Airbag Application for Structural Racing Car Component

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1 Introduction

In motorsports, there is a deep research in order to make cars more and more competitive, throughout an accurate study on aerodynamics, powerful and advanced engines, structural component design, materials and, of course, on racing strategy. That's even more true when racing conditions are extremely severe, like in endurance races, such as 24 Hours of Le Mans, where changes in drivers and in racing conditions make the race more exciting. To improve performances, weight is one of the most strict design conditions: a lighter car is faster, more efficient and more competitive so that performances can be improved, with more controllability in acceleration and braking phases, reducing emissions and consumptions.

Evolution in studies upon materials and structural applications has got a key role to reduce weight and the use of innovative structures is an open field for experimental tests.

Many research works were performed upon materials used in motorsports, especially composite fiber reinforced ones. In [1], Adam presented a general overview on composite mechanical characteristics, production methods, and design principles for racing cars composite applications. In [2], a similar study was presented by Cole and Sherman referring to different light-metals and their use for automotive structural components.

Innovative structural applications on car components were also studied in order to improve strength and reduce, at the same time, weight. In the fifties experimental tests carried out at Langley Aeronautical Laboratory of National Advisory Committee for Aeronautics (NACA) revealed that a small amount of pressure inside cylindrical components could increase strength. The first rigorous study upon this topic was performed by Lo, Crate and Schwartz [3]. From the comparison of experimental tests and analytical studies, they demonstrated that internal pressure can positively influence the resistance of cylindrical structures under torsional and compressive loads. Later some studies were carried out on specific cases, like silos and pipes, and Mathon and Limam [4] showed that the effects of internal pressure on closed cylinders under pure bending are dependent on the geometry and, particularly, on the ratio radius/thickness (R/t) and length/radius (L/R). Other studies [5] presented the effects on composite structures with different loads and with or without internal pressure.

In this work, the effects of internal pressure on closed cylinders subjected to different loads were numerically investigated. Internal pressure was created throughout the use of LS-DYNA® 971 airbag models and increasing levels of pressure were tested to evaluate the effect on the analyzed structure. Several FE models of different cylindrical geometries and loads were created and a comparison between metals and composite materials was numerically performed. A focused research on an innovative shape, that can take advantages from this kind of application, was also performed and its results compared with previous model ones.

2 Internal pressure model

In order to numerically model the preload, thanks to the internal pressure inside the cylinder, different approaches can be considered.

Using a solid model of the air, the pressure on the wall of the cylinder is a sum of all the contributions of the solid elements pushing on shell elements of the structure. Although this application is interesting, it shows some difficulty due to initial inflation and to the explosion of computational cost.

Another interesting approach is the use of a complete model of thermodynamic behavior of air inside an airbag. It is useful not only for crash applications, but it can be used also to simulate inflation of wheels, to model landing systems of spacecraft or as complementary elements for road restraint systems. In [6], Gupta and Kelkan presented a new airbag technology, fluid-structure interaction effect based, for energy absorbing barriers designed and tested for high velocity impacts. Tutt, Johnson and Lyle [7] in their research work showed the development of the conceptual design, fabrication of prototype assemblies and component level testing of the airbag landing system for the Orion Crew Module.

In LS-DYNA® [8] many different airbag models are available. The purpose of the present research is to find a proper solution to inflate the closed cylinder at a stable level of desired internal pressure. For this reason, using the same cylindrical geometry, different airbag models were analyzed and their results compared, in terms of stability of internal pressure, wall stresses and volume inflation. A small pressure was applied to all models with no other external loads.

The first model checked was the *AIRBAG_SIMPLE_PRESSURE_VOLUME . From results, it was shown that the average values of local stress were comparable to those obtained from analytical formulas, but the trend appears to be very unstable (Fig. 1).

