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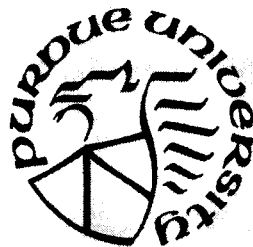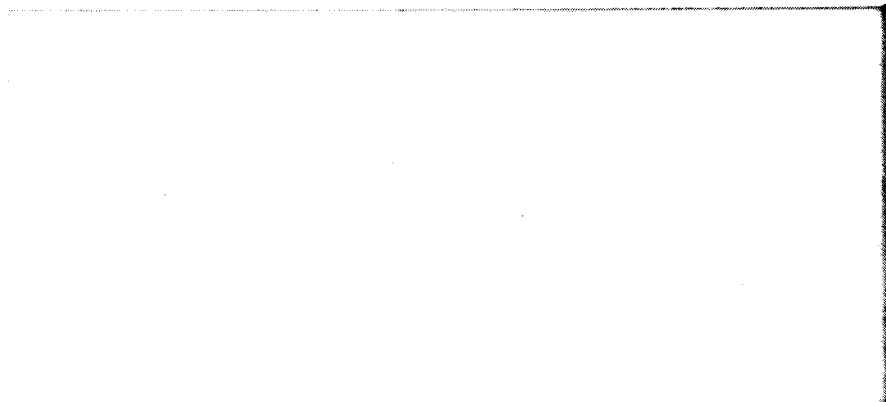
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RAY W. HERRICK LABORATORIES

A Graduate Research Facility
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A STUDY OF METHODS TO PREDICT AND MEASURE THE TRANSMISSION OF SOUND THROUGH THE WALLS OF LIGHT AIRCRAFT

Research Grant # NAG1-58
PRF No. 520-1288-0353

SEMI-ANNUAL STATUS REPORT: REPORTING PERIOD 5/15/87-11/15/87

Sponsored by:
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Submitted by:

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Approved by:

Raymond Cohen, Director
Ray W. Herrick Laboratories

March 1988

CONTENTS

This is a semi-annual status report for NASA Grant NAG1-58 for the period May 15, 1987 through November 15, 1987.

1. RESEARCH PROGRESS

Research investigations either fully or partially supported by NASA for the semi-annual reporting period progressed toward the following objectives:

1. Measurement of dynamic properties of acoustical foams and incorporation of these properties in models governing three-dimensional wave propagation in foams (Christina Bruer)

2. Tests to measure sound transmission paths in the HP137 Jetstream III (Chris Wohlever)

3. Formulation of a finite element energy model (Chris Wohlever)

In addition, the effort to develop a numerical/empirical noise source identification technique was completed by Bryce Gardner in May [1] and the investigation of a design optimization technique for active noise control was completed by Chris Mollo in July [2]. Both theses have been transmitted to NASA.

The monthly progress reports of each of the graduate research assistants are collected in the appendices. The monthly progress reports detail the progress made toward each of the objectives. A brief summary of each effort follows.

The project concerned with the dynamic properties of acoustical foams was completed during this reporting period. The initial thrust of this project concerned the measurement of the dynamic Young's and shear moduli of the type of polyurethane foam that is normally used in noise control applications. Recent theories governing wave propagation in these materials have shown that an accurate knowledge of the dynamic moduli is necessary to make accurate

predictions of the sound absorption and transmission properties of foam layers. It has also been shown that foam may be used quite effectively in fuselage noise control applications. Thus, in the first part of the project, techniques were developed to measure the Young's and shear moduli of foams. These techniques were based on the so-called Oberst method in which the parameters of a material are determined by measuring the effect that an attached layer of the material has on the the modal response of a metal base beam. It did not prove possible to measure the Young's modulus accurately in this way because of the relatively large difference between the Young's modulus of the base beam and the attached foam layer. However, it was possible to make accurate measurements of the foam's shear modulus. In the course of this work, misprints in the published ASTM procedures governing measurements of this type were identified and corrected. The results of this part of the work were the first accurate measurements of the dynamic properties of foam. The Young's modulus was inferred from the shear modulus by using relationships from the theory of linear elasticity. These measured data were relatively close to values previously inferred indirectly from acoustical measurements. The new data provides a firm basis for making theoretical predictions of the acoustical properties of foam layers.

The measurements of foam shear moduli made use of constrained layer specimens: i.e., a foam layer was sandwiched between two steel beams. It was noticed that this arrangement resulted in very large structural damping in certain frequency ranges. In fact, under some conditions the damping provided by a constrained foam layer was considerably in excess of that caused by relatively heavy layers of "conventional" damping material (e.g., polyvinyl chloride). The large damping seemed to be associated with relatively large depths of foam. Under these conditions it was not possible to model the beam and attached layer response properly using existing "thin beam" theories: i.e., it was necessary to account explicitly for the finite depth of the attached damping layer. It was decided to attempt to develop theoretical models which could account explicitly for the finite layer depth and so could be used to predict the damping effect of

deep foam layers.

