TETHERED BALLOON FOR CHECKOUT OF COMPUTER-CONTROLLED ANTENNAS

H.E. BAGGOT
Interstate Electronics Corporation
Subsidiary of A-T-O Inc.
Anaheim, California

J.B. WYNN
Department of the Navy
U.S. Naval Ordnance Test Unit
Patrick Air Force Base, Florida

Summary. During operational tests of the U.S. Navy's Poseidon missile, an instrumented ship tracks every test missile launched by the nuclear subs. The key sensor aboard this launch-area support ship, the *USNS RANGE SENTINEL*, is its antenna system. Onboard computers switch the ship's four independent, main S-band antennas (Fig. 1) to capture up to four missiles fired in succession and to expedite command action (e.g., continued flight or destruct). This multi-antenna control by computer leads to a complex testing problem for the computer software, constrained by the need for cost effectively proving the software's operational capability without penalizing hardware development. Rigid control of hardware-caused variables, and a near-operational test environment, are vital Software test prerequisites. To this end, using a stable RF pointing source at altitude above the antennas (i.e., to reduce parallax distortion and multipath effects) is a preferred approach in testing antenna-management software.

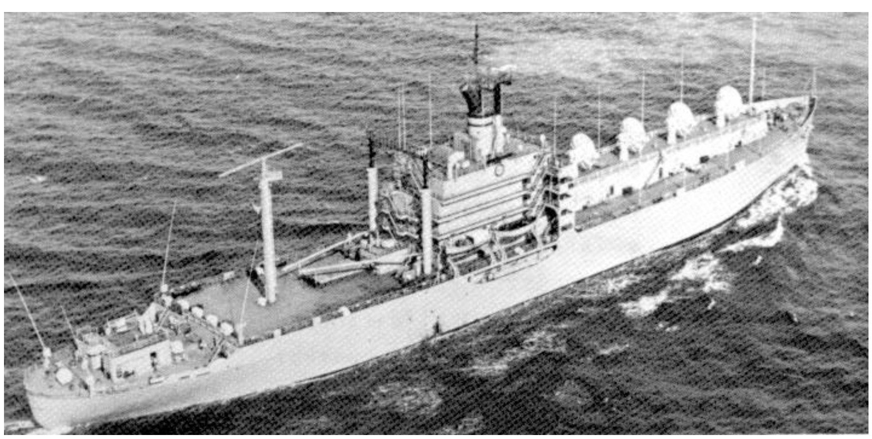

Fig. 1 - USNS RANGE SENTINEL (TAGM-22)

This paper describes two experiments* to (1) initially establish the feasibility of using an *airborne* S-band telemetry transmitter as an RF signal source for checking out the *USNS RANGE SENTINEL's* antenna control, and then (2) demonstrate the effectiveness of this

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RF source in verifying the ship's antenna alignment and validating the operational antenna software.

Introduction. A good RF source is hard to find, especially one free of multipath and located far enough away from large antennas to be in their far field. This problem is compounded by the fact that the *USNS RANGE SENTINEL's* antenna system is governed by rather sophisticated software. This ship has four 16-foot, narrow-beamwidth autotracking antennas with a broad-beam acquisition antenna that track every Poseidon missile for an extended time during flight tests. (A fifth, acquisition or auxiliary autotracker–electrically similar to the four acquisition antennas–furnishes initial missile signal input to the computer, enabling it to select which main antenna to switch on until the missile is beyond sea-surface multipath interference.) Software management of these five antennas that cover four inflight missiles is in real time. This all-working antenna approach (Fig. 2) significantly boosts the probability of antenna acquisition and target track. Thus, with all four main antennas busy during various periods of missile flight time, the computer must switch from one antenna to another to ensure tracking of every missile throughout its powered flight.

