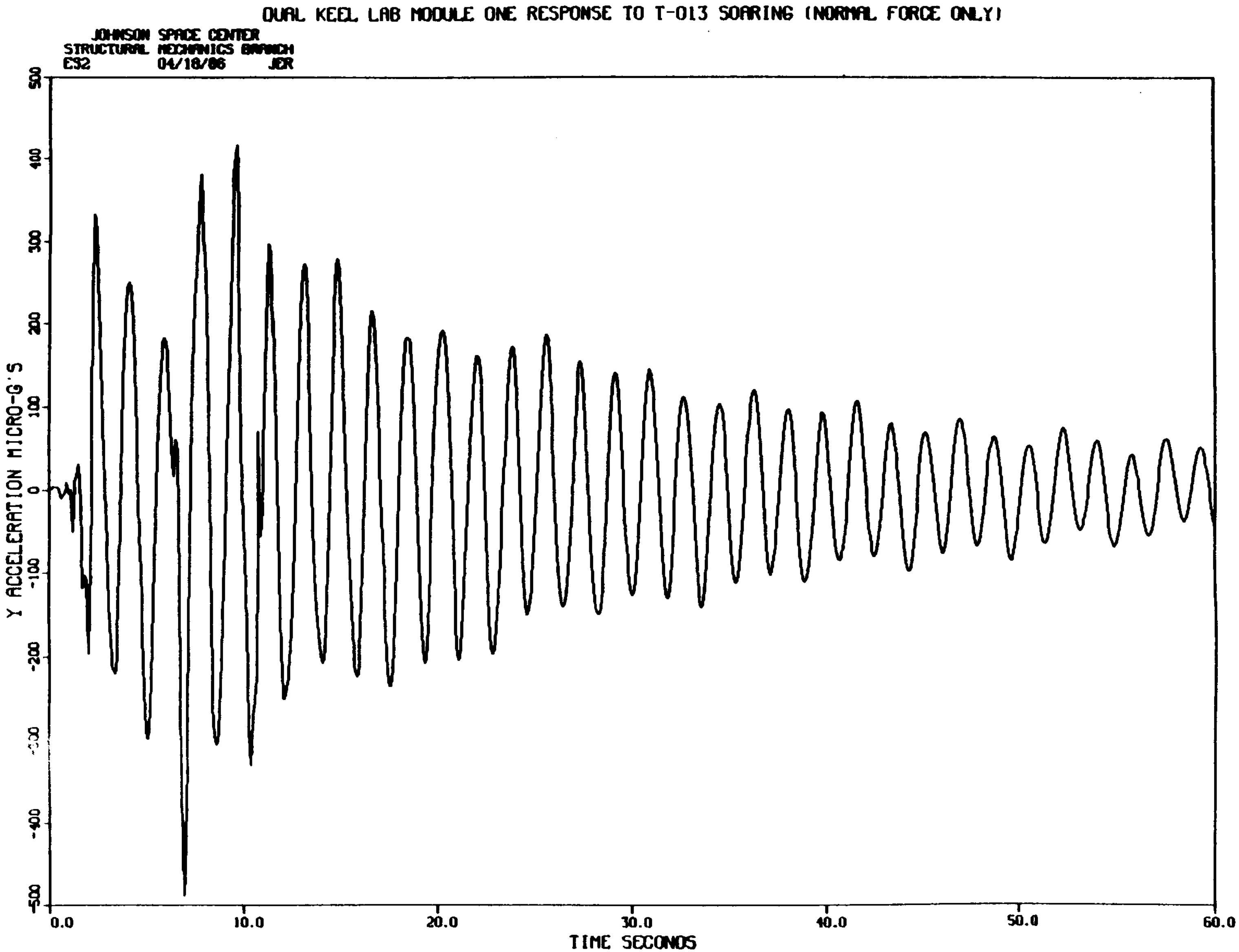


Figure 13 cont.

