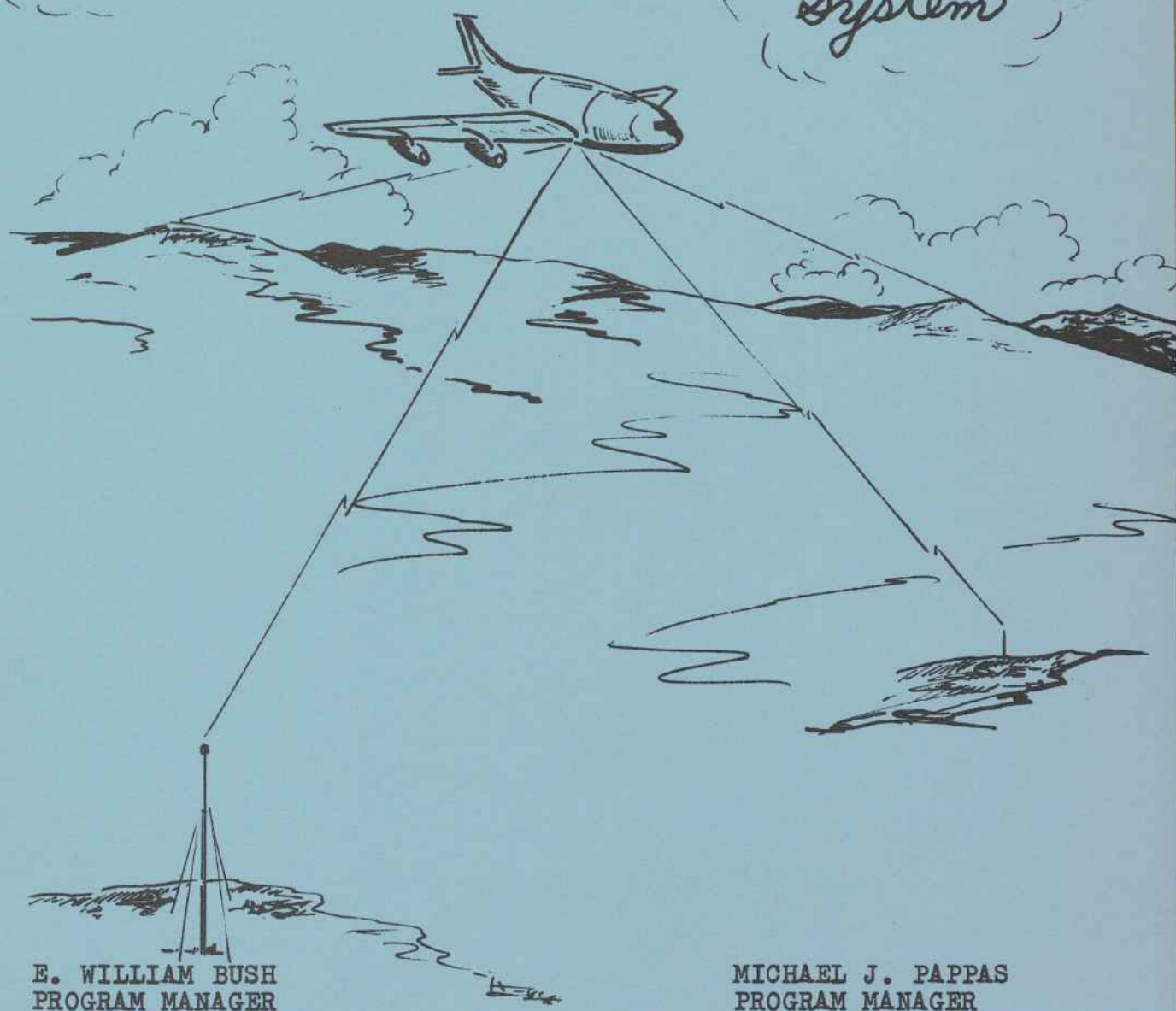
Shiran

an/USQ-32

S-Band Ranging System



E. WILLIAM BUSH
PROGRAM MANAGER
CUBIC CORPORATION
9233 BALBOA AVENUE
SAN DIEGO 23, CALIFORNIA

MICHAEL J. PAPPAS
PROGRAM MANAGER
DIRECTORATE OF RECONNAISSAN
ENGINEERING (SEQDO)
WRIGHT-PATTERSON AFB, OHIO

SHIRAN - AN/USQ-32 MICROWAVE GEODETIC SURVEY SYSTEM

The AN/USQ-32 system, commonly referred to as Shiran (S-band Hiran), has been developed by the Cubic Corporation of San Diego, California, under direction of the Systems Engineering Group of Dayton, Ohio. Development of the system was initiated 28 February 1962. A three (3) phase program was established to achieve the objectives. Primary objectives were to fabricate two (2) developmental models meeting design requirements and to evaluate the system under controlled conditions simulating operational missions. Aerospace ground equipment and training requirements were also determined under the program. Phase I - Systems Analysis & Preliminary Design - consisted of investigations performed on possible problem areas, an error analysis and a survey of the component part state-of-the-art with the purpose of fixing the system design prior to actual hardware fabrication. Several areas investigated that were of special interest were 1) an analysis of multipath propagation effects, 2) a selection of a method of sequencing the range measurements, and 3) an analysis of the dynamic effects of aircraft velocity and acceleration on the range measurement accuracy. Phase II - Development of System - consisted primarily of fabrication of the hardware, laboratory testing, and evaluation. Included under this phase was a

