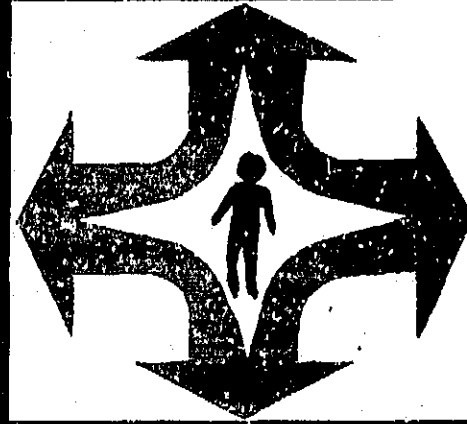


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**UMR** DEPARTMENT OF  
MECHANICAL & AEROSPACE  
ENGINEERING



(NASA-CR-157589) A STUDY OF THE  
STRUCTURAL-ACOUSTIC RESPONSE AND INTERIOR  
NOISE LEVELS OF FUSELAGE STRUCTURES Final  
Report, Sep. 1974 - Aug. 1978 (Missouri  
Univ. -Rolla.) 16 p HC A02/MF A01 CSCL 20A G3/71

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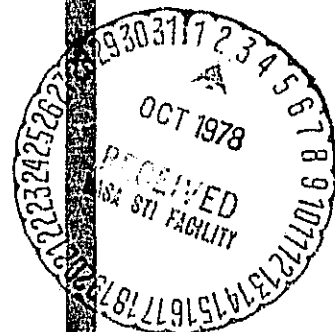
A STUDY OF THE STRUCTURAL-ACOUSTIC RESPONSE AND  
INTERIOR NOISE LEVELS OF FUSELAGE STRUCTURES

FINAL REPORT  
COVERING THE PERIOD SEPT. 1974-AUGUST 1978

LESLIE R. KOVAL  
PRINCIPAL INVESTIGATOR

SEPTEMBER 1978

UNIVERSITY OF MISSOURI - ROLLA



**NASA Grant NSG-1050**

**A Study of The Structural-Acoustic Response and  
Interior Noise Levels of Fuselage Structures**

**Final Report  
Covering the period Sept. 1974-August 1978**

**Leslie R. Koval  
Principal Investigator  
Department of Mechanical and Aerospace Engineering**

**September 1978  
University of Missouri-Rolla  
Rolla, MO 65401**

1.0 Summary

An analytical investigation has been conducted to formulate a mathematical model for the propagation of airborne noise through the sidewalls of an airplane fuselage. This study was motivated by a need to improve the understanding of the noise transmission phenomenon, especially in relation to STOL aircraft for which the jet engines exhaust directly onto the lifting surface and are much closer to the fuselage than they are for conventional jets.

At the time of the initiation of this study, the state-of-the-art in the aircraft industry employed a noise-transmission theory that was originally developed for the transmission of sound through a flat architectural wall. However, there are significant differences between a flat wall separating two rooms and the sidewall of an airplane fuselage. In particular, an airplane fuselage is generally curved and internally pressurized, and when the aircraft is in flight there is an airflow past the vehicle fuselage. At the time this study was initiated, the effects of these features were not known. The purpose of this study was to investigate these effects.

During the summer of 1974, the principal investigator was a NASA/ASEE Faculty Summer Research Fellow at NASA Langley Research Center and began to address this problem. The work continued through August 1978 under NASA Grant NSG-1050 funded by NASA Langley Research Center under the cognizance of the Noise Effects Branch, Acoustics and Noise Reduction Division. The NASA Technical Officer for this grant was Dr. John S. Mixson of the Noise Effects Branch.

The first task was to formulate a mathematical model for the propagation of airborne noise through a fuselage sidewall. Three problems were examined. The first was a study of the effect of airflow on the field-incidence transmission loss of a flat panel. The field-incidence transmission loss of a curved panel was the second problem studied. These results were published

in the "Journal of the Acoustical Society of America", and the abstract of the paper is presented in Appendix A.

