EXTENDED CAPABILITIES OF ZERO-PRESSURE AND SUPERPRESSURE SCIENTIFIC BALLOONING PLATFORMS

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ABSTRACT

The 1.7 million cubic meter (60 million cubic foot) scientific balloon platform, designed and manufactured by Raven Industries, Inc. and funded by NASA, has successfully flown a payload of 680 kg (1500 lb) to a float altitude of over 48.7 km (160 kft). This record-breaking flight, performed in August, 2002, greatly extended the performance envelope of scientific ballooning platforms with regard to its ability to lift significant payloads to extreme altitudes. This has, in turn, generated significant interest from the scientific community regarding the increased altitude and duration capabilities of scientific ballooning platforms.

In order to explore future capabilities and establish a future direction for ultra high-altitude platforms, NASA and Raven have partnered in a study to determine the current practical performance limits of conventional zero-pressure balloons, ULDB-type (Ultra Long Duration Balloon) superpressure elastica balloons, and potential alternative designs. The highlights of this study are presented herein, along with a number of observations pertaining to the design and manufacture of these balloons.

BACKGROUND

The ever-increasing requirement for heavier, more sophisticated payloads has continually driven the expansion of payload capacities of scientific balloons. Additionally, the pursuit of "clean" data, unperturbed by the presence of atmospheric matter, has resulted in requirements for higher float altitudes. The requirement for larger quantities of continuous data has driven the need for longer-duration flights.

In recent months, these upward-spiraling needs have resulted in the infusion of new technology into scientific ballooning vehicles, resulting in several new platforms:

Updated Heavy Lift Designs

Balloons with maximum payloads of up to 3625 kg (8000 lb) have been available for many years. However, the reliability of such balloons is compromised when flown at the maximum payload. Raven Industries, in cooperation with NASA and the National Scientific Balloon Facility (NSBF), has developed a new 1 MCM (36.7 MCF) heavy-load balloon design which utilizes three-layer co-extruded film technologies developed for the ULDB program. This balloon promises to utilize the full gross inflation capacity of NSBF's launch equipment, while delivering the near-100% reliability associated with existing medium-capacity balloons.

Zero-pressure Ultra-high Altitude Balloons (UHABs)

ULDB film technology also found practical application in the 60 MCF "Big 60" balloon[1]. The superior thickness profile of the three-layer co-extruded film allowed the use of film as thin as 10.2µ (0.4 mil), half the thickness of conventional large balloon film. This permitted the construction of a balloon with the necessary lift-to-weight ratio necessary to achieve the targeted load-altitude performance.

Long-duration and Ultra-long Duration Balloons

Long-duration balloons, similar to conventional zero-pressure balloons, are routinely flown in the south pole region during the Antarctic summer. Flight durations of up to one month are routinely possible. Development continues on the superpressure ULDB as new challenges are raised regarding the deployment of its unique lobed structure.

STUDY OBJECTIVES

In the interest of expanding the performance envelope of scientific balloons, NASA's Wallops Flight Facility commissioned Raven Industries to perform a series of trade studies. The first of these studies was intended to define the performance characteristics of High-Altitude ULDB (HAULDB) designs.

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Defining the Envelope

The process of designing an elastica-type superpressure balloon is codified into software which allows the designer to iteratively converge a set of design parameters (e.g., film thickness, tendon denier, etc.) to an optimal design for a given load-altitude requirement. For the superpressure phase of this study, a load-altitude matrix was formed for payloads of 227 kg, 454 kg, and 680 kg (500 lb, 1000 lb, and 1500 lb) to be lifted to altitudes of 45.7 km, 47.2 km, and 48.8 km (150 kft, 155 kft, and 160 kft). For each of these cases, a ULDB-type design was developed and optimized. The results of this sizing study are summarized in Table 1.

Table 1—High-altitude ULDB Design Study Results

Payload (lb)	Altitude	Vol. (mcf)	Gore Len. (ft)
	150000	31.104	589
500	155000	46.429	673
	160000	70.858	775
	150000	43.218	657
1000	155000	62.507	743
	160000	91.609	844
	150000	54.829	712
1500	155000	76.660	799
	160000	111.943	903

Generally speaking, balloons with gore lengths significantly greater than 231 m (750 ft.) cannot be accommodated at Raven's manufacturing facility without further plant expansion (see Figure 1). However, it is notable that Raven Industries has recently purchased the building and grounds currently occupied by its manufacturing facility, which will greatly facilitate any further physical expansion needs.

