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USE OF GENOPT AND BIGBOSOR4 TO OPTIMIZE WELD LANDS IN AXIALLY COMPRESSED STIFFENED CYLINDRICAL SHELLS AND EVALUATION OF THE OPTIMIZED DESIGNS BY STAGS

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(This is an abridged version. See the full-length paper for more: genopt.papers/2010.weldland.pdf)

ABSTRACT

BIGBOSOR4 is used in an optimization loop in which the dimensions of a typical axially oriented weld land and the cross-section dimensions of reinforcing Tee-shaped stringers along the two straight edges (generators) of the weld land are decision variables. The optimization is carried out in a GENOPT context. Any number of equally spaced identical T-stiffened weld lands in a 360-degree cylindrical shell can be accommodated. The weld lands are embedded in an internally stiffened "acreage" cylindrical shell that has been previously optimized by PANDA2. The previously optimized "acreage" cylindrical shell has internal "acreage" stringers and internal "acreage" rings with rectangular cross sections. The spacings, heights, and thicknesses of the internal "acreage" stiffeners are not decision variables for the optimization problem in which the weld land and its reinforcing edge T-stringers are optimized. The design constraints for the cylindrical shell with the T-stiffened weld lands are: 1. general buckling, 2. inter-ring buckling, and 3. stress. The prebuckled state is assumed to be uniform end shortening, with the membrane axial compression in each segment of the structure proportional to the axial membrane stiffness of that segment. The prebuckled state is assumed to be a membrane state: no prebuckling bending. The entire shell structure is fabricated of the same material. In the model for general buckling the previously optimized "acreage" rings and stringers are smeared out and the cylindrical shell is simply supported at its ends. In the model for inter-ring buckling adjacent "acreage" rings are replaced by simple supports, that is, a length of shell equal to the ring spacing is analyzed, and the previously optimized "acreage" stringers are smeared out. The maximum stress in the weld-land-edge-stringer region is computed as if there were no prebuckling bending (membrane compression only). The cylindrical shell is modeled as a 180-degree segment of a huge torus, with symmetry conditions applied along the generators at zero and at 180 degrees. In the GENOPT examples studied here there are three identical T-stiffened weld lands spaced at 120-degree intervals. The adequacy of the optimized "acreage" cylindrical shell with and without the optimized T-stiffened weld lands is evaluated with various STAGS finite element models. There is good agreement between predictions from the GENOPT/BIGBOSOR4 model and the various STAGS models.

SECTION 1 INTRODUCTION AND SUMMARY

Motivation and Previous work done

The effort that resulted in this paper was motivated by Robert Thornburgh's paper on the buckling behavior of axially oriented weld lands in axially compressed, internally ring and stringer stiffened cylindrical shells [1]. A capability to optimize an axially oriented weld land with "extra" stringers added to its two longitudinal edges was needed. This paper reports results from a continuation of the work documented in [1 - 3]. Reference [2], derived from a case called "nasacoldbend", reports results from the use of PANDA2 [4, 13] and BIGBOSOR4 [5]. Reference [3], derived from a case called "wcold", reports results from the use of GENOPT [6] and BIGBOSOR4 [5]. A brief overview of the GENOPT program is given here. Extensive details about how to use GENOPT in connection with BIGBOSOR4 are presented in [7] and will not be repeated here. The GENOPT/BIGBOSOR4 capability has been used to optimize axially compressed cylindrical shells with a composite truss-core sandwich wall construction [8] and a ring-stiffened cylindrical shell with a "wavy" wall [5]. The work reported in [3] and [8] is based on "huge torus" models [9] of cylindrical shells. The results from GENOPT/BIGBOSOR4 reported in this paper are based on a new version of BIGBOSOR4 in which cylindrical shells with and without weld lands are modeled as true prismatic assemblages of shell segments. The "true prismatic shell" formulation is reported in [10]. Brief descriptions of the "huge torus" model and of the "true prismatic shell" model are given in this paper.

Both the PANDA2 [4, 13] and the GENOPT [6] computer programs perform optimization with the use of a gradient-based optimizer called "ADS", created many years ago by Vanderplaats and his colleagues [11,12]. In [2 - 8] ADS is "hard wired" in a "modified-method-of-steepest-descent" (1-5-7) mode. In PANDA2 and GENOPT a matrix of constraint gradients is computed from finite differences of the behavior of the perturbed design minus the behavior of the current design in which the decision variables are perturbed one at a time by a certain percentage, usually five per cent.