The next problem studied was a formulation of the basic mathematical model for the noise transmission into a complete fuselage. The specific problem studied was that for an oblique plane wave incident upon a flexible thin cylindrical shell. The shell was a monocoque structure and there was a uniform flow past the cylinder. The cylinder was internally pressurized, and was assumed to be of infinite length (for mathematical simplicity). The mathematical model computed the sound transmission loss for the cylindrical structure. The results were published in the "Journal of Sound and Vibration", and an abstract is presented in Appendix B.

In the second year of the study, the effect of cavity resonances (which were neglected in the previous phase) was investigated, and the shell model was modified to a stiffened shell, using a smeared-stiffener theory. The results of these studies were published in "Journal of Sound and Vibration", and the "AIAA Journal", respectively. Abstracts of these papers are presented in Appendices C and D.

Additional related studies were conducted on the effect of high damping on sound transmission, and the effect of a flowing acoustic media on the vibrations of a cylindrical shell. These results were published in the "Journal of Sound and Vibration" (as a Letter to the Editor) and in the Proceedings of the Ninth Southeastern Conference of Theoretical and Applied Mechanics", respectively. An abstract of the paper appears in Appendix E.

In the third phase of the study, the shell model was further improved, because the "smeared-stiffener" theory for the stiffened shell was not accurate at higher frequencies. This was improved by formulating the stiffeners as discrete structural elements. The stringers were first modeled in this fashion, and the results are being published in the "Journal of Aircraft" (the abstract

appears in Appendix F). Concurrently with this problem, the sound transmission through an orthotropic shell was investigated by replacing the original monocoque shell by an orthotropic shell. The results of this study will be appearing in the "Journal of Sound and Vibration" (abstract presented in Appendix G).

In the final phase, the shell model was replaced by a finite stiffened shell in which the stringers and ring frames were both modeled as discrete structural elements. Also investigated was the sound transmission through a shell made of composite materials. Both of these studies are now completed, and papers will be written and submitted for publication in recognized technical journals.

During the second phase of the study, a graduate student, Mr. Harold M. Harder, participated in the project, and authored a thesis for his M.S. degree. An abstract of this thesis is presented in Appendix H.

## 2.0 Action Items

During the performance period of the grant, the following actions were generated.

### a. Number of presentations: 7

1. L. R. Koval, "The Effect of Air-Flow, Panel Curvature, and Internal Pressurization on Field-Incidence Transmission Loss", 89th Meeting of Acoustical Society of America, 8-11 April 1975 at University of Texas, Austin, Texas.
2. L. R. Koval, "Analytical Studies of Noise Transmission", General Aviation Interior Noise Workshop, 6-7 October 1975 at NASA Langley Research Center.
3. L. R. Koval, "On Sound Transmission into a Thin Cylindrical Shell under Flight Conditions", 90th Meeting of Acoustical Society of America, 4-7 November 1975 at San Francisco, Calif.
4. L. R. Koval, "Analytical Studies of Noise Transmission in Aircraft Fuselages", SAE 1976 National Business Aircraft Meeting, 7 April 1976, Wichita, Kansas.
5. L. R. Koval, "On Sound Transmission into a Stiffened Cylindrical Shell under Flight Conditions", AIAA 3rd Aero-Acoustics Conference, 20-23 July 1976, at Palo Alto, Calif.
6. L. R. Koval, "A Model for Sound Transmission Through an Airplane Fuselage", 85th Meeting of American Society of Engineering Education, 28 June 1977, at University of North Dakota, Fargo, N.D.
7. L. R. Koval, "The Vibrations of a Cylindrical Shell in A Flowing Acoustic Media", Ninth Southeastern Conference on Theoretical and Applied Mechanics (Ninth SECFAM), 4-5 May 1978, at Vanderbilt University, Nashville, Tenn.