reliability program to insure reliable equipment in operational usage. Phase III - Flight Test and Evaluation - consisted of installing the equipment in an RC-130A mapping and surveying aircraft, and performing aerial surveying, controlled photography, and secondary controlled photography missions similar to actual operational usage. Phase I covered a period of 6½ months, being completed 15 August 1962. The Phase III flight test was completed, 15 November 1963. Figures 1 and 2 show Shiran equipment at the time of the flight test.

Primary function of Shiran is ranging----electronic ranging from an aircraft to ground transponders. It will find application in the RC-135A mapping and surveying aircraft system. Some of the features of Shiran are its capability to measure air to ground ranges of up to 450 nautical miles. Such distances can be measured to a probable error of 10.3 feet. Shiran can be used to position the aircraft from which nadir points of aerial photographs can be determined for mapping applications. Nadir point positioning will be possible to a probable error of 10 feet. Resolution of the range measurement is 0.725 feet. A traveling wave tube with an output of twenty (20) watts average is used in both the airborne transmitter and the ground station transmitter. The Shiran system operates within the 3000 mcs/sec to 3500 mcs/sec frequency range. An

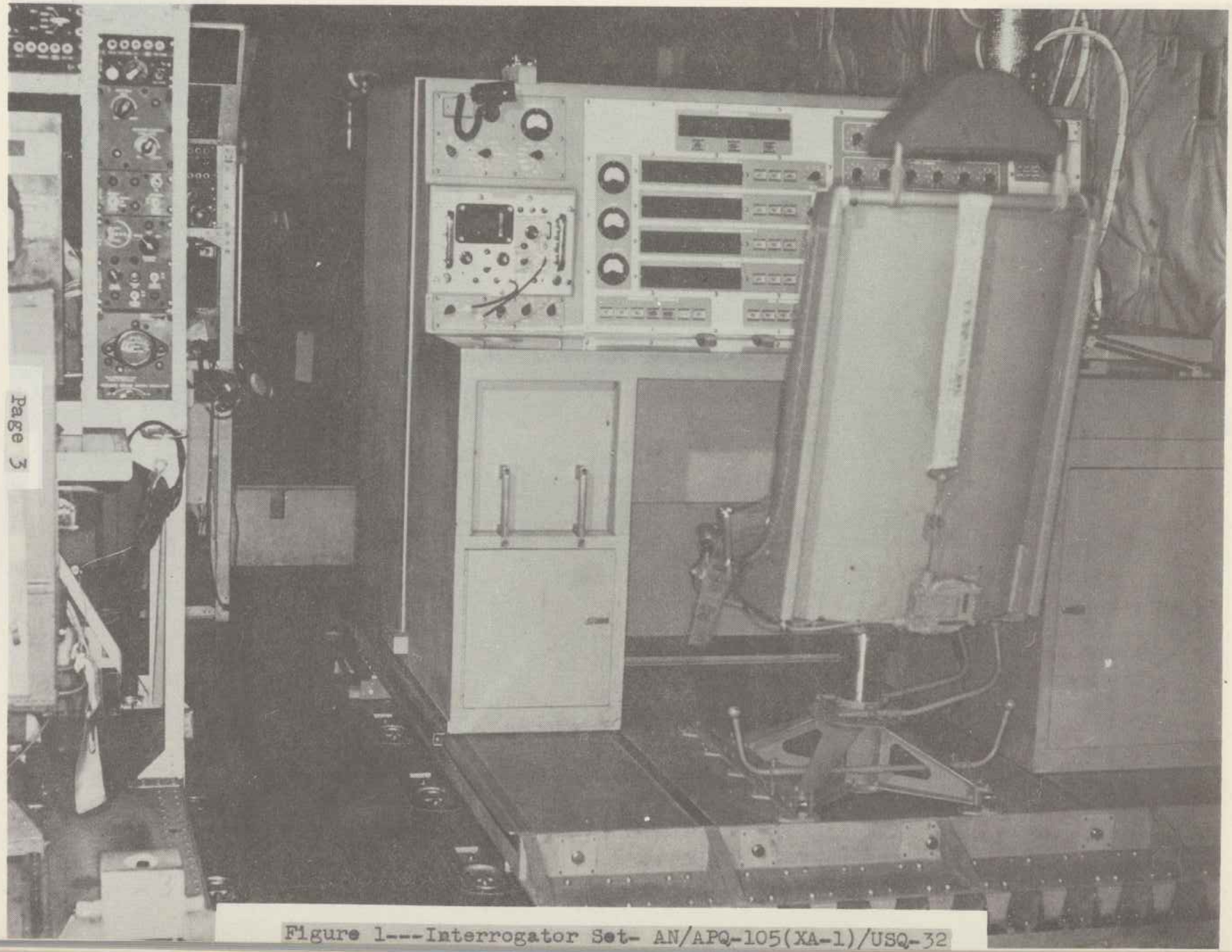


Figure 1---Interrogator Set- AN/APQ-105(XA-1)/USQ-32

Figure 2---Transponder Set-AN/TPQ-24(XA-1)/USQ-32

Ampex 200, seven channel, magnetic tape recorder is used to record all necessary data at a rate of five (5) times per second. Unique features of Shiran are its calibration, built-in test, and four station ranging capability. Calibration of the airborne subsystem can be accomplished by simply pressing a calibrate button. The subsystem, utilizing a built-in test oscillator, measures the phase delay and places it in memory. This phase delay is automatically subtracted from each subsequent range measurement. System calibration is accomplished within ten (10) seconds. Calibration can also be checked at any time to guard against drift. Additional built-in test features have been incorporated that allow for check-out of the system while airborne. Malfunctions in the system can be detected and pinpointed. By use of a maintenance adapter, the system can be repaired. These built-in test features were used exclusively during the flight test and proved out well. Because of these features, no test support equipment was required at the flight test site. The most important feature of the Shiran system is its four station ranging capability. This feature gives the system flexibility, increases its reliability, and enables the performance of controlled photography missions that become most difficult with any two channel system.

Two of the most important missions of Shiran are the line crossing and controlled photography. Referring to Figure 3, the objective of the line crossing is to determine the ground distance between two transponders. This is accomplished aerially by ranging to the two transponders while flying between them. A parabolic curve is formed if you plot the range sum ($R_1 + R_2$) versus time. The minimum range sum denotes the point at which the line between the two transponders was crossed. Having obtained this, the distance between the two stations can be calculated. Shiran obtains this minimum sum. It can determine the minimum sum with but 1-minute or less of range data taken in the vicinity of the center line. The objective of the controlled photography mission is to position the nadir points of photographs for mapping applications. This is accomplished by flying parallel flight lines and taking photographs with specified overlap and sidelap (Refer to Figure 4). Shiran range information is continually recorded to four ground stations. A camera trigger pulse, denoting midpoint of shutter opening, is also recorded. With known ground station positions, the location of the nadir point of each photograph can be determined. Though Shiran ranges are continually recorded, only a 10 to 20-second span around the camera trigger need be used. Advantages of the four

