N76-15069

TWO LIGHTER THAN AIR SYSTEMS IN OPPOSING FLIGHT REGIMES - AN UNMANNED SHORT HAUL, HEAVY LOAD TRANSPORT BALLOON AND A MANNED, LIGHT PAYLOAD AIRSHIP

R. A. Pohl*

ABSTRACT: Lighter Than Air Vehicles are generally defined or categorized by the shape of the balloon, payload capacity and operational flight regime. This paper describes two balloon systems that are classed as being in opposite categories. One is a cable guided, helium filled, short haul, heavy load transport Lighter Than Air system with a natural shaped envelope. The other is a manned, aerodynamic shaped airship which utilizes hot air as the buoyancy medium and is in the light payload class. While the airship is in the design/fabrication phase with flight tests scheduled for the latter part of 1974, the transport balloon system has been operational for some eight years.

INTRODUCTION

Balloon systems have been developed and are currently being used for short haul, heavy load transport operations. These balloons are designed to transport high tonnage log payloads over difficult or rough terrain. Such a transport technique has the obvious advantage of moving heavy loads in an airborne transfer mode without regard to terrain conditions. The balloon provides the lift or "skyhook" and a closed loop cable, powered by a double drum winch is the "power source" for lateral movement. Many years of full scale, commercial balloon logging have proven this Lighter Than Air method of short haul transport to be both reliable and economical.

Both government and commercial sources lead to the analysis of the logging balloon approach to ship-to-shore unloading and construction usage. Some preliminary field tests have demonstrated that a cable powered, natural shaped balloon can be used to unload cargo ships at beach

*Vice President, Raven Industries, Inc., Sioux Falls, South Dakota, USA

PRECEDING PAGE BLANK NOT FILMED

sites or unimproved harbors. Major construction companies are considering this method of materials movement for dam construction, pipeline installation, nuclear reactor locating and tower erection.

Opposed to this type of balloon and ground support system is the aerodynamic shaped airship with a light payload capacity and a buoyancy medium of hot air instead of helium. A hot air airship is being designed and constructed for manned free flight. Flight tests are scheduled for the fall of 1974. This vehicle has a 2.5:1 fineness ratio and is classed as a nonrigid airship. An aircooled power plant drives a propeller while a heat generator plus a powered fan is used to maintain the hull shape.

These two balloon systems, while being diametrically opposed in design and use functions, have one thing in common - they are both useful Lighter Than Air vehicles.

BACKGROUND

Natural shaped, spherical and aerodynamic configured balloons for scientific applications are usually thought of as being able to carry relatively light payloads to high altitudes. Such systems reflect various degrees of sophistication, including high altitude station keeping systems, long duration superpressure designs, and near-space environment thin film balloons with volumes in excess of 30 million cu. ft. Opposed to these high altitude systems are commercial heavy lift balloons which are utilized at very low altitudes. These systems are an outgrowth of the high altitude systems, since the basic technology of ballooning was developed from the high altitude, light payload balloons.

Low altitude, heavy lift balloons are characterized by payloads in the range of many tons, altitudes usually below 1000 ft., and nearly continuous operations. Such characteristics are the result of the need to provide for economic utilization of the system in commercial applications. This need for a high payload capacity for long time durations has led to the development of a class of natural shaped balloons which have nearly an all weather capability. Along with the basic balloon envelope, ground support equipment and operating techniques have been developed for this class of balloons.

Upon detailed analysis of the transport objectives, the natural shaped balloon design was selected. This shape was chosen since it has a high static lift efficiency, is not dependent upon aerodynamic lift, and can be fabricated with heavy coated fabrics which yield long life envelopes. Other parameters, such as the ability to withstand high shock loads entered into the balloon shape selection. Based on an excess of 150,000 hours of operations, the basic balloon design has proven to be correct.

On the other end of this flight spectrum is the aerodynamic shaped, manned, light payload airship which uses hot air as a lifting medium. Airships are usually thought of as being in two general classes - the rigid, classic Hindenberg types or the Goodyear advertising blimps. This paper describes a blimp type Lighter Than Air vehicle with a two man gondola and a nonrigid hull filled with heated ambient air for lift generation. The low drag hull shape, gondola, power plant and flight characteristic selection was based on costs, simplicity and ease of operation. It is intended only for relatively "fair weather" flight of hours' duration. With the nonrigid envelope, the vehicle is storable and transportable in a small truck and its base of operation can be mobile or fixed.

The following sections describe the heavy lift, unmanned natural shaped transport balloons and the manned light payload hot air airship - two vehicles with dissimilar shapes, characteristics and usage, yet both are in the class of Lighter Than Air flight vehicles.

NATURAL SHAPED, HEAVY LIFT, SHORT HAUL TRANSPORT BALLOONS

Balloon Design

The highest static lift efficiency of any balloon shape is a sphere, and the natural shaped balloon approximates that shape (Figure 1). The natural shape does not have any region of excess envelope material or extreme stress concentration. In this shape, the payload force is transmitted primarily into the balloon meridionally, and the circumferential stress is practically zero.

