REPRODUCED AT GOVERNMENT EXPENSE

COMPONENT PART NOTICE

THIS PAPER IS A COMPONENT PART OF THE FOLLOWING COMPILATION REPORT:

TITLE: Vibration Damping Workshop Proceedings Held at Long Beach, California on 27-29 February 1984.

TO ORDER THE COMPLETE COMPILATION REPORT, USE AD-A152 547.

THE COMPONENT PART IS PROVIDED HERE TO ALLOW USERS ACCESS TO INDIVIDUALLY AUTHORED SECTIONS OF PROCEEDING, ANNALS, SYMPOSIA, ETC. HOWEVER, THE COMPONENT SHOULD BE CONSIDERED WITHIN THE CONTEXT OF THE OVERALL COMPILATION REPORT AND NOT AS A STAND-ALONE TECHNICAL REPORT.

THE FOLLOWING COMPONENT PART NUMBERS COMPRISE THE COMPILATION REPORT:

AD#: P004 685 - AD-P004 734 AD#: ______
AD#: ______ AD#: ______
AD#: ______ AD#: ______

Accession For	
NTIS GRA&I	☑
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	

DTIC ELECTE JUN 27 1985 S D A

DTIC FORM MAR 85 463

OPI: DTIC-TID

BEAM DAMPERS FOR SKIN VIBRATION AND NOISE REDUCTION IN THE 747

R. N. Miles
The Boeing Company
P. O. Box 3707
Seattle, Washington 98124

BEAM DAMPERS FOR SKIN VIBRATION AND NOISE REDUCTION IN THE 747

R. N. Miles
The Boeing Company
P.O. Box 3707
Seattle, Washington 98124

ABSTRACT

A special constrained layer damper has been incorporated into the Boeing 747 upper deck fuselage structure. This damper replaces a rivetted stiffener which was installed to reduce noise levels inside the cabin. It has been found that the damper installation produced a noise reduction equal to that achieved by the stiffener and resulted in an $8000 per airplane cost savings and a 130 pound per airplane weight savings. A brief review is presented of the analysis and test that led to this design.

I. INTRODUCTION

In most commercial aircraft, structural vibration of the fuselage sidewall caused by the turbulent boundary layer is the main cause of noise in the passenger cabin. Methods of reducing the cabin noise include blocking the sound by adding fiberglass insulation or mass to the interior panels, or reducing the vibration of the structure by adding stiffeners to the airplane skin or increasing the damping of the structure. In this paper a program is described in which a skin panel stiffener installation for reducing cabin noise was replaced by a novel constrained layer damper design in the 747 upper deck. The damper produced cabin noise levels that are equivalent to those of the stiffener and resulted in an $8000 per airplane cost savings and a 130 pound per airplane weight savings.

The development effort that led to this design began with a careful study of the vibration characteristics of the 747 upper deck fuselage structure. Structural mode shapes were measured to determine the resonant modes that were the primary cause of the cabin noise in the frequency region of interest. Since conventional constrained layer dampers such as sound damping tape did not sufficiently damp the important modes, a new damper was developed 1 which proved to be extremely effective. This "beam damper" concept utilizes thickness deformation in the damping adhesive instead of shear deformation as in conventional designs. Since this light-weight damper is bonded to the skin with a pressure sensitive adhesive it is considerably easier to install than the rivetted stiffeners and a substantial manufacturing cost savings was achieved. Flight test results showed that the beam dampers achieved cabin noise reductions that are equal to those of the stiffener installation.

II. ORIGINAL STIFFENER INSTALLATION FOR NOISE CONTROL IN 747 UPPER DECK

Cabin sound levels obtained in flight in a 747 upper deck without any special sound proofing concepts are shown in figure 1. Also shown in the figure are the sound levels obtained when the skin of the upper deck structure is treated with two layers of 3M Y436 Sound Damping Tape. The figure shows that while the damping tape achieved significant reductions at high frequencies the peak in the spectrum in the 300 - 600 Hz common octave band was not significantly affected.

In order to reduce the noise in this frequency region, stiffeners were added to the structural design as shown in Figure 2. These stiffeners reduced the vibration of the low order skin panel modes which were predicted to be the major cause of the noise between 200 and 700 Hz. As shown in the figure, the stiffeners consisted of hat sections rivetted to each skin panel parallel to the stringers. The addition of these stiffeners produced a noise reduction of approximately 4 dB in the 300 -600 Hz octave band.

Though this noise reduction yielded an acceptable noise environment in the upper deck, the stiffener and damping tape installation caused a 220 pound weight penalty and was extremely time consuming to install. A program was then initiated to develop a constrained layer damper that could achieve the same noise reductions as the stiffener with less cost and weight.

III. BEAM DAMPER DEVELOPMENT PROGRAM

The first task in the damper development program was to obtain measured data that showed which mode needed to be damped. To accomplish this, mode shapes were measured on the upper deck fuselage structure in flight and cabin sound levels were measured to determine which modes contribute to the cabin noise.

The measured mode shapes are shown in Figure 3 along with skin panel vibration spectra. It was found that three modes dominate the response in the 300 - 600 Hz frequency range. The solid curve of the skin panel acceleration was obtained when the skin panel was exposed to the cabin with no fiberglass insulation or trim panel in place. The dashed curve shows the effect of replacing the fiberglass insulation over the skin. In this case the damping in the first two modes has been increased substantially. Note that the fiberglass is installed such that there is a 1.25 inch airgap separating it from the skin panel. For the two lowest modes there is a strong coupling between the skin and the fiberglass through the airgap.

The third mode shown in the figure is not significantly damped by the fiberglass. This mode consists of three half waves between the frames and one-half wave between the stringers. Since the two lower modes have substantial damping when the fiberglass insulation is in place it would be very difficult to achieve further vibration reduction of these modes by increasing the damping.

Figure 4 shows the effect of adding two layers of 3M Y436 Sound Damping Tape to the skin panels. In this case the modes above 700 Hz are heavily damped but the vibration of the first three modes is not reduced significantly more than it was by the fiberglass insulation. Since neither the fiberglass or the damping tape achieved significant reductions for the third mode it was felt that to reduce the vibration and noise in this frequency range a damper could be developed for the third mode.

