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POINTING PAYLOAD FOR SINGLE TETHER BALLOONS, AND OTHER PROJECTS--ETC(U)
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A two-axis, pointing-type payload has been built that can be flown at Holloman Air Force Base on currently available balloons, using launch facilities and launch methods now being employed there. When attached to the flying lines of an aerodynamically shaped balloon it will point toward a target light on the ground in a daylight operation with a precision of $\pm$ 0.75° when elevated to 10,000 feet. Heading of the payload axis is commandable from the ground, and target acquisition is aided by a search feature. The system

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20. ABSTRACT (cont.)

was successfully tested in September 1981 while carrying a hitchhike experiment that measured IR transmission through the atmosphere.

Other work accomplished under the contract included the assembly and modification of four smart valves, the fabrication of five Tufts-type payload releases for use by AFGL, assembling the facts and analyzing the probable reason why an insulating tether failed in Germany with a load of only 3 per cent of the breaking strength of the cable, and studying the problems involved in stabilizing two six-foot dish-type antennas held at the apex of a four-tether balloon arrangement.

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POINTING PAYLOAD FOR SINGLE TETHER BALLOONS, AND OTHER PROJECTS

1. INTRODUCTION

Goals have been very different in each of three time periods, namely the first two quarter years, the next year, and finally the last two quarter years. In the first time segment, roughly two-thirds of the effort was devoted to (1) completing manufacture and assembling four smart valves, and then modifying them to include a new feature; (2) revising four Tufts-type payload releases for use by AFGL in a particular flight at Holloman, and later manufacturing five new units of this design for assignment to AFGL; and (3) an extensive study and analysis of a burned tether problem that appeared in Germany on 26 March 1980. About one-third of the first six-month segment was spent in studying the problems involved in designing a stable platform to keep two dish antennas, each of 6-foot diameter, continuously pointed at different distant targets when the platform is suspended at the apex of a multitether balloon system.

During the second time segment, which began early in the third quarter of the two-year contract and continued for just over a year, all effort was devoted to the design and preliminary fabrication of a two-axis pointing-type payload that can be flown at Holloman on currently available aerodynamically shaped balloons, using launch facilities and launch methods now being employed. Early in the seventh quarter the new payload, which was not completely finished and ready for test, was successfully flown with remarkable success, the premature test being forced by the tight launch schedule at Holloman. Included in this test was a hitchhike experiment which measured IR transmission through the atmosphere in a round trip path to and from the balloon. For this it was necessary to keep the optical axis of a retroreflector mounted on the pointing payload continuously aligned with equipment on the ground, this being positioned next to the target light for the pointing system.

The final time segment spanned the five-month period following the flight test; it was almost entirely devoted to completing the system. Features that were originally contemplated but could not be worked out prior to the test in September were added, and several refinements were made as the system was worked on and shaken down in laboratory testing. A basic modification was introduced as a result of the field test, this being to change the search pattern from an arrangement that moved slowly in azimuth and more rapidly in elevation to one that sweeps faster in azimuth and makes step changes in elevation. Originally it was felt the faster movement should be on the elevation axis because the inertia there is much smaller than on the azimuth axis, but the flight test indicated the azimuth heading of the balloon is too variable to be compatible with a slow azimuth search. In the new arrangement this variability should not be a problem in acquiring the ground target.

2. OTHER PROJECTS

Early in 1977, under contract F19628-77-C-0047, the first so-called smart valve was designed for use in the tethered balloon program at Holloman. It provided the required safety features, and was capable of functioning in a hostile electromagnetic region, so could be used in the then-scheduled operational test of a balloon-supported Loran C/D antenna. Under the present contract, the design of this smart valve was modified to include a flashing light that would be activated whenever the valve was open, thereby supplying a monitor to indicate the time and the duration of valve openings in normal flights when excess internal pressure occasionally has to be relieved. Extra tag-line switches were also manufactured, and these along with four completed valves were turned over to AFGL on 4 August 1980. Drawings of the valves had been supplied to Bedford under the preceding contract for incorporation into the Air Force system so these were updated to include the new monitoring feature. A record of the original valve development was described in Scientific Report No. 2 under the earlier contract, Report AFGL-TR-80-0108.

