DEPARTMENT OF MECHANICAL ENGINEERING AND MECHANICS
COLLEGE OF ENGINEERING
OLD DOMINION UNIVERSITY
NORFOLK, VIRGINIA 23529

PREDICTION OF STRESSES IN AIRCRAFT PANELS SUBJECTED TO ACOUSTIC FORCES

By

Chuh Mei, Principal Investigator

(NASA-CR-182513) PREDICTION OF STRESSES IN
AIRCRAFT PANELS SUBJECTED TO ACOUSTIC FORCES
Final Report, 1 Oct. 1985 - 15 Dec. 1987
(Old Dominion Univ.) 13 p CSCL 20K

N89-12923

Unclas
G3/39 0125203

Final Report
For the period October 1, 1985 To December 15, 1987

Prepared for the
National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia 23665

Under
NASA Master Contract Agreement NAS-1-17993
Task Authorization No. 22
John S. Mixon, Technical Monitor
ACOD - Structural Acoustics Branch

Submitted by the
Old Dominion University Research Foundation
P.O. Box 6369
Norfolk, Virginia 23508

March 1988

PREDICTION OF STRESSES IN AIRCRAFT PANELS SUBJECTED TO ACOUSTIC FORCES

By

Chuh Mei*

SUMMARY

This report summarized the progress and accomplishments performed under NASA/Langley Research Center Master Agreement NAS1-17993, Task Assignment No. 22, entitled "Prediction of Stresses in Aircraft Panels Subjected to Acoustic Forces," for the period October 1, 1985 to December 15, 1987. The primary effort of this task is the development of analytical methods for prediction of stresses in aircraft panels subjected to acoustic forces. The progress and accomplishments of various activities are discussed first. Then, publications, presentations and thesis are followed.

---

*Professor, Department of Mechanical Engineering and Mechanics, Old Dominion University, Norfolk, Virginia 23529-0247.

PROGRESS AND ACCOMPLISHMENTS

Seven activities were supported under the Task Assignment No. 22. The progress and accomplishments of these activities are summarized in the following.

ACTIVITY 1: Analysis of Panel Random Response Using Laminate Theories of Various Degree of Detail.

Two laminated plate theories are used: the classical laminated plate theory (CPT) and the first-order shear deformation plate theory (FSDT by Yang-Norris-Stavsky and Reissner-Mindlin). Large deflection effects are also considered in the formulation. Results showed that the influence of transverse shear deformation on random response is considerable for moderately thick laminates ($a/h < 20$), and the small deflection linear theory with shear deformation included would give accurate predictions. For thin laminates ($a/h > 50$), the linear and nonlinear results agree well at low pressure levels, but disagree at high levels. Thus, the large deflection theory with shear deformation neglected should be used for thin plates at high levels of excitation. Therefore, for a particular value of a/h, one of the three simpler theories can be chosen that will provide accuracy equal to the more cumbersome theory which includes both shear and large deflection effects (see Publication P-1 and Report R-1).

ACTIVITY 2: Effects of Nonlinear Damping on Large Amplitude Response of Beams and Plates.

The test strain spectral data of aircraft panels have repeatedly shown the broadening behavior of the peaks when the panels were excited at high pressure levels. It has demonstrated analytically, the first time, that nonlinear damping terms ($c_1q^2\dot{q}$, and $c_2q\dot{q}^2$) will give the broadening behavior of the strain peaks. Analytical results also showed that it would predict more realistic frequency of vibrations and RMS deflection with nonlinear damping considered in the analysis.

Further analytical efforts are needed to better understand the effects of nonlinear damping on panel response. Experiments are also needed to determine the nonlinear damping coefficients (c_1, c_2 etc.) for beam and plate structures . Other possible nonlinear damping terms should also be considered (Publications P-2 to P-5* and Report R-2).

ACTIVITY 3: Development of Finite Element Large Deflection Random Analysis with a Beam Element and a Rectangular Plate Element.