Since the relation between vibration response and noise radiation is rather complicated for a periodic skin/stringer/frame structure that is excited by a turbulent boundary layer, cabin sound pressures were measured to ensure that the third mode contributes to the cabin noise. Figure 5 shows a comparison of the sound spectrum with the spectrum of the skin panel vibration. This figure shows that the three modes below 700 Hz contribute to the cabin sound levels.

Damper Design

Having determined that the first three modes were the most important and that the mode with three half waves between the frames was a very important one to damp, the next task consisted of selecting the appropriate damper. To select the damper we conducted an analytical study, laboratory tests, and manufacturing and durability studies.

Conventional constrained layer dampers work by creating shear deformation in the adhesive when the structure bends. Unfortunately at low order modes when there isn't much curvature there is very little shear and hence very little damping in damping tape treatments. To overcome this, spacers have been suggested such as shown in Figure 6. This spacer is designed to have infinite shear stiffness and no bending stiffness.

Rather than build a spacer as shown in Figure 6, a constraining layer could be used that is stiff in bending such as a very light I section. In this case if the adhesive is thick enough and flexible enough the constraining layer will cause thickness deformation in the adhesive along with shear. As can be seen from Figure 7 if the I beam is continuous over three half waves as in our third mode the constraining layer will have substantial "leverage" on the adhesive. The damper could be expected to be very effective on this mode.

To investigate the performance of this "beam" damper, laboratory tests were conducted on a skin/stringer/frame test panel as shown in Figure 8. Experimental modal analysis was performed on this panel to ensure that it responded with the same mode as observed on the airplane. Figure 9 shows the mode shape of the 3-1 mode, the third mode observed in fight as measured on test panel. Note that since the test panel was not subjected to tensile pressurization loads this mode occurred at 441 Hz rather than at approximately 600 Hz as on the airplane in flight.

With this simple laboratory test panel a very large number of configurations of the beam damper could be tested with minimal cost. The vibration of the panel with various treatments applied was measured with accelerometers and the panel was excited either with a light weight instrumented hammer or with a sound field.

Based on these laboratory tests, it was felt that the configuration shown in Figure 10 would have a good chance of achieving vibration and noise reductions equivalent to those of the stiffener. This configuration consists of a single layer of 3MY436 Sound Damping Tape and two I sections bonded with 3MISD113 adhesive parallel to the stringers. The I beams are made of .02 gage Kevlar. This installation weights a fraction of the weight of the stiffener and is extremely easy to install.

Since one of the major motives in this program was manufacturing cost savings, the manufacturing organization was consulted to ensure that the damper would not be prohibitively difficult to build. Because of the substantial cost savings potential of replacing the stiffeners, manufacturing personnel enthusiastically responded with test parts made out of aluminum, fiberglass, Kevlar, graphite, extruded thermoplastics, nomex honeycomb, aluminum honeycomb and rigid foams. This coordination with manufacturing people proved to be very valuable in this program.

Laboratory tests were also conducted to study the durability of the installation shown in Figure 10 in the environment of the airplane skin. Since the major concern was reduction in adhesion due to moisture, test panels with the dampers applied were exposed to condensing humidity at 160°F for two weeks and to continuous water submersion for two weeks. As a result of these tests it was found that the dampers with 3M ISD 113 adhesive are not significantly affected by moisture.

Flight Test Verification

Once a configuration was considered acceptable based on laboratory tests, a flight test program was conducted to measure the effectiveness on the airplane. Figure 11 shows the skin panel vibration in flight when the dampers are installed as in Figure 10. The figure shows that the vibration level of the third mode is reduced by more than 10 dB. This is considerably more reduction than obtained by a coventional damping tape installation.

Figure 12 shows the cabin sound levels measured in flight with the beam dampers installed. The figure shows that the dampers achieved sound level reductions that are equivalent to those of the stiffener.

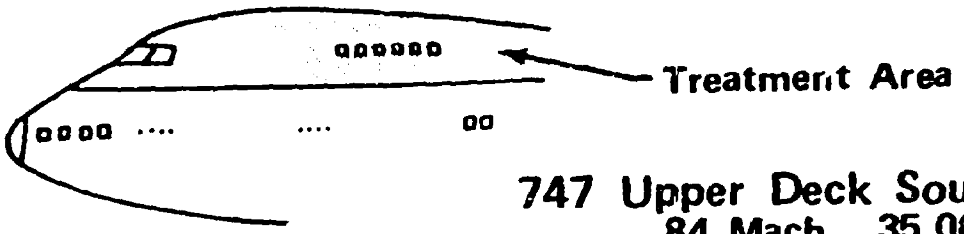
IV. CONCLUSIONS

As a result of these efforts the beam damper configuration shown in Figure 10 has replaced the stiffeners shown in Figure 2 in the 747 upper deck. The stiffener installation weighed 220 pounds and the beam damper installation weighs 90 pounds, giving a 130 pound weight savings. Also, because of the substantial reduction in installation time the damper resulted in an $8000 per airplane cost savings.

REFERENCE

(1) United States Patent 4,425,980, "Beam Dampers for Damping the Vibrations of the skin of Reinforced Structures," January 17, 1984, R. N. Miles.