### b. Number of journal articles published: 8

1. L. R. Koval, "The Effect of Air-Flow, Panel Curvature, and Internal Pressurization on Field-Incidence Transmission Loss", Journal of The Acoustical Society of America, Vol. 54, No. 6, June 1976, pp. 1379-1385.
2. L. R. Koval, "On Sound Transmission into a Thin Cylindrical Shell Under Flight Conditions", Journal of Sound and Vibration, Vol. 48, No. 2, October 1976, pp. 265-275.
3. L. R. Koval, "Effect of Stiffening on Sound Transmission into a Thin Cylindrical Shell in Flight", AIAA Journal, Vol. 15, No. 7, July 1977, pp. 899-900.
4. L. R. Koval, "On Sound Transmission into a Heavily-Damped Cylinder", Journal of Sound and Vibration, Vol. 57, No. 1, 8 March 1978, pp. 155-156.

5. L. R. Koval, "Vibrations of a Cylindrical Shell in a Flowing Acoustic Media", Proc. of Ninth Southeastern Conference on Theoretical and Applied Mechanics, 4-5 May 1978, at Vanderbilt Univ., Nashville, Tenn., pp. 265-273.
6. L. R. Koval, "Effects of Cavity Resonances on Sound Transmission into a Thin Cylindrical Shell", Journal of Sound and Vibration, Vol. 59, No. 1, 8 July 1978, pp. 23-33.
7. L. R. Koval, "Effect of Longitudinal Stringers on Sound Transmission into a Thin Cylindrical Shell", Journal of Aircraft, in press.
8. L. R. Koval, "On Sound Transmission into an Orthotropic Shell", Journal of Sound and Vibration, in press.

There are two papers currently in preparation:

1. "Sound Transmission into a Composite Cylinder"
2. "On Sound Transmission into a Stiffened Cylindrical Shell with Rings and Stringers Treated as Discrete Elements"

d. Thesis: 1

H. Harder, "The Influence of Flight Conditions on the Field-Incidence Transmission Loss of Flat and Curved Panels", M.S. Thesis at the University of Missouri-Rolla, 1976.



**APPENDICES**

## APPENDIX A

THE EFFECT OF AIR FLOW, PANEL CURVATURE, AND INTERNAL  
PRESSURIZATION ON FIELD-INCIDENCE TRANSMISSION LOSS

Journal of The Acoustical Society of America, 54(6), 1379-1385, June 1976

by

L. R. Koval

Department of Mechanical and Aerospace Engineering  
University of Missouri-Rolla, Rolla, MO 65401

## ABSTRACT

In the context of sound transmission through aircraft fuselage panels, equations for the field-incidence transmission loss of a single-walled panel are derived that include the effects of external air flow, panel curvature, and internal fuselage pressurization. These effects are incorporated into the classical equations for the TL of single panels, and the resulting double integral for field-incidence TL is numerically evaluated for a specific set of parameters.

Flow is shown to provide a modest increase in TL that is uniform with frequency up to the critical frequency. The increase is about 2dB at  $M = \text{Mach No.} = 0.5$ , and about 3.5 dB at  $M = 1$ . Above the critical frequency where TL is damping controlled, the increase can be slightly larger at certain frequencies.

Curvature is found to stiffen the panel, thereby increasing the TL at low frequencies, but also to introduce a dip (analogous to the coincidence dip at the critical frequency) at the "ring frequency" of a full cylinder having the same radius as the panel. This effect, up to now qualitatively understood, can now be quantitatively estimated. Pressurization appears to produce a slight decrease in TL throughout the frequency range, and also slightly shifts the dips at the critical frequency and at the ring frequency.

