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AN EVALUATION OF A CONSTRAINED TEST METHOD FOR OBTAINING FREE BODY RESPONSES

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16. Abstract

A method for obtaining free body responses from dynamic tests on a constrained structure is investigated for practical feasibility. The method is based on the principle that a constrained structure can be considered to be a free body acted upon by multiple forces which include the forces of constraint. By measuring these forces and by exciting the structure so as to develop linearly independent sets of forces, one can compute the response of the free body to one force at a time. Techniques for producing these independent forces are discussed.

This report includes the development of the theory, computer simulations of tests of representative aerospace vehicles (including experimental error), a description and listing of the computer programs developed. The procedure appears to be a practical method for obtaining in-flight characteristics of such vehicles.

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LIST OF SYMBOLS

f	applied force
$\bar{f}_k$	vector of complex amplitude of applied force
F	matrix of applied forces
M	number of points at which force excitation is applied
N	number of points at which response measurements are made
r_i	reaction force at constraint i
$\bar{y}_k$	vector of complex amplitude of deflection
y	matrix of complex amplitudes of deflection
Y	complex displacement mobility matrix relating forces and responses
ω	frequency of applied sinusoidal forces

BRACKETS

[ ]	matrix
{ }	column vector

SUPERSCRIPTS

-1	inverse

AN EVALUATION OF A CONSTRAINED TEST METHOD FOR OBTAINING FREE BODY RESPONSES

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INTRODUCTION

Dynamic testing, both full scale and model, is an essential step in predicting the response of aerospace vehicles to the conditions to which they will be subjected in flight. This testing is required for modal analysis, stability and control studies and loads analyses and is applied to design verification and modification studies. The actual in-flight boundary conditions, however, cannot be exactly duplicated on the ground.

In order to simulate the free-body boundary conditions of a vehicle in flight, the usual procedure has been to support the vehicle on a system which is relatively soft so that the "rigid body" frequencies (which should be zero) are low compared to the frequencies of the deformation modes of the structure. A commonly used technique (References 1, 2, and 3) for launch vehicles consists of supporting the vehicle vertically on cables attached to its base. While tests conducted in such a manner seem to have given acceptable results, there are several disadvantages to this scheme. It is necessary to construct a tall structure capable of supporting the total weight of the vehicle. There is some uncertainty in the effects of the cable dynamics and non-linearities on the vehicle response (Reference 2). Various cable configurations have been known to give variation in test results (Reference 1). Certain new problems arise for vehicles which are not axisymmetric. When the center of gravity varies laterally under various fuel loads, the stabilization of such a vehicle on soft supports can become a major consideration. Vehicles which require testing in more than one attitude compound these difficulties.

A procedure which could eliminate the effects of supports would be of significant benefit. It would not be necessary to use soft suspensions with the assumption that the interactions with the supporting structure are not significant. It would be possible to support the system being tested on a relatively stiff base, thus simplifying the problems of static stability and attitude variation. The design of supporting towers would be greatly simplified and the overall cost of testing would be reduced. It is essential, of course, that such a procedure be reliable, accurate, not overly sensitive to measurement errors, and applicable to real test conditions.

There are several analytical methods which convert constrained responses into free body responses. Typical methods are presented in References 4, 5, and 6. These methods, however, are suitable only for analytical procedures where the response on infinitely rigid supports is known (or can be calculated) and where the mass matrix of the structure is available. Since such data is unmeasurable in a test, these methods are not usable.

The method which is examined here uses the measured forces of constraint to convert the measured structural responses to free body responses. The structure under test is considered to be supported on real supports, but their specific characteristics are not required since only their measured reactions are used. The procedure uses only data which are actually measured, and no quantitative assumptions are used. The basis of this method was first discussed in Reference 7.

The primary purpose of the work reported here is to evaluate the suitability of the method for use under realistic conditions and for representative aerospace vehicles. Additional purposes are to establish guidelines for usage of the method and to provide computer software capable of analyzing actual test data.

DESCRIPTION OF THE THEORY

BASIC CONCEPT

Consider a constrained structure which is being shaken by a known force and assume that the reaction forces at the supports are known. The structure responds precisely as if it were a free body being simultaneously subjected to the actual applied forces and to the forces of constraint. Thus, a shake test in which the constraining forces are measured gives direct information about the free body response of the structure when acted upon by several forces. As will be seen below, it is possible to convert information of this type into the free body response of the system when subjected to only one force at a time. This is what is needed to determine resonance data and to predict the effects of arbitrary loads.

ANALYSIS

The analysis assumes that the structure being studied is linear at each frequency. That is, the response is proportional to the force and the principle of superposition holds. For sinusoidal forces at a frequency, ω, applied at M points on a structure, there is defined a vector $\bar{f}_k$, which represents the complex amplitude of applied force at each of the points. Similarly, $\bar{y}_k$, is a vector representing the complex amplitudes of the deflection at each of N points resulting from the force, $\bar{f}_k$. There is no necessity for the force points (represented in $\bar{f}_k$) to coincide with the response points (represented in $\bar{y}_k$). Y is the complex NxM displacement mobility matrix representing the relationship between the forces and responses. $\bar{f}_k$, $\bar{y}_k$, Y and the relationship between them are written:

$$\bar{y}_k = \begin{Bmatrix} y_1 \\ y_2 \\ \vdots \\ y_N \end{Bmatrix} \qquad \bar{f}_k = \begin{Bmatrix} f_1 \\ f_2 \\ \vdots \\ f_M \end{Bmatrix} \qquad Y = \begin{bmatrix} \frac{\partial y_1}{\partial f_1} & \frac{\partial y_1}{\partial f_2} & \cdots & \frac{\partial y_1}{\partial f_M} \\ \frac{\partial y_2}{\partial f_1} & & & \vdots \\ \vdots & & & \\ \frac{\partial y_N}{\partial f_1} & & & \frac{\partial y_N}{\partial f_M} \end{bmatrix}$$

and

$$\bar{y}_k = Y\bar{f}_k \tag{1}$$

The displacement is used only for illustration, exactly the same relationships hold for velocity and acceleration. The displacements can also, with no change in the analysis, represent displacements or rotations in two or three directions at one geometrical point by allowing one element in each vector for each of these generalized displacements. Similar considerations apply to the forces (or moments). Note that there is no necessity for Y to be square, it will contain one row for each displacement measured and one column for each point at which a force is applied and, as will be seen below, one column for each constraint.

Consider, now, a matrix, F, containing several applied load vectors and a matrix, y, containing the corresponding deflections, as follows:

$$F = [\bar{f}_1 \quad \bar{f}_2 \ldots] \qquad\qquad y = [\bar{y}_1 \quad \bar{y}_2 \ldots]$$

and then

$$y = YF \tag{2}$$

If F is a nonsingular matrix, then the desired result, the response of particular points to single forces, may be written

$$Y = yF^{-1} \tag{3}$$

where both y and F are measured. When the "actual" applied loads only are included in F, then Y is the mobility of the structure as tested - i.e. on the actual supports. <u>If F includes any of the forces of constraint, then Y is the mobility of the structure with those constraints removed. If F includes all the forces of constraint, then Y is the mobility of the free body.</u>

As stated above, F must be nonsingular and thus have an inverse. If there are M forces to be considered (including the forces at the constraints) then M sets of forces, $\bar{f}_k$, must be applied and all of these vectors must be independent. There are at least two ways that this may be done: (1) by applying an external force at each constraint or (2) by varying the constraints.

FORCES AT CONSTRAINTS

If an exciting force is applied at the k-th constraint, the force vector will be of the form

$$\bar{f}_k = \begin{Bmatrix} r_1 \\ r_2 \\ \vdots \\ r_k + f \\ \vdots \end{Bmatrix} \tag{4}$$

where the r's are measured forces of constraint and f is the applied force. The force vectors obtained by applying forces to the structure at each of the constraint points will ordinarily be independent of each other and the force matrix will, therefore, be nonsingular. In the event the force matrix is ill-conditioned, the location or characteristics of the constraints may be altered to yield a well behaved force matrix. The matrix of forces at the supports including the applied forces will be called F_s.

At the same time that these forces are measured, the displacements are measured at the points of interest on the structure and one column of y is formed for each column of F_s. Then, as above

$$Y = yF_s^{-1} \tag{5}$$

where Y represents the deflection of each point of interest due to each of the loads applied to the structure (at the supports). This is the free body mobility matrix. This procedure must be carried out over the frequency range of interest.

If it is desired to find the response due to forces applied to the structure at points other than the support points, then the structure must be shaken at these points in addition and the forces at the constraints must be recorded. If F_{SA} is a matrix representing the forces of constraint for each non-constraint point of excitation, then the F matrix becomes

$$F = \left[\begin{array}{c|c} I & 0 \\ \hline F_{SA} & F_S \end{array}\right] \tag{6}$$

where unit forces are applied. The inverse of this matrix involves little more than inverting F_S and is given by

$$F^{-1} = \left[\begin{array}{c|c} I & 0 \\ \hline -F_S^{-1} F_{SA} & F_S^{-1} \end{array}\right] \tag{7}$$

In practice it will often be just as convenient to invert the matrix of Equation (6) directly. Equation (7) illustrates that no numerical complications are introduced by forces at additional points.

VARIED CONSTRAINTS

Any means of varying the constraint forces such that the F matrix is nonsingular will work. Applying a force at each of the constraints was just discussed. Another possible method is to vary the constraints themselves such that the force vectors are independent.

If the structure is supported redundantly, then a procedure which would work is to shake at only one constraint and remove one constraint at a time resulting in an F matrix of the following form (where the force is applied at station 1)

$$F = \begin{bmatrix} f + r_1 & f + r_1 & f + r_1 & f + 0 & f + r_1 & \cdots \\ r_2 & r_2 & 0 & r_2 & \cdots & \\ r_3 & 0 & r_3 & r_3 & \cdots & \\ \vdots & & \vdots & & & \end{bmatrix} \tag{8}$$

where the first column represents the measured loads when all the supports are used, the second represents the loads with constraint number 3 removed, etc.

The same effect can be achieved by varying some parameters, e.g. the stiffness, of each constraint one at a time. This would eliminate the need for redundant supports and reduce the amount of data required.

The other considerations are similar to the previous method.

APPLICATION CONSIDERATIONS

The method has attributes which make it an especially attractive candidate for practical application. These include the use of only measured data and the lack of quantitative assumptions. There are, however, as in all procedures, certain considerations involved in planning an efficient and accurate application of the method.

NUMBER OF CONSTRAINTS

At each frequency it is necessary to conduct one test for each constraint, thus it is desirable to keep this number to a minimum. While it is possible to constrain all rigid body motions with six constraining forces, there is no necessity for such complete constraint, however. During the design of a test, consideration should be given to test configurations which allow freedom of motion, e.g. in the horizontal plane and around the vertical axis. In this case, it would be necessary to shake vertically at each support and measure each of the vertical forces of constraint. In addition, any other shaker position or orientation could be used while the three vertical forces were measured.

For the design of a specific test, it is necessary to evaluate the cost of eliminating constraints compared to the reduced testing required.

SUPPORT CHARACTERISTICS

In a theoretical sense, the characteristics of the supports are immaterial. These characteristics, however, do affect the magnitudes of the forces and displacements which will be measured. The accuracy of the various transducers (accelerometers, load cells, etc) depends on the magnitude and frequency of the quantity being measured. Thus, for the most reliable results, the supports should be designed and the transducers selected so as to operate in their most accurate region. It is not expected that this will be an extremely stringent requirement, but care must be exercised as in planning any test, to insure that the results be meaningful.

In the analysis, the constraint forces are considered to be sinusoidal and at the same frequency as the excitation force. For real supports, it is not uncommon for components of other frequencies to pollute the response. It is implicitly assumed here that any such components have been removed from the data by electronic or digital filtering or by Fourier analysis. Obviously, highly nonlinear supports will increase the uncertainty in the data and should be avoided.

ERRORS

Any correctly derived analytical procedure will work when the input data is exact. When such methods are applied to measured data the effect of the unavoidable experimental errors is critical in the evaluation of the practicality of a particular technique. This process uses a measured force matrix containing errors, inverts this matrix and multiplies by another measured matrix also containing errors. The behavior of these errors will determine whether the method is economically feasible. The expected accuracy of the final results compared to the accuracy of an alternate method is an important consideration.

TEST SIMULATION

A computer simulation of alternative test configurations can be an extremely useful tool in the preliminary design of any test. Such a simulation applied to this method using an approximate analytical model of the vehicle can be used to determine the sensitivity to error and the expected accuracy of the results of the various arrangements considered. It should include realistic experimental errors, approximate constraint characteristics, and vary the frequency over the range of interest.

SIMULATION SOFTWARE

The computer software developed under this study has been designed to serve several purposes. The programs can be used to perform a general evaluation of the feasibility of these techniques. This is the particular application made in the work reported here.

In addition, the program has been designed so as to be capable of analyzing actual test data. This facility was accomplished by dividing the software into two separate logical entities. The first develops simulated test data, the second analyzes the test data which can be either simulated or actual.

A third application of the software is for the planning of an actual test. This usage requires approximate analytical models of the structure to be tested and the constraints. The programs can be used to optimize the locations and general characteristics of the constraints and to estimate the accuracy of the resulting data.

COMPUTER PROGRAM ORGANIZATION

The portion of the software used to develop the simulated test data is itself divided into two separate programs for efficiency reasons. The first program takes as input the mass and stiffness matrices of the structure being modeled. The structural damping coefficient is also specified. This quantity is allowed to vary over the structure. If g_i is the damping coefficient at coordinate i then the diagonal elements of the imaginary damping matrices are given by $g_i K_{ii}$ and the off-diagonal elements are given by $\sqrt{g_i g_j}\, K_{ij}$ where K_{ii} and K_{ij} are diagonal and off-diagonal elements of the stiffness matrix. In addition, and as separate inputs for convenience, the support characteristics are entered. These characteristics include the stiffness, structural damping, and/or viscous damping coefficient.

These quantities, of course, would be unknown during an actual test but they must be estimated for purposes of simulation. The program computes exact values of the constrained system mobility matrices at a set of specified frequencies and writes this data on tape.

The second program uses the exact data computed by the first program and introduces specified errors (see below) to yield simulated acceleration and force measurements. The simulated test data is written on a tape in a format which is compatible with actual test data. The exact data developed in the first program may be reused with different errors or forces. Because the first program is by far the most time consuming, this feature improves the efficiency of the simulation process.

The third program uses as input, either simulated data (as developed above) or actual (but pre-processed) test data. This program reduces the measured constrained accelerations and forces of constraint to yield the free body responses of the system.

Detailed listings of the programs, description of input formats and the various options available are given in the appendix.

SIMULATED ERRORS

In order to simulate test data for the evaluation of a numerical procedure, it is essential that the simulated data contain realistic errors.

The program has provisions for several types of errors to be simultaneously applied to each of the simulated measured accelerations and the simulated measured forces. These errors include: (1) a uniformly distributed random percentage error on amplitude between specified limits; (2) a uniformly distributed random phase angle error between specified limits; (3) a constant specified percentage bias error; (4) a uniformly distributed random amplitude error between limits (simulating system noise).

The simulated measurement errors which are estimated to be representative of the current state-of-the-art and applied in the computations were generally as follows: $\pm 5\%$ random error on amplitude of acceleration and force; $\pm 5^{\circ}$ random phase error on acceleration and force; a random ± 2.54 cm/sec^2 (± 1 in/sec^2) and a random .01 radian/sec^2 on translational and rotational acceleration measurements respectively. However, several computer experiments were conducted using error values ranging to $\pm 15\%$ random and $\pm 15\%$ random phase error to test the sensitivity of the method to error.

MODELS ANALYZED

The analytical models analyzed were representations of a 1/15 scale dynamic model of a space shuttle configuration (described in Reference 8). The various stiffness and consistent mass matrix formulations corresponding to each of the structures considered were obtained using NASTRAN and were supplied by NASA. In addition, structural damping coefficients of 3% and .5% were used for the orbiter and booster fuselages respectively. The basic models studied are illustrated in Figures 1 and 2.

Several models were investigated including: an eight coordinate orbiter fuselage limited to transverse motion; a two-dimensional or 16-degree-of-freedom representation of the orbiter fuselage with each of the eight coordinates possessing a transverse and rotational degree of freedom; a three-dimensional model of the orbiter fuselage with each point having six degrees of freedom, yielding a total of 48 degrees of freedom; a coupled orbiter and booster model consisting of 18 coordinates with each point having transverse and rotational degrees of freedom; a one-dimensional model of the booster fuselage having 10 degrees of freedom.

DISCUSSION OF RESULTS

Computer simulations of dynamic tests were conducted to obtain the free body response of the aforementioned models. A variation of parameters was considered including magnitude and location of constraints, structural and viscous damping of the constraints and experimental error. The simulated tests were carried out at various frequencies over a spectrum of interest peculiar to each model studied.

Except when otherwise noted, the errors used were as follows: uniform random amplitude error of ±5%, uniform random phase error of ±5°, uniform random absolute amplitude error of ±2.54 cm/sec^2 (±1 in/sec^2) on translational accelerations and .01 rad/sec^2 on rotational accelerations. Also, the corresponding force random errors used were ±5% and ±5°. Each simulated test was run with force levels of 4.45, 22.24, 44.48, 111.21N (1, 5, 10, 25 pounds). Each of these was repeated with different random sequences. Thus, every range of data shown in the following plots represents the extreme values obtained in 8 simulated tests. The predominance of the data was obtained using the procedure of shaking at the constraints.

For convenience the plots of acceleration response per unit force are shown without dimensions since only relative amplitudes are of interest here. However, for reference, unity represents .0057 m/sec^2/N (1 in/sec^2/lb)

A large number of simulations were computed. Only a small portion of the data for each of approximately 20% of the cases run is presented in this report. The conditions shown were selected to illustrate typical results. The remaining data, which is available (and easily duplicated), would be purely repetitive and add no new information.

TWO-DIMENSIONAL ORBITER

The two-dimensional orbiter is a relatively simple model and much of the early exploratory work was done with it. Some typical data is presented here. Figure 3 presents for reference the exact normalized acceleration amplitude frequency response and the associated phase angle of the two-dimensional orbiter in free and constrained configurations. For the constrained system, the supports consisted of both 1.75 x 10^{6}N/m (10,000 lb/in.) translational springs and 1129 m-N/rad (10,000 in-lb/rad) rotational springs at stations .69m and 1.66m, with zero structural and viscous damping. Application of the theory to the simulated test constrained response yielded the free body characteristics of the structure. The calculated natural frequencies for the range of frequencies shown are in excellent agreement with those supplied by NASA.

Figure 4 illustrates the effect of including measurement error in the simulated measured accelerations and the simulated measured forces. The ranges of the free body response with errors included are shown superimposed on the exact or zero error free body response. The error bounds indicated at the various frequencies were the maximum and minimum values obtained from several computer runs with the same nominal error, but with different random number seeds. The consistency of results from individual simulated tests indicates the method is relatively insensitive to the level of nominal errors applied. The natural frequencies are accurately defined and the general shape of the response curve is retained even at bounds of the errors. In Figure 5 a typical simulated test frequency response is shown compared to the exact response. It is apparent that the exact response and the response deduced from test are in excellent agreement.

The amplitude of the responses of the structure at 92 Hz, which is approximately at the first natural frequency of the free system, due to a force at station 1.66m is presented in Figure 6. The constrained response and the free body response are shown for the exact conditions. The free body responses including the effect of measurement error are indicated in the figure as ranges of values.

THREE-DIMENSIONAL ORBITER

The three-dimensional orbiter model represents a real structure with six degrees of freedom. The data presented represents the structure on six constraints and illustrates the effect of the stiffness of the supports. Figure 7 presents the constrained normalized acceleration amplitude frequency response and the accompanying phase angle for the three-dimensional orbiter model restrained with 8.75×10^5N/m (5000 lb/in) springs in the transverse, lateral and longitudinal directions at station .69m and 1.66m. The exact free body responses are also shown. The result of applying, simultaneously, the several types of errors to both the simulated measured accelerations and the simulated measured force is indicated in Figure 8. Error bounds at a particular frequency were obtained by several computer experiments at the same nominal error levels but varying the random number seed and applied force. For the error values considered the free body response does not vary significantly from the exact values. Figures 9 and 10 present similar data except that the free body response was obtained from the constrained configuration with 1.75 x 10^6N/m (10,000 lb/in.) and 8.76 x 10^6N/m (50,000 lb/in.) spring rates, respectively. A comparison of Figures 8, 9 and 10 reveals that, as would be expected, the free body response deduced from the constrained structure, for the zero error condition, are identical regardless of constraint configuration employed. The figures also illustrate that the larger ranges in results occur in the response regions of extreme slope. However, at these points the error bounds are incidental in defining the actual response curve.

The data shown in Figure 11 is the transfer response, the transverse acceleration at station .31m due to force excitation at station .69m. The exact response of the structure at 90 Hz, which is slightly below the first natural frequency of the free system, due to a force at station 1.66m is presented in Figure 12 for the free condition and for the restrained structure with constraints at station .69m and 1.66m. The results of the calculated free body responses are shown as ranges of values. Figure 13 illustrates a typical free body response converted from constrained data including measurement error compared to the exact free body response. Figures 14 and 15 present constrained and free body responses similar to Figure 13, however, the constraint spring rates were 1.75 x 10^6N/m (10,000 lb/in.) and 8.75 x 10^6N/m (50,000 lb/in.) respectively. A comparison of Figures 12, 14 and 15 illustrate the significant variation in free body responses obtained from the simulated measured test data, with error, for the different support conditions considered. The results of using the lower spring rate are more consistent and vary least from the zero error response although the same nominal errors were used in the simulated measured data obtained from each support system. In regard to Figure 15, it should be noted that in the frequency response plot, Figure 10, the frequency always resulted in values below the exact. This is the only frequency at which this condition occurred.

The results of the deduced free body responses are presented as ranges of values for each particular frequency at which the simulated tests were conducted. There is no apparent deterioration in the results due to this constraint condition.

To further examine the effect of experimental error on the analysis, simulated tests were performed using error levels ranging to $\pm 15\%$ random error on amplitude of accelerations and forces and $\pm 15°$ random phase error on the same parameters. Only one simulated test was run for each level of error at the indicated frequencies and the results are shown on Figure 25. Also presented in the figure are the ranges of values for the simulated test with nominal measurement error levels as described previously.

BOOSTER LONGITUDINAL RESPONSE

This model is an extremely simple one but does correspond to actual tests. Here the data is used to illustrate that damping in the supports has no ill effect on the results. Figure 26 presents the frequency response of the ten-degree-of-freedom booster fuselage in the free condition. The exact amplitude and the exact phase angle response are shown with the results including error in the simulated measured data given as ranges of values. The free body response was extracted from simulated measured constrained data which incorporated zero structural damping in the restraint system. It is apparent that the free body response is insensitive to the level of applied error, at least for the conditions investigated. Figure 27 presents data similar to that shown in Figure 26, however, the free body response was derived from simulated measured constraint data with 5% structural damping in the supports. Further computer experiments were conducted using 20% structural damping in the restraints. The resulting error bounds superimposed on the exact free body response are effectively the same as those shown in Figure 27, therefore, the range of values for the 20% structural damping condition are not presented. Based on the number of conditions analyzed and the levels of constraint structural damping used, it appears the free body response of the structure is insensitive to the level of structural damping in the constraint system.

The exact free body response and the constrained response from which it was deduced are given in Figure 28. Also shown are the error bounds resulting from the computer experiments in which simulated measurement errors were considered. The responses, due to force excitation at station 3.41m, were calculated at 445 Hz which is the approximate second elastic natural frequency.

IGNORED CONSTRAINTS

The forces at each constraint must be measured in order to obtain the response of the completely free body. It is also necessary to force at each of the constraints when this procedure is being used. In practice, there may actually be constraints in directions where none had been planned. For example, a pin joint under load may exhibit a torsional restraint. The question arises as to whether this method will deteriorate if some of these forces are ignored, either accidentally or intentionally.

It is necessary to reexamine the theory to answer this question. It has been shown that the responses deduced by this method are those for the structure with those constraints removed whose reaction forces are included in the force matrix. Thus, if constraint forces exist and are ignored, the computed responses are those of the structure on those constraints only. When the ignored forces are small, they will have a small influence on the free response. This situation is quite analogous to the soft suspension concept for free body testing (where, in actuality, the forces of constraint are ignored) except that here, the remaining constraints are not required to provide static stability to the structure being tested.

Thus, when the forces of a constraint are small enough to have a negligible effect on the free body response they may be ignored.

Several simulated tests of this condition were run using the two-dimensional orbiter model constrained torsionally as well as translationally (see Figure 3). Program 3 has a capability for masking selected channels of data on the input tape and this facility was used to ignore the torsional forces produced at the constraints. In these cases, the differences between the computed responses and the exact free body responses were too small to illustrate. These tests confirm the theoretical conclusion stated in the previous paragraph.

NUMBERS OF CONSTRAINTS

Some of the simulated tests illustrated had more constraints than necessary. Some allowed freedom in one or more directions.

The two-dimensional orbiter data presented here (Figures 3-6) actually had four constraints where only two were needed for full constraint of the system. Other tests not illustrated used only the two linear springs. There appeared to be no loss in validity through the use of redundant constraints. Redundant constraints, of course, increase the amount of testing required.

The number of constraints also appear to have no particular degrading effect on the data. The three-dimensional orbiter data (Figures 7-16) used six constraints with results as good as data obtained from lesser numbers of supports.

Allowing unconstrained motion in one or more directions also was found to have no noticeable effect on the data. The three-dimensional orbiter tests did not constrain the structure in roll and no loss in accuracy was observed.

From a theoretical point of view none of these conditions was expected to affect the final accuracy and the data obtained verified this conclusion.

VARIATION OF CONSTRAINTS

Figure 29 illustrates the result of applying the variation of constraint technique described in the theoretical development to the two-dimensional orbiter fuselage model. The data was achieved by varying the constraint spring rate while maintaining the same force excitation on the structure. Initially, the structure was restrained with 1.75×10^6N/m (10,000 lb/in.) springs at station .69m and 1.66m with force excitation applied at station 1.66m. Subsequently the spring rate at station .69m was changed to 3.5×10^6N/m (20,000 lb/in.) while the spring rate and force level at station 1.66m were held constant. Figure 29 presents the free body exact acceleration response of station 1.66m to force excitation at the same station. Also shown are the deduced ranges of values obtained from the simulated constrained tests applying error to the measured forces and accelerations.

The results shown on Figure 29 compare favorably with those presented in Figure 4 which were obtained by the method of force application at each of the constraints while the support characteristics remained constant. On the basis of sensitivity to measurement error there appears to be no difference in the results obtained from the two methods.

CONCLUSIONS AND RECOMMENDATIONS

GENERAL

The method of obtaining free-body responses through constrained testing was investigated for practical applicability. A large number of simulations of shake tests were carried out using several representative analytical models of space shuttle components and systems. Constraint locations and characteristics were varied. The procedure appeared to work quite well (subject to considerations discussed below) and its application to actual testing is recommended.

ACCURACY

The accuracy of the deduced free-body responses is believed to be as good as or better than other procedures using soft suspension systems where the constraining forces are assumed small and are ignored. The random errors assumed in the test simulation are believed to be within the present state-of-the-art of acceleration and force measuring systems.

For all the conditions presented, the free-body amplitude and phase data obtained versus frequency adequately defined the response curves including resonances and antiresonances.

SENSITIVITY

The data obtained suggest three general conditions under which the computed free-body response may be especially sensitive to measurement errors:

(1) At a frequency near a free body resonance which is not near a constrained resonance, larger errors occur. This is not unexpected since small responses must be converted into large ones and errors can be expected to be amplified. In general, the data has indicated that even with relatively large uncertainties, the frequency response is still well defined because it is nearly vertical in this region. This situation will only occur at a small number of lower modes, because at higher frequencies the constrained and free responses become closer to each other.

(2) Constraints which are in close proximity tend to increase the error sensitivity. This effect is due to the fact that constraints which act in the same direction and are very close to each other will tend to have nearly the same forces of constraint. This causes the corresponding

columns of the force matrix to be nearly equal and the matrix to be ill-conditioned. In general it is good policy to keep the constraints well separated when possible. However, this is not always possible, for example, when a space vehicle is in launch attitude and it is resting on several supports at its base. Under these conditions the supports should not be considered to be independent but should be treated as a single support with up to three perpendicular force constraints and up to three moment constraints. This treatment will eliminate the ill-conditioning of the force matrix. There is one condition which should be avoided. This is when the supports are not close enough to be treated as a single support, as above, and yet not far enough separated to yield a well-conditioned force matrix. This condition is expected to be rare.

(3) The third situation which appears to aggravate the error sensitivity is when the constraints are excessively stiff. This, also, is not unexpected. There are two reasons for this effect. First, the stiffer the supports, the further the actual response will be from the free-body response and the more the data has to be modified. Second, the stiffer the supports, the smaller the response of the structure for the same force and the greater the error to be expected in the raw data. This effect will show up in the data obtained in these simulations because of the noise type error included in addition to the percentage amplitude and the phase errors used.

The use of very stiff supports is to be discouraged, in general, if for no other reason than to reduce the exciter force requirements. In general, the supports should not be so soft that there is only a small difference between free and constrained responses because of the problems associated with static stability, etc, as discussed in the Introduction. On the other hand, they should not be so stiff that excitation of the structure will be a problem. There is a very large middle ground where the techniques studied here are especially applicable.

PRE-TEST SIMULATION

Prior to applying these procedures in an actual test, it is recommended that an approximate simulation be carried out. The computer programs supplied are perfectly suited for this purpose. The input required is a simple model (a highly reduced NASTRAN model, for example) and very approximate characteristics of the supporting system under consideration. The simulation will determine whether any of the conditions mentioned above will be approached and will allow the consideration of alternate supports or support locations which will improve the validity of the data.

Simulation is not essential and confidence may be had in the results if the test is set up with the sensitivity considerations, above, in mind. However, such a simulation would be an inexpensive precaution and would probably result in more valid data.

POST-TEST SENSITIVITY ANALYSIS

The program supplied will convert test data into free-body data after the test data has been calibrated and filtered and properly formulated on a tape. The particular tape format used was selected to make this preprocessing as simple as possible.

The addition of a feature to this program is recommended which will establish confidence limits on the free-body data. The procedure would be as follows: (1) the user supplies his best estimates as to the ranges of errors contained in the input data; (2) the program then automatically and randomly varies each element of input within the specified limits and produces a distribution of variances in the deduced free-body responses in a form similar to that of Figure 16. This provides an estimate of the possible error in the free-body response.

IMPLEMENTATION

The primary method considered in this report calls for shaking the system at each constraint. The literal implementation of this system may entail some problems of convenience. Unless multiple shakers are to be used, probably the most feasible method would be to install a shaker at one support, perform a frequency sweep, then move it to another support and perform another frequency sweep until all the required data was obtained. There are two disadvantages to this procedure: (1) the free-body responses cannot be obtained until all the testing has been completed; and, (2) care must be exercised to insure that the data is taken at precisely the same frequencies.

In order to implement this procedure, the supports must be designed to allow for application of the shaker. It is suggested that only linear (and no torsional) constraints be used since moment applications would not be as convenient to apply or measure. A type of constraint worth considering is the cantilever flexible beam as described in Reference 9. It would be possible to mount a shaker directly beneath the support. Because the beam would not have the extreme flexibility requirements as in the reference, it does not have to be cantilevered but may be supported at two or more points. Another advantage to the beam support is that it is possible to easily move the shaker from one position to another by sliding it along the beam.

If several shakers are available it is possible to obtain all the data needed at one frequency before proceeding to the next frequency. This allows the possibility of a simple real time data reduction system yielding on site visualization of the free-body responses. This possibility includes the conveniences of "free-body" testing with the stability and adaptability of constrained testing.

It is recommended that a simple implementation of this technique be tested in practice and that an evaluation of more sophisticated implementation procedures be carried out for future use.

