From the AIAA 39th Structures, Structural Dynamics and Materials Conference, AIAA Paper 98-1990

OPTIMIZATION OF PANELS WITH RIVETED Z-SHAPED STIFFENERS VIA PANDA2

David Bushnell, Dept. HI-61, Bldg.250 Lockheed Martin Advanced Technology Center, 3251 Hanover St., Palo Alto, California 94304

(This is an abridged version. See the full-length paper for more: panda2.papers/1998.zstif.pdf)

ABSTRACT

The PANDA2 computer program has been modified to permit minimum weight design of imperfect panels with riveted Z-shaped stiffeners for service in a load regime in which the panel is in its locally postbuckled state. Perfect and imperfect panels optimized with PANDA2 are evaluated via nonlinear STAGS analyses. The agreement between predictions by PANDA2 and STAGS is sufficient to qualify PANDA2 as a preliminary design tool for panels with riveted Z-shaped stringers. Optimum designs for panels with Z-shaped stringers are compared to those with J-shaped and T-shaped stringers.

INTRODUCTION

In the late 1970's van der Neut [1] obtained approximate buckling load factors for the overall buckling of uniformly axially compressed flat panels with either bonded or riveted Z-shaped stringers. He checked his results by comparing with predictions from the VIPASA code by Wittrick and Williams [2,3].

Riks [4] performed an analysis with use of the STAGSC1 program [5]. He included a study of sensitivity of the load factor corresponding to overall buckling to initial bowing imperfections, finding unstable postbuckling behavior (imperfection sensitivity) caused by deformation of the stringer cross section in the overall buckling mode. In "classical" wide column buckling of a panel stiffened with T-shaped stringers, for example, the T-stringer cross section remains undeformed as it translates normal to the skin surface in the wide column buckling mode. This is not so with Z-stiffened panels. In that case, because the stringers have a non-symmetric cross section, they undergo significant sidesway as the panel skin essentially translates normal to the undeformed panel skin in the overall buckling mode (see Fig. 11, for example). Hence the load at which a Z-stiffened panel collapses under uniform axial compression is sensitive to an initial overall bowing imperfection even if the local buckling load factor significantly exceeds that corresponding to general ("wide column") instability.

Local and overall bifurcation buckling of panels with Z-shaped stringers can also be determined with the BUCLASP code [6] and with the newer successors to BUCLASP and VIPASA: the PANDA2 [7], POSTOP [8], VICONOPT [9], and PASCO [10] codes. PASCO, VICONOPT, PANDA2 and POSTOP are capable of obtaining optimum designs of such panels, and PANDA2 and POSTOP can do so including the effect of local postbuckling [11] of the panel skin and/or parts of the stringers. The authors of VICONOPT [9] are currently working on a postbuckling capability [9]. One of the PANDA2 processors, called STAGSMODEL [12], automatically sets up a finite element model of a panel previously optimized with PANDA2. (2011 NOTE: The newer PANDA2 processor called STAGSUNIT is more general and easier to use than STAGSMODEL.) The PANDA2/STAGSMODEL/STAGS and PANDA2/STAGSUNIT/STAGS combinations have been used many times to optimize and evaluate optimum designs of panels under combined loads for service in the postbuckling regime [11-15].

Other significant contributions to the field of buckling and postbuckling of panels include works by Stein [16], Leissa [17], Arnold and Parekh [18], Starnes, Knight, and Rouse [19], Spier [20,21], Khot and Bauld [22,23], Zhang and Matthews [24], Gürdal and his colleagues [25-31], Haftka and his colleagues [30-36, 61], Librescu and his colleagues [37-39], Sridharan and his colleagues [40,41], Knight and his colleagues [42-44], Myers and Hyer [45], Nemeth [46], Noor, Starnes, and Peters [47], and McGowan and Anderson [48] and Wiggenraad, et al [62].

