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STRUCTURAL DAMPING IN SATURN VEHICLES AND SCALE MODELS

By Larry Kiefling and Homer Pack
Aero-Astrodynamics Laboratory

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16. ABSTRACT

An empirical equation previously used to fit Saturn I dynamic test structural damping data is found to fit Saturn IB and Saturn V bending and torsional modal structural damping data. It is shown that the equation is not applicable to longitudinal mode data or to any data for scale models of the Saturn vehicles.

Since the Saturn series consisted of a large variety of configurations and stage sizes, the equation is believed to be usable for the prediction of structural damping of the bending and torsional modes for many future liquid propelled rocket vehicles.

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I. INTRODUCTION

Through the years, there has been a continued need for an analytical method of obtaining the damping characteristics of lightly damped structures. Chang [1] was able to derive an empirical equation which successfully described the Saturn I Dynamic Test Vehicle (SAD-6) damping characteristics for lateral bending. He did this by equating the energy dissipated per cycle as a function of the maximum kinetic energy in the structure of the vehicle.

This report is aimed at applying the method of Chang to different space vehicle configurations, and attempts to extend the method to the longitudinal and torsional vibration modes. Since this report involves compilation of previously published test data, no details of the particular test equipment, procedures, data reduction methods, etc., are given. The interested reader can find this information in the referenced material.

II. DAMPING CHARACTERISTICS FOR LATERAL VIBRATIONS

Chang's equation is given as

$$D_C = 0.313\, T_o^{0.8}\,, \tag{1}$$

where D_C represents the energy dissipated per cycle and T_o the maximum kinetic energy of the structure. The coefficient of T_o in equation (1) is based on the units of newton-meters for the energy. (Note that the units and coefficient of T_o are different from those used by Chang.)

Chang's results of the SAD-6 test are shown in figure 1. The number of test points has been reduced by averaging the data for each mode given in figure 1. It is seen that 83 percent of the total data lie within a ± 2 db band. This spread in the dissipated energy seems moderate considering the many parameters which enter into the calculation of T_o and D_C and the associated measurement errors of these parameters. Since the publication of reference 1, data for a large number of Saturn type vehicles and stages have become available. In figure 2, the empirical equation (1) was used to fit the damping data for all the vehicle configurations tested. Along with the line representing equation (1), the ±2 db lines are drawn. It is seen that equation (1) yields a surprisingly good fit over all the vehicle configurations, especially when considering that the energy levels range over seven orders of magnitude, the vehicle masses vary from 33,600 to 721,000 kg, and the frequencies vary from 0.5 to 14.0 Hz. One should also notice that the vehicle configurations tested include not only single but multiple tank structures as well. Therefore, it is believed that equation (1) can be used as a good first approximation for predicting damping characteristics of similar space vehicle configurations for the lateral bending modes.

In stability and response analyses, the damping ratio ζ is the most convenient damping characteristic of a structure. It can be readily obtained from equation (1) as

$$\zeta = \frac{D_C}{4\pi \, T_o} . \tag{2}$$

Substituting from equation (1) into equation (2) yields

$$\zeta = \frac{.313}{4\pi \, T_o^{0.2}} . \tag{3}$$

Assuming that equation (1) is a valid representation of the damping characteristics of the investigated structures, it follows from equation (3) that the damping ratio ζ is slightly decreasing with increasing amplitudes of the lateral bending vibration. This is certainly an unusual result, since the damping ratio is usually considered to be independent of the amplitude of the vibration. It is seen from equation (3) that an increase of the amplitude by a factor of two decreases the damping ratio ζ by 32 percent. This fact should be taken into consideration in response analyses in which the amplitudes exceed those of the dynamic test programs. We believe, however, that further research in this area is necessary to obtain a better understanding of the damping mechanism of complex structures.