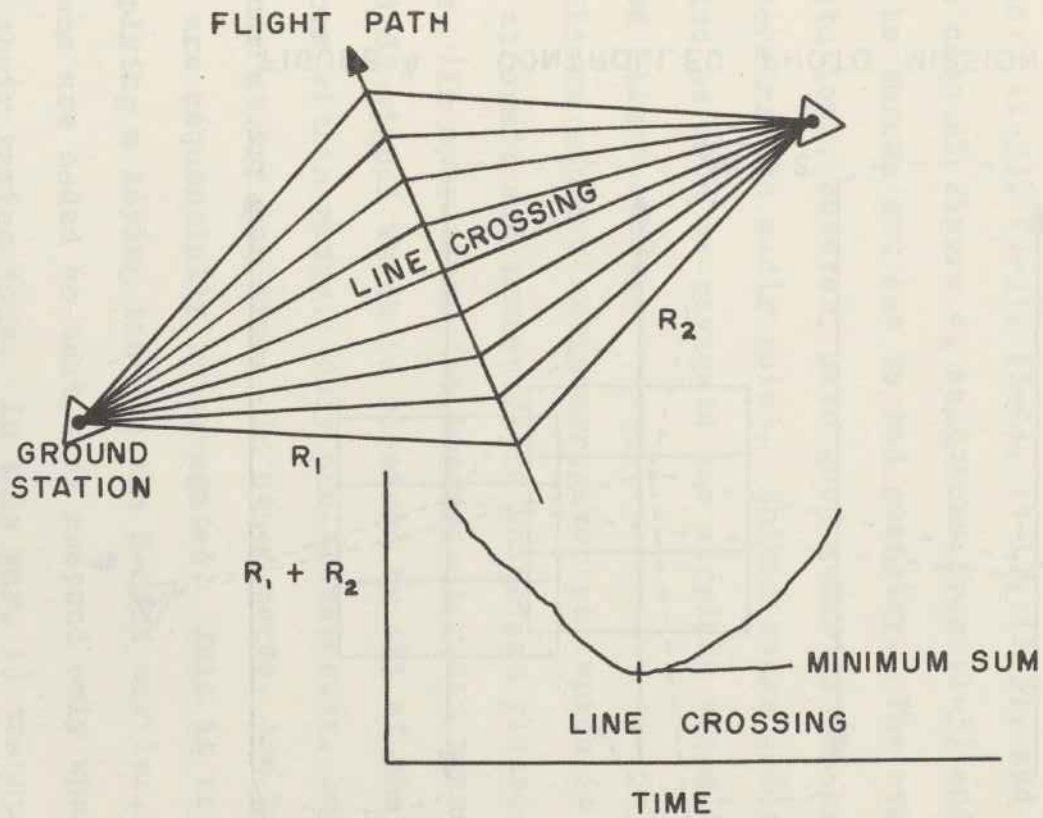


FIGURE 3 – LINE CROSSING MISSION

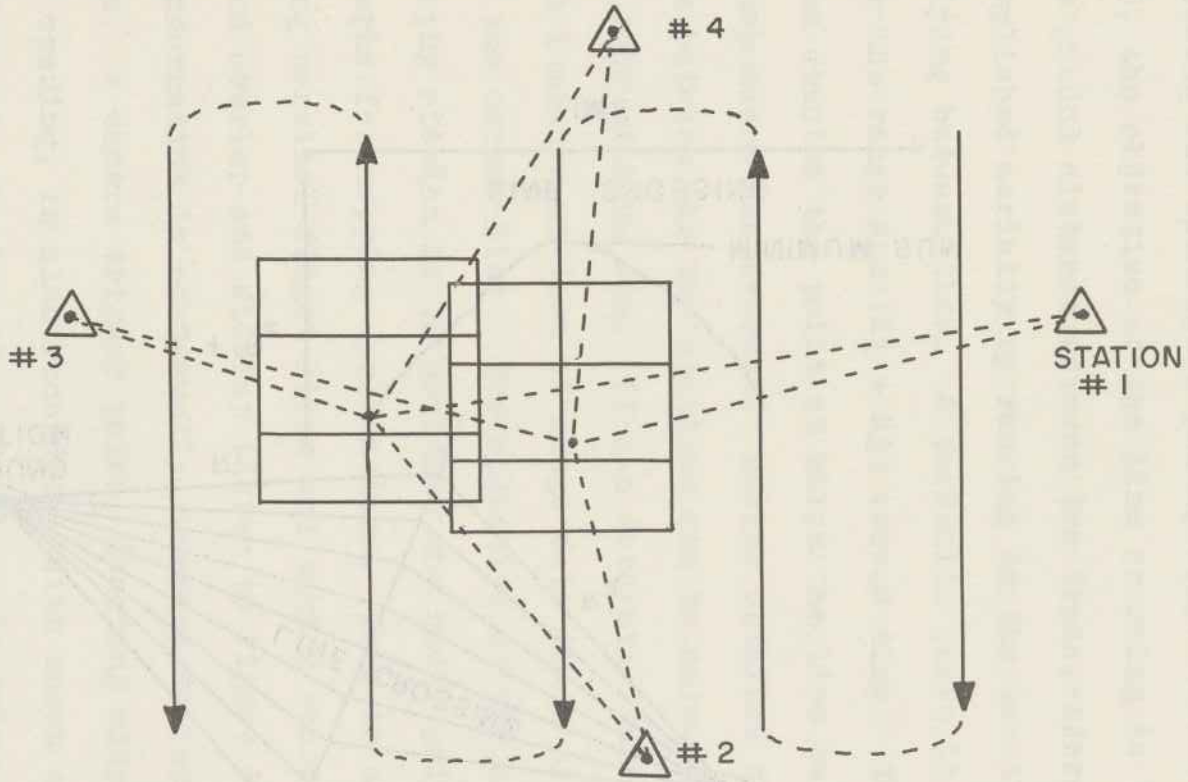


FIGURE 4 – CONTROLLED PHOTO MISSION

station ranging is the elimination of blanking due to poor station geometry and increased precision due to redundant measurements. By ranging to four stations, six independent nadir point solutions can be obtained. They are obtained by using the following ground station combinations: (1-2), (2-3), (3-4), (4-1), (1-3), and (2-4). In the case of Figure 4, solutions from (1-3) and (2-4) would be thrown out due to bad geometry. The remaining four stations, however, have good geometry and can be used to determine the nadir point. Shiran range information can also be used to navigate the airplane along the prescribed flight lines.

Shiran employs an interrogator set which is installed in an aircraft and transponders which are placed on ground points. In operation, the interrogator set transmits an S-band CW signal which is received by all of the ground stations within range. Only one transponder, however, responds at any one time. In other words, the ground stations are sequentially interrogated. This is accomplished by applying a keying tone to the S-band carrier. The ground stations are coded so that they respond only when they receive their keying tone. In this way, 1) transponder 1 is keyed, 2) it responds at an offset frequency, 3) the interrogator receives it, 4) it measures the range, and 5) the range is placed in memory channel #1. Transponder 2 is then

keyed, it responds, its range is measured and placed in memory channel #2. This is repeated for 3 and 4 to complete one cycle. Shiran interrogates in this way at a 10-cycle/sec rate. At any instant in time that range information is needed, a command is given to the interrogator set. The ranges are then frozen and recorded on magnetic tape. The maximum recording rate is 5 times/sec. This maximum rate will be used in operational service. Though Shiran interrogates sequentially, ranges are recorded simultaneously. Refer to Figure 5 for a graphical presentation of Shiran operation.

