29th International Cosmic Ray Conference Pune (2005) **3**, 405-408

Ultra Long Duration Ballooning Technology Development

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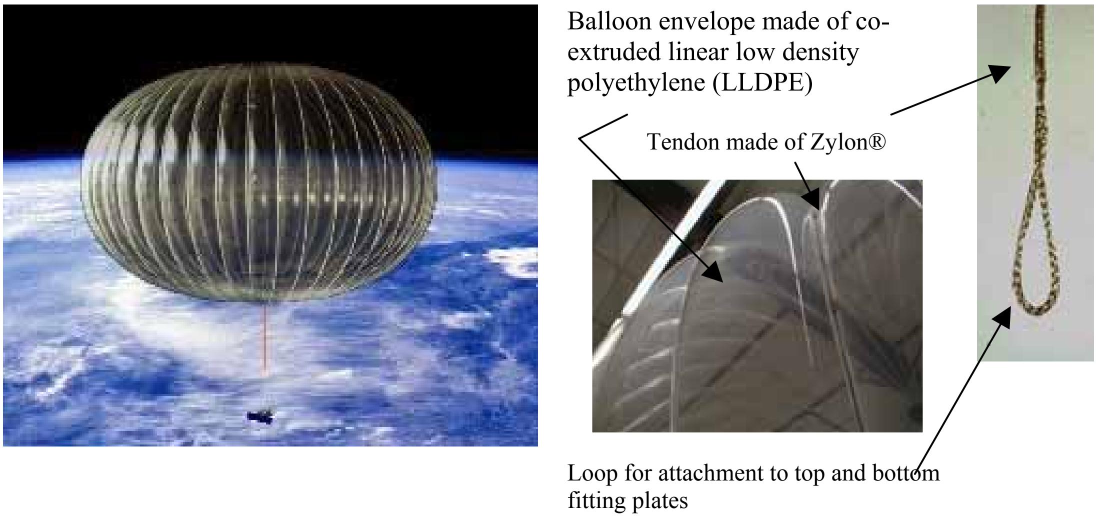
The National Aeronautics and Space Administration (NASA) Balloon Program is pursuing development of a super-pressure balloon that offers a new capability for balloon-borne science investigations by enabling extended duration missions at non-polar latitudes. The key development is an Ultra Long Duration Balloon (ULDB) system capable of flying at a nearly constant density altitude for up to 100 days at any latitude. The technology advancements include utilization of a new structural design, a co-extruded film for the balloon envelope, and structural integrity provided by the highest strength-to-weight fibers commercially available. The ULDB vehicle will be complemented with a newly developed and flight-tested ballooncraft support system. The system will provide power, data handling and communications via a Tracking and Data Relay Satellite System (TDRSS) high gain antenna capable of 100 Kb/s real-time telemetry. Another technology key to realizing this new capability is an active balloon trajectory control system, now in the design stage. ULDB missions would continue the ballooning tradition of training the next generation of instrument builders while facilitating world-class science investigations by a large community of scientists.

1. Introduction

Current scientific ballooning capabilities worldwide are generally limited to large and mid-size payload capacity zero-pressure balloons. These balloons are capable of maintaining their float altitude over the polar regions for extended durations, e.g., up to a record of almost 42 days during a recent campaign in Antarctica. However, they can maintain float altitude for only a few days at mid latitudes. Spherical super-pressure balloons, on the other hand, have been successfully flown for over six months at an average altitude of 16 km (100 millibars) with small payloads [1]. In response to the growing needs of the scientific community, the NASA Balloon Program Office is pursuing the development of a super-pressure balloon capable of maintaining high-altitude, long duration flights worldwide with a load carrying capacity comparable to current zero-pressure balloons.