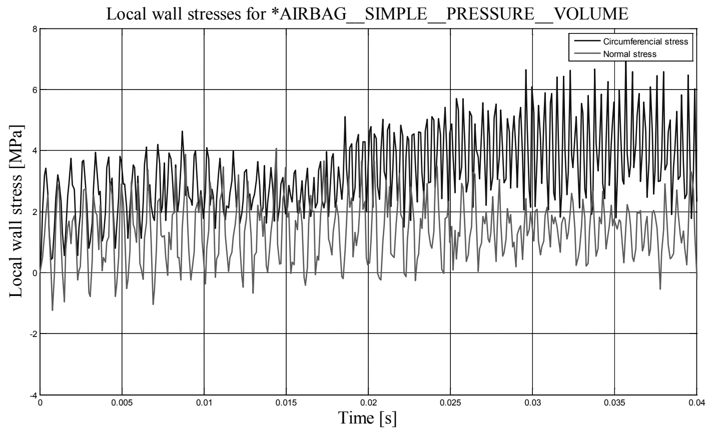


*Fig. 1: Local stress in *AIRBAG_SIMPLE_PRESSURE_VOLUME*

A similar oscillatory behavior appeared also using other numerical cards such as *AIRBAG_LOAD_CURVE and *AIRBAG_ADIABATIC_GAS_MODEL.

In the visualization of the simulation a wrong behavior could be noted (Fig. 2): the structure seemed to be alternatively inflated and deflated, causing in an unreal result.

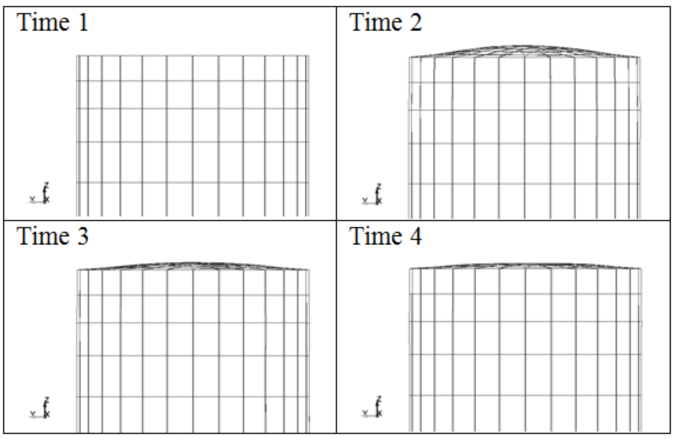


Fig. 2: Internal pressure: cylinder inflated and deflated

To solve this problem, some numerical devices were analyzed and to contrast this bad effect caused by the inflation of airbag a damping was applied to the structure in order to avoid the wrong oscillatory effect. The value for the damping factor was calculated throughout an eigenvalue analysis of the structure and applied only towards the z axis where more oscillating movements were seen (Fig. 2). Comparing the model using damping (Fig. 3) and the previous one (Fig. 1) the problem of the oscillations due to instability seemed to be solved. The airbag model, finally used, was the simpler one: *AIRBAG_LOAD_CURVE, in which only the pressure loading curve is needed.