The first model derived allowed only for extensional strain in the attached layer. This meant that longitudinal wave propagation in the damping material could be modeled but that transverse wave motion was not allowed. This in fact is the situation which arises in unconstrained damping layers: i.e., a layer attached to a single base beam. It was possible to develop a "duct acoustics" model to account for wave propagation in the damping laer and thus to account fully for its depth. Comparison with measured results has indicated that this model is capable of yielding significantly more accurate predictions than previously existing damping models. At this stage work was directed towards a two-dimensional model which would allow for transverse wave propagation in the damping layer. It was felt that such a model would mimic the behavior of constrained damping layer treatments. However, it was discovered that to model the constrained layer arrangement it was necessary to develop either a fully three- dimensional model or to allow for both longitudinal and transverse wave propagation in a two-dimensional model simultaneously; it was decided to pursue the two-dimensional approach. All the necessary governing equations were derived and the boundary conditions to be applied at each interface were established. In the time available it did not prove possible to solve the set of equations which resulted.

Some aspects of the work described above will be pursued in work currently supported by the NASA grant. Specifically, combined longitudinal and transverse wave propagation will be considered, but in connection with infinite rather than finite beams. This will eliminate some of the difficulties of the current model but will still reveal the damping properties of the treatment. Theoretical impulse responses produced using these models will be used in the Wigner Distribution research which is directed at methods of identifying structure-borne noise paths. These results, and those described above, indicate that it may be possible to achieve airborne

noise control and structural damping with a single treatment: i.e., foam layers. Currently, different materials, fiberglass and polyvinyl chloride, are used for these separate tasks. If a single material is used, it may be possible to achieve significant weight savings; this is the promise of the foam study. Results describing this work in more detail have been reported in Christina Bruer's thesis [3] and in an AIAA paper [8].

The measurements of noise in the HP137 due to the propeller vortex loading of the wing were completed during the reporting period. The measurements were made on the HP137 in a stationary, ground based configuration using only the right engine. Two sets of barriers were constructed from plywood for the tests. One set of barriers was used to shield the fuselage from the direct airborne sound field generated by the propeller. The second set of barriers was used to shield the wing and eliminate the loading of the wing by the vortices shed by the propeller. A picture of the HP137 with both sets of barrier in place is shown in Figure 1.

For all tests, the engine was run at prop and torque settings typical of flight conditions. The cabin furnishings came with the aircraft and include 18 seats and 1" of fiberglass insulation behind the trim panels. Fourteen microphones were distributed throughout the cabin. Data was collected using a spectrum analyzer connected to a PC-computer for data storage. The complete measurement of the fourteen frequency averaged pressures took approximately 5 minutes.

Three configurations were measured on each day. Configuration A had both sets of barriers in place. Configuration C had wing shields removed but fuselage barriers in place. Configuration D had both sets of barriers removed. This series of three tests was repeated several times to insure the validity of the results.

Typical results of the tests are shown in Figures 2 and 3. For Figures 2 and 3, the sound pressure at the fourteen microphone locations is averaged. All the energy in a 95 hz band centered about the blade passage frequency (95 hz) and its harmonics has been accumulated into

a band pressure levels as shown in the figures.

A comprehensive report of the test procedures and results is currently being prepared by Chris Wohlever and will be delivered to NASA early in 1988.

The objective of the finite element energy formulation investigation is to determine whether structural/acoustic systems can be modeled using energy density as the primary variable of interest and intensity as the secondary variable. Such a formulation is being considered because it will likely have an advantage in efficiency over typical finite element analysis methods and will be applicable to relatively high frequency. The formulation will also likely have an advantage in accuracy over Statistical Energy Analysis (SEA) and Asymtotic Modal Analysis (AMA) methods since the problem can be discretized such that local effects can be taken into account.

The effort of develop the finite element energy formulation for structure borne noise studies has made significant progress during the reporting period. Chris Wohlever has shown that for second order problems (i.e. acoustical systems, longitudinal vibrations in bars, etc.) the energy density distribution is modeled by a Poisson's equation and that intensity is proportional to the gradient of the energy density. Thus, behavior of the energy density is exponential in character. Furthermore, intensity can be used as a boundary condition. These two properties mean that the finite element method can be used to model power flow and energy density without regard for the wavelength, and thus relatively efficient models can be used. These models will be as valid at high frequency as at low frequency.

In addition, Chris Wohlever has considered the energy model of flexural of a beam (a fourth order system). The energy density function for flexure in a beam is not governed locally by a Poisson's equation. Furthermore, the local intensity is not proportional to the gradient of the local energy density. However, if the energy density and intensity are averaged over one

wavelength, it was found that the energy density is represented by the superposition of four uncoupled Poisson's equations. As many as three of these energy components are negligible for most beams. Furthermore, each averaged energy component has a corresponding averaged intensity component which is proportional to the gradient of the averaged energy density. Investigations are continuing to test the analytical results with a variety of boundary conditions and for various frequency ranges.

2. RELATED WORK OF POSSIBLE INTEREST

There is significant interaction between NASA sponsored research and other investigations at Purdue.

