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Tethered Aerostat Operations in the Marine Environment

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TETHERED AEROSTAT OPERATIONS
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Abstract

An airborne radar platform has been developed using an aerostat system tethered to a 194-ft motor vessel. The United States Coast Guard has successfully used this system for surveillance work in its drug interdiction program. Besides being mobile, the system has a lower operating cost than comparably equipped aircraft. Also, surveillance coverage is much greater than that of radar systems operated from surface vessels. Initially, the system was evaluated for an approximate 2-month period. The excellent results obtained in an initial evaluation period of approximately 2 months demonstrated that the aerostat system could be effectively maintained at sea with a minimum of land-based support. The system then became operational in mid-1984.

Introduction

The Coast Guard has used various surveillance methods in the past to detect the movement of ships on the high seas. The usual sensors have been shipborne radars, which have limited coverage, or aircraft-mounted systems, which have fuel-limited on-station time. To provide greater coverage, greater accuracy and longer duration, it was decided to evaluate a radar system mounted on an aerostat which, in turn, would be tethered to a ship.

The multifaceted program set up to achieve this objective included obtaining a proven aerostat system and integrating it onto a modified 194-ft motor vessel. A radar system linked to a computer-based tracking system was developed simultaneously. The entire system was integrated on the ship in Morgan City, Louisiana. An operational evaluation then commenced in the Caribbean Sea area. The success of the evaluation resulted in the adding of this system to the Coast Guard's Law Enforcement Program.

This paper discusses the planning of the concept and its implementation. Field test results are presented.

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System Definition

The total system consists of many subsystems: major subsystems include the aerostat subsystem, tether subsystem, mooring subsystem, payload, ground electronics and the motor vessel. Prior to a description of each subsystem, the problem of limited surveillance range is addressed.

Problem of Limited Surveillance Range

The present national drug interdiction rate of less than 30 percent is not considered sufficiently effective to stem the flow of illegal drugs into the United States. The Coast Guard, with its responsibility for stopping marine trafficking of illicit drugs, is investigating a number of alternatives for improving this interdiction rate. Coast Guard tactics and resources presently employed in the primary drug transiting routes through the Caribbean include the use of radar surveillance from patrol cutters complemented by periodic aircraft overflights. Available search aircraft cannot provide continuous coverage of even the most active areas and patrol cutters are limited by radar horizons of less than 15 miles for targets up to 40 feet high.

It was believed the Coast Guard's surveillance capability could be significantly increased through the use of radars suspended from tethered aerostats. Employment of an aerostat tethered at altitude could provide continuous radar coverage over a large area. The coverage increase equates to over 10 times the detection envelope of radar mounted on a cutter and could potentially allow the Coast Guard to maintain nearly 100 percent surveillance of a selected maritime area. The increased area coverage alone should enhance the interdiction rate considerably. The advantages of this system become more apparent when one considers that the aerostat can track contacts without disclosing the location of Coast Guard patrol units and thus free these units for interception, identification, boarding, and apprehension functions.

Elements of Overall System

The system consists of a tethered aerostat deployed from the deck of an offshore supply vessel. Figure 1 shows the aerostat on a short tether.

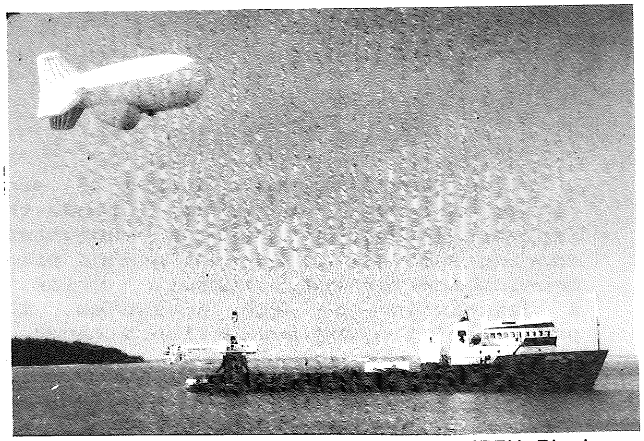

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Figure 1. Aerostat/Ship System

A small lightweight radar system on board the aerostat is linked to displays located on the ship for monitoring purposes.

Aerostat Subsystem

The aerostat used for this application was the TCOM STARS (Small Tethered Aerostat Relocatable System) aerostat; the engineering aspects of this aerostat have been described elsewhere[1,2]. Each aerostat consists of a flexible hull structure with a design volume of 700 cubic meters of helium, three stabilizing fins, an air-inflatable windscreen, a ballonet and appropriate rigging. Air into and out of the ballonet is controlled by a pressurization system consisting of a control unit, pressure sensors, blowers, valves and an emergency battery.

