ARROW 1 ANTENNA TESTS

UNCLASSIFIED

REPORT ON BACKGROUND & PROGRESS

1 Jun 58 CEPE ARROW DETACHMENT.

C O N T E N T S

I L L U S T R A T I O N S

1. INTRODUCTION

The Phase 1 Flight Testing of the Telecommunications System on the MK 1 Arrow Aircraft has been allocated to Arrow Aircraft 25202 and the flight program has been subdivided into the three sections given below. The flight program is preceded by ground tests consisting of post installation tests of which no comment is made herein. The three sections are as follows:

i) Flight checks for Navigation Aids. This entails air swings to check calibrations on the AN/ARN-6 Radio Compass, the AN/ARA-25 UHF Homer, and the J-4 Compass. Also, the Station passage characteristics of the AN/ARN-6 and AN/ARA-25 are to be determined. RFT 5028 is included as Appendix "A" to this report, and the details of the equipment and procedures involved are given in the RFT

ii) Flight Range checks for Telecommunications. Flight Range checks are required to determine the ranges of the AN/ARN-6 Radio Compass, the AN/ARA-25 UHF homer, the AN/ARC-34 UHF Communications set, and the AN/APX-6A I.F.F. set. The details of the equipment and procedure are covered by RFT 5029 which is included as Appendix "B" to this report.

iii) Antenna Evaluation Tests. Flight tests are required to establish verification of model antenna range patterns for a single plane. RFT 5044 covers this requirement and is included as Appendix "C" to this report. The complete Antenna Evaluation procedure is detailed in Avro Report 71/Systems 13/3, a copy of which is included as Appendix "D" to this report.

Some 10 to 15 hours of flight time on 25202 is forseen to fulfill the requirements of the Antenna Evaluation tests alone. There is as yet no detailed flight plan available from Avro on the remaining two sections i.e. the Range checks, and the checks on Navigation Aids. At present, it is Avro's intention to run three separate series of tests to fulfill the requirements of the three sections listed above, which if attempted, will involve more flight time than can be afforded. The possibility of integrating as much of the three sections as feasible into one series of tests has been suggested to the Company, but at this time no further discussions have taken place.

This report will deal mainly with the model range program associated with the antenna tests, and the CF-100 program conceived for the development of the evaluation techniques to be used on the CF-105. The appendices have been included to give some idea of the percentage of flight test time allocated to the Antenna trials.

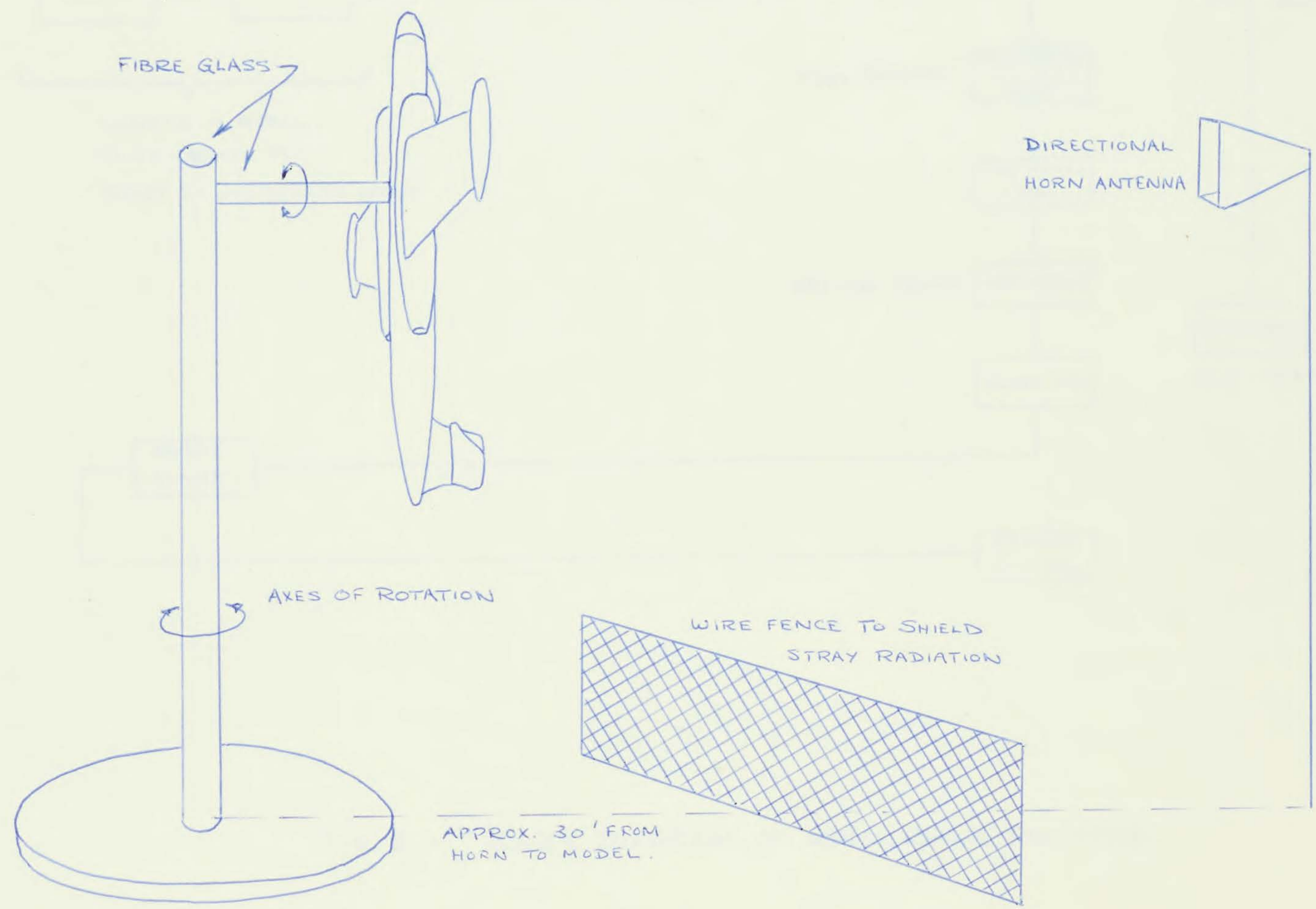

FIG 1 - SKETCH OF MODEL RANGE.

NOT TO SCALE.

