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ULTRA HIGH ALTITUDE BALLOONS FOR MEDIUM-TO-LARGE PAYLOADS

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ABSTRACT

The expanding use of scientific balloons as a cost-effective alternative to orbital and suborbital space flight has driven the development of Ultra-High Altitude Balloon (UHAB) vehicles. Of particular interest is the ability to fly payloads approaching 900-1,000 kg to altitudes in excess of 45 km using traditional zero-pressure designs. A zero-pressure balloon of nearly 1.7 million cubic meters (60 million cubic feet) volume was developed for NASA and launched in Summer 2002. This was the largest balloon ever successfully flown, reaching an altitude of 49 km. Presented in this paper is an overview of the design and material challenges involved in developing large ultra-high altitude balloons, as well as a summary of the Summer 2002 test flight. In addition to providing unprecedented altitudes from which to make scientific observations, the (UHAB) also opens new avenues for long duration ballooning at mid-latitudes. With altitude excursions of 10 – 12 km, these balloons will be able to execute long duration flights without the need for large quantities of ballast. If augmented by a small superpressure anchor balloon, the altitude excursions could be kept to a minimum. While not as capable as the ULDB in carrying large payloads, the UHAB would add another capability for scientists with relatively light payloads who desire to maximize mission time and altitude.

BACKGROUND

Since the inception of scientific ballooning, researchers have sought to lift increasingly heavier, more sophisticated, scientific payloads to higher altitudes. The use of polyethylene film for balloon envelopes was pioneered in the late 1940’s by Winzen Research and General Mills, allowing the construction of balloons with much higher lift-to-weight ratios than were possible with the previously used rubberized fabrics. This in turn enabled balloon systems to achieve significantly higher altitudes than were previously possible.

In 1959, a 170000 cubic meter balloon carried a 43 kilogram payload to an altitude of 45.4K meters. At the time, this was the largest balloon to have been successfully launched. During the 1960’s and 1970’s, advances in film extrusion and balloon fabrication techniques facilitated the construction of increasingly larger balloons, culminating with a 1.5 million cubic meter (MCM) behemoth launched in 1975. Beyond this point, the ability to successfully launch larger balloons was constrained by limitations in materials and launch techniques. Although balloons of up to 2 MCM in size were constructed, none were successfully launched, and the 1.5 MCM balloon held the size record for over 25 years.

THE CURRENT STATE

The late 1990's began a period of renaissance in scientific ballooning, fueled by significant funding toward the development of Ultra Long Duration Balloon (ULDB) platforms. This, coupled with programs improving the reliability of standard zero-pressure balloons, catalyzed improvements in the quality of balloon film, as well as the incorporation of new launch techniques. In March, 2002, NASA requested that Raven Industries perform a trade study on a series of ultra-high altitude zero pressure balloon platforms.

DETAILED DESIGN AND DEVELOPMENT

After analyzing several load-altitude targets, NASA chose a 1.7 million cubic meter (60 million cubic feet) design with an ultimate payload capacity of 750 kg. While the balloon was designed using traditional zero-pressure techniques, the shell and cap material was chosen to be Stratofilm-430, which was based upon the Stratofilm-420 developed for the ULDB program.

Stratofilm-430 is a three-layer co-extruded film using the same resins as Stratofilm-420. The total film thickness is 10.2μ for the shell and 13.2μ for each of the two cap layers. Compared to traditional zero-pressure balloon film, the Stratofilm-430 has higher strength and ductility at normal surface temperatures, making the shell better able to withstand dynamic launch loads.

PRODUCTION

Production of the balloon, now unofficially christened the "Big 60", required some minor rearrangement of production space to accommodate the almost 230 meter gore length. The use of Raven's patented *Stable Table* arrangement, shown in Figure 1, allowed existing production tables to be partitioned and extended, avoiding a massive reconstruction effort. Most of the production personnel were accustomed to handling 20μ film, therefore special training and handling exercises were implemented to acclimate personnel to the more delicate films. Fabrication of the balloon was relatively straightforward and uneventful due to its similarity to standard zero-pressure designs. Because of the delicate film, special considerations were made for the processes of expelling excess air and loading the balloon.