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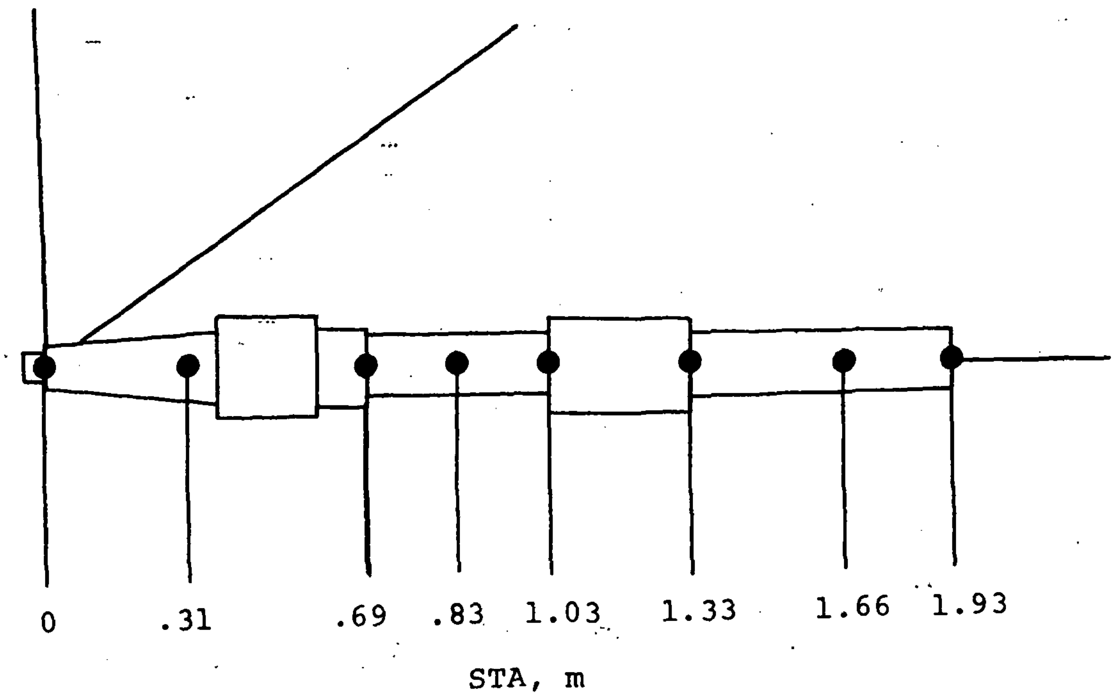


Figure 1. Orbiter Fuselage Model

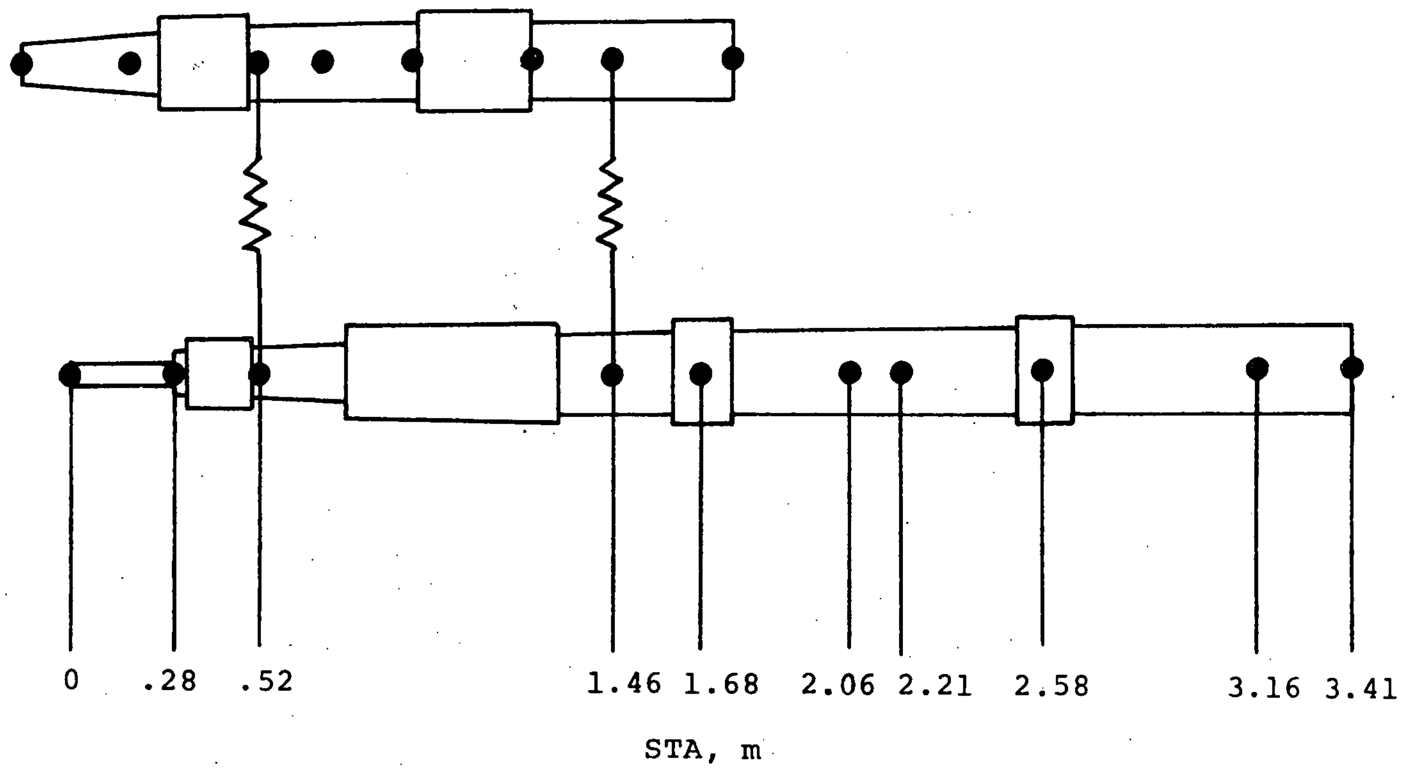
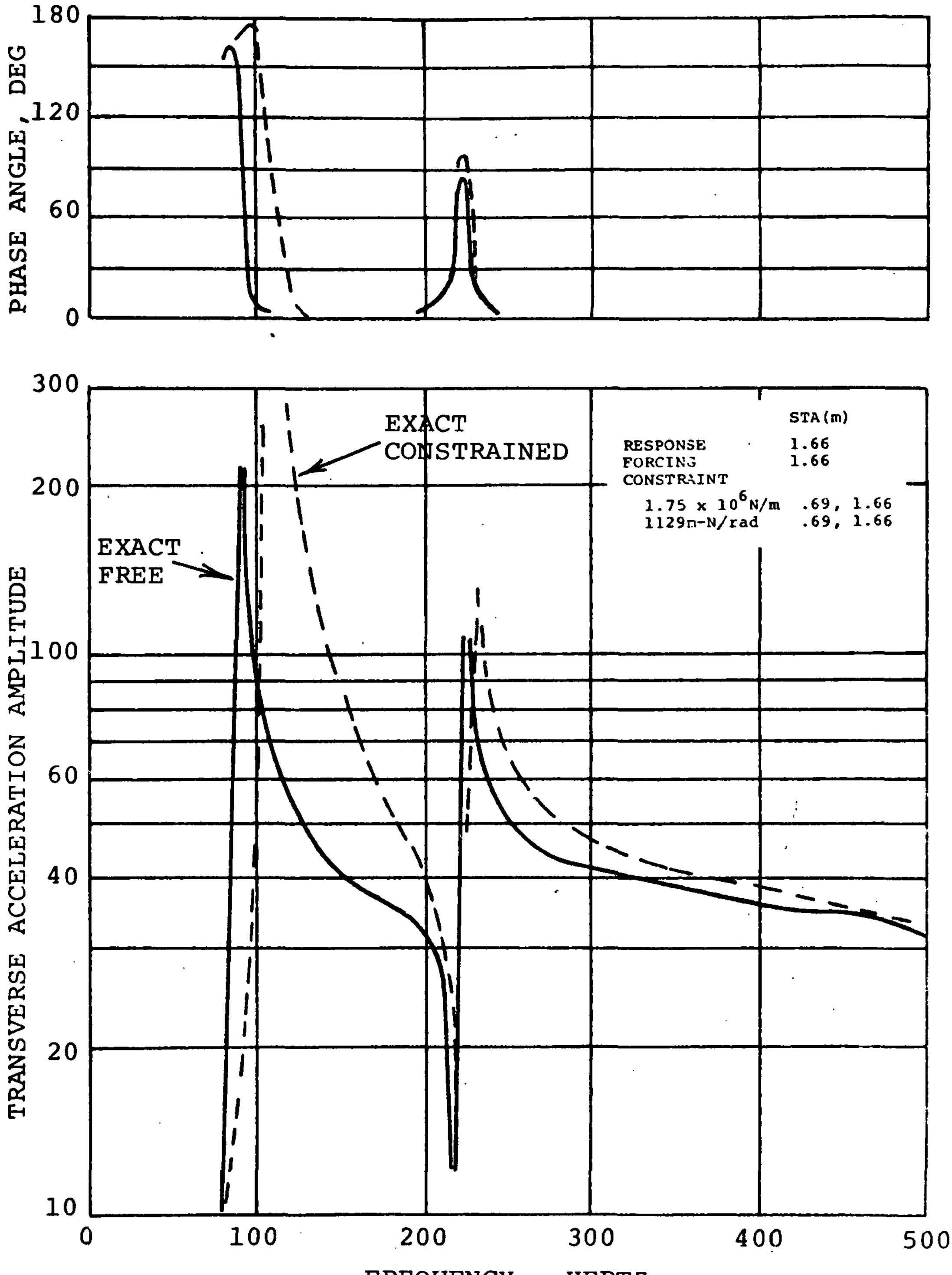
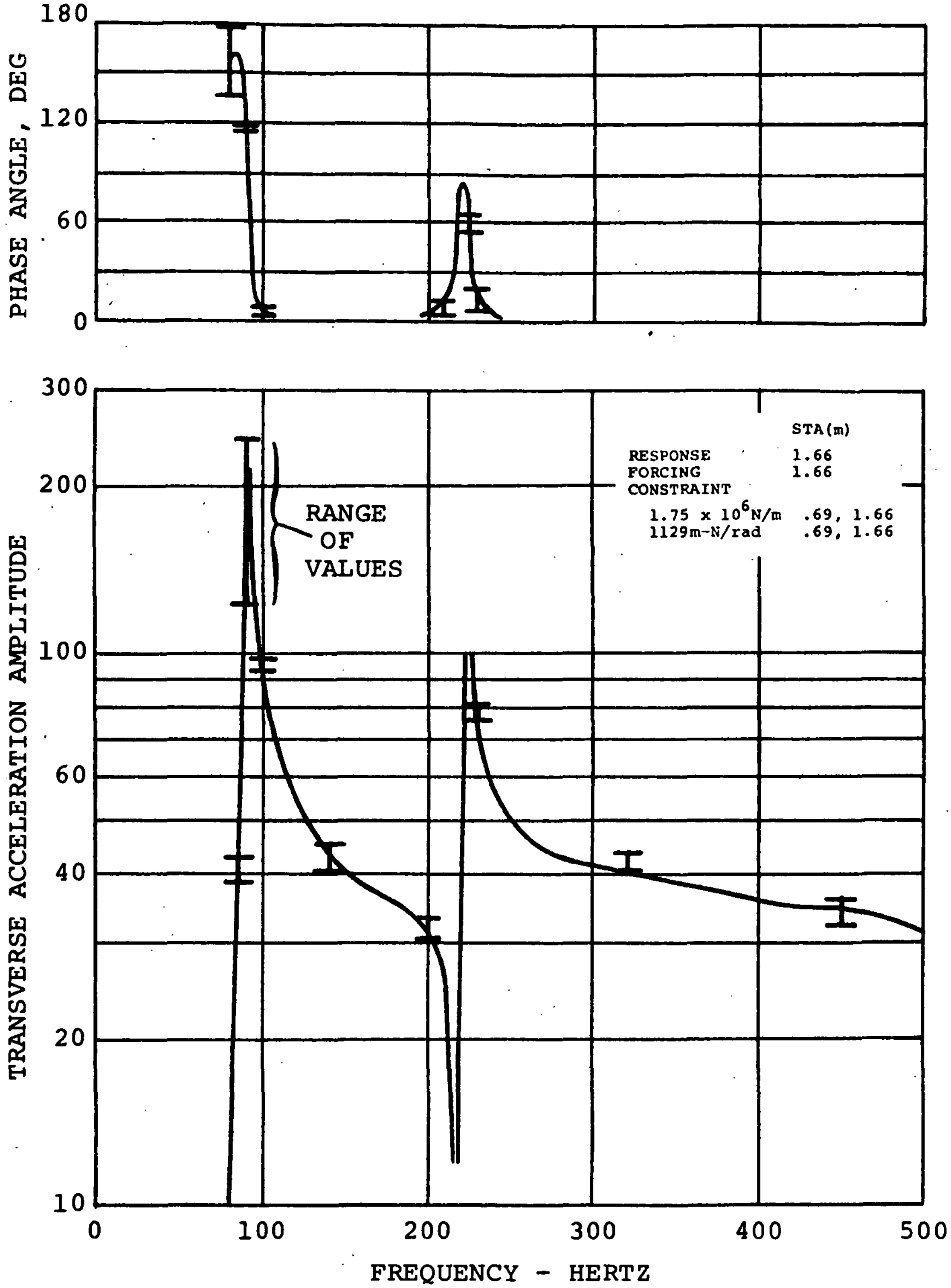


