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BALLOON PLATFORM FOR EXTENDED-LIFE ASTRONOMY RESEARCH

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ABSTRACT

A configuration has been developed for a long-life balloon platform to carry pointing telescopes weighing as much as 80 pounds (36 kg) to point at selected celestial targets. A platform of this configuration weighs about 375 pounds (170 kg) gross and can be suspended from a high altitude super pressure balloon for a lifetime of several months.

The balloon platform contains a solar array and storage batteries for electrical power, up and down link communications equipment, and navigational and attitude control systems for orienting the scientific instrument.

A biaxial controller maintains the telescope attitude in response to look-angle data stored in an on-board computer memory which is updated periodically by ground command. Gimbal angles are computed by using location data derived by an on-board navigational receiver.

High instrument data rates necessitate increased electrical power consumption and directional antennas for transmission to a data satellite. The maximum usable real-time data rate within weight limitation is about 1000 bps with a 100 percent duty cycle. Higher data rates would be used with reduced duty cycles.

An extended-life balloon platform for astronomy missions appears to be basically feasible; however, the effectiveness of the mission is strongly dependent on the availability and location of ground control and data acquisition facilities.

DISCUSSION

Observation times for instruments lifted by conventional balloons are usually limited to a maximum of two days because the fill-gas is vented as the balloon is subjected to day-to-night temperature fluctuations, and because the balloons usually drift out of range of the ground stations.

Recent flights of "super pressure" balloons, have demonstrated the feasibility of keeping payloads aloft for extended periods. During a lifetime of three months, the balloon might encircle the globe several times, at a rather constant latitude, at an altitude of about 100,000 feet (30 km).

A brief investigation has been conducted to configure and size a balloon gondola to provide electrical power, attitude control, and data handling capability for an X-ray telescope used to observe selected celestial targets while it is suspended from an extended-life balloon. The basic characteristics of a typical balloon-borne instrument are given in Table 1. (The data for the table were supplied by James Kurfess, Naval Research Laboratories, Washington, D. C., who also supplied many of the systems concepts which influenced the gondola configuration.)

Table 1

TELESCOPE INSTRUMENT CHARACTERISTICS AND REQUIREMENTS

Size:	2 by 2 by 2 feet (60 cm)
Weight:	80 pounds (36 kg)
Electrical power:	15 watts
Data rate:	2,000 bps minimum
Pointing accuracy:	1-1/2 degrees
Pointing modes:	Fixed point and raster scan

Important auxiliary networks are required to maintain control and retrieve the data from the scientific instrument and gondola which may be situated at any longitude during its lifetime. Furthermore, the problem of determining the location of the balloon and instrument platform requires a system with nearly global coverage.

A conceptual view of the systems involved is shown in Figure 1.

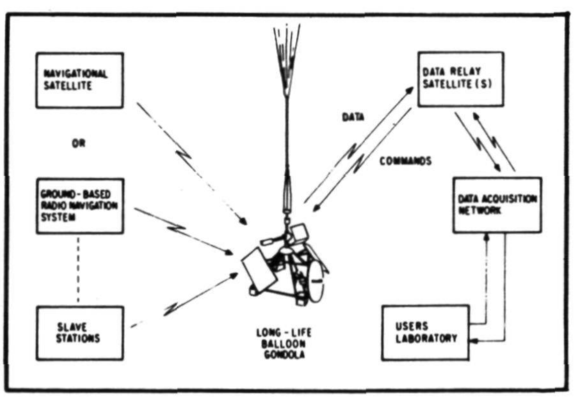

Figure 1. Extended Life Balloon Navigation and Communications Systems

Data are retrieved through a communications channel on one or more data relay satellites, orbiting the earth at synchronous altitudes, stationary with respect to the earth.

Position determination is made from signals received by equipment on the balloon gondola from either ground-based navigational systems such as the OMEGA system or from orbiting navigational satellites such as TRANSIT. Similarly, ground control of the instrument and gondola also uses a time-shared data relay satellite channel or ground-based command network.

The basic configuration of the instrument gondola is shown in Figure 2. The arrangement of the subsystem parts is dictated primarily by the telescope's need for an unobstructed view of the celestial hemisphere, a line-of-sight path from the data link antenna to the data relay satellite orbiting above the earth's equator, and the position of the solar cell array panels to maximize the energy available from the sun.

