Tethered Aerostats Used in TCOM Systems

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Tethered aerostats are employed as high-altitude platforms for a wide range of communications services. These aerostats are capable of reliably supporting large electronics payloads at altitudes between 10,000 and 15,000 ft, to provide services over ground areas in excess of 50,000 square miles.

Aerostat System

IN this paper a description is given of the aerostat and mooring systems (Fig. 1) that are currently being utilized along with their lightning protection and telemetry and command systems. Currently, TCOM has two different size aerostats in use: the Mark VII and the Mark VII-S (stretch), shown in scaled comparison to a 747 jet transport in Fig. 2. The Mark VII has a minimum volume of 250,000 ft^3, a length of 175 ft, a diameter of 56.8 ft at the maximum point, and a tail span of 81.5 ft. The Mark VII can carry approximately 4000 lb of equipment to 10,000 ft and is designed to operate safely in 100-knot winds at altitude. The "stretched" version of this aerostat has a minimum volume of 350,000 ft^3 and is designated the Mark VII-S. This aerostat has an overall length of 215 ft, a vertical tail span of 99 ft, and a load-carrying capacity of approximately 8000 lb at 10,000 ft or approximately 3700 lb at 15,000 ft. Since all TCOM aerostats have similar construction and flight characteristics, the following discussions are directed to the Mark VII but are applicable to the Mark VII-S as well, except as otherwise noted.

Description

The aerostat (Fig. 3) is a body of revolution with four tail fins spaced 90 deg apart on the aft section of the hull. A lift-to-drag ratio of 3-to-1 is normally obtained. Electrically powered blowers and release valves operate automatically to maintain proper pressurization of the aerostat.

The hull is inflated with helium, an inert gas, to provide safe buoyant lift. In the design of such a vehicle, size is governed primarily by the volume of gas required to lift the aerostat, payload, and tether cable to a given altitude in a zero-wind condition. The fins and windscreen are air-filled and are operated at slightly lower differential pressures than the hull in the Mark VII. In the Mark VII-S, the hull and fins are operated at the same differential pressure with the windscreen pressures slightly lower.

The fins impart static and dynamic flight stability. They return the aerostat to its designed equilibrium position if it is displaced from that position. Selection of the fin shape and structural type was based on extensive analyses and tests of both rigid and inflatable structures.

Ballonet System

To maintain the proper aerodynamic shape of each aerostat and prevent cupping or dimpling of the nose under wind pressure, the pressure within the envelope is kept slightly above the ambient atmospheric pressure by a ballonet-blower system. Illustrated in Fig. 4, the ballonet-blower system consists of a curtained-off volume within a fixed-volume envelope into which ambient air is pumped under slight pressure. This air-filled compartment is formed by a flexible fabric or diaphragm. As the aerostat ascends, air is expelled from the ballonet, through valves, due to expansion of the helium which increases pressure on the ballonet diaphragm. As the aerostat is retrieved from altitude, the helium contracts and air is automatically forced into the ballonet compartment by electrically powered blowers. To prevent overpressurization of the aerostat and possible structural failures, pressure relief valves are incorporated in the design.

Load Bearing Patches

Aerodynamic and aerostatic loads are applied to the tether cable through suspension lines and load bearing patches attached to the surface of the aerostat.

Airborne Power Generator

In-flight power for the aerostat and electronic payload is generated at the ground station and carried aloft via conductors within the tether cable. This power system provides 25 kW of three-phase, 400-Hz ac power at the aerostat. The tether contains three insulated copper conductors armored by two layers of galvanized, improved plow steel. The steel layers provide the tether strength member and a conductive path for carrying lightning currents to ground, protecting the cable from these currents.

Other Aerostat Components

For initial inflation, and in the event that additional helium must be added to the aerostat during periodic ground maintenance, a hose is connected to a helium port on the vehicle. Helium and air access sleeves on the aerostat permit entry into the vehicle for interior inspection and internal repair activities.

Aerostat Performance Summary

Aerostat performance is summarized in Table 1.

