NORMAL MODE ANALYSIS OF THE IUS/TDRS PAYLOAD

IN A

PAYLOAD CANISTER/TRANSPORTER ENVIRONMENT*

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SUMMARY

Special modeling techniques were developed to simulate an accurate mathematical model of the Transporter/Canister/Payload (T/C/P) system during ground transport of the Inertial Upper Stage/Tracking and Data Relay Satellite (IUS/TDRS) payload on the John F. Kennedy Space Center (KSC). The three finite element models -- the transporter, the canister, and the IUS/TDRS payload -- were merged into one model and used along with the NASTRAN normal mode analysis. Deficiencies were found in the NASTRAN program that make a total analysis using modal transient response impractical. It was also discovered that inaccuracies may exist for NASTRAN rigid body modes on large models when Given's method for eigenvalue extraction is employed. The deficiencies as well as recommendations for improving the NASTRAN program are discussed.

INTRODUCTION

The capability to predict the operational life of a Space Shuttle payload is essential to the success of an orbital mission. The amplitudes and approximate number of load cycles that will be induced in each individual payload during ground transport between facilities must be predictable in advance of each flight into space.

This paper presents a solution to the problem of determining the dynamic response of one particular payload: the IUS/TDRS. The TDRS, which will be boosted to a geo-synchronous Earth orbit by the IUS, presents a problem in that it has a flexible diaphragm tank that contains approximately 1,400 pounds of hydrazine fuel. The tank is extremely sensitive to cyclic fatigue.

Though the original purpose of the study was to determine the dynamic response of the IUS/TDRS payload to ground-induced, time-dependent displacements

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using the NASTRAN computer program, it became apparent that a modal transient response analysis (solution 12) was not feasible due to deficiencies in the program.

Instead, it was necessary to perform a normal mode analysis (solution 3). Selected results from the NASTRAN program were used as input to a FORTRAN program in which time-dependent displacements were imposed and the response was computed.

THE T/C/P SYSTEM

The T/C/P system transports Space Shuttle payloads between facilities at KSC. It consists of a canister that houses the payload and a transporter on which the payload canister is carried. The canister is a steel shell with rigid steel frames and two large aluminum doors; it can be used in either a vertical or horizontal position. The transporter has a steel flatbed frame that contains supporting subsystems such as environmental control, instrumentation and communication, fluids and gases, as well as the diesel generators required for self-propulsion. The frame is mounted on 12 bogie units (6 drive units and 6 braking units) with 4 tires per unit.

The IUS/TDRS payload, the subject of this study, is carried with the canister in the vertical position.

NORMAL MODE ANALYSIS

To perform a normal mode analysis, a NASTRAN model was developed to determine the normal mode shapes, eigenvalues, and generalized mass for selected mode shapes as well as the total mass, mass moment of inertia, and center-of-gravity location of the T/C/P system. It contained 900 grid points in which ASET1 (ref. 1) bulk data cards were used to reduce the mass Degrees of Freedom to a total of 338, using the Guyan reduction technique and the Givens method for eigenvalue extraction. A total of 2915 CBAR, CELAS2, CQUAD1, CTRIA1, and CONM2 elements were used in the model.

Figure 1 shows a NASTRAN undeformed structural plot of the T/C/P system. Figure 2 shows a NASTRAN undeformed structural plot of the T/C/P system in which the canister was plotted using NASTRAN PLOTEL elements. The second plot configuration was used for modal deformed plots to clarify mode shapes.

Modeling - IUS/TDRS Payload

The IUS/TDRS payload was modeled using CBAR and CØNM2 elements and connected to the payload canister with CELAS2 elements. The IUS/TDRS payload was modeled in its own coordinate system using CØRD2R bulk data cards.

Modeling - Payload Canister

The payload canister was modeled using CBAR, CQUAD1, CTRIA1, and CØNM2 elements. Connections between payload canister and transporter were made using CELAS2 elements. The payload canister steel shell was in the basic coordinate system, and each canister aluminum door was modeled in its own coordinate system using CØRD2R bulk data cards.

Modeling - Transporter

The transporter was modeled using CBAR, CTRIA1, and CØNM2 elements. It was modeled in its own coordinate system using the CORD2R bulk data cards.