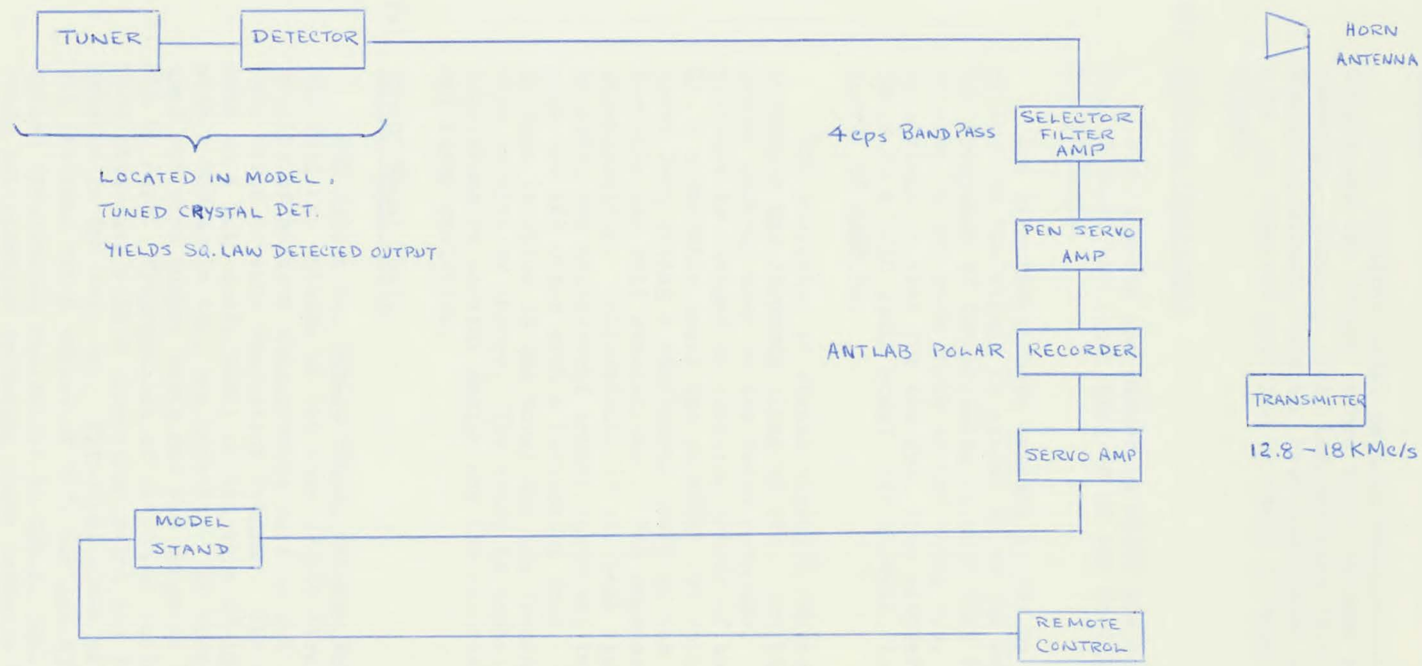

FIG 2. - BLOCK DIAGRAM OF MODEL RANGE FACILITIES.

(2) MODEL RANGE PROGRAM

(a) General

Avro required model pattern measurements for both the CF-105 and the CF-100 before their antenna program could commence. Sinclair Radio Laboratories (S.R.L.) at 70 Sheffield Street, Toronto, have undertaken to provide Avro with the required patterns by means of model testing techniques.

(b) Testing Techniques

Fig. 1 shows the manner in which the model was mounted. Fig. 2 shows the block diagram of the facilities used to obtain the patterns.

The directional horn antenna is fed by a 500 m Watt transmitter and the signal is picked up by the antenna in the model. The frequency of transmission is such that the wavelength is reduced in the same scale as the model i.e. to obtain thepattern equivalent to that for the full size aircraft at a frequency of 226.8 Mc a 1/10 scale model, for example, is tested at a frequency of 2268 Mc.

The variation in signal strength causes a pen to move backwards and forwards along an arm, (similar to a record player pick-up arm) on the trace recorder. As the model attitude is changed by rotating either of the shafts (see fig. 1), a turn-table under the recorder arm rotates at the same speed thus giving a continuous trace on the recording sheet. Normally two full revolutions of 360 degrees are made to check repeatability. Calibrations of the test apparatus are done by using two cylindrical copper antennae; one with a vertical slot and the other with a horizontal slot. These are tested in turn in place of the model and the traces obtained compared with results by theory. The model is tested under "free space" conditions by careful design and the elimination of ground effects and stray radiation.

(c) CF-100 Model Tests

SRL Report No. 182-49 "Model Pattern Measurements for a UHF Tail Cap Antenna on the Avro CF-100 Aircraft" presents the results of pattern measurements carried out in support of the Avro Arrow Antenna Evaluation Program. The measurements were made on a 0.10 scale model of the Avro CF-100 aeroplane fitted with a UHF scale tail cap antenna. The model was previously used for wind tunnel tests and was prepared and supplied to SRL by Avro. Preparations of the model included spraying the wood structure with a conducting paint and fitting the scale antenna in the tail cap. Principal plane patterns and conical cut patterns for Ø values of 91°, 92° and 93° are given for scaled frequencies equivalent to 226.8, 324.3, and 384.3 Mc. Cross polarization principal plane patterns for the center frequency are also included in the report.

The model pattern measurements were utilized in the CF-100 program for the development of evaluation techniques which is discussed later in this report.

(d) CF-105 Model Tests

SRL Reports on the CF-105 Model Pattern Measurements have not been seen as yet, but the results will be followed as they become available. The model being tested is a 0.07 scale wind tunnel model with a wooden fuselage and metal wings. Scale antennae for the UHF and L-Band fin cap and belly have been fitted to the model. The wooden parts have been sprayed with a conducting paint and the model is designed for mounting in either the belly position or dorsal position; the former for Fin cap antennae measurements and the latter for belly antennae measurements.

Avro have also provided SRL with 0.07 models of the external fuel tank and half missiles. Pattern measurements have been made for the following configurations:

1) Clean aircraft (IR dome fitted)
2) As above plus external fuel tank
3) As in (2) above plus half missiles
4) As in (1) above plus half missiles

(3) The CF-100 PRELIMINARY PROGRAM

(a) General

A preliminary program for the Development of UHF Antenna Evaluation Techniques using a CF-100 aircraft has recently been completed at Avro in support of the CF-105 Antenna program in order to minimize the flight time required to obtain full 360 degree coverage of the UHF and L-Band antenna patterns. The purpose of flight tests is to establish verification of model range pattern for a single plane. It is assumed that if close correlation between flight test and model range data can be established for one plane, then model range patterns for complete 360° coverage will be highly representative of in-flight performance of a full scale aircraft. With this in mind, Avro have conducted a preliminary program utilizing CF-100 aircraft 18186 to establish ground station test facilities for use in evaluating UHF and L-Band antennae installations in the Arrow 1, and to check the antenna evaluation technique.

The pre-flight installation of the necessary ground equipment, and five preliminary flights were carried out as the first stage in the program between 26 Nov 57 and 4 Dec 57. Owing to the onset of bad weather the tests were discontinued at that time, but resumed again in May 58 for a further 5 flights to complete the preliminary program. The final report is not yet available, but the Company have indicated good results fulfilling their objectives.