The hull is built from a laminate fabric consisting of an outer layer of Tedlar bonded to a substrate of Dacron fabric, which is the strength member of the hull structure. The bonding resin used in the laminate, is Hytrel. Hytrel is a hydrolytically stable polyester resin.

The hull is 25 meters in length and 8 meters at its major diameter.

Tether Subsystem

An airborne swivel slipring, a tether, a drum slipring and a rotating Rotek slipring on the mooring subsystem turntable form the tether subsystem. The airborne swivel slipring allows free movement of the aerostat at the end of the tether. Both the drum slipring and Rotek slipring allow electrical transfer between rotating and stationary equipment.

The tether is a high-strength electro-optical-mechanical cable that employs duPont Kevlar aramid fiber as the strength member. The cable's construction is unique; the cable has a multi-function core that contains three electrical conductors for the transmission of 400 Hz-power and three fiber optic filaments for telemetry-data/command control links. This complex core is surrounded by several layers of contrahelically wound Kevlar yarn and the cable is jacketed with a metallic/Dacron braid embedded in a semiconductive polymer. The overall tether diameter is 0.460 inch. The terminated breaking strength of the cable is 12,400 pounds.

Mooring Subsystem

The purpose of the mooring subsystem is to provide a launching, retrieval and maintenance platform for the aerostat. During flight operations, altitude adjustments are made using mooring subsystem equipment.

A special gantry was designed, fabricated and installed on the motor vessel. The gantry allowed the mooring subsystem/aerostat assembly to clear the ship's deck and surrounding deck structures. Once the gantry was in place, the mooring subsystem was mounted on top of it. Figure 2 shows the gantry with the mooring subsystem in place.

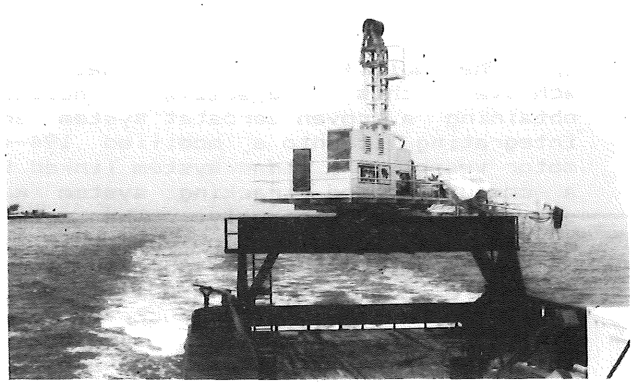

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Figure 2. Gantry/Mooring Subsystem

It is possible to move the gantry the full length of the cargo deck. When the aerostat is moored, the gantry is at the stern position, which allows the aerostat to weathervane with the changing wind direction. During flight operations, the gantry is just aft of the superstructure. During flight operations the motion of the aerostat has no effect on the ship handling characteristics.

The mooring subsystem tower is attached to a turntable; a cantilevered boom also attaches to the turntable. This structure is mounted on top of a Rotek turntable bearing that is supported by the gantry. This structure is allowed to rotate 360 degrees when forces are applied by wind acting on the aerostat. Rotation can also be initiated by activating the rotary drive device. This latter feature is used to align the boom and tower with the aerostat during docking operations.

The aerostat is supported on the mooring subsystem by a nose latch at the top of the tower and closehaul lines attached to the side of the aerostat and moored onto closehaul winches mounted on two boom outriggers at the end of the boom.

Other mooring subsystem elements include a control console, tether winch and a nose line winch. The control console is located at the base of the tower, where it affords an unobstructed view of all aerostat-related activities. Power is provided through cabling and sliprings from the ship's diesel electric generators.

Radar Payload

Figure 3 shows the radar suspended beneath the aerostat. The radar assembly is positioned within the aerostat's windscreen, where it is protected from the elements.

