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ADDITIONAL BUCKLING SOLUTIONS IN PANDA2

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(This is an abridged version. See the full-length paper for more: panda2.papers/1999.addlsolns.pdf)

ABSTRACT

Three new buckling models have been incorporated into PANDA2, a program for minimum weight design of stiffened composite panels and shells: 1. buckling of unstiffened panels or unstiffened portions of panels with use of double-trigonometric series expansions for buckling modal displacement components, u, u, w; 2. general buckling of cylindrical, stiffened panels with both rings and stringers treated as discrete beams; and 3. inter-ring buckling of cylindrical panels based on a discretized single module model containing discretized ring segments and a discretized skin-smeared-stringer cylindrical surface to which the ring is attached. Examples are provided of buckling of certain isotropic and laminated composite flat and cylindrical unstiffened and stiffened panels and shells for which the predictions from the modified PANDA2, formerly unacceptably inaccurate, are compared with predictions from STAGS, a general-purpose finite element code. The new comparisons demonstrate that the modified PANDA2 is now well qualified for preliminary design in particular cases for which it previously yielded unreliable designs and designs that were overly conservative. The optimum design of a composite ring and stringer stiffened cylindrical shell derived by PANDA2 is evaluated with use of STAGS. The optimum design of an isotropic hydrostatically compressed internally T-ring stiffened cylindrical shell optimized by PANDA2 is evaluated with use of the shell-of-revolution code BOSOR4. There is good agreement between PANDA2 predictions and STAGS and BOSOR4 predictions for buckling of the optimized designs. (2011 NOTE: BOSOR4 has been superseded by BIGBOSOR4, which handles more shell segments.)

INTRODUCTION

PANDA2, a program for minimum weight design of stiffened panels and shells, has been under development since the early 1980's [1,2]. Brief surveys of previous work on buckling and optimization of stiffened panels and shells appear in [1], the most recent in AIAA Paper 98-1990. Therefore, no additional survey will be included here.

Previously PANDA2 included the following buckling models:

1. A discretized single skin-stringer module of the type shown in Fig. 1, for example. This model is used for local buckling, local postbuckling, and wide column buckling of the panel region between adjacent rings (transverse stiffeners).

2. Simple models for the buckling of the panel skin and stiffener segments of the type described in [2]. Typical buckling modes of the panel skin and stiffeners are shown in Fig. 6 of [2] and Fig. 180 on p. 209 of [27]. In the panel skin the buckling nodal lines are assumed to be straight, as shown in Fig. 2. This type of buckling model is used in some of the software written by Arbocz and Ho1 [3] and by Khot and his colleagues [4-61. These models are called "PANDA-type (closed form)" in PANDA2 jargon because they are the only ones used in the original PANDA program [2], which is superseded by PANDA2 [1].

Now three new buckling models have been added to PANDA2, as follows:

1, local buckling between adjacent stringers and rings of a cylindrical or flat panel obtained from a Ritz model in which the buckling modal displacement components, u, v, w, are expanded in double trigonometric series. The local region is assumed to be simply supported on all four edges.

2. general buckling of a cylindrical panel in which stringers and rings are treated as discrete beams with undeformable cross sections. Again, the general buckling modal displacement components, u, v, w, are expanded in double trigonometric series. The edges of the domain are assumed to be simply supported and to have discrete stiffeners of half the user-specified modulus. The domain for this model is usually a sub-domain of the entire panel.

3. a discretized single module model for a cylindrical panel in which the RING segments and panel skin-with-smeared-stringers are discretized as shown in Fig. 1. Until now, the only discretized module model in PANDA2 involved the panel skin and STRINGER segments. The RINGS were "second-class citizens". In this "branched shell" model the cross sections of the stiffeners can deform in the buckling mode, since they are subdivided into finite elements of the type used in BOSOR4 [28].

