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UNMANNED POWERED BALLOONS

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ABSTRACT: In the late 1960's several governmental agencies sponsored efforts to develop unmanned, powered balloon systems for scientific experimentation and military operations. Some of the programs resulted in hardware and limited flight tests; others, to date, have not progressed beyond the paper study stage. This paper briefly describes the balloon system designs, materials, propulsion units and capabilities, and points out critical problem areas that require further study in order to achieve operational powered balloon systems capable of long duration flight at high altitudes.

HISTORY

The early balloons would only go up and down or float in the direction of the prevailing winds. In order to make the balloon more useful it was soon concluded that it should be "dirigible" or directable. Throughout the nineteenth century ingenious men such as Meusnier, Giffard, Tissandier, Renard and Krebs worked on this problem. They built manned airships shaped as spindles, torpedos, cigars, string beans and even whales. Their biggest problem was the lack of a lightweight, efficient power plant. The steam engine, while dependable, was very heavy. In 1852, Giffard built a small engine using steam, but it weighed 100 lb per HP. (Today's automobile engines weigh as little as 2 lb per HP, and airplane engines, less than 1 lb per HP.) Those early inventors experimented with feather-bladed oars and screw propellers turned by hand using a crew of eight men! Engines were built

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that used coal gas or hydrogen lifting gas from the airship. In 1884, Renard built an electric motor powered from a storage battery. Real progress in powered balloons had to wait for the invention of the internal combustion engine. In the 1890's the gasoline engine proved to be the long sought key to the (low altitude) propulsion problem. In 1901, Santos Dumont won the 100,000 franc prize for flying across Paris to circle the Eiffel Tower and return to his starting point. In the early 1900's Count Zeppelin started to develop big ships in Germany. The airship Clement Bayard II flew the English Channel in 1910 and made a 242-mile trip to London in 6 hours. Great progress continued throughout World War I into the 1930's. The blimp proved its usefulness during World Wars I and II. All of these airships flew at very low altitudes.

I will not dwell on blimps and zeppelins, since they are well recalled, but will now skip to the late 1960's when several U.S. Government agencies sponsored efforts with private industry to develop unmanned powered balloon systems for scientific experimentation and military operations. Some of the programs resulted in hardware and limited flight tests; others generated system designs and concepts that, to date, have not progressed beyond the paperwork stage. This paper gives an overview of these various programs.

BACKGROUND

For many years balloon flight managers have been minimizing the horizontal displacement of free balloons by preselecting the float altitude where the winds are known to be near minimum, monitoring the trajectory and correcting the drift by ballasting or valving to nearby altitudes where the wind will drive the balloon in the proper direction. This technique is based upon the seasonal atmospheric phenomenon illustrated in Figure 1. The westerly winds above easterly winds result in a transition level where the winds are essentially zero. Just above and below this level are bands of altitude where the winds are less than 10 knots. It was reasoned that if some small amount of propulsion could be added to a free balloon, the stationkeeping capability and flight duration in the minimum wind fields could be greatly enhanced. With some margin in available thrust, such a powered balloon is not limited to stationkeeping, of course, but can travel in any direction.

HIGH ALTITUDE FLIGHTS

High Platform I (HPI) was one of the earliest attempts at powering a balloon at high altitude. It was developed and flown by Goodyear Aerospace Corp. and Winzen Research, Inc. In Figure 2 the system is shown being launched. The program objectives were (1) to demonstrate that it is feasible to maintain a free balloon on station at high altitude using an electrically driven propeller; (2) to examine the accuracy and output of a simple, single-axis-oriented silicon solar array for application as the eventual primary power source. The program was limited in scope in that off-the-shelf hardware was required for all systems. This requirement necessitated using a natural-shaped balloon, which has an undesirably high coefficient of drag. Because of the high drag force the flight test was planned during a period of minimum upper atmosphere winds. The design goals were: (1) float altitude, 70,000 ft; (2) maximum airspeed, 10 knots; (3) maximum deviation from station ±50 miles. Flight duration was dependent on battery life. The balloon had a volume of 106,000 cu ft and was 63 ft in diameter. A 2.75 HP motor drove a 14-ft diameter propeller with power from 112 lbs of silver zinc batteries. The goal was to control balloon orientation and heading at an airspeed of 10 knots by remote control of a styrofoam rudder in the propeller slipstream. The wooden propeller was designed to provide 25 lb thrust at 1000 RPM. Total system weight was 555 lb of which 106 lb was balloon. HPI was launched in the early morning and ascended at nearly 1000 ft/min. On its first power cycle the motor was run for 31 minutes. Directional response to rudder commands was good with no evidence of instability, but time delay between command and rudder actuation, the rate of rudder movement, and the time required to calculate and verify the actual heading resulted in a rather erratic flight path. During the second power cycle the rudder control was erratic. Rudder response then disappeared and recovery procedures were initiated. The direct current motor, when recovered, was severely charred and showed evidence of brush arcing. During the first 30 minute power cycle the system did demonstrate the capability to fly into the wind at an airspeed in excess of 10 knots, and to change the direction of the flight path. The sun sensor consistently tracked the sun accurately enough to estimate the maximum output of the solar array. The results show that an electrically driven propeller is a feasible method of station-keeping a high altitude balloon.

