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FINAL REPORT
BUOYANT VENUS STATION
FEASIBILITY STUDY

Volume V - Technical Analysis of a 200-Pound BVS

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FOREWORD

This final report on the Buoyant Venus Station Feasibility Study is submitted by the Martin Marietta Corporation, Denver Division, in accordance with Contract NAS1-6607.

The report is submitted in six volumes as follows:

- Volume I - Summary and Problem Identification;
- Volume II - Mode Mobility Studies;
- Volume III - Instrumentation Study;
- Volume IV - Communication and Power;
- Volume V - Technical Analysis of a 200-lb BVS;
- Volume VI - Technical Analysis of a 2000- and 5000-lb BVS.

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FINAL REPORT

BUOYANT VENUS STATION FEASIBILITY STUDY

VOLUME V - TECHNICAL ANALYSIS OF A 200-POUND BVS

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MISSION MODE TRADEOFF STUDIES - TASK 4.5

For each mission mode investigated, the contractor shall select, subject to government approval, the most promising mobility method or methods and perform mission mode tradeoff studies in the prescribed range of the Venusian atmosphere.

As part of the midterm Oral Briefing, the recommendation was made and accepted, that during the remaining period of the study (Mission Mode Tradeoff) part of the effort would be concentrated on a nominal 200-lb station.

SUMMARY

This volume presents the results of an analysis of the feasibility of a small (nominally 200 lb) buoyant Venus station (BVS). It is intended that this station would be generally compatible with a 1972, Atlas/Centaur-launched, mission to Venus.

The results of the study indicate that the concept is both feasible and attractive. A duration in the atmosphere of as much as seven days with several opportunities to probe to the surface as well as the ability to collect wind pattern information and to make measurements at more than one (horizontal) location will significantly enhance the usefulness of the data collected. In comparison, a single probe to the surface with one short opportunity to collect and transmit data appears severely limited.

All of the possibilities for a small station concept have not yet been explored. The 225-lb weight limitation was developed on the basis that both a bus and capsule would be put into orbit. Equally attractive, however, is the concept of deflecting the capsule (BVS) before placing the bus into orbit or a BVS in conjunction with a flyby mission.

The major development areas that would be associated with this concept have been identified. To develop and demonstrate a high degree of reliability in the balloon is the most fundamental problem. By selecting a well-understood material (Mylar) and an altitude with moderate temperature (225°K) the problem has been alleviated; however, the mechanics of failure are not well understood and little applicable test (reliability) data are available. How to best use a weight allowance to enhance reliability will be an early problem to be solved.

Of next significance are the development of balloon controls (sensors, relief valves, etc.), lightweight tankage, science instrumentation, and the remaining electronics. The fundamental problem in all these areas is one of keeping the weight low. The predeployment environment, particularly entry deceleration, must also be considered.

In this study, it has not been possible to adequately consider the entire mission (or alternative missions) and the interfaces with other portions of the complete system. No attempt has been made to define an orbit satisfactory to both the BVS and the bus. In addition, the functional and physical interfaces between the BVS and the bus and entry capsule have not been considered in depth.

Finally, the uncertainty in the atmosphere of Venus presents a problem. By present models, achieving subsonic velocity above the clouds in the low density atmosphere appears difficult. The level of cloud tops is a significant uncertainty to a balloon as it may affect gas temperature, and nothing is known of local conditions such as storms, turbulence, etc. For this concept it has been attempted to minimize these problems by operating at the cloud tops. Mariner 67 data are anticipated to better define at least this one plane in the atmosphere.

This design has been based, as far as possible, on conservative interpretation of the above uncertainties. Nonoptimum orbits, gas weight penalties for shaded (in the cloud) situations, and minimum imposition on the spacecraft interfaces are examples. The conclusions of feasibility of the small station concept includes this conservatism.

The design concept described herein was developed for the purpose of demonstrating feasibility and is not presented as an attempt at optimization. In addition, the study constraints made it necessary to make assumptions for the initial conditions (subsonic above the clouds), the shape and nature of the aeroshell, the orbit and the BVS target, and the capabilities of the orbiter.

INTRODUCTION

The starting points for this concept were a weight limitation of 225 lb; a desired scientific payload developed during the preceding instrumentation studies and suitable for a minimum size "early" Venus mission; and a wind pattern model also developed during the preceding effort.

From the wind pattern model, a desired targeting point for a short mission was defined. In figure 1, the deployment areas indicated will cause the balloon to drift with a trajectory, which will reach the terminator in less than seven days. Deployment areas that will cause the BVS to pass within 10° of the pole are considered desirable. A desirable mission then would be to start within these boundaries and pass within a few days over the terminator near the pole.

For purposes of defining communication parameters, elevations, distances, and times between the drifting BVS and a bus, an orbit 1000 km by 10 000 km with an inclination of 70° from the Venus orbital plane was formulated as indicated in figure 1. For this analysis, the BVS was assumed to be deployed at a latitude with respect to the Venus orbital plane of -55° and a longitude, with respect to the subsolar point of 15°. A BVS trajectory (drift in atmosphere) directly across the pole was assumed.

A scientific mission of measuring temperature, pressure, density, and composition over this path and three probes to the surface were then defined. Position location and communication are performed in conjunction with the orbiter.

The overall mission consists of the initial deployment and stabilization of the balloon, the periodic collection of scientific data at altitude as the BVS travels toward the terminator, probing to the surface three times on command (twice with sondes and finally by allowing the entire station to descend), and the periodic transmission of data and position determination in conjunction with the orbiter.

Figure 2 shows the deployment sequence. A separate mode of data collection including engineering information is provided for this critical phase to assure that fundamental information is not lost.

The remainder of the mission is controlled by an onboard sequencer and keyed to the periodic command of the orbiter. In addition, 10 discrete commands have been identified.

A concept of packaging the BVS in an aeroshell is indicated in figure 3. The gondola is a cylinder (tapered slightly) 1 ft high and approximately 2 ft in diameter with a volume of approximately 2 cu ft. This implies a packing density of 25 to 30 lb/cu ft. The taper to the cylinder is to permit free deployment of the balloon, which is packed in the annulus around the gondola. The packing density is 20 lb/cu ft, which is considered moderate.

The parachute is deployed by mortar from its position above the gondola and separation of the entire BVS from the aeroshell is by explosive bolts. The high-pressure hydrogen tankage is in the form of an oblate spheroid, which is optimum for filament-wrapped tanks.

The inflation controls are designed to be dropped with the tankage after inflation and the relief valve is installed in the gondola for thermal protection.

The antennas are not shown. Detail design will be required to create a suitable antenna configuration without excessive weight penalty. The problem is aggravated by the desire to transmit during the deployment phase. Also not shown is a Pitot/static arrangement, which is required to adequately sense ambient pressure for initial balloon deployment. The Pitot tube has to be deployed from the aeroshell.

The internal arrangement does not appear to be critical. Both batteries and an RTG are shown. Two sondes are indicated, and 1/2 in. of insulation is provided, which is suitable if 100 W of heat is available. This provides for an internal temperature of 40°F, which is desirable for proper battery operation.

Figure 4 defines the configuration in a deployed condition -- after the tankage and controls have been dropped. The balloon is 25.4 ft in diameter providing a total lift of 95 lb of which approximately 70 lb is available for the gondola. (This is for a midrange 200-lb station. The 225-lb station will support a gondola weighing approximately 80 lb).

The overall weight breakdown is indicated in table 1. Further breakdowns are given in each of the subsystem sections later in this report. The approach taken was to define the capability of range of systems weighing from 175 to 225 lb. This volume is written in terms of a 200-lb station. Growth or possible decrease in payload weight can thus be determined easily in terms of overall weight.

As can be seen from table 1, a 12-lb margin exists between the total subsystems weight and the allowable gondola weight. This margin includes structure and thermal control. The thermal control is estimated at 2.4 lb, allowing 10 lb for structure.

In defining the individual weights, it was attempted not to choose the most optimistic values for all systems. Thus, while weight growth is inevitable, some improvement is also conceivable. Significant areas for improvement are:

1) The spread of design atmospheres considered may be an unnecessary penalty. The Mariner 67 flyby may further refine the conditions at cloud top. A considerable saving could be achieved if it were known that the station would be floating in the sun above the clouds;

2) The orbit chosen for the communication link analysis and the path assumed for the BVS are far from optimum, placing a penalty on the communication and ranging system weights.

SYMBOLS

A/D	analog to digital
AGC	automatic gain control
APC	automatic phase control
BPF	bandpass filter
BPS	bits per second
B_{rf}	radio frequency bandwidth (predetection)
B_v	video bandwidth
BVS	buoyant Venus station
BW	bandwidth, cps

CP&S	central programer and sequencer
DAS	data automation system
f_c	center frequency of filter
f_o	sync subcarrier frequency
g	acceleration of gravity, ft/sec^2
mil	one-thousandth of an inch
NRZ	nonreturn to zero
PBI	Polybenzimidazole (polymer)
P_e^b	bit error probability
RTG	radioisotope thermal generator
SNR	signal-to-noise ratio
SNR_i	input signal-to-noise ratio
SNR_o	output signal-to-noise ratio
ST/(N-B)	signal energy per bit
VCO	voltage-controlled oscillator
α	solar absorptivity, dimensionless
β_o	modulation index, radians (data channel)
β_s	modulation index, radians (sync channel)
ϵ	infrared emissivity, dimensionless
θ	true anomaly (refers to orbit)
σ_n^2	limiter noise supression factor
σ_s^2	limiter signal supression factor
φ	drift angle of station on great circle path from initial position toward planet's South Pole

SCIENCE/INSTRUMENTATION SUBSYSTEM

Experiments

The scientific instrumentation for the 200-lb BVS is summarized in table 2. The instruments listed provide the capability for answering the most important questions about the Venus atmosphere. Pressure, temperature, composition, and density define the atmosphere and the environment for life. Pressure and temperature profile measurements from the drop sondes permit altitude to be inferred from pressure measurements on the station. The tracking of the station from the orbiter determines the wind pattern.

The experiments for the drop sondes are shown in table 3 and the weight and power allocations in table 4. The temperature sensor and its tube are mounted on the nose; the water vapor detector inlet port is located near the nose with the exit port near a static pressure point to provide flow; and the pressure sensor ports are located at static pressure points around the body as shown in figure 5.

Data Acquisition

There are three modes of data acquisition for the science subsystem. They are:

Mode I - Pressure, temperature, density, and composition measurements while at equilibrium altitude. These data, amounting to 91 bits, are read every 1.25 hr three times during each orbit and stored for transmission when the orbiter comes into view;

Mode II - Drop sonde data (pressure, temperature, and water) received and stored. No data from Mode I are collected during this period (1 orbit). This mode is initiated on command from the orbiter;

Mode III - During station descent at the end of the mission, Mode I measurements are taken and transmitted to the orbiter every 13.3 sec.

Sequencing

After balloon deployment is complete and the equilibrium altitude attained, Mode I measurements begin and are continued until a command from earth initiates drop sonde release and Mode II. As soon as Mode II data are satisfactorily received on earth, another command causes the Mode I measurements to resume. The process is repeated for the second drop sonde. At the end of the mission, after the station has crossed the terminator at or near the south pole, a third command initiates station descent and Mode III. An approximate timetable is shown in table 5.

Problem Areas

The design and development of a 5-lb drop sonde to survive the high temperatures and pressures of the lower atmosphere presents a major problem. However, this appears within the state of the art using miniaturization techniques, thermal insulation and phase-change heat-sink material, and by developing the sonde as a single package rather than a stack of black boxes.

The experiments, with the exception of some of the single gas detectors, have been developed to at least the breadboard stage, but none are yet in a form suitable for use on the BVS. However, there appear to be no fundamental problems that time and development effort cannot solve.

Special requirements of problems such as deployment, look angles, protection, contamination by leakage gases, etc., present some difficulty but appear to be amenable to solution during the preliminary design phase.

The only fundamental problem concerns the wind pattern on Venus. While a theoretical model has been assumed for calculating the BVS trajectories and flight times, there is very little experimental data to substantiate either the general pattern or the magnitude of the wind velocities used.

BALLOON SUBSYSTEM

The balloon is designed for a minimum mission duration of seven days floating at 57 km in the mean density atmosphere with a superpressure of 6 mb. In this atmosphere, the station is approximately 1.8 km above the clouds. In the lower density model the station floats at approximately 40 km, which may be within the clouds. In the upper density atmosphere, the station will float at approximately 79 km, which is above the clouds.

Hydrogen gas is used as the inflation media, and the balloon inflation sequence is initiated at one selected static pressure. The inflation results from the blowdown of the high-pressure (4500 psia) pressurant tank.

The balloon is fabricated from Mylar. This is based on good physical properties and on the current state of technology with respect to balloon fabrication and design. The basic construction is a lamination of two films of 0.5 mil each. The resulting balloon design is shown in figure 6.

Pertinent data are as follows:

1) Volume, 8630 cu ft;

2) Diameter, 25.4 ft;

3) Surface area, 2025 sq ft.

Balloon design details are shown in figures 7 and 8. Nylon-reinforced Mylar is used for the cap attachment loads and the inflation fitting mating area to produce a gradual transition to high stress points. A diffuser plate and sock is used to reduce the velocity of the inflation gas and eliminate the possibility of direct impingement of a high-velocity gas stream on the balloon skin.

The basic balloon shell fabrication shown consists of attaching identical gores together with Mylar adhesive-backed tape. The laminated Mylar has improved properties over single film with regard to gas permeation and handling characteristics. The load suspension consists of a nylon cone attached to the balloon skin forming a tangent harness. The included angle is approximately 120°.

The calculated skin stress resulting from the 6-mb superpressure is approximately 7000 psi. The suspended load imposes a load of approximately 0.3 lb/in. The stress of 7000 psi corresponds to a skin stress of 7 lb/in. This substantial differential ensures a minimum deformation from the spherical shape.

A schematic of the balloon inflation and control subsystem is shown in figure 9. The hydrogen gas is stored at a nominal pressure of 4500 psia and is loaded through a manual fill valve. Pressure and temperature of the stored gas are monitored with transducers. The ordnance shutoff valve is opened on signal from a pressure switch sensing static pressure. The filter protects the balloon and downstream components from metallic particles generated from an ordnance valve firing. The orifice restricts the flow to ensure that the balloon is not subjected to an initial damaging flow rate. The guillotine is the separation device that allows the tank and upstream components to be disconnected from the station. The balloon shutoff valve is a normally open ordnance valve that is closed on signal from the flowmeter signal conditioner. The flowmeter signal is sent when the gas flow has reached a selected minimum value. Two other methods are considered for controlling the shutoff valve. A pressure switch that opens at a tank pressure in the range of 300 to 500 mb could be used; another method of control is using a selected time interval. The pressure switch sensing balloon superpressure controls the solenoid valve for the relief function. An alternative method would be use of a relief valve.

The hydrogen gas pressurant tank weight is based on a nickel-lined, filament-wound vessel because nickel is not known to be attacked by hydrogen. The filament may be glass or boron, which are compatible, and results in a weight of 11 lb of tank per pound of hydrogen gas. This weight is predicated on heat sterilization being accomplished in the unpressurized condition. The hydrogen would be loaded after being sterilized in a separate container.

The station deployment sequence is shown in figure 10. The equipment required for the station deployment is shown in figure 11. Pressure switches are used to initiate both parachute and balloon deployment. Ordnance devices, such as pin pullers and explosive nuts, are used for separating and opening functions.

The hardware required for balloon inflation along with quantity of each component required, unit weights, volumes, and power requirements are listed in table 6. The values shown are typical for similar components found on spacecraft to date. The development status and flight usage of the components are shown in table 7. Mariner and Surveyor have used similar hardware. The primary difference between these flight-proven components and those required for this mission is sterilization. Ordnance squibs and valves have been subjected to sterilization temperatures at Jet Propulsion Laboratory and have functioned properly.

The pressure switch that controls the balloon superpressure appears to be within state of the art for the 1970 time period. The Air Force Cambridge Research Laboratory has flown a pressure switch with a setting of 10 mb and a bandwidth of 10%. A supplier of pressure switches, Servonic Instruments, has a pressure switch in engineering with a setting of 7 mb for production in 1968.

The relief valve presents a greater extension of the present state of the art. The requirements are shown in table 8. The small differential pressures for cracking, full flow and reseat present problems of minimizing seat leakage. A pressure switch operating a solenoid valve is an alternative approach that eliminates the requirement for this valve.

Analyses were performed to evaluate hydrazine and hydrogen, single vs multiple balloons, deployment sensing methods, balloon effects of the station crossing the terminator, and three inflation methods.

The high-pressure hydrogen gas inflation system was compared to the decomposed hydrazine inflation system to determine the resulting gross payload capability of each. The 200-lb station weight breakdown using each method is shown in tables 9 and 10. It is seen that the station using hydrogen supports a gondola weight of 69.4 lb whereas the hydrazine inflated station supports 61.0 lb. The range of gondola weights that can be supported for a range of station weights is shown in figure 12. The major differences are found in the larger balloon required (see figs. 13 and 14) for the hydrazine and a significant difference, 9 lb, in valving and controls.