METHOD OF ANALYSIS

In PANDA2 local buckling of a stringer-stiffened panel is predicted from a single-module discretized model described in [7]. (See Fig. 22(a,b) in [7] and Fig. 8 in this paper, for examples). Overall buckling is predicted from both a single-module discretized “wide column” model, such as shown in Fig. 22c of [7] and in Fig. 11 of this paper, and from a model in which the stiffeners are "smeared out" (averaged) over the panel in the manner of Baruch and Singer [49]. Discretization is via the finite difference energy method, as described in [50]. There are a number of nodal points in each of the segments of the module cross section, and variation along the axis of the panel is assumed to be trigonometric with the critical number of axial half-waves and critical slope of buckling nodal lines in the panel skin (for an anisotropic panel and/or a panel in which in-plane shear loading Nxy is present) determined in the analysis described in detail in [11].

The purpose of the work reported here is to enhance the capability of PANDA2 by the inclusion of Z-shaped stiffeners riveted to the panel skin. A discretized panel skin-stringer single module is constructed as shown in Fig. 1. The stringer spacing is called "b", and the rivet line, considered to be continuous in the axial direction and located at the mid-width of the attached flange (Segment 2 of the single module), is located at b/2, the mid-width of the entire module. The toe and heel of the attached flange are free to separate from or to "penetrate" the panel skin in the local buckling mode and in the post-local buckling regime: no intermittent contact conditions are imposed in the PANDA2 model. At the rivet line compatibility conditions are imposed between panel skin and attached flange with eccentricity of the attached flange with respect to the reference surface of the panel skin accounted for.

Local buckling modes typically have a form such as that shown in Fig. 10, which is assumed to be sinusoidal in the axial direction (normal to the plane of the paper) with a computed critical number of axial half-waves and a computed slope of the local buckling nodal lines [11, 22, 23] in the critical local buckling mode. The local buckling nodal lines are assumed to be straight. The nonlinear local postbuckling analysis [11] is analogous to that of Koiter [51]. In PANDA2 the axial wavelength and the slope of the nodal lines of the postbuckled pattern are permitted to change as the applied load is increased above that corresponding to initial local bifurcation buckling.

Details of the nonlinear post-local buckling analysis and predictions from PANDA2 and STAGS [52] appear in [11].

The "wide column" buckling mode has a form such as that shown in Fig. 11. There is assumed to be one-half wave in the axial direction in the "wide column" mode. The "softening" effect which influences the effective overall axial, hoop, and in-plane shear membrane stiffness components of a locally imperfect and/or locally postbuckled panel module (See Fig. 15 of [12], for example) is accounted for in the computation of the bending-torsional, "wide column" and overall buckling load factors.

