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THE L-BAND AIR-TRAFFIC CONTROL SATELLITE SIMULATION EXPERIMENT USING BALLOONS

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July 1970

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SUMMARY

This report deals with an ATC satellite simulation experiment using high altitude balloons. There is an urgent need for useful engineering data concerning signal multipath, rf noise background, antenna gain factors, L-band system performance and the like. The balloon experiment will provide data about all these factors even though it cannot completely simulate a satellite experiment. In addition, the balloon experiment is economical costwise and will satisfy the need for data that cannot be obtained by a satellite experiment. The data obtained from the balloon experiment will be useful in the design of a preoperational satellite system for air traffic control (ATC). The best field sites for conducting the experiment are the California desert area (Edwards AFB/NASA) and the Wallops Station area (NASA). Both the field sites have excellent radar and ground support. The California desert field site is fully described and used as an example in the experimental plan in this report since the experiment was originally planned to be performed there.

THE L-BAND AIR-TRAFFIC CONTROL SATELLITE SIMULATION EXPERIMENT USING BALLONS

INTRODUCTION

Description of the Project

There is a need for the use of satellites in future air traffic control systems over such busy routes as over the North Atlantic. The technical definition of a feasible satellite system is, however, very unclear at the moment. There is a great need for flight test data necessary to evaluate the feasibility of using the L-band frequency spectrum for position location and data communications in an air traffic control system. The experiment described in this report will concentrate on the following measurements:

a. land and ocean multipath
b. background rf noise characteristics
c. position location through BINOR ranging techniques (single line of position)

In the present experimental configuration, the satellite is replaced by a high altitude balloon or a high altitude aircraft (RB-57F). The balloon carries a transponder similar to the one used on a satellite (for example, the input-output frequencies and the bandwidth are the same but the output power is much lower). It is also of interest to study the voice channel articulation index and intelligibility as a function of the signal to noise ratio for both high and low gain atennas on the receiving aircraft. This experimental program will give the engineering data necessary for the design of a preoperational satellite ATC system. From user's point of view, it is an opportunity to test, within a short time scale and at low cost, various techniques for voice data and ranging signal transmissions in a simulated and reasonably realistic environment.

Review of Past Experimental Work with ATS Satellites

In December 1966, the first experiment at VHF (149.22 MHz for transmission to the satellite and 135.6 MHz from satellite to the aircraft) was performed between an aircraft and a ground station using ATS-1 satellite. A series of tests were coordinated by Aeronautic Radio Inc. (USA) performing communications tests between in-flight aircraft and various geographically distributed ground stations and ships over the pacific ocean and continental U.S. Among some of the tests performed were FM voice transmissions, data and teletype transmissions and multipath propagation measurements.

During 1967-1968, (General Electric) and NASA/Goddard Space Flight Center performed VHF ranging measurements using the VHF transponders on ATS-1 and ATS-3 satellites.

The general conclusions arrived at were that satisfactory voice communications is feasible using the VHF satellite link provided the aircraft antenna is circularly polarized and the transionospheric propagation path does not intercept the auroral ionosphere during periods of extreme solar activity. Whenever the propagation path intercepted the auroral ionosphere during solar flare activity, severe amplitude and phase scintillations in the VHF signal were observed.

In order to overcome the drawbacks that a VHF system suffered as a result of spectrum crowding and the deterring effects of the propagating medium, L-band has been considered for navigational purposes in the recent past. An L-band transponder was included in the ATS-5 satellite in order to gather useful experimental data.

ATS-5 satellite was launched in 1969. It is stationed at 105°W longitude. However, the satellite failed to stabilize and is spinning at a rate of 76.2 rpm, the spin-axis being perpendicular to the orbital plane. As a result, the intended continuous signal is received only for 50 milliseconds every 790 milliseconds. The spinning action results in a doppler rate of approximately 475 Hz/sec on a signal translated by the satellite. The major effect of this is the problem of locking a demodulator loop within a short period of the 52 msec window and then passing sufficient data through the satellite transponder before "loss of lock." There also have been serious doubts as to the ability to obtain the true amplitude and phase characteristics of the multipath signal.

NASA/Electronics Research Center and Applied Information Industries (AII) have performed some ranging and propagation measurements at L-band from on-board the ship S.S. Manhattan to ATS-5 satellite (R. M. Waetjen – Personal Communications). Their results are very significant and has dismissed the doubt that multipath could be a serious problem at L-band for ranging measurements.

However, the past experiments have not provided all the engineering and design data necessary for the development of an operational satellite air-traffic control system.

EXPERIMENTAL CONFIGURATION

The experimental configuration is shown in Figure 1. It consists of a high altitude balloon (which can be replaced by a high altitude aircraft, for example, RB-57F), an instrumented jet aircraft (HANSA jet) and a Ground station with L-band instrumentation. L-band signals at 1651 MHz, either unmodulated (CW) or modulated with the BINOR code are generated at the ground station and transmitted to the balloon. The L-band repeater on the balloon translates the received 1651 MHz signal to 1550 MHz and transmits it. It is then acquired by the low altitude instrumented aircraft and the Ground Station. The various components of the experiment are as follows:

1. The low altitude jet aircraft (HANSA jet) carrying the L-band instrumentation. It also carries suitable L-band antennas for receiving the ranging signals and a C-band transponder for accurate ground-radar tracking.

2. The Mojave Ground Station which generates and transmits both CW and BINOR L-band ranging signals.

3. The high altitude balloon or aircraft carrying an L-band transponder and antenna. It also carries a C-band transponder for accurate ground-radar tracking.

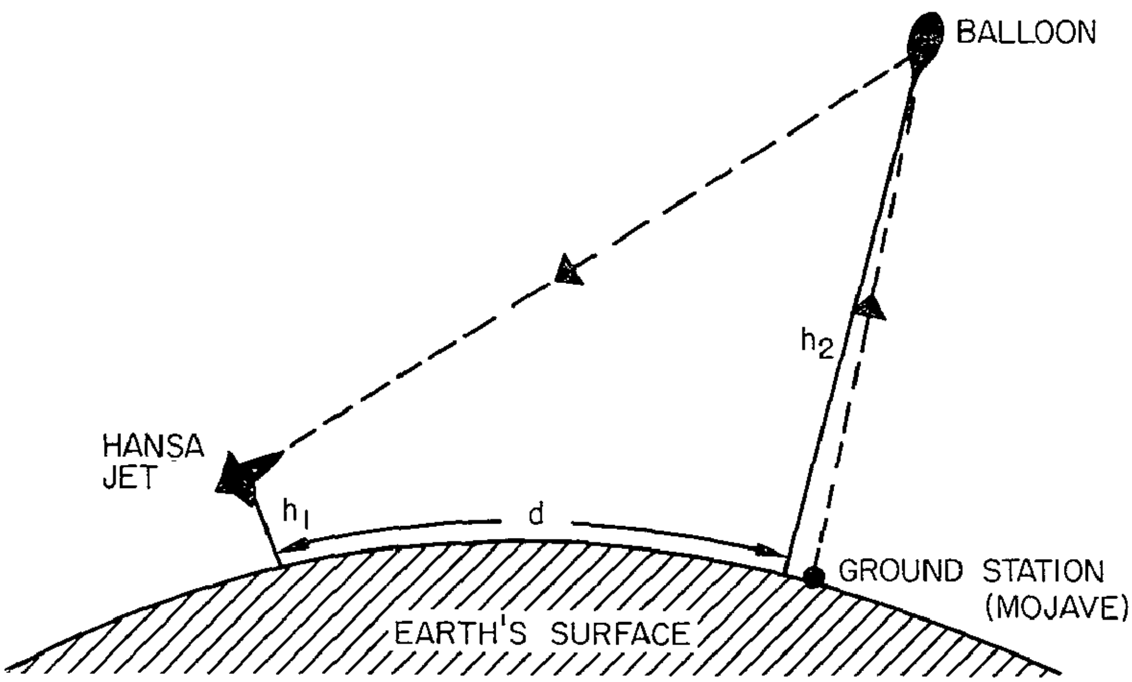

Figure 1. Configuration of a Ground Station-Balloon-Test aircraft experiment

4. Ground radars for accurate tracking of both the balloon and the aircraft.

5. Ground facilities for launching of the balloons.

6. Take-off and landing facilities for the jet aircrafts.

Figure 2 shows the geographical location of a possible site for the experiment on the west coast. The balloon will be launched in the vicinity of either Edwards AFFTC or San Nichols Island (Pt. Mugu), PMR. The optimum balloon altitude will be in the range of 100,000 - 125,000 ft. The total float time of the balloon at the optimum altitude will be about 5 hours. The balloon is recoverable. The low flying jet aircraft will fly at an altitude of 15,000 - 20,000 ft in a predetermined flight path. Part of the flight-path of the aircraft will be over the Pacific Ocean 50 to 100 miles from the coast. If a high altitude aircraft is used in the place of a balloon, both the aircrafts will fly over the ocean in predetermined flight paths. The HANSA jet can then fly much farther away from the coastal region (200 miles). The high altitude aircraft will be flown close to the coastal region since it has to acquire the Mojave L-band signal at elevation angles greater than 5°. However, several flights will be planned when the high altitude aircraft will fly beyond such distances with elevation angles smaller than 5°.

It is planned to seek range support from both the Pacific Missile Range (PMR), Pt. Mugu, California, and AFFTC and FRC/NASA at Edwards Air Force Base for the accurate tracking of both the balloon and the aircraft. The Pacific Missile Range maybe designated as the Control Center. PMR has a net work of radars in and out of the Coastal region. PMR radars can track the low altitude aircraft and the balloon (or the high altitude aircraft). Edwards' Radars will also be used to track the balloon. The tracking requirements depend upon the nature of the experiment.

1. For multipath and noise measurements, nominal accuracy in tracking is sufficient since the precise knowledge of the positions of the aircraft and the balloon is not necessary for a realistic interpretation of the data.

2. For the one-way ranging experiment, it is extremely important to know the positions of the aircraft and the balloon very accurately. Ranging accuracies of the order of 5 ft rms and 0.05 mil will be necessary to evaluate the performance of the L-band ranging experiment. Since the ranging experiment in principle, gives the time-delay of the signal between two points in space (balloon and the aircraft), the measured time-delay can be realistically compared with the theoretical estimate only if the positions of the two points are accurately known. Since the ranging errors at L-band are expected to be of the order of only several feet, the need of accurate tracking of the balloon and the aircraft is apparent.