Figure 2. Orbiter-Booster Combination Model



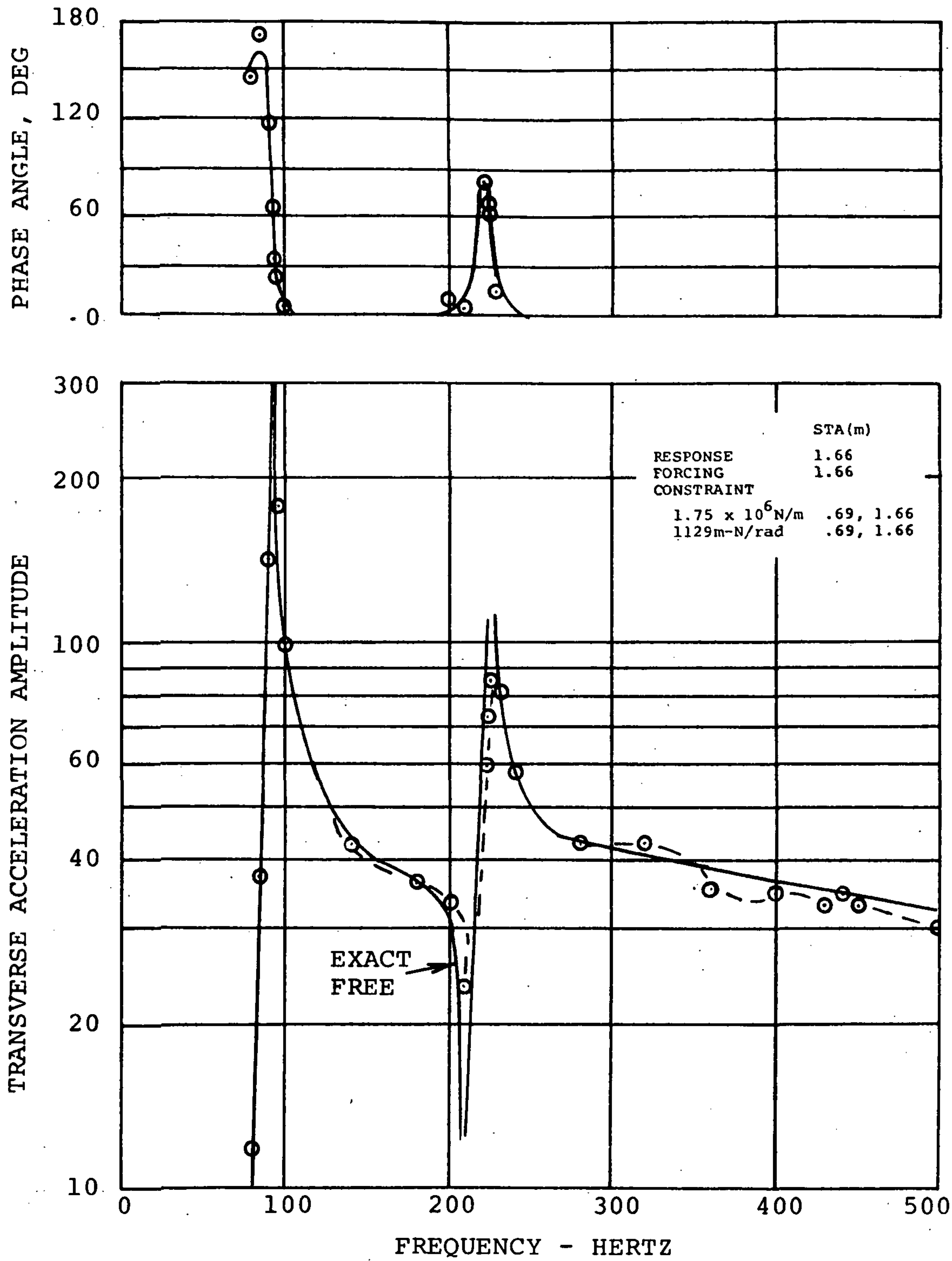
TWO-DIMENSIONAL ORBITER

Figure 3. Frequency Response



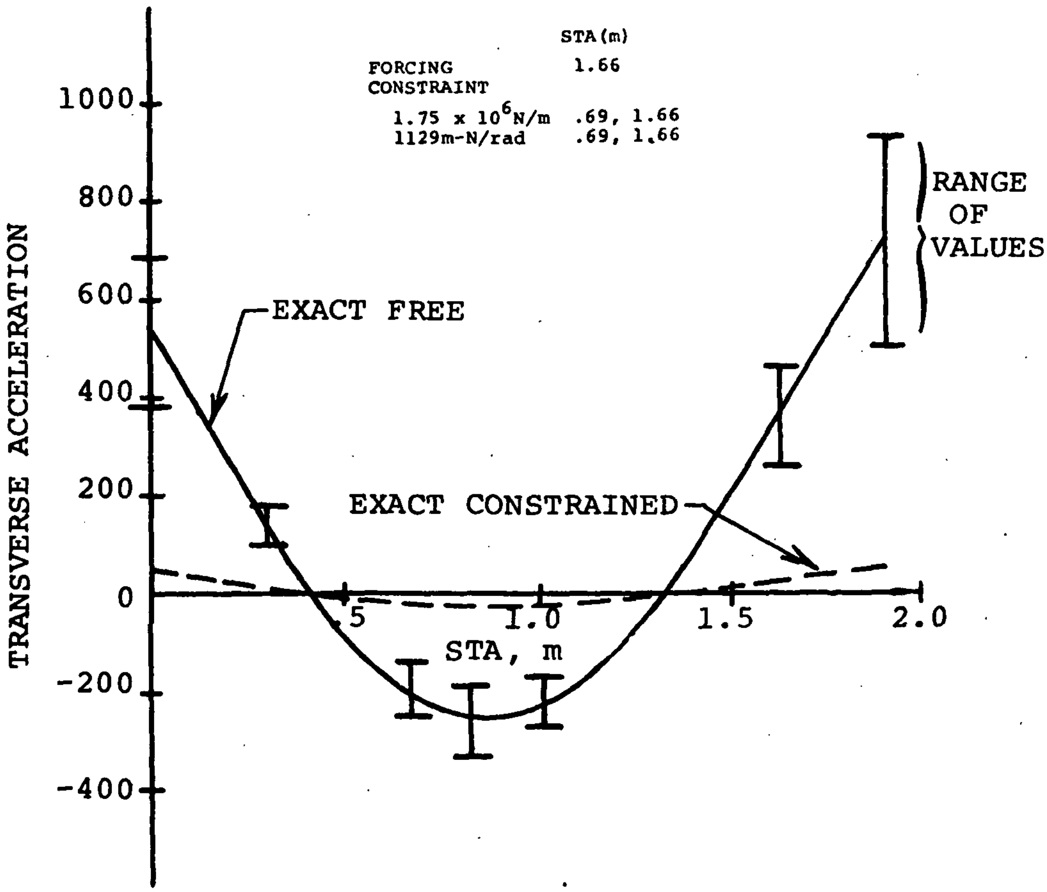
TWO-DIMENSIONAL ORBITER

Figure 4. Effect of Error on Frequency Response



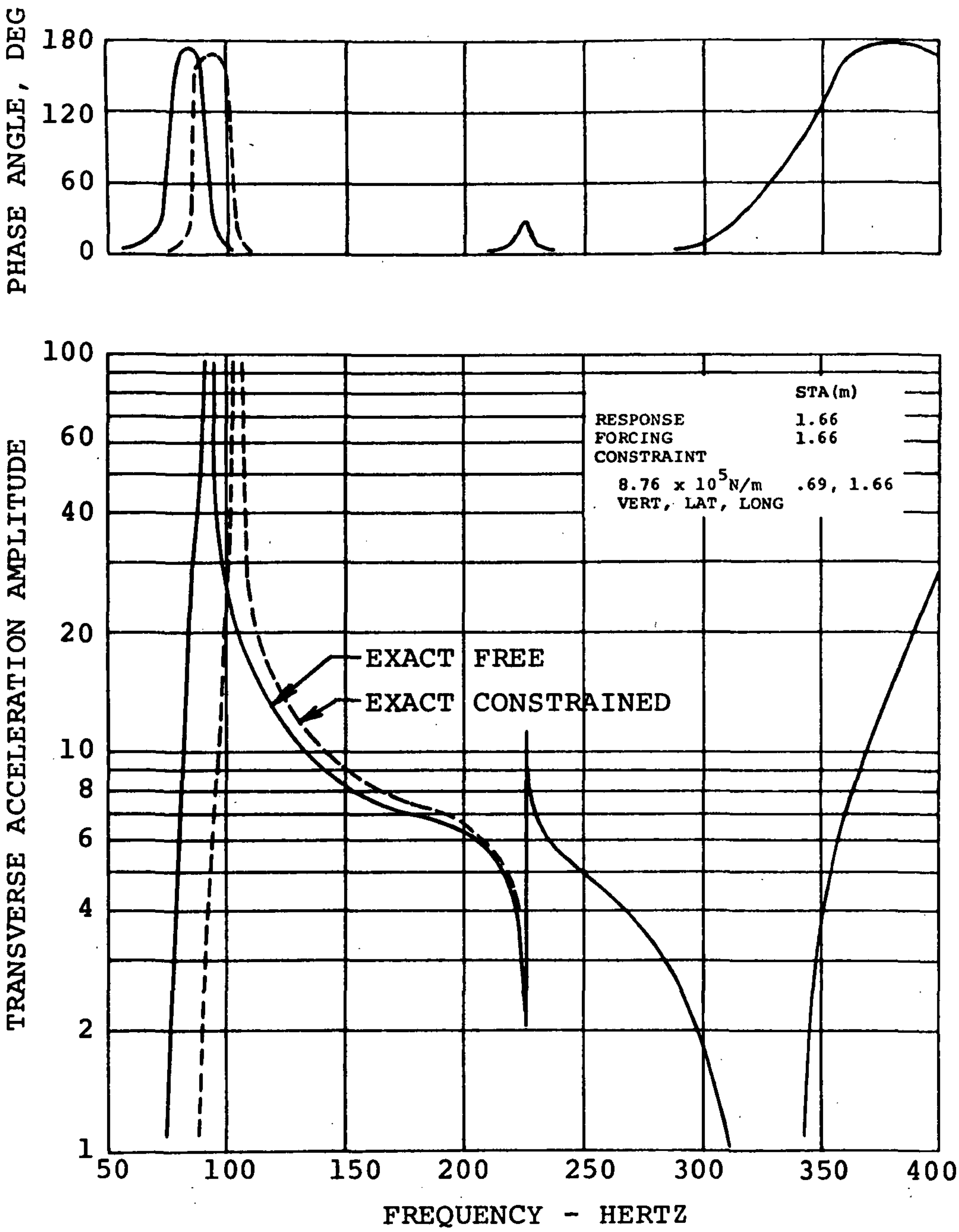
TWO-DIMENSIONAL ORBITER

Figure 5. Typical Deduced Frequency Response



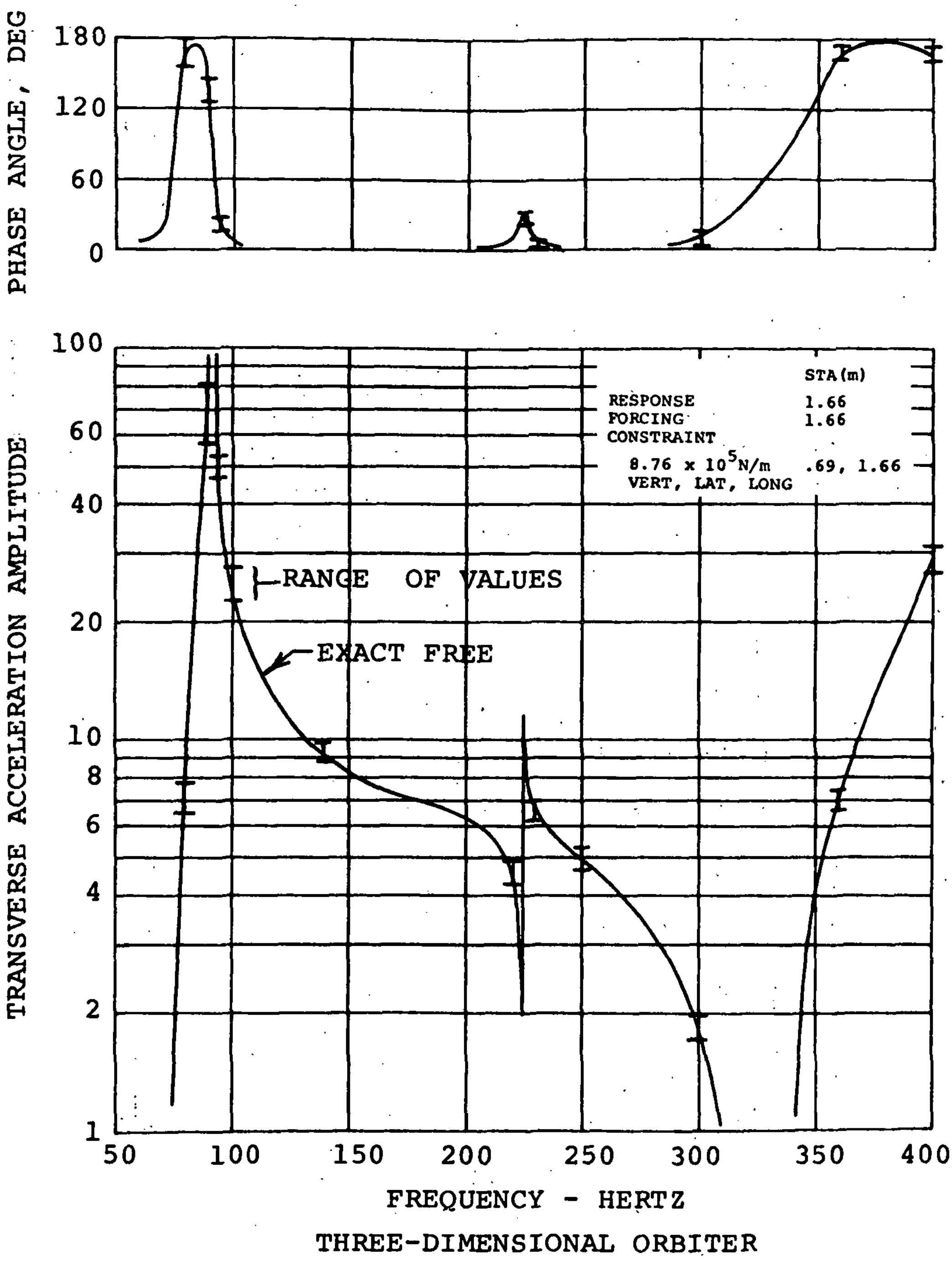
TWO-DIMENSIONAL ORBITER

Figure 6. Transverse Bending Response at 92 Hz



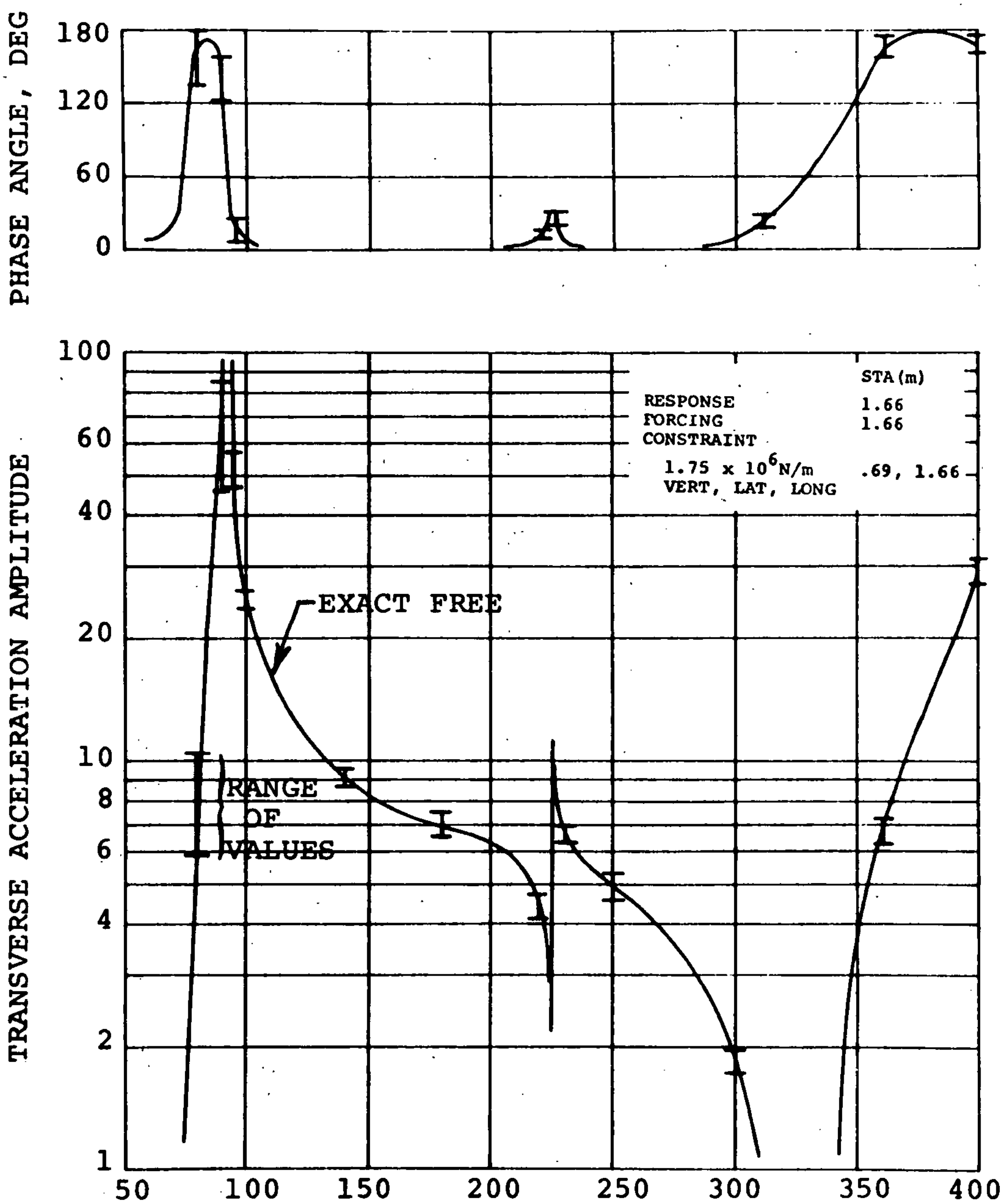
THREE-DIMENSIONAL ORBITER

Figure 7. Frequency Response



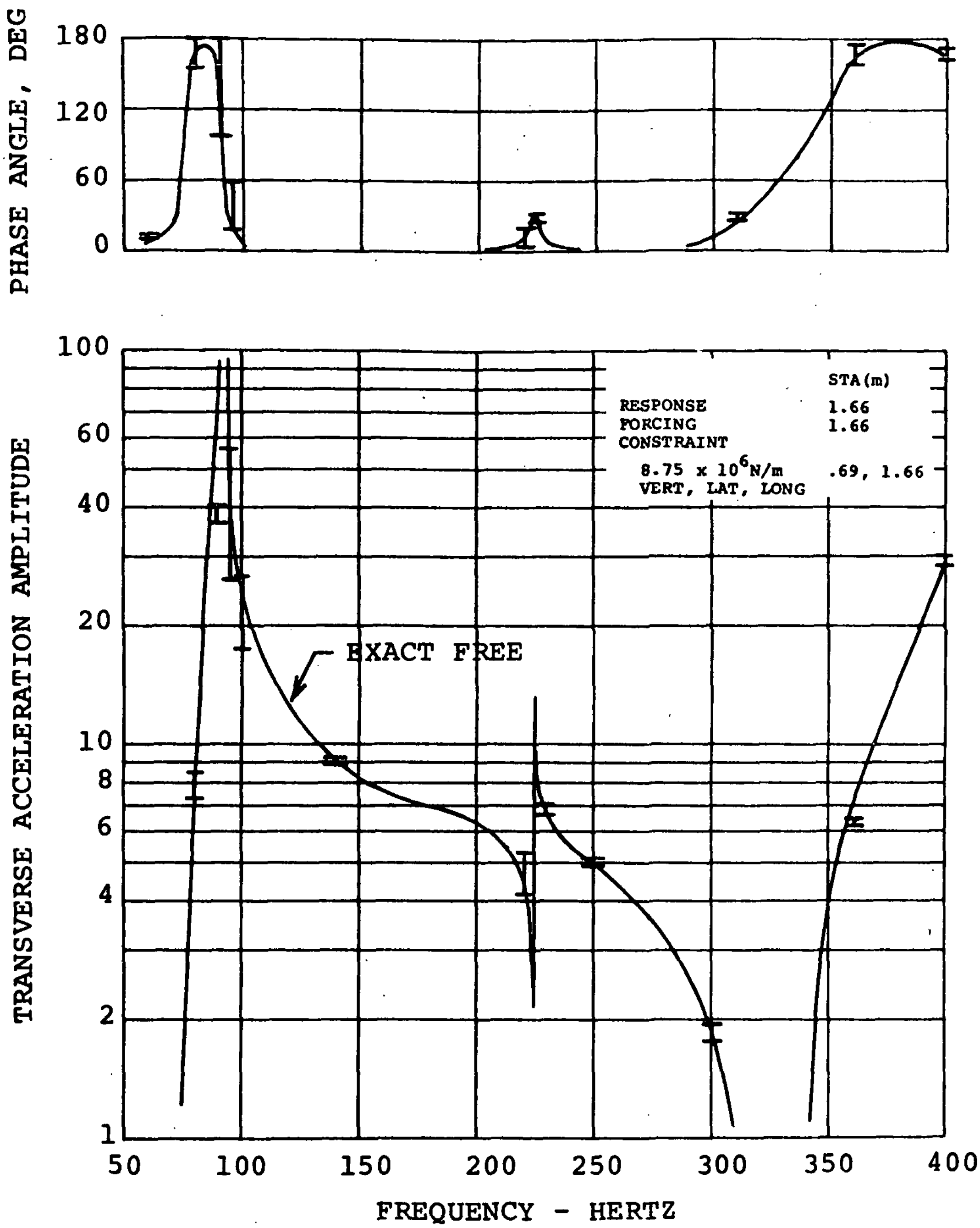
THREE-DIMENSIONAL ORBITER

Figure 8. Effect of Error on Frequency Response, 8.75×10^5 N/m Restraints



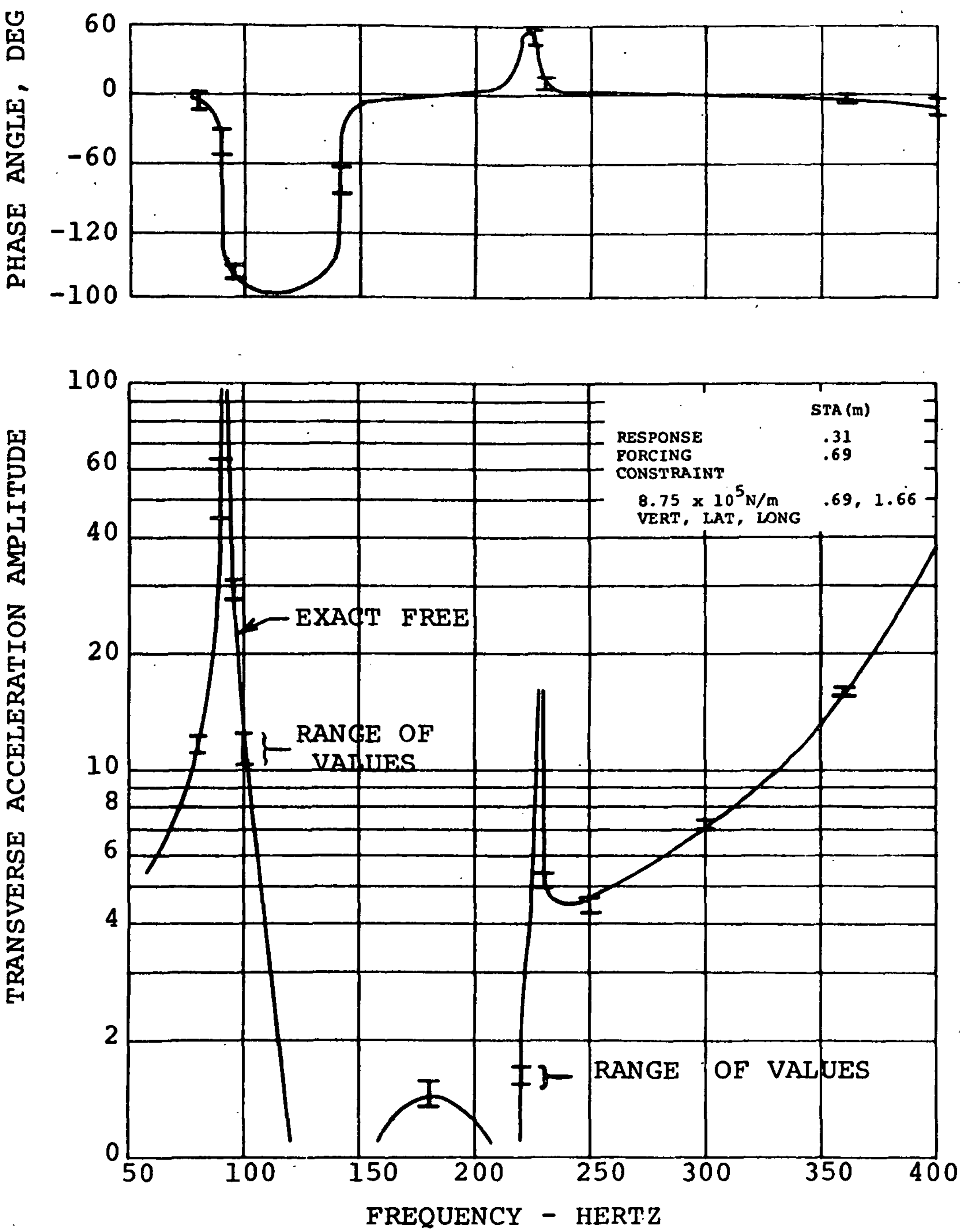
THREE-DIMENSIONAL ORBITER

Figure 9. Effect of Error on Frequency Response, 1.75×10^6 N/m Restraints



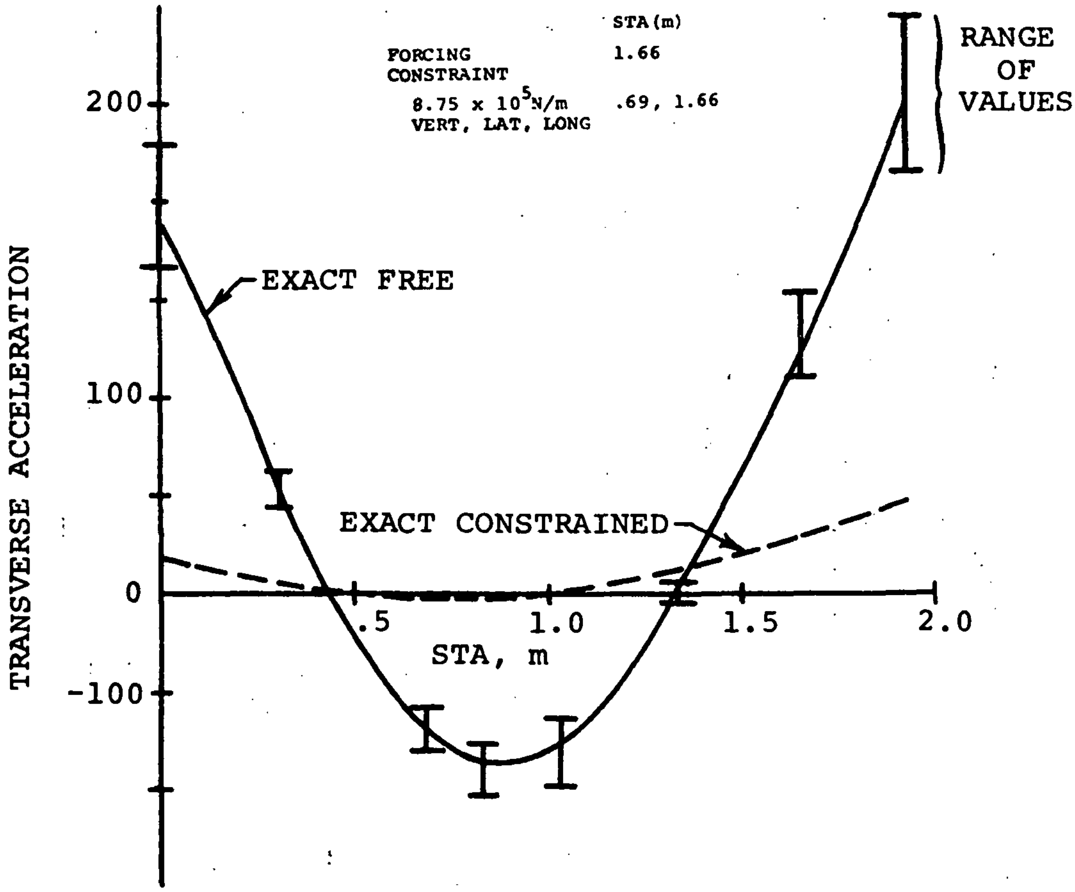
THREE-DIMENSIONAL ORBITER

Figure 10. Effect of Error on Frequency Response, 8.75×10^6 N/m Constraints



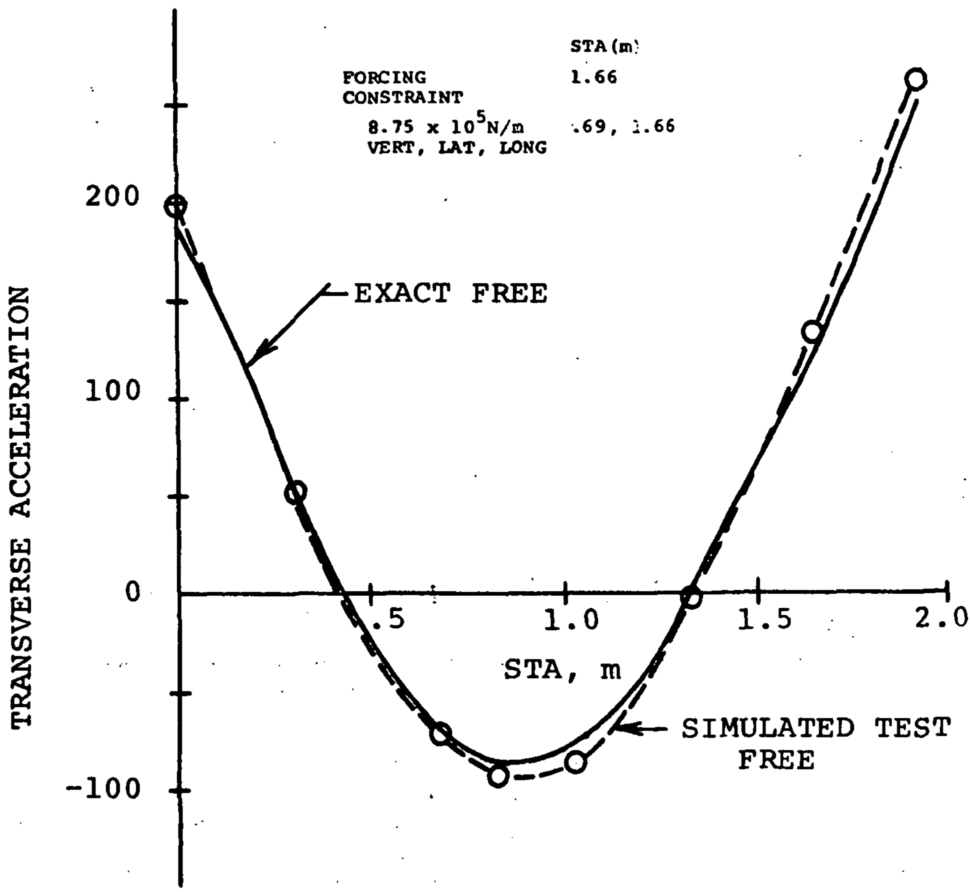
THREE-DIMENSIONAL ORBITER

Figure 11. Transfer Frequency Response



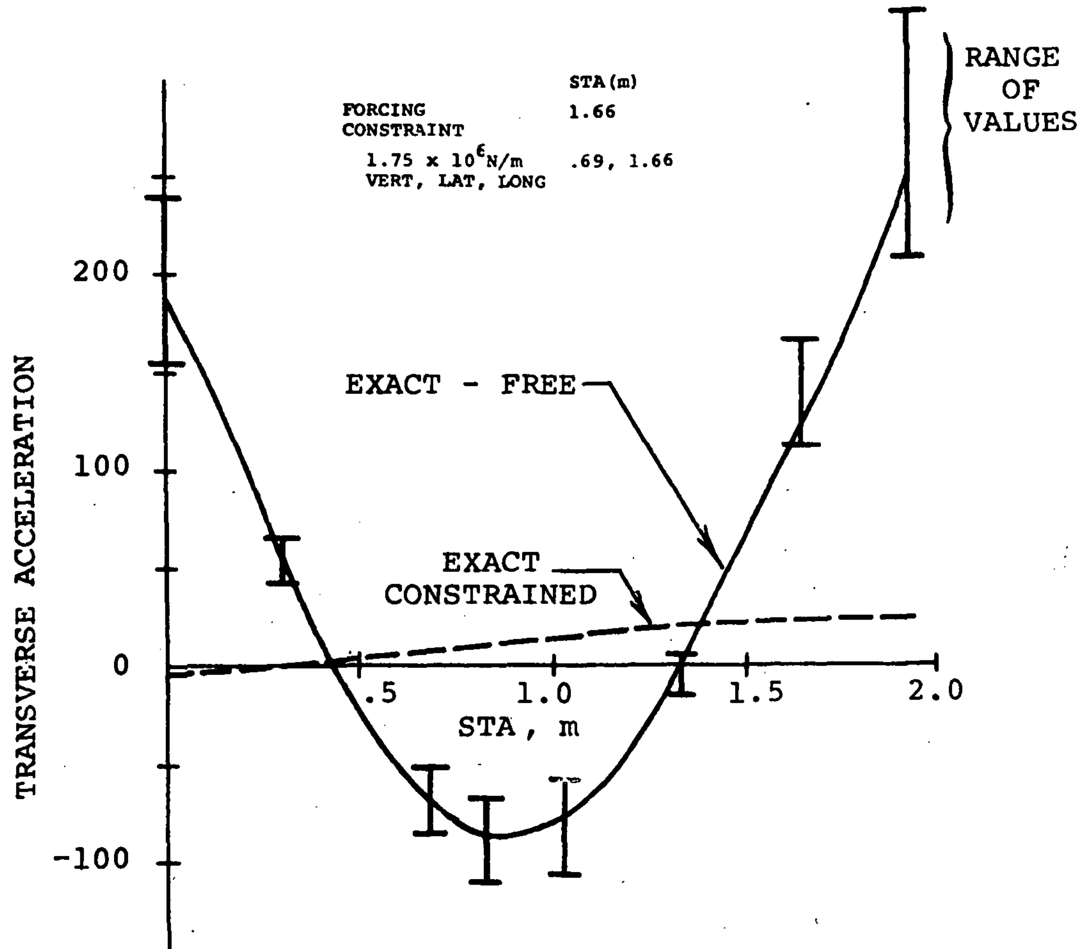
THREE-DIMENSIONAL ORBITER

Figure 12. Transverse Bending Response at 90 Hz, 8.75×10^5 N/m Restraints



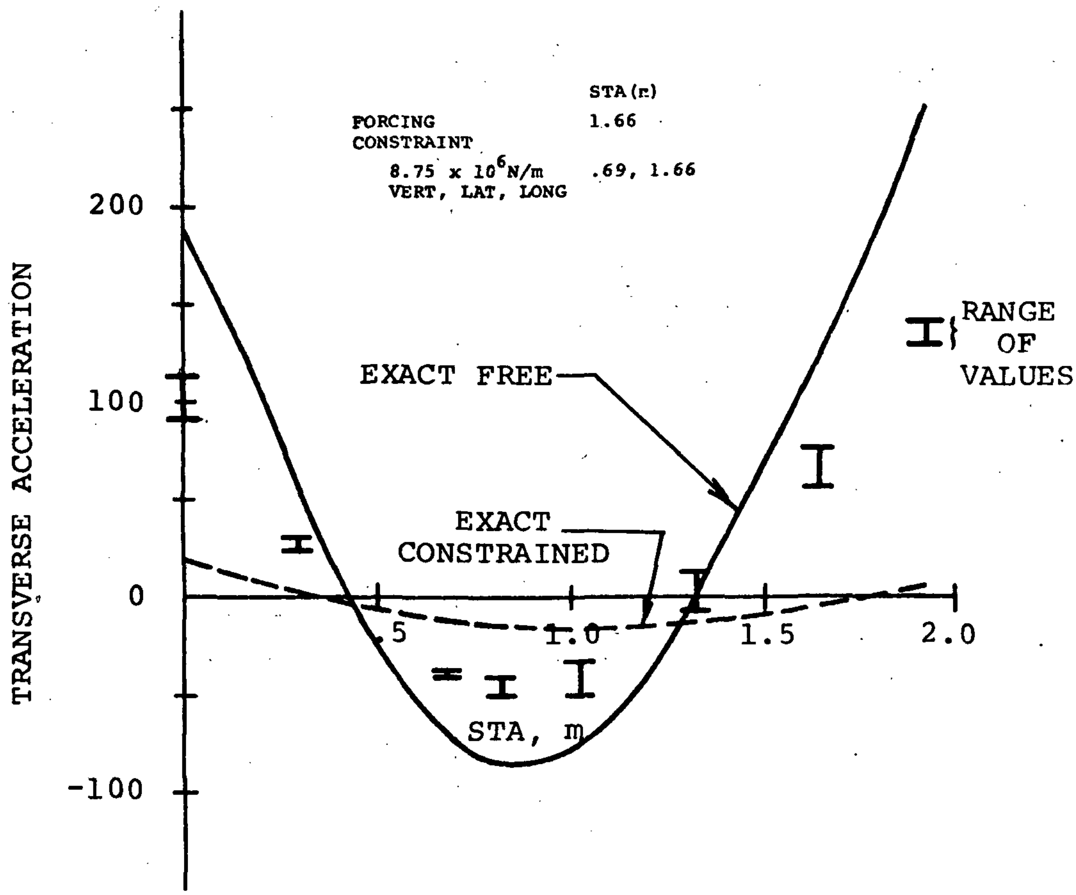
THREE-DIMENSIONAL ORBITER

Figure 13. Typical Deduced Transverse Bending Response at 90 Hz



THREE-DIMENSIONAL ORBITER

Figure 14. Transverse Bending Response at 90 Hz, 1.75×10^6 N/m Restraints



THREE-DIMENSIONAL ORBITER

Figure 15. Transverse Bending Response at 90 Hz, 8.75×10^6 N/m Restraints

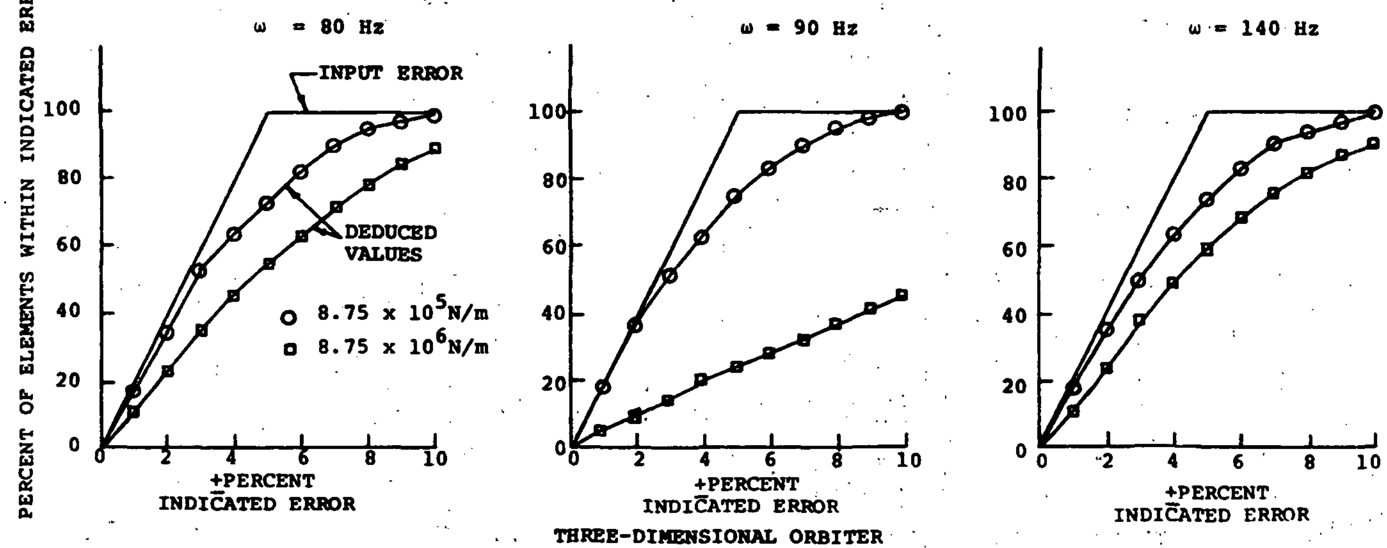
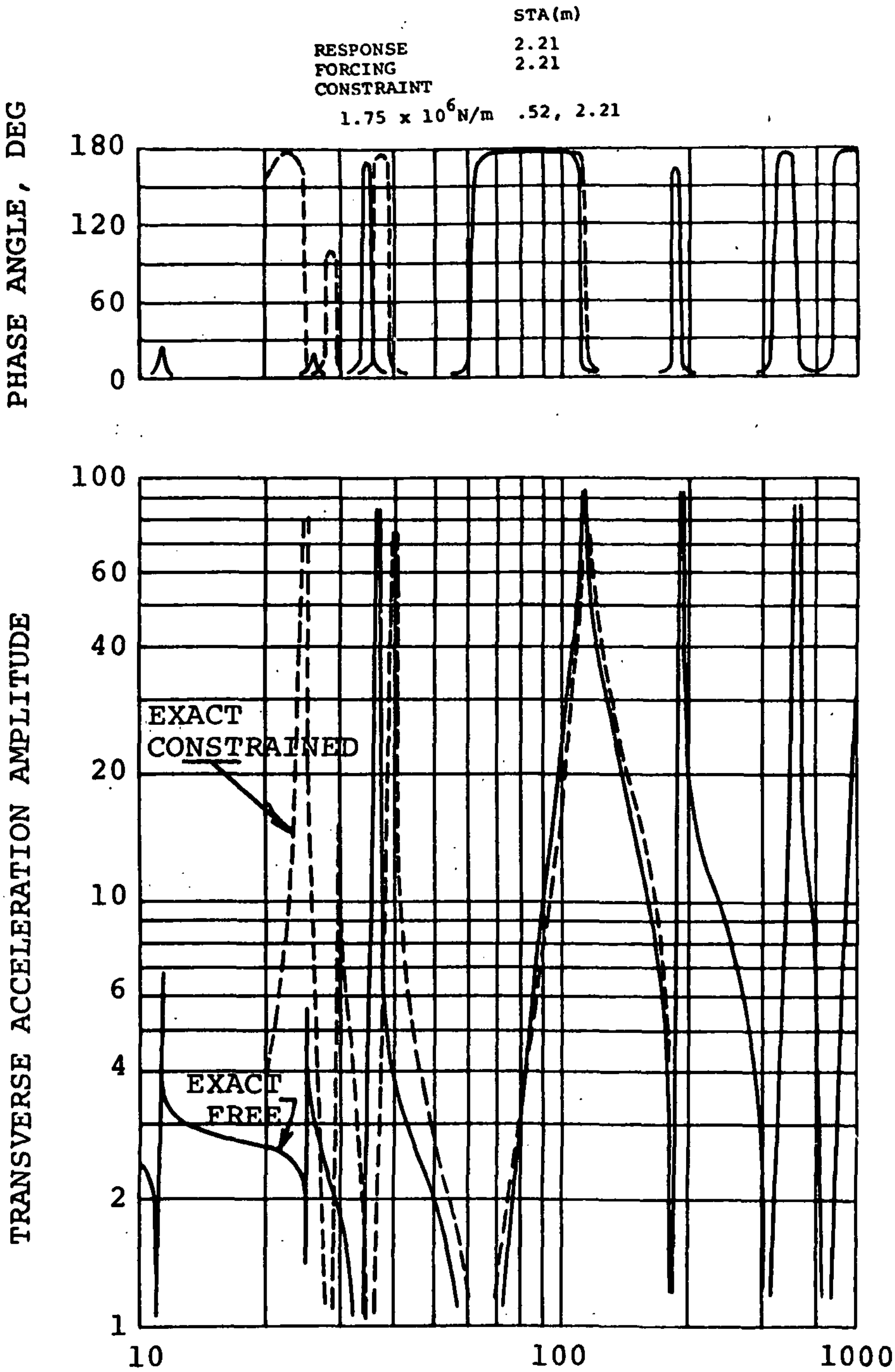
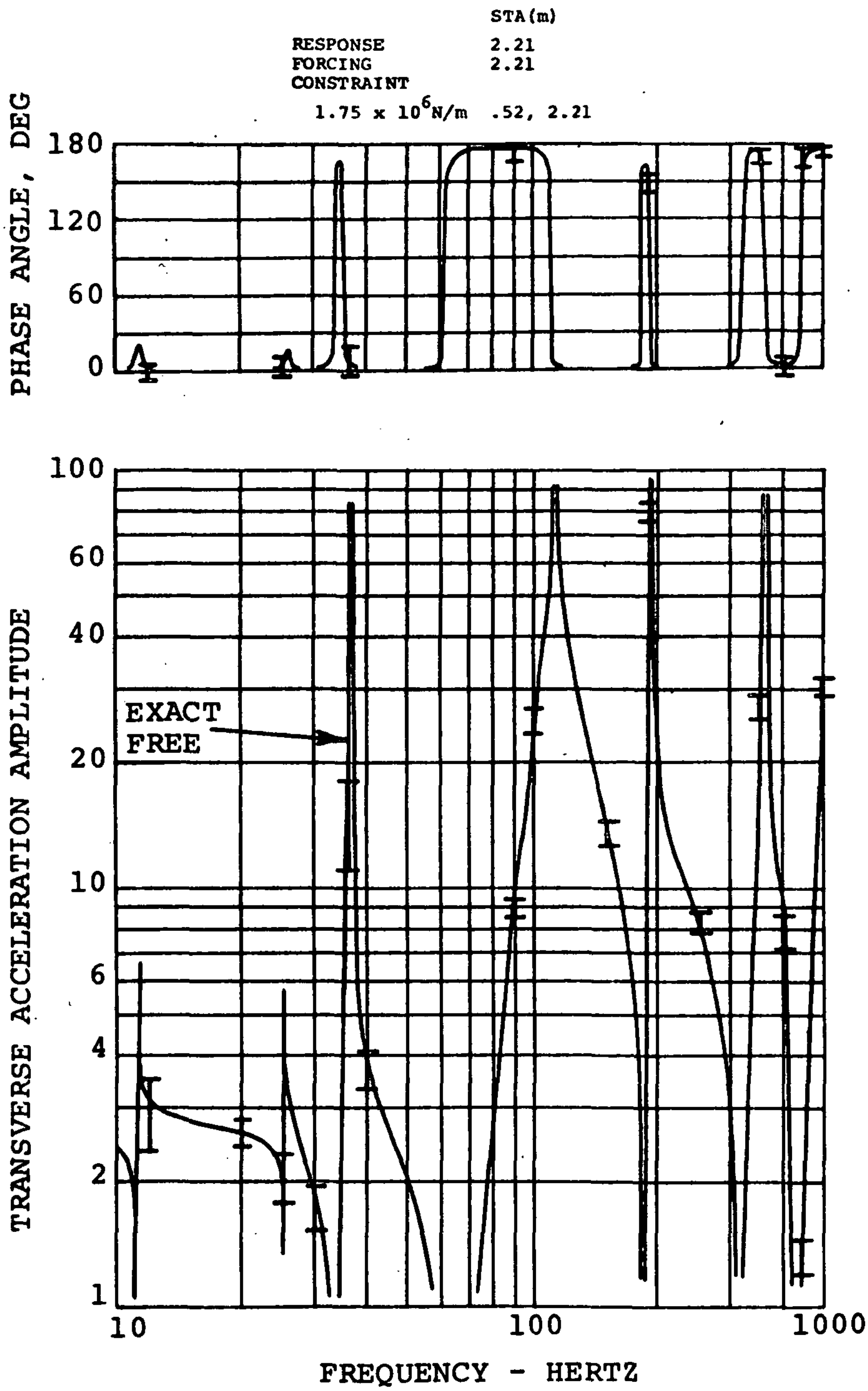


Figure 16. Error Distribution for Free Response 3D Orbiter Model, Constrained at Stations .69 and 1.66 Meters



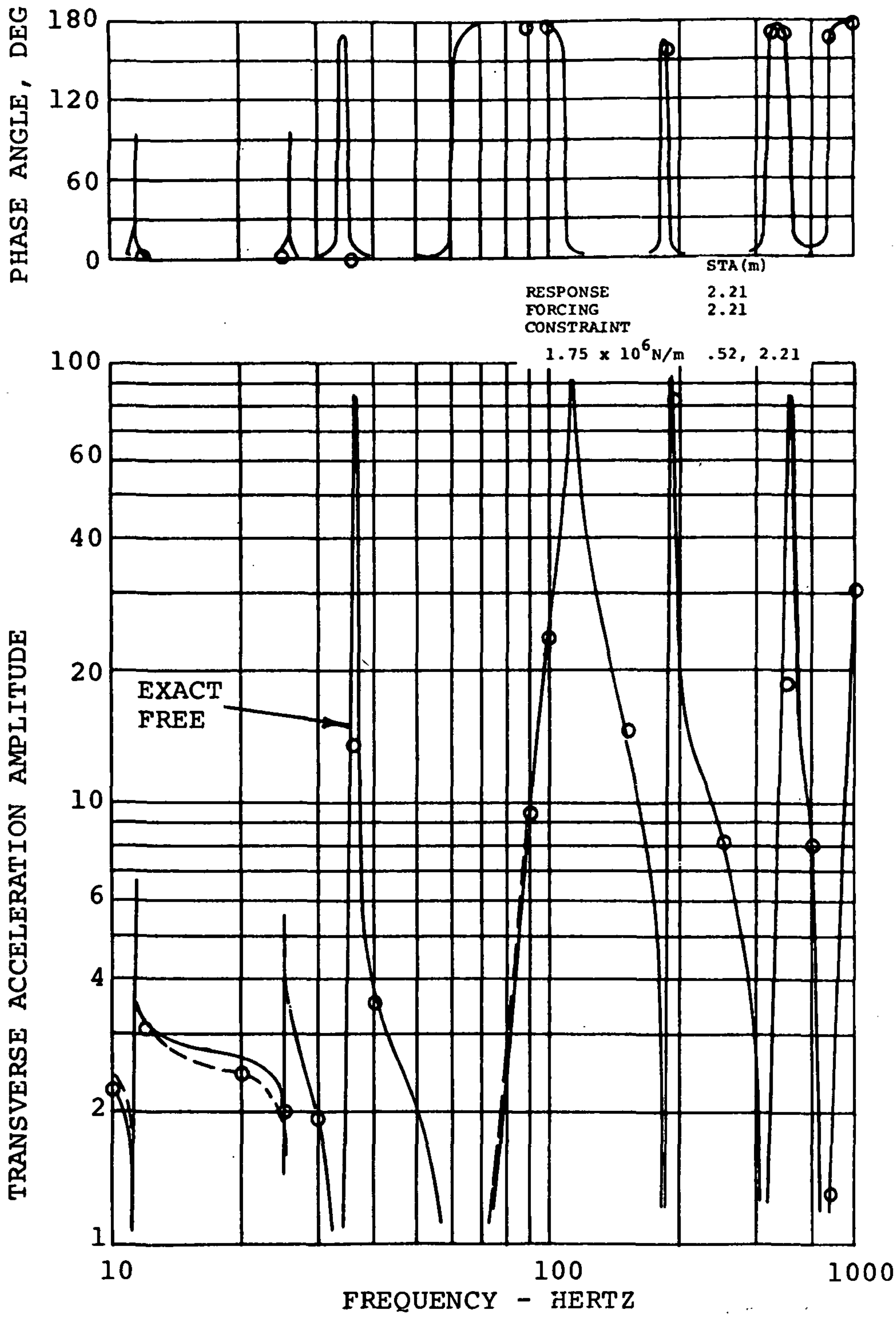
ORBITER-BOOSTER COMBINATION

Figure 17. Frequency Response



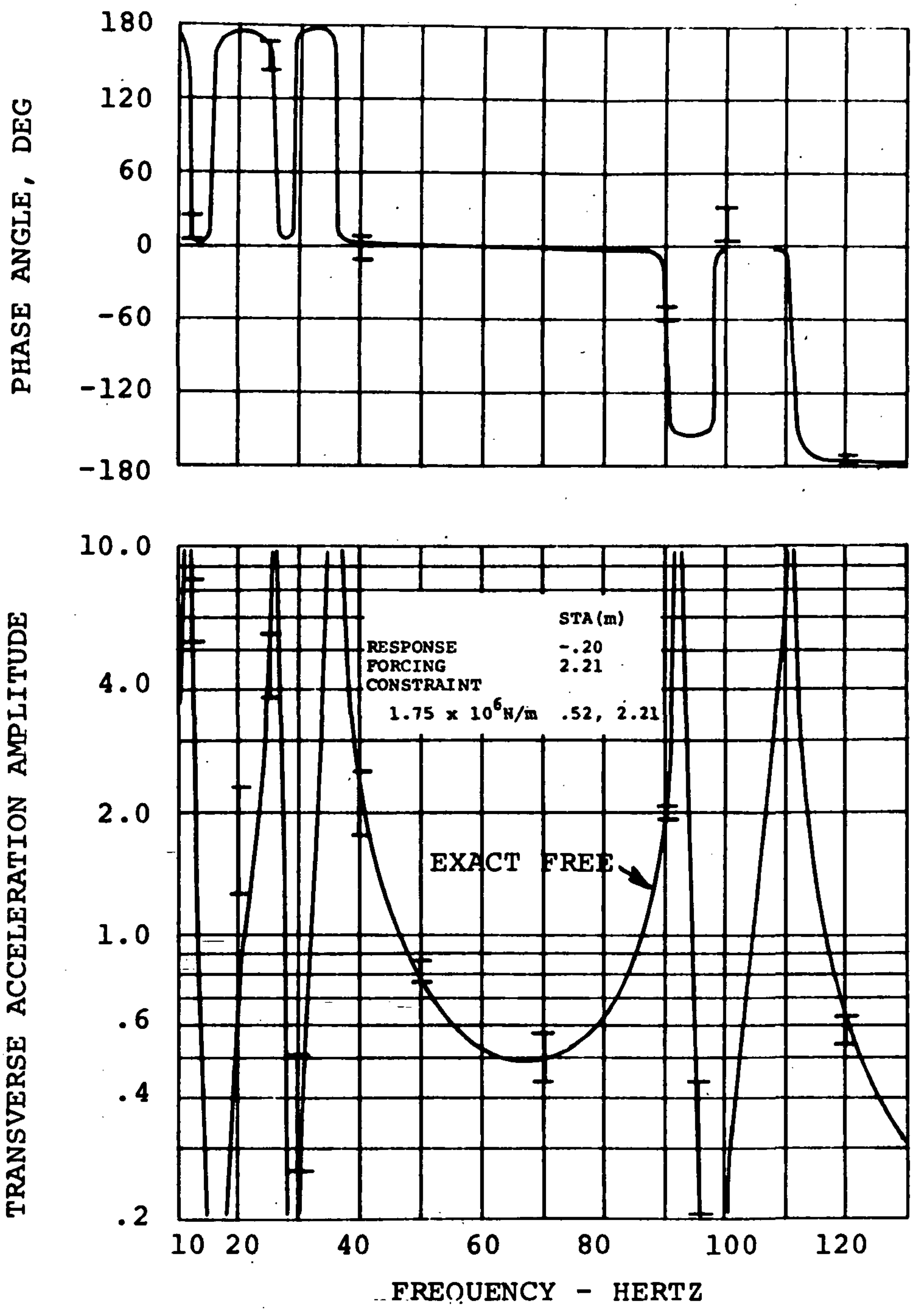
ORBITER-BOOSTER COMBINATION

Figure 18. Effect of Error on Frequency Response



ORBITER-BOOSTER COMBINATION

Figure 19. Typical Deduced Frequency Response



ORBITER-BOOSTER COMBINATION

Figure 20. Transfer Frequency Response

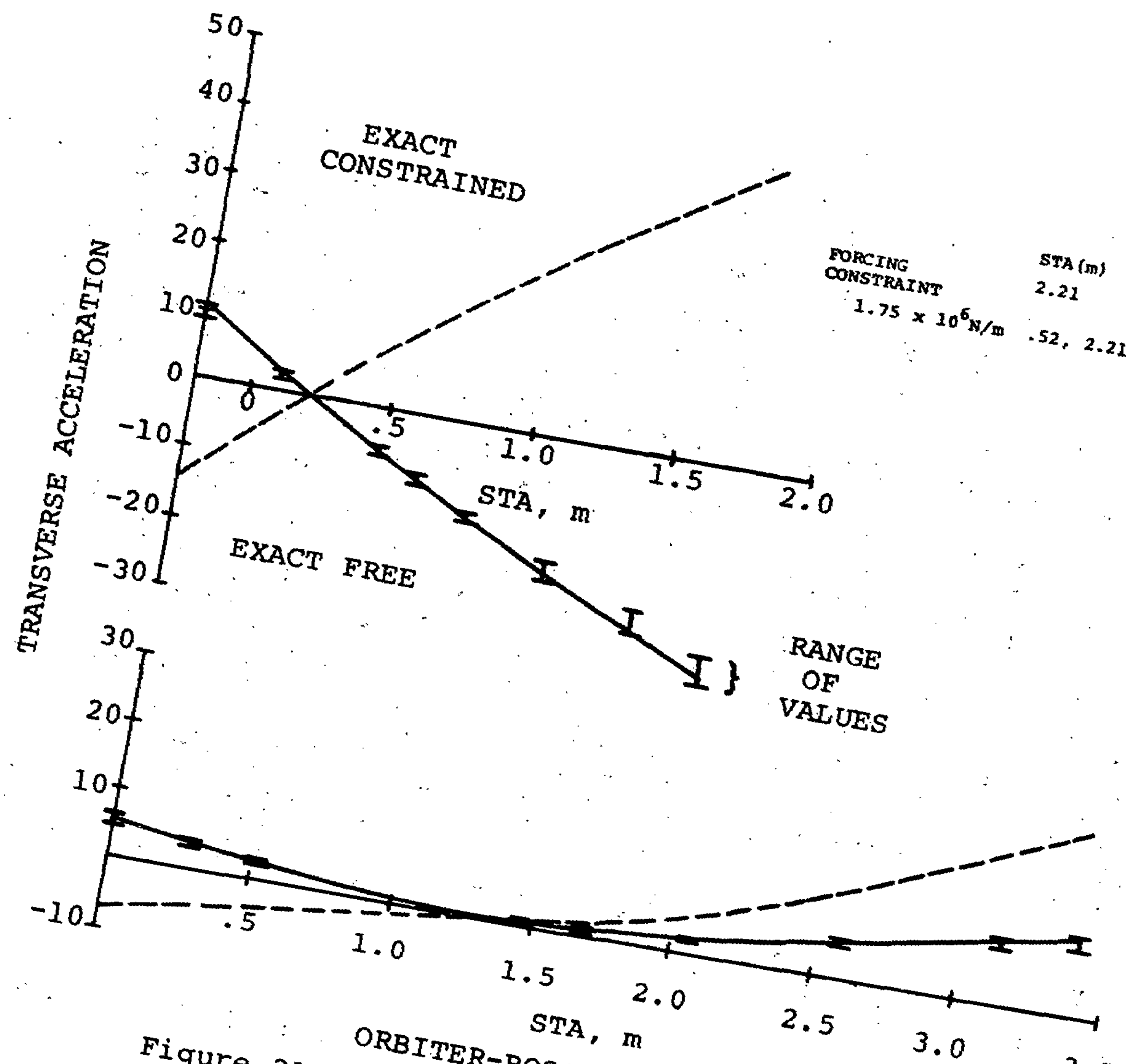
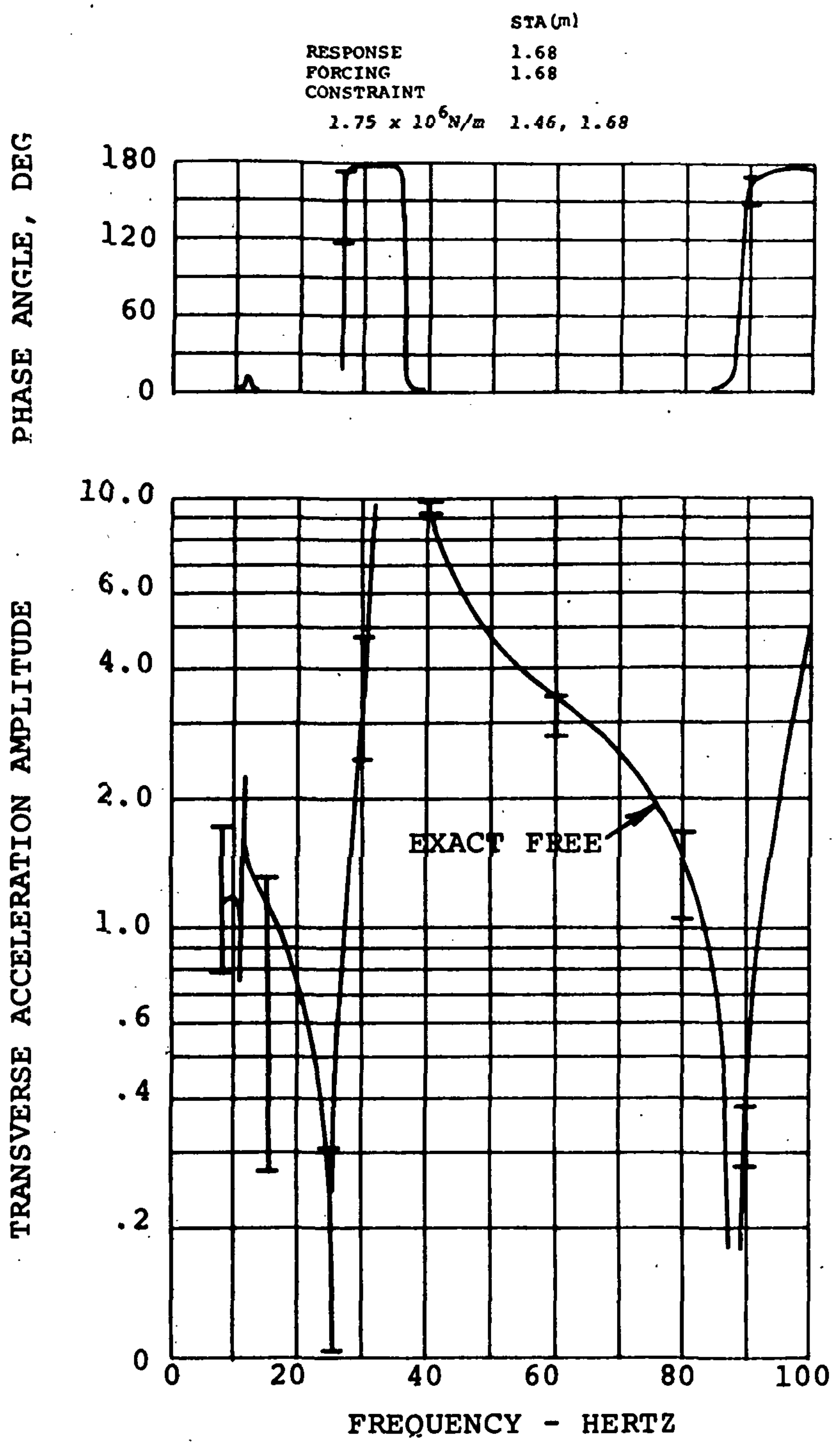
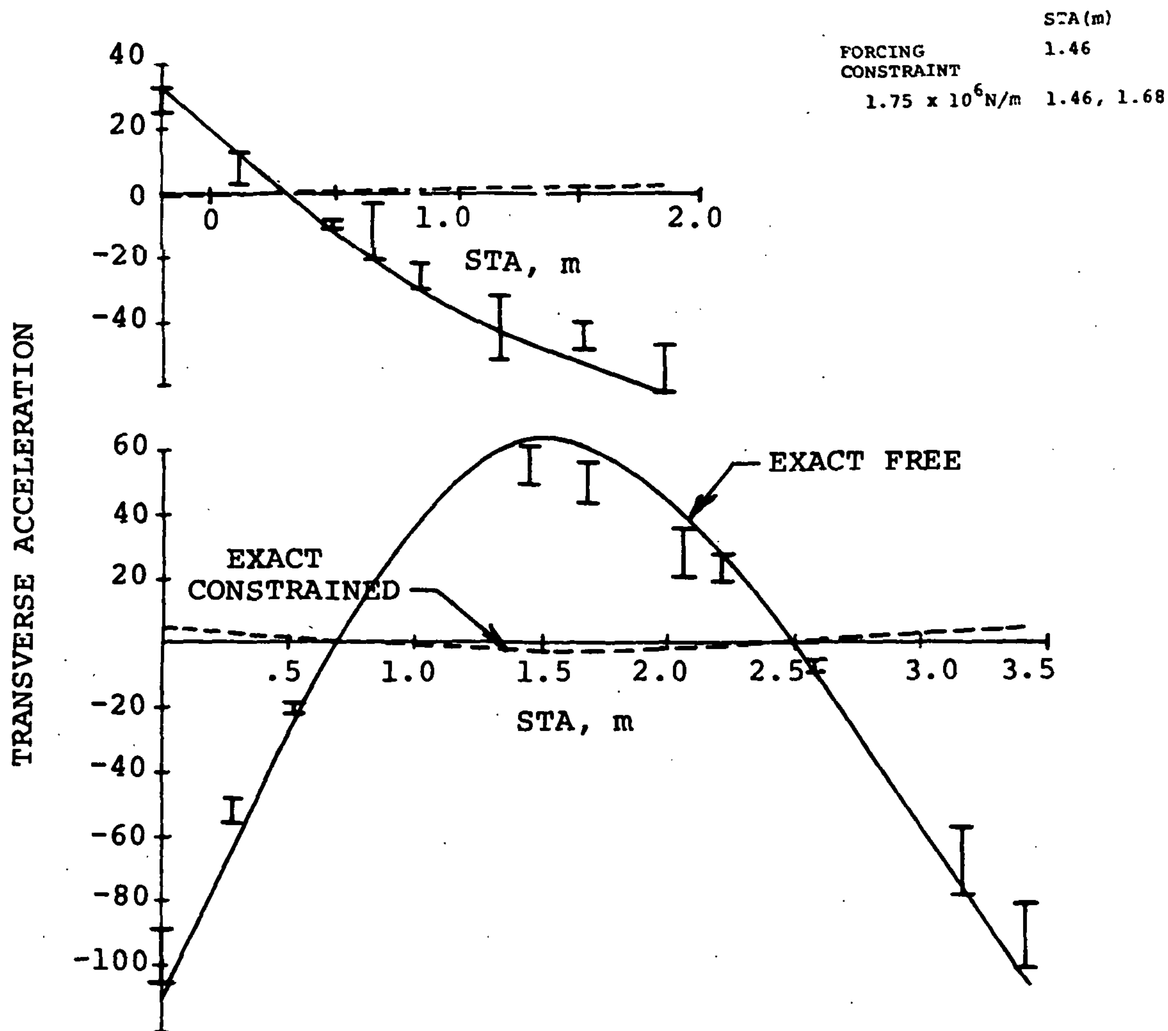