A literature search on this subject was conducted in June 1986. The development of finite element formulation using single-mode and multiple-mode for large deflection random response analysis of beams and plates has been completed. Finite element single-mode results agreed well with solutions using the Fokker-Planck-Kolmogorov (exact solution) equation and the equivalent linearization (EL) methods. Finite element (FE) multiple-mode beam results are shown in Figs. 1 and 2. RMS maximum strains and equivalent linear frequencies vs. sound spectrum level for simply supported and clamped beams using 3 modes in the analyses are shown in Figs. 1 and 2, respectively. The EL 3-mode solutions are also given for comparison. The finite element results by neglecting the axial displacement and the axial inertia degrees-of-freedom are denoted by FE* in Figs. 1 and 2. The FE* results agree well with the EL solutions, since both approaches are formulated in

---

*Publication P-4 received the best paper award presented at the AIAA 10th Aeronautics Conference.

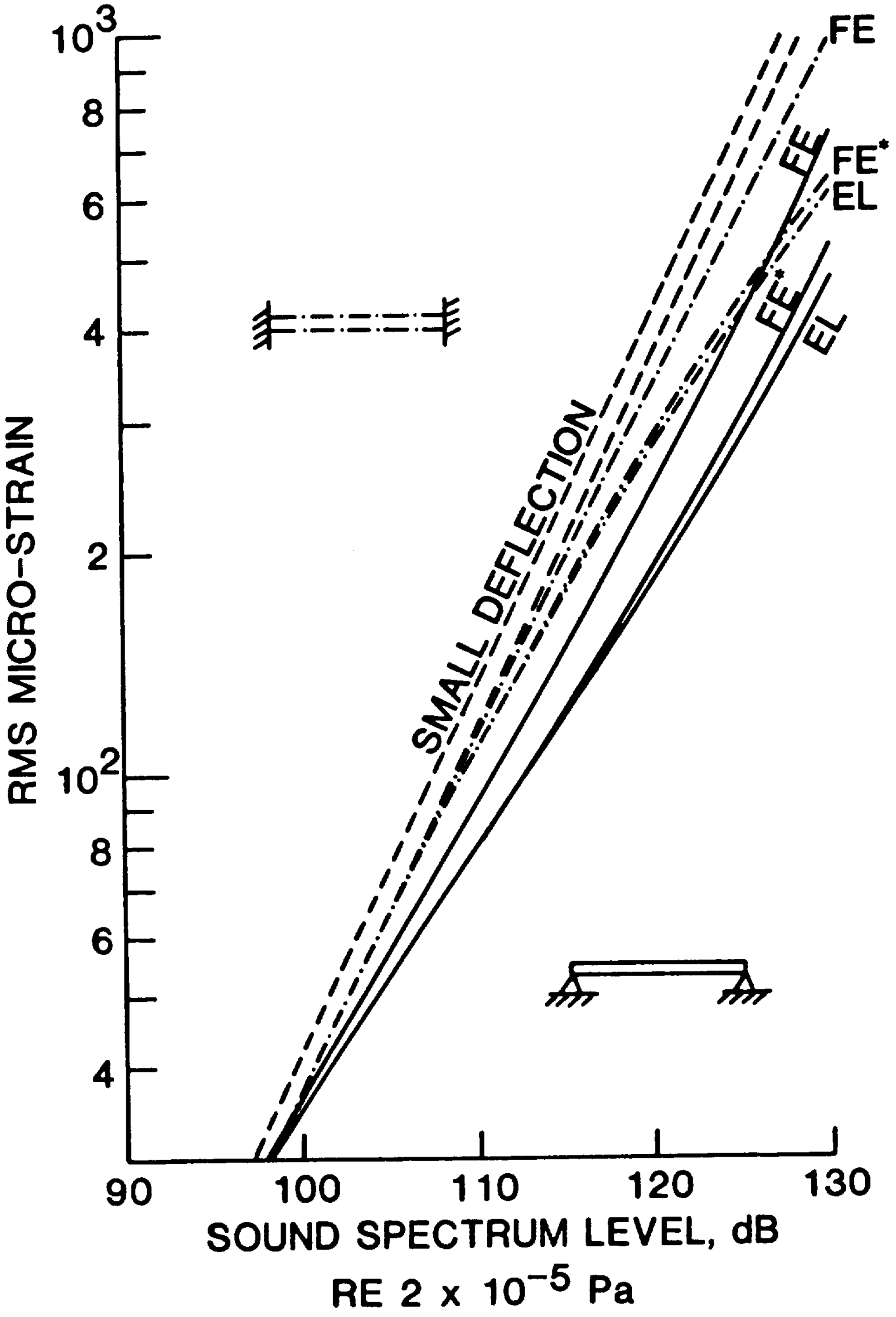

Fig. 1. RMS maximum strain vs. sound spectrum level for simply supported and clamped beams (3-mode and ζ = 0.01).