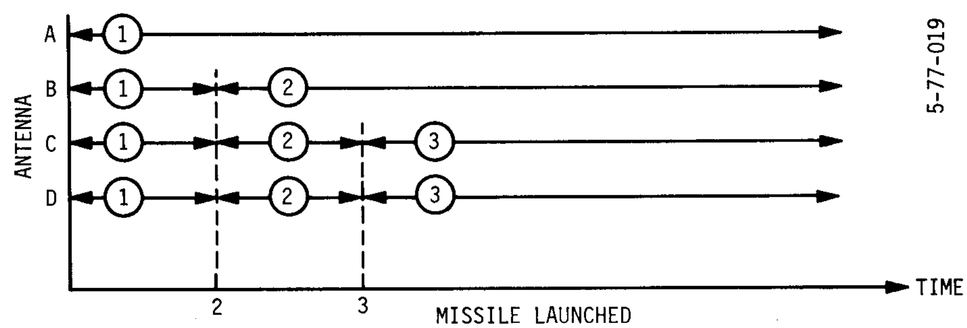

Fig. 2 - Typical Antenna Management Plan

Other antenna-management responsibilities include:

- Side lobe checks
- False-target images (reflections)
- Target dynamic checks
- Acquisition/main antenna switching
- Autotrack validations
- Servo bandwidth control

An elevated, stable-position, and mobile RF source is by definition the only means of checking out such a shipboard antenna-management system*.

Initially, five candidate platforms were considered: (1) tower, (2) the sun, (3) kite, (4) helicopter, and (5) balloon. All but the helicopter and balloon were rejected for reasons of cost, (e.g., the tower would have to be 1500-feet tall, etc.), technical inadequacy, or lack of mobility.

A. Feasibility Criteria. - With the candidates narrowed to the helicopter and balloon for reasons of practicality, the next step was to define the criteria necessary to determine the feasibility of flying an RF transmitter in any test with the *USNS RANGE SENTINEL*. Basically, the test vehicle would have to be capable of flying the package at a transmitter-to-antenna elevation angle large enough in the antenna far field to minimize multipath; at a slant range exceeding 200 feet; and with sufficient position stability for both long and short durations. In addition, the transmitter would have-to perform two types of functions: for the antennas, and for the antenna-management software. These functions are categorized as follows:

Boresight Reference for Checking:

- Antenna-to-navigation alignment
- Antenna servo gain and stability settings
- Monoscan converter and feed linearity
- Parallelism between acquisition and main antennas

Signal Reference for Checking:

- Side-lobe effects on a simulated missile
- Two- and four- missile simulations for normal modes and submodes of slave and recovery

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* J. Stone, "TAGM-22 Boresight Tower and RF Signal Source Requirements for the Software Validation Test," Interstate Electronics Corporation, Anaheim, California, Interoffice Memorandum 119-576, (to SP-25), 21 April 1972.

B. Requirements. - Tables 1, 2, and 3 summarize the specific requirements imposed on the test vehicle and transmitter.

Table 1. - Position Stability Requirements

Short-Term	Long-Term
±1.5 deg for 10 sec after RF off; ±4.5 deg for next 60 sec	Initial position to known point in space, maintain that position for several hours within 8 deg

Table 2 - Required Distances and Elevation Angles

Antenna	Slant Range (ft)	Elevation Angle (deg)
Auxiliary or Acquisition (1)	230	15
Main (4)	600	6

Table 3 - RF Transmitter Requirements

Frequency (MHz)	Power (mW)	Control Capability
All Channels (4) within 2200-2300 bandwidth	20	Remote On/Off

Experiments. - The feasibility study and initial flight test were conducted at Cape Canaveral Air Force Station (CCAFS), Florida. In the first experiment, an S-band telemetry transmitter weighing under 15 pounds (including battery) was flown aboard a U.S. Air Force HH-53C helicopter near the *USNS RANGE SENTINEL*, berthed at Port Canaveral. The second test at CCAFS used a tethered, commercially available, 44-foot-long balloon. Operational balloon tests were conducted in the airspace above the Norfolk Naval Shipyard in Virginia, where the ship was docked for a 30-day yard period.

A. Helicopter Trial. - The helicopter was investigated first–mainly because it was readily available to meet the ship's schedule and because it had a known hovering capability that seemed likely to meet the stability criteria. It became evident, however, that this was not so. Helicopters are not equipped for long-duration precise hovering at 1500 feet above a reference point. They hover precisely at very low altitudes and/or very close to targets; also, hovering tends to overtax both the pilot and the engines.

