The following items are from emails sent from David Bushnell to Allen Waters in September and October, 2009

**----------------- Substiffener Issues --------------------------------------------------**

18 September 2009 @ 1302 PDT

About how PANDA2 works with regard to the "exact" arrangement of substiffeners within a single major stiffener spacing (Refs. [1,2]): **The PANDA2 theory does not at all deal with the "exact" arrangement of substiffeners within a single major stiffener spacing**. All it does is determine what would be the optimum spacing and cross section dimensions as if the "subpanel" (panel between two adjacent major stiffeners) has a field of equally spaced substiffeners. It says nothing about where the first and last substiffener in the field are to be located with respect to the nearest major stiffener. (This is the same way that PANDA2 handles a panel with just major stiffeners; it doesn't deal with exactly what the stiffener arrangement is in the neighborhood of the panel edges.) In general the optimum design will not contain exactly an integral number of uniform stiffener spacings within the domain. ("domain" = entire panel width or length in the case of spacing of the major stiffeners; "domain" = region between adjacent major stiffeners in the case of spacing of the substiffeners between adjacent major stiffeners).

In view of the above paragraph, what does one do whenever they want to make comparisons of PANDA2 and STAGS predictions for optimized designs? These are the five steps in this process:

**Step 1**: Set up a new PANDA2 model that is as close as possible to the optimized design, except that in the new model there are exactly **an integral number of major stiffener spacings over the entire panel and exactly an integral number of substiffener spacings between adjacent major stiffeners.** In setting up this new PANDA2 model one has to make some decisions: Should the stiffener and substiffener spacings be increased or decreased to ensure that there exist integral numbers of major stiffeners over the entire panel and integral numbers of substiffeners between major stiffeners? What is done here is entirely up to the analyst. One approach is to change the optimized values of the spacings and subspacings to values that are closest to those obtained for the optimized design (except see below).

NOTE: First modify the spacings of the major stiffeners so that there exist integral numbers of these over the entire panel, then modify the spacings of the substiffeners so that there exist integral numbers of these over the **newly established** spacings of the major stiffeners. Use the "CHANGE" processor of PANDA2 to do this. [In this Step 1 process there is a small bias toward **decreasing** the stiffener and substiffener spacings to achieve integral numbers of stiffeners and substiffeners over their respective domains, that is, one usually (but not always) alters the previously obtained optimum design in such a way that the altered design will still be FEASIBLE or ALMOST FEASIBLE, albeit somewhat heavier.]

**Step 2**: Eliminate the major stiffener spacings and the substiffener spacings as decision variables. One can use the "DECIDE" processor of PANDA2 to do this, or edit the *.DEC file and then re-execute DECIDE. If editing the *.DEC file, be very careful because you may also have to eliminate linking and or inequality constraints that involve what were formerly decision variables but now are no longer decision variables. It is best to be safe and just go through the DECIDE processor interactively in the same way done for the original optimization except that now the major stiffener spacings and substiffener spacings are no longer to be chosen as decision variables. If there are no linking constraints or inequality constraints that involve stiffener spacings and/or substiffener spacings, then it would be easiest simply to delete the entries in the *.DEC file that correspond to stiffener and substiffener spacings and execute DECIDE. (Remember to save your original *.DEC file!)

**Step 3**: Re-optimize, using SUPEROPT or maybe just executing PANDAOPT (with ITYPE = 1 in the *.OPT file) a few times.

**Step 4**: The new optimum design, which presumably has a weight fairly close to that obtained for the original optimum design with the non-integral numbers of stiffener and substiffener spacings, now has integral numbers of spacings of major stiffeners over the entire panel and integral numbers of spacings of substiffeners within the domain between adjacent major stiffeners. Use the processor, STAGSUNIT, to set up a STAGS model of the newly optimized panel. What STAGSUNIT does is automatically choose the substiffener closest to the major stiffener to be one half a substiffener spacing away from its neighboring major stiffener.

**Step 5**: Run STAGS, using the *.inp and *.bin files produced automatically by STAGSUNIT. Compare with the PANDA2 prediction.

REFERENCES

D. Bushnell an C. Rankin, "Optimum design of stiffened panels with substiffeners", AIAA Paper AIAA-2005-1932, 46th AIAA Structures Meeting, 2005

D. Bushnell, "Optimum designs from PANDA2 of a uniformly axially compressed cylindrical shell with internal rectangular stringers and rings and with internal substringers and the evaluation of the optimum designs by STAGS and BIGBOSOR4, 25 February, 2009 (the file called: Bushnell_Report_200902-1.pdf)

**------------------ "stiffener crippling" = "stiffener collapse" ?---------------------**

10 October 2009 @ 1600 PDT

The following distinct phenomena are related to what one might possibly term "stiffener collapse" in the context of an axially compressed, axially stiffened panel. All the phenomena described next involve deformation of a stiffener that could cause overall failure of a stiffened panel. Often it is difficult to assign the overall failure of a panel to a particular phenomenon, such as "stiffener collapse". Usually the overall failure of the panel is a process rather than a single event.