Damping Tape Installation - 747 Upper Deck



747 Upper Deck Sound Levels
.84 Mach, 35,000 ft

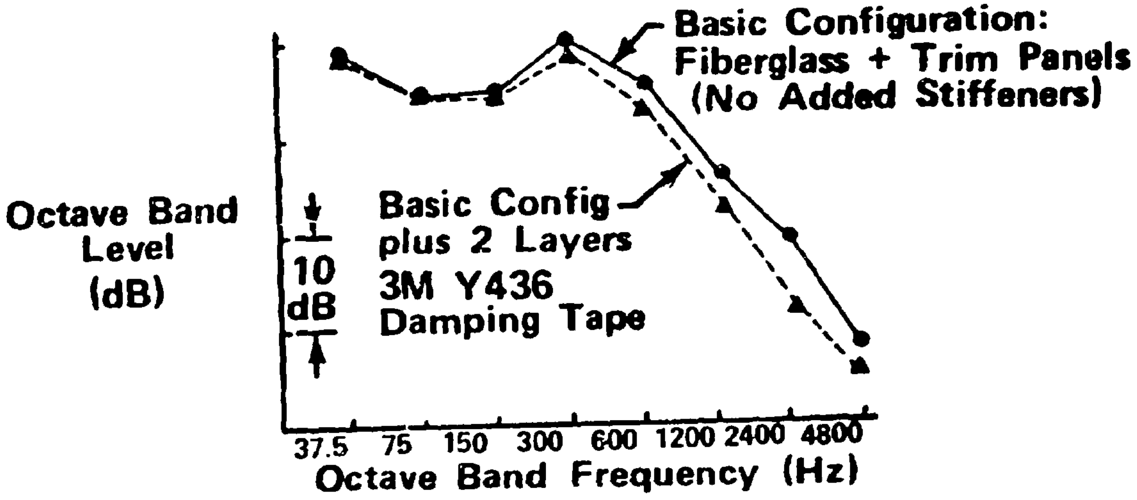


FIGURE 1

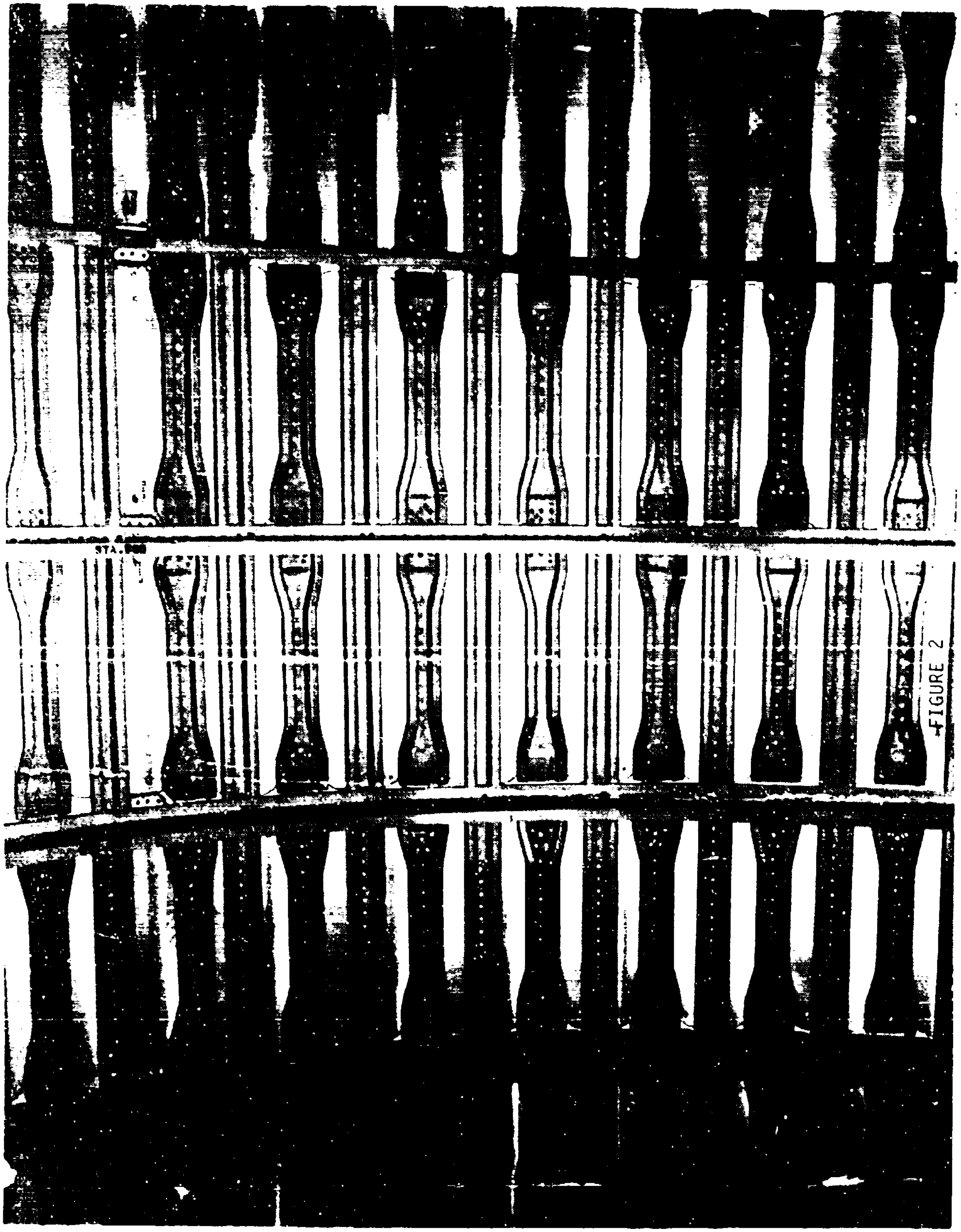
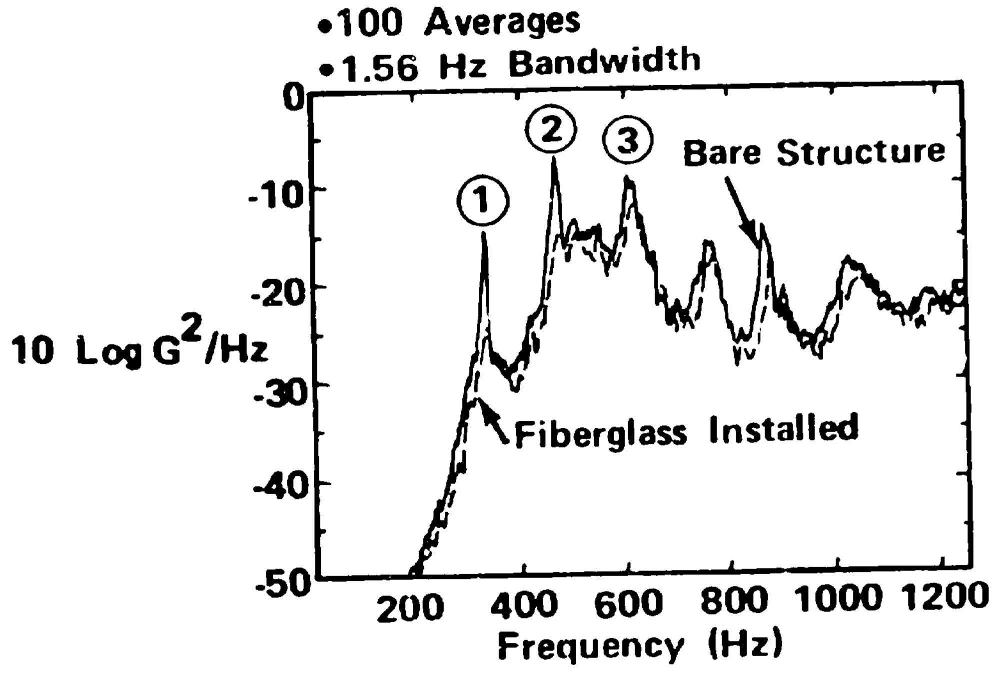