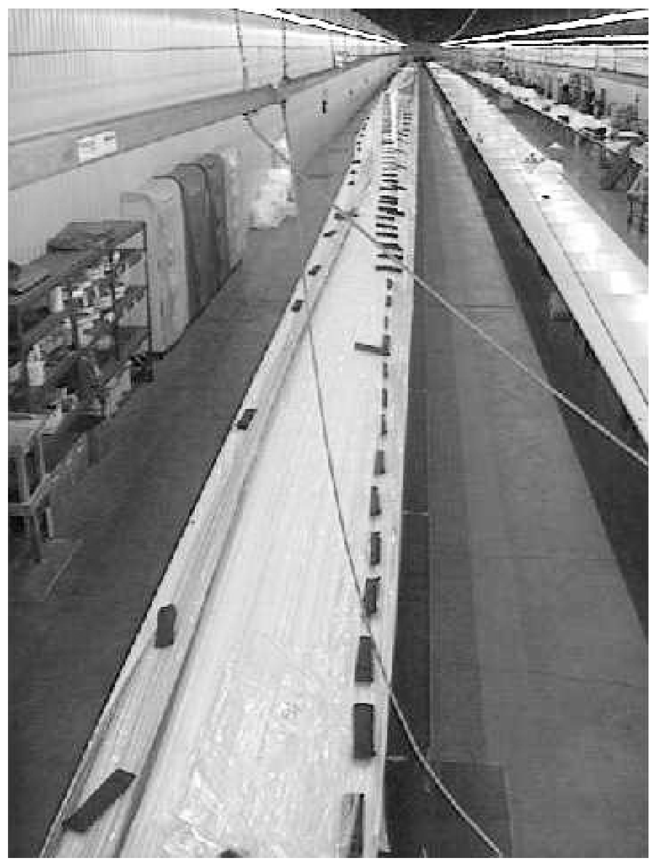

Fig. 1 – The "Big 60" production table.

LAUNCH AND FLIGHT

On August 25, 2002, after several weeks of weather delays and two trips to Lynn Lake, Manitoba, Canada, the "Big 60" was successfully launched. It carried a 690 kg cosmic ray instrument called Low Energy Electrons (LEE) provided by Dr. Paul Evenson of the University of Delaware. The balloon climbed to a peak altitude of 49.4 km, and was terminated normally after approximately 23 hours of flight time. The flight profile is shown as Figure 2.

