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NASA Balloon Program Capabilities in Support of Cosmic Ray Research

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Abstract: The National Aeronautics and Space Administration (NASA) Balloon program offers a reliable low cost platform for conducting cutting edge cosmic ray research and scientific investigations. New payload support facilities were recently completed in Antarctica. They were used during the 2007 Campaign NASA to demonstrate, for the first time, the ability to launch three science payloads in the same season. The long-duration balloon missions in Antarctica are conducted in coordination with the U. S. National Science Foundation Office of Polar Programs. Most of the Antarctic flights have flown one time around the South Pole in 8-20 days using conventional (zero differential pressure) balloons, but two flights went twice around the Pole in 28 and 31 days, respectively. Two other flights went around three times in 35 and 42 days. NASA and the Swedish Space Corporation/Esrange have negotiated an agreement to enable medium-duration heavy-load scientific balloon flights from Sweden to Canada. This paper will highlight the capabilities of the balloon program in support of advanced cosmic-ray investigations

Introduction

The NASA Scientific Balloon Program is a sub-orbital space flight program utilized primarily in support of space and Earth sciences research activities sponsored by NASA. Most of the operational and engineering aspects of the Program are accomplished through the activities of the Columbia Scientific Balloon Facility (CSBF), located at Palestine, Texas. CSBF is managed and operated by the Physical Science Laboratory of New Mexico State University located in Las Cruces, New Mexico.

The CSBF personnel have conducted more than 2,000 scientific balloon flights, with ~80 percent being launched at the permanent launch sites in Palestine, Texas and Ft. Sumner, New Mexico. The other 20 percent were launched at remote sites and within the contiguous United States, Alaska and Hawaii. Active remote launch sites include locations in Canada, Sweden, Australia, and Antarctica. In the past, flights were launched from locations in Brazil, New Zealand, Argentina, Sicily and India. Although some special-purpose larger balloons [1] and heavier suspended payload weights have been launched by CSBF personnel, standard operating limits of approximately 1.11 million cubic-meter (MCM) volume balloons and suspended weights of 3600 kg are currently in effect. The routine launching of balloons with volumes greater than 0.7 MCM with suspended weights greater than 2000 kg is a scientific ballooning capability uniquely provided by NASA. The suspended load capabilities of NASA's zero differential pressure, more commonly referred to as zero-pressure, balloons are shown in Figure 1.

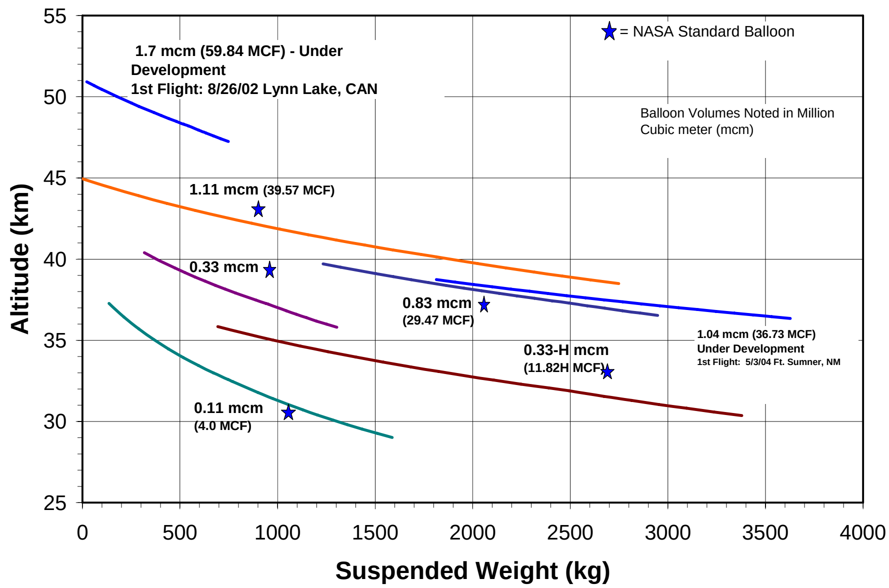

Figure 1: Suspended load capabilities of NASA's zero differential pressure balloons.