(b) Equipment Involved

(i) Ground

The Avro Telecommunications Trailor was installed at Nottawaga Beach as a ground receiving and transmitting station. The equipment included the following:

- Radio Transmitter
- Radio Receiver
- VHF Signal Generator
- Brown Pen Recorder
- UHF omni-directional, isotropic discone type antenna AT-197/GR
- 60 foot 3-section telescopic aluminum antenna tower
- Surveying Instruments

(ii) Airborne Equipment

The CF-100 aircraft 18186 was fitted with an AN/ARC-34 UHF transceiver, a Micro-Match coupler, and a 50-0-50 microammeter with 5K ohm potentiometer (for the ARC-34 output power monitor).

(c) Test Procedure

The north end of Nottawasaga Bay was chosen as the test area using Nottawaga Beach as the trailor site, and the tip of Cape Rich as the aircraft check point. Fig. 3 shows a sketch of the location.

This area appeared to meet the requirements except for a small island approximately half mile off the shore from the trailor site, and slightly south of a direct line from the site of Cape Rich. A check flight was made to assess the effect of the island. The aircraft was flown in an area of large constant radius about the ground station extending either side of a line connecting the ground station to the check point. The aircraft transmitted a continuous carrier during this time and a pen recorder trace was made, at the ground station, of the field strength. Results showed that the island had a negligible effect and it was therefore ignored on succeeding flights.

Tests were carried out to establish the area of constant signal strength over the check point. Under calm water conditions, the optimum height of the antenna for 226.8 Mc was found to be 35' 8" above the water. This gave a region of approximately 2-1/4 miles either side of Cape Rich where the variation in signal strength was less than ≠ 1 lb. Fig. 4 gives a sample of the traces obtained.

As mentioned earlier, five flights were made between 26 Nov 57 and 4 Dec 57 and a further five flights in May 58 to obtain loop swings over the check point. These were adequate to establish the suitability of the test area and to develop a standard technique to be used at a later date on the Arrow program.