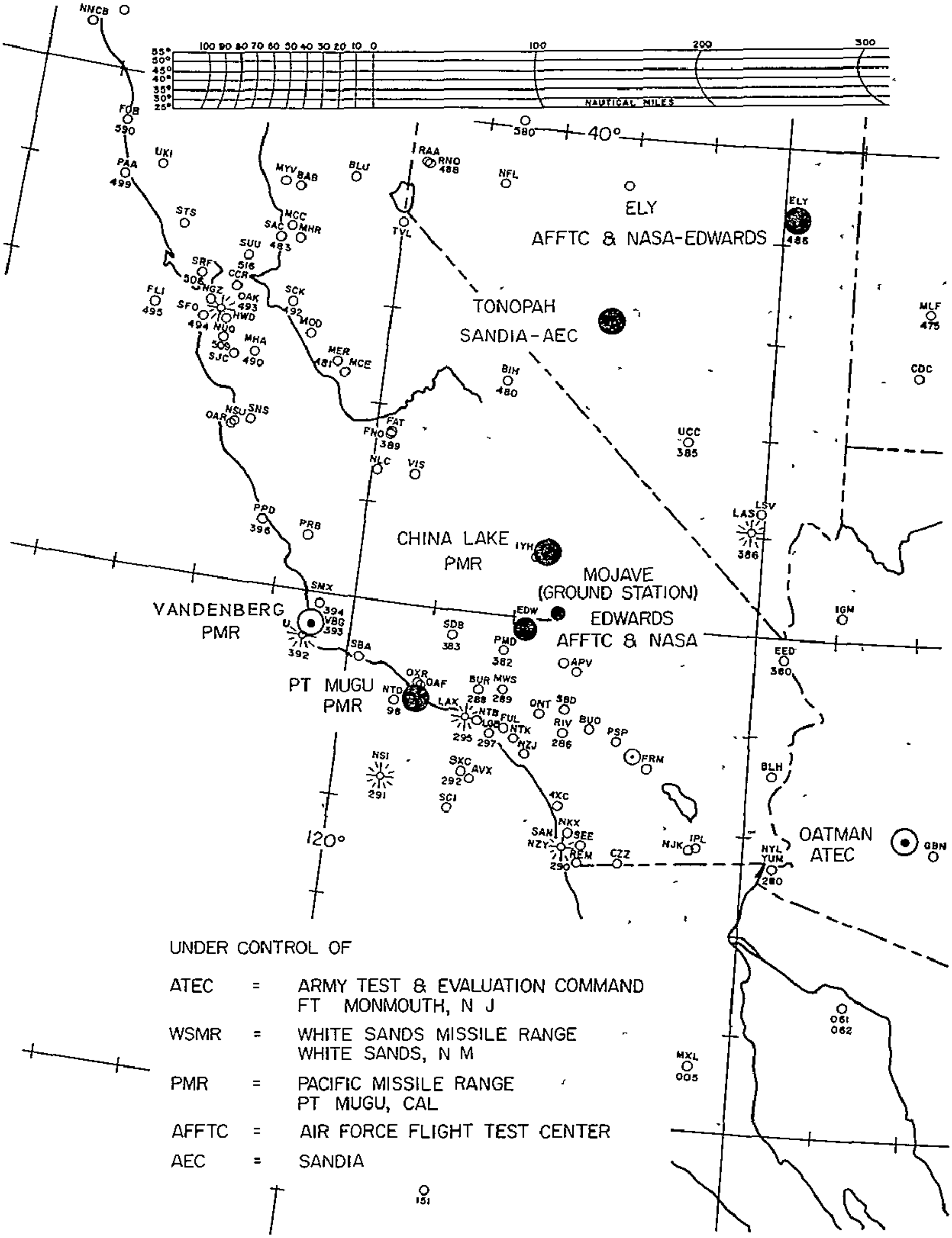

Figure 2. Geographic location of a possible site for the experiment on the west coast

EXPERIMENTAL PACKAGE

The five components of the experimental configuration are: (a) ground station, (b) balloon or high altitude aircraft, (c) low altitude aircraft (HANSA jet), (d) radar range support, and (e) ground facilities. They will be discussed in detail in this section.

Ground Station

The ground station is located at the NASA STADAN site in Mojave, California. It is equipped with a high-gain L-band antenna (15' parabolic dish) and an L-band transmitter/receiver. The transmitting gain is 35.36 db at 1651.02 MHz and the receiving gain is 35.17 db at 1550.00 MHz. The antenna uses righthand circular (RHC) polarization. In addition, a VHF communications transceiver is also available. The ground station will be furnished with the following equipment:

1. 70 MHz - 11 MHz Down converter
2. Phase demodulator
3. Binor processor
4. Data format converter
5. Variable attenuator
6. 70 MHz crystal oscillator
7. Phase modulator
8. Binor signal generator
9. Time interval counter
10. Rubidium Frequency standard
11. Coaxial switches and power supply

The ground station is also equipped with magnetic tape recorder, strip-chart recorder and a time code generator.

The RF interface of the experimental package of the L-band transmitter is at 70 MHz through suitable up-and down-converters. The two primary modes of operation of the ground system are:

(1) CW transmission and reception (transmission at 1651 MHz, reception at 1550 MHz). This mode is used for CW multipath experiments.

(2) BINOR transmission and reception (same carrier frequencies as for CW case for transmission and reception). This mode is used for range and range multipath requirements.

During the CW mode, the BINOR signal generator is disconnected and the 70 MHz crystal oscillator directly drives the L-band transmitter. For the BINOR mode, the BINOR generator phase-modulates the 70 MHz signal.

The received signal from the balloon is down-converted from 70 MHz to 11 MHz and then phase tracked and demodulated. For BINOR reception, the BINOR processor generates stop pulses at 76.3 Hz rate from the received BINOR signal. Corresponding start pulses are generated by the BINOR signal generator. The time lag between the transmitted and received BINOR code phases is measured by the time interval counter. A rubidium frequency standard is used for the transmitter and receiver time reference for accurate range measurement. The range measurements along with the received signal strength (AGC) and the BINOR processor-receiver lock-status are recorded on magnetic tapes in a digital format.

Balloon or High Altitude Aircraft

The balloon should have an altitude capability of 100,000 - 125,000 feet or over. The probable launch place is Edwards Air Force Base. The flight paths of balloons are difficult to predict exactly. However, it is possible to work out optimum flight paths for reasonable wind conditions during summer or winter. During summer months the westerly winds above 100,000 feet make the balloon drift towards the sea. During winter months, the easterly winds above 100,000 feet make the balloon drift away from the coast. It is desirable that the balloon be not more than 150 miles away from the ocean at the farthest point. It is also desirable that the balloon flight path comes as close to the ocean as possible without losing the payload recovery capability. The float time of the balloon is about 4 to 5 hours and the total time (from launch to recovery) is about 10 hours. Since the launch is dictated by ground wind conditions, sufficient stand-by arrangements should be made. Extensive upper atmosphere wind surveys are needed prior to the actual balloon launching to obtain low drift levels and stable flight paths.

The balloon should have a capability to carry the L-band electronics weighing approximately 15 - 30 lbs.

The package consists of L-band transponder system and an L-band antenna (hemisphere type). The balloon will also be furnished with a C-band transponder system to be used for accurate radar tracking. The balloon should carry the standard command system for flight control. No transponder telemetry is required. However, the standard balloon telemetry should be operational for monitoring and guiding the balloon system. The role of the balloon in the L-band experiment is to receive the ground generated 1651.02 MHz signals, translate them in frequency to 1550.00 MHz and retransmit them. The balloon will be tracked by a surveillance type of radar to obtain its time-position history during the flight.

If a high altitude aircraft (for example, RB-57F or U-2) is used in the place of a balloon, the experimental package and the system requirements remain the same. The rôle of the aircraft will be the same as that of the balloon in the experiment. However, the flight paths of the aircraft-balloon configuration will have to be modified for the two aircraft configuration. The high altitude aircraft will be flown both over land and over the ocean. The HANSA jet will then be flown at flexible distances, in a predetermined flight path, from the high altitude aircraft. It is planned to do the experiment with both the balloon and the high altitude aircraft.

Test Aircraft (HANSA jet)

It is planned to use the small commercial jet, HANSA for the experiment. It is economical, does possess the altitude capability of up to 40,000 feet and has sufficient space for the installation of L-band instrumentation. Flight durations of three to four hours are planned to provide adequate time for reaching the test area, conducting preliminary tests and performing the different experiments that are planned. The aircraft will use either Pt. Mugu (PMR) or Edwards AFB as the take-off and landing strip. A test crew of two or three persons will be required to maintain and operate the aircraft L-band equipment. The transmitter and other equipment used in the experiment will require approximately 2,000 watts of 115 V, 400 cps power.

The mechanical design and installation of the L-band experiment in the aircraft will satisfy the requirements for mechanical stability and safety. The aircraft test crew will be able to talk to the ground station via the aircraft communications transceiver, and talk to the aircraft crew and each other by an intercom system.

The aircraft will fly in predetermined flight paths and will be beacon tracked by ground radars. More than one ground radar will be employed when precision tracking of the aircraft is needed.

The L-band instrumentation on the aircraft may be divided into the following subsystems signifying their functional characteristic:

(1) Antenna subsystem
(2) RF switching unit
(3) BINOR RF processing
(4) Noise measurement
(5) CW calibration signal generator/synchronizer

(6) Calibrated noise source
(7) Rubidium frequency standard
(8) Phase comparator
(9) Timing equipment
(10) Digital processing equipment
(11) Data recording equipment
(12) Power supplies.

A brief qualitative description of each of the above subsystems will be provided below.

(1) Antenna subsystem: No definite plan has been arrived at for the antenna configuration on the aircraft. A total of five (5) L-band antennas might be installed on the aircraft. They consist of.

(a) Low gain hemispherical antennas (4). They are also called operational antennas. They will be located at the top centerline, bottom centerline and on either side of the aircraft. The turnstile antenna developed by TRW may possibly be used. The expected gain of these antennas is 0 to 4 db nominal with the operational frequency range 1540 - 1660 MHz. Right hand circular polarization will be employed. The roles of these antennas in the experiment will be described in the next section.

(b) High gain narrow-beam antenna (1). This will be installed at the top. A gain of 10 - 15 db with a beam width of 50° - 70° is anticipated.

Another requirement is that the antenna possess a side-lobe suppression capability of 20 db. Once again, circular polarization will be employed. The antenna patterns of all the five antennas are expected to be known very accurately.

As a part of the antenna subsystem, there will be 3 RF preamplifiers, line drivers, calibration switches, and diplexers (for providing antenna output to a desired preamplifier). The RF gain of the preamplifier is about 25 db with a noise figure of 5 db and a bandwidth of 100 MHz (minimum). The preamplifiers will be located at the base of the antennas.

(2) RF switching unit: The RF signal switching unit interconnects the five aircraft antennas, the CW calibration signal source and the noise source with the three BINOR receivers and the spectrum analyzer.

(3) BINOR processing unit: The BINOR processing unit consists of three BINOR receivers, a range-multipath correlator and a receiver slave control unit.

The BINOR receivers operate at a nominal frequency of 1550 MHz with a search range of ±25 KHz. The IF band width is 5 MHz. Receiver noise figure is 6.0 db with a carrier-acquisition threshold of -130 dbm. A video output of 0 to 2 MHz range and -10 dbm into 50 Ω is available.

The range-multipath correlator receives the quadrature 312.5 MHz square-wave clock-tone of the receiver No. 1 BINOR PROCESSOR and multiplies this by the broad-band video output of receiver No. 2. The result of this multiplication is weighted by a low pass filter (freq $\simeq$ 50 Hz) and amplified to the specified output level. Receiver No. 1 uses the output from the high-gain directional antenna and receiver No. 2 uses the output from the uplooking low-gain hemispherical antenna.

The receiver slave control unit allows the BINOR receivers to operate independently or it allows receivers 2 and 3 to be slaved to 1 with a 5 KHz reference oscillator offset.

(4) Noise measurement equipment - The RF noise measurement equipment consists of a spectrum analyzer and a post-detection integrator. A preamplifier (AVANTEX model AM-1000) is placed before the spectrum analyzer to provide additional low-noise gain to increase its sensitivity.

The spectrum analyzer (Model HP851B/8551B) operates in one of five measurement modes and provides a Y-axis output (0 to -4V) for the post detection integrator and an X-axis output (-5V to +5V) for frequency determination. The analyzer sensitivity is about -100 dbm.

The post detection integrator is used at the output of the spectrum analyzer. Four outputs permit recording of vertical and horizontal spectrum analyzer outputs simultaneously on the tape and chart recorders. The post detection integrator is packaged within the receiver slave control unit.

(5) CW Calibration Signal Generator/Synchronizer - The CW calibration Signal generator consists of an HP-8614B rf signal generator and an HP-2605A microwave synchronizer. The synchronizer provides a crystal stabilized reference source which the CW signal source phase locks thereby providing the necessary instantaneous phase stability required by the three BINOR receivers. Thus, they provide the capability of in-flight calibration of the three receivers in terms of rf frequency and sensitivity.

(6) Calibrated Noise Source - The calibrated noise source consists of a noise generator and a power supply. The noise generator uses an Argon gas discharge tube inserted in a helical line, which is centered in an outer conductor. One end of the helix is terminated in a 50 Ω resistor and the other end is

brought out through a type N connector. The noise generator power supply provides both filament and adjustable high voltage power to the Argon gas tube. The operating frequency range is 0.2 to 2.6 GHz.

(7) Rubidium Frequency Standard - The rubidium frequency standard supplies accurate frequency standards for the experiment. The 5 MHz signal is for BINOR processor, the 1 MHz signal to the time code generator and another 5 MHz signal to the phase comparator. The frequency standard accuracy is ±1 part in 10^{+11}. Reproducibility is ±5 parts in 10^{+12}. The long term stability is +1 part in 10^{+11}.