Figure 21. ORBITER-BOOSTER COMBINATION
Transverse Bending Response at 26 Hz, 1.75×10^6 N/m Restraints



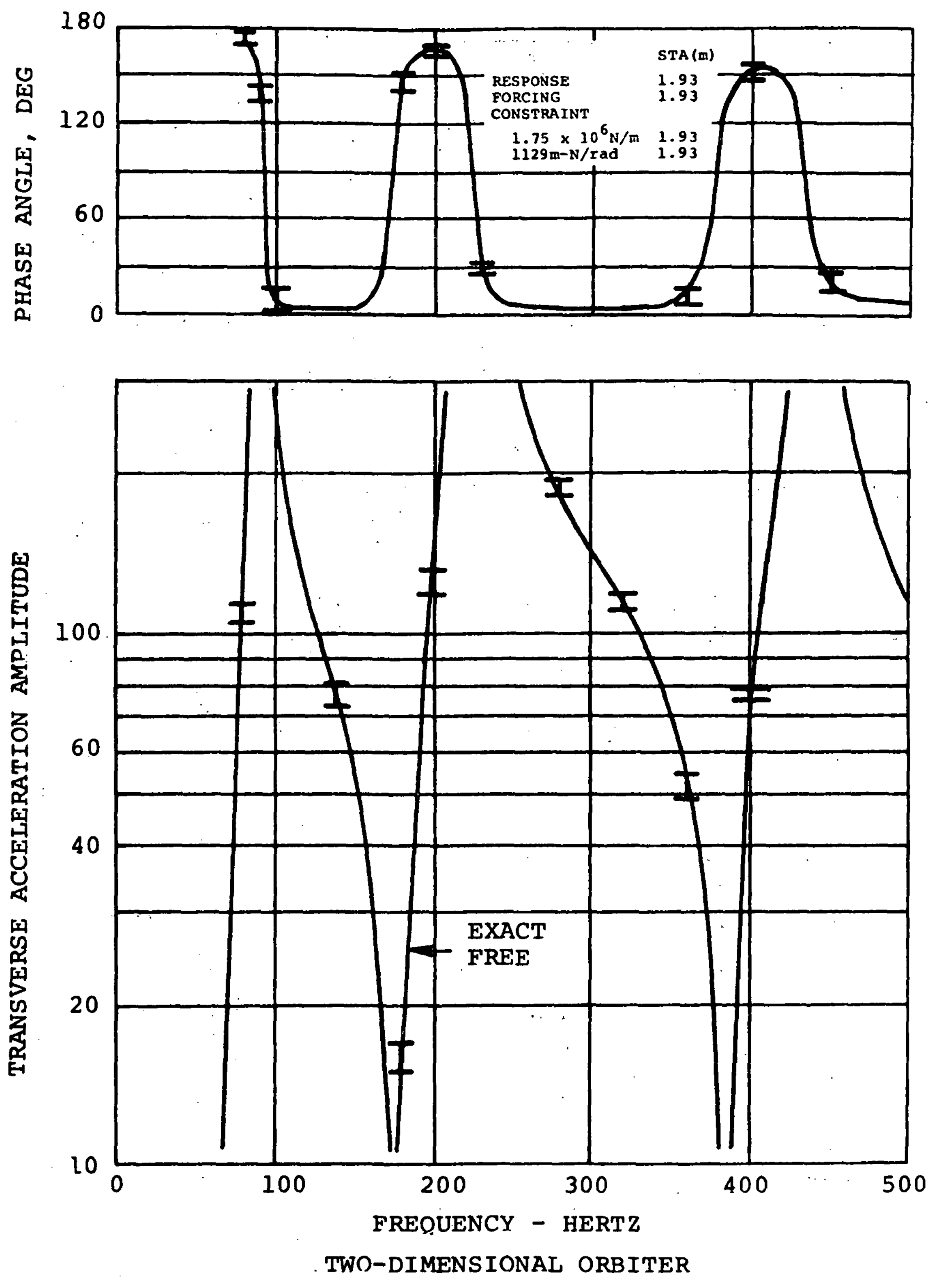
ORBITER-BOOSTER COMBINATION

Figure 22. Effect of Error on Frequency Response



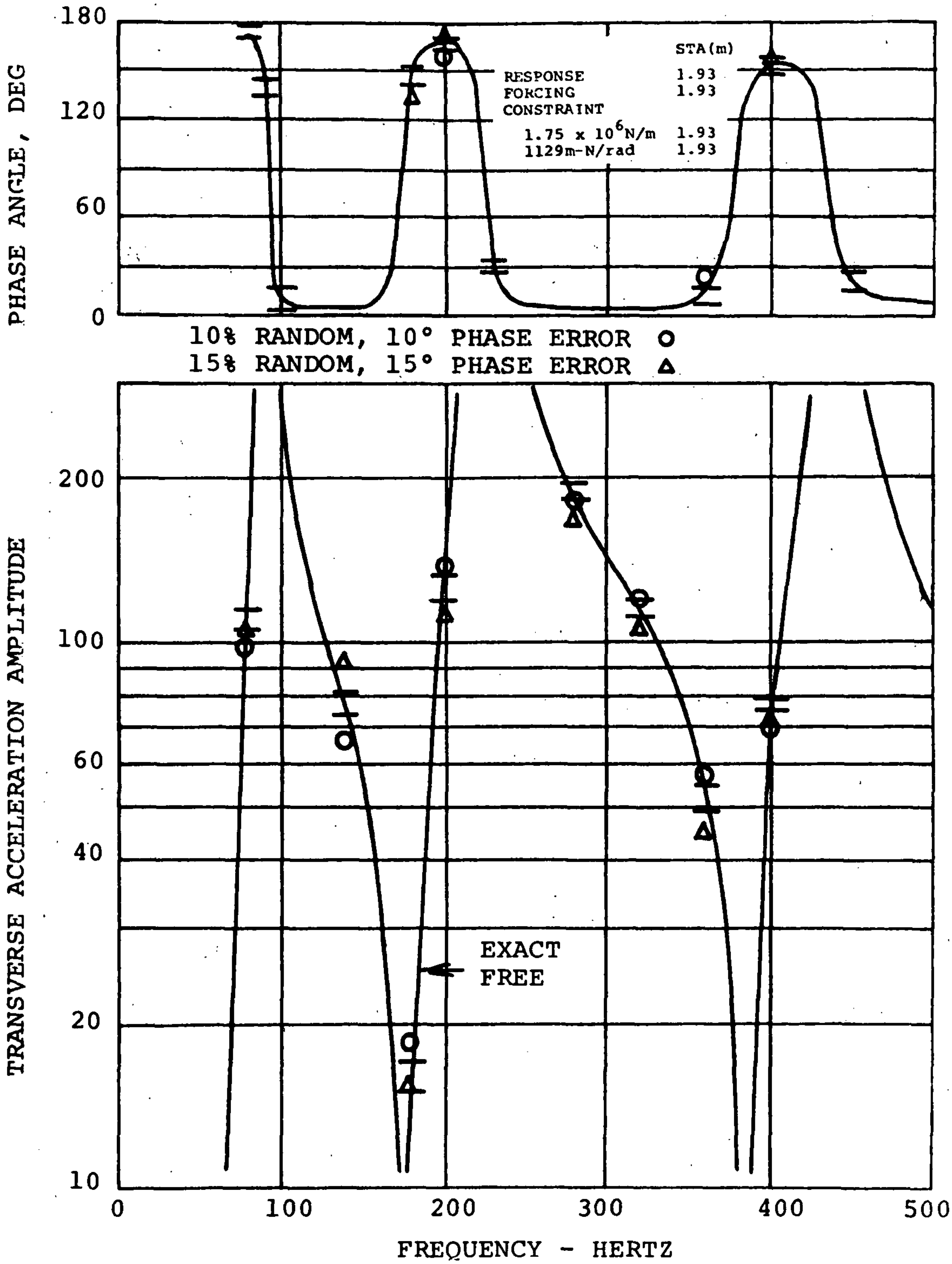
ORBITER-BOOSTER COMBINATION

Figure 23. Transverse Bending Response at 36 Hz, 1.75×10^6 N/m Restraints



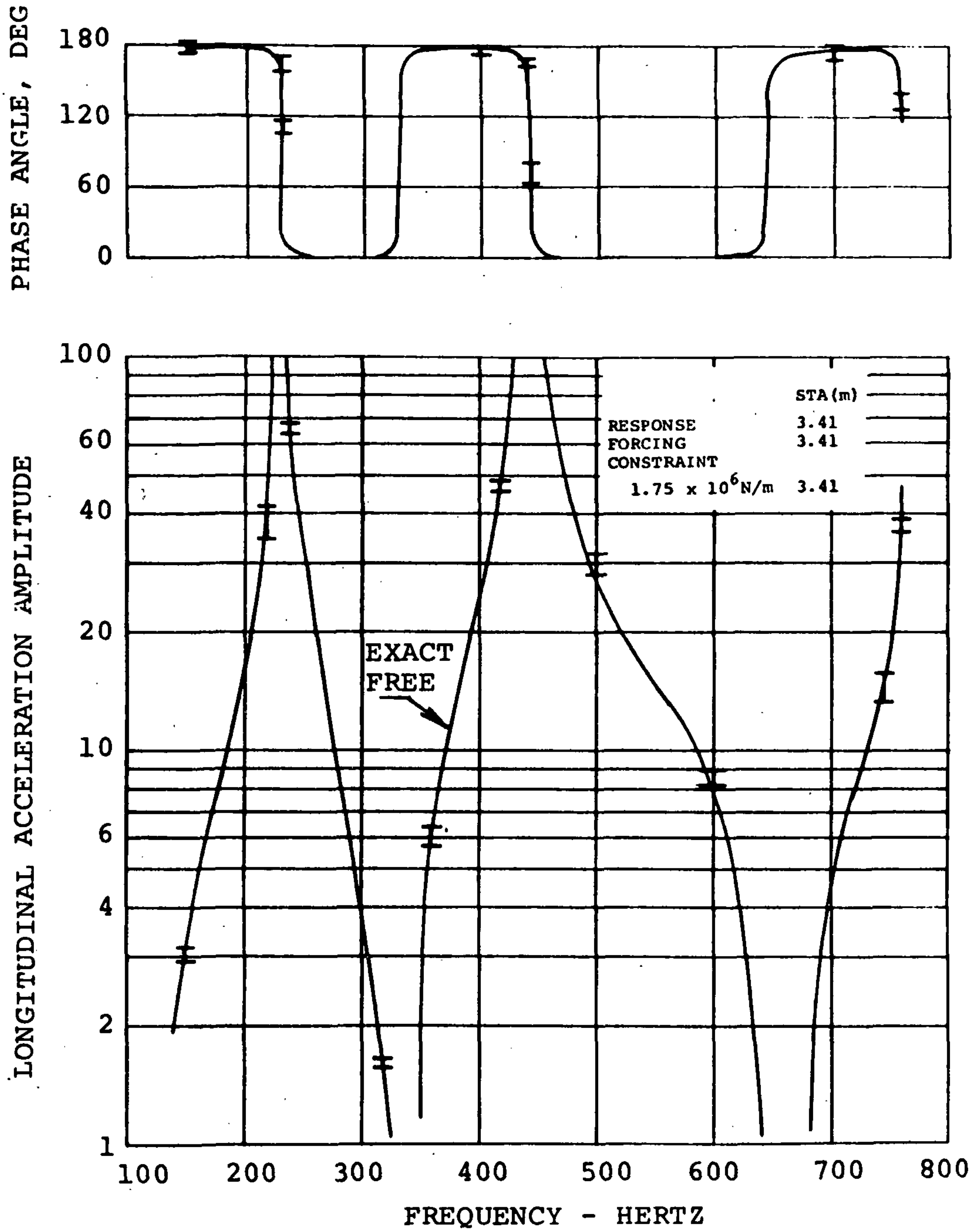
TWO-DIMENSIONAL ORBITER

Figure 24. Effect of Error on Frequency Response



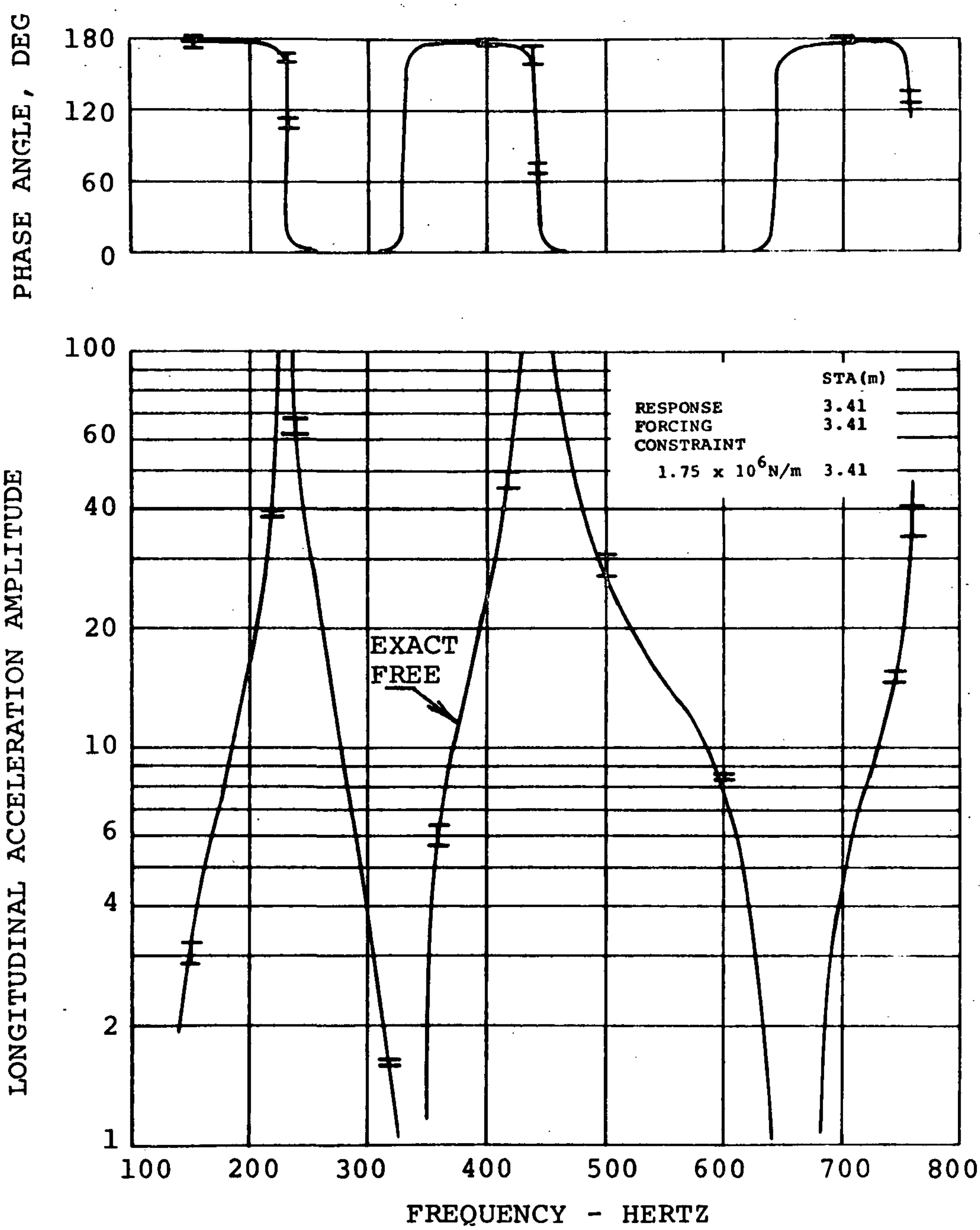
TWO-DIMENSIONAL ORBITER

Figure 25. Effect of Error on Frequency Response



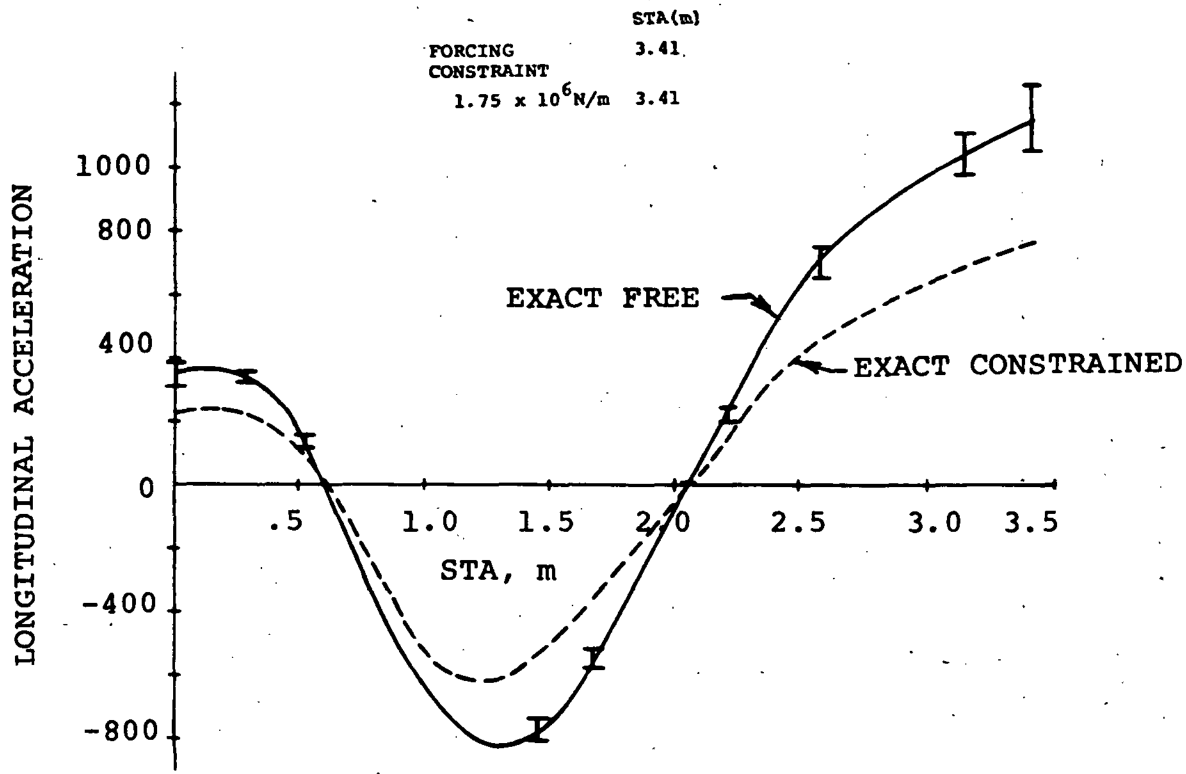
ONE-DIMENSIONAL BOOSTER

Figure 26. Effect of Error on Frequency Response



ONE-DIMENSIONAL BOOSTER

Figure 27. Effect of Error on Frequency Response, Constraint Structural Damping 5%



ONE-DIMENSIONAL BOOSTER

Figure 28. Longitudinal Response at 445 Hz

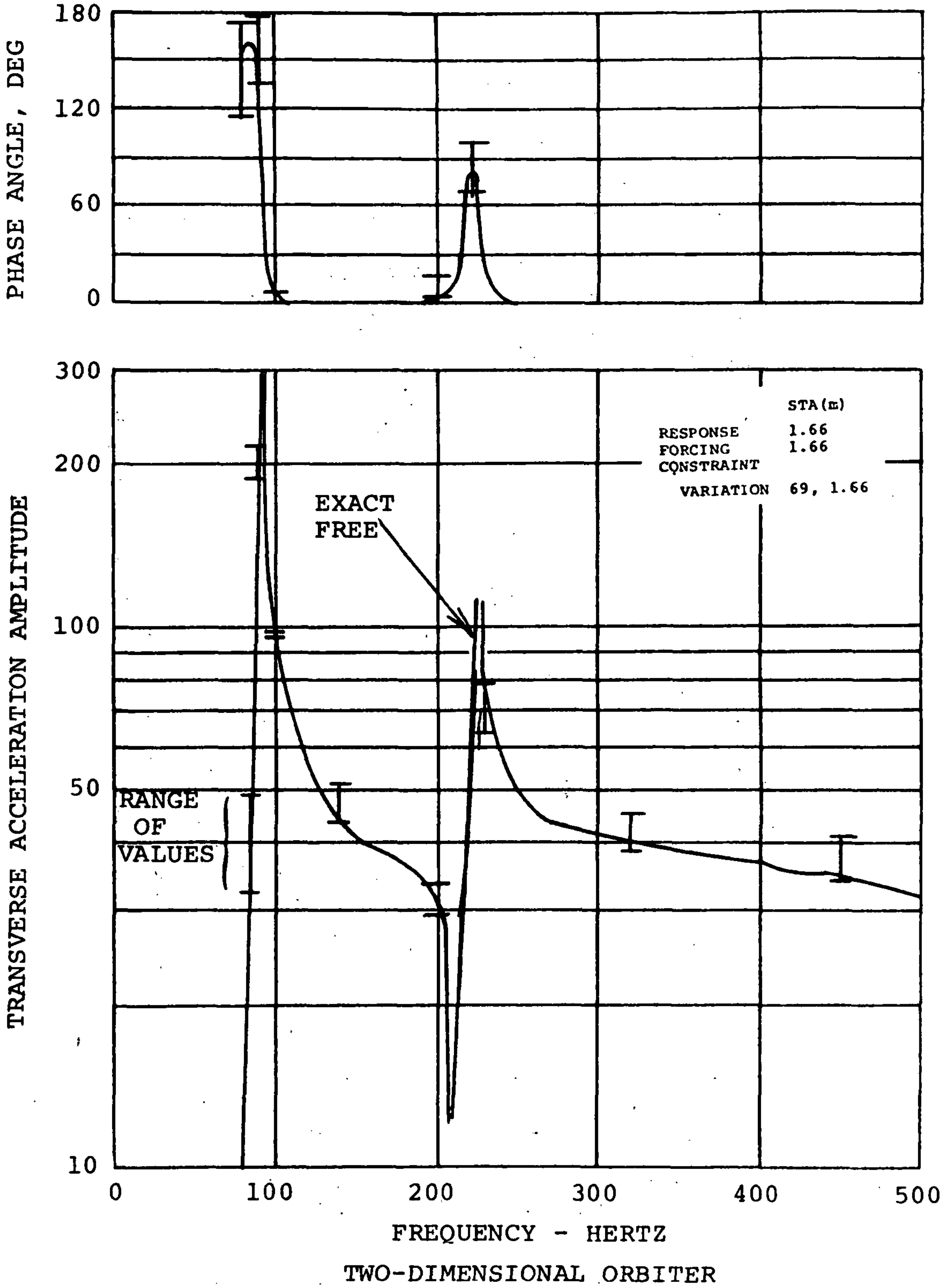


Figure 29. Effect of Error on Frequency Response Obtained From Variation of Constraints Technique

COMPUTER PROGRAM DESCRIPTION

The digital computer program was designed to test and evaluate the concepts presented in the theoretical development. The program generates simulated test data which is as realistic as possible and operates on this data to yield the free body response of the structure. The program was written using CDC FORTRAN 2.3 language and can be run on the CDC 6400 and 6600 computer.

The program is limited presently to sixty degrees of freedom. However, with slight modification this restriction can be removed depending upon the storage capacity of the computer used for program implementation.

GENERAL NOTES

All integer variables must be right justified with no decimal point.

Tape Assignments

IT1 = 1 contains complex mobility matrices at specified frequencies. Tape IT1 is used as input to PROGRAM K2LRC.

IT2 = 2 contains constrained complex acceleration matrices and simulated measured force data. Tape IT2 is used as input to PROGRAM K3LRC.

All input data must be in consistent units, frequency in Hertz.

Card reader used as input devices.

Printer used as output device.

PROGRAM K1LRC

INPUT

Card	Columns	Parameter	Definition
Card 1	Columns 1	IC1	= 0 Normal Program Execution Read Mass, Stiffness and Constraint Data = 1 Read New Constraint Data After Initial Run = 9 End Program
	2	IC2	Not Used
	3	IC3	Not Used
	4	IC4	Not Used
	5	IC5	≠ 1 Diagonal Mass Matrix = 1 Full Mass Matrix
	6	IC6	= 0 Constant Structural Damping ≠ 0 Variable Structural Damping
	7	IC7	Not Used
	8	IC8	Not Used
		HEADC	Program Heading
Card 2	Columns 1-10	ND	Number of Degrees of Freedom
	11-20	GG	Constant Structural Damping
Card(s) 3		AM	Mass Matrix If IC5 ≠ 1 Input Diagonal Mass Matrix, Cards Contain Diagonal Elements in Sequence, Format (8E10.0) If IC5 = 1 Full Symmetric Mass Matrix Input Lower Triangular Portion Starting Each Row on a New Card. Use as Many Cards as Necessary, Ending With Diagonal Element Format (8E10.0)

		Parameter	Definition
Card(s) 4		AK	Stiffness Matrix. Input Lower. Triangular Matrix Similar to Procedure for Mass Matrix Format (8E10.0)
Card(s) 5		G	If IC6 $\neq$ 0 Input Variable Structural Damping Vector, One Element for Each Degree of Freedom Format (8E10.0)
Card 6 Columns	1-10	NCON	Number of Constraints
Card(s) 7 Columns	1-10	NCOR	Coordinate Number at Constraint
	11-20	AKR	Constraint Spring Rate
	21-30	GR	Constraint Structural Damping
	31-40	DAMP	Constraint Viscous Damping

Repeat Card 7, One Card for Each Constraint

Card 8 Columns	1-10	NF	Number of Frequencies at Which Mobility Matrices Will be Calculated
Card(s) 9		HZ	Frequency Values at Which Mobility Matrices Will be Calculated Format (8E10.0) Ten Columns Per Value, Eight Values Per Card

PROGRAM K1LRC - SUBROUTINES

SYM — Forms symmetric matrix from lower triangular matrix. Uses object time dimensions. Used to form symmetric mass and stiffness matrices from corresponding lower triangular matrices. NRA is the dimensioned number of rows of the matrix and N is the order of the square matrix being considered.

MOUT2 — Used to print real matrices. Uses object time dimensions. Prints maximum of 10 columns per page. Number of rows printed is the same as the number of degrees of freedom. NRA is the dimensioned number of rows of the matrix and M and N are the number of rows and columns respectively of the matrix to be printed.

MOUTC — Used to print real and imaginary components of complex matrices. Uses object time dimensions. Prints maximum of 5 columns of real and imaginary data per page. NRA is the dimensioned number of rows of the matrix. The matrix to be printed is of order LxM.

INVC — Calculates the inverse of the complex impedance matrix to yield the complex mobility matrix. Uses object time dimensions. The original impedance matrix is destroyed. NRA is the dimensioned number of rows of the matrix and N is the order of the matrix. If the original matrix is singular IERR = -1 is returned to the main program, otherwise IERR = 0.

PROGRAM K2LRC

INPUT

		Parameter	Definition
Card 1 Columns	1	IC1	Program Control = 1 Normal Program Execution = 9 Terminate Program ≠ 1 Another Case Follows
	2	IC2	IC2 = 0 Applied Forces Only at Constrained Points IC2 > 0 Applied Forces at Non-Constraint Points in Addition to Applied Forces at Constraint Points
	3	IC3	Not Used
	4	IC4	>0 Print Simulated Measured Constrained Acceleration and Simulated Measured Free Body Force Matrix = 0 Above Not Printed
	5	IC5	Not Used
	6	IC6	
	7-8	IC7	= 0 Use Mobility Data for Complete Frequency Spectrum from Tape IT1 Transmitted From Program KILRC >0 Use Mobility Data for Specific Frequencies as Indicated on Card, Maximum of 99
	9-80	HEADN	Program Heading

		Parameter	Definition
Card(s) 2		FAMP	Applied Force Vector One Force for Each Constraint Format (8F10.0). Ten Columns Per Value, Eight Values Per Card, Maximum of 24 Applied Forces
Card(s) 3		FAMP	This card(s) Included Only IF IC2 > 0. Applied Forces at Non-Constraint Points. Format (8F10.0). Sum of the Number of Applied Forces at Constraint and Non-Constraint Points is Limited to 24
Card 4 Columns	1-5	PCT	Uniformly Distributed ($\pm$) Random Percentage Error on Amplitude. Applied to Simulated Measured Constrained Acceleration
	6-10	PCTB	Constant Specified Percentage Error. Applied to Simulated Measured Constrained Acceleration
	11-15	PHE	Uniformly Distributed ($\pm$) Phase Angle Error in Degrees. Applied to Simulated Measured Constrained Acceleration
	16-20	FPCT	FPCT, FPCTB, FPHE are the same as PCT, PCTB, PHE Except Applied to Simulated Measured Forces
	21-25	FPCTB	
	26-30	FPHE	
	31-40	IZ	Random Number Seed

			Parameter	Definition
Card 4	Columns	41-50	AMPL	Uniformly Distributed (±) Random Amplitude Error. (Simulating System Noise) Applied to Translational Acceleration
		51-60	AMPR	Uniformly Distributed (±) Amplitude Error. (Simulating System Noise) Applied to Rotational Acceleration
		61-70	AMPF	Uniformly Distributed (±) Random Amplitude Error. (Simulating System Noise Applied to Forces)
Card(s) 5			INDX	This Card(s) Included Only IF IC7 > 0. Vector of Indices, in Ascending Order, Associated With Specific Frequencies, Indicating Which Corresponding Mobility Matrices Will be Used on Tape IT1 Transmitted From Program KILRC Format (8I10). Ten Columns Per Value, Eight Values Per Card

Card 6 Repeat Card 1 for options defined.

PROGRAM K2LRC - SUBROUTINES

MOUTC Described in Program KILRC Subroutines.

ERR2 Used to apply error to each element of a complex matrix. The errors include: a uniformly distributed random (±) percentage error on amplitude; a uniformly distributed (±) random phase angle; a constant specified percentage bias error; a uniformly distributed (±) random amplitude error (simulating system noise). Object time dimensions are used, with NRA the dimensioned number of rows. N1 and N2 are the number of rows and columns respectively of the matrix.

GETRAN This subroutine is from the LRC Library of Subroutines. The subroutine computes uniformly distributed random real numbers between 0 and 1.0 (For Operation on the CDC 6400 and 6600 Computers).

PROGRAM K3LRC

INPUT

	Column	Parameter	Definition
Card 1	1	IC1	Program Control = 1 Normal Program Execution = 9 Terminate Program ≠ 1 Another Case Follows
	2	IC2	= 0 Standard Printed Output, Only Free Body Data = 1 Print Optional Output, Constrained Response Data = 2 Print Optional Output Force Matrix and Inverse
	3	IC3	Not Used
	4	IC4	IC4 ≠ 0 Modify Response and Force Data on Tape IT1 Transmitted From Program K2LRC IC4 = 0 No Modification of Above Data
	5	IC5	Not Used
	6	IC6	Not Used
	7	IC7	Not Used
	8	IC8	IC8 ≠ 0 Print Complex Force and Response Data in Real and Imaginary Component Form IC8 = 0 Print Above Data in Amplitude and Phase Angle Form
	9-80	HEADC	Program Heading

		Parameter	Definition
Card	2 Column 1-80	ICHC	Read only if IC4 $\neq$ 0 Vector Indicating Which Response and Force Data to be Eliminated; One Element Per Channel ICHC = 0 No Modification ICHC = 1 Corresponding Data are Deleted Maximum of 80. Format (80I1).
Card	3	IW	Read only if IC4 $\neq$ 0 Vector Indicating Which Response Data to be Eliminated IW = 0 No Modification IW = 1 Corresponding Data are Deleted. One Element of IW for Each Force Eliminated. Maximum of 24 Format (24I1).

Card 4 Repeat Card 1 for options defined.

PROGRAM K3LRC

(INPUT TAPE DESCRIPTION)

This program converts constrained test data to free-body responses. The program accepts tape input in a form which would be generated from actual test data after processing. The input tape is unformatted and contains the following records of information.

Record	Parameters	Description
1	HEADT	80 characters (10 words) of heading
	NC	Number of channels of data. Maximum of 80, 60 of which may be response data
	NF	Number of channels containing force data (24 maximum); also the number of sets of data at each frequency. The remaining (NC - NF) channels contain response data (60 maximum)
	ICH	Array (NC elements), one element corresponding to each channel. 0 indicates channel contains response data. 2 indicates channel contains force data. 1 added in the program indicates data to be ignored.
2	FREQ	Frequency at which NF records were taken. Identifies data which follows.
3 (Repeated NF times)	W	Complex array (NC complex elements), each element represents complex response or force data. There are as many W arrays as number of forces (NF). Each W represents data taken under a single condition of forcing.

Records 2 and 3 are repeated until FREQ = -1 to signal end of condition followed by next RECORD 1. Final condition on tape is signalled by FREQ = -2.

PROGRAM K3LRC - SUBROUTINES

MMPYC Performs multiplication of two complex matrices to yield a complex matrix as the result (C = A*B). A is of order (LxM). B is of order (MxN) and the resulting matrix C is of order (LxN). Object time dimensions with NRA, NRB and NRC being the dimensioned rows in A, B and C, respectively.

MOUTC Defined in Program K1LRC Subroutines.

INVC Defined in Program K1LRC Subroutines.

AMPHAS Converts the real and imaginary components of a complex matrix into amplitude and phase angle form. Object time dimensions with NRA being the dimensioned numbers of rows of the matrix. NROW and NFA are the actual number of rows and columns respectively of the matrix under consideration.

VARIED CONSTRAINTS PROGRAM

ZK1LRC, ZK2LRC, K3LRC

These digital computer programs were designed to test and evaluate the concepts presented in the varied constraints portion of the theoretical development. The programs are similar to programs K1LRC and K2LRC. Both versions utilize program K3LRC to reduce the simulated constrained test data to the free body response of the structure.

