Applied Dynamics Research Corporation

Final Report

Investigation of Empirical Damping Laws for the Space Shuttle

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FOREWORD

This report presents the work performed by Applied Dynamics Research Corporation under Contract NAS8-28513 for the Marshall Space Flight Center of NASA. Mr. Larry Kiefling, S&E-AERO-DDS is the technical monitor.

SUMMARY

An analysis of dynamic test data from vibration testing of a number of aerospace vehicles is made to develop an empirical structural damping law. A systematic attempt is made to fit dissipated energy/cycle to combinations of all dynamic variables. The best-fit laws for bending, torsion and longitudinal motion are given, with error bounds. A discussion and estimate are made of error sources. Programs are developed for predicting equivalent linear structural damping coefficient and finding the response of nonlinearly damped structures.

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Section 1

INTRODUCTION

A number of full scale dynamic tests on aerospace vehicles have been made which produced enough data for the calculation of damping properties. Some preliminary analyses of the data (Ref. 1 and 2) indicated a correlation between dissipated energy per cycle and the total vibratory energy of the vehicle. Based on the success of these analyses, and a number of suggestions proposed (e. g., Ref. 3) on other parameters which might influence damping, a comprehensive study was made to determine an empirical damping law.

Dissipated energy/cycle was selected as the physical quantity which provides the best measure of damping. Damping in a complicated structure is a combination of a number of types of phenomena, and is often nonlinear. When an elastic structure is excited periodically, a steady-state situation is reached when the rate of energy dissipation through the damping mechanisms becomes equal to the rate of work put into the system by the excitation force. The rate of work can be calculated independently of the type of damping, and is therefore chosen as the logical dependent variable for an investigation of structural damping.

The work done, per cycle of vibration, can be calculated as follows: Let

$$f(t) = F \sin \omega t$$

denote the exciting force, and

$$x_E = X_E \sin (\omega t + \theta)$$

be the displacement at the point of application of the force. Here, ω is the frequency of the excitation force, and θ is the phase angle of the response, relative to the phase of the excitation.

The work per cycle, W, is then by definition

$$W = \int_0^{2\pi/\omega} f(t)\, \dot{x}_E dt$$

$$= \pi F X_E \sin \theta$$

At resonance, $\theta = \pi/2$. Thus,

$$W = \pi F X_E \tag{1}$$

which, from the previous discussion may be set equal to the energy dissipated per cycle, D:

$$D = \pi F X_E \tag{2}$$

An alternate method of calculating D can also be used, based on the value of the equivalent linear damping coefficient ζ. The damping at a particular modal amplitude is described by this quantity, although it will not be valid at other amplitudes if the structure is nonlinear. The dissipated energy is then given by

$$D = 4\pi\zeta T \tag{3}$$

where T is the maximum kinetic energy.

Dissipated energy was calculated from both formulas when sufficient information was available. A comparison of the two values provided a measure of the accuracy of some of the basic data used.

The data available for this study included the results of a number of full scale dynamic tests on space vehicles, as well as the results of tests on a Boeing 747 prototype. These tests were performed to determine natural modes and frequencies of these vehicles. Most tests of this sort were not run with the intent of obtaining nonlinear damping data. Therefore, as far as this program is concerned, useable damping data were relatively limited. In addition, the accuracy of some of the damping data produced is poorer than the accuracy of the frequency determination alone, which generally was the main purpose of the experimentation. Most of the tests were run on Saturn vehicles, and an evolution through the years of increased accuracy of methods for determining the dynamic parameters is seen.

A considerable attempt was made to locate data on dynamic analyses of solid-fueled rockets which might be most applicable to the space shuttle. This attempt, however, was unsuccessful. As far as could be determined, the data were unavailable.

The data available for this study comprise the results of the tests given in Table 1. Altogether, there are 15 tests representing seven structures. Five of the structures are configurations or stages of the

Saturn V. The Saturn I tests were run in 1964. Damping constants were available for some of the modes from ringout decay tests. This data was not considered too reliable due to the beating phenomenon which frequently occurred. Generalized mass was obtained by measuring the bandwidth of the half-power point on resonance peaks of the amplitude/frequency curves.

The S-IVB tests were run in 1965-66. Generalized mass was found from the mode shape and mass distribution and also from a complex curve-fit for the amplitude of the response curve. Damping values were obtained from bandwidth and phase angle methods, and, for some tests, from a complex curve-fit technique.

The Saturn V tests were performed in 1966-67, and represent a well-documented and more accurate effort. Generalized masses and damping constants were found from complex curve-fit techniques.

The Boeing 747 tests were performed in 1969. Dynamic properties were determined from complex admittance (acceleration divided by force) plots in polar coordinates, following the method of Kennedy and Pancu (Ref. 4).

The first indication of the existence of an empirical damping law arose from analysis of the Saturn I data (Ref. 1). In this analysis, 118 data points were used. The reason for elimination of the remaining data is not known. The missing data mostly consist of entire tests in the series. Very likely, at the time of the analysis, facts were available indicating the unreliability of these particular tests. The conclusion reported in Ref. 1 was that a law of the form

$$D = 0.313\, T^{0.8} \tag{4}$$

[dimensions in SI(International System) units] predicted structural damping. It was reported that 83% of the data lay within a $\pm$ 2 db band of this law. The data used was reexamined, using the methods of the present study. It was found that the law was not quite so good as reported. The best law for the S-I data was found to be

$$D = 0.350\, T^{0.72}$$

with 75% of the data within a $\pm$ 2 db band. This result still is encouraging for the existence of a structural damping law.

Based on the S-I analysis, Kiefling and Pack (Ref. 2) analyzed samples of data points from the Saturn V and the S-IVB tests. From these tests, data on torsional and longitudinal vibrations were also available. The results reported in Ref. 2 indicated that the law (4) predicted damping in bending quite well for these structures. As a matter of fact, the plotted results in Ref. 2 indicate that 89% of the data fall within a $\pm$ 2 db band.

For torsional vibrations a law of the form

$$D = 0.34\, T^{0.80}$$

is reported in Ref. 2, with 67% of the data within a $\pm$ 2 db band. The results for longitudinal vibrations are reported as inconclusive.

In Ref. 5, Riley took vibration data from a Boeing 747 airplane and applied the Chang law (Eq. 4). He found that this law correctly predicted damping to within ± 2 db for 75% of the data.

While the accuracy of the law, based on these preliminary studies, is not all that might be hoped for (± 2 db represents a + 50% and - 37% error in D), yet it represents a remarkable correlation. A wide variety of vehicles are included (single tank, multi-tank and winged) and a five-decade range of energy levels. Taking into consideration the fact that dissipated energy is an overall quantity, depending on an unknown variety and number of damping mechanisms acting within each structure, it therefore appears that an investigation to uncover a damping law is worthwhile.

The studies reported above indicate a dependence of dissipated energy on total vibration energy. Other suggestions have been made that frequency ω may have some influence. In Ref. 3, it is reported that the ratio of amplitude x to some characteristic vehicle length L gives good correlation for certain cases.

Section 2

SCOPE AND METHOD OF THE INVESTIGATION

In order not to exclude any possible empirical laws, dependency on almost all variables available from dynamic testing was investigated. In addition, all possible combinations of these variables were tried. The variables used, together with their units in the SI system, are

T -- kinetic energy (Newton-meters)
X -- mode shape amplitude (meters)
ω -- frequency (rad/sec)
m -- generalized mass (kilograms)
X/L -- amplitude/length

These quantities are not all independent, since the kinetic energy is given by

$$T = (1/2)m\omega^2X^2 \tag{5}$$

Correlations were sought for three cases: transverse bending, torsion, and longitudinal motion. The length L, in the last of the independent variables, was chosen to be the length of the structure in the case of bending and longitudinal motion, and maximum radius for the case of torsion.

Equation (4) for the empirical damping law is not independent of the dimensional units of the variables. Some effort was made to find a satisfactory nondimensional formulation. The effort, however, was unsuccessful. Therefore, for the sake of uniformity, and to conform with current standards, all units were converted to the SI system.

The energy levels in these tests covered a five-decade range. Based on the preliminary analyses, a law was sought of the form

$$D = C P_1^{a_1} P_2^{a_2} P_3^{a_3} \tag{6}$$

where C, a_1, a_2, a_3 are constants to be determined, and P_1, P_2, P_3 are independent parameters.

Taking the natural logarithm of both sides, we have

$$d = \ln D = c + a_1 p_1 + a_2 p_2 + a_3 p_3 \tag{7}$$

where

$$c = \ln C$$

$$p_1, p_2, p_3 = \ln (P_1, P_2, P_3)$$

The least-squares criterion was used to find the constants. Let the data points determined from the tests be denoted by a superscripted bar. Then the error, E, is given by the expression

$$E = \sum_{i=1}^{n} (c + a_1 \bar{p}_{1i} + a_2 \bar{p}_{2i} + a_3 \bar{p}_{3i} - \bar{d}_i)^2 \tag{8}$$

where

$$\bar{d}_i = \ln \bar{D}_i$$

$$\bar{p}_{1i}, \bar{p}_{2i}, \bar{p}_{3i} = \ln (\bar{P}_{1i}, \bar{P}_{2i}, \bar{P}_{3i})$$

and the summation is over N data points.

We note that on a log-log scale the sought-after empirical law is a straight line. The optimal values of C, a_1, a_2, a_3 are found from the equations for minimizing E:

$$\frac{\partial E}{\partial c} = \frac{\partial E}{\partial a_1} = \frac{\partial E}{\partial a_2} = \frac{\partial E}{\partial a_3} = 0 \tag{9}$$

Upon substitution of (8) into (9), we have

$$\begin{aligned}
&\sum (c + a_1\overline{p}_{1i} + a_2\overline{p}_{2i} + a_3\overline{p}_{3i} - \overline{d}_i) = 0 \\
&\sum \overline{p}_{1i}\,(c + a_1\overline{p}_{1i} + a_2\overline{p}_{2i} + a_3\overline{p}_{3i} - \overline{d}_i) = 0 \\
&\sum \overline{p}_{2i}\,(c + a_1\overline{p}_{1i} + a_2\overline{p}_{2i} + a_3\overline{p}_{3i} - \overline{d}_i) = 0 \\
&\sum \overline{p}_{3i}\,(c + a_1\overline{p}_{1i} + a_2\overline{p}_{2i} + a_3\overline{p}_{3i} - \overline{d}_i) = 0
\end{aligned} \tag{10}$$

The simultaneous solution of these equations yields the best-fit values of C, a_1, a_2, a_3.

The following formulas were used in searching for a best fit:

$$\begin{aligned}
&D = C\,T^{a_1} \\
&D = C\,X_n^{\,a_1} \\
&D = C\,\omega^{a_1} \\
&D = Cm^{a_1} \\
&D = Cm^{a_1}X^{a_2} \\
&D = Cm^{a_1}\omega^{a_2}
\end{aligned} \tag{11}$$

$$D = C X^{a_1} \omega^{a_2}$$

$$D = C T^{a_1} (X/L)^{a_2}$$

$$D = C m^{a_1} \omega^{a_2} X^{a_3}$$

$$D = C m^{a_1} \omega^{a_2} (X/L)^{a_3}$$

$$D = C_1 + C_2 T + C_3 T^2$$

A program was written for the digital computer (an XDS 930) which performed the least-squares analysis and calculated the error of the final result. The program performed several functions. Data in a number of dimensional units were read into the program and converted into SI units. Dissipation energy and maximum kinetic energy were calculated. Each of the formulas (11) was used with the least-squares criteria (10), and best-fit values for the unknown constants found. Finally, the error was calculated by finding the percentage of data points which fell within $\pm$ 1 db, $\pm$ 2 db, $\pm$ 3 db, and $\pm$ 4 db bands of the empirical law. A listing of the program is given in Appendix B.

As mentioned previously, there are two ways to calculate D. Equation (2) is the preferred way, since it is a direct calculation involving measured dynamic parameters. However, measurements of the amplitude at the location of the excitation force may be inaccurate due to the small magnitude there. For those tests where the damping constant was available, the dissipated energy was calculated according to both equations (2) and (3). For each test, the computer program was used to find the best-fit law of the form

$$D = C T^n$$

and the scatter calculated (percentage of data points varying by $\pm$ 1 db, $\pm$ 2 db, $\pm$ 3 db, $\pm$ 4 db). In this way, an empirical measure of the accuracy of both formulations could be gauged. This subject will be more fully discussed in a subsequent section on error analysis. The conclusion reached was that the calculation of D from equation (3) was generally more accurate. This was markedly noticeable for the S-IVB tests, and to a much lesser extent the case for the S-V tests.

In the Saturn V series of tests, dynamic parameters were measured in two types of tests. The primary test, conducted to find the dynamic parameters, was a frequency sweep test. An additional test run was a force level test, mostly for the purpose of checking linearity of response over a range of excitation forces. The results of this test, however, did supply sufficient information to calculate the dynamic parameters. In the force level tests, responses were found at a large number of vehicle locations for three force levels. The maximum level was approximately the same as in the frequency sweep test. For this magnitude of force, the results of the two types of test were compared for consistency.

The results of the force level test were potentially quite valuable, since it presented an opportunity to determine damping in a situation where all but one parameter remained constant. However, for the torsional and longitudinal tests, there was poor correlation between the force level tests and the frequency sweep tests for the same excitation force. In addition, the scatter was quite large. Therefore, the force level tests for torsion and longitudinal motion were not used in this analysis.

Section 3

RESULTS

The results are given in Tables 2-5, which cover bending, torsion and longitudinal motion. Each table gives the damping laws which fit the data best, for each of the formulations tried from equations (11). The scatter is given by the percentage of data points falling within $\pm$ 1 db, $\pm$ 2 db, $\pm$ 3 db, and $\pm$ 4 db bands around the basic law. Figures 1-4 show the data as a function of kinetic energy, with the line representing the damping law.

The laws for bending represent an analysis of 330 data points, much more than the results for torsion or longitudinal motion. For this reason, it is felt the results are more accurate and likely to be of general application. The conclusion derived from Table 2 is that a law of the form

$$D = 0.286\, T^{0.746} \tag{12}$$

describes the damping energy of a large class of aerospace structures. Figure 1 illustrates the fit of this law to the data.

Of the 330 bending data points, 196 or 60% are associated with Test No. 1. Therefore, the damping law (12) may be biased by the inclusion of this data. For this reason, an alternate damping law for bending was derived, based on tests 2, 5, 8, 11, 13 and 15. The law derived was

$$D = 0.153\, T^{0.893} \tag{13}$$

with 71% of the data falling within a $\pm$ 2 db band. The results of the investigation are given in Table 3. Figure 2 illustrates this law.

It is interesting to note that when a damping law was sought of the form

$$D = Cm^{a_1}\omega^{a_2}X^{a_3}$$

the law which fits the data best produced the approximate relationship

$$a_3 \approx 2a_1$$

That is, the quantity mX^2 influences the damping. A glance at Tables 2, 3, 4 and 5 reveals this is true for bending, torsion and longitudinal motion. Although a law of this form gave the best fit to the data, it was not significantly better than the simpler law (12)--not enough to recommend its use.

For torsional vibration, the best law was found to be

$$D = 0.095m^{1.01}\omega^{2.69}X^{2.33}$$

with 81% of the data falling within a $\pm$ 2 db band. The law

$$D = 0.101T^{1.279} \tag{14}$$

had a 63% accuracy for $\pm$ 2 db. While the former law shows a better fit, it should be borne in mind that the total number of data points is only 26, so that a small uncertainty in the five points which lie just outside the $\pm$ 2 db band (see Fig. 3) would change 63% accuracy to 81% accuracy.

The law for torsion is less reliable than the bending law, since it represents an analysis of only 26 points, all relating to configurations of the Saturn V. It is noteworthy that the law (14) for torsion has an exponent greater than unity, implying damping ratio increasing with amplitude. This is the reverse of the situation for bending.

For longitudinal vibration, the best law was found to be

$$D = 0.0002m^{1.259}\omega^{3.315}X^{2.405} \tag{15}$$

with 77% of the data falling within a $\pm$ 2 db band. The law

$$D = 0.057T^{1.104} \tag{16}$$

had a 67% accuracy for $\pm$ 2 db. Here, the number of data points is 39, all representing the Saturn V with and without the SI-C stage. Figure 4 reveals that a small uncertainty in the data could give as much as 77% accuracy for the law (16)

Again, the law for longitudinal motion has an exponent greater than one.

Section 4

ERROR ANALYSIS

One cannot help noticing that the empirical laws shown in Figures 2-5 are subject to a considerable degree of scatter. The natural question to ask is how much accuracy can be inherently expected from the data generated. The tests were not primarily designed for the purpose of measuring dissipated energy, and a careful look at the origins and accuracy of the dynamic parameters is therefore in order.

The quantities plotted in Figures 2-5 are derived from the formulas

$$T = (1/2)m\omega^2X^2 \tag{5}$$

and

$$D = 4\pi\zeta T \tag{3}$$

or

$$D = \pi F X_E \tag{2}$$

First, it is necessary to derive expressions for the error in the derived quantities T and D propagated from the independently determined quantities m, ω, X, X_E, ζ, F. Of course, some of these quantities themselves are derived from other independently determined variables.

In general, if there is a continuously differentiable function

$$U = U(x, y, z)$$

and x, y, z are replaced by their approximate values

$$x = x + \epsilon_x$$

$$y = y + \epsilon_y$$

$$z = z + \epsilon_z$$

where ϵ_x, ϵ_y, ϵ_z are the errors in x, y, z, then the error in U is ϵ_u given by (Ref. 17)

$$\epsilon_u = \frac{\partial U}{\partial x}\epsilon_x + \frac{\partial U}{\partial y}\epsilon_y + \frac{\partial U}{\partial z}\epsilon_z \tag{17}$$

Applying equation (17) to formulas (2), (3) and (5), we have the following expressions for relative error:

$$\frac{\epsilon_T}{T} = \frac{\epsilon_m}{m} + 2\frac{\epsilon_\omega}{\omega} + 2\frac{\epsilon_x}{x} \tag{18}$$

and

$$\frac{\epsilon_D}{D} = \frac{\epsilon_\zeta}{\zeta} + \frac{\epsilon_T}{T} \tag{19}$$

or

$$\frac{\epsilon_D}{D} = \frac{\epsilon_F}{F} + \frac{\epsilon_{X_E}}{X_E} \tag{20}$$

Thus, if some measure can be assigned to the errors of the independent variables (independent with respect to T and D), then the errors in T and D are known.

Of the several series of dynamic tests, the Boeing tests on the Saturn V (tests nos. 2-10) are the best documented and, at least on the basis of currently available information, the most accurate. The accuracy of these tests is discussed below.

For many of the tests, the energy dissipated/cycle could be calculated from either formula (2) or (3) independently. A comparison of the values calculated is shown in Table 6, as a measure of accuracy. It is seen that agreement is poor for many cases. In the bending tests, however, cases 2, 5 and 8 (the Boeing tests) show relatively good accuracy. The discussion of probable error in the recorded values of dissipated energy and kinetic energy will begin with the Saturn V tests in bending.

For the Saturn V bending tests, References (18) and (19) provide a source for estimation of errors. Errors accumulate from sensor calibration, instrument resolution, hysteretic effects in vehicle response, noise and scalar errors in the data acquisition system, and round-off and approximation errors in the data reduction methods.

The Boeing tests incorporated a number of accuracy-correction techniques. Calibration curves for the amplitude and phase of each sensor were determined and used in the data reduction system to modify the final output. In addition, on-site calibration was periodically performed to check drift and malfunction. A Fourier analysis was performed on the response to remove noise and harmonic content. The output data (in the form of transfer functions for each sensor) is curve-fitted to yield the dynamic parameters.

The measurement of force was subject to two sources of error. It is not possible to assign a value to the error, which could have been important in the evaluation of dissipated energy for those cases where formula (2) was used.

Misalignment of the load cell can cause significant error in the force reading. Misalignment will occur to some extent because of the bending curvature of the structure as it undergoes deformation. A second cause of misalignment is due to the out-of-plane motion of the structure. Since the excitation was not applied in a principal plane, the vehicle response was at an angle with respect to the force. Therefore, the axis of the load cell may suffer misorientation and show only a component of the applied force. This component will generally be quite small. However, the out-of-plane component can cause a moment acting on the load cell, depending on its displacement from the shaker, which is a potentially more serious cause of error.

Another source of error is due to the mass of the shaker armature causing an effective inertial force showing up in the load cell readings. The total test system should properly be considered to be the test vehicle plus the shaker armature. A mass compensation procedure should be performed to eliminate the effect of the additional mass. No indication was found in the documentation that this procedure was used. An example of the possible error from this cause is as follows.

For the Boeing tests, a 20,000 lb. (88,965 N) thruster system was used. A system of this magnitude uses about a 350 lb. (159 kg.) armature. For a frequency of 8.69 Hz, and a thruster travel of 5.35×10^{-4} m., the corresponding inertial force is 253 N. This compares to a measured force of 5791 N, or a 4.4% error. It is therefore possible, especially at the higher frequencies, that lack of mass compensation could be a significant source of error in the force measurements.

One of the principal objects of the dynamic tests was to determine modal natural frequencies. It is to be expected, therefore, that the accuracy associated with this quantity is relatively good. There are several sources of error: 1. Numerical error associated with the curve-fit procedure. In Reference (18) an error analysis of the curve-fit technique is performed. For the one example given, the error in amplitude varies from 0.1-0.7% over the frequency range. 2. The possibility of a double peak in the vicinity of the resonant frequency. This effect is due to the fact that the excitation is not applied in a principal plane, and therefore the response is a summation of motion in two planes, each of which may have a slightly different peak due to asymmetry of the vehicle. In this case, as pointed out in Reference (19), the curve-fit method will not separate modes closer than 1% in frequency.

From the above discussion, a value of 1.5% is assigned, in a purely estimatory manner, as a typical error to associate with experimental frequency values. Sensor inaccuracy may have little effect on frequency, since only the location of an amplitude peak is sought, and not its value.

Errors associated with X (response amplitude) are influenced by sensor error and data acquisition and reduction error. The sensor error depends on the response magnitude. According to Reference (19), sensor error averaged 5% for measurements at 1% of full scale, while for full scale measurements, they averaged 1%.

A check of the accuracy for determination of response amplitude X comes from comparison of the results of the frequency sweep tests with the force level tests. The force level tests were conducted as a check on the linearity of response as a function of force. The force levels of the frequency sweep tests were approximately reproduced, as well as two lower levels, and responses at these values recorded. Obviously, we expect agreement between the two tests at the same level. Comparison of the results of the two tests reveals that the average agreement for X is within 5%.

The determination of generalized mass is subject to the greatest inaccuracy of all the quantities making up the kinetic energy. This quantity is derived from the curve-fit technique. According to Reference (19), comparison of generalized mass values gave agreement to within 10%.

The modal damping values, likewise determined from curve fitting, were found in Reference (19) to give agreement within 5%.