The results of the analysis of a five-balloon concept that allows for a single balloon failure compared to the single balloon is also shown in figures 12 thru 14. The multiple balloon station requires several more valves and sensors. The weight of the single balloon controls is 6.7 lb, whereas the multiple balloon controls weigh 21.4 lb. This decreases the payload capability by approximately 10%.

Deploying a balloon in an unknown atmosphere, in this case defined by three models, is difficult. The balloon will settle out at a density level, but molecular weight and temperature difference allow the ambient pressure to vary. During inflation, the differential pressure across the balloon material must not exceed the design limits. If the balloon is inflated below the equilibrium altitude, additional gas must be transported to provide sufficient buoyancy to reverse deployment direction. If the balloon is inflated above equilibrium altitude, gas must be relieved to ensure that the design superpressure is not exceeded. This gas must be made up after obtaining equilibrium altitude to produce the proper superpressure.

One method of sensing for proper balloon inflation is to sense static pressure. At a given pressure level, the inflation sequence would be initiated for all three model atmospheres.

The static pressure at the flotation altitudes for the three model atmospheres (at a common density of 0.011 lb/cu ft) is:

1) Upper density atmosphere,

   a) Altitude, 79 km,

   b) Pressure, 89 mb;

2) Mean density atmosphere,

   a) Altitude, 57 km,

   b) Pressure, 105 mb;

3) Low density atmosphere,

   a) Altitude, 40 km,

   b) Pressure, 104 mb.

Assume the balloon is designed for a 6-mb superpressure condition. For the mean atmosphere, inflation must be complete at an atmospheric pressure of 105 mb or higher so that the design superpressure is not exceeded. The maximum pressure should not exceed 111 mb because pressure in excess of this will produce a gas penalty.

An alternative method for sensing the proper conditions for balloon deployment would be to sense ambient density with a densitometer, establish average molecular weight of the atmosphere by a mass spectrometer, and measure static temperature with a probe. The ambient pressure can then be defined if the perfect gas law is assumed. The following example indicates the inaccuracy of this method:

1) Measure molecular weight, ±10%;

2) Measure density of atmosphere, ±5%;

3) Measure static temperature, ±1%.

For the mean atmosphere this will result in quantities of:

1) Molecular weight, 28.8 to 35.2 lb;

2) Density, 0.0105 to 0.0115 lb/cu ft;

3) Temperature, 223 to 227.4°K.

This produces a pressure uncertainty of between 90 and 123 mb, which is unacceptable because of the weight penalty to the balloon subsystem.

From this analysis, a static pressure measurement is the desired method for initiating the balloon deployment. If a 2% pressure switch can be realized, there are no weight penalties associated with the balloon (6 mb superpressure) or hydrogen gas subsystems. A 5% accuracy switch results in a weight penalty of approximately 3 lb.

An effect of the station crossing the terminator from the sunlight side to the dark side is the change in balloon gas temperature and the resulting decrease in pressure. The case of the station floating approximately 2 km above the clouds in the mean density atmosphere has been analyzed for a range of balloon coatings. The resultant balloon temperature ranges are shown in figure 15. Incident and reflected radiation was considered. It is seen that an aluminized finish will produce a temperature change of approximately 25°C or 11% of the total temperature. To maintain a superpressure condition above the 105 mb ambient pressure, the superpressure required is approximately 12 mb. This would result in an increased balloon weight of 15 lb plus 5 lb of additional hydrogen gas system. It is practical for the station to pass from the dark to the light side of the planet since this would only involve venting of the gas as it is heated.

The undeployed station is shown in figure 3. The balloon is folded into a sleeve that is used to reduce balloon film flutter during deployment. The sleeve-bound balloon is wrapped around the gondola in a torus. The first half of the balloon to be wrapped would be wound in one direction around the gondola. The last half would be wound in the opposite direction. This method eliminates twisting in the balloon material when the balloon is extended by the parachute for inflation.

If balloon inflation is initiated slightly above equilibrium altitude with a single step blowdown process, there is no resulting gas weight penalty. A deployment profile is shown in figure 16 for the mean density atmosphere. This can be accomplished by sensing ambient pressure with a sensing accuracy of ±2% in all three atmospheres.

Balloon inflation initiation slightly above equilibrium altitude with controls to maintain proper differential pressure may be required if the sensing accuracy is on the order of 10%. The trade being approximately 2 lb of controls and their complexity against 6 lb of gas system weight.

There are no advantages to initiating inflation below equilibrium altitude in the mean or lower density atmospheres. As shown above, the inflation should be initiated slightly above equilibrium altitude. However, for a given pressure setting of a sensor, the inflation will take place slightly below equilibrium altitude in the upper density atmosphere. For the 2% accuracy sensor, the nominal initiation inflation altitude is 78.1 km for the 79-km station.

The engineering measurements that should be made during station deployment and for monitoring balloon parameters are shown in table 11.

TELECOMMUNICATIONS OPERATING MODES AND SUBSYSTEM DESCRIPTION

Sequences and Modes

The station is programed on a fixed basis to operate in several modes as shown in table 12. The system is turned on initially at separation of the station from the aeroshell, after which the telemetry transmitter transmits deployment and other engineering data to the orbiter for a fixed period. The system then enters a mode in which science data are sampled and stored periodically in core storage until the orbiter again appears above the communication horizon.

When the station's command receiver acquires the orbiter's command carrier, the station transmitter is turned on. As soon as the orbiter acquires the station transmitter signal, a command to begin ranging measurements is sent, and a ranging measurement orbiter to station is made. This is followed by repeated transmission of the stored science and real-time engineering data. After a fixed period, a ranging measurement is again commanded and the station transmitter is turned off.

The above orbital sequence (storing and transmitting science data) is repeated for another orbit, after which the station will drop a drop sonde that falls to the surface while transmitting data to the station at a rate of 1 BPS. At the next appearance of the orbiter the stored drop sonde data will be transmitted from the station to the orbiter.

The data transmission rate and time of transmission is such that data may be repeated at least three times per orbital transmission period with the exception of the stored drop sonde data. To be repeated, the drop sonde data may be held in the station storage and repeated on the next data transmission pass.

The above sequences may be repeated until both sondes have been dropped. Then the initial science sample, store and transmit modes will resume for additional orbits until a command from the orbiter causes the station to enter the final descent mode. At this time, the station telemetry transmitter will remain on and transmit science data until the station is destroyed on impact, or until the orbiter drops below the communications horizon. A typical station sequence including deployment is shown in table 13.

Telecommunications Subsystem Description

A simple block diagram of the baseline telecommunications subsystem is shown in figure 17. This subsystem features an integrated coherent command, ranging and telemetry approach for the BVS/orbiter links. Dual subcarriers for telemetry and command, and a pseudonoise turnaround ranging code are used. For the drop sonde to station link, noncoherent frequency shift key modulation is used.

The command link plays a vital role in the success of the mission with the approach taken for this station. The station command receiver searches continuously for the orbiter command carrier until it locks on, this causes the station telemetry transmitter to be turned on. Meanwhile the orbiter's receiver, which has been searching for the station transmitter signal, can now acquire the station's signal.

At lock on, the orbiter commands a ranging mode and then begins transmitting a PN ranging code for a fixed period to measure the round trip range to the station. The command to transmit telemetry data is then given, and the station begins data transmission to the orbiter. After a fixed interval, the orbiter commands another ranging measurement that continues until the maximum station transmitter "on" time has been reached or until the orbiter moves out of communications range. The station transmitter is turned off by the station central programer sequencer.

Station to orbiter link. - The station to orbiter telemetry link operates at 30 BPS using 7-bit/word NRZ format during all data transmission modes. A 5 W 200 MHz solid-state transmitter is phase-modulated by the sum of two coherent subcarriers as shown in figure 18. The lower frequency subcarrier is modulated by a square wave at half the bit rate and the upper subcarrier which is twice the frequency of the lower subcarrier is modulated by the data.

At the receiving end, the carrier phase lock loop locks onto the incoming carrier, the lower frequency subcarrier is doubled and tracked using a phase lock loop to provide a VCO reference for demodulating the data subcarrier. Unambiguous bit sync is derived in the second phase lock loop and the data are recovered from the data channel using a matched filter (integrate and dump) as shown in figure 18 (ref. 1).

The lowest frequency subcarrier operates at 7.68 KHz to allow an adequate band for the carrier search mode. If the subcarrier were placed too close to the carrier, the carrier loop could lock onto the subcarrier instead of the carrier.

Table 14 shows link margins, thresholds, system temperature, adverse tolerances, and other link characteristics for a maximum range of 10 000 km. Tables 15 thru 17 tabulate the engineering and science data transmitted over the link.

Command link. - The command link operates at a frequency of 230 MHz and bit rate of 30 BPS. The orbiter transmitter is solid state with a power output of 10 W.

Two subcarriers are used as in the station-to-orbiter telemetry link. The two-channel modulator and demodulator are identical in principle of operation to those for the telemetry link.

The station receiver sweeps in search of the orbiter's command carrier; thus, like the telemetry link, the lowest frequency subcarrier must be placed well outside the sweep band to prevent the carrier tracking loop from locking onto the subcarrier or one of the modulation sidebands. Link calculations and characteristics are shown in table 18. The link margin under worst-case tolerance conditions maintains a maximum bit error probability of 1×10^{-5}.

Only real-time discrete commands have been identified as indicated by the command list, table 19. Therefore, no command storage has been provided in the station other than fixed time delays in initiation of sequences.

It appears that a fixed matrix decoder is the simplest design approach that is consistent with the PCM link constraints. This type of decoder consists essentially of a prewired, fixed logic matrix that decodes each received command word and supplies the appropriate switching function.

For reliable operation, a word frame structure of two address words followed by three command words is appropriate. Each address word is made up of two "ones" and four "zeros," whereas each command data word consists of four "ones" and four "zeros." If the words do not meet the above bit ratio criterion the command is rejected.

Ranging orbiter to station. - Ranging measurements between the orbiter and the station are made by using the command and telemetry links to provide a turnaround ranging capability.

Following two-way carrier lock, a repetitive command is transmitted to the station to switch the command receiver into the ranging mode.

The orbiter then begins transmission of a PN ranging code, which is received by the station and retransmitted on the telemetry link. The time required for the spacecraft to acquire the code depends on the received code power, the desired error probability, and the composite code structure. Golomb (ref. 2) has shown the acquisition time can be minimized by using several subcode elements and acquiring the elements in sequence. For example, if three codes are being used of length p_1, p_2, and p_3, at most $p_1 + p_2 + p_3$ trials are required to acquire the code. If a single component code of the same length is used, the number of trials for acquisition would be $p_1 \times p_2 \times p_3$. Consequently in the cases when acquisition time is to be reduced, a multiple component code should be used. The code length should exceed twice the maximum round-trip time to provide unambiguous range data.

For the particular case under consideration, the desired range accuracy is ± 2 km. Therefore, the PN bit rate must be 37 700 BPS or a transmission data rate of 18 750 BPS.

The ranging link calculations are shown in table 20. The 10-W down link is required to obtain an adequate SNR in the ranging channel and carrier tracking loop at 10 000 km. It would be desirable to optimize the modulation index to ensure equal margins in the carrier and ranging channels. However, because of the variation in the ranging channel's modulation index with SNR, this is not possible. Consequently the maximum up-link modulation index was selected at 1.1 rad to ensure that carrier suppression does not take place under high SNRs. This would result in an equivalent ranging modulation index of 1.07 rad if the station happens to drift under periapsis. The up-link noise, which also modulates the transmitter, varies as the SNR in the ranging channel changes. This causes an increasing noise modulation loss on the up link as the down-link SNR decreases. For the link parameters presented in table 20, this has resulted in a 1.9 dB modulation loss because of noise.

The above difficulties can be avoided at the expense of station complexity and acquisition time by regenerating the code at the station. This would eliminate the variation of modulation index with range, the noise modulation problem, and would require less spacecraft transmitter power. However, because of weight limitations and complexity, regeneration of the code is not considered desirable.

Antennas. - The station has two antennas, one for station/orbiter links (ranging, telemetry and command). The other antenna is used to receive radio drop sonde data.

The antenna for the station/orbiter link is a crossed dipole arrangement mounted above a ground plane. For the link frequencies chosen, the antenna is centered at a wavelength of 215 MHz and must operate over a range of $\pm$15 MHz. An antenna of this type was chosen because of its low weight.

Figure 19 shows the elevation angle to the orbiter vs θ the true anomaly for various locations of the station as it drifts toward the pole. The maximum view time above 20° elevation angles from initial station placement to the time it crosses the south pole varies from about 10 to 14 minutes for the example of orbit and station location chosen. The elevation angle from the station to orbiter never exceeds 25° near the planet's south pole for the given conditions and station drift assumptions. The maximum communications range at the horizon vs the station great circle drift angle is shown in figure 20.

The station antenna for the station/drop sonde link is not critical in that it can be a conical crossed dipole or a deployable helix (compressed like a spring and released) for example. However, the antenna used should have circular polarization and be lightweight.

Central programer and sequencer. - The CP&S generates all repetitive sequences such as bit and word times and also generates the operational plan and its alterations by command inputs with respect to time. All timing functions are referenced to a master oscillator to ensure system synchronization over the entire mission.

Data encoder. - The data encoder consists of an engineering data multiplexer, A/D converter, data registers, and output data selector. The analog data are sequentially applied to the A/D converter and digitized in proper sequence as required for the engineering data format. Digital data and switch position verification data are contained in registers that are also inserted in specific locations in the format. The data selector is controlled by the CP&S so that the required data are supplied to the data modulator during the proper time interval.

Data automation system. - Digitized science data are input to the DAS where they are formatted in the proper sequence and placed in a magnetic core memory. During drop sonde operations, the drop sonde data are placed in the memory. This requires no change in operating sequences since the data formats (frame and word lengths) are identical as shown in figure 21. Timing, however, is derived from the bit synchronizer so the operations are synchronized with the incoming data. The readout mode is initiated by the command system, which commands the DAS to read out the memory. The data output from the memory is applied to the data selector of the data encoder that in turn passes the data to the modulator. During the final descent mode, the DAS accepts science data; the data are not stored, however, since the memory is operating in a real-time mode that immediately outputs the data received rather than storing it. In this mode the two engineering formats are inserted between each science format to cut the sampling rate of the atmospheric composition sensors.

Radio drop sonde link. - For the 200-lb class station, a bit rate of only 1 BPS is planned for the drop sonde to station telemetry link due to weight limitations for the station equipment. A 10 mW transmitter operating at 300 MHz is used in the sonde. It is frequency shift keyed by a PCM wave train of biphase mark format to provide a zero crossing at the beginning of each bit period for deriving bit synchronization. The antenna consists of four monopoles fed to provide circular polarization. The balance of the subsystem consists of a programer, master oscillator, frame sync generator and a four-channel multiverter.

Higher bit rates can be readily provided if weight allocations can be increased for added station storage etc. A sample link calculation is provided in table 21.

Subsystem weight, power, and volume estimates. - Estimates of weight, volume and power for the telecommunications subsystems are given in table 22. Where possible, the unit characteristics have been based on existing items of representative hardware with allowance for weight reduction through anticipated improvements in design and manufacturing techniques over a period of the next three years. Items of unique design are the data encoder, central programer, phase-lock receiver, transmitter, and decoder.

Telecommunications Trades

One of the major tradeoffs in the communications area is that of a coherent integrated command ranging and telemetry system for the station to orbiter links vs noncoherent and nonintegrated links (separate ranging, command, and telemetry equipment).

Although noncoherent, nonintegrated command telemetry and ranging was considered, the ranging requirement could not be effectively implemented because of excessive power requirements for a pulsed transponder system (several kilowatts peak power) and because of the complexity of combining ranging tones or PN codes with FSK or other noncoherent links.

Table 23 shows the link calculations for an FSK 30-BPS telemetry link. A 10-W transmitter is required in this case.

Table 24 shows the calculations for a simple tone sequential command system with no provision for making range measurements.

Antenna Tradeoffs

An initial objective for the communications design was to do all transmission between orbiter and station at high elevation angles (40° or above). However, because of the initial conditions chosen for station and orbit, transmission is conducted mostly at elevation angles of 20 to 30°. This factor combined with the stringent weight limitations for the station eleminated many of the candidate antennas for the station. Eliminated were the helix, crossed dipole in a cup, cavity-backed cross slot, and cavity-backed log spiral. The anetnna selected for this class of station is a crossed dipole mounted above a ground plane where the ground plane may become part of the upper gondola structure. Station antenna gains at the elevations of major interest vary from approximately +3 to -1 dB.

POWER AND THERMAL SUBSYSTEMS

Power Subsystem

The power requirements of the various components making up the communication and data handling system are given in table 25. The sequence of events is given in the power profile of figure 22. The transmitter is in operation during balloon deployment, and, once each orbit, when the orbiter is overhead, ranging is accomplished before and after completion of transmission with a 5-minute separation between the periods. Science readings are taken three times each orbit with data stored for transmission. The command receiver, detects the orbiter's carrier and causes power to be applied to the transmitter. In the orbits when a sonde is to be dropped, only one science reading is taken. Following the reading, the sonde receiver is commanded "on" to receive the sonde data.