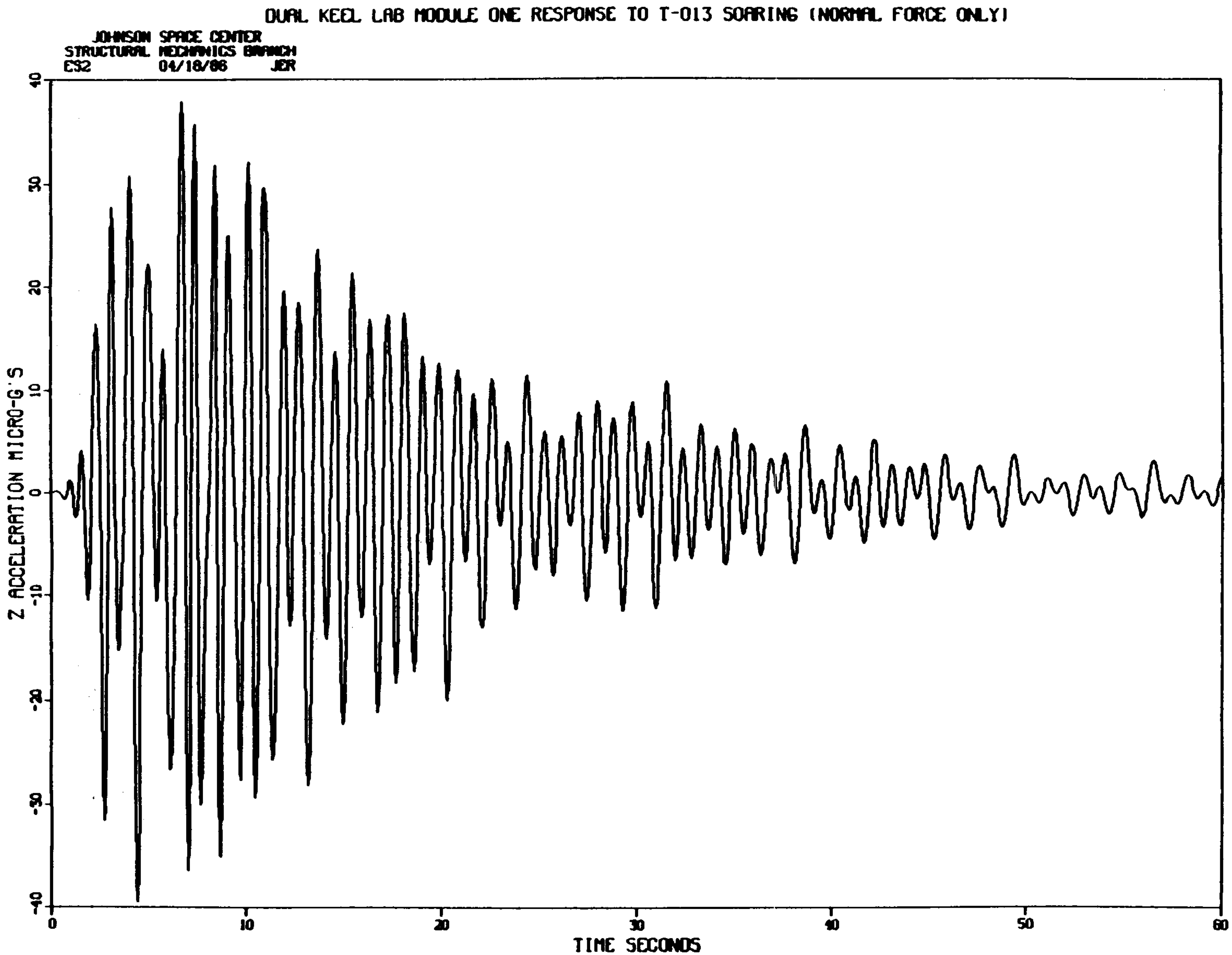


Figure 13 concluded

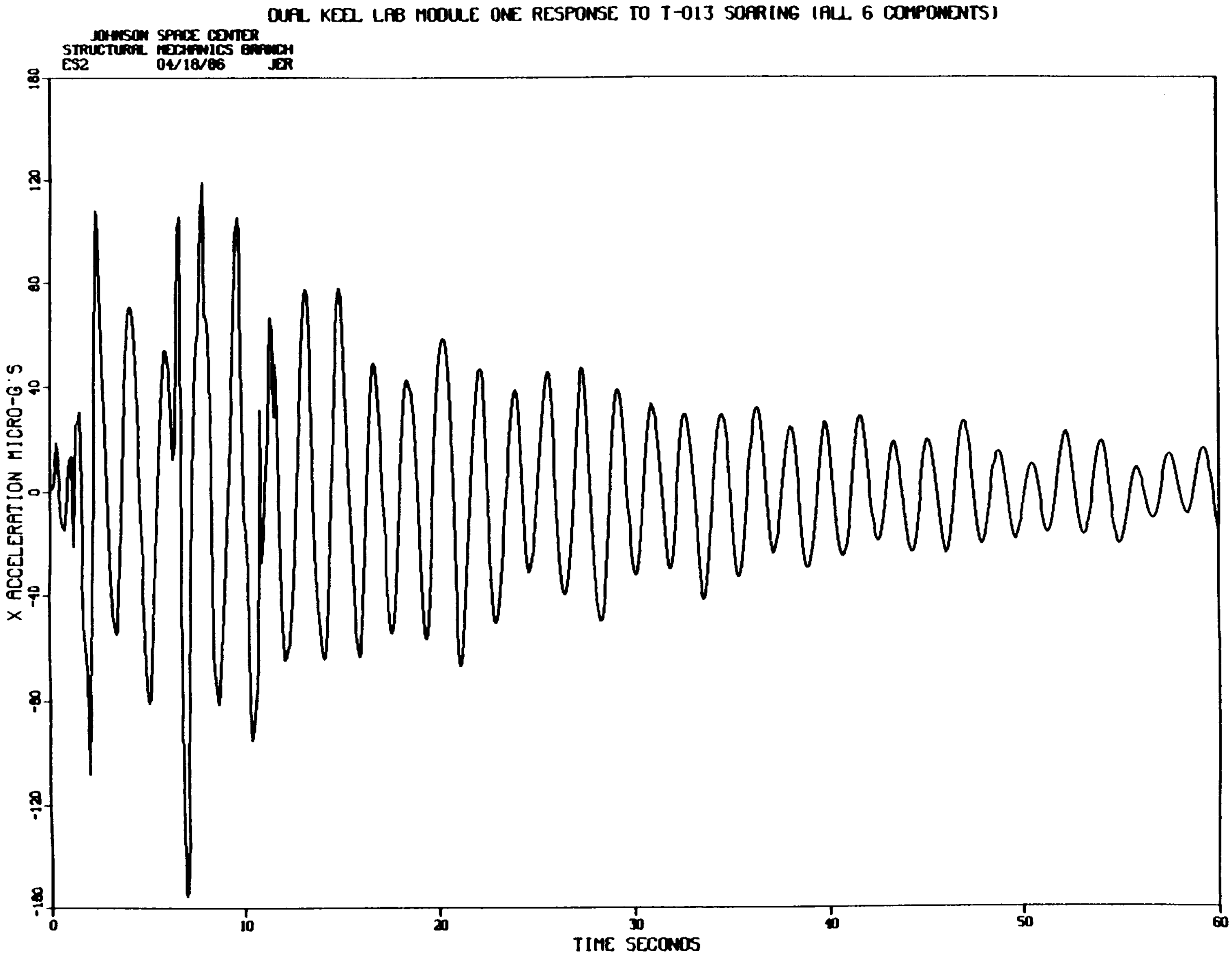

DUAL KEEL LAB MODULE ONE RESPONSE TO T-013 SOARING (ALL 6 COMPONENTS)
JOHNSON SPACE CENTER
STRUCTURAL MECHANICS BRANCH
ES2 04/18/86 JER
X ACCELERATION MICRO-G'S
180
120
80
40
0
-40
-80
-120
-180
0
10
20
30
40
50
60
TIME SECONDS

Figure 14

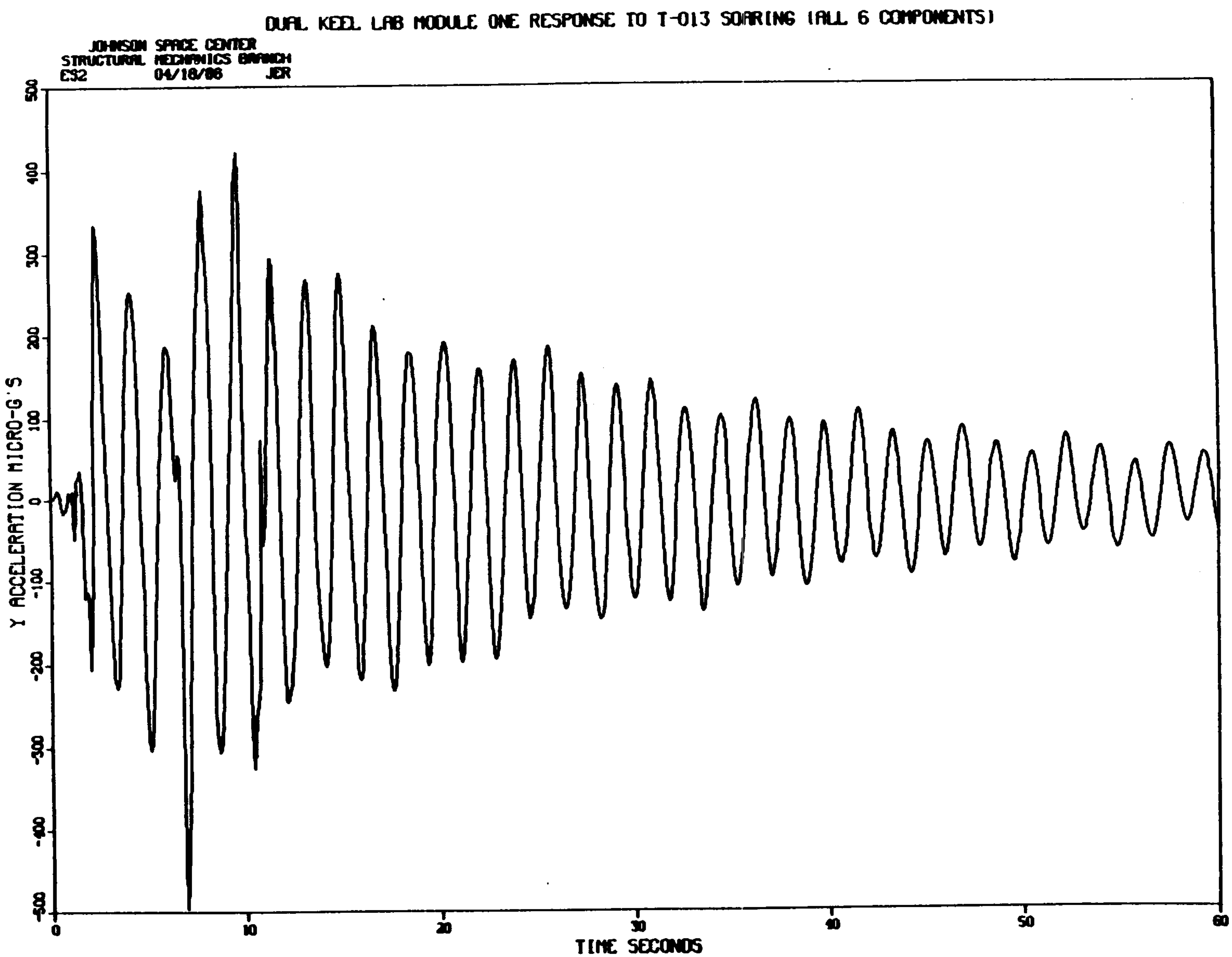


Figure 14 cont.