The above error figures may be used to give an order-of-magnitude estimate of the error involved in the dynamic parameters of the Boeing tests. From equations (18) and (19) it follows that the error in determination of kinetic energy is

$$\frac{\epsilon_T}{T} = 0.1 + 2(0.015) + 2(0.05) = 0.23 = 23\%$$

and

$$\frac{\epsilon_D}{D} = 0.05 + 0.23 = 0.28 = 28\%$$

This may be compared with the variation due to the $\pm$ 2db bands in Figures 1 and 2. Since the definition of a 2 db difference between two quantities T_1 and T_2 is

$$2 \text{ db} \rightarrow \log \frac{T_1}{T_2} = 0.2$$

then it follows that 2 db corresponds to an error of +59%, -37% in T.

It is interesting to note that if we assume a Gaussian distribution of error, and that the nominal errors estimated represent a variation from the mean error of one standard deviation, then 68% of the data would lie within these error bounds. This figure correlates well with the 71%

of data falling within the $\pm$ 2 db bands of Figure 1 and 60% of data in Figure 2.

The Boeing tests include 38% of the data points for all the dynamic bending tests, or 71% of all data points excluding the Saturn I data.

The other data available on the remaining dynamic tests is generally lacking in enough information to estimate the accuracy. This data falls into three categories. Test No. 15 was a ground vibration test of a Boeing 747 airplane. A frequency sweep was made, and frequency determined from polar plots of complex admittance (Ref. 5). From this plot, generalized mass and damping coefficients are also determined. From the rather sketchy details available concerning the conduct of the tests, no separate determination of accuracy can be made.

Tests 11 and 13 were dynamic tests of the Saturn upper stages, performed by the Chrysler Corporation. The resonant frequencies were determined from inspection of the response and phase angle plots. Damping coefficients were found from an average of frequency bandwidth and phase angle methods. Generalized mass was found from integration of mass and mode shapes, using 70 equally spaced points along the vehicle.

Not enough information was available to accurately assess the error bounds. Inspection of the response and phase angle plots indicates an up to 2% possible uncertainty in determining the resonance point. The generalized mass was found from the integration method mentioned and compared with values found from a complex curve-fit for the amplitude of the response curve at the nose of the vehicle. Agreement between the two values was very poor. The integration method seemed to produce more consistent values and was the basis for the values used in this report. An estimated 15% error is associated with these values. The Chrysler tests account for 11% of all data points when the Saturn I is included, and 21% without the Saturn I data.

Finally, the Saturn I tests, which formed the original basis for the Chang law, consist of 196 data points, or 59% of all data points considered. Apparently, frequencies were found from inspection of response and phase angle plots. Generalized mass was found by integration of the mode shapes with a lumped-mass model. Damping constants were not used for determining dissipated energy, but rather equation (3), using force and excitation point response measurements. Insufficient information is available for error estimation.

Section 5

CALCULATION OF EQUIVALENT LINEAR DAMPING COEFFICIENT

The results of the preceding section indicate that structural damping in bending can be predicted by equation (12) or (13). With less certainty, equations (14) and (16) may also be useful for predicting damping for torsion and longitudinal motion. Damping, at a particular amplitude, may be described by an equivalent linear damping coefficient ζ, given by

$$\zeta = \frac{D}{4\pi T} \tag{21}$$

From equation (17), the coefficient for bending is

$$\zeta = 0.0228\ T^{-0.254}$$

For the range of T covered in the tests (see Fig. 1), this equation gives the variation of ζ to be

$$0.07 > \zeta > 0.004, \text{ for } 0.01 \text{ N-m} < T < 1000 \text{ N-m}$$

For torsion, from equation (14), the coefficient is

$$\zeta = 0.00804\ T^{0.279}$$

and gives a variation over the range of T (Fig. 2) of

$$0.004 < \zeta < 0.029, \text{ for } 0.1 \text{ N-m} < T < 100 \text{ N-m}$$

Finally, for longitudinal motion, equation (16) gives

$$\zeta = 0.00454\ T^{0.104}$$

with ζ varying (Fig. 3) as

$$0.006 < \zeta < 0.009, \text{ for } 10 \text{ N-m} < T < 1000 \text{ N-m}$$

A small digital computer program was written to calculate for a range of amplitudes of kinetic energy. Therefore, the results of modal analyses of the space shuttle, or other large aerospace vehicles, can be used to produce predicted values of ζ for further application in response studies. A listing of the program is given in Appendix B.

Section 6

RESPONSE OF NONLINEARLY DAMPED STRUCTURES

The results for the equivalent linear damping coefficient, found in the preceding section, can be used to find the complete dynamic characteristics of a complex structure. We let the response at a point x of the structure by U(x, t). Then U may be expanded into a series of modal functions of the form

$$U(x, t) = \sum q_n(t)\, \Phi_n(x) \tag{22}$$

where

$\Phi_n(x)$ is a mode shape function, and

q_n is the generalized coordinate corresponding to Φ.

The modal equation of motion for the n-th mode is

$$\ddot{q}_n + \omega_n^2 q_n + F_n/m_n = Q_n(x) \tag{23}$$

where

ω_n is the natural frequency,

m_n is the generalized mass,

F_n is a nonlinear function including damping, and

$Q_n(t)$ is the generalized force, written, for periodic excitation, as

$$Q_n = \overline{Q}_n \cos \omega t$$

The fundamental response is

$$q_n(t) = \bar{q}_n(\omega) \cos(\omega_n t - \theta_n)$$

where θ_n is the phase angle.

F_n is expanded into the first terms of a Fourier Series as

$$F_n = I_1 \cos(\omega_n t - \theta_n) + I_2 \sin(\omega_n t - \theta_n)$$

$$= I_1 \cos(\omega_n t - \theta_n) - \frac{D_n}{n\bar{q}_n} \sin(\omega_n t - \theta_n) \tag{24}$$

$$\text{where } I_n = \frac{1}{\pi} \int_0^{2\pi/\omega_n} F_n \sin(\omega_n t - \theta_n)\, \omega_n dt$$

and D_n is the energy dissipated/cycle. Substitution of equation (24) into equation (23) gives the two equations

$$\bar{q}_n(\omega_n^2 - \omega^2) + \frac{I_1}{m_n} = \bar{Q}_n \cos\theta_n$$

$$\frac{D_n}{\pi q_n m_n} = \bar{Q}_n \sin\theta_n \tag{25}$$

The peak kinetic energy/cycle, T_n, may be written in terms of q_n as

$$T_n = \frac{1}{2}\,\omega^2 \bar{q}_n^{\,2} m_n$$

Substitution of this equation into equations (25) and recombining gives

$$\bar{q}_n = \bar{Q}_n \left[(\omega_n^2 - \omega^2 + I_1/m_n\bar{q}_n)^2 + (D_n\omega^2/2\pi T_n)^2 \right]^{-1/2}$$

$$\tan\theta_n = \omega^2 D_n/2\pi T_n\,(\omega_n^2 - \omega^2 + I_1/m_n\bar{q}_n)$$

If the natural frequency ω_n does not vary significantly with response amplitude, $I_1 = 0$. Then $\bar{q}_n$ and θ_n can be found by the simultaneous solution of the nonlinear equations (25).

A digital computer program was written to accomplish this. The program requires as input the dynamic modal parameters ω_n, m_n and the amplitude and frequency of the applied force. It then solves equations (25) iteratively through the use of Newton's method. The resulting solutions are then used in equation (22) to find responses for arbitrary forcing functions. A listing of the program is given in Appendix B.

Section 7

CONCLUSIONS

This study represents a comprehensive analysis of all available dynamic test data in an attempt to verify the existence of an empirical law to predict structural damping in large aerospace structures. Based on a number of previous studies, it was determined that the quantity D, energy dissipated/cycle, was the most appropriate measure of damping. A number of different hypotheses were checked. It was found that for bending vibrations, the formula

$$D = 0.286\ T^{0.746}$$

where T is the peak kinetic energy and units are in Newton-meters predicted damping to within $\pm$ 2 db levels for 60% of the data examined. Since more than half of the data pertained to one vehicle, another formula

$$D = 0.153\ T^{0.893}$$

was developed to fit the rest of the data within a $\pm$ 2 db range for 71% of the data points.

Formulas for torsional and longitudinal vibrations were also found. It was found for these cases too that the best law, in the sense of a least-squares fit, related dissipated energy to kinetic energy as an independent parameter. The formulas found, however, differ from the formula for dissipated energy in bending in that the exponents are greater than unity. Therefore, at higher energy levels, damping will increase, in contrast with bending. A relatively small number of data points were available for torsional and longitudinal tests, so that the validity of conclusions established for these cases is indeterminate.

There is a considerable amount of scatter in the D vs. T data. The error associated with the various dynamic parameters was estimated and an analysis made to determine the probable error in D and T. It was found that a good part of the scatter, but still not all, could be due to measurement, data acquisition, and numerical error.

Because of the enormity of the testing program required to come up with just one data point, it is an unfortunate fact that not nearly enough data are available for a reliable statistical analysis to determine a trustworthy damping law. This situation is complicated by the use of different test procedures, equipment, and numerical methods, all of different degrees of accuracy, in different systems of units, and with different degrees of care in documenting. The present study, then, cannot do more than establish a quantitative relationship of encouraging, but not definitive, reliability.

It is recommended that the data from the recently performed Skylab modal survey be analyzed in the manner of this study to add to the statistical base for determination of an empirical damping law.

As an aid to future researchers of structural damping in large structures, all the raw data used for the analyses in this report are given in Appendix A, all converted to the Standard International system of units.

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Table 1

Dynamic Tests for Damping

Test No.	Vehicle Description	Type of Test	No. Data Points	Ref.
1	Saturn I	Bending	196	1
2	Saturn V, Configuration I*	Bending	19	6
3	" "	Torsion	10	7
4	" "	Longitudinal	11	8
5	Saturn V, Configuration II**	Bending	15	9
6	" "	Torsion	6	10
7	" "	Longitudinal	21	11
8	Saturn V, Configuration II, (MSFC C. O. 201)***	Bending	14	12
9	" "	Torsion	3	13
10	" "	Longitudinal	7	14
	S-IVB‡	Bending	26	15
12	" "	Torsion	6	15
13	S-IVB‡, SAD-202	Bending	20	16
14	" "	Torsion	9	16
15	Boeing 747	Bending	16	5

* Configuration I consists of the entire Apollo Saturn V vehicle

** Configuration II consists of the S-II stage, S-IVB Stage, instrument unit, and the Apollo spacecraft

*** A modified configuration II for a stronger torsional support at the command module/service module interface.

‡ These configurations consist of the S-IVB Stage, instrument unit, and Apollo spacecraft

Table 2

Damping Laws for Bending

The results given include the data from test nos. 1, 2, 5, 8, 11, 13 and 15 (330 data points)

Damping Law	Percentage of data points within ± 1, ± 2, ± 3, ± 4 db band			
	± 1 db	± 2 db	± 3 db	± 4 db
$D = .286\ T^{.746}$	32%	60%	80%	88%
* $D = 261\ X^{.371}$	21	39	50	63
$D = 694\ \omega^{-1.04}$	18	31	41	51
$D = 2.82\ m^{-.091}$	11	18	24	31
* $D = 4.31\ m^{.593}\ X^{1.020}$	33	55	73	82
$D = 1485\ m^{.020}\ \omega^{-2.15}$	17	30	41	51
* $D = 270\ X^{.685}\ \omega^{-.202}$	21	37	51	63
* $D = .785\ T^{.678}\ (X/L)^{.0828}$	33	60	79	87
* $D = .671\ m^{.675}\ \omega^{1.04}\ X^{1.369}$	35	62	79	87
* $D = 261\ m^{.620}\ \omega^{.646}\ (X/L)^{1.244}$	32	56	73	84
$D = .596 + .095\ T - .000015\ T^2$	11	28	60	66

* Does not include test 15 (X is not available from this test)

Dimensions are in SI units as follows:

D, T (Newton-meters), X (meters), ω (radians/second), m (kilograms)

Table 3

Damping Laws for Bending
(without Saturn I data)

The results given include the data from
tests 2, 5, 8, 11, 13, 15 (174 points)

Damping Law	Percentage of data points within $\pm$ 1-4 db band			
	$\pm$ 1 db	$\pm$ 2 db	$\pm$ 3 db	$\pm$ 4 db
$D = .153\ T^{.893}$	45%	71%	89%	95%
*$D = 63.4\ X^{.190}$	22	38	53	66
$D = 225\ \ {}^{-.647}$	16	32	50	60
$D = 16.2\ m^{-.110}$	15	25	39	52
*$D = 3.41\ m^{.626} X^{1.015}$	37	63	79	88
$D = 460\ m^{.012}\ \ {}^{-1.42}$	15	30	49	64
*$D = 294\ X^{.082}\ \ {}^{-1.103}$	15	35	51	63
*$D = .132\ T^{.882} (X/L)^{-.014}$	47	75	92	96
*$D = .080\ m^{.881}\ \ {}^{1.731} X^{1.741}$	47	75	92	96
*$D = 300\ m^{.835}\ \ {}^{.807} (X/L)^{1.529}$	34	58	82	90

*Does not include test 15 (X is unavailable from this test).

Dimensions are in SI units as follows: D, T (Newton-meters), X (meters), (radians/second), m (kilograms).

Table 4

Damping Laws for Torsion

The results given include the data from test nos. 3, 6, 9, 12 and 14 (26 data points)

Damping Law	Percentage of Data Points within ± 1, ± 2, ± 3, ± 4 db band of basic law			
	± 1 db	± 2 db	± 3 db	± 4 db
$D = .101\ T^{1.279}$	33%	66%	85%	96%
$D = 870\ X^{.378}$	4	22	48	67
$D = 13.4\ \omega^{-.415}$	4	15	30	33
$D = 95.7\ m^{-.405}$	19	26	33	52
$D = 245\ m^{.946}\ X^{1.977}$	22	37	59	81
$D = 4.94\ m^{-.476}\ \omega^{1.094}$	22	33	37	56
$D = .587\ X^{.998}\ \omega^{2.431}$	22	52	56	67
$D = .934\ T^{1.11}\ (X/L)^{.150}$	29	74	93	100
$D = .095\ m^{1.01}\ \omega^{2.69}\ X^{2.33}$	37	81	93	100
$D = 4.77\ m^{.588}\ \omega^{2.573}(X/L)^{1.456}$	41	78	96	100
$D = -.524 + .333\ T - .0013\ T^2$	37	59	63	70

Dimensions are in SI units as follows: D, T (Newton-meters), X (radians), ω (radians/second), m(kilogram-meters^2)

Table 5

Damping Laws for Longitudinal Motion

The results given include the data from test nos. 4, 7 and 10 (39 data points)

Damping Law	Percentage of Data Points within ± 1, ± 2, ± 3, ± 4 db band of basic law			
	± 1 db	± 2 db	± 3 db	± 4 db
$D = .057\ T^{1.104}$	41%	67%	90%	100%
$D = 269\ X^{.192}$	13	23	44	51
$D = 235,930\ \omega^{-1.380}$	15	38	49	56
$D = .993\ m^{-.191}$	13	26	38	49
$D = 25.1\ m^{.847}\ X^{1.537}$	38	59	72	77
$D = 42,108\ m^{.159}\ \omega^{-.262}$	18	31	49	54
$D = 590,740\ X^{.158}\ \omega^{-2.433}$	18	36	51	56
$D = .0084\ T^{1.158}\ (X/L)^{-.133}$	49	74	82	100
$D = .0002\ m^{1.259}\ \omega^{3.315}\ X^{2.405}$	54	77	92	100
$D = 58.37\ m^{1.164}\ \omega^{2.379}(X/L)^{2.145}$	26	59	79	82

Dimensions are: D, T (Newton-meters), X (meters), ω(radians/second), m (kilograms)

Table 6

Comparison of Dissipated Energy Values

Test No.	No. Data Pts.	Average percent difference for D calculated two ways*
Bending		
3	16	73.6
4	18	91.1
5	19	13.1
6	14	1.0
19	15	12.0
Torsion		
9	3	65.1
10	6	37.3
12	5	50.3
13	3	24.8
17	10	42.8
Longitudinal		
15	21	315.6
18	11	9.0
21	7	247.8

*The average percent difference was calculated for each test by taking the average value of the quantity $100 \times |D_1 - D_2|/D_2$ where $D = \pi F X_E$ and $D = 4\pi \zeta T$. For each case, a few data points showing untypically large error were excluded from the average.

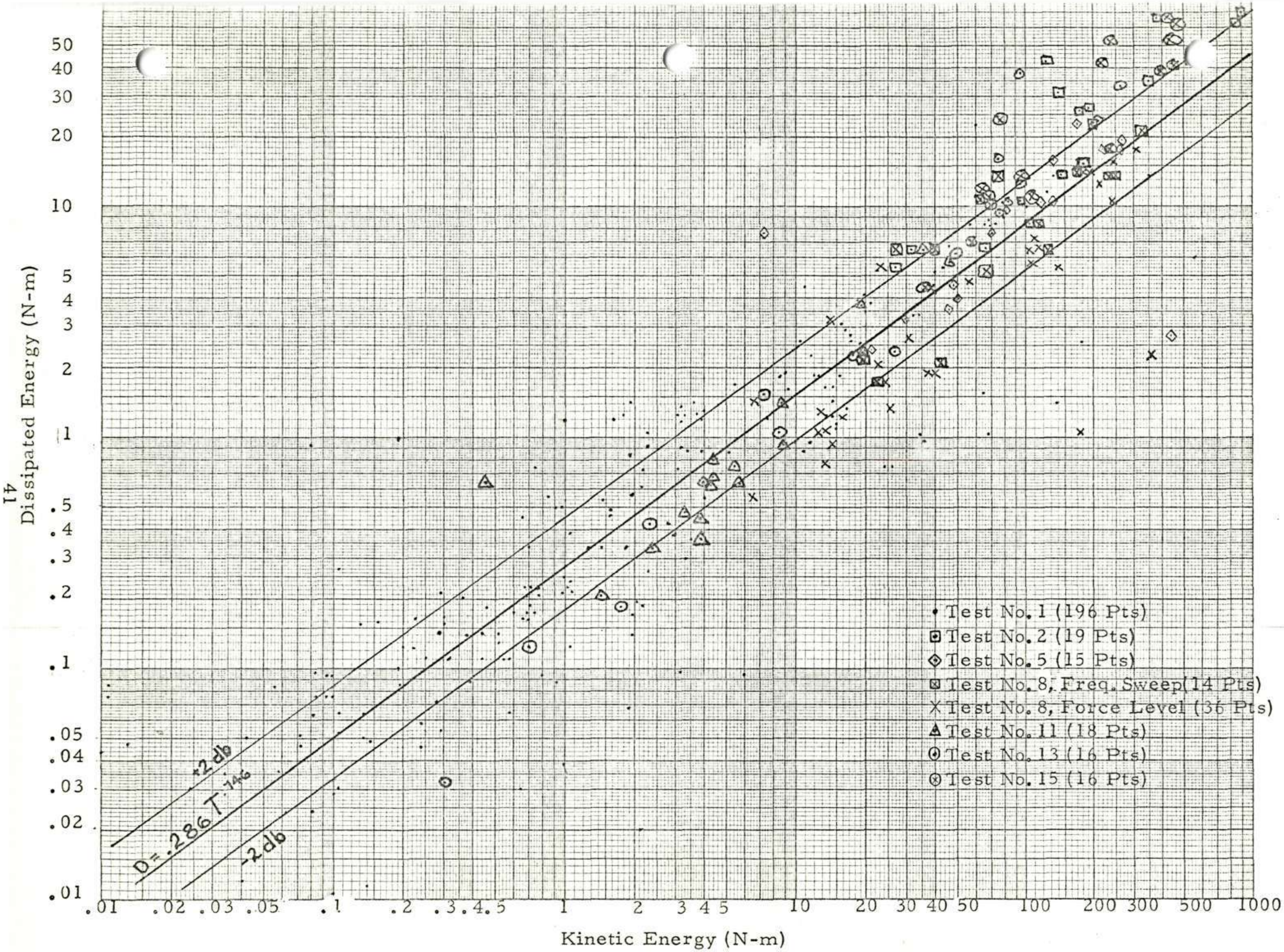

Figure 1. Dissipated Energy/Cycle vs. Maximum Kinetic Energy for Bending Tests

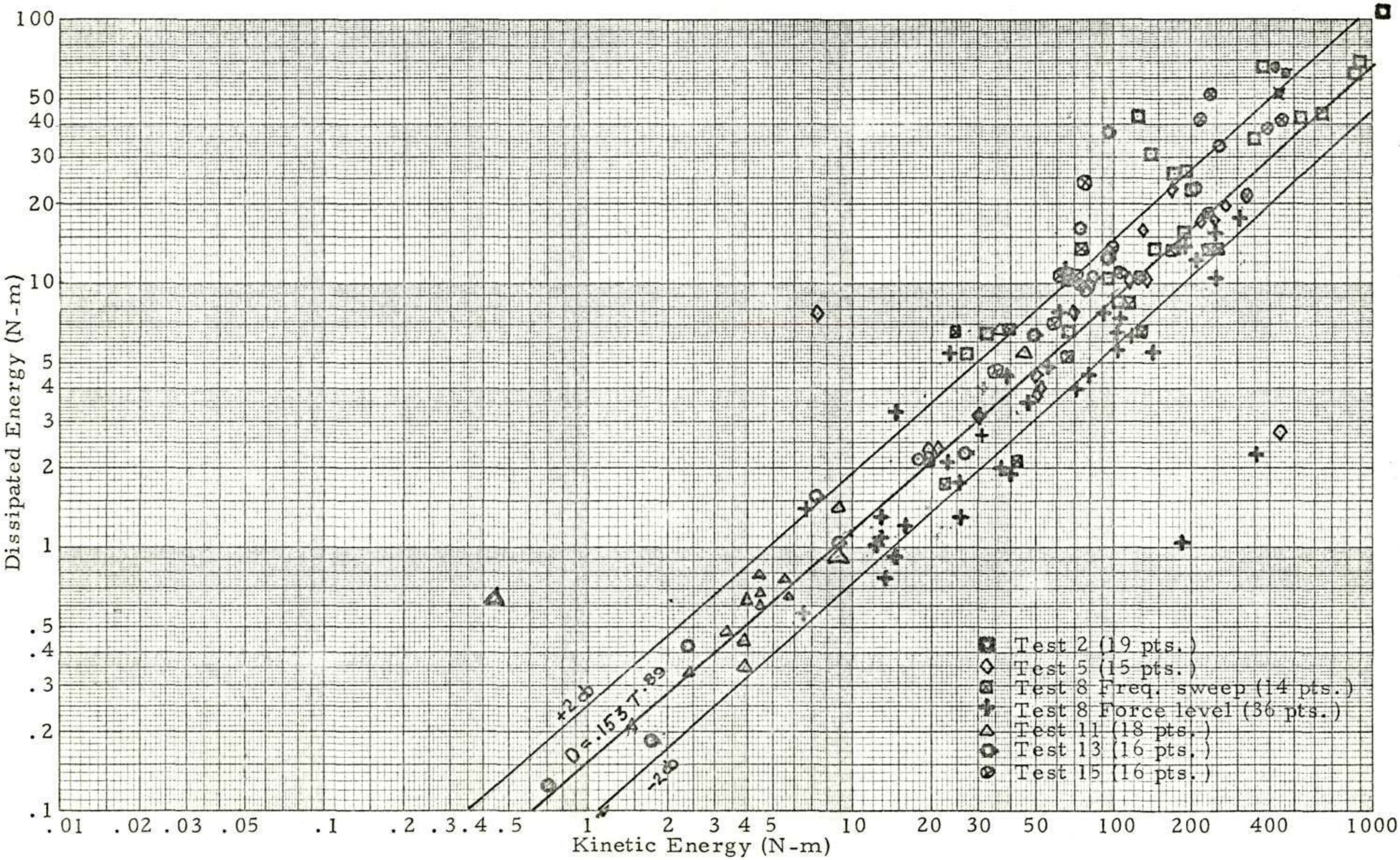

Figure 2. Dissipated Energy/Cycle vs. Maximum Kinetic Energy for Bending Tests (Excluding Saturn I Data)