Computation of energy needs from the power matrix and profile show the following energy requirements per orbit:

1) Normal orbit, 5.72 Wh;

2) Orbit with dropped sonde, 5.75 Wh.

The average daily energy needs are 36.2 Wh. If this energy is supplied by a sterilized silver-zinc battery with a specific weight of 25 Wh/lb, 1.45 lb of battery would be required for each Earth day of operation. A seven-day mission then requires approximately 10 lb of battery.

The required battery weight as a function of days of operation is shown in figure 23. For comparison the weight of an RTG together with a battery and a charger to provide for load peaks is shown. Derivation of the weight of RTG system is described below. Even though the electrical function the two systems perform are equivalent, from a systems point of view, they are not equivalent from thermal control considerations since the gondola may be subjected to ambient temperatures as low as 195°K. A battery needs to be maintained at 278°K (40°F). This may require an active thermal control system in the upper and mean density atmospheres. This is described in the Thermal Control Subsystem subsection.

For extended periods of operation, an RTG offers promise because it can supply heat for thermal control as well as electric power. Given a load profile having high peak power demands, a minimum weight system will result if a rechargeable battery is used to supply peak demands. Such an arrangement is shown in figure 24. The RTG that operates at a low voltage (3 to 6 V) supplies a regulator converter and a battery charger. Loads operating continuously, and those having relatively low level requirements, are operated from the regulator-converter, while those having high peak demands operate from the battery. The battery is replenished by a charger. The energy supplied by the battery per orbit is as tabulated.

Science	0.52 Wh
Transmitter	2.08 Wh
Command decoder	0.02 Wh
	2.62 Wh

At the required charge rate 20% overcharge is needed by the battery. The voltage efficiency is 78.5%. These factors together with a 1.2 factor for battery deterioriation and an 80% charger efficiency give 6.0 Wh/orbit required from the RTG to maintain the battery. This is an average of 1.6 W. This combined with a maximum requirement of 2.3 W for the converter regulator gives 3.9 W peak power required of the RTG. This requirement, together with a margin for growth, can be met by use of a 5-W RTG. Table 26 summarizes information on the components making up the power system. The engineering measurements required are shown in table 27.

Thermal Control Subsystem

The ambient temperature of the Venusian atmosphere at the altitude of equilibrium floatation (57 km in the mean atmosphere) is between 195 and 287°K. The average electric power consumption is less than 2 W, which presents a problem in maintaining the payload at a minimum acceptable temperature for operation. The most critical element is the battery that needs to be maintained at a minimum temperature of 278°K, however similar requirements exist for the other systems.

In figure 25 the weight of micro-quartz insulation required is plotted against the input power available for heating. On this basis, if 100 W of heat is available, an insulation weight of slightly more than 2 lb would be required. This is compatible with the heat output of a 5-W RTG. Figure 26 indicates thickness of insulation for a range of power input.

Heat may be generated in various ways by using latent heat and chemical reactions. Zirconium borohydride, for example, in freezing at 29°C liberates 0.086 kcal/g. Lithium oxide when mixed with water gives off 0.472 kcal/g. The light metals when oxidized have high energy releases as shown below:

Formation of	Energy release
Beryllium oxide	5.7 kcal/g
Lithium oxide	4.4 kcal/g

The reactions mentioned have the advantage that no gaseous byproducts are liberated that could interfere with science composition measurements. Hydrogen peroxide could be used as an oxidizer, but hydrogen would be liberated during the reaction.

A program (ref. 3) has been described to demonstrate the feasibility of using the atmospheres of the planets (Earth, Venus, Mars) as oxidizer sources for chemical energy. Lithium powder ignited when heated in all three atmospheres. The beryllium powder burned vigorously in each of the three atmospheres. At ambient temperatures it ignited on contact with both air and, on several occasions, in the Venusian atmosphere. The combustion products in mole percent were:

Beryllium	Beryllium oxide	Beryllium nitride	Beryllium carbide
2.93	61.02	1.78	10.20

The calculated heat of combustion was 7.551 kcal/g of metal. It was concluded that the work should be extended, prototype burners be developed, and engineering studies made to optimize the combustion characteristics of lithium and beryllium in the simulated Venusian and Martian atmospheres.

The results of these studies may be used to estimate the capability of a thermal control system for the BVS. If the weight of a burner of the metal fuel is assumed to equal the fuel weight, the resulting combined weights of insulation, and heat source are shown in figure 27.

It will be seen that an allowance of 4.54 kg (10 lb) will allow operation for 8½ days, when the heat output of the burner is 60 W.

CONCLUSIONS

The results of the study indicate that the concept of a small (nominally 200 lb) buoyant Venus station is both feasible and attractive. A duration in the atmosphere of as much as seven days with several opportunities to probe to the surface as well as the ability to collect wind pattern information and to make measurements at more than one (horizontal) location will significantly enhance the usefulness of the data collected.

A 225-lb weight limitation was developed on the basis that both a bus and capsule would be put into orbit. Equally attractive, however, is the concept of deflecting the capsule (BVS) before placing the bus into orbit or a BVS in conjunction with a flyby mission.

To develop and demonstrate a high degree of reliability in the balloon is the most fundamental problem. By selecting a well-understood material (Mylar) and an altitude with moderate temperature (225°) the problem has been alleviated; however, the mechanics of failure are not well understood and few applicable test (reliability) data are available.

Of significance are the development of balloon controls (sensors, relief valves, etc.), lightweight tankage, science instrumentation, and the remaining electronics. The fundamental problem in all these areas is one of keeping the weight low. The predeployment environment, particularly entry deceleration, must also be considered.

Finally, the uncertainty in the atmosphere of Venus presents a problem. By present models, achieving subsonic velocity above the clouds in the low density atmosphere appears difficult. The level of the cloud tops is a significant uncertainty to a balloon as it may affect gas temperature, and nothing is known of local conditions such as storms or turbulence.

Martin Marietta Corporation
Denver, Colorado
May 4, 1967

TABLE 1. - WEIGHT SUMMARY

		Predeployment weight, lb	Postdeployment weight, lb
Parachute system		12	
Balloon system		23.8	19.2
Hydrogen system		94.8	6.4
Science	23.5		
Telecommunications	20.5	57.0	57.0
Power	13		
Margin[a]		12.4	12.4
		200.0	95.0

[a]To include structure and thermal control for gondola only.

TABLE 2. - SCIENCE INSTRUMENTS

	Weight, lb	Power, W	Data per measurement	Range of measurement	Data acquisition
4 platinum resistance temperature sensors	1.0	.8	14 bits	200 to 500°K 450 to 800°K	Three times per orbit; every 1.25 hr except during acquisition of drop sonde data Measure every 13.3 sec during descent
6 pressure sensors	3.0	.6	14	6 ranges: 1 to 10^4 mb	
Composition:					
Water	1.5	1.0	7	.01%	
Nitrogen	1.0	1.0	7	1%	
Oxygen	1.5	1.0	7	.01%	
Argon	1.5	1.0	7	.01%	
Carbon dioxide	1.0	1.0	7	1%	
Acoustic transmission line	3.0	4.0	28	10^{-2} to 10^{-5} g/cm^3	
Drop sondes (2)	10 (5 each)	5	28 (3192 total)	Station to surface	On command
Total weight:	23.5 lb (including two 5-lb drop sondes)				

TABLE 3. - DROP SONDE EXPERIMENTS

	Weight, lb	Power, W	Data
Platinum resistance temperature sensor	.25	.2	7 bits every 30 sec
Pressure sensors (2) (wide range)	.75	.2	14 bits every 30 sec
Water vapor detector	.5	.5	7 bits every 30 sec
Totals	1.5	.9	28

TABLE 4. - FIVE-POUND DROP SONDE WEIGHT AND POWER ALLOCATIONS

	Weight, lb	Power, W
Experiments	1.5	.9
Telemetry	1.5	2.0
Batteries	.25	-
Structure, wires	.5	-
Thermal insulation	.85	-
Parachute	.4	
Totals	5	2.9

TABLE 5. - APPROXIMATE TIMETABLE

Event	Time
1. Deployment (~55°S lat., ~15°E long.)	0
2. Pressure, temperature, density, composition at altitude	-
3. Release drop sonde - on command	~1 day
4. Pressure, temperature, density, composition at altitude	-
5. Release drop sonde - on command near pole	~6-7 days
6. Pressure, temperature, density, composition at altitude	-
7. Pressure, temperature, density, composition during station descent	>7 days

TABLE 6. - BALLOON INFLATION HARDWARE

Item	Quantity	Unit weight, lb	Unit volume, cu in.	Unit energy requirement	Total weight, lb	Total volume, cu in.	Total energy
Pressure Switch	2	.3	3	None	.6	6	None
Timer	3	.4	.5	28 Vdc, .05 A, 10 sec	1.2	1.5	42 W-sec
Ordnance squib	3	.07	.5	28 Vdc, 5 A, .025 sec	.2	1.5	11
Ordnance Valve	2	.15	2	None	.3	4	None
Guillotine	1	.15	3	None	.2	3	None
Flowmeter (reed type)	1	.1	1	None	.2	1	None
Flowmeter signal conditioner	1	.5	12	28 Vdc, .05 A, 30 sec	.5	12	42 W-sec
Battery (thermal)	2	.5	3	1015 W-sec	1.0	6	5 wh
Pressure transducer[a]	2	.27	3	28 Vdc, .01 A, 180 sec	.55	6	100 W-sec
Temperature transducer[a]	2	.02	2	28 Vdc, .04 A, 180 sec	.05	4	400 W-sec
Tubing, fittings, wiring, and connectors	-	--	--	None	2.0	-	None
Hydrogen tank	1	80.7	9350	None	80.7	9350	None
Manual fill valve	1	.25	3	None	.25	3	None
Filter	1	.10	2	None	.10	2	None
Solenoid valve	1	.50	5	28 Vdc, .5 A	.50	5	420 W-sec
				Totals	88.4	9400	1015 W-sec

[a]For engineering measurements only.

TABLE 7. - BALLOON INFLATION HARDWARE

Item	Characteristic	Flight usage	Development status	Remarks
Pressure switch	6 ± 2 mb	None	On drawing board	Feasible for 1970 time period
Timer	R-C circuit	Mariner	Qualified as used	
Ordnance squib; Ordnance valve	Sterilizable	Mariner, Surveyor	Passed sterilization tests	
Guillotine	Sterilizable	Titan III	Qualified as used	
Flowmeter (Read); Flowmeter signal conditioner	Sterilizable	None	Used for ground tests in Titan III program	Feasible for 1970 time period
Battery (thermal)	Sterilizable	B-57, weapon systems	Qualified as used	
Pressure transducer	0 to 4500 psia	Mariner, Surveyor	↓	
Temperature transducer	100 to 400°K	Mariner, Surveyor	↓	
Manual fill valve	Sterilizable	Mariner, Surveyor	↓	
Filter		Mariner, Surveyor	↓	
Solenoid valve	Sterilizable	Mariner, Surveyor	Qualified as used	
Relief valve	6 mb cracking pressure	None	None	A development and qualification program is required

TABLE 8. - REQUIREMENTS FOR A RELIEF VALVE

Cracking pressure	6 mb differential pressure[a]
Full flow pressure	10 mb differential pressure[b]
	Flow rate, .25 lb/sec hydrogen at
	T = 225°K
	P = 110 mb (absolute)
Reseat pressure	4 mb differential pressure
Leakage	.15 lb hydrogen in 2 hr at reseat pressure[c] (This corresponds to approximately 100 scc/sec)
Temperature	Operating 195 to 300°K
	Nonoperating 195 to 345°K
Acceleration	Operating 1.0 (Earth) g
	Nonoperating 500 (Earth) g for 3 sec
Sterilization	The valve shall be capable of being sterilized

[a]Based on 6 mb producing a fabric stress of 6880 psi. Mylar yield is 12 000 psi, Kapton yield is 10 000 psi.

[b]Full flow rate is based on relief valve ability to handle filling rate. Pressure is based on not exceeding Mylar yield, see above.

[c]Leakage rate is based on not losing more than 2 of the 4 mb superpressure in 2 hr before the relief valve system is disabled.

TABLE 9. - HYDROGEN GAS, 6-MB SUPERPRESSURE, 200-LB STATION

Parachute and deployment hardware weight			12.0 lb
Parachute diameter	16.4	ft	
Deployed by mortar			
Balloon			
Volume	8630	cu ft	
Diameter	25.4	ft	
Surface area	2025	sq ft	
Balloon fabric	14.8	lb	
Risers and attachments	4.4	lb	
Balloon canister	4.6	lb	
Weight			23.8 lb
Hydrogen inflation			
Gas for balloon inflation	7.33	lb	
Gas residual in tank	.02	lb	
Gas tank	80.7	lb	
Controls, valving, etc.	6.7	lb	
Weight			94.8 lb
Gondola			
Weight			69.4 lb
Buoyancy of station volume x density			95.0 lb
Weight lofted			
Balloon	19.2	lb	
Gas	6.4	lb	
Gondola	69.4	lb	
Total weight lofted			95.0 lb

TABLE 10. - DECOMPOSED HYDRAZINE GAS, 6-MB SUPERPRESSURE, 200-LB STATION

Parachute and deployment hardware weight		12.0 lb
Balloon		
Volume	14 00 ft^3	
Diameter	30 ft	
Surface area	2825 ft^2	
Balloon fabric	24.2 lb	
Risers and attachments	4.5 lb	
Balloon canister	610 lb	
Weight		34.7 lb
Hydrazine inflation subsystem		
Decomposed hydrazine in balloon	65.5 lb	
Residuals in tankage	3.2 lb	
Tankage	6.9 lb	
Controls, valving, etc.	15.90 lb	
Weight		91.5 lb
Gondola		
Weight		61.0 lb
Buoyancy of balloon volume x density		155.2 lb
Weight lofted		
Balloon	28.7 lb	
Gas	65.5 lb	
Gondola	61.0 lb	
Total weight lofted		155.2 lb

TABLE 11. - ENGINEERING MEASUREMENTS FOR STATION DEPLOYMENT AND BALLOON MONITORING

Measurement	Range	Desired accuracy
Total pressure	0 to 50 mb	±2%
Static pressure	0 to 500 mb	±2%
Total temperature	100 to 800°K	±5%
Inflation gas tank pressure	0 to 350 000 mb	±5%
Inflation gas tank temperature	100 to 400°K	±5%
Inflation gas flow rate	0 to .5 lb/sec	±2%
Balloon pressure	0 to 25 mb	±2%
Balloon gas temperature	100 to 400°K	±5%

TABLE 12. - NORMAL AND MODIFIED MODES OF OPERATION

Normal Modes	Station deployment mode Sample science and store data in memory (data acquisition mode I) Receive and store drop sonde data (data acquisition mode II) Turnaround ranging mode Data transmission modes Transmit stored science data followed by real-time engineering Transmit stored sonde data only Transmit real-time science and engineering (in final descent mode only) Final descent mode (data acquisition mode III)
Modified modes	Various commanded backup failure modes (see command list)

TABLE 13. - BUOYANT VENUS STATION OPERATING SEQUENCE

Step	Function	Initiated by
	Phase I - Separation from aeroshell through the deployment phase	
1.	Blow station/aeroshell separation bolts	Aeroshell
2.	Start station central programer/sequencer (CP&S) activate thermal battery (for pyrotechnics) arm station ordnance	Aeroshell
3.	Release parachute cover	Pressure sensor
4.	Mortar deploys parachute	Pressure sensor
5.	Turn on command receiver and decoder; start sampling deployment engineering data	Central programer/sequencer (CP&S)
6.	Turn on transmitter	Main receiver AGC (detects orbiter carrier)
7.	Release balloon canister cover	Pressure sensor
8.	Initiate balloon inflation	Pressure sensor
9.	Release parachute	Deploy programer
10.	Terminate balloon inflation (close valve)	Flow rate detector
11.	Sever balloon inflation line	Deploy programer - time delay
12.	Release tankage and controls	Deploy programer - time delay
13.	Transmitter turn off	CP&S
	End Phase I	
14.	Turn on science sample and store data	CP&S
15.	Turn off science	CP&S
16.	Repeat steps 14 and 15	CP&S
17.	Repeat steps 14 and 15	CP&S
18.	Acquire phase lock and turn transmitter on	Station receiver AGC
19.	Begin ranging measurement	Orbiter command
20.	End ranging and transmit data to orbiter	Orbiter command or CP&S
21.	Begin ranging measurement	Orbiter command
22.	End ranging measurement	Orbiter command and/or CP&S
23.	Station transmitter off	Orbiter command, CP&S backup
	End second communications pass	
24.	Repeat steps 14 thru 20	If not changed by command
25.	Command station to release drop sonde after fixed time delay	Orbiter
26.	Repeat steps 21 thru 23	
	End third pass	
27.	Station sonde receiver on; bit synchronizer on (prepare to receive and store data)	CP&S (commanded)
28.	Power on to drop sonde system	CP&S
29.	Release sonde	CP&S
30.	Receive and store sonde data	CP&S
31.	Rescind step 27 (after total of 1 hr on)	CP&S
32.	Transmitter on	Station receiver AGC (detects orbiter signal)
33.	Perform ranging measurement	Command
34.	Play back station storage	CP&S
35.	Command next mode	Orbiter command
36.	Perform ranging measurement	Orbiter command
37.	Station transmitter off	Command or CP&S
	Final phase	
F1.	Enable balloon descent mode	CP&S
F2.	Transmitter on	Station AGC
F3.	Science in final descent mode; Engineering in final descent mode; Destruct balloon	Orbiter command
F4.	Transmitter remains on until station destruct by impact on planet's surface	

TABLE 14. - TELEMETRY LINK CALCULATION[a]

Total transmitter power	37	dBm
Antenna gain product	3.0	dB
Total miscellaneous losses	-3.5	dB
Space loss (200 MHz at 10 000 km)	-158.49	dB
Total received power	-121.99	dBm
Receiver noise spectral density	-167.6	dBm/Hz
Carrier performance		
Modulation loss	-1.32	dB
Threshold SNR	8.70	dB
APC noise bandwidth	22.04	dB
Threshold carrier power	-136.9	dBm
Received carrier power	-123.31	dBm
Margin[b]	13.6	dB
Data channel performance		
Modulation loss	-9.28	dB
Bit rate (30 BPS)	14.77	dB
Required ST/(N/B) P_e[b] $= 5 \times 10^{-3}$	8.0	dB
Threshold data power	-144.8	dBm
Received data power	-131.3	dBm
Margin[b]	13.5	dB
Synchronous channel performance[c]		
Modulation loss	-9.06	dB
Threshold SNR	20.0	dB
APC noise bandwidth	3.0	dB
Threshold synchronous power	-144.6	dBm
Received synchronous power	-131.1	dBm
Margin[b]	13.5	dB

[a]Data transmission and ranging are not done simultaneously.