Practical HAULDB Considerations

One significant observation regarding the HAULDB is that its tendon strength requirement is significantly lessened as compared to the conventional ULDB. This is because of the much lower diurnal cycle pressure differential at higher altitudes. If future ULDB test programs show that tendon foreshortening can be eliminated, the tendon material can simply be incorporated into conventional-type load tapes. This would greatly reduce the cost of this platform as compared to current designs. The low diurnal cycle pressure differential also raises the possibility of hybridizing ULDB and zero-pressure designs.

CHALLENGING ISSUES & FUTURE DIRECTIONS

Heavy Lift Applications

With respect to maximum gross inflation, the performance envelope of heavy-lift balloons is currently most limited by the capacity of available launch equipment. Available equipment at NSBF limits the gross inflation to 64.5 kN (14500 lb_f). The 1 MCM heavy-load balloon is optimized to fully utilize this capacity, lifting a 3625 kg payload to an altitude of 36 km, while maintaining launch stress parameters within reliable limits. Extending the capacity of the launch equipment to 71.2 kN (16000 lb_f) could allow the launch of heavy-lift balloons of up to approximately 1.7 MCM (60 MCF) volume, lifting a full 3625 kg payload to a 39 km (128 kft) float altitude. The placement of heavier payloads at lower altitudes would be feasible with appropriately higher-capacity launch equipment.

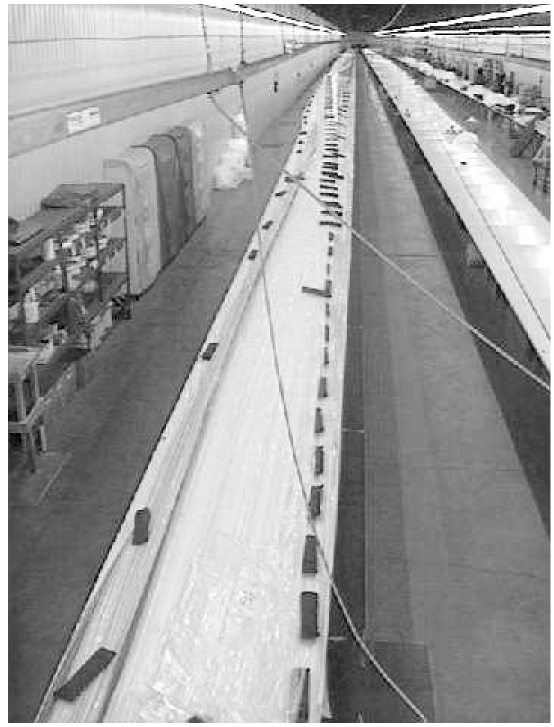

Figure 1—Raven's "Big 60" fabrication table

UHAB Applications

A significant feature of the UHAB platform is the high ratio of helium mass to surface area. This results in a low rate of heat loss for the lifting gas during the night portion of the diurnal cycle. Consequently, ballasting requirements are reduced, or even eliminated where appropriate altitude excursions are permissible. This technique of allowing altitude excursions, while remaining above the cold tropopause is known as Radiation-controlled Ballooning[2] (RACOONing). For researchers with relatively light payloads, this technique could enable mid-latitude flights of duration approaching that of summer circumpolar flights. Presented in Figure 2, a trajectory simulation for the 1.7

MCM “Big 60” balloon has been developed for a four-day flight with no ballast drops.

The limiting factors in the design of extreme-altitude balloons are the material weight and available manufacturing space. As stated previously, the current maximum gore length that can be accommodated by Raven’s manufacturing facility is approximately 231 m (750 ft). While the resultant balloon volume varies according to the balloon’s sigma factor[3], this corresponds to a balloon volume of approximately 1.75 MCM.

Total system mass becomes especially critical at higher altitudes. For example, for a hypothetical 1.7 MCM balloon at an altitude of 52.7 km, approximately 65 m of altitude is lost for each kilogram of additional mass. Where maximum altitude is desired, all systems, including payload and recovery systems, must be designed in order to minimize mass according to paradigms used for spacecraft design.

The balloon vehicle itself has several potential areas for mass savings. Placing valve telemetry and power modules on the apex could eliminate 16 kg of valve cabling, thereby gaining up to an additional kilometer in altitude. Where the gore width is sufficiently wide for the film to bear the longitudinal loads, load tapes could be terminated as opposed to running the full length of the seal. An additional 15–25 kg of load tape material could be thusly eliminated.