Long Duration Ballooning (LDB)

In the late 1980's, NASA made a decision to extend the capabilities of zero-pressure balloons and to develop a near global Long Duration Ballooning (LDB) capability. The LDB plan included systems required to conduct flights with scientific experiments having mass of 680 kg or more on zero-pressure and special-purpose balloons for periods of up to three weeks. Operational implementation of LDB represented a new capability in scientific ballooning. Further development of flight support systems and the balloon vehicle has continued to increase the flight capability and duration of LDB missions.

Most of the LDB missions are currently conducted from Antarctica during the Austral summer. Typical missions are 8 - 20 days. In 2002, a record was set when a 0.83 MCM balloon carrying the Trans Iron Galactic Element Recorder (TIGER) payload flew for a duration exceeding 31 days [2]. In 2005 a new LDB flight record was set when a 1.11 MCM balloon carrying the Cosmic Ray Energetics and Mass (CREAM) experiment flew for over 41 days [3]. During the 2006/07 Antarctica Campaign, three payloads utilized the new launch support facilities for payload preparation and integration for the first time.

NASA's LDB missions are not limited to the southern hemisphere. Recently, NASA and the Swedish Space Corporation/Esrange inaugurated a joint capability for medium-duration heavy-load scientific balloon flights from Sweden to Canada or Alaska. In June 2005, a 1.11 MCM balloon was launched from Kiruna, Sweden carrying the 2700 kg Balloon-borne Large-Aperture Submillimeter Telescope (BLAST) payload [4]. The westerly flight, which lasted for 4.2 days, was terminated over Northern Canada, approximately 315 km northwest of Cambridge Bay on Victoria Island. The average float altitude was 39 km. In 2006, two successful flights were also launched from Kiruna. The Anti-Electron Sub Orbital Payload (AESOP) was launched in June 2006 to a float altitude of about 36 km. The flight lasted for a bit more than 5 days [5]. The payload impacted 302 km west of Cambridge Bay, Victoria Island, Canada. In July 2006 the Transition Radiation Array for Cosmic Energetic Radiation (TRACER) was launched to an altitude of about 37 km. TRACER flew successfully for about 4-1/2days [6]. The payload landed 139 km south-southeast of Resolute, Nunavut Province, Canada.

Ultra Long Duration Ballooning (ULDB)

The NASA Ultra Long Duration Balloon (ULDB) development effort has focused on providing a new flight platform for the science community. The ability to fly longer duration stratospheric flights at constant float altitudes with heavy payloads will allow more science to be accomplished. The near-term goal of the ULDB project is to demonstrate a balloon vehicle capable of carrying a 2,720 kg payload to 33.5 km for up to one hundred days. The ULDB effort continues the development in incremental steps [7]. A number of test flights and ground test models have expanded the knowledge of the materials, fabrication methods, and balloon design.

These balloon designs include load-carrying tendons and film gores. As the project progresses toward flying larger balloons to higher altitudes, further design challenges have been encountered. Recent efforts have focused on ground testing and analysis to understand the previously observed issue of balloon deployment at float. The revised approach to developing the pumpkin balloon has involved ground testing of model balloons, two test flights, and additional scaled model testing.

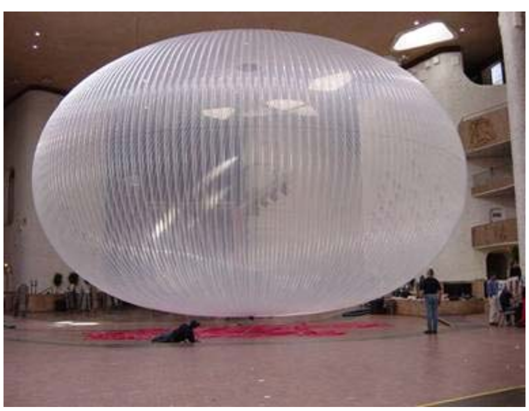

Figure 2: 14.3 m diameter, 200 gore model test balloon

Scaled model balloons were used to study their deployment and stability during extensive laboratory tests leading up to flight tests of two ~ 6 MCF (million cubic feet), ~ 0.17 MCM (million cubic meter) balloons. Figure 2 shows the 200 gore 14.3-meter diameter model of the 0.17 MCM super-pressure balloon. It was designed to replicate the first flight balloon, having the same equatorial lobe angle as the flight structures. This model demonstrated full deployment at almost no differential pressure, and it provided valuable strain data while being incrementally pressurized. It demonstrated stability under pressure, and it was purposely pressurized to failure. Pre-test analysis predicted instability above 1,379 Pa (0.2 psi). This scaled model deformed and burst after reaching 1,551 Pa (0.225 psi) level, ~40% above its maximum design pressure, 1,103 Pa (0.16 psi).