The same subroutines listed under program K1LRC and K2LRC apply.

PROGRAM ZK1LRC

The input data for program ZK1LRC is the same as that for K1LRC with one exception. Card(s) 7 are repeated with the modified constraint characteristics. The number of sets of constraint data equals the number of constraints. Card(s) 7 are repeated one set for each constraint.

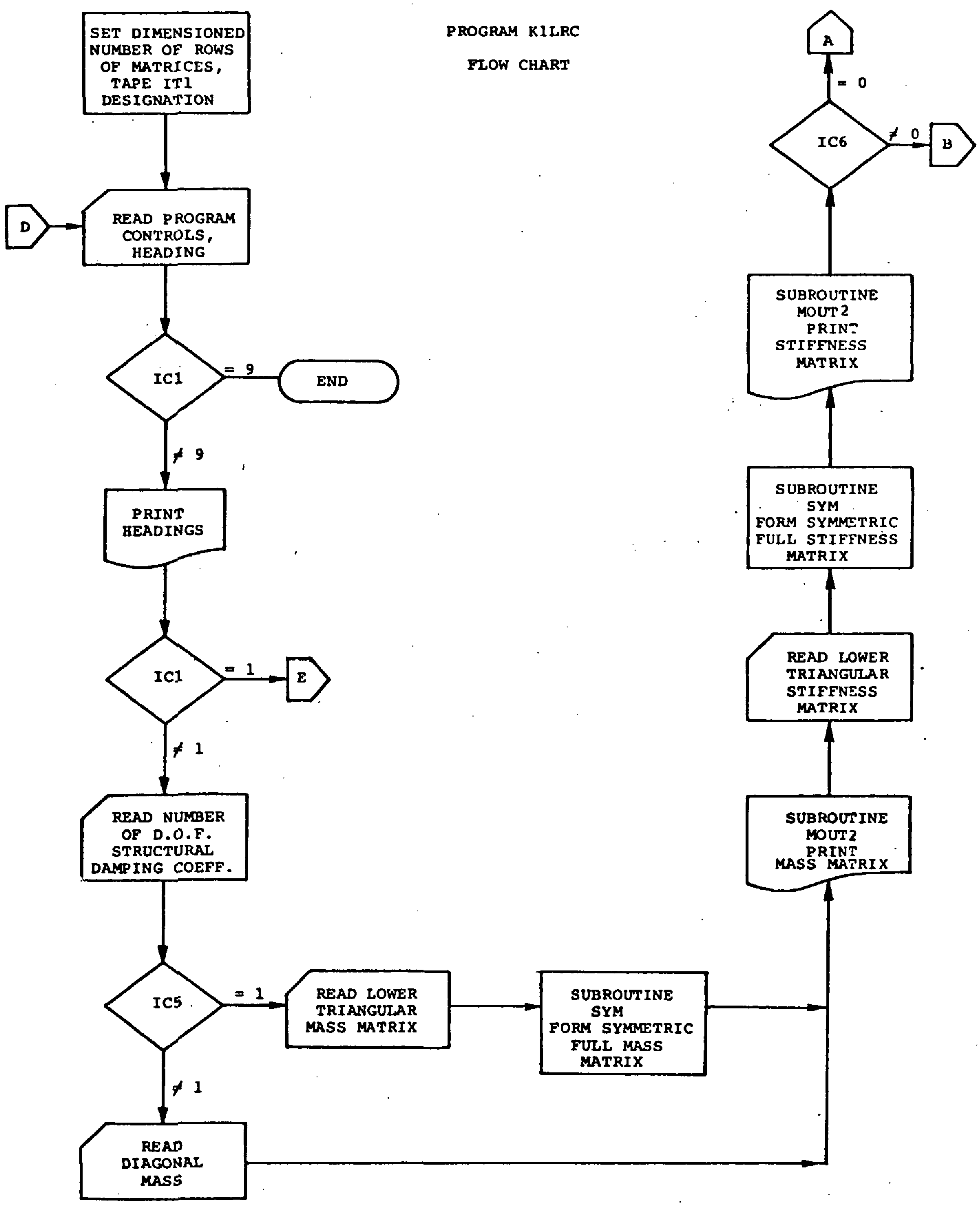
PROGRAM ZK2LRC

The input data is the same as that for K2LRC with the exception of Card(s) 2. For program ZK2LRC, Card(s) 20 are replaced with only one card having the following data:

		Parameter	Definition
Card 2	Column 1-10	F	Applied Force
	11-20	NFS	Coordinate Number of Constraint at Which Force is Applied

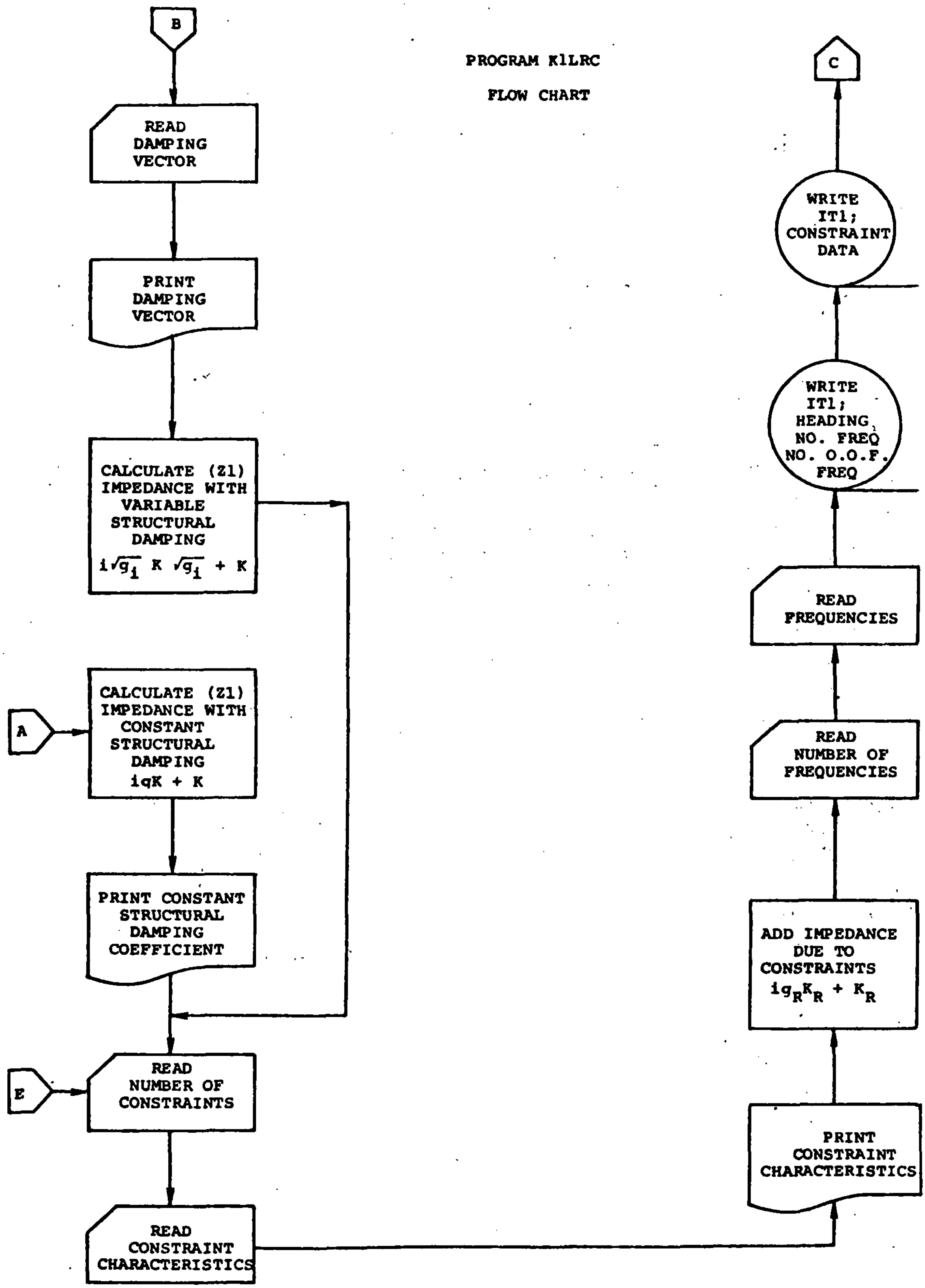
PROGRAM K1LRC

FLOW CHART



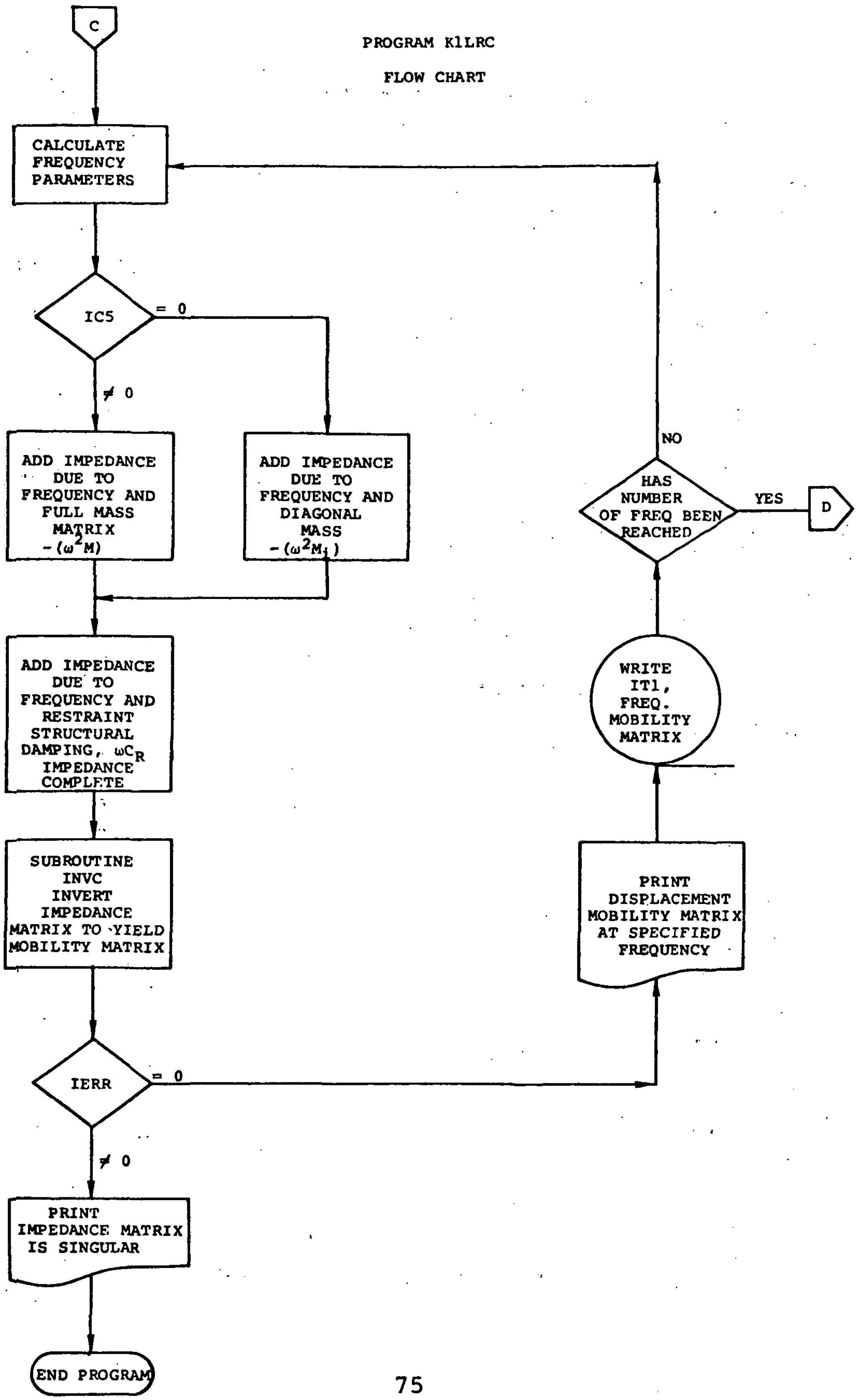
PROGRAM K1LRC

FLOW CHART



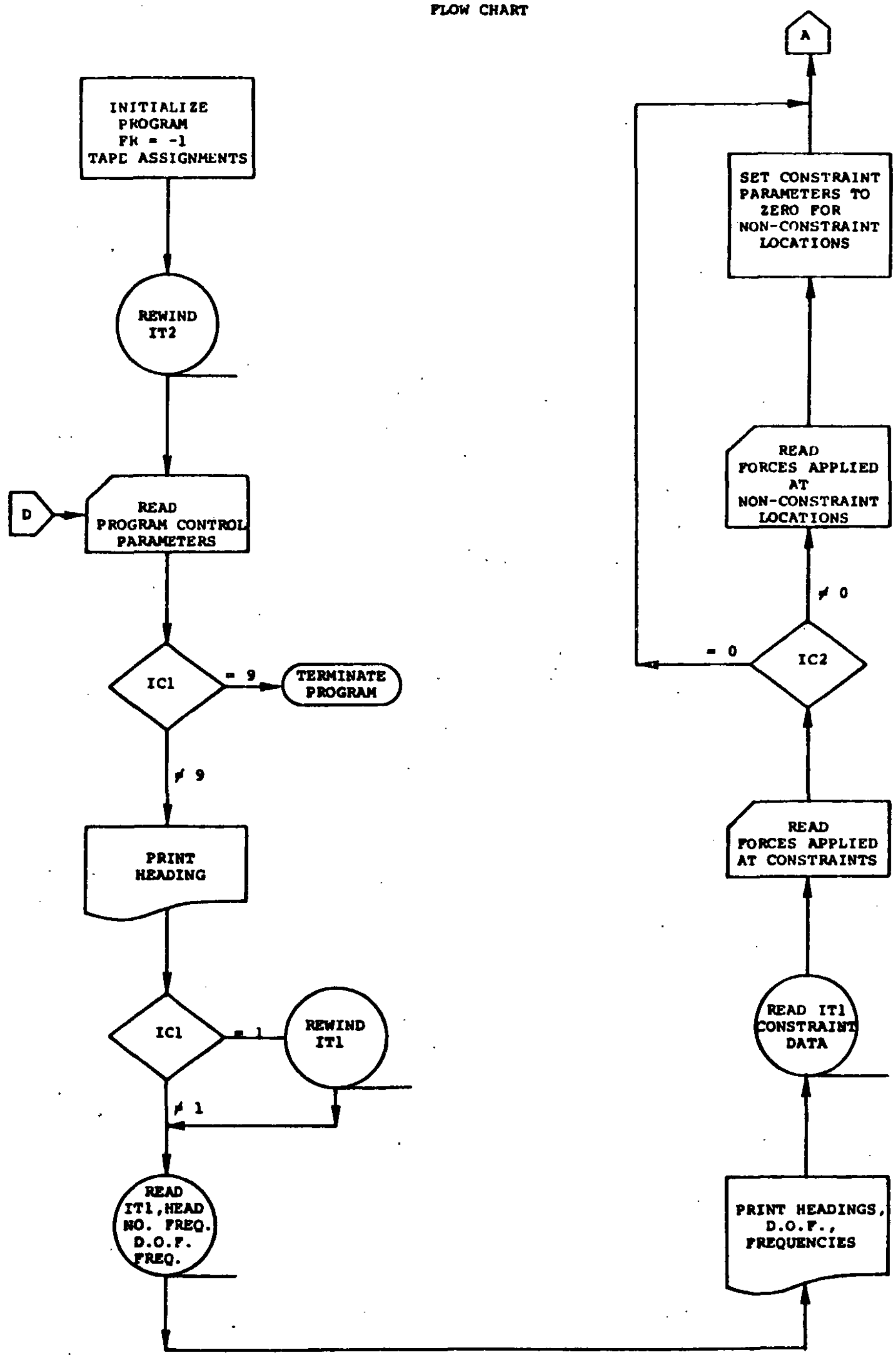
PROGRAM K1LRC

FLOW CHART



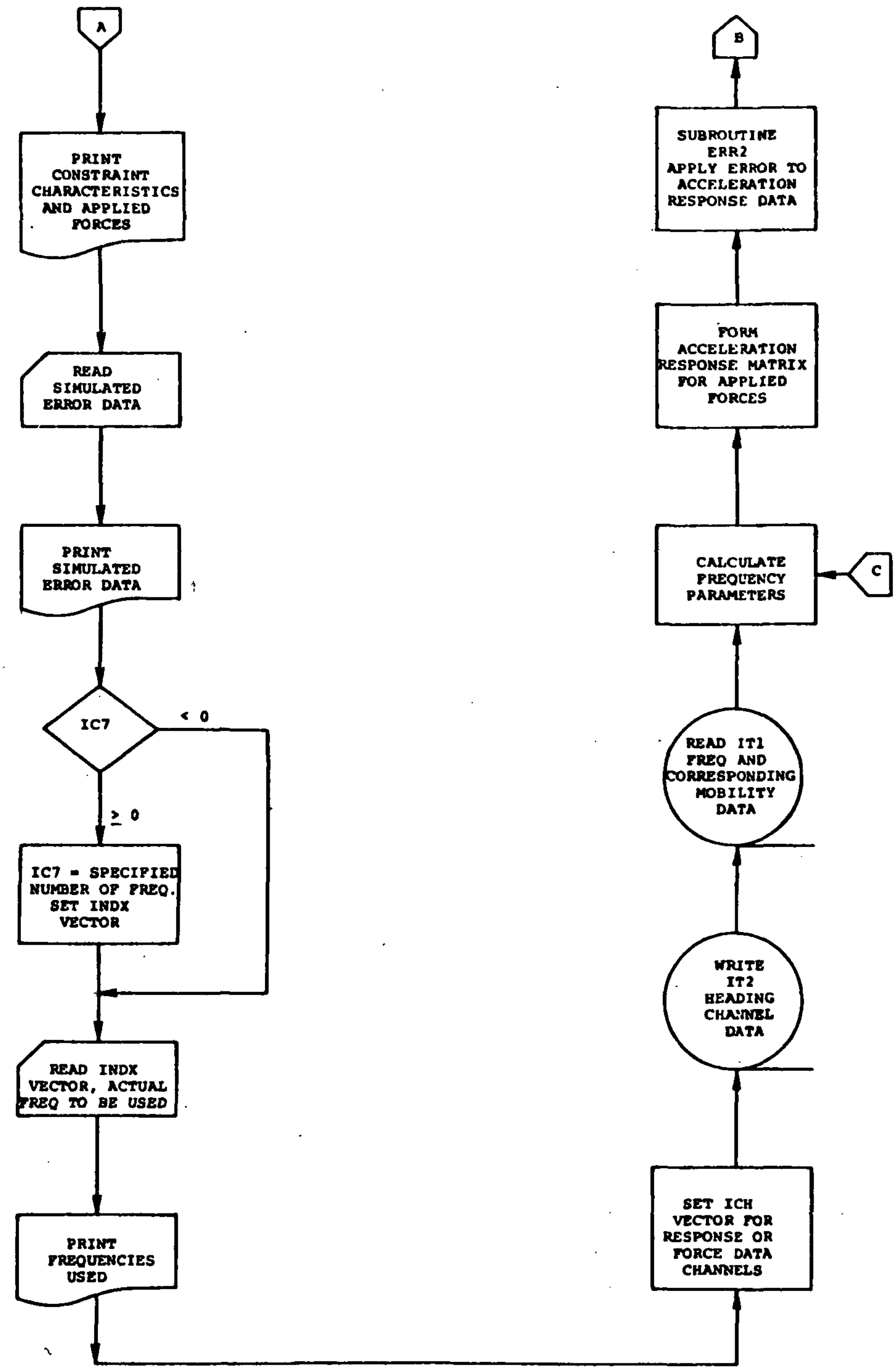
PROGRAM K2LRC

FLOW CHART



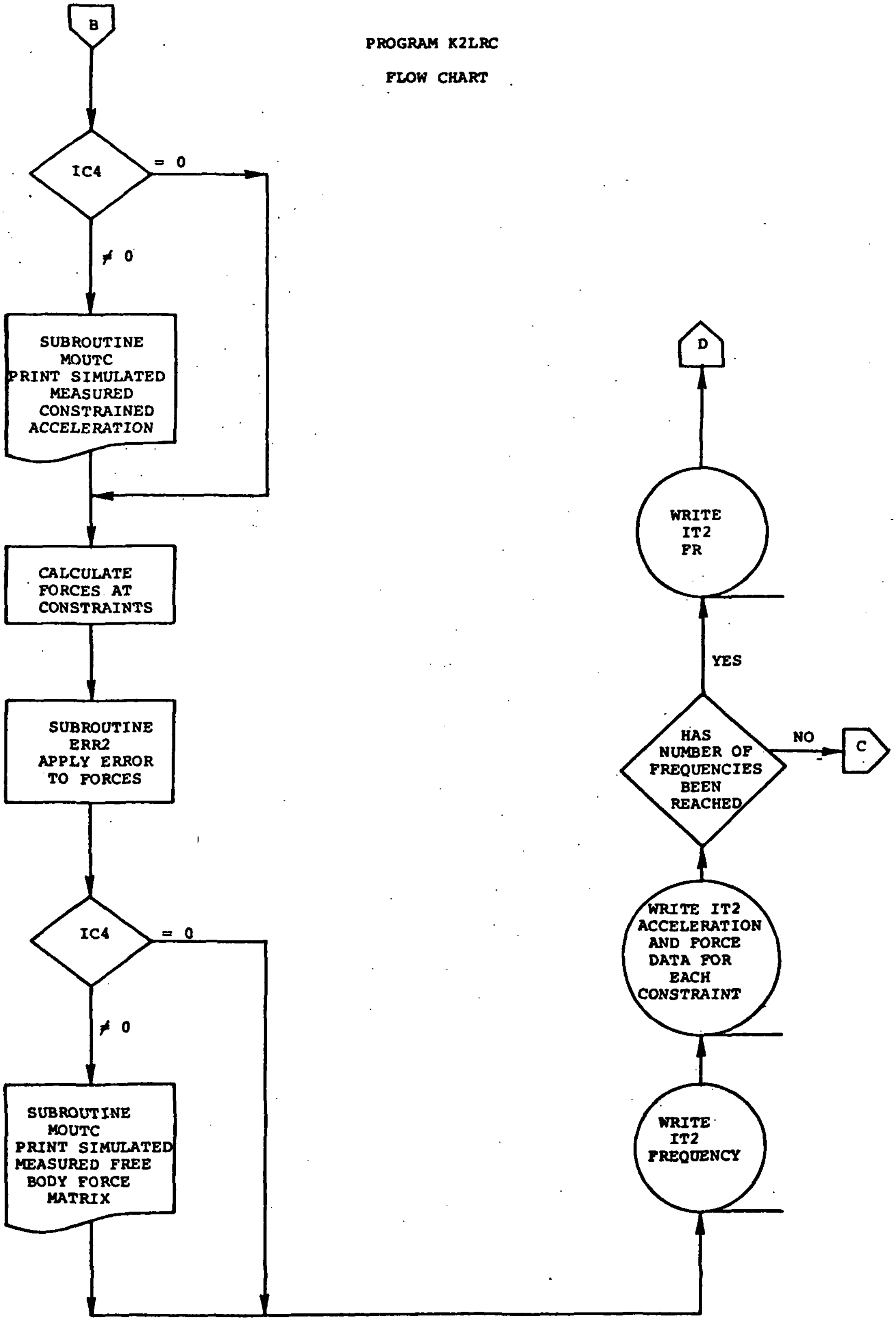
PROGRAM K2LRC

FLOW CHART

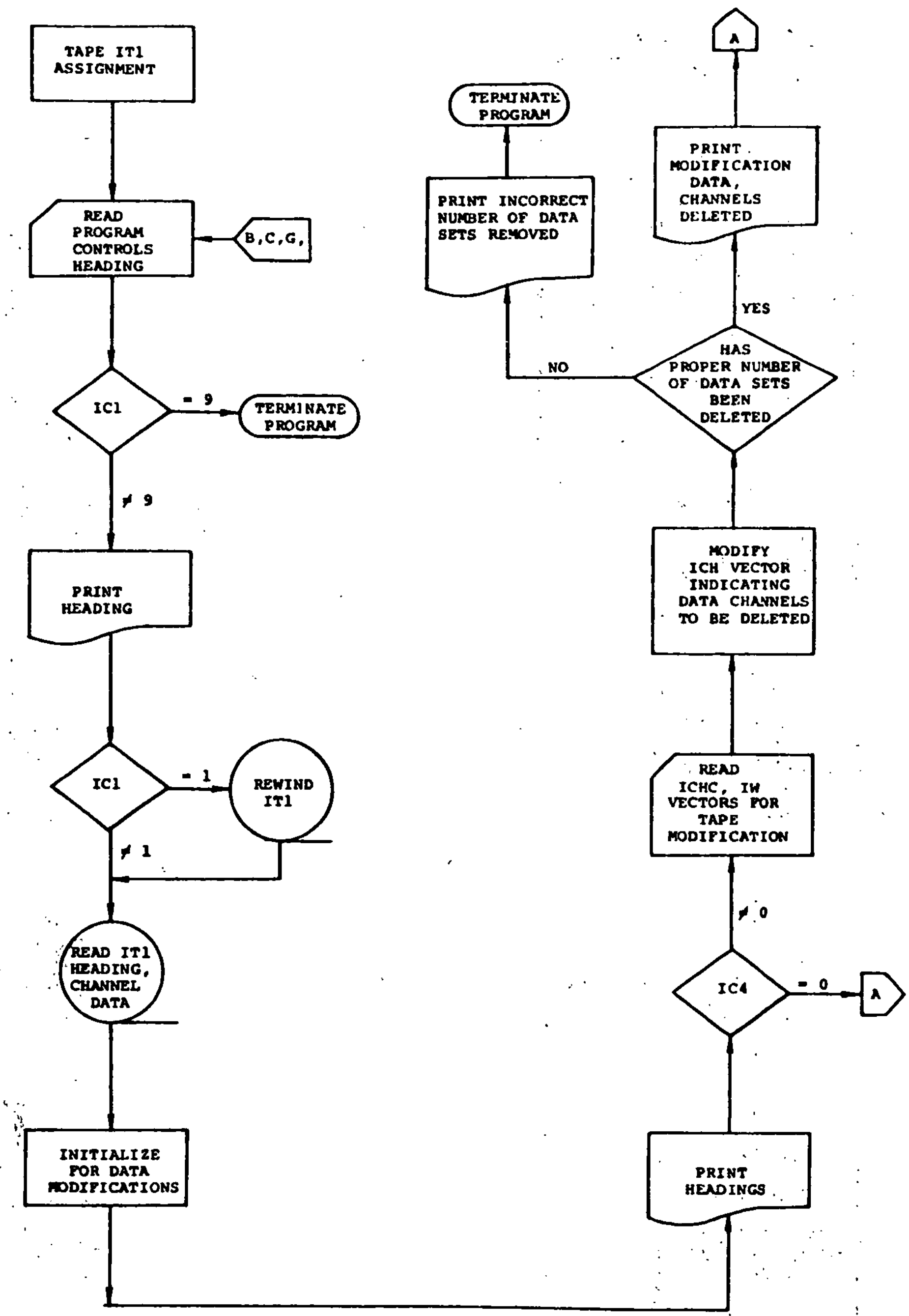


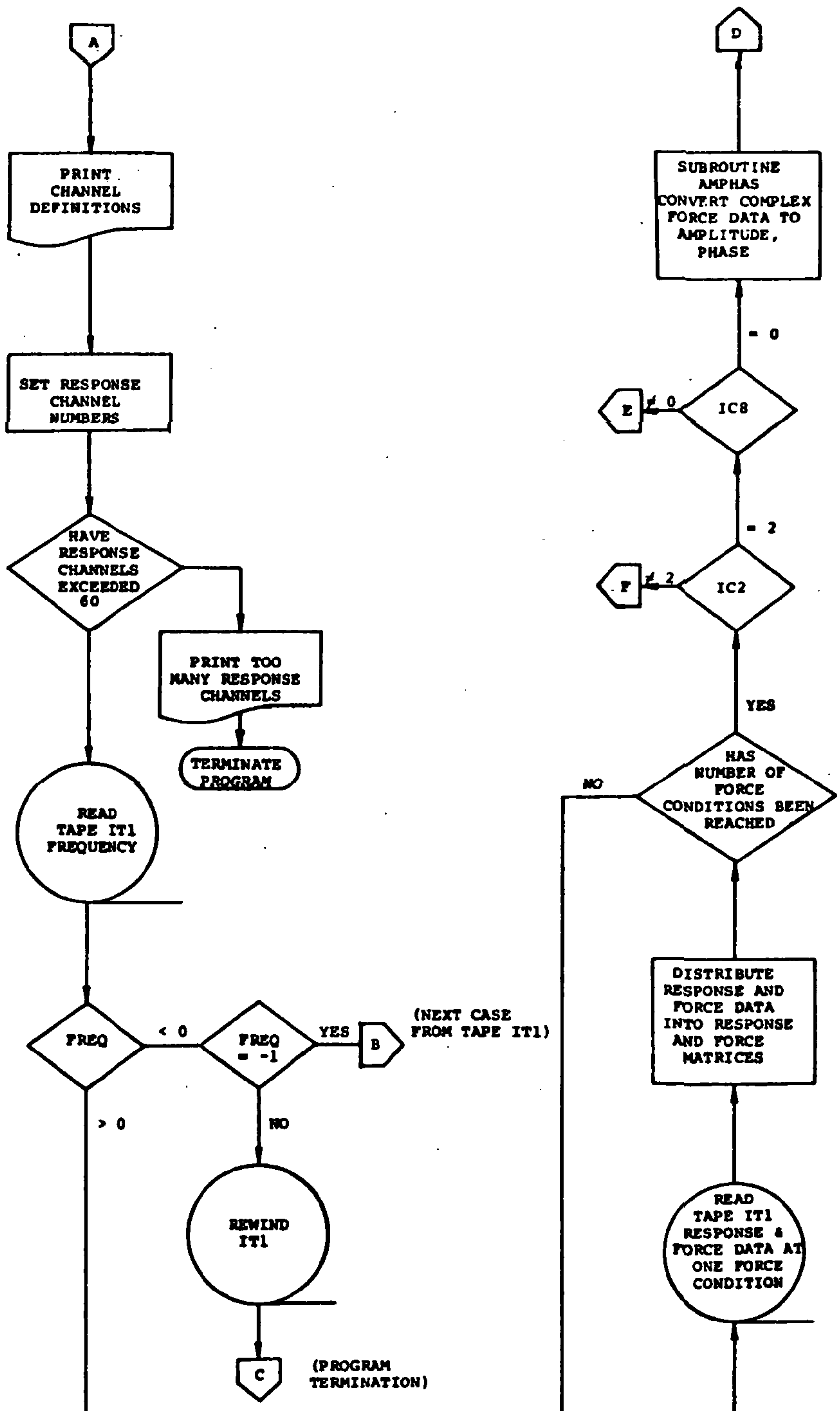
PROGRAM K2LRC

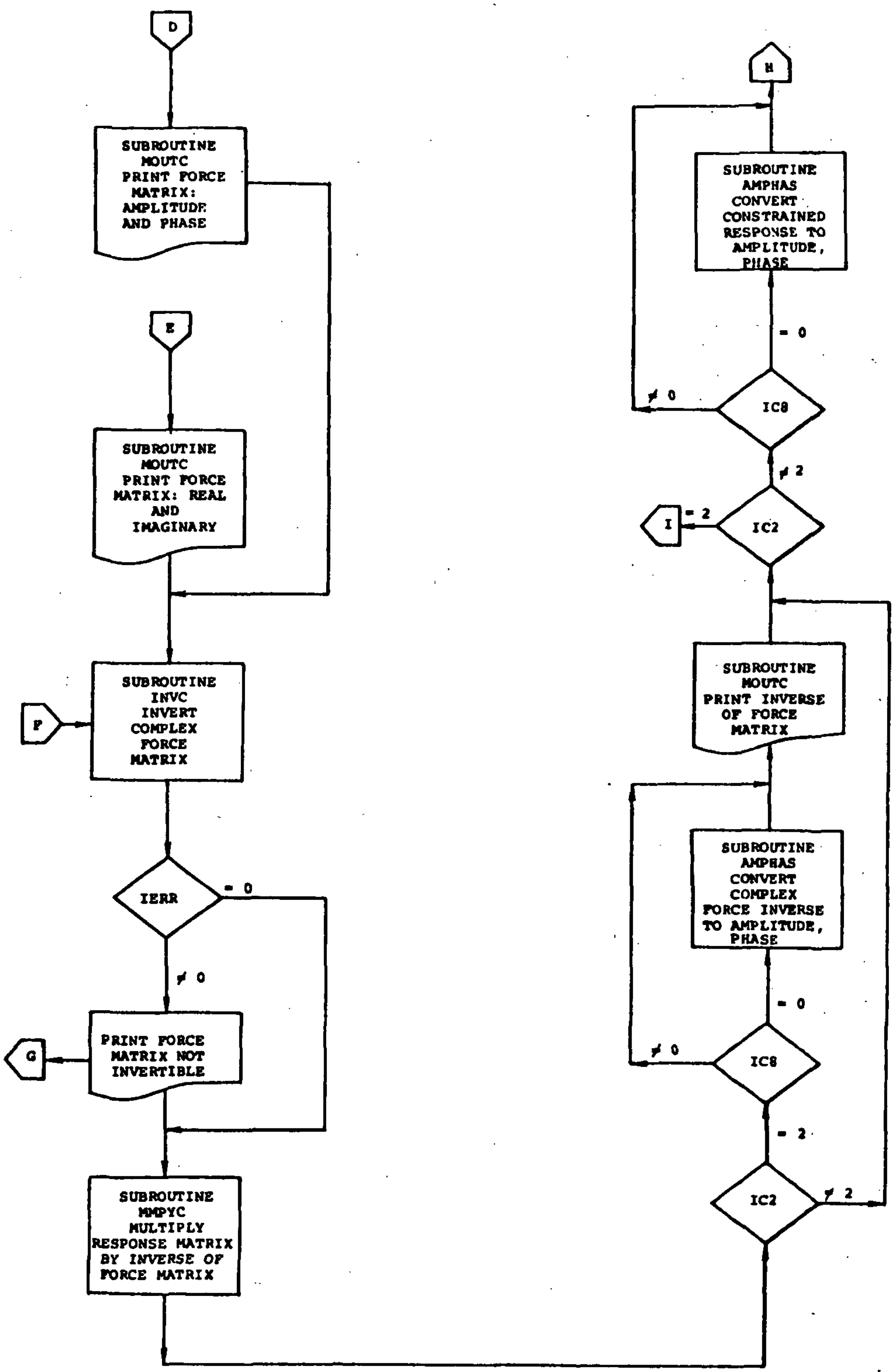
FLOW CHART

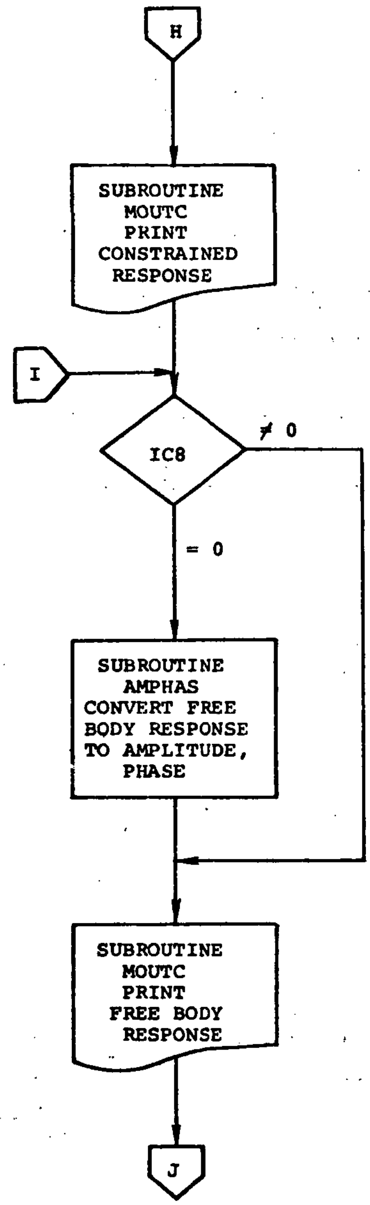


PROGRAM K3LRC



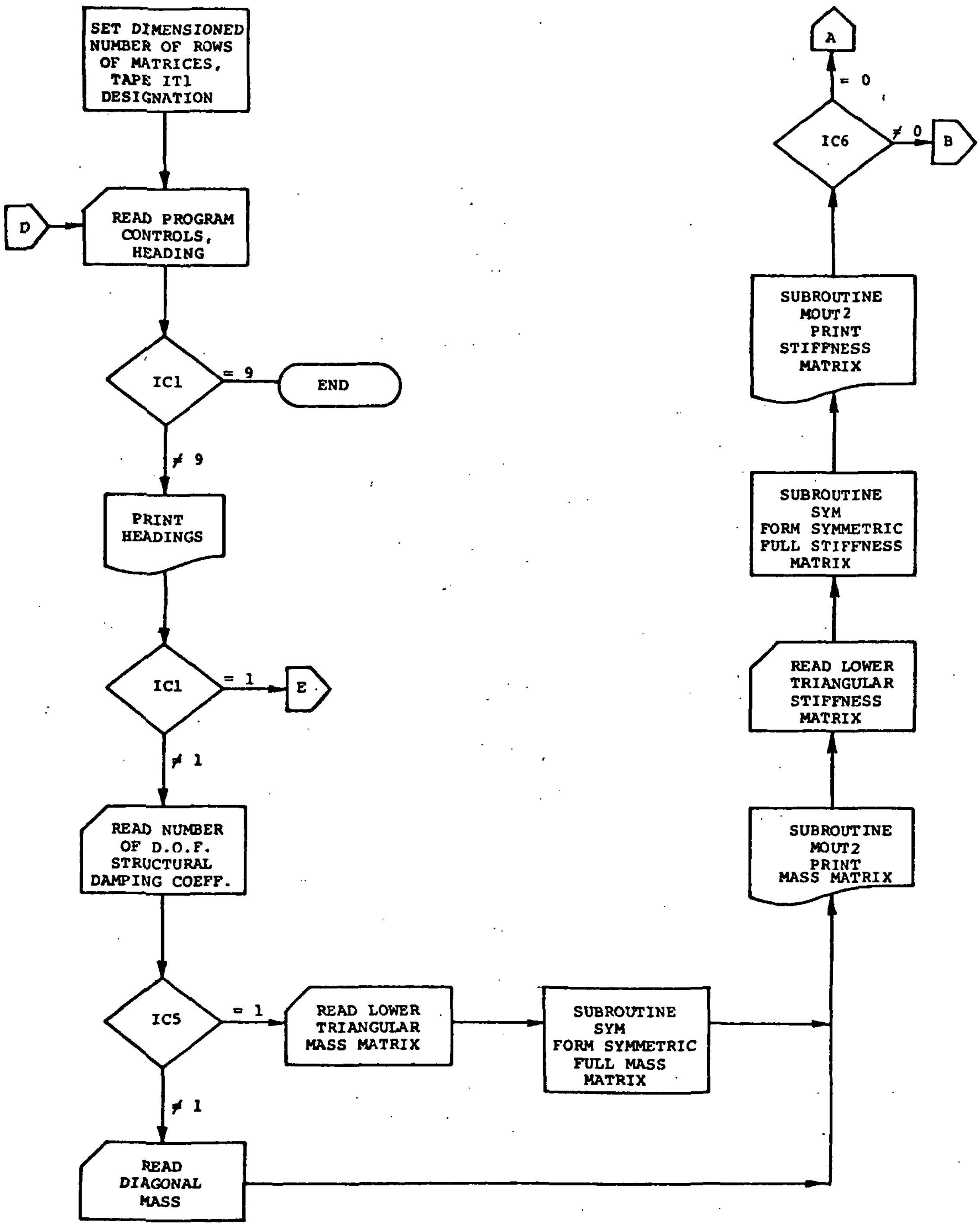

A
PRINT CHANNEL DEFINITIONS
SET RESPONSE CHANNEL NUMBERS
HAVE RESPONSE CHANNELS EXCEEDED 60
PRINT TOO MANY RESPONSE CHANNELS
TERMINATE PROGRAM
READ TAPE IT1 FREQUENCY
FREQ
< 0
FREQ = -1
YES
B
(NEXT CASE FROM TAPE IT1)
> 0
NO
REWIND IT1
C
(PROGRAM TERMINATION)
READ TAPE IT1 RESPONSE & FORCE DATA AT ONE FORCE CONDITION
DISTRIBUTE RESPONSE AND FORCE DATA INTO RESPONSE AND FORCE MATRICES
HAS NUMBER OF FORCE CONDITIONS BEEN REACHED
NO
YES
IC2
≠ 2
F
= 2
IC8
≠ 0
E
= 0
SUBROUTINE AMPHAS CONVERT COMPLEX FORCE DATA TO AMPLITUDE, PHASE
D