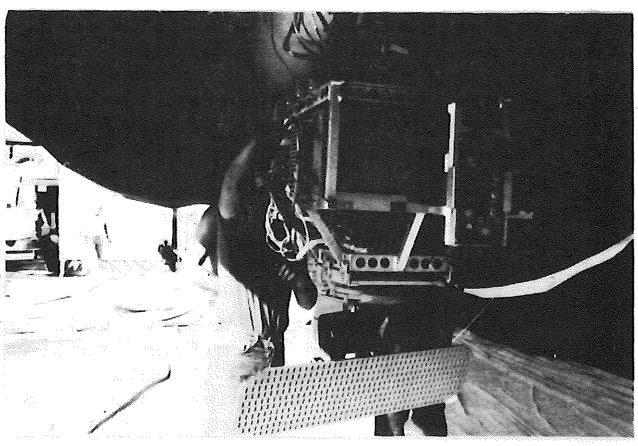

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Figure 3. Radar Assembly

The radar shown in the figure is an AN/APS-504(V)2 system. This high-power radar was developed by Litton Systems Canada Limited for use onboard Canadian Armed Forces helicopters. The antenna rotates 360 degrees; its pencil beam is especially suited to maritime patrol duties.

The basic radar system is packaged into a number of replaceable units.

Procurement Phase

Because of the radar aerostat system's obvious potential contribution to the effectiveness of the Coast Guard's Enforcement of Laws and Treaties (ELT) Program, the Office of Operations in Coast Guard Headquarters requested that the Coast Guard Office of Research and Development conduct a 60-day technical evaluation and operational demonstration of a mobile Marine Interdiction and Surveillance Team (MIST) in which a radar aerostat system would be the primary detection resource. The Coast Guard Research and Development (R&D) Center was tasked to plan and implement this evaluation.

The aerostat with its necessary equipment, including the mooring subsystem, radar components, envelope monitoring equipment, and helium supply were leased for the test from TCOM Corporation, a Westinghouse Electric subsidiary based in Columbia, Maryland. TCOM also provided support personnel to operate the system. TCOM subcontracted with Tidewater Marine, Inc., of New Orleans, Louisiana, for the support vessel, M/V Abshire Tide and personnel to operate the vessel and food for all Tidewater, TCOM, and Coast Guard personnel assigned to the support vessel. Fresh water, fuel, and lube oils were directly funded by the Coast Guard. The Coast Guard provided the other resources of the MIST system.

Tracking System Description

General Description of the Data Link

The description of the data link begins at the surface-search radar on the tethered aerostat. From the bubble belly of the aerostat, known as the windscreen, where the rotating radar antenna is carried, but hidden from view, radar information is telemetered down to the operations center of the Mobile Aerostat Platform (MAP). The operations center, in a container located aft of the pilot house houses the necessary electronic equipment and provides space for two USCG crew members to monitor and operate the equipment.

In the operations center the radar picture is displayed on the familiar radar screen, a plan position indicator

(PPI). Next to the radar screen is a computer that is used for manually inputting all target data regarding time and position of radar contacts. Next to the computer is equipment to transmit a computer-generated surface picture to USCG patrol vessels and cutters working with the MAP as part of the Marine Interdiction and Surveillance Team (MIST).

On vessels working with the MAP, equipment installation includes the same type of computer used aboard the MAP. The data received by any of the patrol vessels and stored in the computer can be manipulated and analyzed exactly the same as the original data in the computer aboard the MAP. Therefore, the following description of the computer program applies to both the MAP and the patrol vessels.

Origin of the Software

The original software (Version 1.0) was written in just 2 months at the USCG R&D Center to support data gathering for research purposes. As such, all data was immediately stored on disks for later analysis back at the R&D Center to determine the effectiveness of the aerostat radar. About the time the research effort was ending, a decision was made to change the aerostat from a research tool to an operational tool. In addition, it was noted that the software should be rewritten to support the day-to-day needs of operations rather than to collect data for later analysis. The most desirable feature of the original software was that it displayed current target positions in color on a digitized nautical chart. The position of the USCG vessels was represented by yellow digits, the position of targets by orange letters, while the land was green on a blue background with white latitude and longitude lines.

New Software

The first major rewrite of the software required 3 months' effort. By building on the foundation of the original software, it was possible to develop a program that is easy to learn and use, that operates without annoying delays and which recovers quickly from any bugs without loss of data. The program developed recovers in about 5 seconds from anything but a power failure with all data intact. (The computer runs off of an uninterruptible power supply.)

Version 2.0 of the computer program automates to a high degree all facets of target data handling including the process of tracking targets, analyzing their movements and transmitting the stored data or messages to other patrol vessels. The user knows at all times what his options are by the on-screen display of labels from the ten menu, or function keys. As the user calls up different menus by pressing a single key, the labels instantly change at the bottom of the screen. In all menus, a help key brings up a full screen of text to elaborate on the short labels for the keys. Major menus are: the main menu, a disk menu, a zoom control menu, a data charts menu, a data tables menu, a data entry menu, a print menu, and a transmit menu.