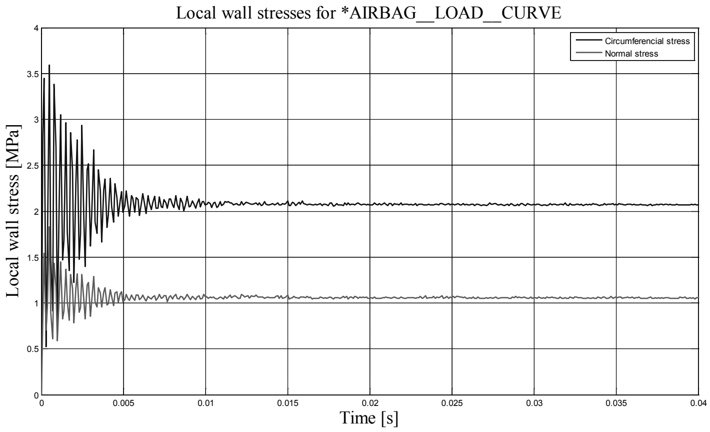


*Fig. 3: Local stress in *AIRBAG_LOAD_CURVE, with damping*

3 Preliminary metal cylinder FE model

The purpose of this research work was to evaluate the effects of the use of pressure into cylinders subjected also to external loads. For this reason, numerical models of simple cylinders were created.
For initial analysis metal material (Aluminum) was taken into account, as a very used and common structural material for racing cars. These structures were analyzed with different levels on internal pressure and with torsional and compressive external loads. Some of the geometrical parameters were modified in order to fully investigate the effects of the preload. All the analyses were carried out with the explicit code LS-DYNA® 971.

3.1 Numerical model

Cylinders were 1000 mm length, 0.7 mm thick and with a diameter of 30 mm. A FE model of the cylinder was accomplished with HyperMesh® using 0.7 mm thin shell element size (Fig. 4).