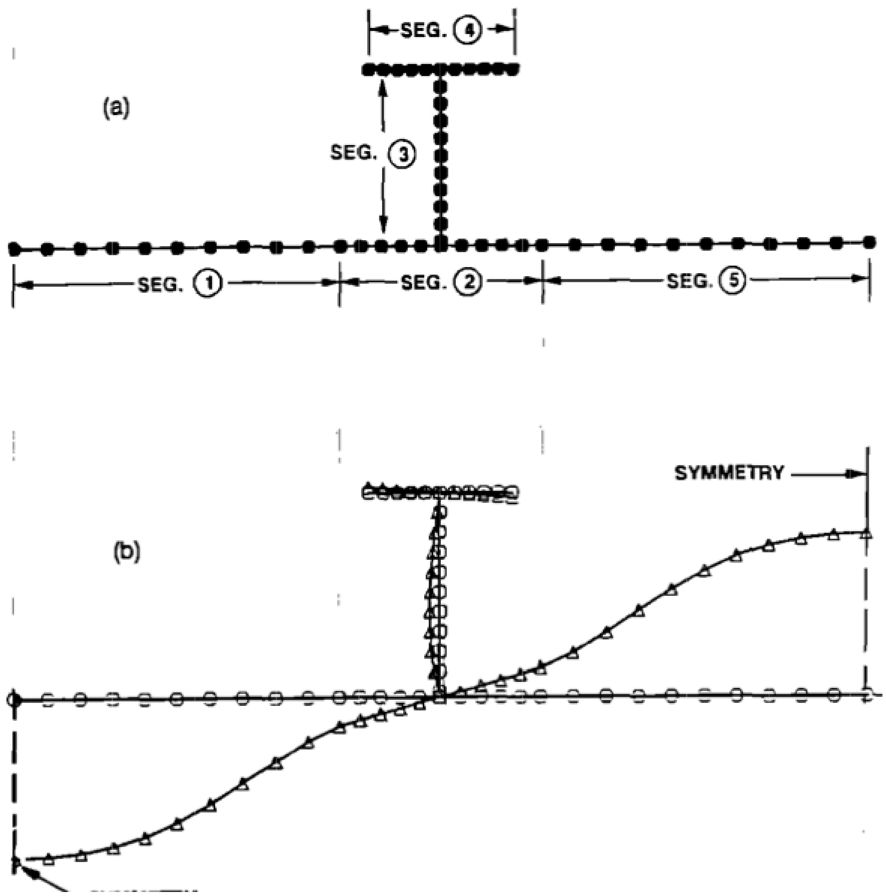
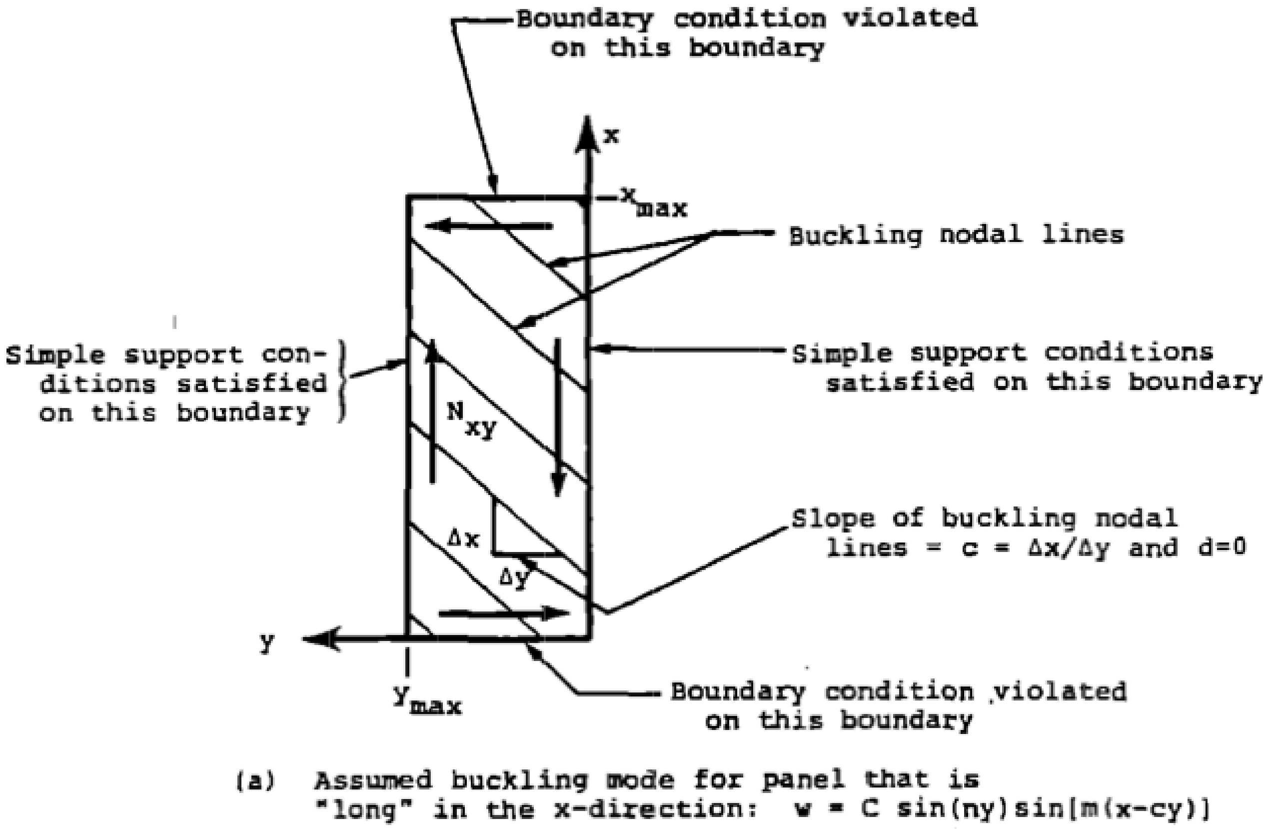