Shape - A natural shape is variable within bounds. A complex shape factor, called Σ, basically describes the relationship between the inflated height and diameter. The Σ value varies from 0 to 0.4, where at $\Sigma=0$, the balloon weight is small compared to the gross lift, and at $\Sigma=0.4$, the payload is light compared to the balloon weight. A high Σ value results in a fatter shape (i.e., diameter over height is larger). Heavy lift balloons are designed at low Σ values, since the balloon weight is relatively smaller than the gross lift.

An important feature of a natural shaped balloon is the ability of the design to carry heavy loads with relatively uniform load distribution into the envelope. This uniform distribution also enables the design to take shock loads with minimal introduction of stress concentrations and bending moments as is typical in our aerodynamic shape balloons. This basic balloon design property is of paramount importance to transport operations. A natural shaped balloon is also conducive to the addition of meridional direction, load carrying members to the gores, thereby permitting heavy payload designs.

Aerodynamic Considerations - The aerodynamic force coefficient properties of natural shapes are shown in Figure 2. Since a natural shaped balloon is a symmetrical body of revolution about the vertical axis, the force coefficients are independent of wind direction. This property is of prime importance in transport functions because the balloon must operate at or near full lift capacity regardless of wind direction. As shown in Figure 2, aerodynamic lift cannot be relied upon under normal wind conditions. In fact, the system will normally operate in the negative aerodynamic lift region. Since system design is predicated on static lift only, this coefficient is not considered in determining maximum usable lift. However, in designing a system for a specific payload, allowance is made, in the form of excess static lift, for predicted negative aerodynamic lift. This added lift is relatively small, since the negative lift coefficient is encountered only at lower wind speeds.

The drag coefficient for natural shapes generally falls between 0.2 and 0.3 for the Raynold's number range considered applicable in transport systems. While the drag coefficient range is considerably higher than that of aerodynamic shaped balloons, for the applications described herein, the advantages of volumetric efficiency, independence of aerodynamic force generation, (i.e., ability to operate at full lift capacity regardless of wind direction), high mass moment of inertia, gust stability, and uniform envelope loading far outweigh the advantage of a lower drag coefficient.

The natural shaped hull is very stable at low altitude operations due to its uniform cross section and the static lift. Gusty wind conditions effects on an inverted tear drop shape are minute in comparison to an aerodynamic shape, and oscillations are typically slow and quite limited in normal operating configurations.

Envelope stresses in a natural shape are due to the envelope internal pressure generated by the dynamic pressure and the distribution of the payload forces into the envelope. In a 530,000 cu. ft. balloon, the envelope stress, due to a 60 knot wind is 32.1 lb/in. (includes an over-pressurization factor). The maximum load input to a natural shape is at the skirt/balloon interface. Under a 60 knot flight condition, the load input at this interface is approximately 46,340 lbs. Assuming uniform loading, the skin stress is then 43.1 lb/in., and the gross load input in a 60 knot wind is 75.2 lb/in. The basic fabric strength is approximately 300 lb/in., thus the safety factor in the "material only" case is approximately 4. In the actual design, the applied loads are carried by the load webbings which are located on the balloon gores and the envelope material. A 530,000 cu. ft. balloon has 78 load webbings rated at 2,500 lbs. tensile. Considering the point of load input to the envelope, the safety factor relative to these applied loads will be in excess of 11.

Materials - The envelope material utilized in this class and shape of balloon is a 10.75 oz/yd^2 coated dacron fabric. This material has a tensile strength of approximately 300 lb/in., is UV resistant, and has a low permeability in the range of 0.3 liters/m^2/24 hours. The elastomeric coatings are also highly resistant to abrasion and wear.

A continuous loop of steel cable is used as the top end fitting for the load webbing terminations. Steel cables form the interface couplings between the load webbings and the bottom end fitting. Lightning protection is provided by a top mounted tower and multiple braided cables extending down the load webbings to the bottom end fitting. This fitting incorporates a multiple swivel, and is coupled to double tether lines.

These balloons are normally inflated to 90% of their full volume to allow for temperature and pressure altitude changes. At this inflation level, the lower portion of the balloon is slack. An ambient wind pressurization skirt is used to protect the lower slack portion of the balloon. The skirt also serves as a load transfer coupling between the balloon and the bottom end fitting.

Advanced Developments - Based on some nine years of design, test, and operational usage, the envelope design and materials are presently being modified to increase the operational limits of these balloons. The new envelope material has been developed with better physical characteristics. The natural shape has been modified to a "round top" configuration and the skirt is being eliminated. A ballonet is being installed to enable higher operational conditions. These basic features are being incorporated into a logging balloon currently under construction.