DISCUSSION

Each component of the T/C/P system was modeled in its own coordinate system for ease of analysis for future payloads. This modeling technique is particularly useful for cases in which the location of the payload relative to the payload canister may change and/or the transportation position of the payload canister could be either horizontal or vertical. It points out the value of the NASTRAN coordinate system bulk data cards: components of a total structural system may be translated and/or rotated relative to one another, and only minor changes in the NASTRAN bulk data cards are required.

The NASTRAN PARAM GRDPNT bulk data card was used to locate center of gravity, to compute total mass, and to compute mass moment of inertia relative to the center of gravity. This output was used as input to the previously mentioned FORTRAN program.

When modeling a plane frame in which the members have open sections and substantial depth and are rigidly connected to one another, as in the transporter bed frame, the torsional mode eigenvalues are inaccurate unless a specific modeling technique is used. This inaccuracy occurs because warping normal and warping shear strains (ref. 2) resulting from internal torsional loads are not properly accounted for in the model and result in torsional mode eigenvalues that are much smaller in value than actually occur.

To test this fact, two small NASTRAN models of plane frames were analyzed. Both models consisted of plane frames made up of I-shaped members; flanges of the members were parallel to the plane of the frame. NASTRAN CBAR elements were used in both models. The second model had additional members that consisted of CBAR elements offset from the neutral axis of the total section to the neutral axis of each flange. The PBAR bulk data card for these offset CBAR elements consisted only of moment of inertia in the plane of the flange. All other values of this PBAR bulk data card were zero. This modeling technique produces additional stiffness terms that increase the torsional rigidity of the structural elements. A NASTRAN undeformed structural plot of these models is shown in figure 3.

A normal mode analysis was performed on both models. The results of the first model analysis gave a first torsional mode frequency of 2.716209 Hz. The second model first torsional mode frequency was 13.55733 Hz. The error of the first model torsional frequency relative to the second model torsional frequency was 499%. Figures 4 and 5 show modal deformed plots of the first torsional modes of the first and second models, respectively.

The first model and second model first bending mode frequencies were 44.00233 Hz and 44.42864 Hz, respectively, which shows that the modeling technique has little effect on pure bending mode. It also points out the importance of the offset feature on the NASTRAN CBAR bulk data card. Figures 6 and 7 show modal deformed plots of the first and second model, respectively.

This modeling technique was used on the transporter bed frame. Tests were run on a similar type frame and results show that this and similar modeling techniques produce accurate eigenvalues.

NASTRAN RESULTS

The T/C/P system was analyzed using the Givens method for eigenvalue extraction in a free body configuration. A Univac 1108 computer was used with level 16.0 NASTRAN.

Table I summarizes the T/C/P system real eigenvalues and frequencies for the first six rigid body modes. The eigenvalues and frequencies are not zero, thus raising the question of the accuracy of these modes. Also, the force and stress output of NASTRAN showed appreciable strain energy at certain locations, which raised additional doubts as to the the accuracy of the rigid body modes. Because of these questions, the mode shapes were hand calculated at points of interest and used as input to the previously mentioned FORTRAN program.

Table II summarizes the T/C/P system real eigenvalues, frequencies, and mode type for the first 12 flexible body modes. No tests related to this T/C/P system have been made at this time, so no comment can be made on the accuracy of these modes. Figures 8 and 9 show typical modal deformed plots of the T/C/P system.

It should also be noted that the Forward - Backward Substitution time in module SMP1 was approximately 23,000 CPU-seconds on a Univac 1108 computer running level 16.0 NASTRAN.

DEFICIENCIES IN NASTRAN

It would have been desirable to run a full analysis of the T/C/P system (solution 12, Modal Transient Response); however, certain deficiencies became apparent as the analysis progressed. These include:

1. Questionable accuracy of rigid body modes when using Givens method for eigenvalue extraction for free body systems

2. No provisions for non-zero initial conditions relative to modal transient response rigid format

3. No provisions for time-dependent or frequency-dependent displacements

4. No provisions for checking accuracy of numerical integration for each time or frequency step

Alteration of the NASTRAN program and the use of special modeling techniques were considered; however, the time frame of the analysis and the magnitude of these deficiencies made these considerations infeasible.