2. Ultra Long Duration Balloon Vehicle Development

The proposed flight duration for these new balloon platforms is 100 days, or more, hence the label Ultra Long Duration Balloon (ULDB). The enabling technologies are improved lightweight membrane materials, high strength, high stiffness, light-weight tendons, and the pumpkin shape introduced theoretically in the 1970's [2]. The pumpkin shape balloon concept (Figure 1a) allows clear separation of the load-transferring functions of the major structural elements of the pneumatic envelope, the tendons and the film (Figure 1b). In this lobed structural design, the film essentially provides the gas barrier and transfers only local pressure loads to the tendons, thereby minimizing the strength requirements on the film. The tendons provide the global pressure-containing strength. Thus, the film strength requirement for the design pressure level depends only on local parameters. The selected tendon, a key member of the structure, is made of p-phenylene-2, 6- benzobisoxazole (PBO), which is manufactured by Toyobo Co. Ltd, Japan, and sold under the commercial name Zylon®.



(a) Pumpkin Shape Design (b) Major Components of Design

Figure 1. Pumpkin-shaped Design of the ULDB Vehicle

A successful test of the mid-scale ULDB vehicle with a 711 kg payload from Ft. Sumner, New Mexico in June 2000 broke the records for volume and payload mass on a super-pressure balloon [3]. This was followed by two full-scale test flights from Australia in early 2001 with 2038 kg payloads. Although not fully successful, the full-scale vehicle did reach float altitude and pressurize, while establishing a new super-pressure balloon volume and payload record [4].

The development effort has recently been re-planned to allow for a stair-step approach to the development as well as increased emphasis on the analytical modeling capability. Numerous scaled model balloons have been fabricated and tested to study their deployment and stability [5]. The analytical models have been compared to the physical results of the model tests. The first balloon size in the stepwise development is a 0.17 million cubic meter (MCM) balloon capable of lifting 1360 kg to an altitude of 30 km. A test flight of this balloon is scheduled for late August 2005 from Ft. Sumner, New Mexico. Following its successful test, a 0.34 MCM balloon will be developed to lift 1360 kg to 33.5 km. That will be followed by developing a 0.51 MCM balloon to lift 2721 kg to 33.5 km. It is planned to use the latter to demonstrate a ULDB capability for flying a 1000 kg science instrument for a target duration of 100 days. Subsequently, it is planned to develop a balloon large enough to extend the altitude for such massive payloads to 38 km.

3. ULDB Support Systems

While the balloon vehicle is being developed and test flown, the NASA Wallops Flight Facility (WFF) has developed and tested a support system that would complement the ULDB vehicle. This support system provides power, telecommunications, command and data handling including flight computers, mechanical structures, thermal management, and solar array pointing for these anticipated long duration missions. The Command Data Module (CDM) houses the power distribution system, command and data electronics, and telecommunication electronics.

The new support system was launched for the first time in Antarctica in December 2004 on a 1.1 MCM zero-pressure balloon carrying a suspended payload of 2750 kg. The mission set a flight duration record of 42 days after circumnavigating the Antarctic continent three times. Although the flight was operating nominally, the decision to terminate it was made for operation and recovery concerns. The ballooncraft consisted of the science instrument and the support systems, as shown in Figure 2. The Cosmic Ray Energetics and Mass (CREAM) science instrument was provided by the University of Maryland, College Park [6]. The CDM, which was attached to the bottom of the instrument structure, provided the science instrument with power and communications. The power system was designed to deliver 900 W of 28V-dc $\pm$ 4V unregulated power to the ballooncraft. It consisted of 10 solar arrays and 4 lithium-ion batteries that provide unregulated 28V power to the science instrument and 5, 12, and 28V (regulated and unregulated) power to the support system components. The batteries are capable of providing power at night for up to 11.5 hours for worst-case mid-latitude flights.