Fig. 1 Single-discretized-BOSOR4-type module model used by PANDA2 for the prediction of local buckling and local post-buckling behavior of stiffened panels and shells. (from AIAA 40th Structures, Structural Dynamics and Materials Conference, AIAA Paper 99-1233, 1999)



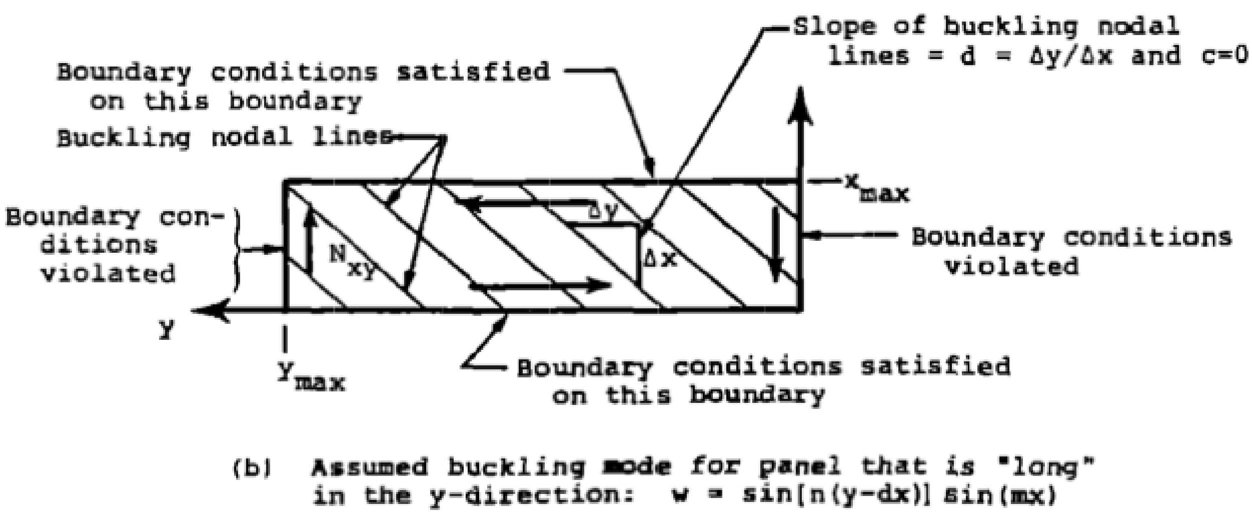


Fig. 2 PANDA-type (closed form) solution depends on which coordinate direction (x or y) that PANDA2 judges the panel to be longest in. (from AIAA 40th Structures, Structural Dynamics and Materials Conference, AIAA Paper 99-1233, 1999)