The High Platform II program (HPII) began in early 1969. This effort was conducted by Raven Industries. The statement of work called for the development of a unique airship having a capability of operating for very extended durations at an altitude of 70,000 ft. The flight system is shown in Figure 3. A completely sealed superpressure balloon was required to provide a duration capability of greater than 6 months. Desired speed capability was 20 knots. The motor-propeller assembly was powered by solar cells. A 3/1 fineness ratio, Class C hull configuration was used on HPII because of its greatly reduced coefficient of drag compared with HPI. The envelope was constructed of a bi-laminate of 1.0 mil and 0.35 mil Mylar S and was 81 ft in length. Control surfaces on the hull included one vertical, stationary fin, one rudder, two horizontal stabilizers and two elevators. Rudder and elevators were servo motor controlled. The lightened molded foam propeller, 10 ft in diameter, was designed to operate at 360 RPM with an efficiency of 78%. Propulsion motor characteristics were: 0.25 brake HP at 8200 RPM with an input of 24 VDC; predicted efficiency, 72%. A belt speed reducer dropped the motor speed to the desired 260 RPM of the propeller. The power supply was a 300 watt CdS solar array of 13 panels. CdS cells were chosen over silicon because of their greater flexibility and lighter weight. The gondola supported the mechanical components of the propulsion system and an anemometer was suspended beneath the gondola. The airship gross weight was 136 lb.

In May, 1970, the airship was test flown. The tow balloon launch technique was used to better control the very fragile system. When the motor was turned on, the airship immediately swung into the selected heading. The system rose in altitude, indicative of a positive angle of attack and forward speed which provided the airship with some aerodynamic lift. After 76 minutes the motor was turned off. Reflected light falling on the solar cell array prevented further acquisition of accurate heading data. The experimenters concluded that the airspeed was 10 knots rather than 17 knots, and that the reduction in speed was due to too low a design value for drag coefficient (C_d = 0.11 rather than the design value, C_d = 0.045, which was based upon wind tunnel data), and mismatch between the solar cell array and propulsion system. They further concluded that a high altitude airship having a superpressure envelope to obtain extremely long duration flight, and thin film solar cells for power can be designed, constructed, successfully launched and remotely controlled.

POBAL (Powered Balloon) was an unclassified program started in 1969 by AFCRL with Goodyear Aerospace Corp. under contract to study feasibility of stationkeeping by remote control of a powered balloon at high altitudes. Both streamlined and natural shaped balloon configurations were considered, with reciprocating engines, turbines and electric motors as candidates for propulsion, and fuel cells, solar cells and batteries for electric power sources. As a result of this study an inexpensive system was designed for flight demonstration. The system built and flown by AFCRL, Figure 4, was larger, heavier and more powerful than High Platform I. For reasons of economy, the balloon, parachute system, rigging hardware and control system were off-the-shelf items currently used for conventional ballooning. A 711,000 cu ft, double wall polyethylene balloon was used on POBAL to carry nearly 4000 pounds to 60,000 ft altitude. An 8 HP DC electric motor drove a 35-ft diameter, FH-1100 helicopter rotor (through a gear reducer) at 200 RPM. Based on C_d=0.19, design speed capability was 15 knots, and duration, 8 hours - the life available from the residual, F-105 fighter starter batteries. (Nearly 2000 pounds of the payload were comprised of these batteries). Thrust direction was controlled by a rudder in the slip stream of the propeller. After the mission the balloon was expended and the gondola recovered by parachute.

The first flight was in September, 1972. All systems functioned for the first 43 minutes of power. The propulsion motor was then allowed to cool for 11 minutes and then another powered cycle was initiated. Various headings were commanded into the autopilot system during these powered cycles. The system also was flown via manual control of right and left rudder. After four power "on" cycles (3 hours of flight time) control of azimuth heading was no longer possible. It was then confirmed that the rudder had broken free of the payload. Subsequent examination of the failed rudder support tube indicated improper heat treatment after welding. The system did, however, attain air speeds in excess of 11 knots and demonstrated that the concept is feasible. It is felt that the design speed of 15 knots was not attained because of one or a combination of both of the following: (1) too low a design value for drag coefficient for the round balloon or (2) the propeller was not producing the calculated thrust.