NASTRAN PROGRAM RECOMMENDATIONS

The following recommendations are made for the improvement of the NASTRAN program for dynamic modal response problems:

1. Develop a timing equation check of the Forward - Backward Substitution method used by NASTRAN.

2. Check the accuracy of rigid body modes for large problems for all types of eigenvalue extraction methods.

3. Make provisions for non-zero initial conditions as NASTRAN bulk data input in the solution of modal response type of rigid formats.

4. Add time and frequency-dependent displacement equations in the form of NASTRAN bulk data cards.

5. Develop a numerical integration technique (variable step integration) that would check each integration step for accuracy. Some allowable maximum error should be used as input by the user in the form of a NASTRAN bulk data parameter card.

CONCLUSIONS

NASTRAN is an excellent tool when used for the extraction of eigenvalues and eigenvectors. The use of several methods of eigenvalue extraction and the existence of useful types of NASTRAN bulk data cards, such as ASET1, coordinate system cards, and PARAM GRDPNT bulk data cards, make it an efficient, time-saving program.

The author concludes, however, that considerable care must be exercised in the choice of modeling techniques and that there are deficiencies in the NASTRAN program that make a total analysis of some types of problems using modal transient response impractical. The above-mentioned recommendations would improve the NASTRAN program, making it more useful and efficient for solving modal response-type problems.

Table I. NASTRAN Rigid Body Modes

MODE NO.	EIGENVALUE	FREQUENCY (HZ)
1	−5.583629	0.376078
2	−3.456232	0.295884
3	−0.273054	0.083165
4	1.667725	0.205533
5	4.727485	0.346047
6	5.503941	0.373385

Table II. NASTRAN Flexible Body Modes

MODE NO.	EIGENVALUE	FREQUENCY (HZ)	MODE TYPE
7	723.2128	4.280093	IUS/TDRS BENDING
8	812.9676	4.537919	IUS/TDRS BENDING
9	1140.882	5.375767	T/C/P SYSTEM COUPLED
10	1478.755	6.120238	TRANSPORTER BENDING
11	2033.65	7.177253	TRANSPORTER TORSIONAL
12	2330.44	7.683147	IUS/TDRS BENDING
13	2685.299	8.247388	IUS/TDRS BENDING
14	2982.683	8.692079	IUS/TDRS BENDING
15	3236.141	9.053861	T/C/P COUPLED
16	3517.725	9.439545	PAYLOAD CANISTER BENDING
17	3751.85	9.748613	T/C/P COUPLED
18	3880.339	9.914138	T/C/P COUPLED