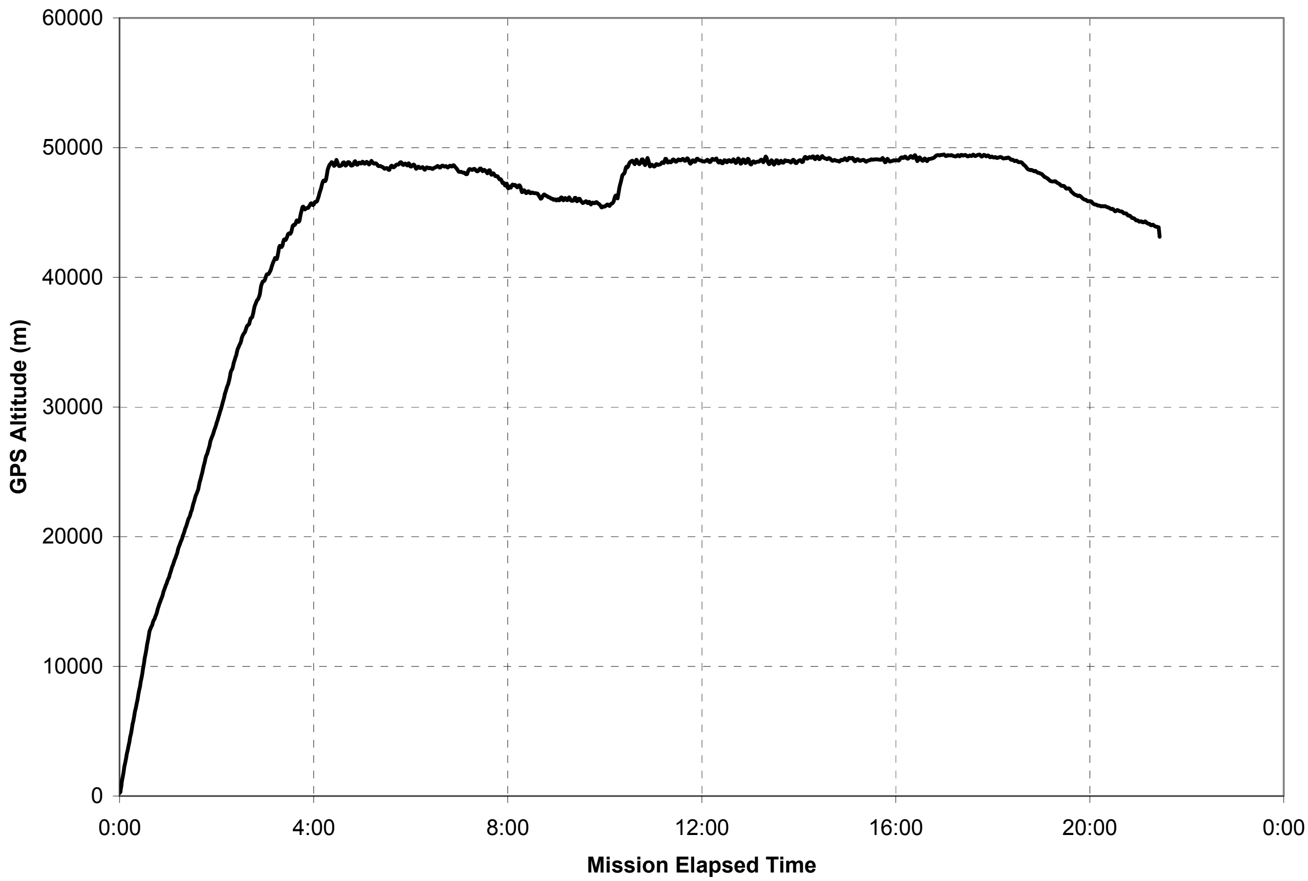

Fig. 2 – Balloon Flight Profile, 1.7 Million m³ Balloon

FURTHER APPLICATIONS

During the summer of 2002, The Institute of Space and Astronautical Science (ISAS) of Japan successfully launched an ultra-thin film balloon which carried a 10 kg payload to a world-record altitude of 53 km. While the UHAB platform does not yet attain such extreme altitudes, it now affords scientists the opportunity to place medium-sized payloads (250–750 kg) in an altitude band (47–50 km) that was not previously accessible to such instruments. This is of particular interest to scientists performing observations of lower-energy cosmic ray electrons, as well as other disciplines that require ultra-high altitudes to facilitate the collection of clean data.

Raccooning and Long-duration Ballooning

One important advantage of the UHAB platform is that the relatively large helium volume results in a relatively low rate of negative heat flux during the nighttime portion of the diurnal cycle. Smaller balloons must drop ballast at night to remain above the cold tropopause, and their endurance is limited by the amount of ballast that can be carried.

With its high altitude and low cooling rate, the UHAB is predicted to have the capability to traverse many successive diurnal cycles with the use of little or no ballast. This technique is known as Radiation-Controlled Ballooning (RACOONing). The diurnal altitude excursions of 10–12 km could be significantly lessened through the use of a small superpressure anchor balloon, which would "buffer" the relative change in system density through each cycle. For scientists with relatively light payloads, this technique would facilitate middle-latitude flights of duration currently approached only by summer circumpolar flights. A trajectory simulation for the 1.7 mcm balloon over four days with no ballast drops is presented in Figure 3.

