ISTS 2000-k-16

DESIGN AND TEST RESULTS FROM THE ULTRA LONG DURATION BALLOON PROGRAM[1]

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Abstract

For the last four years, Raven Industries has been working with NASA and New Mexico State University's Physical Science Laboratory (PSL) to develop a new type of balloon design. The goal of the Ultra Long Duration Balloon (ULDB) project is to carry 1600 kg to 35 km for up to three months. This capability will allow long duration stratospheric balloon flights that will rival the capabilities of orbital missions. The development of the ULDB has followed a logical stepped approach toward the production and flight of prototype balloons in the Fall of 1999 and the Spring of 2000. The design efforts have been accompanied by parallel efforts in the development of advanced materials for use in the ULDB envelope. Design efforts in the ULDB have involved balloon performance analysis, structural finite element analysis, detailed design of balloon subsystems, and testing of model balloons. The results of the test flight program and plans for future flights will be presented.

1.The Significance of the Ultra Long Duration Balloon

Long duration flight capability has been identified as a top priority need for a large number of scientific balloon users since scientific ballooning began. Cosmic ray, cosmic microwave background observation, and a host of other applications would benefit tremendously if their flights could be extended from the current capability of one or two days to several months. This gap is currently being bridged by NASA's Long Duration Balloon (LDB) project which flies balloons in Arctic and Antarctic regions during their respective summers. These flights have been very successful and have yielded durations approaching one month. The logistical problems associated with launching balloons in Antarctica are obvious. The political problems associated with launching balloons from northern Alaska or Canada for circumnavigation are also obvious. It is highly desirable to conduct flight operations from established launch facilities and still have flight durations that exceed one month.

In order to accomplish the goal of long duration mid-latitude flight, NASA established the Ultra Long Duration Balloon (ULDB) project in 1997. The goal of this project is to carry a 1600 kg payload to 35 km for up to 100 days. This capability will rival that of scientific flights on satellites with the added benefit of returning the payload to the scientist after the flight is over.

A superpressure balloon is required to allow stable altitudes in the diurnal cycles at mid-latitudes. Prior to the start of the ULDB project, superpressure balloons were limited to volumes in

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the 20,000 cubic meter range. The balloon required for this performance goal will be on the order of 600,000 cubic meters. The development of new design techniques, materials, and fabrication techniques is required for success.

2.Balloon Design Evolution

The ULDB project is structured with Raven Industries responsible for balloon fabrication and design of detailed subsystems. Some structural analysis and refined shape calculations are also being performed by Raven. NASA and the Physical Science Laboratory of New Mexico State University are responsible for overall project management and for selection of balloon shape and overall design. When the ULDB project was in the proposal stages in the Summer of 1997, a sphere design with a composite film/fabric materia was envisioned. When Raven was awarded the contract for the ULDB fabrication, NASA instructed Raven to approach the fabrication and detailed design of the ULDB with an elastica or "pumpkin" shape as described in [1] and [2]. This NASA directive began the design evolution which is shown in Figure 1.

The first stage in design resulted in the development of a pumpkin balloon with composite fabric/film composite material as described in [3] and [4], and longitudinal tendons along the seams to hold the pressure forces. The test flight in October of 1999 used this design. Even as the film/fabric balloon was being fabricated and readied for flight, the design of an advanced film pumpkin balloon was underway. Finite element analysis had shown that, with longitudinal tendons reacting most of the pressure loads, a lighter material with lower modulus could be used in place of the fabric/film

