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DEVELOPMENT OF A SMALL STRATOSPHERIC STATION KEEPING BALLOON SYSTEM[1]

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Abstract

The development of a station-keeping platform in the stratosphere has long been an unattainable goal in the ballooning and LTA community. The applications of such a platform and the problems associated with operating such a platform are obvious. In past attempts, the goals of payload size and operational concepts have proven to be insurmountable. The use of a large, expensive system necessitated complicated ground launch and recovery systems. Miniaturization of electronic systems has allowed a usable payload of less than 25 kg. This light weight payload has allowed the use of a small, inexpensive aerostat that will be destroyed at the end of its mission. The overall shape of the system is a simple hemisphere on cylinder on cone blimp shape. There are several unique aspects of this system that help alleviate some of the problems of size and complexity. The first is that the system is small enough and inexpensive enough to consider the hull disposable. Design details along with flight test results will be presented.

1. Program Overview

The goal of the SOUNDER program was to develop a small, inexpensive stratospheric station keeping platform that could carry a modest payload of ten kilograms and maintain station for several weeks and that could be launched, operated and recovered with a minimum of ground support. Such a platform would have a multitude of applications, such as a communications relay, or as a platform for reconnaissance and atmospheric investigations.

2. Operational Concept

Traditional airships have always been designed for robust operations with the ability to survive in high surface winds. This requirement has allowed the vehicles to withstand hostile environments near the ground, but caused a large weight penalty. The design of a stratospheric airship is very sensitive to material and structural weight. Very early in the project, it was obvious that a non-traditional operational concept must be employed. The launch and ascent of the SOUNDER system resembles a scientific balloon flight instead of an airship. Shown in Figure 1, the SOUNDER system is launched with a helium volume only 5% of the fully inflated volume. As the airship ascends, the helium expands until the hull is fully inflated. When a stable superpressure float condition is achieved, the hull is aerodynamic in shape and in a horizontal attitude. The airship then starts the mission activities flying to way points and station keeping, while the payload

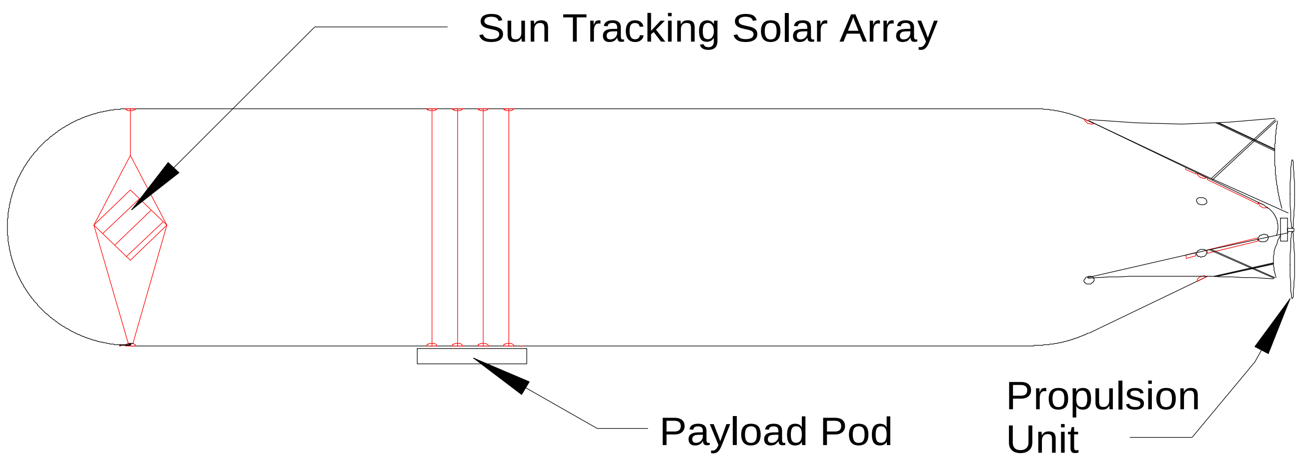


Figure 1 - Sounder Vehicle Configuration (patent pending)

performs it's function. After the mission is over, the payload pod is dropped away from the hull and is recovered by parachute. The hull is opened by a pyrotechnic device and descends on a separate parachute.

3. SOUNDER Subsystems

The major subsystems of the patent pending SOUNDER design include the hull, tail structure, propulsion system, power system, control system, and the ground station.

3.1 Hull

In order to demonstrate a system as quickly as possible, a torpedo shape hull was selected over the more traditional Class C shape. The prototype airship design has a hemispherical nose and cylindrical middle section both with a radius of 3.66 m. The overall hull length was 37.8 m. The hull volume was 1371 m^3. The hull was constructed from a single layer of 25 micron thick Biaxially Oriented Nylon-6 in eighteen longitudinal gores. No ballonets are used since changing flight altitude is not required. A liquid ballast system is used to adjust angle of attack.