III. DAMPING CHARACTERISTICS FOR TORSIONAL VIBRATIONS

The damping characteristics for torsional vibration tests are shown in figure 3 for four Saturn V configurations. It was found that the test data can be better fitted by a relationship which is slightly different from equation (1), which was used for the lateral vibration data. This relationship is given by

$$D_C = 0.34\ T_o^{0.80}. \tag{4}$$

This equation indicates that the energy dissipation in the torsional mode is a little higher than that of the bending mode for the same test amplitudes. However, the data show a greater scatter, because only 67 percent of the data (rather than 83 percent for the lateral vibration) fall between the ±2 db bounds. This greater scatter is likely to be caused by the high concentration of potential energy in the Service Module/ Command Module connecting structure. In addition, the energy levels for the torsional modes were generally smaller than those for the lateral modes. The smaller energy levels tend to increase the scatter. Unfortunately, only a limited range of data is available. Because of this high scatter, it is felt that the difference between equation (1) and equation (4) is not statistically significant, and that equation (1) can be used for both the lateral and torsional vibration.

IV. DAMPING CHARACTERISTICS FOR LONGITUDINAL VIBRATIONS

The damping characteristics for the longitudinal vibration tests are shown in figure 4 for two Saturn V configurations. It is seen that the slopes for the energy dissipation vs the energy level of the longitudinal vibration is significantly different for the two configurations tested. Therefore, no unique equation for predicting the damping characteristics of the longitudinal vibration of a structure can be established. However, further research in this area might unveil a missing parameter which could explain the difference in the damping behavior of these configurations.

There is one important difference which should be noticed. The straight lines which were fitted to the longitudinal test data have a slope which is greater than unity. As a consequence, the damping ratio for the longitudinal vibration mode is increasing for increasing amplitude. This result is opposite to the damping behavior of the structure vibrating in its lateral or torsional mode, where it was found that the damping ratio was decreasing with increasing amplitude. At the present time, no conclusive physical explanation can be given for this different behavior.

V. DAMPING CHARACTERISTICS FOR SCALE MODELS

Several attempts have been made in recent years to predict the damping characteristics of a structure from dynamic tests on scale models. Figure 5 is included to show that the Chang equation could not be used for the test data obtained from a 1/5 scale model Saturn I and a 1/10 scale model Saturn V. This would indicate that the damping characteristics cannot be predicted from scale model tests or that the Saturn scale models were deficient in modeling some still unknown parameter.

VI. CONCLUSIONS

1. The structural damping equation established by Chang can be applied to the bending and torsional vibrations of Saturn-type vehicles and similar configurations.

2. The Chang equation or any similar equation cannot be applied to the longitudinal vibrations or to the scale models of the Saturn-type vehicles.

3. The damping ratio ζ depends on the amplitude of the vibration. For the lateral and torsional modes, it decreases with increasing amplitudes.