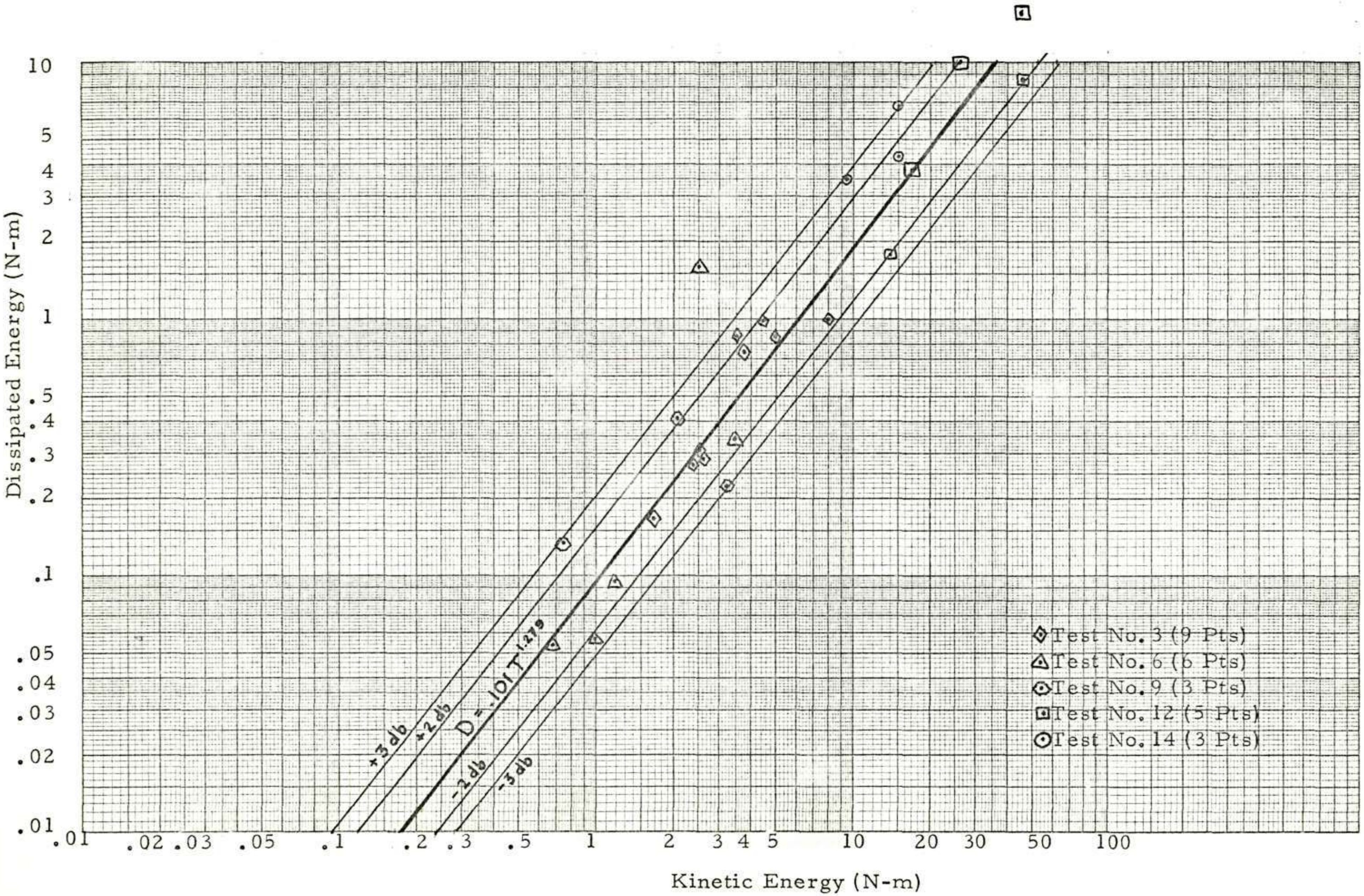

Figure 3. Dissipated Energy/Cyc vs. Maximum Kinetic Energy for Torsional Tes

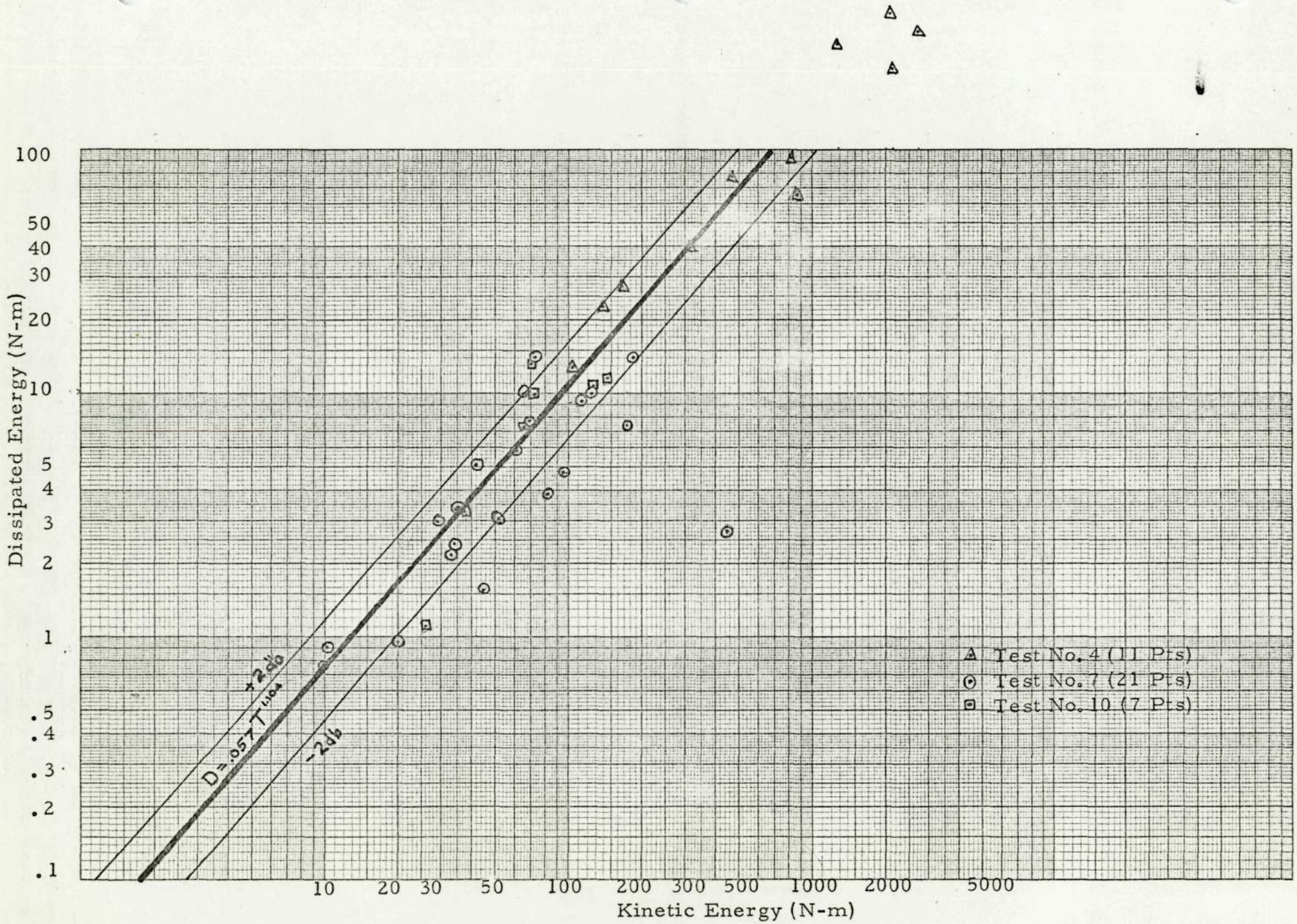

Figure 4. Dissipated Energy/Cycle vs. Maximum Kinetic Energy for Longitudinal Tests

APPENDIX A

DYNAMIC TEST DATA USED FOR DETERMINATION OF EMPIRICAL DAMPING LAW

TEST NO. 1 SATURN I DYNAMIC TEST VEHICLE SAD-6 PITCH + YAW

	FREQUENCY [HZ]	FORCE [N]	XN [M]	XE [M]	GENL MASS [KG-SEC2/M]	ZETA	D[=PI*XE*F] [N-M]	T [N-M]	D[=4*PI*ZETA*T] [N-M]
1	3.570	2284.949	1.6800E-02	1.7741E-03	8.1984E 02	.0000E 00	1.2735E 01	5.8212E 01	.0000E 00
2	8.860	2088.816	6.3000E-04	1.8648E-04	2.6478E 03	.0000E 00	1.2237E 00	1.6284E 00	.0000E 00
3	14.440	1117.958	1.7100E-04	4.8598E-05	9.1202E 02	.0000E 00	1.7068E-01	1.0976E-01	.0000E 00
4	1.600	2098.623	3.4650E-03	5.5301E-04	3.2470E 04	.0000E 00	3.6460E 00	1.9700E 01	.0000E 00
5	2.450	2088.816	6.5500E-04	1.9034E-04	7.3795E 04	.0000E 00	1.2491E 00	3.7512E 00	.0000E 00
6	3.220	2128.043	5.7180E-03	2.8018E-04	1.8927E 03	.0000E 00	1.8731E 00	1.2665E 01	.0000E 00
7	3.800	2235.916	1.1090E-03	2.7614E-05	6.2076E 03	.0000E 00	1.9397E-01	2.1761E 00	.0000E 00
8	4.290	2235.916	5.9300E-04	2.0126E-04	1.5063E 04	.0000E 00	1.4137E 00	1.9243E 00	.0000E 00
9	5.020	2118.236	3.5280E-03	1.9369E-04	2.3928E 03	.0000E 00	1.2889E 00	1.4515E 01	.0000E 00
10	5.800	2118.236	3.9200E-05	1.2948E-05	1.8839E 04	.0000E 00	8.6163E-02	1.9222E-02	.0000E 00
11	7.210	2118.236	2.0100E-05	6.6792E-06	2.5890E 04	.0000E 00	4.4448E-02	1.0733E-02	.0000E 00
12	7.400	2265.336	1.9600E-04	7.1266E-05	2.2820E 04	.0000E 00	5.0718E-01	9.4759E-01	.0000E 00
13	10.490	2177.076	3.9000E-05	1.1376E-05	2.8204E 04	.0000E 00	7.7808E-02	9.3179E-02	.0000E 00
14	13.870	2128.043	7.0000E-05	2.5263E-05	3.4608E 04	.0000E 00	1.6889E-01	6.4395E-01	.0000E 00
15	1.720	2059.396	1.9072E-02	1.2683E-03	3.2950E 03	.0000E 00	8.2055E 00	6.9990E 01	.0000E 00
16	1.600	2137.850	3.3060E-03	5.4318E-04	3.2382E 04	.0000E 00	3.6481E 00	1.7884E 01	.0000E 00
17	1.730	2128.043	1.8142E-02	1.2845E-03	3.3048E 03	.0000E 00	8.5871E 00	6.4260E 01	.0000E 00
18	2.450	2118.236	6.2500E-04	1.9562E-04	6.8088E 04	.0000E 00	1.3018E 00	3.1513E 00	.0000E 00
19	3.230	2128.043	5.7170E-03	2.8128E-04	1.9515E 03	.0000E 00	1.8805E 00	1.3135E 01	.0000E 00
20	3.810	2157.463	8.9400E-04	3.0575E-05	9.2084E 03	.0000E 00	2.0723E-01	2.1088E 00	.0000E 00
21	4.370	2157.463	3.3900E-04	1.3723E-04	1.8642E 04	.0000E 00	9.3011E-01	8.0760E-01	.0000E 00
22	5.050	2137.250	3.5210E-03	2.0492E-04	2.4811E 03	.0000E 00	1.3763E 00	1.5484E 01	.0000E 00
23	5.810	2128.043	4.6300E-04	1.4955E-04	1.6103E 04	.0000E 00	9.9980E-01	2.3000E 00	.0000E 00
24	7.210	2157.463	2.8700E-04	8.5095E-05	2.2624E 04	.0000E 00	5.7577E-01	1.9122E 00	.0000E 00
25	7.510	2157.463	1.9100E-04	8.1481E-05	2.0751E 04	.0000E 00	5.5226E-01	8.4278E-01	.0000E 00
26	9.480	2186.883	9.6000E-05	9.5040E-06	3.5824E 04	.0000E 00	6.5295E-02	5.8568E-01	.0000E 00
27	10.540	2177.076	3.5000E-05	1.3853E-05	3.4931E 04	.0000E 00	9.4747E-02	9.3834E-02	.0000E 00
28	13.950	2079.010	6.3000E-05	3.0391E-05	4.4797E 04	.0000E 00	1.9850E-01	6.8298E-01	.0000E 00
29	1.600	2098.623	3.4700E-03	5.5520E-04	3.2470E 04	.0000E 00	3.6604E 00	1.9756E 01	.0000E 00
30	1.720	2059.396	1.9070E-02	1.2682E-03	3.2950E 03	.0000E 00	8.2047E 00	6.9976E 01	.0000E 00
31	2.450	2088.816	6.5500E-04	1.9060E-04	7.3795E 04	.0000E 00	1.2508E 00	3.7512E 00	.0000E 00
32	3.220	2128.043	5.7200E-03	2.8028E-04	1.8927E 03	.0000E 00	1.8738E 00	1.2674E 01	.0000E 00
33	3.800	2235.916	1.1090E-03	2.7614E-05	6.2076E 03	.0000E 00	1.9397E-01	2.1761E 00	.0000E 00
34	4.290	2235.916	5.9300E-04	2.0103E-04	1.5063E 04	.0000E 00	1.4121E 00	1.9243E 00	.0000E 00
35	5.020	2118.236	3.5300E-03	1.9380E-04	2.3928E 03	.0000E 00	1.2896E 00	1.4832E 01	.0000E 00
36	5.800	2118.236	3.9200E-04	1.2936E-04	1.8839E 04	.0000E 00	8.6084E-01	1.9222E 00	.0000E 00
37	7.400	2265.336	1.9600E-04	7.1344E-05	2.2820E 04	.0000E 00	5.0774E-01	9.4759E-01	.0000E 00
38	9.490	2177.076	9.4000E-05	4.8316E-06	4.0855E 04	.0000E 00	3.3046E-02	6.4174E-01	.0000E 00
39	10.490	2177.076	3.9000E-05	1.1388E-05	2.8204E 04	.0000E 00	7.7888E-02	9.3179E-02	.0000E 00
40	13.870	2128.043	7.0000E-05	2.5270E-05	3.4608E 04	.0000E 00	1.6894E-01	6.4395E-01	.0000E 00
41	1.590	1647.517	3.0100E-03	5.1772E-04	4.0727E 04	.0000E 00	2.6796E 00	1.8414E 01	.0000E 00
42	1.740	2177.076	2.5070E-02	1.9254E-03	3.6088E 03	.0000E 00	1.3169E 01	1.3555E 02	.0000E 00
43	2.390	2206.496	7.2800E-04	2.7300E-04	1.4939E 05	.0000E 00	1.8924E 00	8.9273E 00	.0000E 00
44	3.310	2284.949	8.9700E-03	4.8348E-04	1.9613E 03	.0000E 00	3.4706E 00	3.4129E 01	.0000E 00
45	3.830	2373.209	6.4600E-04	2.9910E-05	6.3841E 03	.0000E 00	2.2300E-01	7.7142E-01	.0000E 00
46	4.310	2088.816	4.4600E-04	1.9802E-04	2.4978E 04	.0000E 00	1.2995E 00	1.8218E 00	.0000E 00
47	5.140	2079.010	3.3000E-03	2.1615E-04	2.6320E 03	.0000E 00	1.4118E 00	1.4982E 01	.0000E 00
48	5.810	2186.883	5.6100E-04	1.5371E-04	1.1003E 04	.0000E 00	1.0561E 00	2.3074E 00	.0000E 00
49	7.410	2147.656	1.9400E-04	6.9646E-05	1.6044E 04	.0000E 00	4.6991E-01	6.5444E-01	.0000E 00

46

50	9.540	941.438	3.1000E-05	2.6040E-06	4.3296E 04	.0000E 00	7.7016E-03	7.4748E-02	.0000E 00
51	10.4[illegible]	1971.137	2.8000E-05	1.0892E-06	5.4299E 04	[illegible]000E 00	6.7449E-03	9.1589E-02	.00[illegible] 00
52	13.8[illegible]	745.305	6.5000E-05	5.0115E-06	8.9829E 03	[illegible]000E 00	1.1734E-02	1.4288E-01	.00[illegible] 00
53	1.600	1049.312	1.6040E-03	2.2039E-04	2.4468E 04	.0000E 00	7.2652E-01	3.1810E 00	.0000E 00
54	1.750	2235.916	2.3148E-02	1.6759E-03	3.7354E 03	.0000E 00	1.1772E 01	1.2261E 02	.0000E 00
55	1.750	1216.025	1.2274E-02	9.0337E-04	3.6481E 03	.0000E 00	3.4511E 00	3.3223E 01	.0000E 00
56	2.400	2177.076	7.9000E-04	1.7886E-04	4.5699E 04	.0000E 00	1.2233E 00	3.2427E 00	.0000E 00
57	3.250	2118.236	2.2950E-03	8.6522E-05	3.7069E 03	.0000E 00	5.7577E-01	4.0707E 00	.0000E 00
58	3.330	2069.203	6.6440E-03	3.4283E-04	1.9221E 03	.0000E 00	2.2286E 00	1.8572E 01	.0000E 00
59	3.820	2000.557	8.3800E-04	3.8967E-05	5.1387E 03	.0000E 00	2.4490E-01	1.0394E 00	.0000E 00
60	4.310	669.794	1.3500E-04	4.7075E-05	1.2651E 04	.0000E 00	9.9055E-02	8.4540E-02	.0000E 00
61	5.160	1990.750	3.0010E-03	1.8576E-04	2.4124E 03	.0000E 00	1.1618E 00	1.1419E 01	.0000E 00
62	5.810	1686.744	7.0300E-04	1.6450E-04	1.0052E 04	.0000E 00	8.7171E-01	3.3101E 00	.0000E 00
63	7.260	1833.644	1.3600E-04	3.6842E-05	3.8148E 04	.0000E 00	2.1226E-01	7.3[illegible]09E-01	.0000E 00
64	9.530	1814.230	2.7000E-05	5.4270E-06	8.8554E 04	.0000E 00	3.0932E-02	1.1573E-01	.0000E 00
65	10.98[illegible]	1902.490	1.6000E-05	1.7008E-06	1.9045E 05	.0000E 00	1.0165E-02	1.1602E-01	.0000E 00
66	13.840	1176.798	3.9000E-05	6.5130E-06	1.4220E 04	.0000E 00	2.4079E-02	8.1775E-02	.0000E 00
67	1.750	2034.880	2.0815E-02	1.5507E-03	3.9325E 03	.0000E 00	9.9134E 00	1.0300E 02	.0000E 00
68	1.750	931.632	9.3170E-03	7.0064E-04	4.0109E 03	.0000E 00	2.0506E 00	2.1048E 01	.0000E 00
69	2.400	2079.010	7.8500E-04	2.1470E-04	5.1583E 04	.0000E 00	1.4023E 00	3.6141E 00	.0000E 00
70	3.240	1328.801	1.3690E-03	5.2433E-05	2.5595E 03	.0000E 00	2.1888E-01	9.9400E-01	.0000E 00
71	3.330	1898.567	5.5070E-03	2.8361E-04	2.0104E 03	.0000E 00	1.6916E 00	1.3345E 01	.0000E 00
72	3.820	2000.557	7.6400E-04	2.0552E-05	6.3841E 03	.0000E 00	1.2917E-01	1.0734E 00	.0000E 00
73	4.360	2275.143	4.0700E-04	1.6813E-04	1.6436E 04	.0000E 00	1.2017E 00	1.0216E 00	.0000E 00
74	5.150	1941.717	2.8390E-03	1.7517E-04	2.4615E 03	.0000E 00	1.0685E 00	1.0386E 01	.0000E 00
75	5.810	1745.584	7.1400E-04	1.6429E-04	9.6301E 03	.0000E 00	9.0096E-01	3.2712E 00	.0000E 00
76	7.390	1500.417	1.2800E-04	4.6298E-05	1.6966E 04	.0000E 00	2.1823E-01	2.9964E-01	.0000E 00
77	9.520	1814.230	3.2000E-05	8.6272E-06	7.8159E 04	.0000E 00	4.9171E-02	1.4318E-01	.0000E 00
78	10.990	1448.442	1.6000E-05	1.1798E-05	1.7015E 05	.0000E 00	5.3688E-02	1.0384E-01	.0000E 00
79	13.850	1667.130	7.3000E-05	1.2403E-05	1.4465E 04	.0000E 00	6.4958E-02	2.9187E-01	.0000E 00
80	1.730	2147.656	1.7940E-02	1.3240E-03	3.5500E 03	.0000E 00	8.9329E 00	6.7499E 01	.0000E 00
81	2.520	2196.690	8.3200E-04	1.7805E-04	8.4190E 04	.0000E 00	1.2287E 00	7.3053E 00	.0000E 00
82	3.270	2235.916	6.2000E-03	3.8316E-04	2.0692E 03	0000E 00	2.6914E 00	1.6788E 01	.0000E 00
83	3.820	2186.683	8.7500E-04	3.2988E-05	4.7170E 03	.0000E 00	2.2663E-01	1.0402E 00	.0000E 00
84	4.660	2245.723	2.4400E-03	3.7356E-04	3.9815E 03	.0000E 00	2.6355E 00	1.0161E 01	.0000E 00
85	5.3[illegible]0	2128.043	5.5500E-04	4.3068E-05	2.6576E 03	.0000E 00	2.8793E-01	4.5905E-01	.0000E 00
86	7.690	2128.043	1.8000E-05	1.1408E-05	4.1168E 04	.0000E 00	7.6270E-02	1.5570E-02	.0000E 00
87	9.600	2059.396	4.9000E-05	9.8637E-06	5.5633E 04	.0000E 00	6.3816E-02	2.4299E-01	.0000E 00
88	11.110	2118.236	1.0500E-04	7.1715E-06	2.7164E 03	.0000E 00	4.7724E-02	7.2969E-02	.0000E 00
89	12.920	2029.977	2.1000E-05	2.5013E-05	1.0859E 05	.0000E 00	1.5952E-01	1.5779E-01	.0000E 00
90	1.730	2294.756	1.9390E-02	1.4465E-03	3.5696E 03	.0000E 00	1.0428E 01	7.9286E 01	.0000E 00
91	2.520	2304.563	1.0810E-03	2.2723E-04	6.4410E 04	.0000E 00	1.6451E 00	9.4349E 00	.0000E 00
92	3.270	2353.596	6.1500E-03	3.8253E-04	2.1182E 03	.0000E 00	2.8284E 00	1.6910E 01	.0000E 00
93	3.830	2383.016	7.3600E-04	3.2310E-05	6.6587E 03	.0000E 00	2.4189E-01	1.0444E 00	.0000E 00
94	4.680	2343.789	2.5400E-04	3.7414E-05	3.8540E 03	.0000E 00	2.7549E-01	1.0750E-01	.0000E 00
95	5.340	2373.209	8.4000E-04	5.2332E-05	2.7066E 03	.0000E 00	3.9017E-01	1.0750E 00	.0000F 00
96	7.700	2383.016	2.7400E-04	1.6626E-04	4.3846E 04	.0000E 00	1.2447E 00	3.8524E 00	.0000E 00
97	9.600	2363.403	3.2000E-05	1.6400E-05	1.1945E 05	.0000E 00	1.2177E-01	2.2252E-01	.0000E 00
98	11.120	2363.403	1.2400E-04	8.8660E-06	2.8341E 03	.0000E 00	6.5829E-02	1.0637E-01	.0000E 00
99	13.290	2294.756	2.1000E-05	2.1021E-05	8.5367E 04	.0000E 00	1.5154E-01	1.3125E-01	.0000E 00
100	1.810	2118.236	1.6840E-02	1.0508E-03	2.5399E 03	.0000E 00	6.9928E 00	4.6579E 01	.0000E 00
101	2.880	4334.539	1.4580E-03	1.1533E-04	1.5259E 04	.0000E 00	1.5705E 00	5.3108E 00	.0000E 00
102	3.470	2020.[illegible]70	5.5980E-03	4.8255E-04	2.0300E 03	.0000E 00	3.0625E 00	1.5120E 01	.0000E 00
103	4.010	2039.783	1.1760E-03	5.3273E-05	4.2267E 03	.0000E 00	3.4138E-01	1.8554E 00	.0000E 00