[b]Margin exclusive of adverse tolerance.

[c]Synchronous subcarrier is half the data subcarrier frequency and is modulated at half the data rate. After frequency doubling, it is used to provide a reference and bit synchronization.

TABLE 15. - STATION SCIENCE DATA TABULATION

Station measurement	No. bits	Sampling rate: Sample & store mode	Sampling rate: Final descent mode
Ambient temperature 1	7	Once per 1¼ hr except taking drop sonde data	Once every 13.3 seconds
Ambient temperature 2	7		
Ambient pressure 1	7		
Ambient pressure 2	7		
Atmospheric density	28		
Atmospheric compositions			
H_2O	7		
N_2	7		
O_2	7		
A	7		
CO_2	7		
Drop sonde		Sample and store rates	
Pressure 1	7	Sampled once per 33⅓ sec	
Pressure 2	7	↓	
Temperature	7	↓	
Water vapor	7	↓	

Note: Approximately 3000 bits/drop sonde.

TABLE 16. - DEPLOYMENT/ENGINEERING DATA MODE

Station measurements	No. bits	Measurements/ format	Measurements/sec during deployment
Inflation tank pressure	7	1	1/4.4 sec
Inflation tank temperature	7	1	1/4.4 sec
Inflation tank flow rate	7	3	3/4.4 sec
Static pressure	7	5	5/4.4 sec
Total pressure	7	5	5/4.4 sec
Total temperature	7	1	7/4.4 sec
Measurements below are substituted for above following deployment			
	No. bits		Sample rate[a]
Master oscillator temperature	7		1/22.2 sec
+6 V bus			
-12 V bus			
Transmitter internal temperature			
Receiver internal temperature			
Battery temperature			
Sonde compartment temperature			
Sonde battery temperature			
Science package internal temperature			
Transmitter current			
Decoder internal temperature			
Main receiver carrier VCO output			
Sync subcarrier VCO output			
Data subcarrier VCO output			
Station time (fine)			
Station time (coarse)	7		1/22.2 sec

[a]Sample rate increase to 1/13.3 sec during final descent.

TABLE 17. - ENGINEERING DATA MODE

Station measurements	No. bits	Sample rate	Note
Transmitter output	7	1/22.2 sec	1. 133 bits/format
Main receiver AGC			2. Real-time only
Station receiver (sonde data) AGC			3. Two sync words and one frame identity word
Transmitter temperature			
Seven discretes			4. During final descent, sample rate increased to 1/13.3 sec
Drop sonde battery voltage			
Command status (7 discretes)			
+5 V bus boltage			
RTG current out			
RTG voltage out			
RTG temperature			
Battery charge current			
Battery voltage (fine)			
Battery voltage (course)			
Battery output current			
Converter regulator	7	1/22.2 sec	

TABLE 18. - COMMAND LINK CALCULATIONS

Total transmitter power	40	dBm
Antenna gain product	3	dB
Total miscellaneous losses	-3.5	dB
Space loss (220 MHz at 10 000 km)	-159.6	dB
Total received power	-120.1	dBm
Receive system noise spectral density (2000°K)	-165.6	dBm/Hz
Carrier performance		
Modulation loss	-1.90	dB
Threshold SNR	8.70	dB
Carrier APC noise bandwidth	22.0	dB
Threshold carrier power	-134.9	dB
Received carrier power	-122.0	dB
Margin[a]	12.9	dB
Data channel performance (β_o = 0.514)		
Modulation loss	-6.88	dB
Data rate	14.8	dB
Required ST/(N/B) $P_e^b = 10^{-5}$	11.0	dB
Threshold data power	-139.8	dBm
Received data power	-127.0	dBm
Margin[a]	12.8	dB
Synchronous channel performance (β_s = 0.396)		
Modulation loss	-9.47	dB
APC noise bandwidth	3.0	dB
Threshold SNR	20.0	dB
Threshold synchronous power	-142.6	dBm
Received synchronous power	-129.6	dBm
Margin[a]	13.0	dB

[a]Margin exclusive of adverse tolerance.

TABLE 19. - COMMAND LIST, BUOYANT VENUS STATION, 200-LB CLASS

Command no.	Function	Decoder output and remarks
1.	Initiate sequence for dropping of drop sonde	Momentary
2.	Initiate final descent mode of station	Momentary
3.	Dump fixed increment of inflation gas from balloon	Momentary
4.	Turn on station transmitter	Latching (backup only)
5.	Turn off station transmitter	Backup for the programer
6.	Battery charger on	Momentary
7.	Battery charger off	Momentary
8.	Enter ranging mode	Momentary
9.	Terminate ranging mode	Momentary

TABLE 20. - TURNAROUND RANGING LINK CALCULATIONS[a]

Down link		
Total transmitter power	40	dBm
Antenna gain product $(G_T G_R)$	3.0	dB
Total miscellaneous losses	-3.5	dB
Space loss (230 MHz at 10 000 km)	-159.69	dB
Total received power	-120.19	dBm
Receiver bandwidth	51.3	dB
Receiver noise spectral density	-165.6	dBm/Hz
Total received SNR $(1/\beta)$	-5.90	dB
Limiter signal suppression factor	.168	
$\sigma s^2 = 1/\left(1 + \frac{4}{\pi}\beta\right)$		
Limiter noise suppression factor	.662	
$\sigma n^2 = \beta/(\beta + 2)$		
Up-link performance		
Total transmitter power	37	dBm
Antenna gain product $G_T G_R$	3.0	dB
Total miscellaneous losses	-3.5	dB
Space loss (200 MHz at 10 000 km)	-158.49	dB
Total received power	-121.99	dBm
Receiver noise spectral density	-167.6	dBm/Hz
Ranging performance		
Modulation loss $\left(\beta_R^{\,1} = 0.450,\ \sigma n^2 = .440\right)$	-8.16	dB
Threshold SNR	22.0	dB
APC noise bandwidth	3.0	dB
Threshold ranging power	-142.6	dBm
Received ranging power	-130.15	dBm
Margin	12.45	dB
Carrier performance		
Modulation loss	-2.84	dB
Threshold SNR	8.70	dB
APC noise bandwidth	22.00	dB
Threshold carrier power	-136.9	dBm
Received carrier power	-124.83	dBm
Margin	15.07	dB

[a]Ranging and data transmission are not done simultaneously.

TABLE 21. - LINK CALCULATION, DROP SONDE TO STATION LINK, 300-MHZ FREQUENCY SHIFT KEY

System losses	5.0 dB	
Adverse tolerance	4.5 dB	
Space loss (100 km)	122.5 dB	300 MHz
Total losses	132.0 dB	
Receiver noise/cycle	-167.4 dBm	
Receiver rf BW	44.0 dB	25 KHz
System noise power	-123.4 dBm	
Required S/N in	-5.6 dBm	25 dB S/N out - (video) 1 BPS
Required receive signal	-129.0 dBm	
Required $P_T \times G_T \times G_R$	3.0 dBm	
Assuming antenna gain product	-6.0 dB	
The transmitter power =	9.0 dBm	
or approximately 10 mW		

TABLE 22. - ESTIMATES OF WEIGHT, VOLUME, AND POWER FOR TELECOMMUNICATION SUBSYSTEM, 200-LB STATION

Unit	Power		Weight, lb	Size	Voltage, Vdc
	Standby	On			
Command receiver	85 MW	[a]170 MW	3.9	2.9x7.0x6.5	12
Command decoder and matrix	10 MW	[a]2 W	2.0	3.5x5.0x1.5	28
Diplexer	-	-	1.0	3.5x3.75x6.5	
VHF antenna (main)			2.5		
VHF antenna (sonde)			1.4		
Telemetry transmitter	NA	12.5 W	1.8	5-5/8x4-5/8x1-5/16	28
Station sonde receiver and bit synchronizer	100 MW	300 MW	1.0	3.5x5.0x1.0	12
Central programer/sequencer	300 MW	300 MW	1.3	35 $in.^3$	5
Science data automation system					
Electronics	175 MW	[b]200 MW	.7	16 $in.^3$	5
Memory	30 MW	[b]175 MW	1.7	150 $in.^3$	12, -6
Data encoder	100 MW	[a]500 MW	2.3	65 $in.^3$	5
Signal conditioning	-	[b]560 MW	.9	23 $in.^3$	5, 12 -6
Total			20.5		

[a]On when being commanded.

[b]On 1 min every 1¼ hr and when telemetry transmitter is on.

TABLE 23. - STATION-TO-ORBITER TELEMETRY LINK CALCULATION, FSK SPLIT PHASE

Adverse system tolerance	4.5 dB	
System losses	5.0 dB	
Space loss (10 000 km)	159.0 dB	
Losses	168.5 dB	
System noise/cycle	-167.4 dBm	
25 KHz bandwidth	44.0 dB	30 BPS
Required SNR_i	-5.3 dB	for 13.2 db SNR_o out
Required signal	-128.7 dBm	
Losses	168.5 dB	
	-128.7 dBm	
Transmitter power	39.8 dBm	(assuming 0 dB antenna gain product)
Transmitter power	10 W	

where:

$$SNR_i = \frac{B_v}{B_{rf}} SNR_o + \sqrt{\frac{B_v}{B_{rf}} SNR_o \left(1 + \frac{B_v}{B_{rf}} SNR_o\right)}$$

$$\text{Let } a = \frac{B_v}{B_{rf}} SNR_o$$

$$a = \left(\frac{60}{25\ 000}\ 22.9\right)$$

$$SNR_i = a + \sqrt{a(1 + a)}$$

$$= .296$$

$$SNR_i = -5.3 \text{ dB for } 13.2 \text{ dB } SNR_o$$

TABLE 24. - COMMAND LINK CALCULATION, TONE SEQUENTIAL, 70% AM MODULATION

Orbiter transmitter power	40.0 dBm	
System loss	-5.0 dB	
Adverse tolerance	-4.5 dB	
Path loss 220 MHz, 10 000 km	-159.4 dB	
Received carrier power	-128.9 dBm	
Required receive carrier power (70% AM)	-133.5 dBm	25 KHz i.f. BW
Carrier/noise ratio	4.6 dB	
Tone channel mod loss	-5.5 dB	
Tone channel bandwidth ratio	19.2 dB	300 Hz tone BW
Tone SNR_o	18.3 dB	

TABLE 25. - POWER MATRIX, 200-LB BUOYANT VENUS STATION

Item	Standby, W	Data sampling, W	Command, W	Transmit, W	Remarks
Programer and sequencer	.300	.300	.300	.300	
Command receiver	.085	.085	.170	.085	Operates 12 min during command
Command decoder	.010	.010	2.0	.010	Operates 30 sec during command
Data encoder	.100	.500	.100	.500	Operates 1 min 3 times/orbit
Data automation system	.205	.375	.205	.375	Samples 1 min 3 times/orbit and during sonde drop
Science		10.4			Operates 1 min 3 times/orbit
Engineering measurements signal conditioner				.560	
Station sonde receiver	(.100)	(.300)			Warms up 1 hr and operates 1 hr
Transmitter				12.5	Operates 10 min/orbit
Total	.700	11.670	2.775	14.33	

TABLE 26. - POWER SUBSYSTEM COMPONENTS

Item	Rating	Weight	Volume	Status
Radioisotope thermoelectric generator	5 W	2.3 kg (5 lb)	3000 cm^3 (180 $in.^3$)	Uprated design similar to SNAP-3
Converter regulator	2 W	1.1 kg (2.5 lb)	100 cm^3 (6 $in.^3$)	Similar to existing solid state designs
Battery charger	1.5 W	.45 kg (1 lb)	40 cm^3 (2.5 $in.^3$)	Similar to existing solid state designs
Nickel-cadmium battery	28 V, .43 AH (22 AA Cells)	.7 kg (1.5 lb)	600 cm^3 (36 $in.^3$)	Nickel-cadmium batteries have withstood heat sterilization
Wiring and connectors		1.1 kg (2.5 lb)		

TABLE 27. - POWER SUBSYSTEM ENGINEERING MEASUREMENTS

	Range
1. RTG voltage	0 to 10 V
RTG current	0 to 3 A
RTG radiator temperature	250 to 500°F
2. Converter regulator	
Output voltages	0 to 10 V
3. Battery charger	
Output voltage	0 to 36 V
Output current	0 to 0.1 A
4. Battery	
Output voltage	0 to 36 V
Output current	0 to 1 A
Temperature	0 to 65°C