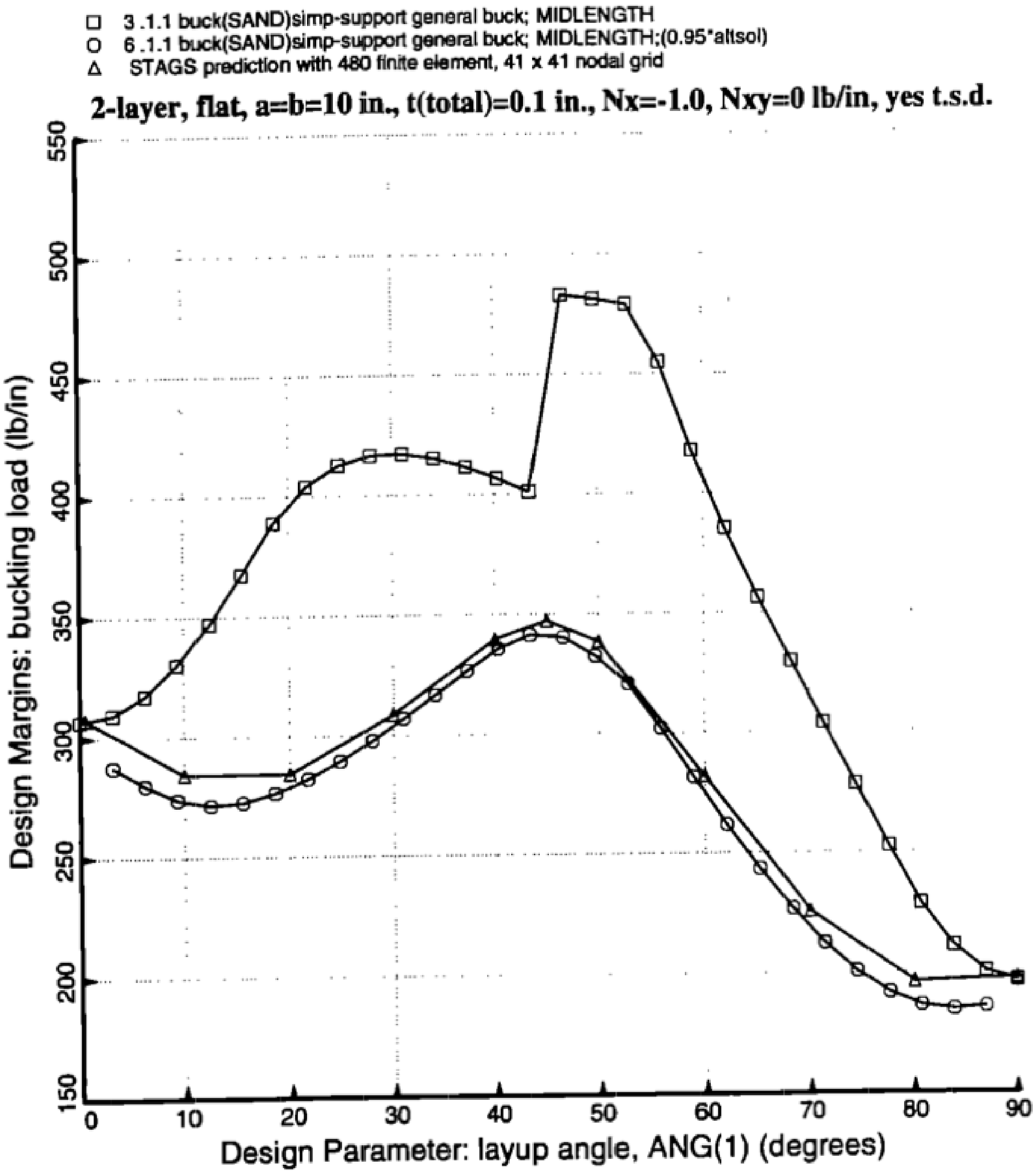


Fig. 5 Buckling of an axially compressed, composite, two-layered, angle-ply ($[+ANG, -ANG]_{total}$), unstiffened flat plate. The margin that reads, "buck(SAND)simp-support general buck; MIDLENGTH" (small squares) is computed from the PANDA-type (closed form) equation. The margin that reads, "buck(SAND)simp-support general buck; MIDLENGTH; (0.95*altsol)" (small circles) is computed from the much more elaborate double trigonometric series expansion alternate solution ("altsol"). The trace with the small triangles is from STAGS, a general-purpose finite element computer program. The discontinuity at ANG(1)=45 degrees in the PANDA-type curve arises because of an abrupt change in the PANDA-type (closed form) model illustrated by the two sketches in Fig. 2. (from AIAA 40th Structures, Structural Dynamics and Materials Conference, AIAA Paper 99-1233, 1999)