## APPENDIX B

ON SOUND TRANSMISSION INTO A THIN CYLINDRICAL  
SHELL UNDER "FLIGHT CONDITIONS"Journal of Sound and Vibration, 48(2), 265-275, October 1976

by

L. R. Koval

Department of Mechanical and Aerospace Engineering  
University of Missouri-Rolla, Rolla, MO 65401

## ABSTRACT

In the context of the transmission of airborne noise into an aircraft fuselage, a mathematical model for sound transmission into a thin cylindrical shell is used to study sound transmission under "flight conditions," i.e., under conditions of external air flow past a pressurized cylinder at flight altitude. Numerical results for different incidence angles are presented for a typical narrow-bodied jet in cruising flight at 10,660 m (35,000 ft.) with interior pressure at 2440 m (8000 ft.). A comparison is made between no-flow sound transmission at standard conditions on the ground to sound transmission under flight conditions. It is shown that at  $M = 0$ , the cylinder transmission loss has dips at  $f_R$  (cylinder ring frequency) and  $f_c$  (critical frequency for a flat panel of same material and thickness as shell). Below  $f_R$ , cylinder resonances affect TL. Between  $f_F$  and  $f_c$ , cylinder TL follows a mass-law behavior. Flow provides a modest increase in TL in the mass-law region, and strongly interacts with the cylinder resonances below  $f_R$ . For normally-incident waves, TL is unaffected by flow.

## APPENDIX C

EFFECTS OF CAVITY RESONANCES ON SOUND TRANSMISSION  
INTO A THIN CYLINDRICAL SHELL

Journal of Sound and Vibration, 59(1), 22-33, 8 July 1978

by

L. R. Koval

Department of Mechanical and Aerospace Engineering  
University of Missouri-Rolla, Rolla, MO 65401

ABSTRACT

In the context of the transmission of airborne noise into an aircraft fuselage, a mathematical model is presented for the effects of internal cavity resonances on sound transmission into a thin cylindrical shell. The "noise reduction" of the cylinder is defined and computed, with and without including the effects of internal cavity resonances. As would be expected, the noise reduction in the absence of cavity resonances follows the same qualitative pattern as does transmission loss. Numerical results show that cavity resonances lead to wide fluctuations in noise reduction and to a general reduction in level, especially at cavity resonances. Modest internal absorption is shown to greatly reduce the effect of cavity resonances. The effects of external airflow, internal cabin pressurization, and different acoustical properties inside and outside the cylinder are also included and briefly examined.

## APPENDIX D

EFFECT OF STIFFENING ON SOUND TRANSMISSION INTO  
A CYLINDRICAL SHELL IN FLIGHTAIAA Journal, 15(7), 899-900, July 1977

by

L. R. Koval

Department of Mechanical and Aerospace Engineering  
University of Missouri-Rolla, Rolla, MO 65401ABSTRACT

In the context of airborne-noise transmission through an aircraft fuselage, a mathematical model is presented for sound transmission into a stiffened cylindrical shell. The stiffening effect of the ring frames and stringers is approximated by a "smeared"-stiffener theory which includes the eccentricity of the stiffeners. Numerical results are presented for a typical narrow-bodied jet in cruising flight. A comparison is made between noise transmission into a monocoque shell and into a stiffened shell. The stiffeners are shown to greatly increase TL for small incidence angles, so that the effective "window" for noise transmission is restricted to the neighborhood of normal incidence. Flow is shown to increase TL for sound waves propagating "upstream" against the flow. Stiffeners are also shown to raise the ring frequency at which a dip in cylinder TL occurs. Limitations of the "smeared"-stiffener theory are also discussed.