(8) Phase Comparator (Model K05-5060A) - The phase Comparator measures the relative phase difference between the 5 MHz signal from the rubidium frequency standard (reference) and the signal from the crystal oscillator within the BINOR processor. The output is in the form of a dc analog voltage (0 to +1 volt range) proportional to relative phase of inputs.

(9) Timing Equipment - The timing equipment consists of a WWV receiver system and a time code generator.

The WWV receiver system (Model WVTR-A) is used to acquire epoch information from Station WWV in order to synchronize the time code generator.

Part of the time information broadcast by Station WWV is a one second pulse tone. Every fifty-ninth pulse is missing, making it possible to identify an even one minute pulse. By presetting the time code generator to a specific time and opening its arm switch at the fifty-ninth second, the time code generator can be activated by WWV's one minute pulse.

The time code generator (CHRONOLOGY 4610) provides time annotation with each data sample taken by the system. It supplies the NASA-36 (1 KHz carrier) time code format and a parallel 8421 BCD output for hours, minutes and seconds. The BCD output of the generator is accepted by the digital data formatter for subsequent recording on magnetic tape. The generator has a resolution of 1 second with an accuracy of 0.1 second.

(10) Digital Processing Equipment - The digital processing equipment consists of a Binor Code Processor, a time interval counter, a digital data formatter and a multiplexed analog to a digital converter.

The Binor Code processor performs the range measurement by acquiring a clock component (F_1 = 312.50 KHz) with a phase-lock loop followed by 12 correlations in sequence of the code with its twelve subfrequencies. The lowest subfrequency (F_{13} = 76.3 Hz) is reconstructed and the range is obtained by the phase measurement between this reconstructed wave and a locally generated reference. The output of the subfrequency correlator is integrated and is used to establish the correct phase of the subfrequency square waves. Detection performance can be increased at the cost of longer acquisition time. The unit features seven digit range measurement with ±10 feet quantization per measurement.

The time interval counter unit is the 400 Hz version of the commercial HP-5248L HP-5276A. The unit is utilized to obtain range data information using the start/stop signals from the Binor Code processor. Output BCS-8421 data lines are subcommutated by the digital data formatter.

The digital data formatter converts all input data into six bit tape characters. This conversion takes place at a 20 KHz rate continuously; thus the output of the formatter is suitable for recording by a seven track digital tape unit with internal lateral parity generation.

The multiplexed analog to digital (A/D) Converter (HP 5610A) is used for selecting and digitizing each of the 16 analog data inputs to be recorded on magnetic tape. It will have one each option 01 and two each option 02. Option 01 is a multiplexer sequencer. Option 02 is a provision for 8 channels of ±1 volt full scale input.

(11) Data Recording Equipment - The data recording system consists of a tape controller, two magnetic tape units and a strip-chart recorder.

The tape controller interfaces the digital data formatter with the two magnetic tape units and controls the tape units for the most efficient data storage. In the primary record mode, data is alternately recorded on the two magnetic tapes. The interleaving of data results in the generation of two IBM compatible, gapped tapes with approximately thirty-five minutes of total continuous recording time. In the secondary recording mode, the tapes can be operated singly and the selection is made manually. The data is recorded on one or both of the tape units either in a simple ungapped format or with non-stop gapping and consequent data loss.

Two magnetic tape units (Kennedy Model 3110) are employed for data recording. The code format is IBM compatible. Each unit has seven tracks/800 bpi tapes written on 2,400 feet (1.5 mil.) tape. The ungapped recording time is 19.2 minutes per tape.

The strip-chart recorder (Techni Rite Model TR-888) has 8 analog channels. It provides a quick look at data and has variable channel speeds.

(12) Power Supplies - The power supply unit consists of primary ac power source, a dc power source and a power frequency converter.

The primary power source supplies 115 volts ac at 400 Hz. The dc power source (HP-60155C) provides a regulated ±15 volts for the test system, the rf processing equipment and the post detection integrator. The power frequency converter converts the aircraft primary power (115 ac, 400 Hz) to 115 volts ac, 60 Hz to supply power for the strip-chart recorder (400 watts) and the analog to digital converter (90 watts).

Radar Range Support

All field tests will require reliable voice communications between the user aircraft, the high altitude (RB-57F) aircraft if it is used and the ground control station. It is desirable that one or more ground radars be used to obtain time-position history of the user aircraft and the balloon/high altitude aircraft (RB-57). For the study of multipath effects, radars capable of giving coarse time-position flight history are sufficient. For ranging measurements, since the measured position data at L-band is going to be compared with the radar position data, it is extremely important to obtain highly accurate radar tracking. Three-dimensional surveillance type of radars are to be used in the experiment. A standard for measuring ground transmitter frequency and phase before, during and after the aircraft fly-by tests is accomplished by using a portable cesium beam atomic standard.

Some of the field test-sites under consideration are evaluated in the following table (Table 1) in terms various experimental criteria. Ground control, tracking and aircraft logistics facilities are adequate at all the test-sites considered.

FPS-16 is a high accuracy, long range, amplitude comparison, monopulse radar, capable of manual or automatic acquisition and tracking with characteristic tracking accuracies of 0.2 ± 0.05 mil in angle and 10 to 20 ft. in range. It is a C-band radar (5.6 - 5.9 KMHz) either skin tracked or beam tracked with a transponder on the target.

MPS-19 is a long range conical scan automatic angle and range tracking radar designed to provide azimuth and elevation angle and slant range data. The C-band MPS-19 has a 2500 mile ranging capability. In some radars, an 80" focal length boresight telescope and closed circuit TV is installed. These systems provide collimation capability and optical comparison. An accuracy of $\approx$ 0.5 to 0.75 mil in angle and 15 to 30 ft in range is obtainable.

These angle and range accuracies are nominal accuracies of single radar. Suitable calibration techniques and geometric triangulation techniques with two or more radars could be employed to give much better accuracy. It should be

Table 1

Evaluation of Field Test-Sites

Field Test Site	Terrain Features	Variability of Weather	Remarks
Eastern Test Range (ETR) Florida	No nearby arid on mountainous terrain. Proximity to forest terrain. Nearest large urban area is Miami	Good - high incidence of electrical storms	Adequate but not as attractive as Wallops Island
Western Test Range (WTR) Pacific Missile Range (PMR)/ Edwards Test Range (AFFTA)	Excellent - forests, mountains, deserts, ocean and ultra high density urban area (Los Angeles) close by	Poor - very low incidence of electrical storms. High sea states seldom occur.	Lack of variability in weather is the only draw-back. Balloon support is good. Many balloon experiments are run regularly in a well coordinated fashion.
Wallops/Langley	Good - Proximity to forests, mountains, oceans and two urban areas (Washington & Baltimore)	Good	Probably the best all around test site.
Eglin AFB, Florida	Same as ETR except the nearby urban area is New Orleans	Good	Adequate but not as attractive as Wallops Island.

remembered that the calibration techniques are often complicated and time consuming. They also test the competence of the radar support crew. However, simultaneous availability of several radars and crew is very difficult.

In this context, we can discuss the tracking accuracy requirements for various experiment to be done. Table 2 specifies the needed resolutions in radar tracking data for various experiments.

Table 2

Required Accuracies in Radar Tracking

Parameters	Multipath Expt		BINOR Ranging Expt	RF Noise Expt	
	CW	BINOR	BINOR	CW	BINOR
Range	20 ft	5 to 10 ft	5 to 10 ft	50 ft	50 ft
Angle	0.5 mil	0.1 mil	0.1 mil	0.5 to 1.0 mil	0.5 to 1.0 mil
Data rate	at least 10 samples per sec	at least 10 samples per sec	at least 10 samples per sec	at least 10 samples per sec	0.5 to 1.0 mil

FPS-16 and/or MPS-19 radars are available at the site locations discussed earlier.

Some of the data format requirements are:

a. IRIG-B time of day
b. Digital Data recorded on magnetic tape
c. At least 16 bit binary for each of azimuth, elevation and angle.

Time, latitude, longitude, altitude, velocity components should be recorded in a digital format. A time resolution of 1 sec is substantial. Such a data format is available at all of the radar stations.

Normally, a complete mission is recorded on magnetic tape and replayed at a later time including the plotting board information, voice communications, correlation tones, etc. At AFFTC/Edwards and PMR/Pt. Mugu, real-time interchange of radar data is also available.

The TACDACS (Target Acquisition and Data Collection System) that is available at Edwards is a real-time, digital computer centered, sampled data system. The radar subsystems receive tracking data from their associated radars and format the data for transmission to the space positioning range control subsystem. The tracking data received from selected radars is then combined into two channels of formatted tracking data which is then fed into the computer. The computer also provides target acquisition data derived from tracking data for all the radars. All the radar locations are tied together by means of a microwave carrier system.

Continuous communications between the test vehicles and the test controller is made possible by four independent, simultaneous lines of communications.

Ground Support

The operation of a ground station for transmitting L-band signals calls for all the facilities that go with a regular operational ground station.

Landing facilities should be available for the HANSA aircraft (low altitude aircraft) and the high altitude aircraft (RB-57F) if it is used.

Logistic and communication support should be available to the balloon launching crew. In addition, uninterrupted communications should be maintained between the balloon crew and the ground station personnel. The balloon recovery operation should be well coordinated with the ground station personnel. Balloon position control should meet the requirements of the experimenting scientists on board the HANSA jet and at the ground station.

Meteorological data should be available to select suitable balloon launch time. Weather condition should be continuously monitored throughout the experiment.

Helium supply for the balloons should be planned so that mobile launching of balloons from remote sites is made possible. In this context it may be mentioned that an ideal way to collect sufficient sea-multipath data in a west coast experiment is to launch the balloon from San Nichols Island. However, the launch is complicated by the fact that it is very difficult to supply Helium to the island. It is expected that the balloon contractor would handle all the supply and logistic problems that are associated with the balloon launching.

Data Analysis Facility

Facilities for a limited amount of data processing and analysis are required near the testing area, preferably at the ground station or the lead range support agency. Data processing will be restricted to preliminary correlations of test results. The experiment will be designed to perform a maximum number of tests per flight in order to take advantage of the long floating times of the balloon, and also minimize the number of individual experiments. In keeping with this scheme, the data processing should preferably be performed in or close to the staging area to provide rapid feed back of the test results from the analysis group to the flight test group and thereby implement the immediate modification of test results as test procedures to provide maximum accuracy and efficiency in performing the data collection.

The data will be in the following forms:

(a) Digital data tapes of transmitted signals, receiver signals, noise and range measurements and equipment modes versus time of day will be recorded both at ground station and on the aircraft. These tapes will be arranged for computer reduction.

(b) Tracking data tapes from radar sites tracking the aircraft and the balloon.

(c) Aircraft navigation data from the flight crew.

(d) Test events data from the test crew.

(e) Any pertinent information from the ground station.

USE OF HIGH ALTITUDE BALLOONS

Introduction

Balloons offer certain advantages over high altitude aircrafts (RB-57F, U-2 and the like) in that their positional stability is better than of an aircraft and consequently are tracked precisely. Moreover, balloons can be flown well over 100,000 feet which is advantageous to the multipath test. However, there are certain limitations in the use of balloons. There are the possible limitations on location because of hazards to aviation and the public. Balloon launching and flight-path are dependent on meteorological (wind) conditions. There is also the possibility of failure of recovery operations and consequent loss of equipment. However, recoverability of instrument packages from high altitude free balloons can be accomplished with very good reliability. Balloon costs will be less than that for a jet aircraft for several hours flight. Experiments involving balloons requires experienced field test crews and very careful attention to meteorological factors. Extensive upper atmosphere wind surveys are needed prior to the actual balloon launching to obtain the low drift levels that are mandatory for satisfactory performance of the experiment.

Launch Site Selection

Balloon launch site has to meet three requirements.

(a) ability to attain a flight path conducive for accomplishing the desired objectives of the experiment.

(b) Availability of tracking radars in the vicinity.

(c) Availability of reliable meteorological information.