Purposes of this paper

The main purpose of the work reported here is to produce a "quick and dirty" way of optimizing axially oriented T-stiffened weld lands embedded in previously optimized stiffened cylindrical shells. Figure 1 presents an end view of a typical configuration. An auxiliary purpose is to provide enough information in this paper so that the reader can use GENOPT/BIGBOSOR4 [6,5] to optimize other shell structures and can subsequently use STAGS [15-18] or some other general-purpose finite element computer program to evaluate those optimized designs.

Summary of this paper

The objective of the optimization is to minimize the weight per axial length of one T-stiffened weld land such as one of the six identical T-stiffened weld lands shown in Fig. 1. Next and in SECTIONS 2 - 4 descriptions are given of the "quick and dirty" models of stiffened cylindrical shells with embedded T-stiffened weld lands. A brief description of GENOPT [6] appears in SECTION 5. SECTION 6 describes how GENOPT is used to produce a user-friendly capability to optimize any number of identical T-stiffened weld lands embedded in a previously optimized "acreage" cylindrical shell. SECTION 7 emphasizes that there is a two-phase optimization process: first the acreage stiffened cylindrical shell must be optimized, then a typical T-stiffened weld land to be embedded in that previously optimized acreage must be optimized. SECTIONS 8 - 12 present results for optimized acreage and T-stiffened weld lands that evolve when there is no constraint with regard to the slenderness (height/thickness) of the T-stringers that reinforce the weld land curved plate. SECTION 13 presents results for a T-stiffened weld land optimized under the condition that the height/thickness of the T-stringer web and outstanding flange are constrained to be less than or equal to 10. Some conclusions are given in SECTION 14.

Models used

The models used in this paper are much simpler than those used by Thornburgh [1]. Thornburgh used STAGS [15 - 18], a general-purpose finite element code. Naturally, the models here are approximate. For example, the prebuckled state is assumed to be a membrane state: there is no prebuckling bending of the axially compressed cylindrical shell with multiple identical axially oriented, edge-stiffened weld lands. The axial compression, Nx, in the various segments of the model such as that displayed in Fig. 1 is distributed in proportion to the membrane axial stiffness of those segments, and this distribution of Nx is prismatic, that is, it does not vary along the axis of the cylindrical shell. There is no "boundary layer" prebuckling nonuniformity of radial displacement w in the neighborhoods of the two ends of the axially compressed cylindrical shell caused by the restriction of Poisson ratio radial expansion there. The prebuckled state is a membrane state.

The models used here for the optimization of T-stiffened weld lands are BIGBOSOR4 models [5]. Therefore, the discretization is one-dimensional (strip method), which causes solution times on the computer to be much less than for the usual two-dimensionally discretized models such as those used in connection with the STAGS general-purpose finite element computer program [15-18]. This property leads to efficient optimization.