4. The damping ratio ζ increases with increasing amplitude for the longitudinal modes of Saturn-type vehicles.

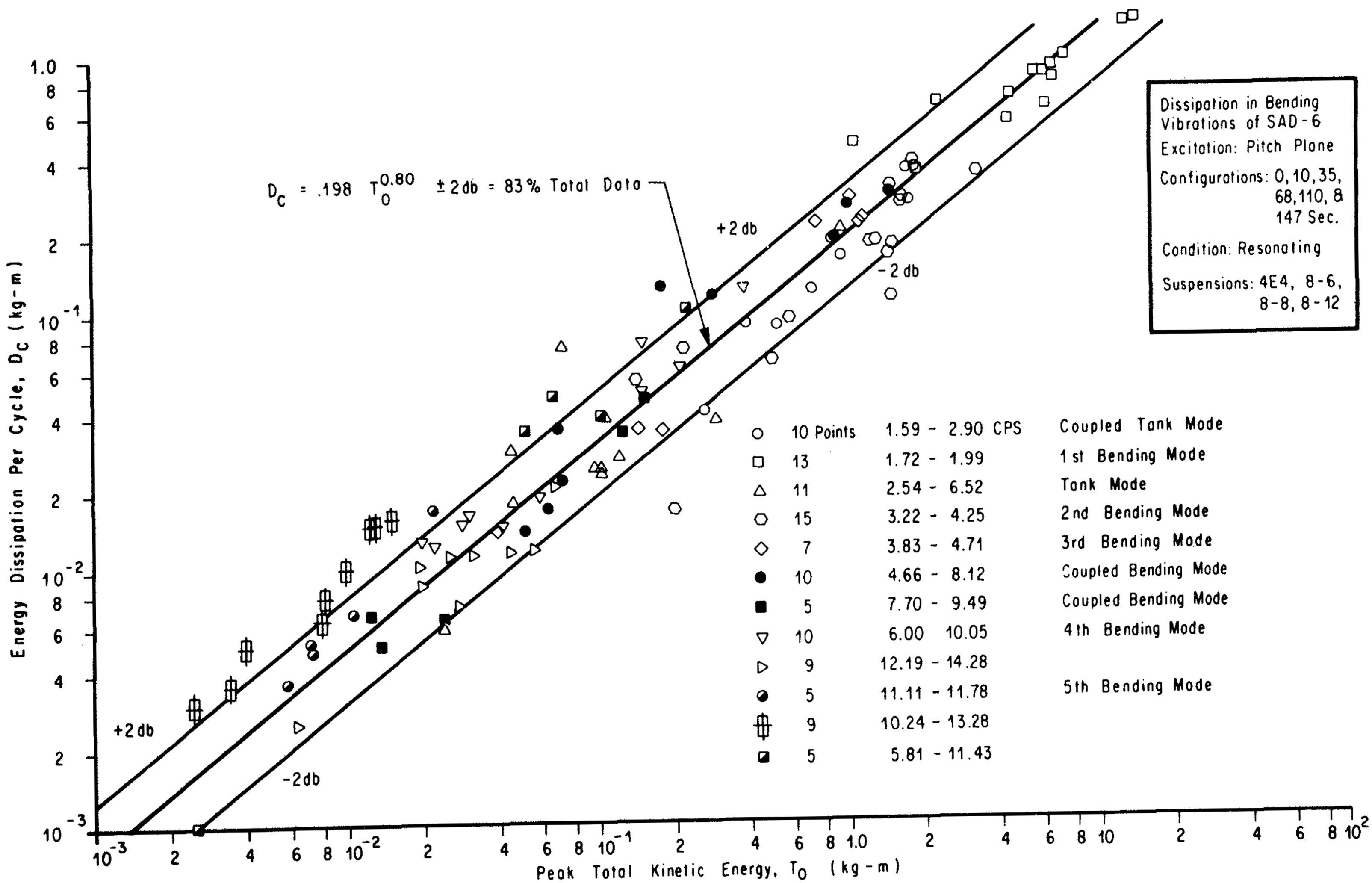

Figure 1. Damping in Bending Vibrations of SAD-6 (from reference 1)

