AD-783 234

CONSTRAINED LAYER TREATMENTS FOR NOISE CONTROL IN A HELICOPTER

David I. G. Jones

Air Force Materials Laboratory
Wright-Patterson Air Force Base, Ohio

March 1974

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: AFML-TR-73-305	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER: AD-783 234	
4. TITLE (and Subtitle): CONSTRAINED LAYER TREATMENTS FOR NOISE CONTROL IN A HELICOPTER	5. TYPE OF REPORT & PERIOD COVERED: Final Report, Sept 1972-Dec 1972
	6. PERFORMING ORG. REPORT NUMBER: 7351
7. AUTHOR(s): David I. G. Jones	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Air Force Materials Laboratory (AFML/LLN), Air Force Systems Command, Wright-Patterson Air Force Base, Ohio 45433	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 735106
11. CONTROLLING OFFICE NAME AND ADDRESS: Air Force Materials Laboratory (AFML/LLN), Air Force Systems Command, Wright-Patterson Air Force Base, Ohio 45433	12. REPORT DATE: March 1974
	13. NUMBER OF PAGES: 54
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This research was conducted as a cooperative program between the Air Force Materials Laboratory (AFML/LLN); the Air Force Flight Dynamics Laboratory (AFFDL/FYS); the HH-53 System Program Office, Military Airlift Command, Hill AFB, Utah; the University of Dayton and the Sikorsky Aircraft Company.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Helicopters Cabin Noise, Damping Treatments, Flight Tests, Vibration Tests, and Temperature

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes some of the results of an investigation to evaluate the effect of constrained layer damping treatments on cabin noise levels in an HH-53C helicopter. Vibration and noise levels were measured for various flight conditions, including hover, forward flight and banked, and in each case it was observed that the damping treatment reduced vibration and noise levels in certain frequency bands within which natural modes of vibration were strongly excited. Ground vibration tests under artificial excitation and laboratory vibration tests on simpler but related structures were also conducted to further

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

i

understand the phenomena involved and to develop appropriate damping treatments for broad temperature range noise control applications.

*U.S. Government Printing Office: 1974 — 758-435/672

AFML-TR-73-305

CONSTRAINED LAYER TREATMENTS FOR NOISE CONTROL IN A HELICOPTER

Approved for public release; distribution unlimited.

FOREWORD

This report was prepared by the Metals and Ceramics Division, Air Force Materials Laboratory, Air Force Systems Command, under Project No. 7351, "Metallic Materials", Task No. 735106, "Behavior of Metals". This research was conducted as a cooperative program between the Air Force Materials Laboratory (AFML/LLN), the Air Force Flight Dynamics Laboratory (AFFDL/FYS), the HH-53 Systems Program Office, Military Airlift Command, Hill AFB, Utah, the University of Dayton, under Contract No. F33615-73-C-5028 and the Sikorsky Aircraft Company. This report was written by Dr. David I. G. Jones (AFML/LLN). Ground vibration tests were conducted by Dr. J. P. Henderson (AFML/LLN) and A. D. Nashif and G. E. Buchhalter, University of Dayton. Laboratory vibration tests on beams and stiffened plates were conducted by Dr. D. Jones (AFML/LLN), M. L. Parin, and C. Porubcansky, University of Dayton. Analyses of modal damping of beams and plates with constrained layer damping were conducted by Dr. D.I.G. Jones (AFML/LLN). Assistance with electronic instrumentation for both field and laboratory testing was provided by S. Askins, University of Dayton. The manuscript was typed by D. Gochoel and B. Dues, University of Dayton. Flight tests were conducted by E. Hotz, J. McIntosh, and J. A. Willenborg (AFFDL/FYS). Data analysis was conducted by C. E. Thomas, John Ach, and Lowell Vaughn (AFFDL/FYS).

This report covers work conducted from 11 September 1972 to 25 September 1972, and analyzed from September 1972 to December 1972. The report was submitted to the Air Force Materials Laboratory by the authors in November 1973.

This report has been reviewed and cleared for open publication and/or public release by the appropriate Office of Information (OI) in accordance with AFR 190-17 and DODD 5230.9. There is no objection to unlimited distribution of this report to the public at large, or by DDC to the National Technical Information Service (NTIS).

AFML-TR-73-305

This technical report has been reviewed and is approved.

David I. G. Jones

DAVID I.G. JONES
Project Monitor

FOR THE COMMANDER

Vincent J. Russo

VINCENT J. RUSSO
Actg Chief, Metals Behavior Branch
Metals & Ceramics Division

ABSTRACT

This report describes some of the results of an investigation to evaluate the effect of constrained layer damping treatments on cabin noise levels in an HH-53C helicopter. Vibration and noise levels were measured for various flight conditions, including hover, forward flight and banked, and in each case it was observed that the damping treatment reduced vibration and noise levels in certain frequency bands within which natural modes of vibration were strongly excited. Ground vibration tests under artificial excitation and laboratory vibration tests on simpler but related structures were also conducted to further understand the phenomena involved and to develop appropriate damping treatments for broad temperature range noise control applications.

TABLE OF CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (CONTD)

NOMENCLATURE

A	dimensionless constant
B	dimensionless constant
D	subscript denoting damping material
E	Young's modulus of elastic material
E_D	real part of Young's modulus of damping material
E_c	constraining layer modulus
E_e	effective Young's modulus
e	E_D/E - modulus ratio
f	frequency (Hz) also function
f_n	n th resonant frequency
f_{on}	n th natural frequency
f_{nm}	n m th resonant frequency
f_{onm}	n m th natural frequency
f_r	resonant frequency of damped system
g	function
h	thickness of plate or beam
h_D	thickness of damping material
h_c	thickness of contraining layer
L	length of plate between stringers
ℓ	breadth of plate
n	h_D/h = thickness ratio
N	number of layers
r	ratio of λ_n to half wavelength of plate in direction parallel to stringers
S	area of skin

NOMENCLATURE (CONTD)

x,y	coordinates
β_{nm}	dimensionless constant
γ_{nm}	non-dimensional parameter
η_D	loss factor in tension-compression
η_e	effective loss factor
η_s	loss factor - see text
λ_n,λ_{nm}	modal half wavelengths
ν	Poisson's ratio
ξ_{nm}	n m th eigenvalue
ρ,ρ_e,ρ_D	densities
ϕ_{nm}	n m th normal mode. Also shear parameter
ω	frequency (rad/sec)

SECTION I
INTRODUCTION

In many large helicopters, such as the HH-53 system, a significant fraction of the high noise levels encountered inside the cabin is often due to clearly identifiable structural resonances of the fuselage skin structure, the supporting frames, the transmission oil-pan cover and housing, etc. For such resonant modes of vibration, the use of suitably optimized damping treatments might be expected to contribute significantly to the reduction of internal cabin noise levels, and the question arises as to how effective damping is as a noise control technique. A clear need exists for a simple, effective, technique to reduce internal noise levels as much as possible without obstructing access to the various hydraulic and electrical lines running along the fuselage. This requirement is necessary in combat situations, and the damping treatment being considered in this report, used perhaps in conjunction with a relatively thin acoustical foam for sound absorption, will meet all of these criteria, at least for the HH-53 system.

It is the purpose of this report to describe the results of an investigation conducted during a two week period in September 1972, at Hill Air Force Base, Utah. The purpose of this investigation was (a) to delineate the role of resonant modes of the structure as secondary sources of noise within the cabin of one particular type of helicopter, namely a USAF MAC HH-53C system and (b) to determine the possible reduction in cabin noise levels which might be attainable by use of optimized damping treatments, by reducing the level of the most important resonances contributing to the noise. The flight test investigation was conducted as part of a joint effort between the Air Force Materials Laboratory, the Air Force Flight Dynamics Laboratory, the HH-53 System Program Office, USAF Military Airlift Command (MAC) at Hill AFB, Ogden, Utah, and the University of Dayton. Ground vibration tests were also conducted by Air Force Materials Laboratory and University of Dayton personnel, and optimization studies of suitable damping treatments were carried out at the Air Force Materials Laboratory. Only the Air Force Materials Laboratory and University of Dayton efforts will be described in detail, since the complete flight test results are to be published as an Air Force Flight Dynamics Laboratory report (Reference 1). The two reports are complimentary, since one describes the damping technology used in some detail, while the other concentrates on the flight test investigations. Further details are also discussed in Reference 2.

SECTION II
DESCRIPTION OF SYSTEM

Figure 1 illustrates the helicopter under investigation. Figures 2 to 4 show some details of the particular helicopter geometry examined in these tests. Figure 2 is a sketch of the sideview of the aircraft, with station numbers superimposed. Figure 3 shows an isometric view of the center cabin structure, where the damping treatment was applied. Figure 4 shows the center cabin skin-stringer structure, with locations of some of the transducers indicated.

In the test series, the approach adopted was to:

(a) use artificial excitation with a small shaker to determine structural response behavior and modal damping on the ground.

(b) remove a small section of the acoustic blankets between two frame stations (ST #322 and ST #362) and from waterline 140 to a point under the transmission and apply an appropriate multiple layer damping treatment to exposed skin panels.

(c) conduct further artificial excitation tests on the damped structure to determine effects on structural response behavior and modal damping.

(d) conduct in-flight vibration and acoustic tests to measure internal noise levels and panel response behavior at several locations for the helicopter in the acoustically untreated condition, the acoustically treated condition, and the partly acoustically treated, partly damped condition.

(e) conduct narrow band spectral analysis of the in-flight data to determine the effect of the various treatments on noise and vibration spectra. Figures 5 and 6 show the treated area in more detail.

(f) conduct laboratory vibration tests and analysis to determine the behavior of various modifications of the basic multiple constrained layer treatment with a view to broadening the useful temperature range of the damping treatment.

SECTION III
GROUND VIBRATION TESTS

1. VIBRATION TESTS ON HH-53C HELICOPTER

The purpose of the ground vibration tests was to establish the effectiveness of the damping treatment in reducing vibration levels in the skin panels prior to donducting the in-flight tests. The structure was excited at a discrete frequency, swept through the range 100 Hz to 3500 Hz, by means of a small shaker through an impedance head applied at the center of panel A-14. The block diagram of the system is shown in Figure 7. The test setup is shown in Figure 8. Typical response spectra obtained at panel A-14, through a miniature accelerometer at the center of the panel, are shown in Figure 9 for the undamped system, the system with Panel A-14 damped only, and all panels treated, respectively. It is seen that putting a damping treatment on panel A-14 achieved little or no reduction in amplitude but that the full treatment gave a vibration level reduction of the order of 10 db in the frequency band around 1370 Hz. This means, as might be expected, that adjacent panels are important in determining the response behavior of a given panel.

It is important to realize that the treatment used in these ground vibration tests, and in the subsequent in-flight tests, utilized one particular room-temperature viscoelastic adhesive, which is not intended for application at other temperatures. Specifically, the treatment consisted of three layers of room temperature adhesive (Reference 3), 0.002 inches thick, sandwiched between three layers of aluminum foil, 0.005 inches thick, and attached to the skin-panel surface by the outside layer of adhesive, as sketched in Figure 10. The complex modulus behavior of this adhesive, as measured by the variation of the real part of the Young's modulus and the loss factor with temperature and frequency, is illustrated in Figure 11. This material is both temperature and frequency sensitive and is most effective in a layered damping treatment. It should be recognized that the treatment considered in these particular tests utilized only one adhesive material and was optimized for operation near room temperature. The next two sections are concerned in part with the approach used to broaden the effective temperature range of the treatment.

2. VIBRATION TESTS ON CLAMPED-CLAMPED BEAM

In order to demonstrate the typical behavior of structures damped by multiple constrained layer treatments, it is convenient to report also on some tests carried out, for different purposes, on a clamped-clamped beam. The test system is illustrated in Figures 12 and 13. Tests were carried out in which modal damping and resonant frequencies were measured for a 7 inch by 1 inch by 0.05 inch thick aluminum beam with various layered treatments added. The first type of treatment

(a) considered was the same as that used on the HH-53 tests, namely alternate layers of RT adhesive 0.002 inches thick and aluminum foil 0.005 inches thick. Graphs of modal loss factor η_s versus temperature and frequency are illustrated in Figure 14, for several modes of vibration. Further details are available in References 4 and 5. In Reference 4 it is shown that for three or more layer pairs in the treatment, it may be treated as if it were an equivalent homogeneous free layer treatment having appropriate complex modulus values which depend on the properties of the adhesive, the properties of the constraining layer, and the modal half-wavelength. The equivalent Young's modulus and loss factor of the treatment are shown in Reference 4 to be a function of the "shear parameter" ϕ_n and the thickness ratio h_c/h_D, in the following manner:

$$E_e/E_c = f(\phi_n, h_c/h_D) \tag{1}$$

$$\eta_e/\eta_D = g(\phi_n, h_c/h_D) \tag{2}$$

where

$$\phi_n = \frac{E_D}{E_c} \frac{1-\nu^2}{r^2+1} \frac{\lambda_n^2}{h_c h_D} \tag{3}$$

AFML-TR-73-305

CONSTRAINED LAYER TREATMENTS FOR NOISE CONTROL IN A HELICOPTER

Approved for public release; distribution unlimited.