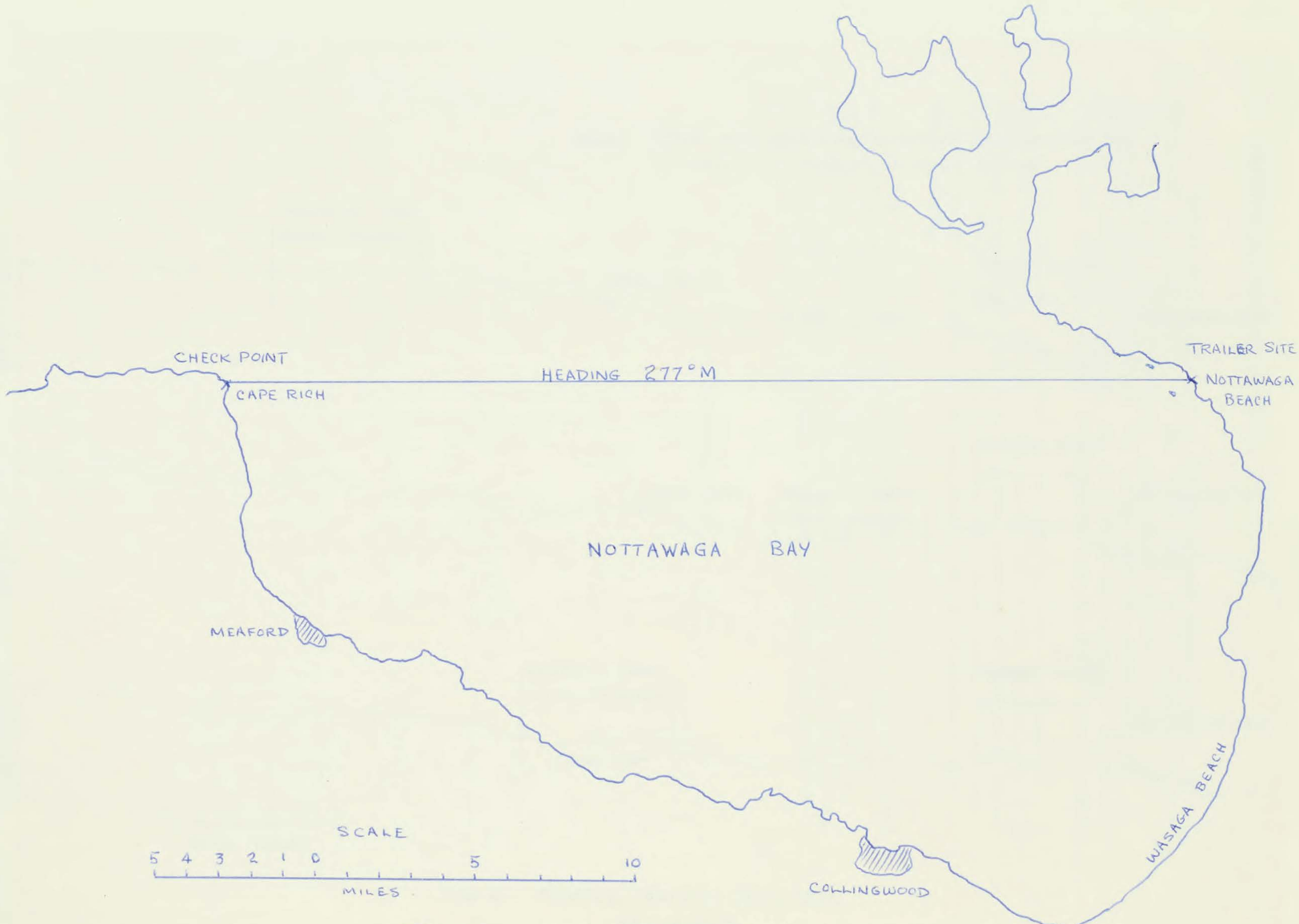

FIG. 3 - SKETCH OF TEST AREA

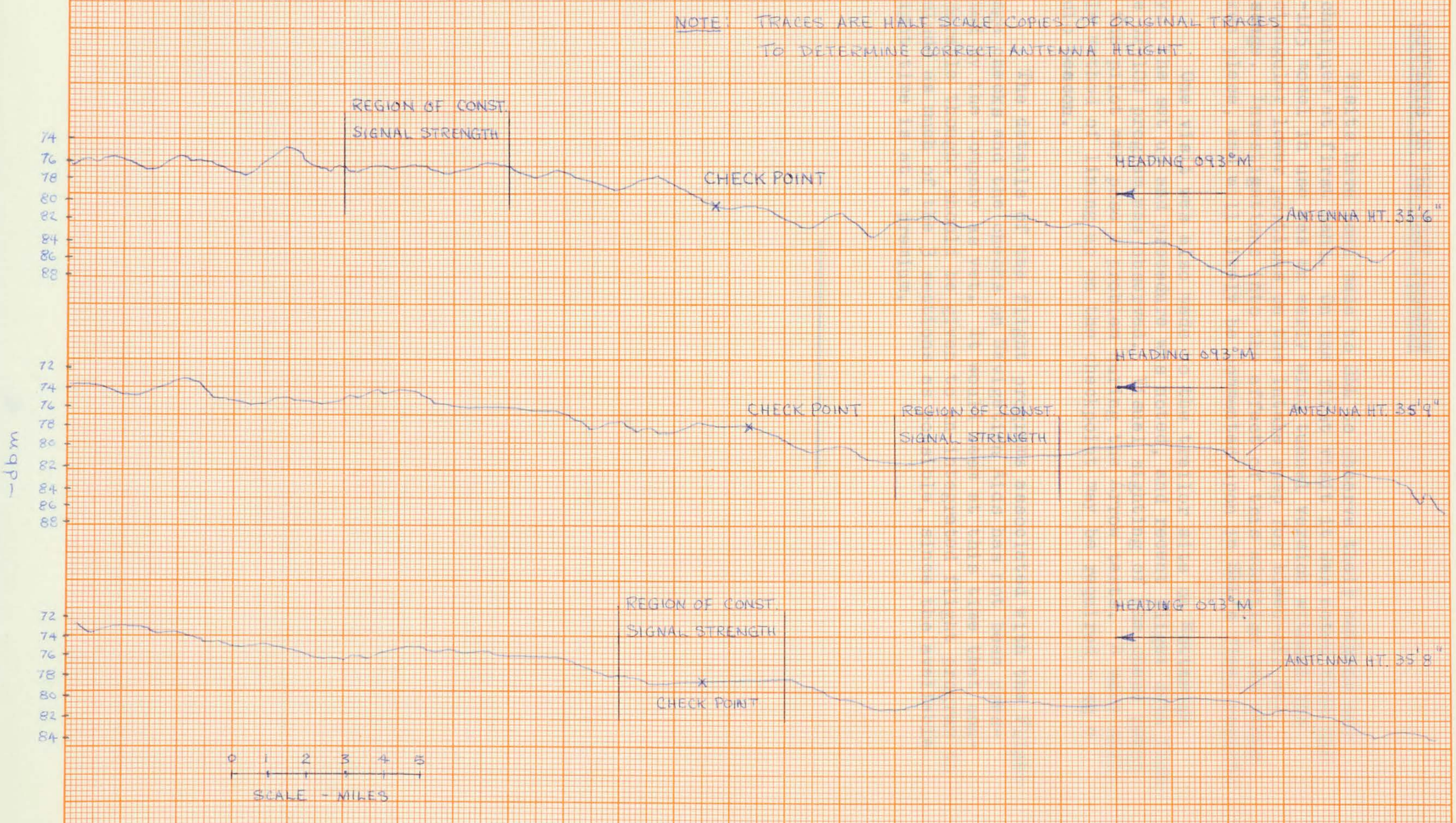

FIG 4 - SAMPLE TRACES - TEST DATA
226.8 Mc/s

4. COMMENTS ON THE TEST PROGRAM

Visits have been made to SRL to observe their methods and techniques at first hand. On the first visit it was noted that the CF-105 model in use was an early wind tunnel version without the rectangular lower portions on the intake ramp for bleed-off air passage. Investigations into the effect of this addition has since taken place, and will likely be commented upon in SRL's final report.

One visit was also made to the trailor site on Nottawaga Bay. The set up and procedure was noted, and recent flight data from the CF-100 program was observed. Visual sighting of the check point by the pilot may pose a problem during the Arrow tests. A more suitable method of lining up on the checkpoint may be required - eg a radio beacon.

The details of the flight programs associated with the Flight Range checks and the checks on Navigation Aids has not been presented by the Company as yet. It would seem at this time that considerable thought should be given to an integrated flight program to include as much of the 3 sections as possible, since the available flight time is at a premium.

APPENDIX "A"

RFT No. 5028

FLIGHT CHECKS OF NAVIGATION AIDS

(COPY)

CALIBRATION CHECKS FOR NAVIGATION AIDS

1. OBJECT

1.1 Air swings are required:

(i) to check calibration and to compensate the AN/ARN-6 Radio Compass.

(ii) to check calibration of AN/ARA-25 U.H.F. Homer
(iii) to check calibration of J-4 Compass.

1.2 Station passage characteristics of the AN/ARN-6 Radio Compass and the AN/ARA-25 U.H.F. Homer are to be determined.

2. EQUIPMENT

2.1 A K-24 camera (or equivalent) is to be mounted in the aircraft so that it can photograph a check point while the aircraft is flying over it.

2.2 A recorder camera (or an auto-observer) is to be mounted in the aircraft to record the AN/ARN-6, AN/ARA-25, and J-4 Compass displays.

3. PROCEDURE

3.1 With the AN/ARN-6 tuned in to a Broadcast station and the AN/ARA-25 tuned in to a U.H.F. station, runs will be made from a number of directions over a known checkpoint.

The complete procedure for the AN/ARN-6 Radio Compass is given in T.I.B. 7-13-2, and the same procedure can be followed for the AN/ARA-25 U.H.F. Homer.

The true course of the aircraft can be obtained from the photographs of the checkpoint, and can be compared with the readings photographed by the recording camera to check out the navigation aids.

3.2 Station passage characteristics of the AN/ARN-6 Radio Compass and the AN/ARA-25 U.H.F. Homer should be obtained by the procedure given in T.I.B. 7-13-2.

4. CONDITIONS

4.1 The tests described in this R.F.T. should be carried out at the earliest practical time in the Phase 1 Engineering Test program.

The Radio Compass calibration and compensation is particularly important, as this is the most useful navigation aid for operation of the aircraft from Malton.

5. <u>DATA</u>

5.1 Calibration and Compensation curves.

5.2 Station passage data.

APPENDIX "B"

RFT No. 5029

FLIGHT RANGE CHECKS FOR TELECOMMUNICATIONS

(COPY)

FLIGHT RANGE CHECKS FOR TELECOMMUNICATIONS

1. OBJECT

Flight Checks are required to determine the ranges of:-

1.1 the AN/ARN-6 Radio Compass.

1.2 the AN/ARA-25 U.H.F. Homer

1.3 the AN/ARC-34 U.H.F. Communications set, working with both the fin and belly antennas.

1.4 the AN/APX-6A I.F.F. set working with both the fin and belly antennas.

2. EQUIPMENT

2.1 A recorder camera (or an auto-observer) will be required, as for R.F.T. 5028, to record the AN/ARN-6 and AN/ARA-25 displays.

3. PROCEDURE

3.1 It is proposed that range checks be carried out with the cooperation of the nearest RCAF G.C.I. facility, which can be used to check the range of the I.F.F. and U.H.F. sets. Strength and readability should be recorded for various ranges.

4. DATA

Ranges for the telecommunications systems listed in section 1.

