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(This is an abridged version. See the full-length paper for more: genopt.papers/2000.wavycyl.pdf)

AUTOMATED OPTIMUM DESIGN OF SHELLS OF REVOLUTION WITH APPLICATION TO RING-STIFFENED CYLINDRICAL SHELLS WITH WAVY WALLS

David Bushnell, Senior Consulting Scientist, retired
Dept. L9-24, Bldg. 250

Lockheed Martin Advanced Technology Center
3251 Hanover St., Palo Alto, California 94304

ABSTRACT

GENOPT, a program that writes user-friendly optimization code, and BOSOR4, a program for stress, buckling, and vibration analysis of segmented, branched, stiffened shells of revolution, are combined to create a capability to optimize specific classes of shells of revolution. Examples are provided of aluminum cylindrical shells with wavy walls with and without ring stiffeners and a laminated composite cylindrical shell without rings. GENOPT and BOSOR4 and recent improvements to them are described. In the examples the objective of the optimization is minimum weight and the design constraints involve stress, buckling, modal vibration, and random response to base excitation. An Appendix is provided in which a very simple example is used to demonstrate in detail how a user can create a capability to optimize any shell of revolution.

1.0 INTRODUCTION

About 10 years ago Cohen and Haftka [1] took a step toward creating a capability for automated design of shells of revolution. In this paper a further step is taken by combination of two computer program systems, GENOPT [2] and BOSOR4 [3]. GENOPT and BOSOR4 are combined to permit optimization of a certain class of shell of revolution, called here "WAVYCYL". This class includes ring-stiffened cylindrical shells with a "wavy" wall. The waviness is in the axial direction, that is the cylindrical shell is corrugated with the axis of the corrugations running around the circumference. This "wavy" cylindrical shell, if perfect, is axisymmetric. The rings may be rectangular or Tee-shaped, external or internal. They are modeled as consisting of little shell segments, as in [4].

Figure 1 shows an example studied intensively here, and Figs. 2 - 6 display additional members of the class called "WAVYCYL". Classical simple support or clamping is imposed at the bottom of the models (z = 0). Prebuckling symmetry and buckling symmetry or antisymmetry are imposed at the top of the models (z=90 in), which represents the midlength of the entire cylindrical tube. In the computer models the material stiffness and density of the ring at the symmetry plane, if any, are half those of the rings elsewhere in the models.

In the models shown in Figs. 1 - 3 the wavy portion is a multi-segmented model consisting entirely of joined toroidal frustra, that is, segments within each of which the meridional curvature is constant and fixed by the amplitude and axial halfwavelength of the waviness. The meridional slope is continuous at junctions between adjacent toroidal frustra. In the model shown in Fig. 4 the wavy portion consists of very short toroidal segments connected by little conical segments. The model depicted in Fig. 5 is of the same class: The "little conical segments" have become annular segments. The model shown in Fig. 6 is simply a ring-stiffened cylindrical shell.

Note that the models shown in Figs. 1 - 5 all have a straight cylindrical segment near the bottom. This is Segment 1 of the multi-segmented model. Its wall properties are derived by a "smearing" of the waviness as described in Item 10 of Section 5.

One of the input data defined by the GENOPT user is called "MAXDOF" (maximum allowable number of degrees of freedom in the BOSOR4 model). The WAVYCYL system uses this datum, MAXDOF, to determine the axial extent of the wavy portion of the model. The user can do initial optimizations setting MAXDOF to a relatively low number, such as 1500 - 3000. In such a model there may be a relatively long straight segment, such as is shown in Fig. 3, for which MAXDOF was set equal to 1500.

The results obtained with such a model are approximate because less than half of the BOSOR4 model consists of explicit waviness and the behavior of the straight segment only approximates the behavior of the actual wavy shell. After optimizing with the "rough" model, the WAVYCYL user can increase MAXDOF and re-optimize. This strategy was used in the studies reported here, for example, to determine that the best ring stiffeners have no outstanding flanges, given the applied loading and lower bounds of 10 inches on ring spacing and 0.03 inches on the thickness of the wavy wall.

Note that, given MAXDOF, the extent of the wavy portion of the BOSOR4 model depends on the axial halfwavelength, WAVLEN, of the waviness and on how many nodal points, NMESHC, are used in each of the little toroidal segments that form the explicitly wavy part of the BOSOR4 model. Results from convergence studies with respect to MAXDOF and NMESHC are presented later.

The WAVYCYL models can be loaded by arbitrary combinations of axisymmetric axial load, N_x, uniform internal or external pressure, p, lateral and axial accelerations, g(lateral) and g(axial), and random lateral excitation of the support at axial station, z = 0.

Decision variables in the optimization of "WAVYCYLs" are the wall thickness of the "wavy" cylindrical shell (or ply thicknesses if the wall is laminated), the axial halfwavelength and amplitude of the "waviness", the spacing of the rings, and the thicknesses and heights of the web and outstanding flange of a ring. (All rings are identical.)

