On a New Scientific Approach to Shell Design

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With the arrival of the era of supercomputing there is a tendency to replace the relatively expensive experimental investigations by numerical simulation. The use of large general purpose computer codes for the analysis of different types of aerospace, marine, and civil engineering structures is by now well accepted. These programs have been used successfully to calculate the stress and deformation patterns of very complicated structural configurations with the accuracy demanded in engineering analysis.

However, there exist numerous complex physical phenomena where only a combined experimental, analytical, and numerical procedure can lead to an acceptable solution. One such problem is the prediction of the behavior of buckling sensitive structures under the different loading conditions that can occur in everyday usage.

The axially compressed cylindrical shells represent one of the best known examples of the very complicated stability behavior that can occur with thin-walled structures. For thin shells that buckle elastically initial geometric imperfections and the effect of the different boundary conditions have been identified as the main cause for the wide scatter of the experimental results. However, this knowledge had not been, as yet, incorporated into the current shell design manuals.

These design recommendations all adhere to the so-called lower bound design philosophy and as such recommend the use of the following buckling formula:

(1)

where allowable applied load; lowest buckling load of the perfect structure; ' "knock-down factor"; and F.S. = factor of safety.

The empirical knockdown factor ' is so chosen that when it is multiplied with , the lowest buckling load of the perfect structure, a lower bound to all available experimental data is obtained.

The central goal of the research reported in this paper is the development of "improved shell design criteria" for buckling critical isotropic and orthotropic shells. The improvements with respect to the presently recommended shell design procedures are primarily sought in a more selective approach by the definition of the "knockdown" factor ' . The proposed new improved shell design procedure can be represented by the following formula

(2)

where allowable applied load; lowest buckling load of the "perfect" structure computed via one of the shell codes; verified high fidelity (higher) knockdown factor; and F.S. = factor of safety.

As a step towards developing such a new design philosophy, one that moves away from the traditional empirical approach used today in design towards a science-based design technology approach, two test series, one of 7 seamless isotropic shells and another of 5 lightly stiffened orthotropic shells, carried out at Caltech in the late 1960ties are used.

In earlier publications a hierarchical high-fidelity analysis procedure for predicting the critical buckling load of compression-loaded thin-walled shells is described. This hierarchical procedure includes three levels of fidelity for the analysis, Level-1 assumes that the shell buckling load can be predicted by the classical solution with simply supported boundary condition, and with a linear membrane prebuckling solution. Level-2 includes the effects of a nonlinear prebuckling solution and the effects of boundary conditions. Level-3 is a two-dimensional analysis, which includes the nonlinear interaction between nearly simultaneous buckling modes. As a final step in the hierarchical analysis approach, in the present paper the Level-3 buckling load prediction based on the experimentally measured initial imperfections are verified by the experimental buckling loads. Since the simulated buckling loads yield a lower bound to the experimental buckling loads of all shells tested, it is believed that the proposed hierarchical analysis procedure can be used in the design process to rapidly converge to an accurate prediction of the expected buckling load of a thin-shell design problem. The steps involved in the derivation of such a verified high-fidelity (higher) knockdown factor are the subject of this paper.