APPENDIX "C"

RFT No. 5044

ANTENNA EVALUATION TESTS

ARROW 1

(COPY)

ANTENNA EVALUATION TESTS - ARROW 1

1. OBJECT

To establish verification of model antenna range patterns for a single plane.

2. EQUIPMENT

2.1 A ground station should be set up as detailed in Section 3 "Ground Station Equipment" of Report No. 71/Systems 13/3.

2.2 The Arrow 1 should be equipped for UHF transmission, with the AN/ARC-34 or equivalent, and for L-Band transmission, with the AN/APX-6. Details of the operation and modification of this equipment or given in sections 4.1, 4.2 and 4.3 of Report No. 71/Systems 13/3.

2.3 Also required for calibration purposed is a C100 aircraft with the same equipment installed as the Arrow 1.

2.4 Throughout the tests the dummy Irdome will be fitted to the Arrow 1.

3. PROCEDURE

The complete evaluation procedure for flight tests is given in section 5 of Report No 71/Systems 13/3. The C100 aircraft is to be used for calibration purposes in order to cut the required flight time of the Arrow 1 to a minimum.

Three UHF frequencies and two L-band frequencies will be tested and each pattern will be tested at least once and checked on a different day in order to establish repeatability. In order to consider the repeatability successfully established an accuracy of $\leq$ 1 db must be achieved.

The Irdome will be fitted in these tests, and dependent on the results of this assessment, the Irdome or the fin antenna may need to be relocated. The proposal as laid out in Report No. 71/Systems 13/3 required that for each antenna coverage for only a single plane to measured by flight test, the entire antenna pattern then being determined by model range techniques.

4. DATA

Report should include complete details of tests carried out and results obtained.

APPENDIX "D"

AVRO REPORT 71/SYSTEMS 13/3

ANTENNA EVALUATION PROGRAM - CF-105

A. V. ROE CANADA LIMITED
MALTON - ONTARIO

TECHNICAL DEPARTMENT (Aircraft)

AIRCRAFT CF-105

REPORT No 71/SYSTEM S 13/3

FILE No

NO OF SHEETS 34

TITLE: ANTENNA EVALUATION PROGRAM, CF-105

PREPARED BY H.L. Pollock DATE July/57

CHECKED BY K.J. Keeping DATE July/57

SUPERVISED BY W. Taylor DATE July/57

APPROVED BY DATE

ISSUE No	REVISION No	REVISED BY	APPROVED BY	DATE	REMARKS

FORM 1316A

AVRO AIRCRAFT LIMITED
MALTON ONTARIO
TECHNICAL DEPARTMENT

AIRCRAFT: CF-105	ANTENNA EVALUATION PROGRAM, CF-105	REPORT NO 71/Systems 13/3	SHEET NO i
		PREPARED BY H.L. Pollock	DATE July/57
		CHECKED BY	DATE

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FORM 1319A

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HLP/jmy

1. INTRODUCTION

This report will describe a preferred method of evaluating the UHF and L-Band antenna installation on the CF-105 aircraft and will supersede all previous reports issued by the Technical Department on this subject. In view of major revisions to flight time allocation and information recently obtained on the "state of the art", a review of all previous proposals for this program has been necessitated.

It is assumed that the necessary flight time, specifically programmed for antenna evaluation, will be allocated this project. Since space in the aircraft is at a premium, the minimum amount of airborne instrumentation required to successfully perform the evaluation program, will be employed.

Only transmitting equipment and such other equipment as may be required to monitor transmission, will be installed in the aircraft. Field strength measurements, calibration, etc. will be performed at the ground station.

The final results of this program will be a series of antenna coverage diagrams obtained from model range studies, but verified to within 1 db by actual flight tests.

2. GENERAL

The purpose of flight tests will be to establish verification of model range patterns for a single plane. It is assumed that if close correlation between flight test and model range data can be established for one plane, then model range patterns for complete 360° coverage will be highly representative of in-flight performance of a full scale aircraft.

It is proposed to select a location about 25 miles from the ground station, having a sufficiently good land mark that the pilot may fly over it and consistently pin point a fixed position. The pilot would then perform straight and level flights at a fixed altitude (say 4000 feet) for several headings and field strength measurements would be recorded at the ground station. The flight test results would then be compared with the model range data.

1. INTRODUCTION

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It is proposed to select a location about 25 miles from the ground station, having a sufficiently good land mark that the pilot may fly over it and consistently pin point a fixed position. The pilot would then perform straight and level flights at a fixed altitude (say 4000 feet) for several headings and field strength measurements would be recorded at the ground station. The flight test results would then be compared with the model range data.

2. GENERAL Cont'd.....

It will be a requirement for this program that all flight test data be repeatable to within 1 db. In-flight pattern measurements will be repeated at least once, and on a different day, in order to ensure that atmospheric conditions and faulty equipment do not influence the data obtained.

Data will be obtained for several frequencies within each of the UHF and L-Band spectra.

Calibration of the ground station antennas will be performed for each flight immediately before commencing pattern measurements. This will ensure that the effect of ground station lobe structure does not influence the results.

It is proposed to choose a flight path such that the Fresnel zones of interference lie in a body of water, thereby ensuring a constant ground conductivity in the significant portion of the region surrounding the ground station antenna installation.

Since fresh water, rather than sea water, is immediately available in the Toronto area, the ground station will be designed using it as a reflecting media.

3. GROUND STATION EQUIPMENT

3.1 Antenna Installation

In order to ensure that the ground station antennas provide the necessary coverage to the aircraft when it is over the test location, it is necessary to adjust the height of the isotropic UHF antenna for each frequency to be tested in that band. Only one L-Band antenna height is required since this antenna is directional and will not be affected by multipath transmission.

It is proposed to evaluate the UHF System at any three of the four frequencies, 226.8 Mc/s, 277.0 Mc/s, 324.3 Mc/s and 384.3 Mc/s; and the L-Band system at 970 Mc/s and 1060 Mc/s.

IFF Clearance

3.1 Antenna Installation Cont'd...

The procedure for determining the correct ground station heights for the UHF isotropic antenna is detailed in Appendix I.

Table I gives the value of g (Θ), the earth gain factor for surface distances between aircraft and ground station ranging from 15-35 miles.

Table I - Ground Station Antenna Gain

f = 226.8 Mc/s Station Height 39.214'		f = 277.0 Mc/s Station Height 32.120'	
d (miles	g (Θ)	d (miles)	g (Θ)
15.151	0.7760	15.123	0.7819
17.678	1.1133	17.646	1.1070
20.206	1.3862	20.168	1.3887
22.729	1.5366	22.692	1.5261
25.266	1.5900	25.217	1.5901
27.798	1.6061	27.743	1.6100
30.331	1.5778	30.271	1.5793
32.867	1.5263	32.800	1.5081
35.405	1.4640	35.331	1.4644

f = 324.3 Mc/s Station Height 27.408'		f = 384.3 Mc/s Station Height 23.096'	
d (miles)	g (Θ)	d (miles)	g (Θ)
15.105	0.7807	15.089	0.7704
17.624	1.1154	17.605	1.1070
20.144	1.3835	20.121	1.3870
22.664	1.5254	22.638	1.5264
25.185	1.5903	25.156	1.5904
27.707	1.6097	27.765	1.0110
30.231	1.5792	30.195	1.5802
32.756	1.5275	32.716	1.5283
35.283	1.4669	35.328	1.4657

* See Appendix I

3.1 Antenna Installation Cont'd....

The reflection coefficients for fresh water are given in the graph of figure (2). It should be noted that the reflection coefficients in this case are independent of frequency over the UHF L-band regions.

