Technical Comments

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Comment on "An Optimization Method for the Determination of the Important Flutter Modes"

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IN a recent paper,[1] Nissim and Lottati criticized the systematic order-reduction method of determining the important flutter modes used by Baldock[2] on the grounds that the computational labor involved was heavy. The method that Baldock used was developed at RAE and is economical in computation because it is based on an inverse-iteration procedure in which attention is confined to finding out, for each subsystem, whether there is a critical root sufficiently close, in speed and frequency, to the critical root of the full system to be considered the latter's equivalent.

The flutter equations are taken to be in the form

$$\begin{bmatrix} i\omega A + B\nu + D & C\nu^2 + E \\ -I & i\omega I \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \tag{1}$$

an eigenvalue problem in $i\omega$, where A, D, and E are square matrices of structural inertia, damping, and stiffness coefficients, B and C are square matrices of real aerodynamic coefficients, ω is the frequency, and ν is the airspeed. Subtracting $i(\omega-\pi)\lceil A,\ I \rfloor\ \{p,q\}$, where π is any scalar, from each side of Eq. (1) gives

$$\begin{bmatrix} i\pi A + B\nu + D & C\nu^2 + E \\ -I & i\pi I \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} = -i(\omega-\pi) \begin{bmatrix} A & \\ & I \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \tag{2}$$

The inverse-iteration formula is the above equation with the $(r+1)$th $\{p,q\}$ vector on the left-hand side and the (r)th vector on the right. Within the usual restrictions of the power method, the values of ω will converge to the solution of Eq. (1) which is nearest π. The iteration formula can be reduced to the more-convenient form[3]

$$[-\pi^2 A + i\pi(B\nu + D) + C\nu^2 + E]p_{r+1}$$
$$= -i(\omega-\pi)[i\pi A p_r - (C\nu^2 + E)q_r]$$
$$i\pi q_{r+1} = p_{r+1} - i(\omega-\pi)q_r \tag{3}$$

In the application of inverse iteration to order reduction, π is put equal to the flutter frequency of the full system. One row and column are removed from the flutter matrix at a time and the eigenvalues nearest π found for a series of values of ν starting with the flutter speed of the full system and aiming to find the value which gives a purely real value of ω for the reduced system. Limits are placed on the amounts by which ω and ν can diverge from their full-system values and if either or both of these limits are exceeded the row and column are reinstated.

If π is taken as purely real there is little danger of convergence to the wrong eigenvalue because the eigenvalues other than the critical one which are close to π will normally have imaginary parts which are sufficiently large for them to be further from π than the critical eigenvalue is. The aerodynamic coefficients can be kept constant throughout the calculation since the reduced frequency changes little because the airspeed and frequency change little.

The computation time depends on how many rows and columns can be dropped permanently but the time taken to reduce a quinary to a binary on a DEC VAX 11/780 is of the order of 5 CPU seconds.

References

[1] Nissim, E. and Lottati, I., "An Optimization Method for the Determination of the Important Flutter Modes," *Journal of Aircraft*, Vol. 18, Aug. 1981, pp. 663-668.

[2] Baldock, J.C.A., "A Technique for Analysing the Results of a Flutter Calculation," ARC R and M 3765, Oct. 1973.

[3] Wilkinson, J.H., *The Algebraic Eigenvalue Problem*, Clarendon, Oxford, 1965, pp. 633-635.

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Reply by Authors to Ll. T. Niblett

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IN reviewing the current methods for the determination of the important flutter modes, we mentioned Baldock's[1] method and remarked that it involves considerable computational labor. We reread Baldock's paper and nowhere could we find a reference to the inverse iteration procedure as being the method used to determine the flutter condition. The above Comment by Niblett is therefore important since it clarifies Baldock's method and supplements his paper.

We would like, however, to note that the inverse iteration procedure, as described by Niblett, converges to the mode with complex frequency nearest to π (using Niblett's notation) and it does not necessarily follow the critical flutter mode. This is especially true when a lightly damped mode is present around the flutter frequency and the reduction in the order of the system is accompanied by some changes in the flutter frequency. Niblett claimed (in a private communication during the course of publication of our paper) "the dangers of roots close in modulus to be more apparent than real. When failures occur, they are failures of the vector to converge."

We firmly believe that this vector convergence problem is a direct result of roots close in modulus and it thus indicates that the above dangers are indeed real and by no means apparent.

Reference

[1] Baldock, J.C.A., "A Technique for Analysing the Results of a Flutter Calculation," Royal Aircraft Establishment, TR 73168, Dec. 1973.

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