Figures 1, 2, and 3a by Robert P. Thornburgh

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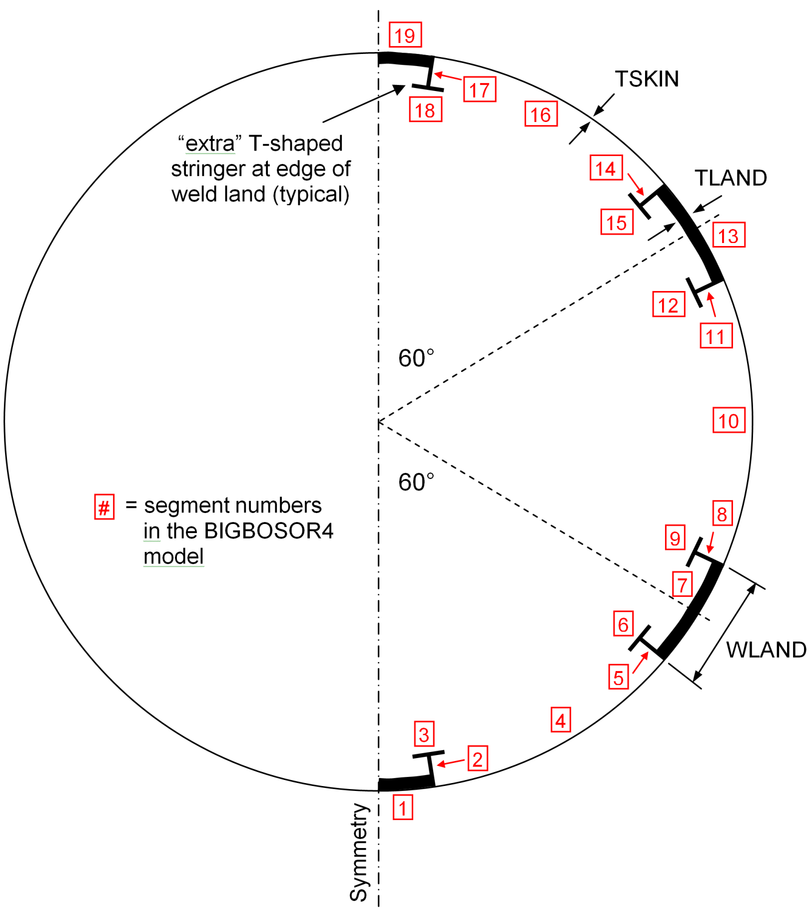
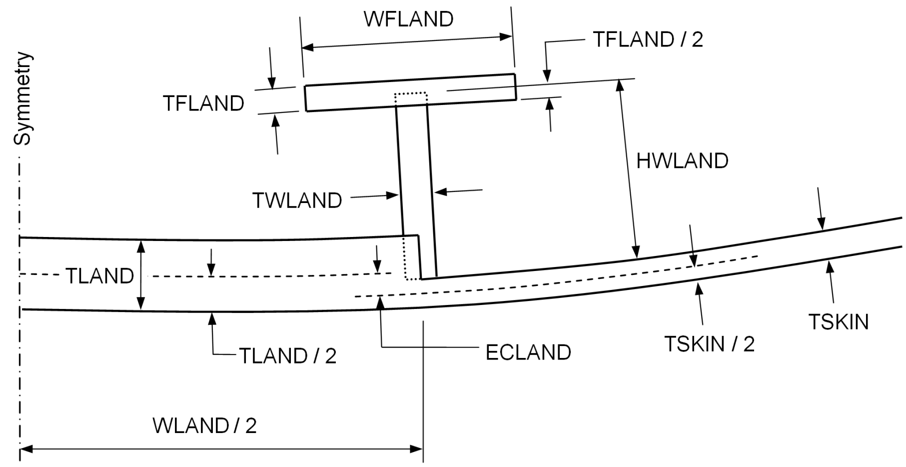


Fig .1 Example in which there are T-stiffened weld lands spaced at intervals of 60 degrees. Results in this paper correspond to weld lands spaced at intervals of 120 degrees. (drawing by Robert P. Thornburgh)



.Fig. 2 Half of a T-stiffened weld land showing the decision variables for the “wcold” optimization with the use of GENOPT/BIGBOSOR4 [6,5]. Although TSKIN is a decision variable, it has very tight lower and upper bounds so that during “wcold” optimization cycles TSKIN will not differ materially from the optimized value determined during the previous optimization of the “acreage” into which the T-stiffened weld land is embedded. ECLAND is not a decision variable but is established by a linking expression that forces the outer surfaces of the curved weld land plate of thickness TLAND and the acreage cylindrical shell of thickness TSKIN always to be flush during optimization cycles. (drawing by Robert Thornburgh)