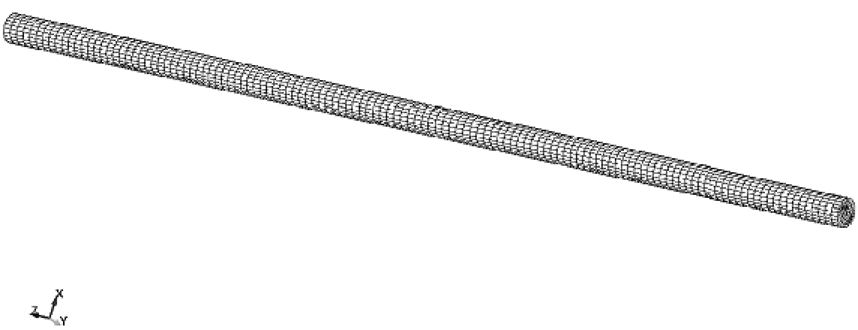


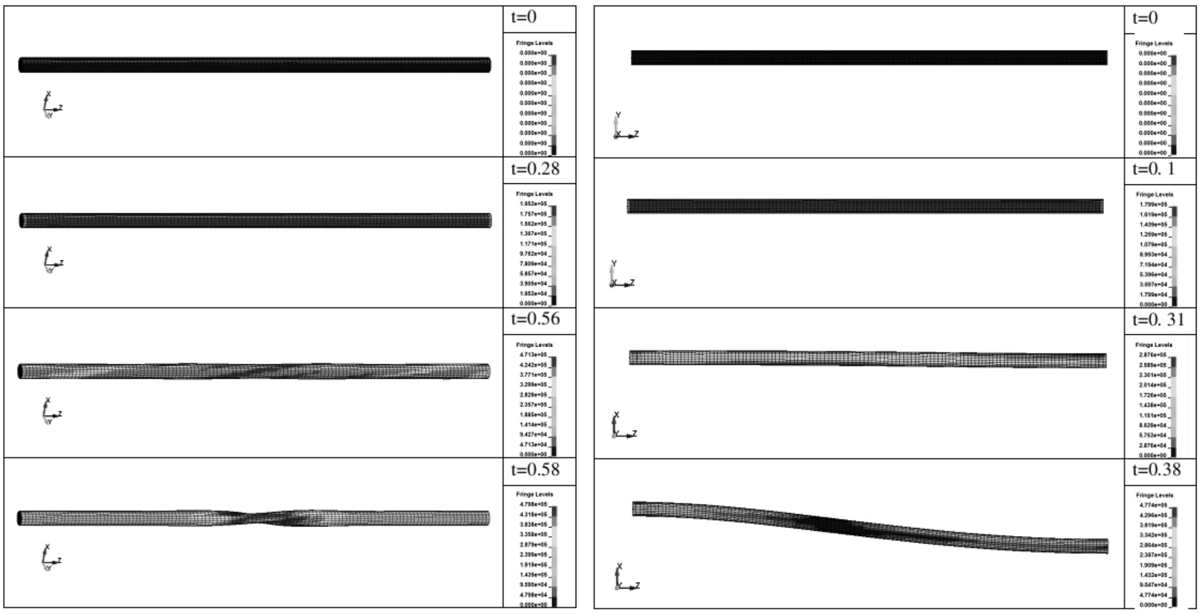
Fig. 4: Cylinder FE model

The element formulation used was the fully integrated one, type 16, which is based on the Hugens-Liu formulation. Its characteristics of accuracy, reliability and stability make it one of the most powerful and used shell element formulation.
Aluminum 7075 was taken into account and used in the numerical models. Parameters needed for the definition of the material card *MAT_PIECEWIESE_LINEAR_PLASTICITY permitted to fully describe the behavior of an elasto-plastic material.

Regarding constraints, the cylinder was bounded with fixed nodes at one end.
Compressive and torsional static loads were applied to the free edge of the cylinder as imposed translations throughout the card *BOUNDARY_PRESCRIBED_MOTION_NODES. Compression was applied as a translation towards z axis, in opposite sense of the reference axis. Regarding the torsion it was applied as a rotation around z-axis; translations towards x and y axis were permitted but rotations were bounded.
In the early tests, it was noticed that all the nodes involved in the applied translations, showed no displacement, despite the action of the internal pressure. The reason lied in the displacement imposed to z, which limited the possibility of cylinder to inflate. To overcome this problem, a delay, equal to the time required to the model of airbag to stabilize, was applied to the external load (Fig. 3).

3.1.1 Results

To fully investigate the phenomenon, numerical tests were performed using three different levels of internal pressure (0 bar,1 bar and 2 bar) and external loads, both compressive and torsional.
Referring to torsional tests, the presence of internal pressure influenced the stability limit and therefore increased the capability of the structure to resist to that type of loads (Fig. 5-A). Waves characteristics of the torsional instability could be found in the simulation's frames.
Considering the compression load, the effect of internal pressure was negligible and it didn't affect the stability limit. The reasons for this behavior were the presence of global instability and the small cross section of the structure (Fig. 5-B).



(A) (B)

Fig. 5: Deformation of cylinders: A – torsional load; B – compression load

4 Modified metal cylinder FE model

From literature [3], [4] it was shown that in short cylinders a local instability was established and the effect of internal pressure was so considerable. With compressive loads, the presence of internal pressure increased the strength of the structure. Considering instead a torsional load, the ultimate load before the instability could be increased of about 50%.
For this reasons other cylindrical models with different diameter (60,120 and 220 mm) were created in order to better investigate this phenomenon. The load conditions and internal pressure levels were the same previously presented.

4.1 Numerical model

Cylinders (Fig. 6) presented the same element dimension, thickness and element formulation used for preliminary models, previously showed.

Also material card, constraining, load conditions and internal pressure levels were the same of previous models. Since they are related to the geometry, damping values were recalculated for each new model by an eigenvalue analysis.

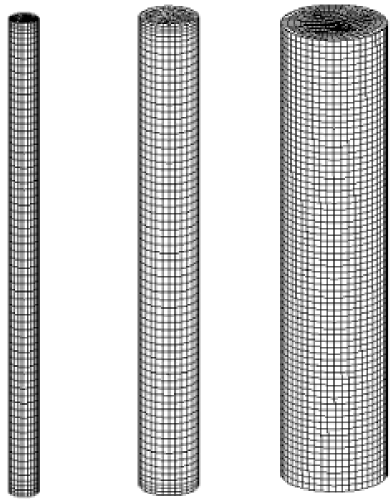


Fig. 6: Modified metal cylinder FE models

4.1.1 Results

For a cylinder with a diameter of 60 mm and an internal pressure of 2 bar, subjected to a torsional load, the gain in terms of increased strength was more than 50%. For the same structure if a compressive load was applied a global instability was shown and the effect of internal pressure was negligible.
If a compressive load was applied to a cylinder with a larger diameter, the stability limit increased as the diameter increased (Fig. 7), because of the presence of local instabilities and for its peculiar geometrical characteristics.