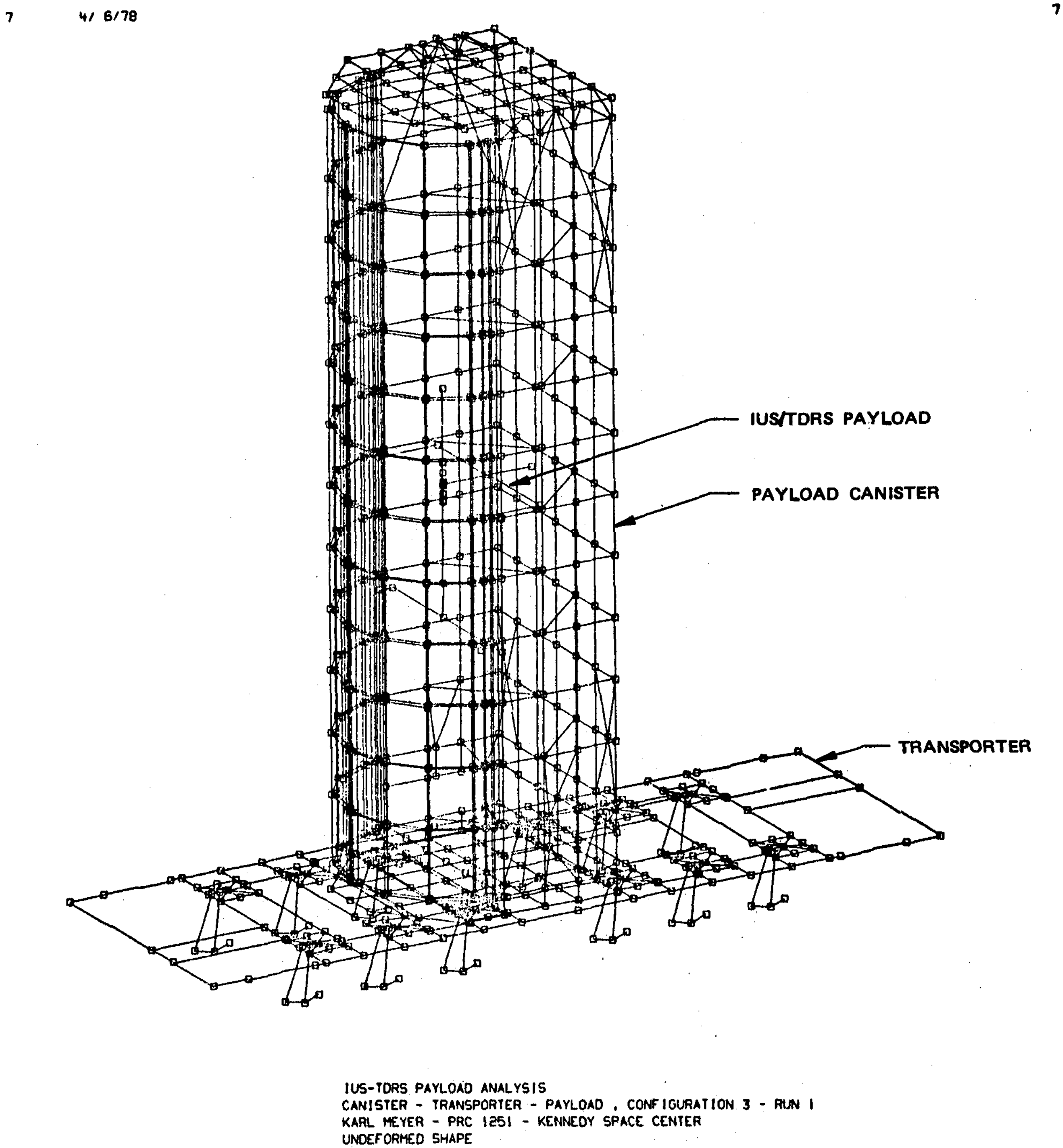


Figure 1. NASTRAN Undeformed Structural Plot of the T/C/P System

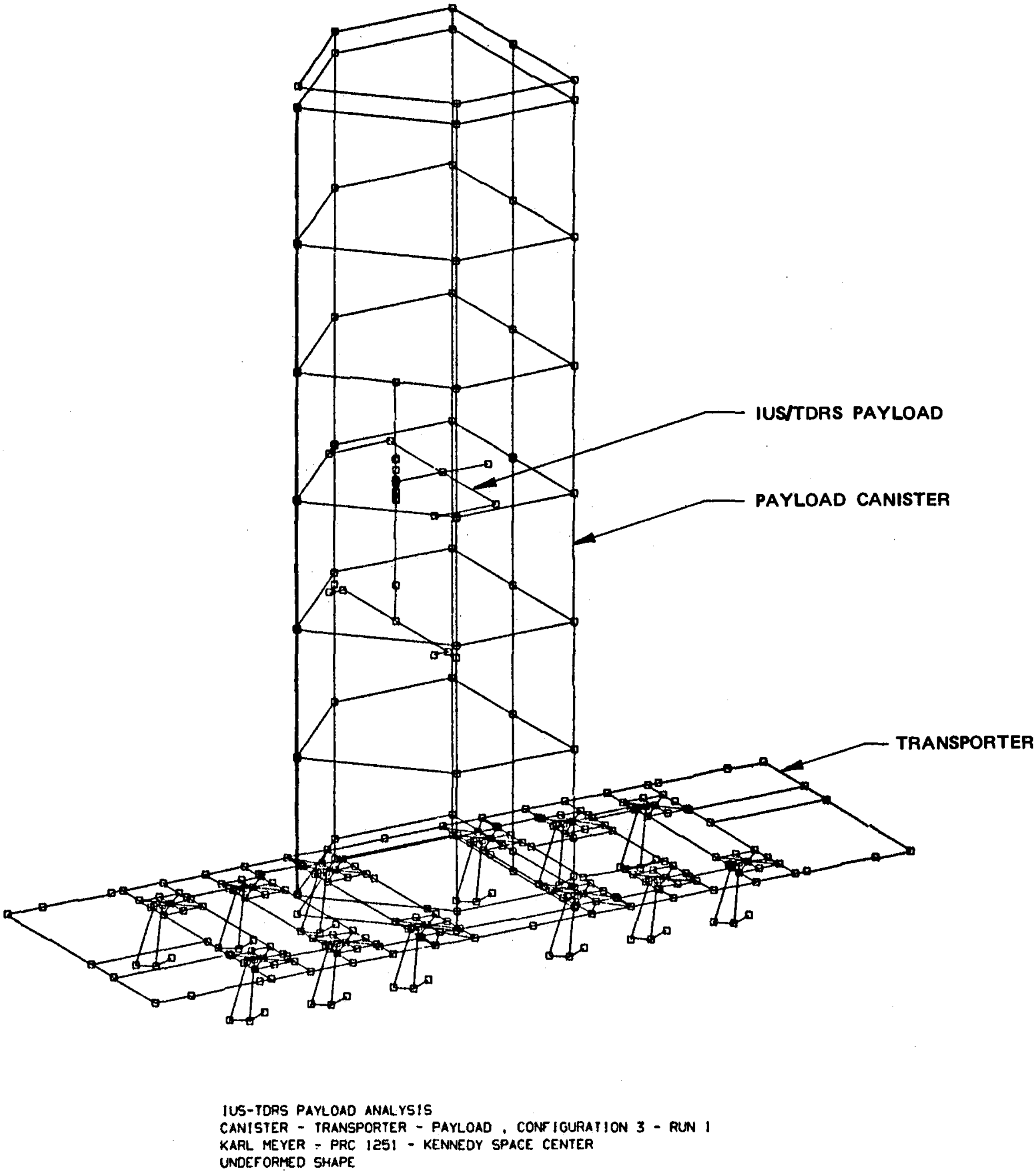