(c) a treatment consisting of alternate layers pairs of RT adhesive 0.002 inches thick and aluminum foil 0.005 inches thick, and low temperature (LT) damping tapes (Figure 16). The adhesive in the LT treatment is a low temperature damping material (Reference 7) while the RT adhesive is most effective near room temperature.

(d) a treatment consisting of two layers of LT damping tape, and one layer of RT adhesive with a 0.005 inch thick aluminum foil containing layer (Figure 16).

Test results for treatment (b) through (d) are illustrated in Figures 17 to 19. Treatments (b) and (c) both increase the temperature range over which a significant amount of damping can be achieved, whereas treatment (d) does not. Figure 20 shows the variation of E_D and η_D with temperature and frequency for the LT adhesive system.

3. VIBRATION TESTS ON SIMPLE STIFFENED STRUCTURES

It is possible to estimate, to some degree of accuracy, the effect of these damping treatments on stiffened structures more representative of the HH-53 helicopter fuselage. It has been shown in Reference 8 that the modal damping and resonant frequency of a multi-span stiffened plate structure uniformly covered with a multiple layer damping treatment having a single adhesive material and a single constraining layer material, are given by:

$$\eta_s/\eta_e = 1 + (A - 2 + \gamma_{nm})/Be \qquad (6)$$

$$(1 + \rho_e h_e/\rho h)(f_{nm}/f_{onm})^2 = 1 + (A - 2 + Be)/\gamma_{nm} \qquad (7)$$

$$\text{where } \gamma_{nm} = \frac{\rho\,\omega_{nm}^4 \iint_S \phi_{nm}^2\, dx\,dy \,/\, D^4}{\iint_D \left[\left(\frac{\partial^2 \phi_{nm}}{\partial x^2}\right)^2 + \left(\frac{\partial^2 \phi_{nm}}{\partial y^2}\right)^2 + 2\nu\left(\frac{\partial^2 \phi_{nm}}{\partial y^2}\right)\left(\frac{\partial^2 \phi_{nm}}{\partial x^2}\right)\right] dx\,dy} \qquad (8)$$

$$A = [(1 - n^2e)^3 + (1 + [2n+n^2]e)^3]/(1 + ne)^3 \quad (9)$$

$$B = [(2n + 1 + n^2e)^3 - (1 - n^2e)^3]/(1 + ne)^3 \quad (10)$$

β_{nm} is a non-dimensional parameter depending on the eigenvalues, normal modes, and second derivatives of the structure. The normal modes and eigenvalues can be measured or calculated by transfer matrix techniques (Reference 9) or in other ways. In the absence of such data, as was the case for the HH-53 investigation, it is necessary to estimate β_{nm} by some other means. One such way is to apply a known homogeneous free layer material to the skin of the structure, measure the modal damping η_s, and deduce the value of β_{nm} from Equation 6, using known values of $e = E_D/E$ and $n = h_D/h$. For a skin-stringer structure of geometry very similar to that of the HH-53 system, and illustrated in Figure 21, β_{nm} has been estimated to be about 8.0, as compared with a value of 2.0 for the clamped-clamped beam (Reference 11). On the basis of this value of β_{nm}, one can then estimate η_s for the structure with a constrained layer treatment added, of type (a). Results for such calculations are illustrated in Figure 22, along with some of the measured test results. It is seen that changing β_{nm} from 2 to 8 alters the numerical values of η_s but does not appreciably change the qualitative manner in which η_s varies with temperature. It is this fact which makes the clamped-clamped beam tests a fairly reliable indicator of the general behavior of more complex damped systems, such as the HH-53.

SECITON IV
IN-FLIGHT TESTS

Accelerometer, microphone, and thermocouple measurements were recorded on magnetic tape, for each operating condition of the helicopter. A total of 44 sets of records was obtained. The test system used is illustrated in Figure 23. The data was recorded on a Honeywell Model 7600 tape recorder/reproducer system. Automatic gain changing amplifiers were used, with the gain levels determined for each transducer during each test condition. Narrow band analysis of the test data recorded on the magnetic tapes was conducted using a Spectral Dynamics Model SD101A Dynamic Analyzer, with a 50 Hz bandwidth and a scan rate of 10 Hz per second. Third octave band analysis was also conducted for preliminary evaluation of the data, but these results are not discussed in this report. Figures 23 to 25 show some aspects of the measuring system used in more detail.

The full test series is described in Reference 1, therefore only a few cases will be reported herein. Figure 26 shows narrow band spectra obtained for accelerometer A-14 and microphone M-3 for three flights, in the condition of 100% OGE Hover, Flight 1 corresponds to the aircraft completely stripped of all acoustic treatments, i.e. the usual service condition. Flight 2 had acoustical blankets over the entire fuselage area except for the area under the transmission housing where the damping treatment was to be applied, as illustrated in Figures 2 and 5, and with the drip pan cover under the transmission also treated. Flight 3 was identical to Flight 2 except that the damping treatment was added to the skin in the designated area. Some difficulty was experienced during Flight 2 due to improper closing of a door, but the results obtained seem to indicate some improvement due to damping. Figure 24 shows the position of accelerometer A-14 and microphone M-3 relative to the fuselage skin and the panel frames. Figure 27 illustrates the block diagram of the flight test instrumentation.

SECTION V
SUMMARY AND CONCLUSIONS

Four flight tests, plus additional ground tests, were performed on an HH-53 C Helicopter to evaluate the effectiveness of multiple layer damping treatments, applied to the fuselage skin, as a means of reducing high frequency cabin noises associated with re-radiation of sound by the skin structure.

Acceleration, acoustic, and temperature measurements were made on the aircraft at several locations and for several flight conditions. Cabin noise peaks which occurred near 1370 Hz, 2600 Hz, and 5400 Hz corresponded to specific gear clash frequencies. At these frequencies, the transmission caused the heavy supporting frame to vibrate. This in turn excited resonant frequencies in the skin-stringer structure of the fuselage. Several resonant frequencies occurred near 1370 Hz so that slight changes in the excitation frequencies did not de-tune the system but simply excited different modes in the skin-stringer structure, with no significant change in sound levels. The higher frequency peaks corresponded to resonances in the heavy supporting frame as well as in the skin-stringer structure.

Only a small portion of the structure was covered with damping treatment, the remainder of the cabin being covered with acoustic blankets. This was done to conserve the limited amounts of damping material available. The treatment was optimized for room temperature application only, since materials and treatments for broader temperature ranges were not available at the time of the tests. More suitable treatments have been designed and are discussed here. The damping treatment used in the test was shown to be effective in reducing skin vibrations and hence the radiated noise in the cabin, particularly near the 1370 Hz peak. Significant reductions, up to 12 dB, in skin acceleration were noted at frequencies where the skin was a major noise source. Acoustic measurements in the cabin demonstrated a 5 to 11 dB reduction in noise level, although fully representative quantitative measurements were difficult to make because of the relatively small area treated by damping, the large number of noise sources and differences in cabin door positions during some of the tests. Further efforts using broader temperature range damping treatments and more coverage are clearly needed.

It was also observed that the transmission drip pan was a major source of cabin noise and an effort to increase its acoustic transmission loss should be made in any future tests. In the present tests, some reduction was achieved by adding a combination of fiberglass and lead vinyl blankets under the drip pan.

The following conclusions are therefore drawn from this effort:

(1) Significant cabin noise peaks were found to occur near 1370 Hz, 2600 Hz, and 5400 Hz.

(2) The 1370 Hz peak corresponds mainly to vibrations of the skin.

(3) The 2600 Hz and 5400 Hz peaks were mainly related to resonances of the heavy supporting frame, as well as the skin-stringer structure.

(4) The damping treatment used in these tests, which was of limited useful temperature range and covered a limited area, resulted in 12 dB vibration level reduction at certain frequencies and a 5 - 11 dB reduction in cabin noise level.

(5) For broad temperature range applications, it was found that damping treatment configuration (b), illustrated in Figure 16, gave the best results in tests on a clamped-clamped beam, other treatment configurations with other stacking sequences not being as effective. While these results are appropriate for somewhat different structural configurations than the HH-53 fuselage, these results should be borne in mind in future tests. It should also be noted that these damping techniques are appropriate for controlling noise resulting from radiating resonant structures and the presence of such resonances should be verified before applications are considered.

REFERENCES

1. Test Report on HH-53 Helicopter; Effect of Multilayer Damping Treatment on Vibratory and Interior Acoustic Environment, Air Force Flight Dynamics Laboratory report to be published.

2. J.P. Henderson and A.D. Nashif, "Reduction of Interior Cabin Noise Levels in a Helicopter Through Additive Damping", to be presented at 44th Shock and Vibration Symposium, Houston, Texas, December 1973, and subsequently published in the Shock and Vibration Bulletin.

3. Acrylic adhesive manufactured by Minnesota Mining and Manufacturing Company, Minneapolis, Minnesota. Properties are same as ISD-112 adhesive, same company.

4. D.I.G. Jones, A.D. Nashif, and M.L. Parin, "Parametric Study of Multiple Layer Damping Treatments on Beams", Journal of Sound and Vibration, 29 (3), 1973.

5. D.I.G. Jones and M.L. Parin, "Technique for Measuring Damping Properties of Thin Viscoelastic Layers", Journal of Sound and Vibration, 24 (2), pp 201 - 210, 1972.

6. H. Oberst and K. Frankenfeld, "Uber die Dampfung Dunner Bleche Durch Festhaltende Belage", Acustica, 1952, Vol. 2, pp 181 - 194, 1954.

7. Acrylic adhesive sold in form of damping tape by Minnesota Mining and Manufacturing Company, Minneapolis, Minnesota. Properties are same as ISD-113 adhesive.

8. D.I.G. Jones, "Damping of Stiffened Plates by Multiple Layer Treatments", to be published.

9. J.P. Henderson and A.D. Nashif, "The Effect of Stringer Width and Damping on Response of Skin-Stringer Structure", Journal of Engineering for Industry (ASME), pp 159 - 166, 1972.

10. D.I.G. Jones and W.J. Trapp, "Influence of Additive Damping on Resonance Fatigue of Structures", Journal of Sound and Vibration, 17 (2), pp 157 - 185, 1971.

11. D.I.G. Jones, "Effect of Free-Layer Damping on Response of Stiffened Plate Structures", Shock and Vibration Bulletin 41, Part 2, pp 105 - 120, 1970.