Early in the first quarter three special payload releases were loaned to AFGL for use at Holloman in testing the BAMM payload manufactured by Visidyne. These releases had been used when the Tufts-built BAMM payload was flown. They are general purpose, squib-operated devices that can be actuated in two ways to provide primary and back-up termination. Only five per cent of the total load is carried by either release pin, this to assure positive operation with small squibs. Shielded electrical filters are installed next to the enclosed squibs to eliminate the possibility of firing by rf transmissions from balloon-borne transmitters. Connections to the circuitry within are made through sturdy connectors, thus eliminating the danger of severing squib connections. Prior to turning over the loaned units they were modified to add a feature that makes for easy mounting of the ripline cutter used by the Balloon Branch. Additionally, the essential facts about the releases, and their use, were written out as an aid for the new users, and several copies were delivered along with the units on 9 April 1980. After the BAMM payload test, the releases were used for several other Holloman flights, and subsequently five new units were manufactured under the contract for permanent use by AFGL. The five new units were turned over on 18 November 1981.

Considerable time was spent in assembling the evidence and studying the probable reason why an insulating tether cable failed in Germany under a load equal to only 3 per cent of the rated break strength of the cable. The tether operation was being carried out in wet weather and on several occasions the wet cable had extended well up into low-hanging clouds where intense electric fields no doubt existed. Conclusion was that corona-type discharges were established at imbeded particles or surface irregularities along the wet, and therefore conducting, cable. Attendant burning reduced the cross-section of the cable, and of course its strength, damage being done on one or more of the ascents prior to failure. When the break actually occurred the weakened segment had just emerged from the supply reel, this happening right at the moment the let-up was being stopped to attach a warning flag to the cable. There was no possibility of burning at the time of the break, and the extra tug in stopping the ascent wasn't important either, though it probably was the last straw. Trouble showed up on 9 April not because there was difficulty at that particular time, but because the cable had been virtually severed during earlier use. A write-up of this investigation was submitted as a memorandum on 12 May 1980.

3. DISH-ANTENNA PAYLOAD

Just when the contract started the question was being asked of AFGL--can tethered balloons be used as emergency support for dish-type antennas? In an attempt to answer a specific query, a feasibility study was made of the problems involved in designing a stable platform to keep two dish-type antennas of six-foot diameter continuously pointed at different distant targets when the platform is held aloft by a tethered balloon. About two months was spent on this problem before concluding the proposed project was unrealistic. Wind forces on each antenna could reach 200 pounds in a wind of 45 knots, the specified requirement, and these would be applied at substantial lever arms in the payload designs considered. Any hope of coping with such moments necessitated a multitether arrangement. Both tritether and four tether arrangements were examined, tritethers being simpler but having poor azimuth stiffness for wind directions aligned with one of the tethers. Attempts were made to place a rigid structure at the apex of a four-tether configuration, and to have each antenna be separately servo controlled using inclinometers and a magnetometer for references, these being adequate for the $\pm$ 0.75 degree requirement. Heading of each antenna with respect to the references was to be adjusted by command from the ground. Arranging the needed power-hungry controls appeared feasible, but no satisfactory way could be found for dealing with the disturbing wind forces. Launching and handling problems were looked at too, with discouraging results. These considerations pointed up the enormous departure from the original idea which was to produce a lightweight unit that could be readily launched at Holloman using existing balloons and presently employed launch methods and equipment. Also the contract goal was to have the pointing payload operate at altitudes up to 10,000 feet, which is unthinkable with a multitether system.

Investigating the two-dish antenna problem did make clear that a design could be worked out if payload dimensions were kept small, but such an arrangement can also be managed by a much simpler single tether configuration which can be more easily launched, and can reach much higher altitudes. On 4 August 1980 the conclusions of the investigation were presented to AFGL personnel at a meeting held there, and small models were used to indicate the mechanical features of a possible structure for a four-tether arrangement. Means for launching a small payload of this general type were also considered, and a plan for doing it with available facilities was suggested. Multitether arrangements have the advantage that the tether apex does not translate very much, and it does not rotate appreciably, but a structure at the apex will be tossed about by the wind unless there are large tensions in the tethers, and the attainable altitude is relatively small, in the range of 500 to 1000 feet.