104	4.800	1912.297	2.5700E-03	3.1996E-04	3.0499E 03	.0000E 00	1.9222E 00	9.1613E 00	.0000E 00
105	6.0[illegible]	1922.103	5.9400E-04	5.5836E-05	5.0112E 03	[illegible]000E 00	3.3716E-01	1.2565E 00	.00[illegible] 00
106	8.7[illegible]	2079.010	2.2600E-04	7.3631E-05	1.9917E 04	[illegible]000E 00	4.8091E-01	1.5304E 00	.00[illegible] 00
107	9.490	2039.783	4.3000E-05	2.2764E-05	1.2945E 05	.0000E 00	1.4588E-01	4.2549E-01	.0000E 00
108	10.660	1980.943	8.9000E-05	1.0164E-05	4.5111E 03	.0000E 00	6.3252E-02	8.0150E-02	.0000E 00
109	11.740	1608.291	6.9000E-05	1.0219E-05	5.5604E 03	.0000E 00	5.1632E-02	7.2022E-02	.0000E 00
110	13.560	1470.997	7.1000E-05	1.5208E-05	1.5210E 04	.0000E 00	7.0281E-02	2.7829E-01	.0000E 00
111	1.820	2245.723	1.8510E-02	1.2124E-03	2.5693E 03	.0000E 00	8.5537E 00	5.7553E 01	.0000E 00
112	2.900	2324.176	7.3400E-04	5.8353E-05	3.0705E 04	.0000E 00	4.2607E-01	2.7461E 00	.0000E 00
113	3.500	2343.789	6.0630E-03	5.3294E-04	2.0888E 03	.0000E 00	3.9241E 00	1.8567E 01	.0000E 00
114	4.040	2284.949	9.0700E-04	4.8252E-05	5.5702E 03	.0000E 00	3.4637E-01	1.4763E 00	.0000E 00
115	4.830	2284.949	3.4490E-03	4.0871E-04	2.9224E 03	.0000E 00	2.9338E 00	1.6008E 01	.0000E 00
116	6.040	2304.563	6.7800E-04	6.3461E-05	4.6974E 03	.0000E 00	4.5946E-01	1.5550E 00	.0000E 00
117	8.760	2294.756	2.5700E-04	8.3962E-05	2.1555E 04	.0000E 00	6.0530E-01	2.1[illegible]5E 00	.0000E 00
118	9.480	2363.403	4.6000E-05	2.5553E-05	1.5846E 05	.0000E 00	1.8973E-01	5.9480E-01	.0000E 00
119	10.7[illegible]	2324.176	7.4000E-05	1.2758E-05	7.9238E 03	.0000E 00	9.3151E-02	9.9347E-02	.0000E 00
120	11.730	2343.789	1.3200E-04	2.2836E-05	4.7170E 03	.0000E 00	1.6815E-01	2.2322E-01	.0000E 00
121	13.560	2333.983	1.3000E-04	2.8028E-05	1.0993E 04	.0000E 00	2.0551E-01	6.7431E-01	.0000E 00
122	1.890	2128.043	1.5990E-02	7.9630E-04	2.2751E 03	.0000E 00	5.3236E 00	4.1016E 01	.0000E 00
123	2.540	2059.396	5.7200E-04	5.6113E-05	8.4592E 04	.0000E 00	3.6304E-01	3.5247E 00	.0000E 00
124	2.860	2069.203	5.9200E-04	1.3462E-04	9.2741E 04	.0000E 00	8.7511E-01	5.2478E 00	.0000E 00
125	3.750	1971.137	9.4000E-04	4.0608E-05	4.0403E 03	.0000E 00	2.5147E-01	9.9098E-01	.0000E 00
126	3.980	2069.203	3.9500E-03	2.5873E-04	3.0401E 03	.0000E 00	1.6819E 00	1.4831E 01	.0000E 00
127	4.690	2029.977	1.7500E-03	3.5542E-04	8.5612E 03	.0000E 00	2.2667E 00	1.1384E 01	.0000E 00
128	5.440	2049.590	5.1200E-04	1.6154E-04	1.5416E 04	.0000E 00	1.0401E 00	2.3607E 00	.0000E 00
129	7.550	2079.010	1.2200E-04	2.2875E-05	1.7122E 04	.0000E 00	1.4941E-01	2.8675E-01	.0000E 00
130	10.070	2059.396	1.0900E-04	1.0137E-05	5.5506E 03	.0000E 00	6.5584E-02	1.3200E-01	.0000E 00
131	12.190	2059.396	1.8000E-04	1.7730E-05	4.6680E 03	.0000E 00	1.1471E-01	4.4362E-01	.0000E 00
132	14.210	2029.977	5.3000E-05	1.7665E-05	2.8351E 04	.0000E 00	1.1266E-01	3.1742E-01	.0000E 00
133	1.900	2128.043	1.7070E-02	8.2448E-04	2.1477E 03	.0000E 00	5.5120E 00	4.4593E 01	.0000E 00
134	2.540	2039.783	6.0600E-04	5.9024E-05	6.3371E 04	.0000E 00	3.7824E-01	2.9637E 00	.0000E 00
135	2.860	2010.363	6.6800E-04	1.4222E-04	5.5290E 04	.0000E 00	8.9821E-01	3.9835E 00	.0000E 00
136	3.750	2039.783	1.0570E-03	4.1752E-05	7.2765E 03	.0000E 00	2.6755E-01	2.2567E 00	.0000E 00
137	3.990	2059.396	4.6360E-03	2.8419E-04	2.2849E 03	.0000E 00	1.8386E 00	1.5433E 01	.0000E 00
138	4.710	1941.717	1.7250E-03	3.7588E-04	8.9142E 03	.0000E 00	2.2929E 00	1.1615E 01	.0000E 00
139	5.4[illegible]	1971.137	6.1000E-04	1.9569E-04	1.4504E 04	.0000E 00	1.2118E 00	3.1992E 00	.0000E 00
140	7.580	2029.977	1.4700E-04	2.5343E-05	1.2513E 04	.0000E 00	1.6162E-01	3.0667E-01	.0000E 00
141	10.050	2128.043	1.1900E-04	7.5922E-06	4.8151E 03	.0000E 00	5.0757E-02	1.3594E-01	.0000E 00
142	12.250	2088.816	1.9300E-04	1.7775E-05	5.0897E 03	.0000E 00	1.1665E-01	5.6157E-01	.0000E 00
143	14.280	1990.750	4.8000E-05	1.7683E-05	2.7321E 04	.0000E 00	1.1059E-01	2.5338E-01	.0000E 00
144	2.010	2029.977	1.6408E-02	9.2541E-04	2.6547E 04	.0000E 00	5.9017E 00	5.6996E 02	.0000E 00
145	2.010	1029.698	7.3770E-03	4.7803E-04	3.2019E 04	.0000E 00	1.5464E 00	1.3896E 02	.0000E 00
146	2.860	1853.457	7.8200E-04	1.7384E-04	6.9617E 05	.0000E 00	1.0414E 00	6.8737E 01	.0000E 00
147	3.800	1814.230	6.0600E-04	1.5817E-05	3.0371E 04	.0000E 00	9.0148E-02	3.1791E 00	.0000E 00
148	4.010	1784.810	2.1790E-03	1.8216E-04	2.3271E 04	.0000E 00	1.0214E 00	3.5071E 01	.0000E 00
149	4.050	1784.810	1.9440E-03	1.3997E-04	2.1065E 04	.0000E 00	7.8482E-01	2.5774E 01	.0000E 00
150	4.120	2088.816	5.8380E-03	4.0574E-04	1.5985E 04	.0000E 00	2.6626E 00	1.8254E 02	.0000E 00
151	4.780	1892.683	1.3050E-03	2.5878E-04	8.3582E 04	.0000E 00	1.5387E 00	6.4198E 01	.0000E 00
152	5.410	1990.750	3.7400E-04	4.9331E-05	4.1453E 04	.0000E 00	3.0852E-01	3.3498E 00	.0000E 00
153	5.400	1647.517	7.9100E-04	2.0083E-04	1.0309E 05	.0000E 00	1.0395E 00	3.7126E 01	.0000E 00
154	7.620	2039.783	1.1100E-04	2.1978E-05	1.4147E 05	.0000E 00	1.4084E-01	1.9978E 00	.0000E 00
155	10.290	1686.744	1.2500E-04	1.3025E-05	5.9438E 04	.0000E 00	6.9020E-02	1.9411E 00	.0000E 00
156	12.400	2186.[illegible]83	5.0000E-06	1.3012E-05	1.2131E 07	.0000E 00	8.9400E-02	9.2046E-01	.0000E 00
157	1.910	2118.236	1.1729E-02	5.3836E-04	1.9515E 03	.0000E 00	3.5826E 00	1.9333E 01	.0000E 00

158	4.000	1176.798	2.1390E-03	4.6202E-05	1.3729E 03	.0000E 00	1.7081E-01	1.9839E 00	.00[illegible]E 00
159	4.2[illegible]	1873.070	8.4600E-04	2.3434E-05	1.5495E 03	[illegible]000E 00	1.3790E-01	3.9353E-01	.00[illegible] 00
160	4.7[illegible]	1010.085	7.7000E-05	1.8334E-05	9.3565E 04	[illegible]000E 00	5.8178E-02	2.4499E-01	.0000E 00
161	5.590	2020.170	9.5000E-05	2.8623E-05	8.3925E 04	.0000E 00	1.8166E-01	4.6719E-01	.0000E 00
162	6.520	1990.750	6.7000E-05	1.1881E-04	1.9841E 05	.0000E 00	7.4306E-01	7.4737E-01	.0000E 00
163	7.160	1912.297	1.1000E-04	5.7981E-05	5.7104E 04	.0000E 00	3.4833E-01	6.9921E-01	.0000E 00
164	8.660	1843.650	1.2200E-04	2.2228E-05	9.1986E 03	.0000E 00	1.2875E-01	2.0268E-01	.0000E 00
165	12.060	1068.925	3.7000E-05	8.9503E-06	6.2370E 03	.0000E 00	3.0056E-02	2.4513E-02	.0000E 00
166	1.950	1843.650	7.9680E-03	7.9202E-04	2.2948E 03	.0000E 00	4.5874E 00	1.0935E 01	.0000E 00
167	4.010	1725.970	3.5260E-03	1.1883E-04	1.2749E 03	.0000E 00	6.4431E-01	5.0309E 00	.0000E 00
168	4.250	2069.203	2.1250E-03	1.1071E-04	1.3729E 03	.0000E 00	7.1970E-01	2.2104E 00	.0000E 00
169	7.990	1931.910	2.7500E-04	2.8737E-05	6.9137E 03	.0000E 00	1.7442E-01	6.5887E-01	.0000E 00
170	10.260	1490.611	4.9000E-05	7.4872E-06	6.8450E 03	.0000E 00	3.5062E-02	3.4150E-02	.0000E 00
171	11.380	1127.765	3.4000E-05	4.1412E-06	4.3345E 03	.0000E 00	1.4672E-02	1.2309E-02	.0000E 00
172	13.160	1725.970	9.6000E-05	1.5859E-05	6.2174E 03	.0000E 00	8.5993E-02	1.9588E-01	.0000E 00
173	1.950	1892.683	2.5460E-02	2.1896E-03	2.5890E 03	.0000E 00	1.3019E 01	1.3118E 02	.0000E 00
174	4.210	2079.010	5.6300E-03	1.7509E-04	1.3533E 03	.0000E 00	1.1436E 00	1.5008E 01	.0000E 00
175	8.120	1990.750	2.9500E-04	3.5724E-05	6.2959E 03	.0000E 00	2.2343E-01	7.1308E-01	.0000E 00
176	10.390	1814.230	4.1000E-05	8.8232E-06	1.1454E 04	.0000E 00	5.0288E-02	4.1029E-02	.0000E 00
177	11.430	764.919	4.7000E-05	3.9903E-06	4.3836E 03	.0000E 00	9.5889E-03	2.4972E-02	.0000E 00
178	13.290	2039.783	7.5000E-05	1.5667E-05	9.9145E 03	.0000E 00	1.0040E-01	1.9443E-01	.0000E 00
179	1.930	2118.236	1.2850E-02	9.9073E-04	1.9613E 03	.0000E 00	6.5930E 00	2.3812E 01	.0000E 00
180	4.000	2059.396	3.7900E-03	1.4554E-04	1.3141E 03	.0000E 00	9.4159E-01	5.9615E 00	.0000E 00
181	4.250	2039.783	1.6460E-03	8.5757E-05	1.4906E 03	.0000E 00	5.4954E-01	1.4399E 00	.0000E 00
182	8.010	1824.037	2.4400E-04	2.4327E-05	6.8352E 03	.0000E 00	1.3940E-01	5.1538E-01	.0000E 00
183	10.240	2088.816	7.3000E-05	1.1746E-05	7.5021E 03	.0000E 00	7.7078E-02	8.2748E-02	.0000E 00
184	11.780	1922.103	8.8000E-05	5.9488E-06	2.7361E 03	.0000E 00	3.5922E-02	5.8038E-02	.0000E 00
185	13.210	951.245	5.8000E-05	8.2186E-06	5.4133E 03	.0000E 00	2.4561E-02	6.2726E-02	.0000E 00
186	2.040	1882.877	2.0522E-02	1.5350E-03	2.2163E 03	.0000E 00	9.0801E 00	7.6676E 01	.0000E 00
187	4.070	1098.345	7.3300E-04	6.0766E-05	2.0790E 03	.0000E 00	2.0968E-01	3.6524E-01	.0000E 00
188	4.240	1951.523	5.3650E-03	1.5719E-04	1.1572E 03	.0000E 00	9.6374E-01	1.1820E 01	.0000E 00
189	8.120	2128.043	2.7500E-04	3.3495E-05	6.8941E 03	.0000E 00	2.2393E-01	6.7855E-01	.0000E 00
190	10.400	2108.430	4.9000E-05	1.2750E-05	1.0817E 04	0000E 00	8.4452E-02	5.5448E-02	.0000E 00
191	13.040	2216.303	1.3300E-04	1.7117E-05	9.7282E 03	.0000E 00	1.1918E-01	5.7759E-01	.0000E 00
192	2.050	2020.170	3.0097E-02	2.2212E-03	2.1869E 03	.0000E 00	1.4097E 01	1.6433E 02	.0000E 00
193	4.250	1990.750	5.1700E-03	1.4011E-04	1.1376E 03	.0000E 00	8.7625E-01	1.0995E 01	.0000E 00
194	8.170	2010.363	2.5600E-04	2.2426E-05	5.9624E 03	.0000E 00	1.4163E-01	5.1485E-01	.0000E 00
195	10.360	2000.557	5.0000E-05	1.8600E-06	7.6884E 03	.0000E 00	1.1690E-02	4.0722E-02	.0000E 00
196	13.120	1990.750	1.1200E-04	1.4202E-05	9.2673E 03	.0000E 00	8.8819E-02	3.9499E-01	.0000F 00

TEST NO. 2 SATURN V DTV CONFIG. I PITCH + YAW (1967)

	FREQUENCY [HZ]	FORCE [N]	XN [M]	XE [M]	GENL MASS [KG-SEC2/M]	ZETA	D[=PI*XE*F] [N-M]	T [N-M]	D[=4*PI*ZETA*T] [N-M]
1	1.106	5800.479	6.5937E-02	5.6139E-03	1.0185E 04	7.5000E-03	1.0077E 02	1.0692E 03	1.0077E 02
2	2.547	6347.610	9.1799E-03	2.7867E-04	3.5000E 03	1.0000E-02	4.7461E 00	3.7768E 01	4.7461E 00
3	3.443	21155.734	4.3652E-03	3.9865E-04	4.2875E 04	1.0000E-02	2.4023E 01	1.9117E 02	2.4023E 01
4	1.216	4635.045	6.1968E-02	4.6213E-03	8.2775E 03	6.0000E-03	6.9950E 01	9.2774E 02	6.9950E 01
5	2.000	3958.916	2.5037E-02	1.2436E-03	3.5000E 03	7.0000E-03	1.5239E 01	1.7324E 02	1.5239E 01
6	2.706	7633.146	1.6533E-02	1.0187E-03	5.6875E 03	7.4000E-03	2.0894E 01	2.2469E 02	2.0894E 01
7	3.531	23348.707	5.0616E-03	9.4121E-04	6.1250E 04	1.1000E-02	5.3384E 01	3.8620E 02	5.3384E 01
8	1.257	3407.337	5.2285E-02	4.3594E-03	6.9650E 03	6.0000E-03	4.4947E 01	5.9613E 02	4.4947E 01
9	2.124	3336.165	1.5734E-02	6.4010E-04	2.9925E 03	9.0000E-03	7.4611E 00	6.5971E 01	7.4611E 00
10	2.976	16000.247	9.4430E-03	6.0532E-04	9.1000E 03	1.2000E-02	2.1392E 01	1.4186E 02	2.1392E 01
11	1.560	5386.794	3.9926E-02	2.0643E-03	4.4450E 03	7.0000E-03	2.9942E 01	3.4038E 02	2.9942E 01
12	4.460	21605.005	5.1981E-03	8.1883E-04	1.1900E 04	9.0000E-03	1.4278E 01	1.2625E 02	1.4278E 01
13	1.112	4359.256	5.7880E-02	4.7642E-03	1.1357E 04	6.0000E-03	7.0022E 01	9.2869E 02	7.0022E 01
14	1.810	3340.613	2.0443E-02	8.3138E-04	3.7800E 03	7.5000E-03	9.6278E 00	1.0215E 02	9.6278E 00
15	1.821	4159.086	2.4444E-02	1.0296E-03	3.6400E 03	8.5000E-03	1.5207E 01	1.4237E 02	1.5207E 01
16	2.578	6690.123	9.8936E-03	3.0918E-04	3.5350E 03	9.0000E-03	5.1339E 00	4.5394E 01	5.1339E 00
17	3.450	21702.865	4.3377E-03	3.7675E-04	4.1475E 04	1.2000E-02	2.7649E 01	1.8335E 02	2.7649E 01
18	1.258	3385.095	5.2200E-02	4.3360E-03	6.7200E 03	6.0000E-03	4.3127E 01	5.7200E 02	4.3127E 01
19	2.138	4350.359	1.8867E-02	7.7596E-04	2.8875E 03	8.0000E-03	9.3238E 00	9.2746E 01	9.3238E 00

TEST NO. 3 SATURN V DTV CONFIG. I TORSIONAL (1967)

	FREQUENCY [HZ]	TORQUE [N-M]	XN [RAD]	XE [RAD]	GENL MASS [KG-M2]	ZETA	D[=PI*XE*F] [N-M]	T [N-M]	D[=4*PI*ZETA*T] [N-M]
1	5.660	24756.178	6.0920E-05	5.4780E-06	1.0620E 06	1.0000E-02	3.1320E-01	2.4924E 00	3.1320E-01
2	6.162	25650.979	8.4690E-05	5.9030E-06	3.3894E 05	8.0000E-03	1.8317E-01	1.8220E 00	1.8317E-01
3	8.117	23115.708	3.1920E-05	4.9104E-06	2.8245E 06	1.6000E-02	7.5252E-01	3.7427E 00	7.5252E-01
4	8.839	20580.437	1.4860E-04	8.1972E-06	4.3836E 05	1.0000E-02	1.8759E 00	1.4928E 01	1.8759E 00
5	11.326	27142.315	6.7030E-05	1.9219E-05	3.0505E 05	2.0000E-02	8.7222E-01	3.4705E 00	8.7222E-01
6	5.691	22708.980	6.2710E-05	6.0300E-06	1.0281E 06	9.0000E-03	2.9233E-01	2.5848E 00	2.9233E-01
7	6.194	22708.980	6.4320E-05	6.0300E-06	7.6826E 05	9.0000E-03	2.7222E-01	2.4070E 00	2.7222E-01
8	8.113	21918.120	3.2980E-05	7.7600E-06	3.5024E 06	1.4000E-02	8.7075E-01	4.9494E 00	8.7075E-01
9	8.895	23160.900	1.4430E-04	2.8700E-05	4.5192E 05	1.1000E-02	2.0315E 00	1.4697E 01	2.0315E 00
10	11.428	26889.240	6.6400E-05	1.1900E-05	3.8413E 05	1.8000E-02	9.8930E-01	4.3737E 00	9.8930E-01

TEST NO. 4 SATURN V DTV CONFIG. I LONGITUDINAL (1967)