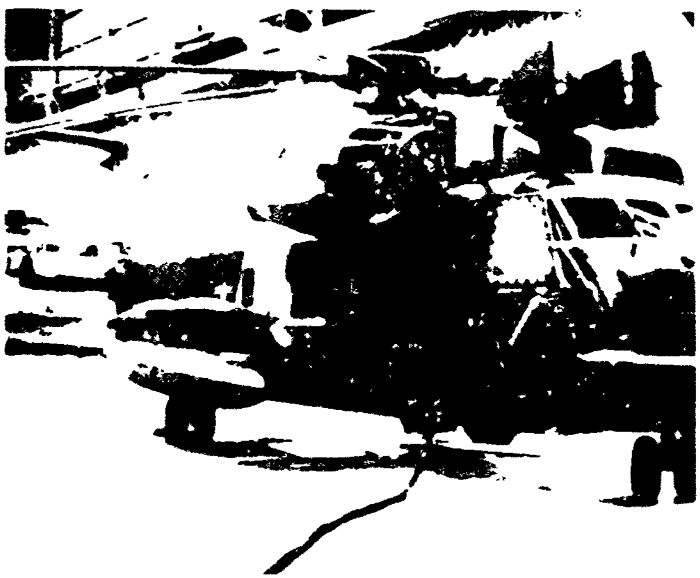

Figure 7 Photograph of HH-53 Helicopter

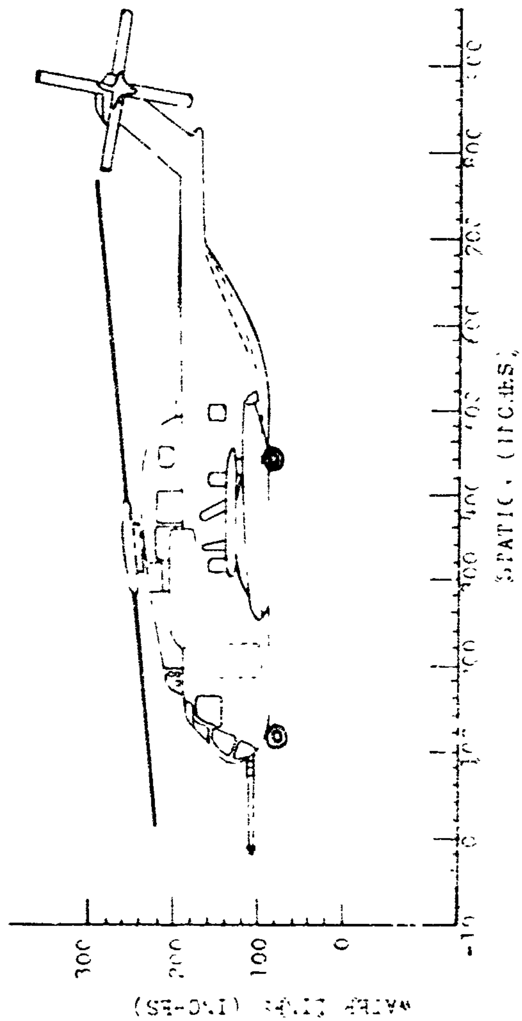

Figure 2. Sideview of HH-53

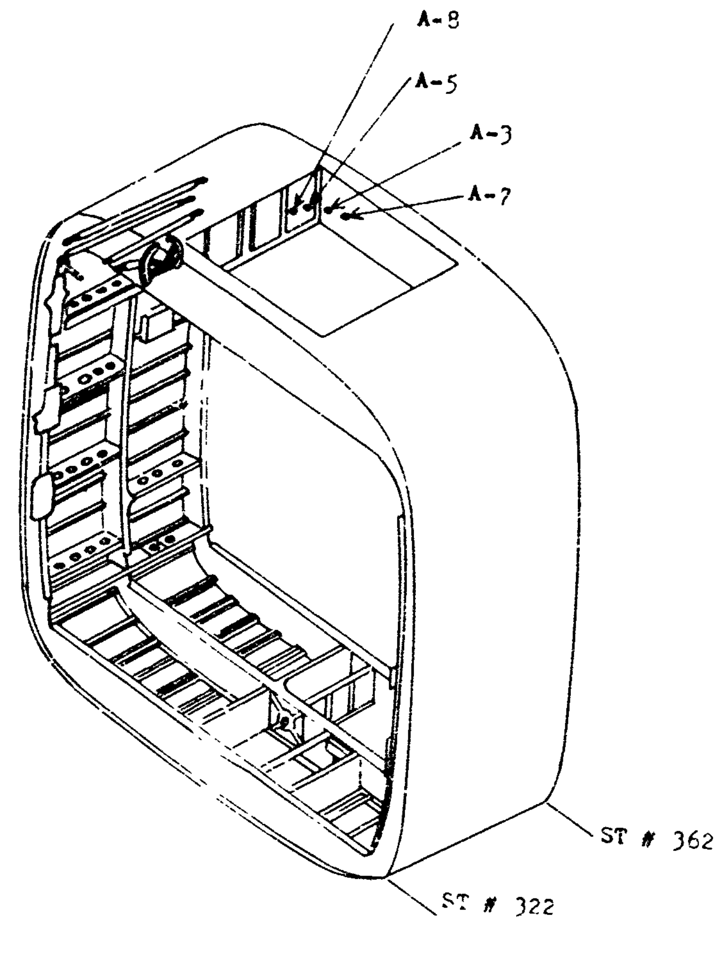

Figure 3. Isometric View of Center Cabin Structure Where Damping Was Applied

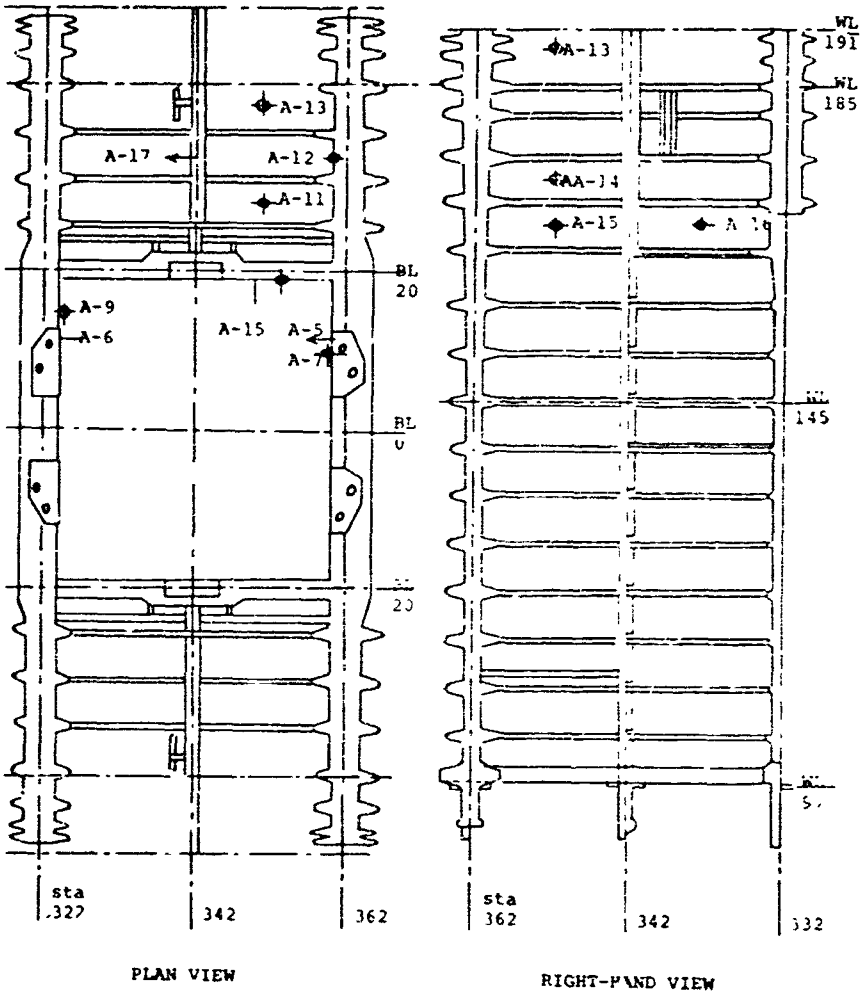

Figure 4. Center Cabin Skin-Stringer Structure Layout

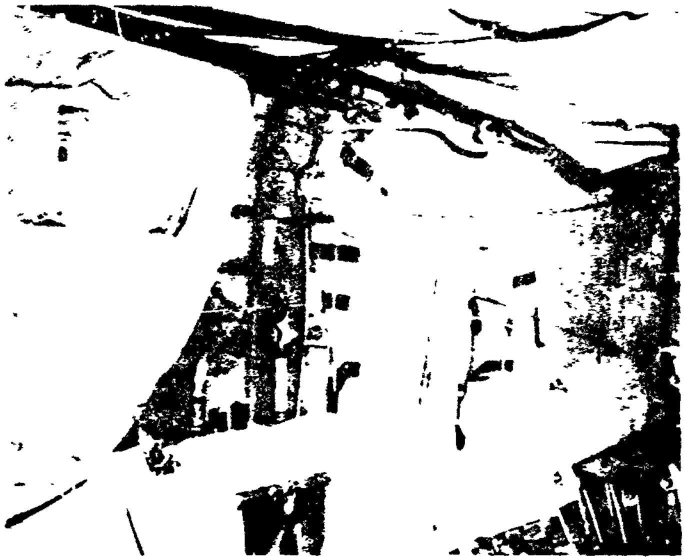

Figure 5. Photograph of Treated Area

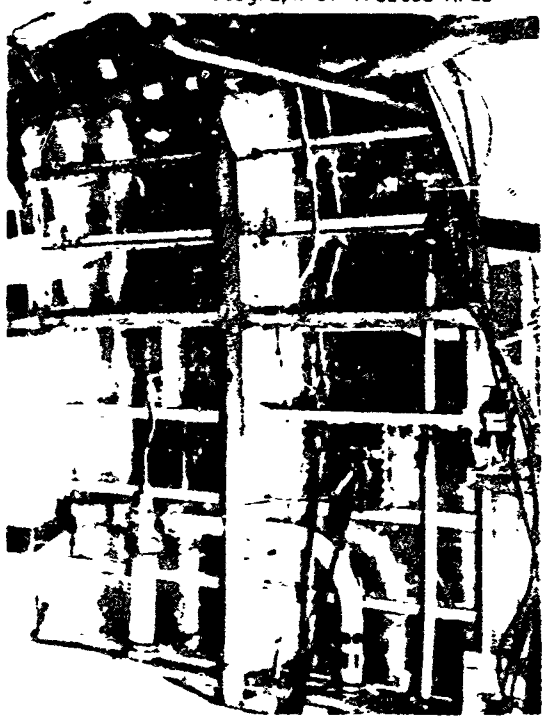

Figure 6. Photograph of Treated Area