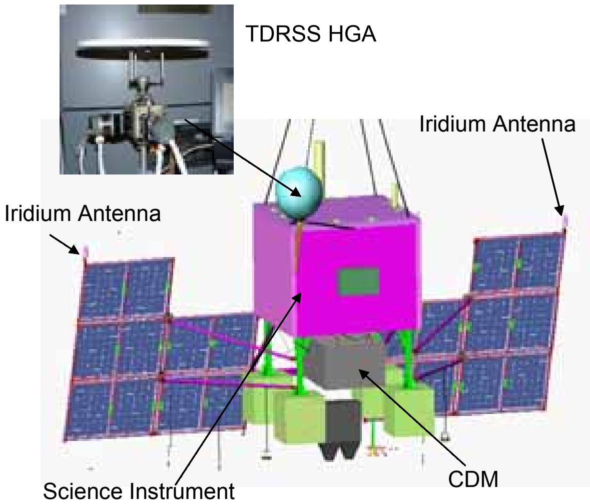


Figure 2. ULDB Gondola with Major Components Shown

The communication interface between the science instrument and the CDM is through the flight computers. The science flight computer is connected to the CDM flight computer by a 10Base-T Ethernet connection utilizing the Universal Datagram Protocol (UDP). All commands are uplinked via the TDRSS network, received by the CDM flight computer, and forwarded to either the science flight computer or the support system components. Telecommunications are provided through two independent systems. The primary communications are provided through the TDRSS. Two antennas support the system: an Omni data downlink antenna rated at 6 kbps; and a High Gain Antenna (HGA) downlink rated at 100 kbps. The HGA is capable of providing nearly continuous down-link, as well as scheduled uplinks, at 125 bps. Backup communications are provided by two Iridium-based communication systems. The primary Iridium system connected to the WFF flight computers can uplink commands and downlink data at a rate of 2400 baud. The second Iridium system is a stand-alone Over the Horizon (OTH) Termination System with its own control computer and Global Positioning System (GPS) receiver. The OTH is used to receive termination commands and route them to the Universal Termination Package (UTP), independent of the flight computers. The ARGOS based uGPSI is another independent backup communication system, which is used to receive GPS position data and transmit critical parameters and position data through the ARGOS ground system via email.

4. Trajectory Modification

Some level of trajectory modification will be required to realize the full ULDB potential. This technology, which is currently only at the conceptual design stage, is important for several reasons. Payloads need to be recovered on dry land in accessible locations, and heavily populated regions must be avoided due to safety concerns. Geopolitical concerns about over-flights of sovereign territories are of special concern for global ULDB flights. The concept feasibility assessment currently underway is for a solar-powered electric-motor/propeller based Trajectory Control System (TCS) to be operated in a latitude corridor maintenance mode. This system was selected as the concept showing the most promise for bringing a simple short-term solution to operational deployment. Initial efforts in feasibility analysis and concept design have concentrated on the ability of the propeller to generate enough thrust to meet the stated operational control authority requirements, while satisfying the constraints on launch size and power consumption. Propeller efficiency at balloon altitudes (low Reynolds number) is a major technological challenge. A system performance model based on the combination of a blade element propeller model, a linear DC electric motor model, and a drag model of the balloon envelope was created. System parameters were optimized for the baseline ULDB 0.57 MCM vehicle operating at 37 km. The TCS average continuous power consumption allowance will be no greater than 500W. The design goal is a system that requires less than 300W. The TCS will be designed to impart a wind relative velocity of no less than 1.3 m/s (approximately 1° of latitude per day). It will also provide a consistent level of control authority on demand, rather than dependence on favorable wind conditions. The system is being designed to be attached to the cable ladder of the flight train, in order to minimize impact on the gondola and improve the efficiency of the propellers.

5. Conclusions

Two key subsystems for ULDB development are the balloon vehicle and the associated support systems. The ULDB vehicle, which is currently in the final stages of development, is expected to be operational by 2007. The specially designed CDM support system has been flown successfully on a record-breaking 42-day flight that circumnavigated Antarctica three times. The CDM provides power, telecommunications, command and data handling including flight computers, mechanical structures, thermal management, and solar array pointing. A trajectory modification system is currently being designed to increase the capability of ULDB missions. The successful completion of the ULDB development efforts will place world-class science within the reach of a large community of scientists. The payloads can be flown longer at virtually any latitude and at nearly constant float altitude, thereby enabling new science investigations not possible on existing balloon platforms.

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