Typical Balloon Sizes

Heavy lift balloon sizes that have been or are currently in operation have volumes of approximately 240,000, 530,000, 700,000 and 815,000 cu. ft. In volumetric comparison to high altitude balloons, these sizes are small. However, since these units are used at very low altitudes, the payload capacities are large when compared to other types of balloons. The payload range for the above mentioned systems is 11,000 to 40,000 lbs.

The specifications for the balloon sizes that have been used operationally are shown below:

Balloon Specifications

Models	250K	530K	700K*	815K
Volume (cu. ft., max)	250,000	530,000	700,000	815,000
Diameter (ft.)	81	105	109	123
Height (ft.)	87	113	131	121
Approximate Balloon Weight (lbs.)	3,000	6,200	8,000	9,000
Net Usable Lift (lb.)				
Sea Level	11,000	25,000	33,000	40,500
5,000 Ft.	9,500	20,700	27,700	33,790
Approximate Wind Drag @ 45 mph, S.L.	2,400	4,100	3,100	5,600
Lift-to-Drag Ratio	4.6	6.1	11	7.0
Lean-Over Angle @ 25 mph	12°	9°	6°	8°
Estimated Lift Loss (lb./day)	25	40	45	50

*700K design based on advanced round top, no skirt configuration.

A 530,000 cu. ft. balloon, as shown in Figure 3, is normally flown in winds up to 40 mph. This 105 ft. diameter balloon is shown in the bedded down condition in Figure 4. In this condition, winds of approximately 100 mph have not had any detrimental effect on the balloon.

CABLE POWERED SHORT HAUL TRANSPORT

Natural shaped, heavy lift balloons were primarily developed for the logging industry. Large volumes of timber located in mountainous terrain cannot be harvested using ground skidding or cable systems due to their physical limitations, extensive road construction, and deleterious impact on the terrain. Other timber located in rough mountainous terrain is expensive to harvest with conventional equipment, and in many cases, cannot be transported from the cutting site to a road landing for hauling by truck to processing mills. Mountain road construction costs range from $20,000 to $75,000 per mile, and their usage is being restricted because of the damage to forest regions.

During the mid-1960's Raven Industries, Inc. and Bohemia Lumber Company initiated the development of an airborne log transport system using a natural shaped balloon. The balloon design was selected upon thorough analysis of the operating requirements and flight regime involved in carrying a payload of logs from the cutting site to the landing site (this phase of moving logs from the forest to a road site is called yarding).

Yarding logs with a balloon involves the use of the balloon to supply the lift and a winch powered cable arrangement for lateral direction movement. A typical layout is shown in Figure 5. The technique can be used practically anywhere a line can be strung - across steep slopes, valleys, swamps, high timber, rivers, and other obstructions. The winch or yarder (Figure 6), as it is commonly called, has two power driven