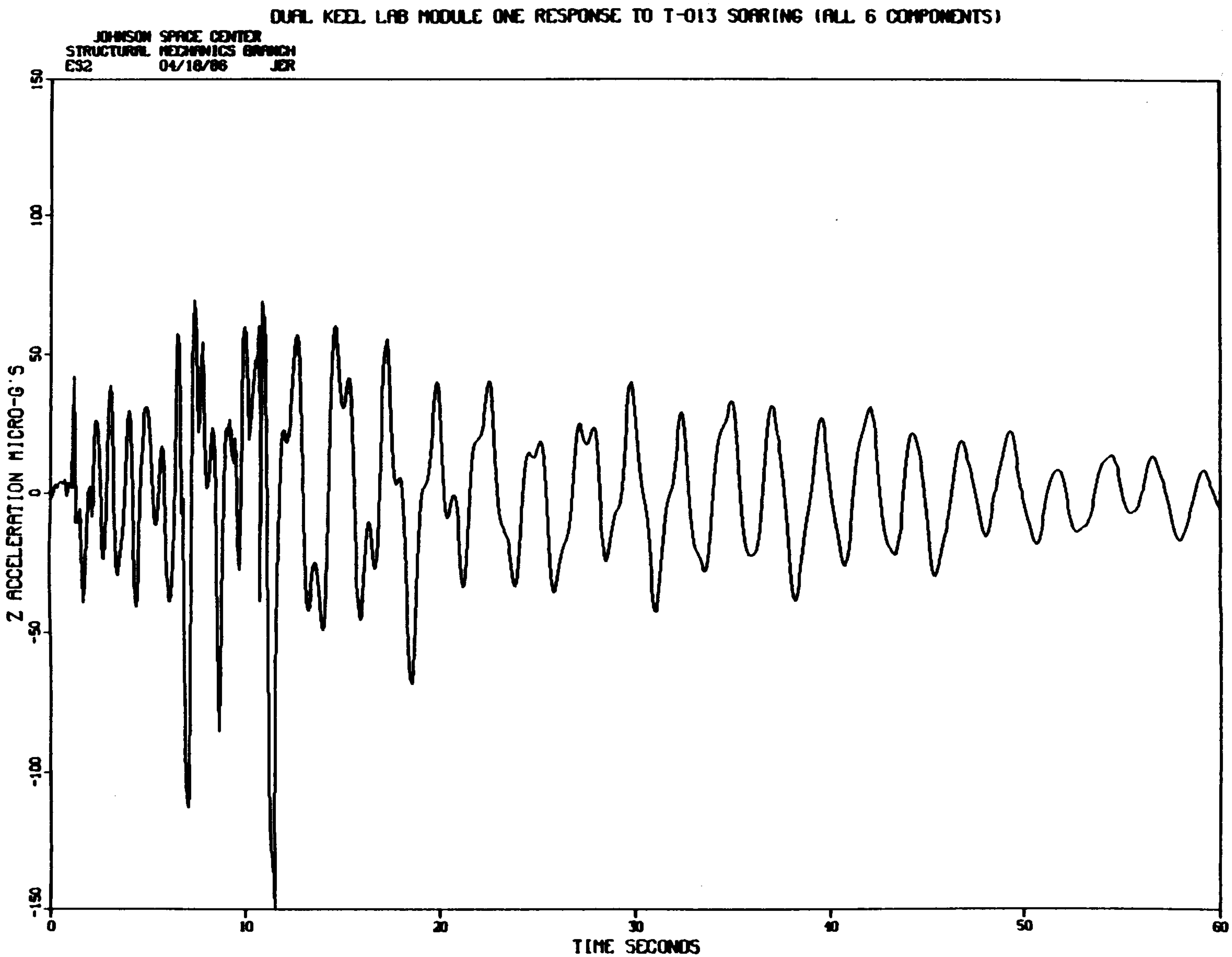


Figure 14 concluded

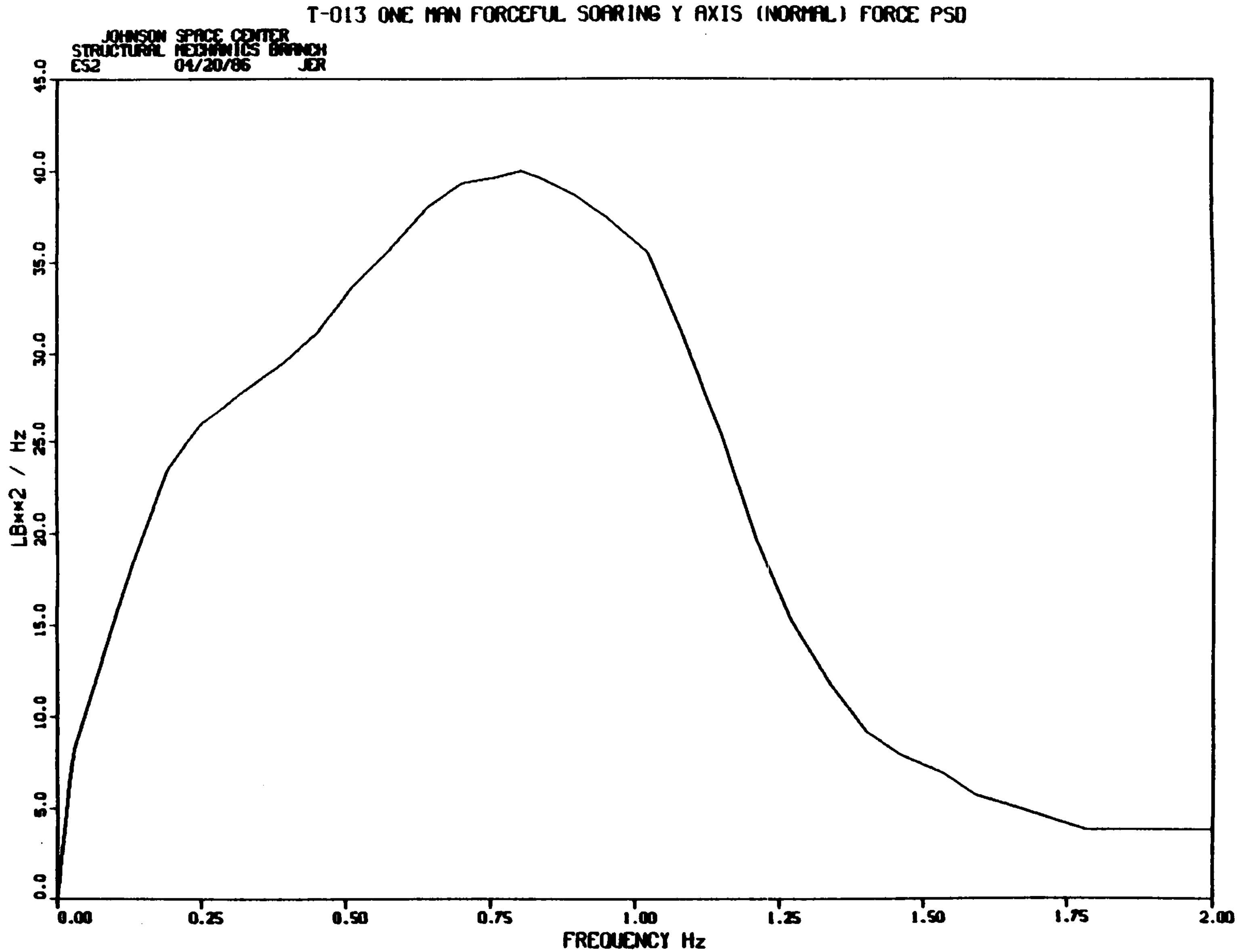

T-013 ONE MAN FORCEFUL SOARING Y AXIS (NORMAL) FORCE PSD
JOHNSON SPACE CENTER
STRUCTURAL MECHANICS BRANCH
ES2 04/20/86 JER
LB**2 / Hz
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
FREQUENCY Hz

Figure 15

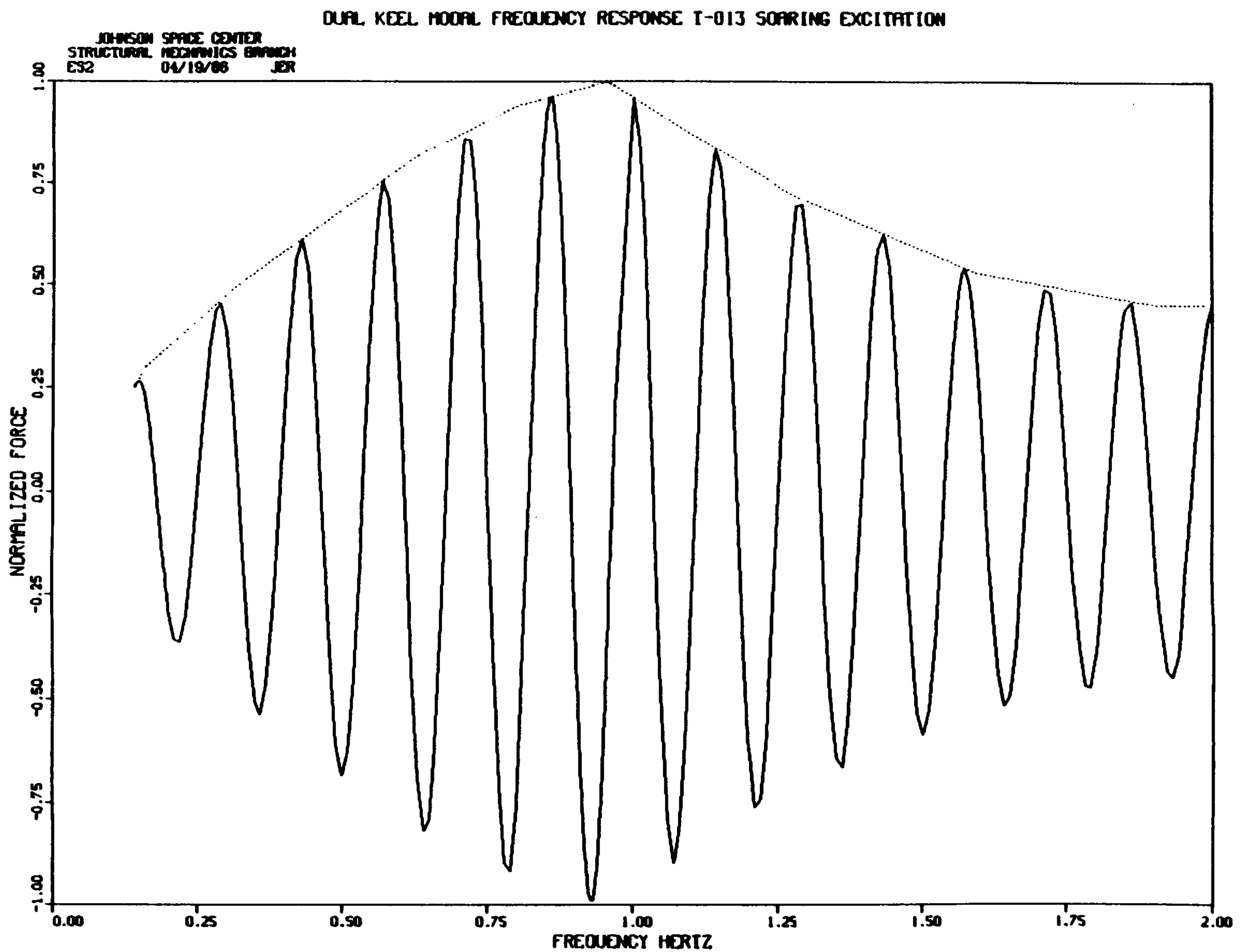

DUAL KEEL MODAL FREQUENCY RESPONSE I-013 SOARING EXCITATION
JOHNSON SPACE CENTER
STRUCTURAL MECHANICS BRANCH
ES2 04/19/86 JER
NORMALIZED FORCE
1.00
0.75
0.50
0.25
0.00
-0.25
-0.50
-0.75
-1.00
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
FREQUENCY HERTZ

Figure 16

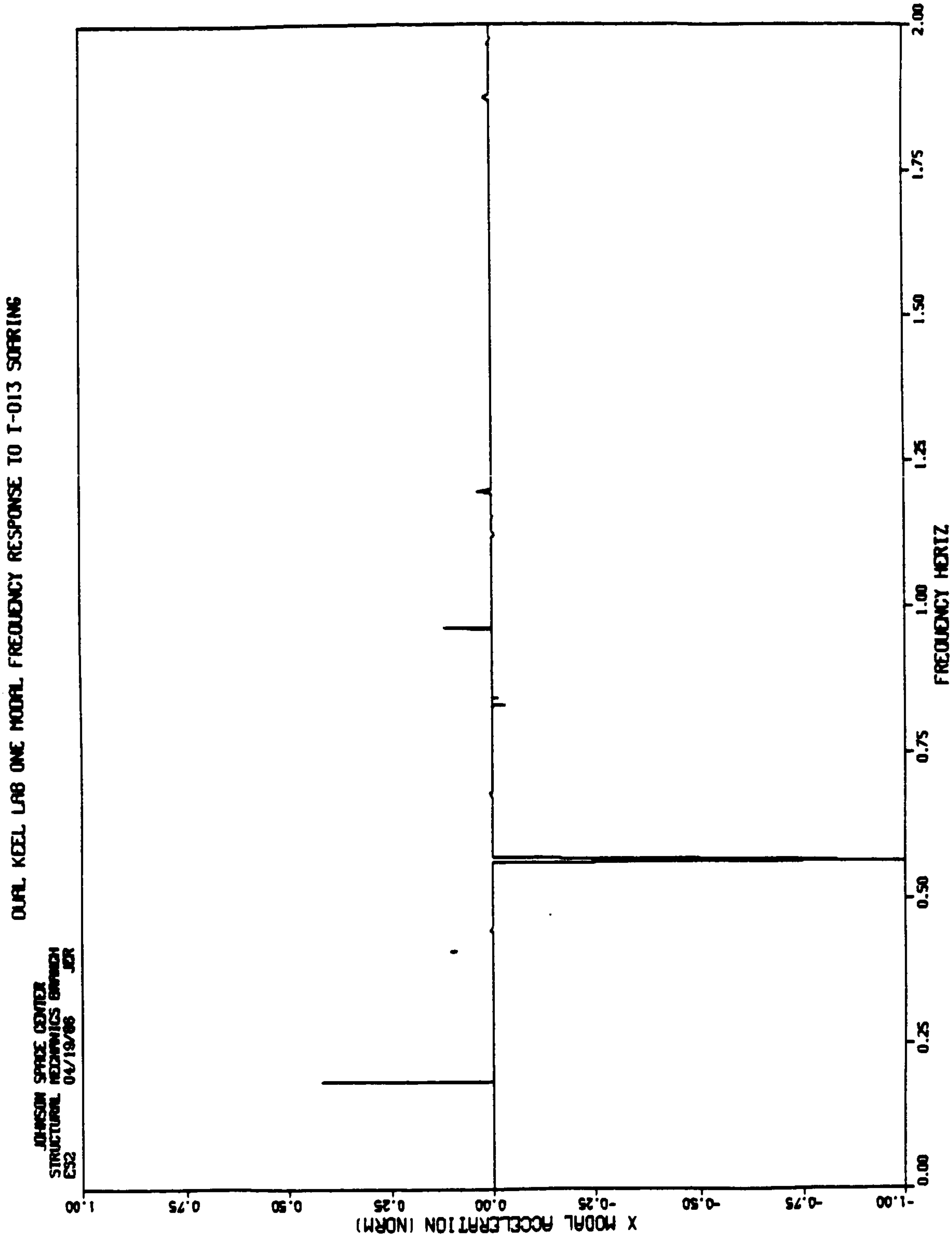

DUAL KEEL LAB ONE MODAL FREQUENCY RESPONSE TO T-013 SOARING
JOHNSON SPACE CENTER
STRUCTURAL MECHANICS BRANCH
ES2 04/19/86 JDR
X MODAL ACCELERATION (NORM)
1.00
0.75
0.50
0.25
0.00
-0.25
-0.50
-0.75
-1.00
FREQUENCY HERTZ
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00