LOW ALTITUDE FLIGHTS

Silent Joe I is shown in Figure 5. The balloon was a 5500 cu ft, Class C hull with a 3/1 fineness ratio developed by the Sheldahl Co. Design speed was 12 to 15 knots. The first version used two 3 HP McCulloch chain saw engines for propulsion. Steering was accomplished by varying the speed of either outboard-mounted engine. Problems were encountered in synchronization of the motor throttles and the gasoline engines were replaced with electric motors. This second version of Silent Joe I used two 2.5 HP electric motors powered by NiCd batteries for a planned flight duration of two hours. Silent Joe I was successfully flown on several occasions in Southeast Asia. It had well controlled performance at flight speeds of 10 to 12 knots.

Silent Joe II followed Joe I. Its configuration is shown in Figure 6. This program was conducted by Goodyear Aerospace Corp. and used the 150,000 cu ft Goodyear Mayflower blimp as the hull. The hull was modified to add a propulsion unit in the stern. The propeller was driven by a hydraulic motor, pressure for which was generated from a unit in the forward end of the hull. The propulsion unit had a servo-controlled pitch and yaw gimbal system for vectoring the propeller thrust in order to achieve flight-path control. Nine flights of Silent Joe II were conducted in 1968 and 1969.

Micro Blimp was a low altitude airship program accomplished by Raven Industries. The hull was Class C shape with a 3/1 fineness ratio. The system is shown prior to launch in Figure 7. Hull volume was 2750 cu ft, and length, 37 ft. Propulsive power was provided by a stern-mounted, 4 HP Wankel engine driving an 8-ft diameter, molded polyurethane, three-bladed propeller Directional control was obtained by gimbaling the engine-propeller assembly. Heading and pitch stability were maintained by an autopilot. Maximum cruise altitude was 5000 feet MSL and cruise speed, 30 knots. Maximum radio-controlled range was 5 miles with a control accuracy of 1500 ft. Endurance was 10 hours with a full load of fuel. Payload capacity was 20 to 50 pounds depending upon the amount of fuel carried. Many successful flights were made with the Micro Blimp. Its major problem was propeller breakage, but this was solved with propeller stiffeners.

STUDIES

Several programs generated system designs and concepts that, to date, have not progressed beyond the paperwork stage.

High Platform III, by Raven Industries, required the design of a solar-powered aerostat and the definition of a development program for a prototype system. The airship designed under the program has a volume of 600,000 cu ft. Envelope length is 309 feet and diameter, 62 feet. The airship is designed to be a constant altitude system and as such is superpressured. Nylon film is used for the hull. Fins are pressurized by a small air-compressor. Propulsion and control are accomplished by rear-mounted, gimbaled propeller powered by an electric motor. The power supply is a solar array. The system is designed to be capable of maintaining airspeed of 15 knots continuously for 4 months. Flight altitude is 85,000 feet. Payload capacity is 10 pounds.

Several assumptions were made throughout the design study:

(a) A high strength nylon film will be sufficiently developed for superpressure balloons.

(b) The coefficient of drag of the airship is 0.048.

(c) Pulse charging techniques can be developed to increase the life of the battery.

(d) Cd S thin film solar cells of characteristics equal to or better than the cells used on High Platform II will be available.

If these assumptions cannot be met, changes in system size or capabilities will result. The proposed High Platform III airship is shown in Figure 8.

The HASKV (High Altitude Station Keeping Vehicle) program reviewed all past efforts in high altitude powered balloon stationkeeping. A comprehensive analysis of various system concepts was undertaken and a preliminary design for a system was completed. Primary emphasis was placed on superpressure airships capable of flying for durations up to several months at altitudes ranging from 60,000 ft to 85,000 ft with speeds up to 30 knots. The major effort on HASKV was devoted to parametric analysis and trade-off studies of the many system components and concepts. Much valuable information was thus generated and reported upon in the HASKV Final Report. Using this information a system was designed that is similar to that proposed in the High Platform III Study. The major differences concern the construction of the balloon envelope and the use of the power cycle. The final HASKV design was for a vehicle capable of supporting a 200 lb payload at an altitude of 70,000 feet for a four-month duration. It is to be solar powered, to operate at 30-knot airspeed during the day and 10 knots during the night. This program was completed in 1973.