Since a helicopter's gross weight is an inverse factor in maintaining a precise hovering point, the fuel allocated in the experiment was limited to just enough for 30 minutes of on-station hovering, as opposed to a normal 4 1/2-hour flight. This in itself handicapped the test.

Three stability runs each of 10-minute duration were made with the helicopter. Flight plans for the first two used a ground reference point 4200 feet from the ship, with the helicopter hovering at 1500 feet; the last run used a ground reference point 4500 feet from the ship, with the hovering point at 1800 feet.

B. Balloon. - The U.S. Air Force Range Measurements Laboratory (RML) of the Air Force Eastern Test Range has an active Tethered Lighter Tahn Air (TELTA) project flying balloons near the *USNS RANGE SENTINEL* berth at Port Canaveral. A preliminary test was planned with RML assistance to determine if a balloon could serve satisfactorily as a stable RF platform. Based on a need to lift a 50-to-100-pound payload to an altitude of 1500 feet, the laboratory recommended use of an RML 5300-cubic-foot "Baldy" balloon, an aerodynamically shaped, tethered balloon designed and fabricated by the G.T. Schjeldahl Company[*]. Table 4 lists the characteristics and performance specifications of the balloon and winch.

Fig. 3 shows the balloon during its initial flight test. It was relatively easy to handle especially when the wind ground speed was less than about 10 knots and the wind velocity at altitude less than 15 knots. (The weather is an important constraint because a balloon cannot be controlled if wind velocities exceed these limits; in addition, safety precludes flying a balloon during electrical storms or when visibility is limited.) The balloon and payload had to be trimmed for an angle of attack of +5 to 10 degrees for the most stable aerodynamic control.

The Baldy needs approximately 5300 cubic feet of helium for proper inflation and lift. A male quick-disconnect fitting below the aft fuselage (Fig. 4) serves for inflation. A flexible line is snapped on this fitting and attached to a bulk-helium tank truck (preferably) or a manifold for ganging about five or six "K" bottles. Adequate balloon inflation in this test was determined by measuring the internal pressure with a Magnehelix gauge attached to a standard innertube valve fitting on the lower vertical stabilizer (Fig. 4). (The balloon pressure should not register less than 0.8 or more than 1.2 inches of water on the Magnehelix gauge.)

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[*]Anon., "Tethered Balloon Systems," Technical Bulletin TB-3, G.T. Schjeldahl Company, Northfield, Minnesota, September 1968.

Table 4 - Characteristics and Performance Specifications of Baldy Balloon and Winch

Balloon Characteristics	
Volume (cu ft)	5300
Float Altitude, MSL (ft)	5000
Payload Weight (lb)	90
Length (ft)	44.0
Diameter (ft)	12.5
Weight (lb)	125.0
Tether Harness	1000-lb Nylon
Winch Specifications	
Type	Powered
Load Capacity (lb)	1000 at 150 ft/min.
Drum Capacity (ft of 0.25-in. line)	4700
Performance Specifications	
Maximum Wind (kn)	25
Angle of Attack (deg)	Variable (5-10 Most Stable for Tests)
Payout Rate	Free-Spooling
Reel-in Rate	120 ft/min.
Min. Ground Crew Required	Four (plus three for winch/flatbed)