Edwards AFB (California desert) area on the west coast or Wallops Island area on the east coast are two ideal locations for the experiment. At the time of writing this report, no satisfactory balloon flight path prediction data is available for the Wallops Island area. However, during the months of August-November, the wind conditions are satisfactory for performance of the experiment. If the balloon is allowed to drift towards the Atlantic ocean, sea recovery operations have to be planned. Sea recovery operations, while feasible, are risky and expensive. Radar support at Wallops Island is the best obtainable. Also, as mentioned earlier, multipath data collected over the Atlantic where the sea state is extremely variable will be directly applicable to an operational ATC system to be built to operate over the North Atlantic.

However, Edwards AFB area has many unique features. It has a fine record of many successful balloon launches. California deserts provide the ideal locale for balloon launches. The surface winds in the morning hours are extremely light which enables employment of low risk flexible launch techniques. The winds aloft are predominantly west-southwesterly in the troposphere and change to easterly in the stratosphere. This wind reversal provides low resultant drift over the expected flight profile. Edwards is a ready source for first hand meteorological data and the vast California desert is unsurpassed as a recovery area. Its numerous roads and trails enable very close ground- and air-tracking cooperation. Payload recovery probability is very high under these conditions. There are several C-band radars at Edwards and at Pt. Mugu (Pacific Missile Range) on the coast. There are several radars in the Pacific ocean at San Nichols Island. Therefore, it will be possible to let the balloon drift over the ocean and the HANSA jet (low altitude aircraft) fly much farther from the coast. The data collected in such a configuration will be highly representative of multipath due to reflections from the sea surface.

Flight Path Planning

Figures 3 and 4 represent percent number of days in a month when balloon launching is possible due to favorable wind conditions as a function of the months of a year. The data is derived from 25 year average of wind data collected between 0600-0800 LT. Figure 3 represents the case when the surface wind speed is between 1 to 6 knots when launching can be accomplished within tolerable limits. Figure 4 represents the case when the surface wind speed is ≤ 1 knot

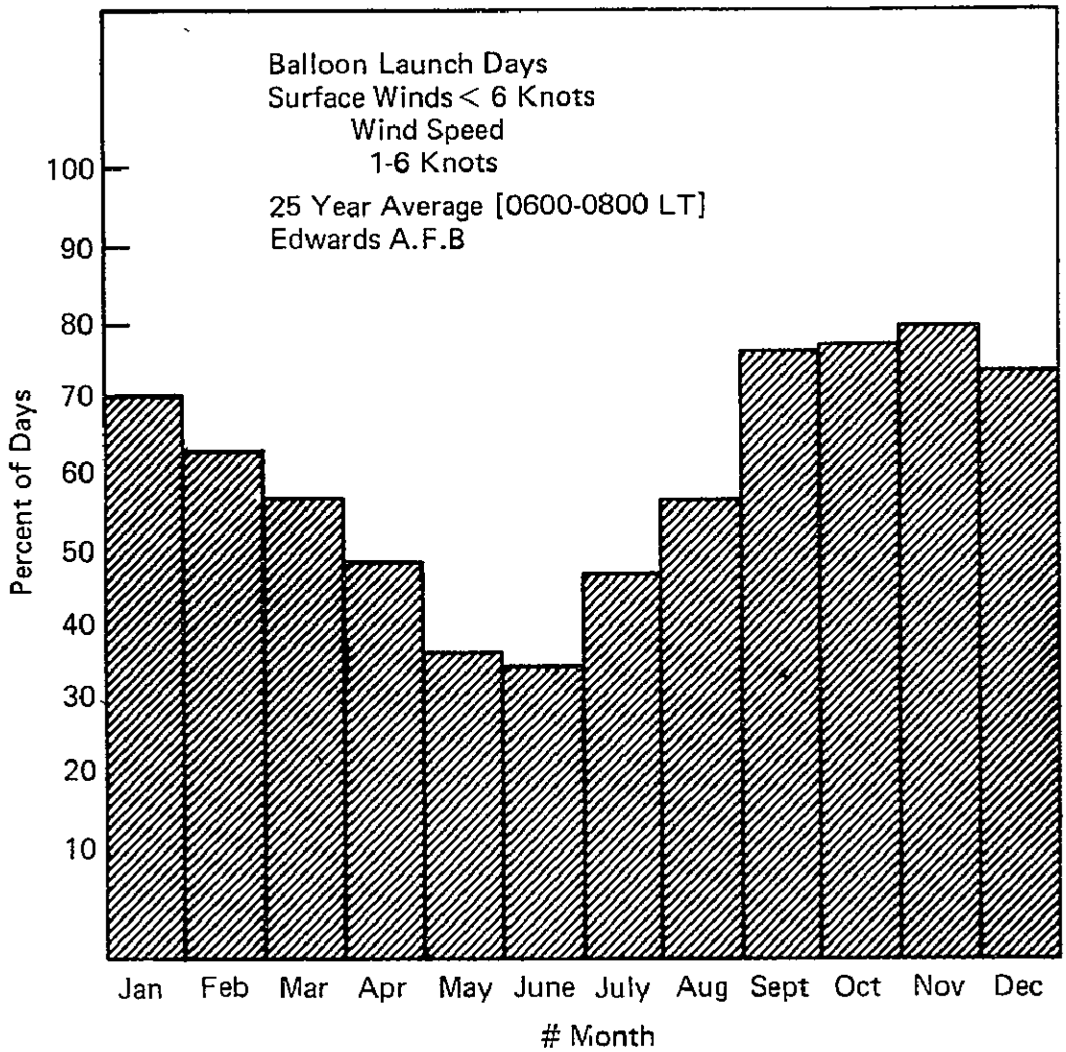

Figure 3 Percent number of days favorable for balloon launching versus months of the year. Wind Speeds ~ 1 to 6 knots 25 year average wind data

and are categorized as calm days. On such days, launch operations are extremely successful.

Figure 5 shows monthly-mean flight trajectories using the wind data published by ESSA and Edwards AFFTC. The flight paths (May-September) represent only a statistical average and are calculated on the basis of some of the following balloon parameters:

1. Fixed rate of climb at 800 ft/minute.
2. Float at 100,000 ft for 4 hours.

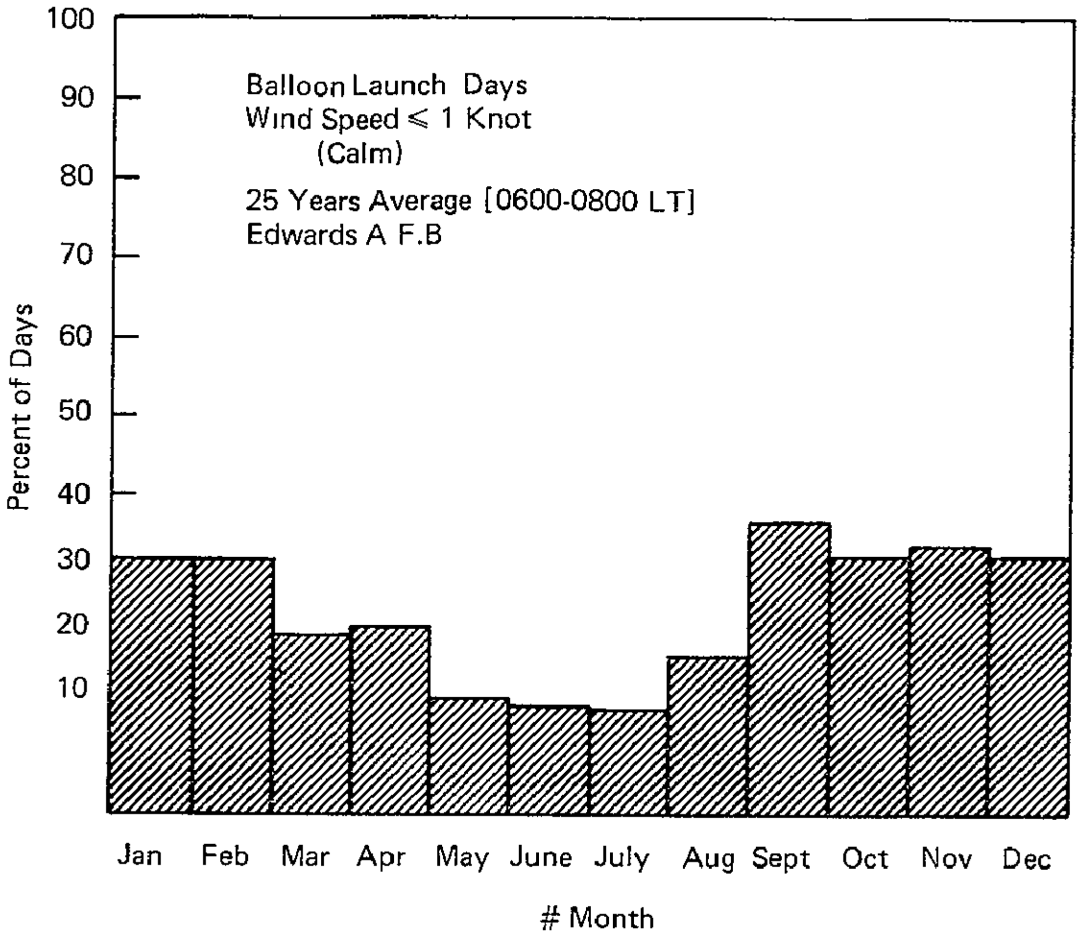

Figure 4 Percent number of days favorable for balloon launching versus months of the year. Wind speed ≤ 1 knot 25 year average wind data.

3. Fixed descent rate of 1,000 ft/minute to an altitude of 10,000 ft.

4. Rapid deceleration below 10,000 ft. for controlled soft landing.

These flight paths are presented only to indicate how they are computed given a set of parameters and wind velocities. It should be remembered that the launch point could be shifted to either east or west and the ascent rate could be changed also. The float altitude is selected and accomplished by using rawinsonde data available while the flight is in progress.

This mission requires positioning of the balloon vehicle over a specified area at a particular time and altitude. Consequently, to improve the flight paths, the balloon may be guided through one or more course changes. For as the balloon ascends, it passes through many different wind regimes of both speed and direction. The resulting trajectory is a function of time spent in each. Therefore, by controlling the rates of climb and by introducing intermediate