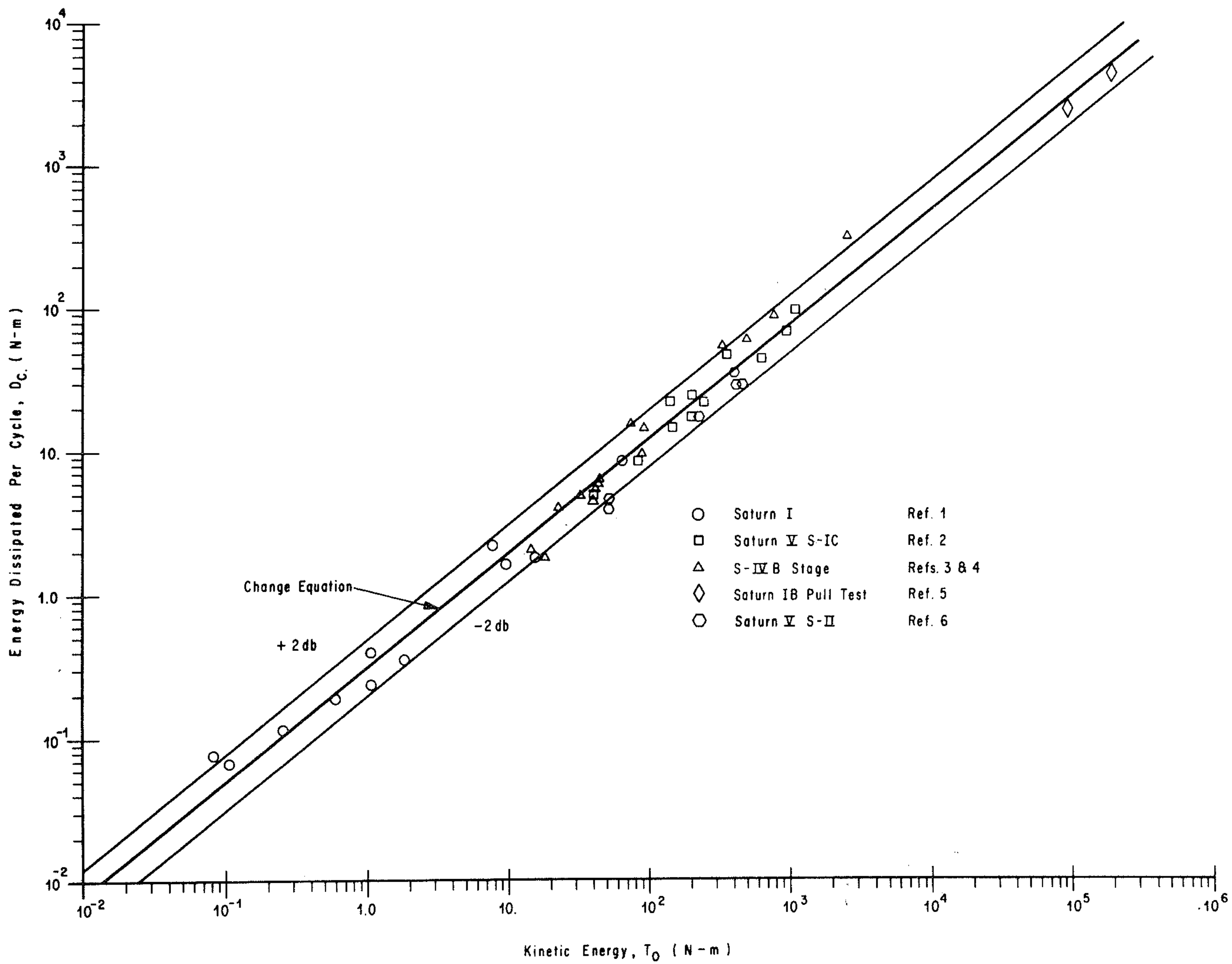

Figure 2. Damping in Bending Vibrations of Saturn Vehicles

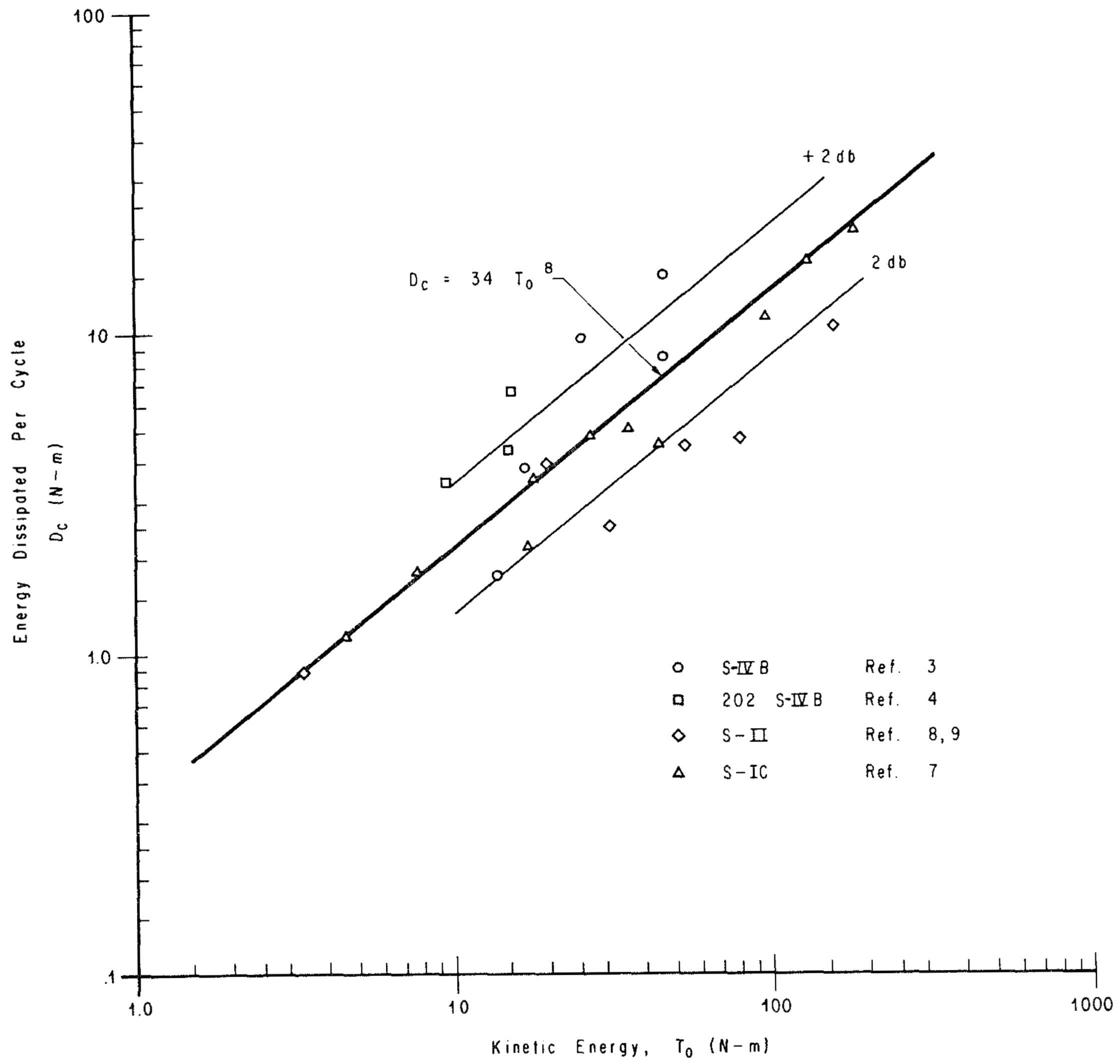

Figure 3. Damping in Torsional Vibrations of Saturn Vehicles

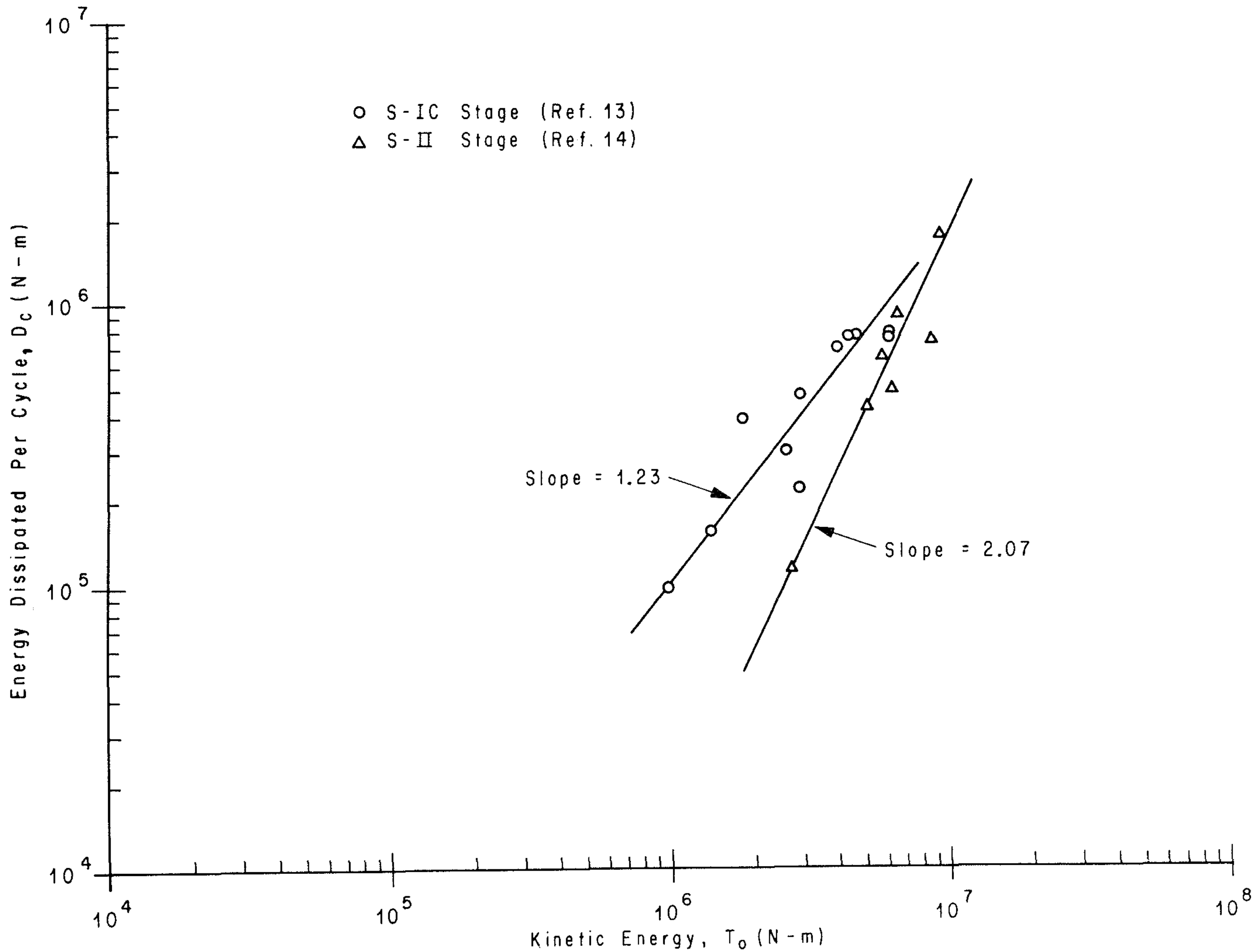

Figure 4. Damping in Longitudinal Vibrations of Saturn V Vehicles

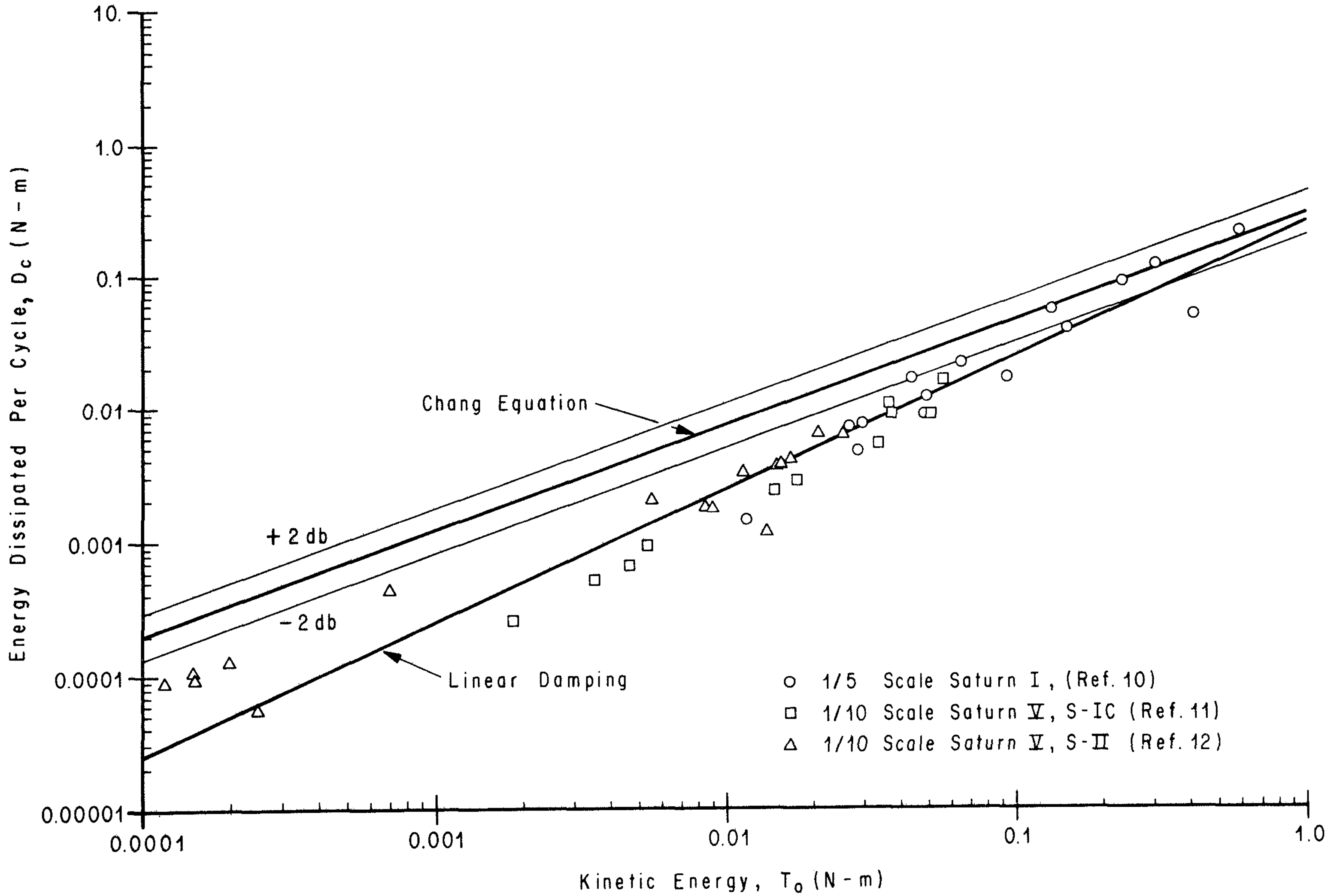

Figure 5. Damping in Bending Vibrations of Saturn Scale Models

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APPROVAL

