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APPROXIMATE METHOD FOR THE OPTIMUM DESIGN OF RING AND STRINGER STIFFENED CYLINDRICAL PANELS AND SHELLS WITH LOCAL, INTER-RING, AND GENERAL BUCKLING MODAL IMPERFECTIONS

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(This is an abridged version. See the full-length paper for more: panda2.papers/1996.p2imperf.pdf)

ABSTRACT

The PANDA2 computer program for minimum-weight design of stiffened composite panels is expanded to handle optimization of ring and stringer stiffened cylindrical panels and shells with three types of initial imperfections in the form of buckling modes, any combination of which may be present: local (buckling between adjacent stringers and rings), inter-ring (buckling between rings with stringers bending with the panel skin), and general (buckling in which both stringers and rings bend with the panel skin). Stresses and buckling load factors of the imperfect panels are computed with use of the assumption that the amplitudes of the buckling modal imperfections grow hyperbolically with increasing load factor according to the formula AMP(i) = EIG(i)/[EIG(i) – 1], in which AMP(i) is a factor to be multiplied by the initial buckling modal imperfection and EIG(i) represents the critical load factor for the ith type of buckling mode (i = 1 = local buckling, i = 2 = inter-ring buckling, i = 3 = general buckling). Buckling load factors corresponding to local, inter-ring, and general buckling of the imperfect panel are computed with use of the maximum radius of curvature that develops in whatever portion of the panel (between stiffeners, inter-ring, overall) is being considered in the calculations and including redistribution of stress resultants over panel skin and stiffener cross-sections caused by prebuckling bending. Stress constraints in the optimization problem are computed including local, inter-ring, and general bending stresses generated by the growth of the initial local, inter-ring, and general imperfections. These bending stresses are added to the stresses from other sources (thermal, in-plane loading, normal pressure, curing, redistribution of membrane stresses from overall prebuckling bending of the imperfect panel). Minimum-weight designs for various imperfect unstiffened and stiffened cylindrical shells derived by PANDA2 are evaluated with use of the STAGS general-purpose finite element code. The agreement of results from PANDA2 and STAGS appears to qualify PANDA2 for the preliminary design of imperfect, stiffened, composite cylindrical shells.

INTRODUCTION

Previous work done: There is extensive literature on the buckling and postbuckling behavior of stiffened plates and shells. This literature covers metallic panels and panels fabricated from laminated composite materials. A brief survey of previous work in this field is given by Bushnell and Bushnell [1]. That survey will not be repeated here.

There have recently appeared many new papers on the buckling and postbuckling behavior of panels and on optimization of composite panels. New methods for the optimization of laminated composite panels have been explored by Haftka and his colleagues [2 – 5]. Preliminary feasibility and design studies of hypersonic aerospace planes have stimulated research on thermal buckling and postbuckling [6 – 11]. The relatively large effect of transverse shear deformation on the buckling and postbuckling behavior of laminated composite and sandwich panels is studied in several new papers [12 – 18]. Other new papers on the buckling and postbuckling of laminated composite panels and shells include Refs. [19 – 29]. Of particular interest is a paper by Arbocz and Hol [30] on the development and linking of a suite of programs of increasing complexity operated on workstations at the Delft University of Technology.

Bushnell and Bushnell [1, 31] present the results of optimization of metallic and laminated composite Tee-stiffened and Hat-stiffened panels by the PANDA2 program [1, 32 – 37] and verification of the optimum designs with the use of the STAGS general-purpose finite element computer program [39 – 41, 48 – 50].

Purpose of this paper: The purpose of this paper is to describe extensions to the PANDA2 program that permit the optimum design of imperfect, stiffened cylindrical panels and shells as summarized in the abstract and to present examples. The unique and most significant aspects of the work are felt to be:

(1) the generation of a reasonably user-friendly and practical computer program for the quick preliminary design of stiffened composite panels that may be imperfect, subject to multiple combinations of loads, and in which the panel skin may be in its locally postbuckled state, and

(2) the verification of this program through evaluation of optimum designs generated by it with use of the widely used general-purpose code for nonlinear shell analysis, STAGS.

