Buckling and Post-Buckling of Pumpkin Balloons

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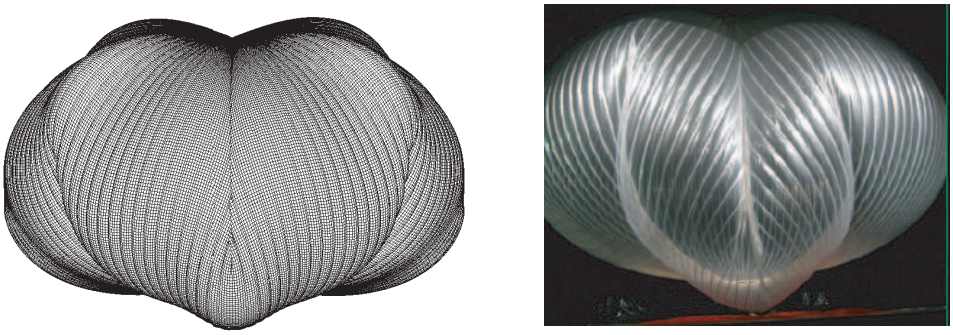
Balloon technology continues to evolve in a number of diverse and exciting areas. One particular type of application, at the edge of the earth's atmosphere, is NASA Ultra Long Duration Ballooning (ULDB) Program. This program aims to develop a low cost, long duration balloon system to support global scientific observations above most of the earth's atmosphere for durations approaching 100 days.

A new design paradigm has been adopted for these balloons. The basic concept is to form a high curvature structure by constraining very thin material with stiff and strong meridional tendons. A problem of this design, though, is that these balloons are prone to becoming unstable. This paper presents a computational study of the stability and post-buckling behaviour of a 10 m diameter, 145 lobe pumpkin balloon, with lobes of approximately uniform radius. The ABAQUS commercial finite-element package is used. Membrane and truss elements are used to model the balloon skin and tendons.

Our simulation technique can be summarized as follows. First, a geometrically non-linear analysis is carried out to inflate the balloon to a pressure high enough to make the balloon fully wrinkle free. This is followed by an eigen-value buckling analysis to predict the critical pressures corresponding to different buckling modes. Then, a new model is set up with an initial imperfection mode based on the critical eigenmode. Finally, a geometrically non-linear post-buckling analysis is carried out to simulate the response of the balloon beyond the critical pressure. To achieve convergence, we use the automatic pseudo-dynamic stabilisation option available in ABAQUS, but gradually decrease the numerical damping factor to the lowest possible value.

It has been found that the balloon has several global buckling modes and the predicted critical pressure is very close to experimental results. From the post-buckling simulation, the final distorted shape closely resembles the clefted shape of a ULDB balloon shown below.



(a) (b)

Figure 1: (a) Final distorted shape from ABAQUS simulation. (b) Buckled shape from an experiment.

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