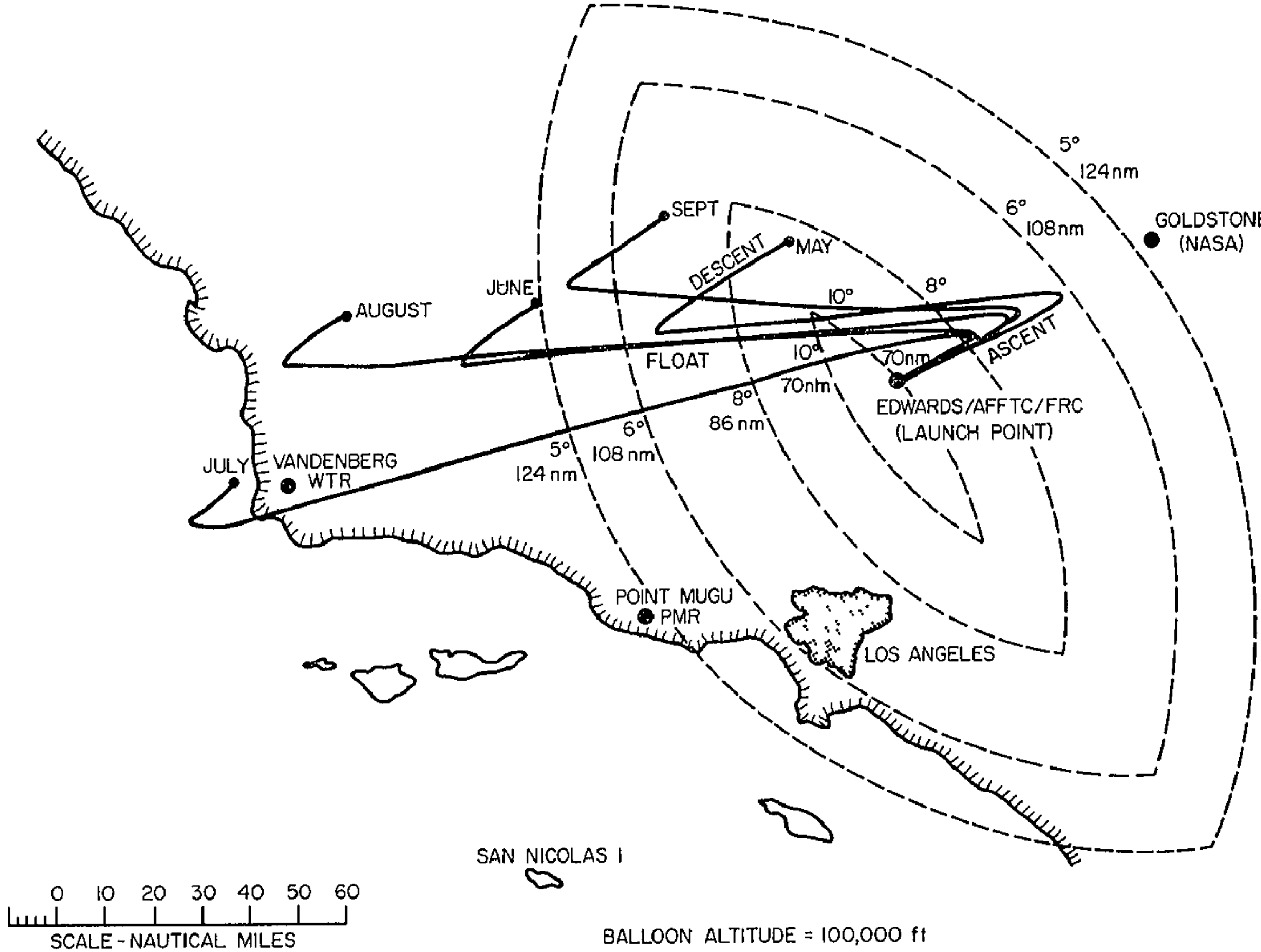

Figure 5 Monthly mean flight trajectories of balloons in the California desert.

float levels through sequential valving and ballasting operations, the balloon flight path can be modified. Nevertheless, flexibility of flight path requirements is also important since the actual balloon track will inevitably be subjected to anomalies due to variable wind conditions.

For spring and summer seasons, a pertinent consideration from the point of view of tracking and recovery is the location of the minimum wind field relative to the nominal design float altitude (100 - 150 kft). Since in the spring and summer, 100 kft tends to mark the dividing line between the stronger winds of the stratosphere and the more benign conditions which occur nearer the troposphere, it will be desirable to select an altitude immediately before launch which will facilitate the execution of the experiment and ease tracking and recovery requirements.

Recent advances in balloon technology permits payloads of hundreds of pounds to be carried at altitudes well above 100,000 feet. Altitudes of 130,000 - 150,000 ft are also obtainable with more sophisticated balloons with a payload weight of the planned L-band experiment. Various sophisticated launching techniques (for example, Reefed balloon technique, anchor line launching technique and the like) are also available.

EXPERIMENTAL OBJECTIVES

Experiments

Many experiments are necessary to obtain satisfactory data on system operational parameters. Some of them are elicidated below.

Multipath—Since an error is introduced in the position determination accuracy from the presence of multipath signals, it is of great importance to study the amplitude and phase probability density characteristics as a function of elevation angle for both the specular and diffuse signals. These statistics should enable antenna engineers to design the antennas with sufficient multipath rejection capability. The plan is to measure the reflected signal relative to the direct signal level for an aircraft flying over land or sea. The motion of the aircraft and the size of the reflecting surface combine to provide doppler shifting of the reflected energy over a considerable range of frequency. The doppler shift is approximately given by the expression

$$\Delta f = \frac{f V}{3 \times 10^5} \text{ cycles/sec}$$

where f is the operating frequency and V is the vehicle velocity (relative) in kilometers/sec.

The broadened spectrum of energy has properties similar to noise and will tend to increase signal acquisition times and decrease the accuracy of range measurement. In addition, the reflected signal causes fading on the direct component of the signal to an extent determined by the antenna gain and beam-width.

The purpose of the experiment is to characterize the multipath signal sufficiently to allow prediction of fade depths when aircraft antenna patterns are specified. Also, direct measurements of the amplitude and phase of the reflected signals will be used in correlating the fading data.

RF Noise Measurement—In view of the tight power budgets for L-band operation, the question of effective rf noise environment is of considerable importance. External noise sources, including aircraft generated RFI, ground RFI and precipitation static are all subject to a wide range of prediction uncertainty and should be measured under relevant conditions. Theoretical predictions of ground RFI indicate as much as 3000°K effective temperature in or over heavily populated urban areas. Consequently, this will be a separate test objective. Results will be correlated with population density and antenna coverage pattern (for example, downlooking versus uplooking). The effective noise temperature due to precipitation static is expected to be very small at 1600 MHz. Measured noise temperature of 10^5 °K at 100 MHz corresponds to about 2°K at 1600 MHz based on the observation that the noise temp decreases as the inverse fourth power of the frequency above 100 MHz. These estimates are based on theoretical models and existing experimental data are very rare and unreliable. Therefore, it is planned to carry out special flights to encounter severe thunderstorm belts (characterized by precipitation static activity).

Position Location Experiment—The position location experiment will measure the distance from the balloon to the aircraft using a binary coded signal called BINOR. Simultaneous with this measurement, precision ground tracking will be used to determine the positions of the aircraft and the balloon accurately and thus provide a basis for evaluation of this range measurement. The acquisition time of the range signal will be expressed as a function of the received signal to noise ratio and elevation angle. Simultaneous signal recordings from the hemispherical coverage top-mounted antenna and the down-looking antenna will be used to predict multipath ratios and the associated ranging errors.

In addition, a voice modulation experiment to test the intelligibility of transmitted ATC messages is also planned. The resultant articulation index will be expressed as a function of antenna parameters and the received signal to noise ratio.

System Parameters and Techniques

Introduction–Owing to the limited aircraft antenna gain and the power limitation of a spacecraft, the critical design parameter of a future aeronautical satellite system is the spacecraft RF power required for the satellite to aircraft link. The spacecraft rf power depends on the following link parameters:

1. Propagation path-losses
2. RF noise environment
3. Spacecraft antenna gain
4. Link margin
5. Aircraft antenna gain
6. Modulation technique
7. Number of voice and data channels.

The first parameter is more or less fixed by the specified coverage area of the spacecraft, the satellite configuration at geostationary altitudes and the planned frequency band (L-band). The remaining link parameters cannot, at present, be specified explicitly for lack of experimental data.

Link Margin–The satellite to aircraft link margin is dictated by the nature of multipath reflections which depends on aircraft antenna pattern and modulation techniques. A high gain aircraft antenna has a small beam-width and consequently a high multipath suppression ratio while a low gain antenna has a broad antenna beam and low multipath suppression ratio.

At L-band, differing theoretical analyses on multipath reflections have been performed. No study has taken into account the aircraft antenna pattern and the voice quality degradation due to multipath at various elevation angles.

Because the available aircraft power is rather marginal and because an increase or decrease of the link margin by 1 db will result in 20% more or less spacecraft rf power, experiments on the effect of multipath reflections on the signal quality for various aircraft antenna parameters and modulation techniques are to be performed.

Aircraft Antenna Gain–In an operational system, simple hemispheric coverage antennae are desired for simplicity and low cost. On the other hand, gain should be maximized to cut down on satellite power. In the present balloon-aircraft experiment, both high gain and low gain (hemispheric) antennas will be tested. The feasibility of a hemispherical coverage aircraft antenna will be fully tested. High gain narrow beam antennas will be used to be able to separate the multipath component from the direct signal.

Modulation Techniques—The voice link of an aeronautical satellite system cannot be up to CCIR standards because of gain and power problems. However, ICAO has recommended a voice quality equivalent to an articulation index of about 0.6. At present, there is not much experimental data available on achievable voice quality of various modulation techniques under flight conditions.

For the transmission of digital data and ranging signals, the theoretical investigations give only an approximate bit error probability and range measurement accuracy to be achieved by the various modulation techniques envisaged for digital data transmission. It is very desirable to conduct voice and data transmission experiments.

The number of voice and data channels which can be provided depends on (a) aircraft antenna gain and quality factor, (b) spacecraft primary power and the erp, (c) channel bandwidth, (d) allowable spacecraft size dictated by booster capability, (e) the type of stabilization system that is employed, and many other minor factors. At present, it seems that one voice and one data channel per satellite may not be sufficient.

Theoretical Analysis

Introduction—It is necessary to take into consideration various effects that affect the measured data. It is also necessary to develop a qualitative comparison between the satellite to test aircraft link and the balloon to test aircraft link. Since the purpose of the present experiment is to use high altitude balloons in the place of satellite, it is significant to learn the ways in which the balloon link differs from the satellite link. This will help in a realistic interpretation of the measured data. Some of the problems considered are

1. Relative doppler between direct and indirect signals. This is important in a VHF voice link since it will determine the fade rate and thus have an effect on the intelligibility of the received signal.

2. Fading bandwidth due to scattering of the multipath signal. This is used to determine the spectrum associated with an L-band multipath signal.

3. Space-loss difference between the direct and indirect (reflected) signals. This is zero (db) for a satellite link. It should be minimized in any alternate link.

Relative Doppler—Figure 6 describes the geometric configuration of a multipath experiment. The components are a test aircraft (A), and the signal source [either a satellite or a balloon - (B)]. Both the direct and indirect rays

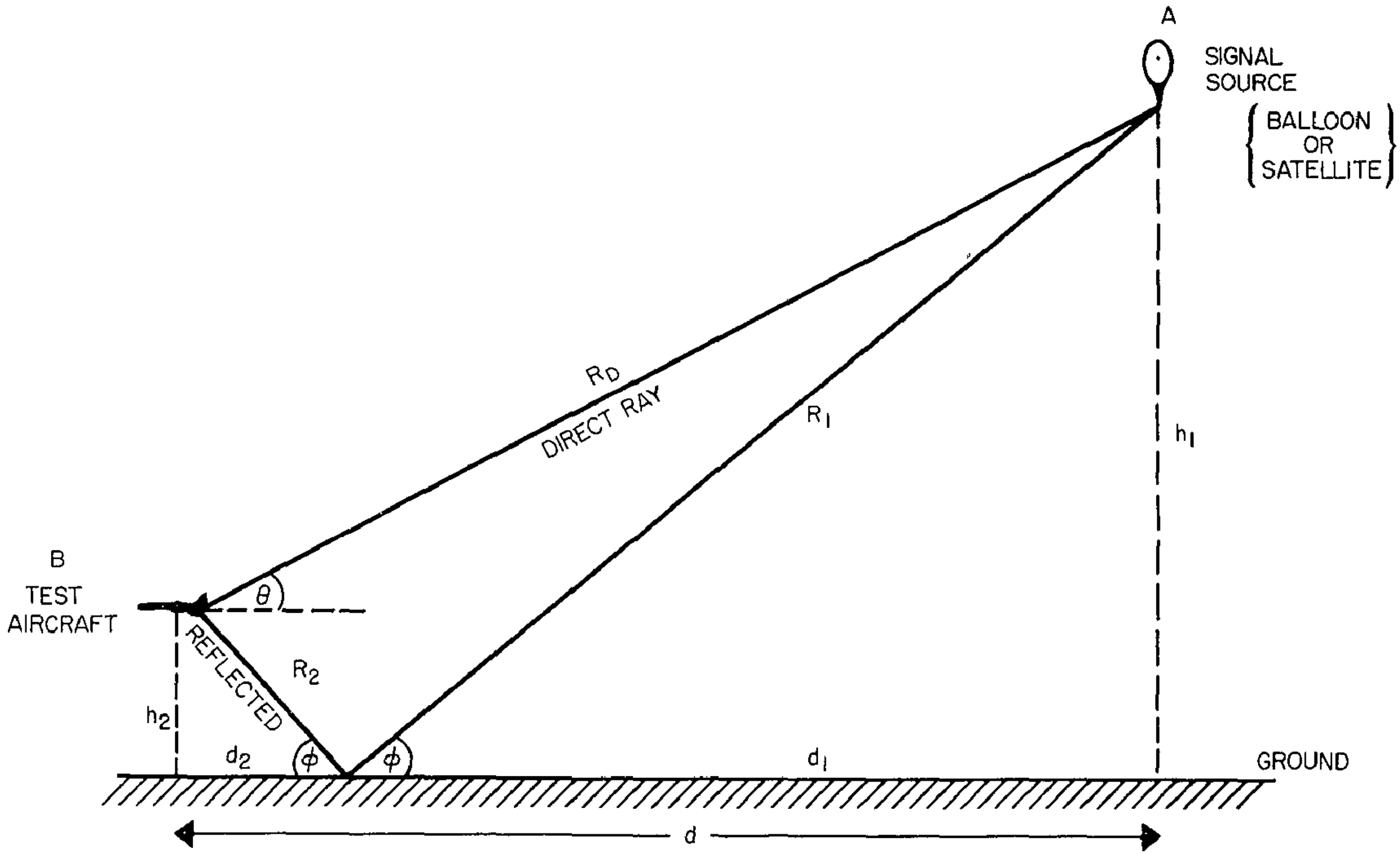

Figure 6. Geometric Configuration of a Multipath Experiment

received at the test aircraft from the signal source are shown in the figure. The indirect ray is due to reflection from the earth's surface. The curvature of the earth is neglected for the sake of simplicity of representation even though it is included in the final calculations.