	FREQUENCY [HZ]	FORCE [N]	XN [M]	XE [M]	GENL MASS [KG-SEC2/M]	ZETA	D[=PI*XE*F] [N-M]	T [N-M]	D[=4*PI*ZETA*T] [N-M]
1	3.752	76509.384	1.8547E-03	9.2751E-04	2.2400E 06	8.0000E-03	2.1526E 02	2.1412E 03	2.1526E 02
2	4.463	78955.905	4.2303E-03	1.3114E-03	3.9200E 05	9.0000E-03	3.1193E 02	2.7581E 03	3.1193E 02
3	6.506	84516.180	4.1736E-04	8.7641E-05	9.5375E 05	1.3000E-02	2.2676E 01	1.3881E 02	2.2676E 01
4	7.568	77843.850	6.8362E-06	1.0937E-04	2.9750E 09	1.4000E-02	2.7654E 01	1.5719E 02	2.7654E 01
5	5.114	78066.261	3.0855E-03	9.8732E-04	2.6250E 05	1.7000E-02	2.7560E 02	1.2901E 03	2.7560E 02
6	6.492	69837.054	1.8720E-03	2.2467E-04	2.9750E 05	6.0000E-03	6.5393E 01	8.6731E 02	6.5393E 01
7	8.276	68280.177	8.9686E-05	3.6771E-04	4.3750E 07	1.3000E-02	7.7723E 01	4.7577E 02	7.7723E 01
8	9.376	69837.054	9.1699E-05	7.0627E-05	7.0000E 06	1.0000E-02	1.2835E 01	1.0214E 02	1.2835E 01
9	6.176	56714.805	3.0540E-03	5.4969E-04	1.1637E 05	9.0000E-03	9.2426E 01	8.1722E 02	9.2426E 01
10	7.976	53378.640	3.9589E-04	2.4544E-03	1.0675E 07	1.4000E-02	3.6962E 02	2.1010E 03	3.6962E 02
11	9.406	64054.368	1.6241E-03	3.2482E-04	6.8250E 04	1.0000E-02	3.9508E 01	3.1439E 02	3.9508E 01

TEST NO. 5 SATURN V DTV CONFIG. II PITCH + YAW FREQ. SWEEP (1967)

	FREQUENCY [HZ]	FORCE [N]	XN [M]	XE [M]	GENL MASS [KG-SEC2/M]	ZETA	D[=PI*XE*F] [N-M]	T [N-M]	D[=4*PI*ZETA*T] [N-M]
1	1.667	6325.369	4.9193E-02	1.4745E-03	3.3425E 03	5.2000E-03	2.8993E 01	4.4368E 02	2.8993E 01
2	2.701	6707.916	9.6019E-03	1.9204E-04	3.7450E 03	7.4000E-03	4.6236E 00	4.9721E 01	4.6236E 00
3	5.979	9194.471	7.0235E-04	1.2639E-04	1.4385E 05	6.3000E-03	3.9642E 00	5.0073E 01	3.9642E 00
4	2.224	3927.778	6.2084E-03	8.1153E-04	3.5875E 04	6.3000E-03	1.0688E 01	1.3501E 02	1.0688E 01
5	5.953	9425.778	4.0995E-04	1.1066E-04	4.2350E 05	6.3000E-03	3.9415E 00	4.9787E 01	3.9415E 00
6	8.555	8660.684	2.1146E-05	8.8551E-04	2.8000E 08	1.0300E-02	2.3413E 01	1.8088E 02	2.3413E 01
7	2.229	4870.801	7.6645E-03	9.1974E-04	3.9025E 04	6.3000E-03	1.7800E 01	2.2483E 02	1.7800E 01
8	5.897	17321.369	7.1487E-04	7.1487E-05	3.2900E 05	7.3000E-03	1.0587E 01	1.1541E 02	1.0587E 01
9	8.690	5791.582	1.0536E-05	5.3536E-04	4.7775E 08	9.5000E-03	9.4371E 00	7.9051E 01	9.4371E 00
10	2.264	2993.652	8.6757E-03	2.1686E-03	3.5175E 04	5.8000E-03	1.9524E 01	2.6787E 02	1.9524E 01
11	5.916	14950.467	4.2223E-04	1.0558E-04	5.7400E 05	9.0000E-03	7.9955E 00	7.0695E 01	7.9955E 00
12	1.661	5489.103	3.4210E-02	6.8430E-04	3.8150E 03	6.0000E-03	1.8332E 01	2.4314E 02	1.8332E 01
13	2.701	12704.116	1.4509E-02	4.3517E-04	4.3575E 03	9.3000E-03	1.5438E 01	1.3210E 02	1.5438E 01
14	5.732	7241.702	2.3669E-04	1.0175E-04	5.5125E 05	9.6000E-03	2.4162E 00	2.0029E 01	2.4162E 00
15	6.303	8416.032	2.2004E-04	1.2895E-04	7.7875E 05	9.0000E-03	3.3441E 00	2.9568E 01	3.3441E 00

TEST NO. 5 SATURN V DTV CONFIG. II PITCH + YAW FORCE LEVEL (1967)

	FREQUENCY [HZ]	FORCE [N]	XN [M]	XE [M]	GENL MASS [KG-SEC2/M]	ZETA	D[=PI*XE*F] [N-M]	T [N-M]	D[=4*PI*ZETA*T] [N-M]
1	1.665	7210.565	5.5195E-02	1.5978E-03	3.3425E 03	.0000E 00	3.6193E 01	5.5722E 02	.0000E 00
2	1.671	5689.273	4.7334E-02	1.3995E-03	3.3425E 03	.0000E 00	2.5014E 01	4.1276E 02	.0000E 00
3	1.676	3829.917	3.7385E-02	1.1193E-03	3.3425E 03	.0000E 00	1.3467E 01	2.5903E 02	.0000E 00
4	2.710	6965.913	9.8521E-03	2.5743E-04	3.7450E 03	.0000E 00	5.6335E 00	5.2696E 01	.0000E 00
5	2.720	5564.723	7.9806E-03	2.1002E-04	3.7450E 03	.0000E 00	3.6715E 00	3.4833E 01	.0000E 00
6	2.722	3696.471	5.9621E-03	1.6159E-04	3.7450E 03	.0000E 00	1.8765E 00	1.9470E 01	.0000E 00
7	2.224	3491.853	5.2434E-03	7.0963E-04	3.5875E 04	.0000E 00	7.7847E 00	9.6298E 01	.0000E 00
8	2.223	2388.694	3.6171E-03	4.9668E-04	3.5875E 04	.0000E 00	3.7272E 00	4.5785E 01	.0000E 00
9	2.225	1797.081	2.7366E-03	3.7097E-04	3.5875E 04	.0000E 00	2.0944E 00	2.6235E 01	.0000E 00
10	5.955	5395.691	2.5661E-04	7.0439E-05	4.2350E 05	.0000E 00	1.1940E 00	1.9520E 01	.0000E 00
11	5.956	3647.540	6.9479E-05	4.9611E-05	4.2350E 05	.0000E 00	5.6850E-01	1.4315E 00	.0000E 00
12	5.954	2771.241	4.7147E-05	3.5753E-05	4.2350E 05	.0000E 00	3.1127E-01	6.5874E-01	.0000E 00
13	8.765	9999.599	1.4247E-05	4.4848E-04	2.8000E 08	.0000E 00	1.4089E 01	8.6181E 01	.0000E 00
14	8.766	7139.393	1.5306E-05	4.1248E-04	2.8000E 08	.0000E 00	9.2515E 00	9.9495E 01	.0000E 00
15	8.764	5422.380	9.1464E-06	3.5994E-04	2.8000E 08	.0000E 00	6.1316E 00	3.5513E 01	.0000E 00
16	2.222	5449.069	8.6902E-03	1.3128E-03	3.9025E 04	.0000E 00	2.2473E 01	2.8722E 02	.0000E 00
17	2.223	3629.748	5.6194E-03	8.4087E-04	3.9025E 04	.0000E 00	9.5885E 00	1.2021E 02	.0000E 00
18	2.224	2620.002	4.2596E-03	6.3598E-04	3.9025E 04	.0000E 00	5.2348E 00	6.9132E 01	.0000E 00
19	5.876	17023.338	7.2412E-04	1.5143E-04	3.2900E 05	.0000E 00	8.0987E 00	1.1757E 02	.0000E 00
20	5.883	12566.221	5.7989E-04	1.1578E-04	3.2900E 05	.0000E 00	4.5706E 00	7.5582E 01	.0000E 00
21	5.898	8656.236	4.1411E-04	8.6573E-05	3.2900E 05	.0000E 00	2.3543E 00	3.8740E 01	.0000E 00
22	8.620	10408.835	1.8227E-05	1.2829E-03	4.7775E 08	.0000E 00	4.1953E 01	2.3280E 02	.0000E 00
23	8.621	7170.531	1.3954E-05	7.7584E-04	4.7775E 08	.0000E 00	1.7477E 01	1.3648E 02	.0000E 00
24	2.268	3629.748	9.4575E-03	2.3526E-03	3.5175E 04	.0000E 00	2.6827E 01	3.1945E 02	.0000E 00
25	2.270	1712.565	4.4172E-03	1.0783E-03	3.5175E 04	.0000E 00	5.8015E 00	6.9809E 01	.0000E 00
26	5.945	14790.331	4.7674E-04	8.9038E-05	5.7400E 05	.0000E 00	4.1372E 00	9.1013E 01	.0000E 00
27	5.946	11285.134	3.4224E-04	6.1675E-05	5.7400E 05	.0000E 00	2.1866E 00	4.6920E 01	.0000E 00
28	5.943	7788.833	2.5369E-04	3.2019E-05	5.7400E 05	.0000E 00	7.8349E-01	2.5755E 01	.0000E 00
29	1.658	5217.762	3.9325E-02	1.1660E-03	3.8150E 03	.0000E 00	1.9112E 01	3.2013E 02	.0000E 00
30	1.658	4328.118	3.5609E-02	1.0375E-03	3.8150E 03	.0000E 00	1.4107E 01	2.6249E 02	.0000E 00
31	1.658	3487.404	2.9046E-02	8.1472E-04	3.8150E 03	.0000E 00	8.9260E 00	1.7465E 02	.0000E 00
32	2.701	12761.943	1.4946E-02	4.2983E-04	4.3575E 03	.0000E 00	1.7233E 01	1.4018E 02	.0000E 00
33	2.701	9305.676	1.2181E-02	3.4832E-04	4.3575E 03	.0000E 00	1.0183E 01	9.3101E 01	.0000E 00
34	2.701	6338.713	6.9870E-03	1.9214E-04	4.3575E 03	.0000E 00	3.8262E 00	3.0633E 01	.0000E 00
35	5.750	6752.398	2.4065E-04	8.8047E-05	5.5125E 05	.0000E 00	1.8678E 00	2.0834E 01	.0000E 00
36	5.750	5137.694	1.3277E-04	7.0550E-05	5.5125E 05	.0000E 00	1.1387E 00	6.3418E 00	.0000E 00
37	5.750	2219.662	1.1735E-04	2.9543E-05	5.5125E 05	.0000E 00	2.0601E-01	4.9540E 00	.0000E 00
38	6.290	7993.451	2.4370E-04	1.1734E-04	7.7875E 05	.0000E 00	2.9466E 00	3.6120E 01	.0000E 00
39	6.290	6467.712	1.8075E-04	9.6768E-05	7.7875E 05	.0000E 00	1.9662E 00	1.9870E 01	.0000E 00
40	6.290	4412.634	3.9924E-04	6.6643E-05	7.7875E 05	.0000E 00	9.2385E-01	9.6937E 01	.0000E 00

TEST NO. 6 SATURN V DTV CONFIG. II TORSIONAL FREQ. SWEEP (1967)

	FREQUENCY [HZ]	TORQUE [N-M]	XN [RAD]	XE [RAD]	GENL MASS [KG-M2]	ZETA	D[=PI*XE*F] [N-M]	T [N-M]	D[=4*PI*ZETA*T] [N-M]
1	5.605	17715.264	5.1400E-05	6.5856E-06	1.5252E 06	5.1000E-03	3.6652E-01	2.4989E 00	1.6015E-01
2	6.290	6134.814	3.3200E-05	3.6381E-06	1.1637E 06	4.6000E-03	7.0117E-02	1.0017E 00	5.7905E-02
3	9.736	9885.750	1.1400E-04	1.2862E-05	2.2596E 05	6.0000E-03	3.9947E-01	5.4945E 00	4.1428E-01
4	5.530	17398.920	3.4600E-05	8.0234E-06	1.6269E 06	6.5000E-03	4.3856E-01	1.1757E 00	9.6033E-02
5	6.255	6281.688	3.3400E-05	3.5584E-06	7.9086E 05	6.3000E-03	7.0223E-02	6.8136E-01	5.3942E-02
6	9.644	9648.492	9.3300E-05	1.1017E-05	2.1353E 05	8.0000E-03	3.3393E-01	3.4125E 00	3.4306E-01

TEST NO. 6 SATURN V DTV CONFIG. II TORSIONAL FORCE LEVEL (1967)

	FREQU[illegible]Y [HZ]	TORQUE [N-M]	XN [RAD]	XE [RAD]	GENL MASS [KG-M2]	ZETA	D[=PI*XE*F] [N-M]	T [N-M]	D[=4*PI*Z[illegible]A*T] [N-M]
1	5.605	17686.703	1.0200E-04	7.2276E-06	1.5252E 06	.0000E 00	4.0159E-01	9.8407E 00	.0000E 00
2	5.611	13649.521	8.5837E-05	5.3921E-06	1.5252E 06	.0000E 00	2.3122E-01	6.9838E 00	.0000E 00
3	5.620	8362.734	6.5058E-05	3.2544E-06	1.5252E 06	.0000E 00	8.5500E-02	4.0248E 00	.0000E 00
4	6.268	5983.681	1.1181E-04	4.0727E-06	1.1637E 06	.0000E 00	7.6560E-02	1.1282E 01	.0000E 00
5	6.275	4854.231	9.5650E-05	3.4714E-06	1.1637E 06	.0000E 00	5.2939E-02	8.2750E 00	.0000E 00
6	6.284	3532.534	7.4656E-05	2.6367E-06	1.1637E 06	.0000E 00	2.9261E-02	5.0556E 00	.0000E 00
7	9.735	10573.572	2.5003E-05	1.0147E-05	2.2596E 05	.0000E 00	3.3708E-01	2.6424E-01	.0000E 00
8	9.745	7665.840	1.5619E-05	7.5641E-06	2.2596E 05	.0000E 00	1.8217E-01	1.0334E-01	.0000E 00
9	9.775	5118.570	7.6360E-06	5.2124E-06	2.2596E 05	.0000E 00	8.3818E-02	2.4850E-02	.0000E 00
10	5.510	17566.548	3.8043E-05	1.5353E-05	1.6269E 06	.0000E 00	8.4730E-01	1.4110E 00	.0000E 00
11	5.517	13048.749	2.6646E-05	1.0072E-05	1.6269E 06	.0000E 00	4.1288E-01	6.9403E-01	.0000E 00
12	5.540	8482.889	2.1883E-05	7.2488E-06	1.6269E 06	.0000E 00	1.9318E-01	4.7198E-01	.0000E 00
13	6.239	10044.894	2.0609E-04	9.2344E-06	7.9086E 05	.0000E 00	2.9141E-01	2.5808E 01	.0000E 00
14	6.237	7689.871	1.7417E-04	6.3954E-06	7.9086E 05	.0000E 00	1.5450E-01	1.8421E 01	.0000E 00
15	6.241	5334.848	1.2104E-04	3.2487E-06	7.9086E 05	.0000E 00	5.4448E-02	8.9079E 00	.0000E 00
16	9.635	11919.300	1.7264E-04	2.6250E-05	2.1353E 05	.0000E 00	9.8295E-01	1.1662E 01	.0000E 00
17	9.636	9780.554	1.5048E-04	2.2343E-05	2.1353E 05	.0000E 00	6.8652E-01	8.8625E 00	.0000E 00
18	9.641	6079.804	9.4275E-05	1.3485E-05	2.1353E 05	.0000E 00	2.5756E-01	3.4820E 00	.0000E 00

TEST NO. 7 SATURN V DTV CONFIG. II LONGITUDINAL FREQ. SWEEP (1967)

	FREQU[illegible]Y [HZ]	FORCE [N]	XN [M]	XE [M]	GENL MASS [KG-SEC2/M]	ZETA	D[=PI*XE*F] [N-M]	T [N-M]	D[=4*PI*[illegible]A*T] [N-M]
1	6.213	5529.137	5.8560E-04	5.2705E-05	7.6825E 04	3.8000E-03	9.5858E-01	2.0074E 01	9.5858E-01
2	9.205	21769.589	8.4435E-04	1.3510E-04	9.5900E 04	6.5000E-03	9.3404E 00	1.1435E 02	9.3404E 00
3	9.846	17299.128	5.3811E-05	1.6143E-04	1.1847E 07	1.2000E-02	9.8995E 00	6.5648E 01	9.8995E 00
4	11.217	16867.650	3.2970E-04	6.5941E-05	1.3177E 05	7.6000E-03	3.3977E 00	3.5576E 01	3.3977E 00
5	6.346	5511.345	6.8469E-04	8.2156E-05	1.1900E 05	2.8000E-03	1.5604E 00	4.4347E 01	1.5604E 00
6	9.435	21231.354	3.0420E-04	1.3692E-04	6.2300E 04	7.2000E-03	9.1659E-01	1.0131E 01	9.1659E-01
7	10.100	8344.861	7.5514E-05	1.1329E-04	2.5375E 06	8.0000E-03	2.9290E 00	2.9136E 01	2.9290E 00
8	11.410	20773.187	2.4807E-04	7.4421E-05	3.8500E 05	7.6000E-03	5.8148E 00	6.0886E 01	5.8148E 00
9	6.425	11632.095	1.2576E-03	2.2644E-04	1.3405E 05	3.4000E-03	7.3810E 00	1.7[illegible]75E 02	7.3810E 00
10	9.965	5564.723	1.1757E-04	2.3514E-04	3.5000E 06	4.0000E-03	4.7669E 00	9.4834E 01	4.7669E 00
11	11.4[illegible]	21929.725	2.4296E-04	9.7147E-05	4.4625E 05	9.0000E-03	7.6950E 00	6.8039E 01	7.6950E 00
12	6.693	6218.612	8.3724E-04	2.0094E-04	1.3142E 05	3.7000E-03	3.7876E 00	8.1461E 01	3.7876E 00
13	10.227	5675.929	1.2113E-04	1.9380E-04	1.0920E 06	5.4000E-03	2.2447E 00	3.3079E 01	2.2447E 00
14	11.535	5920.581	1.3441E-04	4.0330E-05	2.1000E 05	6.2000E-03	7.7630E-01	9.9638E 00	7.7630E-01
15	7.265	12406.086	1.7458E-03	7.3323E-04	1.4385E 05	4.7000E-03	2.6977E 01	4.5676E 02	2.6977E 01
16	10.793	8371.550	1.8124E-04	1.8124E-04	5.4075E 05	1.0000E-02	5.1324E 00	4.0842E 01	5.1324E 00
17	11.776	5164.383	1.7734E-04	1.7734E-04	5.8975E 05	4.9000E-03	3.1260E 00	5.0767E 01	3.1260E 00
18	4.858	3251.649	4.1564E-05	2.1051E-03	3.8150E 08	5.7000E-03	2.1992E 01	3.0703E 02	2.1992E 01
19	8.628	5440.173	1.0843E-03	7.2642E-04	1.0675E 05	6.2000E-03	1.4369E 01	1.8443E 02	1.4369E 01
20	9.502	17583.814	6.2731E-04	1.8815E-04	1.7675E 05	6.7000E-03	1.0437E 01	1.2396E 02	1.0437E 01
21	11.576	16987.752	3.3924E-04	2.2052E-04	2.3800E 05	1.5000E-02	1.3657E 01	7.2451E 01	1.3657E 01

TEST NO. 7 SATURN V DTV CONFIG. II LONGITUDINAL FORCE LEVEL (1967)