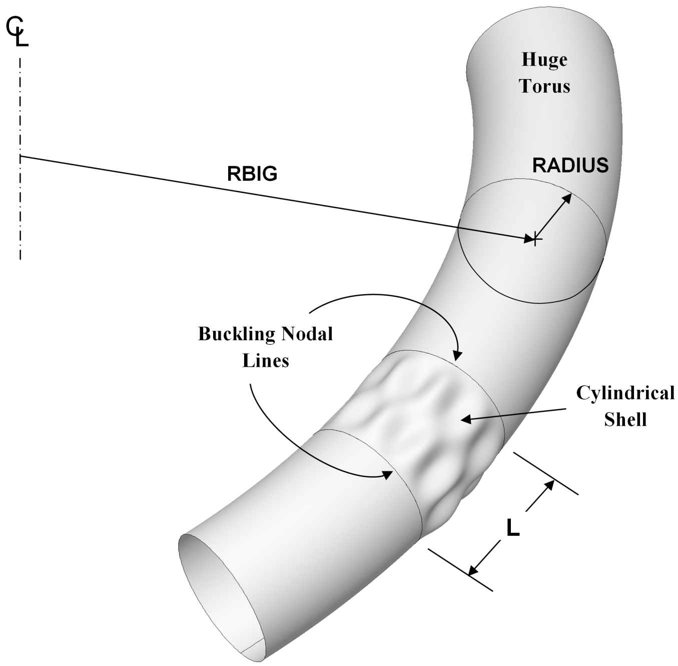


Fig. 3a Schematic of a “huge torus” model. For most “huge torus” models, a good choice of RBIG is RBIG = 100xL/pi. The cylindrical shells studied here have RADIUS = 48 inches. For the “true prismatic” shell model the kinematic relationships introduced recently into BIGBOSOR4 correspond essentially to RBIG = infinity. (drawing by Robert P. Thornburgh)