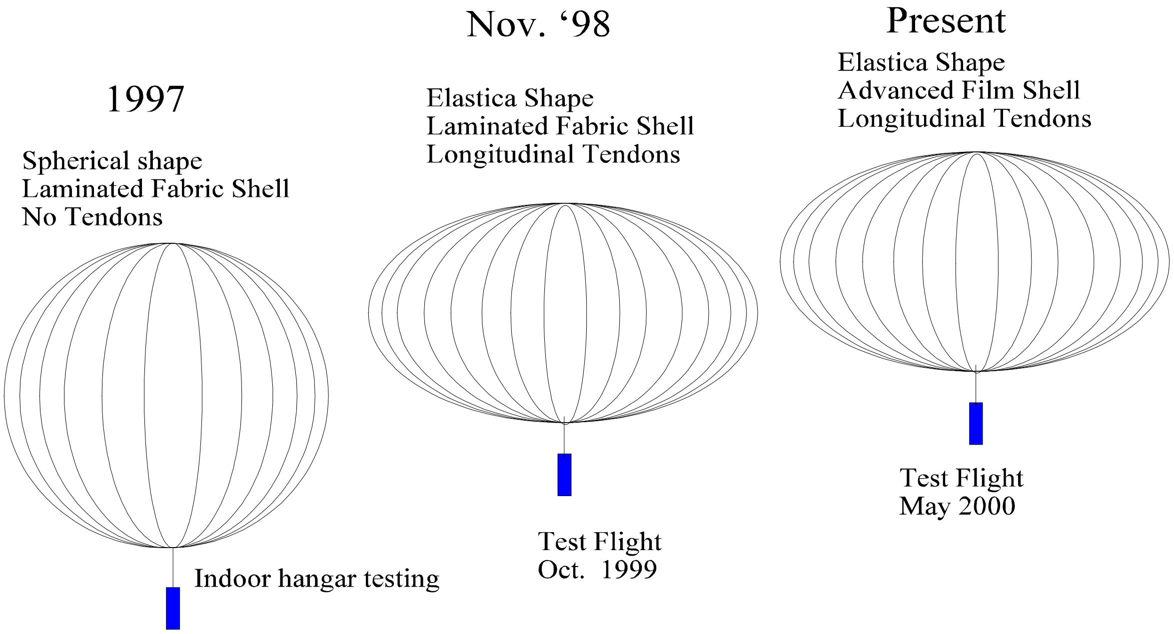


Figure 1 - ULDB Design Evolution

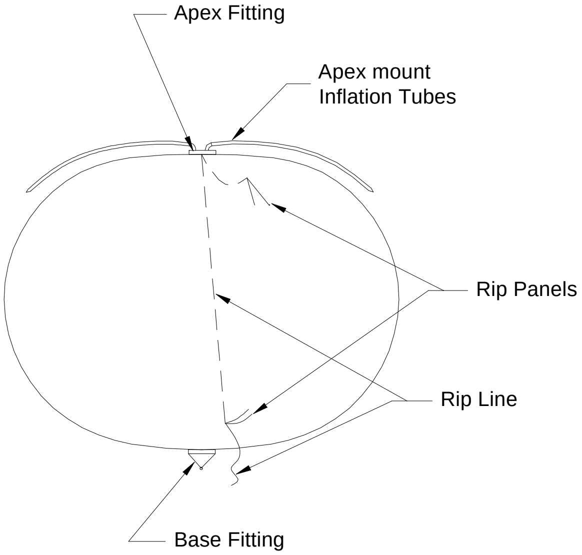


Figure 2 - ULDB Assembly

composite. This balloon, completed in May of 2000 will be flown in the May/June 2000 time period.

3.Current ULDB Design

The shell of the current ULDB design, shown in Figure 2, is composed of an advanced composite film 38 : thick, and PBO longitudinal tendons. The seams of the balloon are approximately2% shorter than the tendons to allow lobing in the gores. This lobing significantly reduces the transverse stresses in the shell film while almost completely eliminating longitudinal stresses. The tendons are covered in an Ultraviolet radiation protective sleeve.