By exploring the theoretical and practical capabilities of large scientific balloons, it is possible to define a performance envelope that summarizes these capabilities. Such an envelope is illustrated in Figure 3.

CONCLUSION

The last year has seen significant new technologies traverse from experimental programs into practical scientific ballooning platforms. Other developments are progressing rapidly, with the coming year expected to be a watershed with regard to balloon technology applications. For the first time, the practical performance envelope of ULDB and large zero-pressure balloons is understood, and the technology is in place to utilize these capabilities.

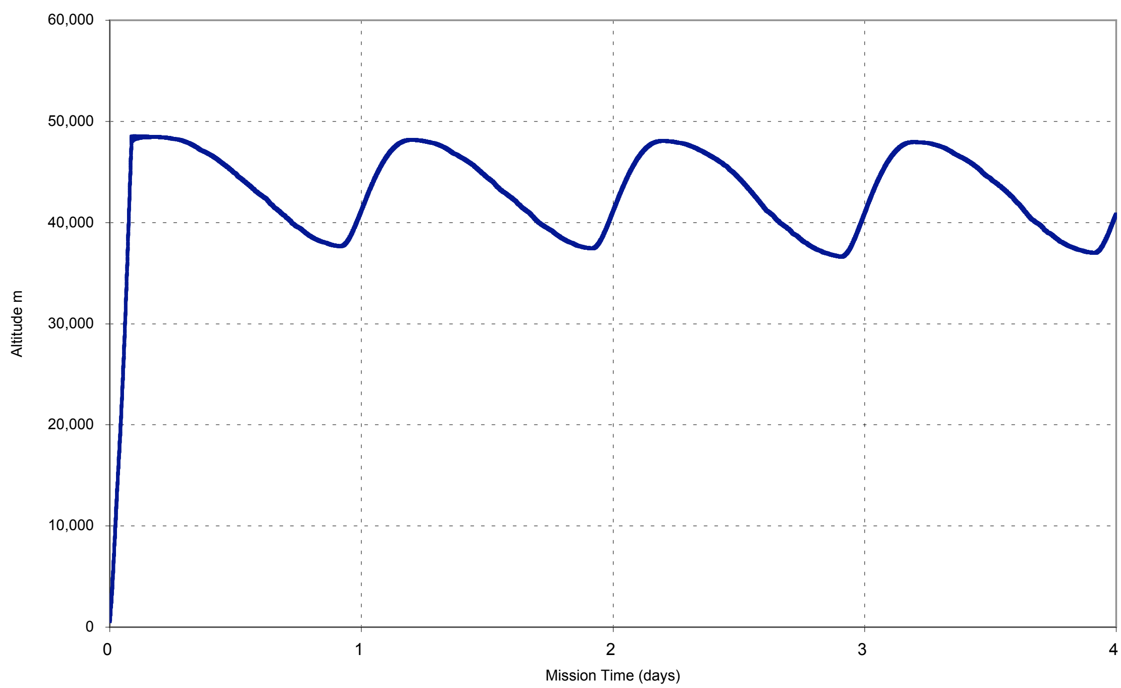

Figure 2—Four-day trajectory simulation for the 1.7 MCM "Big 60" balloon with no ballast drops (1500 lb/680 kg payload).

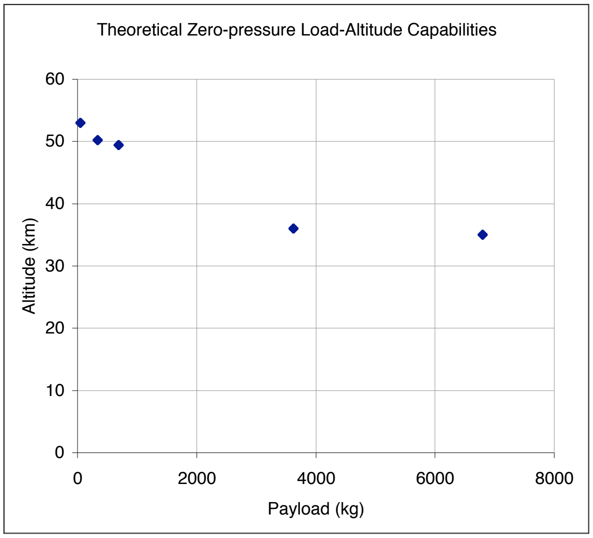

Figure 3—Large balloon performance envelope

ACKNOWLEDGEMENTS

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