D
SUBROUTINE MOUTC PRINT FORCE MATRIX: AMPLITUDE AND PHASE
E
SUBROUTINE MOUTC PRINT FORCE MATRIX: REAL AND IMAGINARY
F
SUBROUTINE INVC INVERT COMPLEX FORCE MATRIX
IERR
= 0
≠ 0
PRINT FORCE MATRIX NOT INVERTIBLE
G
SUBROUTINE MMPYC MULTIPLY RESPONSE MATRIX BY INVERSE OF FORCE MATRIX
IC2
= 2
≠ 2
IC8
= 0
≠ 0
SUBROUTINE AMPHAS CONVERT COMPLEX FORCE INVERSE TO AMPLITUDE, PHASE
SUBROUTINE MOUTC PRINT INVERSE OF FORCE MATRIX
IC2
= 2
I
≠ 2
IC8
= 0
≠ 0
SUBROUTINE AMPHAS CONVERT CONSTRAINED RESPONSE TO AMPLITUDE, PHASE
H


H
SUBROUTINE
MOUTC
PRINT
CONSTRAINED
RESPONSE
I
IC8
≠ 0
= 0
SUBROUTINE
AMPHAS
CONVERT FREE
BODY RESPONSE
TO AMPLITUDE,
PHASE
SUBROUTINE
MOUTC
PRINT
FREE BODY
RESPONSE
J

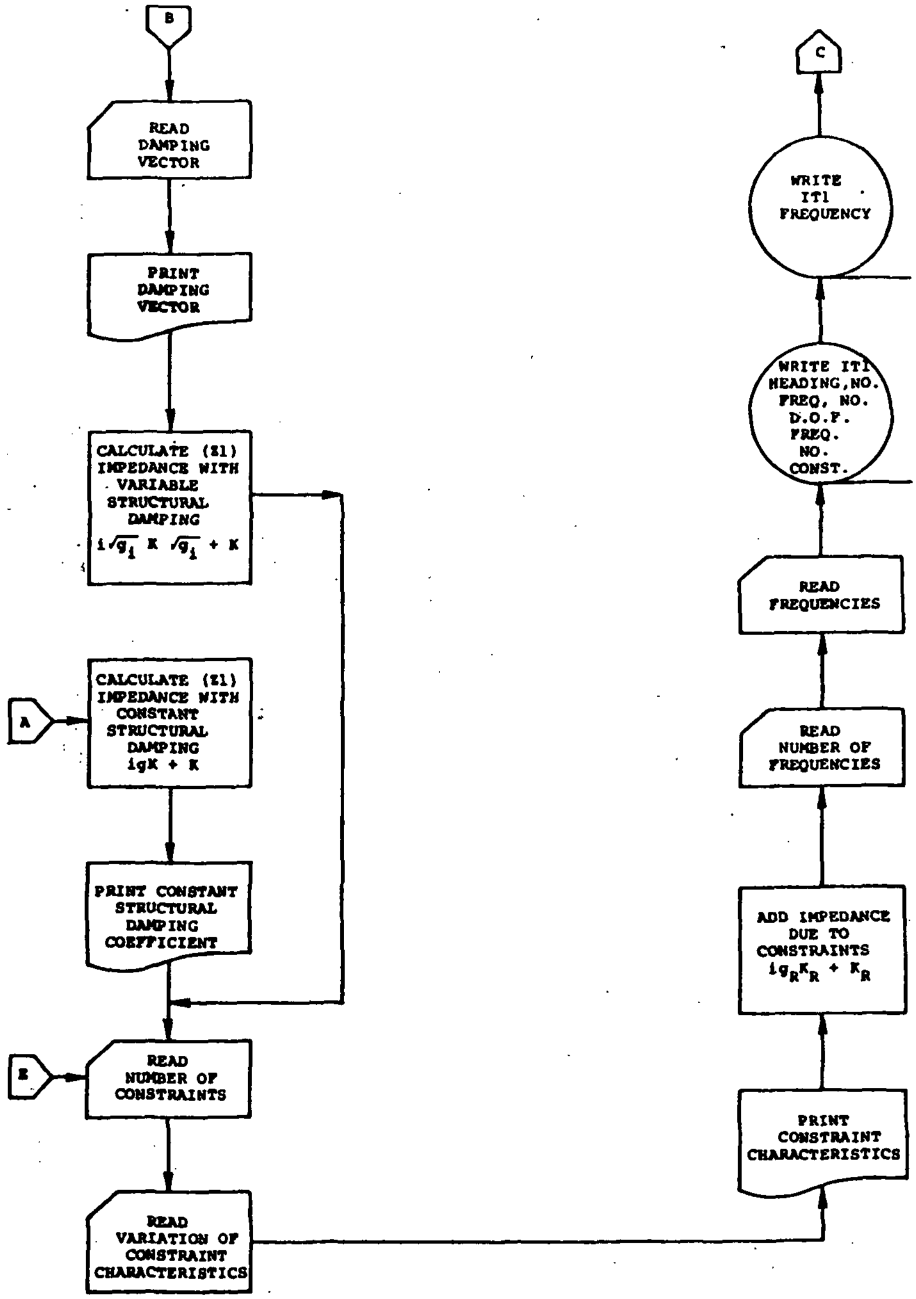
PROGRAM ZK1LRC

(VARIATION OF CONSTRAINTS)



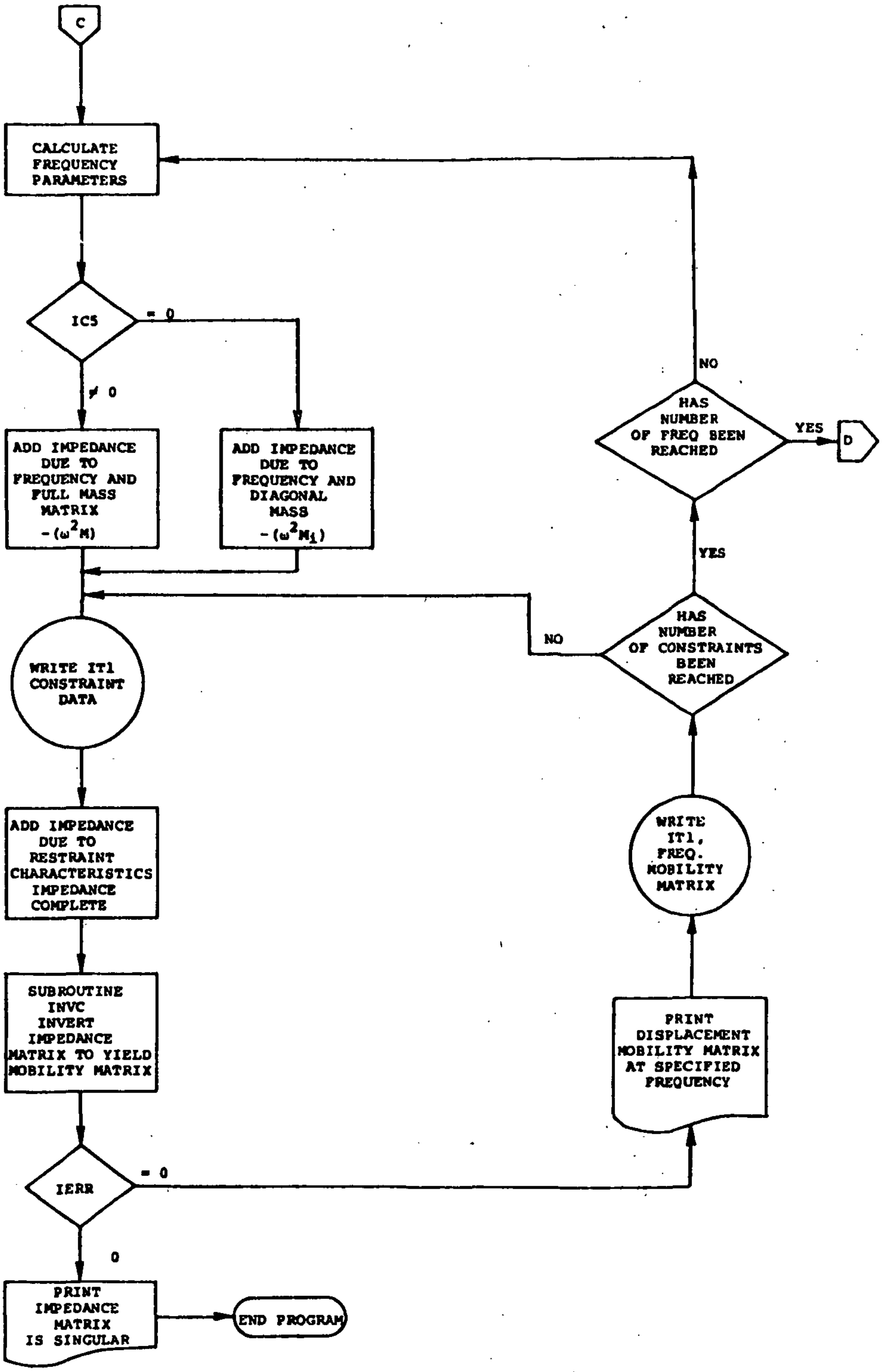
PROGRAM ZK1LRC

(VARIATION OF CONSTRAINTS)



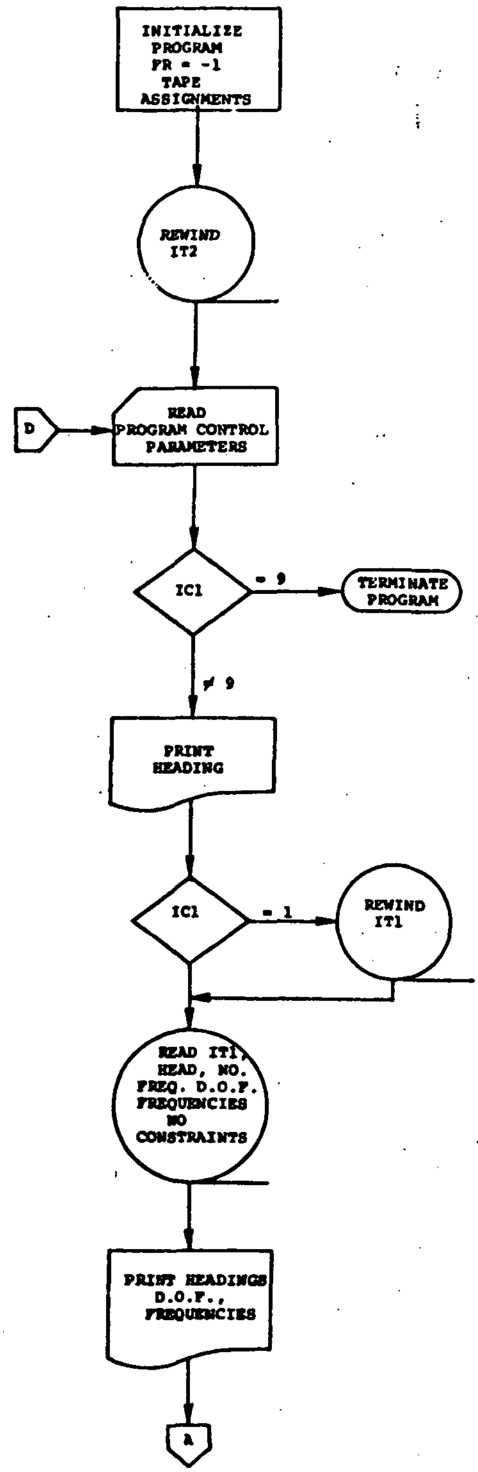
PROGRAM ZK1LRC

(VARIATION OF CONSTRAINTS)



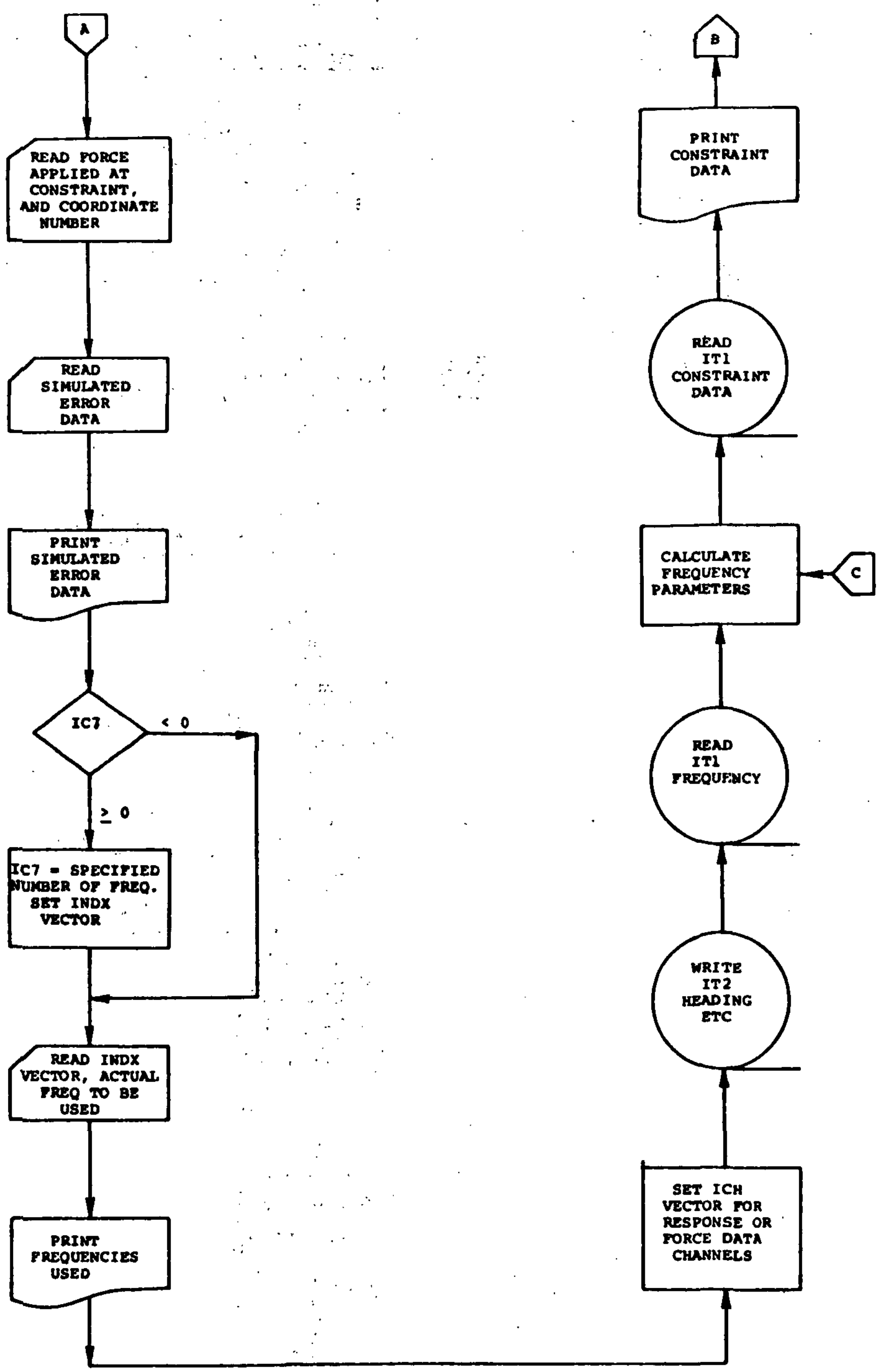
PROGRAM ZK2LRC

(VARIATION OF CONSTRAINTS)



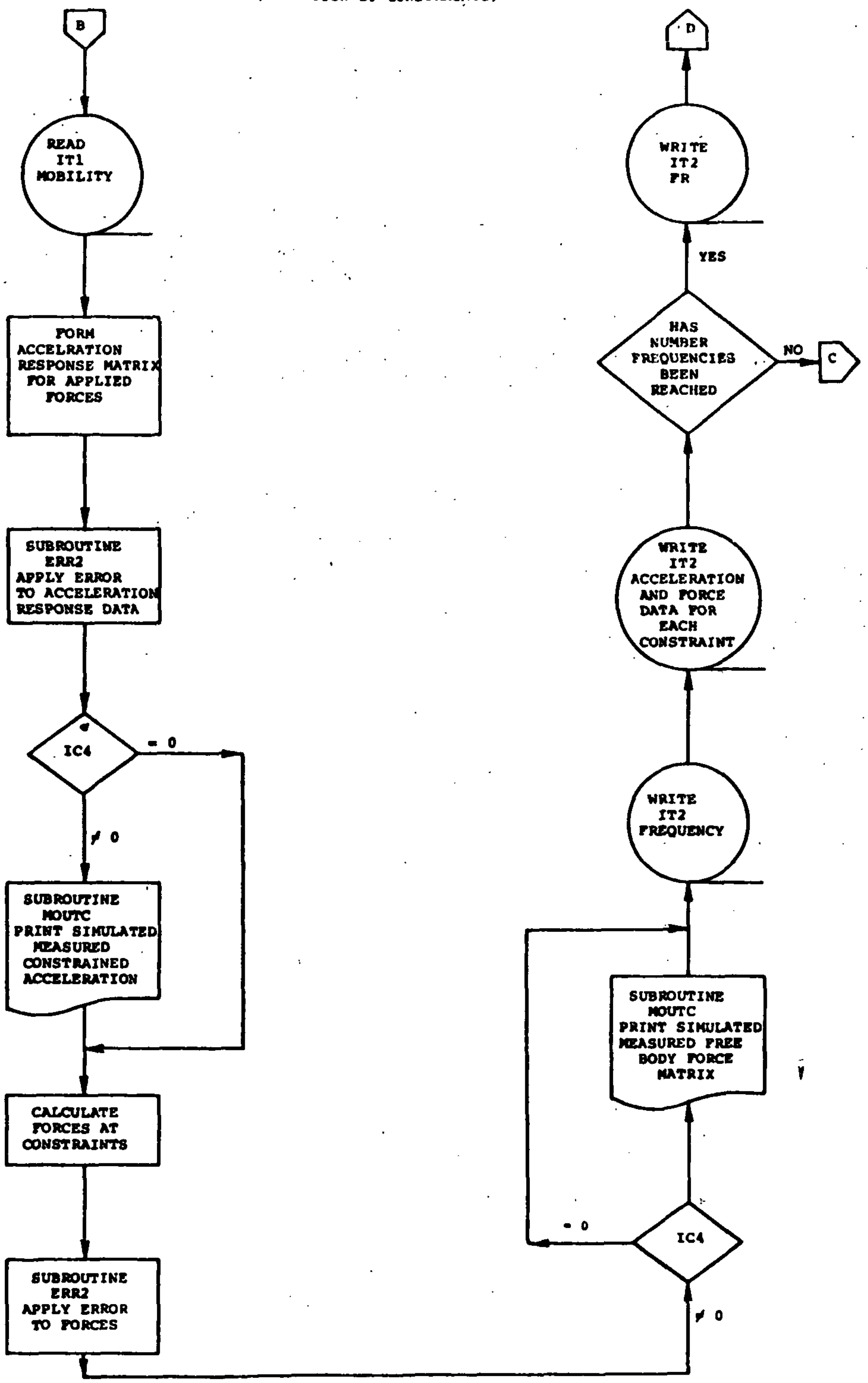
PROGRAM ZK2LRC

(VARIATION OF CONSTRAINTS)