Shiran is a coherent CW system employing phase comparison techniques for the measurement of range. By coherent, we mean that the phase relationship of the outgoing signal is the same as the returning signal. This is absolutely essential for proper system operation. To determine range, the interrogator set merely compares the phase of the outgoing and incoming signal. Determining the phase shift in this way, the range to the transponder can be calculated by the following equation:

$$R = \frac{\phi \lambda}{4\pi}$$

ϕ = Phase shift measured by Shiran

λ = Wavelength of ranging signal, accurately predetermined

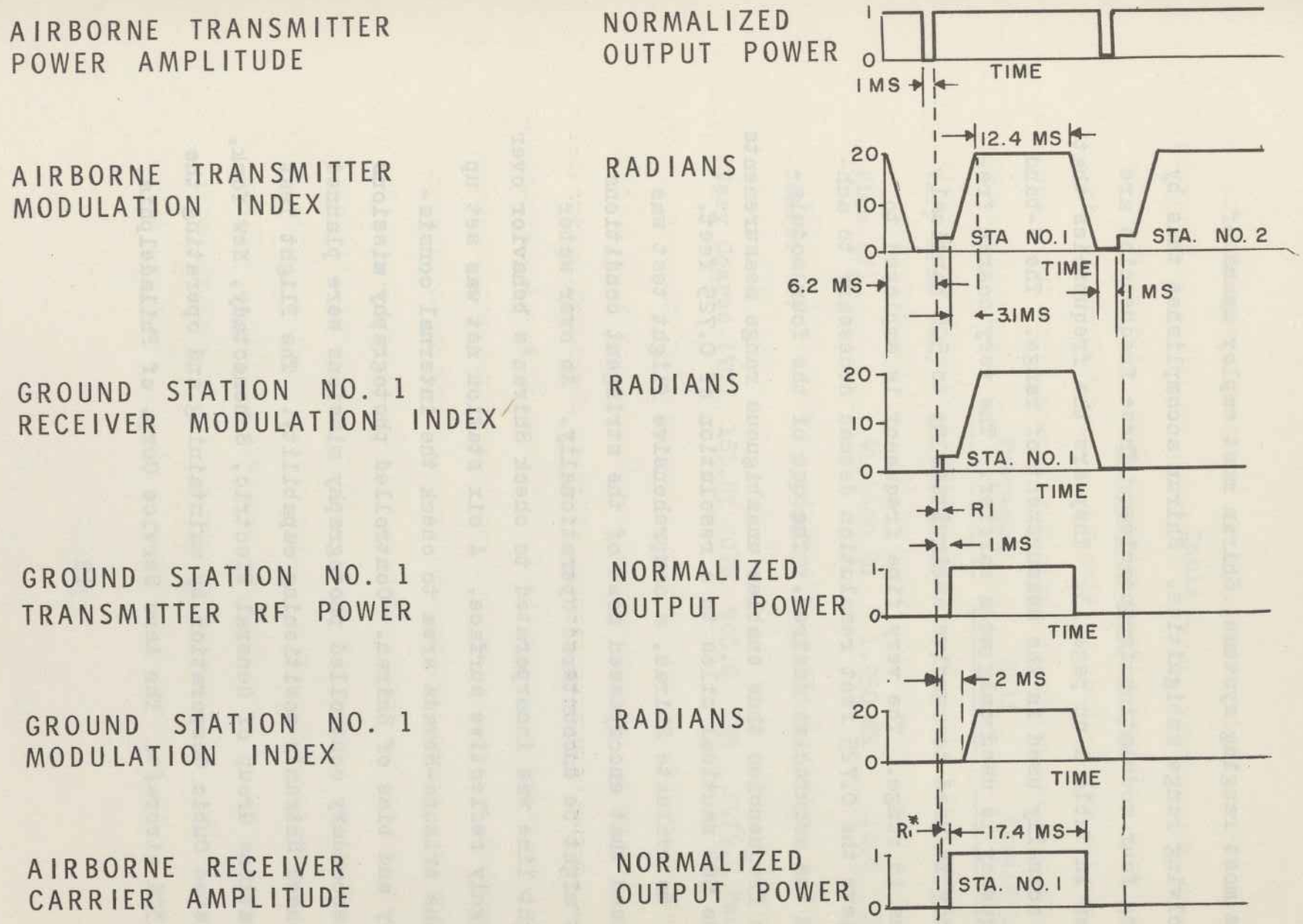


Figure 5 — SHIRAN INTERROGATION SEQUENCE TIMING

Like most ranging systems, Shiran must employ means of resolving range ambiguities. Shiran accomplishes this by using four modulation frequencies. These frequencies are shown in Table 1 on page 13. They are the frequencies that are actually used in the measurement of range. The S-band frequency is used only as a carrier. The very coarse frequency is used to resolve ambiguities up to 500 nautical miles in range. The very fine frequency is employed to achieve the 0.725 feet resolution deemed necessary to achieve the accuracies desired. The use of the four modulation frequencies thus enables unambiguous range measurements up to 500 nautical miles to a resolution of 0.725 feet.