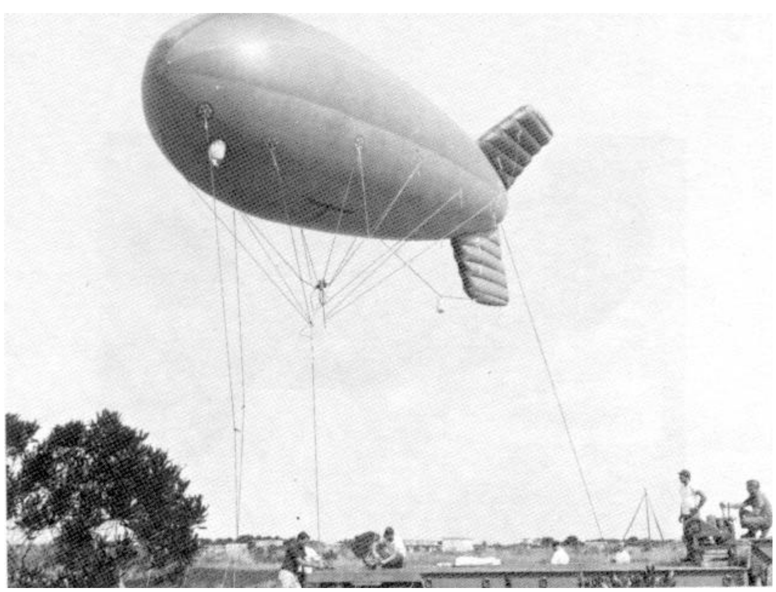

Fig. 3 - Tethering Balloon

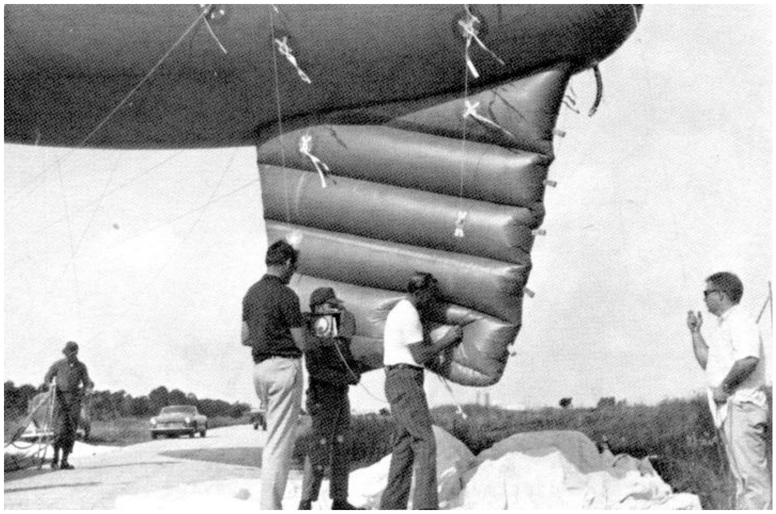

Fig. 4 - Measuring Balloon's Internal Pressure

The RF package was attached to the shrouds just above their confluence point (Fig. 5). For proper balloon trim and attitude, a sand ballast bag supplemented the lightweight payload. The bag was suspended between the aft shrouds and the stabilizer's lower-leading handling line attachments (Fig. 5). Fig. 6 shows adjustment of the telemetry package before ascent.

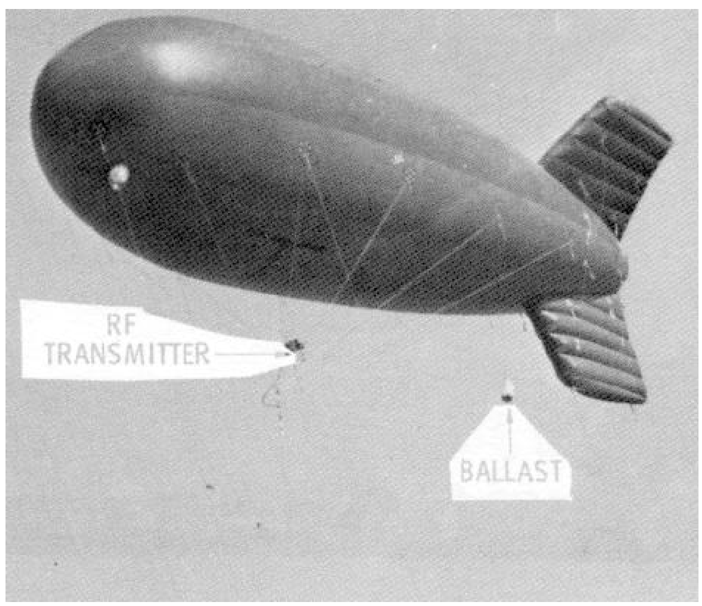

Fig. 5 - Inflight Balloon

For safety and compliance with FAA regulations for a rapid deflation device*, a small aneroid-sensing squibcutter (Fig. 7) was attached to a sleeve under the balloon's nose.