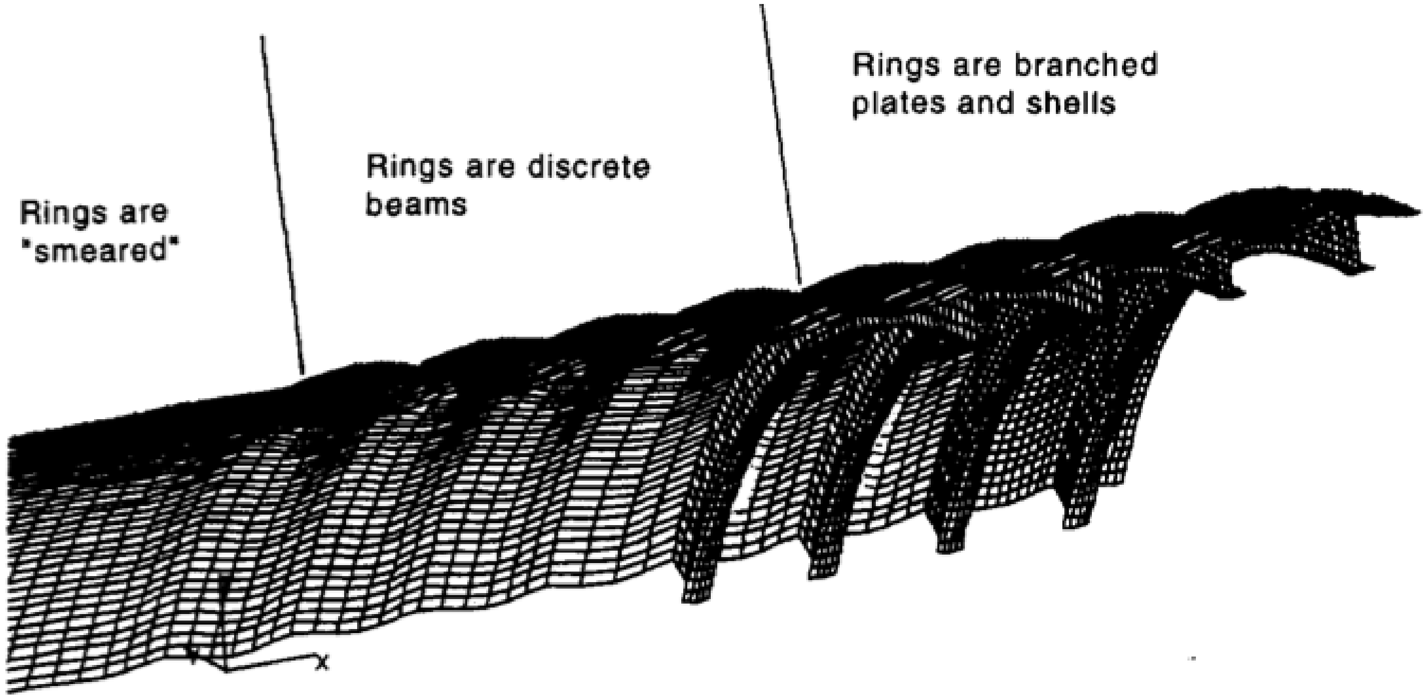

Fig. 1 STAGS finite element model of a perfect externally pressurized ring-stiffened cylindrical shell. (from Computers & Structures, Vol. 59, No. 3, pp. 489 – 527, 1996)