	FREQUENCY [HZ]	FORCE [N]	XN [M]	XE [M]	GENL MASS [KG-SEC2/M]	ZETA	D[=PI*XE*F] [N-M]	T [N-M]	D[=4*PI*ZETA*T] [N-M]
1	6.220	5675.929	6.1290E-04	6.3240E-05	7.6825E 04	.0000E 00	1.1277E 00	2.2039E 01	.0000E 00
2	6.225	4150.189	4.6884E-04	4.7058E-05	7.6825E 04	.0000E 00	6.1354E-01	1.2917E 01	.0000E 00
3	6.230	2802.379	3.1793E-04	3.1756E-05	7.6825E 04	.0000E 00	2.7958E-01	5.9493E 00	.0000E 00
4	9.180	21636.142	7.1529E-04	1.5542E-04	9.5900E 04	.0000E 00	1.0564E 01	8.1621E 01	.0000E 00
5	9.182	16026.937	5.0149E-04	1.1072E-04	9.5900E 04	.0000E 00	5.5749E 00	4.0137E 01	.0000E 00
6	9.184	10617.901	3.7230E-04	7.3955E-05	9.5900E 04	.0000E 00	2.4669E 00	2.2131E 01	.0000E 00
7	11.200	21934.173	3.6969E-04	9.8917E-05	1.3177E 05	.0000E 00	6.8162E 00	4.4594E 01	.0000E 00
8	11.190	16089.212	3.0202E-04	7.2544E-05	1.3177E 05	.0000E 00	3.6668E 00	2.9708E 01	.0000E 00
9	11.195	10795.830	2.1632E-04	4.5786E-04	1.3177E 05	.0000E 00	1.5529E 01	1.5[illegible]55E 01	.0000E 00
10	6.343	5876.099	7.2588E-04	9.6403E-05	1.1900E 05	.0000E 00	1.7796E 00	4.9796E 01	.0000E 00
11	6.345	4052.328	5.0061E-04	6.5598E-05	1.1900E 05	.0000E 00	8.3511E-01	2.3699E 01	.0000E 00
12	6.346	2771.241	3.4824E-04	4.5422E-05	1.1900E 05	.0000E 00	3.9545E-01	1.1472E 01	.0000E 00
13	9.410	21177.975	2.7714E-04	1.4077E-04	6.2300E 04	.0000E 00	9.3660E 00	8.3636E 00	.0000E 00
14	9.411	15920.179	1.2979E-04	9.4298E-05	6.2300E 04	.0000E 00	4.7163E 00	1.8348E 00	.0000E 00
15	9.412	11076.068	7.0591E-05	6.1563E-05	6.2300E 04	.0000E 00	2.1422E 00	5.4285E-01	.0000E 00
16	10.067	8456.066	7.3528E-05	1.3126E-04	2.5375E 06	.0000E 00	3.4870E 00	2.7443E 01	.0000E 00
17	10.068	6276.438	6.5457E-05	1.0488E-04	2.5375E 06	.0000E 00	2.0679E 00	2.1753E 01	.0000E 00
18	10.080	4225.809	4.5684E-05	6.1733E-05	2.5375E 06	.0000E 00	8.1956E-01	1.0622E 01	.0000E 00
19	11.535	21435.972	2.4795E-04	7.5914E-05	3.8500E 05	.0000E 00	5.1123E 00	6.2166E 01	.0000E 00
20	11.437	15720.009	1.4805E-04	5.6173E-05	3.8500E 05	.0000E 00	2.7742E 00	2.1789E 01	.0000E 00
21	6.419	10809.175	1.1904E-03	1.9484E-04	1.3405E 05	.0000E 00	6.6165E 00	1.5451E 02	.0000E 00
22	6.420	8042.382	9.1444E-04	1.5059E-04	1.3405E 05	.0000E 00	3.8048E 00	9.1196E 01	.0000E 00
23	6.421	5333.416	6.2328E-04	1.0259E-04	1.3405E 05	.0000E 00	1.7188E 00	4.2381E 01	.0000E 00
24	9.955	6094.061	1.2826E-04	2.8379E-04	3.5000E 06	.0000E 00	5.4331E 00	1.1263E 02	.0000E 00
25	9.960	4377.048	9.7968E-05	2.0126E-04	3.5000E 06	.0000E 00	2.7675E 00	6.5779E 01	.0000E 00
26	9.961	2966.963	6.2253E-05	1.2759E-04	3.5000E 06	.0000E 00	1.1893E 00	2.6565E 01	.0000E 00
27	11.530	15728.906	1.3677E-04	6.5437E-05	4.4625E 05	.0000E 00	3.2335E 00	2.1905E 01	.0000E 00
28	11.525	10684.624	1.3467E-04	4.3753E-05	4.4625E 05	0000E 00	1.4687E 00	2.1221E 01	.0000E 00
29	6.705	6458.815	8.6407E-04	2.0089E-04	1.3142E 05	.0000E 00	4.0763E 00	8.7076E 01	.0000E 00
30	6.707	4910.835	6.5780E-04	1.5314E-04	1.3142E 05	.0000E 00	2.3626E 00	5.0496E 01	.0000E 00
31	6.709	3180.477	4.4984E-04	1.0571E-04	1.3142E 05	.0000E 00	1.0562E 00	2.3629E 01	.0000E 00
32	10.299	5925.029	2.1334E-04	2.8961E-04	1.0920E 06	.0000E 00	5.3908E 00	1.0406E 02	.0000E 00
33	10.310	2851.309	9.8926E-05	1.3125E-04	1.0920E 06	.0000E 00	1.1757E 00	2.2423E 01	.0000E 00
34	10.320	2139.594	8.0809E-05	1.0485E-04	1.0920E 06	.0000E 00	7.0478E-01	1.4991E 01	.0000E 00
35	7.269	12205.916	1.7531E-03	7.3557E-04	1.4385E 05	.0000E 00	2.8206E 01	4.6113E 02	.0000E 00
36	7.272	10297.629	1.5213E-03	6.3996E-04	1.4385E 05	.0000E 00	2.0703E 01	3.4753E 02	.0000E 00
37	7.275	6360.955	9.9467E-04	4.1190E-04	1.4385E 05	.0000E 00	8.2311E 00	1.4868E 02	.0000E 00
38	10.793	9012.094	2.0643E-04	1.8945E-04	5.4075E 05	.0000E 00	5.3637E 00	5.2983E 01	.0000E 00
39	10.795	6734.605	1.2580E-04	1.3632E-04	5.4075E 05	.0000E 00	2.8842E 00	1.9685E 01	.0000E 00
40	10.798	4621.701	6.2223E-05	8.5687E-05	5.4075E 05	.0000E 00	1.2441E 00	4.8185E 00	.0000E 00
41	11.782	6196.370	1.8302E-04	1.9675E-04	5.8975E 05	.0000E 00	3.8300E 00	5.4127E 01	.0000E 00
42	11.790	4746.251	1.4892E-04	1.5468E-04	5.8975E 05	.0000E 00	2.3064E 00	3.5886E 01	.0000E 00
43	11.793	3180.477	1.0441E-04	1.0505E-04	5.8975E 05	.0000E 00	1.0497E 00	1.7651E 01	.0000E 00
44	8.613	5506.896	1.1102E-03	7.3416E-04	1.0675E 05	.0000E 00	1.2701E 01	1.9265E 02	.0000E 00
45	8.611	4701.769	9.5891E-04	6.3668E-04	1.0675E 05	.0000E 00	9.4044E 00	1.4367E 02	.0000E 00
46	8.609	3874.400	7.7594E-04	5.1467E-04	1.0675E 05	.0000E 00	6.2644E 00	9.4029E 01	.0000E 00
47	9.577	17730.605	3.8594E-04	2.6740E-04	1.7675E 05	.0000E 00	1.4895E 01	4.7663E 01	.0000E 00
48	9.575	13157.135	2.7202E-04	1.9940E-04	1.7675E 05	.0000E 00	8.2426E 00	2.3668E 01	.0000E 00
49	9.573	8451.618	2.1167E-04	1.2855E-04	1.7675E 05	.0000E 00	3.4131E 00	1.4325E 01	.0000E 00

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50	11·630	21569·419	3·3093E-04	2·7277E-04	2·3800E 05	·0000E 00	1·8484E 01	6·9587E 01	·0000E 00
51	11·6[illegible]	16240·451	2·7186E-04	1·9475E-04	2·3800E 05	[illegible]0000E 00	9·9365E 00	4·6924E 01	·00[illegible] 00
52	11·[illegible]	10933·725	2·3326E-04	1·2788E-04	2·3800E 05	[illegible]000E 00	4·3927E 00	3·4525E 01	·00[illegible] 00

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TEST NO. 8 SATURN V DTV CONFIG. II C9 MSFC 201 PITCH + YAW FREQ. SWEEP (1967)

	FREQUENCY [HZ]	FORCE [N]	XN [M]	XE [M]	GENL MASS [KG-SEC2/M]	ZETA	D[=PI*XE*F] [N-M]	T [N-M]	D[=4*PI*ZETA*T] [N-M]
1	1.660	4830.767	2.8126E-02	9.0948E-04	5.4950E 03	4.5000E-03	1.3371E 01	2.3645E 02	1.3371E 01
2	2.706	8491.652	7.6353E-03	2.4285E-04	4.4100E 03	1.4000E-02	6.5375E 00	3.7160E 01	6.5375E 00
3	5.988	10742.451	9.2839E-04	1.5225E-04	1.1375E 05	5.8000E-03	5.0576E 00	6.9391E 01	5.0576E 00
4	8.490	7268.391	2.7593E-05	4.5500E-04	5.8275E 07	1.3000E-02	1.0313E 01	6.3127E 01	1.0313E 01
5	2.215	4554.977	6.5326E-03	9.8507E-04	3.9375E 04	6.8000E-03	1.3905E 01	1.6273E 02	1.3905E 01
6	5.900	16876.547	8.3497E-04	1.6515E-04	2.3625E 05	6.1000E-03	8.6753E 00	1.1317E 02	8.6753E 00
7	8.515	5702.618	6.8518E-06	3.6648E-04	3.9900E 08	1.3000E-02	4.3796E 00	2.6809E 01	4.3796E 00
8	2.255	2909.136	9.2810E-03	2.3546E-03	3.9550E 04	5.0000E-03	2.1485E 01	3.4194E 02	2.1485E 01
9	5.903	136[illegible]7.139	6.2726E-04	4.1555E-05	8.4000E 04	6.3000E-03	1.7997E 00	2.2733E 01	1.7997E 00
10	1.625	5293.382	2.7471E-02	8.2167E-04	6.1950E 03	4.5000E-03	1.3780E 01	2.4369E 02	1.3780E 01
11	2.6[illegible]2	12512.843	1.0211E-02	3.3536E-04	5.2150E 03	1.4000E-02	1.3180E 01	7.4917E 01	1.31[illegible]0E 01
12	5.922	6934.775	6.9414E-04	9.6402E-05	1.2250E 05	4.1000E-03	2.1052E 00	4.0859E 01	2.1052E 00
13	2.255	1565.773	5.6659E-03	1.4169E-03	3.7800E 04	4.6000E-03	7.0407E 00	1.2180E 02	7.04[illegible]7E 00
14	5.800	14670.230	4.9486E-04	4.9437E-05	1.1987E 05	8.0000E-03	1.9596E 00	1.9493E 01	1.95[illegible]6E 00

TEST NO. 8 SATURN V DTV CONFIG. II CO MSFC 201 PITCH + YAW FORCE LEVEL (1967)

	FREQUENCY [HZ]	FORCE [N]	XN [M]	XE [M]	GENL MASS [KG-SEC2/M]	ZETA	D[=PI*XE*F] [N-M]	T [N-M]	D[=4*PI*ZETA*T] [N-M]
1	1.656	4995.351	2.8442E-02	9.6668E-04	5.4950E 03	.0000E 00	1.5170E 01	2.4062E 02	.0000E 00
2	1.660	3144.892	1.9980E-02	6.8003E-04	5.4950E 03	.0000E 00	6.7187E 00	1.1932E 02	.0000E 00
3	1.661	2402.039	1.5524E-02	5.3190E-04	5.4950E 03	.0000E 00	4.0139E 00	7.2122E 01	.0000E 00
4	2.686	8776.338	6.2545E-03	2.0638E-04	4.4100E 03	.0000E 00	5.6902E 00	2.4568E 01	.0000E 00
5	2.687	6636.744	4.6564E-03	1.5657E-04	4.4100E 03	.0000E 00	3.2644E 00	1.3627E 01	.0000E 00
6	2.688	4292.532	3.3342E-03	1.1001E-04	4.4100E 03	.0000E 00	1.4836E 00	6.9923E 00	.0000E 00
7	5.986	10600.108	8.5128E-04	1.5008E-04	1.1375E 05	.0000E 00	4.9980E 00	5.8304E 01	.0000E 00
8	5.995	7779.937	6.1869E-04	1.1028E-04	1.1375E 05	.0000E 00	2.6955E 00	3.0889E 01	.0000E 00
9	6.007	5266.692	4.0306E-04	7.8337E-05	1.1375E 05	.0000E 00	1.2961E 00	1.3162E 01	.0000E 00
10	2.219	4652.838	6.5697E-03	9.9944E-04	3.9375E 04	.0000E 00	1.4609E 01	1.6518E 02	.0000E 00
11	2.22[illegible]	3447.370	4.8789E-03	7.3867E-04	3.9375E 04	.0000E 00	7.9999E 00	9.1179E 01	.0000E 00
12	2.222	2250.799	3.4750E-03	5.2851E-04	3.9375E 04	.0000E 00	3.7371E 00	4.6339E 01	.0000E 00
13	5.911	16062.522	8.4103E-04	1.5262E-04	2.3625E 05	.0000E 00	7.7016E 00	1.1525E 02	.0000E 00
14	5.908	12005.746	6.9514E-04	1.2143E-04	2.3625E 05	.0000E 00	4.5801E 00	7.8655E 01	.0000E 00
15	5.920	7882.246	4.8996E-04	8.0182E-05	2.3625E 05	.0000E 00	1.9855E 00	3.9234E 01	.0000E 00
16	2.255	2975.859	9.4579E-03	2.4001E-03	3.9550E 04	.0000E 00	2.2438E 01	3.5510E 02	.0000E 00
17	2.256	2224.110	7.2967E-03	1.8544E-03	3.9550E 04	.0000E 00	1.2957E 01	2.1155E 02	.0000E 00
18	2.257	1485.705	5.0230E-03	1.2631E-03	3.9550E 04	.0000E 00	5.8953E 00	1.0034E 02	.0000E 00
19	5.916	12864.252	6.5580E-04	4.4233E-05	8.4000E 04	.0000E 00	1.7877E 00	2.4958E 01	.0000E 00
20	5.917	9639.293	4.9831E-04	3.2441E-05	8.4000E 04	.0000E 00	9.8241E-01	1.4415E 01	.0000E 00
21	5.935	6481.057	3.3486E-04	2.3006E-05	8.4000E 04	.0000E 00	4.6841E-01	6.5490E 00	.0000E 00
22	1.626	6378.747	3.0975E-02	8.8990E-04	6.1950E 03	.0000E 00	1.7833E 01	3.1019E 02	.0000E 00
23	1.622	4621.701	2.7596E-02	7.4175E-04	6.1950E 03	.0000E 00	1.0770E 01	2.4500E 02	.0000E 00
24	1.624	3233.856	2.0467E-02	5.6491E-04	6.1950E 03	.0000E 00	5.7392E 00	1.3510E 02	.0000E 00
25	2.688	12570.670	1.0056E-02	2.9924E-04	5.2150E 03	.0000E 00	1.1818E 01	7.5210E 01	.0000E 00
26	2.695	8843.061	9.2538E-03	2.8006E-04	5.2150E 03	.0000E 00	7.7804E 00	6.4023E 01	.0000E 00
27	2.700	6494.401	7.1539E-03	2.2278E-04	5.2150E 03	.0000E 00	4.5453E 00	3.8406E 01	.0000E 00
28	5.922	6779.087	6.6128E-04	9.3428E-05	1.2250E 05	.0000E 00	1.9897E 00	3.7083E 01	.0000E 00
29	5.930	5546.930	5.4395E-04	7.7033E-05	1.2250E 05	.0000E 00	1.3424E 00	2.5159E 01	.0000E 00
30	5.945	4301.429	3.9522E-04	6.0455E-05	1.2250E 05	.0000E 00	8.1694E-01	1.3349E 01	.0000E 00
31	2.25[illegible]	1957.217	6.8452E-03	1.7107E-03	3.7800E 04	.0000E 00	1.0519E 01	1.7841E 02	.0000E 00
32	2.261	1570.222	5.3688E-03	1.3486E-03	3.7800E 04	.0000E 00	6.6524E 00	1.0995E 02	.0000E 00
33	5.795	14710.264	5.3033E-04	4.3738E-05	1.1987E 05	.0000E 00	2.0213E 00	2.2349E 01	.0000E 00
34	5.813	11280.686	4.4202E-04	3.5496E-05	1.1987E 05	.0000E 00	1.2579E 00	1.5622E 01	.0000E 00
35	5.817	10044.081	3.9916E-04	3.2307E-05	1.1987E 05	.0000E 00	1.0194E 00	1.2757E 01	.0000E 00

TEST NO. 9 SATURN V DTV CONFIG. II CO MSFC 201 TORSIONAL FREQ. SWEEP (1967)

	FREQUENCY [HZ]	TORQUE [N-M]	XN [RAD]	XE [RAD]	GENL MASS [KG-M2]	ZETA	D[=PI*XE*F] [N-M]	T [N-M]	D[=4*PI*ZETA*T] [N-M]
1	7.893	18099.396	4.8000E-05	4.3735E-06	2.2483E 05	2.1000E-02	1.6810E-01	6.3702E-01	1.6810E-01
2	8.626	16483.782	1.0000E-04	9.0458E-06	1.4122E 05	1.6000E-02	4.1705E-01	2.0742E 00	4.1705E-01
3	11.539	14156.394	3.8000E-06	4.5108E-06	7.0951E 07	6.9000E-03	2.3348E-01	2.6927E 00	2.3348E-01

TEST NO. 9 SATURN V DTV CONFIG. II CO MSFC 201 TORSIONAL FORCE LEVEL (1967)

	FREQU[illegible]CY [HZ]	TORQUE [N-M]	XN [RAD]	XE [RAD]	GENL MASS [KG-M2]	ZETA	D[=PI*XE*F] [N-M]	T [N-M]	D[=4*PI*[illegible]A*T] [N-M]
1	8.605	17446.394	1.0550E-04	9.5171E-06	1.4122E 05	.0000E 00	5.2163E-01	2.2974E 00	.0000E 00
2	8.630	12784.410	9.1097E-05	7.9960E-06	1.4122E 05	.0000E 00	3.2114E-01	1.7229E 00	.0000E 00
3	8.675	8122.426	6.1814E-05	5.4040E-06	1.4122E 05	.0000E 00	1.3790E-01	8.0158E-01	.0000E 00
4	11.625	14034.014	2.6400E-06	4.4502E-06	7.0951E 07	.0000E 00	1.9620E-01	1.3192E 00	.0000E 00
5	11.632	9323.968	2.1187E-06	3.1852E-06	7.0951E 07	.0000E 00	9.3301E-02	8.5058E-01	.0000E 00
6	11.655	4661.984	1.4441E-06	1.6713E-06	7.0951E 07	.0000E 00	2.4478E-02	3.9675E-01	.0000E 00

TEST NO. 10 SATURN V DTV CONFIG. II CS MSFC 201 LONGITUDINAL FREQ. SWEEP (1967)

	FREQUENCY [HZ]	FORCE [N]	XN [M]	XE [M]	GENL MASS [KG-SEC2/M]	ZETA	D[=PI*XE*F] [N-M]	T [N-M]	D[=4*PI*ZETA*T] [N-M]
1	6.211	5667.032	6.1175E-04	7.3423E-05	9.1175E 04	3.4000E-03	1.1101E 00	2.5982E 01	1.1101E 00
2	9.195	19803.475	5.6703E-04	8.5021E-05	1.2197E 05	8.9000E-03	7.3199E 00	6.5450E 01	7.3199E 00
3	9.758	17183.474	2.8702E-05	2.0055E-04	4.6200E 07	1.1000E-02	9.8879E 00	7.1532E 01	9.8879E 00
4	11.212	17232.404	3.2603E-04	8.1145E-05	1.4455E 05	6.8000E-03	3.2580E 00	3.8128E 01	3.2580E 00
5	8.628	4790.733	9.2433E-04	6.1814E-04	1.0097E 05	6.7000E-03	1.0673E 01	1.2677E 02	1.0673E 01
6	9.513	17232.404	6.0113E-04	1.5632E-04	2.2575E 05	6.3000E-03	1.1536E 01	1.4572E 02	1.1536E 01
7	11.587	17499.297	3.2376E-04	2.4311E-04	2.5200E 05	1.5000E-02	1.3195E 01	7.0002E 01	1.3195E 01

TEST NO. 10 SATURN V DTV CONFIG. II CO MSFC 201 LONGITUDINAL FORCE LEVEL (1967)

	FREQU[illegible]CY [HZ]	FORCE [N]	XN [M]	XE [M]	GENL MASS [KG-SEC2/M]	ZETA	D[=PI*XE*F] [N-M]	T [N-M]	D[=4*PI*[illegible]A*T] [N-M]
1	6.212	5168.832	5.6482E-04	6.2279E-05	9.1175E 04	.0000E 00	1.0113E 00	2.2156E 01	.0000E 00
2	6.211	3932.226	4.9296E-04	5.2523E-05	9.1175E 04	.0000E 00	6.4884E-01	1.6871E 01	.0000E 00
3	9.170	17445.919	4.1118E-04	1.1549E-04	1.2197E 05	.0000E 00	6.3297E 00	3.4230E 01	.0000E 00
4	9.169	12837.563	2.8788E-04	8.1257E-05	1.2197E 05	.0000E 00	3.2771E 00	1.6776E 01	.0000E 00
5	9.168	8718.511	1.8693E-04	5.4421E-05	1.2197E 05	.0000E 00	1.4906E 00	7.0711E 00	.0000E 00
6	11.200	17343.610	3.1718E-04	6.9899E-05	1.4455E 05	.0000E 00	3.8086E 00	3.6008E 01	.0000E 00
7	11.199	12579.566	2.4897E-04	5.2315E-05	1.4455E 05	.0000E 00	2.0675E 00	2.2183E 01	.0000E 00
8	11.190	8340.412	1.6448E-04	3.5508E-05	1.4455E 05	.0000E 00	9.3038E-01	9.6661E 00	.0000E 00
9	8.628	4670.631	9.3970E-04	6.1070E-04	1.0097E 05	.0000E 00	8.9609E 00	1.3102E 02	.0000E 00
10	8.626	4261.395	8.5584E-04	5.5777E-04	1.0097E 05	.0000E 00	7.4672E 00	1.0863E 02	.0000E 00
11	8.624	2579.968	4.8468E-04	3.1731E-04	1.0097E 05	.0000E 00	2.5719E 00	3.4824E 01	.0000E 00
12	9.553	17116.751	5.0726E-04	2.6793E-04	2.2575E 05	.0000E 00	1.4407E 01	1.0464E 02	.0000E 00
13	9.549	13015.492	3.9792E-04	2.1793E-04	2.2575E 05	.0000E 00	8.9110E 00	6.4337E 01	.0000E 00
14	9.544	8553.927	2.6777E-04	1.4511E-04	2.2575E 05	.0000E 00	3.8995E 00	2.9103E 01	.0000E 00
15	11.634	17281.335	3.0873E-04	1.9843E-04	2.5200E 05	.0000E 00	1.0773E 01	6.4173E 01	.0000E 00
16	11.645	13300.178	2.8487E-04	1.5539E-04	2.5200E 05	.0000E 00	6.4926E 00	5.4738E 01	.0000E 00
17	11.635	8727.408	1.8844E-04	9.7314E-05	2.5200E 05	.0000E 00	2.6681E 00	2.3910E 01	.0000E 00

TEST NO. 11 S-IV-B-D, LEM, AND APOLLO PITCH + YAW (1966)

	FREQUENCY [HZ]	FORCE [N]	XN [M]	XE [M]	GENL MASS [KG-SEC2/M]	ZETA	D[=PI*XE*F] [N-M]	T [N-M]	D[=4*PI*ZETA*T] [N-M]
1	4.980	3229.000	1.3010E-03	2.2546E-04	1.0555E 04	8.9000E-03	9.7814E-01	8.7458E 00	9.7814E-01
2	9.660	3481.000	3.8500E-04	9.0128E-05	1.6048E 04	1.1800E-02	6.4971E-01	4.3815E 00	6.4971E-01
3	10.000	3346.000	2.9000E-04	9.0973E-05	1.9421E 04	1.2300E-02	4.9832E-01	3.2240E 00	4.9832E-01
4	10.580	3449.000	2.2800E-04	9.1314E-05	3.7114E 04	1.1400E-02	6.1069E-01	4.2629E 00	6.1069E-01
5	14.800	3305.000	1.9000E-04	1.2969E-04	5.6828E 04	1.3000E-02	1.4490E 00	8.8700E 00	1.4490E 00
6	5.200	3705.000	2.2820E-03	1.5561E-03	1.1824E 04	1.3700E-02	5.6580E 00	3.2865E 01	5.6580E 00
7	9.680	3774.000	3.9300E-04	8.6578E-05	1.3646E 04	9.4000E-03	4.6048E-01	3.8983E 00	4.6048E-01
8	10.910	3736.000	1.6300E-04	7.2568E-05	2.2986E 04	1.1500E-02	2.0736E-01	1.4349E 00	2.0736E-01
9	15.000	3373.000	2.0000E-04	1.1468E-04	2.2630E 04	1.0800E-02	5.4562E-01	4.0203E 00	5.4562E-01
10	4.900	3371.000	1.9850E-03	3.5015E-04	1.0284E 04	1.9400E-02	4.6818E 00	1.9205E 01	4.6818E 00
11	9.390	3609.000	3.6100E-04	9.9347E-05	2.3731E 04	1.0900E-02	7.3727E-01	5.3826E 00	7.3727E-01
12	10.900	3395.000	2.3100E-04	6.2693E-05	3.0539E 04	7.6000E-03	3.6499E-01	3.8217E 00	3.6499E-01
13	14.420	3502.000	1.5900E-04	1.1644E-04	1.8682E 05	9.5000E-03	2.3142E 00	1.9385E 01	2.3142E 00
14	5.090	3346.000	8.3100E-04	7.5604E-04	1.2523E 04	1.4400E-02	8.0029E-01	4.4226E 00	8.0029E-01
15	9.440	3415.000	5.4600E-04	1.3426E-04	1.0630E 04	9.0000E-03	6.3044E-01	5.5743E 00	6.3044E-01
16	10.950	3546.000	3.5700E-04	9.2570E-05	1.4796E 04	1.1400E-02	6.3937E-01	4.4631E 00	6.3937E-01
17	13.490	3732.000	1.5100E-04	6.9098E-05	5.5456E 05	1.0000E-02	5.7078E 00	4.5421E 01	5.7078E 00
18	15.200	3907.000	1.5800E-04	4.7447E-05	2.1740E 04	1.0900E-02	3.3902E-01	2.4751E 00	3.3902E-01