4.Subsystem Design

4.1 Destruct Device

The destruct device for the ULDB was designed to operate properly during ascent or pressurized float conditions. A dual rip panel configuration is used. Upon separation from the balloon, the payload falls away and opens the rip panel on the bottom of the balloon. A line is attached from the bottom button to a button at the peak of the top rip panel. Since the apex fitting of the balloon is heavier than the base fitting, the balloon could invert if a destruct is commanded during ascent. The bottom rip panel will prevent the balloon from going into a ducted float condition if the balloon inverts.

4.2 Inflation System

The inflation of the ULDB must be as similar to the inflation of a traditional balloon as possible without compromising the structure of the balloon. It was decided to inflate the balloon through the apex fitting to avoid stress concentrations around a side inflation installation point. On the first flight test balloon, the tubes were tied to the side of the balloon. On the second flight test balloon, a tube release system was designed and tested which allows the balloon to be inflated through the tubes which are released prior to launch.

End Fittings

The end fittings of the ULDB must provide attachment points for external accessories as well as the payload. In addition to these traditional roles, the end fittings must be designed to be leak free throughout the pressure and temperature range that the ULDB is expected to encounter and withstand the huge total forces that will be exerted by the tendon pressure loads. Because of this structural requirement, the end fittings for the ULDB are more massive than similar sized fittings for zero pressure balloons. The apex fitting, shown in Figure 3, is about the same size as a zero pressure balloon fitting but weighs twice as much. Note the apex mounted inflation tube attachment elbows.

The apex fitting also houses the Commandable Apex Package (CAP) which houses pressure and temperature sensors, valve control systems, and release circuitry for the tow balloon and inflation tubes.

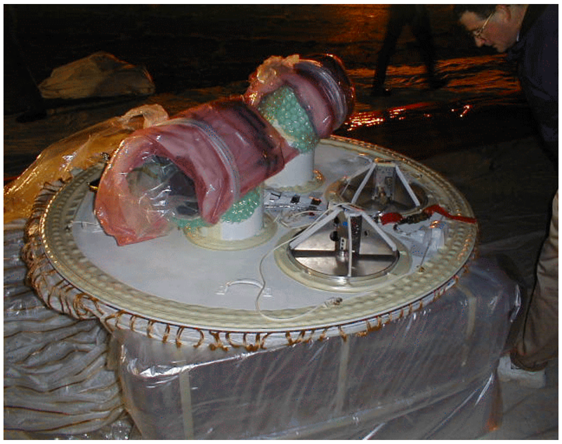


Figure 3-ULDB Apex Fitting

The base fitting for the ULDB is similar to the apex fitting. The material and tendons are held by a clamp ring. This allows the material to remain flat and smooth to provide a positive gas seal. Payload attachment is by means of a harness arrangement similar to the ones used at the top rings of the payload recovery parachutes. The base fitting for the first test flight is shown in Figure 4.

Figure 4-ULDB Base Fitting

5.Testing

5.1 Hangar Tests

Numerous indoor inflation tests have been conducted which have validated stress analysis calculations and fabrications techniques. The first set of 14 m^3 sphere hangar tests is well documented in previous reports. The results of these tests prompted NASA to switch the design of the ULDB to a pumpkin shape. The indoor tests of pumpkin shaped balloons continued with the test of a pumpkin made with a fabric/film composite material. This pumpkin, shown in Figure 5, confirmed calculations that a much softer material, such as polyethylene could be used in place of the very stiff fabric based materials.

The next set of tests focused on validating fabrication methods being developed for a heat sealed pumpkin shell. These tests were also used to verify the properties of newly developed heat sealable shell materials. One of the first tests is shown in Figure 5. This test of a 14 m^3 pumpkin showed that a lobed pumpkin with tendons could be built with a heat sealed material. The strains and pressures measured during the test confirmed the stress calculations.

After the 14 m³ pumpkin balloons were tested, two 60 m³ balloon were fabricated and tested as a final check out prior to building the 60,000 m³ (60 kcm) flight test balloon. This 60 m³ balloon, shown in Figure 5, had exactly the same fabrication method and materials as the 60 kcm flight test balloon. The pressure test again confirmed that stress calculations were valid.