Figure 17

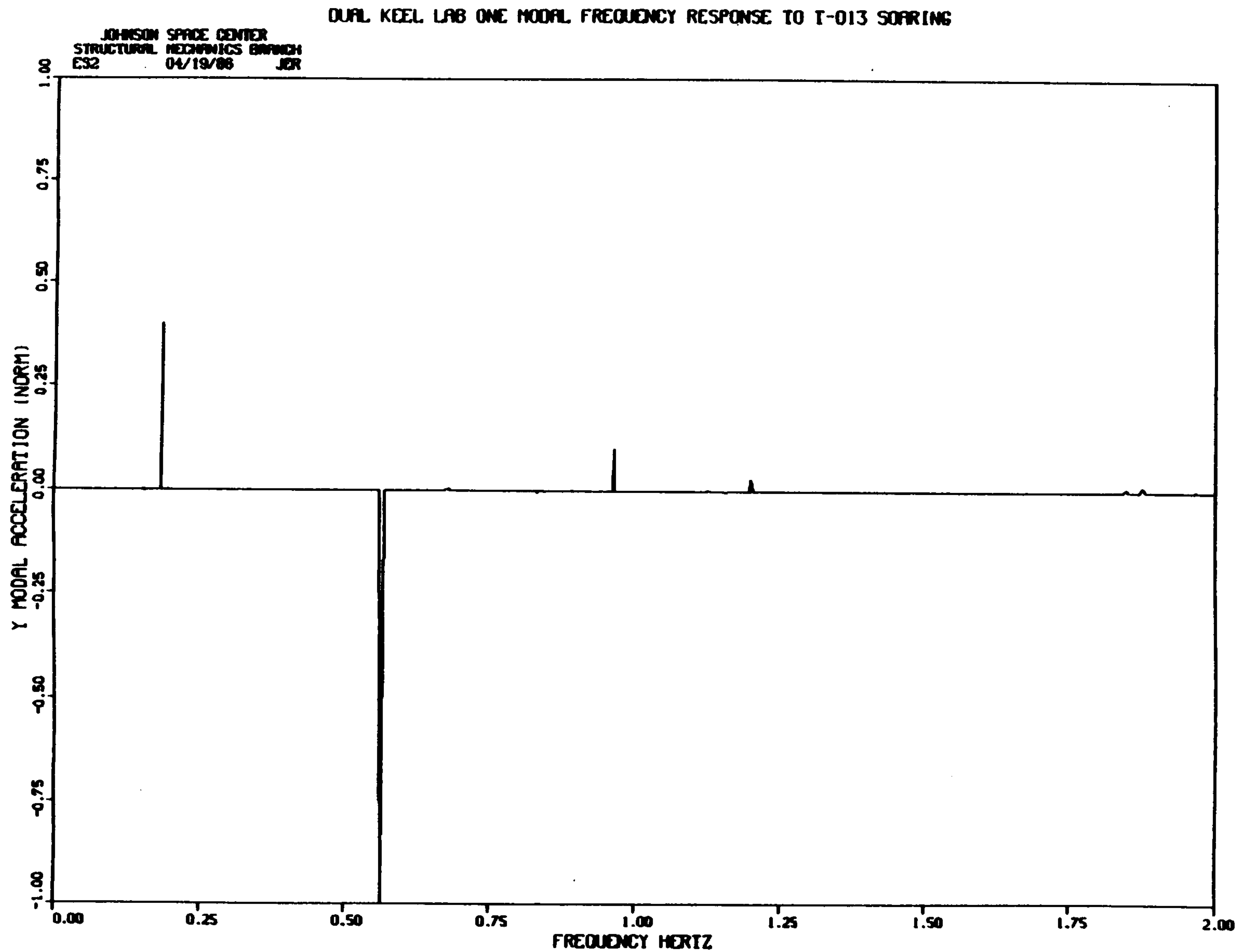


Figure 17 cont.