The path length difference between the direct and reflected rays is given by (ref 3)

$$\Delta = [(R_1 + R_2) - R_D] = \frac{(k-1)\,h_2}{\sin\theta}\left[\sqrt{1 + \frac{4k}{(k-1)^2}\sin^2\theta} - 1\right]$$

where

θ is the elevation angle

h_1 is the altitude of the signal source (satellite or balloon)

h_2 is the altitude of the test aircraft

$k = h_1/h_2$.

For cases under consideration,

$$k > 5 \quad \text{and} \quad \theta \le 25°$$

Then

$$\Delta \approx \frac{2kh_2}{(k-1)}\sin\theta.$$

For the synchronous satellite case, k is rather large since $h_1 \approx$ 19323 nautical miles and h_2 is of the order of 25,000 feet.

Then

$$\Delta \approx 2h_2 \sin\theta$$

Time rate of change of path length difference

$$\dot{\Delta} = 2\ [\dot{h}_2 \sin\theta + h_2\, \dot{\nu}]$$

where $\nu = \sin\theta$.

$$\nu = \sin\theta = \frac{h_1 - h_2}{R_D} = \frac{H}{R_D}$$

$$\dot{\nu} = \frac{1}{R_D}\ [\dot{H} - \dot{R}_D \sin\theta]$$

$$R_D = H^2 + d^2$$

$$\dot{R}_D = \dot{H} \sin\theta + \dot{d} \cos\theta$$

Therefore,

$$\dot{\nu} = 2\,\dot{h}_2 \sin\theta + \frac{2\,h_2}{R_D}\left[\dot{H}\cos^2\theta - \frac{\dot{d}}{2}\sin 2\theta\right]$$

For a stationary satellite case, $\dot{H} = -\dot{h}_2$. Then

$$\dot{\Delta} = 2\,\dot{h}_2\left[\sin\theta - \frac{h_2}{R_D}\cos^2\theta\right] - \dot{d}\,\frac{h_2}{R_D}\sin 2\theta$$

Since $h_2 << R_D$ for a satellite to aircraft link

$$\dot{\Delta} = 2\,\dot{h}_2 \sin\theta - \dot{d}\,\frac{h_2}{R_D} \sin 2\theta$$

Δf, Relative doppler = $\dot{\Delta}/\lambda$ cps where λ is the wavelength of the link frequency. The relative doppler is equivalent to absolute doppler if the source (satellite) is assumed to be stationary.

$$R_D^2 = H^2 + d^2$$

For a balloon to aircraft link,

$$\Delta = \frac{2\,k\,h_2 \sin\theta}{(k-1)}$$

$$\dot{\Delta} \approx \frac{2\,\dot{k}\,h_2 \sin\theta}{(k-1)^2} + \frac{2k}{(k-1)} (h_2 \sin\theta + h_2\,\dot{\nu})$$

$$\simeq \frac{2\,k\,(k-2)}{(k-1)^2}\,\dot{h}_2 \sin\theta \left[1 + \frac{\dot{h}_1}{k\,(k-2)\,\dot{h}_2} + \frac{\dot{H}}{(k-2)\,\dot{h}_2} \cos^2\theta\right]$$

$$- \frac{k\,\dot{d}}{(k-1)^2} \sin\theta \sin 2\theta$$

Relative doppler, $\Delta f = \dot{\Delta}/\lambda$ where λ is the wavelength of the link frequency. In the following tables, some computations are presented for both the satellite and balloon links. VHF (120 MHz) and L-band (1600 MHz) frequencies are also compared.

Satellite altitude = 19323 nautical miles [1 nm = 6076 ft]
Balloon altitude = 120,000 ft.
Test aircraft altitude = 25,000 ft.

Case A: Relative ground speed between the test aircraft and the signal source = 400 knots. Vertical velocity of the signal source and the test aircraft = 0.

Table 3

Elevation Angle Versus Relative Doppler for Case (A)

Elevation Angle, θ (degrees)	Δf (Hz) at 1600 MHz (L-band)		Δf (Hz) at 120 MHz (VHF)	
	Satellite	Balloon	Satellite	Balloon
10°	2.455	21.996	0.1841	1.649
20°	2.295	78.979	0.1721	5.923
30°	2.051	124.033	0.1538	9.302

Case B: Relative ground speed between the test aircraft and the signal source = 0. Vertical motion of the signal source = 0. Vertical motion of the test aircraft = 5 ft/sec.

Table 4

Elevation Angle Versus Relative Doppler for Case (B)

Elevation Angle, θ (degrees)	ΔF (Hz) at 1600 MHz (L-band)		ΔF (Hz) at 120 MHz (VHF)	
	Satellite	Balloon	Satellite	Balloon
10°	3.098	3.724	0.232	0.279
20°	5.823	7.156	0.436	0.536
30°	8.370	9.351	0.627	0.701

Case C: Ground speed between the signal source and the test aircraft = 0. Vertical motion of the balloon = 5 ft/sec. Vertical motion of the test aircraft = 0.

Table 5

Elevation Angle Versus Relative Doppler for Case (C)

Elevation Angle, θ (degrees)	ΔF (Hz) at 1600 MHz (L-band) for balloon case	ΔF (Hz) at 120 MHz (VHF) for balloon case
10°	0.756	0.057
20°	1.216	0.091
30°	1.314	0.099

Fading Bandwidth—For a multipath signal reflected from the earth's surface, the received signal at the test aircraft will be composed of not only a specular component but also scattered components which will not only beat with the direct signal to cause fading but also with each other. Thus the fading will occur at various rates.

The Durranni and Staras formula for the fading or scatter bandspread is

$$B_s \approx \frac{1}{2\,\tau_0}$$

τ_0 is the time at which $C(\tau)$, the time autocorrelation function is 1/e of its maximum value C(0). The scatter bandwidth is evaluated for two cases.

Case (a): When the motion of the test aircraft is in the plane of the aircraft and the signal source (satellite or balloon). It is given by

$$B_s \approx k V \sqrt{2}\,\frac{\sigma}{T}\,\frac{(1 - H\tan^2 A)\cos A}{1 - H\tan^2 A + \dfrac{4\,\theta_s}{\sin 2A}}$$

Case (b): When the motion of the test aircraft is normal to the plane containing the aircraft and the signal source.

$$B_s \approx k\,V\left(\sqrt{2}\,\frac{\sigma}{T}\right)\frac{\sin A}{1 - B}$$

where

$k = 2\pi/\lambda$ = wave number

v = velocity of the test plane

$H = h_2/R_E$ where R_E is the radius of the earth

h_2 = altitude of the test aircraft

$A = V - \theta_s$

$B = V - 2\,\theta_s$

$\sqrt{2}\,\frac{\sigma}{T}$ = measure of the roughness of the reflecting surface

σ = rms height of the surface irregularities

T = Surface Correlating distance and corresponds to a distance between irregularities.

The Durranni and Staras model (see reference 8) is based on the following assumptions:

1. the surface undulations can be described by a two dimensional Gaussian distribution.
2. σ/T is fairly small
3. σ/λ is fairly large
4. the autocorrelation function of the surface fluctuation is an analytic function
5. the transmitting source does not change its position in the period τ.

The above five conditions hold very well for the L-band frequencies.

In the following table, some computations are presented for both the satellite and balloon links. Only L-band frequencies are considered.

Input Parameters: Satellite altitude = 19323 nautical miles
Balloon altitude = 120,000 ft.
Test aircraft altitude = 25,000 ft.
Vehicle Velocity = 400 knots

Case (a): Fading bandwidth, B_s at L-band versus elevation angle, θ and surface roughness $\sqrt{2}\,\sigma/T$

Table 6

Fading Bandwidth Versus Elevation Angle for Case (a)

Elevation Angle, θ degrees	$\sqrt{2}\,\sigma/T = 0.1$		$\sqrt{2}\,\sigma/T = 0.2$		$\sqrt{2}\,\sigma/T = 0\ 3$	
	Satellite	Balloon	Satellite	Balloon	Satellite	Balloon
5	38.1	39.3	76.2	78.6	111.4	117.9
10	80.7	82.3	161.4	164.6	242.2	246.9
20	164.3	165.4	328.6	330.8	492.8	496.2
30	241.8	242.8	483.8	485.6	725.6	728.4

Case (b): Normalized bandwidth, $\sqrt{2}\,\sigma/T\ B_s$ versus elevation angle

Table 7

Normalized Fading Bandwidth Versus Elevation Angle for Case (b)

Elevation Angle, θ (degrees)	$\sqrt{2}\,\sigma/T\ B_s$ (Satellite Case)	$\sqrt{2}\,\sigma/T\ B_s$ (Balloon Case)
5	16.1	16.6
10	34.0	34.7
15	69.3	69.8
20	102.0	102.0
25	157.0	157.00
30	193.00	193.00

Space Loss Difference—Space loss difference is the difference of space loss of the direct signal to the multipath signal and is given by

$$\Delta S = \frac{(R_1 + R_2)^2}{R_D^2} = 1 + \frac{4k}{(k-1)^2} \sin^2 \theta,$$

where $k = h_1/h_2$ and θ is the elevation angle.

Case (a): For the satellite case, k is very large and ΔS is practically equal to 0 db.

Case (b): Balloon altitude (h_1) = 125,000 ft.
Test aircraft altitude (h_2) = 25,000 ft.
$k = h_1/h_2 = 5$

Table 8

Space Loss Difference (dB) Versus Elevation Angle

Elevation Angle θ, degrees	Δ S (db)
10	0.161
20	0.592
30	1.179

For an elevation angle of 20°, the space loss difference of the balloon link is 0.6 db as compared to 0 db of the satellite link. This is a tolerable limit.

Rate of Change of Elevation Angle ($\dot{\theta}$) versus Elevation Angle (θ)—It is important to know for given balloon (or satellite) and aircraft altitudes, the time rate of change of elevation angle for any arbitrary relative ground speed between the aircraft and the balloon. Figure 7 shows the rate of change of elevation angle, $\dot{\theta}$, as a function of the elevation angle, θ. Satellite to aircraft and balloon to aircraft links are both considered. The satellite altitude is 19323 nm (geostationary), the balloon altitude is 120,000 ft. The test aircraft is flying at an altitude of 25,000 feet with a relative ground speed of ≈ 400 knots. The data presented here will be very useful in planning the multipath experiments.