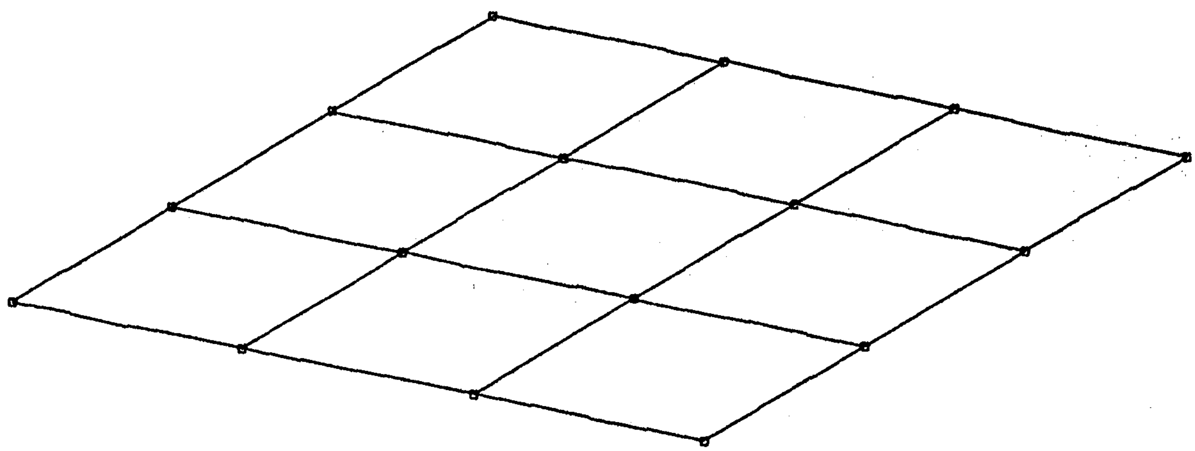


Figure 2. NASTRAN Undeformed Structural Plot of T/C/P System with PLOTEL used for Canister Plot