4. POINTING-TYPE PAYLOAD FOR SINGLE TETHER USE

On the day following the presentation of the feasibility study there was another extended conference at AFGL to discuss an atmospheric measurements experiment which required an elevated retroreflector to be continuously pointed toward an experiment located on the ground. This, of course, is precisely the kind of requirement that was envisioned when it was first proposed to build a pointing payload for tether balloon use. For the newly contemplated application the multitether arrangement would not be adequate because the altitude requirement of the experiment is approximately two kilometers, well above what appeared to be possible with a payload of the type that had been discussed on the preceding day. It was at this point in time that all effort under the contract was directed toward producing a convenient lightweight pointing structure that could be launched on existing aerodynamically shaped balloons at Holloman using equipment and techniques commonly employed there. Considerable thought had already been given to this problem, and in fact it had been concluded that a workable arrangement could be located at the confluence point of the flying lines, and would attach to them to obtain rigidity in the azimuth direction. With such a plan the structure would rotate about the tether line to provide an azimuth axis that would usually be tipped from the vertical by a small amount, up to about 15 degrees. A second axis, normal to the first, would be approximately horizontal. The guided experiment, and the pointing device for controlling the system, would be mounted on the second axis, referred to as the elevation axis. Use of slip rings would be avoided because the entire assembly would rotate around the azimuth axis, and the limited movement about the elevation axis could be accommodated by flexible cables. Within the next twelve-month period such a payload was worked out, and was flight-tested just twelve months later.

In implementing the design, particular attention was given to making it easy to launch using existing techniques and facilities at HAFB, and to make it versatile so it could be adapted to a variety of experiments. It was built in two rigidly-joined parts, the lower section being a mechanical mechanism that includes gearing and torque motors to produce motions about the two orthogonal axes, with 360 degrees of azimuth movement and 120 degrees of elevation movement. Power amplifiers for driving the torque motors, and a 400 Hz inverter, were incorporated in the mechanical assembly as a means of providing a heat sink for those items. Also included in the mechanism were shaft encoders for monitoring the angular positions of the two shafts, this information being useful for understanding the motions of the balloon itself. A three-level instrument container was mounted above the basic mechanical mechanism to house batteries and other equipment needed to make the payload useful. This, of course, includes facilities associated with the experiment, namely the command and telemetry equipment, and circuitry and components needed to accomplish pointing. Provision was made for conveniently bringing wiring from equipment inside the instrument container down to the mechanical section and, through cable belts, to the experiment and to the pointing equipment mounted on the horizontal axis. It should be easy to incorporate an experiment of reasonable size, weighing up to the prescribed 100 pounds, and to find convenient space in the instrument package for associated equipment.

Available torque on each axis was set at 20 lb-ft so it will be necessary to balance the masses about both axes. Balance about the elevation axis can be partly accomplished by carefully positioning the experiment with respect to that axis, and finished by adding appropriate balance weights on an 18-inch diameter plate that carries the optical assembly for pointing. Balance about the vertical axis, and such a balance is necessary because that axis can be off vertical by as much as 15 degrees, may be partly accomplished by judicious placement of heavy batteries, and possibly other equipment as well, in the instrument container. To complete the balance, provision was made for easily fastening weights along the outer corners of the box. If reasonable care is used in planning an experiment, and in loading the instrument container, the necessary balancing can be readily accomplished with minimum additional weight.

Attachment of the payload to the balloon is an important consideration. A coupling mechanism hangs from the two sets of flying lines from the aerodynamically shaped balloon to provide azimuth stiffness for torquing. Upper end of the azimuth shaft is joined to the coupling by a no-backlash universal joint, thereby allowing freedom for the vertical axis to be tilted away in any direction.

Tensile strength of the system was made consistent with the expected use, the design value being 20,000 pounds. In addition to having adequate tensile strength the vertical shaft is big enough to permit handling of the payload with no real danger of bending. Of course the mechanical mechanism is made of metal, principally aluminum, but the instrument container was built as a wooden cabinet using marine plywood with reenforced joints made with waterproof glue. It is a carefully built container with no raw plywood edges in evidence anywhere. Such a design provides some desirable thermal features, but it principally provides very essential mechanical rigidity for that part of the payload.