The NSF funded investigation on active noise control continued throughout the reporting period. A digital non-adaptive, recursive filter has been implemented and was tested in the HP137 cabin. Results were published at the AIAA Aeroacoustics Conference in October. To complement the experimental applications, several simulations of adaptive, recursive digital filters have been developed. The simulations are capable of using either measured or artificial data to model the structural/acoustic behavior of the system. A variety of adaptive recursive algorithms, system configurations, and input noise signals have been studied. These experimental and analytical results are reported in detail in Jay Warner's M.S. Thesis. A Ph.D. dissertation by Jeff Dohner was also completed during the reporting period on the application of modern control theory to active noise control systems.

A project funded by the Purdue Research Foundation is directed towards an investigation of multi-dimensional wave propagation in elastic porous materials such as foams. In the last year equations governing three-dimensional wave propagation in foams have been developed. These equations take full account of the two longitudinal and are transverse wave types which

propagate simultaneously in elastic porous materials. These equations have been used to predict oblique incidence sound transmission through double panel structures of fuselage-like dimension. These calculations have confirmed earlier findings (based on normal incidence transmission) that the behavior of foam linings depends critically on the way the lining is mounted. Optimum attachment methods have been identified. This work was presented at the AIAA Aeroacoustics Conference in October 1987 [14]. More recently ways of optimizing the random incidence absorption coefficient of foam treatments has been studied [15]. This work may be applicable to the design of absorptive treatments for aircraft interiors.

3. TRAVEL

Travel funds from the Grant were used by Professor Bernhard to attend the AIAA 11th Aeroacoustics Conference in Palo Alto, CA on October 19-21, 1987, where he presented 3 papers.

4. PUBLICATIONS

[1] Gardner, B.I., "Noise Source Identification Using a Numerical/ Experimental Helmholtz Integral Equation Method", M.S. Thesis, Purdue University, 1987.

[2] Mollo, C.G., "A Numerical Method for Analyzing the Optimal Performance of Active Noise Controllers," M.S. Thesis, Purdue University, 1987.

[3] Bruer, C.U., "Measurements and Prediction of the Effect of Damping Layers on the Dynamic Response of Beams", MSME Thesis, Purdue University, 1987.

[4] Gardner, B.K. and R.J. Bernhard, "An Experimental/Numerical Noise Source Identification Technique" SAE Paper No. 870995, April 1987.

[5] Gardner, B.K. and R.J. Bernhard, "A Noise Source Identification Technique Using An Inverse Helmholtz Integral Equation Method", ASME Paper No. 87-WA/NCA-12, Dec. 1987. (Also published in the Journal of Vibration, Acoustics, Stress and Reliability in Design, Vol. 110(1) pp. 84-90.

[6] Mollo, C.G. and R.J. Bernhard, "The Optimal Performance of Active Noise Controllers in Three Dimensional Cavities", SAE Paper No. 840994, April 1987.

[7] Mollo, C.G. and R.J. Bernhard, "A Generalized Method for Optimization of Active Noise Controllers in Three-Dimensional Spaces", AIAA Paper AIAA-87-2905, October 1987.

[8] Bruer, C. and J.S. Bolton, "Vibro-Acoustic Damping of Extended Vibrating Systems", AIAA Paper No. AIAA-87-2661, 1987.

[9] Wohlever, C. and R.J. Bernhard, "An Investigation of Structureborne Noise in a Handley Page 137 'Jetstream III' Aircraft", Purdue University, Herrick Laboratories Report # HL 88-5.

[10] Bernhard, R.J., B.K. Gardner, C.G. Mollo and C.R. Kipp, "Prediction of Sound Fields in Cavities Using Boundary Element Methods", *AIAA Journal*, Vol 25, NO. 9, Sept. 1987, pp. 1176-1183.

[11] Mickol, J.D. and R.J. Bernhard, "Structural Intensity Due to Flexoral Wave Propagation in Lightweight, Build-up Structures", AIAA Paper No. AIAA-87-2683.

[12] Warner, J.V. and R.J. Bernhard, "Digital Control of Sound Fields in Three-Dimensional Enclosures", AIAA Paper No. AIAA-87-2906.

[13] Bernhard, R.J. and J.D. Mickol, "The Effect of Probe Inertia on the Accuracy of Structural Intensity Measurements in Lightweight, Built-up Structures", Paper pp. 5, 113th Meeting of the Acoustical Society of America, May 1987.

[14] Bolton, J.S. and N.M. Shiau, "Oblique Incidence Sound Transmission Through Multi-Panel Structures Lined With Elastic Porous Materials" AIAA Paper AIAA-87-2660.

[15] Bolton, J.S., "Optimal Use of Noise Control Foams", Initial Paper 3 presented at the 114th meeting of the Acoustical Society of America, Miami, 16-20 November 1987.