The AFCRL POBAL-S design effort with Raven Industries resulted in an airship very similar to the HASKV vehicle. The major difference lies in the system used to power the electric propulsion motor. You will recall that the HASKV airship is solar cell powered; POBAL-S obtains electric energy from a H_2-O_2 fuel cell. The fuel cell was selected so that more electric power, 500 watts, can be made available on a continuous basis to the user's payload. Duration is 7 days rather than 4 months for the solar-powered HASKV. Obviously, the two systems are designed for different operational missions. POBAL-S is shown in Figure 9. To summarize the capabilities of AFCRL's POBAL-S: it flies at a 70,000 ft altitude; has a payload capacity of 200 lb; continuous power of 500 watts for operation of the payload; speed capability of 16 knots continuously for a 7-day duration. The final report and drawings for the fabrication of a POBAL-S airship are due to be completed in the fall of 1974.

The U. S. Navy (NRL, NOL) HASPA (High Altitude Superpressure Powered Airship) is the largest active program in high altitude powered ballooning. HASPA is listed as a "study" only because the contract award for its development was still being negotiated at this writing. The goal is to carry a useful payload of 200 lb at 70,000 feet for durations exceeding one month. HASPA is to have a continuous speed capability of 15 knots, with maximum, shorter duration capability of 25 knots. Four flight tests are planned: (1) an unpowered flight to evaluate the launch technique and the integrity of the superpressured hull; (2) a battery powered flight to evaluate the propulsion system; (3) a fuel-cell evaluation flight; and (4) an all-up, long-duration, solar-cell powered flight. The program will take place over the next three years. The HASPA vehicle is shown in Figure 10.

SUMMARY

In the past six years much useful work has been accomplished without a great expenditure of funds. Several governmental agencies have been involved with all of the major balloon companies. The total result has not been outstanding, but, considering the very low funding and manning budget, and the magnitude of the problem, very good progress has been made toward achieving operational, long-duration, high-altitude powered balloons with usefully heavy payloads. The experimental systems that have been flown have clearly defined the remaining practical and theoretical problems to be solved. For example, future programs should spend more effort to obtain accurate drag coefficient measurements at the low Reynolds numbers encountered in the minimum wind fields. Another important area of uncertainty is the propeller design. More basic work is required to predict accurately the propeller performance in the 60,000 to 85,000 ft altitude levels. Propellers have not normally been used at those altitudes; conventional procedures for scaling from ground level data are not adequate. We also must make use of the modern analytical tools for accurately determining the dynamic stresses in the structure and their distribution over the airship surface. If the pressurized hull volume to support a usefully heavy payload is to be kept within manageable limits without sacrificing structural reliability, then the allowable weight, strength and elastic properties of the materials are critical design parameters. It is hoped that future high altitude powered balloon programs will benefit from the experience reported herein.

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FIGURES:

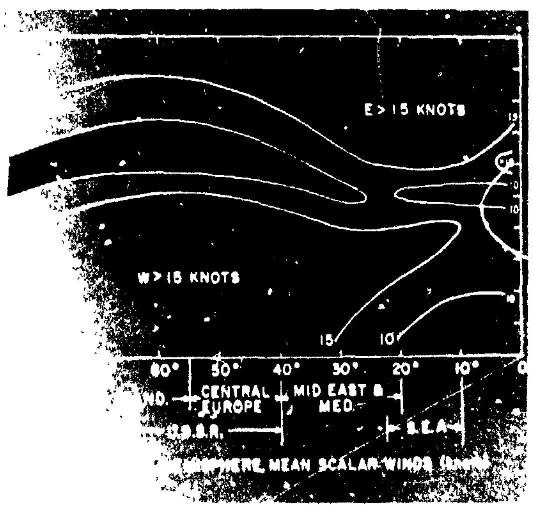
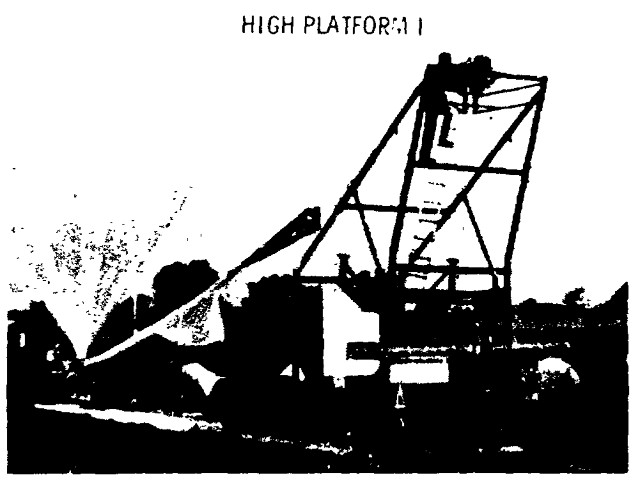