PAYLOAD - TRANSPORTER DYNAMIC ANALYSIS
TEST MODEL 2, WO 2018C
ROSELLE HANSON, PRC-1275, KSC
UNDEFORMED SHAPE

Figure 3. Test Models 1 and 2

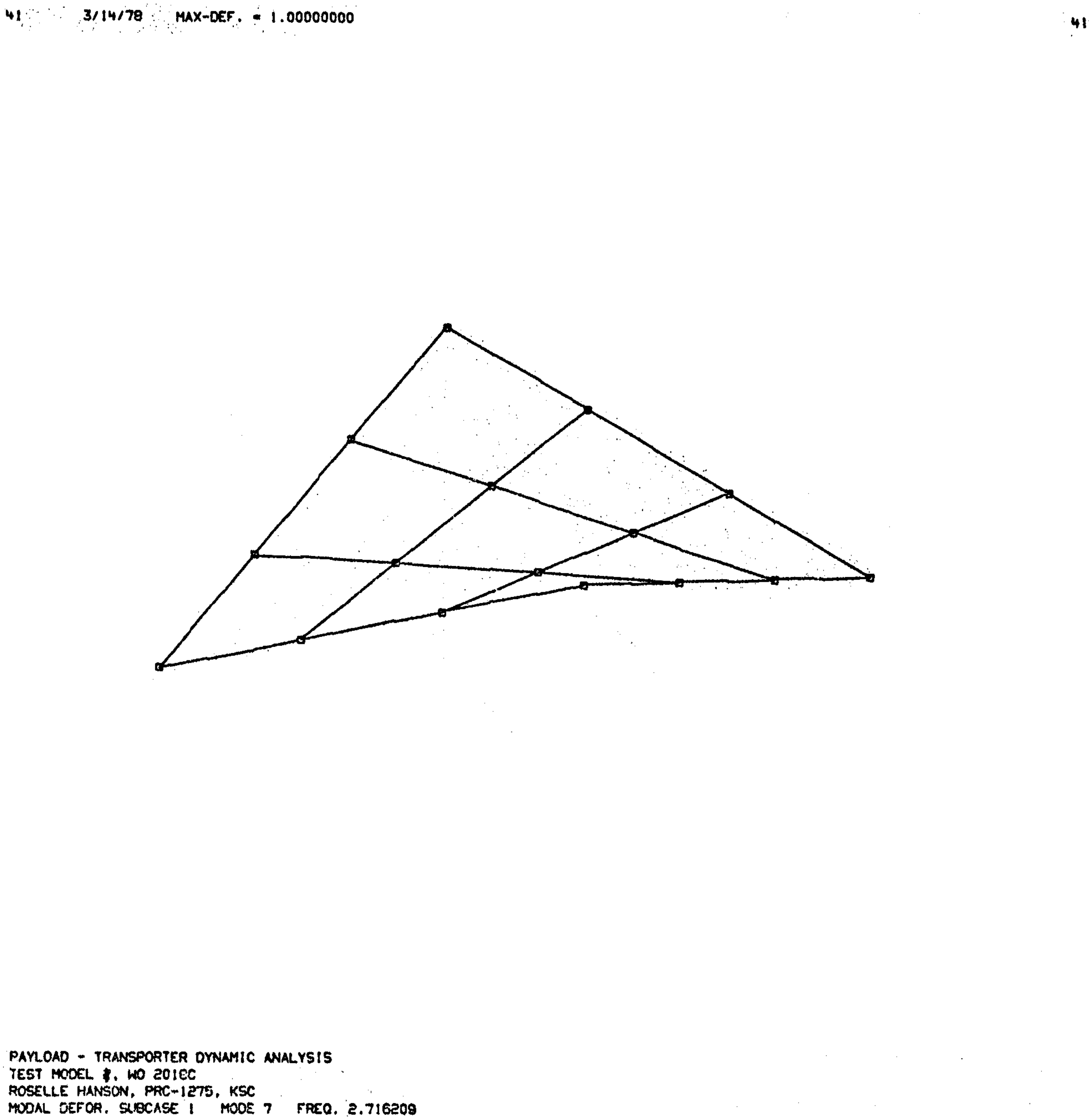
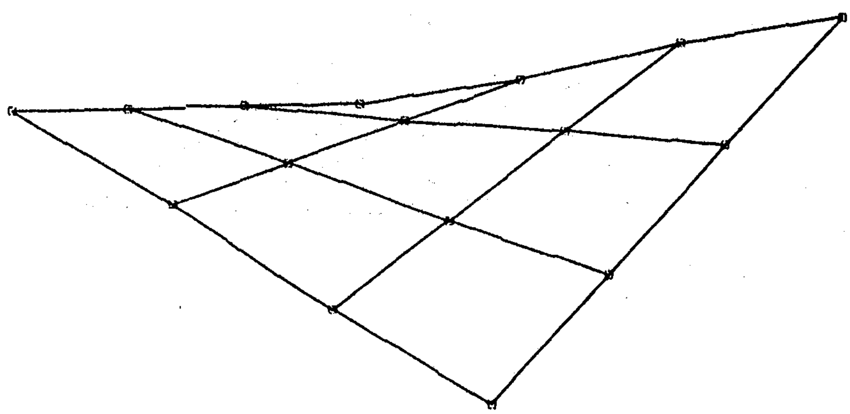