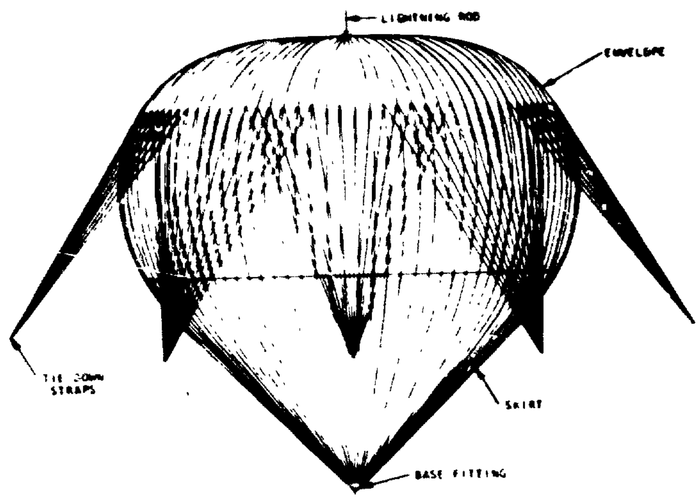

Figure 1. Natural Shaped Balloon Configuration

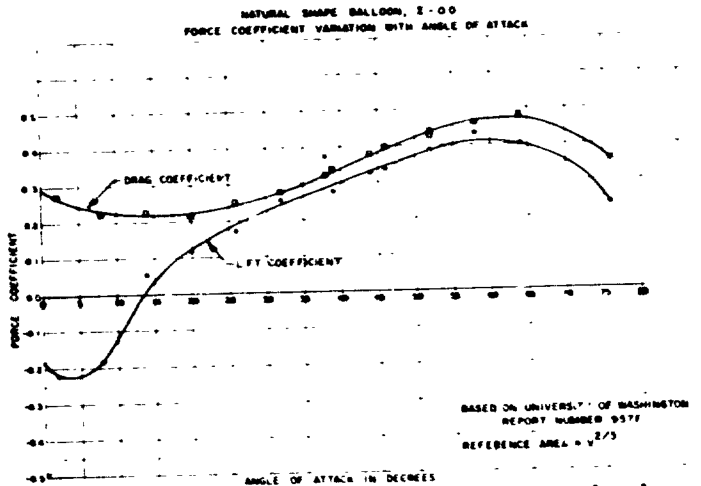

Figure 2. Force Coefficient Variation with Angle of Attack

Figure 3. Natural Shaped Balloon in Flight

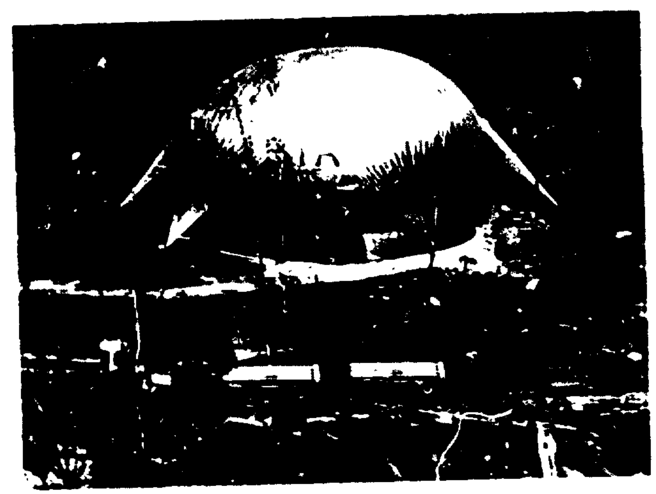

Figure 4. Natural Shaped Balloon in Bedded Down Condition

drums that can either be run in an interlock or independent manner. One drum contains the main line which extends to the balloon and powers the balloon on an inbound trajectory. The other drum is used to hold and power the haulback line for the outbound trajectory. With the mainline and haulback drums powered in interlock, both lines can be either taken in or let out, thus controlling the balloon altitude over a fixed point (i.e., the mainline and haulback act as a two-point tether line). The balloon is moved horizontally by letting out on either the haulback or mainline and pulling in the other line. Obviously, these two modes of coupling and uncoupling the haulback and mainline drums in either direction enable the balloon to be flown in a trajectory along the cable layout path. Maximum line speed is about 2,000 ft./minute.

Both lines from the drums go through fairleaders located on a tower on the front of the yarder. The haulback line is passed through a number of stump anchored tailblocks located on the upper end of the timber area being harvested. The free end is attached to the butt rigging, which is the main tether point of the balloon. The mainline extends from the yarder to the butt rigging, thereby forming a closed loop cable system.

The balloon is normally flown 250 to 300 ft. above the butt rigging, while the tag line, which extends down from the butt rigging, varies in length up to 500 ft. Chokers, which are short cables with quick couplers, are wrapped around the logs, and are connected to the tag line by a ring and toggle connection.

The "cable track" is initially set up with a lightweight straw line that enables the one in. steel cable to be strung through the tailblock layout under power from the yarder. Relocation of the cable layout in a given logging area is done by progressive movement of the tailblocks on the upper end of the area being harvested.

Yarding distances are presently limited to approximately 3600 ft. This distance is primarily determined by the mainline and the haulback drum size. Future systems, now in the planning stage, will extend this distance beyond a mile, and possibly, many miles.

A 530,000 cu. ft. balloon with 90% inflation level has a net lift of 25,000 lbs. at sea level. The nominal log payload range is 20,000 to 22,000 lbs., when allowances are made for the suspended cable and rigging.

The average transported load is lower than this, since the log selection process is done by gross scale estimates rather than a weigh-off. A turn of complete cycle time will vary from 5 to 8 minutes, depending on the yarding distance, log felling conditions, and timber density. In general, it can be said that the balloon logging system has a transport rate of 10 to 11 tons over distances up to 3500 ft. every 5 to 8 minutes. Actual tonnage rates vary from 50 to 100 tons per hour.

Balloon logging operations are conducted in winds up to 40 mph. Balloons have survived in partially sheltered bedding areas when winds in the vicinity have been recorded in excess of 100 mph. Two shift operations have been utilized with the use of portable illumination devices. During recent years some 150,000 hours of full inflation time have been recorded on natural shaped logging balloons. The only mishaps which occurred during this period were cases in which the balloon was flown in conditions outside the rated flight regime or because of malfunction of the ground support equipment. The cases were (1) balloon on tether in winds of 100 mph, (2) icing conditions, (3) balloon struck by lightning prior to installation of a lightning protection device, and (4) breakage of pull down cable due to overtensioning by operator.

Relocation of balloon logging equipment is relatively simple. The yarder is track mounted and can be moved short distances under its own power. Larger hauls are made by loading the yarder on a low-boy trailer. The balloon is moved in a tethered state 200 to 300 ft. above a transfer vehicle, which is shown in Figure 7. Both rubber tired and crawler type transfer vehicles are used. The transfer vehicle is loaded on a lowboy trailer for long moves. The equipment and balloon have been moved over distances up to 80 miles in one night.