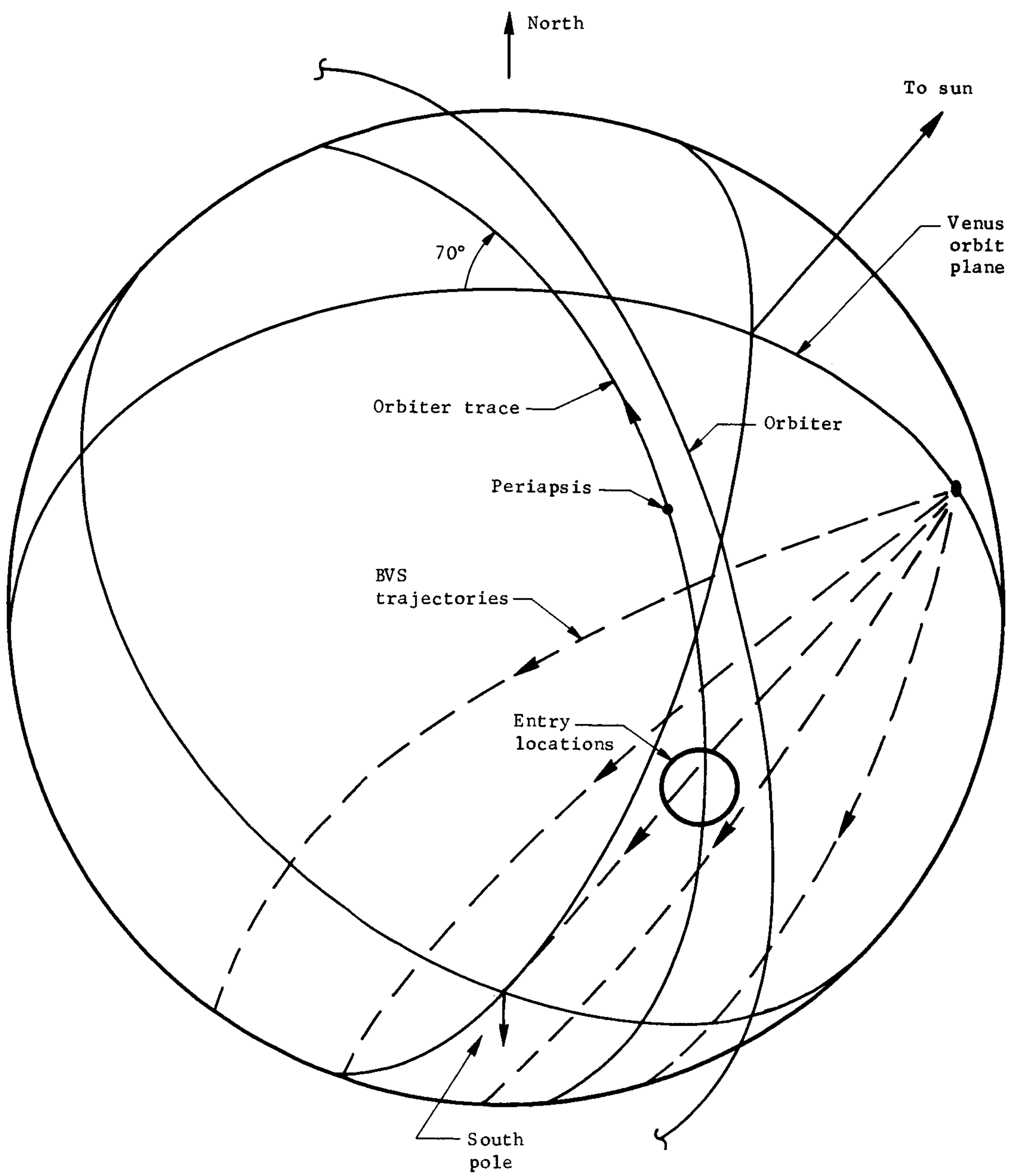


Figure 1. - Orbit Altitude and Inclination Angle for BVS

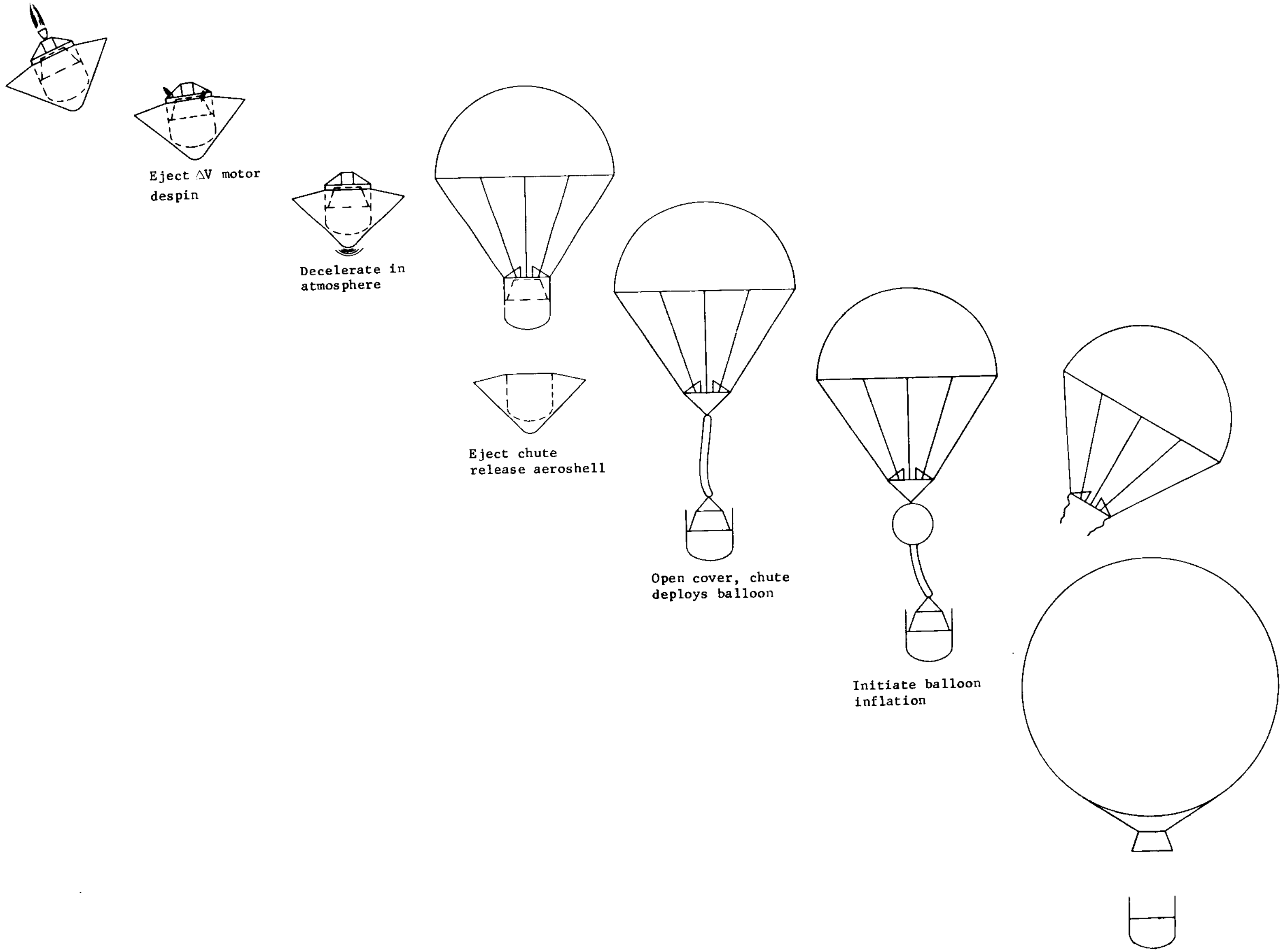


Figure 2. - Deployment Sequence

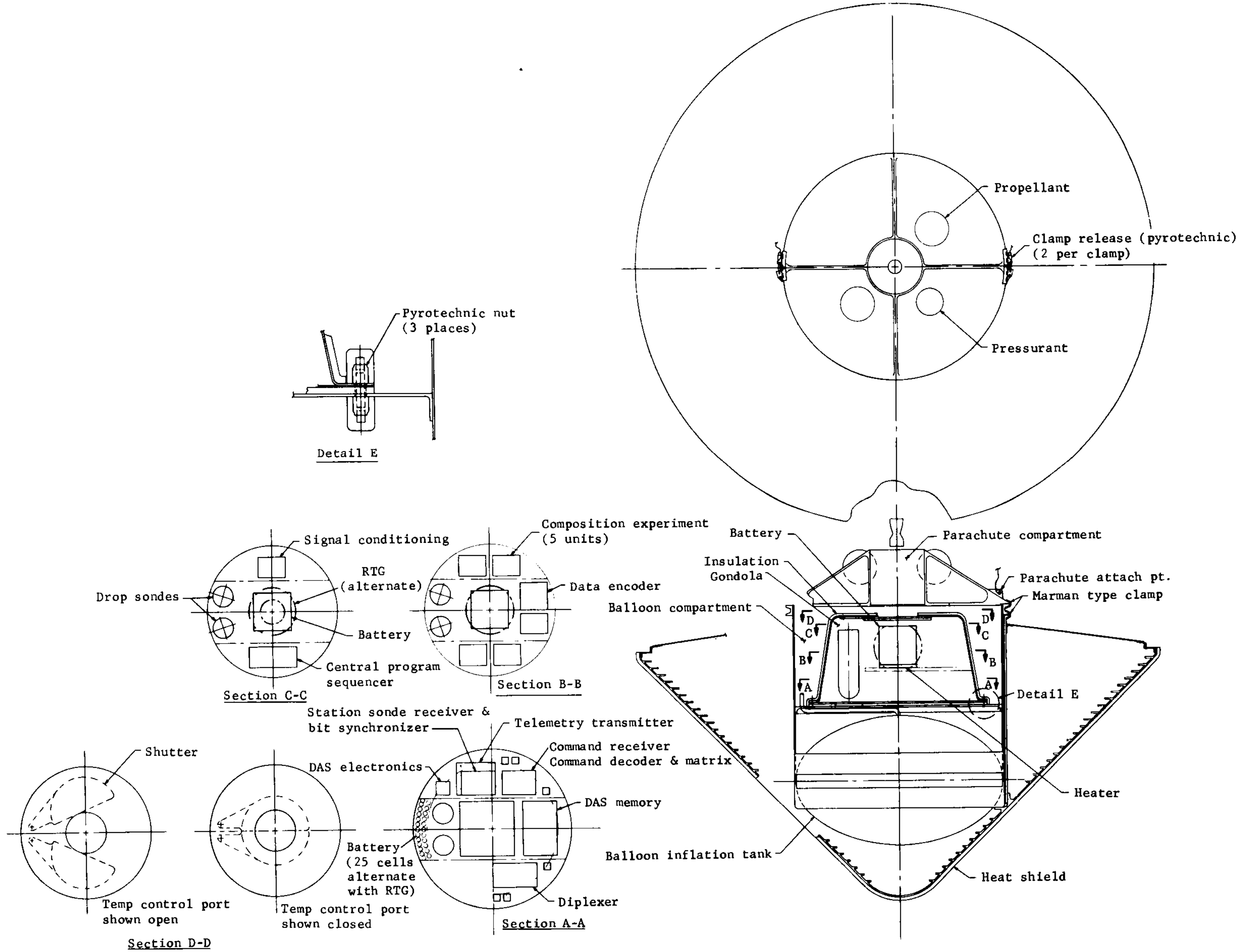


Figure 3. - Buoyant Venus Station, General Arrangement

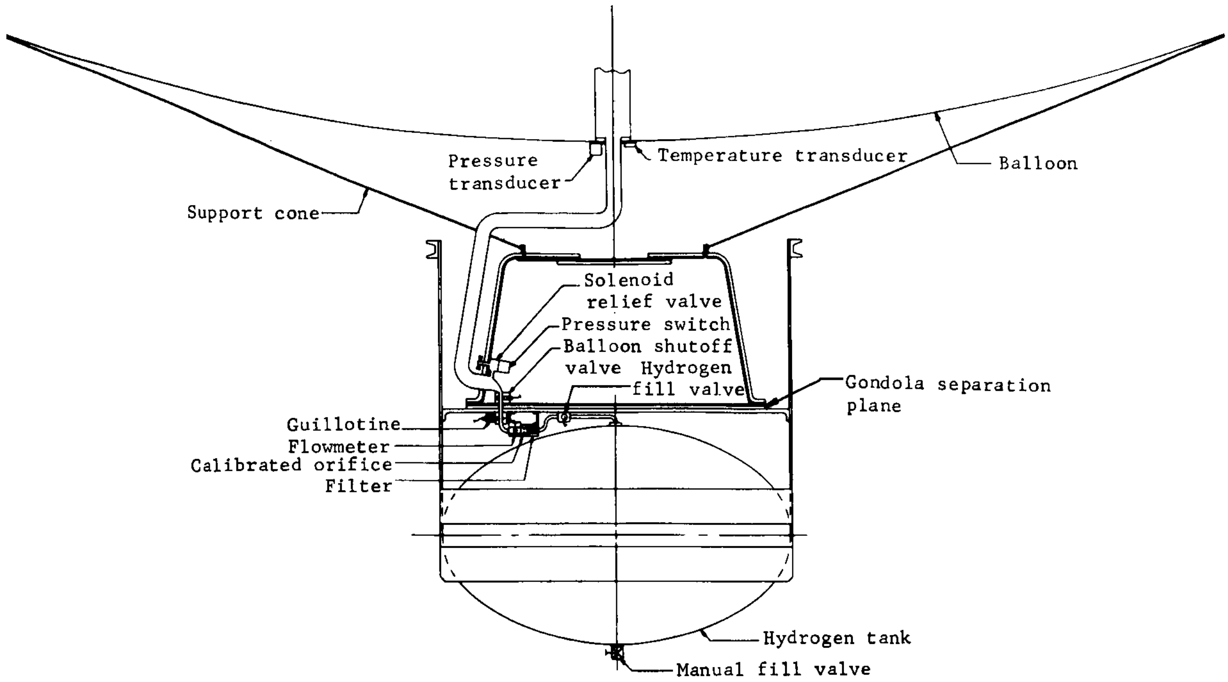


Figure 4. - Buoyant Venus Station, Tanking and Plumbing (Single Balloon)

