VICONOPT: Program for Exact Vibration and Buckling Analysis or Design of Prismatic Plate Assemblies

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Abstract

A SUMMARY is given of key features of the computer program VICONOPT,[1] which covers prismatic assemblies of anisotropic plates exactly for buckling and vibration analysis and also for design subject to buckling constraints.

Contents

VICONOPT (VIpasa with CONstraints and OPTimization) is a 23,000 line Fortran 77 computer program that incorporates the earlier programs VIPASA[2] and VICON.[3] It covers any prismatic assembly of anisotropic plates and Fig. 1 shows typical cross sections. Each plate can carry any combination of N_L, N_T, and N_S, the longitudinally invariant in-plane forces per unit length of plate edge shown in Fig. 1. VICONOPT performs analysis or optimum design. The analysis includes calculation of critical buckling load factors, or undamped natural frequencies, and mode shapes.

VIPASA uses the stiffness matrix method based on exact flat plate theory with Winkler foundations. It also uses an algorithm that guarantees convergence on all required eigenvalues and permits the user to employ nested (to any level) substructuring very concisely and flexibly to reduce solution times, data preparation, and computer memory usage. The mode of buckling or vibration is assumed to vary sinusoidally in the longitudinal direction x, with the displacement amplitudes u, v, w, and ψ shown in Fig. 1 and with computations being repeated for a user specified set of half-wavelengths λ. Plate bending and membrane behaviors are uncoupled and the bending and in-plane stiffness matrices D and A are respectively fully populated and orthotropic, which treats balanced symmetric laminates. The global stiffness matrix becomes complex when anisotropy or shear loading are present, thus, increasing solution time. The nodal lines of zero displacement are straight and in the y direction if all plates are orthotropic with $N_S = 0$, and so satisfy simply supported end conditions. Otherwise, solutions only approximate such end conditions and become excessively conservative as λ approaches ℓ. Dead load values of N_L, N_T, and N_S are permitted for both buckling and vibration problems. In the former case they are additional to live load values that are factored until buckling occurs. Plate loadings may be given as data, although N_L is usually calculated from the total longitudinal load on the panel or from a uniform longitudinal strain, optionally allowing for temperature changes between layers in laminated plates.

VICONOPT uses Lagrangian multipliers to minimize the total energy of the panel subject to constraints that represent rigid or elastic point supports, so that a shear loaded panel supported along rectangular boundaries can be accurately represented. Transverse beam supporting structures can also be represented (see Fig. 2). The solution is a Fourier series involving appropriate half-wavelengths λ. Thus, results are for an infinitely long plate assembly, with supports repeating at intervals of ℓ. This accounts for the continuity over several bays of typical aerospace construction.

Very concise data input allows for offset connections between plates and multiple load cases. Laminated walls are assembled from any sequence of arbitrarily oriented orthotropic layers. Mode calculations include the displacements of all internal nodes of substructures and associated stresses including in-plane direct and shear stresses in laminates and interlaminar shear stresses. The many plot options are easily portable between computers and include contour plots of any of these stresses for selected plates and contour, isometric or cross-sectional plots of deflections. Appropriately derived equations enable VICONOPT to predict run times from the data.

Plate assemblies that repeat in the global y direction are analyzed by using infinite width recurrence relations so that analysis involves only a datum repeating portion. When used with cylindrical coordinates this rapid analysis gives the same results for regular polygonal cross sections, including stiffened or corrugated ones, as modeling the complete polygon.

Results for a composite blade stiffened panel (i.e., the first cross section of Fig. 1) with six blades indicate that to obtain

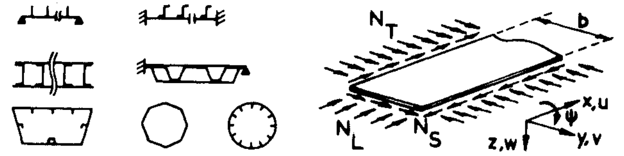

Fig. 1 Plate assemblies treated.

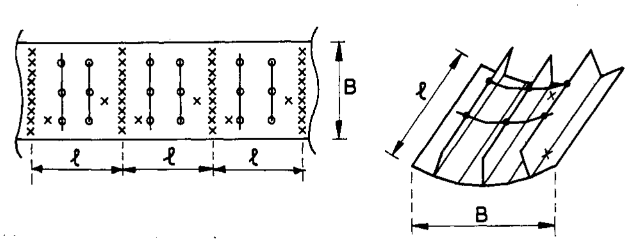

Fig. 2 Illustrative infinitely long assembly for the Lagrangian multiplier method. On the plan and isometric (only length ℓ shown) views of this polygonal blade-stiffened panel, crosses denote point supports and circles denote point attachments to transverse beam columns.

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Table 1 VICONOPT sizing strategy

1	Initial analysis	5	CONMIN optimization
2	Initial stabilization	6	Stabilization
3	Constraint and sensitivity analysis	7	Go to 4 or stop CONMIN cycle
		8	Go to 3 or stop sizing cycle
4	Move limit calculation	9	Final analysis

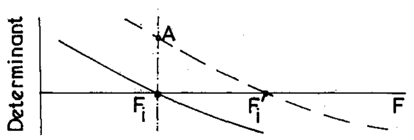

Fig. 3 Perturbed eigenvalue finding.