The coarse orientation of the gondola platform is maintained by an azimuth controller so that the solar array panels are to the east and west. The solar array panels are attached to the structure with mission-selectable brackets so that the normals to the panels are nearly in the ecliptic, and thus maximizing the available energy.

The high gain data transmission antenna is oriented by a biax gimbal located on the north side of the gondola, for flights in the southern hemisphere. Full 180° movement of the antenna is required in the east-west direction, but the north-south excursion is quite small.

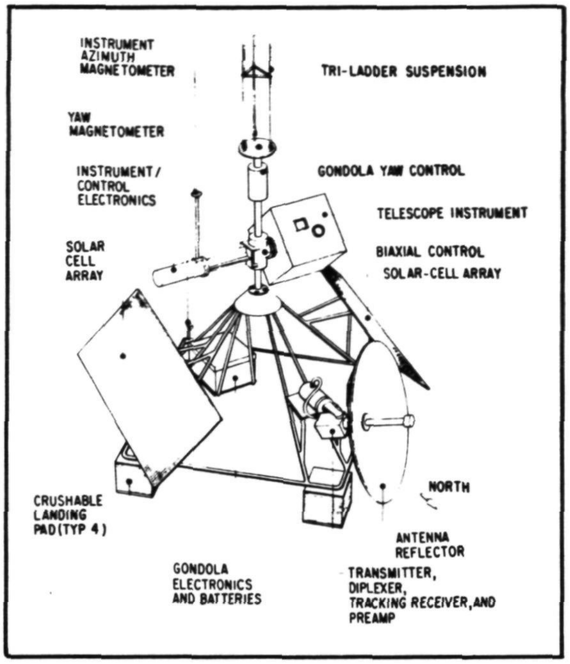

Figure 2. Gondola Configuration

The telescope instrument is oriented to selected stellar targets in azimuth and elevation by a biaxial controller located on the main azimuth stem above the gondola base structure.

The gondola suspension system is a ladder formed by three cables spaced in the shape of a triangle. By also spacing the shroud lines on the folded recovery chute in the same manner, the suspension system torsional stiffness is increased.

Weights of the gondola components are given in Table 2. To minimize the structural weight, no roll cage was included in the structural framework. The crushable pads were widely spaced to lessen the likelihood of upset on landing.

NAVIGATION AND CONTROL

Orientation of the telescope instrument and data relay antenna involves the use of an on-board computer to compute gimbal angles from stored data loaded by ground based command data, and geo-position data obtained from a navigational system.

Figure 3 is a simplified diagram of the control and navigational system. Target sequence and coordinate data are entered in the storage by the command receiver when the gondola is within range of ground command stations. The navigational receiver and initial processor supply geo-position coordinates for the balloon based on the signals from ground-based transmitters such as the OMEGA system. The on-board computer performs the coordinate transformations required to derive gimbal angles in the gondola coordinate system.

Table 2

WEIGHT BREAKDOWN

	Wt-kg	Wt-Pounds
EXPERIMENT TELESCOPE ASSEMBLY	36	80
COMMUNICATIONS		
• Command Receiver-Decoder	.91	2
• Navigation Receiver	.45	1
• Communications Antennas	.91	2
• Housekeeping Data System	2.72	6
• L-Band Antenna (5-foot diameter) and Feed	2.27	5
• Tracking Receiver and Preamplifier	1.36	3
• Diplexer	.45	1
CONTROLS		
• Telescope Attitude Cont Elec	1.36	3
• Computer	3.6	8
• Antenna Att Cont Elec	1.36	3
• Magnetometers	.91	2
• Yaw Control Electronics	.45	1
POWER		
• 2 to 15 ft^2 Solar Array Panels	13.6	30
• Battery - 40 amp/hr Capacity	18.1	40
DRIVES AND MECHANISMS		
• Telescope Biaxial Gimbal	7.26	16
• L-Band Antenna Biaxial Gimbal	4.08	9
• Yaw Drive Assembly	2.72	6
MISCELLANEOUS		
• ATC Transponder	1.81	4
• Altitude Transducer	.45	1
STRUCTURE		
(Cage, Bracketry, Crushable Pads)	34	75
TOTAL BASIC GONDOLA AND TELESCOPE	~135	298
BALLOON SUSPENSION	4.5	10
RECOVERY PARACHUTE AND CUTDOWN ASSEMBLY	10.4	23
LAUNCH ASSIST BALLOON AND BALLAST BOTTLE	4.5	10
TOTAL GROSS WEIGHT	~155	341