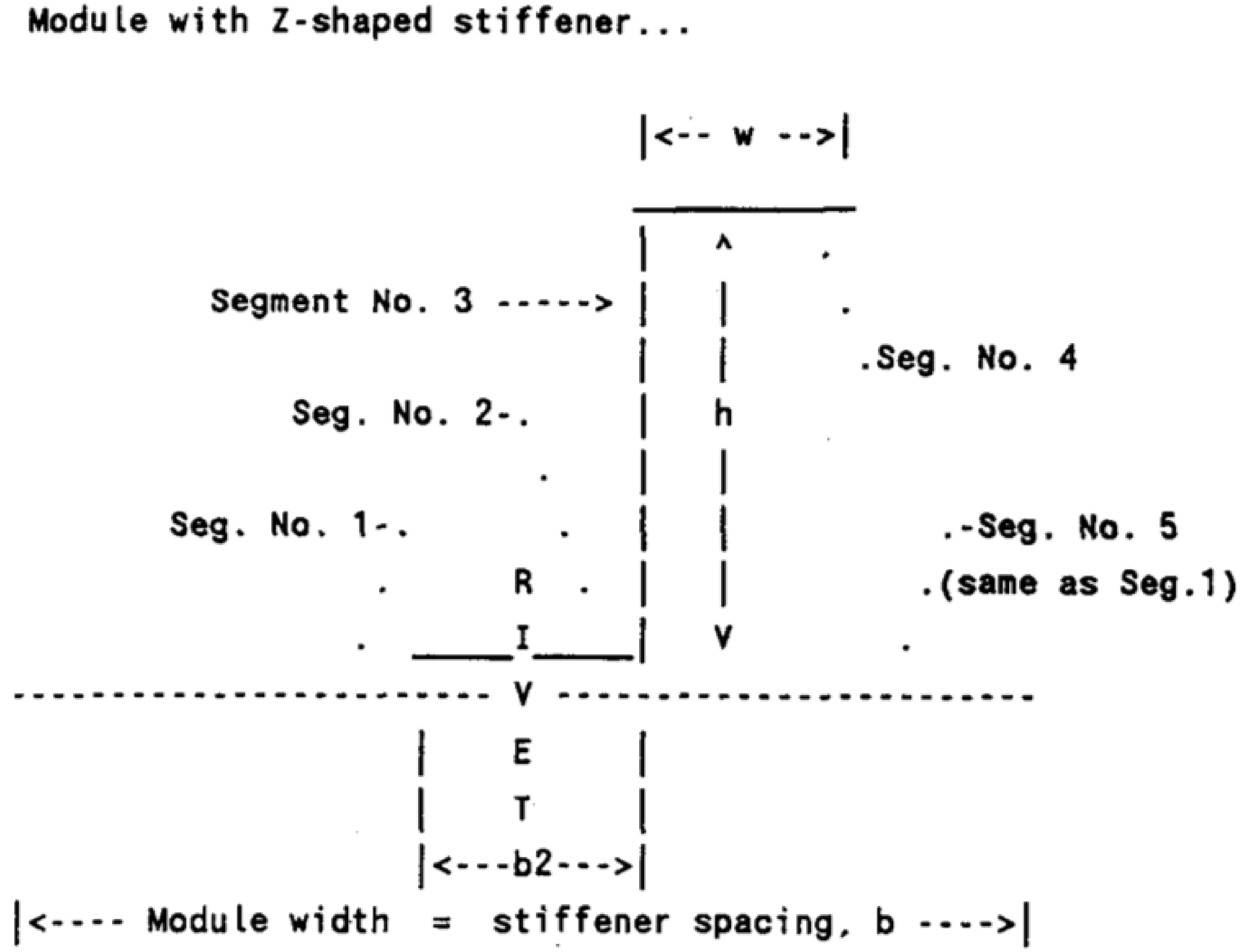

Fig. 1(a) Sketch of the Z-shaped stiffener as riveted to the panel skin in the PANDA2 prompting file called PROMPT.DAT. This sketch appears on the PANDA2 user's screen during the interactive “BEGIN” session. (from AIAA 39th Structures, Structural Dynamics and Materials Conference, AIAA Paper 98-1990)

```
   EXPLODED VIEW, SHOWING LAYERS and (SEGMENT, NODE) NUMBERS

                      Layer No. 1___
                                    .
                                     .
            (Segment,Node)=(4,1)____________(4,11)
                                        .
                             (3,11)      .__Layer No. j
                               !
            Layer No. 1 -----> ! <----------- Layer No. k
                               !
            Layer No. 1-.      !
Layer No. 1-.            .     !         .-Layer No. 1
           .              .    !          .
          .             R  . (3,1)         .
         .   (2,1)______I______(2,11)       .
---------------------- V  ------------------------
(1,1)    .       (1,11) E (5,1)                  .   (5,11)
          .             T                         .
           .                                       .
            Layer No. m                             Layer No. m
```

Fig. 1(b) Sketch of the Z-shaped stiffener showing layer numbering convention and (segment, node) numbering convention. The riveting of the faying flange to the panel skin is simulated by a junction constraint on the displacements, u, v, w, and rotation ROT at the mid-width of the faying flange (2,6) to the end node of Segment 1 (1,11). The toe and heel of the Z-shaped stiffener (2,11) are free to lift off the panel skin or to penetrate the panel skin. This renders the behavior of Z-shaped stringers considerably different from that of J-shaped stringers, especially for non-optimum designs. (from AIAA 39th Structures, Structural Dynamics and Materials Conference, AIAA Paper 98-1990)