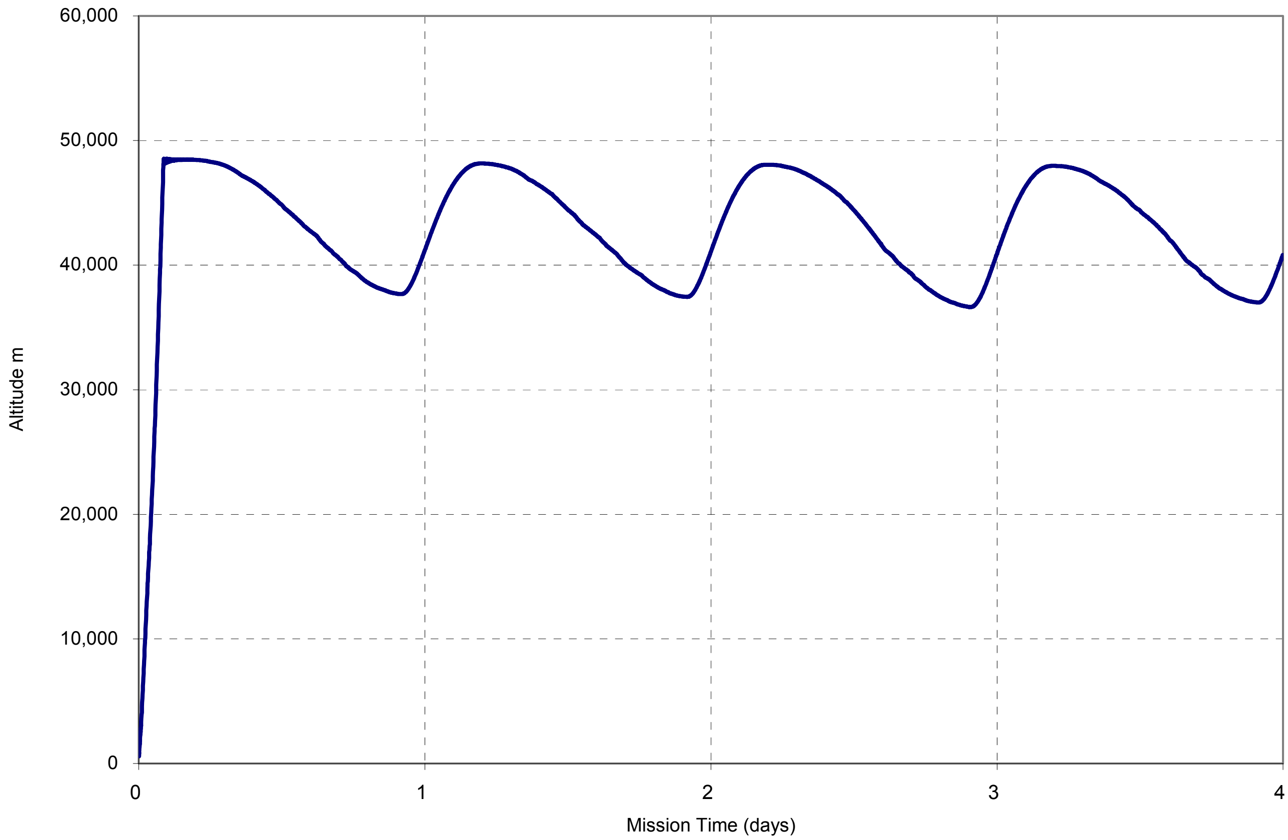

Fig. 3 – Simulated trajectory of the 1.7 mcm balloon with no ballast drops for a four day mission. Maximum altitude is 48 km and minimum altitude is 38 km.

Achieving the Highest Possible Altitudes with the Highest Possible Payloads

The altitude that is achievable with a scientific balloon is limited by the available material strength and thickness along with the physical production space available. The length of the Raven balloon plant is 244 m, which limits the maximum volume of a producible balloon to approximately 2.1 mcm. The thinnest film producible using the currently available SF-430 process is 5 μ. Using the maximum possible volume and the thinnest possible shell results in a 2.1 mcm balloon that weighs 774 kg and could theoretically carry 60 kg to 56 km. In accordance with established launch stress limitations, this balloon could carry a maximum payload of 63 kg, if equipped with caps of 5 and 10 μ each. However, the shell strength of a balloon with a 2.1 mcm volume and a 5 μ shell would be insufficient for the balloon to lift itself without catastrophic failure. A 2.0 mcm balloon with the same shell and cap configuration as NASA's 1.7 mcm balloon would carry a much heavier payload than the ultra thin 2.1 mcm balloon, but the resulting float altitude would be lower.

As shown in Figure 4, a performance envelope for polyethylene balloons can be visualized. The upper left bound of the envelope shows that the Raven Balloon Plant is aptly sized. The practical limit of balloon size is also the practical limit of polyethylene film. The only way to move the performance envelope to the right, allowing heavier payloads, would be to develop stronger films. Even so, if a film with twice the strength of current balloon film were developed, the payload capacity of the 2.1 mcm balloon would only be increased to 130 kg. The payload capabilities for even slightly lower altitudes would increase significantly. When considering missions to extremely high altitudes, the scientific value of achieving that altitude must be kept in mind. If the weights of highly sensitive cosmic ray detectors can be kept below 500 kg, then altitudes above 50 km will be possible with current technology.

