Shape optimization applied to stratospheric balloons

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Abstract

The French Space Agency (CNES) has been developing and operating stratospheric balloons since the early 1960's for the national and international scientific community. The current range of performance is defined by 3 months flights at 20 km with 20 kg gondolas with Superpressure Balloons and about 35 hours flights at up to 40 km with over 1 metric ton gondolas with Zero Pressure Balloon. Widening this range of stratospheric flights with heavier instruments for a longer duration motivates new developments on materials and shapes of balloon envelopes.

Through partnerships with several research laboratories and companies, advanced studies have been performed on different steps towards optimization of envelopes design:

- Characterizing thermo-mechanical features of envelope materials,
- Developing constitutive equations and identifying materials parameters,
- Adapting and enhancing a finite element software to balloon applications,
- Working on an experimental methodology to validate the whole strategy, through measurements on a balloon or a mockup.

These four steps have been applied to Zero Pressure Balloons. A Hyper-Hysteresis model is used to catch the nonlinear mechanical behavior of LLDPE thin films [1]. This model is implemented into the IRDL Laboratory finite element software Herezh++ [2]. Considering Dynamic Relaxation Method [3], plane stress and wrinkles influence and a specific strategy for applying loading conditions allows to simulate envelopes deployment and pressurization. Thus, the stress distribution is obtained and analyzed. Working on the shape of the gores, an optimization in terms of stress levels, mass, ascent rate and wind exposure is conducted. While the historical shape is based on avoiding any circumferential stress, some shapes of gores present a more balanced stress distribution between meridional and circumferential directions and less mechanical loading. Designing envelopes with circumferential stresses should also have a positive influence on preventing formation of clefts during balloon inflation.

Finally, ground experiments on an instrumented balloon are carried out to validate results of simulation. Notably, photogrammetry is evaluated as a mean to compare the theoretical and actual shapes.

References

[1] M. Zrida, H. Laurent, G. Rio, S. Pimbert, V. Grolleau, N. Masmoudi, and C. Bradai, "Experimental and numerical study of polypropylene behavior using an hyper-visco-hysteresis constitutive law", *Computational Materials Science*, vol. 45, pp. 516–527, 2009.

[2] G. Rio, Herezh++ : FEM software for large transformations in solids, Institut de Recherche Dupuy de Lôme (IRDL Lorient), dépôt APP (Agence pour la Protection des Programmes).

[3] J. Rodriguez, G. Rio, J. M. Cadou, and J. Troufflard, "Numerical study of dynamic relaxation with kinetic damping applied to inflatable fabric structures with extensions for 3d solid element and non-linear behavior", *Thin-Walled Structures*, vol. 49, pp. 1468-1474, 2011.