Figures (3), (4), (5) and (6) give the ground station gain for the test frequencies over the range 15-35 miles. It is clear that maximum gain is obtained over the range 25.5 to 29 miles in all cases. Test flights should be conducted at a distance along the ground of 27.5 to 28.0 statute miles for best results.

3.2 UHF Field Strength Measurement

UHF field strength will be measured using the receiver section of Radio Set AN/GRT-3. In this equipment, a jack is provided to permit the measurement of AVC voltage. The equipment is so designed that the AVC voltage output is directly proportional to the logarithm of the R.F. voltage input. AVC voltage is thus a measure of relative field intensity.

3.3 L-band Field Strength Measurement

It is proposed to operate an APX-6, installed in the aircraft as an L-band pulsed transmitter. An APX-6, modified as stated below, will be used at the ground station as the L-band receiver. An output from the last I.F. stage will be fed to a slide-back voltmeter (a slide-back voltmeter indicates peak voltage) which has previously been calibrated for the pulse repetition frequency and width of the transmitted signal. The voltmeter reading will then be proportional to field intensity.

Measurements Corporation Model 67, Slide-back Voltmeter will adequately fulfill the requirements for this program.

3.4 Recording And Calibration

The UHF and L-band field strength measurements will be recorded on chart type recorders and system operation will be monitored continuously throughout the flight.

3.4 Recording And Calibration Cont'd....

The check-point, the aircraft is approaching at an attitude different from straight and level flight, the recorder will indicate a wavy field strength pattern due to shielding effects of the aircraft as the pilot attempts to properly orient it. On the other hand, if the aircraft is approaching the check-point at a straight and level attitude, the recorder will indicate a constant field strength pattern and the measurement at the check-point is then valid.

Figure (7) illustrates a typical recorder pattern for the above situations. Ground station equipment will be calibrated for relative field intensity by simulating antenna signals with appropriate signal generators before and after each flight.

For each flight, prior to commencing evaluation tests, the aircraft will fly radially from the ground station passing over and beyond the check-point, transmitting continuously on UHF. Transmission will also be made for several other headings in the region of the check-point. Field strength readings for the above will be recorded.

If the maximum lobe of the UHF antenna does not occur at the check-point and surrounding region, the antenna height will be adjusted and this procedure repeated until the fault is corrected.

It should be noted that the ground station is so designed that the antenna lobe maximum is sufficiently broad as to minimize errors in field strength measurement which are caused by inaccuracies in locating the ground check-point.

A system diagram for the ground station is given in figure (8)

3.5 Communication

The transmitter section of AN/GRT-3 and the Stoddart UHF receiver will be used for normal communication with the aircraft. In addition, it is suggested that a telephone line hook-up be established with the Avro plant.

A separate UHF antenna will be required for communication purposes.

4. AIRBORNE EQUIPMENT

4.1 UHF Transmission

UHF transmission will be accomplished using the AN/ARC-34 or equivalent. This equipment is presently installed for normal UHF communication purposes. As the aircraft approaches the region of of the check-point, the pilot will depress the press-to-talk button and ground station measurements will be recorded.

A suitable monitor will be installed in the aircraft and the pilot will be required to check and record the output power at various times throughout the flight.

4.2 L-Band Transmission

L-Band transmission will be accomplished using the AN/APX-6, modified as follows. The modulator delay line should be replaced by a line having twice the delay of the present component. This will enable transmission of one pulse, two microseconds width, rather than the present transmission of one pulse, one microsecond width.

It is necessary to transmit at a pulse repetition frequency of the order of several thousand pulses per second in order to present a usable signal level at the ground station. This may be accomplished by connecting a suitable pulse generator to the "BM TRIGGER" input of the AN/APX-6. A push button control should be provided for activation of the pulse generator. At the appropriate time, the pilot would then depress the button and L-Band transmission would commence.

As in the case of UHF transmission, a suitable power monitor will be installed in the aircraft and the pilot will be required to check and record the output power at various times throughout the flight.

A block diagram of the airborne system is given in figure (9).

4.3 Communication

Since aircraft installation space is at a premium, normal communications and UHF field strength measurement will be accomplished using the same equipment. The pilot will transmit signals for measurement purposes only for short periods of time when approaching the region of the ground check-point, during which time it will not be possible for him to receive other communications. It is felt that this will not endanger the mission, since time of transmission is relatively short.

5. EVALUATION PROCEDURE

5.1 Flight Plan

Prior to commencing field strength measurements for each flight, the aircraft will fly radially from the ground station, passing over and beyond the check-point, transmitting continuously on UHF. Straight and level flights for several other headings passing over the check-point will also be required. Calibration of the ground station will be accomplished as previously indicated.

When the ground station has been satisfactorily adjusted, field strength measurements will be made for straight and level flight over the check-point at twelve headings spaced 30° apart. It is proposed to measure both UHF and L-Band field strengths concurrently, however, if interference problems should arise, UHF and L-Band measurements will be measured consecutively.

Three UHF frequencies and two L-Band frequencies will be tested.

A certain amount of pilot training will be required in order to properly orient the aircraft in a straight and level flight over the check point. The flight procedure is similar to Radio Compass procedures.

Each pattern will be checked at least once and on a different day, in order to establish repeatability.

5.2 Repeatability

For each frequency tested, patterns taken on different days must agree within 1 db in order for repeatability to be satisfactorily established.

When this has been done, these patterns will be checked against model range data for the same plane. If there is agreement between in-flight and model range data to within 1 db, the model range data will be accepted as the final pattern for the antenna in question. If model data is not in agreement with flight data, it will be necessary to repeat model range measurements in order to establish the necessary correlation.

5.3 Development Of Measurement Techniques

The major advantage in using the above method for antenna evaluation, is that the flight time requirements for the CF-105 are minimized. It would appear most desirable, therefore, to perfect measurement techniques well in advance of scheduled tests for the CF-105. In order to develop the necessary pilot and ground crew skills required for successful performance of this program, it is suggested that preliminary UHF pattern measurements be made, using a CF-100 aircraft as a test vehicle.

5.4 Aircraft Program

A summary of the aircraft program is given in Table II. It should be noted that prior to commencing pattern measurements, the ground station must be calibrated as previously described in paragraph 5.1. Calibration may be performed using some other aircraft, such as the CF-100, prior to each CF-105 flight.