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

M. H. Rheinfurth
Chief, Dynamics Analysis Branch

J. A. Lovingood
Chief, Dynamics and Control Division

E. D. Geissler
Director, Aero-Astrodynamics Laboratory

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Mr. Douglas Michael
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ES-2
NASA, MSC
Houston, Texas 77058

Mr. S. A. Leadbetter
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NASA-LRC
Langley Sta.
Hampton, VA 23365

Mr. H. Morgan
Mail Stop 340
NASA-LRC
Langley Sta.
Hampton, VA 23365

Mr. T. G. Butler
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Mr. W. Gayman
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Space Div.
Seal Beach, CA 90740

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Univ. of Ala. Huntsville
4701 University Drive NW
Huntsville, AL 35805

Dr. J. T. Oden
Univ. of Ala. Huntsville
4701 University Drive NW
Huntsville, AL 35805

Mr. E. Lerner
Grumman Aerospace Corp.
Structural Mech. - Plant 35
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Dr. R. Mallett
Structural Systems Dept.
Bell Aerosystems Co.
Buffalo, N. Y. 14240

Mr. Grady Riley
The Boeing Co.
P. O. Box 1470
Huntsville, AL 35807

Mr. J. J. O'Conner
Bellcomm, Inc.
955 L'Enfant Plaza North, SW
Washington, DC 20024

Dr. W. A. McNeill
Engineering Div.
Univ. of South Alabama
Mobile, AL 36608

Dr. P. X. Bellini
Civil Engineering Dept.
Youngston State University
Youngstown, Ohio 44503

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