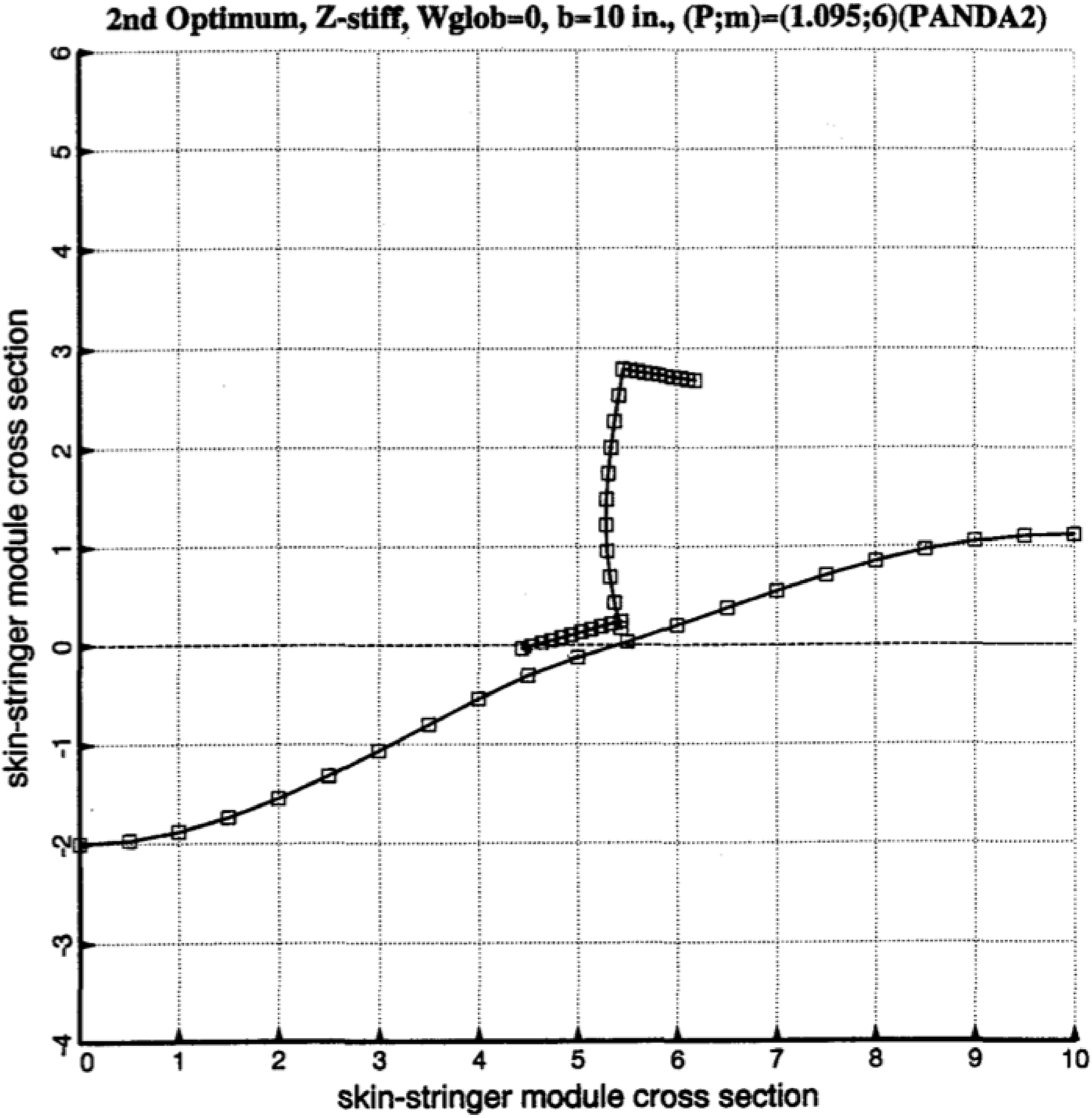

Fig. 10 Local skin buckling mode of an axially compressed optimized panel with riveted Z-shaped stringers. The stringer spacing is 10 inches. The axial compression is normal to the plane of the paper, and the buckling modal displacement components, u, v, w, vary in this direction (axially) trigonometrically with m axial half waves. (from AIAA 39th Structures, Structural Dynamics and Materials Conference, AIAA Paper 98-1990)