Figure 1 - Minimum Wind Field Phenomenon



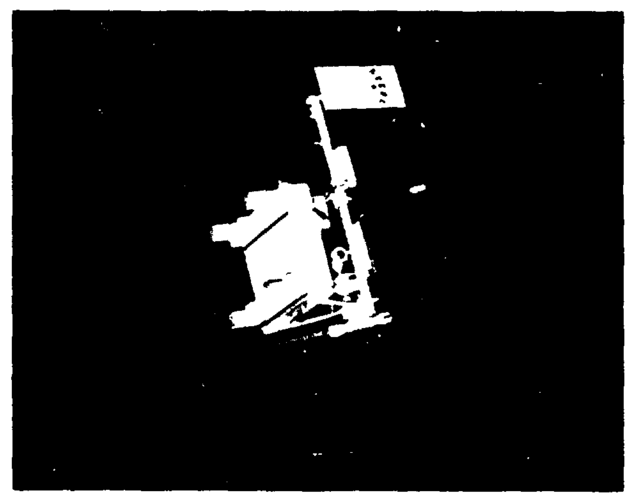
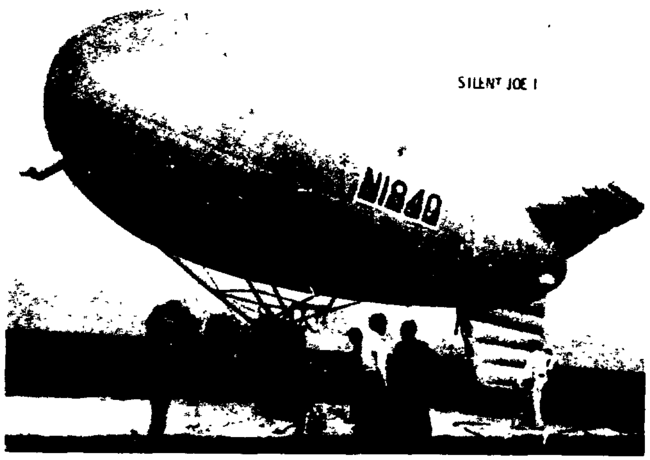


Figure 2 - High Platform I at Launch (Above).

Figure 3 - High Platform II During Test (Above-right).

Figure 4 - Pobal Undergoing Hangar Tests (Right).



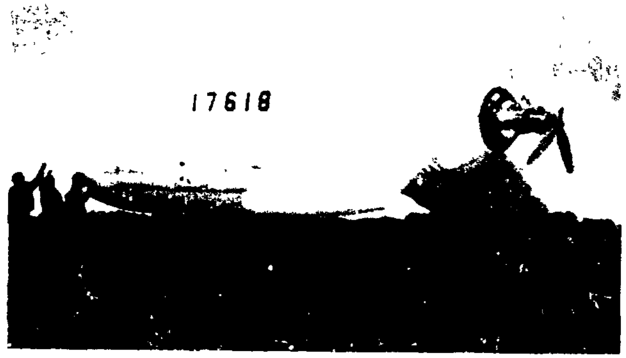


Figure 5 - Silent Joe I (Above).

Figure 6 - Silent Joe II in Flight
(Above-right).

Figure 7 - Micro Blimp at Launch
(Right).

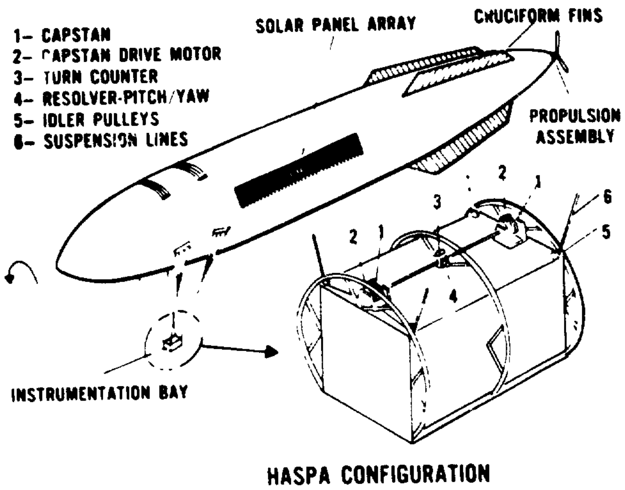


Figure 8 - High Platform III
Arrangement (Above).

Figure 9 - Pobal - S Arrangement
(Above-right).

Figure 10- HASPA Arrangement (Right).