Data Entry

In actual use, the operator loads and runs the program with a selected navigational chart from a growing library of digitized charts. Cold start of the program takes about a minute. At the end of the minute, the program is loaded, a digitized chart is displayed on the screen and the computer is ready to respond to the menu keys. For old data entry, the operator can load stored target data from a disk. For new data entry, the operator has several menu options: new USCG vessel, new target, old target, drop target or reactivate target. Target positions can be entered manually from the keyboard or automatically from the radar repeater. For manual data, entry a minimum number of keystrokes are necessary. The computer prompts the operator with a target ID. The operator can override the prompt by specifying an ID. The operator can then enter bearing and range from the MAP, or latitude and longitude. Latitude and longitude can be entered as decimal degrees or as degrees and minutes. The program determines which it has been given. After all current targets are updated, all target data can be transmitted by pressing a single key in the transmit menu. The computer keys the transmitter as necessary.

Tabular Data Display

Data in computer memory can be displayed on screen in either tabular form or graphic form. Tabular form allows viewing or printing columns of numbers for all active targets with both instantaneous and average courses and speeds, time, position and other operator-generated comments. Any of the many thousands of target sightings in memory, whether active or inactive, can be randomly located and displayed or printed. Analyzed data in tabular form is possible. For example, a table of bearing and range of all targets from all USCG vessels can be instantly calculated and displayed. Target vessels close to USCG vessels are highlighted by using different colors on the screen.

Graphical Data Display

Graphic data is displayed on the digitized chart. The normal display mode shows the active targets where last reported by the aerostat's radar and can be thought of as the near present. To review what happened in the past, track histories using dots, digits or lines for one or more targets can quickly be displayed on the chart because several days' or weeks' worth of data can be kept in memory. Another mode of display dead reckons all vessels to a new position based on last known course and speed. This display shows the present while a final mode of display predicts the future as it calculates an intercept course and speed from any vessel to any target and displays the positions of the vessels at the time of intercept or closest point of approach. Each of these graphic displays is created on the computer screen within a few seconds with the digitized chart in the background and can quickly be printed by a black and white ink jet printer without loss of any information as the color picture is converted to black and white.

Graphical Analysis Tools

A course and speed vector for any vessel can be plotted on the current chart and moved by spinning a knob on the keyboard. The course and speed vector for the vessel is immediately redrawn and the new course and speed is numerically displayed. A range and bearing vector similar to the course and speed vector is available. Bearing, range, pivot latitude and longitude and tip latitude and longitude are continuously displayed on the screen. The vector pivot or tip can be moved directly to any target or to any latitude and longitude. It can also be rotated, changed in length or moved up and down or left and right by spinning the knob. The tips of these vectors as they are rotated 360 degrees will describe an ellipse because the computer uses a Mercator projection algorithm from the original program while the screen shows equal intervals for equal increments of latitude and longitude.

Zoom-In Capability

The program will expand any portion of the full chart to fill the computer screen. When the zoom-in menu is called up, a yellow rectangle appears. Use of the cursor movement keys permits the movement of the rectangle anywhere on the chart. Rotating the knob on the computer keyboard will change the size of the rectangle. The portion of the chart inside the rectangle can be expanded between 2 times through 40 times. Then, pressing one key causes the computer to redraw the chart as desired.

Because the computer memory holds the locations of all the targets to speed up the zoom-in process, one dedicated menu key will automatically size and position the rectangle so that all active targets will be centered in a rectangle. This function was added after observing the operator motions before zooming in. Sizing and locating the rectangle took the operator between 1 and 3 minutes before zooming in. The computer does it in a fraction of a second.

Data Storage

For target data filing, data can be stored to disk by pressing one button in the disk menu. Disks are automatically initialized if necessary, files are created and data is stored under automatically generated names for each day. Loading data from disk is just as easy as storing it. When the data disk is inserted, the computer reads it and assigns a day's worth of data to each menu key. Pressing a single key loads and displays the data on the current chart. This technique can be used to move data from one chart to another. It is possible to preview another digitized chart in about 20 seconds while the program is running by pressing a single menu key.

Finally, disk utility functions in the program include initializing blank disks, copying disks and cataloguing disks to indicate to the user how full the disk is by percent.