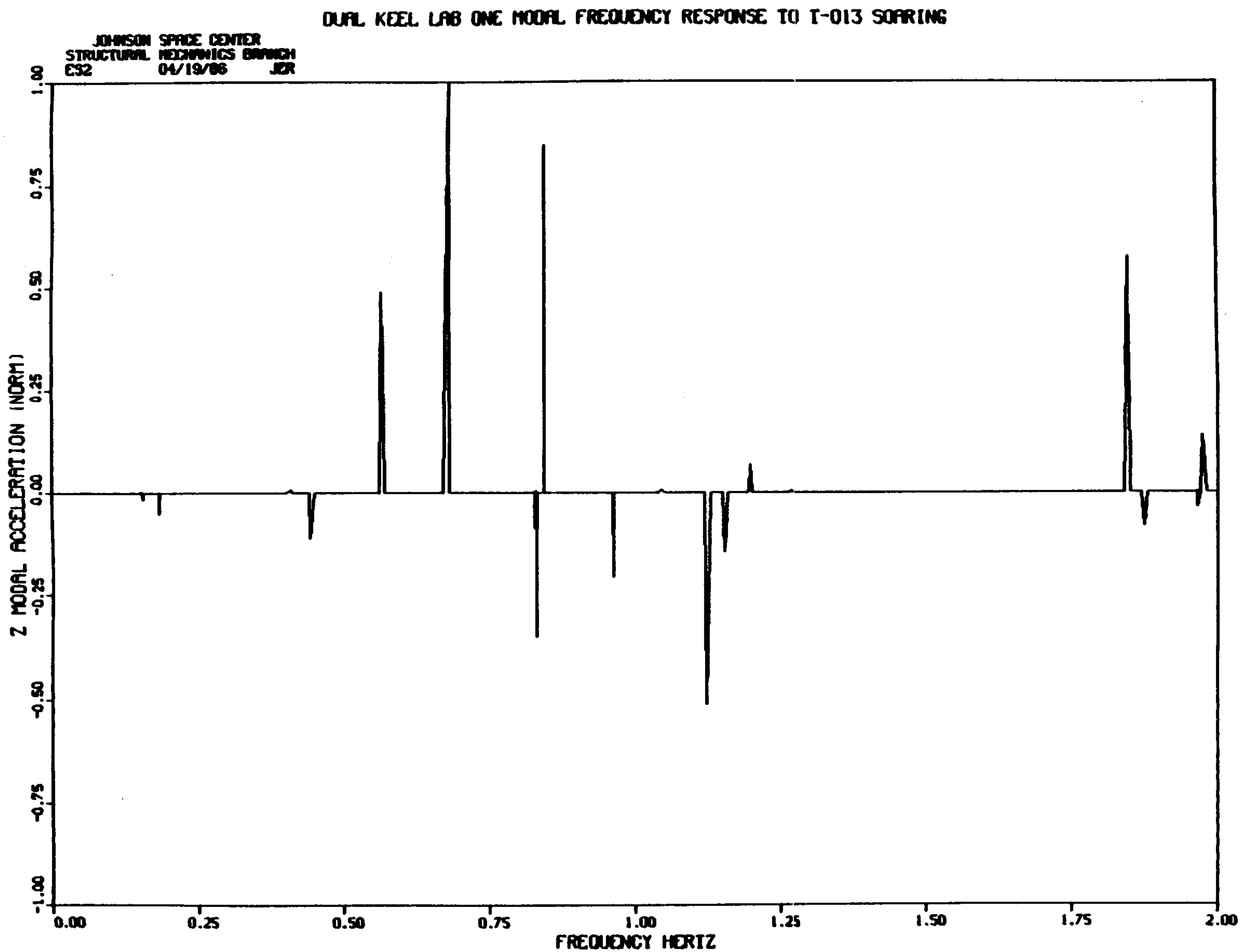


Figure 17 concluded

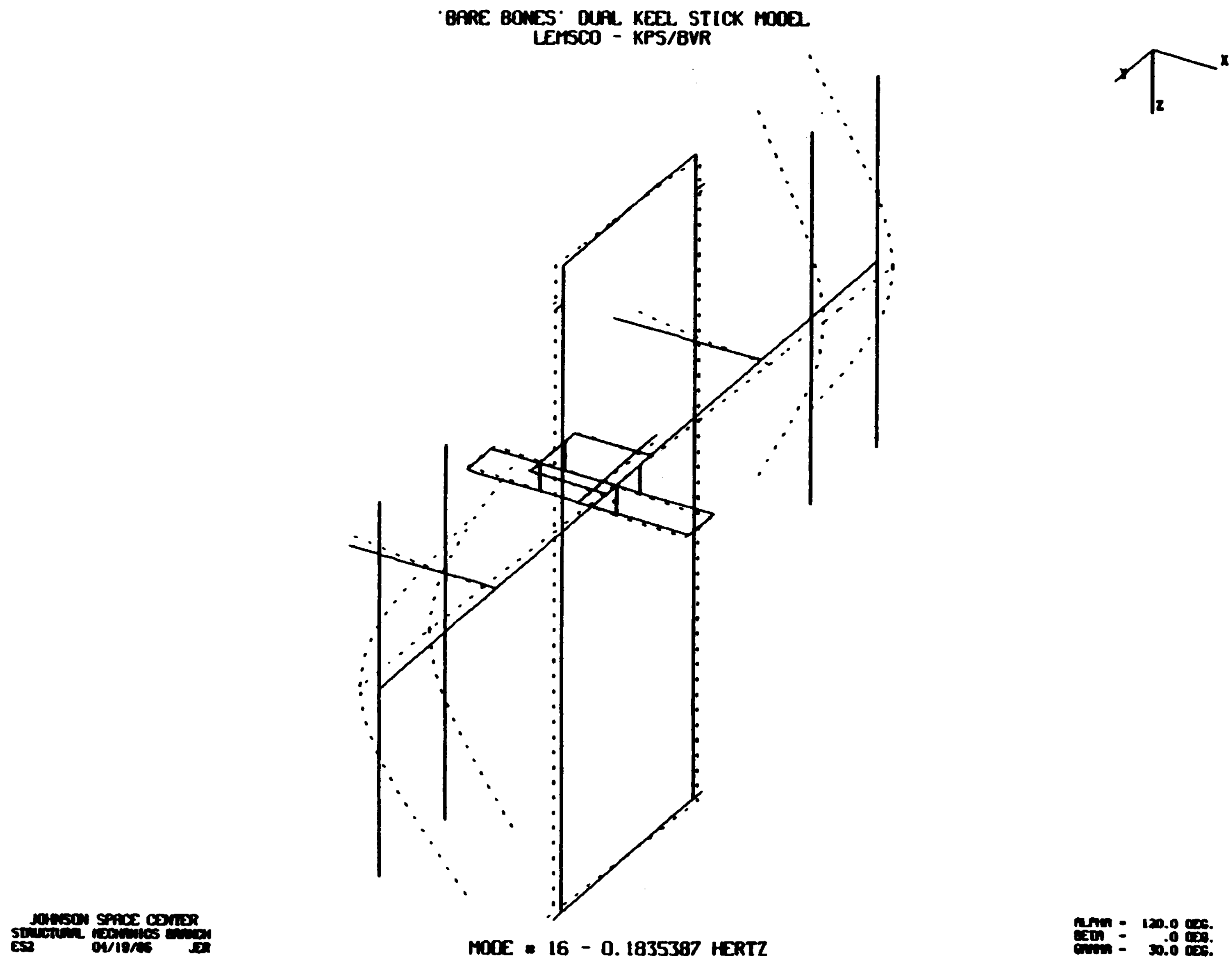

'BARE BONES' DUAL KEEL STICK MODEL
LEMSCO - KPS/BVR
X
Y
Z
JOHNSON SPACE CENTER
STRUCTURAL MECHANICS BRANCH
ES2 04/19/86 JER
MODE = 16 - 0.1835387 HERTZ
ALPHA = 120.0 DEG.
BETA - .0 DEG.
GAMMA - 30.0 DEG.

Figure 18

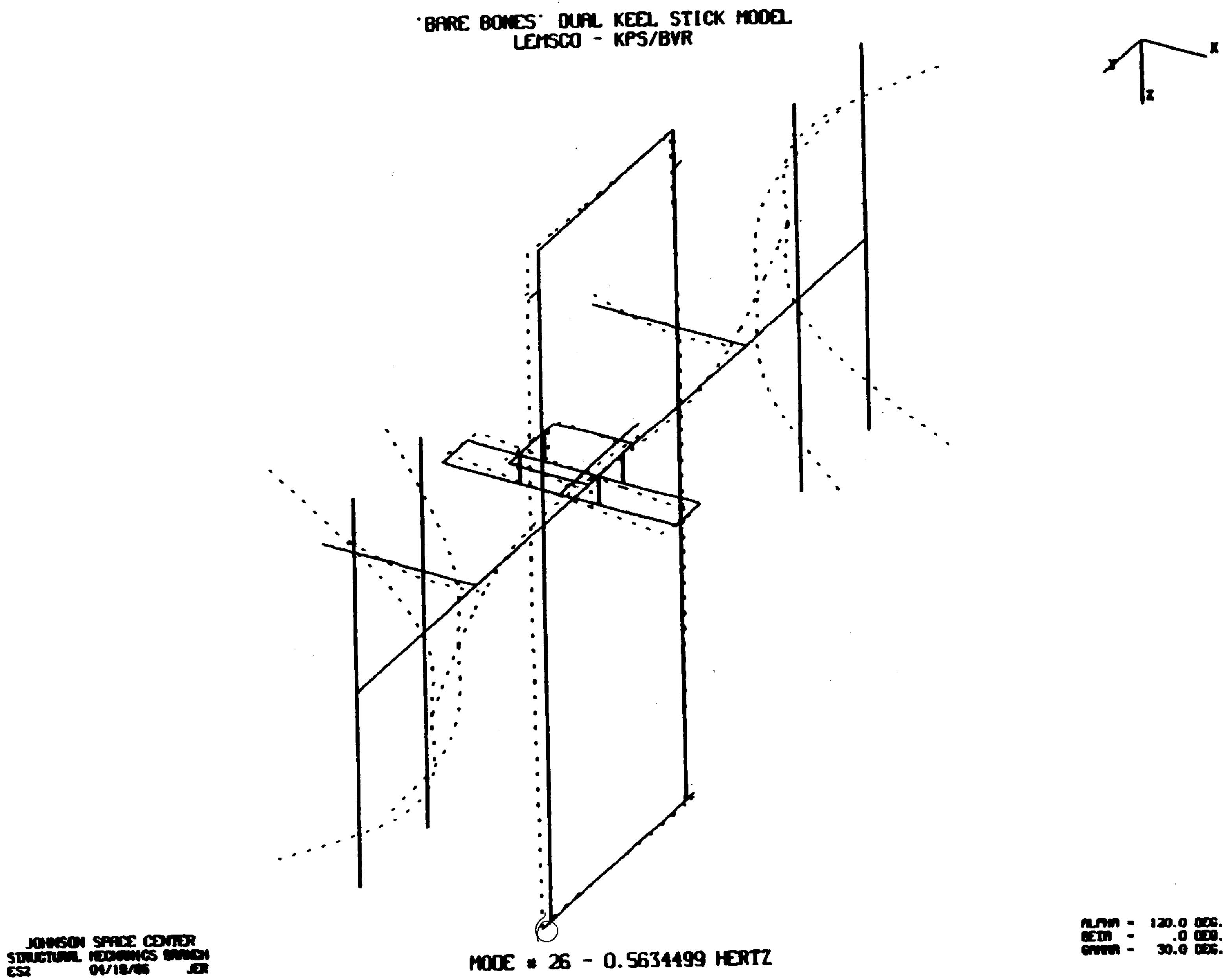

'BARE BONES' DUAL KEEL STICK MODEL
LEMSCO - KPS/BVR
X
Y
Z
JOHNSON SPACE CENTER
STRUCTURAL MECHANICS BRANCH
ES2 04/19/86 JER
MODE = 26 - 0.5634499 HERTZ
ALPHA - 120.0 DEG.
BETA - .0 DEG.
GAMMA - 30.0 DEG.

Figure 19

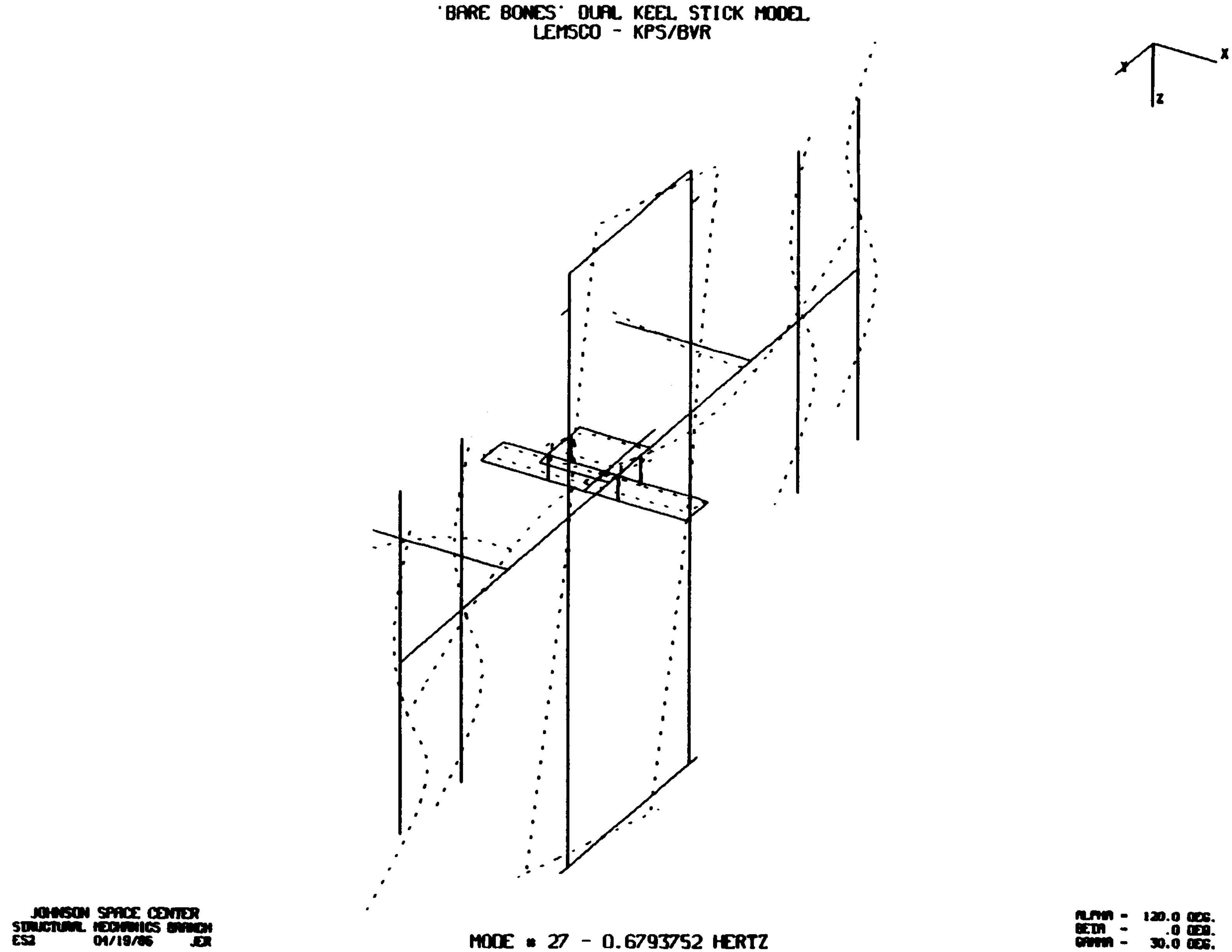

'BARE BONES' DUAL KEEL STICK MODEL
LEMSCO - KPS/BVR
X
Y
Z
JOHNSON SPACE CENTER
STRUCTURAL MECHANICS BRANCH
ES2 04/19/86 JER
MODE = 27 - 0.6793752 HERTZ
ALPHA - 120.0 DEG.
BETA - .0 DEG.
GAMMA - 30.0 DEG.