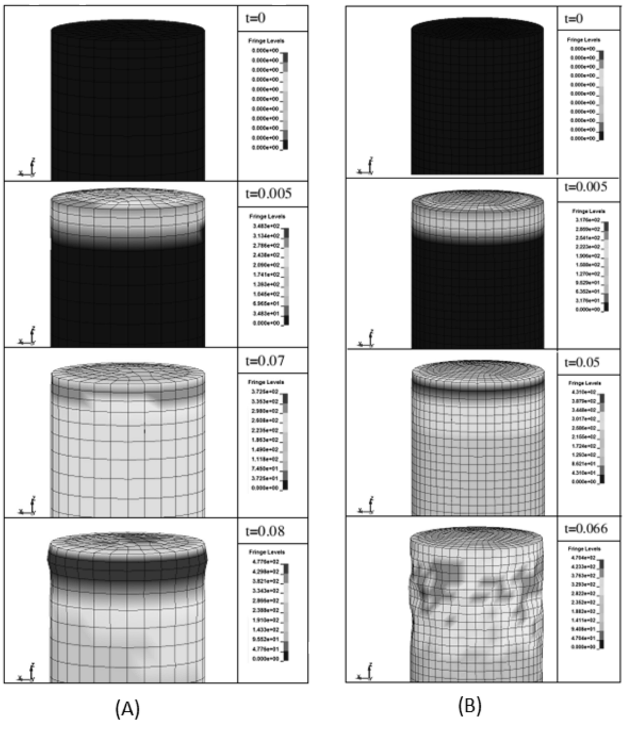


Fig. 7: Modified metal cylinder: A - compression load (diameter 120 mm); B – compression load (diameter 220 mm)

5 Composite cylinder FE model

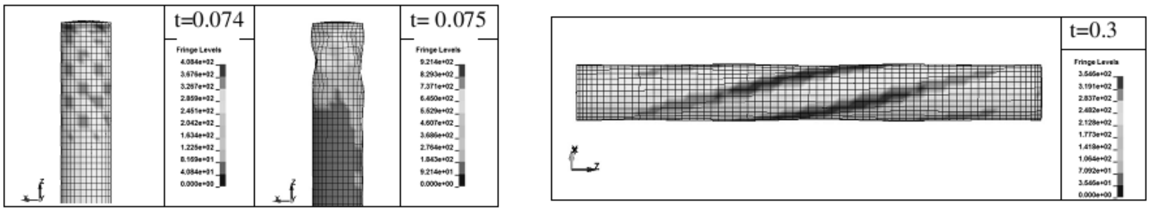
In order to evaluate the effect of the use of different materials on cylinders subjected to the same load conditions and internal pressure levels, carbon fibre reinforced composite (CFRC) structures were taken into account and analyzed.
Parameters needed to assess material card were experimentally and numerically performed by Prato et al., in their research work [9].

5.1 Numerical model

Composite cylinder numerical models were carried out using the same element dimensions and formulations adopted for the other samples. *MAT_LAMINATED_COMPOSITE_FABRIC and *PART_COMPOSITE were used to define the composite characteristics. The stack sequence was [45/0/90/-45] where each ply was 0.2 mm thick in order to have a full thicknessm similar to the metal model one.

5.1.1 Results

Referring to the cylinders with a diameter of 120 mm, the birth of local instabilities for the structure under compressive load conditions (Fig. 8-A) and the effect of the internal pressure were leading to the increase of the strength limit, even more evident than in the metal model.
Similar consideration can be done with a torsional load (Fig. 8-B).



(A) (B)

Fig. 8: Cylinder: A - compression load (120 mm diam.); B – torsional load (220 mm diam.)

6 Optimized cylinder FE model

Looking at all previous results a new cylindrical model was created. Its shape presented a larger diameter at the end of the structure in order to take advantage of the good effects of the internal pressure.
Its results were then compared to other models.

6.1 Numerical model

The FE model of this new structure (Fig. 9) had the same element dimension and formulation, as previously discussed and the same were also constraints and loading conditions.
For the material both aluminium and CFRC were used.