TEST NO. 12 S-IV-B-D, LEM, AND APOLLO TORSIONAL (1966)

	FREQUENCY [HZ]	TORQUE [N-M]	XN [RAD]	XE [RAD]	GENL MASS [KG-M2]	ZETA	D[=PI*XE*F] [N-M]	T [N-M]	D[=4*PI*ZETA*T] [N-M]
1	4.900	16341.000	8.6926E-04	3.2250E-05	2.9000E 04	1.3600E-02	1.6556E 00	1.0385E 01	1.7749E 00
2	5.610	16330.000	1.6401E-03	1.6237E-05	1.5340E 04	3.0600E-02	8.3297E-01	2.5633E 01	9.8566E 00
3	9.330	15750.000	9.3619E-05	5.1743E-05	3.0861E 06	1.4600E-02	2.5603E 00	4.6477E 01	8.5270E 00
4	5.160	17027.000	9.0398E-04	1.5625E-04	1.0704E 05	2.5900E-02	8.3583E 00	4.6481E 01	1.5128E 01
5	5.700	16999.000	1.6313E-03	9.8532E-05	9.9050E 03	1.7900E-02	5.2620E 00	1.6905E 01	3.8026E 00
6	9.430	16279.000	7.4403E-05	3.8348E-05	3.8921E 06	.0000E 00	1.9612E 00	3.7820E 01	.0000E 00

TEST NO. 13 SAD-202 UPPER ST[illegible]S PITCH + YAW (1966)

	FREQUENCY [HZ]	FORCE [N]	XN [M]	XE [M]	GENL MASS [KG-SEC2/M]	ZETA	D[=PI*XE*F] [N-M]	T [N-M]	D[=4*PI*ZETA*T] [N-M]
1	2.090	3022.000	1.0870E-03	4.4784E-04	9.7334E 05	3.1000E-02	3.8629E 01	9.9162E 01	3.8629E 01
2	7.810	5199.000	2.0590E-03	7.3280E-04	5.0200E 04	1.0400E-02	3.3488E 01	2.5624E 02	3.3488E 01
3	10.090	5466.000	4.5000E-06	1.8142E-05	7.5717E 06	8.6000E-03	3.3299E-02	3.0813E-01	3.3299E-02
4	10.820	5482.000	1.4100E-04	6.7116E-05	1.5866E 05	1.6800E-02	1.5389E 00	7.2893E 00	1.5389E 00
5	14.310	4478.000	1.4000E-04	8.6730E-05	2.8820E 04	1.4000E-02	4.0169E-01	2.2833E 00	4.0169E-01
6	8.160	2327.000	1.6450E-03	4.5912E-04	2.1164E 04	9.8000E-03	9.2699E 00	7.5273E 01	9.2699E 00
7	14.070	2380.000	1.5200E-04	5.3884E-05	1.9634E 04	8.5000E-03	1.8934E-01	1.7726E 00	1.8934E-01
8	8.490	1988.000	1.5930E-03	7.5859E-04	1.3517E 04	1.0300E-02	6.3169E 00	4.8804E 01	6.3169E 00
9	14.270	2277.000	1.0700E-04	3.8456E-05	1.5436E 04	1.4000E-02	1.2497E-01	7.1036E-01	1.2497E-01
10	2.080	3345.000	8.6400E-04	3.1113E-04	1.1934E 06	1.8000E-02	1.7209E 01	7.6082E 01	1.7209E 01
11	7.690	3536.000	2.0340E-03	5.2233E-04	4.7160E 04	8.4000E-03	2.4041E 01	2.2775E 02	2.4041E 01
12	10.380	3782.000	2.4000E-05	1.2057E-04	2.1985E 07	7.2000E-03	2.4367E 00	2.6932E 01	2.4367E 00
13	11.010	3533.000	1.2600E-04	4.6696E-05	4.5709E 05	1.0200E-02	2.2256E 00	1.7364E 01	2.2256E 00
14	8.060	2303.000	1.8490E-03	4.1787E-04	2.1705E 04	1.0800E-02	1.2914E 01	9.5155E 01	1.2914E 01
15	13.580	2463.000	4.4000E-05	3.3546E-05	1.1366E 06	1.0800E-02	1.0871E 00	8.0102E 00	1.0871E 00
16	8.310	2014.000	2.1660E-03	8.2005E-04	1.2720E 04	9.9000E-03	1.0120E 01	8.1346E 01	1.0120E 01

TEST NO. 14 SAD-202 UPPER STAGES TORSIONAL (1966)

	FREQUENCY [HZ]	TORQUE [N-M]	XN [RAD]	XE [RAD]	GENL MASS [KG-M2]	ZETA	D[=PI*XE*F] [N-M]	T [N-M]	D[=4*PI*ZETA*T] [N-M]
1	7.850	10564.000	5.7020E-05	1.4130E-05	1.3073E 06	.0000E 00	4.6893E-01	5.1701E 00	.0000E 00
2	4.990	10636.000	2.0883E-03	1.0462E-04	7.0020E 03	2.3100E-02	3.4958E 00	1.5008E 01	4.3566E 00
3	10.800	10864.000	3.0770E-05	2.6745E-05	1.7699E 06	.0000E 00	9.1283E-01	3.8582E 00	.0000E 00
4	5.110	11430.000	1.8712E-03	1.2237E-04	8.5500E 03	3.4400E-02	4.3943E 00	1.5430E 01	6.6701E 00
5	8.190	11268.000	6.8434E-05	1.9757E-05	1.4126E 06	.0000E 00	6.9939E-01	8.7592E 00	.0000E 00
6	10.800	10963.000	4.4262E-05	2.4773E-05	1.6815E 06	.0000E 00	8.5322E-01	7.5845E 00	.0000E 00
7	5.160	12980.000	1.8203E-03	7.6270E-05	5.4600E 03	2.9300E-02	3.1101E 00	9.5083E 00	3.5009E 00
8	8.490	12042.000	7.2693E-05	3.6172E-05	2.6596E 06	.0000E 00	1.3684E 00	1.9996E 01	.0000E 00
9	11.200	12149.000	5.0108E-05	4.5143E-05	2.4450E 06	.0000E 00	1.7230E 00	1.5201E 01	.0000E 00

TEST NO. 15 BOEING 747 (196

	FREQUENCY [HZ]	FORCE [N]	XN [M]	XE [M]	GENL MASS [KG-SEC2/M]	ZETA	D[=PI*XE*F] [N-M]	T [N-M]	D[=4*PI*ZETA*T] [N-M]
1	1.015	2499.000	7.0500E-05	2.4964E-05	4.5587E 05	.0000E 00	5.7000E 01	2.4430E 02	.0000E 00
2	1.685	2499.000	7.0500E-05	2.4964E-05	4.5587E 05	.0000E 00	3.9400E 01	4.0800E 02	.0000E 00
3	2.100	2499.000	7.0500E-05	2.4964E-05	4.5587E 05	.0000E 00	6.8800E 01	4.0400E 02	.0000E 00
4	2.425	2499.000	7.0500E-05	2.4964E-05	4.5587E 05	.0000E 00	4.1100E 01	4.6700E 02	.0000E 00
5	2.500	2499.000	7.0500E-05	2.4964E-05	4.5587E 05	.0000E 00	6.3400E 01	4.3600E 02	.0000E 00
6	3.160	2499.000	7.0500E-05	2.4964E-05	4.5587E 05	.0000E 00	4.5600E 00	3.7200E 01	.0000E 00
7	3.460	2499.000	7.0500E-05	2.4964E-05	4.5587E 05	.0000E 00	5.4800E 01	4.3700E 02	.0000E 00
8	.948	2499.000	7.0500E-05	2.4964E-05	4.5587E 05	.0000E 00	4.2500E 01	2.1300E 02	.0000E 00
9	1.775	2499.000	7.0500E-05	2.4964E-05	4.5587E 05	.0000E 00	1.7700E 01	2.3650E 02	.0000E 00
10	1.900	2499.000	7.0500E-05	2.4964E-05	4.5587E 05	.0000E 00	1.1000E 01	6.4600E 01	.0000E 00
11	2.290	2499.000	7.0500E-05	2.4964E-05	4.5587E 05	.0000E 00	1.0000E 01	6.9700E 01	.0000E 00
12	3.090	2499.000	7.0500E-05	2.4964E-05	4.5587E 05	.0000E 00	1.1200E 01	1.0900E 02	.0000E 00
13	3.620	2499.000	7.0500E-05	2.4964E-05	4.5587E 05	.0000E 00	1.0200E 01	6.6700E 01	.0000E 00
14	4.820	2499.000	7.0500E-05	2.4964E-05	4.5587E 05	.0000E 00	1.3600E 01	9.8400E 01	.0000E 00
15	5.060	2499.000	7.0500E-05	2.4964E-05	4.5587E 05	.0000E 00	2.4600E 01	7.8500E 01	.0000E 00
16	5.460	2499.000	7.0500E-05	2.4964E-05	4.5587E 05	.0000E 00	7.0000E 00	5.8700E 01	.0000E 00

APPENDIX B

DIGITAL COMPUTER PROGRAMS

71

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Odd Number, Right Page

```
      COMMON D,T,W,X
      DIMENSION D(340),T(340),W(340),X(340)
      DIMENSION Z(4),ARRAY(14)
      NMAX = 340
      READ 5,INDEX,I2,I8
C
C INDEX = 1 - D=C*X1**A1
C INDEX = 2 - D=C*(X1**A1) * (X2**A2)
C INDEX = 4 - D=A1+A2*X1 + A3*X1*X1
C INDEX = 5 - D=C*(M**A1) * (W**A2) * (X**A3) (UNLESS I2=7)
C
C I2=0 - D   C*T**A1
C I2=1 - D = C*X**A1
C I2=2 - D = C*W**A1
C I2=3 - D = C*M**A1
C I2=4 - D = C*(M**A1)*(X**A2)
C I2=5 - D = C*(M**A1)*(W**A2)
C I2=6 - D = C*(X**A1)*(W**A2)
C I2=7 - D = C*(T**A1)*(X/L)**A2 OR C*(M**A1) * (W**A2) * (X/L)**A3
C
    1 READ 15, (ARRAY(I), I = 1,14),ISTOP
   15 FORMAT (13A6,A1,I1)
      IF(ISTOP-9)25,101,25
   25 PRINT 110,  (ARRAY(I), I = 1,14), INDEX, I2
  110 FORMAT (1H1, 35X, 13A6,A2/ 55X, 7HINDEX =, I2, 5H I2 =, I2/
     *           55X,10HINPUT DATA// 6X,9HFREQUENCY, 5X,5HFORCE, 9X,
     * 2HXN,10X,2HXE, 6X,9HGENL MASS, 7X,2HXO,8X,4HZETA,12X,1HD,11X,
     * 1HT, 10X, 2HD2)
      I = 0
    4 READ 5,I1,IDUM,I3
    5 FORMAT (10I5)
C
C I1=1 - INPUT UNITS - CPS, KGF,     M, XE/XO,   KG-S2/M
C I1=2 -               CPS,  LB, G/LB,  G/LB, LB-S2/IN
C I1=3 -               CPS,   N,     M, XE/XO,        KG
C I1=4 -               CPS, D,T IN N-M
C I1=5 -               CPS, N-M,  DEG, XE/XO,    KG-M2
C I1=6 -               CPS, IN-KIP, RAD, RAD/IN-LB, LB-S2-IN
C I1=7 -               CPS, LB, G/LB, G/LB, LB-S2-IN, R(IN),RE(IN)
C
C I3=1 - D=PI*XE*F
C I3=2 - D=4*PI*ZETA*T
C I3=4 - GM = 1, D=PI*XE*F
C
  126 IF (I1-1) 132,112,112
  112 READ 10,CLGTH
      IF (I8) 102,102,106
  102 IF (I1-2) 103,148,104
  103 PRINT 115
  115 FORMAT ( 8X, 5H(CPS),  7X, 5H(KGF),  9X, 3H(M), 6X, 7H(XE/XO), 3X,
     * 11H(KG-SEC2/M),30X,5H(N-M), 7X, 5H(N-M),8X,5H(N-M)/)
      GOTO 106
  104 IF (I1-4) 109,109,146
```

PROGRAM TO FIND BEST-FIT EMPIRICAL DAMPING LAW THROUGH LEAST-SQUARES METHOD

```
ΔENDJØB.
ΔASSIGN S=[illegible].SI=CR,B8=MT1,L8=LP.
ΔREWIND MT1.
ΔFØRTRAN B8,L8.
            CØMMØN D,T,W,X
            DIMENSIØN D[340],T[340],W[340],X[340]
            DIMENSIØN Z[4],ARRAY[14]
            NMAX = 340
            READ 2,INDEX,I2,CGIVN,EGIVN,I8
          2 FØRMAT[2I5,F10.4,F10.4,I5]
      C
      C INDEX = 1 - D=C*X1**A1
      C INDEX = 2 - D=C*[X1**A1] * [X2**A2]
      C INDEX = 3 - D=C*T*W**A1
      C INDEX = 4 - D=A1+A2*X1 + A3*X1*X1
      C INDEX = 5 - D=C*[M**A1] * [W**A2] * [X**A3] [UNLESS I2=7]
      C
      C I2=0 - D = C*T**A1
      C I2=1 - D = C*X**A1
      C I2=2 - D = C*W**A1
      C I2=3 - D = C*M**A1
      C I2=4 - D = C*[M**A1]*[X**A2]
      C I2=5 - D = C*[M**A1]*[W**A2]
      C I2=6 - D = C*[X**A1]*[W**A2]
      C I2=7 - D = C*[T**A1]*[X/L]**A2 ØR C*[M**A1] * [W**A2] * [X/L]**A3
      C
            CGIVN=ALØG[CGIVN]
          1 READ 15, [ARRAY[I], I = 1,14],ISTØP
         15 FØRMAT [13A6,A1,I1]
            IF[ISTØP-9]25,101,25
         25 PRINT 110,  [ARRAY[I], I = 1,14], INDEX, I2
        110 FØRMAT [1H1, 35X, 13A6,A2/ 55X, 7HINDEX =, I2, 5H I2 =, I2/
           *                 55X,10HINPUT DATA// 6X,9HFREQUENCY, 5X,5HFØRCE, 9X,
           * 2HXN,10X,2HXE, 6X,9HGENL MASS, 7X,2HXO,8X,4HZETA,12X,1HD,11X,
           * 1HT, 10X, 2HD2]
            I = 0
          4 READ 5,I1,IDUM,I3
          5 FØRMAT [10I5]
      C
      C I1=1 - INPUT UNITS - CPS, KGF,     M, XE/XO,   KG-S2/M
      C I1=2 -               CPS,  LB, G/LB,  G/LB, LB-S2/IN
      C I1=3 -               CPS,   N,     M, XE/XO,        KG
      C I1=4 -               CPS, D,T IN N-M
      C I1=5 -               CPS, N-M,  DEG, XF/XO,     KG-M2
      C I1=6 -               CPS, IN-KIP, RAD, RAD/IN-LB, LB-S2-IN
      C I1=7 -               CPS, LB, G/LB, G/LB, LB-S2-IN, R[IN],RE[I5]
      C
      C I3=1 - D=PI*XE*F
      C I3=2 - D=4*PI*ZETA*T
      C I3=4 - GY = 1, D=PI*XE*F
      C
            IF[IDUM-9]126,101,126
        126 IF [I1-1] 132,112,112
```

```
109 PRINT 145
145 FORMAT (   8X,5H(CPS), 8X, 3H(N), 10X, 3H(M), 6X, 7H(XE/X0), 7X,
   *  4H(KG),33X,5H(N-M),7X,5H(N-M),8X,5H(N-M)/)
    GOTO 106
146 IF(I1-6)144,149,148
144 PRINT 147
147 FORMAT ( 8X,5H(CPS), 7X, 5H(N-M), 8X, 5H(DEG), 5X, 7H(XE/X0), 6X,
   *  7H(KG-M2),31X, 5H(N-M), 7X, 5H(N-M), 8X,5H(N-M)/)
    GOTO 106
149 PRINT 151
151 FORMAT ( 8X, 5H(CPS), 6X, 8H(IN-KIP) 6X,19H(RAD)    (RAD/IN-LB), 2X
   * 12H(LB-SEC2-IN),28X, 5H(N-M), 7X, 5H(N-M), 8X, 5H(N-M)/)
    GOTO 106
148 PRINT 125
125 FORMAT ( 8X,5H(CPS), 7X,4H(LB),8X,6H(G/LB),6X,6H(G/LB),3X,
   * 12H(LB-SEC2/IN), 29X,5H(N-M), 7X,5H(N-M),8X, 5H(N-M)/)
106 JMASS = IMASS
106 READ 10, FREQ,XN,GM,F,XE,XO,ZETA
 10 FORMAT (7E10.3)
    IF (ABS(FREQ) - 1.E-10) 4,4,128
128 I = I + 1
    IF (I-NMAX) 129,129,130
129 W(I) = 6.28318*FREQ
    W2 = W(I)*W(I)
    TS = 9.80665/W2
    IF (I1-2) 107,57,54
107 GM1 = 9.80665*GM
    F1 = 9.80665*F
    XN1 = XN
    XE1 = XN1*XE
    GOTO 43
 54 IF(I1-4)58,59,55
 55 IF(I1-6) 52,51,48
 52 XN1 = XN*.017453293
    GOTO 53
 58 XN1 = XN
 53 GM1 = GM
    F1 = F
    XE1 = XN1*XE
    GOTO  43
 51 GM1 = .11298*GM
    F1 = 112.98*F
    XN1 = XN
    XE1 = XE*F*1000.
    GOTO 43
 48 GM1 = .11298*GM
    F1 = 24.030846*F
    R = XO*.0254
    R1=ZETA*.0254
    ZETA=0.
    XN1 = TS*F*XN/R
    XE1 = TS*F*XE/R1
    GOTO 43
 57 GM1 = 175.*GM
```

```
      F1 = 4.44822*F
      XN1 = TS*F*XN
      XE1 = TS*F*XE
   43 D(I) = 3.14159*F1*XE1
      TBAR=.5*W2*GM1*XN1*XN1
      IF(I2-1)46,44,70
   44 W2=1.
      FREQ=1.
      GM1=1.
      GM =1.
      GO TO 46
   70 IF(I2-3)71,72,73
   71 XN1=1.
      XN=1.
      GM1=1.
      GM =1.
      GO TO 46
   72 W2 =1.
      FREQ =1.
      XN1=1.
      XN =1.
      GO TO 46
   73 IF(I2-5)74,75,76
   74 W(I)=XN1
      XN1=1.
      FREQ =1.
      GO TO 46
   75 XN1=1.
      XN =1.
      GO TO 46
   76 IF (I2-7)77,46,46
   77 GM1=1.
      GM =1.
      XN1=SQRT(XN1)
   46 XM     = GM1*XN1*XN1
      T(I) = .5*W2*XM
      GOTO 56
   59 T(I) = GM
      D(I) = F
      XM     = 2.*GM/W2
      GM     = 0.
      F = 0.
   56 D2 = 12.56636*ZETA*TBAR
      DIFF=(D(I)-D2)/D2*100.
      IF (I3-2) 117,118,117
  118 D(I) = D2
      IF (ABS(D(I)) - 1.E-10) 119,119,117
  119 I = I - 1
      GOTO 106
  117 IF (I9) 116,116,114
  116 PRINT 120,I,FREQ,F,XN,XE,GM,XO,ZETA,D(I), T(I), D2
  120 FORMAT (I4,F9.3,F13.3,1PE14.4,4E12.4,E14.4,E12.4,1X,E12.4)
  114 IF (INDEX-4) 121,106, 121
  121 D(I) = ALOG(D(I))
```

```
      T(I) = ALOG(T(I))
      W(I) =ALOG (W(I))
      X(I)=ALOG(XN1)
      IF (INDEX - 2) 106,60,122
  122 IF(INDEX-4)106,106,170
   60 IF (I2-7)61,65,65
   61 T(I)=ALOG(XM)
      GO TO 106
  170 T(I)=ALOG(GM1)
      IF(I2-7)106,137,137
  137 X(I)=ALOG(XN1/CLGTH)
      GO TO 106
   65 W(I)=ALOG(XN1/CLGTH)
      GOTO 106
  132 NPTS = I
  135 CALL LESTSQ(Z, NPTS, INDEX)
      GOTO 1
  130 PRINT 165, I
  165 FORMAT (//55X, 21HTOO MANY DATA POINTS., I4)
  101 STOP
      END
```

```
      SUBROUTINE LESTSQ (Z, N,  IND)
C
C     LINEAR LEAST SQUARES FIT OVER TWO INDEPENDENT VARIABLES
C
      COMMON D,X1,X2,X3
      DIMENSION D(200), X1(200), X2(200), X3(200),A(4,4), B(4,4), C(4,4)
      DIMENSION Z(4), S(4), Y(4), KT(4),       TOL(4),AKT(4)
C
C    CALCULATE COEFFICIENTS OF EQUATIONS
C
      DO 5  I=1,4
      Y(I) = 0.
      Z(I) = 0.
      S(I) = 0.
      DO 5  J=1,4
      C(I,J) = 0.
    5 A(I,J) = 0.
      A(1,1) = N
      DO 10 I = 1,N
      X1SQ = X1(I)*X1(I)
      A(1,2) = A(1,2) + X1(I)
      A(2,2) = A(2,2) + X1SQ
      Y(1) = Y(1) + D(I)
      Y(2) = Y(2) + D(I)*X1(I)
      IF (IND-3) 7,7,8
    7 A(1,3) = A(1,3) + X2(I)
      A(2,3) = A(2,3) + X1(I)*X2(I)
      A(3,3) = A(3,3) + X2(I)*X2(I)
      Y(3) = Y(3) + D(I)*X2(I)
      IF(IND-5)10,40,40
   40 A(1,4)=A(1,4)+X3(I)
      A(2,4)=A(2,4)+X1(I)*X3(I)
      A(3,4)=A(3,4)+X2(I)*X3(I)
      A(4,4)=A(4,4)+X3(I)*X3(I)
      Y(4) = Y(4)+D(I)*X3(I)
      GOTO 10
    8 IF(IND-5)9,7,7
    9 X2(I)=X1SQ
      A(2,3) = A(2,3) + X1SQ*X1(I)
      A(3,3) = A(3,3) + X1SQ*X1SQ
      Y(3) = Y(3) + D(I)*X1SQ
   10 CONTINUE
      A(2,1) = A(1,2)
      A(3,2) = A(2,3)
      A(4,1)=A(1,4)
      A(4,2)=A(2,4)
      A(4,3)=A(3,4)
      LIM = IND + 1
      IF (IND-3) 13,11,12
   11 LIM = 2
      GOTO 13
   12 IF(IND-5)14,16,16
   14 A(1,3)=A(2,2)
```

```
      LIM = 3
      GO TO 13
   16 LIM=4
   13 A(3,1) = A(1,3)
      PRINT 100,((A(I,J), J= 1,I), Y(I), I = 1,LIM)
  100 FORMAT (///46X,38HCOEFFICIENTS OF LEAST SQUARES EQUATION//
     *1PE36.4, E74.4/E36.4,E16.4,E58.4/E36.4,2E16.4,E42.4/
     *  E36.4,3E16.4,E26.4)
C
C     INVERT EQUATIONS
C
      DO 140 I = 1,4
      DO 140 J = 1,4
      DO 140 J = 1,3
  140 B(I,J) = A(I,J)
      IF (IND-2) 160,170,165
  165 IF(IND - 4 )160,170,191
  170 CALL MATINV(A,3,B,0,DET,3)
      GOTO 180
  160 CALL MATINV(A,2,B,0,DET,2)
      GO TO 180
  191 CALL MATINV(A, 4, B, 0, DET, 4)
  180 CONTINUE
      DO 20 I = 1,LIM
      DO 20 K = 1,LIM
   20 Z(I) = Z(I) + A(I,K)*Y(K)
      E = EXP(Z(1))
      PRINT 120, Z(1), E, (Z(I), I = 2,LIM)
  120 FORMAT (///47X,36HSOLUTION FOR LEAST SQUARES CONSTANTS//
     * 55X,3HC =, 1PE16.4, 10X, 8HEXP(C) =, E16.4/
     *    54X,4HA1 =,E16.4/54X,4HA2 =,E16.4/54X,4HA3 =,E16.4)
      PRINT 130
  130 FORMAT (///50X,30HERROR OF LEAST SQUARES APPROX.)
C 130 FORMAT (///50X,30HERROR OF LEAST SQUARES APPROX.//53X,8HTERM NO.,
C    *  8X, 5HERROR, 5X, 16HLOG DBAR/DAPPROX, 5X, 15HLOG DBAR/DCHANG/)
      DO 190 I=1,4
      HI=I
      KT(I)=0
  190 TOL(I)=HI*.23026
      DO 25 I = 1,N
      DEL = D(I) - Z(1) - Z(2)*X1(I) - Z(3)*X2(I) - Z(4)*X3(I)
      ERR = EXP(-DEL)- 1.
      DO 260 L=1,4
      J=-L+5
      IF (ABS(DEL) -TOL(J))210,210,260
  210 KT(J)=KT(J)+1
  260 CONTINUE
   25 CONTINUE
C  25 PRINT 131, I,ERR, DEL, DEL2
  131 FORMAT (I58,2F16.4, F21.4)
      DO 280 I=1,4
      AKT(I)=KT(I)
      PC=100.*AKT(I)/B(1,1)
  280 PRINT 230,PC,I
```