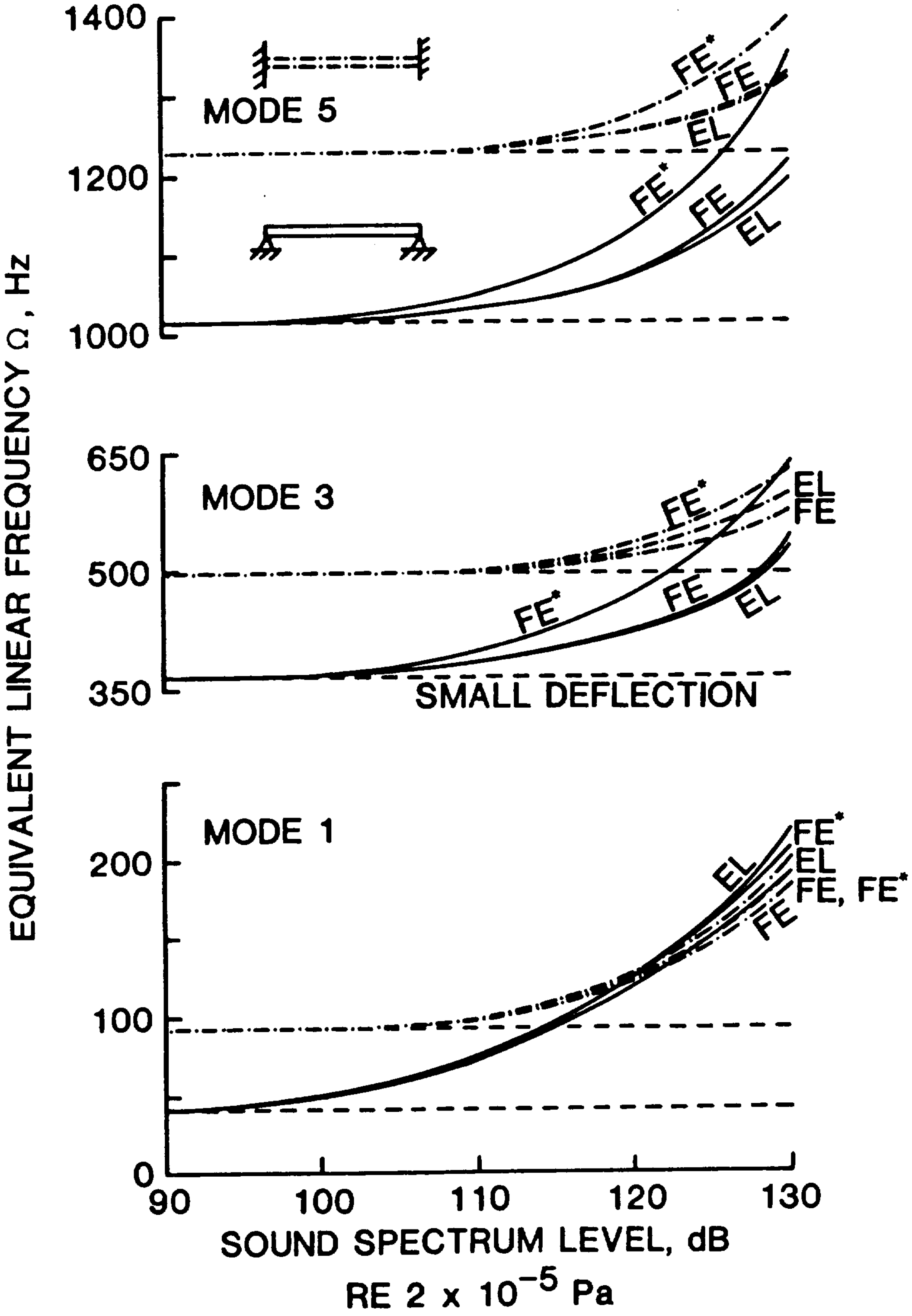

Fig. 2. Equivalent linear frequency vs. sound spectrum level for simply supported and clamped beams (3-mode and ζ =0.01).

terms of the transverse displacement only.

Work is continued on the development of finite element large deflection random response of built-up structures (Publications P-6 and P-7).

ACTIVITY 5: Comparison of Time Domain and Equivalent Linearization Solutions.

A comparison of maximum deflection spectra using the time domain and the EL methods for a 12 x 12 x 0.040 in. clamped, $(0, \pm 45, 90)_s$ composite plate is shown in Fig. 3. The time domain solution in Fig. 3 is obtained by Dr. E. Thomas Moyer of George Washington University. At 70 dB sound spectrum level, the two methods predict very similar responses. At 110 dB, the EL method predicts essentially the same equivalent linear frequency as the time domain simulation; however, the time domain approach predicts the bandwidth of the response peak about 2 to 3 times broader than that of the EL method. The broader spectral response yields a 10% higher value of the RMS maximum deflection. The very same results have been obtained by Dr. Ron N. Miles in his Ph.D. dissertation (University of Washington, 1987).

The real challenge is the search for an analytical model that will be able to correlate better with the experimental data so that the strain spectral peaks are broadened 40 to 50 times instead of 2 to 3 at high SPL. The solutions obtained by Drs. Moyer and Miles demonstrated that time domain analysis with nonlinear stiffness term alone (without nonlinear damping) can not broaden the spectral peaks to the orders observed experimentally. Nonlinear damping effects will have to be considered in the analysis for panels excited at high pressure levels.