Figure 5 - 14 m³ Polyethylene Pumpkin

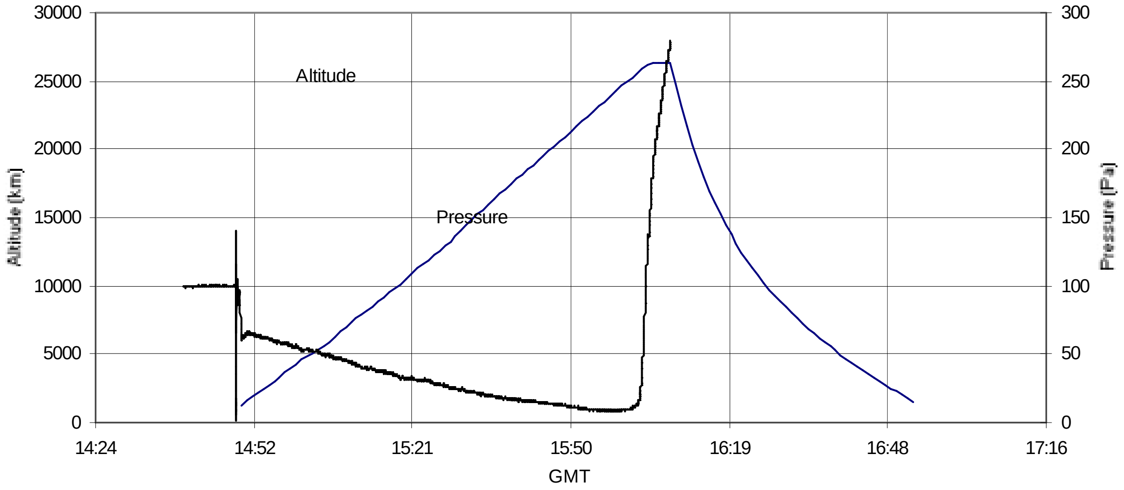
Figure 6 - 60 m³ Advanced Film Balloon

5.2 Flight Tests

As previously reported, the ULDB project undertook a parallel effort in the development of balloons fabricated with the fabric/film composite material and with advanced film material. The first 60 kcm balloon built with fabric/film material was flown on October 23, 1999. The goals of the test flight were to evaluate the balloon itself and to evaluate launch techniques developed for the ULDB. From these general goals, the flight was classified as a success. The balloon was inflated and launched successfully and much valuable information was gained from the flight. As the balloon was being inflated, one of the tendons could be seen peeling away from the balloon shell in the sub pressure area of the launch bubble which is shown in Figure 7.

Figure 7 - 60 kcm Balloon Inflation

After a successful launch, the on board cameras were used to find that the tendon had continued to



peel away from the balloon shell. As the balloon began to pressurize, the tendon was displaced to a position on top of an adjacent tendon. The continued pressurization of the balloon caused the displaced tendon to roll across the surface of the balloon and carry adjacent tendons with it. The balloon shell failed after a sudden displacement of nearly twenty tendons. An altitude profile of the flight is shown in Figure 8.

As shown in the graph, the pressure inside the balloon gradually decreases until the balloon becomes fully inflated. The balloon stops its ascent 26.3 km. The balloon gas, recovering from the adiabatic expansion, continues to pressurize the balloon until failure occurs at 279 Pa. At this point, the nominal load on the fabric is only 420 N/m which is only 12 % of the material's design stress limit.

6. Future Development Plans

The next step in the development of the ULDB will be the flight of the coextruded film balloon. This balloon concept has been the most thoroughly tested so far in the project. Following the flight of the 60 kcm film balloon, a pair of 600 kcm film balloons will be fabricated and shipped so Australia for the first full scale demonstration flights in December 2000.

7. Acknowledgment

The authors wish to gratefully acknowledge the sponsorship of NASA and New Mexico State University's Physical Science Laboratory in this important work.

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