Other balloon transport applications being evaluated include ship-to-shore unloading, construction operations (i.e., a pipeline installation, swamp logging, and mining). A typical ship-to-shore setup is shown in Figure 8. Construction projects are close to being tried in a number of different areas.

These balloons have been used by major logging companies since May of 1967 when a Model 250K was made operational in timber country near Reedsport, Oregon. The first Model 530K was put into logging service in April of 1969. Today there are four Model 530K balloons at various locations in Oregon, Washington, and Alaska. These logging balloons have demonstrated that the transport of logs over rough terrain by a cable controlled balloon is both reliable and economical. In general, the costs of transporting timber from the cutting site to the landing site range from $20 to $25/1000 bd. ft. Doing this same transport function with a helicopter will cost in the neighborhood of $100/1000 bd. ft. Direct comparison of these costs is not always justified since the total logging operation must be evaluated - both balloons and helicopters have their places in timber operations which require "free and clear of the ground" timber transport.

A turnkey balloon logging system which includes the balloon, yarder, running lines, cables, blocks, transport, helium, helium trailer, costs some $500,000 to $750,000 depending on the balloon size and ground support equipment. The continued use and expected expansion of this market proves that such capital equipment expenditures do yield a good return on investment. Both the federal and state governments are now specifying on numerous timber sales that logs must be yarded "clear and free of the ground" - in other words, they cannot use conventional logging systems for the most part on these particular logging sites.

The maintenance of a logging balloon is generally rather minimal. Upon initial inflation the balloon is thoroughly checked over the the lightning mast installed on top of the balloon. For the most part, the loss of helium through the heavy coated fabric envelope is minimal. A helium top-off (addition of helium after initial fill) is usually not required for the first 5 to 6 months. As the envelope material "wears in" top off operations are made on an as needed basis - usually 3 to 6 month intervals. Such helium additions are in the range of hundreds of pounds of lift.

Early in the program, the balloons were painted with elastomeric paints about every year. In recent years, new fabric coatings have minimized this - for example, the 530,000 cu. ft. balloon being used by Bohemia, Inc. has been in service two and one-half years and has not been painted