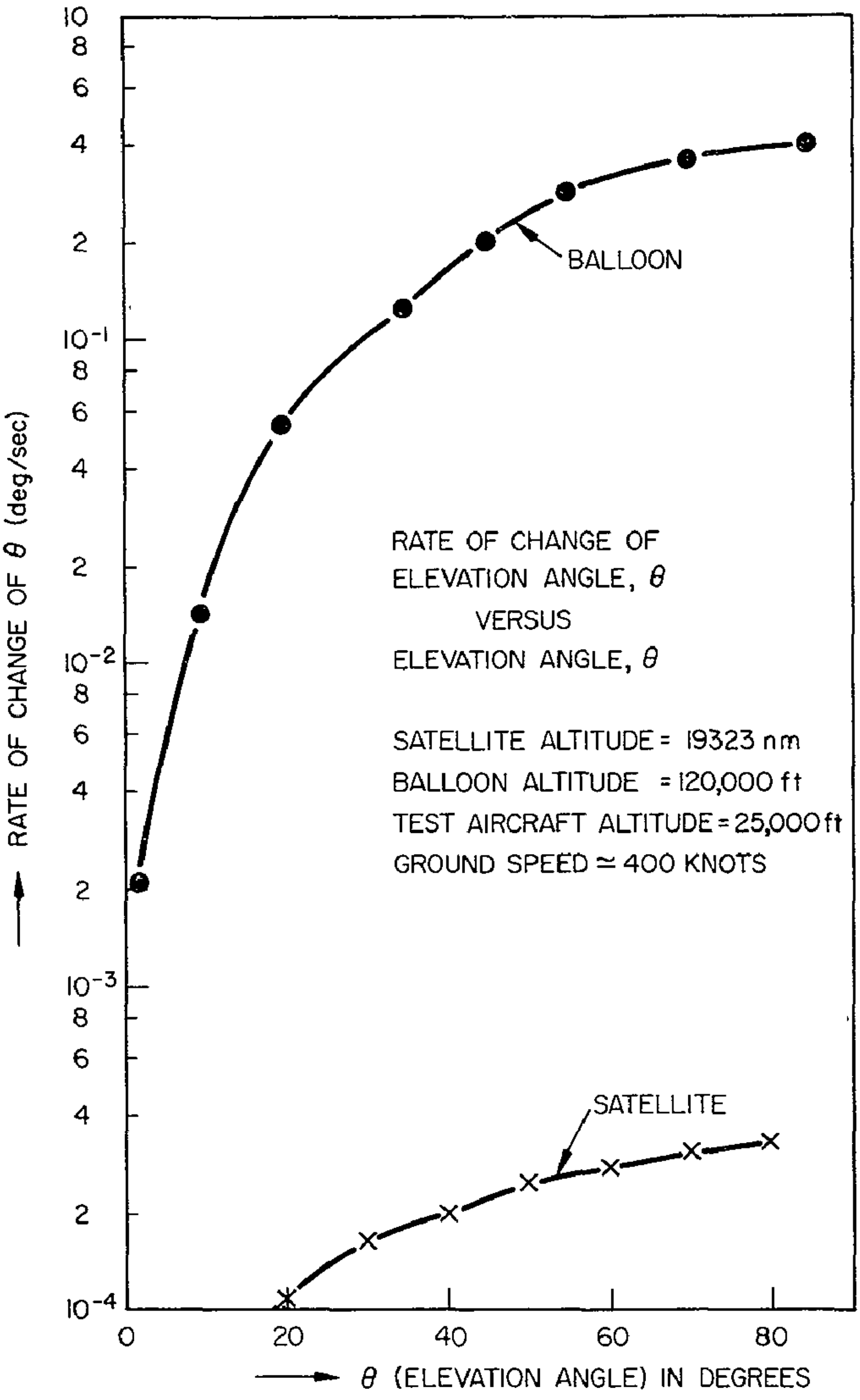

Figure 7. Rate of change of Elevation Angle, $\dot{\theta}$ versus Elevation Angle, θ.

Conclusions–The fading bandwidth for the balloon-aircraft configuration is about the same as that expected for a satellite to aircraft link. The major drawback of a balloon-aircraft link is the sensitivity of the relative doppler to horizontal motion which will affect fading and intelligibility of a voice signal, particularly at VHF. This may be overcome by selecting a near circular - constant elevation angle flight path for the aircraft around the balloon. Such a flight path would also help multipath measurements since data collected in a constant elevation angle flight track is statistically significant.

The relative space loss difference for the balloon to aircraft link gives a little over 1 db loss at a 30° elevation angle compared to 0 db loss difference of a satellite link. Thus the balloon to aircraft configuration is a reasonable simulation of the operational aircraft to satellite link.

FLIGHT-PATH PLANNING AND TESTS

Flight Path-Planning (Test Aircraft)

Every aspect of the experimental program is taken into consideration in planning the flight-path of the test aircraft. Several geometrical criteria have to be followed in the balloon-aircraft configuration to obtain a meaningful simulation of the satellite-aircraft configuration.

As discussed in the previous chapter, a near circular constant elevation angle flightpath for the test aircraft will help to overcome the problem of the sensitivity of the relative doppler to horizontal motion in a balloon-aircraft link. Fading problems can then be minimized.

It is then proposed to fly the test aircraft at successively increasing ranges r from, and decreasing elevation angles θ with respect to the balloon to provide a variation in signal to noise ratio and a true variation in the multipath characteristics. The aircraft would turn into a near circular track at each increment of range so that the multipath, rf noise and range measurements are performed at constant r and θ. Reciprocal heading in approximately the same (r, θ) track is performed to repeat the system tests and study the variability in data under such conditions.

Any flight planning should also take into consideration whether the test aircraft can be tracked by ground radars at elevation angles greater than 5°. For multipath measurements within the radar coverage area, flight path for the test aircraft should cover areas over land and sea. For rf noise measurements, the aircraft should fly over or close to metropolitan areas in addition to flying over different terrain and sea. Based on the above mentioned thoughts, a sample flight path for the test aircraft over the Mojave desert and the Pacific ocean is described below:

Figure 8 shows the typical flight-path. The wide horizontal strip represents a range within which the balloon flight is limited east to west. The balloon path is within a region where both Pt. Mugu and Edwards radars can sight it at elevation angles larger than 5°. If simultaneous tracking by both the radars is not needed, the balloon could be allowed to drift farther towards the sea where the Pt. Mugu radar could maintain the tracking. However, as mentioned earlier, the balloon flight-path is dependent upon favorable meteorological conditions. A typical experimental mission will be detailed in Table 9.

Many modification could be made in the example of a flight plan outlined in Table 9. The individual tracks could be made more circular and longer. The tracks could be separated by eliminating close spacing. The selection of experiments to be performed while the aircraft is in a particular track could also be changed. It is also assumed that the cross-turn time while reversing the direction of the flight path would be sufficient for changing the magnetic tapes and getting the equipment ready for another experiment. The schedule is flexible and the experiment will be performed in a sequence. Care should be taken to maintain the equipment performance at a high degree of reliability and sufficient time is spent to assure such a performance before each experiment is performed.

A variety of flight configurations could be planned for the test aircraft in a similar fashion. The balloon flight path experimental objectives and the number of hours the aircraft could fly without refuelling stops dictate the planning of a flight configuration.

System Tests

Balloon/Ground Station Tests—In preparation for the aircraft/balloon tests, a number of tests are to be performed between the balloon and ground station to ensure reliable operation of these systems. Ground station equipment will be aligned and calibrated using the calibration tower transponder. About fifteen (15) minutes are required for this test and it will be conducted prior to all scheduled flight tests which involve use of this equipment.

L-band and C-band ranging codes transmitted from the ground station would be transponded back from the balloon transponder on the ground at a known distance and received by the receivers at the ground station. The correct sequencing and acquisition of the BINOR Coder and decoder will be determined while making the L-band range measurement on ground between two known points. The L-band range measurement is compared quantitatively with that obtained by the C-band ranging system and is used to verify tracking accuracies of all ranging systems.

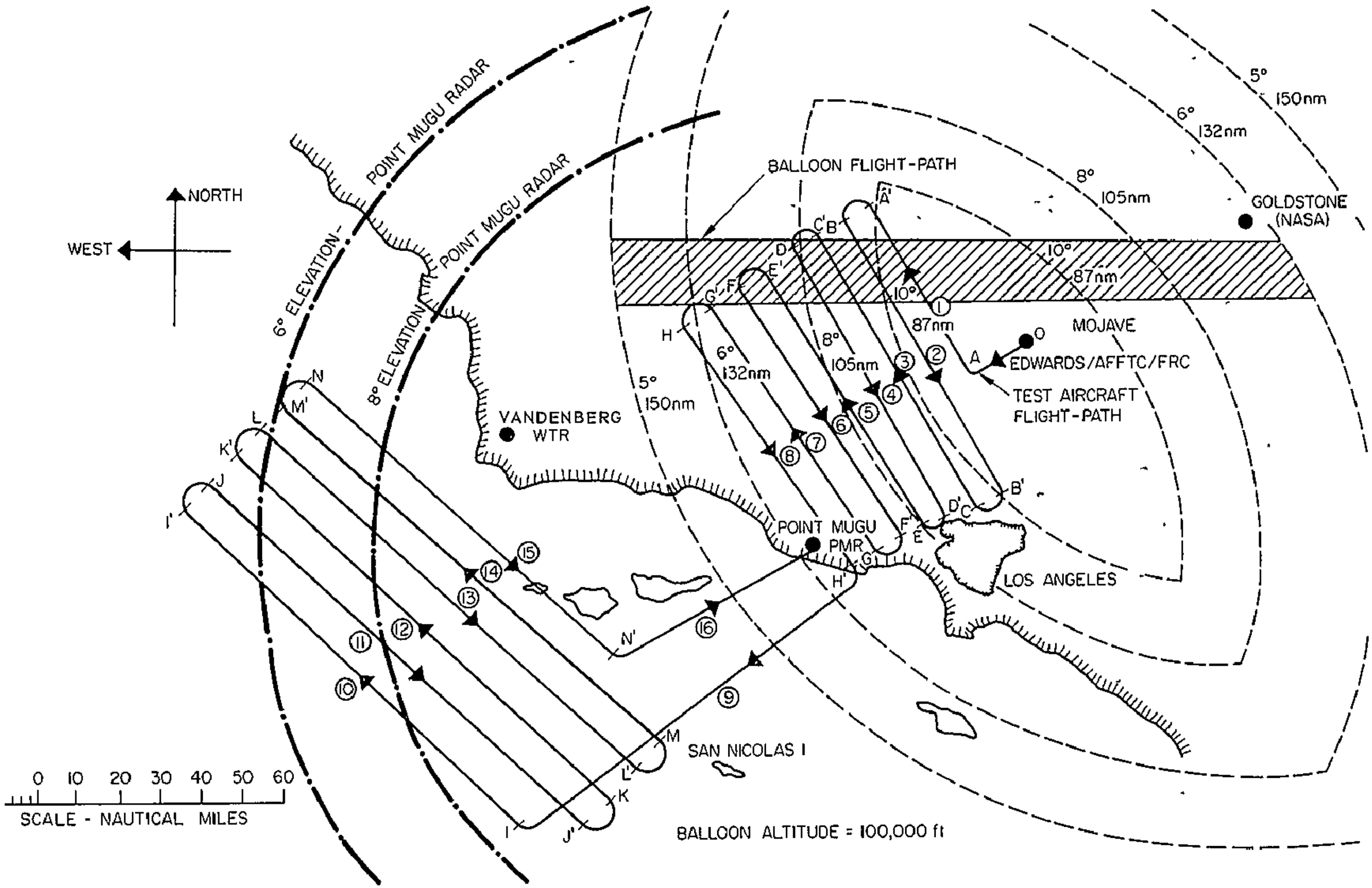

Figure 8. Typical flight-path of the test aircraft during an experimental mission

Table 9

Sequential Description of an Experimental Mission

Ground control is involved in all the phases of the experiment

Test Aircraft Path or Position	Decimal Hours (LT) Time	Function	Coordination
Edwards/ AFFTC	X	Balloon launching from Edwards area	(a) Launch (b) Tracking radars (c) Ground Station (MOJAVE)
Edwards/ AFFTC	X+0.10	Balloon equipment test	(a) Ground station
Edwards/ AFFTC	X+0.15	Balloon Flight-Path Control	(a) Balloon Ground Crew (b) Tracking radars
Edwards/ AFFTC	X+0.30	A/C** equipment warmup	(a) Aircraft Test Crew
Edwards/ AFFTC	X+0.40	Ground equipment C/O and Preliminary Calibration	(a) Ground Station (MOJAVE) (b) A/C Crew
Point O	X+0.50	A/C engine start and taxi	(a) Aircraft crew
Path OA	X+0.60	Take off and follow flight path OA	(a) A/C test crew (b) Tracking radars
Point A	X+0.80	(a) A/C and Ground station (MOJAVE) equipment (b) Aircraft positioning towards flight path AA' at a determined altitude. Path AA' is chosen to be near circular around the balloon	(a) A/C test crew (b) Ground Station (MOJAVE)

*Ground control can be located either at the MOJAVE Ground Station or at Edwards/AFFTC.
**A/C stands for test aircraft.