In this paper the capabilities of GENOPT and BOSOR4 are summarized, with details given where these computer programs have been modified from the versions described in [2] and [3]. Then instructions are given on the use of GENOPT and on the use of the system of computer programs created by GENOPT, called "WAVYCYL". The flow of computations for each design evaluation is described. Finally, numerical results are given for several examples. A long appendix is provided in which a simple example is used to demonstrate how a user can set up a user-friendly system of programs to optimize any shell of revolution.

2.0 GENOPT (GENeral OPTimization)

2.1 Summary of capabilities and properties of GENOPT [2]

The purpose of GENOPT [2] is to enable an engineer to create a user-friendly system of computer programs for analyzing and/or optimizing anything. The application of

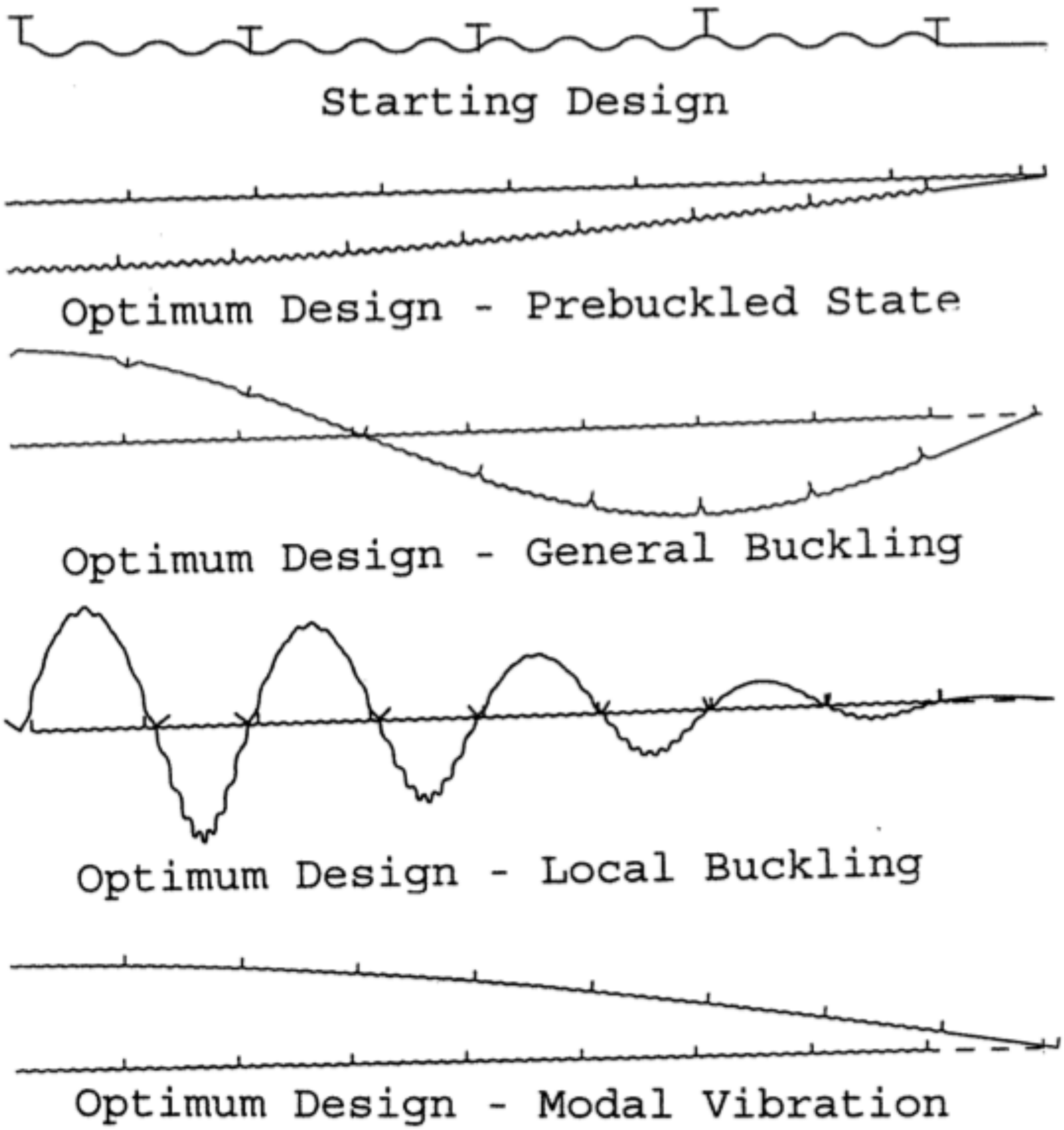

Fig. a (from the cover of the "wavycyl" report, LMMS P525674, November, 1999) Externally ring-stiffened cylindrical shell with a "wavy" wall. (from the AIAA 41st Structures, Structural Dynamics, and Materials Conference, AIAA Paper 2000-1663, 2000; also, Lockheed Martin Missiles & Space Company Report LMMS P525674, November, 1999)