Figure 5. Typical Schematic of Logging Balloon Operation

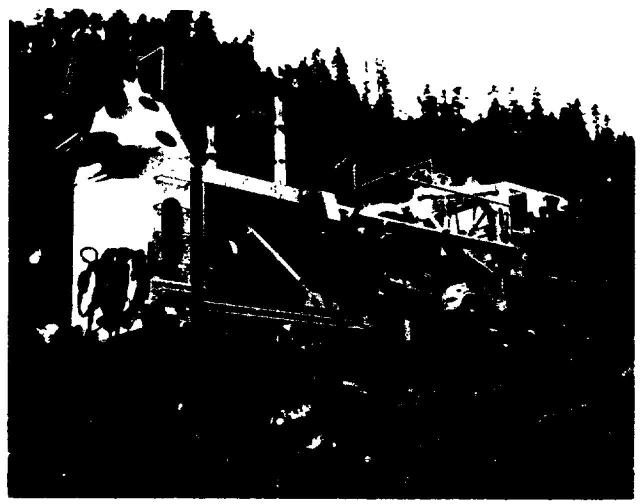

Figure 6. Balloon Yarder

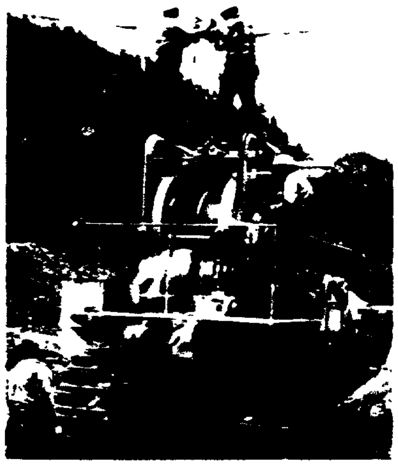

Figure 7. Balloon Transfer Vehicle

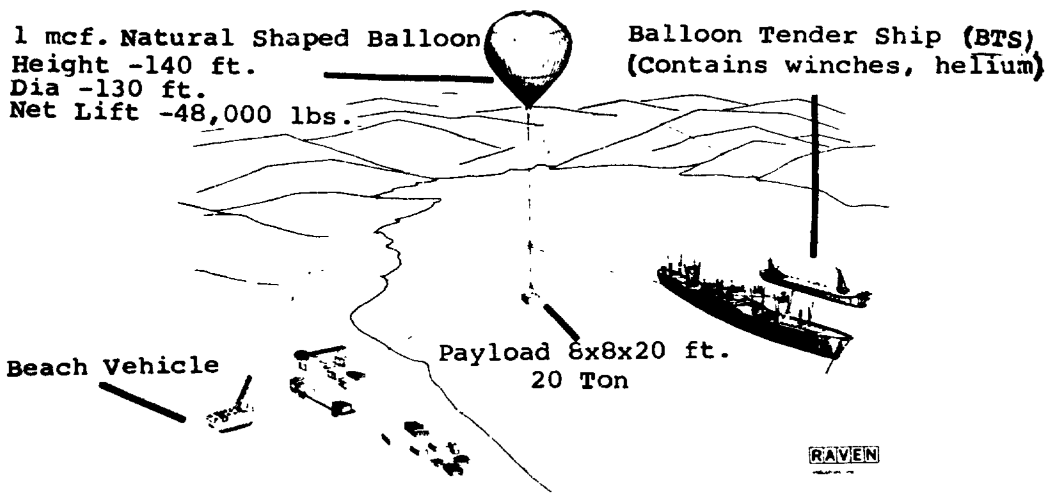

Figure 8. Typical Ship-to-Shore Balloon Transport Layout

since being put into service. Upon recent inspection of this balloon it appears that the coated fabric is still in a near new condition after some 13,000 hours of being at full inflation.

Some small holes do occur during logging. These are due to the balloon being struck by a branch, or some wear. Such minor holes are repaired in the field with a cold patch being applied by a crew member being suspended on a rope ladder from the top molly or by literally walking around on the top of the balloon should a hole occur on the upper portion of the balloon. Maintenance problems for the most part are much more prevalent in the ground support equipment than in the balloons. New ground support currently being tested in the Pacific Northwest should reduce these maintenance costs to a minimum.

Natural shaped balloons with high payload capacities and long duration flight capabilities have been developed for use as transport vehicles. Current commercial operations in the forestry industry have demonstrated that this family of aerostats is both reliable and economical as a primary lift component in an airborne log transport system. Other current and future transport projects indicate a rather high degree of versatility for this area of Lighter Than Air technology which is based on natural shaped balloons that are cable guided. Some recent developments indicate great promise for hybrid systems that increase the payload capacities, extend the transport distance and overall system efficiency.

HOT AIR AIRSHIP

Introduction

Hot air sport balloons with a natural shaped configuration are a reliable and economical method of free ballooning at low altitudes. These balloons are primarily used as sport vehicles and in some cases, for advertising and promotion. With an onboard burner(s) and a hydrocarbon fuel source for maintenance and control of the buoyancy state, the balloons float with the wind and have practically no directional control other than the wind vector variations as a function of altitude. This flight regime is acceptable for the type of flying done by sport balloonists.

Hot air is an economical buoyancy medium for relatively short duration, low altitude flights with manned balloons. The obvious advantage of thermal buoyancy in a balloon is that it can be "generated" as needed or desired by the combustion of liquid fuels in relatively simple onboard burners. This basic fact has made hot air ballooning a popular sport that is quite commonplace throughout the United States.

The obvious next generation of hot air ballooning is a thermal airship with a low drag hull and an onboard power plant so the balloonist can control his direction. Such an airship is presently under construction this year. The general design and operating characteristics of this vehicle are described herein. This project and the vehicle are called STAR.

Hull Design

The hull of the STAR airship is based on a class C shape with a fineness ratio of 2.5:1 and a volume of 140,000 ft^3. These parameters result in a hull length of 120 ft. and a diameter of 48 ft. (Figure 9). Four inflatable fins are located on the aft hull section for stability and directional control. The fins are inflated through gas transfer ports located in the fin root/hull interface. Interweb sections maintain the fin thickness and determine taper angles. A movable rudder section is located on the upper vertical fin while both horizontal fins have elevator control surfaces.

The hull is constructed of a urethane coated polyester ripstop fabric (3 oz/yd^2) with MD/TD strengths of 100 and 70 lb/in. Longitudinal gores constructed of panel sections are utilized to maximize the fabric properties. The hull is a single compartment cell with catenary suspensions located near the top of the hull as shown in Figure 10. These load suspensions are used to transfer the gondola loads into the hull at maximum lift locations and distribute the center of buoyancy/gravity intersection planes. Temperature distribution in the hull is anticipated to yield a somewhat uniform center of buoyancy area; however, one of the twin burners used to supply heat to the ship is gimbaled to permit burner plane variations along the longitudinal axis.

Heat Generators and Hull Pressurization

Twin burners with a combined output of 4.5 million BTU/hr. are used to heat the air in the hull. The burners are located on the top of the gondola and within the hull and are combined with a pressurization fan to maintain the hull at 0.5 in. of H_2O. Liquid propane is used as a fuel and is contained in stainless steel tanks located in the gondola. Both the burners and pressurization fan are standard hot air sport balloon components. The pressure fan is powered by a small gasoline engine. A redundant feature of the fan power source is an engageable power takeoff from the main power plant.