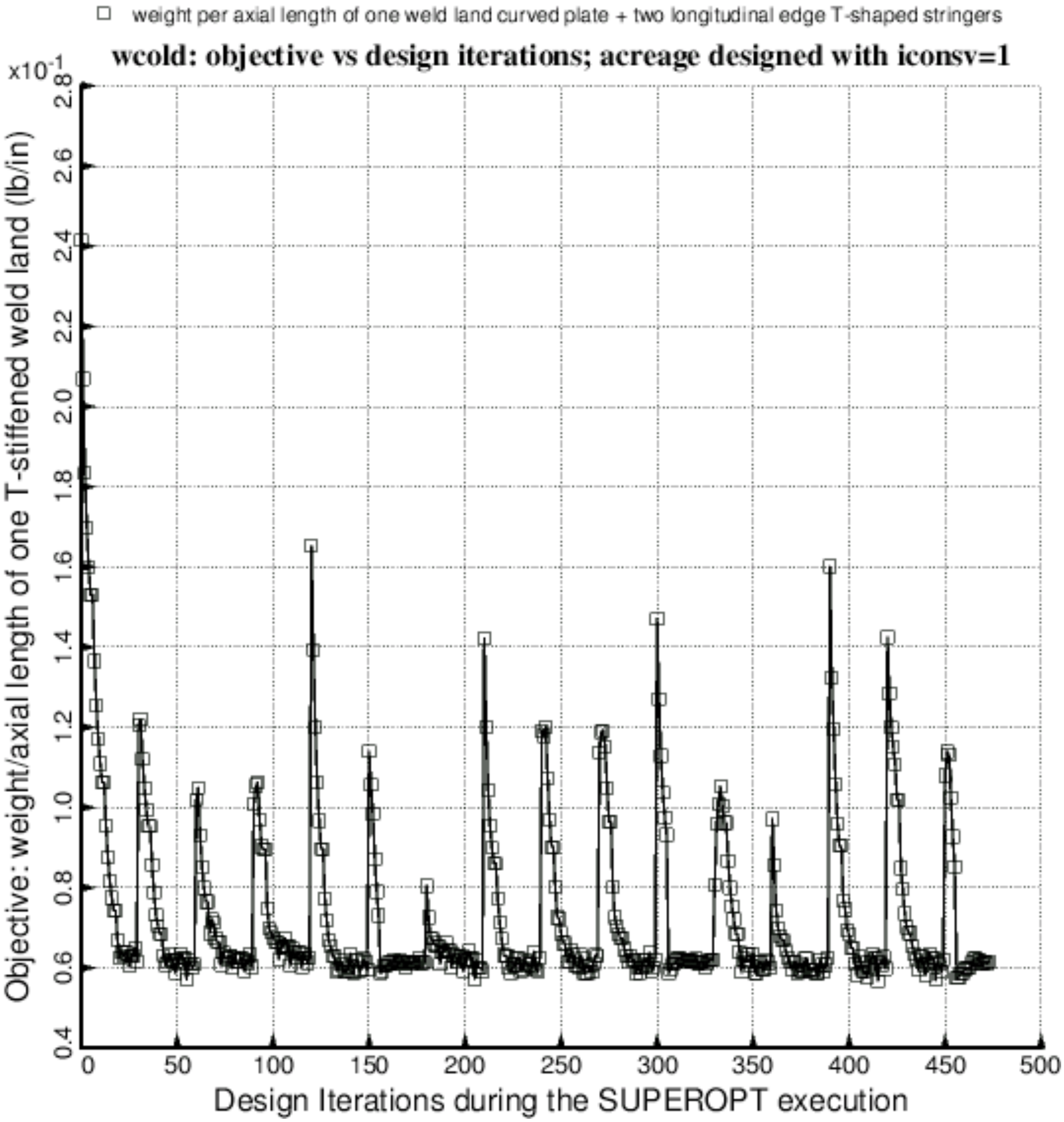


Fig. 4 Optimization of an internally ring and stringer stiffened cylindrical shell with a weld land. This plot shows the objective versus design iterations during an execution of SUPEROPT. Each "spike" in the curve corresponds to a new "starting" design obtained randomly by the GENOPT processor, AUTOCHANGE. The results shown here were obtained with 5 executions of OPTIMIZE for each execution of AUTOCHANGE. In this "weld land" study GENOPT is combined with BIGBOSOR4.
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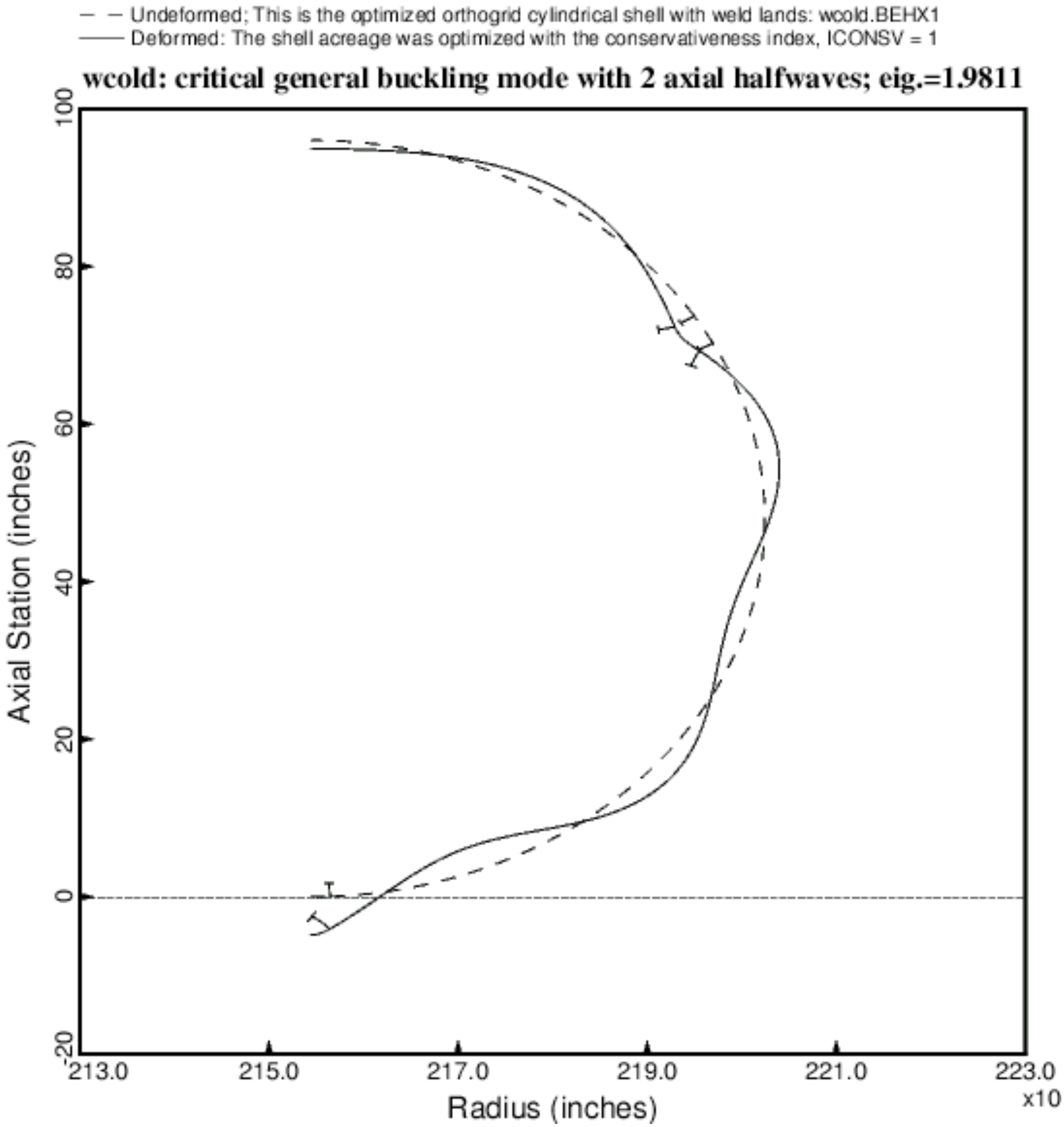