Table 9 (continued)

Test Aircraft Path or Position	Decimal Hours (LT) Time	Function	Coordination
Point A (cont'd)		(c) Tracking radars are coordinated	(c) Balloon Ground Crew (d) Tracking radars
Path AA'	X+1.00	(a) rf noise experiment (b) near-range multipath experiment (c) Detailed in-flight experiment rehersal (d) Smoothening out communication and logistics problems	(a) A/C test crew (b) Ground station (c) Balloon Control Center
Point A'	X+1.05	(a) Tape change (b) Maneuver the aircraft towards the point B	(a) A/C test crew (b) Tracking radars (c) Ground station
Path BB'	X+1.35	(a) rf noise experiment (b) change of tape speeds, recording speeds (c) Equipment adjustments (d) Voice experiment	(a) A/C test crew (b) Ground Station (c) Tracking radars
Point B'	X+1.40	(a) Tape change (b) Maneuver the aircraft towards the point C (c) Altitude adjustments if needed	(a) A/C test crew (b) Ground station (c) Tracking radars
Path CC'	X+1.70	(a) Multipath experiment (CW and BINOR) (b) ranging (BINOR)	(a) A/C test crew (b) Ground station

Table 9 (continued)

Test Aircraft Path or Position	Decimal Hours (LT) Time	Function	Coordination
Point C'	X+1.75	(a) Tape change (b) Maneuver the A/C towards the point D (c) Check with ground control about progress of experiments (d) Execute alternate flight plans, if necessary	(a) A/C test crew (b) Ground control (c) Ground station (d) Tracking stations
Path DD'	X+2.05	(a) Same experiments as during CC' to obtain data in revised path (A/C motion is in the opposite direction)	(a) A/C test crew (b) Ground station
Point D'	X+2.10	(a) Tape change (b) Maneuver the A/C towards the point E	(a) A/C test crew
Path EE'	X+2.36	(a) rf noise experiment (b) Calibration tests (c) adjustments	(a) A/C test crew
Point E'	X+2.45	(a) Tape change (b) Maneuver the A/C towards the point F	(a) A/C test crew
Path FF'	X+2.71	(a) rf noise experiment (b) Calibration tests (c) Experiment adjustments	(a) A/C test crew
Point F'	X+2.80	(a) Tape Change (b) Maneuver the A/C to position G	(a) A/C test crew

Table 9 (continued)

Test Aircraft Path or Position	Decimal Hours (LT) Time	Function	Coordination
Path GG'	X+3.06	(a) Ranging (BINOR, CW) experiment	(a) A/C test crew (b) Ground station (c) Tracking station (d) Balloon control
Point G'	X+3.15	(a) Tape change (b) Maneuver the A/C to position H (c) Attention to technical difficulties	(a) A/C test crew (b) Ground station
Path HH'	X+3.41	(a) Ranging experiment (BINOR, CW) in a reversed path	(a) A/C test crew (b) Ground station (c) Tracking stations (d) Balloon control
Path H'	X+3.77	(a) Tape change (b) Long flight path for repositioning the A/C (c) Attention to all the technical problems (d) Constant communications with the ground control center Continuation of the experiment dependent on the satisfactory float position of the balloon.	(a) A/C test crew (b) Tracking stations (c) Balloon control center
Path II'	X+4.17	(a) Multipath experiment (BINOR and CW)	(a) A/C test crew (b) Ground station (c) Tracking stations
Point I'	X+4.22	(a) Tape change (b) Maneuvering the A/C to position J	(a) A/C test crew (b) Ground station
Path JJ'	X+4.65	(a) Multipath experiment (BINOR and CW)	(a) A/C test crew (b) Ground station (c) Tracking stations

Table 9 (continued)

Test Aircraft Path or Position	Decimal Hours (LT) Time	Function	Coordination
Point J'	X+4.70	(a) Tape change (b) Maneuvering the A/C to position K	(a) A/C test crew
Path KK'	X+5.13	(a) Ranging experiment (BINOR)	(a) A/C test crew (b) Tracking stations (c) Ground station (d) Balloon control
Point K'	X+5.20	(a) Tape change (b) Maneuvering the A/C to position L	(a) A/C test crew (b) Tracking stations
Path LL'	X+5.63	(a) Ranging experiment (BINOR)	(a) A/C test crew (b) Tracking stations (c) Ground station (d) Balloon control
Point L'	X+5.70	(a) Tape change (b) Maneuvering the A/C to position M	(a) A/C test crew (b) Ground station (c) Balloon control (d) Tracking stations
Path MM'	X+6.13	Performance of any experiment decided on by Ground Control	(a) A/C test crew (b) Ground station (c) Tracking stations (d) Balloon control
Point M'	X+6.20	(a) Tape change (b) Maneuvering the A/C to position (N)	(a) A/C test crew
Path NN'	X+6.56	Performance of any other experiment decided on by Ground Control. Experiment is over.	(a) A/C test crew (b) Ground station (c) Tracking stations (d) Balloon control
Path N'O'	X + 6.77	Flight back to Pt. Mugu for landing. Tapes collected. Strip chart recording properly collated with tapes. Total of 6.80 hours of flight.	

Balloon/Stationary Aircraft Tests—The test aircraft will be located on ground at a known position throughout these tests with both ground station and aircraft equipment operational.

One purpose of these tests is to gather data while operating the aircraft system in a non-varying RFI and multipath environment. A second purpose is to perform tests while operating the L-band equipment in an aircraft environment in order to determine the limitations of the equipment.

a. Antenna Checkout:

This test is planned to determine the performance of the aircraft antennas and the various antenna configurations and characteristics needed to separate the direct and reflected rf energy received at the aircraft. Hemispheric, low gain antennas are to be mounted on the aircraft sides and the top. A downlooking antenna with two polarizations is installed to obtain the reflected component. It is also desirable to mount a high-gain steerable narrow-beam antenna at the top. Such a high gain antenna could be used to measure the direct signal. In the antenna check-out tests the individual antennas are expected to be known before hand.

b. Background rf noise calibration

A standard radiometer will be used to measure the temperature of all the antennas. Thus, the level of noise environment presented to the airborne receivers through the antennas is determined. The data collected in this non-flight condition will provide reference data for determination of aircraft noise generated in flight. These noise calibration measurements will be performed under conditions matching those planned for the flight tests. Calibration will be done several times during the day and night and under various weather conditions. Approximately an hour is required for each test period and about 10 test periods should provide sufficient information.

c. Position location

In this test, the distance from the balloon to the test aircraft will be measured using a binary coded signal called BINOR which will be generated at the ground station, transponed via the balloon to the aircraft. In the aircraft, the signal is decoded, recorded and simultaneously monitored. The purpose of this test is to determine the accuracy of the range coding technique by knowing the position of the balloon and the aircraft as accurately as possible.

For the BINOR range code tests, the top mounted hemispherical coverage aircraft antenna, an FM receiver/transmitter, a signal processor and a rubidium frequency standard will be used in the aircraft. The demodulated BINOR signal from the FM receiver is decoded and the time-delay is measured by the signal processor. The decoding operation is a digital correlation process which produces an accurate 78.12 Hz square wave. The time delay of this square wave is measured digitally using a rubidium frequency standard as a reference. The time-delay of the square wave is a direct measure of the range to the balloon.

The aircraft will be equipped with a rubidium frequency standard for making BINOR range code measurement and maintaining the stability of crystal oscillators employed in the aircraft experiment system. The airborne and ground based clocks will be synchronized prior to and after each flight.

All data generated or measured in the aircraft will be multiplexed, converted to digital form and recorded on magnetic tape for post test analysis. In addition, real-time analog strip-chart recording will be made of the experimental data and other operational information about equipment performance characteristics.

In-Flight Aircraft Tests–

a. RF Noise Environment

This test does not involve use of the balloon and the ground station. An onboard radiometer and other noise measuring instruments will monitor background noise through a hemispherical coverage antenna located at the top of the fuselage. Flights will be scheduled in the vicinity of aircraft terminals over cities and during periods of heavy precipitation. Sufficient number of measurements will be made so as to characterize the rf noise background. Approximately 6 to 10 flights should provide sufficient information.

b. Multipath Tests

Three hemispheric, low gain antennas are to be installed on the two sides and at the top of the fuselage of the aircraft. Another antenna with two polarizations is to be installed at the bottom of the aircraft so that the center of its beam is directed towards ground. For multipath tests, it is desirable to have a high gain antenna with a side lobe suppression ratio of ≈ 15 db. Such an antenna will have good multipath rejection capabilities. If it is installed at the top of the fuselage and its narrow beam is steered towards the balloon, accurate measurement of the 'direct' signal level could be made with this antenna. Thus, attempts will be made to isolate the multipath component and correlate it with the received signal characteristics of the hemispheric antennas.

Measurement of the correlation bandwidth of the multipath signal will be made by modulating the carrier with two tones of different frequencies. A correlation will be performed between the tones contained in the reflected signal.

In addition, it is planned to make measurements with a distinct signal which has a single sharply peaked autocorrelation function (PRN code). Examination of spreading and distortion of the autocorrelation function of the received signal is expected to yield additional information about the multipath signal.

c. Position Location Accuracy Tests

Position location accuracy will be limited to a single line of position. It is planned to employ multiple radar techniques to obtain high resolution tracking information of both the aircraft and the balloon.

The BINOR code will be transmitted to the balloon from the ground station at L-band and the balloon-transponded signal will be received at the aircraft, where a one way range measurement will be made. Knowledge of the aircraft's altitude leads to a circular line of position of the aircraft with respect to the balloon. Accurate C-band radar tracking information about the position of the aircraft and the balloon leads to the determination of another line of position of the test aircraft. From supplementary information, the precise position of the aircraft can be determined to (1σ) accuracy. While comparisons between the two techniques (L-band ranging and radar tracking) in this case can be ambiguous, some qualitative information can be obtained about the L-band ranging technique.

It is expected that the following aircraft parameters be available for data-processing analysis:

Parameter	Accuracy
Altitude	± 300 ft (1σ)
Heading	± 5° (1σ)
Pitch	± 3° (1σ)
Roll	± 3° (1σ)
Speed	± 10 ft (1σ)
Standard Time	± 1 sec (IRIG-B)

Schedule

Facilities requirements and schedule of the various stages of the experimental program are presented in Table 10.

Table 10

Facilities Requirements and Schedule

Test	Ground Station			Balloon	Test Aircraft				Schedule		
	L-band Xmtr	L-band Recr.	Collimation Tower Transponder	Transponder	L-Band Recr.	Hi-Gain Antenna	Bottom Antenna	Side Antennas	Duration (Mts)	No. of Tests	Flight Plan
Ground-System Check-out	✓	✓	✓	–	–	–	–	–	15	10	–
L-band and C-band ranging test	✓	✓		✓	–	–	–	–	15	10	–
Test aircraft antenna check-out	✓	–	–	✓	✓	✓	✓	✓	120	2	Ground
RF Noise Background System check	–	–	–	–	✓	✓	✓	✓	60	10	Ground
Position location ranging system calibration	✓	✓	–	✓	✓	✓	✓	✓	15	10	Ground
In-Flight RF Noise Environment Test	–	–	–	–	✓	✓	✓	✓	60	10	(a) over land (b) over water (c) over different terrains (d) day and night (e) different weather conditions
CW Multipath Test	✓	✓	–	✓	✓	✓	✓	✓	15	20	(a) over water (b) over land
BINOR Multipath Test	✓	✓	–	✓	✓	✓	✓	✓	15	20	(a) over water (b) over land
Position location Accuracy of L-band ranging system	✓	✓	–	✓	✓	✓	✓	✓	15	20	Within range of tracking radars. Both the balloon and the aircraft to be tracked.

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