Gondola and Power Plant

A fabric covered, aluminum frame gondola is located under the hull at a location which will yield a 6° negative angle of pitch with zero power application. This ten foot long gondola is configured for a side-by-side pilot/copilot in the forward section with the main power plant, fuel tanks, and blower/burner in the aft section (Figure 11). A pusher propeller located on the gondola aft section is driven by a 65 horsepower Revmaster Volkswagen aircraft engine with single ignition starter, and a 12 volt generator. Aviation 100 octane gasoline is the fuel source. An annular ring duct around the prop is used to maximize prop efficiency and thrust direction.

Controls and Instrumentation

Controls include rudder, elevators, propane flow to burners, main power plant throttle, burner override, propane pressure to burners, blower speed and aft burner gimbal. These basic controls are used for flight direction and internal hull temperature variations for gross lift modification. As is commonplace in manned hot air sport balloons, the large inertia mass of the ship will yield a somewhat slow response to the heat and/or rudder-elevator control inputs.

The panel in the forward section of the gondola will have the standard engine condition monitoring instrumentation. Also included on the panel are an airspeed indicator, altimeter, rate-of-climb, balloon internal temperature, hull pressure, fuel quantity and pressure gauges.

Operations

The STAR airship with its 65 horsepower engine is intended to have a service ceiling of 4,000 ft. at a gross load of 2,030 lbs. which includes 78 gallons of propane and a 100 lb. payload. The anticipated flight duration is three hours. Under these conditions and at the maximum available thrust of approximately 350 lbs. STAR is predicted to have a top airspeed of 25-30 mph.

As has been noted, airship response to control surface deflection will not be rapid. For example, analysis indicated that at low airspeeds (up to 10 fps), large elevator deflections will have little impact on the pitch of the airship. This analysis predicts elevator deflections in excess of 40° (upwards) to achieve trim at airspeeds in this range. On the other hand, at maximum speed, response in pitch to elevator deflection is predicted to be quite sensitive, to the extent that pilot experience will be a major factor in achieving level flight. Nevertheless, since altitude control of STAR is for all practical purposes a function of thermal rather than aerodynamic considerations, these response characteristics will not affect system usability and the flying attitude accepted by the pilot will be largely a function of the flight conditions and his comfort.

Figure 12 indicates the elevator deflections required to achieve an angle of attach of 0°. The system weights for which this information has been derived are as follows:

2187 lb. - Full load, Pilot and Copilot, 100% fuel.
2007 lb. - Full load, Pilot only, 100% fuel.
1827 lb. - Full load, Pilot and copilot, 20% fuel.
1647 lb. - Full load, Pilot only, 20% fuel.

In this figure, the lack of low speed response is evident. Also it is here seen that the low speed "reversal" of control surface deflection at low speeds common in airships is predicted for STAR. However, since the medium static pitch angle is only approximately 6° at the maximum gross weight (approximately -1.5° at the minimum listed system weight), it will probably be found that no elevator deflections will be necessary at these speeds to give acceptable performance. This region of the flight envelope in which reversal occurs will be a factor only under higher gross weight conditions.

The size of all control surfaces was selected on the basis of those surfaces which have provided controllability in previous manned and unmanned airships. This predicted controllability in yaw has been verified by comparison to wind tunnel data available in general circulation for a specific airship model (not STAR). However, response to rudder deflection is expected to be quite slow, to the extent that it may be necessary under certain conditions to accelerate to the upper range of airspeed in order to achieve the required response characteristics. Control surface deflection will be achieved through a cable and hand crank system which will provide some mechanical advantage in deflecting the surfaces. Application of this force will be near the trailing edge of the control surfaces.

Normal flight operations are to be VFR in light to moderate wind conditions. Both takeoff and landings are the same as normal airship operations. VTOL operations will also be possible in light wind conditions. Since the hull is nonrigid and the buoyancy medium is generated onboard, the vehicle will be inflated at the takeoff site and deflated upon landing. The deflated hull, along with the gondola, can be transported with a medium sized truck.