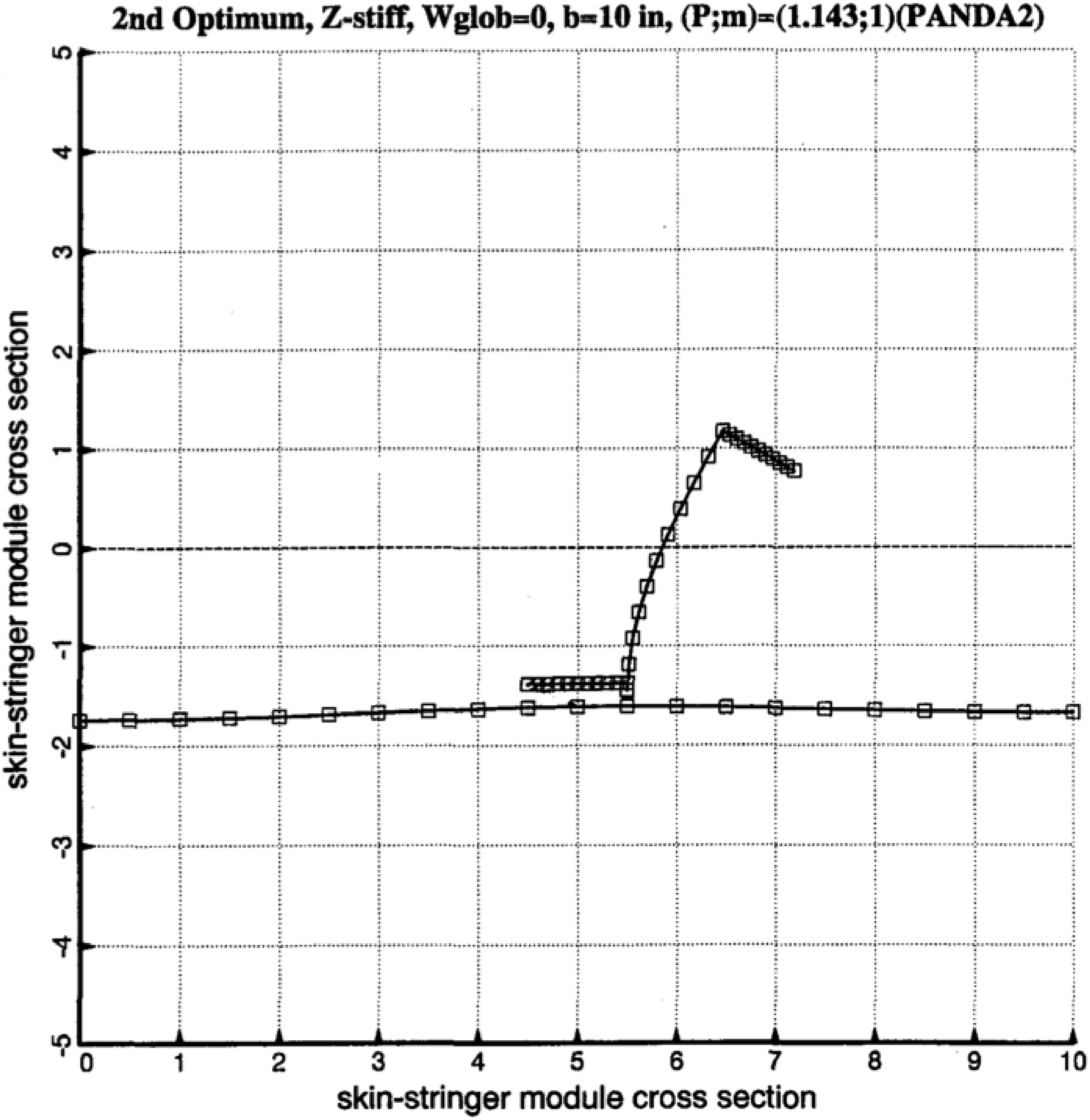

Fig. 11 Wide-column buckling mode of an axially compressed optimized panel with riveted Z-shaped stringers. The stringer spacing is 10 inches. Note especially that there is considerable side-sway of the stringer as the panel buckles in the wide-column mode shape. (from AIAA 39th Structures, Structural Dynamics and Materials Conference, AIAA Paper 98-1990)