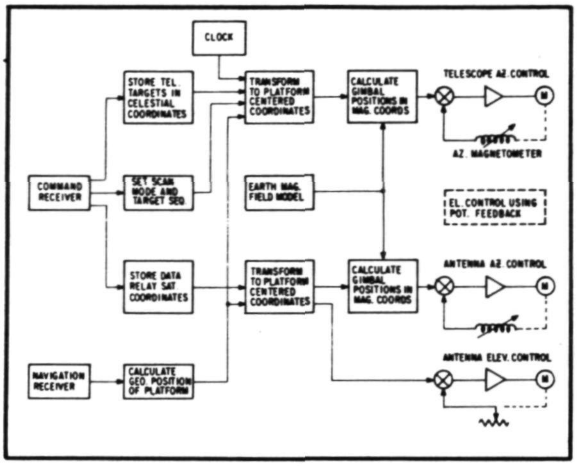

Figure 3. Gondola Navigation and Control System

Azimuth angles are expressed in terms of the local magnetic field and command signals are synthesized for the azimuth servos scaled to the output of the azimuth magnetometers. Elevation angles relative to the local vertical are derived from geo-position data and the stored commands from the ground operator.

The coarse azimuth orientation of the gondola is maintained by a yaw servo with a dead band of several degrees. The yaw controller applies a small, limited torque between the gondola frame and the relatively stiff balloon suspension, rotating the gondola until the output of the yaw magnetometer nulls a synthesized command signal from the on-board computer.

The gondola remains in the dead band until disturbances from the balloon or gondola cause the gondola yaw position to drift outside the dead band.

The biaxial gimbal systems for both the telescope and antenna control are similar to those used in numerous balloon and spacecraft pointing control applications. The gondola frame and fixed components provide a relatively large inertia against which the azimuth and elevation controllers may react.

The stability and accuracy of azimuth control is limited principally by the limits with which the magnetic field can be resolved on board. Since elevation control is "open-loop", motions of the gondola also affect pointing accuracy. It is predicted that absolute pointing accuracies of better than 1-1/2 degrees can be achieved. A method of reducing the uncertainty resulting from errors in resolving and modeling the magnetic field might be to calibrate the azimuth magnetometers at sunrise using signals from an azimuth solar sensor.

Gimbal rates for the data relay antenna will be quite low once acquisition is complete. Since the antenna beamwidth will be about 1-1/2 degrees, some means of semi-active tracking of the data relay satellite will probably be required.

One method of mechanizing a semi-active tracking system would be to detect the housekeeping data signal originating at the data relay satellite, using a receiver located in the balloon gondola. The gondola data transmission antenna would be positioned initially by using computer-derived gimbal data. Then a scan would be initiated over a raster several degrees in width. When the signal level from the data relay satellite housekeeping telemetry channel became sufficiently strong, the raster scan would be interrupted. As the look angle to the DRS drifted and the signal level decreased below a predetermined level, the raster would be automatically reinitiated, and the acquisition sequence repeated.

POWER

Power requirements for the gondola subsystems and components are given in Table 3. Total energy requirements are affected sharply by the data rate employed because of the increased bandwidth and RF power required as shown by the items in the lower part of the table.

Table 3

POWER BUDGET

Component/Subsystem	Power-Watts at 28 Volts
COMMUNICATIONS	
• Command Receiver-Decoder	2
• PCM Telemeter and Subcom	3
• OMEGA Receiver	.5
• Tracking Receiver and Preamplifier	3
CONTROLS	
• Computer	10
• Telescope Att Control	3
• Magnetometers	2
• Antenna Control Elec	3
• Yaw Controller	1
POWER DISTRIBUTION AND CONTROL	3
TOTAL CONTINUOUS LOADS	30.5
ALTERNATE OR DUTY CYCLED LOADS	
• X-Ray Experiment	15
• L-Band Transmitter at 100 bps	10
• L-Band Transmitter at 1000 bps	67
• L-Band Transmitter 25 K bps	240
• ATC Transponder	6
• Tape Rec - Rec Mode	8
• Tape Rec - PB Mode	14.5

The solar cell array panels are tipped inward at an angle of 45 degrees, so that the energy obtainable during the day is relatively constant. The "effective" efficiency of the array panels, when positioned so their normals are parallel to the ecliptic is shown in Figure 4 to be about 54 percent.

Another important determinant of total gondola weight is the energy consumed during the night hours, since battery capacity and the corresponding weight must be increased to enable storage of energy for night operation. The effect of various duty cycle modes on the total gondola weight is shown in Table 4.