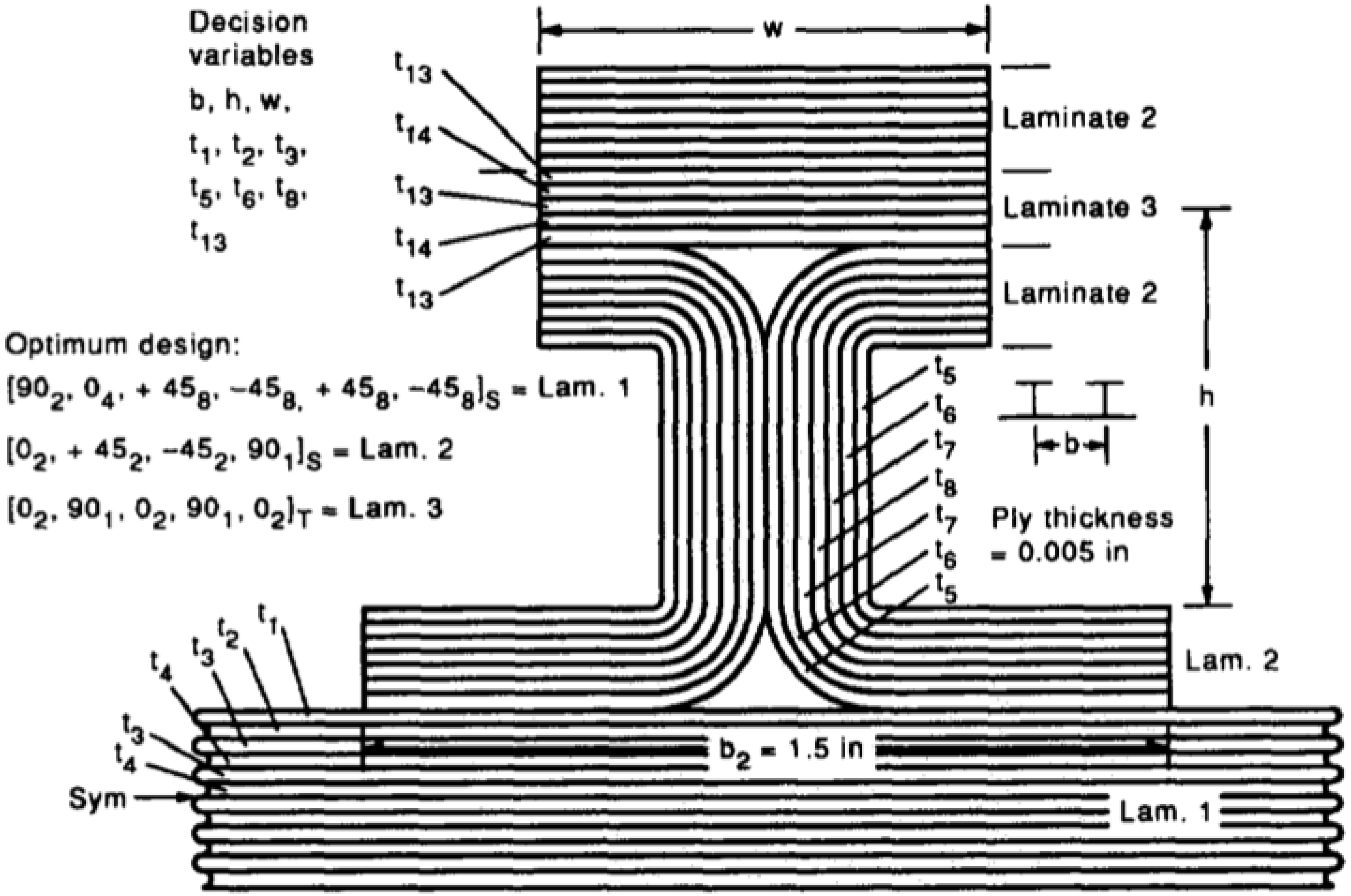

Fig. 36 Layup scheme for all the laminated composite T-ring stiffened cylindrical shells treated in this paper. Optimum ply distribution for the 70-inch-long cylindrical shell optimized with “reduced skin” and “tsd” (“transverse shear deformation”) switches turned on during optimization with PANDA2. (from Computers & Structures, Vol. 59, No. 3, pp. 489 – 527, 1996)