## APPENDIX K

THE VIBRATIONS OF A CYLINDRICAL SHELL IN A  
FLOWING ACOUSTIC MEDIA

"Proceedings of The Ninth Southwestern Conference on Theoretical and Applied  
Mechanics", Vanderbilt University, Nashville, TN, 265-273, May 1978

by

L. R. Koval  
Professor of Mechanical Engineering  
University of Missouri-Rolla  
Rolla, Missouri 65401

ABSTRACT

A mathematical model is presented for the effect of flow on the vibrations of a thin cylindrical shell in a subsonically flowing acoustic media. Free vibrations are treated first. The effect of the external acoustic fluid consists of a mass-like term caused by the "virtual-mass" effect of the fluid and a "damping-like" term which accounts for the radiation of energy away from the cylinder. For a flowing medium, both of these terms are shown to involve the flow velocity. Next, the forced vibration of the cylinder is studied, and the effect of flow on the cylinder resonances examined numerically. Numerical results representative of a narrow-bodied jet in flight show that, while not all modes are affected by the flow, there are some modes which are significantly affected by the presence of flow. Usually, the added mass of the fluid increases with flow velocity causing a reduction in the resonant frequency of the shell mode.

## APPENDIX F

EFFECT OF LONGITUDINAL STRINGERS ON SOUND TRANSMISSION  
INTO A THIN CYLINDRICAL SHELL

Journal of Aircraft, In Press

by

L. R. Koval

Department of Mechanical and Aerospace Engineering  
University of Missouri-Rolla, Rolla, MO 65401ABSTRACT

In the context of the transmission of airborne noise into an aircraft fuselage, a mathematical model is presented for the transmission of airborne noise into a stiffened cylindrical shell. The stiffeners are longitudinal stringers and are modeled as discrete structural elements. The numerical cases examined were typical of a narrow-bodied jet transport fuselage. The stringers appeared to raise the cylinder transmission loss in the mass-controlled region, although they produced dips at the stringer resonances. The ring-frequency dip in TL, which is characteristic of monocoque shells, was found to still be present. There appeared to be a small increase in TL as the number of stringers was increased. The effect of high damping was also investigated.

## APPENDIX G

## ON SOUND TRANSMISSION INTO AN ORTHOTROPIC SHELL

Journal of Sound and Vibration, In Press

by

L. R. Koval

Department of Mechanical and Aerospace Engineering  
University of Missouri-Rolla, Rolla, MO 65401ABSTRACT

In the context of the transmission of airborne noise into an aircraft fuselage, a mathematical model is presented for the transmission of airborne noise through the walls of an orthotropic cylindrical shell. Parameters were varied to see how orthotropicity affected noise transmission. When compared to that for a monocoque shell, the cylinder transmission loss was found to be quite sensitive to the ratio of circumferential to axial modulus of elasticity. A modulus ratio greater than unity appears to enhance transmission loss, while a ratio less than unity degrades it. The cylinder transmission loss appears to be relatively insensitive to changes in the shear modulus.



## APPENDIX II

"The Influence of Flight Conditions on the Field-Incidence  
Transmission Loss of Flat and Curved Panels"

Harold N. Harder

Thesis for M.S. Degree, 1978  
University of Missouri-Rolla, Rolla, MO 65401

ABSTRACT

As an extension to previous theoretical work done on sound transmission through aircraft fuselage panels, models of both flat and curved fuselage panels were tested for their sound transmission characteristics. The effect of external air flow on transmission loss was simulated in a subsonic wind-tunnel. By numerically evaluating the known equations for field-incidence transmission loss of single-walled panels in a computer program, a comparison of the theory with the test results was made.

As a further extension to aircraft fuselage simulation, equations for the field-incidence transmission loss of a double-walled panel are derived that include the effects of external air flow, panel curvature, internal fuselage pressurization, and different panel properties. Numerical results are presented for a typical aircraft fuselage.

Although limitations on windtunnel velocity prevented the effect of air flow from being uniform, flow is shown to provide a small increase in transmission loss for a flat panel. Curvature is shown to increase transmission loss for low frequencies, while also providing a sharp decrease, or "dip", in transmission loss at the "ring frequency" of the cylindrical panel.

The field-incidence transmission loss of a double-walled panel was found to be approximately twice that for a single-walled panel, with the addition of dips in the transmission loss at the "air gap" resonances and at the critical frequency of the internal panel.