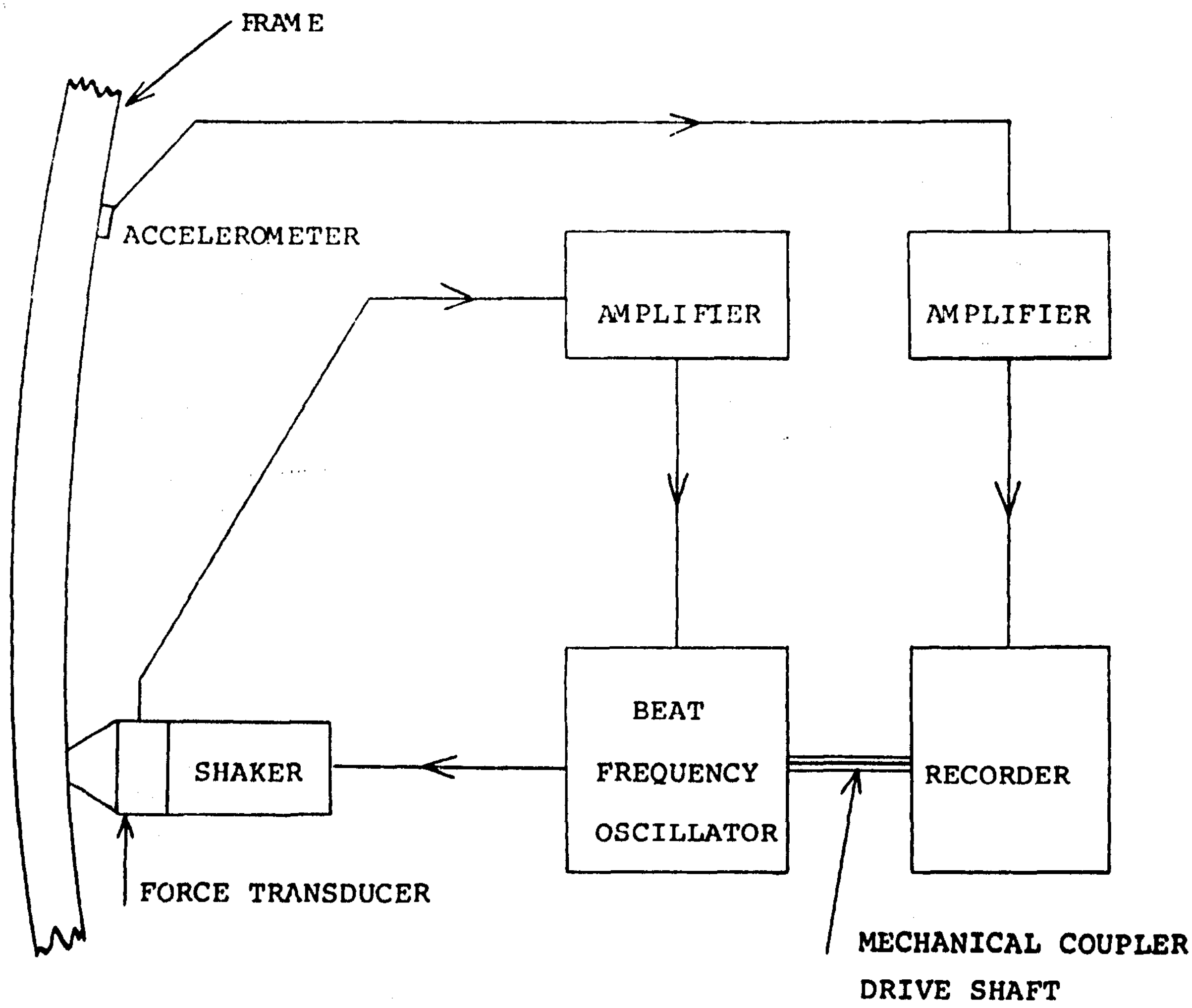

Figure 7. Block Diagram of Ground Test System

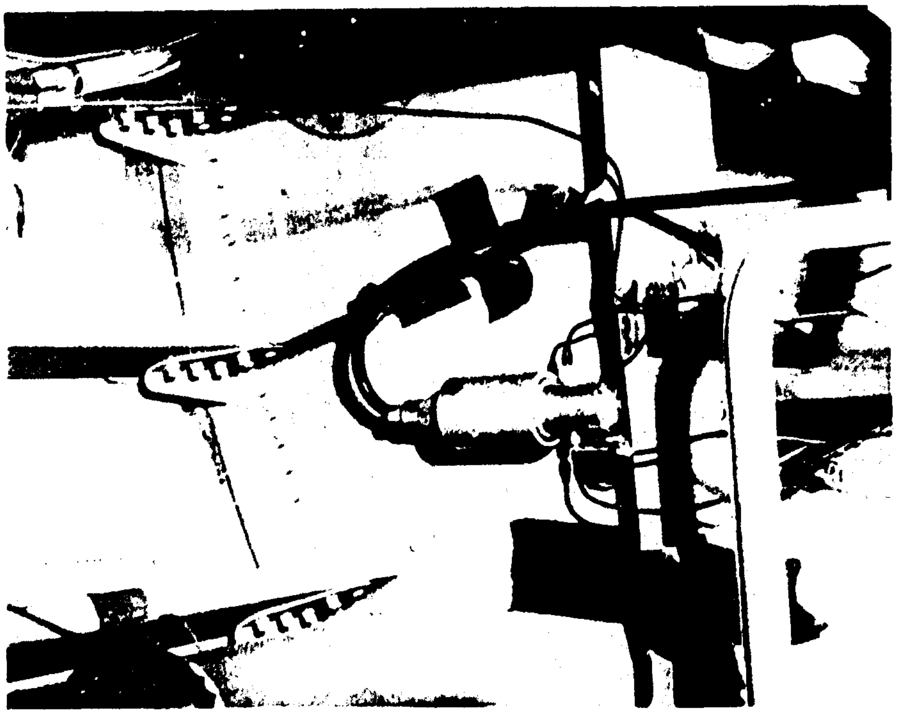

Figure 8. Photograph of Ground Vibration Test System

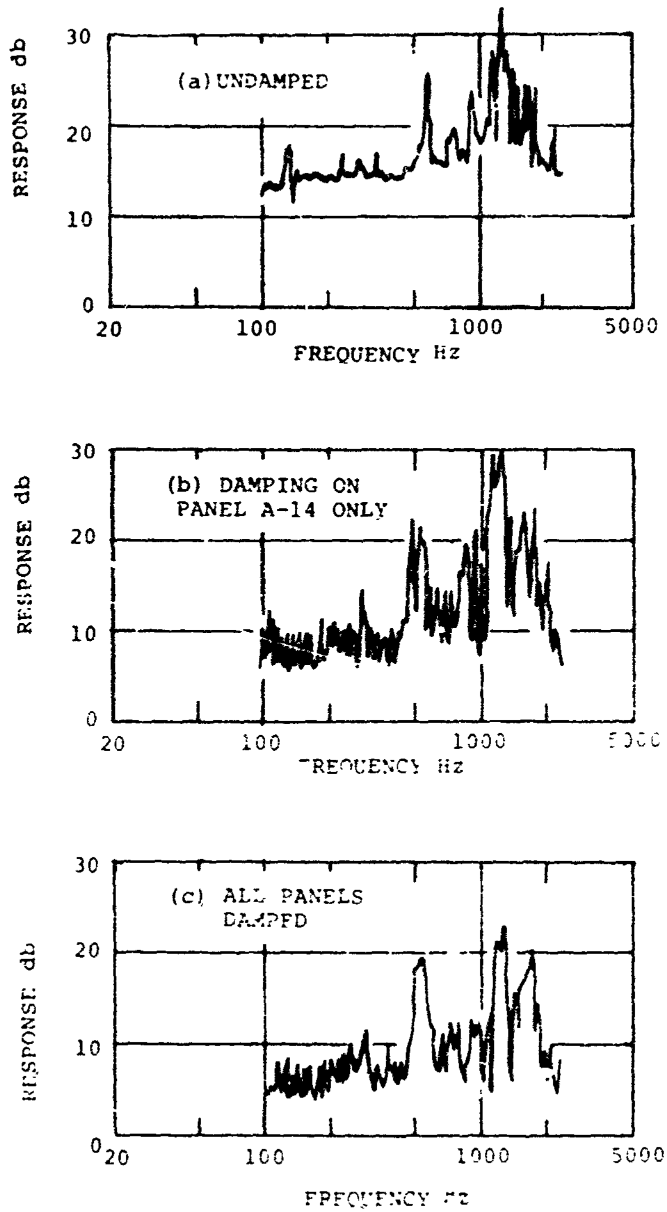

Figure 9. Typical Ground Vibration Test Spectra

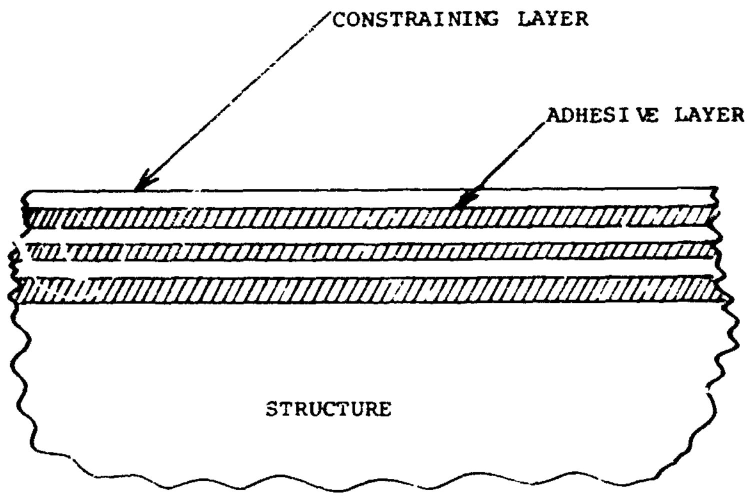

Figure 10. Sketch of Damping Treatment (Type a)

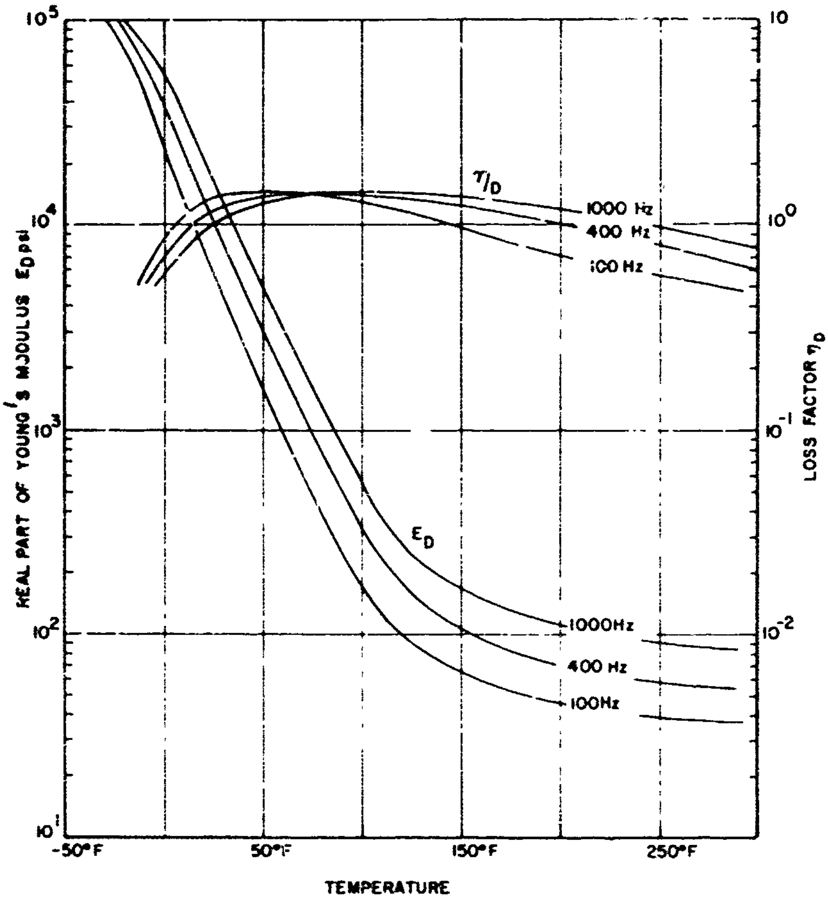

Figure 11. Graphs of E_D and η_D Versus Temperature and Frequency for 3M-467 Adhesive