1% accuracy the STAGS finite element program takes about 1000 times longer than VICONOPT to solve problems for which all plates are orthotropic with $N_S = 0$, so that the VIPASA route of VICONOPT is sufficient, and otherwise (i.e., when Lagrangian multipliers are used) takes about 100 times longer. These savings are appreciated during optimum design.

For design, VICONOPT uses the specially developed optimization technique of Table 1 to converge on a feasible plate assembly design of low (i.e., hopefully near-optimum) mass. The program calculates the critical, i.e., lowest, buckling load factors for each possible buckling mode. The potentially critical near to lowest values are also included. The user may select any set of plate breadths, layer thicknesses, and layer ply angles as design, i.e., independent, variables. The other plate breadths, layer thicknesses, and layer ply angles, along with any plate (or substructure) rotations and offsets, can be held fixed or can be linked to the design variables.

The CONMIN optimization step of Table 1 uses the linear optimization capability of the well-proven mathematical programming optimizer CONMIN to minimize mass subject to buckling and configuration constraints. The two powerful stabilization steps of Table 1 factor individual layer thicknesses to achieve stability, thus making unsafe or over-safe designs 'just' feasible. Within the CONMIN cycle, such stabilization encourages large design moves where buckling behavior varies reasonably linearly and discouarges them otherwise, as follows. The cycle tries various sets of move limits, i.e., maximum changes of design variables, to find the set for which the mass after stabilization is least. This is a more intelligent choice of move limits than the usual practice of imposing predetermined limits, as was done in the earlier VIPASA based optimization program PASCO.[4]

Because the VICONOPT stiffness matrix is a transcendental function of eigenvalue and λ, buckling sensitivities cannot be obtained by linear eigenvalue problem techniques and so they are calculated numerically from $(F_i' - F_i)/\alpha_{ij}x_j$ where F_i is the eigenvalue for the unperturbed case and F_i' is the eigenvalue with the jth design variable, x_j, perturbed by $\alpha_{ij}x_j$. The choice of α_{ij} is automated to ensure the calculation of reliable sensitivities. The eigenvalue F_i is found by an efficient iterative technique, which is shown by theory and results to be reliable and twice as fast as bisection. This technique chooses a suitable determinant and uses parabolic interpolation wherever possible to converge on F_i, the load factor for which it is zero. Each iteration involves assembly and triangularization of a large matrix. VICONOPT uses an approximate method to find perturbed eigenvalues that is quick, robust, and ensures sufficient accuracy. This method uses the mathematical similarity of perturbed and unperturbed problems by horizontally displacing the parabola that gave the eigenvalue in the unperturbed case (see Fig. 3) and so requires only one iteration to give the point A on Fig. 3 and hence F_i'.

To illustrate optimization, Fig. 4 shows a panel that is simply supported along its longitudinal edges and loaded axially. The plates are all of symmetric carbon fiber composite construction with eight layers and the design variables are the stiffener web and stiffener lower flange breadth plus all the layer thicknesses. The offsets that are used to model the connection of plates more accurately are linked to the design variables. VIPASA type analysis was applied for half-wavelengths $\lambda = \ell/i$, for $i = 1,2,3,\ldots,30$. Ten is the number of sizing cycles recommended in the PASCO user manual. Figure 4 shows, as cases A and B respectively, the PASCO and VICONOPT mass reductions for this problem with initial move limits set at 45 and 15%. The VICONOPT design starts off slightly higher than the PASCO design because of initial stabilization. Each of the VICONOPT sizing cycles shown on Fig. 4 for case A contains three CONMIN cycles; solution time was about half of that for PASCO, for which the seemingly near-optimum design after two cycles was unstable and so was unacceptable, whereas the stabilization step makes all VICONOPT designs just stable. Figure 4 also shows that PASCO was unable to achieve a near-minimum mass with initial move limits of 15%. Case C is identical to case A, except that all of the design variables were initially at their lower bounds. After 10 sizing cycles the PASCO design, although 19% heavier than the VICONOPT final design, was unstable, its buckling load factor being 56% of that required. The example of cases A through C was also modified by adding shear to the skin so that the Langrangian multiplier method was needed. VICONOPT achieved a 14% mass reduction and needed seven sizing cycles.

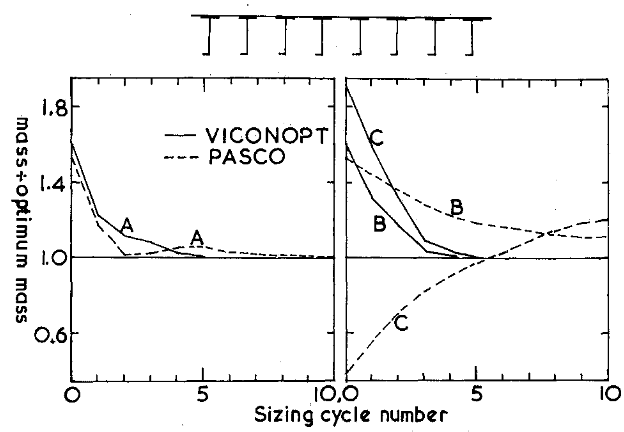

Fig. 4 VICONOPT and PASCO convergence for *J* stiffened panel shown.

VICONOPT has been released to U.S. users from COSMIC and details of release to other users are available from the first author.

Further developments of VICONOPT will permit the replacement of PASCO by PASCO2, which will be VICONOPT plus material constraints, panel imperfection, exact treatment of transverse shear flexibility of plates, etc.

Acknowledgments

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