PROGRAM ZK2KRC

(VARIATION OF CONSTRAINTS)



```
      PROGRAM K1LRC(INPUT,OUTPUT,TAPE1)
C
C     NCON IS THE NUMBER OF CONSTRAINTS
C     ONE INPUT CARD PER CONSTRAINT CONTAINING
C     COORDINATE NUMBER,CONSTRAINT STIFFNESS,CONSTRAINT DAMPING
C     NCOR IS THE INDICES OF THE STATIONS AT WHICH THE CONSTRAINTS ARE
C     LOCATED
C
      COMPLEX Z2,Y,Z1
      DIMENSION HEADC(9),AM(60,61),G(60) ,Z1(60,61),GS(60),AK(60,61),
     1 NCOR(24),AKR(24),DAMP(24),GR(24),HZ(100),
     2IROW(61),ICOL(61),IRLAB(61),ICLAB(61),Y(60,61),Z2(60,61)
C     NRA ON NEXT CARD MUST BE THE DIMENSIONED NUMBER OF ROWS OF MATRICES
      NRA=60
      IT1=1
C                                READ FIRST CARD
    1 READ 1000,IC1,IC2,IC3,IC4,IC5,IC6,IC7,IC8,HEADC
 1000 FORMAT (8I1,9A8)
      IF (IC1.EQ.9) CALL EXIT
      PRINT 1005
 1005 FORMAT (54H1   K1LRC  KAMAN AEROSPACE CORPORATION  NOV 27, 1972  )
      PRINT 1006, HEADC
 1006 FORMAT (//25X,9A8//)
      IF(IC1 .EQ. 1) GO TO 100
C                             READ FREE STRUCTURE DATA
      READ 1010,ND,GC
 1010 FORMAT (I10,7E10.0)
C                             MASS MATRIX
      IF(IC5 .EQ. 1) GO TO 10
 1002 FORMAT (8E10.0)
C                                DIAGONAL MASS
      DO 5 I=1,ND
      DO 5 J=1,ND
    5 AM(I,J)=0.
      READ    1002, (AM(I,1),I=1,ND)
      GO TO 20
C                                FULL MASS MATRIX
   10 DO 15 I=1,ND
   15 READ    1002,(AM(I,J),J=1,I)
      CALL SYM (AM,ND,NRA )
   20 PRINT 1100
 1100 FORMAT (1H1/40X,11HMASS MATRIX//)
      CALL MOUT2 ( AM,ND,ND,NRA )
C                                K INPUT
      DO 25 I=1,ND
   25 READ    1002, (AK(I,J),J=1,I)
      CALL SYM (AK,ND,NRA )
      PRINT 1200
 1200 FORMAT (1H1/40X,16HSTIFFNESS MATRIX//)
      CALL MOUT2 ( AK,ND,ND,NRA)
C                             VARIABLE DAMPING
      IF (IC6 .EQ. 0) GO TO 50
      READ 1002, (G(I),I=1,ND)
      PRINT 1011,(G(I),I=1,ND)
```

```
 1011 FORMAT (10X,13HDAMPING COEFS /(10X,10F10.3))
      DO 30 I = 1,ND
   30 GS(I) =  SQRT(G(I))
      DO 40 I = 1,ND
      DO 40 J = 1,ND
   40 Z1(I,J) =   CMPLX (AK(I,J),AK(I,J)*GS(I)*GS(J))
      GO TO  100
C                            CONSTANT STRUCTURAL DAMPING
   50 DO 60 I = 1,ND
      DO 60 J = 1,ND
   60 Z1(I,J) =  CMPLX(AK(I,J),GC*AK(I,J))
      PRINT 1025, GC
 1025 FORMAT (//10X,27HSTRUCTURAL DAMPING COEFF. =, F6.3)
C                            CONSTRAINT DATA
  100 READ 1010, NCON
      DO 180 I=1,NCON
  180 READ 1010, NCOR(I),AKR(I),GR(I),DAMP(I)
      PRINT 1040,  (NCOR(I),AKR(I),GR(I),DAMP(I),I=1,NCON)
 1040 FORMAT (1H1//10X,70HCOORDINATE      SPRING RATE          STR DAMPIN
     1G       VISCOUS DAMPING   ///(I16,1P3E20.3))
      DO 110 I = 1,NCON
      K = NCOR(I)
  110 Z1(K,K) = Z1(K,K) +  CMPLX (AKR(I), GR(I)*AKR(I))
C
C                              FREQUENCY DATA
C
      READ 1010,NF
      READ 1002, (HZ(I),I=1,NF)
      WRITE (IT1) HEADC,NF,ND,(HZ(I),I=1,NF)
      WRITE (IT1) NCON,(NCOR(I),AKR(I),DAMP(I),GR(I),I=1,NCON )
      DO 170 L=1,NF
      OMR=HZ(L)*6.283185
      OMRS=OMR*OMR
      IF(IC5.EQ.0) GO TO 140
      DO 130 I=1,ND
      DO 130 J=1,ND
  130 Z2(I,J)=Z1(I,J)-OMRS*AM(I,J)
      GO TO 120
  140 DO 135 I=1,ND
      DO 135 J=1,ND
  135 Z2(I,J)=Z1(I,J)
      DO 150 I=1,ND
  150 Z2(I,I)=Z2(I,I)-OMRS*AM(I,I)
  120 DO 160 I=1,NCON
      K=NCOR(I)
  160 Z2(K,K)=Z2(K,K)+ CMPLX( 0.0 ,OMR*DAMP(I) )
      CALL INVC ( Z2,Y,ND,NRA,NRA,IERR,IROW,ICOL )
      IF ( IERR.EQ.0 ) GO TO 151
      PRINT 1015
 1015 FORMAT  (1H1/48H  IMPEDANCE MATRIX IS SINGULAR    JOB TERMINATED/)
      CALL EXIT
C     PRINTED OLTPUT IS DISPLACEMENT DATA
C
  151 PRINT    1017, HZ(L)
```

```
 1017 FORMAT(1H1/40X,48HDISPLACEMENT MOBILITY      REAL,IMAGINARY   FREQ=
     1F10.2,6H HERTZ//)
      CALL MOUTC ( Y,ND,ND,NRA, 0, 0,IRLAB,ICLAB,7)
  190 WRITE (IT1) HZ(L),((Y(I,J),I=1,ND ),J=1,ND)
  170 CONTINUE
      GO TO 1
C
      END
```

```
      SUBROUTINE SYM (A,N,NRA )
C                FORMS SYMMETRIC MATRIX FROM LOWER TRIANGLE
      DIMENSION A(NRA,1 )
      N1=N-1
      DO 10 I=1,N1
      I1=I+1
      DO 10 J=I1,N
   10 A(I,J)=A(J,I)
      RETURN
      END
```

```
      SUBROUTINE MOUT2 (A,M,N,NRA )
      DIMENSION
     1     A(NRA,1 )
      ID=MINO(N,10)
      PRINT    1000, (I,I=1,ID)
 1000 FORMAT (/5X,10I12)
      PRINT 100C
      DO 10 I=1,M
   10 PRINT    1001, I,(A(I,J),J=1,ID)
 1001 FORMAT (I5,5X,1P10E12.4)
      IF (ID-N) 20,50,50
   20 K=N/10-1
      DO 40 L=1,K
      N1=L*10+1
      N2=10*(L+1)
      ID=MINO( N,N2 )
      PRINT    1000, (I,I=N1,ID)
      PRINT 1000
      DO 30 I=1,M
   30 PRINT    1001, I,(A(I,J),J=N1,ID)
   40 CONTINUE
      IF(N2-N) 60,50,50
   60 N2=N2+1
      PRINT    1000,  (I,I=N2,N)
      PRINT 1000
      DO 70 I=1,M
   70 PRINT    1001,  I,(A(I,J),J=N2,N )
   50 RETURN
      END
```

```
      SUBROUTINE MOUTC (A,L,M,NRA,IR,IC,IRLAB,ICLAB,LINE )
C
C                        A IS COMPLEX ARRAY  (*16 ON IBM )  LXM
C                    IRLAB IS ARRAY OF INDICES FOR ROW  (USED WHEN IR=1 )
C                    ICLAB IS ARRAY OF INDICES FOR COL  (USED WHEN IC=1)
C                        NRA IS DIMENSIONED NO OF ROWS IN A
C                 OUTPUT FORM   RE,IM    X.XXXE XX,  X.XXXE XX
C                        LINE IS LINE NO ON PAGE OF FIRST OUTPUT LINE
      COMPLEX A(NRA,1)
      DIMENSION IRLAB(1),ICLAB(1)
      IC1=1
      IC2=MINO(5,M)
   10 IL1=1
      IL2=MINO (55-LINE,L )
   15 IF (IC.EQ.1) GO TO 20
      PRINT 1000, (I,I=IC1,IC2 )
      GO TO 30
   20 PRINT 1000, (ICLAB(I),I=IC1,IC2 )
 1000 FORMAT (/ I23,4I24/)
   30 DO 50 I=IL1,IL2
      IF (IR .EQ.1 ) GO TO 40
      PRINT 1010, I,(A(I,J),J=IC1,IC2)
      GO TO 50
   40 PRINT 1010 , IRLAB(I),(A(I,J),J=IC1,IC2 )
 1010 FORMAT ( I6,4X,1P5(E12.3,1H,,E11.3))
   50 CONTINUE
      IF (I.GE.L ) GO TO 100
      IL1=IL2+1
      IL2=MINO(IL2+55,L )
      PRINT 1015
 1015 FORMAT (1H1 )
      GO TO 15
  100 IF (IC2.GE.M ) GO TO 120
      IC1=IC2+1
      IC2=MINO (IC2+5,M )
      PRINT 1015
      GO TO 10
  120 RETURN
      END
```

```
      SUBROUTINE INVC   (D,A,N,NRA,NRB,IERR,IROW,ICOL )
C     A = INVERSE OF D          ORIGINAL MATRIX D IS DESTROYED
      COMPLEX A,D,AMAX,E,PVT,AMULT
      DIMENSION A(NRB,1),D(NRA,1),IROW(1),ICOL(1)
      IERR=0
      DO 1 I=1,N
      DO 1 J=1,N
    1 A(I,J)=D(I,J)
      M=N+1
      DO 7  I=1,N
      IROW(I)=I
    7 ICOL(I)=I
      DO 20 K=1,N
      AMAX= A(K,K)
      DO 10 I=K,N
      DO 10 J=K,N
      IF( CABS( A(I,J))- CABS(AMAX))10,9,9
    9 AMAX= A(I,J)
      IC=I
      JC=J
   10 CONTINUE
      KI=ICOL(K)
      ICOL(K)=ICOL(IC)
      ICOL(IC)=KI
      KI=IROW(K)
      IROW(K)=IROW(JC)
      IROW(JC)=KI
      IF( CABS(AMAX)) 11,12,11
   12 IERR=-1
       GO TO 100
   11 DO 14 J=1,N
      E=A(K,J)
      A(K,J)=A(IC,J)
   14 A(IC,J)=E
      DO 15 I=1,N
      E=A(I,K)
      A(I,K)=A(I,JC)
   15 A(I,JC)=E
      DO 16 I=1,N
      IF(I-K) 18,17,18
   17 A(I,M)=(1.,0.)
      GO TO 16
   18 A(I,M)=(0.,0.)
   16 CONTINUE
      PVT=A(K,K)
      DO 8 J=1,M
    8 A(K,J)=A(K,J)/PVT
      DO 19 I=1,N
      IF(I-K)21,19,21
   21 AMULT=A(I,K)
      DO 22 J=1,M
   22 A(I,J)=A(I,J)-AMULT*A(K,J)
   19 CONTINUE
      DO 20 I=1,N
```

```
 20  A(I,K)=A(I,M)
     DO 25 I=1,N
     DO 24 L=1,N
     IF(IROW(I)-L)24,23,24
 24  CONTINUE
 23  DO 25 J=1,N
 25  D(L,J)=A(I,J)
     DO 26 J=1,N
     DO 28 L=1,N
     IF(ICOL(J)-L) 28,29,28
 28  CONTINUE
 29  DO 26 I=1,N
 26  A(I,L)=D(I,J)
100  RETURN
     END
```

```
      PROGRAM K2LRC(INPUT,OUTPUT,TAPE1,TAPE2)
C         FREE BODY TEST METHOD SIMULATION
C
C                   USES MOBILITY DATA FROM 'K1LRC'
C
C
C
C     IC6 IS NUMBER OF DEGREES OF FREEDOM AT  EACH COORDINATE
C     USED IN SUBROUTINE ERR2
      COMPLEX Y,YA
      DIMENSION HEADN( 9),HEAD( 9),INDS(24),INDX(100)
      DIMENSION HZ(100),SPR(24),FAMP(24),DAMP(24),ICH(72),INDR(20)
      DIMENSION Y(60,61),YA(60,61),GT(24),IRLAB(61),ICLAB(61)
C
      COMMON/SET/LRCL,LRCN,LRCIX(2)
C
C     TAPE UNIT IT1 CONTAINS DATA FROM K1LRC PROGRAM
C
C     TAPE UNIT IT2 USED FOR DATA TRANSMITTAL TO K3LRC PROGRAM
C
C
C
      IT1=1
      IT2=2
      NRA=60
      FR=-1
      REWIND IT2
C
C                   READ FIRST CARD
    1 READ 1000,IC1,IC2,IC3,IC4,IC5,IC6,IC7,    HEADN
 1000 FORMAT (6I1,I2,9A8 )
      IF (IC1.EQ.9) CALL EXIT
      PRINT 1002
 1002 FORMAT (54H1   K2LRC  KAMAN AEROSPACE CORPORATION  NOV 27, 1972  )
      IF (IC1.EQ.1) REWIND IT1
   15 READ (IT1) HEAD,NF,ND,(HZ(I),I=1,NF)
      PRINT 1011,    HEADN,HEAD,ND,(HZ(I),I=1,NF)
 1011 FORMAT (1H1//25X,9A8//
     125X, 9A8   /25X,I2,19H DEGREES OF FREEDOM /25X,23H FREQUENCIES(HZ)
     2ON TAPE //(10X, 10F10.2))
C                   TAPE INPUT
C        CONSTRAINT SPRINGS,VISCOUS DAMPERS,STRUCTURAL DAMPING
      READ (IT1) NS,(INDS(I),SPR(I),DAMP(I),GT(I),I=1,NS )
C        INPUT APPLIED FORCES AT CONSTRAINTS
      READ  130 , (FAMP(I),I=1,NS)
C        INPUT APPLIED FORCES AT NON-CONSTRAINT CORDINATES
      IF(IC2.EQ.0) GO TO 7
      NS1=NS+1
      NS=IC2+NS
      READ 130, (FAMP(I),I=NS1,NS )
      READ 131, (INDS(I),I=NS1,NS )
  131 FORMAT (8I10 )
  130 FORMAT (8F10.0 )
      DO 11 I=NS1,NS
```

```
      SPR(I)=0.
      DAMP(I)=0.
   11 GT(I)=0.
    7 PRINT 1003,    (INDS(I),I=1,NS)
      PRINT 1004,    ( SPR(I),I=1,NS)
      PRINT 1005,    (FAMP(I),I=1,NS)
      PRINT 1001 ,  (DAMP(I),I=1,NS)
      PRINT 1008,  (GT(I),I=1,NS )
 1001 FORMAT (//10X,7HDAMPERS,10X,3(8F10.0)//)
 1003 FORMAT (/10X,22HCONSTRAINTS AND FORCES //10X,9HSTATION    ,5X,
     13(8I10)//)
 1004 FORMAT (//10X, 6HSPRING ,11X,3(8F10.0)//)
 1005 FORMAT (//10X,13HAPPLIED FORCE ,4X,3(8F10.0)//)
 1008 FORMAT (//10X,18HSTRUCTURAL DAMPING,2X,3(8F10.3)//)
C                    INPUT ERRORS, FREQUENCIES
      READ  1006,      PCT,PCTB,PHE,FPCT,FPCTB,FPHE,IZ,AMPL,AMPR,AMPF
 1006 FORMAT (6F5.0,I10,3F10.0)
      LRCIX(1)=IZ*2+1
      LRCN=1
      LRCL=1
      PRINT 1007,    PCT,PCTB,PHE,IZ,FPCT,FPCTB,FPHE,AMPL,AMPR,AMPF
 1007 FORMAT (/10X,16HMAX RAND ERROR =,F5.3,13H BIAS ERROR =,F5.3,37H OF
     1 RESPONSE  MAX RAND PHASE ERROR = ,F5.2,16H DEG.       SEED =, I10/
     210X,12HFORCE ERRORS, 4X,F5.3,13X,F5.3,37X,F5.2//10X,38HMAX RAND LI
     3NEAR ACCEL(REAL,IMAG)ERROR=E12.4/9X,39HMAX RAND ANGULAR ACCEL(REAL
     4,IMAG)ERROR=E12.4/17X,31HMAX RAND FORCE(REAL,IMAG)ERROR=E12.4//)
      IF (IC7.GT.0) GO TO 20
      IC7=NF
      DO 10 I=1,NF
   10 INDX(I)=I
      PRINT 1009,NF
 1009 FORMAT (/10X, 4HALL  ,I3,1X, 16HFREQUENCIES USED)
      GO TO 30
   20 READ  1040,    (INDX(I),I=1,IC7)
      DO 12 I=1,IC7
      K=INDX(I)
   12 HZ(I)=HZ(K)
   30 PRINT 1010,    (HZ(K),K=1,IC7 )
 1010 FORMAT (/10X,16HFREQUENCIES USED//(10X, 10F12.4))
      INFR=1
      DO 2 I=1,ND
    2 ICH(I)=0
      NB=ND+1
      NC=ND+NS
      DO 3 I=NB,NC
    3 ICH(I)=2
      WRITE (IT2) HEADN,NC,NS,(ICH(I),I=1,NC )
C                              START MAIN LOOP
      DO 500 L=1,NF
      READ (IT1)  FREQ,((Y(I,J),I=1,ND),J=1,ND )
      IF(L.NE.INDX(INFR)) GO TO 500
C                   ELIMINATE COLUMNS AND CONVERT TO ACCL MOB
      OMR=FREQ *6.2832
      OMRS=OMR*OMR
```

```
      DO 50 J=1,NS
      F=FAMP(J)
      K=INDS(J)
      DO 50 I=1,ND
      Y(I,J)=Y(I,K)*F
   50 YA(I,J)=-Y(I,J)*OMRS
C                        FORM CONSTRAINT DISP MATRIX AND ADD ERROR
      CALL ERR2 (      YA,PCT,PCTB,PHE,ND,NS,IX,NRA,AMPL,AMPR,0.,IC6 )
C
      IF (IC4.EQ.0) GO TO 60
C
      PRINT 1020,       HZ(INFR)
 1020 FORMAT (1H1,20X,71HSIMULATED MEASURED CONSTRAINED ACCELERATION
     1                    F =  , F10.2,3H HZ/)
      CALL MOUTC ( YA ,ND,NS,NRA, 0, 0,IRLAB,ICLAB,5 )
C                      ACCELERATIONS DUE TO FORCES AND FORCES AT CONSTRAINTS
C                                 WITH ERRORS ON TOTAL FORCES
C                        ACCELERATIONS DUE TO FORCES
   60 DO 70 J=1,NS
C                        FORCES AT CONSTRAINTS
      DO 70 II=1,NS
      I=INDS(II)
   70 Y(II,J)=-SPR(II)*Y(I,J)-(GT(II)*SPR(II)+OMR*DAMP(II))*Y(I,J)*
     1 (0.,1.)
      DO 91 I=1,NS
   91 Y(I,I)=Y(I,I)+FAMP(I)
      CALL ERR2 (         Y,FPCT,FPCTB,FPHE,NS,NS,IX,NRA,0.,0.,AMPF,0 )
C
      IF (IC4.EQ.0) GO TO 100
C
      PRINT 1025,       HZ(INFR)
 1025 FORMAT (1H1,20X,60HSIMULATED MEASURED FREE BODY FORCE MATRIX
     1           F =  , F10.2,3H HZ/ )
      CALL MOUTC ( Y,NS,NS,NRA, 0, 0,IRLAB,ICLAB,5 )
  100 WRITE (IT2 ) HZ(INFR)
C
C       ACCELERATION DATA ON TAPE
    9 DO 5 J=1,NS
    5 WRITE (IT2 ) (YA(I,J),I=1,ND),(Y(I,J),I=1,NS )
 1040  FORMAT (8I10 )
  502 INFR=INFR+1
      IF (INFR.GT.IC7) GO TO 501
  500 CONTINUE
  501 WRITE (IT2 ) FR
   13 GO TO 1
      END
```

```
      SUBROUTINE MOUTC (A,L,M,NRA,IR,IC,IRLAB,ICLAB,LINE )
C
C                     A IS COMPLEX ARRAY  (*16 ON IBM )  LXM
C                  IRLAB IS ARRAY OF INDICES FOR ROW  (USED WHEN IR=1 )
C                  ICLAB IS ARRAY OF INDICES FOR COL  (USED WHEN IC=1)
C                     NRA IS DIMENSIONED NO OF ROWS IN A
C                OUTPUT FORM   RE,IM    X.XXXE XX,  X.XXXE XX
C                     LINE IS LINE NO ON PAGE OF FIRST OUTPUT LINE
      COMPLEX A(NRA,1)
      DIMENSION IRLAB(1),ICLAB(1)
      IC1=1
      IC2=MINO(5,M)
   10 IL1=1
      IL2=MINO (55-LINE,L )
   15 IF (IC.EQ.1) GO TO 20
      PRINT 1000, (I,I=IC1,IC2 )
      GO TO 30
   20 PRINT 1000, (ICLAB(I),I=IC1,IC2 )
 1000 FORMAT (/ I23,4I24/)
   30 DO 50 I=IL1,IL2
      IF (IR .EQ.1 ) GO TO 40
      PRINT 1010, I,(A(I,J),J=IC1,IC2)
      GO TO 50
   40 PRINT 1010 , IRLAB(I),(A(I,J),J=IC1,IC2 )
 1010 FORMAT ( I6,4X,1P5(E12.3,1H,,E11.3))
   50 CONTINUE
      IF (I.GE.L ) GO TO 100
      IL1=IL2+1
      IL2=MINO(IL2+55,L )
      PRINT 1015
 1015 FORMAT (1H1 )
      GO TO 15
  100 IF (IC2.GE.M ) GO TO 120
      IC1=IC2+1
      IC2=MINO (IC2+5,M )
      PRINT 1015
      GO TO 10
  120 RETURN
      END
```

```
      SUBROUTINE ERR2 ( ZA,PCT,PCTB,PHE,N1,N2,IX,NR,AMPL,AMPR,AMP,IC6 )
C             OBJECT TIME DIMENSIONS
C             EACH ELEMENT OF A COMPLEX MATRIX, A  IS MODIFIED TO
C             INCLUDE A SMALL PHASE ERROR, PNE (DEG),  A BIAS ERROR,
C             PCTB (RATIO) ON AMPLITUDE, A UNIFORM RANDOM ERROR
C             HAVING A +/- MAXIMUM OF PCT (RATIO) ON AMPLITUDE,
C             AND A UNIFORM RANDOM ERROR HAVING A +/-
C             MAXIMUM ON AMPLITUDE
C             THE PHASE ERROR IS ALSO RANDOMLY DISTRIBUTED
C    NOTE   NO SYMMETRIZATION IS PERFORMED
C      IC6 IS THE NUMBER OF DEGREES OF FREEDOM OF EACH COORDINATE
C
C      USES GETRAN(UNIFORM DISTRIBUTION)
C      LRCIX(1)=ARBITRARILY SELECTED LOSITIVE INTEGER
C      LRCN=1 FOR FIRST CALL TO GETRAN
C      SET LRCN GREATER THAN 1 FOR SUBSEQUENT CALLS TO GETRAN
C      LRCL=1 FOR UNIFORM DISTRIBUTION
C      LRCIX(2),DUM1,DUM2, NOT USED
C      YFL=UNIFORMLY DISTRIBUTED RANDOM NUMBER
C
C
      COMPLEX ZA(NR,1)
      COMMON/SET/LRCL,LRCN,LRCIX(2)
      IF(PCT ) 120,100,120
  100 IF(PCTB) 120,110,120
  110 IF(PHE) 120,140,120
  140 IF (AMPL) 120,145,120
  145 IF( AMPR ) 120,155,120
  155 IF( AMP ) 120,135,120
  120 P=PHE/57.296
      DO 130 J=1,N2
      K=(IC6+1)/2
      K1=IC6
      DO 130 I=1,N1
      CALL GETRAN(LRCIX(1),LRCN,LRCL,DUM1,YFL,DUM2)
      IF(LRCN.EQ.1)LRCN=LRCN+1
      E=2.0*P*(YFL-0.5)
      AR=ZA(I,J)
      AI=(0.,-1.)*ZA(I,J)
      R1= ABS( AR )
      R2= ABS( AI )
      R3=R1+R2
      IF (R3.EQ.0.) GO TO 130
      R1=R1/R3
      R2=R2/R3
      A1=AR-E*AI
      AI=AI+E*AR
      AR=A1
      CALL GETRAN(LRCIX(1),LRCN,LRCL,DUM1,YFL,DUM2)
      E=1.0+2.0*PCT*(YFL-0.5)+PCTB
      AR=AR*E
      AI=AI*E
      CALL GETRAN(LRCIX(1),LRCN,LRCL,DUM1,YFL,DUM2)
C     AMP ERROR DIST IN PROPORTION TO RATIOS OF REAL AND IMAG TO (REAL+IMAG)
```

```
      IF (IC6.EQ. 0 ) GO TO 170
      IF( I-K ) 175,175,185
  175 AMP=AMPL
      GO TO 170
  185 AMP=AMPR
  170 E=2.*(YFL-.5 )*AMP*R1
      AR=AR+E
      CALL GETRAN(LRCIX(1),LRCN,LRCL,DUM1,YFL,DUM2)
      E=2.*(YFL-.5 )*AMP*R2
      AI=AI+E
  160 ZA(I,J)= CMPLX (AR,AI )
      IF ( IC6.EQ. 0 ) GO TO 130
      IF (I.NE. K1 ) GO TO 130
      K=K+IC6
      K1=K1+IC6
  130 CONTINUE
  135 RETURN
      END
```

```
      PROGRAM K3LRC(INPUT,OUTPUT,TAPE2)
      COMPLEX W,WF,WR,Y,WFINV,WF1
      DIMENSION W(80),HEADC(9),HEADT( 9),ICH(80),ICHC(80),IW(24),
     1 WF(24,25),WR(60,24),Y(60,24),ICHNO(60),WFINV(24,25),
     2 IROW(25),ICOL(25),WF1(24,25)
C
C     TAPE UNIT IT1 CONTAINS DATA FROM FREBODY PROGRAM
C
      IT1=2
C                               READ FIRST CARD
    1 READ 1000,IC1,IC2,IC3,IC4,IC5,IC6,IC7,IC8,HEADC
 1000 FORMAT (8I1,9A8)
      IF (IC1.EQ.9) CALL EXIT
      PRINT 1005
 1005 FORMAT (54H1   K3LRC  KAMAN AEROSPACE CORPORATION  NOV 27 1972    )
      IF (IC1.EQ.1) REWIND IT1
C                               READ FIRST TAPE RECORD
      READ (IT1) HEADT,NC,NF,(ICH(I),I=1,NC)
      NIX=0
      NCA=NC
      NFA=NF
C                               PRINT HEADINGS
      PRINT 1010,        HEADC,HEADT
 1010 FORMAT (//20X,9A8//20H     TAPE HEADING----,  9A8 )
      PRINT 1015,        NC,NF
 1015 FORMAT (/20X,20HNUMBER OF CHANNELS = ,I4,10X,18HNUMBER OF FORCES =
     1 ,I4)
      IF (IC4.EQ.0) GO TO 50
C                               MODIFY TAPE DATA
      READ 1020,ICHC,IW
 1020 FORMAT (80I1)
      DO 10 I=1,NC
      IF (ICHC(I).EQ.0) GO TO 10
      NCA=NCA-1
      IF (ICH(I).EQ.2) NFA=NFA-1
      ICH(I)=1
   10 CONTINUE
      NIX=NF-NFA
      IF(NIX.EQ.0) GO TO 30
      IX=0
      DO 20 I=1,24
      IF(IW(I).GT.0) IX=IX+1
  20  CONTINUE
      IF (IX.EQ.NIX) GO TO 30
      PRINT 1025, NIX,IX
 1025 FORMAT(//10X,40HINCORRECT NUMBER OF DATA SETS ELIMINATED ,  I5,
     1  9HREQUIRED, ,I5,10HDESIGNATED)
      CALL EXIT
C                               PRINT MODIFICATIONS
   30 PRINT 1030,NCA,NFA, (I,     IW(I),I=1,NIX)
 1030 FORMAT (20H         MODIFIED TO  ,20X,I4,28X,I4//20X,34HDATA SETS EL
     1IMINATED = 1, KEPT = 0  //  7X,12(I5,3H = ,I2)/7X,12(I5,3H = ,I2))
C                               CHANNEL INFORMATION
  50  PRINT 1035,       (I,ICH(I),I=1,NC)
```

```
1035 FORMAT (//20X,70HCHANNEL DEFINITIONS, = 0   RESP DATA, = 1   NOT U
    1SED, = 2   FORCE DATA //   7X,12(I5,3H = ,I2)/7X,12(I5,3H = ,I2)/
    27X,12(I5,3H = ,I2)/7X,12(I5,3H = ,I2)/7X,12(I5,3H = ,I2))
C                               SET UP RESPONSE CHANNEL NOS
      NROW=0
      DO 60 I=1,NC
      IF (ICH(I).NE.0) GO TO 60
      NROW = NROW+1
      ICHNO(NROW)=I
   60 CONTINUE
      IF(NROW.GT.60) PRINT 1036
 1036 FORMAT(10X,34H----TOO MANY RESPONSE CHANNELS---- )
      CALL EXIT
  310 READ (IT1)  FREQ
      IF (FREQ.GE.0) GO TO 90
      IF (FREQ.EQ.-1) GO TO 1
      REWIND IT1
      GO TO 1
C                               READ TAPE DATA
   90 NW=0
      ICOLO=0
  100 NW=NW+1
      IF(NW.GT.NF) GO TO 200
      READ (IT1) (W(I),I=1,NC)
      IF(NIX.EQ.0) GO TO 120
      IF(IW(NW).NE.0) GO TO 100
C                               DISTRIBUTE TAPE DATA
  120 ICOLO=ICOLO+1
      IROWF=0
      IROWR=0
      DO 150 I=1,NC
      IF (ICH(I)-1) 130,150,140
  130 IROWR=IROWR+1
      WR(IROWR,ICOLO)=W(I)
      GO TO 150
  140 IROWF=IROWF+1
      WF(IROWF,ICOLO)=W(I)
  150 CONTINUE
      GO TO 100
C                               ALL INPUT MATRICES READ-IN      INVERT WF
  200 IF(IC2.NE.2) GO TO 250
C                               PRINT FORCES
      IF( IC8.NE. 0) GO TO 340
      PRINT 1051,FREQ
 1051 FORMAT (1H1,///10X,12H FREQUENCY =  G14.4//10X,31HFORCE MATRIX
    1AMP,PHASE(DEG)   //)
      DO 341 I=1,NFA
      DO 341 J=1,NFA
  341 WF1(I,J)=WF(I,J)
      CALL AMPHAS ( WF1,NFA,NFA ,24 )
      CALL MOUTC (WF1,NFA,NFA,24,0,0,ICHNO,ICHNO,7,IC8 )
      GO TO 250
  340 PRINT 1050, FREQ
 1050 FORMAT (1H1,///10X,12H FREQUENCY =  G14.4//10X,31HFORCE MATRIX
```

```
     1REAL, IMAGINARY //)
  320 CALL MOUTC (WF,NFA,NFA,24,0,0,ICHNO,ICHNO,7,IC8 )
  250 CALL INVC (WF,WFINV,NFA,24,24,IERR,IROW,ICOL)
      IF (IERR.EQ.0) GO TO 210
      PRINT 1040
 1040 FORMAT (///10X,45H--------- FORCE MATRIX NOT INVERTIBLE--------   )
      GO TO 1
  210 CALL MMPYC (WR,WFINV,Y,NROW,NFA,NFA,60,24,60 )
C                             CALCULATIONS COMPLETE
C                             PRINT OUTPUT
      IF (IC2.NE.2) GO TO 260
      IF( IC8.NE.0 ) GO TO 261
      CALL AMPHAS ( WFINV,NFA,NFA,24 )
  261 PRINT 1055,FREQ
 1055 FORMAT (1H1///10X,12H FREQUENCY =  G14.4//10X,23HINVERSE OF FORCE
     1MATRIX  //)
      CALL MOUTC (WFINV,NFA,NFA,24,0,0,ICHNO,ICHNO,7,IC8 )
  260 IF (IC2.EQ.0) GO TO 330
C                             PRINT CONSTRAINED RESPONSES
      IF( IC8.NE. 0 ) GO TO 270
      PRINT 1061,FREQ
 1061 FORMAT (1H1,///12H FREQUENCY =  G14.4//10X,45HCONSTRAINED RESPONSE
     1 MATRIX   AMP,PHASE (DEG)  //)
      CALL AMPHAS ( WR,NROW,NFA ,60 )
      GO TO 280
  270 PRINT 1060, FREQ
 1060 FORMAT (1H1,///12H FREQUENCY =  G14.4//10X,45HCONSTRAINED RESPONSE
     1 MATRIX   REAL, IMAGINARY  //)
  280 CALL MOUTC (WR,NROW,NFA,60,1,0,ICHNO,ICHNO,7,IC8 )
  330 IF ( IC8 .NE. 0 ) GO TO 300
      PRINT 1071,FREQ
 1071 FORMAT (1H1,///12H FREQUENCY =  G14.4//10X,43HFREE BODY RESPONSE M
     1ATRIX   AMP,PHASE(DEG)  //)
      CALL AMPHAS (Y,NROW,NFA ,60 )
      GO TO 290
  300 PRINT 1070,FREQ
 1070 FORMAT (1H1,///12H FREQUENCY =  G14.4//10X,43HFREE BODY RESPONSE M
     1ATRIX   REAL, IMAGINARY //)
  290 CALL MOUTC (Y,NROW,NFA,60,1,0,ICHNO,ICHNO,7,IC8 )
      GO TO 310
      END
```

```
      SUBROUTINE MMPYC ( A,B,C,L,M,N,NRA,NRB,NRC )
C
C             A,B,C  COMPLEX MATRICES (*16 ON IBM )
C
C             C = A * B     A IS L X M,  B IS M X N,  C IS L X N
C
C             NRA,NRB,NRC  DIMENSIONED ROWS IN A,B,C
C
      COMPLEX A(NRA,1), B(NRB,1), C(NRC,1)
      DO 100 I=1,L
      DO 100 J=1,N
      C(I,J) =(0.0,0.0)
      DO 100 K=1,M
  100 C(I,J) = C(I,J) + A(I,K) * B(K,J)
      RETURN
      END
```

```
      SUBROUTINE MOUTC (A,L,M,NRA,IR,IC,IRLAB,ICLAB,LINE )
C
C                      A IS COMPLEX ARRAY  (*16 ON IBM )  LXM
C                  IRLAB IS ARRAY OF INDICES FOR ROW  (USED WHEN IR=1 )
C                  ICLAB IS ARRAY OF INDICES FOR COL  (USED WHEN IC=1)
C                      NRA IS DIMENSIONED NO OF ROWS IN A
C                 OUTPUT FORM   RE,IM    X.XXXE XX,  X.XXXE XX
C                      LINE IS LINE NO ON PAGE OF FIRST OUTPUT LINE
      COMPLEX A(NRA,1)
      DIMENSION IRLAB(1),ICLAB(1)
      IC1=1
      IC2=MINO(5,M)
   10 IL1=1
      IL2=MINO (55-LINE,L )
   15 IF (IC.EQ.1) GO TO 20
      PRINT 1000, (I,I=IC1,IC2 )
      GO TO 30
   20 PRINT 1000, (ICLAB(I),I=IC1,IC2 )
 1000 FORMAT (/ I23,4I24/)
   30 DO 50 I=IL1,IL2
      IF (IR .EQ.1 ) GO TO 40
      PRINT 1010, I,(A(I,J),J=IC1,IC2)
      GO TO 50
   40 PRINT 1010 , IRLAB(I),(A(I,J),J=IC1,IC2 )
 1010 FORMAT ( I6,4X,1P5(E12.3,1H,,E11.3))
   50 CONTINUE
      IF (I.GE.L ) GO TO 100
      IL1=IL2+1
      IL2=MINO(IL2+55,L )
      PRINT 1015
 1015 FORMAT (1H1 )
      GO TO 15
  100 IF (IC2.GE.M ) GO TO 120
      IC1=IC2+1
      IC2=MINO (IC2+5,M )
      PRINT 1015
      GO TO 10
  120 RETURN
      END
```

```
      SUBROUTINE INVC  (D,A,N,NRA,NRB,IERR,IROW,ICOL )
C     A = INVERSE OF D         ORIGINAL MATRIX D IS DESTROYED
      COMPLEX A,D,AMAX,E,PVT,AMULT
      DIMENSION A(NRB,1),D(NRA,1),IROW(1),ICOL(1)
      IERR=0
      DO 1 I=1,N
      DO 1 J=1,N
    1 A(I,J)=D(I,J)
      M=N+1
      DO 7  I=1,N
      IROW(I)=I
    7 ICOL(I)=I
      DO 20 K=1,N
      AMAX= A(K,K)
      DO 10 I=K,N
      DO 10 J=K,N
      IF( CABS( A(I,J))- CABS(AMAX))10,9,9
    9 AMAX= A(I,J)
      IC=I
      JC=J
   10 CONTINUE
      KI=ICOL(K)
      ICOL(K)=ICOL(IC)
      ICOL(IC)=KI
      KI=IROW(K)
      IROW(K)=IROW(JC)
      IROW(JC)=KI
      IF( CABS(AMAX)) 11,12,11
   12 IERR=-1
       GO TO 100
   11 DO 14 J=1,N
      E=A(K,J)
      A(K,J)=A(IC,J)
   14 A(IC,J)=E
      DO 15 I=1,N
      E=A(I,K)
      A(I,K)=A(I,JC)
   15 A(I,JC)=E
      DO 16 I=1,N
      IF(I-K) 18,17,18
   17 A(I,M)=(1.,0.)
      GO TO 16
   18 A(I,M)=(0.,0.)
   16 CONTINUE
      PVT=A(K,K)
      DO 8 J=1,M
    8 A(K,J)=A(K,J)/PVT
      DO 19 I=1,N
      IF(I-K)21,19,21
   21 AMULT=A(I,K)
      DO 22 J=1,M
   22 A(I,J)=A(I,J)-AMULT*A(K,J)
   19 CONTINUE
      DO 20 I=1,N
```

```
 20  A(I,K)=A(I,M)
     DO 25 I=1,N
     DO 24 L=1,N
     IF(IROW(I)-L)24,23,24
 24  CONTINUE
 23  DO 25 J=1,N
 25  D(L,J)=A(I,J)
     DO 26 J=1,N
     DO 28 L=1,N
     IF(ICOL(J)-L) 28,29,28
 28  CONTINUE
 29  DO 26 I=1,N
 26  A(I,L)=D(I,J)
100  RETURN
     END
```

```
      SUBROUTINE AMPHAS ( Y,NROW,NFA ,NRA )
C     CONVERTS REAL AND IMAGINARY COMPONENTS TO AMPLITUDE AND PHASE ANGLE
      COMPLEX Y
      DIMENSION Y(NRA,1 )
      DO 1 I=1,NROW
      DO 1 J=1,NFA
      AI=Y(I,J)*(0.,-1.)
      AR=Y(I,J)
      IF( AI.EQ.0.0.AND.AR.EQ.0.0 ) GO TO 2
      AM= SQRT( AR*AR+AI*AI )
      AI= ATAN2(AI,AR)*57.2958
      GO TO 1
    2 AM=0.
    1 Y(I,J)= CMPLX(AM,AI )
      RETURN
      END
```

```
C       PROGRAM ZKILRC      (INPUT,OUTPUT,TAPE1,TAPE2)
C
C       VARIATION OF CONSTRAINT CHARACTERISTICS
C
C       NCON IS THE NUMBER OF CONSTRAINTS
C       ONE INPUT CARD PER CONSTRAINT CONTAINING
C       COORDINATE NUMBER,CONSTRAINT STIFFNESS,CONSTRAINT DAMPING
C       NCOR IS THE INDICES OF THE STATIONS AT WHICH THE CONSTRAINTS ARE
C       LOCATED
C
C
        COMPLEX Z2,Y,Z1,Z2A,Z3
        DIMENSION HEADC(9),AM(60,61),G(60) ,Z1(60,61),GS(60),AK(60,61),
      1 NCOR(24,24),AKR(24,24),DAMP(24,24),GR(24,24),HZ(100),
      2IROW(61),ICOL(61),IRLAB(61),ICLAB(61),Y(60,61),Z2(60,61),Z3(24)
        DIMENSION Z2A(60,61)
C       NRA ON NEXT CARD MUST BE THE DIMENSIONED NUMBER OF ROWS OF MATRICES
        NRA=60
        IT1=1
C                                   READ FIRST CARD
      1 READ 1000,IC1,IC2,IC3,IC4,IC5,IC6,IC7,IC8,HEADC
   1000 FORMAT (8I1,9A8)
        IF (IC1.EQ.9) CALL EXIT
        PRINT 1005
   1005 FORMAT (54H1   KILRC  KAMAN AEROSPACE CORPORATION  DEC 14, 1972   )
        PRINT 1006, HEADC
   1006 FORMAT (//25X,9A8//)
        IF( IC1 .EQ. 1) GO TO 100
C                               READ FREE STRUCTURE DATA
        READ 1010,ND,GC
   1010 FORMAT (I10,7E10.0)
C                               MASS MATRIX
        IF( IC5 .EQ. 1) GO TO 10
   1002 FORMAT (8E10.0)
C                                   DIAGONAL MASS
        DO 5 I=1,ND
        DO 5 J=1,ND
      5 AM(I,J)=0.
        READ    1002, (AM(I,I),I=1,ND)
        GO TO 20
C                                   FULL MASS MATRIX
     10 DO 15 I=1,ND
     15 READ     1002,(AM(I,J),J=1,I)
        CALL SYM (AM,ND,NRA )
     20 PRINT 1100
   1100 FORMAT (1H1/40X,11HMASS MATRIX//)
        CALL MOUT2 ( AM,ND,ND,NRA )
C                                   K INPUT
        DO 25 I=1,ND
     25 READ     1002, (AK(I,J),J=1,I)
        CALL SYM (AK,ND,NRA )
        PRINT 1200
   1200 FORMAT (1H1/40X,16HSTIFFNESS MATRIX//)
       CALL MOUT2 ( AK,ND,ND,NRA)
```

```
C                              VARIABLE DAMPING
      IF (IC6 .EQ. 0) GO TO 50
      READ 1002, (G(I),I=1,ND)
      PRINT 1011,(G(I),I=1,ND)
 1011 FORMAT (1CX,13HDAMPING COEFS /(10X,10F10.3))
      DO 30 I = 1,ND
   30 GS(I) =  SQRT(G(I))
      DO 40 I = 1,ND
      DO 40 J = 1,ND
   40 Z1(I,J) =   CMPLX (AK(I,J),AK(I,J)*GS(I)*GS(J))
      GO TO  100
C                              CONSTANT STRUCTURAL DAMPING
   50 DO 60 I = 1,ND
      DO 60 J = 1,ND
   60 Z1(I,J) =  CMPLX(AK(I,J),GC*AK(I,J))
      PRINT 1025, GC
 1025 FORMAT (//10X,27HSTRUCTURAL DAMPING COEFF. =, F6.3)
C                              CONSTRAINT DATA
  100 PRINT 1050
 1050 FORMAT (1H1///10X,21HCONSTRAINT VARIATIONS///)
      READ 1010, NCON
      DO 125 J=1,NCON
      DO 125 I=1,NCON
  125 READ 1010, (NCOR(I,J),AKR(I,J),GR(I,J),DAMP(I,J) )
      DO 110 J=1,NCON
      PRINT 1040,(NCOR(I,J),AKR(I,J),GR(I,J),DAMP(I,J),I=1,NCON )
  110 PRINT 1060
 1060 FORMAT (////)
C                              FREQUENCY DATA
      READ 1010,NF
      READ 1002, (HZ(I),I=1,NF)
      WRITE (IT1) HEADC,NF,ND,(HZ(I),I=1,NF),NCON
      DO 170 L=1,NF
      WRITE(IT1) HZ(L)
      OMR=HZ(L)*6.283185
      OMRS=OMR*OMR
      IF(IC5.EQ.0) GO TO 140
      DO 130 I=1,ND
      DO 130 J=1,ND
  130 Z2(I,J)=Z1(I,J)-OMRS*AM(I,J)
      GO TO 120
  140 DO 135 I=1,ND
      DO 135 J=1,ND
  135 Z2(I,J)=Z1(I,J)
      DO 150 I=1,ND
  150 Z2(I,I)=Z2(I,I)-OMRS*AM(I,I)
  120 DO 170 II=1,NCON
      WRITE (IT1) (NCOR(I,II),AKR(I,II),DAMP(I,II),GR(I,II),I=1,NCON )
      DO 160 I=1,NCON
      K = NCOR(I,II)
      Z3(I)=Z2(K,K)
  160 Z2(K,K) = Z2(K,K) +  CMPLX (AKR(I,II), OMR*DAMP(I,II)+GR(I,II)*
     1AKR(I,II))
 1040 FORMAT (   //10X,70HCOORDINATE      SPRING RATE          STR DAMPIN
```

```
     1G       VISCOUS DAMPING    ///(I16,1P3E20.3)////)
C
C
      DO 152 I=1,ND
      DO 152 J=1,ND
  152 Z2A(I,J)=Z2(I,J)
      CALL INVC ( Z2A,Y,ND,NRA,NRA,IERR,IROW,ICOL )
      IF ( IERR.EQ.0 ) GO TO 151
      PRINT 1015
 1015 FORMAT  (1H1/48H  IMPEDANCE MATRIX IS SINGULAR    JOB TERMINATED/)
      CALL EXIT
C     PRINTED OUTPUT IS DISPLACEMENT DATA
C
  151 PRINT    1017, HZ(L)
 1017 FORMAT(1H1/40X,48HDISPLACEMENT MOBILITY     REAL,IMAGINARY   FREQ=
     1F10.2,6H HERTZ//)
      CALL MOUTC ( Y,ND,ND,NRA, 0, 0,IRLAB,ICLAB,7)
      DO 162 I=1,NCON
      K = NCOR(I,II)
  162 Z2(K,K)=Z3(I)
  190 WRITE (IT1) ((Y(I,J),I=1,ND ),J=1,ND)
  170 CONTINUE
      GO TO 1
C
      END
```

```
      SUBROUTINE SYM (A,N,NRA )
C                 FORMS SYMMETRIC MATRIX FROM LOWER TRIANGLE
      DIMENSION A(NRA,1 )
      N1=N-1
      DO 10 I=1,N1
      I1=I+1
      DO 10 J=I1,N
   10 A(I,J)=A(J,I)
      RETURN
      END
```

```
      SUBROUTINE MOUTZ (A,M,N,NRA )
      DIMENSION
     1      A(NRA,1 )
      ID=MINO(N,10)
      PRINT    1000, (I,I=1,ID)
 1000 FORMAT (/5X,10I12)
      PRINT 100C
      DO 10 I=1,M
   10 PRINT    1001, I,(A(I,J),J=1,ID)
 1001 FORMAT (I5,5X,1P10E12.4)
      IF (ID-N) 20,50,50
   20 K=N/10-1
      DO 40 L=1,K
      N1=L*10+1
      N2=10*(L+1)
      ID=MINO( N,N2 )
      PRINT    1000, (I,I=N1,ID)
      PRINT 1000
      DO 30 I=1,M
   30 PRINT    1001, I,(A(I,J),J=N1,ID)
   40 CONTINUE
      IF(N2-N) 60,50,50
   60 N2=N2+1
      PRINT    1000,  (I,I=N2,N)
      PRINT 1000
      DO 70 I=1,M
   70 PRINT    1001,  I,(A(I,J),J=N2,N )
   50 RETURN
      END
```

```
      SUBROUTINE MOUTC (A,L,M,NRA,IR,IC,IRLAB,ICLAB,LINE )
C
C                       A IS COMPLEX ARRAY  (*16 ON IBM )  LXM
C                   IRLAB IS ARRAY OF INDICES FOR ROW  (USED WHEN IR=1 )
C                   ICLAB IS ARRAY OF INDICES FOR COL  (USED WHEN IC=1)
C                       NRA IS DIMENSIONED NO OF ROWS IN A
C                  OUTPUT FORM   RE,IM    X.XXXE XX,  X.XXXE XX
C                       LINE IS LINE NO ON PAGE OF FIRST OUTPUT LINE
      COMPLEX A(NRA,1)
      DIMENSION IRLAB(1),ICLAB(1)
      IC1=1
      IC2=MINO(5,M)
   10 IL1=1
      IL2=MINO (55-LINE,L )
   15 IF (IC.EQ.1) GO TO 20
      PRINT 1000, (I,I=IC1,IC2 )
      GO TO 30
   20 PRINT 1000, (ICLAB(I),I=IC1,IC2 )
 1000 FORMAT (/ I23,4I24/)
   30 DO 50 I=IL1,IL2
      IF (IR .EQ.1 ) GO TO 40
      PRINT 1010, I,(A(I,J),J=IC1,IC2)
      GO TO 50
   40 PRINT 1010 , IRLAB(I),(A(I,J),J=IC1,IC2 )
 1010 FORMAT ( I6,4X,1P5(E12.3,1H,,E11.3))
   50 CONTINUE
      IF (I.GE.L ) GO TO 100
      IL1=IL2+1
      IL2=MINO(IL2+55,L )
      PRINT 1015
 1015 FORMAT (1H1 )
      GO TO 15
  100 IF (IC2.GE.M ) GO TO 120
      IC1=IC2+1
      IC2=MINO (IC2+5,M )
      PRINT 1015
      GO TO 10
  120 RETURN
      END
```

```
      SUBROUTINE INVC   (D,A,N,NRA,NRB,IERR,IROW,ICOL )
C     A = INVERSE OF D            ORIGINAL MATRIX D IS DESTROYED
      COMPLEX A,D,AMAX,E,PVT,AMULT
      DIMENSION A(NRB,1),D(NRA,1),IROW(1),ICOL(1)
      IERR=0
      DO 1 I=1,N
      DO 1 J=1,N
    1 A(I,J)=D(I,J)
      M=N+1
      DO 7  I=1,N
      IROW(I)=I
    7 ICOL(I)=I
      DO 20 K=1,N
      AMAX= A(K,K)
      DO 10 I=K,N
      DO 10 J=K,N
      IF( CABS( A(I,J))- CABS(AMAX))10,9,9
    9 AMAX= A(I,J)
      IC=I
      JC=J
   10 CONTINUE
      KI=ICOL(K)
      ICOL(K)=ICOL(IC)
      ICOL(IC)=KI
      KI=IROW(K)
      IROW(K)=IROW(JC)
      IROW(JC)=KI
      IF( CABS(AMAX)) 11,12,11
   12 IERR=-1
       GO TO 100
   11 DO 14 J=1,N
      E=A(K,J)
      A(K,J)=A(IC,J)
   14 A(IC,J)=E
      DO 15 I=1,N
      E=A(I,K)
      A(I,K)=A(I,JC)
   15 A(I,JC)=E
      DO 16 I=1,N
      IF(I-K) 18,17,18
   17 A(I,M)=(1.,0.)
      GO TO 16
   18 A(I,M)=(0.,0.)
   16 CONTINUE
      PVT=A(K,K)
      DO 8 J=1,M
    8 A(K,J)=A(K,J)/PVT
      DO 19 I=1,N
      IF(I-K)21,19,21
   21 AMULT=A(I,K)
      DO 22 J=1,M
   22 A(I,J)=A(I,J)-AMULT*A(K,J)
   19 CONTINUE
      DO 20 I=1,N
```

```
 20  A(I,K)=A(I,M)
     DO 25 I=1,N
     DO 24 L=1,N
     IF(IROW(I)-L)24,23,24
 24  CONTINUE
 23  DO 25 J=1,N
 25  D(L,J)=A(I,J)
     DO 26 J=1,N
     DO 28 L=1,N
     IF(ICOL(J)-L) 28,29,28
 28  CONTINUE
 29  DO 26 I=1,N
 26  A(I,L)=D(I,J)
100  RETURN
     END
```

```
C      PROGRAM ZK2LRC( INPUT,OUTPUT,TAPE1,TAPE2)
C          FREE BODY TEST METHOD SIMULATION
C
C      VARIATION OF CONSTRAINT CHARACTERISTICS
C
C                    USES MOBILITY DATA FROM 'ZK1LRC'
C
C
C      IC6 IS NUMBER OF DEGREES OF FREEDOM AT  EACH COORDINATE
C      USED IN SUBROUTINE ERR2
       COMPLEX Y,YA,Y1
       DIMENSION HEADN( 9),HEAD( 9),INDS(24),INDX(100)
       DIMENSION HZ(100),ICH(84),INDR(20)
       DIMENSION Y(60,61),YA(60,61),IRLAB(61),ICLAB(61)
       DIMENSION SPR(24,24),DAMP(24,24),GT(24,24),Y1(60,61)
       COMMON/SET/LRCL,LRCN,LRCIX(2)
C
C
C      TAPE UNIT IT1 CONTAINS DATA FROM K1LRC PROGRAM
C
C      TAPE UNIT IT2 USED FOR DATA TRANSMITTAL TO K3LRC PROGRAM
C
C
C
       IT1=1
       IT2=2
       NRA=60
       FR=-1
       REWIND IT2
C
C                    READ FIRST CARD
     1 READ 1000,IC1,IC2,IC3,IC4,IC5,IC6,IC7,     HEADN
  1000 FORMAT (6I1,I2,9A8 )
       IF (IC1.EQ.9) CALL EXIT
       PRINT 1002
  1002 FORMAT (54H1   K2LRC  KAMAN AEROSPACE CORPORATION  DEC 20, 1972   )
       IF (IC1.EQ.1) REWIND IT1
    15 READ (IT1) HEAD,NF,ND,(HZ(I),I=1,NF),NS
       PRINT 1011,     HEADN,HEAD,ND,(HZ(I),I=1,NF)
  1011 FORMAT (1H1//25X,9A8//
      125X, 9A8   /25X,I2,19H DEGREES OF FREEDOM /25X,23H FREQUENCIES(HZ)
      2ON TAPE //(10X, 10F10.2))
C          INPUT APPLIED FORCE AT CONSTRAINT
       READ 140 , F,NFS
   140 FORMAT (F10.0,I10 )
C                    INPUT ERRORS, FREQUENCIES
       READ  1006,      PCT,PCTB,PHE,FPCT,FPCTB,FPHE,IZ,AMPL,AMPR,AMPF
  1006 FORMAT (6F5.0,I10,3F10.0)
       LRCIX(1)=IZ*2+1
       LRCN=1
       LRCL=1
       PRINT 1007,     PCT,PCTB,PHE,IZ,FPCT,FPCTB,FPHE,AMPL,AMPR,AMPF
  1007 FORMAT (/10X,16HMAX RAND ERROR =,F5.3,13H BIAS ERROR =,F5.3,37H OF
      1 RESPONSE  MAX RAND PHASE ERROR = ,F5.2,16H DEG.      SEED =, I10/
```

```
     210X,12HFORCE ERRORS, 4X,F5.3,13X,F5.3,37X,F5.2//10X,38HMAX RAND LI
     3NEAR ACCEL(REAL,IMAG)ERROR=E12.4/9X,39HMAX RAND ANGULAR ACCEL(REAL
     4,IMAG)ERROR=E12.4/17X,31HMAX RAND FORCE(REAL,IMAG)ERROR=E12.4//)
      IF (IC7.GT.0) GO TO 20
      IC7=NF
      DO 10 I=1,NF
   10 INDX(I)=I
      PRINT 1009,NF
 1009 FORMAT (/10X, 4HALL  ,I3,1X, 16HFREQUENCIES USED)
      GO TO 30
   20 READ  1040,    (INDX(I),I=1,IC7)
      DO 12 I=1,IC7
      K=INDX(I)
   12 HZ(I)=HZ(K)
   30 PRINT 1010,    (HZ(K),K=1,IC7 )
 1010 FORMAT (/10X,16HFREQUENCIES USED//(10X, 10F12.4))
      INFR=1
      DO 2 I=1,ND
    2 ICH(I)=0
      NB=ND+1
      NC=ND+NS
      DO 3 I=NB,NC
    3 ICH(I)=2
      WRITE (IT2) HEADN,NC,NS,(ICH(I),I=1,NC )
C                             START MAIN LOOP
      DO 500 L=1,NF
      IF(L.NE.INDX(INFR)) GO TO 500
C                 TAPE INPUT
C          CONSTRAINT SPRINGS,VISCOUS DAMPERS,STRUCTURAL DAMPING
      READ (IT1 ) FREQ
      OMR=FREQ *6.2832
      OMRS=OMR*OMR
      DO 21 LL=1,NS
      PRINT 1016,FREQ
 1016 FORMAT (///39H   CONSTRAINT CHARACTERISTICS FOR FREQ=,F7.2,3H HZ/)
      READ (IT1 ) (INDS(I),SPR(I,LL),DAMP(I,LL),GT(I,LL),I=1,NS )
      IF(L.NE.1) GO TO 7
      PRINT 1003, (INDS(I),I=1,NS)
      PRINT 1004,     ( SPR(I,LL),I=1,NS)
      PRINT 1001 , (DAMP(I,LL),I=1,NS)
    7 READ (IT1)  ((Y1(I,J),I=1,ND),J=1,ND )
C                 ELIMINATE COLUMNS AND CONVERT TO ACCL MOB
      DO 21 I=1,ND
      Y(I,LL)=Y1(I,NFS)*F
   21 YA(I,LL)=-Y(I,LL)*OMRS
 1001 FORMAT (//10X,7HDAMPERS,10X,3(8F10.0)//)
 1003 FORMAT (//10X,9HSTATION    ,5X,3(8I10)//)
 1004 FORMAT (//10X, 6HSPRING ,11X,3(8F10.0)//)
      PRINT 1005,F,NFS
 1005 FORMAT (//10X,13HAPPLIED FORCE ,4X,F10.1,3X,10HCOORDINATE,I3//)
C                 FORM CONSTRAINT DISP MATRIX AND ADD ERROR
      CALL ERR2 (      YA,PCT,PCTB,PHE,ND,NS,IX,NRA,AMPL,AMPR,0.,IC6 )
      IF (IC4.EQ.0) GO TO 60
      PRINT 1020,       HZ(INFR)
```

```
 1020 FORMAT (1H1,20X,71HSIMULATED MEASURED CONSTRAINED ACCELERATION
     1                         F = , F10.2,3H HZ/)
      CALL MOUTC ( YA ,ND,NS,NRA, 0, 0,IRLAB,ICLAB,5 )
C                 ACCELERATIONS DUE TO FORCES AND FORCES AT CONSTRAINTS
C                              WITH ERRORS ON TOTAL FORCES
C                   ACCELERATIONS DUE TO FORCES
   60 DO 70 J=1,NS
C                   FORCES AT CONSTRAINTS
      DO 70 II=1,NS
      I=INDS(II)
   70 Y(II,J)=-SPR(II,J) *Y(I,J)-(GT(II,J) *SPR(II,J) +OMR*DAMP(II,J))*
     1Y(I,J)*(0.,1.)
      DO 91 J=1,NS
      DO 91 I=1,NS
      IF( NFS.NE.INDS(I) ) GO TO 91
      Y(I,J)=Y(I,J)+F
   91 CONTINUE
      CALL ERR2 (          Y,FPCT,FPCTB,FPHE,NS,NS,IX,NRA,0.,0.,AMPF,0 )
      IF (IC4.EQ.0) GO TO 100
      PRINT 1025,       HZ(INFR)
 1025 FORMAT (1H1,20X,60HSIMULATED MEASURED FREE BODY FORCE MATRIX
     1            F = , F10.2,3H HZ/ )
      CALL MOUTC ( Y,NS,NS,NRA, 0, 0,IRLAB,ICLAB,5 )
  100 WRITE (IT2 ) HZ(INFR)
C
C         ACCELERATION DATA ON TAPE
    9 DO 5 J=1,NS
    5 WRITE (IT2 ) (YA(I,J),I=1,ND),(Y(I,J),I=1,NS )
 1040  FORMAT (8I10 )
  502 INFR=INFR+1
      IF (INFR.GT.IC7) GO TO 501
  500 CONTINUE
  501 WRITE (IT2 ) FR
   13 GO TO 1
      END
```

```
      SUBROUTINE MOUTC (A,L,M,NRA,IR,IC,IRLAB,ICLAB,LINE )
C
C                    A IS COMPLEX ARRAY  (*16 ON IBM )  LXM
C                 IRLAB IS ARRAY OF INDICES FOR ROW  (USED WHEN IR=1 )
C                 ICLAB IS ARRAY OF INDICES FOR COL  (USED WHEN IC=1)
C                    NRA IS DIMENSIONED NO OF ROWS IN A
C               OUTPUT FORM   RE,IM    X.XXXE XX,  X.XXXE XX
C                    LINE IS LINE NO ON PAGE OF FIRST OUTPUT LINE
      COMPLEX A(NRA,1)
      DIMENSION IRLAB(1),ICLAB(1)
      IC1=1
      IC2=MINO(5,M)
   10 IL1=1
      IL2=MINO (55-LINE,L )
   15 IF (IC.EQ.1) GO TO 20
      PRINT 1000, (I,I=IC1,IC2 )
      GO TO 30
   20 PRINT 1000, (ICLAB(I),I=IC1,IC2 )
 1000 FORMAT (/ I23,4I24/)
   30 DO 50 I=IL1,IL2
      IF (IR .EQ.1 ) GO TO 40
      PRINT 1010, I,(A(I,J),J=IC1,IC2)
      GO TO 50
   40 PRINT 1010 , IRLAB(I),(A(I,J),J=IC1,IC2 )
 1010 FORMAT ( I6,4X,1P5(E12.3,1H,,E11.3))
   50 CONTINUE
      IF (I.GE.L ) GO TO 100
      IL1=IL2+1
      IL2=MINO(IL2+55,L )
      PRINT 1015
 1015 FORMAT (1H1 )
      GO TO 15
  100 IF (IC2.GE.M ) GO TO 120
      IC1=IC2+1
      IC2=MINO (IC2+5,M )
      PRINT 1015
      GO TO 10
  120 RETURN
      END
```

```
      SUBROUTINE ERR2 ( ZA,PCT,PCTB,PHE,N1,N2,IX,NR,AMPL,AMPR,AMP,IC6 )
C              OBJECT TIME DIMENSIONS
C              EACH ELEMENT OF A COMPLEX MATRIX, A  IS MODIFIED TO
C              INCLUDE A SMALL PHASE ERROR, PNE (DEG),  A BIAS ERROR,
C              PCTB (RATIO) ON AMPLITUDE, A UNIFORM RANDOM ERROR
C              HAVING A +/- MAXIMUM OF PCT (RATIO) ON AMPLITUDE,
C              AND A UNIFORM RANDOM ERROR HAVING A +/-
C              MAXIMUM ON AMPLITUDE
C              THE PHASE ERROR IS ALSO RANDOMLY DISTRIBUTED
C   NOTE    NO SYMMETRIZATION IS PERFORMED
C     IC6 IS THE NUMBER OF DEGREES OF FREEDOM OF EACH COORDINATE
C
C     USES GETRAN(UNIFORM DISTRIBUTION)
C     LRCIX(1)=ARBITRARILY SELECTED LOSITIVE INTEGER
C     LRCN=1 FOR FIRST CALL TO GETRAN
C     SET LRCN GREATER THAN 1 FOR SUBSEQUENT CALLS TO GETRAN
C     LRCL=1 FOR UNIFORM DISTRIBUTION
C     LRCIX(2),DUM1,DUM2, NOT USED
C     YFL=UNIFORMLY DISTRIBUTED RANDOM NUMBER
C
C
      COMPLEX ZA(NR,1)
      COMMON/SET/LRCL,LRCN,LRCIX(2)
      IF(PCT ) 120,100,120
  100 IF(PCTB) 120,110,120
  110 IF(PHE) 120,140,120
  140 IF (AMPL) 120,145,120
  145 IF( AMPR ) 120,155,120
  155 IF( AMP ) 120,135,120
  120 P=PHE/57.296
      DO 130 J=1,N2
      K=(IC6+1)/2
      K1=IC6
      DO 130 I=1,N1
      CALL GETRAN(LRCIX(1),LRCN,LRCL,DUM1,YFL,DUM2)
      IF(LRCN.EQ.1)LRCN=LRCN+1
      E=2.0*P*(YFL-0.5)
      AR=ZA(I,J)
      AI=(0.,-1.)*ZA(I,J)
      R1= ABS( AR )
      R2= ABS( AI )
      R3=R1+R2
      IF (R3.EQ.0.) GO TO 130
      R1=R1/R3
      R2=R2/R3
      A1=AR-E*AI
      AI=AI+E*AR
      AR=A1
      CALL GETRAN(LRCIX(1),LRCN,LRCL,DUM1,YFL,DUM2)
      E=1.0+2.0*PCT*(YFL-0.5)+PCTB
      AR=AR*E
      AI=AI*E
      CALL GETRAN(LRCIX(1),LRCN,LRCL,DUM1,YFL,DUM2)
C     AMP ERROR DIST IN PROPORTION TO RATIOS OF REAL AND IMAG TO (REAL+IMAG)
```

```
      IF (IC6.EQ. 0 ) GO TO 170
      IF( I-K ) 175,175,185
  175 AMP=AMPL
      GO TO 170
  185 AMP=AMPR
  170 E=2.*(YFL-.5 )*AMP*R1
      AR=AR+E
      CALL GETRAN(LRCIX(I),LRCN,LRCL,DUM1,YFL,DUM2)
      E=2.*(YFL-.5 )*AMP*R2
      AI=AI+E
  160 ZA(I,J)= CMPLX (AR,AI )
      IF ( IC6.EQ. 0 ) GO TO 130
      IF (I.NE. K1 ) GO TO 130
      K=K+IC6
      K1=K1+IC6
  130 CONTINUE
  135 RETURN
      END
```