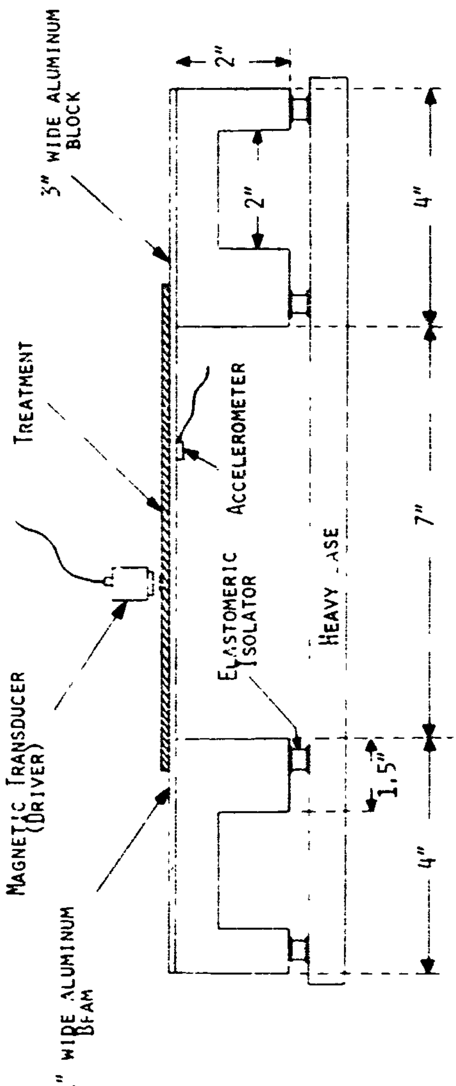

Figure 12 Clamped-Clamped Beam Test System

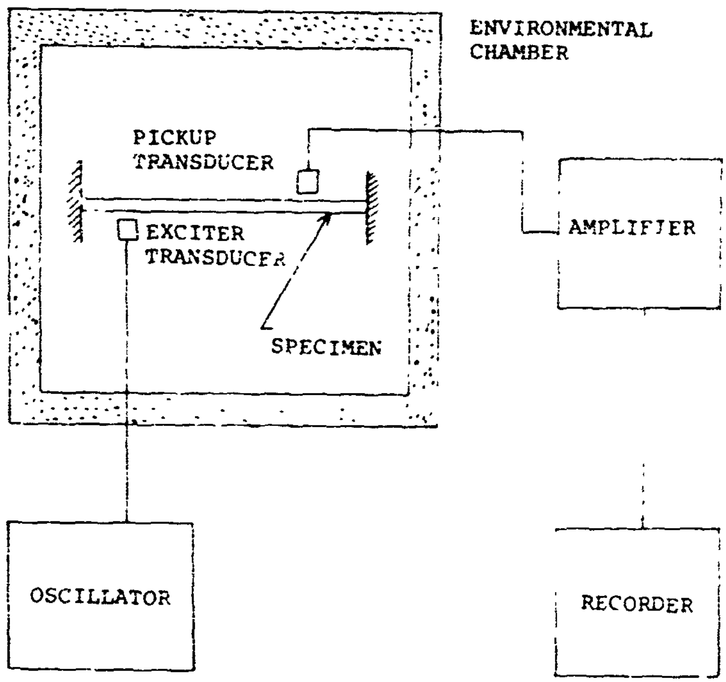

Figure 13. Block Diagram of Test System for Clamped-Clamped Beam

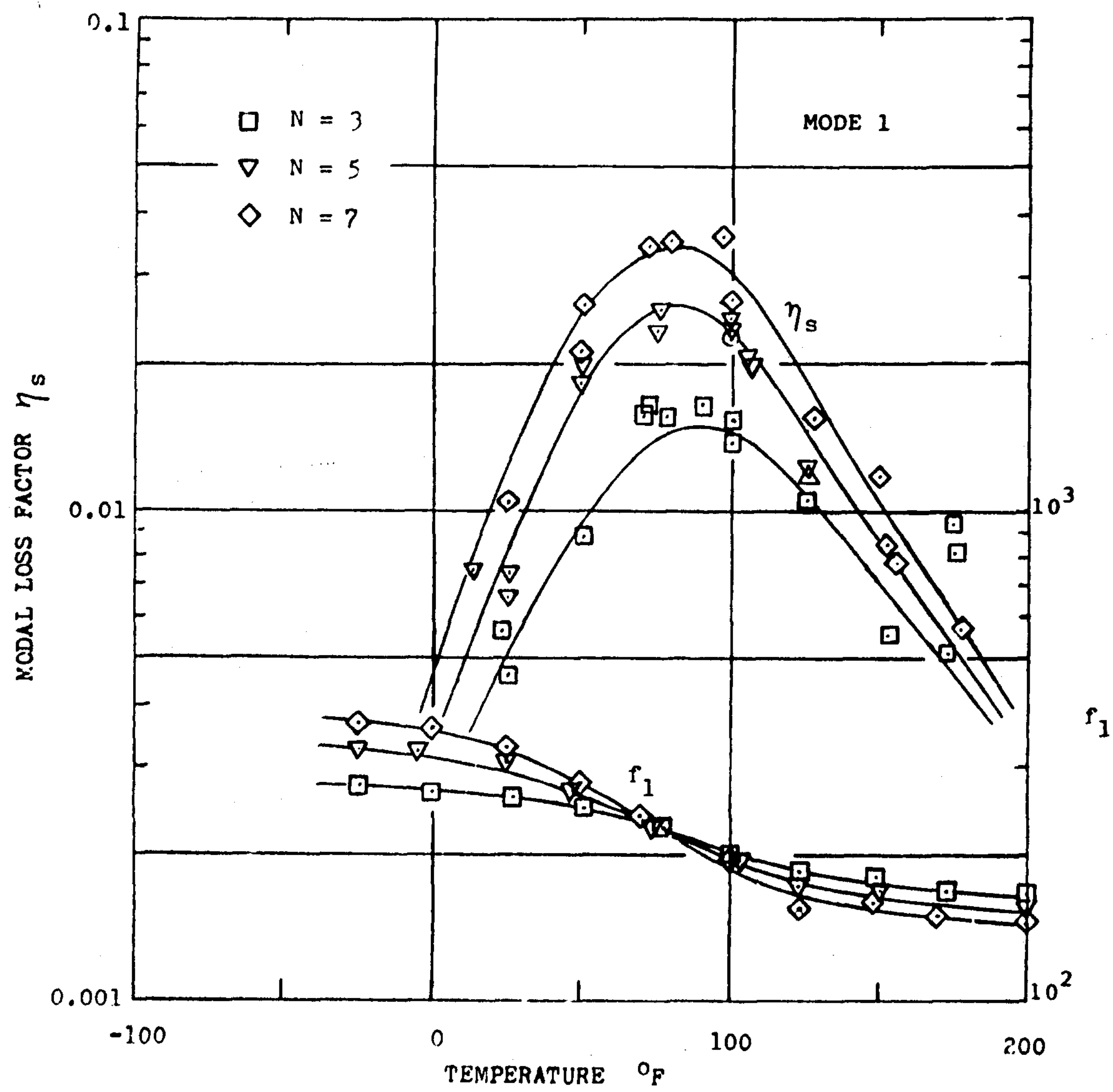

Figure 14. Mode 1 - η_s and f_n Versus Temperature for Configuration (a)

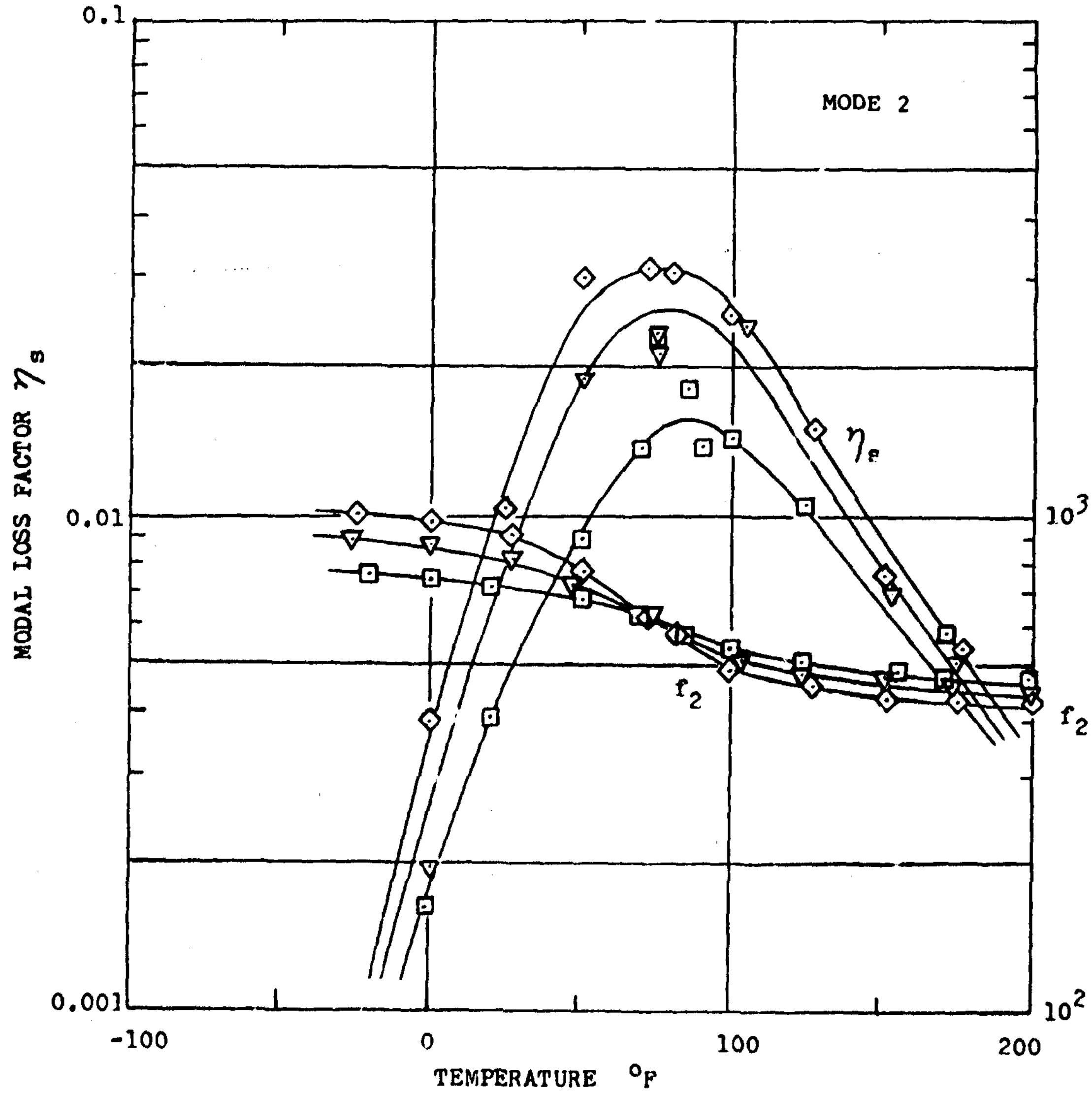

Figure 14. Mode 2 - η_s and f_n Versus Temperature for Configuration (a)

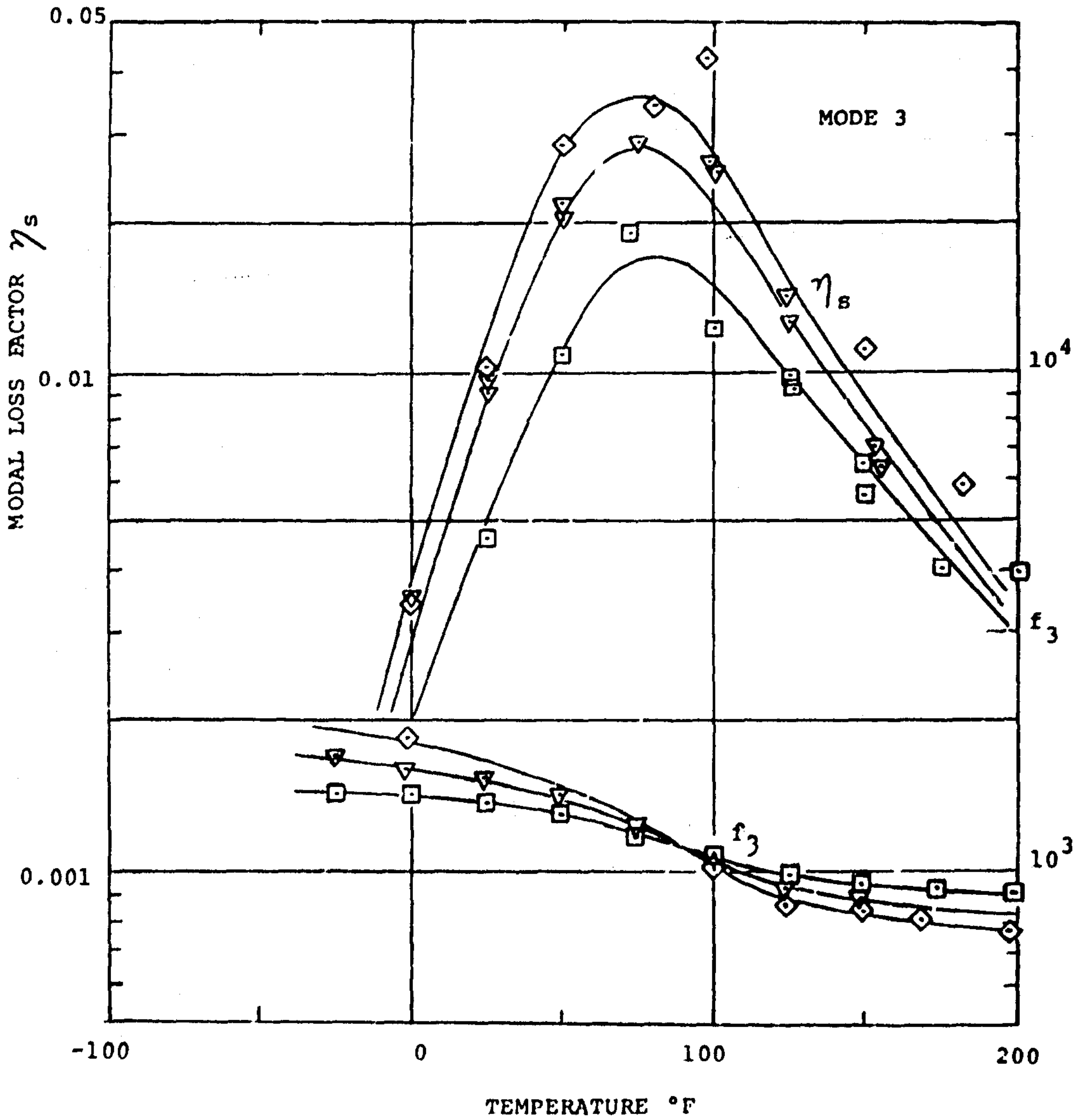

Figure 14. Mode 3 - η_s and f_n Versus Temperature for Configuration (a)

