BUCKLING OF IMPERFECTION SENSITIVE SHELL STRUCTURES: EXPERIMENTAL CHARACTERIZATION OF THE KNOCK-DOWN FACTOR USING THE MULTIPLE PERTURBATION LOAD APPROACH

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Abstract

This work presents an experimental study to compare the effects on the buckling load of imperfection sensitive cylindrical shell structures using the "Multiple Perturbation Load Approach" (MPLA) and the "Single Perturbation Load Approach" (SPLA). A benchmark case is developed using a composite cylindrical shell with a radius over thickness ratio of 400. An experimental test setup is set to provide reliable results. The knock-down factor on the buckling load using one, two and three perturbation loads distributed along the surface of the cylinder is characterized, presented and discussed in this paper. The experimental result shows that lowest knock-down factor are achieved when the number of perturbation loads is increased.

1 Introduction

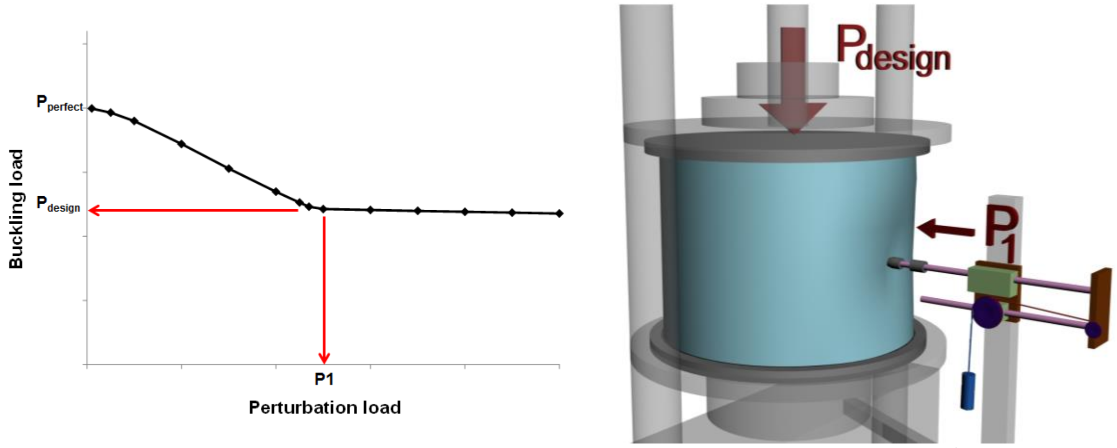
Imperfection sensitive structures such as unstiffened or skin-dominant shell structures are commonly used for aeronautic and aerospace applications. Cylindrical shells are dominating satellite launcher structures and a reliable methodology to calculate their behavior in the early stages of design is fundamental to achieve optimum results.

Launcher design requires fast and precise prediction of structural weight as well its weight distribution already in the early design phase, because in that phase different concepts of the whole launcher system have to be evaluated in order to identify the optimal one. The prediction has to be precise, because less reliable ones might lead to basic changes, later in the detailed design phase, which might also influence the design of the whole system. Such changes in later design phases are extremely costly in terms of time and money; they definitely have to be avoided.

The dimensioning criterion with the design of launcher structures is *buckling not before ultimate load*, thus they do not have an exploitable post-buckling area. The most critical aspect for numerical buckling prediction is the structure's sensitivity to geometric and loading imperfections. Currently, imperfection sensitive shell structures prone to buckling are designed according to the NASA SP-8007 guideline[1], from 1968, using its conservative lower bound curve. In this guideline the structural behavior of composite materials is not appropriately considered, since the imperfection sensitivity and the buckling load of shells made of such materials depend on the lay-up design. There is no specific design guideline for imperfection sensitive composite structures prone to buckling. Currently the European project DESICOS[2] (New Robust **DES**ign Guideline for **I**mperfection Sensitive **CO**mposite Launcher **S**tructures), which started in 2012, is trying to implement a new methodology to predict the knock-down factor of unstiffened cylinders using the so called "Single Perturbation Load Approach". The concept of single perturbation load approach (SPLA) was developed by Hühne et al[3], and uses the influence of radially applied load on the buckling load as an indication of imperfection sensitivity. With increasing radial load the buckling load is reduced, however, only until a certain radial load value, called P1. After P1 the buckling load remains nearly constant (see Figure 1-a). The SPLA define the cylinder buckling load obtained at P1 as the design buckling load which allow estimating the knock-down factor of the structure. However one opened question remains about this approach: is the SPLA the worst case imperfection for instability analysis? Numerical results presented by Arbelo et al[4] and Wang et al[5] show that the use of several perturbation loads applied along the surface of the cylinder can induce a worst geometrical imperfection case.