77

```
230 FORMAT(//F58.3, 11H PERCENT IN,I2,8H DB BAND)
    RETURN
    END
```

```
      SUBRØUTINE MATINV (A,N,B,M,DETERM,NMAX)
C
      DIMENSIØN A(4,4),B(4,4),PIVØT(4),INDEX(4)
      DETERM=1.0
      DØ 20 I=1,N
      PIVØT(I)=0.0
   20 INDEX(I)=0.0
      DØ 550 I=1,N
      AMAX=0.0
      DØ 105 J=1,N
      IF (PIVØT(J)) 105,21,105
   21 DØ 100 K=1,N
      IF (PIVØT(K)) 100,22,100
   22 TEMP= ABS(A(J,K))
      IF (TEMP-AMAX) 100,23,23
   23 IRØW=J
      ICØLUM=K
      AMAX=TEMP
  100 CØNTINUE
  105 CØNTINUE
      INDEX(I)=4096*IRØW+ICØLUM
      J=IRØW
      AMAX=A(J,ICØLUM)
      DETERM=AMAX*DETERM
      IF (DETERM) 24,600,24
   24 PIVØT(ICØLUM)=AMAX
      IF (IRØW-ICØLUM) 26,260,26
   26 DETERM=-DETERM
      DØ 200 K=1,N
      SWAP=A(J,K)
      A(J,K) A(ICØLUM,K)
      A(ICØLUM,K)=SWAP
  200 CØNTINUE
      IF (M) 260,260,27
   27 DØ 250 K=1,M
      SWAP=B(J,K)
      B(J,K)=B(ICØLUM,K)
      B(ICØLUM,K)=SWAP
  250 CØNTINUE
  260 K=ICØLUM
      A(ICØLUM,K)=1.0
      DØ 350 K=1,N
      A(ICØLUM,K)=A(ICØLUM,K)/AMAX
  350 CØNTINUE
      IF (M) 380,380,28
   28 DØ 370 K=1,M
      B(ICØLUM,K)=B(ICØLUM,K)/AMAX
  370 CØNTINUE
  380 DØ 550 J=1,N
      IF (J-ICØLUM) 29,550,29
   29 T=A( J,ICØLUM)
      A( J,ICØLUM)=0.0
      DØ 450 K=1,N
```

```
      A( J,K)=A( J,K)-A(ICØLUM,K)*T
  450 CØNTINUE
      IF (M) 550,550,31
   31 DØ 500 K=1,M
      B( J,K)=B( J,K)-B(ICØLUM,K)*T
  500 CØNTINUE
  550 CØNTINUE
  600 DØ 710 I=1,N
      I1=N+1-I
      K=INDEX(I1)/4096
      ICØLUM=INDEX(I1)-4096*K
      IF (K-ICØLUM) 32,710,32
   32 DØ 705 J=1,N
      SWAP-A(J,K)
      A(J,K)=A(J,ICØLUM)
      A(J,ICØLUM)=SWAP
  705 CØNTINUE
  710 CØNTINUE
      RETURN
      END
```

USERS MANUAL

PROGRAM TO FIND BEST-FIT EMPIRICAL DAMPING LAW THROUGH LEAST SQUARES METHOD

```
  READ (3I5) INDEX, I2, I0

       INDEX = 1 - FIND DAMPING LAW OF FORM D = C*X1**A1
             = 2                            D = C*X1**A1*X2**A2
             = 4                            D = A1+A2*X1+A3*X1**2
             = 5 (I2 =7                     D = C*M**A1*   **A2*X**A3
             = 5 (I2 =7)                    D = C*M**A1*   **A2*(X/L)**A3

       I2 = 0 - X1 = T
          = 1 - X1 = X          USED WITH INDEX = 1
          = 2 - X1 =
          = 3 - X1 = M
          = 4 - X1 = M, X2 = X
          = 5 - X1 = M, X2 =    USED WITH INDEX = 2
          = 6 - X1 = X, X2 =
          = 7 - X1 = T, X2 = X/L (USED WITH INDEX = 2) OR X3 = X/L (INDEX = 5)

       I0 = 0 - PRINT EACH DATA POINT
          = 1 - MINIMAL PRINT

1 READ (13A6,A1,I1) (ARRAY(I), I=1,14), ISTOP

       ARRAY = TITLE OF DATA DECK
       ISTOP = 9 - STOP
             = 0 - CONTINUE

2 READ (I5,I10) I1,I3

       I1 = 0 - GO TO 1
                              FREQ  XN   GEN. MASS   FORCE    XE       XO
          = 1 - INPUT UNITS -  HZ   M    KG-S**2/M   KGF     XE/XN
          = 2                  HZ  G/LB  LB-S**2/IN  LB       G/LB
          = 3                  HZ   M      KG         N      XE/XN
          = 4                  HZ          N-M       N-M
          = 5                  HZ   DEG  KG-M**2     N-M     XE/XN
          = 6                  HZ   RAD  LB-S**2/IN  IN-KIP RAD/IN-LB
          = 7                  HZ  G/LB  LB-S**2/IN  LB       G/LB      IN

         I3 = 1 - D CALCULATED FROM D = PI*XE*F
         I3 = 2 -                   D = 4*PI*ZETA*T

  READ (E10.3) CLGTH

       CLGTH = CHARACTERISTIC LENGTH OF VEHICLE IN METERS

3 READ (7E10.3) FREQ, XN, GM, F, XE, XO, ZETA

       FREQ = FREQUENCY
       XN = DEFLECTION AT STATION USED FOR NORMALIZATION OF GEN. MASS
```

```
      GM = GENERALIZED MASS (OR KINETIC ENERGY FOR I1 = 4)
      F = EXCITATION FORCE (OR DISSIPATED ENERGY FOR I1 = 4)
      XE = DEFLECTION AT EXCITATION STATION
      XO = RADIUS AT NORMALIZATION STATION FOR I1 = 7
    ZETA = MODAL DAMPING COEFFICIENT (OR RADIUS (INCHES) AT EXCITATION STATION
           FOR I1 = 7)

  IF (/FREQ/.LE.1.E-10) GO TO 2

  GO TO 3
```

SAMPLE DATA DECK

```
   1    0    .313      .75       0
TESTS NO. 11 + 13, SATURN UPPER STAGES BENDING TESTS
   3         2
  33.858
   4.98     .1301 -2     10555.  3229.       .1733           1     .0089   4 -  1
   9.66     .0385 -2     16048.  3481.       .2341                 .0118   4 -  2
  10.00     .0290 -2     19421.  3346.       .3137                 .0123   4 -  3
  10.58     .0228 -2     37114.  3449.       .4005                 .0114   4 -  4
  14.80     .0190 -2     56828.  3305.       .6826                 .0130   4 -  5
  19.01     .0151 -3   1053120.  3412.      5.169                          4 -  6
  23.12     .0158 -3  17980500.  2763.     16.138                          4 -  7
   4.90     .1985 -2     10284.  3371.       .1764                 .0194   4 - 15
   9.39     .361  -3     23731.  3609.       .2752                 .0109   4 - 16
  10.90      231  -3     30539.  3395.       .2714                 .0076   4 - 17
  13.38     .99   -4   2284183.  3325.       .6684                         4 - 18
  14.42     .159  -3    186818.  3502.       .7323                 .0095   4 - 19
  16.40     .38   -4    701443.  3574.      1.6274                         4 - 20
  22.97     .19   -4   8261987.  4558.     29.323                          4 - 21
   5.20     .2282 -2     11824.  3705.       .6819           2     .0137   4 -  8
   9.68     .393  -3     13646.  3774.       .2203                 .0094   4 -  9
  10.59     .218  -3     21531.  3438.       .3998                         4 - 10
  10.91     .163  -3     22986.  3736.       .4452                 .0115   4 - 11
  15.00     .200  -3     22630.  3373.       .5734                 .0108   4 - 12
  24.26     .570  -5  82876450.  4111.     44.2231                         4 - 13
  26.82     .104  -4  28463950.  5444.     71.8714                         4 - 14
   5.09     .831  -3     12523.  3346.       .9098                 .0144   4 - 22
   9.44     .546  -3     10630.  3415.       .2459                 .009    4 - 23
  10.95     .357  -3     14796.  3546.       .2593                 .0114   4 - 24
  13.49     .151  -3    554562.  3732.       .4576                 .0100   4 - 25
  15.20     .158  -3     21740.  3907.       .3003                 .0109   4 - 26

   3         2
  33.858
   2.09     .1087 -2    973344.  3022.       .4120           1     .0110   3 -  1
   7.81     .2059 -2     50200.  5199.       .3559                 .0104   3 -  2
  10.09     .45   -5   7571678.  5466.      4.0316                 .0086   3 -  3
```

10.82	.141	-3	158658.	5482.	.4760		.0168	3 - 4
14.31	.140	-3	28820.	4478.	.6195		.0140	3 - 5
17.02	.14	-4	1591757.	4369.	5.3168			3 - 6
2.08	.864	-3	1193429.	3345.	.3601		.0180	3 - 11
7.69	.2034	-2	47160.	3536.	.2568		.0084	3 - 12
10.38	.24	-4	21984770.	3782.	5.0237		.0072	3 - 13
11.01	.126	-3	457090.	3533.	.3706		.0102	3 - 14
14.60	.37	-4	859699.	3476.	1.2591			3 - 15
17.22	.26	-4	776740.	3452.	2.1896			3 - 16
8.16	.1645	-2	21164.	2327.	.2791	2	.0098	3 - 7
14.07	.152	-3	9634.	2380.	.3545		.0085	3 - 8
8.06	.1849	-2	21705.	2303.	.2260		.0108	3 - 17
13.58	.44	-4	1136601.	2463.	.7624		.0108	3 - 18
8.49	.1593	-2	13517.	1988.	.4762	3	.0103	3 - 9
14.27	.107	-3	15436.	2277.	.3594		.0140	3 - 10
8.31	.2166	-2	12720.	2014.	.3786		.0099	3 - 19
13.60	.705	-4	455873.	2499.	.3541			3 - 20

TEST NO. 3 SATURN V DTV CONFIG. I TORSIONAL (1967)

6	0		2						17-B
5.029									17-0
5.660	6.092	-5	9.40	+6	219.12	2.5	-11	.01	17- 1
6.162	8.469	-5	3.0	+6	227.04	2.6	-11	.008	17- 2
8.117	3.192	-5	2.5	+7	204.60	2.4	-11	.016	17- 3
8.839	1.486	-4	3.88	+6	182.16	4.5	-11	.01	17- 4
11.326	6.703	-5	2.7	+6	240.24	8.0	-11	.02	17- 5
5.691	6.271	-5	9.1	+6	201.	30.	-12	.009	17- 6
6.194	6.432	-5	6.8	+6	201.	30.	-12	.009	17- 7
8.113	3.298	-5	3.1	+7	194.	40.	-12	.014	17- 8
8.895	1.443	-4	4.0	+6	205.	140.	-12	.011	17- 9
11.438	6.640	-5	3.4	+6	238.	50.	-12	.018	17-10

83

```
ΔENDJOB.
ΔASSIGN  S=MTC,SI=CR,BO=MT1,L9=LP,
ΔREWIND MT1.
ΔFORTRAN BO,L9.
=          DIMENSION WN[25], GM[25], TABLEQ[25], TABLEW[25]
=          READ 25, NMODES,ITMAX,NQ,NW,TOL
=       25 FORMAT [ 4I5,F10.3]
=          DO 27 I = 1,NMODES
=       27 READ 35, WN[I], GM[I]
=       30 FORMAT [10F8.3]
=       35 FORMAT [8F10.3]
=          READ 30, C,EN
=          READ 30, [TABLEQ[I], I = 1,NQ]
=          READ 30, [TABLEW[I], I = 1,NW]
=          PRINT 40
=       40 FORMAT [1H1,28X,4HFREQ,10X,9HGENL MASS, 7X,9HFORC AMPL, 7X
=         * 9HFORC FREQ,7X,9HRESP AMPL,7X,10HRESP PHASE//]
=          DO 75 I = 1,NMODES
=          DO 75 J = 1,NW
=          W = TABLEW[J]
=          DO 75 K = 1,NQ
=          QN = TABLEQ[K]
=          Q = 1.
=          N = 0
=          IND = 0
=      100 X = Q
=          N = N+1
=          PRINT 501, N
=      501 FORMAT [I2]
=          CALL F[WN[I], W, GM[I], X, EN, C, QN, T, PHI]
=          Q  = X- T
=          ERR = [Q -X]/X
=          IF [ABS[ERR] - TOL] 150,150,120
=      120 IF [N -ITMAX] 100,200,200
=      150 PRINT 160, WN[I], GM[I], QN, W, Q, PHI
=      160 FORMAT [1PE36.4,5E16.4]
=          GOTO 75
=      200 PRINT 210,ITMAX,TOL,Q,X
=      210 FORMAT [//16X,26HSOLUTION DIDNT CONVERGE IN,I3,26H STEPS WITHIN TO
=         *LERANCE OF,F9.6, 7H X[N] =, 1PE10.3, 9H X[N-1] =,E10.3]
=          STOP
=       75 CONTINUE
=          END
```

```
PROGRAM ALLOCATION

  00002 WN        00064 GM        00146 TABLEQ    00230 TABLEW
  00312 NMODES    00313 ITMAX     00314 NQ        00315 NW
  00316 I         00317 J         00320 K         00321 N
  00322 IND       00323 TOL       00325 C         00327 EN
  00331 W         00333 QN        00335 Q         00337 X
  00341 T         00343 PHI       00345 ERR
```

```
SUBROUTINE F [WN,W,GM,Q,EN,C,QN,T,PHI]
W2 = W*W
TA = WN*WN - W2
T1 = TA*TA
TB = GM*Q*Q
TC = W2*TB/2.
TE = C/TB/3.14159
TF = TE*TE
TG = TC**EN
TD = TG*TG
T2 = TD*TF
DENOM = SQRT[T1+T2]
F = Q - QN/DENOM
ARG = TE*TG/TA
PHI = ATAN[ARG]
T3 = 2.*[EN-1.]*T2/Q
T4 = DENOM*DENOM*DENOM
FP = 1. + QN*T3/T4
T = F/FP
RETURN
END
```


PROGRAM ALLOCATION

00026 F	00030 W2	DUMMY W	00032 TA
DUMMY WN	00034 T1	00036 TB	DUMMY GM
DUMMY Q	00040 TC	00042 TE	DUMMY C
00044 TF	00046 TG	DUMMY EN	00050 TD
00052 T2	00054 DENOM	DUMMY QN	00056 ARG
DUMMY PHI	00060 T3	00062 T4	00064 FP
DUMMY T			

SUBPROGRAMS REQUIRED

SQRT ATAN

THE END

USERS MANUAL

PROGRAM TO FIND RESPONSE OF A NONLINEARLY DAMPED SYSTEM TO A PERIODIC EXCITATION

```
  READ (4I5,F10.3) NMODES, ITMAX, NQ, NW, TOL

        NMODES = NO. OF MODAL EQUATIONS TO SOLVE
        ITMAX = MAXIMUM NUMBER OF ITERATIONS FOR NEWTONS METHOD
        NQ = NO. OF VALUES OF Q (AMPL. OF FORCING FN.) FOR EACH FORCING FREQ.
        NW = NO. OF VALUES OF W (FREQ. OF FORCING FN.)
        TOL = ERROR TOLERANCE REQUIRING ANOTHER NEWTON ITERATION

  DO 1 I = 1,NMODES
1 READ (2F8.3) (WN(I), GM(I), I = 1,NMODES)

        WN(I) = MODAL FREQUENCY OF THE I-TH MODE
        GM(I) = GEN. MASS OF I-TH MODE

  READ (2F8.3) C,EN

        C = COEFFICIENT OF EMPIRICAL DAMPING LAW
        EN = EXPONENT OF EMPIRICAL DAMPING LAW

  READ (8F10.3) (TABLEQ(I), I = 1,NQ)
  READ (8F10.3) (TABLEW(I), I = 1,NW)

        TABLEQ(I) = VALUES OF Q(I)
        TABLEW(I) = VALUES OF W(I) (RAD/SEC)
                             SAMPLE DATA DECK

    4   10     5     5        .001
   6.6266      8598.9
  11.0207      3121.6
  16.6826      4791.6
  23.2190     10493.6
 .313     .8
   1.-6    1.-4    1.-2    1.     100.
   6.      12.     18.     24.     30.

                         ALL SATURN, 747 DATA

    1
```

PROGRAM TO CALCULATE EQUIVALENT LINEAR DAMPING COEFFICIENT

```
ΔENDJOB.
ΔASSIGN  S=MT0,SI=CR,B9=MT1,L9=LP.
ΔREWIND MT1.
ΔFORTRAN B9,L9.
      CALCULATION OF EQUIVALENT LINEAR DAMPING COEFFICIENT
C
      DIMENSION TABLE(20), TITLE(14)
      READ 10,C,E
      PRINT 2,C,E
    2 FORMAT (1H1,43X,25HDAMPING LAW CONSTANTS C =F7.3, 4H E =,F7.3)
      READ 5, NAMP
    5 FORMAT (10I5)
      READ 10, (TABLE(I), I = 1,NAMP)
   10 FORMAT (10F8.3)
   12 READ 5,NMODES
      IF (NMODES) 15,900,15
   15 READ 20, (TITLE(I), I = 1,14)
   20 FORMAT (13A6,A2)
      PRINT 30, (TITLE(I), I = 1,14)
   30 FORMAT (1H0,29X,13A6,A2//20X,4HMODE, 5X,4HFREQ, 8X,9HGENL MASS
     *  7X,9HAMPLITUDE, 11X, 1HT, 15X, 1HD, 14X,4HZETA/ 26X, 9H(RAD/SEC)
     *  8X, 4H(KG), 13X, 3H(M), 12X, 5H(M-M), 11X,5H(N-M)/)
      DO  75 I = 1,NMODES
      READ 50, W,GM
   50 FORMAT (8E10.3)
      T = .5*GM*W*W
      DO 75 J = 1,NAMP
      T1 = T*TABLE(J)*TABLE(J)
      D = C*T1**E
      Z = D/12.56636/T1
      IF (J-1) 70,60,70
   60 PRINT 65, I,W,GM,TABLE(J),T1,D,Z
      GOTO 75
   65 FORMAT (I23,F12.3,1P5E16.4)
   70 PRINT 72, TABLE(J),T1,D,Z
   72 FORMAT (1PE67.4,3E16.4)
   75 CONTINUE
      GOTO 12
  900 STOP
      END

PROGRAM ALLOCATION

  00000 TABLE      00050 TITLE      00104 NAMP       00105 I
  00106 NMODES     00107 J          00110 C          00112 E
  00114 W          00116 GM         00120 T          00122 T1
  00124 D          00126 Z
THE END
```

USER'S MANUAL

```
PRØGRAM TØ CALCULATE EQUIVALENT LINEAR DAMPING CØEFFICIENT FRØM EMPIRICAL
DAMPING LAW D = C*T**E

  READ (2E8.3) C,E

       C = CØEFFICIENT ØF EMPIRICAL DAMPING LAW
       E = EXPØNENT ØF EMPIRICAL DAMPING LAW

  READ (I5) NAMP

       NAMP = NØ. ØF MØDAL AMPLITUDES PER MØDE FØR WHICH DAMPING CØEFF. FØUND

  READ (10E8.3) (TABLE(I), I = 1,NAMP)

       TABLE(I) = VALUES ØF MØDAL AMPLITUDES

1 READ (I5) NMØDES

       NMØDES = NØ. ØF MØDES FØR WHICH DAMPING CØEFF. TØ BE FØUND

  READ (13A6,A2) (TITLE(I), I = 1,14)

       TITLE(I) = IDENTIFICATIØN ØF STRUCTURE EXAMINED

  DØ 2 I = 1,NMØDES

2 READ (2E10.3) W,GM

       W = FREQUENCY (RAD/SEC) ØF I-TH MØDE
       GM = GEN. MASS (KG) ØF I-TH MØDE

  GØ TØ 1
  IF (NMØDES. EQ.0) STØP
```

SAMPLE DATA DECK

```
  .313    .8
    5
    1.-6     5.-6     1.-5     5.-5     1.-4
    4
SA 500D TIME PØINT 2 (DTV)
    6.6266      8598.9
   11.0207      3121.6
   16.6826      4791.6
   23.2190     10493.6
```