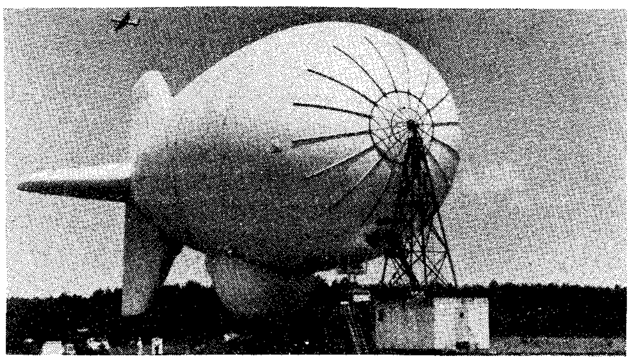

Fig. 1 TCOM aerostat and mooring system.

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Materials

The realization of an operational all-weather, tethered aerostat resulted from advances made in various technical disciplines. Perhaps the most important work was the development of improved flexible materials used in the construction of the hull, empennage (tail fin assembly), and ballonet. For the sake of brevity, only the hull material requirements and testing will be addressed in this paper.

The hull envelope for a nonrigid aerostat must possess high strength-to-weight and low permeability. Depending on anticipated hazards, it may be essential that the envelope resist the attacks of weather or that repeated handling not degrade other required properties. Minor damage should not lead to catastrophic failure. The cost of the hull envelope, although secondary to most other requirements, must remain within reason. Lastly, high-strength sealing techniques must be available to weld panels into a continuum that possesses all essential envelope characteristics.

Strength

Tensile

The basic hull material strength requirement is a safety factor of 2 in a 70-knot wind at 120°F.

Shear

A minimum shear modulus (modulus = stress/strain) of 200 lb/in. is required.

Tear

The tear hazard is spontaneous tear propagation initiated by minor damage to an inflated vehicle. Minor damage of 1 in. or less should not lead to catastrophic failure.

Ply Adhesion

The minimum required peel value is typically 10 lb/in.

Flex Life

The hull material must be capable of surviving hundreds of crease cycles.

Permeability requirements limit outgassing to 0.5 liter/m^2 per 24 hr, maximum, for virgin hull material. Durability requirements set a design lifetime goal of 15 yr.

Seams

The strength, permeability, and durability requirements apply as much to seams as to the envelope material itself. Seams must provide panel-to-panel continuity for all required envelope characteristics without introducing deficiencies such as excessive stiffness.

Table 1 Aerostat performance summary

	Model number	
	Mark VII	Mark VII-S
Weight	5000 lb	6400 lb
Dimensions		
Hull volume	267,000 cu ft	375,000 cu ft
Overall length	175 ft	215 ft
Hull length	148 ft	188 ft
Hull diameter	56.8 ft	56.8 ft
Fin span	81.5 ft	81.5 ft – horizontal 99.0 ft – vertical
Payload enclosure width	25 ft	25 ft
Payload enclosure height	15 ft	15 ft
Operational performance		
Wind speed @ MSL	90 knots	90 knots
Wind speed @ 10,000 ft	105 knots	105 knots
Ceiling altitude above MSL (std day)	15,000 ft	15,000 ft
Maximum load (payload, power plant, fuel) (std day)		
@ 10,000 ft	4000 lb	8000 lb
@ 15,000 ft	1000 lb	3700 lb

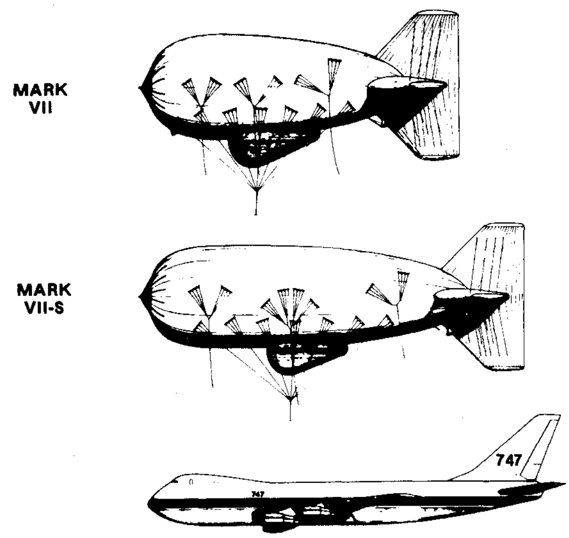

Fig. 2 TCOM aerostats – scaled size comparison.