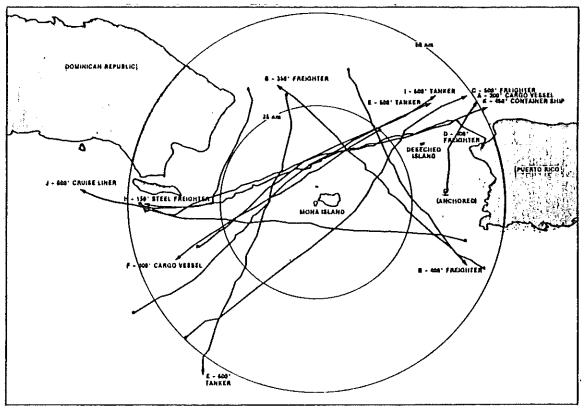
Figure 4 shows two examples of actual field tracking exercises.

Field Testing and Evaluation Phase

Ship Modifications

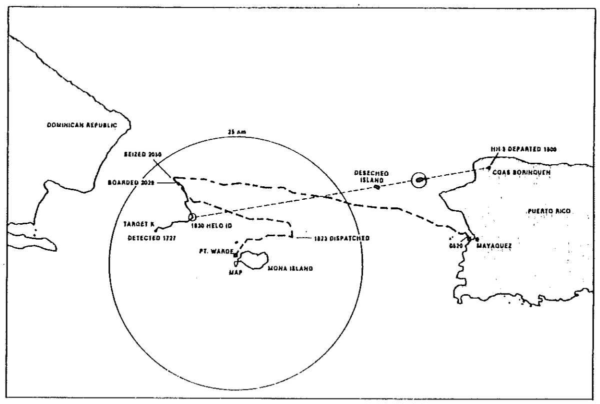
Late in 1983, fabrication of the M/V Abshire Tide was completed at the Tidewater Marine Service, Inc. facility at Morgan City, Louisiana. This type of vessel is normally used as a supply vessel for offshore oil operations.

During early 1984, the M/V Abshire Tide was modified for use in the Coast Guard's Law Enforcement Program. A movable gantry was installed with a



From OPEVAL Report prepared by R&DC[3]

Figure 4a. Traffic Flow Pattern Over 4-Hour Period



From OPEVAL Report prepared by R&DC[3]

Figure 4b. Single Vessel Tracking

chain drive to allow movement along the complete length of the cargo deck. Three containers were also installed; the first served as an auxiliary power-house complete with a diesel engine/generator. The second container was placed on top of the power container. Its purpose was to hold the Coast Guard tracking equipment. A third container was placed approximately along the center-line of the ship 90 degrees to the first two containers. This container serves as an electronics lab, storeroom, and office for TCOM personnel.

A skid of pressurized helium was placed next to the TCOM container; the onboard source of helium for the aerostat. Also, a motorized man-lift was placed on the ship to service equipment on the aerostat.

After the gantry was installed, the mooring subsystem was placed on top of it. Three manually operated inflation winches were also added on the deck of the ship for use during inflation.

Lastly, an intercom system was installed which linked the wheelhouse to the radar container and the mooring subsystem.

Systems Integration

Following the completion of the ship, the installation of the mooring subsystem, containers and associated wiring, the aerostat was inflated on the deck and then mated with the tower. The aerostat housekeeping equipment and the radar payload were then installed.

During this period, the engine generator was installed in the power container and the radar monitor and associated tracking equipment were installed in the radar container. An electronics workshop was set up in the TCOM container and storage area was built for spare parts.

Development Phase

The development phase of the OPEVAL (operational evaluation) was conducted in the Mona Passage between the Dominican Republic and Puerto Rico (Figure 5).

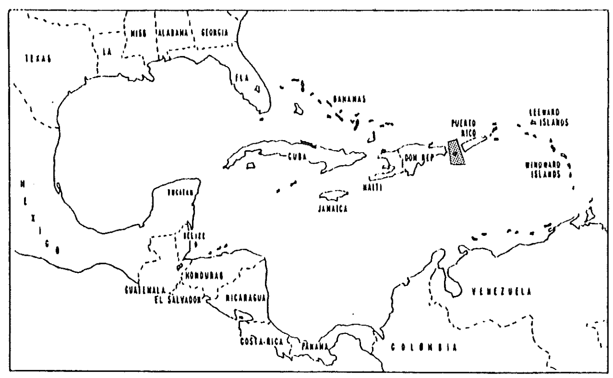
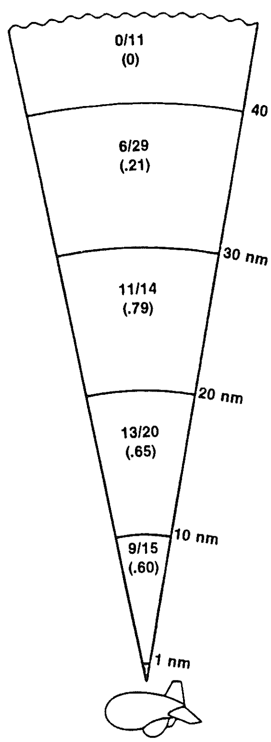