FIGURE 2

Flight Test Vibration Data

747 Upper Deck

Skin Panel Response



Mode Shapes Measured in Flight

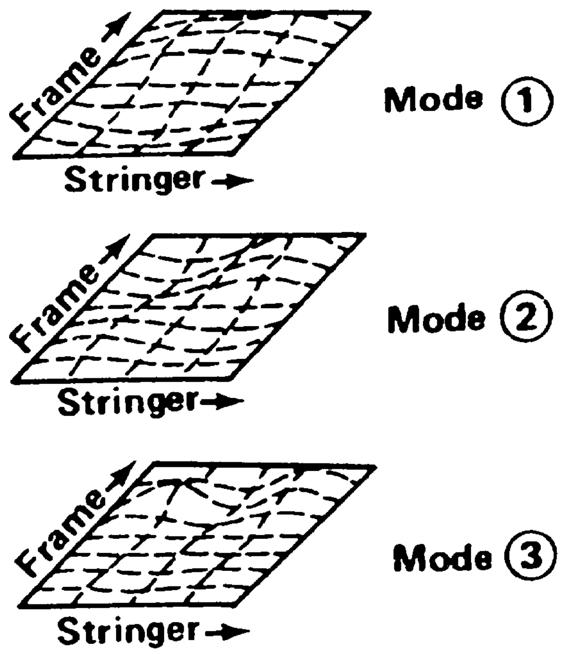
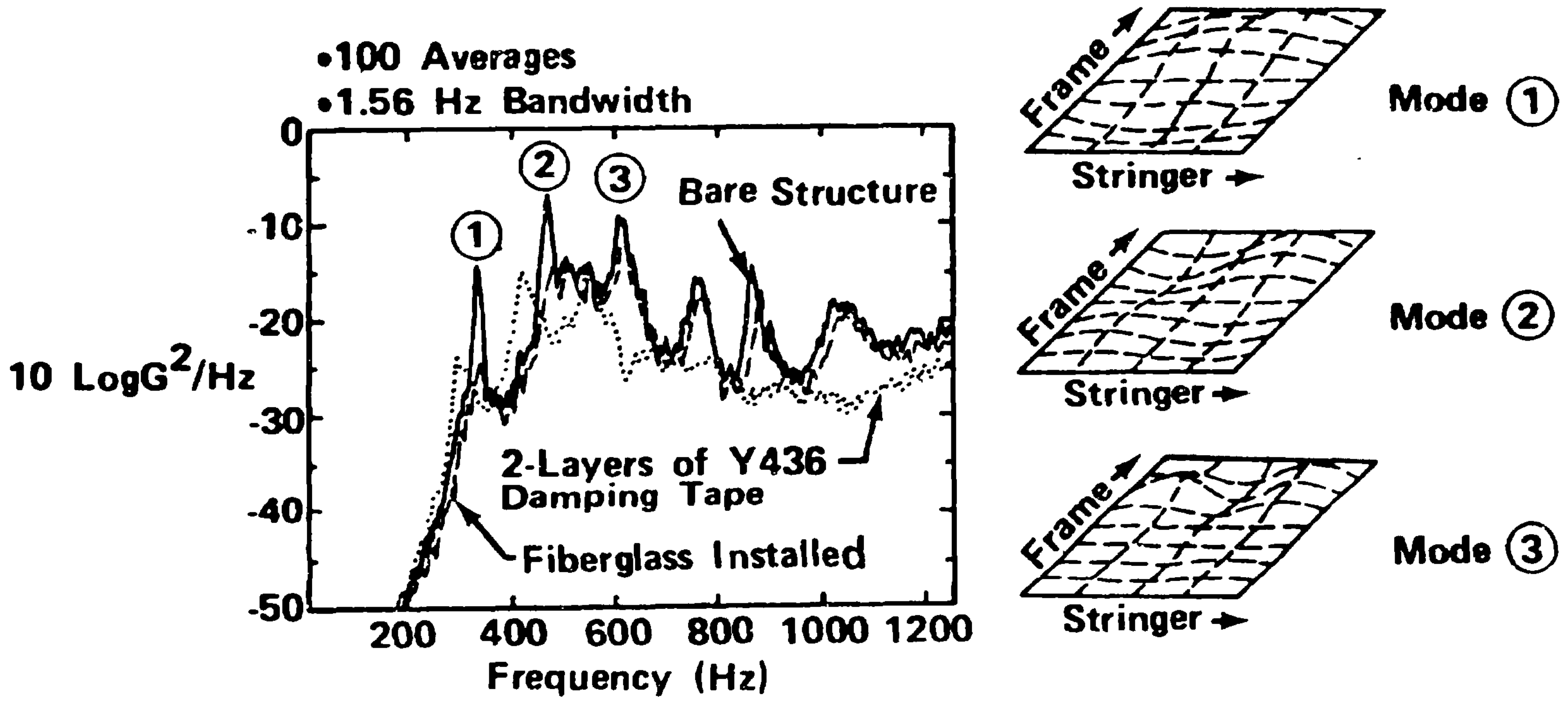