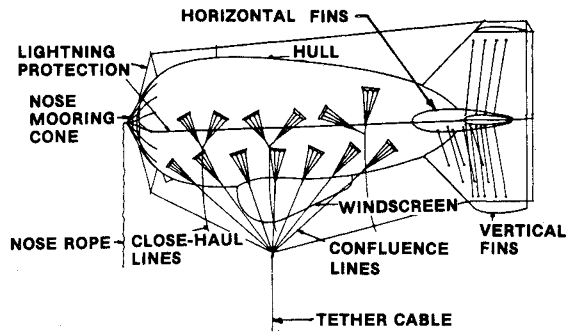

Fig. 3 Aerostat configuration.

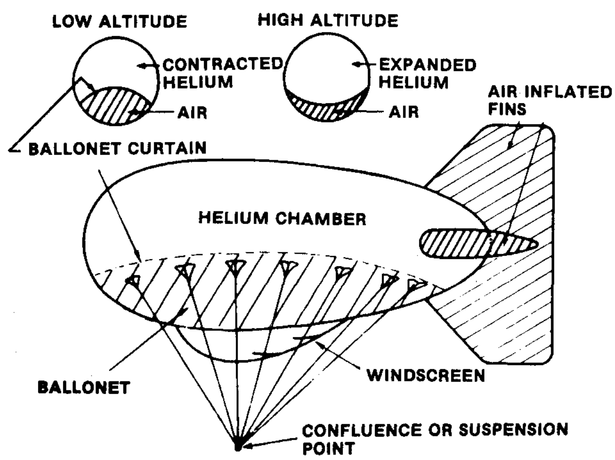

Fig. 4 Internal ballonet configuration.

Design

Based on a detailed and comprehensive review of known materials, no monolithic material satisfies all of the requirements. Therefore, a composite of materials, either a coated fabric or a laminate, was developed (Fig. 5). Dacron was chosen as the structural cloth for its excellent dimensional stability, high tenacity, and hydrolytic stability. The 13 by 13 count, 1000-denier cloth has low twist, low crimp, and is a balanced weave. This results in minimum elongation, low crimp interchange, and high tear resistance. The Mylar film provides an effective helium gas barrier at 1/5 the weight of an elastomer such as neoprene or polyurethane. The Tedlar exterior weathering surface represents another advance in aerostat technology. Experience has shown that elastomer

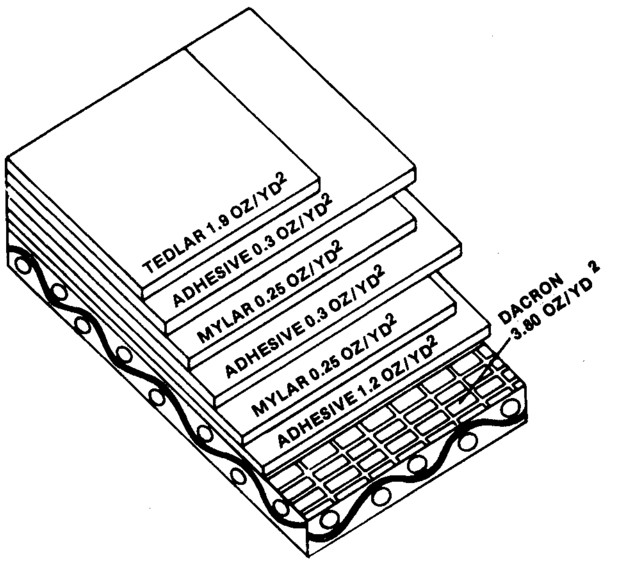

Fig. 5 Hull envelope laminate.