The hull of the SOUNDER vehicle is designed as a superpressure balloon. Its function is to provide the buoyant lift to the system and maintain it for many days. As previously stated, lightweight design is essential in the success of a stratospheric system. The seams are assembled in a traditional superpressure balloon seam using a bi-taped butt seam. The attachment points for the payload pod and tail structure use the same adhesive as the seams. The payload pod is attached to the hull using a novel suspension method, which supports the weight of the pod both from the bottom and top of the hull.

3.2 Tail Structure

The SOUNDER tail structure provides longitudinal and roll stability to the system. The three tail fins are fabricated with biaxially oriented nylon and are attached to the hull with lightweight composite struts. The struts are held to the hull with attachment patches and guy lines. Masts that are folded back during launch support the three tail fins. These masts self-erect when the hull becomes fully inflated.

3.3 Propulsion System

A lightweight, tail-mounted, electric motor-driven propeller provides propulsion for the SOUNDER airship. A brushless electric motor drives a transmission that rotates the low speed 3 m diameter propeller. The control system monitors the propulsion systems speed, current, voltage,

motor temperature, motor controller temperature and motor torque. The folding propeller is fabricated from carbon fiber composite.

3.4 Power System

Power for the SOUNDER airship is provided by an array of solar cells. The array is internally-mounted in the transparent hull. A two-axis gimbal allows the solar array to be pointed at the sun independent of the airships orientation to maximize power production.

During the day, power from the solar array powers the airship's electronics and the propulsion system, while also charging the batteries. Lithium Ion rechargeable cells are used in the batteries, which provide power for the electronics and propels the airship at a reduced rate at night. The flight controller monitors battery charging, temperatures, voltage and current.

3.5 Control System

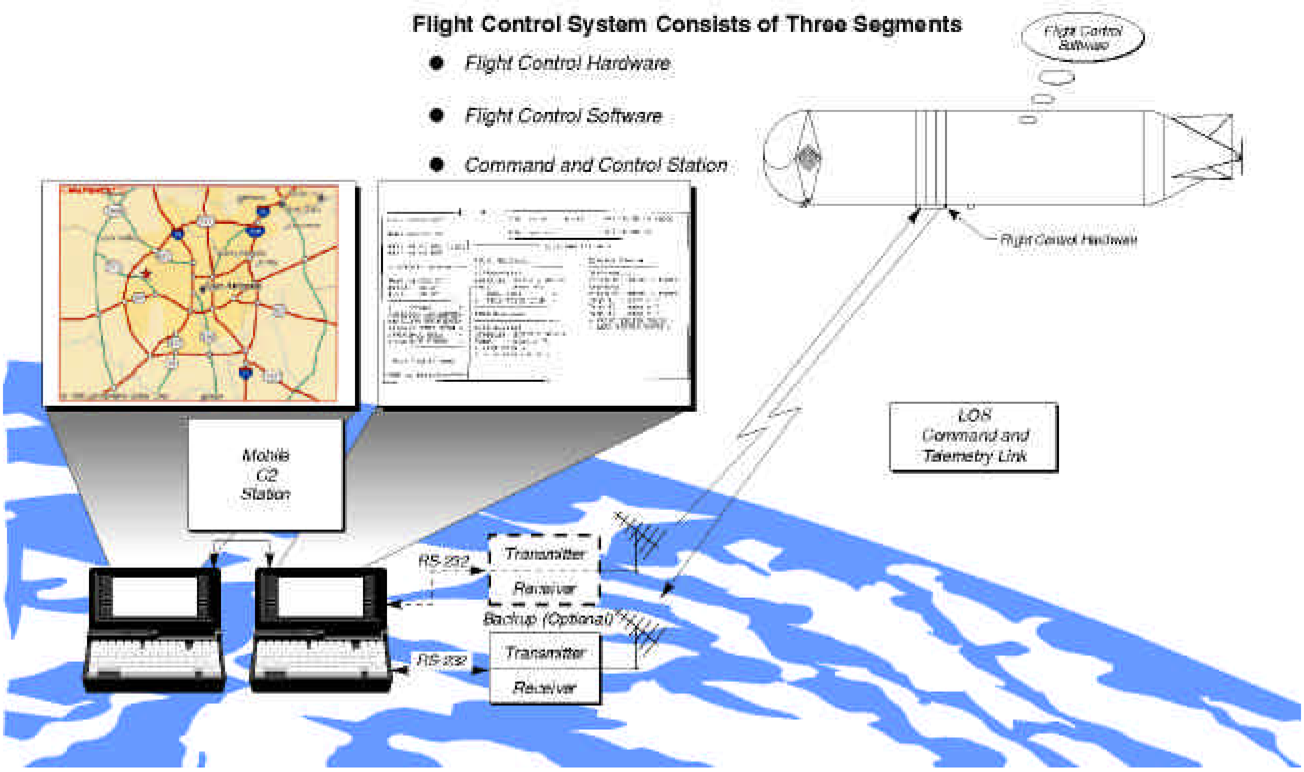
The flight controller is a microprocessor-based system that monitors and controls all of the airship's operations. The controller communicates with the ground station via redundant radio modems. There are three control modes;

- Full remote control of all airship systems
- Semi-automatic control and navigation
- Full autonomous control and navigation.