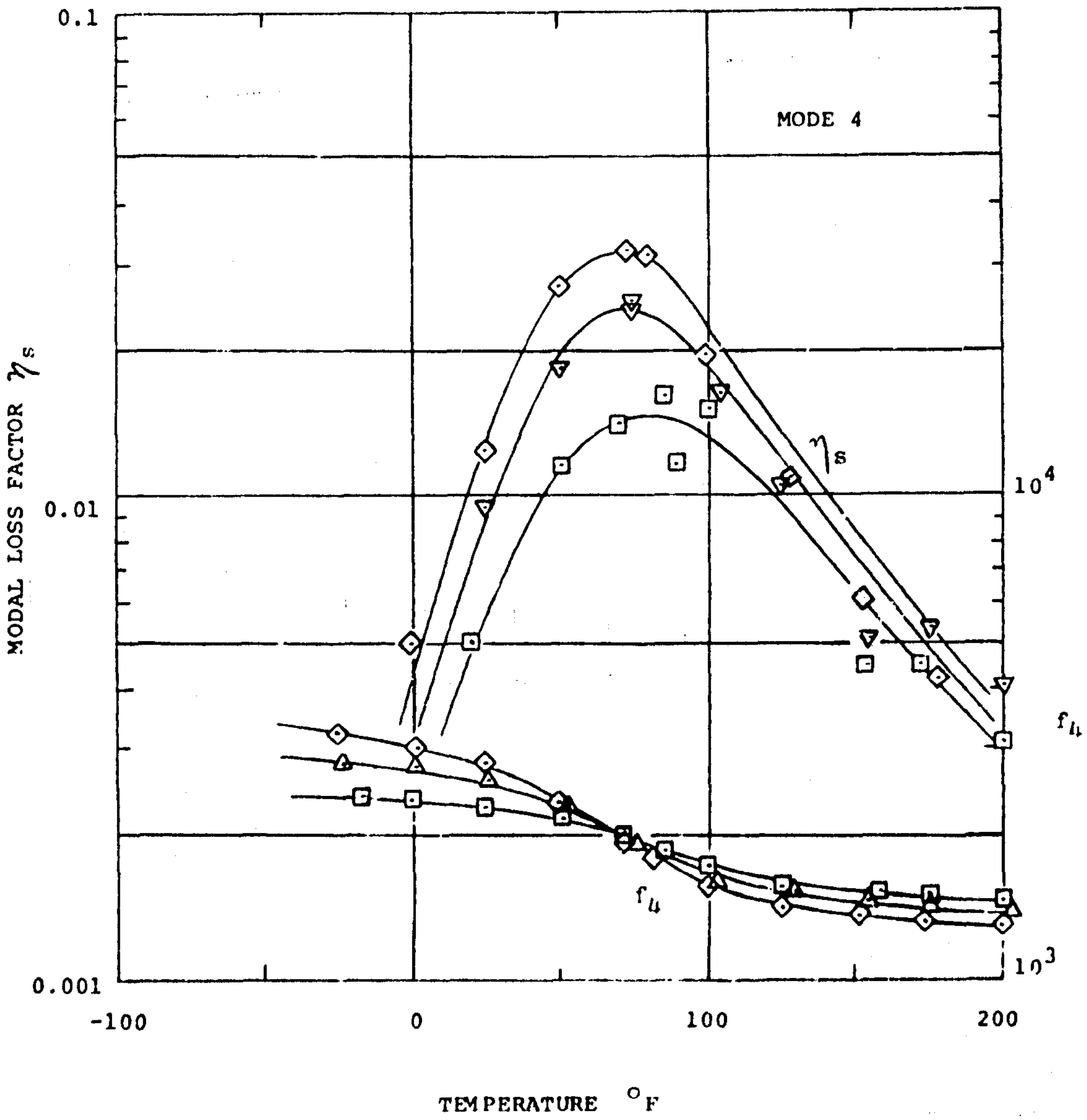

Figure 14. Mode 4 - η_s and f_n Versus Temperature for Configuration (a)

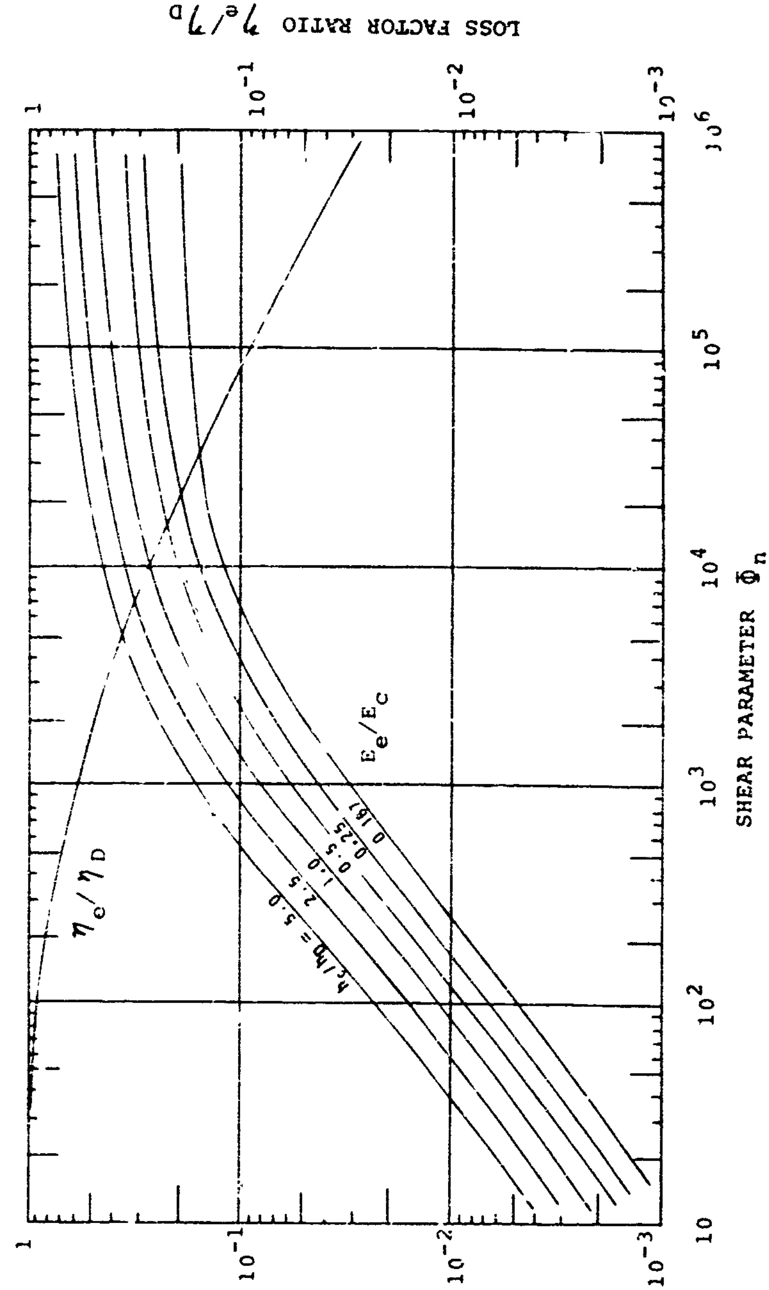

Figure 15. Graphs of E_e/E_c and η_e/η_D Versus Φ_n and h_c/h_D for Multi-Layer Treatment

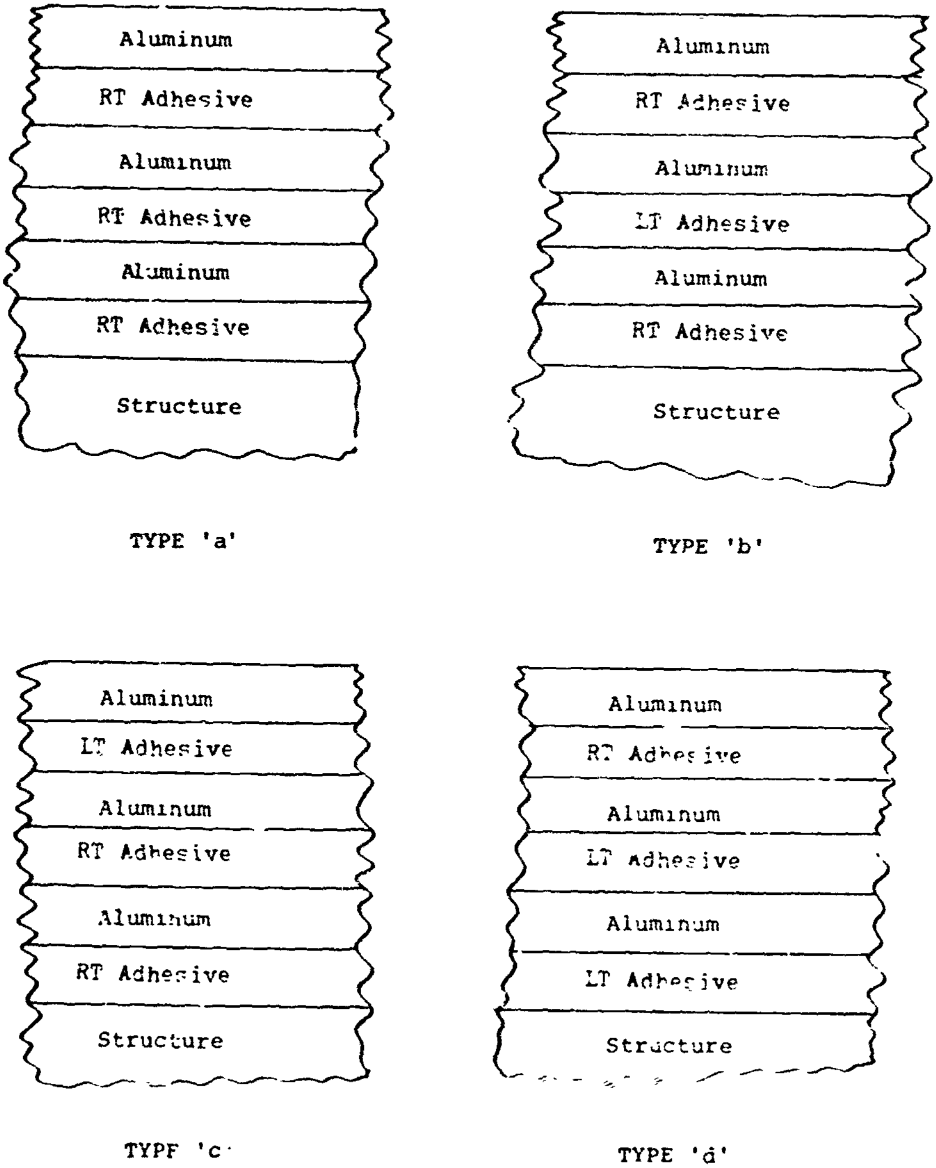

Figure 16. Various Multiple Material/Treatment Configurations

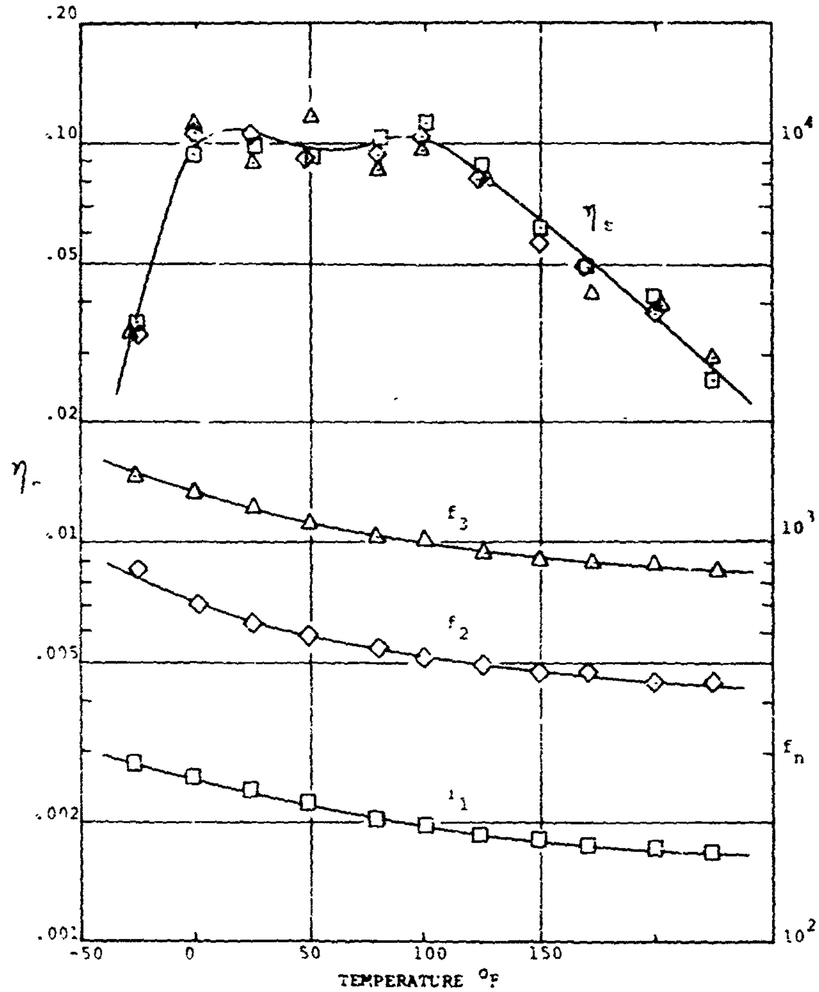

Figure 17. η_s and f_r Versus Temperature for Configuration (b)