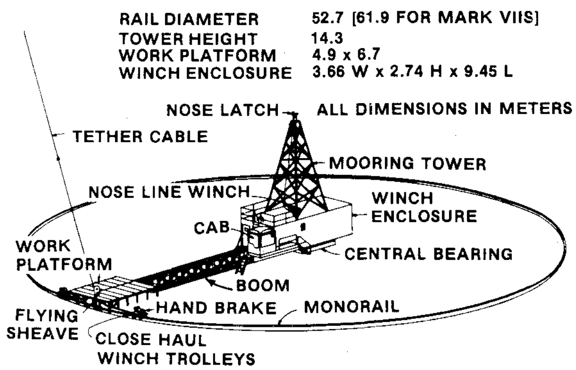

Fig. 6 Aerostat mooring system.

weather coatings require periodic, usually annual, maintenance. Tedlar, on the other hand, has been in service as a maintenance-free protective coating for building roof and siding panels for over 12 yr. By conservative extrapolation, 20+ years of protection from weather and uv can be expected with minimal maintenance.

Fabrication

The manufacturing process starts with the laminations of the multilayered aerostat materials. The flexible, two-dimensional material sheet goods are then accurately cut into the various shaped panels using full-scale patterns. The panels are then bonded together using specially designed thermal impulse sealing equipment. The panel-to-panel bonds are constructed as butt joints using a two-tape system. A structural tape is bonded to the inside of the panel surface while a cover tape for weather protection is bonded to the outside surface. Static and dynamic testing has shown that the thermal impulse bonds are stronger than the basic laminate material.

Mooring System

Historically, mooring systems had one thing in common – the need for a large ground crew for launch and recovery operation. With the emergence of the telecommunications concept using tethered aerostats, however, the need to minimize crew size became critical since the maintenance of a large full-time ground crew is cost prohibitive. In addition, there is a need for all-weather capability on a global scale. Both the mooring system and aerostat had to be designed to withstand the environment, primarily wind and temperature, anywhere in the inhabited world without hangar facilities or any other assistance.

These two requirements, weather and crew size, prompted the design of a mooring system which incorporates several new features, while attempting to retain the knowledge and experience of the past.

Description

The mooring system is a permanent installation to serve as the ground anchor for the aerostat and as a service and maintenance station for the aerostat between missions. The mooring system (Fig. 6) consists of a central machinery enclosure and mast mounted on a large central bearing, a horizontal compression member or boom, and a circular monorail which supports the boom end, flying sheave, and close-haul winches on rollers. A mechanical lock with a remote electrical release is provided at the top of the mast. Work surfaces are provided on the top deck of the machinery enclosure, on the boom, and at the location of the aerostat payload when it is moored. A diesel-powered main winch and an auxiliary power unit located within the machinery enclosure furnish the hydraulic power required to launch and retrieve the aerostat and to moor the aerostat in the close-hauled mode. The main winch is used to control and store the tether cable during flight operations. In the event that the main winch experiences a loss of hydraulic power, the auxiliary power unit can be used to provide backup hydraulic power for the main winch. Three smaller winches, one at the base of the mast and two on the circular rail, provide the restraints and control during early stages of launch and during final recovery. A completely enclosed operator's cab is located on the forward side of the machinery enclosure, providing visibility to all operational areas.

The unique feature of the mooring system, when compared to earlier systems, is its ability to be rotationally driven by the forces generated by wind acting on the aerostat or tether (weather vaning) or to be power driven during flight to align the system properly with the aerostat or its tether cable. The system design allows a single operator to maintain the aerostat in flight and a minimum-sized crew to launch and recover the aerostat. During servicing and maintenance when moored, the crew moves with the system, thereby providing improved accessibility and greater safety and again reducing the crew size.

The following paragraphs describe typical procedures as evidenced by operational experience with mooring systems of this type.

Moored Mode

When moored, the aerostat is mechanically locked to the mooring mast at the nose and secured by its suspension lines to the service platform under the aerostat payload. In this configuration any changes in wind direction will cause a rotation of the complete system and maintain the aerostat headed into the wind. It also allows the field crew to "ride" the mooring system and work without concern for shifting winds and gusts. In relatively calm weather (winds less than 15 knots), the brakes can be engaged so that heavy loads, such as the aerostat payload, can be transferred from truck to work platform. In all other moored operations, the system is free to rotate with the wind.