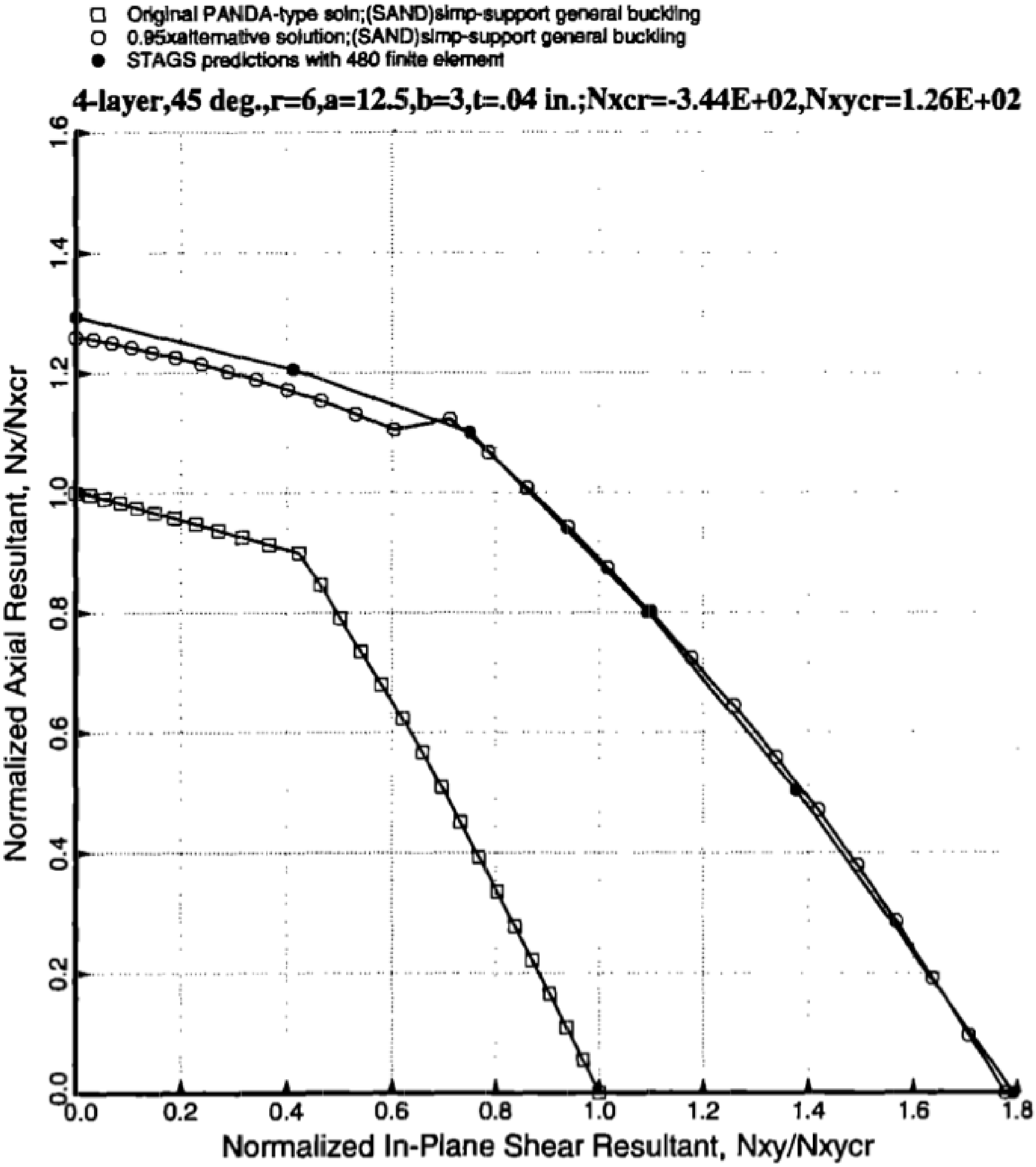


Fig. 20 Load-interaction curves from PANDA2 for a composite, 4-layered angle-ply ([+ANG, -ANG, +ANG, -ANG]$_{total}$, cylindrical panel with radius, r = 6 inches, length, a = 12.5 inches, arc-width, b = 3 inches, and total thickness, t = 0.04 inches. (from AIAA 40th Structures, Structural Dynamics and Materials Conference, AIAA Paper 99-1233, 1999)