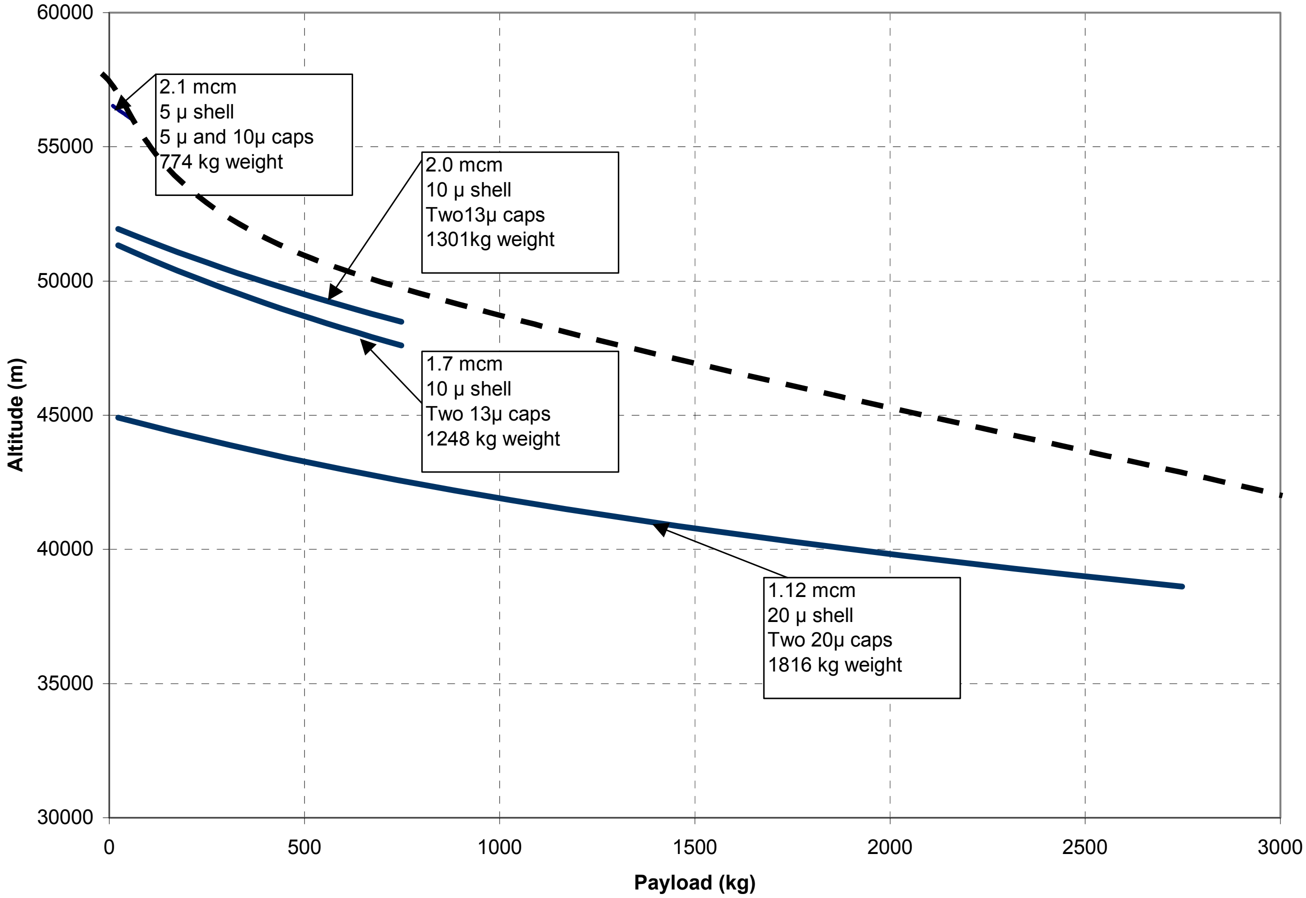

Fig. 4 – Envelope of Producible High-altitude Zero-pressure Balloon Designs

CONCLUSION

It has long been known that high-altitude scientific balloons provide an inexpensive alternative to orbital and sub-orbital space flight when placement above 99.7% to 99.9% of the atmosphere is acceptable. As compared to orbital space flight, scientific balloons permit the safe return of the payload, and offer relief from the accumulation of space debris associated with orbital launch vehicles. The successful flight of the 1.7 million cubic meter balloon demonstrates an expanded reach of balloon-based science by carrying medium-sized payloads to altitudes previously unattainable through the use ofllooncraft. The UHAB platform further offers the opportunity to extend the duration of mid-latitude flights through the implementation of Radiation-Controlled Ballooning.

Balloons made with polyethylene do have limits with respect to payload and altitude combinations. These limits are based on current material strength capability. Balloon films with increased strength to weight ratios would greatly increase payload capabilities for missions requiring flight above 50 km.

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