The flight computer uses information from the on-board GPS for location, ground speed, and altitude, while data from an electronic compass provides airship orientation, pitch and roll. The controller also manages the solar array pointing by calculating the position of the sun from the GPS, time and compass data. The position of the sun, relative to the airship, is calculated and the solar array gimbal motors point the array at the sun. The flight controller also manages all propulsion, communication, and power functions.

3.6 Ground Station

The ground station provides data presentation along with command and control function. A



standard personal computer running custom software is used as the operator's interface for the ground station. Communications with airship is proved by radio modems. Telemetry from the airship updates the status of all airship systems, GPS and direction data every at least every fifteen seconds. The airship's flight controller accepts commands at any time when sent from the ground station. All commands are echoed to the ground station for verification before execution. A second personal computer is used to present a map of the area with the GPS position of the airship plotted at near real-time.

4. Ground Testing

The SOUNDER system was tested with a variety of subsystem tests prior to the full-scale test flight in April of 1999. The first ground test article validated the design of the tail fin assembly and of the propulsion system mounting assembly. A full-scale tail cone was fabricated at Raven Industries and tested at Southwest Research Institute in the summer of 1997.

In the spring of 1997, a 50% scale model of the SOUNDER hull was tested to destruction at a local facility near the Raven plant. The hull was pressurized with helium and air to a pressure 9.7 mb which was well above the anticipated maximum working skin stress for the SOUNDER system. This test validated the gore cutting, seam assembly, and patch attachment methods.

In the fall of 1997 an engineering integration model of the SOUNDER system was fabricated and "flown" in the Southwest Research Institute facility. The integration model provided a test bed for every subsystem on SOUNDER. The hull, while 65% the length of the full-scale system, provided attachment points for the power system, tail structure, and payload pod. The integration model, shown in Figure 3, was fitted with a fully functional payload pod, solar array, and propulsion system. The hull was inflated with the systems installed and being tested under a variety