Figure 5. Development Phase Area of Operation

Initially, after arriving in the Mona Passage, the aerostat radar experienced intermittent waveguide problems that kept the system down for approximately 4 days (the original radar used for the research program has since been replaced with an improved radar system). Once this problem was identified and corrected, the system was up and operating at a 95 percent rate for the duration of the OPEVAL period. During the development phase, Coast Guard aircraft provided target identification information on radar contacts and a limited amount of information on missed targets.

Development Phase Results

Analysis of the development phase data indicated the aerostat radar detected all targets of over 50 feet in length within 50 miles range. Figure 6, reprinted from the Coast Guard Research and Development Center's Proof of Concept Report[3], shows the detection results for targets less than 50 feet in length in sea states 1 and 2. The detection percentages gradually increased throughout the OPEVAL as the radar operators gained proficiency with experience.



Note: Ratios are detections/total targets. Numbers in parentheses are detection percentages

Figure 6. Development Phase Detection Percentages (Sea States 1 and 2, Targets 50 Feet)

Operational Phase

Areas of Operation

Most of the operational phase of the evaluation took place in the Windward Passage between Cuba and Haiti (Figure 7). A 3 day sweep through the Yucatan Channel between Mexico and Cuba was conducted at the conclusion of the OPEVAL.

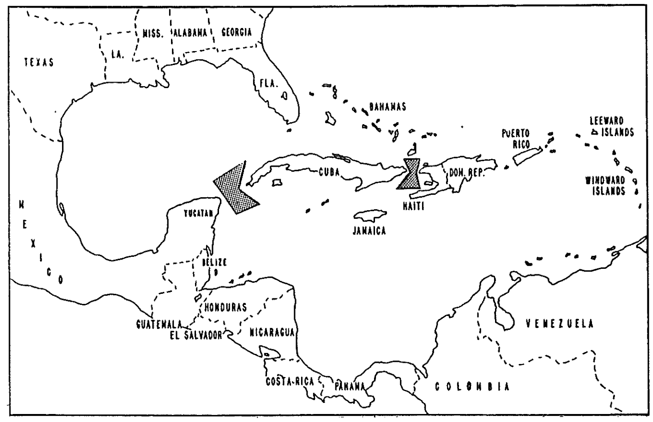


Figure 7. Operational Phase Areas of Operation

Operational Phase Results

In-depth analysis of field results showed the ship-tethered aerostat would be an effective maritime law enforcement resource. During the operational evaluation, the aerostat system was credited with the seizure of two vessels transporting illicit drugs, one vessel attempting to smuggle illegal immigrants into Puerto Rico, and the successful prosecution of a search and rescue case involving a vessel in distress.

Aerostat System Placed in Service

After completion of the OPEVAL, the Coast Guard initiated action to acquire additional systems, which ultimately will number eight ship-tethered aerostats. The first one became fully operational in mid-1984 and has since been used successfully in both drug smuggling and fisheries regulation law enforcement cases. Figure 8 shows a 44-foot sailing vessel detected by the aerostat and seized after 5 tons of marijuana were found in its hold.