The data contained in Table II has been prepared under the following assumptions.

(a) Field strength measurements for twelve headings can be accomplished in one hour of flight time, ground station calibration being performed by a separate aircraft prior to a measurement flight.

5.4 Aircraft Program Cont'd.....

(b) UHF and L-Band field strength measurements can be made coincidentally. If interference problems arise, separate measurements will be made for UHF and L-Band and additional flight time will be required.

(c) Pattern repeatability may be satisfactorily established in each case by one check-flight.

(d) Preliminary UHF measurements using a CF-100 aircraft as a test vehicle are required in order to develop the necessary pilot and ground crew skills. Table II does not provide for these. It is estimated that 5 to 10 hours of CF-100 flight time will be required in support of this program.

From Table II, it is estimated that total CF-105 flight time required in support of this program is 15 hours. This includes a 25% safety factor which would account for equipment breakdown, aircraft malfunction, etc.

5.5. Model Range Program

A summary of the model range program associated with this project is given in Table III. The data contained in this table has been prepared under the following assumptions:

(a) Patterns shall be measured on ~~1/18~~ .07 scale models for both L-Band and UHF frequency bands.

(b) UHF measurements shall be performed for three specified frequencies, on each of two antennas.

(c) L-Band measurement shall be performed for two specified frequencies, on each of two antennas.

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Table II - Aircraft Program For CF-105

Flight No.	Estimated Flight Time (Hours)	Frequency Of Test (Mc/s): Fin Cap Area — UHF-L-Band (UHF Section)	Fin Cap Area — UHF-L-Band (L-Band Section)	Belly Area — UHF	Belly Area — L-Band
1	1	226.8			970
2	1	324.3			1060
3	1	384.3			
4	1	226.8			970
5	1	324.3			1060
6	1	384.3			
7	1		970	226.8	
8	1		1060	324.3	
9	1			384.3	
10	1		970	226.8	
11	1		1060	324.3	
12	1			384.3	

Estimated Flight Time 12 Hours

25% Safety Factor 3 Hours

Total Flight Time 15 Hours

AVRO AIRCRAFT LIMITED
MALTON - ONTARIO
TECHNICAL DEPARTMENT

AIRCRAFT: CF-105

ANTENNA EVALUATION PROGRAM, CF-105

REPORT NO 71/Systems 13/3

SHEET NO 10

PREPARED BY H.L. Polbck DATE July/57

CHECKED BY DATE

5.5 Model Range Program Cont'd....

(d) The allowable tolerance on models used for pattern measurement shall be that which permits the system accuracy for the range (± 1 db in 25 db) to be realized.

(e) Schedules are based on a forty hour week and contain drop-out allowances.

(f) Pattern measurements required in support of preliminary flight tests with a CF-100, are not included in Table III. It is estimated that 172 man hours are required for CF-100 model measurements and range utilization would be 30 days.

Table III - Model Range Program For CF-105

Frequency (Mc/s)	Antenna Model	Range Utilization (days)	Labour (Man-hours)
226.8 324.3 384.3	UHF Belly		
226.8 324.3 384.3	UHF Fin-cap	120	1032
970 1060	L-Band Belly		
970 1060	L-Band Fin-cap	120	860

6. CONCLUSIONS

The advantages of employing the above method for the antenna evaluation program are listed below.

(1) Requirements for CF-105 flight time are minimized. Previous proposals required that flight tests for complete 360° coverage be performed for each antenna. This proposal requires that for each antenna, coverage for only a single

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

Table IV - Work Schedule

Item	Description	Date Required
1	Procure slideback voltmeter, power monitors (UHF and L-band), recording meters, etc, as detailed in this report.	Sept.1, 1957
2.	Modify AN/APX-6 (GFE) for airborne installation as described in this report.	Sept.1, 1957
3.	Operate AN/GRT-3 (GFE) and check AVC characteristic for linearity.	Sept.1, 1957
4.	Modify and equip existing mobile trailer, property of Experimental Flight Test, with electrical wiring, dust filters, air conditioning, heating, work benches, etc.	Sept.15, 1957
5.	Purchase two UHF omnidirectional antennas and one telescoping mount. Purchase or fabricate one fixed mount for a UHF antenna.	Sept.15, 1957
6.	Purchase or fabricate one L-band directional antenna and mount.	Sept.15, 1957
7.	Install power monitors, AN/APX-6 (modified), etc. in CF-100 test vehicle.	Oct.1, 1957
8.	Install AN/GRT-3, AN/APX-6, recording voltmeters, etc. in the mobile trailer.	Oct.1, 1957
9.	Allocate 15 hours flight time for CF-100 test vehicle, UHF equipped, for preliminary measurements. Program to commence approximately, October 1, 1957.	Oct.1, 1957

APPENDIX I

CALCULATION OF ANTENNA GAIN FUNCTION

With reference to Fig. (1) an aircraft at A, transmits a signal to a ground station at S. Since the ground station is isotropic, it will be illuminated both by a direct ray emanating from the aircraft and a ray reflected, at an angle ψ by the earth's surface at B.

The true aircraft altitude is h_1 and the altitude referenced to the reflecting plane is h_1'. The true height of the ground station is h_2 and the height referenced to the reflecting plane is h_2'.

The distance measured along the surface of the earth from the point of reflection to the projection of the aircraft position on the earth's surface is d_1. The distance measured along the surface of the earth from the point of reflection to the ground station antenna is d_2.

The reflected ray received by the ground station may be in phase or out of phase with the direct ray causing constructive or destructive interference. It is therefore necessary to optimize the ground station height in order to minimize destructive interference for the aircraft range and altitude of greatest interest.

The method of optimizing the ground station is detailed in the literature' and is summarized briefly below.

The magnitude and phase of the reflected wave for vertical polarization is determined by

$$R\underline{/\phi} = \frac{E_r}{E_i} = \frac{n^2 \sin\psi - \sqrt{n^2 - \cos^2\psi}}{n^2 \sin + \sqrt{n^2 + \cos^2\psi}} \quad \text{------(1)}$$

where E_r and E_i are respectively the intensities of the reflected and incident beams, ψ is the angle between the incident beams and the reflecting plane, and n is the complex index of refraction of the medium.

The index of refraction between air and the reflecting medium is given by.

$$n^2 = \epsilon_r - j60\sigma\lambda \qquad \text{---------------(2)}$$

where ϵ_r is the relative permittivity of the reflecting surface, σ is the conductivity of the reflecting surface in mho-metres per square metre, and λ is the wavelength of the radiant energy in meters.

Values of ϵ_r and σ for average earth, sea water and fresh water are tabulated below [2].