FIGURE 3

Flight Test Vibration Data
747 Upper Deck



Skin Pane! Response

Mode Shapes Measured in Flight

FIGURE 4

Comparison of Skin Panel Response and Cabin Sound Pressure

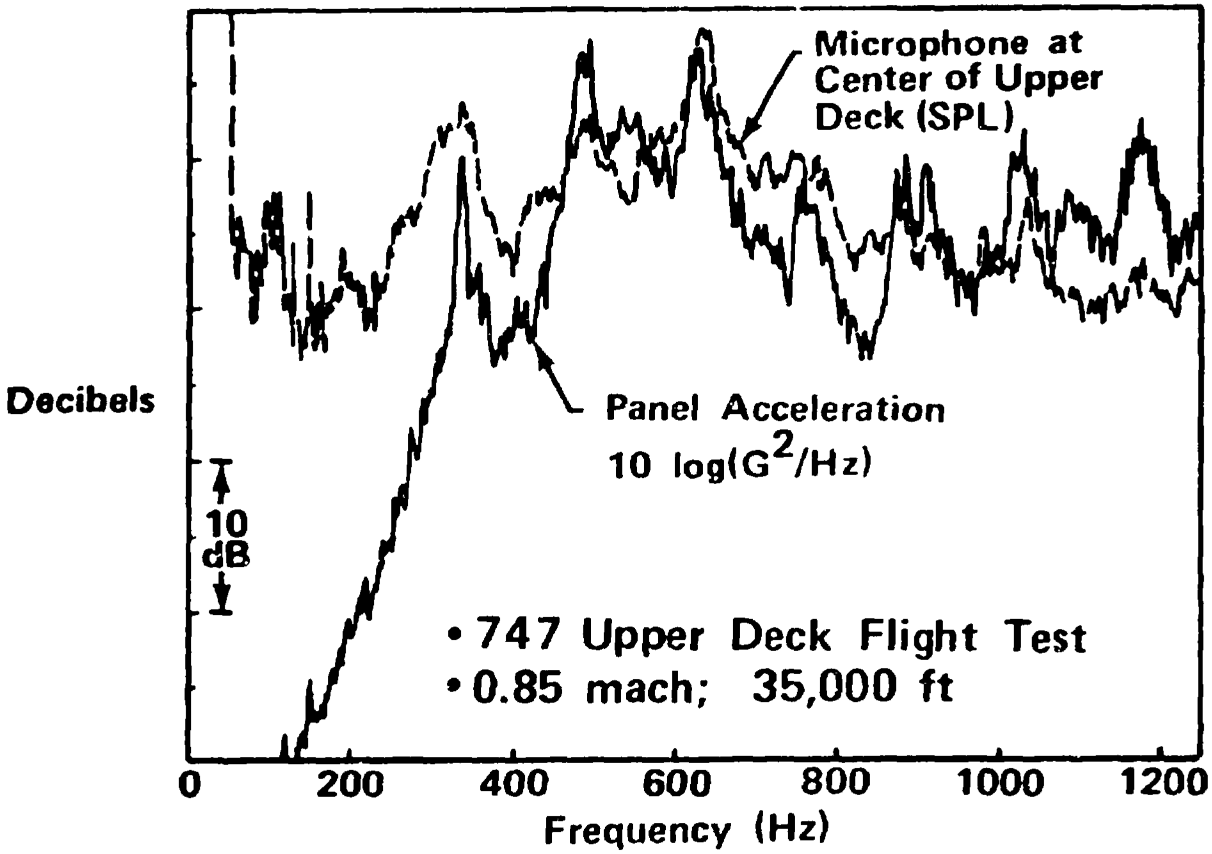


FIGURE 5

Shear Deformation In Conventional Constrained Layer Dampers

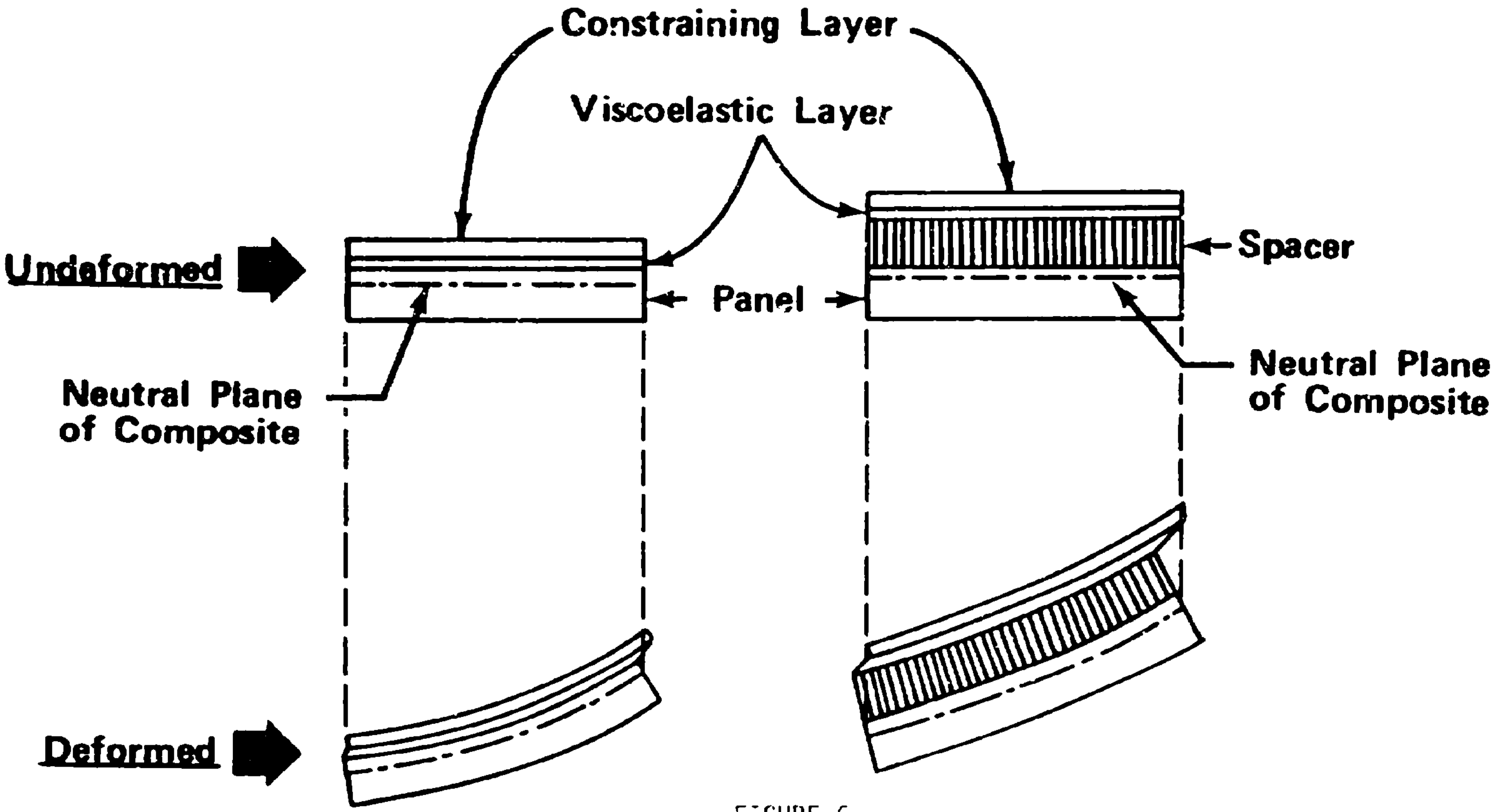
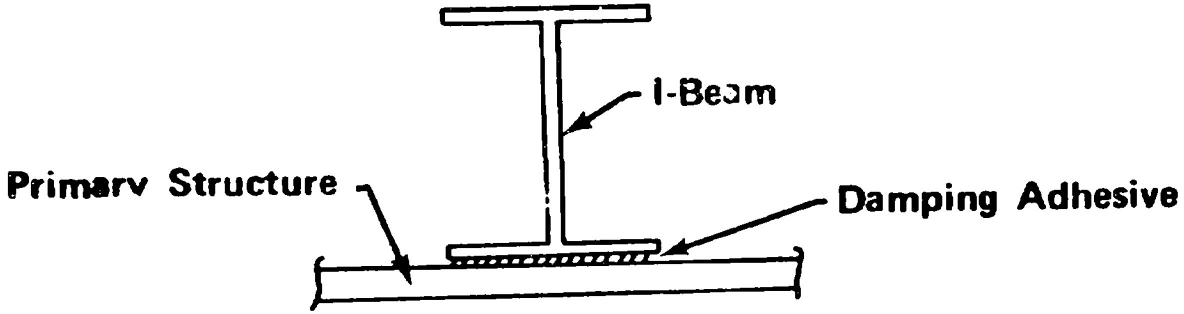


