Variable Complexity Structural Optimization of Shells

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Final Report

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Introduction
Structural designers today face both opportunities and challenges in a vast array of available analysis and optimization programs. Some programs such as NASTRAN, are very general, permitting the designer to model any structure, to any degree of accuracy, but often at a higher computational cost. Additionally, such general procedures often do not allow easy implementation of all constraints of interest to the designer. Other programs, based on algebraic expressions used by designers one generation ago, have limited applicability for general structures with modern materials. However, when applicable, they provide easy understanding of design decisions trade-off. Finally, designers can also use specialized programs suitable for designing efficiently a subset of structural problems. For example, PASCO and PANDA2 are panel design codes, which calculate response and estimate failure much more efficiently than general-purpose codes, but are narrowly applicable in terms of geometry and loading.
Therefore, the problem of optimizing structures based on simultaneous use of several models and computer programs is a subject of considerable interest.

The problem of using several levels of models in optimization has been dubbed *variable complexity modeling*. Work under NASA grant NAG1-2110 has been concerned with the development of variable complexity modeling strategies with special emphasis on response surface techniques. In addition, several modeling issues for the design of shells of revolution were studied.

Response surface techniques:

An important reason for combining various models is that the inexpensive models used by programs like PANDA2 are not accurate enough. One example is the local buckling of a ring-stiffened cylinder in compression. PANDA2 uses an approximation to calculate the local buckling load factor. In PANDA2 it is assumed that the ring stiffener deforms under the hoop load in the prebuckling analysis. In the buckling analysis it is assumed the ring does not deform. In addition, the ring attachment is assumed to be along the circumferential line at the ring locations. Comparison of PANDA2 predictions with discretized models (using STAGS and BOSOR4) where the ring stiffeners are modeled as branched shells shows that the PANDA2 model is overly conservative (by up to about 100%). In order to correct this a correction response surface model was developed. Detailed STAGS analysis was used to obtain local buckling load factors. The ratio of the STAGS to PANDA2 prediction was fitted with a linear response surface function. The fitted response surface model when used with PANDA2 was found to predict local buckling load factors to within 10%. The use of correction response surface function was shown to provide an accurate and less expensive model for use with optimization (Ref. 1). The resulting interaction with Dr. David Bushnell, the developer of PANDA2, led to a discretized shell of revolution (BOSOR4) type model introduced in PANDA2 where the ring stiffeners are now treated as branched shell elements (Ref. 2).

Design trade off studies:

Design optimization of different circular metallic panels (ring and stringer stiffened, sandwich wall with ring frames, isogrid stiffened and orthogrid stiffened) to be used for the liquid hydrogen tank construction were performed using PANDA2. The preliminary designs were performed using a proof pressure load case (internal pressure of 35 psi) and an axial compression load case (1000 lb/in with 5 psi stabilizing pressure). The resulting optimum weights were compared. It was found the hoop stresses were the governing factor for most designs. Since PANDA2 only uses a single repeating element (of one ring with attached skin), the overall bending under pressure could not be calculated. A global model using either a shell of revolution type analysis model or finite element analysis model will be required to capture the overall bowing of the tank wall. However at the panel level, a significant portion of the resulting out of plane deflection was from hoop expansion. Introducing constraints on this deflection was shown to increase the weight significantly. The effect of different allowable deflections on optimum weight of the panels was investigated (Ref. 3). Also in the process of our work a bug was discovered in the implementation simple support boundary condition of PANDA2 model for stringer stiffened or unstiffened cylinders and was corrected subsequently (Ref. 4).

The design of rings frames for the liquid hydrogen tank design is an important issue. It was found the design produced using pure axial compression and pure internal pressure load cases resulted in designs that had very small ring frames. Effect of bending loads was investigated to see if they would stiffen the ring frames. The optimized design were analyzed using closed form formulas for buckling and ovalization under a bending moment. It was found the designs obtained using the present load cases (35 psi proof pressure and 1000 lb/in axial compression with 5 psi stabilizing pressure) were not critical for buckling under the bending loads and the ovalization was not significant.

Optimization of composite panels for the liquid hydrogen tank for cryogenic temperatures was performed. It was shown using constant thermal expansion properties for the entire temperature range resulted in very high stresses in the matrix direction of the plies. The maximum allowable ply strain of 0.6% to prevent micro-cracking was found to be violated due to the thermal mismatch in ply thermal expansions. Hence, designs were obtained using a 2% maximum strain in the matrix and 0.6% maximum strain in the fiber directions.

Finally, a survey paper about optimization of shells of revolution is in preparation (Ref. 4) and joint work with Dr. Todoroki from Japan, led to a procedure for optimum stacking sequence design using genetic algorithms (Ref. 5).

References

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