# STUDIES OF IMPEFECTION SENSITIVE CONICAL COMPOSITE STRUCTURES

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## Introduction

The stability of shell structures has been an object of studies for more than a century. Thin walled cylindrical and conical structures are widely used in aerospace, offshore, marine, civil and other industries. Nowadays, with the growing application of composite materials a deep understanding of the influence of their properties and the laminate stacking sequence on the mechanical behaviour of shell structures is increasingly more important. As it is already known, one of the most significant sources of discrepancy between theoretical predictions and experimental results for the buckling load is the presence of geometric imperfections. Currently, imperfection sensitive shell structures are generally designed, at the preliminary design phase, according to the guideline NASA SP-8007 for cylinders and NASA SP-8019 for truncated cones using the conservative lower bound curve, which does not consider composite material characteristics. Hühne developed the Single Perturbation Load Approach (SPLA), a robust design method that stimulates a single buckle, which is assumed as a "worst-case" geometrical imperfection [1]. There have been carried out considerably more numerical, analytical and experimental studies on cylindrical shells than on conical shells. Currently typical composite launcher structures are investigated by 12 partners in the European project DESICOS [4]. The aim of this paper is to study the SPLA on a conical shell structure and compare it with the NASA design approach.

## Structural model

The conical shell structure to be investigated, denominated Cone SCALED-03-7a, is a scaled down version of the Ariane 5 Equipment Bay structure, shown in Figure 1.

The material properties (taken from the European Project COCOMAT [2]), the stacking sequence and the geometric characteristics are shown in Table 1.

Fig. 1 Ariane 5 Equipment Bay Structure [4]

Table 1 Geometry and material properties

| | |
|---|---|
| Top radius | 200 mm |
| Bottom radius | 400 mm |
| Semi-angle | 45° |
| Height | 200 mm |
| Stacking sequence | [+30/-30/-60/+60/0/+60/-60/-30/+30] |
| Material properties | $E_{11}$=142.5GPa, $E_{22}$ = 8.7GPa, $\nu_{12}$=0.28, $G_{12}$ =5.1GPa, $G_{13}$=5.1GPa, $G_{23}$ = 5.1GPa |

## Single perturbation load approach

In previous studies ([1], [3]), the SPLA was successfully applied to cylindrical structures. The SPLA suggests that one can simulate an initial geometric imperfection with an applied single perturbation (lateral) load that will cause a single buckle to occur along with the following axial compression. As one increases the value of the perturbation load, the buckling load gets smaller and then at some point it remains nearly constant. This value of the buckling load is called $N_1$ and in the SPLA it is the design load. The value of the perturbation load, after the buckling load gets nearly constant, is called $P_1$ or the minimum perturbation load. It is useful to know $P_1$ at the early design stage, so that the designers can directly apply it to the shell structure in order to calculate the design load.

For the Finite Element Analysis (FEA) ABAQUS Standard 6.11 (Implicit) was employed. Newton-Raphson with artificial damping stabilization was used as the non-linear solver.

The SPLA was applied on the structure with perfect geometry and on the structure with real geometric imperfections that include mid-surface imperfection (MSI) and thickness imperfection (TI). The real measured imperfections were taken from cylindrical structure Z15 that was manufactured and tested by DLR within the ESA study and applied to Cone SCALED-03-7a. More details about the geometry and measured imperfections of Z15 could be found in [3].

Figure 2 shows that the deviation of the design loads between SPLA applied on the perfect geometry and the geometry with geometric imperfection is very small.

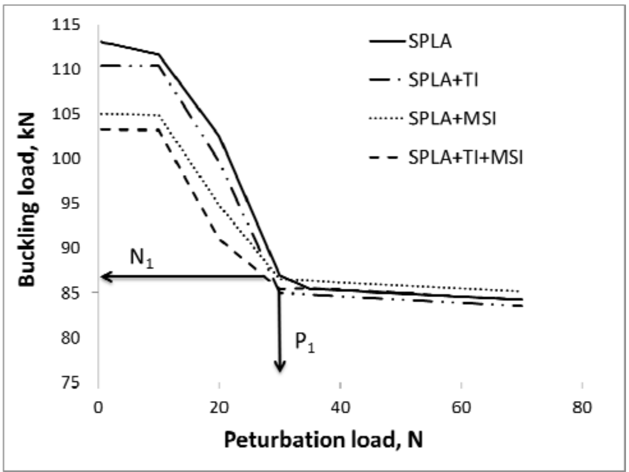


Fig. 2 SPLA compared with perfect and imperfect geometry

Table 2 shows the values of the knock down factors (KDF) obtained with the new proposed methods, showing that they are much less conservative than the NASA KDF. However, it must be mentioned that deviations from constant load distribution, which play also a significant role, are investigated in future studies.

Table 2 KDF of Cone SCALED-03-7a

| | |
|---|---|
| SPLA | 0.68 |
| SPLA+TI | 0.676 |
| SPLA+MSI | 0.688 |
| SPLA+MSI+TI | 0.68 |
| NASA | 0.355 |

## Summary

From the implemented study it could be concluded that the KDF values obtained using SPLA is almost twice as big as the NASA KDF.

SPLA applied to the structure with thickness and/or mid-surface imperfection from Z15 gives 1.8 % deviation between minimum and maximum value of KDF. Therefore, the SPLA applied to the perfect structure could be used in the early stage design to represent with reasonable accuracy the behaviour of a structure with geometric imperfections.

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