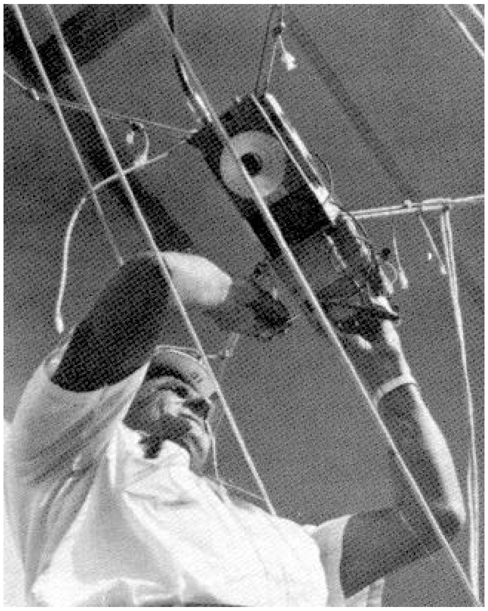

Fig. 6 - Preflight Transmitter Adjustment

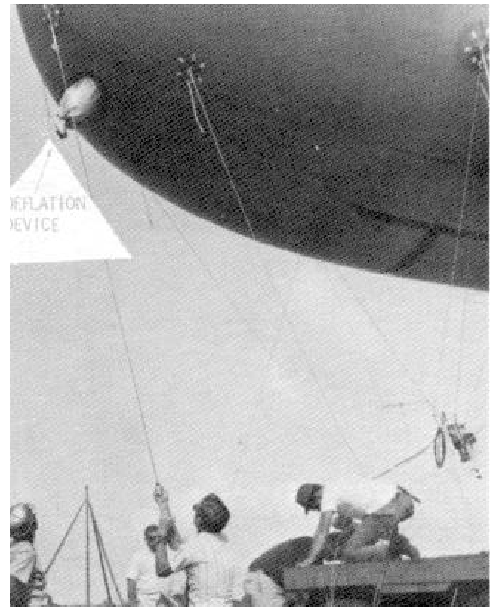

Fig. 7 - Emergency Deflation Device

The aneroid element was set to electrically detonate a self-contained charge at approximately 5600 feet if the balloon accidentally escaped from its moorings. The detonation then would cut the sleeve and vent the helium into the atmosphere. Thus, the test balloon had automatic-deflation capability. Since the balloon was considered to be a Norfolk air traffic hazard, orange-colored, aviation surface flags were attached every 50 feet along the tether line, according to FAA regulations **.

Results. -

A. Helicopter. - During the first experiment, one shipboard antenna observed a ±5-degree deviation of elevation and bearing angles. The third run indicated a slight stability improvement, but the shipboard antenna-elevation-angle variations were still approximately ±3-degrees–twice what was permissible (Table 1).

**Anon., "Moored Balloons, Kites, Unmanned Rockets, and Unmanned Free Balloons," FAA Regulations, vol. 1, part 101, p.5, effective 26 May 1970.

**Anon., "Marking," ch. 3, FAA Advisory Circular AC70/776-1A, 1 January 1972.

B. Balloon. - Figs. 8 and 9 show the results of the first balloon run and a 4-minute trial respectively. A comparison of these results and the requirements (Table 1) leads to the conclusion that the balloon provides adequate stability.