Figure 1:   Test A Configuration
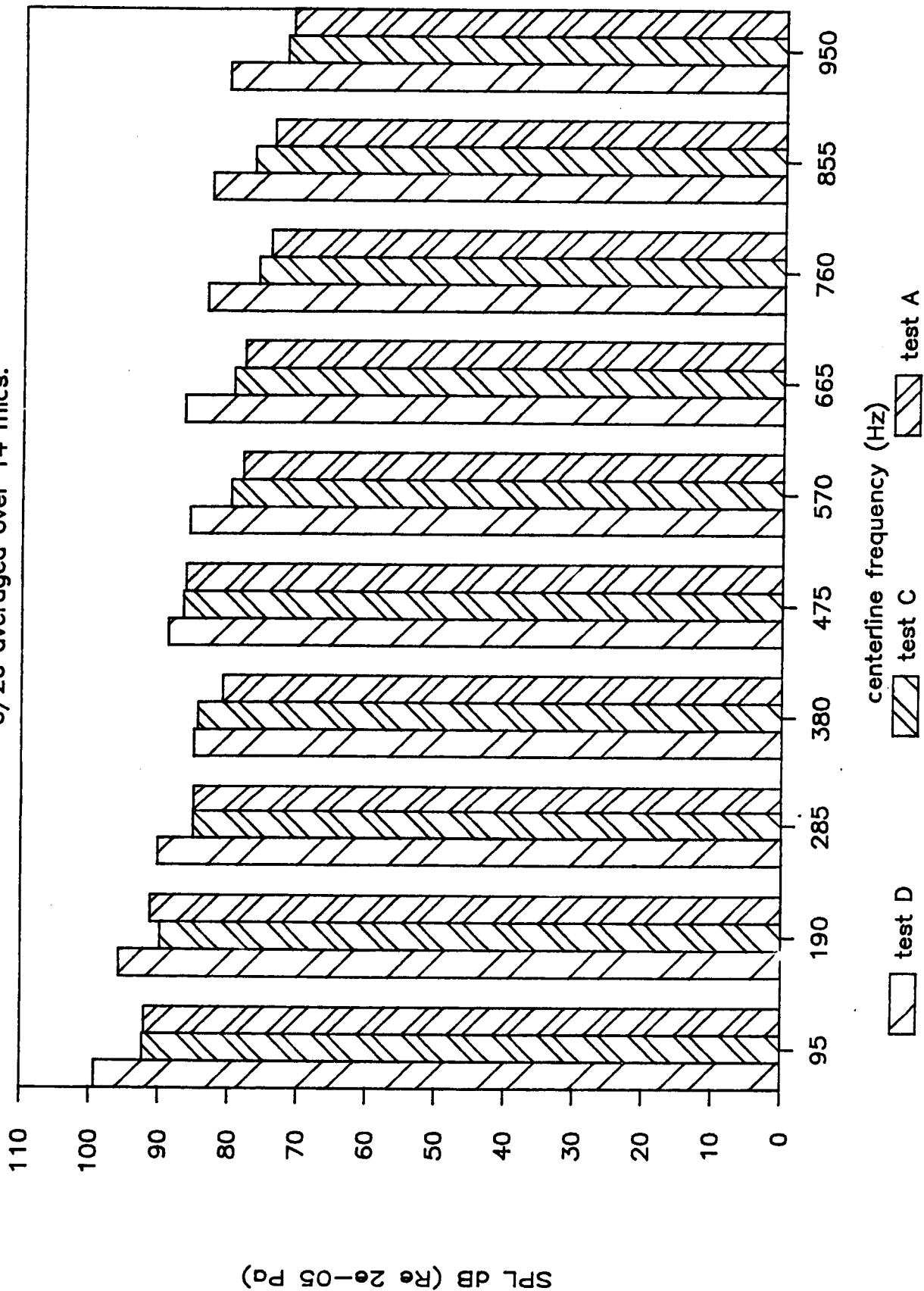
Figure 2: Spatial Averaged Wideband Spectrum
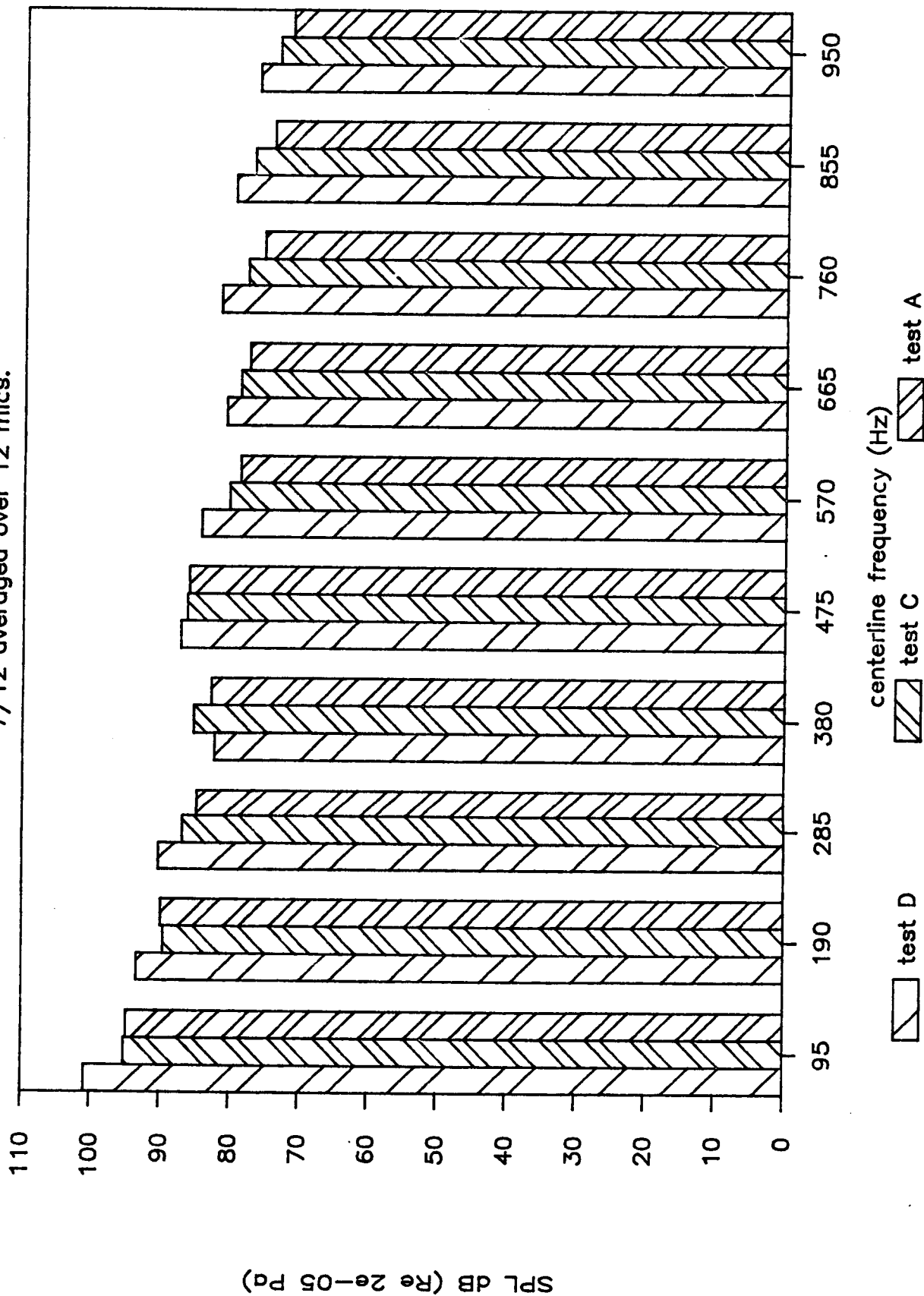
Figure 3:   Spatial. Averaged Wideband Spectrum