Circuitry was incorporated to permit three modes of operation, namely a stare mode, a search mode, and a pointing mode. In the stare mode the azimuth direction is controlled by a servo actuated by a two-speed synchro arrangement, the system operating to force the offset angle between the balloon heading and the payload heading to match the positions of the reference synchros, the latter being positioned by commanding from the ground. Elevation heading of the payload during stare is set by forcing the output of a pot on the elevation axis to follow the output of a reference pot which is also positioned by command. Proper use of commands allows the axis to stare toward any target on the ground. But because the azimuth heading of the balloon is not absolutely steady, and the tilt of the tether line is subject to variation as well, the pointing axis of the payload will continually move, so a search mode was included for finding the ground target. When enabled the azimuth angle is swept back and forth about the stare position, and the elevation angle is moved upward from the stare position in steps of about three-degree size, a step being taken at each reversal of the azimuth sweep. Either four or eight steps may be selected. Experience in the flight test showed it is very easy for an observer at the experiment location on the ground to call for commands that will direct the pointing axis roughly toward the ground target, after which the search mode can be enabled to cause a sizable area in this general direction to be scanned. Tracking begins when an optical tracker sees a target light on the ground, then control of both the azimuth and elevation torque motors comes from error signals derived from the tracker. A photomultiplier of the image dissector type coupled with 10-inch focal length optics constitutes the sensing system for the tracker. When operating in the tracking mode the synchro system and the pots have no effect, and their positions have no relationship to the actual payload heading. Precision of tracking is extremely good when there is no appreciable wind disturbance, and it will always be well inside the ± 0.75 degree specification. Since provision for balancing is provided, it's assumed there will be no constant torque required to compensate for unbalance. Wind disturbances also should never demand the full output torque from either motor, 20 pound-feet, because at the specified velocity of 25 miles per hour the dynamic pressure is only 1.6 pounds per square foot at sea level. Although the lower part of the structure is unsymmetrical, the lever arms are small so the disturbing torques caused by the wind should be well below that available on the control axes.

A feature of considerable importance in simplifying launch preparations was the inclusion of regulator circuitry to eliminate battery-charge problems. Several components in the system cannot be safely operated at 37.5 volts, which is the output from a pack of five BB/405 type batteries, the type used at Holloman. Normally batteries are despiked by withdrawing and wasting 15 or 20 per cent of the available energy, but this difficulty is avoided by incorporating regulators that accept battery voltages in the range from the normal 30-volt level up to the fully-charged level of 37.5 volts. Incorporating the regulators not only eliminates the troublesome despiking problem, but permits the full battery capacity to be utilized.

Commandable actions include System On/Off, Optical Pointing On/Off, Azimuth Increase/Decrease at 2.6 degrees per second, Azimuth Increase/Decrease at 0.5 degrees per second, and Elevation Increase/Decrease at 3.2 degrees per second. Telemetered data include output from three 10-bit shaft encoders which show respectively the programmed azimuth angle measured with respect to the balloon heading; the actual azimuth angle, also measured with respect to the balloon heading; and the elevation angle measured with respect to the azimuth shaft that is a part of the tether line. Analog outputs are telemetered to monitor battery voltage, voltage being applied to the high voltage power supply that feeds the photomultiplier tube, the programmed elevation angle, the actual elevation angle, the peak magnitude of the signal coming from the photomultiplier, the azimuth error, the elevation error, and a constant voltage which is present only when the optical system is tracking.

By rushing the schedule the system was gotten together in a preliminary way for a flight test at Holloman on 16 September 1981, this hasty exercise having been forced by scheduling difficulties. There had been no time to live with the system and shake it down, and indeed it wasn't finished, but the successful experience did confirm the easy launchability of the arrangement, the capability of the system, and it made clear that a change in the search pattern was advisable.

5. FLIGHT TEST

Although the payload had just been made to work for the first time, it was shipped to Holloman by dedicated truck on 8 September 1981, arriving three days later. After only four days of preparation and checkout it was launched on 16 September, including a hitchhike experiment that involved keeping a retroreflector continuously pointed toward equipment on the ground. Added to the haste in preparing the system for flight, and the complications of bringing other groups into the picture, the target light which had been advertised to have 360,000 candlepower, turned out to have only about 25,000. This weakness was first encountered in the very brief outdoor pointing that occurred on the day prior to the flight, an exercise that had to be limited to a few hours because of the inflexible schedule. In spite of the rush, the launch was made with no problems having to do with the payload, though the inflation was considerably delayed because of a forklift difficulty. System performance was essentially perfect, there being only three tracking interruptions in an experiment that lasted three hours and 20 minutes. It's fair to conclude from this single experience that the payload can be handled and launched in the planned way. Only a single additional step in the normally-used launch procedure is necessary, that being to arrest the system during letup and anchor it by means of two cables positioned astride the sheave at ground zero. Thus anchored the tether line can be slacked and the payload inserted, then the tether can be reattached, the twin anchors slacked and released, and the letup continued in the usual fashion. With respect to system functioning, it appears safe to conclude that in the finished state, and with a proper target light, the system should point with no interruptions whatever.