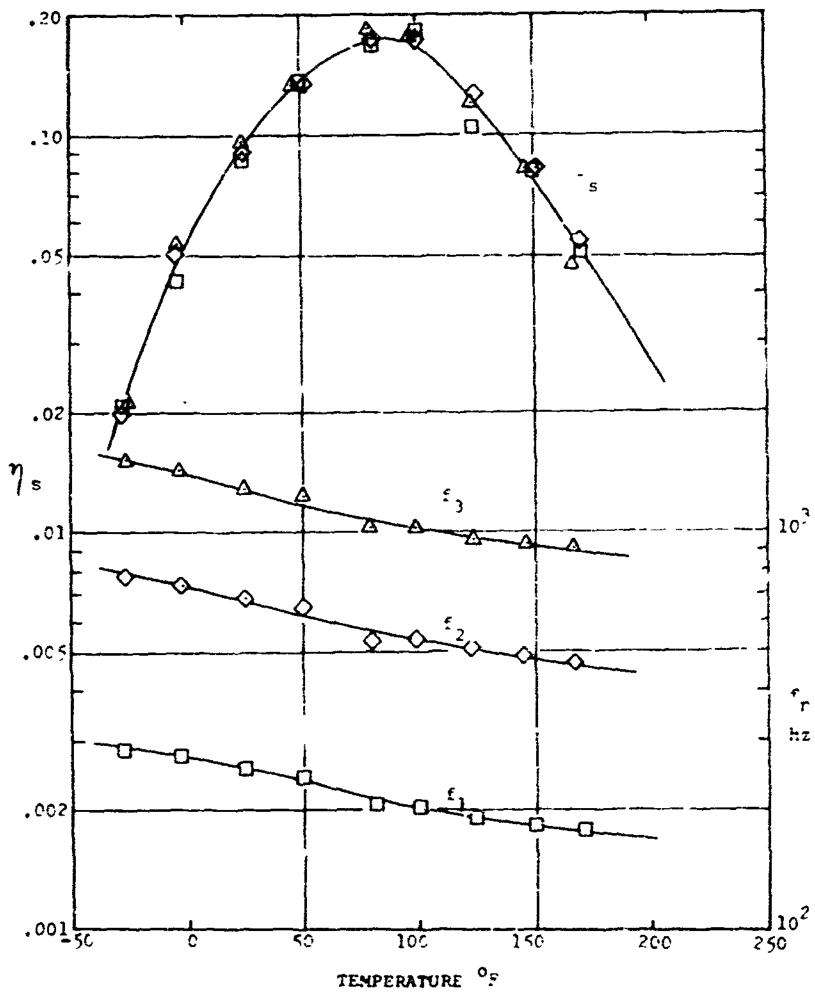

Figure 18. η_s and f_r Versus Temperature for Configuration (c)

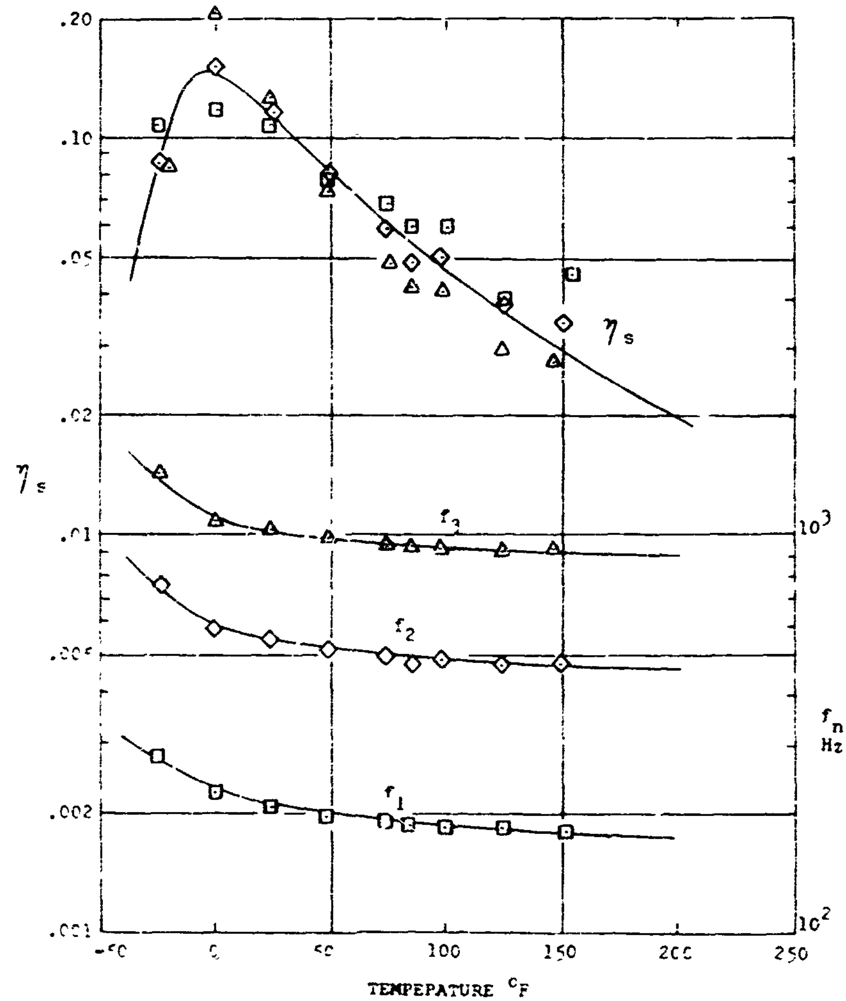

Figure 19. η_s and f_r Versus Temperature for Configuration (d)

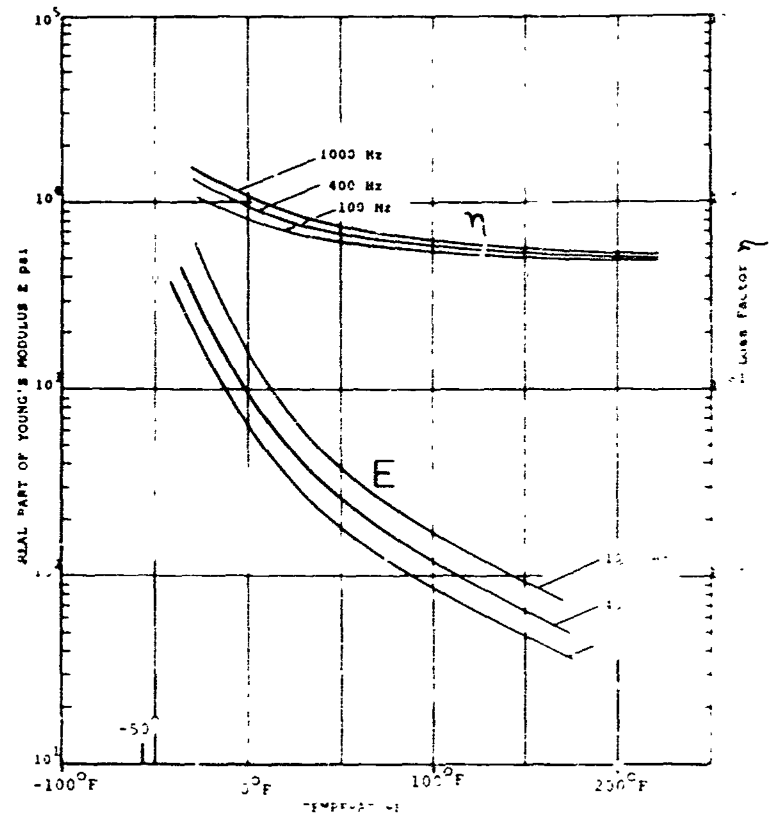

Figure 20. Graphs for E_D and η_D versus Temperature and Frequency for Adhesive in 3M-423 System

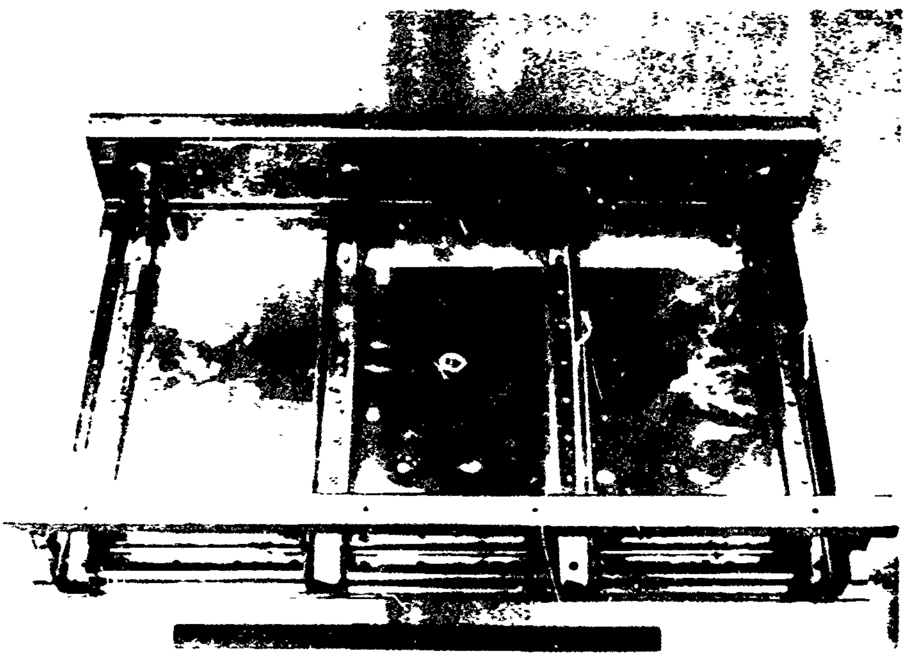

Figure 21. Three Span Structure

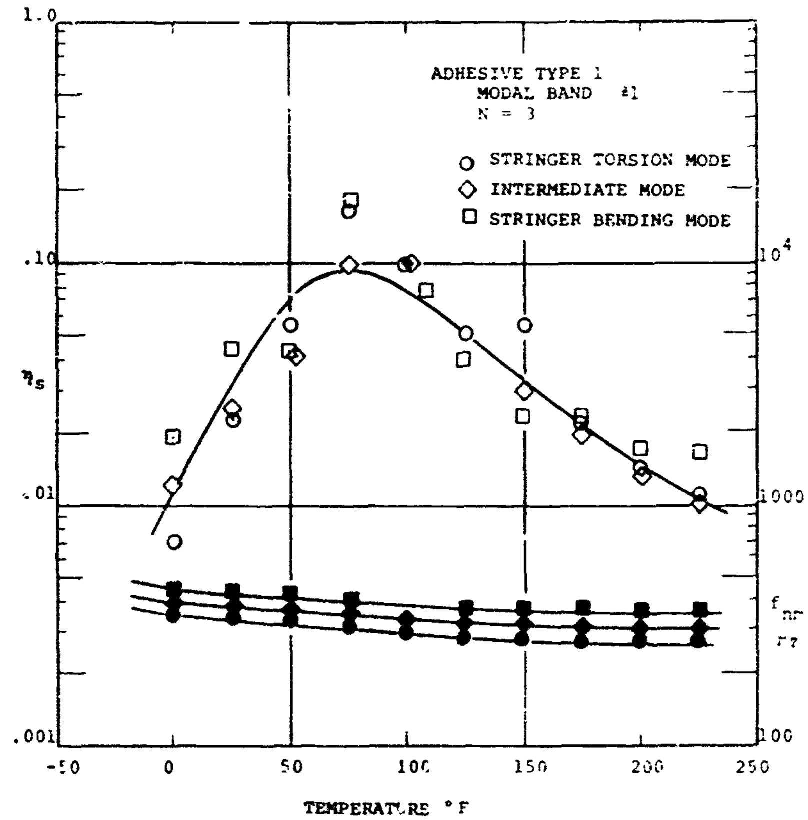

Figure 22. η_s and f_{nr} Versus Temperature for Treatment Configuration (a) on Three-Span Structure