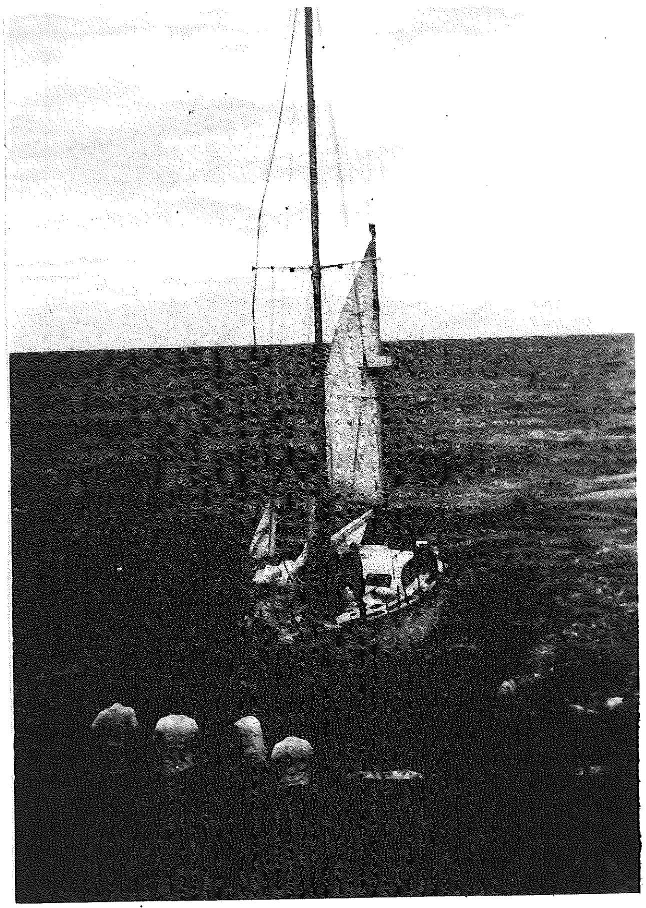
Special Considerations

When flying aerostats from a ship, special considerations must be made for weather, system maintenance, and safety.

Weather

In the area where the aerostat has flown, the weather has been known to change very rapidly, causing potential hazards to the flying aerostat. During stormy conditions, heavy rainfall, lightning and strong downdrafts are factors that must be considered as potential dangers to the flying aerostat.

Storms are avoided, but when this is impossible, procedures have been developed to fly the aerostat safely.



TCOM Photo

Figure 8. Sailing Vessel Seized

These procedures cover rainstorms with and without lightning and high winds. Each of these procedures has been tested in the field.

In addition to the ship's radar for storm detection, a 3M "Stormscope" WX-120 Weather Mapping System has been used for multiple-range lightning prediction. This instrument shows lightning activity in strikes/min up to 200 nautical miles from the ship. The WX-120 display/processor unit is installed in the vicinity of the aerostat ground telemetry unit. Its antenna is mounted at a high location on the ship; instrument reference is the same as the ship's heading.

Maintenance

Maintenance is especially critical since, in general, home port services are remote. Helium and equipment must be available to service the aerostat. Figure 9 shows the helium skid in place and the aerial work platform used to maintain the aerostat subsystem.

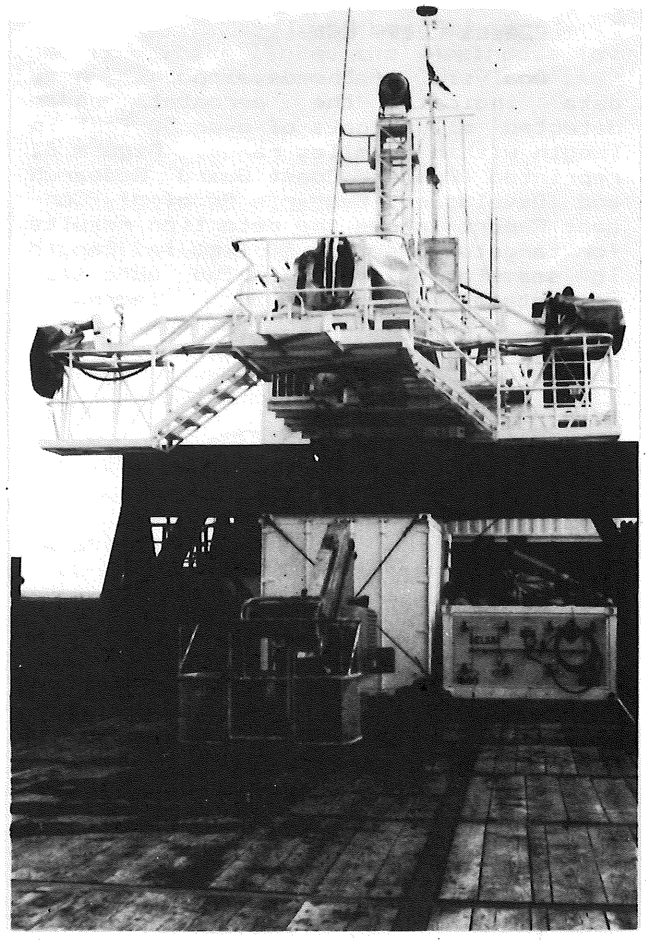


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Figure 9. On-board maintenance equipment

The amount of helium in the aerostat is monitored by determining the variation of gross lift with time. After it is established by lift checks and analysis that helium must be added, the aerostat is moored and the helium addition procedure is initiated. The helium line is connected between the helium skid and the helium fitting on the nose of the aerostat. The initial pressure of the tank is recorded and, since the amount of helium required has been calculated earlier and converted to a tank pressure, helium is then added until the desired lower tank pressure is reached.