To evaluate Shiran, a comprehensive flight test was devised that encompassed most of the stringent conditions that might be encountered operationally. An over water flight line was incorporated to check Shiran's behavior over a highly reflective surface. A six station net was set up in the Arizona-Nevada area to check the internal consistency and bias of Shiran. Controlled photography missions and secondary controlled photography missions were planned to check Shiran's positioning capability. The Flight Test Operations Group of General Electric, Schenectady, New York, assisted Cubic Corporation by maintaining and operating the RC-130A aircraft. The Aero Service Corp. of Philadelphia,

Table 1

MODULATION FREQUENCIES

	Frequency	Half Wavelength	Resolution
Very Fine (VF)	663.0411 KC	0.722 NM	0.725 Feet
Fine (F)	41.4400 KC	1.950 NM	10.6 Feet
Coarse (C)	2.5900 KC	31.200 NM	186. Feet
Very Coarse (VC)	161.87 CPS	500.0 NM	2979.2 Feet

Pennsylvania, assisted by planning and conducting the flight test and by participating in the data reduction and analysis. Refer to Figure 6, for layout of the flight test area. The over water flight line was located between Gaviota in the vicinity of Santa Barbara, California, and Point Loma situated in San Diego, California. The line length was approximately 184 nautical miles. Line crossings were made on 15 August 1963, at altitudes ranging from 34,508 feet down to 11,132 feet at approximately 2,000 foot intervals. Object of this multi-altitude test was to determine the internal consistency of Shiran over a highly reflective surface and over widely varying geometries. The internal consistency of the first eleven (11) crossings was 0.0007 nautical mile or 4.2 feet. The spread of the reduced measurements was 19.2 feet. Refer to Table 2 on page 16 for detailed results. On 4 Nov. 1963, over water line crossings were made at altitudes ranging from 13,671 to 3,440 feet. The probable error of these measurements was 0.0014 nautical mile or 8.4 feet. Results are listed in Table 3 on page 17.

The line measurements performed in the Nevada-Arizona area ranged from 96 nautical miles to 473 nautical miles. Detailed results of the longest line are listed in Table 4 on page 18. The internal consistency of these measurements, obtained on three different days, was 0.0017 nautical mile probable error.