APPENDIX A

MONTHLY RESEARCH PROGRESS REPORT FORM

REPORT FOR MONTH OF: May 1987

STUDENT'S NAME: Chris Mollo

PROJECT TITLE:

   Optimization of Active Noise Control Systems

MAJOR PROFESSOR: R. J. Bernhard

SPONSOR: NASA

REPORT:

   Work during the month of May was devoted to completing my
thesis.   Chapter 4 was completed, and chapters 5, 6, and 7 were
written.   Chapter 5 discusses the free field radiation problem,
and chapter 6 presents the optimal controller for enclosures
where the noise source strengths are not known.   Chapter 7 is the
conclusions and recommendations chapter.

MONTHLY RESEARCH PROGRESS REPORT FORM

REPORT FOR MONTH OF: May 1987

STUDENT'S NAME: Chris Wohlever

PROJECT TITLE:

    Structureborne Noise in Aircraft

MAJOR PROFESSOR: R. J. Bernhard

SPONSOR: NASA -np

REPORT:

    We are in the process of making final preparations for test-
ing on the HP-137 aircraft. We have tentatively scheduled about
10 test dates in June and July, the first being June 12. The
purpose of these tests is to determine the relative importance of
propeller vortices interacting with the wing (i.e., structure-
borne) to the sound field in the cabin.

    I am also continuing my work with power flow analysis on
simple structures (see previous monthly report).

MONTHLY RESEARCH PROGRESS REPORT FORM

REPORT FOR MONTH OF: May 1987

STUDENT'S NAME: Christina Bruer

PROJECT TITLE:

   Measurement of Dynamical Properties of Acoustical Materials

MAJOR PROFESSOR: J. S. Bolton

SPONSOR: NASA

REPORT:

During the past month the programming work on the sandwich beam
vibration, assuming longitudinal wave propagation or transverse
wave propagation only has continued.

   So far it was found that the computed transfer functions
behave only in certain frequency ranges and become distorted
elsewhere. If longitudinal wave propagation is assumed the
transfer function misbehaves for lower frequencies, while it
shows the conventional resonant behavior with sharp, dis-
tinguished peaks in the higher frequency range. This frequency
range varies with different input data for the Young's modulus,
damping factor and core thicknesses.

   The opposite characteristic can be found for the transverse
wave assumption. For lower frequencies the transfer function
behaves well while for higher frequencies it becomes distorted.