Figure 20

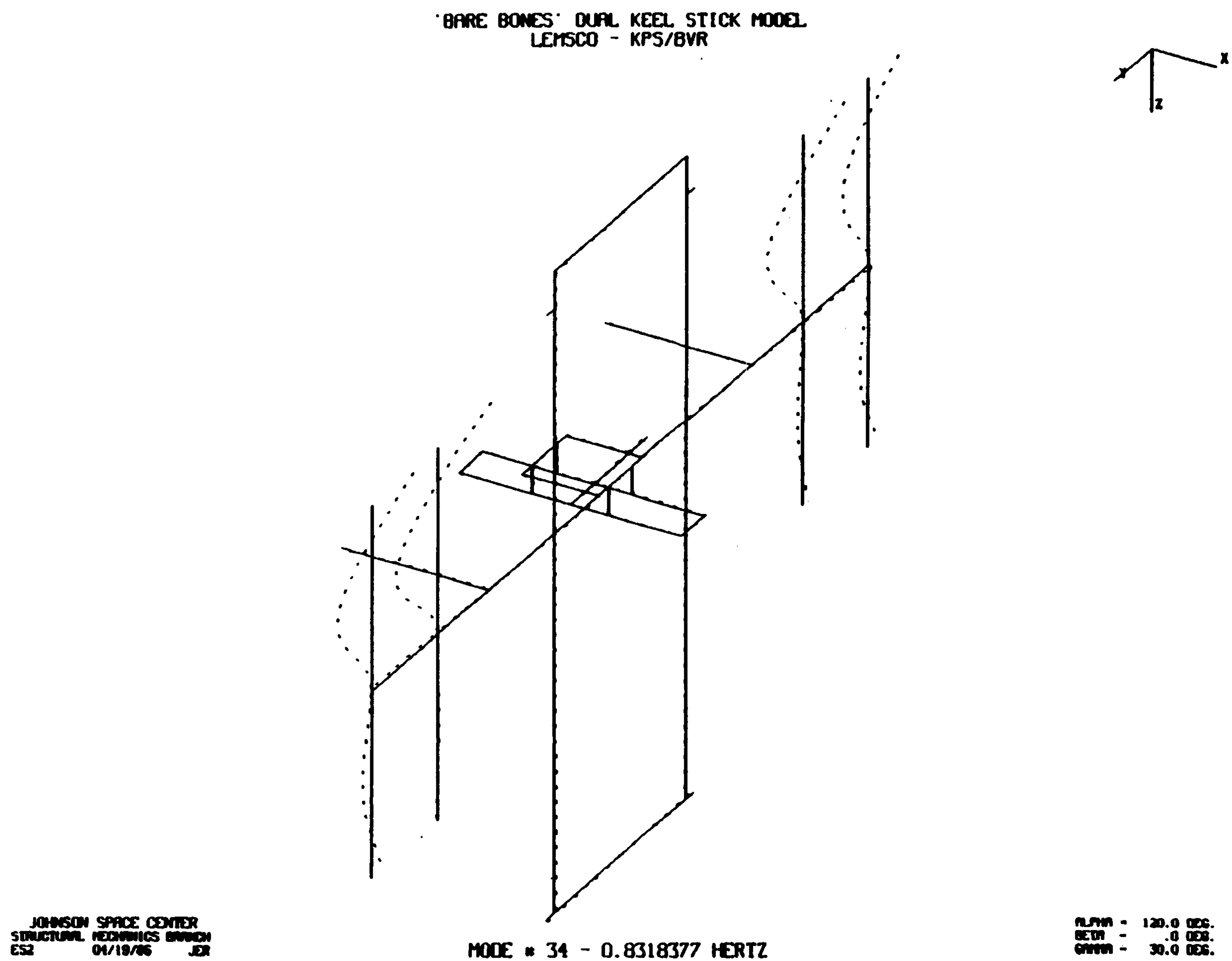
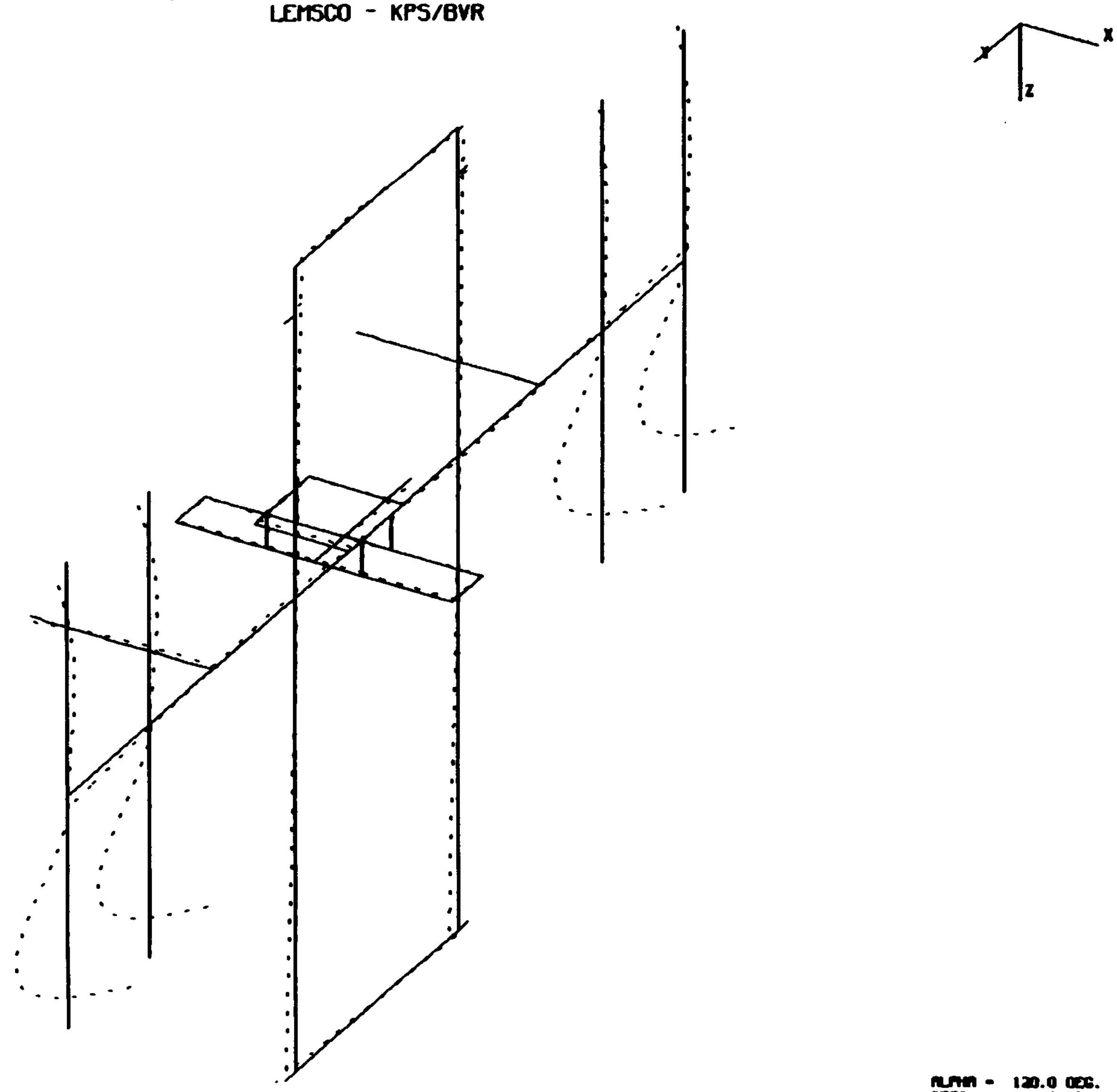

'BARE BONES' DUAL KEEL STICK MODEL
LEMSCO - KPS/BVR
X
Y
Z
JOHNSON SPACE CENTER
STRUCTURAL MECHANICS BRANCH
ES2 04/19/86 JER
MODE # 34 - 0.8318377 HERTZ
ALPHA - 120.0 DEG.
BETA - .0 DEG.
GAMMA - 30.0 DEG.

Figure 21

'BARE BONES' DUAL KEEL STICK MODEL
LEMSCO - KPS/BVR



JOHNSON SPACE CENTER
STRUCTURAL MECHANICS BRANCH
ES2 04/21/86 JER

MODE * 35 - 0.8437495 HERTZ

ALPHA - 120.0 DEG.
BETA - .0 DEG.
GAMMA - 30.0 DEG.