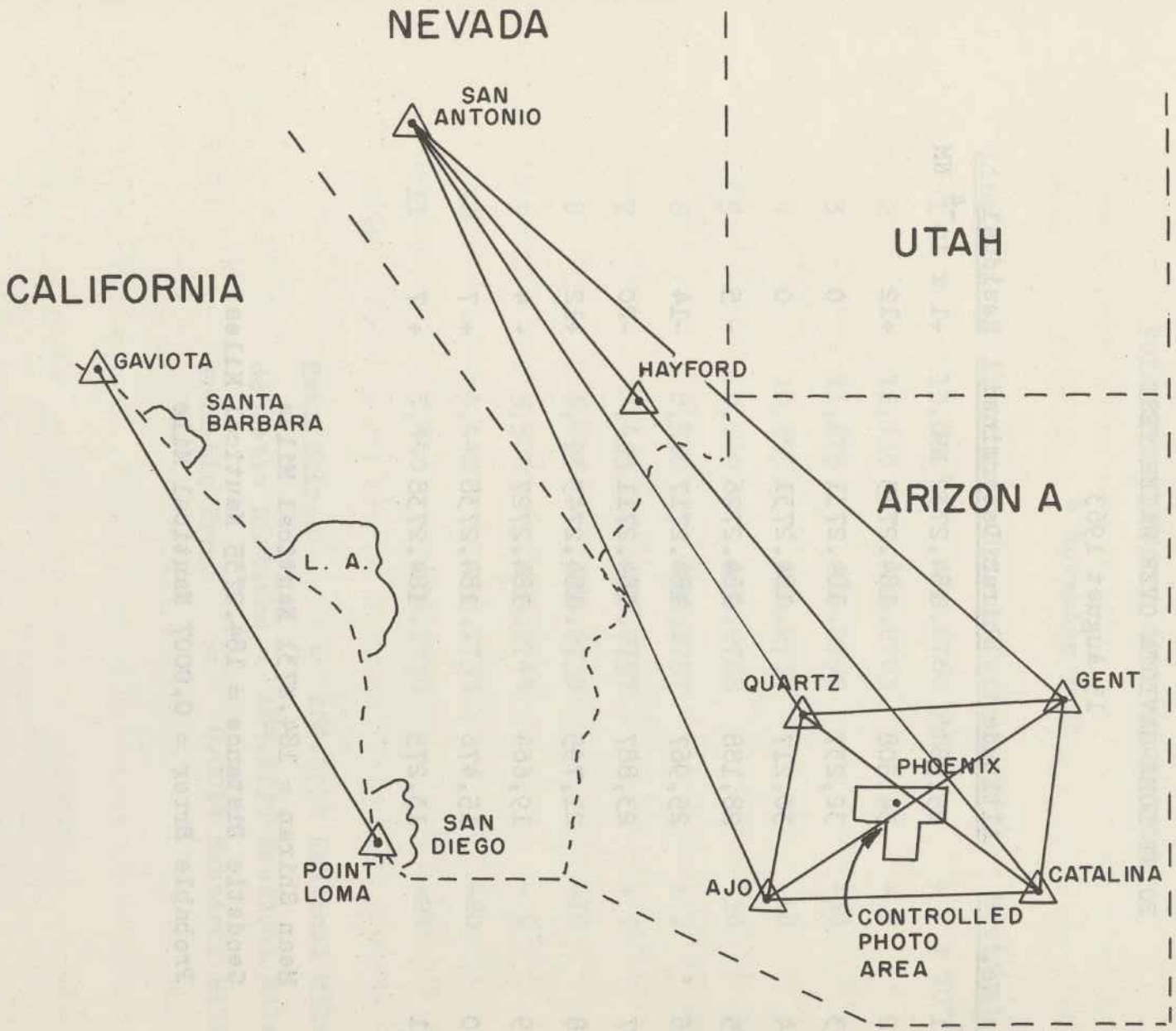


FIG. 6 FLIGHT TEST AREA

Table 2

POINT LOMA-GAVIOTA OVER WATER TEST

15 August 1963

Line No.	Altitude	Shiran Determined	Residual
1	25,964'	184.2732 NM	$+1 \times 10^{-4}$ NM
2	34,508	184.2743	+12
3	32,237	184.2731	0
4	30,217	184.2731	0
5	28,188	184.2726	- 5
6	25,967	184.2717	-14
7	23,887	184.2711	-20
8	21,795	184.2743	+12
9	19,664	184.2727	- 4
10	15,476	184.2738	+ 7
11	13,275	184.2738	+ 7

Mean Shiran = 184.2731 Nautical Miles

Geodetic Distance = 184.2735 Nautical Miles

Probable Error = 0.0007 Nautical Mile

Table 3

POINT LOMA-GAVIOTA OVER WATER TEST

4 November 1963

Line No.	Altitude	Shiran Determined	Residual
1	13,671'	184.2760 NM	$+ 4 \times 10^{-4}$ NM
2	12,750	184.2763	+ 9
3	11,675	184.2792	+38
4	10,655	184.2736	-18
5	9,640	184.2788	+36
6	8,550	184.2757	+ 3
7	7,495	184.2757	+ 3
8	6,495	184.2736	-18
9	5,500	184.2744	- 9
10	4,442	184.2733	-20
11	3,440	184.2730	-24

Mean Shiran = 184.2754 Nautical Miles

Geodetic Distance = 184.2735 Nautical Miles

Probable Error = 0.0014 Nautical Mile

Table 4

CATALINA - SAN ANTONIO LINE

Date 1963	Line No.	Altitude	Shiran Determined	Residual
27 Sep	1	36,288'	472.7676 NM	-25×10^{-4} NM
	2	36,265	472.7681	-20
	3	36,282	472.7698	- 3
	4	36,286	472.7687	-14
	5	36,295	472.7719	+18
	6	36,298	472.7685	-16
	7	36,083	472.7694	Rejected, noise
	8	35,140	472.7686	-15
22 Oct	1	35,857	472.7698	- 3
	2	35,929	472.7671	Rejected, noise
	3	35,840	472.7695	- 6
25 Oct	1	37,552	472.7707	+ 6
	2	37,503	472.7723	+22
	3	37,458	472.7724	+23
	4	37,473	472.7732	+31
	5	37,476	472.7705	+ 4
	6	37,469	472.7697	Rejected, noise

Mean Shiran = 472.7701 Nautical Miles
Geodetic Distance = 472.7712 Nautical Miles
Probable Error_s = 0.0017 Nautical Mile

