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New Design Approach for Axially Compressed Fiber Composite Cylindrical Shells using a Multistep Sensitivity Method

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To ensure the high efficiency in the development and design of next generation aerospace vehicles in the view of economic and safety requirements, a significant but at the same time secure weight reduction of today's structures is crucial. This can be achieved by using modern lightweight composite carbon fiber materials (CFRP) and by increasing the design related efficiency of structures. When it comes to the field of aerospace, cylindrical shells are one of the most commonly used components. Therefore, reducing the required wall thickness of cylindrical shells would offer a significant weight saving potential on the final vehicle.

Thin walled cylindrical shells under axial compression are prone to buckling. The load carrying capability of these structures can significantly depend on deviations from the ideal structure's surface, called geometric imperfections. These imperfections heavily depend on the manufacturing process and are often not known during the design phase. Due to their significant impact on a structure's failure load, they have to be accounted for by adequate design criteria.

Based on Koiter's[1] findings, it became common practice to apply eigenmodes or combinations of eigenmode shapes as imperfections to trigger buckling in numerical analyses during the design phase. In parallel to these approaches, Esslinger[2] and Hühne[3] used high speed camera systems to show that for isotropic as well as anisotropic cylindrical shells, global buckling is initiated by a localized loss of stability in form of a single dimple, not by a global eigenmode shape. Thus, Hühne derived the single perturbation load approach which is based on stimulating a single dimple to obtain a robust design load. Both approaches using eigenmode imperfections or single dimples however often lead to highly conservative design loads.

Another way to account for the uncertainty of the buckling load caused by geometric imperfections is to apply a probabilistic scheme to obtain a robust design load. Many authors like Arbocz[4], Elishakoff[5] and Kriegesmann[6] contributed to different probabilistic schemes which are based on applying randomly chosen imperfection shapes to obtain a probabilistic scatter of the shell's buckling load. By choosing a desired level of safety, a robust but not overly conservative design load can be obtained. While these design procedures entail the advantage of a known safety level of the robust design load, they are in most cases computationally costly as well as heavily dependent on an underlying database of preferably many manufactured and measured specimens.

In this abstract, a new design approach is proposed. This design approach combines the advantage of deterministic and probabilistic approaches by yielding a robust but not too conservative design load while being mostly independent of imperfection measurements of manufactured shells.

The very basis of the design criterion is to find a critical and at the same time realistic imperfection shape depending on the laminate lay-up of the shell. This is achieved by stepwise including more and more parts of a chosen imperfection pattern imposed in the finite element analysis to calculate the corresponding buckling load in each case. In this way, the parts of the imperfection pattern which are most critical for the buckling load can be identified. In a next step, these critical imperfection patterns are combined to a design pattern. By choosing an adequate amplitude for the obtained imperfection shape, a design shell can be composed. It will be shown that the buckling load of this design shell shows to be always lower than the experimental buckling load of a given set of specimens sharing the same dimensions and laminate lay-ups. Therefore, the proposed design approach may contribute to a solution of the heavily discussed problem of offering a robust design load while not being overly conservative.

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