Periodic check of the ballonet curtain height also gives a rough indication of the amount of helium fill in the hull.

While in port, special equipment may be required to service the aerostat. Figure 10 shows a crane needed to reach the lightning protection system.

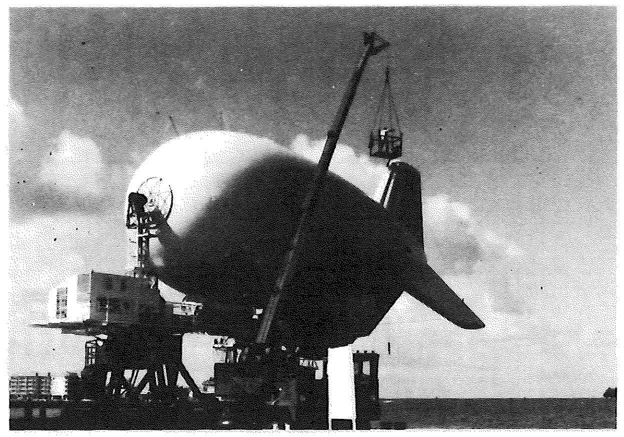

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Figure 10. Special Maintenance Equipment

Both aerostat inflation and deflation procedures have required careful consideration since these operations are performed on the deck of the ship. An aerostat deflated on the deck of the ship is shown in Figure 11. Figure 12 shows part of the net used during the inflation procedure.

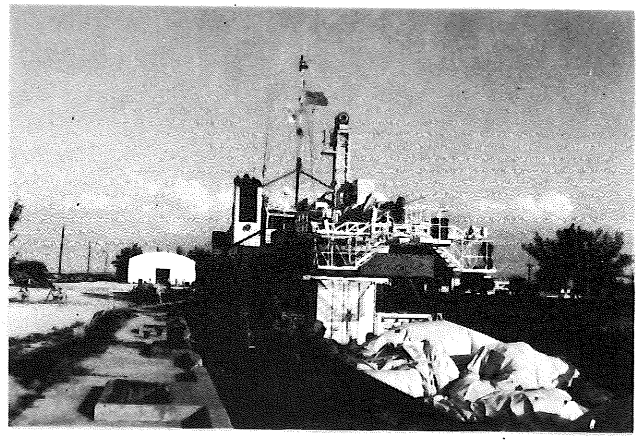

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Figure 11. Flaccid Aerostat On Deck of Ship

<u>Safety</u>

During flight operations, strobe lights located on the aerostat are operational to indicate the aerostat's position to local air traffic. Also, clip on strobe lights are attached to the tether along with brightly colored pennants. These devices clearly outline the location of the tether as a function of altitude.

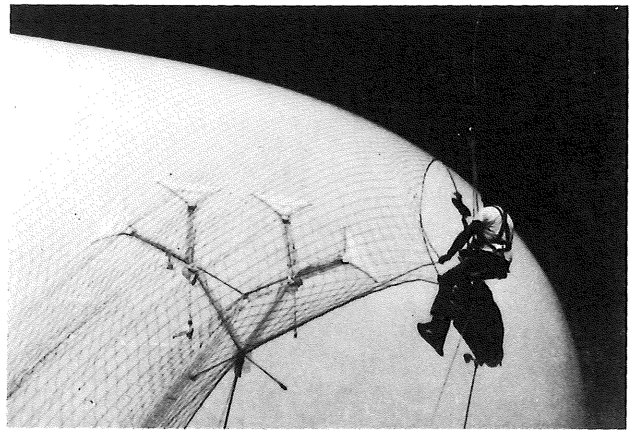

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Figure 12. Inflation Net

<u>Conclusion</u>

Field deployment of an aerostat/radar/ship system has shown it to be an effective method for Coast Guard use in ship surveillance. A much greater sea area can be monitored using this system, providing the potential for detecting a greater number of targets in the same time frame.

When multiple systems are used, this concept can provide effective surveillance and control of both major shipping lanes, remote areas, or both.

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