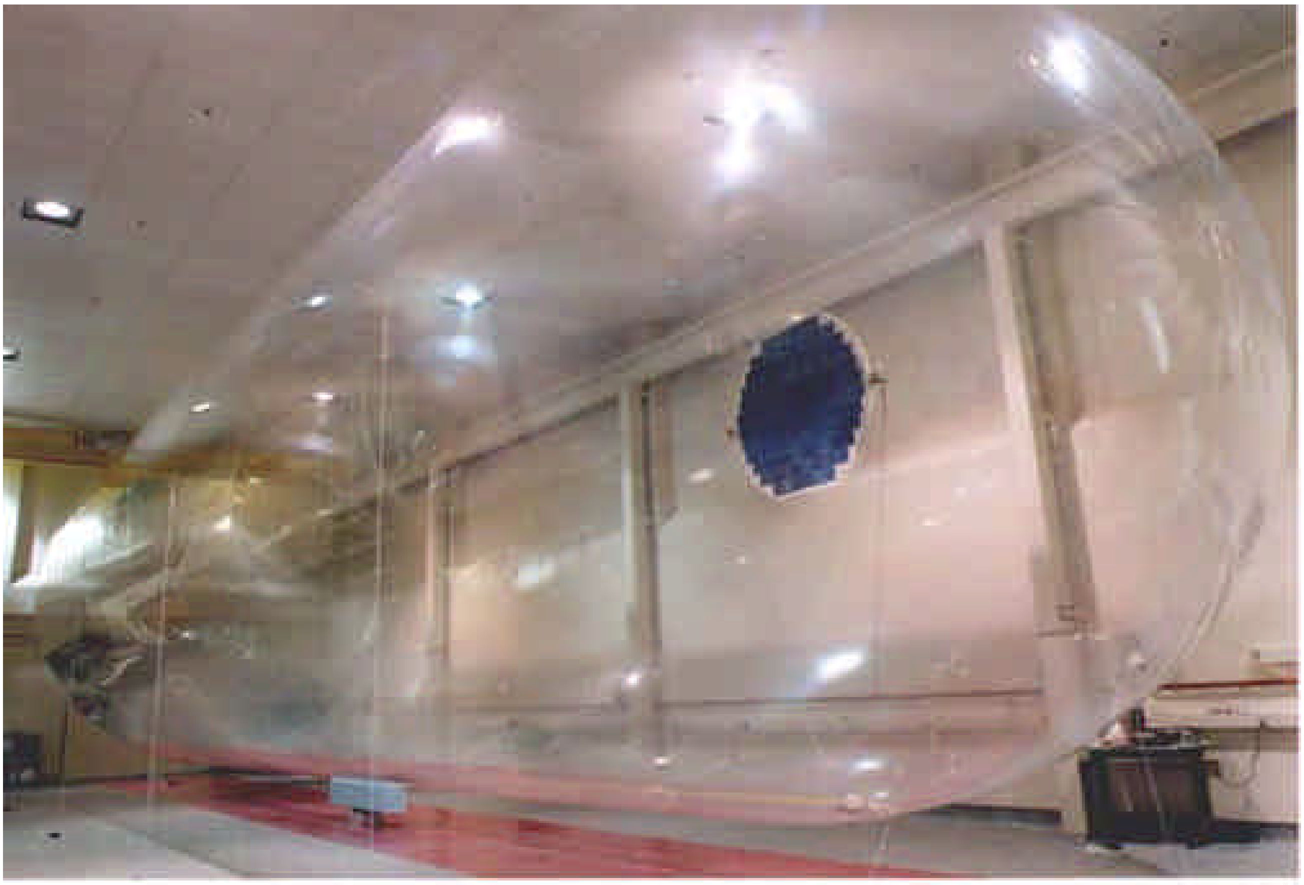


Figure 3 - Sounder Engineering Integration Model (patent pending)

of operational modes for over 26 weeks.

5. Flight Testing

5.1 Validation Tests

The flight-testing portion of the SOUNDER program consisted of a series of hull validation flight tests and a full-scale demonstration flight. The purpose of the hull validation tests was to fly free-floating superpressure balloons built with the same material and fabrication methods as the SOUNDER hull. The test flight phase began with short flights of spherical balloons and progressed to shortened versions of the SOUNDER hull. For the purpose of the free balloon test flights, the balloon envelopes were flown in a "tail down" orientation. On the morning of July 8, 1997 SOUNDER the launch team met to launch from Pratt, Kansas, but the weather was not favorable for that location. So the airship equipment was loaded up and the team drove northward until good weather conditions were found. A nearby airstrip was located, and permission to launch was received from the authorities. A SOUNDER hull was launched that afternoon from Red Cloud, Nebraska. This flight successfully reached its predicted float altitude of 22.4 km and maintained altitude through sunset. The flight was planned to continue out to the Western United States and terminate over the Pacific Ocean. Unfortunately, the balloon was not able to maintain altitude as it passed over a large Summer "super cell" thunderstorm. Calculations based on the descent speed of the system indicated that the balloon could have maintained altitude if 200 grams of ballast could have been dropped. No provisions were made for ballast drops on this flight.

5.2 Full Scale Engineering Prototype Flight

After waiting many months for the right weather conditions, the prototype was launched on April 27, 1999 from the flight apron of the Hondo Texas Municipal Airport. The launch bubble was successfully inflated with the internal solar array suspended from the top of the bubble. The airship hull was carefully erected, with a 27-kilogram equipment pod hanging from one side of the hull. When the partially filled airship was oriented completely vertical, the tail was released by the launch crew. The airship began its un-powered ascent to its final float altitude of 22 kilometers. As the helium began to completely fill the hull, the airship successfully transitioned from a vertical ascent orientation to a horizontal orientation. The video camera system successfully transmitted the images as the airship made this important transition.

The communications system transmitted telemetry and received commands from the ground station to execute various tests. The solar array worked well in automatic sun tracking mode, as well as in manual command mode when the video camera mounted on the back side of the solar array needed to be pointed in certain directions.

The differential pressure across the hull stabilized at 5.6 millibars, which corresponds to a nominal circumferential stress of 80.6 MPa. Figure 4 is a video frame capture from an on-board camera mounted in the back of the gimbaled solar array.

Upon termination of the test, the command to drop the equipment pod and vent the helium was executed. A video camera mounted on the top of the equipment pod captured the successful extraction, deployment and inflation of the recovery parachute. The equipment pod transmitted its GPS position to the ground station during the descent phase, and was recovered soon after landing.

6.Conclusions

Resulting from careful design and fabrication, a superpressure airship made from Nylon-6 was successfully flown while stressed to a level of 80.6 MPa. The biaxially oriented Nylon-6 and the new adhesive tape system were tough enough to withstand repeated handling. The flight hull was packed and removed from its shipping crate a total

Figure 4 - On-Board Camera View From Inside the Hull Looking Toward the Tail. Balloon is at 22 km altitude at this point.

of 5 different times. As the airship entered float, the hull survived significant violent motion without fracturing. The results of this test show that a superpressure airship with an internal-mounted solar array and rear-mounted propulsion can successfully fly at stratospheric altitudes.