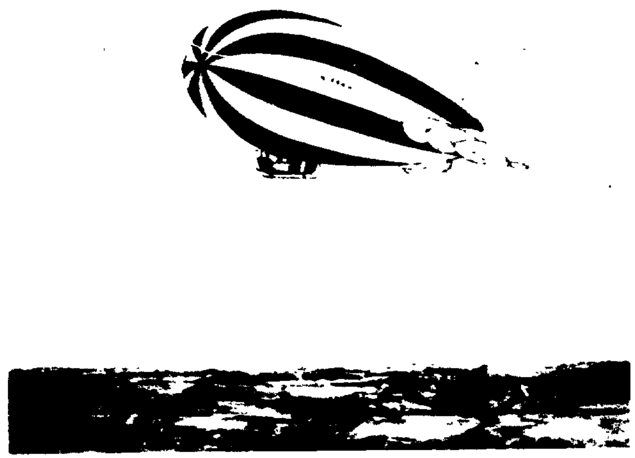

Figure 9. STAR Thermal Airship

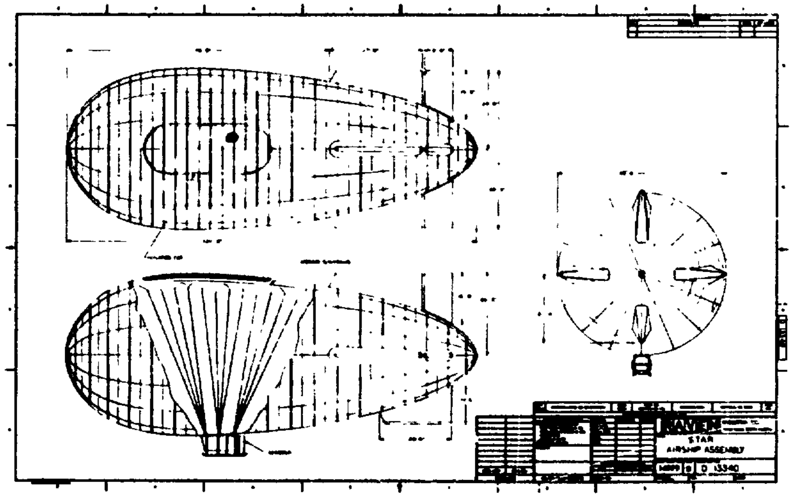

Figure 10. STAR Airship Assembly

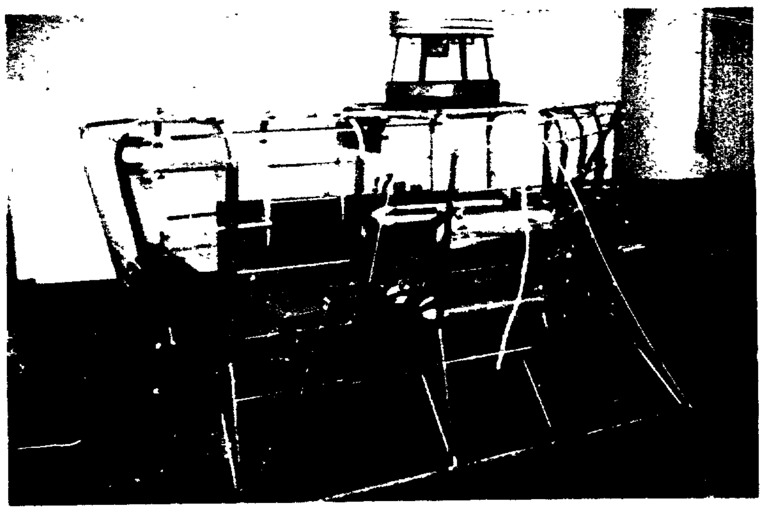

Figure 11. STAR Gondola Under Construction

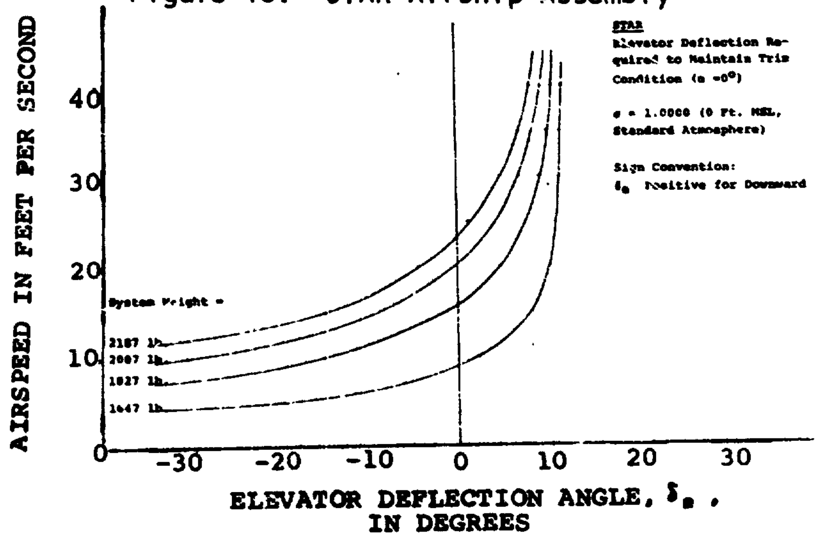

Figure 12. Elevator Deflection Required to Maintain Trim Condition

Handling lines are located around the hull to aid in operations. A deflation panel located on the hull topside will be pulled out by the pilot upon landing. The type of "pull out panel" is the same basic configuration as that used in hot air sport balloons. Once the hull is deflated, the panel is manually replaced.

The STAR vehicle is intended for the low and slow flight regime with directional control. It is designed for ease of maintenance, low operational costs and relatively simple logistics.