1. The stiffeners are possibly under-designed relative to the panel skin and the segments of them therefore each buckle locally with short axial wavelengths in a mode such as that displayed in Fig. 5 at the top of page 546 in Ref. [1]. This type of buckling is covered in PANDA2 in SUBROUTINE STFEIG. This short-axial-wavelength buckling is aptly termed "stiffener crippling". This short-axial-wavelength type of stiffener segment buckling often occurs with axially compressed corrugated semi-sandwich panels. See Fig. 2 on page 357 of Ref. [2], for example.

2. The stiffeners may buckle in a relatively long-axial-wavelength mode- "stiffener rolling" in PANDA2. This stiffener rolling may occur with or without participation of the panel skin. Figures 6(a) and 11 of Ref. [1] show this type of buckling **with participation of the panel skin**. Fig. 29(d, e, f) on page 589 of Ref. [3] show post-buckled states are characterized by long-axial-wavelength rolling of the stiffeners combined with shorter-axial-wavelength buckling of the panel skin. Figures 6(b,c) of Ref. [1] show stiffener rolling **without participation of the panel skin**. These types of buckling are covered in PANDA2 in SUBROUTINE STFEIG and in other subroutines, such as SUBROUTINE BUCKLE (discretized single module "strip" model) and SUBROUTINES GENSTB and ARBOCZ (closed form type solutions), and SUBROUTINE ALTSOL (trigonometric series expansion solution).

3. The panel may be designed to permit local skin/stringer buckling at an axial load smaller than the design load. Figure 20 on page 75 of Ref. [4] shows a single discretized module model from PANDA2 loaded far into the locally post-buckled regime. Failure of the entire panel could occur in various ways. The panel could collapse globally because of reduced effective stiffness of the locally post-buckled panel skin and/or stiffener. On the other hand, elevated stresses in the neighborhood of the intersection of the stringer web and panel skin could lead to fractures there that would cause the stiffener to separate from the panel skin, with subsequent global failure of the entire structure.

Reference 5 discusses the third phenomenon described above (Previous paragraph, numbered “3” above). The designer needs to provide a generous fillet radius at the junction of the stringer and panel skin in order to minimize stress concentrations that might give rise to fractures there that would cause stiffener separation and ultimate failure of the entire panel. PANDA2, being based entirely on thin shell theory, is not capable of predicting stress concentrations caused by intersecting structural segments. **In order to predict the actual maximum effective stress distribution in the immediate neighborhood of the root of the stringer, one must use locally a three-dimensional model with solid finite elements concentrated in this critical area** (e. g., a more elaborate finite element model with STAGS or ABAQUS or some other general-purpose computer program to study this phenomenon in detail). On the other hand, designers and engineers could do the following:

1. compute the dependence of overall panel weight on the fillet radius.
2. use the maximum fillet radius that does not significantly impact the weight.
3. test the panel which has that fillet radius.

REFERENCES

1. D. Bushnell, "Theoretical basis of the PANDA computer program for preliminary design of stiffened panels under combined in-plane loads", Computers & Structures, Col 27, No. 4, pp. 541-563, 1987.
2. David Bushnell, "Crippling and buckling of corrugated ring-stiffened cylinders", J. Spacecraft, Vol. 9, No. 5, pp. 357-363, May, 1972.
3. D. Bushnell and W. D. Bushnell, "Minimum-weight design of a stiffened panel via PANDA2 and evaluation of the optimized panel via STAGS", Computers & Structures, Vol. 50, No. 4, pp. 569-602, 1994.
4. David Bushnell, "Optimization of composite, stiffened, imperfect panels under combined loads for service in the post-buckling regime", Computer Methods in Applied Mechanics and Engineering, Vol. 103, pp. 43-114, 1993.
5. D. Bushnell, "Use of PANDA2 to explore the post-local buckling behavior of an axially compressed isotropic panel with blade stringers," informal report to NASA Langley Research Center (the file called Bushnell_Report_20091009-1.pdf), 9 October 2009 (called the “allen” case), and “STAGS models of the ‘allen’ case” (the file called: Bushnell_Report_20091016-1.pdf), 16 October, 2009

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