   It is assumed that these properties indicate that the
separation of the different wave forms might not be applicable
and that the presence of one kind of waves can not simply be
ignored if all boundary conditions are to be met over the whole
frequency range. This fact needs to be investigated in more
detail.

MONTHLY RESEARCH PROGRESS REPORT FORM

REPORT FOR MONTH OF: June 1987

STUDENT'S NAME: Chris Mollo

PROJECT TITLE:

   Optimization of Active Noise Control Systems

MAJOR PROFESSOR: R. J. Bernhard

SPONSOR: NASA

REPORT:

   Work this past month was mostly dedicated to completing my thesis. The thesis has been completely written and is almost in final form for my thesis defense.

   In addition, I have written the first draft of an AIAA paper to be presented at the 11th Aeroacoustics Conference at Sunnyvale, CA, October 19-21, 1987.

MONTHLY RESEARCH PROGRESS REPORT FORM

REPORT FOR MONTH OF: June 1987

STUDENT'S NAME: Chris Wohlever

PROJECT TITLE:

     Structureborne Noise in Aircraft

MAJOR PROFESSOR: R. J. Bernhard

SPONSOR: NASA -np

REPORT:

     This past month we have been running tests on the Jetstream
III aircraft. The software and acoustical shields, which were put
together during the spring, all worked well.

     The shields were designed to protect various parts of the
aircraft from either acoustical or aerodynamic pressures. The
wing shields were intended to block the vortices shed from the
propeller. The fuselage shields on the other hand were used to
attenuate airborne loading on the fuselage exterior.

     Three basic shield configurations were used in our testing:

     1.   all shields in place

     2.   fuselage shields up, wing shield off

     3.   no shields used.

     Using these three configurations we hope to get some useful
information on the relative importance of airborne versus struc-
tureborne noise. I am in the process now of reducing the data.
We should have some conclusions by the end of next month.

MONTHLY RESEARCH PROGRESS REPORT FORM

REPORT FOR MONTH OF: JUNE 1987

STUDENT'S NAME: Christina Bruer

PROJECT TITLE: Measurement of Dynamical Properties of
                         Acoustical Materials

MAJOR PROFESSOR: J. S. Bolton

SPONSOR: NASA

REPORT:

Most of the time during the month of June was spent on working
out an outline and a table of contents for the thesis. A rough
draft of the first four chapters was written, dealing with the
theoretical derivations of the Oberst technique to measure the
damping properties of the foam. The experimental work and the
computer model, which curve fits the measured data and yields the
material properties were described also.

Some time was further spent on reviewing the procedure how
the new expansion model, in the thesis referred to as the linear
elastic compressible model, has been developed. It encompasses
the superposition of two independent models, an acoustic model,
where the foam is treated as an ideal gas or fluid, and an
incompressible model, where the foam is assumed to have proper-
ties of solid rubber.

Calculations with the acoustic model were repeated and com-
pared to the theoretical results from the elastic compressible
model, when longitudinal waves are considered only. However, the
assumptions of treating the foam as an ideal gas or fluid medium
do not yield any significant results. No change in eigenfrequen-
cies or damping effect is observed for different assumed values
for the Young's modulus or thickness of the foam.

MONTHLY RESEARCH PROGRESS REPORT FORM

REPORT FOR MONTH OF: July 1987

STUDENT'S NAME: Chris Wohlever

PROJECT TITLE:

   Structureborne Noise in Aircraft

MAJOR PROFESSOR: R. J. Bernhard

SPONSOR: NASA -np

REPORT:

      Testing of the HP-137 aircraft has been completed and most
of the data has been reduced and recorded.   I am in the process
now of putting together a final technical report which will have
a full summary of all data taken and conclusions drawn.

      In our tests we did not find that vortices hitting the wing
were a major sound source at the first blade passage tone (about
95 Hz).   However, our results do indicate that structureborne
noise due to wing/vortex interaction might be significant at
higher blade passage tones (i.e., above 600 Hz).

MONTHLY RESEARCH PROGRESS REPORT FORM

REPORT FOR MONTH OF: JULY 1987

STUDENT'S NAME: Christina Bruer

PROJECT TITLE:

   Measurement and Prediction of the Effect of Damping Layers
   on the Vibrational Response of Beams

MAJOR PROFESSOR: J. S. Bolton

SPONSOR: NASA

REPORT:

Work was continued rewriting and correcting the first four
chapters of the thesis.

    Further, tests with all three different long steel beams
(1.0m, 1.362m and 2.0m) with a one sided foam layer and in a
sandwich configuration were repeated in order to present more
graphs and to emphasize the experimental results obtained so far.
In addition all tests were performed with a 1/2" and a 1" thick
foam layer to obtain complete sets of measurements. It can now
be shown that the foam's damping characteristics are almost
equivalent to the PVC-material's damping behavior in certain fre-
quency ranges and configurations. For instance, very high damp-
ing, i.e. no peaks or distinct modes of vibration, is observed
in the higher frequency ranges if the foam material is used in a
sandwich design (1/4" or 1/2" core thickness). In the case of a
one sided layer attached to the steel beam the same high damping
characteristic occurs if the layer is 1" thick.