Fig. 6 Critical general buckling mode of the optimized cylindrical shell with weld lands spaced at 120-degree intervals. The stringers and rings are smeared out in this BIGBOSOR4 model, which is analyzed as a true prismatic shell.

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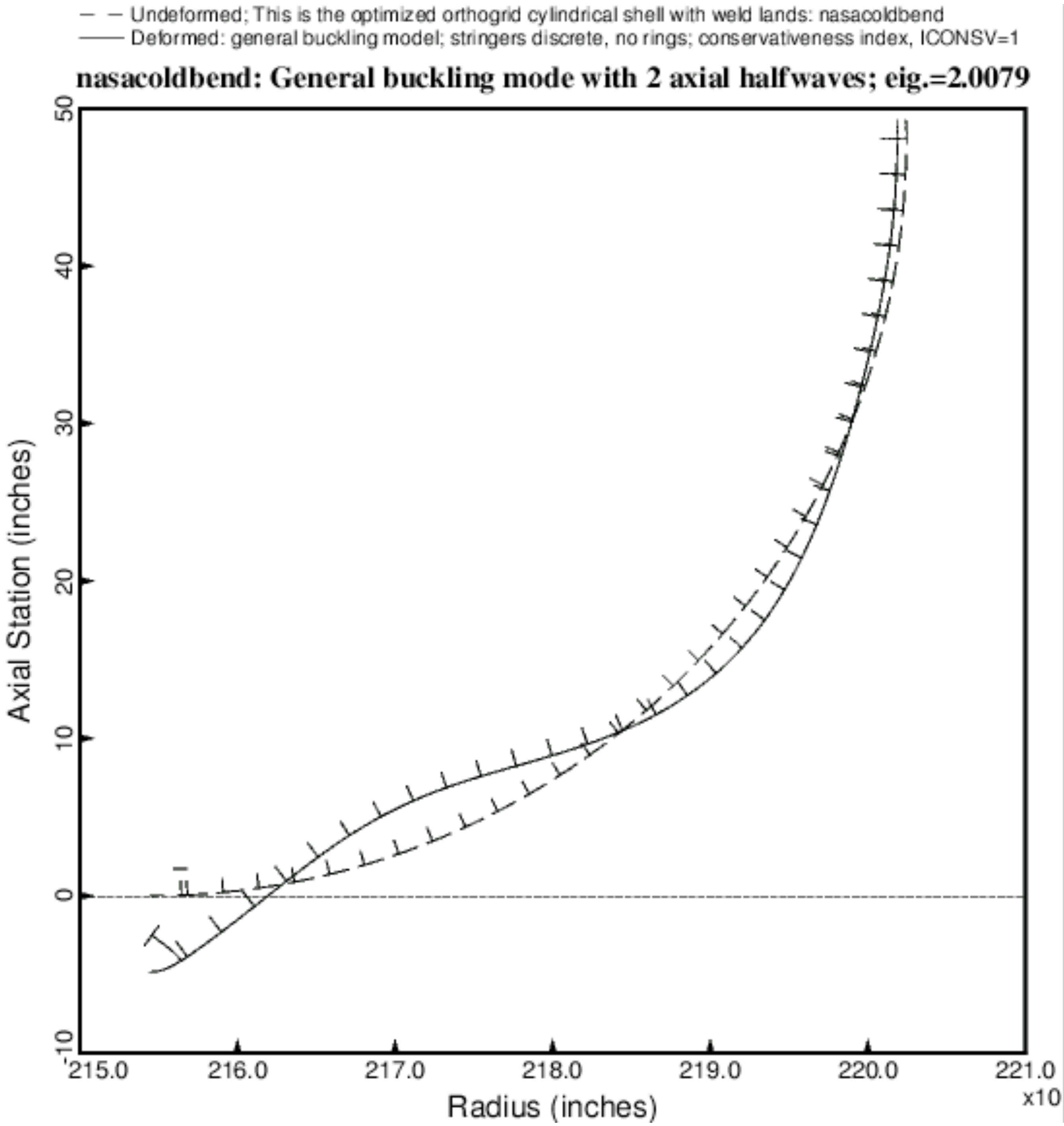

Fig. 7 Critical general buckling mode of the optimized cylindrical shell with weld lands spaced at 120-degree intervals. The rings are smeared out in this BIGBOSOR4 model, which is analyzed as a true prismatic shell. Symmetry conditions are applied at 90 degrees (top of the figure). This model is generated by the PANDA2 processor called PANEL3.