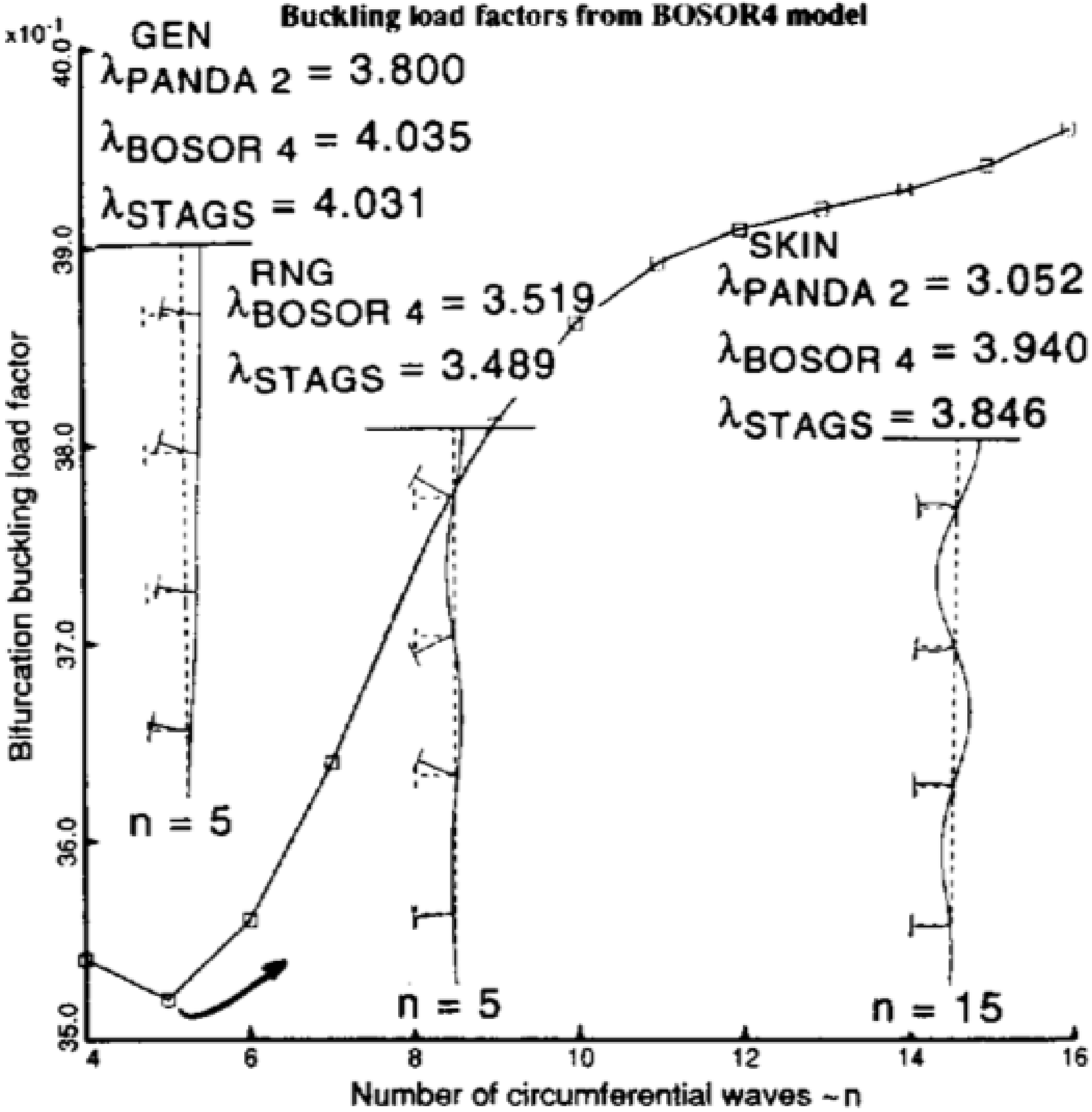

Fig. 42 Buckling mode shapes predicted by BOSOR4 and buckling load factors predicted by PANDA2, BOSOR4, and STAGS for the optimized, perfect, 70-inch-long hydrostatically compressed composite cylindrical shell. (from Computers & Structures, Vol. 59, No. 3, pp. 489 – 527, 1996)