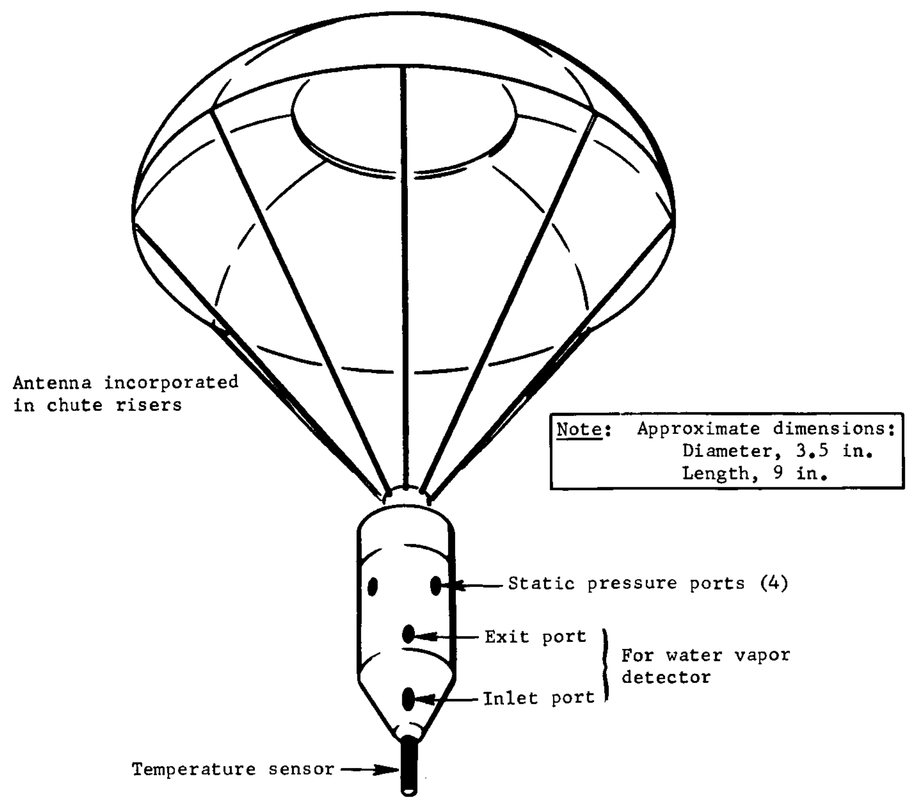


Figure 5. - Five-Pound Drop Sonde

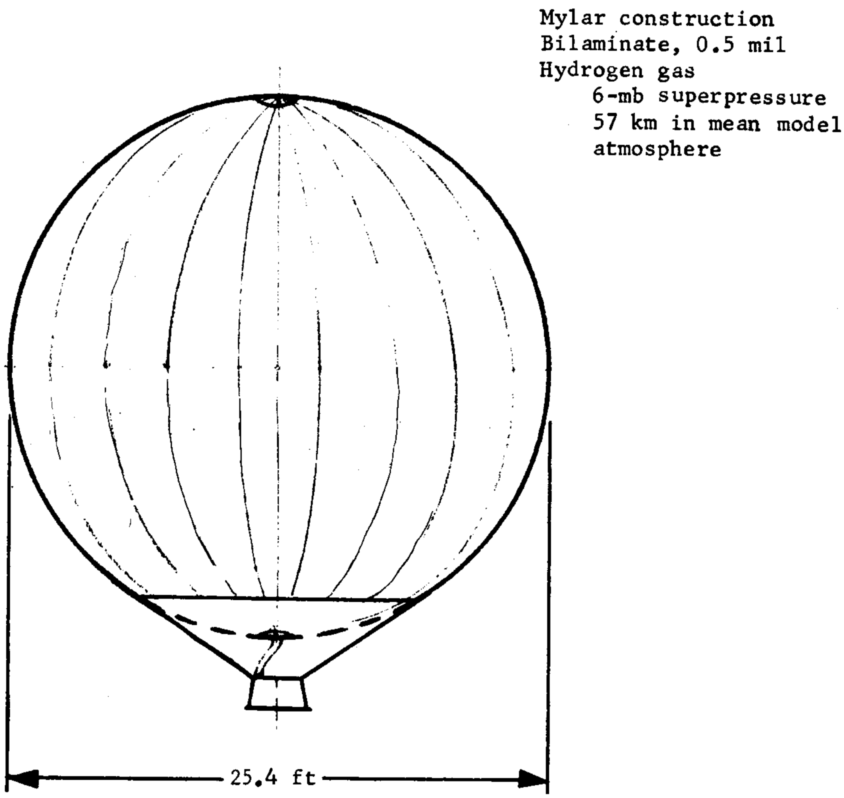


Figure 6. - Nominal 200-lb Station

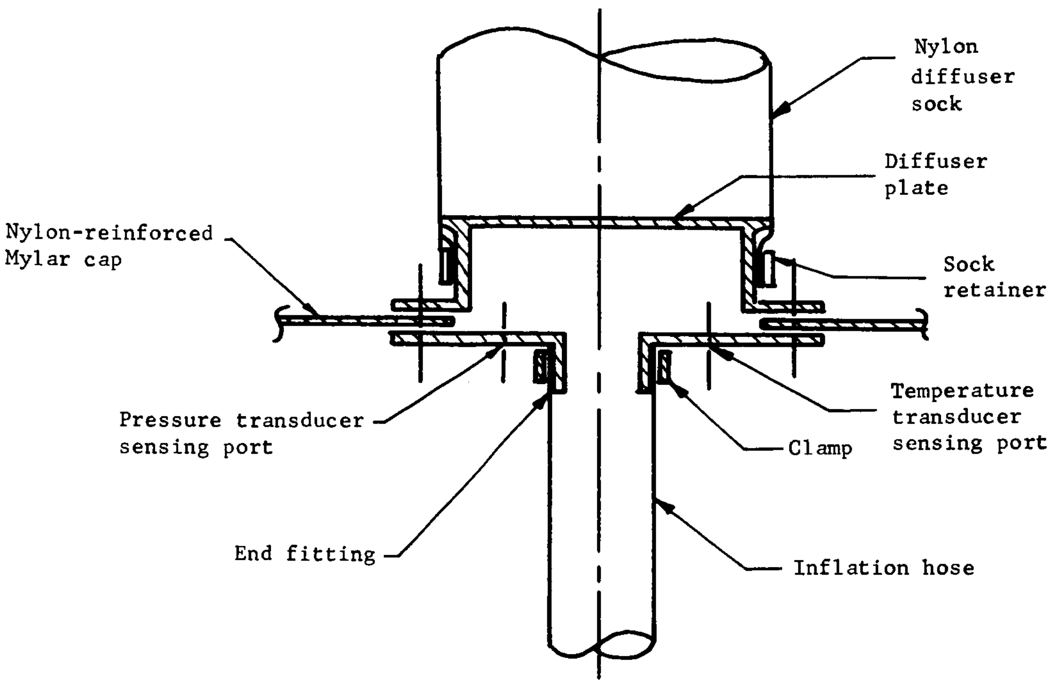


Figure 7. - Balloon Inflation Fitting Details

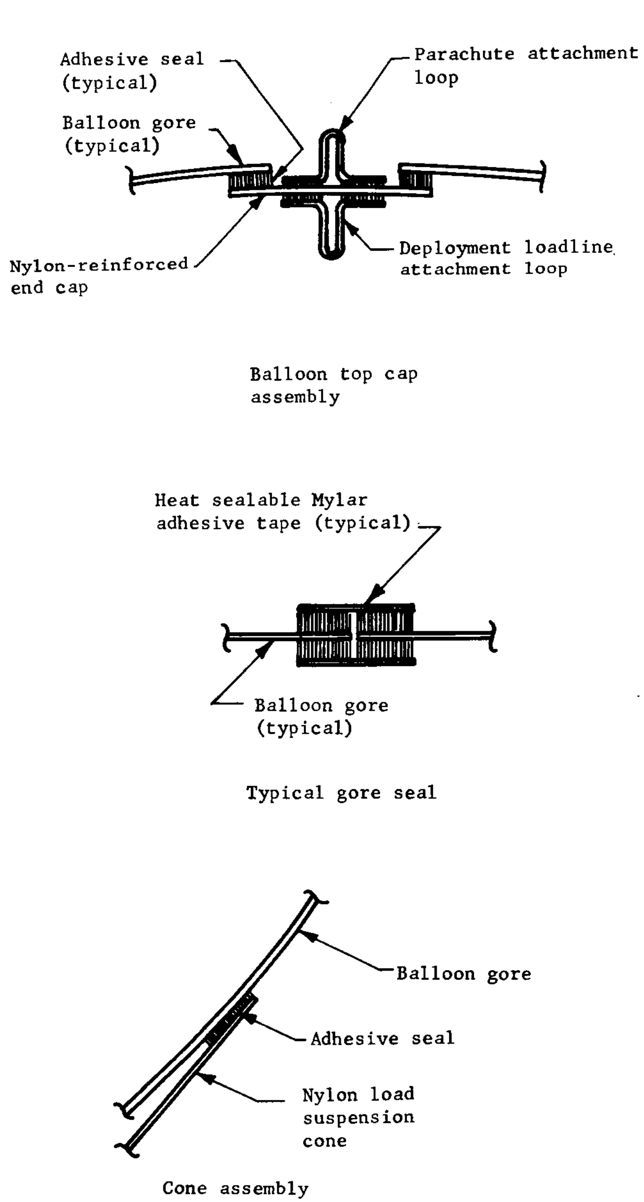


Figure 8. - Balloon Assembly Details

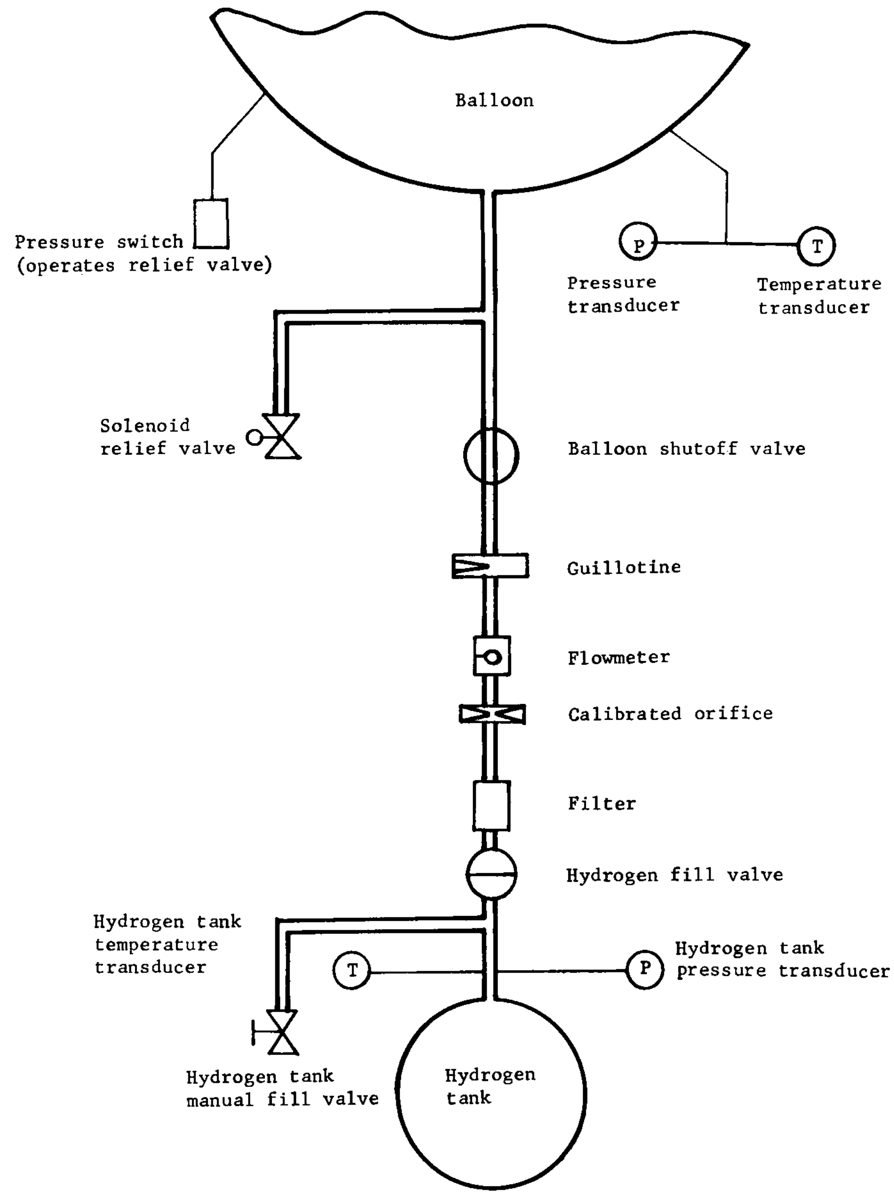


Figure 9. - Balloon Inflation and Control Subsystem Schematic

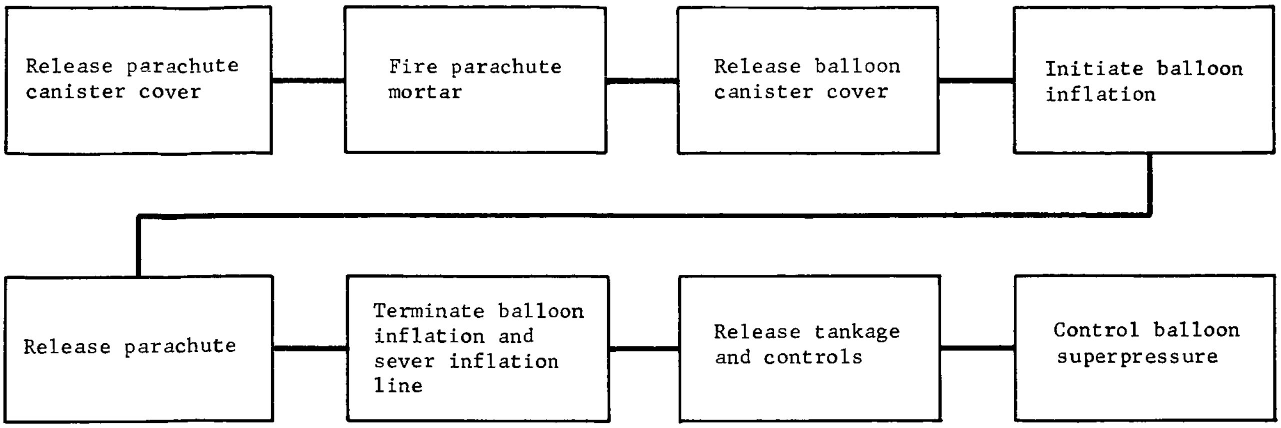


Figure 10. - Station Deployment Sequence

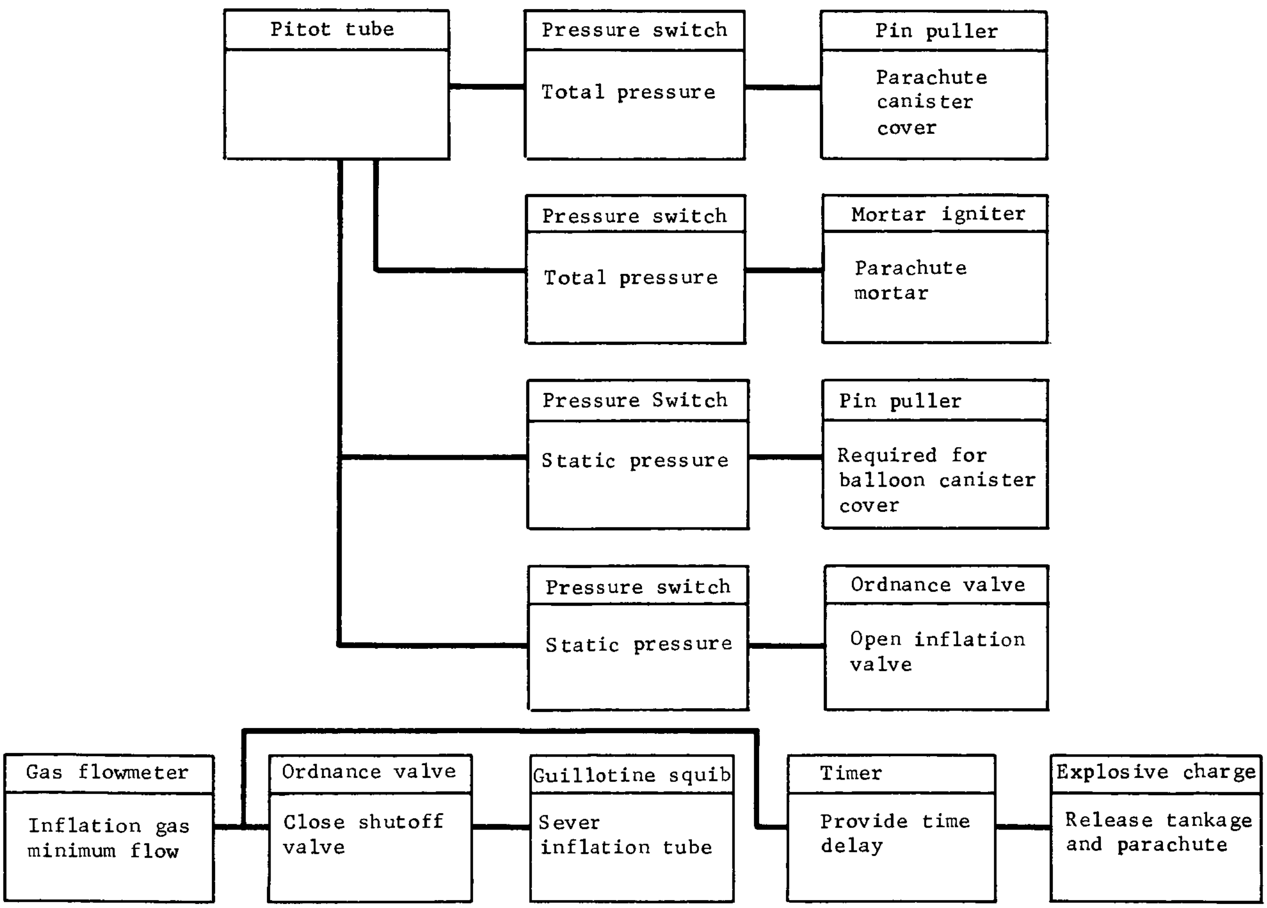


Figure 11. - Station Deployment Equipment

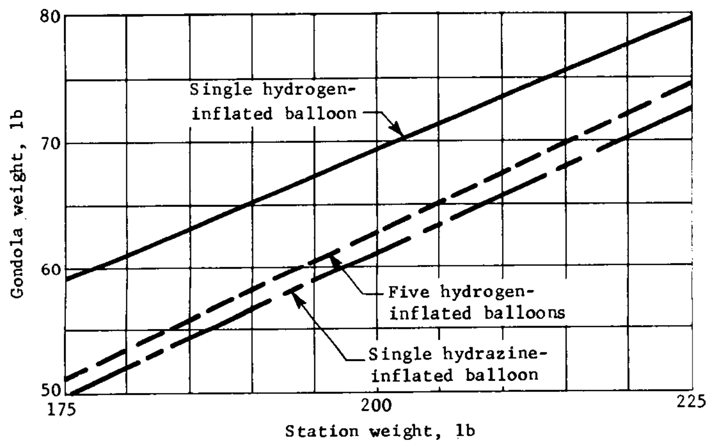


Figure 12. - Gondola Weights for Range of Station Weights

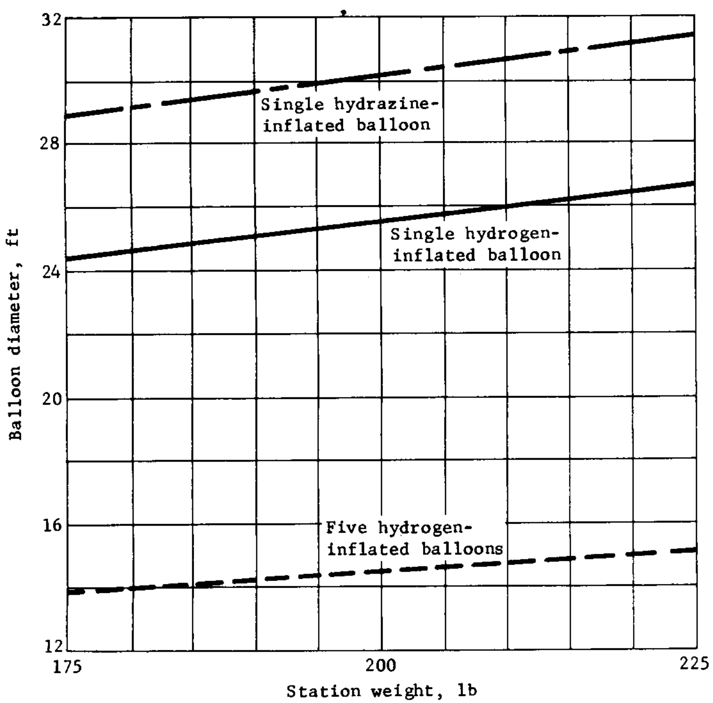


Figure 13. - Balloon Diameter for Given Station Weight

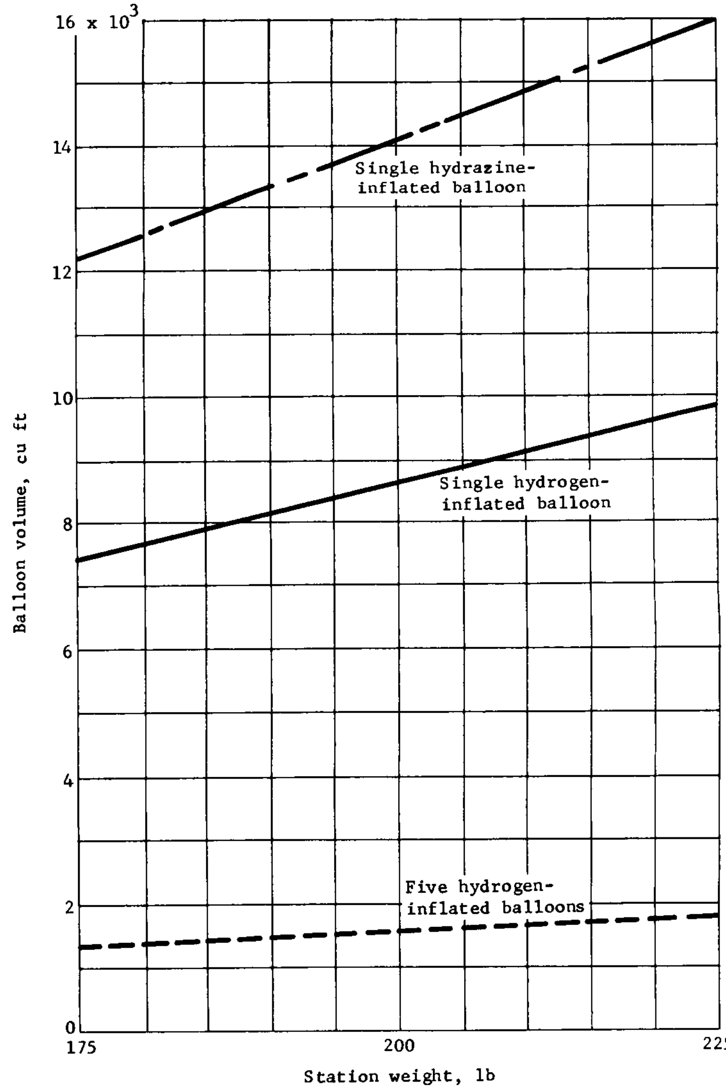


Figure 14. - Balloon Volume for Given Station Weight

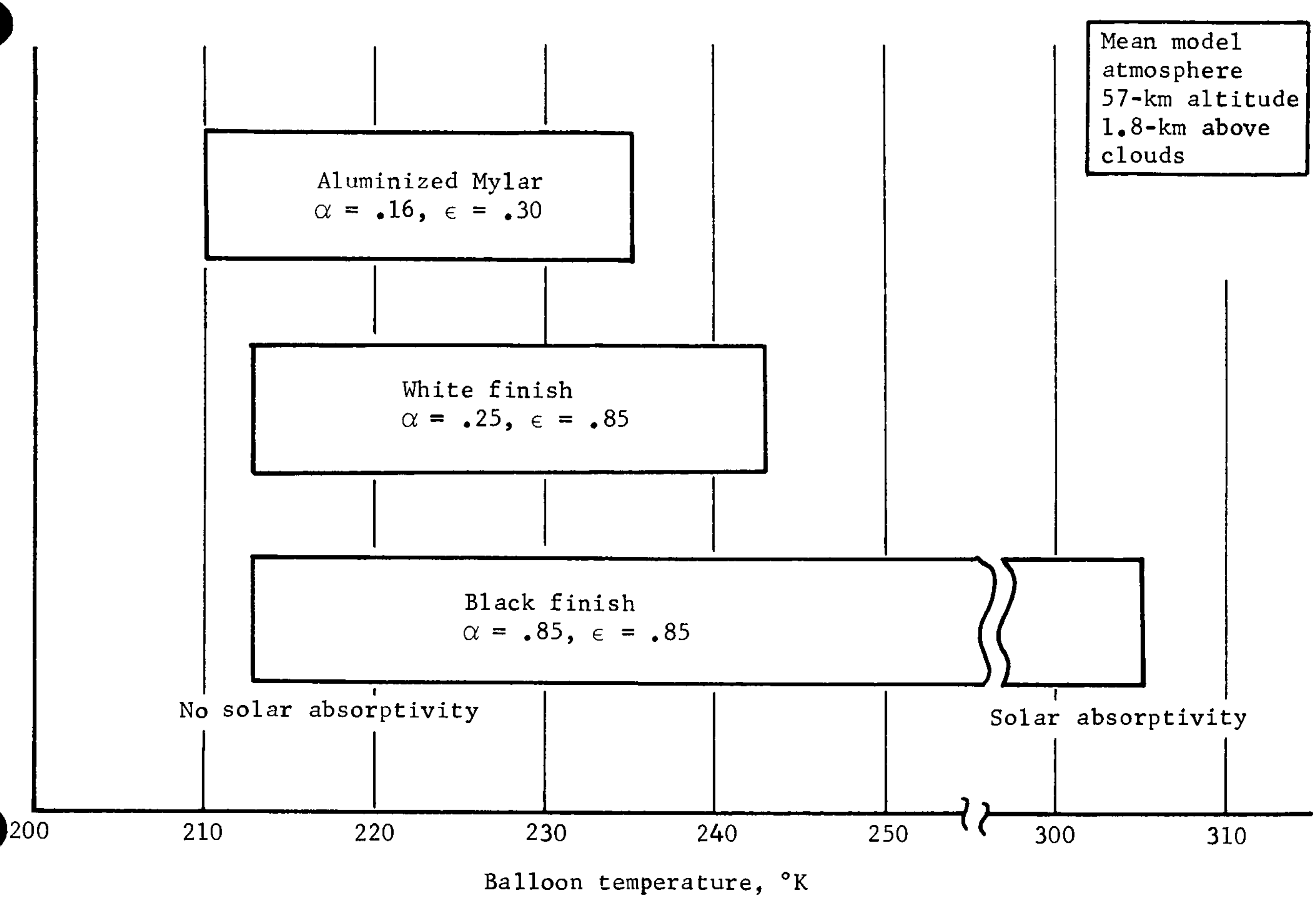


Figure 15. - Coatings for Balloon Temperature Control

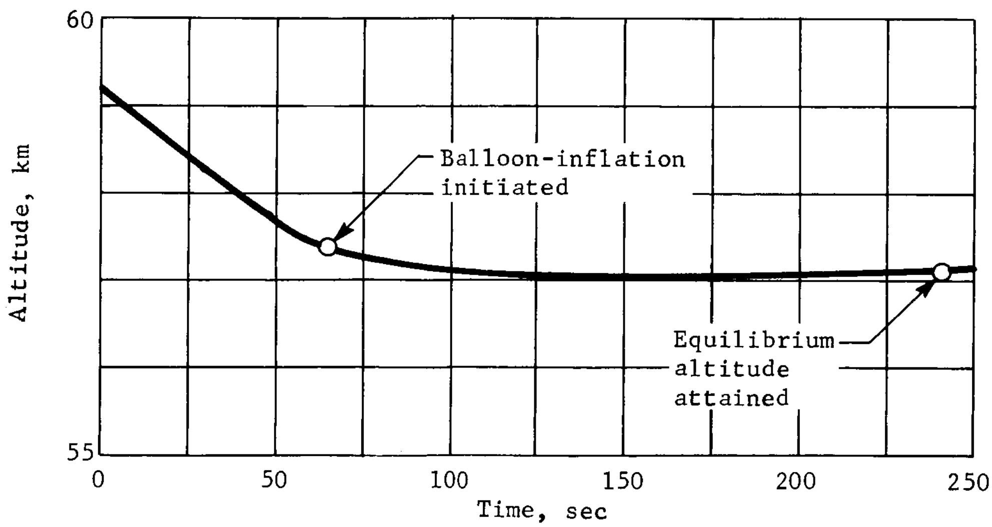


Figure 16. - 200-lb Station, Hydrogen Gas Mean Density Atmosphere, Inflation Initiated at 99 mb Pressure

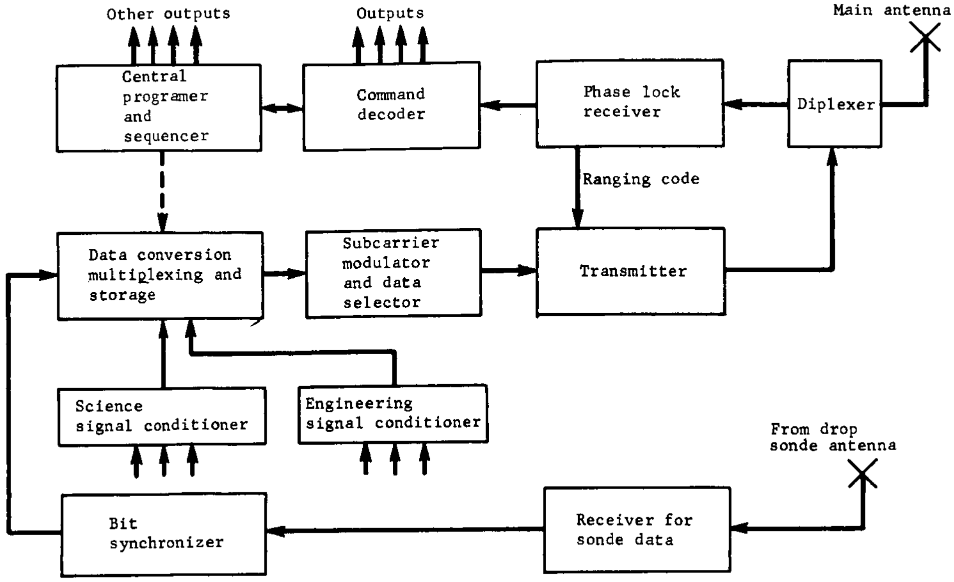
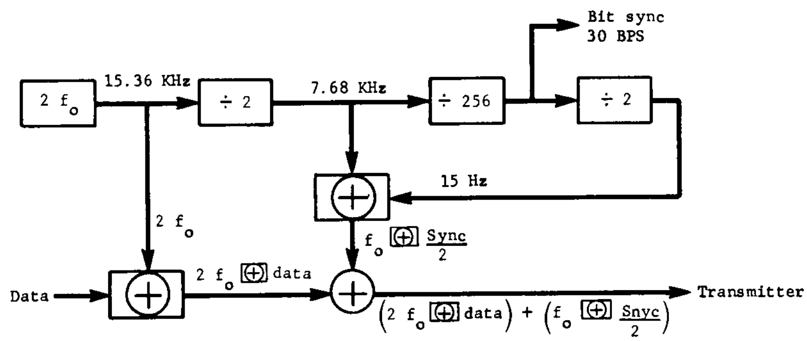
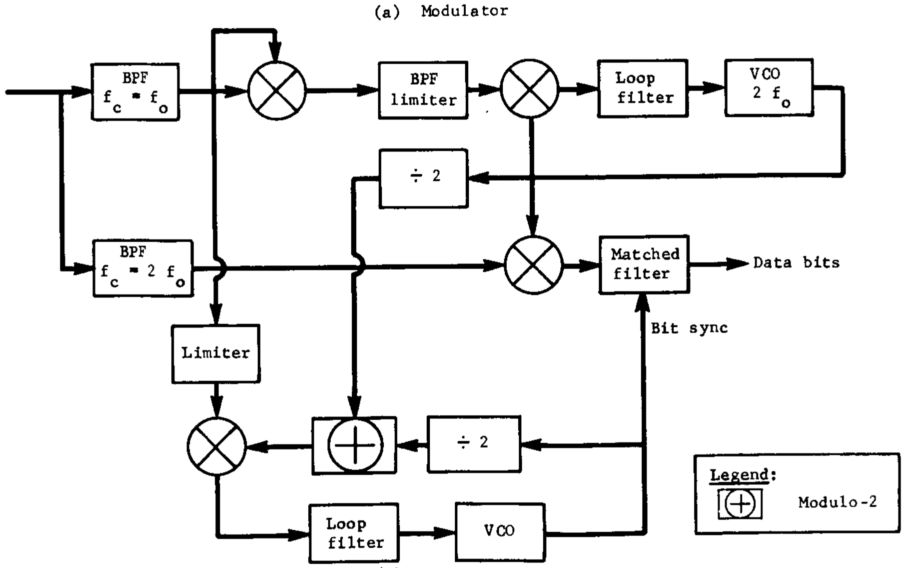


Figure 17. - Telecommunications Simplified Block Diagram



(a) Modulator



(b) Demodulator

Figure 18. Two-Channel Modulator and Demodulator

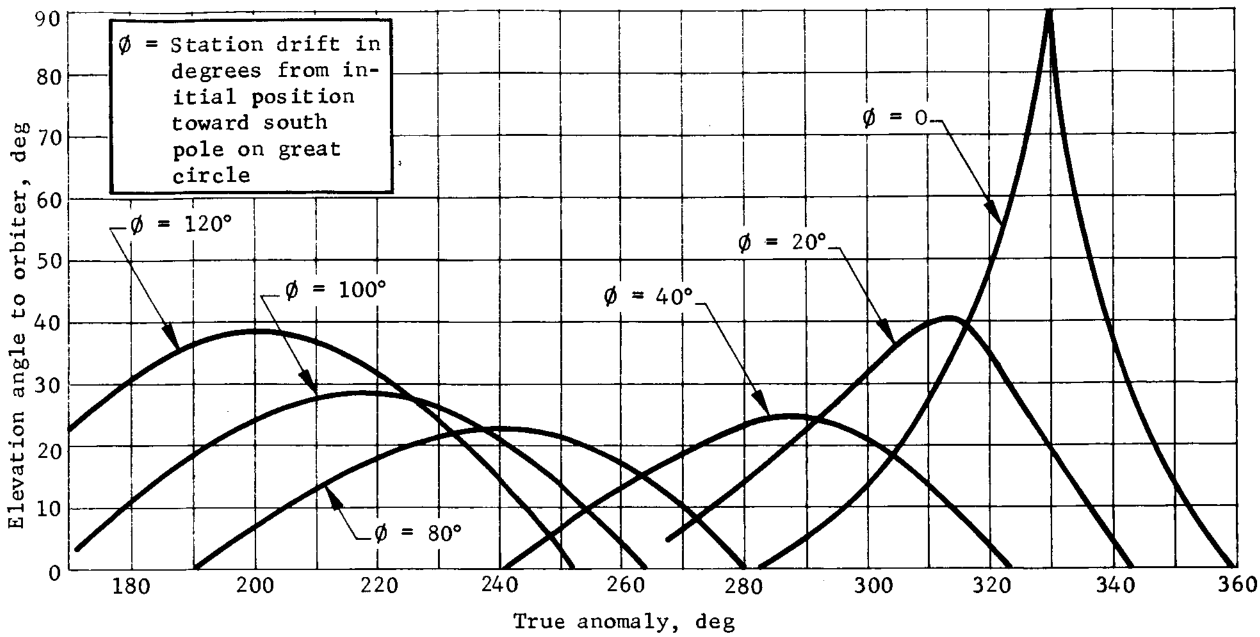


Figure 19. - Orbiter Elevation Angle vs Station Drift Position