Flight Mode

When the aerostat is at altitude, the tether cable is routed from the main winch through the boom to the flying sheave and thence up to the balloon. The tether cable tension is generally strong enough to rotate the mooring system into direct alignment with the horizontal projection of the tether cable. If not, final adjustments are made by driving the system to this condition with the hydraulic rotating motor located on the central bearing. Once aligned, the brakes on the close-haul winch trolleys can be engaged. The system remains in this condition until changes in the direction of winds aloft dictate reorientation. Aerostat altitude variations with windspeed are controlled by inhauling or outhauling of the main winch.

Performance Capabilities

The mooring system, with the aerostat attached, is designed to withstand a wind velocity of 90 knots at sea level. With the aerostat aloft or detached, the system will withstand wind loads in excess of 100 knots. The weather vaning capability is such that, with the aerostat moored, a 3- to 5-knot wind at 10 deg off the aerostat heading will cause the mooring system to realign itself into the new wind direction. When the aerostat is aloft, tether cable side loads of this same magnitude will cause mooring system rotation if it is not braked during flight. Field operations have demonstrated that normal launch and recovery operations can be performed by four men.

Launch/Retrieval Procedure

At the commencement of flight activities, the mooring system is free to rotate with hydraulic damping applied and with the aerostat headed into the wind. The close-haul winches on the rail are used to inhaul the aerostat slightly to loosen and release the aerostat suspension lines from their attachment points on the work platform. The nose is then unlatched and the nose winch and close-haul winches are used to allow the aerostat to rise. When the confluence point of the aerostat suspension system is high enough above the work platform, outhauling is stopped to allow attachment of the tether cable to the confluence point. Outhauling is then resumed on the three small winches and on the main tether winch until the close-haul lines are completely unspooled. All winch controls are operated by one man in the control cab. When the end of the nose line, to which is taped a smaller tag line, is approximately 50 ft above the latch, the nose winch is braked while outhauling on the main tether winch continues. The tape breaks, and the free end of the tag line falls to the ground while the other end remains threaded through the latch and secured on or near the nose winch. This eliminates the need to rethread the nose line through the latch during the recovery operation (see Fig. 7).

Lightning Protection

While no systems are completely free of hazard due to lightning strikes, modern day technology affords numerous techniques which can reduce the hazard to an acceptable level. The aerostat itself is guarded against direct strikes by a lightning protection system of guard wires running from nose to tail which provides an effective Faraday cage "cone of protection" similar to that provided by ground wires positioned above and parallel to power transmission lines. The aerostat guard wires are held at sufficient distance from the aerostat skin by a series of standoffs to prevent the corona from damaging the fabric. The guard wire system is connected to the steel tether member via a low-impedance slip ring assembly. Thus, the system diverts current away from the aerostat and into the steel tether. Additionally, the system aids in bleeding off static charges on the aerostat surface.

Experience has demonstrated that using #8 wire for the power carrying lines provides excellent protection against the possibility of severing by lightning. The TCOM steel tether, which has a higher thermal capacity and a lower surge impedance than the #8 wire due to its larger diameter (0.405 in. vs 0.128 in.), has even considerably higher ability to withstand the effects of lightning than the #8 wire. Further, the tether provides a low-impedance path to ground for both lightning and corona discharge currents from the aerostat.

Since the mooring system is the center of ground operations, extremely careful attention is paid to affording maximum protection from lightning for both personnel and equipment. Numerous devices are employed to provide low-impedance paths to ground for lightning discharge currents. Slip-ring assemblies at the flying sheave and at the Rotek bearing provide suitable low-impedance paths to ground for currents conducted down the steel tether. A steel shoe, similar to that used on electric trains, provides a wiping connection between the monorail and the work platform. Electrical power lines between the winch and the power source and the signal cables to the control van are protected by lightning arresters at both ends. A Faraday cage around the mooring system control cab, and well-grounded controls in the cab provide highly effective protection during winch operations under any conditions.

A carefully designed ground plane provides personnel protection by reducing the voltage potential gradient to an acceptable level. Additional personnel protection, such as the use of conductive clothing with an insulating inner layer and a conductive outer layer which provides a low-impedance path around the body for both static and lightning currents, rubber-soled shoes, and lineman's gloves can be employed when operations are mandatory during periods when conditions conducive to lightning strikes exist. Finally, training of personnel in operational procedures to be followed and actions to be avoided provides the best and most effective personnel protection against lightning.

