frequencies. This author[6] used Fourier series approximations of the input and output time histories before performing the numerical Fourier transform calculations. It was expected by such a technique one could reduce the number of points picked off the time-response graphs without sacrificing overall accuracy. This technique then uses the continuous finite Fourier series approximations in the integration routine. Thus a smaller calculation increment may be used than the time increment n the original sampled data points.

The integration routine used was the Filon-trapezoidal method. This method was necessary because of the rapidly oscillating integrands at high frequencies. This technique was found to improve the transform calcu ations at high frequencies over the existing methods used but did not completely eliminate the "breakdown" phenomenon found by other investigators. The comparison between the pulse method and a strictly analog analyzer method (sinusoidal test ng) for experimental transfer functions showed no distinct accuracy advantage to either method

References

[1] Smith, G. A. and Triplett, W. C., "Experimental Flight Methods for Evaluating Frequency Response Characteristics of Aircraft," *Transactions of the ASME*, Vol. 76, Nov. 1954, pp. 1383–1393.

[2] Lees, S., "Interpreting Dynamic Measurements of Physical Systems," *Transactions of the ASME*, Vol. 80, May 1958, pp. 833–857.

[3] Dreifke, G. E., "Effects of Input Pulse Shape and Width on Accuracy of Dynamic System Analysis from Experimental Pulse Data," Sc.D. dissertation, Washington University, St. Louis, Mo., 1961.

[4] Lees, S. and Daugherty, R. C., "Refinement of the Pulse Testing Procedure: Computer Limitations," Research Rept. 3897(03), 1964, Thayer School of Engineering, Dartmouth College, Hanover, N.H.

[5] Lees, S., "Numerical Fourier Transform Calculations for Pulse Testing Procedures," Paper 66-Aut.-A, 1966, American Society of Mechanical Engineering.

[6] Swisher, G. M., "A Digital Computer Study of Fourier Transform Techniques for System Modeling by Pulse Testing," M.S. thesis, 1968, Ohio State University, Columbus, Ohio.

Thermal Effects on Aircraft Elastic Mode Shapes

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THE day will come, probably before the end of this century, when aircraft will be flying at high supersonic and hypersonic speeds within the atmosphere. Such aircraft will undoubtedly be highly flexible, resulting in total-airframe orthogonal vibration modes with undamped natural frequencies of the same order of magnitude as the rigid-body short-period frequency. Such circumstances will likely give rise to a severe mode interaction, wherein the aerodynamic coupling between the low-frequency elastic modes and the rigid-body motion can result in dynamic instabilities which would otherwise not occur.[1] This interaction phenomenon is extremely sensitive to variations of, or uncertainties in knowledge of, the exact shapes of the elastic modes, and very high accuracy (5% or better) will be required in analytically determining the mode shapes to be used in dynamic stability analyses and stability augmentation control system synthesis.

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Such aircraft will be subjected to severe transient and steady-state aerodynamic heating. The portion of the generated heat that is convected to the aircraft surfaces can cause large nonuniform increases in structural temperatures, which in turn produce thermally-induced stresses in the structure and reduction in the elastic moduli. Both thermal stresses and lower elastic moduli contribute significantly to reduced structural stiffness and aggravated static and dynamic aerothermoelastic problems.

A fair amount of research has been done on the effects of nonuniform temperature distributions on effective stiffness and natural frequencies of structures (although, little in the last 5 or 6 years); a small sampling is referenced.[2–7] However, an extensive literature survey has turned up precious little work on the effects of nonuniform temperature distributions on the normal vibration mode shapes of even simple structural elements such as plates and beams, let alone complex aerospace vehicle structures or structural components. Only one reference was found which contains data on such effects; it presents only experimental data with no analytical method offered.[8] A rectangular, stainless steel, cantilevered lifting surface of rib and spar construction was subjected to transient chordwise heating with quartz lamps, and the first and second vibration mode shapes were determined from vibration data. Even though the maximum temperature (about 600°F) and maximum temperature difference between two chordwise points (about 200°F) were very modest when compared to what a hypersonic aircraft will encounter, the mode shapes varied as much as 20% from their unheated shapes.

As pointed out previously, 5% accuracy will be needed in mode shape determination; thus, the need is apparent for research on analytical methods for calculating elastic mode shapes in the presence of nonuniform temperature distributions. It is urged that sponsoring agencies give attention and support to filling this serious gap in knowledge and analytical methods in order to have the analysis and design tools at hand when the application arises, as it most certainly will in the not too distant future.

References

[1] Swaim, R. L., "Elastic Mode Effects on the Dynamics of a Delta-Winged Aircraft," *IEEE Transactions on Automatic Control*, Vol. AC-9, No. 4, Oct. 1964, pp. 508–513.

[2] Vosteen, L. F., "Effect of Temperature on Dynamic Modulus of Elasticity of Some Structural Alloys," TN 4348, Aug. 1958, NACA.

[3] Heldenfels, R. R. and Vosteen, L. F., "Approximate Analysis of Effects of Large Deflections and Initial Twist on Torsional Stiffness of a Cantilever Plate Subjected to Thermal Stresses," Rept. 1361, 1958, NACA.

[4] McWithey, R. R., and Vosteen, L. F., "Effects of Transient Heating on the Vibration Frequencies of a Prototype of the X-15 Wing," TN D-362, May 1960, NASA.

[5] Budiansky, B. and Mayers, J., "Influence of Aerodynamic Heating on the Effective Torsional Stiffness of Thin Wings," *Journal of Aeronautical Sciences*, Vol. 23, No. 12, 1956, pp. 1081–1093.

[6] Modi, V. J., "Vibration of a Cylinder with Temperature Gradient Across the Thickness," *Canadian Aeronautics and Space Journal*, Vol. 11, No. 7, Sept. 1965, pp. 227–233.

[7] Biot, M. A., "Influence of Thermal Stresses on the Aeroelastic Stability of Supersonic Wings," *Journal of Aeronautical Sciences*, Vol. 24, No. 6, June 1957, pp. 418–420.

[8] Lenk, E. J., "A Method of Measuring Normal Modes and Frequencies with Application to Heated Structures," Rept., NAEC-ASL-1059, May 1963, U.S. Naval Air Engineering Center Philadelphia, Pa.