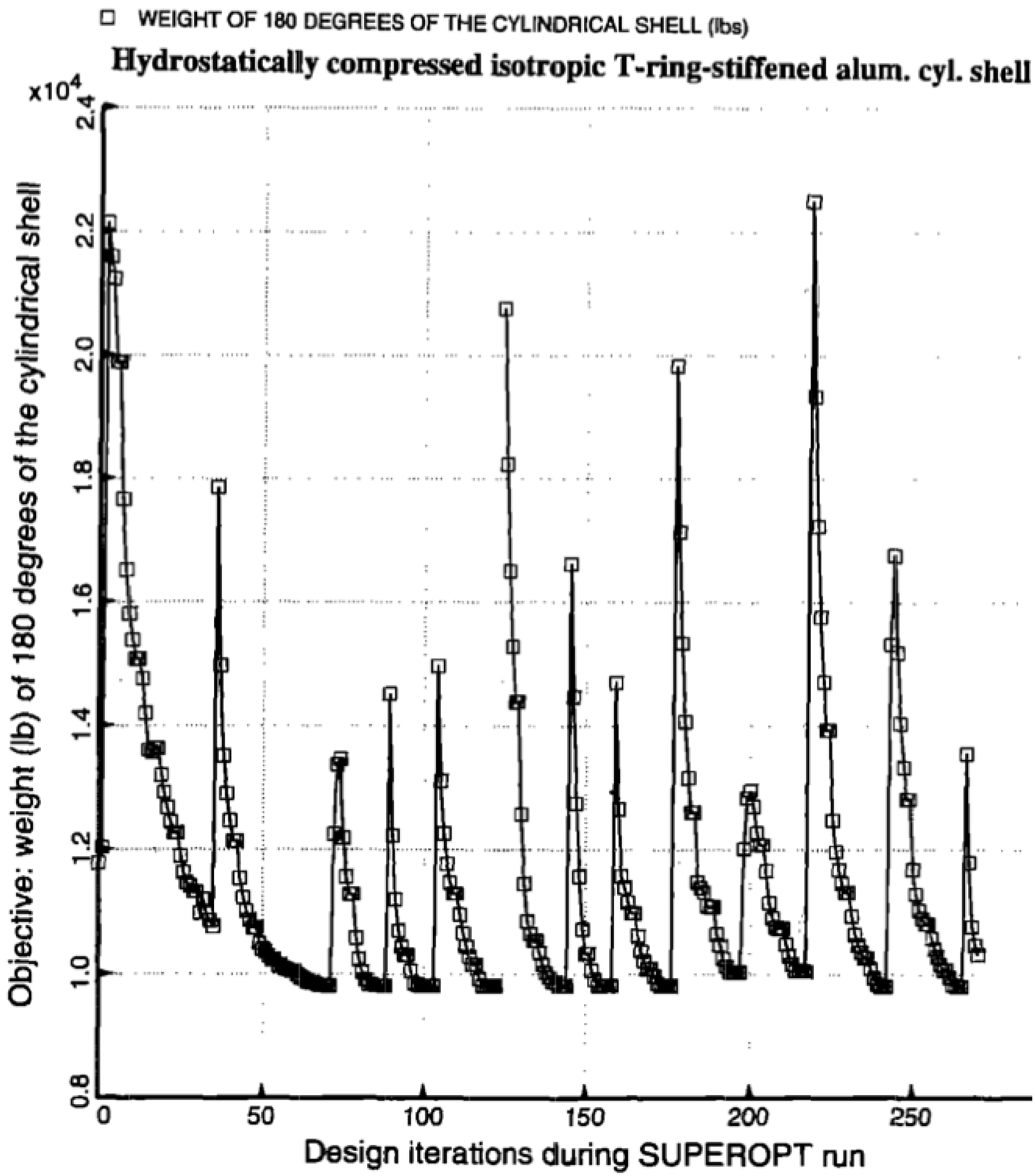


Fig. 31 Optimization via the PANDA2 processor, SUPEROPT, of a T-ring stiffened cylindrical shell. Each "spike" in the plot corresponds to a new "starting" design obtained randomly by the PANDA2 processor called AUTOCHANGE. (from AIAA 40th Structures, Structural Dynamics and Materials Conference, AIAA Paper 99-1233, 1999)