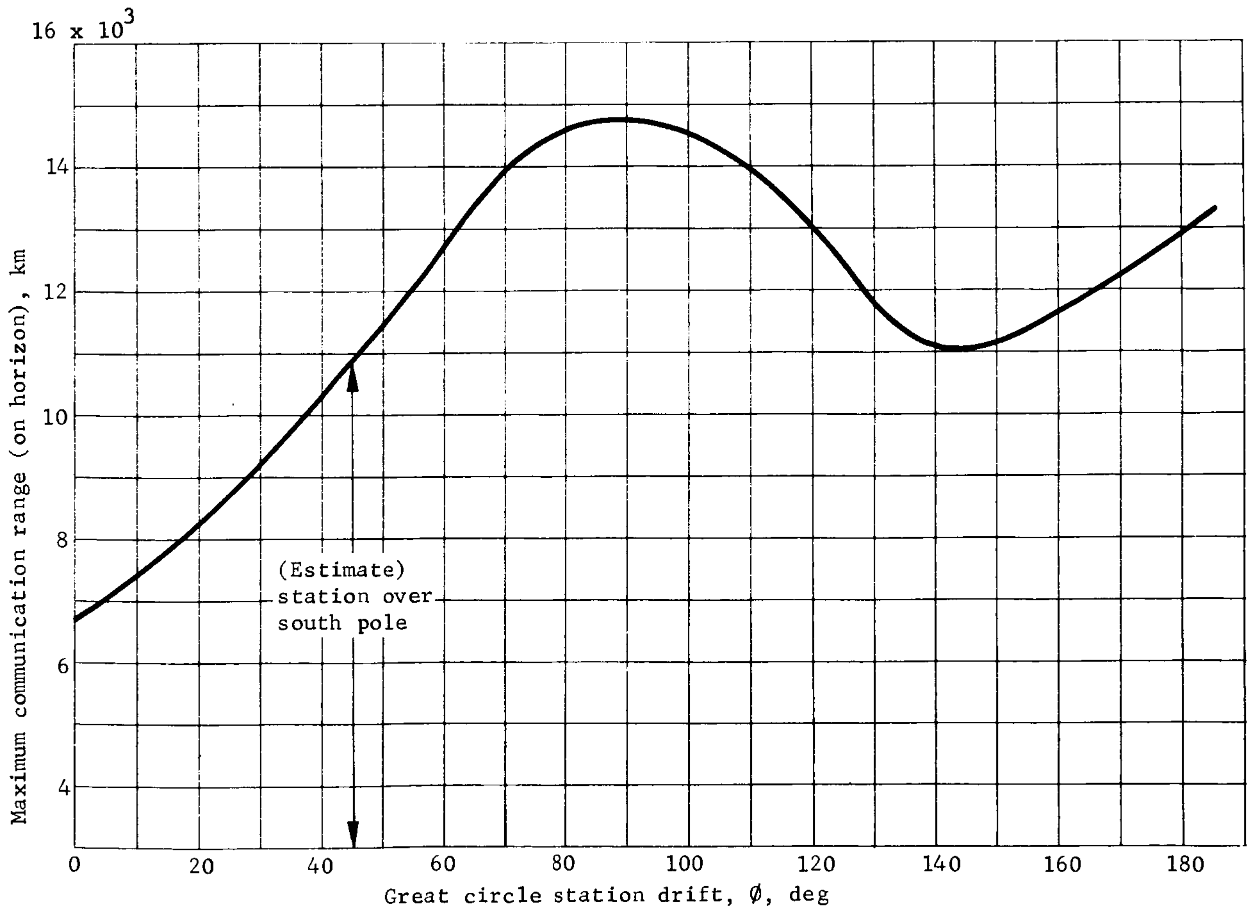


Figure 20. - Maximum Communications Range (on Horizon) vs Station Drift Position

W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19
Frame Sync		ID	A	E	F	D	E	F	B	E	F	D	E	F	C	E	F	D

Deployment/engineering data

A. Total temperature[a]
B. Inflation tank pressure[a]
C. Inflation tank temperature[a]
D. Inflation tank flow rate[a]
E. Static pressure[a]
F. Total pressure[a]

W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19
Frame Sync		ID	G1	G2	G3	G4	G5	G6	G7	G8	G9	H1	H2	H3	J	K1	K2	L

Engineering data

G. Power system
H. Radio system
J. Switch positions
K. Drop sonde subsystem
L. Command status

W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19
Frame Sync		ID	Q	P	M1	Q	P	N1	Q	P	M2	Q	P	N2	Q	R	S	T

Science data

M. Ambient temperature 1 and 2
N. Ambient pressure 1 and 2
P. Atmosphere density
Q. Atmospheric composition
R. Differential gas pressure
S. Balloon temperature
T. Spare

W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19
Frame Sync		ID	U	W1	X	Y	U	W2	X	Y	U	W	X	Y	U	W	X	Y

Drop sonde data

Each four word group UWXY represents one measurement sequence
24 formats or 96 measurements are anticipated

Deployment mode	Science mode		Drop sonde mode	
Deployment/engineering read out continuously	3 science formats stored	399 bits	27 DS formats stored	3591 bits
	6 engineering formats RT	<u>798</u> bits	per readout	3591 bits
	per readout	1197 bits		
	3 readouts/transmission	3591 bits		

[a]Engineering data substituted after deployment.