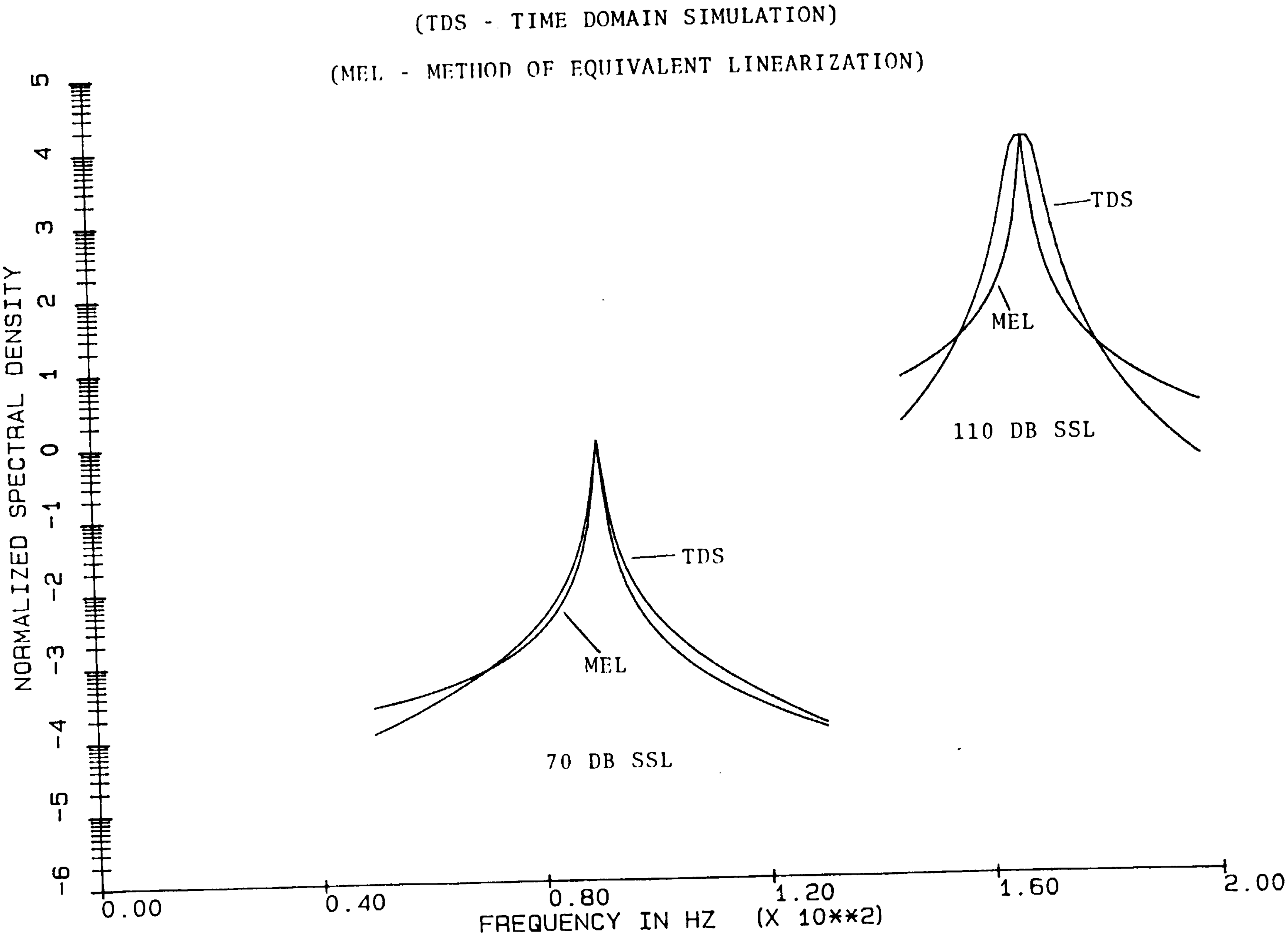

Fig. 3. Comparison of response spectral densities of a clamped $(0, \pm 45, 90)_s$ composite plate ($\zeta = 0.01$).

ACTIVITY 6: Effects of Boundary Conditions and Initial Imperfections on Panel Response.

To improve the agreement between predicted and measured dynamic response of rectangular aluminum panels, both rotational and translational boundary springs are considered at the panel edges. To ease the mathematical manipulations, the MACSYMA program is used. Dynamic response obtained using MACSYMA are compared with the improved Rayleigh-Ritz analytical solutions and NASTRAN results.

Most recently, the effects of initial imperfection and edge rotational restraint on large deflection random response of symmetrically laminated cross-ply rectangular plates have been studied. Figure 4 shows the RMS (maximum deflection/plate thickness) vs. nondimensional edge restraint K ($K = 0$ corresponds to simply supported case, $K = \infty$ clamped case) at four sound spectrum levels from 100 to 130 dB (Re 2×10^{-5} N/M^2) for a flat plate ($W'_{11} = 0$) and plates with non-dimensional initial imperfections of $W'_{11} = 0.1$, 0.2 and 0.4. In general, initial imperfections are to increase the linear frequency and to reduce the RMS deflection and RMS strain (Publication P-8 and Report R-3).