    Therefore, Chapter 4 of the thesis containing the descrip-
tion of the vibration measurements and the experimental results
will be reorganized and rewritten in particular with respect to
the complete results now available.

MONTHLY RESEARCH PROGRESS REPORT FORM

REPORT FOR MONTH OF: August 1987

STUDENT'S NAME: Chris Wohlever

PROJECT TITLE:

    Structureborne Noise in Aircraft

MAJOR PROFESSOR: R. J. Bernhard

SPONSOR: NASA -np

REPORT:

In the past month I have concentrated my efforts on power flow solutions for simple structures. Using a control volume approach it has been shown that an equation describing energy density, which is very similar to the heat equation for conduction, can be formulated.

The difficulties in this approach include formulating conduction and dissipation factors which control energy flow. Also the question remains how one can deal with boundary conditions and situations where two structures are coupled together. The ultimate goal is to provide an alternative to classical, SEA and other power flow methods in the study of dynamic systems.

MONTHLY RESEARCH PROGRESS REPORT FORM

REPORT FOR MONTH OF: AUGUST 1987

STUDENT'S NAME: Christina Bruer

PROJECT TITLE:

    Measurement and Prediction of the Effect of Damping Layers
    on the Vibrational Response of Beams

MAJOR PROFESSOR: J. S. Bolton

SPONSOR: NASA

REPORT:

        The first four chapters of the thesis were completed during
the month of July. Further, a rough draft of Chapter 5, contain-
ing the theory developed for beams with unrestricted deep damping
layer, was started, but the model has not been found satisfactory
yet. As the model comprises the superposition of two simpler
models, the acoustic and the incompressible model, it is expected
that the results obtained from the acoustic model do agree with
measurements of a one-sided damped beam, while the results of the
incompressible model should correspond to the sandwich measure-
ments. Calculations with unconstrained foam layers, using the
properties of foam obtained from the result in Chapter 4, results
in a good match between theoretical and experimental data, at
least as long the observed transfer functions show the conven-
tional resonant behavior. However, the incompressible model does
not yield the expected agreement yet and therefore needs to be
checked again.

MONTHLY RESEARCH PROGRESS REPORT FORM

REPORT FOR MONTH OF: September, 1987

STUDENT'S NAME: Christina Bruer

PROJECT TITLE:

  Measurement and Prediction of the Effect of Damping Layers on the Vibrational Response of Beams

MAJOR PROFESSOR: J. S. Bolton

SPONSOR: NASA

REPORT:

The past month was spent working on the "Incompressible Model" which will be described in a separate section in Chapter 5 of the thesis.

Initially the motivation behind the model was to account for the propagation of transverse waves in the damping medium. Thus, shear forces acting on the interface to the steel beam were the only forces included in the coupling process to the flexure of the base beam. But since the transverse waves may travel at arbitrary angles within the medium, and the displacement associated with transverse waves occurs perpendicular to the direction of propagation, there may also be normal stresses acting at the interface; consequently longitudinal waves may be generated. This fact causes the determination of the damping medium's characteristic equation and eigenfunctions to be more complicated than originally assumed. An approach similar to that taken with the acoustic model in which one velocity potential is used to satisfy the boundary conditions at the free surfaces of the medium fails. If both normal and shear stresses are required to vanish, the one potential approach results in two contradictory characteristic equations. Therefore it was found necessary to include a second velocity potential which will account for the transformation from an incoming shear wave to reflected shear and a longitudinal waves at a free surface. As this kind of approach is very similar to the superimposed solution in the complete model the explicit calculations will therefore not be pursued. The incompressible model is now presented in Chapter 5 as follows:

(i) The concept of modeling the damping layer as an ideal solid medium with rubber-like properties will be introduced and the one potential approach will be derived yielding the contradictory characteristic equations.

(ii) Two alternative approaches will then be outlined. In the first, a second potential is introduced while in the second the incompressible wave field is considered to be three-dimensional.

(iii) The latter approach will be compared with the Ross, Kerwin and Ungar theory. The extension to damping cores of unrestricted depth will be allowed for by the assumption that the stress profile within the core in general an exponential function rather than just a linear function.

(iv) The governing equation of the steel beam and the coupling conditions will then be presented for the superimposed model.

MONTHLY RESEARCH PROGRESS REPORT FORM

REPORT FOR MONTH OF: September, 1987

STUDENT'S NAME: Chris Wohlever

PROJECT TITLE:

    Power Flow Solutions

MAJOR PROFESSOR: R. J. Bernhard

SPONSOR: NASA

REPORT:

    In continuing the work on Power Flow Solutions, I have begun
to study some concepts on energy density and energy flow in
structures. In classical analysis, for the example of a simply
supported beam excited by a harmonic point source at steady state
conditions, there exists no net power flow unless damping is
included. However, even with the absence of a net flow, an
energy density does exist which is constant when integrated over
a period of vibration. This indicates the power delivered to a
structure in steady state must be equal to the power dissipated
by damping in a closed system. Since we are interested in the
total energy density in a system we will need to include this in
our model, as opposed to modeling power flow only.