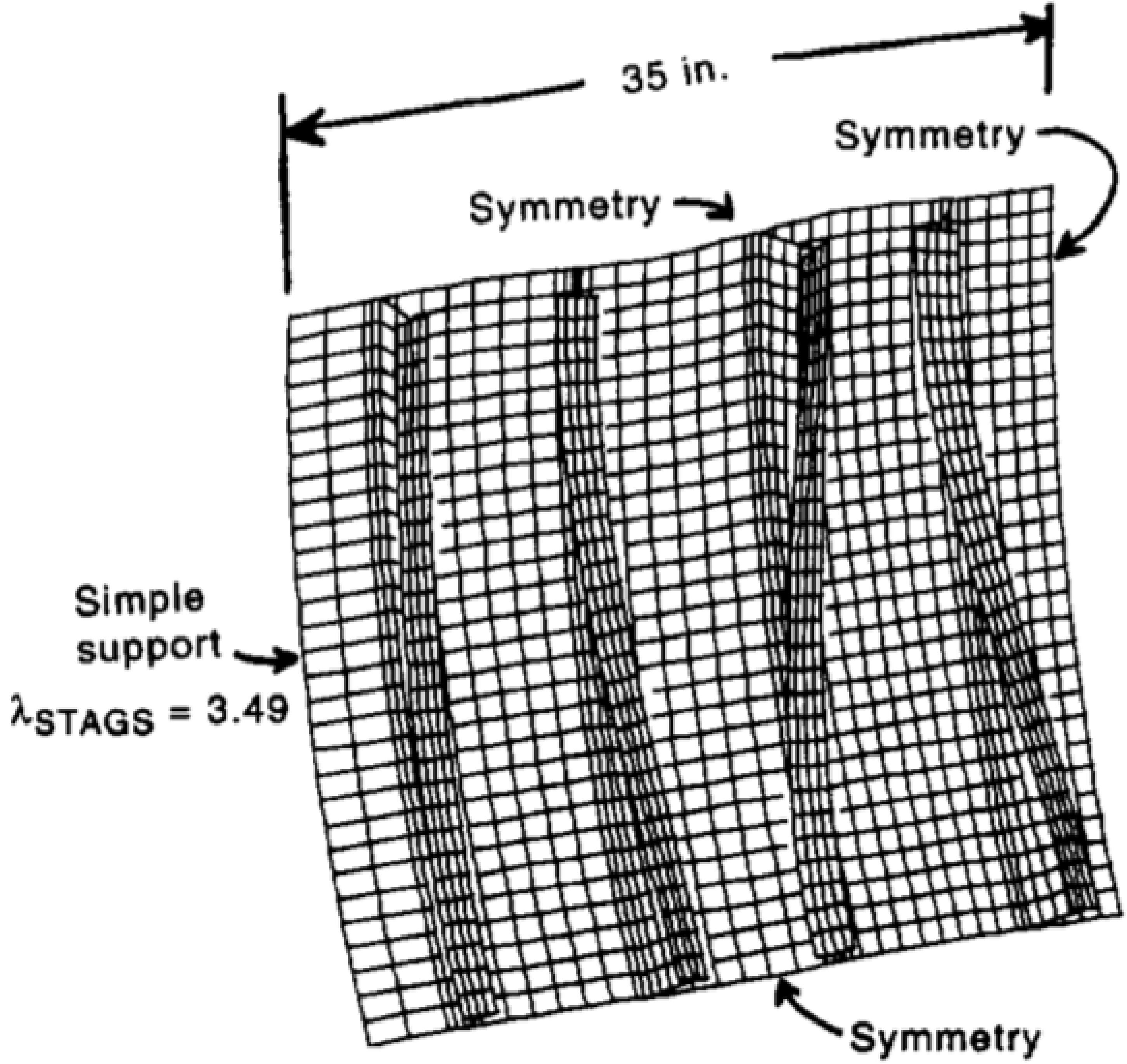

Fig. 43 Ring tripping buckling mode of the T-ring-stiffened, hydrostatically compressed, 70-inch-long, composite cylindrical shell as predicted by STAGS. (from Computers & Structures, Vol. 59, No. 3, pp. 489 – 527, 1996)