Super-Pressure Balloon Test Flights

The first flight test of the 0.17 MCM balloon occurred in February 2005 from Ft. Sumner, New Mexico. The balloon deployed at its design float altitude of 30.5 km with no clefts in the top region. However, an internal camera documented that the closing seal opened near the bottom of the balloon after reaching float altitude. The entire balloon was recovered after termination, and a detailed post-flight investigation indicated a peeled seal in this region. The investigation team concluded that the seal issue was due to a manufacturing problem, and that this balloon would have performed well if the seal had not opened.

After addressing the manufacturing problems, another 0.17 MCM balloon was fabricated and taken to Kiruna, Sweden for a longer test flight. The June 2006 launch was normal, but there were a number of un-deployed areas in the balloon as it ascended [8]. One large cleft remained after the balloon was pressurized to the planned 80 pascals (Pa) at its float altitude of ~30 km (100,000 ft). Both payload-mounted and internal balloon-mounted pan/tilt/zoom cameras were used to document the cleft. The flight rules precluded a long-duration flight with a cleft in the balloon, but it maintained constant float altitude for 4.5 hr. Ballast was dropped to carry out the planned end-of-flight pressurization test to the maximum design pressure of 240 Pa (3 times the nominal maximum operating pressure of 80 Pa). During this test, the balloon reached 265 Pa without rupture, which validated the strength of the seals and the film. The flight was terminated by normal command after a total flight time of 8.5 hr.

In-door Scaled Model Test

The team investigating the test flight results concluded that slight differences in the balloon designs and their operation in very different flight environments put the second balloon on the cusp of deployment [8]. The first balloon was not fully tested to the desired differential pressure levels due to the seal failure, but the results of the second flight indicated that the manufacturing issues had been successfully addressed. Minor pattern differences to address high stress regions and the exposure of the second flight to a very cold environment appeared to have impacted its deployment. It was able to survive differential pressures larger than the design limits even though it was not fully deployed.

It was decided to attempt replication of the "S" Cleft with a model balloon, using the largest balloon possible to be tested indoors, with the possibility of flying a balloon of the same size. The balloon size that balanced this design objective was a ~27 meter diameter structure that could carry at least 20 kg to an altitude of 30.5 km. The indoor test was to explore the balloon deployment and experimentally demonstrate the "S" cleft in a model scaled to the Sweden test flight balloon.

Conclusions and Next Steps

The scaled model test took place in an airship hangar. The first inflation successfully duplicated the "S" cleft observed in the Sweden flight balloon, and it appeared again during a second inflation of the same balloon. Manipulating the balloon structure could shift around the cleft, but it was not possible to remove the cleft. This indoor inflation test provided the following indications relevant to the source of the "S" cleft: The launch spool configuration (twisting) launch dynamics, and balloon folding did not cause the cleft. Since there was little friction between the halves of the clefted material, it was concluded that the structural design determined the S-cleft susceptibility. Specifically, the tendency to form an S-cleft is a function of the excess material in the film gores.

Additional ~27 m indoor model balloons will be fabricated and tested to establish the deployment continuum. The material model will be updated with better data, and additional analyses will be carried out using the updated model. The current plan is to fly a new 6 MCF (~0.17 MCM) balloon for up to a day in 2008, and then to conduct a longer flight with a second balloon. The longer test flight would be similar to the highly successful LDB flights, but it would demonstrate altitude stability and potentially longer durations. The desire is to fly each balloon as long as possible. Possible launch locations include Sweden, Australia, and Antarctica, with the selection being dependent on the schedule of NASA balloon campaigns. Additional test flights will lead toward the planned ULDB Demonstration Mission carrying a ~2,700 kg payload to 33.5 km for 60 - 100 days by 2010 - 2011.

The Balloon Program has also developed a new heavy-lift balloon to provide a reliable 3600 kg lift capability. Several design improvements were implemented to ensure success. The first test flight was conducted from Ft. Sumner, NM on May 3, 2004. The development of a trajectory modification system is also being pursued to allow recovery over dry land and aid in alleviating the safety and geopolitical constraints for ULDB missions.

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