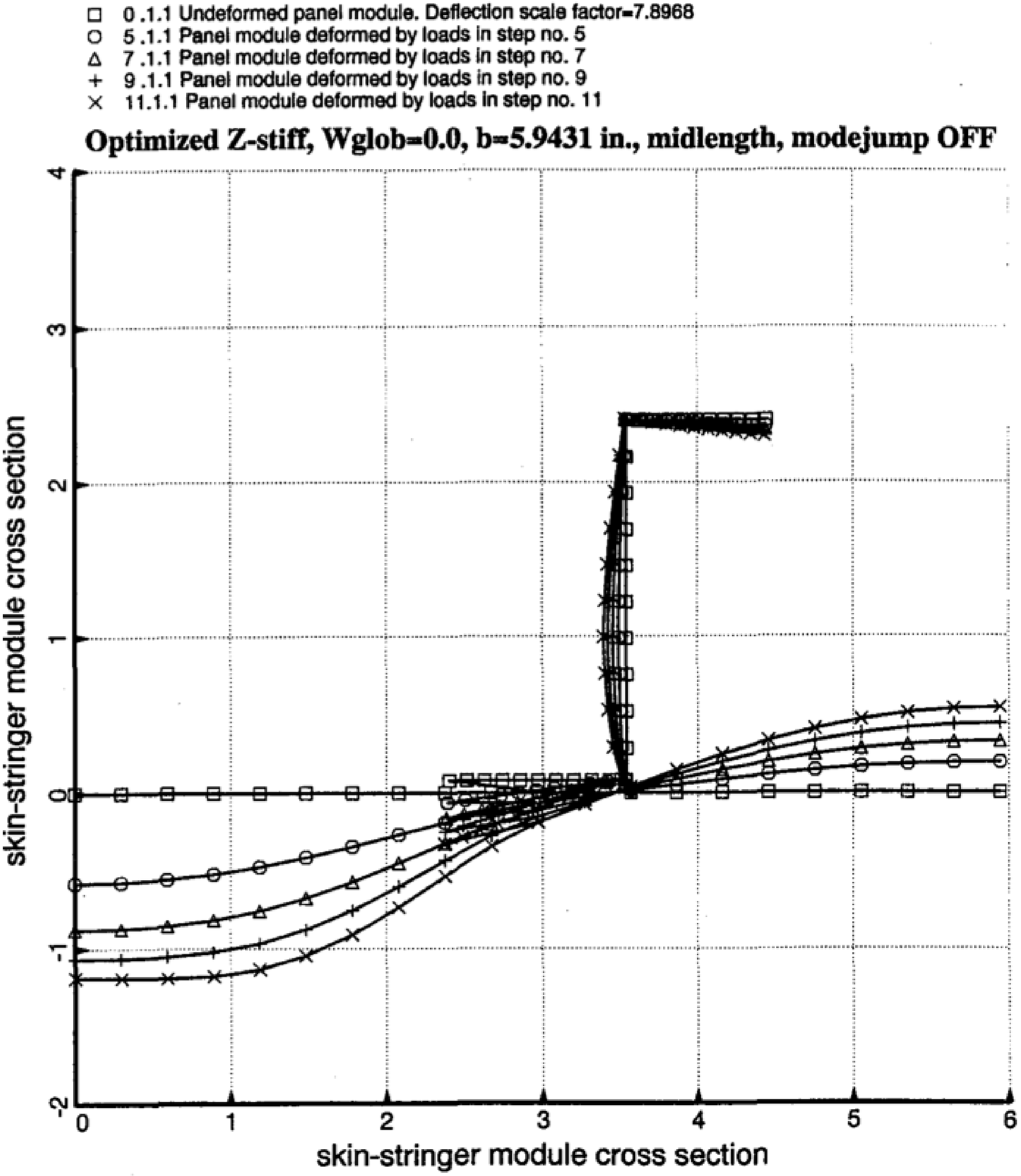

Fig. 13 Local post-buckling of an axially compressed single panel module with a riveted Z-shaped stringer. The optimized stringer spacing is b = 5.9431 inches. (from AIAA 39th Structures, Structural Dynamics and Materials Conference, AIAA Paper 98-1990)