Of significance was the multi-altitude test performed across the Ajo-Catalina line. Data was acquired on two different days approximately three weeks apart. Twenty-eight (28) separate lines were flown at altitudes varying from 36,349 feet to below the line of sight (4,745'). The internal consistency of this data was 0.0006 nautical mile probable error or 3.6 feet. Refer to Table 5 on page 20 for detailed results.

The controlled photography test was performed on two separate days over the 36 mile by 30 mile area located in the vicinity of Phoenix, Arizona. Each mission consisted of seven north and south flight lines and three east and west flight lines. Over one hundred (100) photographs were obtained for each mission. Analysis of this test indicates a capability of determining nadir points to a circular probable error of 3.37 meters. The precision of Shiran was further depicted during the controlled photography tests by the use of the redundant data obtained from the four station ranging capability. Mean northing and easting coordinates were computed for each nadir point from the four station combinations. The deviations of the individual northings and eastings were determined from the mean values and plotted. Figure 7 depicts the plotting of these points for the first photo mapping mission. The

Table 5

AJO - CATALINA MULTI-ALTITUDE TEST

Date 1963	Line No.	Altitude	Shiran Determined	Residual
19 Sep	1	11,061'	104.6153	$+ 5 \times 10^{-4}$ NM
	2	12,044	104.6160	+12
	3	13,186	104.6149	+ 1
	4	14,234	104.6146	- 2
	5	14,234	104.6146	- 2
	6	14,234	104.6150	+ 2
	7	15,286	104.6128	-20
	8	16,361	104.6151	+ 3
	9	17,412	104.6146	- 2
	10	17,412	104.6152	+ 4
	11	18,436	104.6164	+16
	12	19,522	104.6152	+ 4
	13	20,611	104.6142	- 6
	14	22,749	104.6125	-23
	15	24,760	104.6159	+11
	16	27,001	104.6136	-12
	17	30,117	104.6148	0
	18	33,201	104.6155	+ 7
	19	36,252	104.6147	- 1
	20	36,349	104.6147	- 1
11 Oct	1	11,084	104.6146	- 2
	2	9,992	104.6166	+18
	3	8,884	104.6145	- 3
	4	7,798	104.6154	+ 6
	5	6,747	104.6147	- 1
	6	5,676	104.6149	+ 1
	7	4,745	104.6142	- 6
	8	5,646	104.6147	- 1