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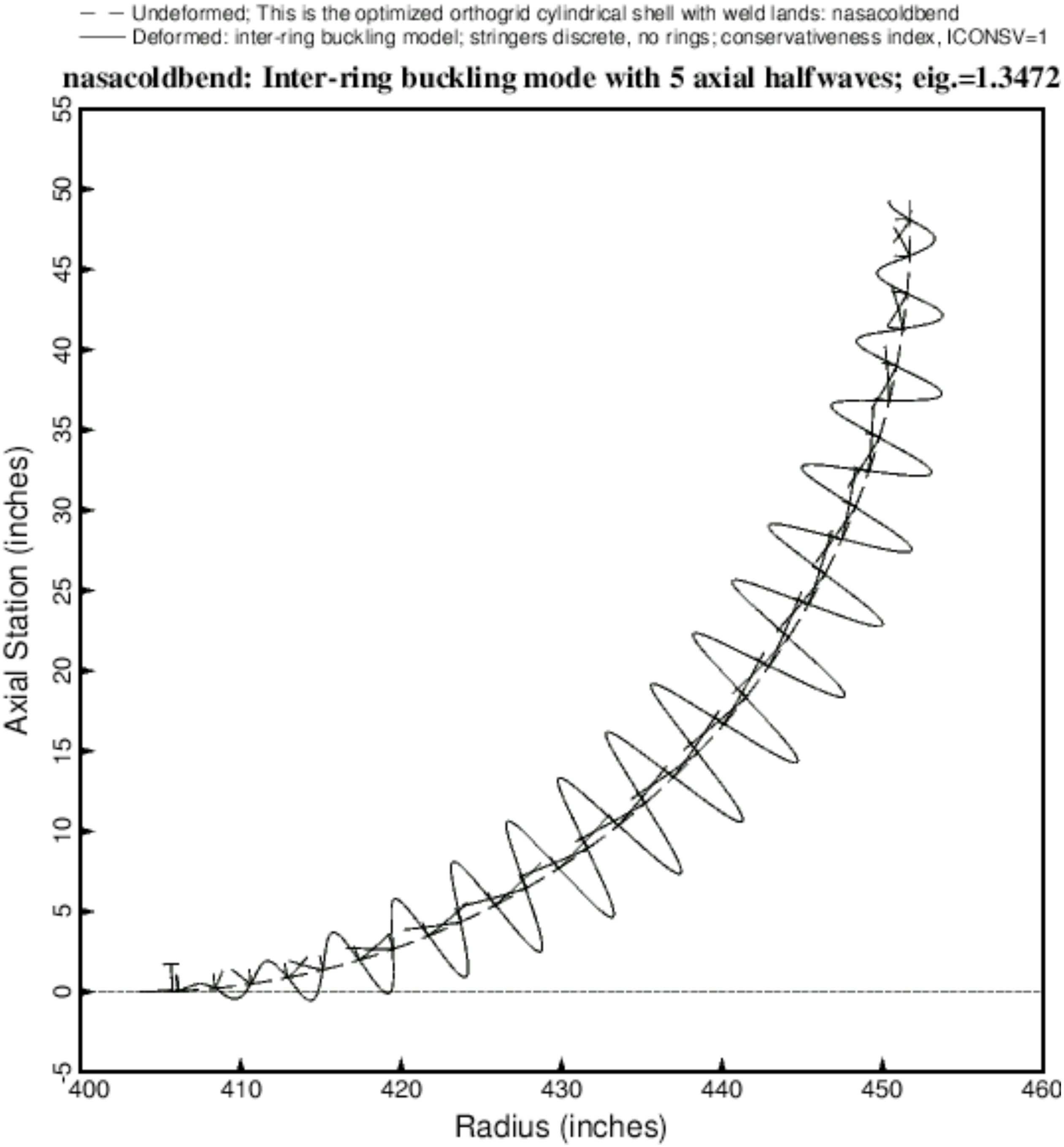