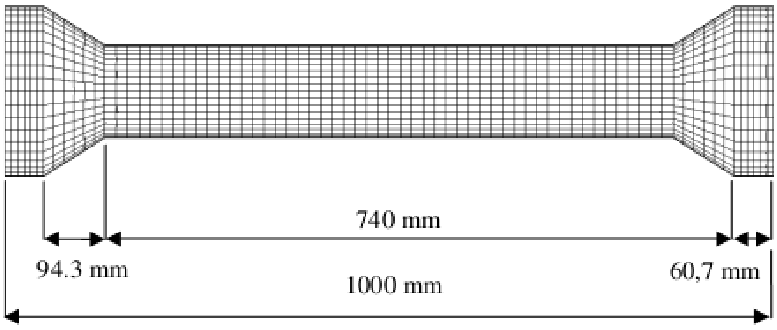
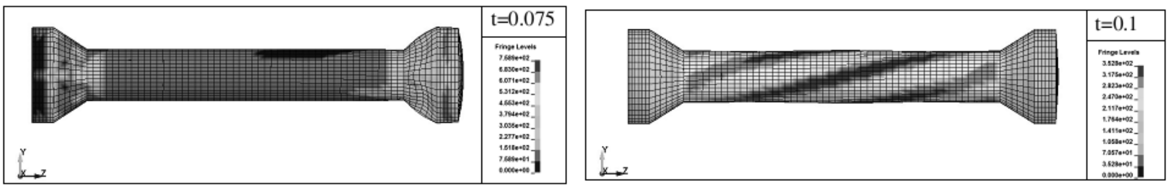


Fig. 9: Optimized cylinder model

6.1.1 Results

For the compressed modified model (Fig. 10-A), the gain in stability was very high, for both the aluminium and the composite one. Those results demonstrated that the hypothesis of changes in the geometry leads to a significant good effect. It was also observed that the failure of the two models was localized in two different areas, near the constrained elements for the aluminium model and closed to the loading end for the composite one.
Even for the torqued modified model (FIG. 10-B) the margin of stability increased considerably. From the simulations the instability behaviour reflected the way other cylindrical models behave.



(A) (B)

7 Conclusions and future works

From a literature review of structural most important manuals and articles, it was evident the remarkable interest in structures with internal pressure, not only for common applications, like silos or pipes, but also as a structural device to increase some mechanical characteristics of components.
Indeed, internal pressure in a closed cylinder can increase the strength to compressive and torsional loads, resulting of a particular interest for structure where changes in loads can also influence weight, like for racing car components.
To better understand the phenomenon and make a comprehensive study, numerical tests were carried out on cylindrical samples, similar or taking inspiration from components of the chassis of 24h Le Mans racing cars.
As showed from results of numerical simulations, there was a real benefit due to internal pressure in a cylindrical structure. From this application the strength under torsional loads could grow till 100% and regarding compressive loads, the margin of compressive strength could grow to a maximum of 30%[1].
As an important remark, it was necessary to underline the influence on results of geometrical characteristics of the structure. In fact if the diameter of the circular section was comparable to the total length of the cylinder, the influence and the benefit of adding internal pressure were more and more important.
The reason can be found in the fact that wall stresses caused by the action of the internal pressure must be of the same order of magnitude of the stresses caused by the action of torsional or compressive external loads, so that internal pressure can effectively contrast them. If the cylinder was very thin, stresses caused by internal pressure were very small and negligible.
Starting from these important results it could be possible to design a structure that could be used in a more efficient way and designed with a different shape in order to contrast the effects of external loads.

[1] The percentages are referred to optimized models

As a consequence, the benefits of the application of internal pressure can be seriously considered for future applications and can be used also in different structures of the racing cars chassis. The gain in the strength can be used to reduce thickness of components and so to decrease the total weight of the car, with a global and remarkable benefit, from an economical and performances point of view.

8 References

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