ACTIVITY 7: Influence of Temperature on Small Deflection Vibratory Analysis of Panels.

Extension of the finite element method to predict small deflection random response and small deflection free vibrations of thermally buckled rectangular plates has been completed. The formulation has been generalized to treat the thermal loads having nonuniform temperature distributions T(x,y) instead of the uniform temperature. Effects of thermal prestress, thermally postbuckled deformation and changes in material properties due to

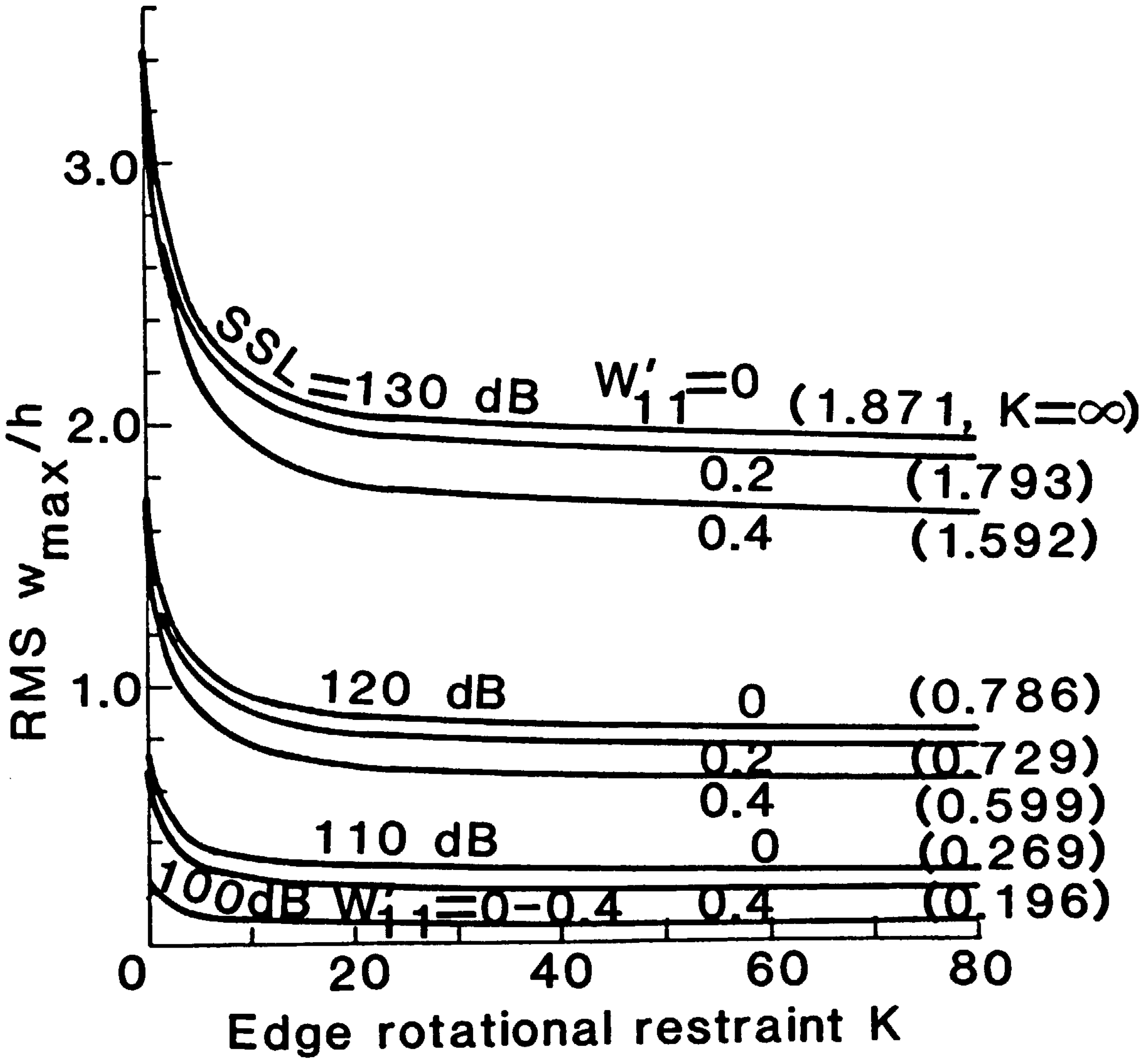

Fig. 4. Effects of initial imperfection and edge restraint on deflection for a square cross-ply laminate (ζ = 0.01) at various SSL.

temperature have all been considered in the formulation. Further development of the finite element formulation for large deflection random response of thermally buckled structures is continued by James E. Locke. The Ph.D. dissertation committee has accepted this as his research topic on January 11, 1988.

PUBLICATIONS AND CONFERENCE PAPERS

P-1. C. Mei and C.B. Prasad, "Effects of Large Deflection and Transverse Shear on Response of Rectangular Symmetric Composite Laminates Subjected to Acoustic Excitation," Proceedings AIAA Dynamics Specialists Conference, Monterey, CA, April 1987, pp. 809-826.

P-2. C. Mei and C.B. Prasad, "Effects of Nonlinear Damping on Random Response of Beams to Acoustic Loading," Proceedings 27th AIAA/ASME-/ASCE/AHS Structures, Structural Dynamics and Materials Conference, San Antonio, TX, May 1986, pp. 644-653.

P-3. C. Mei and C.B. Prasad, "Effects of Nonlinear Damping on Random Response of Beams to Acoustic Loading," Journal Sound Vibration. Vol. 117, 1987, pp. 173-186.