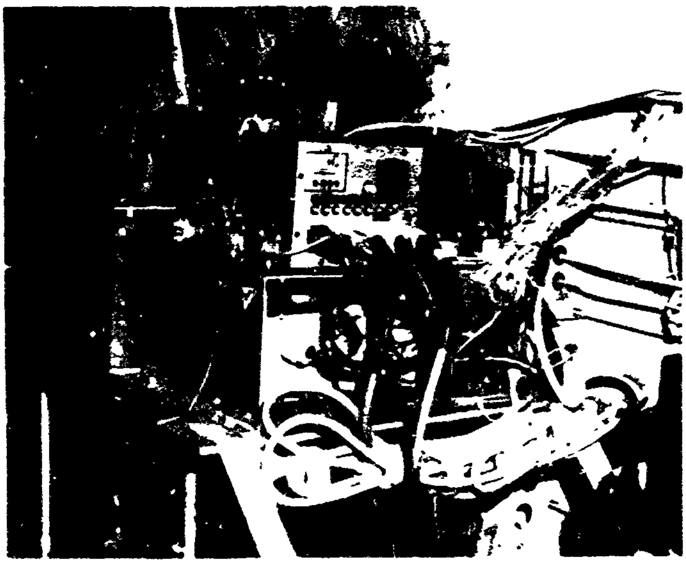

Figure 20. In-Flight Vibration Recording Instrumentation

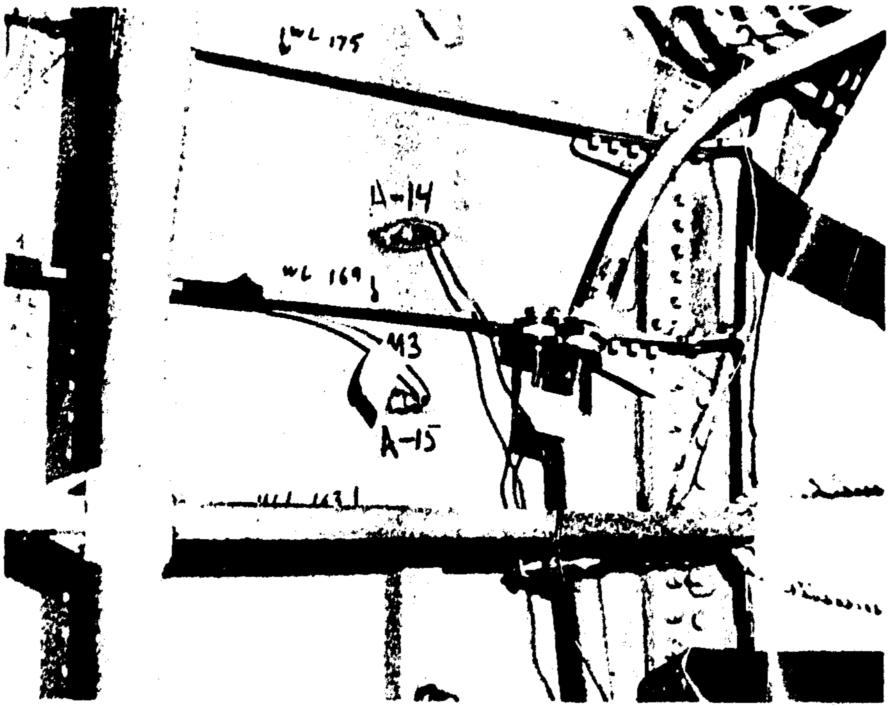

Figure 24. Some Microphone and Accelerometer Locations

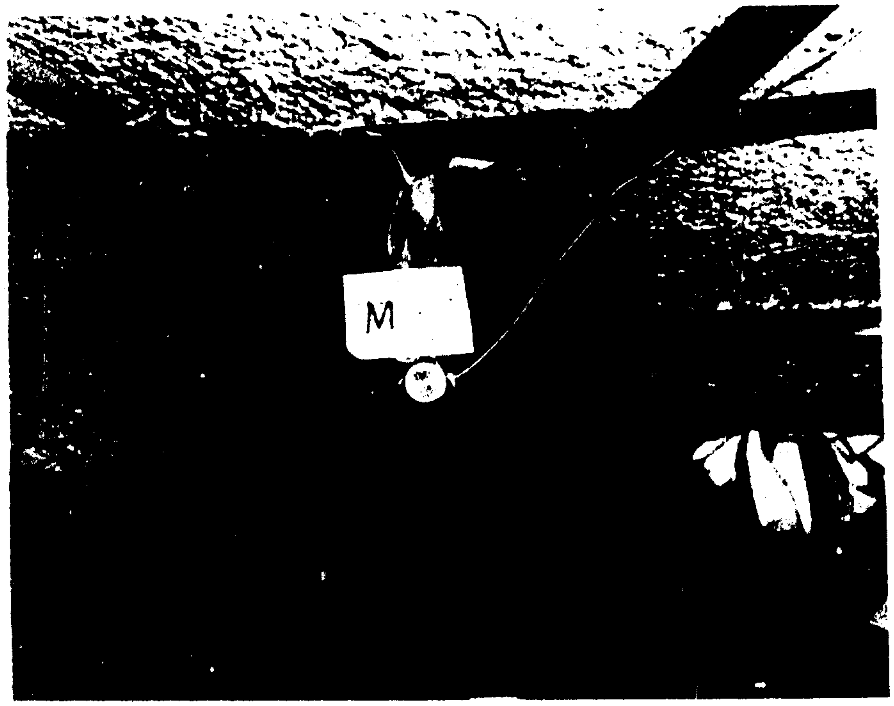

Figure 25. Location of Microphone M_5

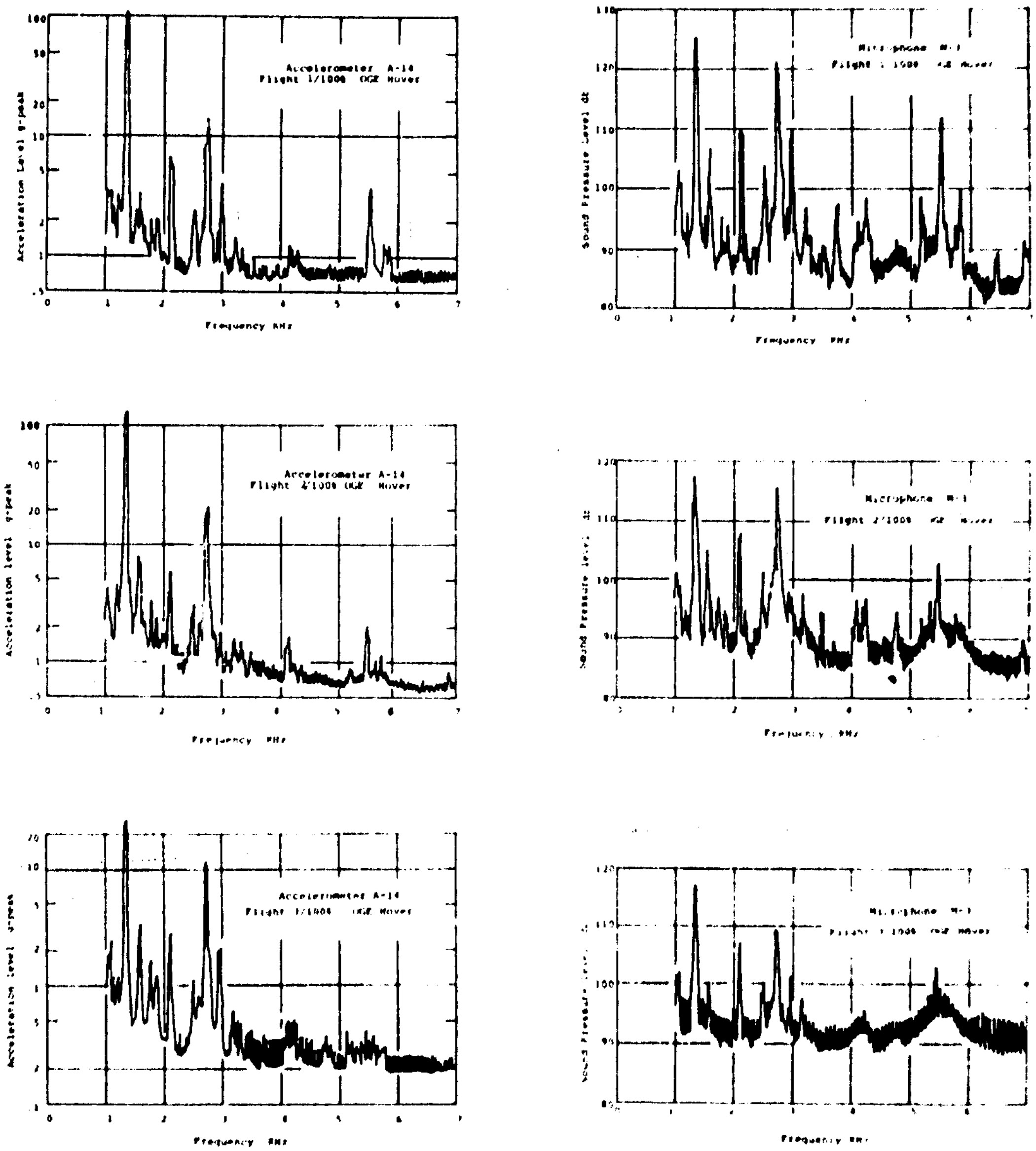

Figure 26. Narrow Band Spectra for Accelerometer A-14 and Microphone M-3

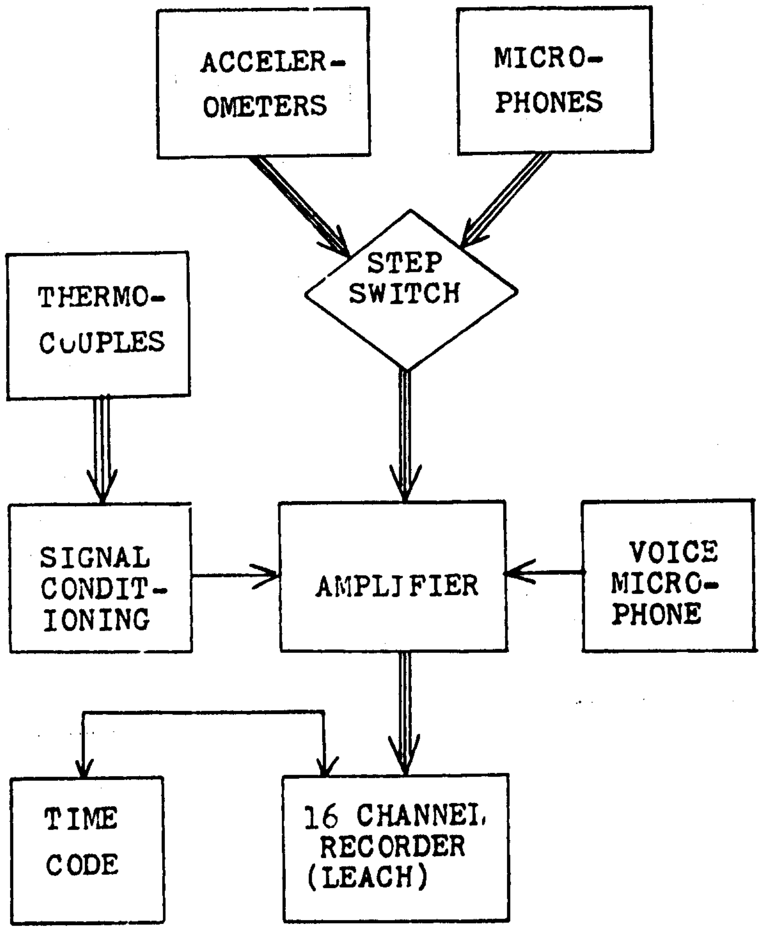

Figure 27. Block Diagram of Flight Test Instrumentation