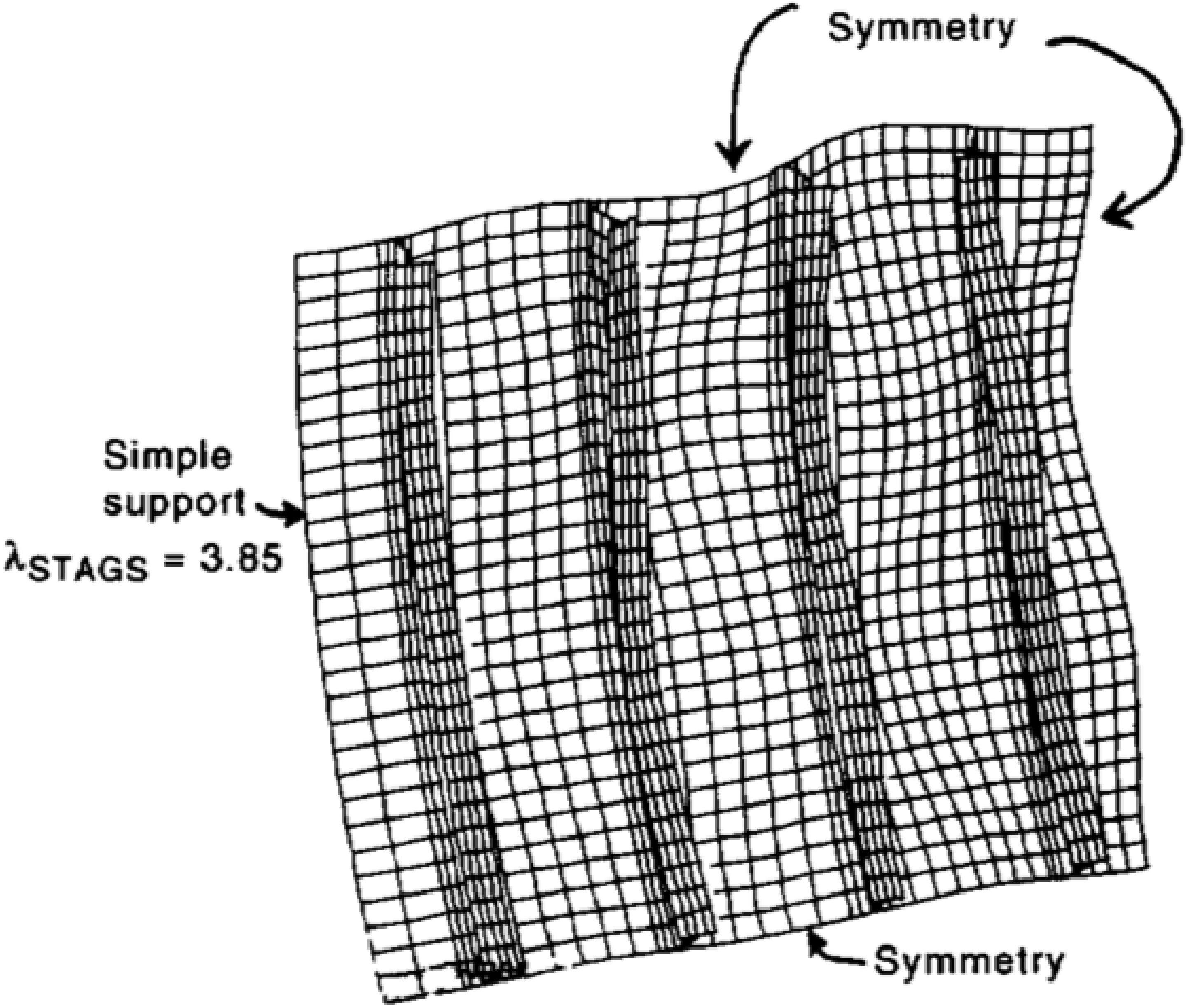

Fig. 44 Local skin buckling mode of the T-ring-stiffened hydrostatically compressed, 70-inch-long, composite cylindrical shell as predicted by STAGS. (from Computers & Structures, Vol. 59, No. 3, pp. 489 – 527, 1996)