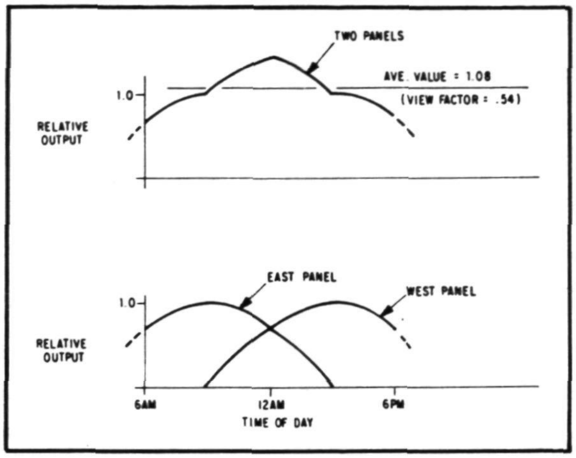

Figure 4. Relative Output of Solar Array Panels

Table 4

IMPACT OF DATA RATES ON SYSTEM WEIGHT

Case	Day Duty Cycle (Percent)	Rate (bps)	Night Duty Cycle (Percent)	Rate (bps)	On-Board Data Storage	Solar Array Area		Battery Capacity (amp/hr)	Total Payload Weight	
						Ft^2	Mtr^2		KG	Pounds
1	100	1000	100	1000	No	34	3.1	48	170	375
2	100	1000	50	1000	No	31	2.9	43	162	357
			50	100						
4	100	250	100	100	No	48	4.4	40	167	379
6	50	2500	100	100	No	35	3.2	32	163	359
	50	100								
7S	80	100	80	100	Yes	27	2.5	40	165	364
	20	250	20	2500						
8S	100	2500	100	2500	Yes	35	3.2	54	177	389
9S	50	100	50	100	Yes	32	3.0	17	175	386
	50	2500	50	2500						

DATA HANDLING

Different data rates and various duty cycles have been evaluated to determine their effect on electrical energy requirements and system weight. The results shown in Table 4 and Figure 5 include cases 7S, 8S, and 9S which involve the use of an on-board tape recorder for data storage.

Without on-board data storage, real-time data rates in excess of 1000 bps require TWT transmitters, and the required DC electrical power takes a step increase over that required for more efficient solid-state units. When on-board data storage is used, the real-time data rates are moderate except during "playback" when the DC power requirements increase drastically.

However, due to the short duty cycle, typically ten percent, the higher power level does not result in a large increase in the total energy consumed.

For the duty cycles and data rates of case 7S the use of an on-board recorder results in a net saving in weight; for other conditions, the weight of the recorder just about offsets any saving in power system capacity.

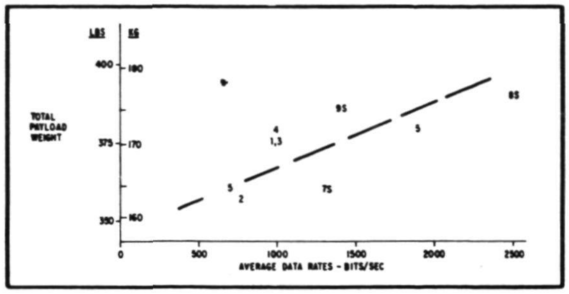

Figure 5. Payload Weights For Various Average Data Rates

CONCLUSIONS

It appears feasible to construct, using current technology, a balloon gondola for extended life astronomy research for altitudes in excess of 100,000 feet (30 km). Thus, many observations could be made over extended periods of time which were previously thought possible only from orbiting satellites, at a substantially greater cost.

Significant further effort is required to implement practical and economical, world-wide communications and navigational systems. Navigational communications may be provided in the future by orbiting satellites. This type of system would be inherently more accessible from remote areas such as the southern latitudes than are the stations of the existing ground-based navigational systems.

Time-sharing of data relay satellite communications channels could be an answer to the need for economical data retrieval and command control of extended life, balloon-borne payloads.

DISCUSSION SUMMARY — PAPER 2.8

The trade-offs associated with using a satellite link for data transmission were considered. It was estimated that a continuous rate of 17 bits per second would cost $10,000 per month.

Since the Omega system is not complete in the Southern Hemisphere, it is of course not satisfactory for this system.

Further discussion of this topic developed during panel discussion 3.3 on February 22.