FIGURE 6

Thickness Deformation in Stiff Constrained Layer Dampers

I-Beam Damper Cross-Section



Adhesive Thickness Deformation

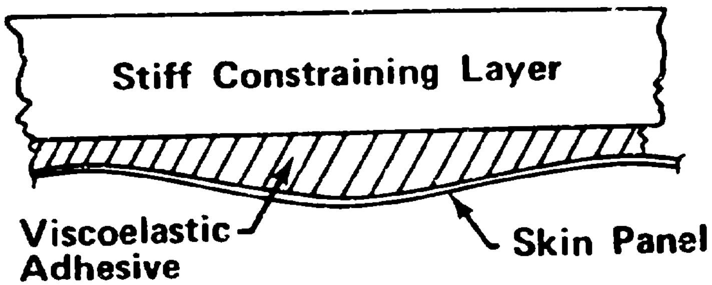


FIGURE 7

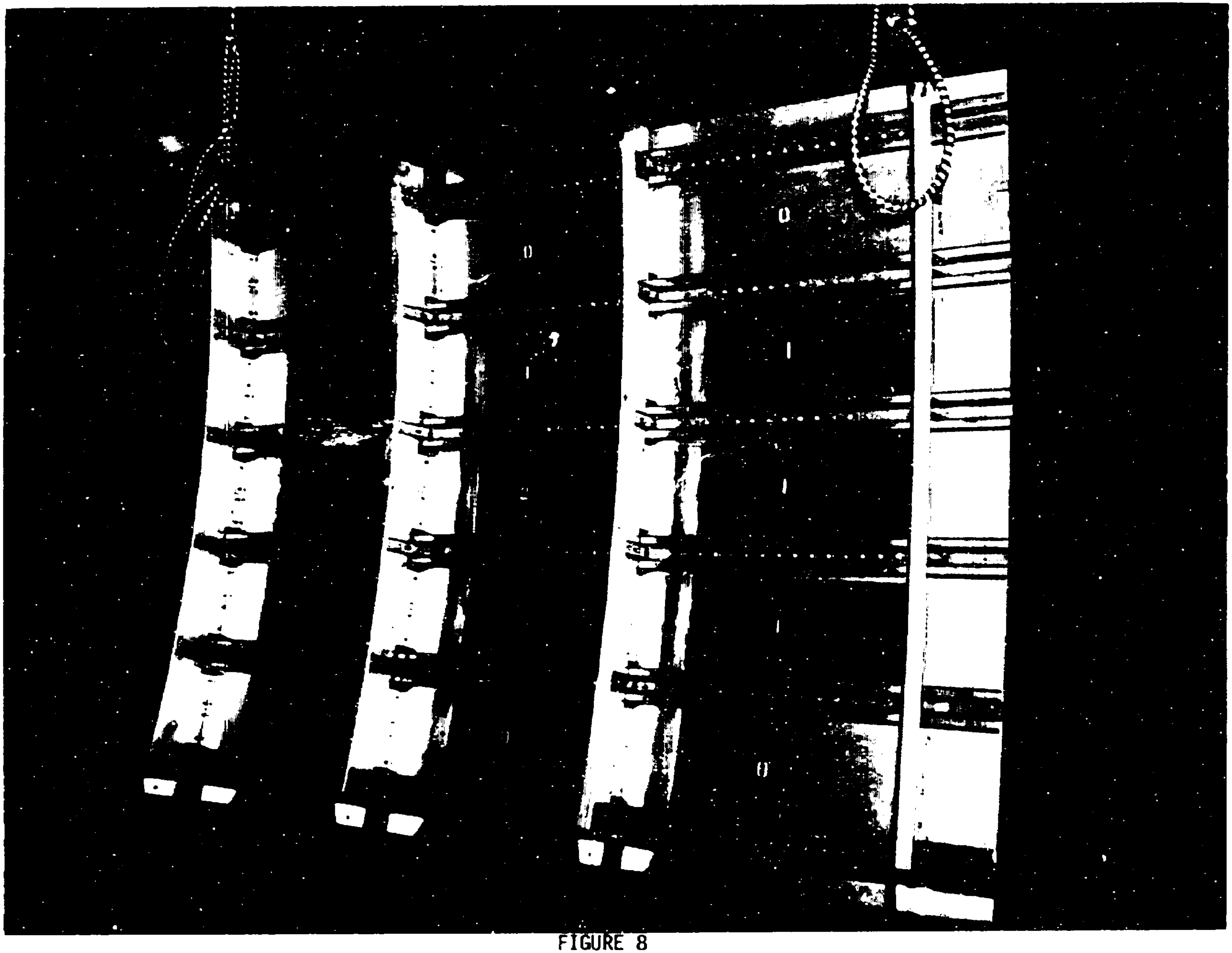


FIGURE 8

Measured Mode Shape in a Laboratory Test Panel

441 Hertz

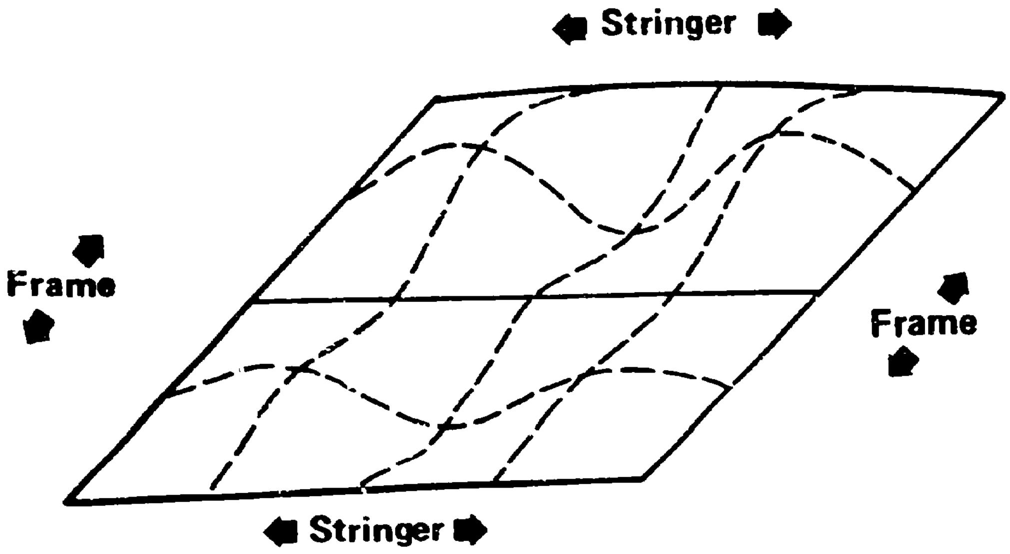
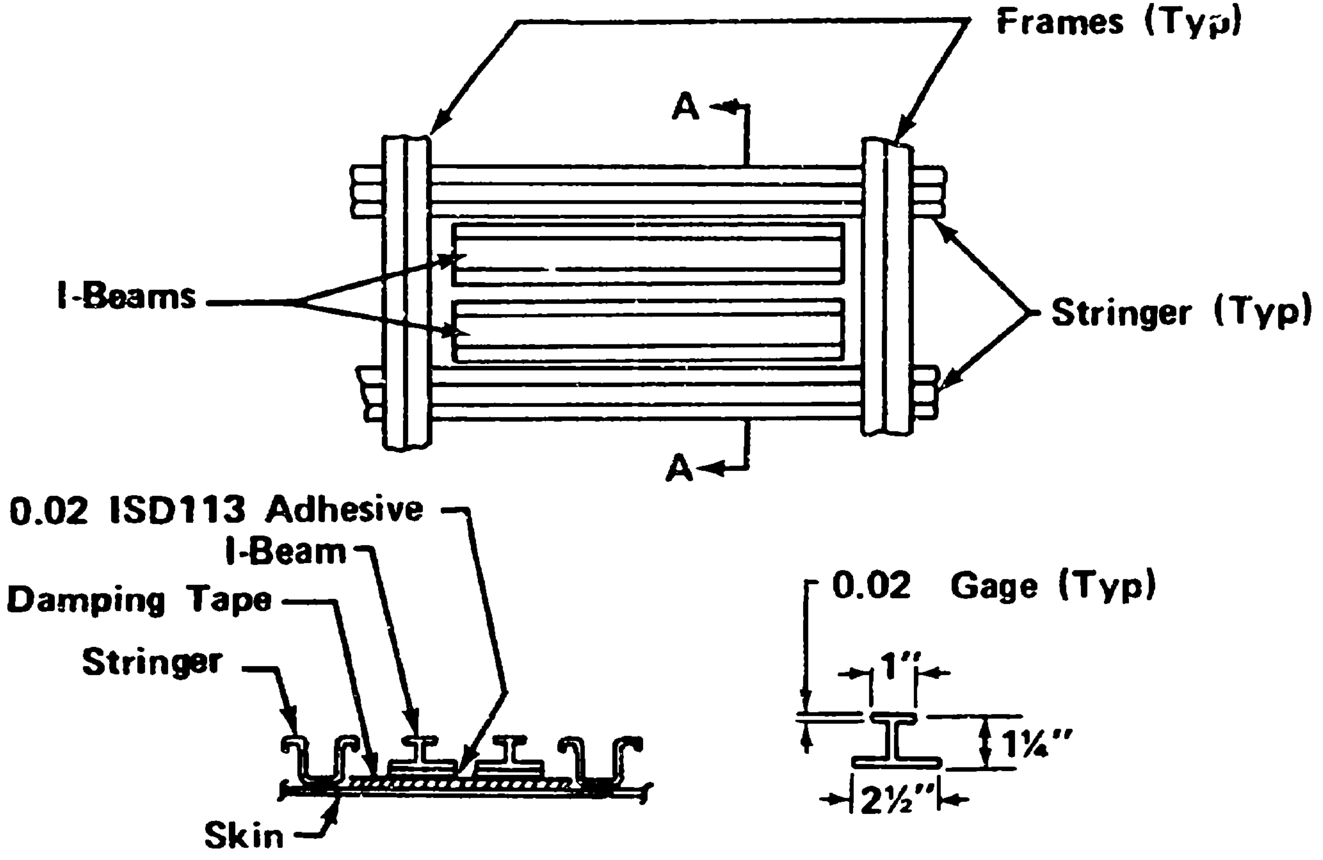