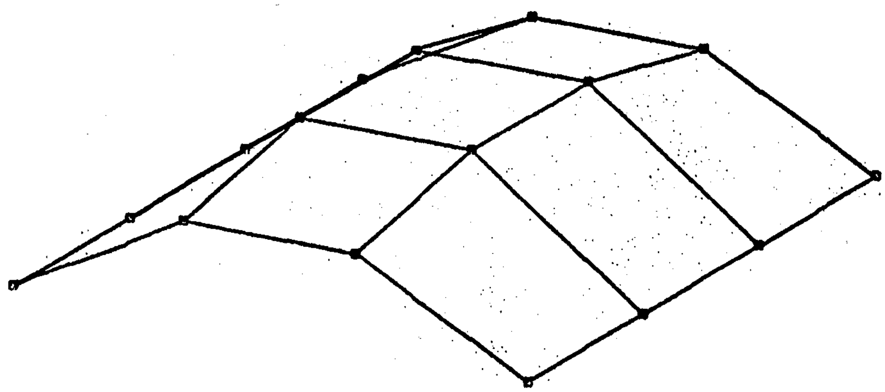
Figure 4. First Torsional Mode, Test Model 1



PAYLOAD - TRANSPORTER DYNAMIC ANALYSIS
TEST MODEL 2, WO 2018C
ROSELLE HANSON, PRC-1275, KSC
MODAL DEFOR. SUBCASE 1 MODE 7 FREQ. 13.55733

Figure 5. First Torsional Mode, Test Model 2

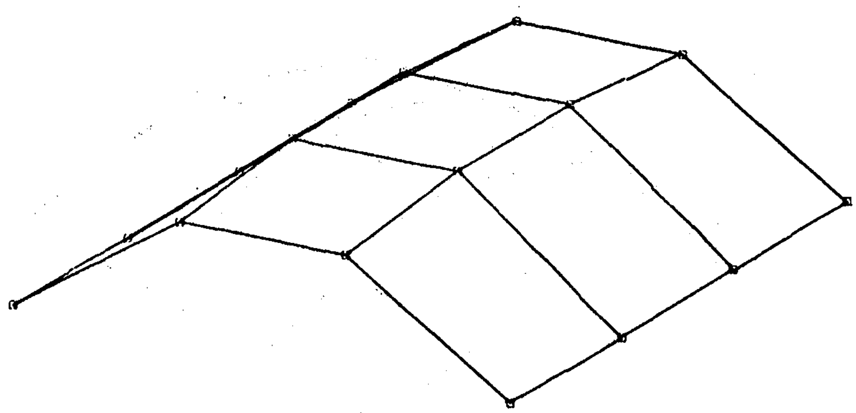
42 3/14/78 MAX-DEF. = 1.00000000 42



PAYLOAD - TRANSPORTER DYNAMIC ANALYSIS
TEST MODEL 2, WO 2018C
ROSELLE HANSON, PRC-1275, KSC
MODAL DEFOR. SUBCASE 1 MODE 8 FREQ. 44.00233