K1LRC KAMAN AEROSPACE CORPCRATION NCV 27, 1972

K1LRC 3/13/73 2-DIM ORBITER 10,000LB/IN AT COORDINATES 5,13

MASS MATRIX

	1	2	3	4	5	6	7	8	9	10
1	1.4773D-02	-2.2388D-03	4.5793D-04	1.3229D-03	0.0	0.0	0.0	0.0	0.0	0.0
2	-2.2388D-03	4.8846D-03	-1.3229D-03	-3.6635D-03	0.0	0.0	0.0	0.0	0.0	0.0
3	4.5793D-04	-1.3229D-03	6.3410D-02	-1.2493D-01	2.0810D-02	7.5146D-02	0.0	0.0	0.0	0.0
4	1.3229D-03	-3.6635D-03	-1.2493D-01	3.5171D-01	-7.5146D-02	-2.6012D-01	0.0	0.0	0.0	0.0
5	0.0	0.0	2.0810D-02	-7.5146D-02	7.9367D-02	1.2659D-01	2.4250D-04	3.4093D-04	0.0	0.0
6	0.0	0.0	7.5146D-02	-2.6012D-01	1.2659D-01	3.4744D-01	-3.4093D-04	-4.5947D-04	0.0	0.0
7	0.0	0.0	0.0	0.0	2.4250D-04	-3.4093D-04	3.2794D-03	-4.1565D-04	3.1807D-04	5.8654D-04
8	0.0	0.0	0.0	0.0	3.4093D-04	-4.5947D-04	-4.1565D-04	1.9951D-03	-5.8654D-04	-1.0368D-03
9	0.0	0.0	0.0	0.0	0.0	0.0	3.1807D-04	-5.8654D-04	1.1874D-02	-1.7547D-02
10	0.0	0.0	0.0	0.0	0.0	0.0	5.8654D-04	-1.0368D-03	-1.7547D-02	4.1833D-02
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.7923D-03	-1.0956D-02
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0956D-02	-3.0338D-02
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

	11	12	13	14	15	16
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0
9	3.7923D-03	1.0956D-02	0.0	0.0	0.0	0.0
10	-1.0956D-02	-3.0338D-02	0.0	0.0	0.0	0.0
11	1.2479D-02	1.5812D-02	5.2735D-04	1.6123D-03	0.0	0.0
12	1.5812D-02	4.6751D-02	-1.6123D-03	-4.7253D-03	0.0	0.0
13	5.2735D-04	-1.6123D-03	1.5479D-02	7.5534D-04	4.4845D-04	1.1660D-03
14	1.6123D-03	-4.7253D-03	7.5534D-04	1.0175D-02	-1.1660D-03	-2.9069D-03
15	0.0	0.0	4.4845D-04	-1.1660D-03	2.5355D-03	1.9732D-03
16	0.0	0.0	1.1660D-03	-2.9065D-03	1.9732D-03	3.8746D-03

STIFFNESS MATRIX

	1	2	3	4	5	6	7	8	9	10
1	2.2164D 05	-1.3298D 06	-2.2164D 05	-1.3298D 06	0.0	0.0	0.0	0.0	0.0	0.0
2	-1.3298D 06	1.0639D 07	1.3298D 06	5.3193D 06	0.0	0.0	0.0	0.0	0.0	0.0
3	-2.2164D 05	1.3298D 06	4.4206D 05	-3.2334D 05	-2.2042D 05	-1.6532D 06	0.0	0.0	0.0	0.0
4	-1.3298D 06	5.3193D 06	-3.2334D 05	2.7170D 07	1.6532D 06	8.2658D 06	0.0	0.0	0.0	0.0
5	0.0	0.0	-2.2042D 05	1.6532D 06	2.6983D 06	-5.5821D 06	-2.4778D 06	-7.2353D 06	0.0	0.0
6	0.0	0.0	-1.6532D 06	8.2658D 06	-5.5821D 06	4.4701D 07	7.2353D 06	1.4085D 07	0.0	0.0
7	0.0	0.0	0.0	0.0	-2.4778D 06	7.2353D 06	3.5759D 06	3.0297D 06	-1.0981D 06	-4.2056D 06
8	0.0	0.0	0.0	0.0	-7.2353D 06	1.4085D 07	3.0297D 06	4.9646D 07	4.2056D 06	1.0738D [illegible]
9	0.0	0.0	0.0	0.0	0.0	0.0	-1.0981D 06	4.2056D 06	1.3837D 06	2.4919D 06
10	0.0	0.0	0.0	0.0	0.0	0.0	-4.2056D 06	1.0738D 07	2.4919D 06	3.5185D 07
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-2.8561D 05	1.7136D 06
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.7136D 06	6.8545D 06
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

	11	12	13	14	15	16
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0
9	-2.8561D 05	-1.7136D 06	0.0	0.0	0.0	0.0
10	1.7136D 06	6.8545D 06	0.0	0.0	0.0	0.0
11	5.2654D 05	1.8370D 05	-2.4094D 05	-1.5299D 06	0.0	0.0
12	1.8370D 05	2.6663D 07	1.5299D 06	6.4767D 06	0.0	0.0
13	-2.4094D 05	1.5299D 06	6.3271D 05	-5.8566D 05	-3.9178D 05	-2.1156D 06
14	-1.5299D 06	6.4767D 06	-5.8566D 05	2.8186D 07	2.1156D 06	7.6162D 06
15	0.0	0.0	-3.9178D 05	2.1156D 06	3.9178D 05	2.1156D 06
16	0.0	0.0	-2.1156D 06	7.6162D 06	2.1156D 06	1.5232D 07

STRUCTURAL DAMPING COEFF. = 0.030

COORDINATE	SPRING RATE	STR DAMPING	VISCOUS DAMPING
5	1.000D 04	0.0	0.0
13	1.000D 04	0.0	0.0

DISPLACEMENT MOBILITY REAL, IMAGINARY FREQ= 92.00 HERTZ

	1		2		3		4		5	
1	-6.730D-05,	-1.014D-06	-1.168D-06,	-1.054D-07	-4.717D-05,	2.373D-08	-2.683D-06,	-4.902D-08	8.200D-06,	1.680D-07
2	-1.168D-06,	-1.054D-07	2.480D-07,	-1.562D-08	-1.942D-06,	1.154D-08	-1.143D-07,	-3.626D-09	1.184D-06,	1.017D-08
3	-4.717D-05,	2.373D-08	-1.942D-06,	1.154D-08	-2.589D-05,	-5.302D-08	-1.427D-06,	-4.139D-09	-5.667D-06,	4.277D-08
4	-2.683D-06,	-4.902D-08	-1.143D-07,	-3.626D-09	-1.427D-06,	-4.139D-09	-8.497D-08,	-3.974D-09	1.097D-06,	1.096D-08
5	8.200D-06,	1.680D-07	1.184D-06,	1.017D-08	-5.667D-06,	4.277D-08	1.097D-06,	1.096D-08	-2.205D-05,	-9.646D-08
6	-4.522D-06,	2.489D-08	-2.774D-07,	3.038D-09	-1.386D-06,	-4.699D-09	-2.283D-07,	1.298D-09	1.237D-06,	2.679D-09
7	3.589D-05,	-4.030D-08	2.910D-06,	-1.272D-08	2.496D-06,	6.469D-08	2.522D-06,	-6.696D-10	-3.042D-05,	-7.097D-08
8	-4.876D-06,	4.331D-08	-3.075D-07,	4.549D-09	-1.395D-06,	-3.174D-09	-2.545D-07,	2.495D-09	1.575D-06,	-9.767D-09
9	7.272D-05,	-3.781D-07	5.249D-06,	-4.825D-08	1.284D-05,	9.161D-08	4.462D-06,	-2.058D-08	-4.280D-05,	2.179D-08
10	-4.609D-06,	3.985D-08	-2.937D-07,	4.328D-09	-1.281D-06,	-4.473D-09	-2.437D-07,	2.399D-09	1.580D-06,	-1.189D-08
11	1.195D-04,	-5.921D-07	8.210D-06,	-7.971D-08	2.611D-05,	1.860D-07	6.914D-06,	-3.452D-08	-5.821D-05,	6.610D-08
12	-3.132D-06,	-7.039D-09	-1.951D-07,	6.865D-10	-9.247D-07,	-1.156D-08	-1.611D-07,	-2.544D-10	9.425D-07,	6.218D-09
13	1.541D-04,	-3.269D-07	1.033D-05,	-7.471D-08	3.668D-05,	3.583D-07	8.662D-06,	-2.117D-08	-6.773D-05,	-8.671D-08
14	-2.649D-06,	-2.376D-08	-1.620D-07,	-6.200D-10	-8.187D-07,	-1.395D-08	-1.332D-07,	-1.223D-09	7.085D-07,	1.346D-08
15	1.842D-04,	-1.184D-07	1.219D-05,	-7.175D-08	4.591D-05,	5.015D-07	1.019D-05,	-1.066D-08	-7.604D-05,	-2.143D-07
16	-2.854D-06,	-1.744D-08	-1.756D-07,	-1.302D-10	-8.696D-07,	-1.297D-08	-1.446D-07,	-8.683D-10	7.938D-07,	1.113D-08

	6		7		8		9		10	
1	-4.522D-06,	2.489D-08	3.589D-05,	-4.030D-08	-4.876D-06,	4.331D-08	7.272D-05,	-3.781D-07	-4.609D-06,	3.985D-08
2	-2.774D-07,	3.038D-09	2.910D-06,	-1.272D-08	-3.075D-07,	4.549D-09	5.249D-06,	-4.825D-08	-2.937D-07,	4.328D-09
3	-1.386D-06,	-4.699D-09	2.496D-06,	6.469D-08	-1.395D-06,	-3.174D-09	1.284D-05,	9.161D-08	-1.281D-06,	-4.473D-09
4	-2.283D-07,	1.298D-09	2.522D-06,	-6.696D-10	-2.545D-07,	2.495D-09	4.462D-06,	-2.058D-08	-2.437D-07,	2.399D-09
5	1.237D-06,	2.679D-09	-3.042D-05,	-7.097D-08	1.575D-06,	-9.767D-09	-4.280D-05,	2.179D-08	1.580D-06,	-1.189D-08
6	-9.930D-08,	-2.896D-09	1.887D-06,	1.741D-08	-1.200D-07,	-2.217D-09	2.820D-06,	3.284D-08	-1.182D-07,	-1.920D-09
7	1.887D-06,	1.741D-08	-4.138D-05,	-1.680D-07	1.936D-06,	1.355D-08	-5.670D-05,	-2.406D-07	1.961D-06,	8.319D-09
8	-1.200D-07,	-2.217D-09	1.936D-06,	1.355D-08	-1.075D-09,	-5.784D-09	1.994D-06,	5.476D-08	-1.029D-08,	-4.992D-09
9	2.820D-06,	3.284D-08	-5.670D-05,	-2.406D-07	1.994D-06,	5.476D-08	-6.946D-05,	-7.028D-07	1.447D-06,	6.157D-08
10	-1.182D-07,	-1.920D-09	1.961D-06,	8.319D-09	-1.029D-08,	-4.992D-09	1.447D-06,	6.157D-08	1.471D-07,	-8.879D-09
11	3.986D-06,	5.810D-08	-7.569D-05,	-4.262D-07	2.033D-06,	1.082D-07	-8.250D-05,	-1.436D-06	-1.794D-07,	1.511D-07
12	-7.332D-08,	-2.378D-09	1.143D-06,	2.475D-08	6.453D-09,	-3.975D-09	6.414D-07,	6.342D-08	1.276D-07,	-6.133D-09
13	4.748D-06,	9.062D-08	-8.705D-05,	-8.132D-07	1.872D-06,	1.561D-07	-8.729D-05,	-2.274D-06	-1.772D-06,	2.212D-07
14	-5.727D-08,	-2.620D-09	8.392D-07,	3.208D-08	1.456D-08,	-3.779D-09	3.110D-07,	6.745D-08	1.266D-07,	-5.493D-09
15	5.413D-06,	1.185D-07	-9.694D-05,	-1.144D-06	1.730D-06,	1.981D-07	-9.144D-05,	-3.004D-06	-3.165D-06,	2.837D-07
16	-6.334D-08,	-2.570D-09	9.481D-07,	3.007D-08	1.256D-08,	-3.939D-09	4.145D-07,	6.766D-08	1.300D-07,	-5.910D-09

	11	12	13	14	15
1	1.195D-04, -5.921D-07	-3.132D-06, -7.039D-09	1.541D-04, -3.269D-07	-2.649D-06, -2.376D-08	1.842D-04, -1.184D-07
2	8.210D-06, -7.971D-08	-1.951D-07, 6.865D-10	1.033D-05, -7.471D-08	-1.620D-07, -6.200D-10	1.219D-05, -7.175D-08
3	2.611D-05, 1.860D-07	-9.247D-07, -1.156D-08	3.668D-05, 3.583D-07	-8.187D-07, -1.395D-08	4.591D-05, 5.015D-07
4	6.914D-06, -3.452D-08	-1.611D-07, -2.544D-10	8.662D-06, -2.117D-08	-1.332D-07, -1.223D-09	1.019D-05, -1.066D-08
5	-5.821D-05, 6.610D-08	9.425D-07, 6.218D-09	-6.773D-05, -8.671D-08	7.085D-07, 1.346D-08	-7.604D-05, -2.143D-07
6	3.986D-06, 5.810D-08	-7.332D-08, -2.378D-09	4.748D-06, 9.062D-08	-5.727D-08, -2.620D-09	5.413D-06, 1.185D-07
7	-7.569D-05, -4.262D-07	1.143D-06, 2.475D-08	-8.705D-05, -8.132D-07	8.392D-07, 3.208D-08	-9.694D-05, -1.144D-06
8	2.033D-06, 1.082D-07	6.453D-09, -3.975D-09	1.872D-06, 1.561D-07	1.456D-08, -3.779D-09	1.730D-06, 1.981D-07
9	-8.250D-05, -1.436D-06	6.414D-07, 6.342D-08	-8.729D-05, -2.274D-06	3.110D-07, 6.745D-08	-9.144D-05, -3.004D-06
10	-1.794D-07, 1.511D-07	1.276D-07, -6.133D-09	-1.772D-06, 2.212D-07	1.266D-07, -5.493D-09	-3.165D-06, 2.837D-07
11	-6.566D-05, -3.374D-06	-2.191D-06, 1.593D-07	-3.559D-05, -5.305D-06	-2.449D-06, 1.533D-07	-9.257D-06, -7.016D-06
12	-2.191D-06, 1.593D-07	3.516D-07, -1.013D-08	-6.514D-06, 2.759D-07	3.421D-07, -9.203D-09	-1.029D-05, 3.810D-07
13	-3.559D-05, -5.305D-06	-6.514D-06, 2.759D-07	6.409D-05, -9.067D-06	-8.631D-06, 3.189D-07	1.586D-04, -1.265D-05
14	-2.449D-06, 1.533D-07	3.421D-07, -9.203D-09	-8.631D-06, 3.189D-07	6.475D-07, -1.798D-08	-1.575D-05, 5.212D-07
15	-9.257D-06, -7.016D-06	-1.029D-05, 3.810D-07	1.586D-04, -1.265D-05	-1.575D-05, 5.212D-07	3.416D-04, -1.883D-05
16	-2.435D-06, 1.606D-07	3.533D-07, -9.958D-09	-8.798D-06, 3.378D-07	6.644D-07, -1.905D-08	-1.753D-05, 5.951D-07

	16	
1	-2.854D-06,	-1.744D-08
2	-1.756D-07,	-1.302D-10
3	-8.696D-07,	-1.297D-08
4	-1.446D-07,	-8.683D-10
5	7.938D-07,	1.113D-08
6	-6.334D-08,	-2.570D-09
7	9.481D-07,	3.007D-08
8	1.256D-08,	-3.939D-09
9	4.145D-07,	6.766D-08
10	1.300D-07,	-5.910D-09
11	-2.435D-06,	1.606D-07
12	3.533D-07,	-9.958D-09
13	-8.798D-06,	3.378D-07
14	6.644D-07,	-1.905D-08
15	-1.753D-05,	5.951D-07
16	9.454D-07,	-2.812D-08

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K2LRC  3/13/73

K1LRC  3/13/73   2-DIM ORBITER  10,000LB/IN AT COORDINATES 5,13
16 DEGREES OF FREEDOM
FREQUENCIES(HZ)ON TAPE

     92.00

CONSTRAINTS AND FORCES

STATION                  5        13


SPRING               10000.    10000.


APPLIED FORCE           25.       25.


DAMPERS                  0.        0.


STRUCTURAL DAMPING      0.0       0.0

MAX RAND ERROR =0.050 BIAS ERROR =0.0   OF RESPONSE  MAX RAND PHASE ERROR =  5.00 DEG.     SEED =       19
FORCE ERRORS    0.050             0.0                                        5.00

MAX RAND LINEAR ACCEL(REAL,IMAG)ERROR=  0.1000D 01
MAX RAND ANGULAR ACCEL(REAL,IMAG)ERROR=  0.1000D-01
        MAX RAND FORCE(REAL,IMAG)ERROR=  0.0


ALL   1 FREQUENCIES USED

FREQUENCIES USED

     92.0000
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K3LRC  KAMAN AEROSPACE CORPORATION  NOV 27 1972

                K3LRC  3/13/73   2-DIM ORBITER  FORCE AT 5,13  25 LBS
TAPE HEADING----  K2LRC  3/13/73
                NUMBER OF CHANNELS =  18          NUMBER OF FORCES =   2

                CHANNEL DEFINITIONS, = 0   RESP DATA, = 1   NOT USED, = 2   FORCE DATA
      1 =  0    2 =  0    3 =  0    4 =  0    5 =  0    6 =  0    7 =  0    8 =  0    9 =  0   10 =  0   11 =  0   12 =  0
     13 =  0   14 =  0   15 =  0   16 =  0   17 =  2   18 =  2
```

FREQUENCY = 92.00

FORCE MATRIX AMP,PHASE(DEG)

	1		2	
1	1.677D 01,	-1.4	4.435D 01,	5.1
2	9.724D 0C,	18.8	2.376D 01,	7.2

FREQUENCY = 92.00

INVERSE OF FORCE MATRIX

	1		2	
1	-1.883D-02,	0.2	2.360D-02,	-0.3
2	2.205D-02,	-0.1	5.132D-03,	0.1

FREQUENCY = 92.0C

CONSTRAINED RESPONSE MATRIX AMP,PHASE (DEG)

	1		2	
1	1.270D 03,	-179.5	1.299D 03,	177.1
2	9.062D 01,	179.1	9.718D 01,	175.9
3	3.191D 02,	-179.8	2.602D 02,	179.7
4	7.501D 01,	-177.6	8.161D 01,	-179.7
5	5.683D 02,	-0.8	7.579D 02,	-0.6
6	4.134D 01,	-177.6	4.860D 01,	-179.9
7	7.415D 02,	4.2	9.080D 02,	-1.5
8	1.617D 01,	-177.3	2.833D 01,	-175.4
9	7.091D 02,	-2.2	1.029D 03,	-1.9
10	1.427D 01,	-2.8	3.932D 00,	-26.9
11	2.878D 02,	8.5	7.104D 02,	5.9
12	5.694D 01,	-1.2	4.990D 01,	0.2
13	5.269D 02,	176.8	8.665D 01,	119.8
14	7.469D 01,	1.1	6.380D 01,	-2.6
15	1.288D 03,	174.8	7.750D 02,	171.9
16	7.535D 01,	-5.2	6.944D 01,	-2.0

FREQUENCY = 92.00

FREE BODY RESPONSE MATRIX AMP,PHASE(DEG)

	1		2	
1	1.316D 02,	-89.1	2.598D 02,	100.8
2	9.081D 00,	-91.3	1.798D 01,	99.7
3	3.793D 01,	-89.1	7.283D 01,	97.4
4	7.467D 00,	-89.0	1.469D 01,	102.4
5	4.796D 01,	81.7	9.364D 01,	-80.4
6	3.863D 00,	-89.9	7.665D 00,	103.5
7	6.578D 01,	94.4	1.354D 02,	-71.6
8	9.856D-01,	-110.2	1.824D 00,	105.8
9	5.514D 01,	77.7	1.078D 02,	-80.9
10	2.235D 00,	94.8	4.273D 00,	-85.4
11	8.130D 00,	15.6	1.571D 01,	-15.5
12	6.569D 00,	87.9	1.254D 01,	-84.5
13	8.843D 01,	-84.1	1.685D 02,	94.2
14	8.615D 00,	93.0	1.679D 01,	-80.0
15	1.717D 02,	-91.9	3.284D 02,	91.7
16	8.523D 00,	82.3	1.614D 01,	-89.3

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