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On the use of refined 1D structural models for reinforced cylinders with ends sealed

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Current design of aircraft fuselage, missiles, and launch vehicles relies extensively on the use of reinforced thin-walled cylinders as the primary structure. The use of stiffening members (stringers, frames and bulkheads) improves the strength/weight ratio and makes the structure cost-effective. Many simplified methods are known to analyze these structures [1]. Since many years, the Finite Element Method (FEM) has been largely employed to accurately describe the static and dynamic behavior of reinforced cylindrical structures. A combination of 1D (beam) and 2D (shell) finite elements is commonly used to build structural models of lifting surfaces and fuselage as well as the full vehicle. Shells and stiffeners are mostly considered as separate elements and a proper simulation of the panels-stiffeners linkage is often necessary. To avoid this non-physical approach, 3D (solid) finite elements can be used. However, the use of solid elements can lead to models whose computational costs are very high.

In the recent past, the authors used the Carrera Unified Formulation (CUF) to provide refined one-dimensional models able to match three-dimensional strain-stress states of complex structures [2]. According to the CUF, the class of the 1D refined model depends on the choice of the polynomials used to interpolate the displacement field over the cross-section of the structure. CUF models are hierarchical since the order of the model is a free parameter of the formulation. This fundamental ability is obtained by exploiting the fundamental nucleus of the problem matrices, which is a 3×3 array whose formulation is independent from the order and the class of the model. Therefore, the fundamental nucleus allows the hierarchical assembly of the stiffness, mass and loading arrays with no need of *ad hoc* formulations. Taylor-like polynomials were recently used for the analysis of reinforced thin-walled structures in [3, 4]. Furthermore, the use of Lagrangian expansions has led to the so-called *component-wise* models [5], which have shown excellent performances in the analysis of complex wings [6, 7] and composite structures [8, 9]. The component-wise approach is able to model each structural component (i.e. skins, stringers and frames as well as their composite layers) through a unique 1D formulation.

$Model$	1^{st} $bending$	1^{st} $torsional$	1^{st} $Shell-like$
Skin and ribs	27.159	66.050	77.512
Skin, ribs and stringers	31.304	75.359	109.567

Table 1: Effect of the stringers on the natural frequencies (Hz) of the thin-walled structure

This work is focused on the analysis of both-end-closed cylinders. Figure 1 shows an example of the structures considered in this paper. Static and free vibration analyses are carried out by means of 1D CUF finite elements. Table 1 shows the first bending, torsional and shell-like natural frequencies of a reinforced cylinder with ends open. The effect of the stringers is evaluated. The length of the cylinder, L, is equal to 15.2 m and the radius, R, is equal to 2 m. The skin is 1 cm thick. Two frames are placed at $L/3$ and $2L/3$, and eight stringers with a rectangular cross-section (2×5 cm) are included. The structure is considered as being made of aluminium and it is clamped at both ends. Figure 2 shows the first shell-like mode of the cylinder without stringers. The results proposed so far were evaluated with a cubic-order Taylor-expansion-based CUF model. Further results will show the effects due to the sealed ends on reinforced cylinders and the effectiveness of the CUF models to deal with this class of structures. Both Taylor and Lagrange expansion will be used and the results will be compared to solutions provided by a commercial code.

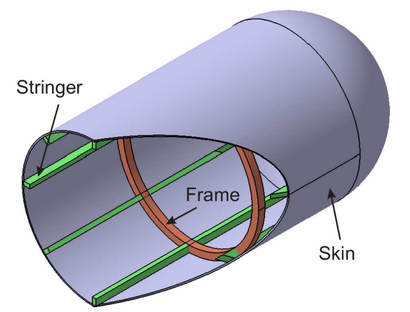

Figure 1: Section of the reinforced cylinder with ends closed

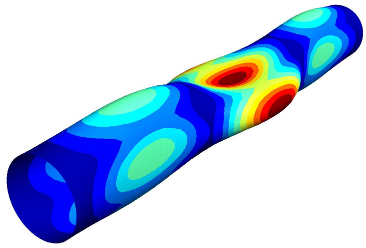

Figure 2: First shell-like mode of the cylinder with no stringers and open ends

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