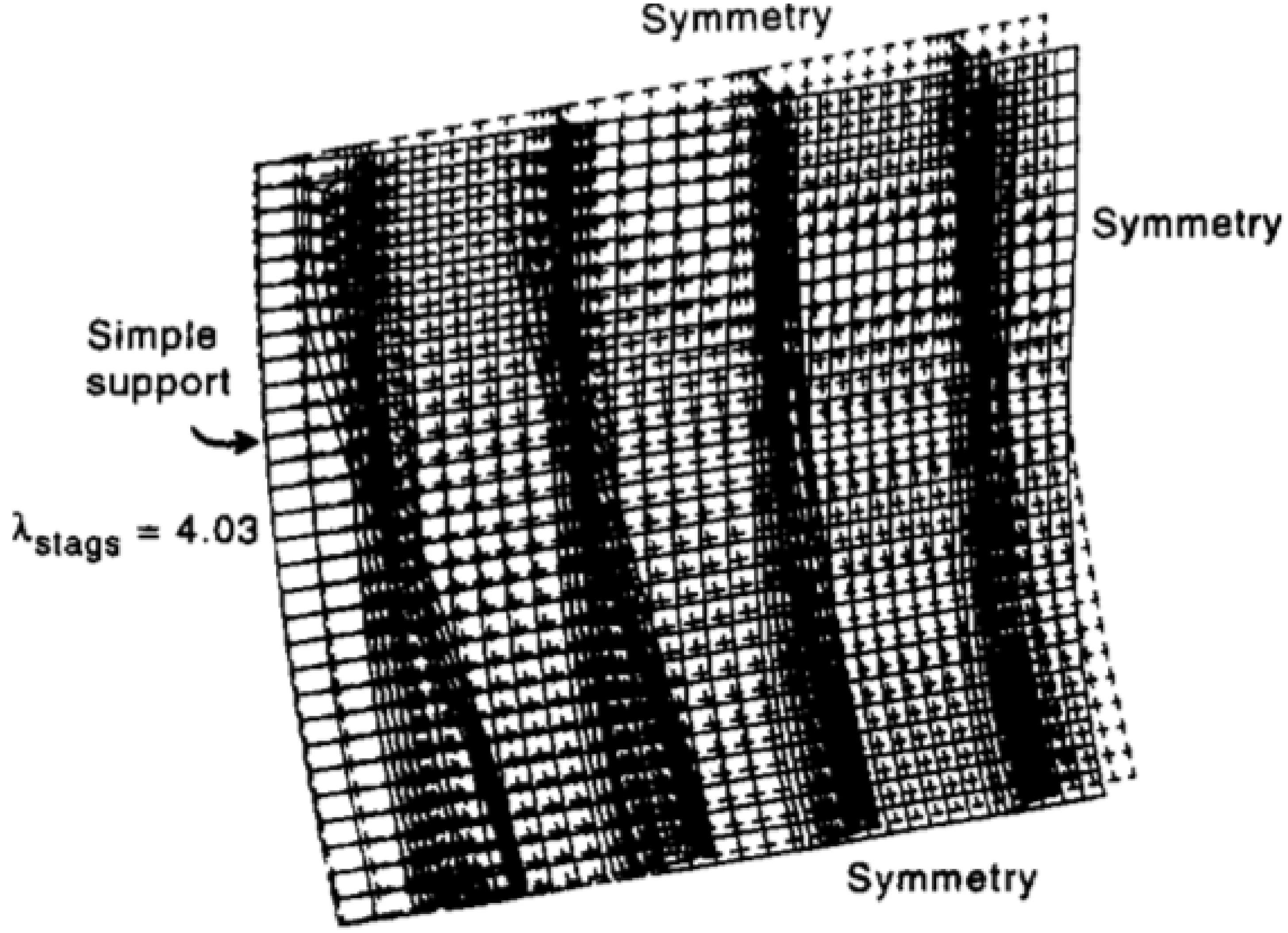

Fig. 45 General buckling mode of the T-ring-stiffened, hydrostatically compressed, 70-inch-long, composite cylindrical shell as predicted by STAGS. (from Computers & Structures, Vol. 59, No. 3, pp. 489 – 527, 1996)