Figure 22

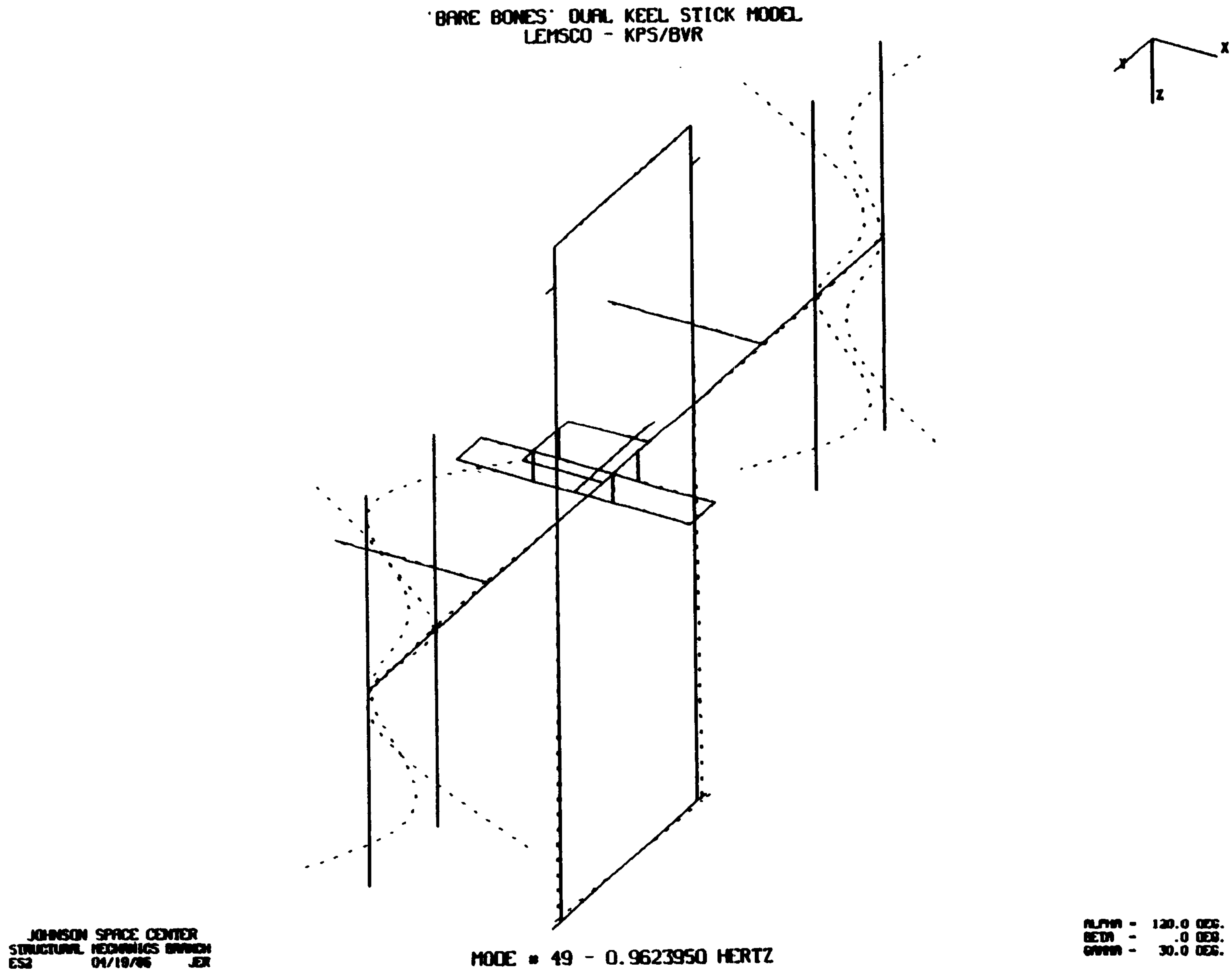

'BARE BONES' DUAL KEEL STICK MODEL
LEMSCO - KPS/BVR
X
Y
Z
JOHNSON SPACE CENTER
STRUCTURAL MECHANICS BRANCH
ES2 04/19/86 JER
MODE # 49 - 0.9623950 HERTZ
ALPHA - 120.0 DEG.
BETA - .0 DEG.
GAMMA - 30.0 DEG.

Figure 23

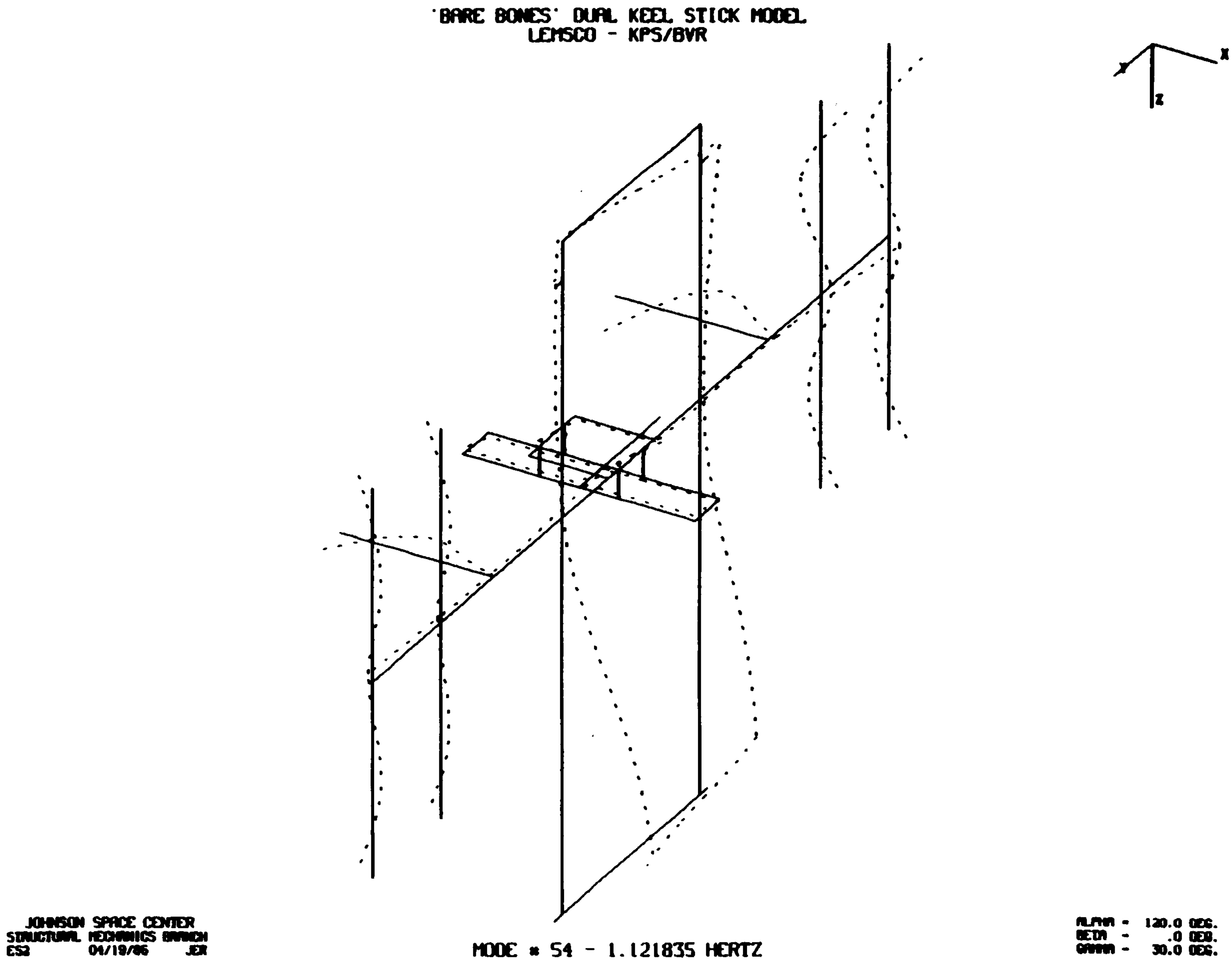
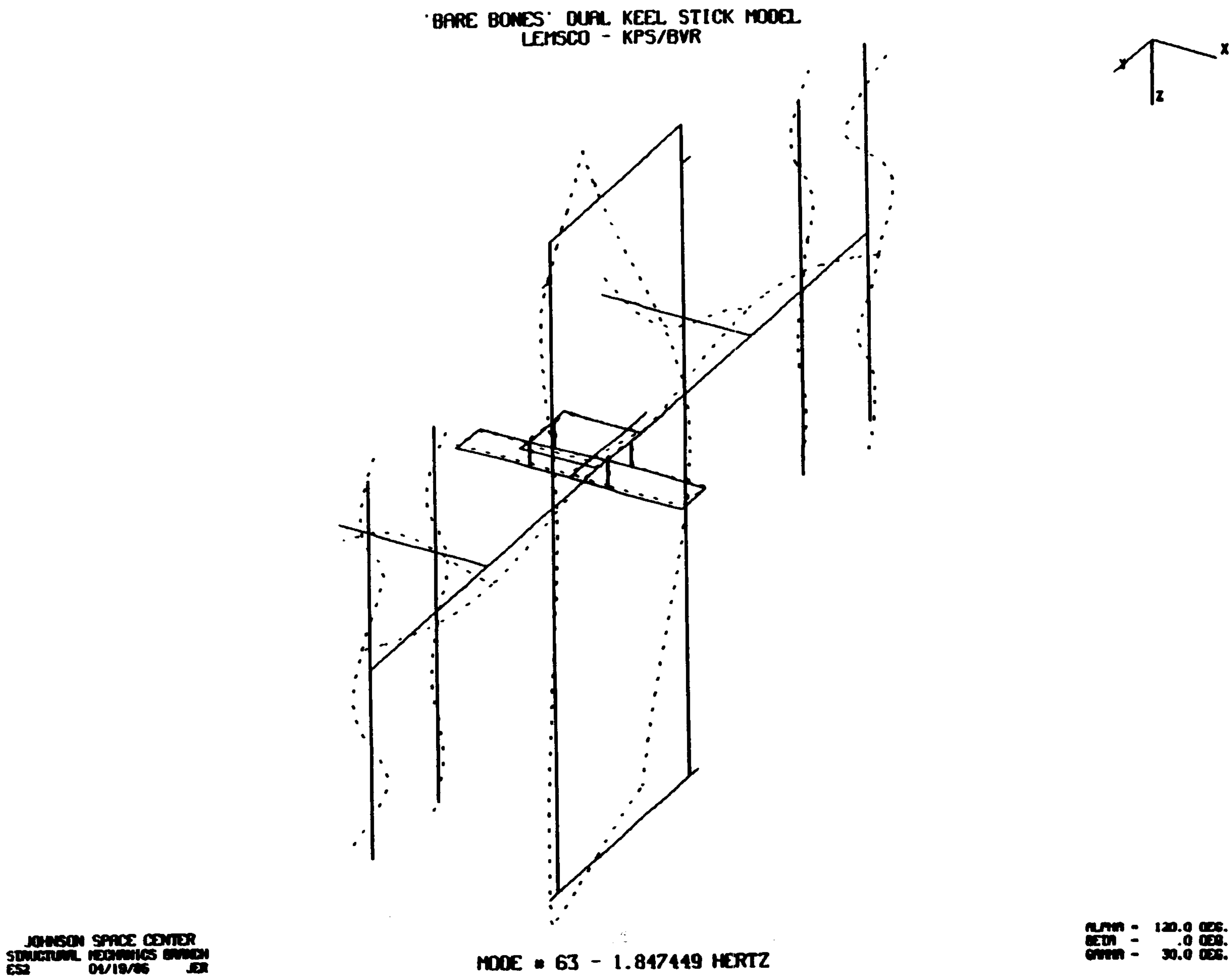

'BARE BONES' DUAL KEEL STICK MODEL
LEMSCO - KPS/BVR
X
Y
Z
JOHNSON SPACE CENTER
STRUCTURAL MECHANICS BRANCH
ES2 04/19/86 JER
MODE * 54 - 1.121835 HERTZ
ALPHA - 120.0 DEG.
BETA - .0 DEG.
GAMMA - 30.0 DEG.