FIGURE 9

747 I-Beam Damper Installation



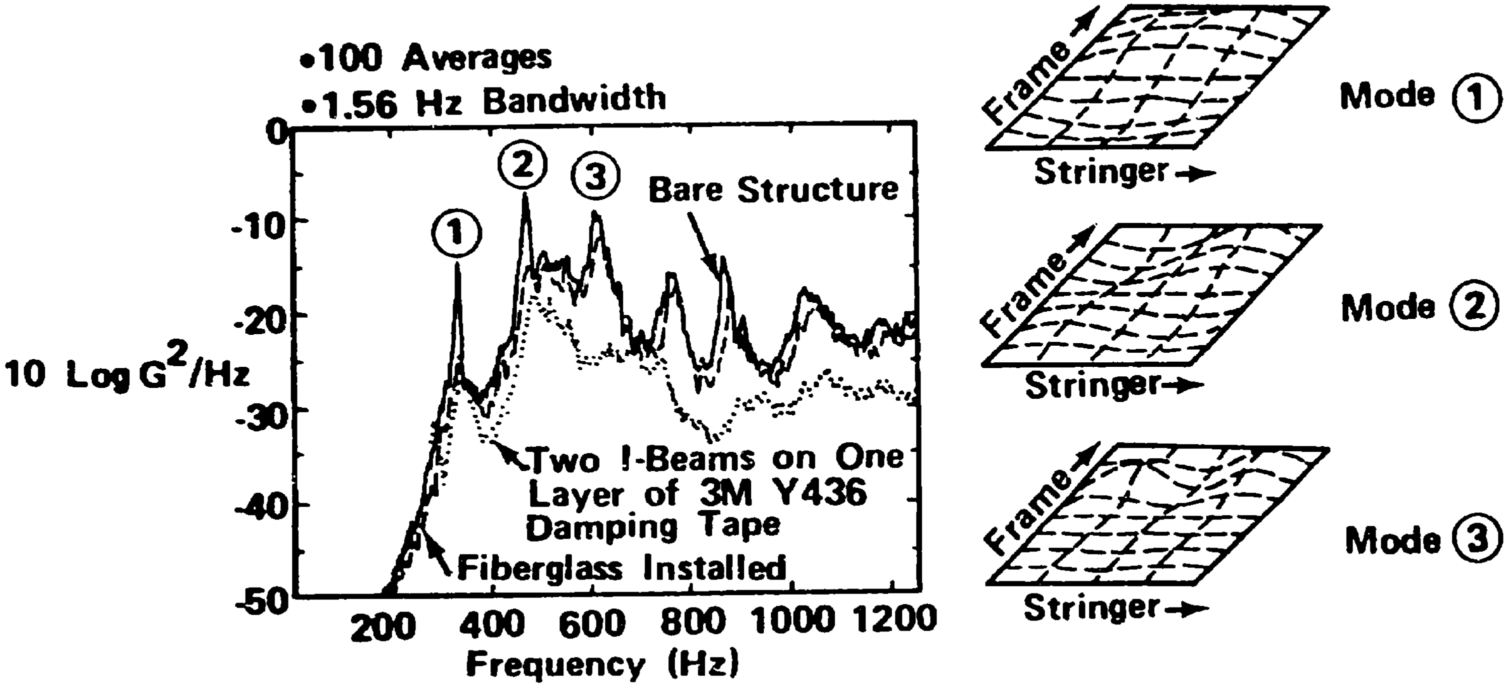
Section A-A
(Rotated 90° CW)
■Up ➡

I-Beam Section
(Kevlar)

FIGURE 10

Flight Test Vibration Data

747 Upper Deck



Skin Panel Response

Mode Shapes Measured in Flight

FIGURE 11

I-Beam Damper Program

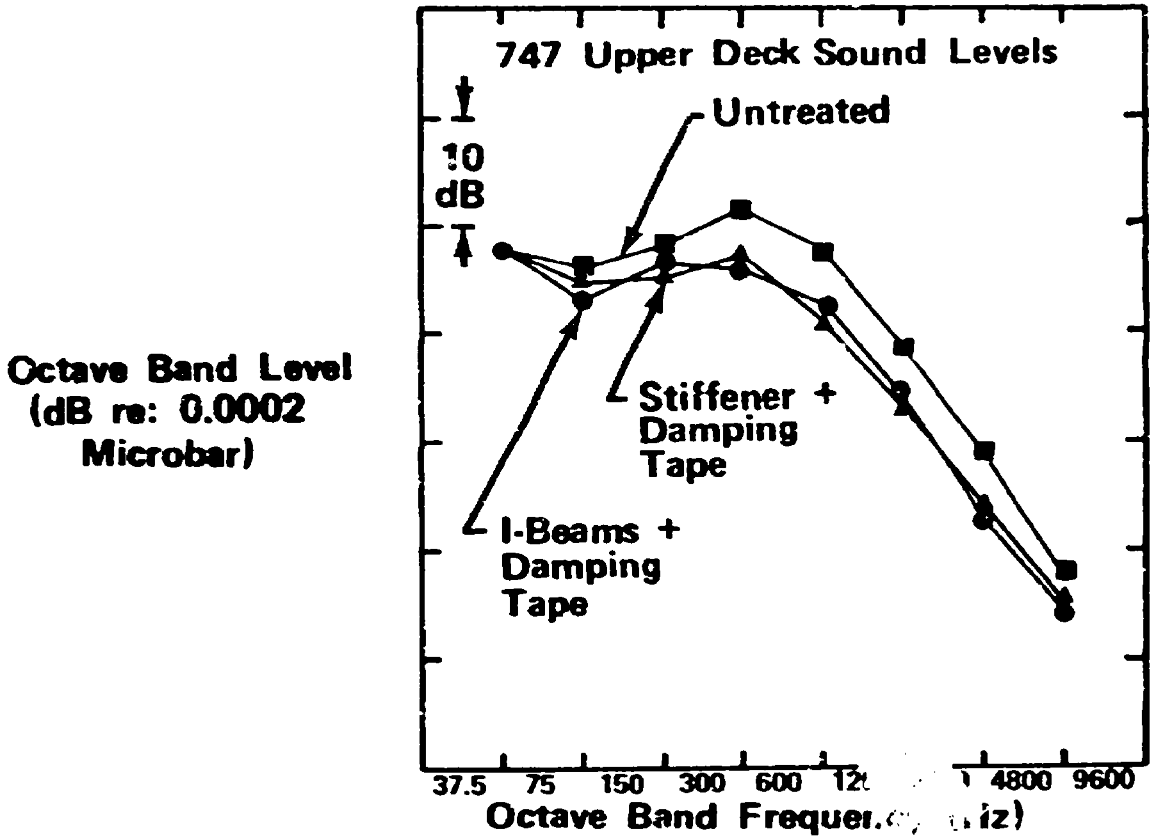


FIGURE 12