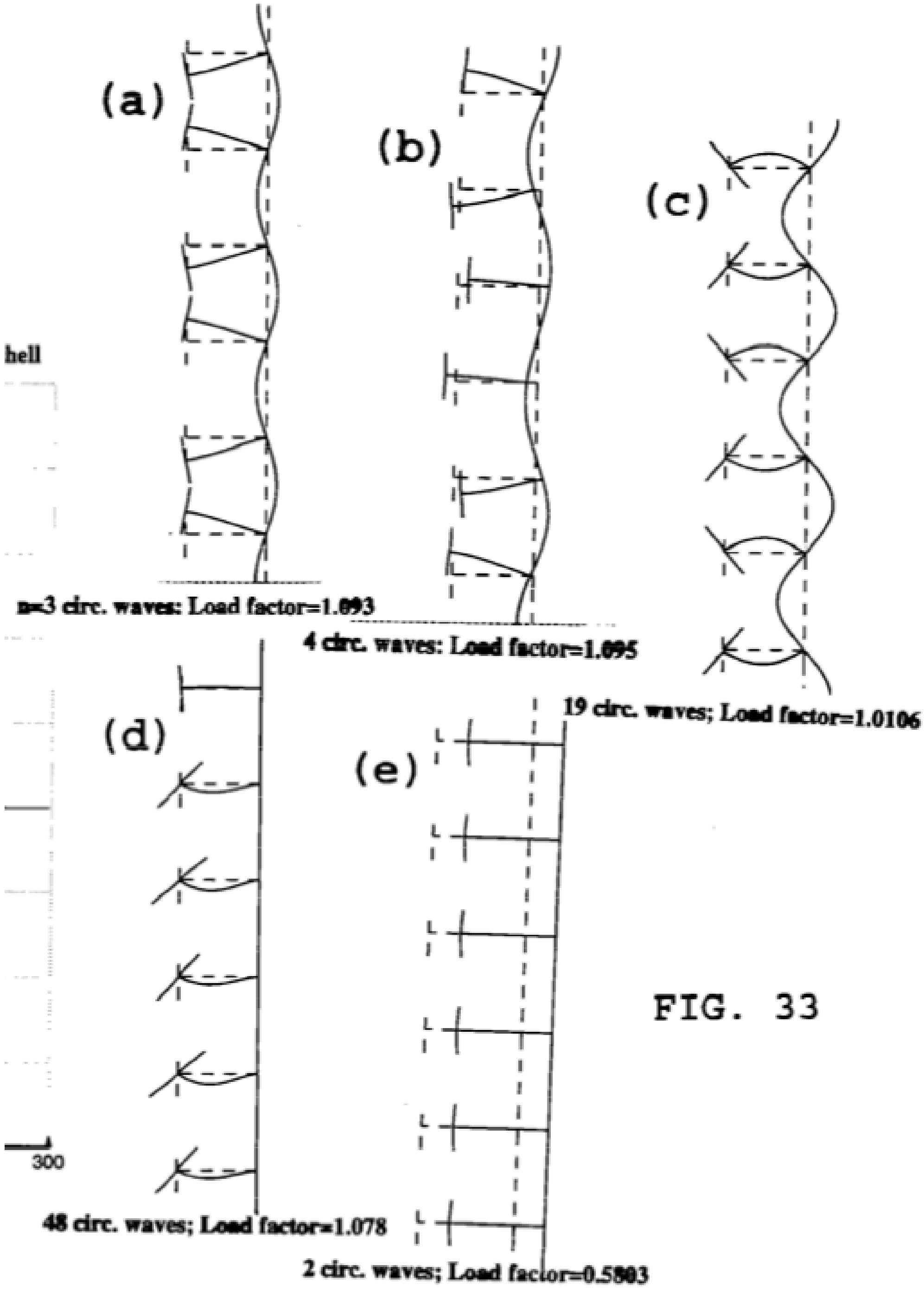


Fig. 33 Several buckling modes from BIGBOSOR4 corresponding to an optimized design previously obtained by PANDA2 of an internally ring-stiffened, hydrostatically compressed cylindrical shell. Notice that the four local buckling modes (a-d), although quite different from one another, have buckling load factors that are close to unity. The buckling mode (e) (ovalization of the entire shell) cannot occur if the radial displacement of the cylindrical shell is prevented at its two ends. (from AIAA 40th Structures, Structural Dynamics and Materials Conference, AIAA Paper 99-1233, 1999)