2 Methodology

Preliminary results presented by Degenhardt et al[5] show that the SPLA can be used as a tool to calculate less conservative knock-down factors. In this context, this paper presents a detailed experimental and numerical investigation in order to define a reliable methodology to estimate the buckling load of composite cylindrical shells prone to buckling. Experimental tests are carried out using a composite cylindrical shell with a radius over thickness ratio of 400. The single perturbation load approach (see Figure 1-b) is used to determine the knock-down factor.



a) Knock-down curve obtained using SPLA b) Experimental setup for SPLA

Figure 1 - Single perturbation load approach concept.

The multiple perturbation load approach is applied using two and three perturbation load applied along the circumference on the specimen at the mean height. For the porpoises of this paper, all the perturbation loads are applied with the same magnitude.

3 Preliminary results

Preliminary results of the SPLA and MPLA are presented in figure 2. The results clearly shown that the buckling load decreases when the number of perturbation load increases. On the other hand, the buckling load remain nearly constant after the P1 threshold for all cases.

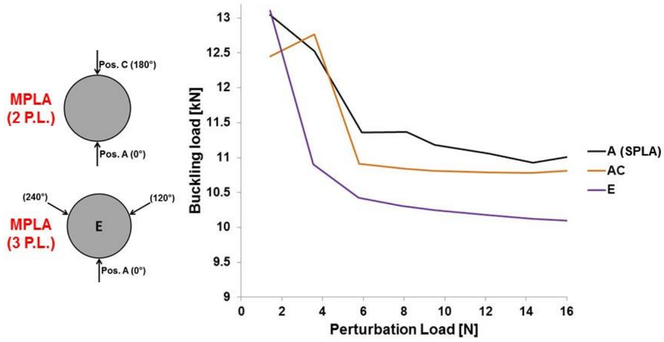


Figure 2 – Experimental buckling load applying SPLA and MPLA.

References

[1] V. I. Weingarten, P. Seide and J. P. Peterson, "NASA SP-8007 - buckling of thin-walled circular cylinders", NASA Space Vehicle Design Criteria - Structures, 1965 (revised 1968).

[2] DESICOS, New Robust **DES**ign Guideline for **I**mperfection Sensitive **CO**mposite Launcher **S**tructures. www.DESICOS.eu. Access on 30/07/2013.

[3] C. Hühne, R. Rolfes, E. Breitbach, and J. Teßmer, "Robust design of composite cylindrical shells under axial compression — Simulation and validation," Thin-Walled Structures, vol. 46, no. 7-9, Jul. 2008, pp. 947-962.

[4] Arbelo, M., Degenhardt, R., Castro, S. and Zimmermann, R., “Numerical Characterization of imperfection sensitive composite structures”, Composite Structures, vol. 108, pp. 295-303, 2014.

[5] Wang, B., Hao, P., Li, G., Tian, K., Wang, X., Zhang, X. and Tang, X., “Improved knockdown factors for cylindrical shells using worst multi-perturbation load approach”, Shell Structures: Theory and Applications, vol. 3, 2014, Taylor & Francis Group, London.

[5] R. Degenhardt, A. Kling, A. Bethge, J. Orf, L. Kärger, K. Rohwer, R. Zimmermann, A. Calvi, “Investigations of imperfection sensitivity of unstiffened CFRP cylindrical shells”, Composite Structures, Vol. 92 (8), (2010), pp. 1939–1946.