Fig. 16 Critical local buckling mode of the optimized cylindrical shell with weld lands spaced at 120-degree intervals. This model includes a length of shell between adjacent rings, with the rings replaced by simple supports. Symmetry conditions are applied at 90 degrees (top of the figure).The shell is analyzed as a true prismatic shell. This model is generated by the PANDA2 processor called PANEL3.
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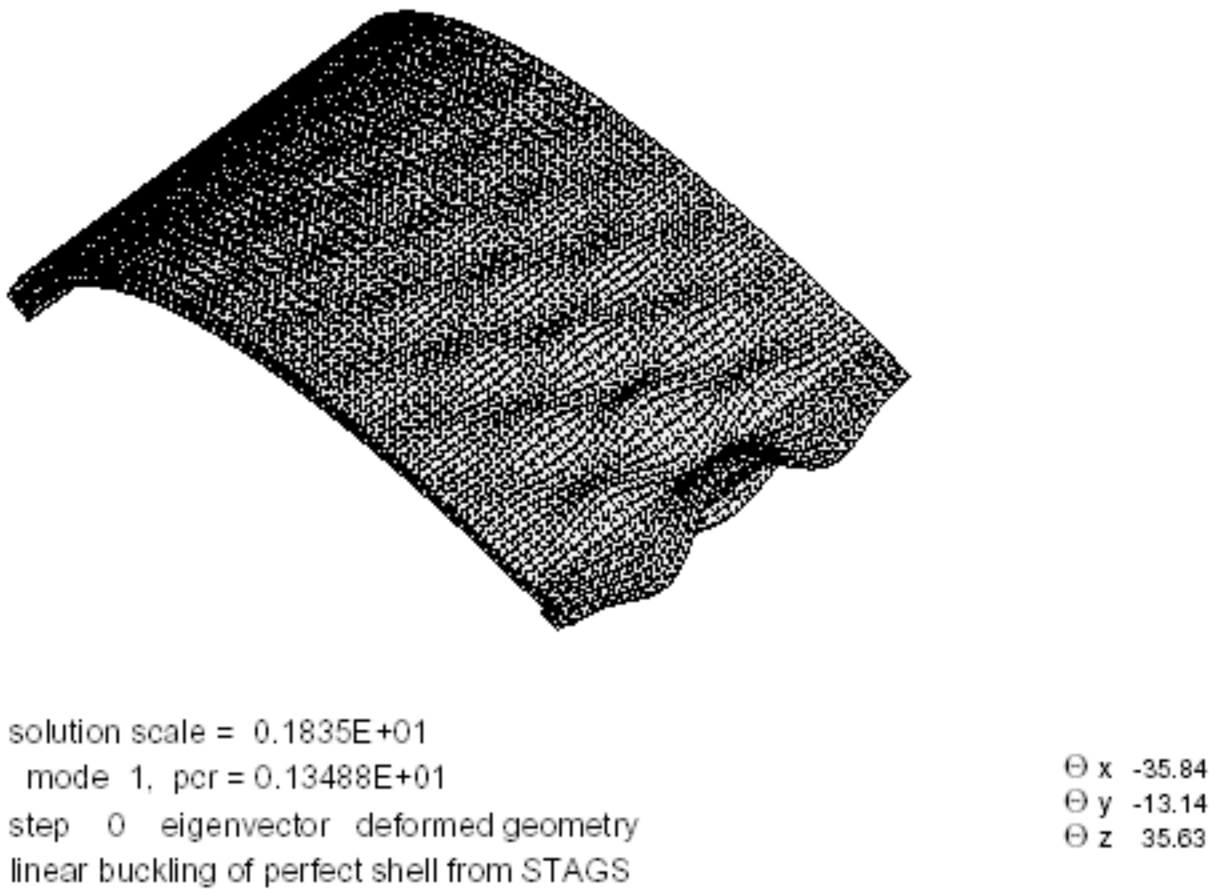

Fig. 25 A STAGS sub-domain model of the optimized internally ring and stringer stiffened axially compressed cylindrical shell with a weld land. Only one ring bay and one weld land are included in this STAGS model. This figure shows the critical local buckling mode shape.
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