Telemetry and Command System

The telemetry and command system continuously monitors all of the vital aerostat data including such functions as altitude, windspeed, pressures (hull, fin, and windscreen), helium and ambient air temperatures; blowers, valves, and power system contour; and vehicle pitch, roll, and heading. The system also controls and monitors all the communications equipment onboard the aerostat. The reliability of this system is assured through use of redundant transmitters and receivers and an automatic switchover capability.

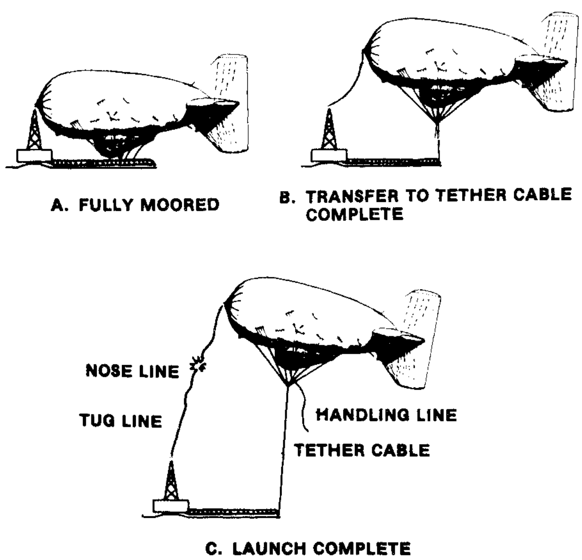

Fig. 7 Launch sequence.

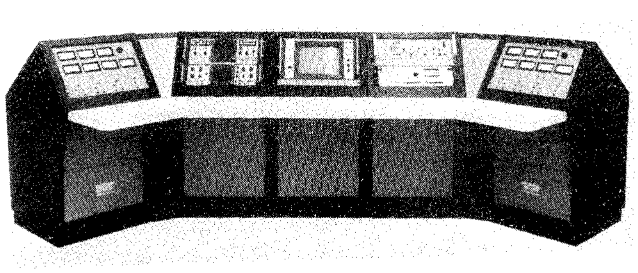

Fig. 8 Telemetry and command system console at ground station.

The system consists of a ground control section, typically housed in a console at the ground control station (such as shown in Fig. 8), and an aerostat control section carried aloft by the aerostat.

A ground system controller formats outgoing command words and monitors all incoming telemetry to immediately detect any breakdown in communications with the aerostat, and executes automatic switchover of the ground command transmitters and telemetry receivers upon failure of a unit. The ground system controller also continuously monitors the status of all console control switches, verifies all commands sent to the aerostat, and inhibits execution of commands until verification has been made.

An aerostat system controller in the airborne equipment formats outgoing telemetry words and checks all incoming commands, monitoring for any breakdown in communications with the station. In the event of a communications breakdown, the aerostat system controller will automatically switch in a backup command receiver or telemetry transmitter. This controller also directs sampling of all internal data lines and the telemetering of these data to the ground control station. All control logic is in a modular format which permits rapid expansion of control and monitoring functions as required.

Flight Testing

The TCOM Corporation has established a Final Assembly, Checkout, and Flight Test Facility in Elizabeth City, N. C., where all aerostats are tested to establish and confirm system parameters that are particularly important when the aerostat is used as a stable platform for an airborne electronics package. Some of the objectives of the testing performed at the Elizabeth City facility include: final inspection of the aerostat flexible structure including the hull, ballonet, empennage, and windscreen; proof pressure of the aerostat at a simulated wind velocity of 90 knots at mean sea level (MSL); initial inflation check; determination of center of gravity and center of buoyancy and center of lift – absolute lift; leakage checks; helium purity over extended period; and payload and power generation configuration (initial power generation and fuel system checks).

Conclusion

Aerostats provide a dependable, stable, airborne platform for communications payloads that simultaneously provide a wide range of services over very large ground areas at a comparatively low cost. The special laminate used for the aerostat hull envelope has a predicted life expectancy of more than 15 yr. An advanced mooring system permits a small ground crew to launch, fly, and retrieve the aerostats.