P-4. C. Mei and C.B. Prasad, "Response of Symmetric Rectangular Composite Laminates with Nonlinear Damping Subjected to Acoustic Loading," AIAA Paper 86-1933, 10th Aeroacoustics Conference, Seattle, WA, July 1986.

P-5. C.B. Prasad and C. Mei, "Multiple-Mode Large Deflection Random Response of Beams with Nonlinear Damping to Acoustic Excitation," AIAA Paper 87-2712, 11th Aeroacoustics Conference, Sunnyvale, CA, October 1987.

P-6. C. Mei and C.K. Chiang, "A Finite Element Large Deflection Random Response Analysis of Beams and Plates Subjected to Acoustic Loading," AIAA Paper 87-2713, 11th Aeroacoustics Conference, Sunnyvale, CA, October 1987.

P-7 C.K. Chiang and C. Mei, "A Finite Element large Deflection Multiple-Mode Random response Analysis of Beams Subjected to Acoustic Loading," accepted for presentation at 3rd International Conference on Recent Advances in Structural Dynamics, University of Southampton, July 1988.

P-8. C.B. Prasad, and C. Mei, "Large Deflection Random Response of Cross-Ply Laminated Plates with Elastically Restrained Edges and Initial Imperfections," accepted for presentation at 29th AIAA/ASME/ASCE/AHS Structures, Structural Dynamics and Materials Conference, Williamsburg, VA, April 1988.

REPORTS AND THESIS

R-1. C. Mei and C.B. Prasad, "Influence of Large Deflection and Transverse Shear on Random Response of Rectangular Symmetric Composite Laminates to Acoustic Loads," NASA Contractor Report-178313, Langley Research Center, June 1987.

R-2. C.B. Prasad, "The Effects of Nonlinear Damping on the Large Deflection Response of Structures Subjected to Random Excitation," Ph.D. Dissertation, Old Dominion University, May 1987.

R-3. T.K. Brewer, "Effect of Elastic Boundary Conditions on the Dynamic Response of Rectangular Plate," M.S. Thesis, Old Dominion University May 1988.