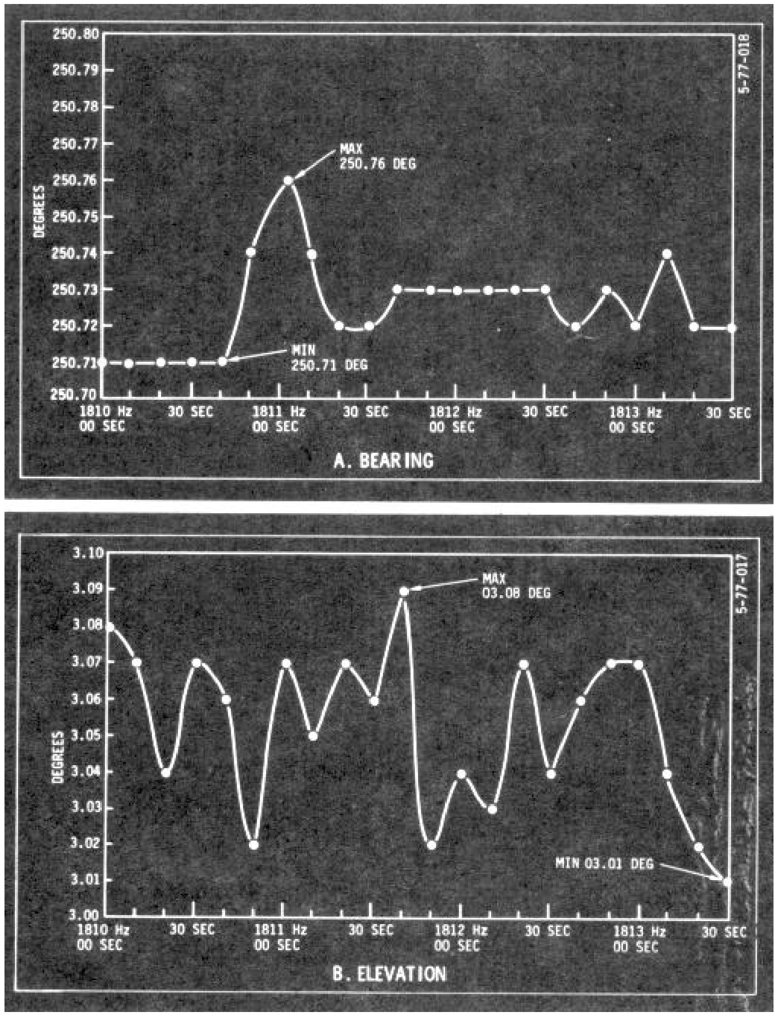

Fig. 8 - Results of First Run of Balloon Test

Conclusions. -

- The helicopter is unsatisfactory as a stable RF platform.
- When flown under favorable weather conditions, the tethered balloon serves as a low-cost, technically efficient stable platform for radiating RF signals to an S-band telemetry antenna system.

Acknowledgement. The co-authors are indebted to personnel of the U.S. Air Force TELTA Project Office and Range Measurements Laboratory at the Air Force Eastern Test Range for their assistance, continued support, and encouragement in making possible the various tests described in this paper.

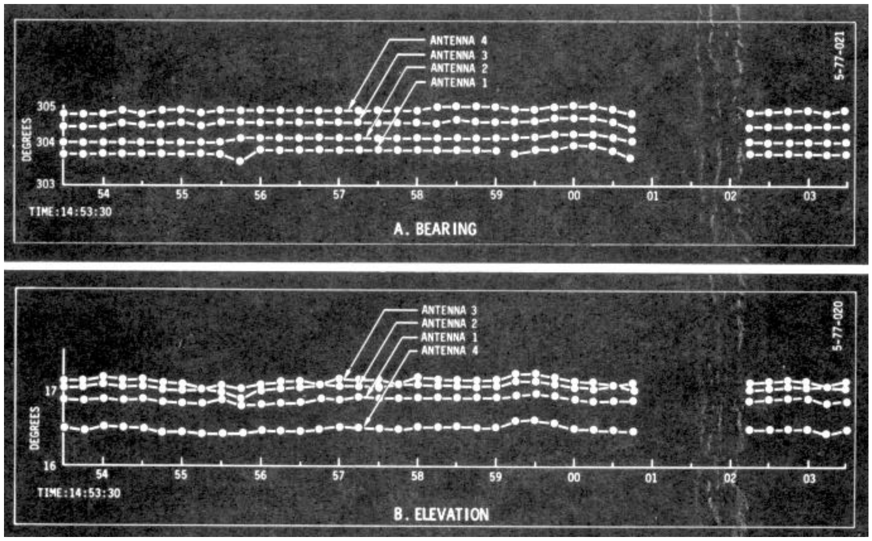

Fig. 9 - Results of 4-Minute Balloon Test