MONTHLY RESEARCH PROGRESS REPORT FORM

REPORT FOR MONTH OF: October, 1987

STUDENT'S NAME: Chris Wohlever

PROJECT TITLE:

Structure Borne Noise in Propeller Aircraft

MAJOR PROFESSOR: R. J. Bernhard

SPONSOR: NASA

REPORT:

This past month I have been working on exact solutions for power flow through beams and rods with damped boundary conditions. These were to be used as a comparison for our alternate power flow solution. Since the alternate power flow solution is in the form of a 1-D heat equation, its solution is one which decays exponentially from a point source. The exact solutions show this same exponential decay, however strong modal effects are superimposed upon this decay, especially at low frequencies. Additional study of energy distribution and energy absorption is being conducted to explain the differences in the two solutions.

MONTHLY RESEARCH PROGRESS REPORT FORM

REPORT FOR MONTH OF: October 1987

STUDENT'S NAME: Christina Bruer

PROJECT TITLE:

·Measurement and Prediction of the Effect of Damping Layers on the Vibrational Response of Beams

MAJOR PROFESSOR: J. S. Bolton

SPONSOR: NASA

REPORT:

· During the month of October the thesis was completed and handed to Dr. Bolton for final corrections. The defense has been scheduled for November 20th.

Further a paper (titled "Vibro-Acoustic Damping of Extended Vibrating Systems") was written and presented at the 11th Aeracoustics Conference in Palo Alto, CA.

MONTHLY RESEARCH PROGRESS REPORT FORM

REPORT FOR MONTH OF: November, 1987

STUDENT'S NAME: Chris Wohlever

PROJECT TITLE:

        Structure Borne Noise in Propeller Aircraft

MAJOR PROFESSOR: R.J. Bernhard

SPONSOR: NASA

REPORT:

During November I continued work on power flow solutions for rods and beams. For a rod excited by a harmonic point source the general solution for displacement can be written as:

$$u(x,t) = [Ae^{-jkx} + Be^{jkx}]e^{j\omega t} \tag{1}$$

where:

$$u(x,t) = \text{displacement in rod}$$

$$k = k_1 + jk_2 \text{ (complex wavenumber)}$$

$$\omega = \text{driving frequency}$$

The time averaged power flow and energy density in a rod are calculated using the formulas

$$\text{Power Flow} = \tfrac{1}{2}\text{Re}(\text{force}(\text{velocity})^*) \tag{2}$$

$$\text{Energy} = \tfrac{1}{2}\text{Re}(\tfrac{1}{2}ES(\partial u/\partial x)(\partial u/\partial x)^*)$$

$$+ \tfrac{1}{2}\text{Re}(\tfrac{1}{2}\rho S(\partial u/\partial x)(\partial u/\partial x)^*) \tag{3}$$

where:

$$E = \text{Young's Modulus}$$

$$S = \text{cross sectional area of rod}$$

$$\rho = \text{material density}$$

$$* = \text{complex conjugate}$$

Plugging equation (1) into equations (2) and (3) and assuming small viscous damping exists in the rod the power flow and energy density can be approximated as

$$\text{Power Flow} = -\tfrac{1}{2}\omega ES[k_1(|B|^2 e^{-2k_2 x} - |A|^2 e^{2k_2 x})] \tag{4}$$

$$\text{Energy} = \tfrac{1}{2}\rho S\omega^2 [|A|^2 e^{2k_2 x} + |B|^2 e^{-2k_2 x}] \tag{5}$$

Using equations (4) & (5) we find the following relation between the power flow and the gradient of the energy density exists.

$$\text{Power Flow} = -\frac{2\rho S\omega}{\lambda}\frac{\partial(\text{energy})}{\partial x} \tag{6}$$

From equation (6) then we find that the power flow at a point in the rod is proportional to the gradient of the energy density at that point. This is analogous to Fourier's Law in heat conduction. With this relation one may do an energy balance on a rod element and get a Poisson's equation which governs the flow of mechanical energy thru a harmonically excited rod. The only thing which is needed is the boundary conditions. These boundary conditions may either specify a known energy density or power flow.

I am presently involved in developing similar equations for a beam excited by a harmonic point source. The beam is more complicated since it is a fourth order equation and thus produces nearfield effects which were non-existent in the rod solutions.

MONTHLY RESEARCH PROGRESS REPORT FORM

REPORT FOR MONTH OF: November, 1987

STUDENT'S NAME: Christina Bruer

PROJECT TITLE:

  Measurements and Prediction of the Effect of Damping Layers on the Vibrational
  Response of Beams

MAJOR PROFESSOR: J. S. Bolton

SPONSOR: NASA

REPORT:

A paper (titled: Damping of Continuous Structures by the Use of Elastic Porous Materials)

for the "Recent Advances in Structural Dynamics" conference was written and submitted. On

November, 20th the defense was passed and the thesis completed and deposited.