Figure 6. First Bending Mode, Test Model 1

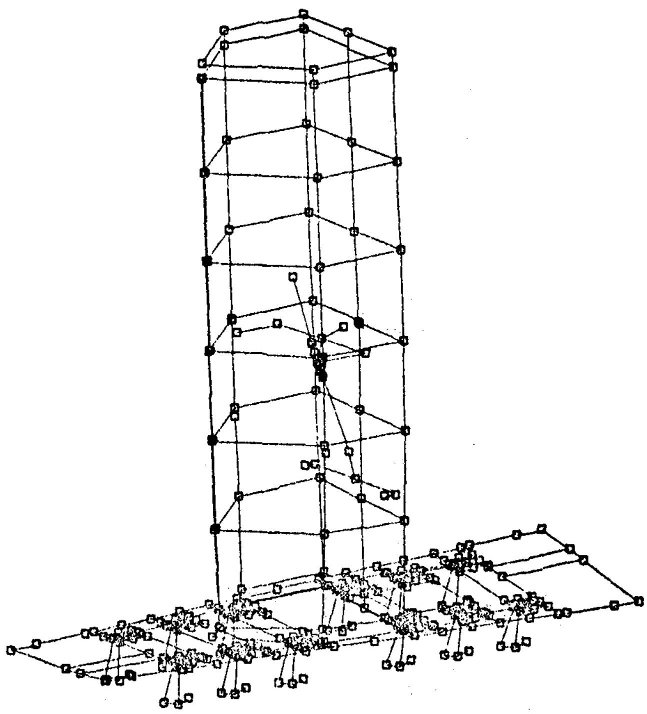
42 3/17/78 MAX-DEF. = 1.00000000 42



PAYLOAD - TRANSPORTER DYNAMIC ANALYSIS
TEST MODEL 2, WO 2018C
ROSELLE HANSON, PRC-1275, KSC
MODAL DEFOR. SUBCASE 1 MODE 8 FREQ. 44.42864

Figure 7. First Bending Mode, Test Model 2

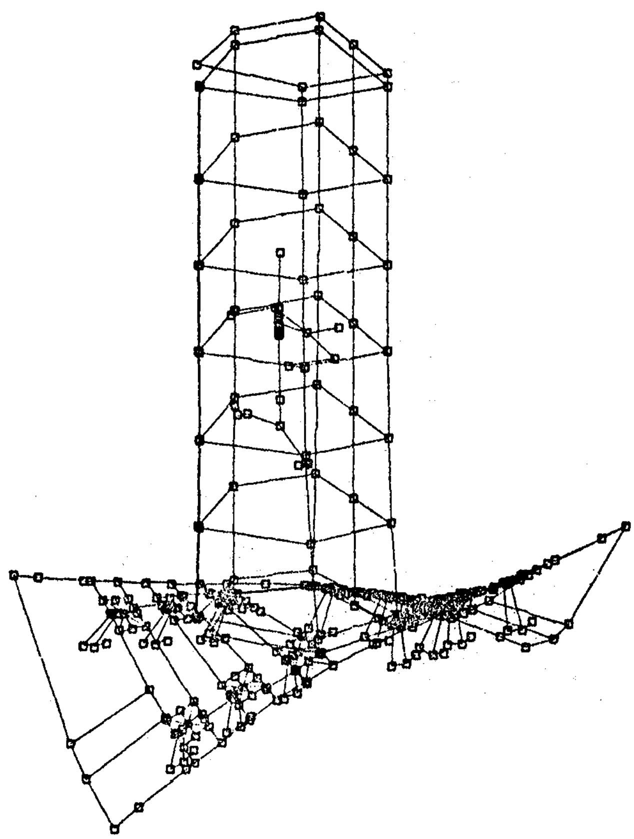
165 4/ 7/78 MAX-DEF. = 1.00000000 165



IUS-TDRS PAYLOAD ANALYSIS
CANISTER - TRANSPORTER - PAYLOAD , CONFIGURATION 3 - RUN 1
KARL MEYER - PRC 1251 - KENNEDY SPACE CENTER
MODAL DEFOR. SUBCASE 1 MODE 7 FREQ. 4.280093

Figure 8. IUS/TDRS Mode

169 4/ 7/78 MAX-DEF. = 1.00000000 169



IUS-TDRS PAYLOAD ANALYSIS
CANISTER - TRANSPORTER - PAYLOAD , CONFIGURATION 3 - RUN 1
KARL MEYER - PRC 1251 - KENNEDY SPACE CENTER
MODAL DEFOR. SUBCASE 1 MODE 11 FREQ. 7.177253

Figure 9. Transporter Torsional Mode

REFERENCES

1. The NASTRAN User's Manual, NASA-SP-222(03), March 1976

2. Torsional Analysis of Rolled Steel Sections, Bethlehem Steel Corporation