6. FINISHING THE SYSTEM

After the payload was returned from the field it was worked on extensively to add features that were not present during the test, and to make one basic change arising from the test experience. This change involved reversing the search pattern from a fast sawtooth elevation scan, accompanied by a slow sawtooth azimuth scan, to the one previously described which sweeps the azimuth angle in sawtooth fashion at 2.4 degrees per second, and changes the elevation angle in steps of about 3-degree size. This change was instituted because the azimuth heading of the balloon changes more rapidly than the tether line tilts, so the new pattern is much more likely to permit capture in the first search of the field being scanned.

Convenience features were added, such as incorporating easily accessible plugs for disconnecting power amplifiers during testing, and adding a plug to one of the shaft encoders to make it impossible to insert another of the same type belonging to the electronics. Improvements were made in the photomultiplier to make for easy focusing when close-in targets are used during test, and a good set of apertures were built for adjusting the light level on the photomultiplier. A metal protective enclosure for the electronics unit was designed and built, and a set of legs to make for easy lab testing of the electronics was added. In addition to the basic circuit changes having to do with reversing the search pattern, two other very important changes were made in the circuitry. The first involved changes at the photomultiplier to eliminate low frequency signals coming from background lighting and from varying photocathode sensitivity. Another important feature that had been planned, but was not working during the field test, was an electronic servo for keeping the pulse height from the photomultiplier at approximately 13-volt level, this being accomplished by controlling the input voltage to the high voltage power supply that feeds the photomultiplier. While making these improvements there was for the first time opportunity to live with the system, to understand it better, and to fine-tune it. Work on the system itself continued for more than four full months after the system was returned from the field, during which time the system was perfected and made more convenient It should now perform in the planned way if a target light is chosen of intensity suitable for the slant range of the experiment, and if the proper aperture for the lens is selected. Width of azimuth scan can be up to 38 degrees, depending on what cam is used, and either four or eight elevation steps may be chosen.

7. CONCLUSIONS

Proposed work to produce a payload that can be used with aerodynamically shaped tethered balloons at Holloman to keep an axis within the payload directed toward a ground target was accomplished and its workability was demonstrated by field testing. Subsequently the payload was further perfected and extensively studied in the laboratory so there is abundant reason to believe that if properly used it will more than meet the contract specifications, which are that it carry an experiment weighing 100 pounds and point with an accuracy of 0.75 degrees when elevated to 10,000 feet in winds up to 25 miles per hour. In the test flight, the slant range was only 2500 feet, but the particularly successful experience then with a partially developed system, and a target light having only seven per cent of the expected intensity, can surely be extrapolated to justify the conclusion that the device being delivered fully meets the specifications.

In designing the new payload special attention was given to making it usable in the program at Holloman Air Force Base without requiring new balloons, new launch equipment, or new launch procedures. A single additional step is required in the currently used launch procedure, that being to arrest the payload and anchor it in an easily managed manner, insert the payload, slack and remove the anchor lines, and finally let the balloon rise in the usual way. Provision was made for easily handling the payload by carrying it on the two tines of a forklift, and the pesky problem of initial high voltage from flight batteries was eliminated by providing suitable regulators, this feature being an important operational feature.

Other work accomplished under this contract included (1) completing manufacture of four smart valves, and incorporating a new feature in these devices, (2) manufacturing for AFGL use five payload releases of the type that has been successfully used here for many years, including prints of drawings for these devices, (3) studying and evaluating the feasibility of a stable platform desired for keeping two six-foot, dish-type antennas continuously pointed in two prescribed directions, and (4) the preparation of a memorandum, evaluating the probable cause of a tether failure in Germany.