Figure 24



'BARE BONES' DUAL KEEL STICK MODEL
LEMSCO - KPS/BVR
X
Y
Z
JOHNSON SPACE CENTER
STRUCTURAL MECHANICS BRANCH
ES2 04/19/86 JER
MODE # 63 - 1.847449 HERTZ
ALPHA - 120.0 DEG.
BETA - .0 DEG.
GAMMA - 30.0 DEG.

Figure 25

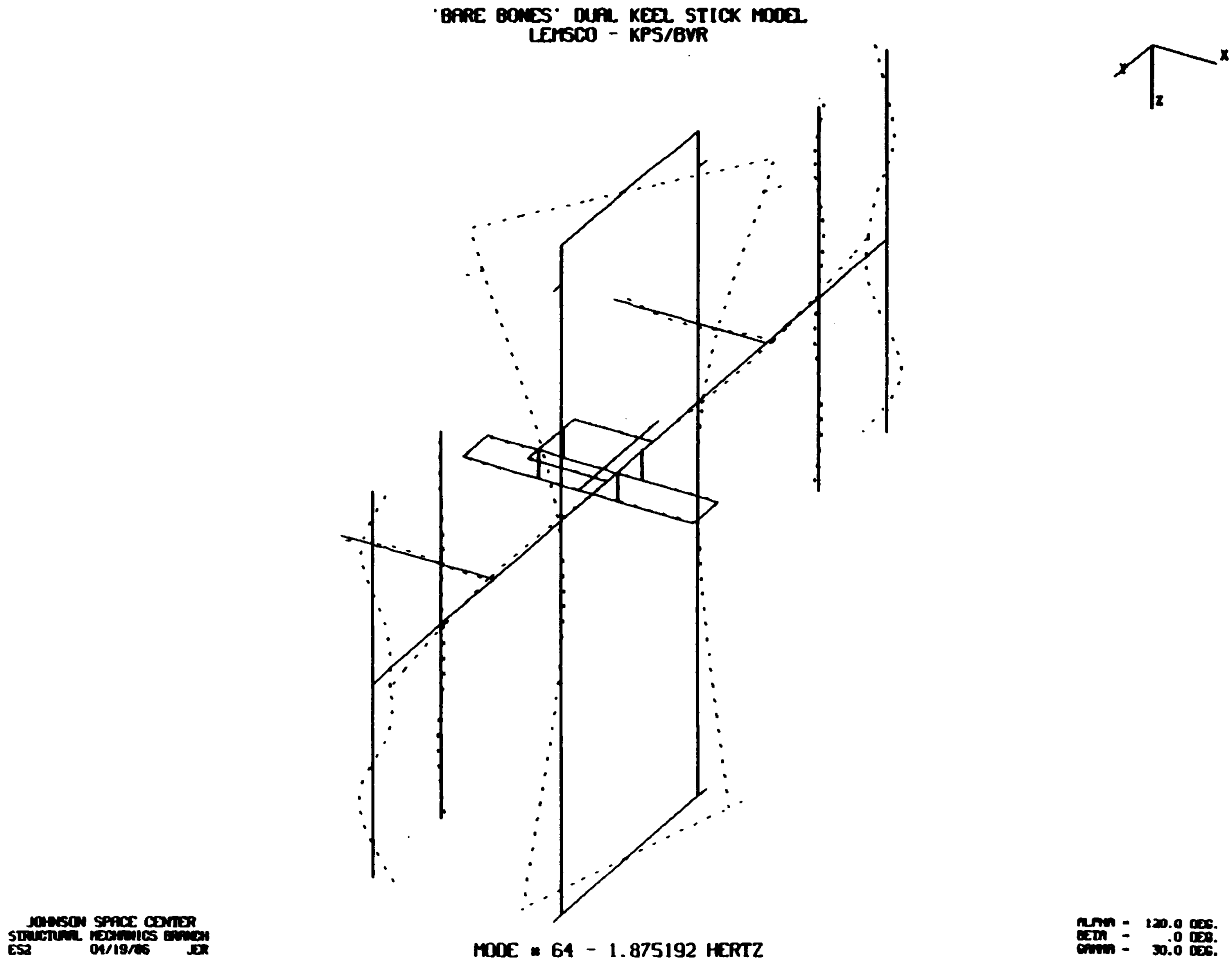

'BARE BONES' DUAL KEEL STICK MODEL
LEMSCO - KPS/BVR
X
Y
Z
JOHNSON SPACE CENTER
STRUCTURAL MECHANICS BRANCH
ES2 04/19/86 JER
MODE # 64 - 1.875192 HERTZ
ALPHA - 120.0 DEG.
BETA - .0 DEG.
GAMMA - 30.0 DEG.

Figure 26

VII. AREAS OF CONTINUED RESEARCH

The major portion of future work in the CA/M disturbance area will be towards expanding the present forcing function database. The current database is limited solely to CA/M results collected from Skylab experiment T-013, so it may be necessary to conduct additional flight experiments. There are deterministic (discrete) CA/M disturbances that cannot be simulated accurately or may have been modeled but need verification experimentally in a zero-g environment.

As part of the proposed work involving continued flight experimentation, a conceptual design is being developed for a force measurement system using a force platform similar to platforms currently used in biomechanics research. It will be a self-contained system integrating all sensors, data acquisition electronics, and power in one package to simplify procedures for flight certification and to eliminate the need for storage space aboard the Space Shuttle (middeck area).

The platform should be able to accomodate different equipment and loads but is presently being configured to handle the treadmill currently used by the crew for exercise aboard the Orbiter. The crew exercise treadmill is expected to be one of the major disturbance sources from CA/M on the Space Station, because it will probably be a part of the Health Maintenance Facility (HMF) so as to satisfy the crew's exercise requirement, which may call for daily use by each crew member. Thus without isolation of the apparatus, a seemingly constant disturbance will be present during its daily use (for a crew of 8). An experiment will be proposed to measure the disturbance caused by a member of the shuttle crew running on the treadmill apparatus. It is planned to gather Orbiter accelerometer data during the experiment; the measured accelerometer and forcing function data could then be used to predict Station and Orbiter response as well as for Orbiter structural math model verification.

It has been suggested to utilize ground simulations rather than actual flight experiments (due to the higher cost and time involved in preparing the experiment) for continued CA/M studies. During development of experiment T-013 questions were raised as to its necessity in light of the availability of a number of ground simulation techniques. However, with the benefit of hindsight and the wealth of T-013 data, there are still questions about the validity of ground simulation results. Several methods of simulation are available but have varying disadvantages and limitations (see Table 1). The results from ground simulations have been satisfactory for stochastic motions such as console operations, meal preparation, and personal hygiene. However, the results from simulating discrete, higher level restrained and translational CA/M did not correlate well with experiment T-013 results. No matter what the results, the simulated activities should be verified by on-orbit experimentation.

The ultimate goal of the work being conducted at NASA/JSC is to put together a handbook of induced loads and the resultant environments expected to affect Space Station operations. A significant portion of this data book will document the effects of CA/M disturbances.

VIII. Conclusions & Recommendations

Construction of the T-013 forcing function database and development of a structural analysis pre-processor has made it possible to evaluate the structural effects and response of CA/M disturbances on the space station. 'CREW' should prove itself invaluable as a tool for analysis in the near term. Efforts on modeling and synthesis of expected CA/M forcing function data are continuing and the results will be easily incorporated into the existing 'CREW' database.

Preliminary analysis has demonstrated that 'CREW', using the T-013 data, can accurately represent CA/M disturbances and that CA/M disturbances appear to be drivers that will compromise the Space Station's micro-g environment.

With crew capabilities and responsibilities expanding on a spacecraft with its purpose dedicated to using the micro-g environment, the spectrum of crew induced disturbances has widened. Thus the existing database needs to be expanded, and a choice has to be made between ground simulation (digital or physical) and flight experimentation. Various references have been reviewed and pertinant comments extracted leading to the recommendations that follow:

1) If the techniques exist for simulation of a disturbance,the results need to be experimentally verified.

2) If the techniques do not exist for simulation of a disturbance, then the disturbance must be measured by experimentation.

Both of the above recommendations lead to the same conclusion that for CA/M disturbance database expansion, a dedicated flight experiment should be conducted.

This conclusion is applicable to the majority of crew disturbances that need to be evaluated. The crew activity/motion requiring investigation falls into the category of gross body/torso motion and translation (exercise, IVA/EVA maintenance, hatch opening/closing, etc.), and based on experience gained from Skylab Experiment T-013, ground simulation of these activities resulted in very poor correlation with actual flight data. The remaining category (low level restrained activity such as console operations, personal hygiene, etc.) can be synthesized from existing flight data and can be modeled using stochastic techniques.

It is recommended that an experiment should be developed to investigate the crew motion/activity that cannot be modeled using the existing T-013 flight data. Such an experiment could use the Shuttle crew cabin or possibly a Spacelab module with a force measurement system similar to the one used in experiment T-013. Supporting this recommendation is the belief that some of the activities investigated will have force levels and frequency content greater than the T-013 activities (especially crew exercising on devices like the treadmill currently slated for use in the Station's HMF).

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