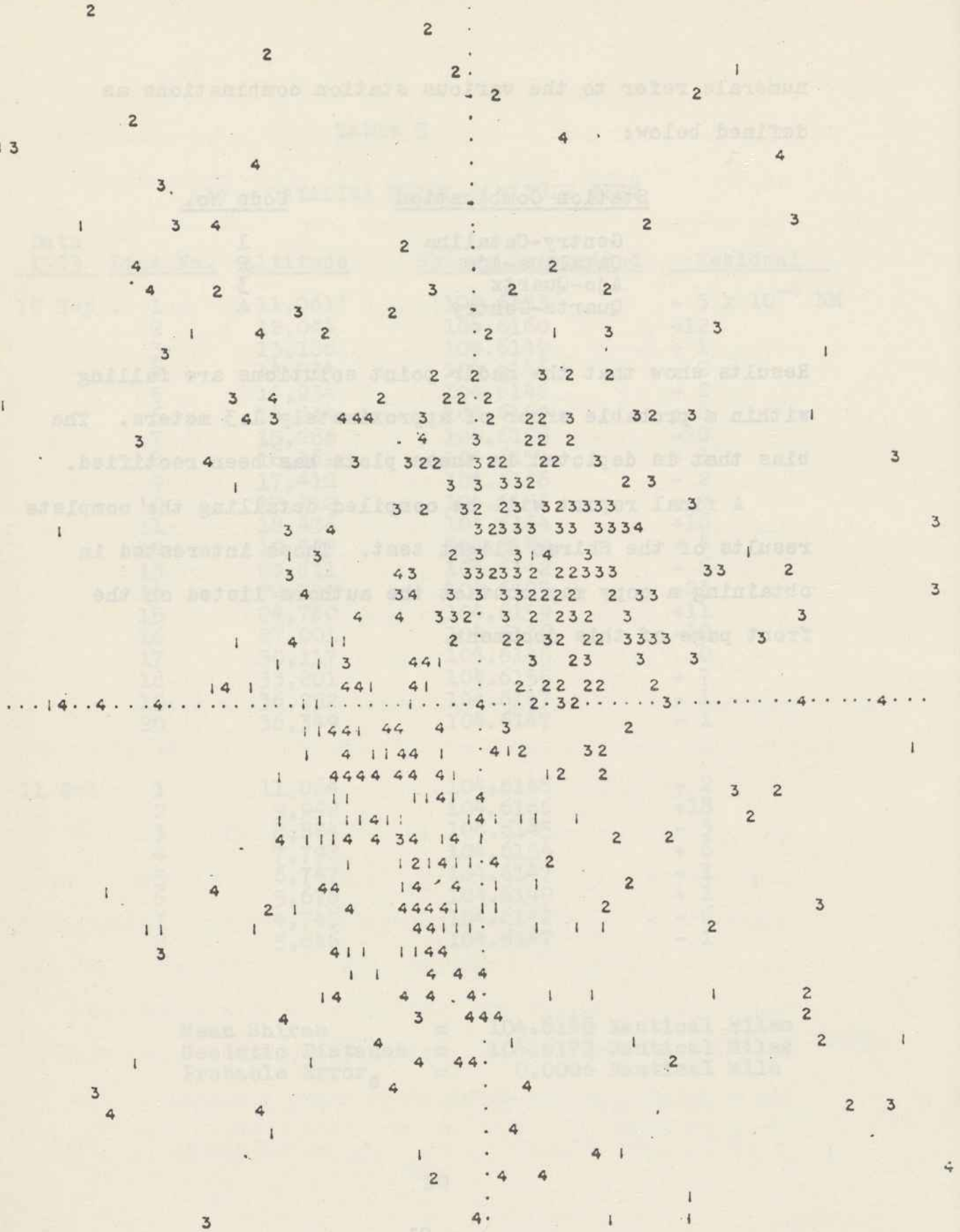
Mean Shiran = 104.6148 Nautical Miles
Geodetic Distance = 104.6172 Nautical Miles
Probable Error_s = 0.0006 Nautical Mile

numerals refer to the various station combinations as defined below:

Station Combination	Code No.
Gentry-Catalina	1
Catalina-Ajo	2
Ajo-Quartz	3
Quartz-Gentry	4

Results show that the nadir point solutions are falling within a probable error of approximately 1.3 meters. The bias that is depicted in these plots has been rectified.

A final report will be compiled detailing the complete results of the Shiran flight test. Those interested in obtaining a copy may contact the authors listed on the front page of this document.



Horiz. Scale: 1" = 1.0 Meter
Vert. Scale: 1" = 0.62 Meter

(10 units = 1 Meter)

Figure 7 SHIRAN Internal Consistency Plot, First Photo Mission