Figure 21. - Telemetry Data Formats

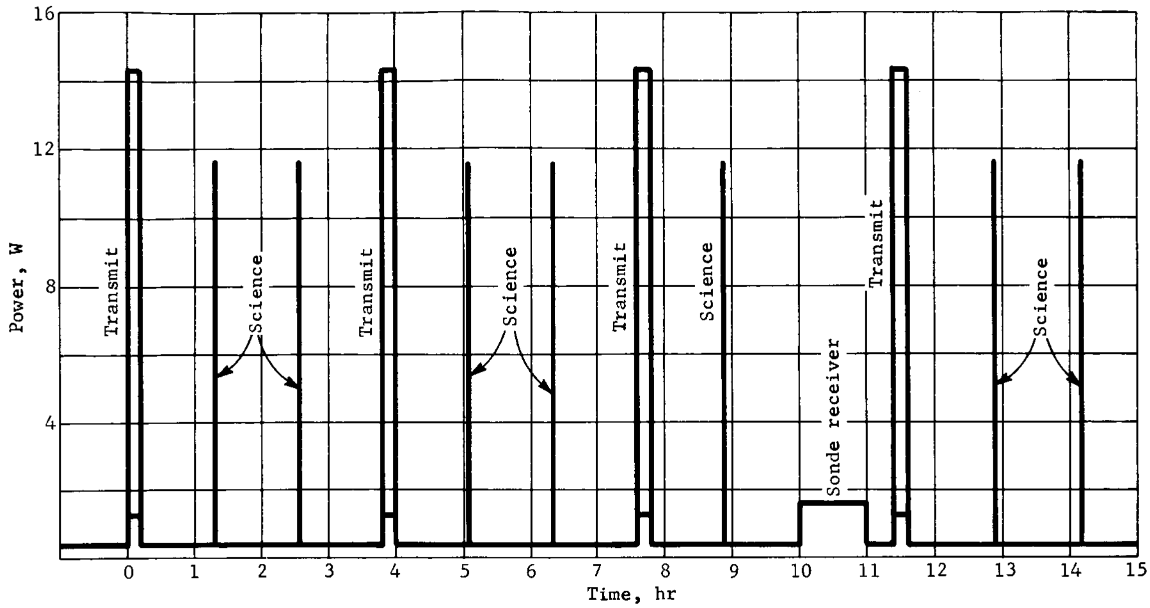


Figure 22. - Power Profile

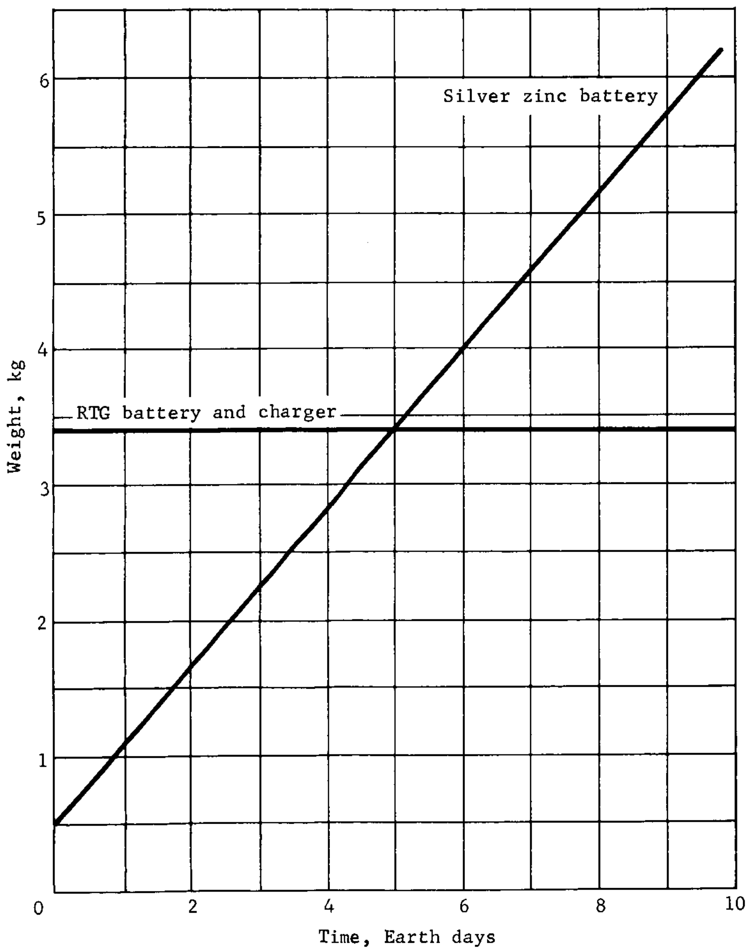


Figure 23. - Comparison of All-Battery System and the RTG System

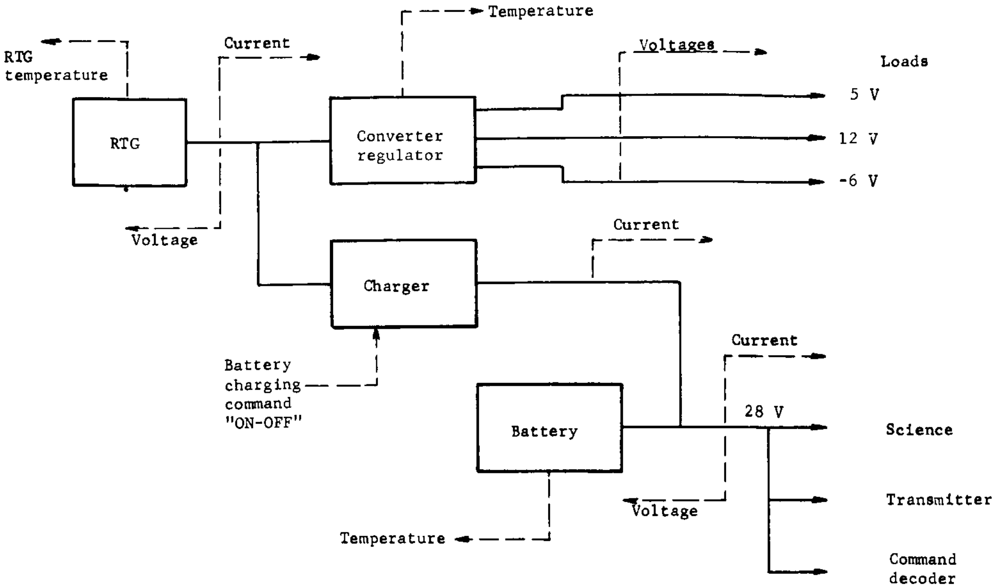


Figure 24. - Power System Block Diagram

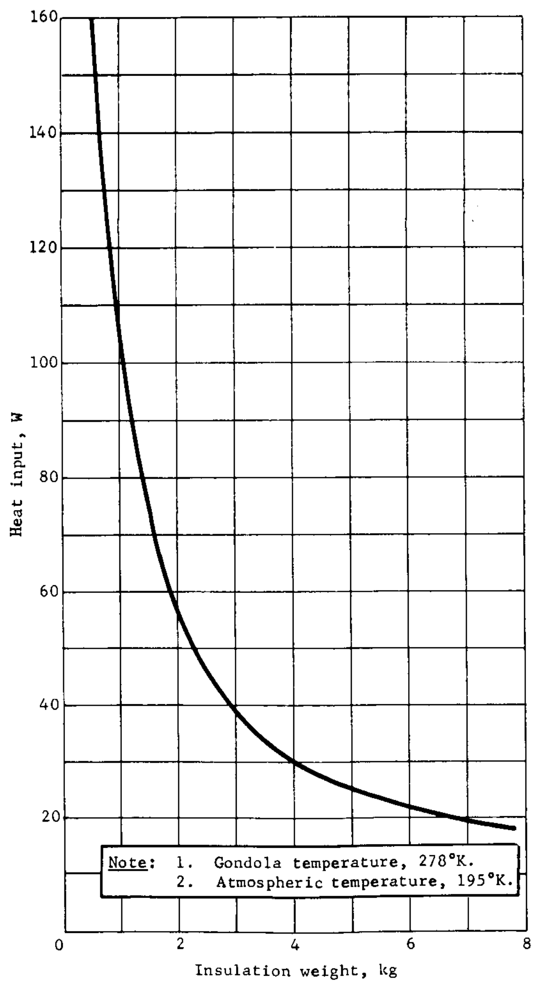


Figure 25. - Insulation Weight for 2.0-cu-ft Gondola in Venusian Atmosphere

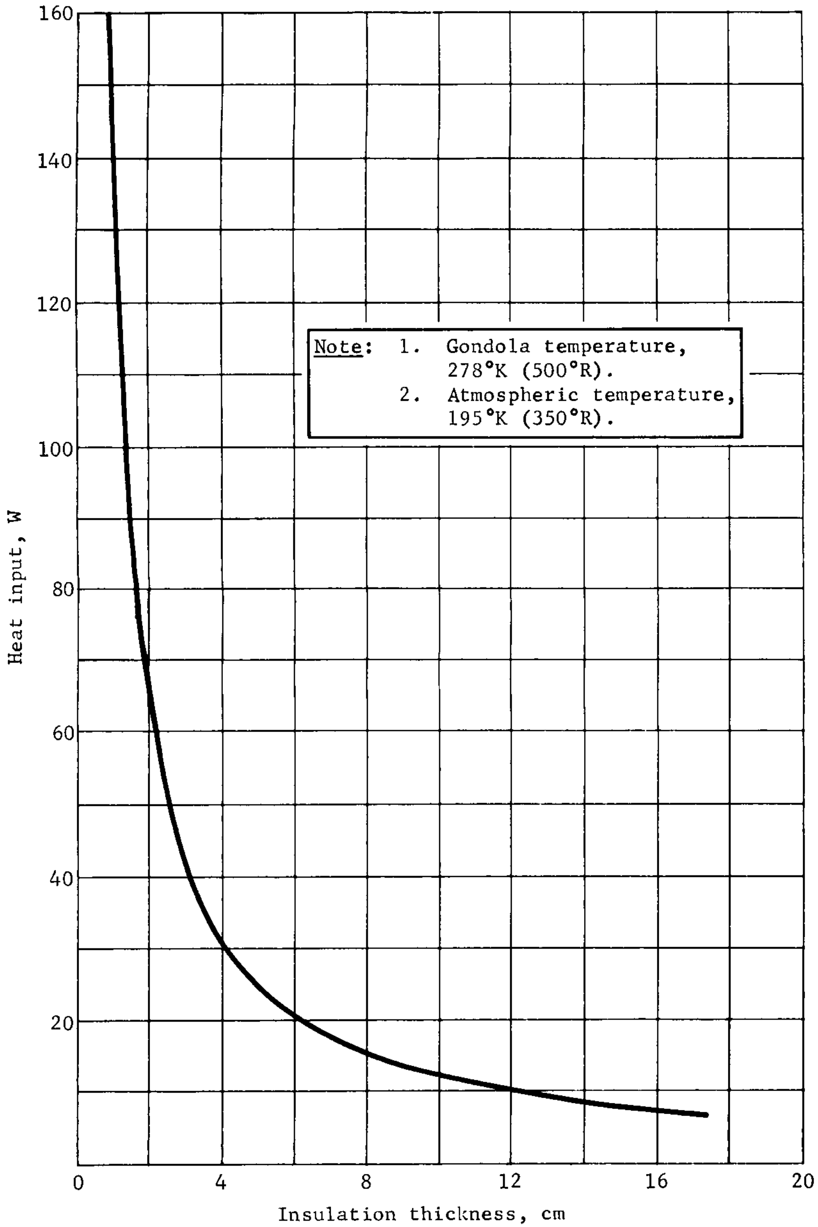


Figure 26. - Insulation Required for 2.0-cu-ft Gondola in Venusian Atmosphere

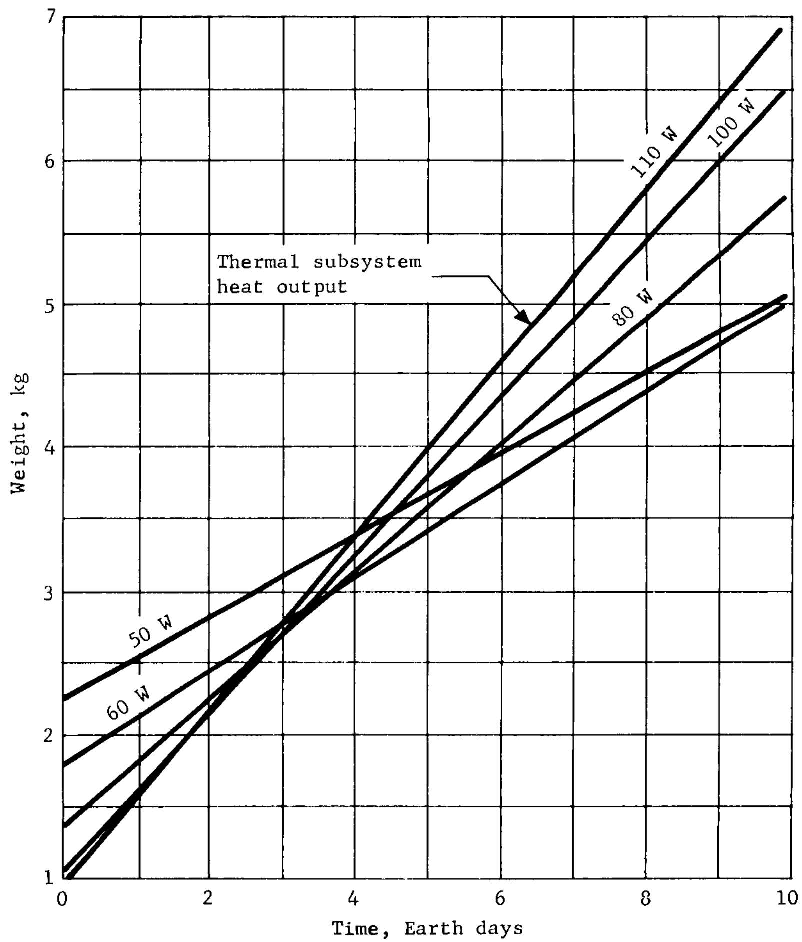


Figure 27. - Thermal Subsystem Weight vs Period of Operation

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1. Anon.: Study of Mars and Venus Orbiter Missions Launched by the Three-Stage Saturn C-IB Vehicle. Vol. III, Engineering Planning Document 139, Jet Propulsion Laboratory, Dec. 31, 1963.

2. Golomb, S. et al.: Digital Communications with Space Applications. Prentice-Hall.

3. Anon.: The Utilization of Powdered Metals as Fuels in the Atmospheres of Venus, Earth, and Mars. Technical Report 32-1073, Jet Propulsion Laboratory, Feb. 28, 1967.