TABLE 1 - PROPERTIES OF REFLECTING MEDIA

Material	ϵ_r	σ (mho-m./sq.m.)
Sea Water	81.0	4.64
Fresh Water	81.0	0.01
Average Earth	15.0	0.015

Values of n^2 for the appropriate test frequencies and reflecting surfaces have been calculated using equation (2) and are given in Table 11.

TABLE 11 - VALUES OF n^2 FOR ANTENNA EVALUATION PROGRAM

Media	Frequency			
	226.8 Mc/s	277.0 Mc/s	324.3 Mc/s	384.3 Mc/s
Sea water	81-j370	81-j 301	81-j 258	81-j 218
Fresh water	81-j0.796	81-j 0.650	81-j 0.555	81-j 0.469
Average Earth	15-j1.19	15-j 0.975	15-j 0.834	15-j 0.703

Table 111 gives the reflection coefficients for an aircraft range 15-35 miles from the ground station at an altitude of 4000'. The reflecting medium prescribed for this test is water and since fresh water, rather than sea water, is immediately available in the Toronto area, the coefficients have been determined for that medium only.

TABLE 111 - REFLECTION COEFFICIENT FOR FRESH WATER
UHF REGION VERTICAL POLARIZATION

ψ	R	$\angle\phi$	ψ	R	$\angle\phi$
0.25°	0.924	-180°	2.75°	0.394	-180°
0.50	0.853	-180	3.00	0.356	-180
0.75	0.788	-180	3.25	0.335	-180
1.00	0.727	-180	3.50	0.288	-180
1.25	0.670	-180	3.75	0.256	-180
1.50	0.616	-180	4.00	0.227	-180
1.75	0.566	-180	4.25	0.197	-180
2.00	0.519	-180	4.50	0.169	-180
2.25	0.475	-180	4.75	0.143	-180
2.50	0.433	-180	5.00	0.118	-180

It should be noted that reflection coefficients for fresh water are independent of frequency in the UHF region and that incident waves are shifted in phase by 180° upon reflection by that medium.

A graph of reflection coefficient versus ψ is given in Fig. (2).

Having determined the reflection coefficients the ground station characteristics are then optimized as follows.

(a) Choose d_1 and h_1 for maximum gain of the ground station antenna. In this case d_1 = 25.0 miles, h_1 = 4000'.

(b) Calculate h_1' for the above values and call it h_1' max.

$$h_1' = h_1 - \frac{d_1^2}{2} \qquad \text{----------------(3)}$$

where h_1', h_1 are in feet and d_1 is in miles.

(c) Calculate ψ for the above values and call it ψ max.

$$\psi = \cot^{-1} \frac{5280\, d_1}{h_1'} \qquad \text{-------------(4)}$$

TABLE 111 - REFLECTION COEFFICIENT FOR FRESH WATER UHF REGION VERTICAL POLARIZATION

ψ	R	$\angle\phi$	ψ	R	$\angle\phi$
0.25°	0.924	-180°	2.75°	0.394	-180°
0.50	0.853	-180	3.00	0.356	-180
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1.00	0.727	-180	3.50	0.288	-180
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where h_1', h_1 are in feet and d_1 is in miles.

(c) Calculate ψ for the above values and call it ψ max.

$$\psi = \cot^{-1} \frac{5280\, d_1}{h_1'} \quad \text{------------(4)}$$

(d) Phase shift due to path length difference is given by

$$\theta = \frac{1.384 \times 10^{-4}\, h_1'\, h_2'\, f_{mc}}{d} \qquad \text{----------------(5)}$$

where θ is the phase shift due to path length difference in degrees, $d = d_1 + d_2$ is the total distance, in miles, along the surface of the earth between the aircraft and the ground station, and f_{mc} is the frequency in Mc/s.

For maximum gain $\theta + \phi = 360°$

i.e. $\theta + 180° = 360°$

$\theta = 180°$

For maximum antenna gain, equation (5) becomes.

$$\frac{(1.384 \times 10^{-4})(5280)\, d_2 h_1' \tan\psi\; f_{mc}}{d_1 + d_2} = 180$$

$$d_2\ max = \frac{d_1}{(1.384 \times 10^{-4})(5280)\, h_1' \tan\psi\; f_{mc} - 180} \qquad (6)$$

Using equ'n (6) calculate $d_2\ max$ for maximum station gain

(e) Calculate h_2',

$$h_2' = \frac{5280\, d_2}{\cot\psi} \qquad \text{----------------(7)}$$

(f) Calculate h_2,

$$h_2 = h_2' + \frac{d_2^2}{2} \qquad \text{----------------(8)}$$

(g) For chosen values of d_1, h_1 and using h_2 as determined for maximum antenna gain in a defined region, determine antenna coverage as follows.

Calculate h_1' using equ'n (3).

Calculate Ψ using equ'n (4).

Calculate d_2 and h_2' by solving equ'ns (7) and (8).

(h) The divergence factor D is defined as the ratio of field strength obtained after reflection from a spherical surface to that obtained after reflection from a plane surface, the radiated power, total axial distance, and type of surface being the same in both cases, and the solid angle being a small elemental angle approaching zero.

Calculate D,

$$D = \frac{1}{\sqrt{1 + \dfrac{2d_1^2\,d_2}{h_1'\,d}}} \qquad \text{------------(9)}$$

(i) Calculate θ using equ'n (5)

(j) Determine the magnitude and phase of the reflection coefficient from the graph of Fig (2).

(k) Determine the earth gain factor $g(\theta)$

$$g(\theta) = \sqrt{1 + (DR)^2 + 2DR\cos(\theta - \phi)} \qquad \text{-------(10)}$$

where $g(\theta)$ is the ratio of the resultant field to the free space field.

Note that $g(\theta) = 1$ if there is no reflected ray - i.e. $g(\theta)$ is a measure of the antenna gain taking account of the multi-path propogation.

<u>EXAMPLE CALCULATION</u>

$f = 226.8$ Mc/s $\qquad h_1 = 4000'$

We will maximize the antenna gain at $d_1 = 25.0$ miles.

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AIRCRAFT: CF-105	ANTENNA EVALUATION PROGRAM CF-105	REPORT NO. 71/Systems 13/3	
		SHEET NO. A6	
		PREPARED BY H. Pollock	DATE July 1957
		CHECKED BY	DATE

Using equ'n (3)

$$h'_{1max} = 4000 - \frac{(25.0)^2}{2} = 3687.5'$$

Using equ'n (4)

$$\psi_{max} = \cot^{-1} \frac{5280 \times 25}{3687.5} = 1.6^o$$

Using equ'n (6)

$$d_{2max} = \frac{25}{(1.384x10^{-4})(5280)(3687.5)(\tan 1.6^o)(226.8)-180}$$

$$= 0.266 \text{ miles}$$

Using equ'n (7)

$$h'_{2\ max} = \frac{5280 \times 0.266}{\cot 1.6^o} = 39.279'$$

Using equ'n (8)

$$h_2 = 39.279 + \frac{(0.266)^2}{2} = 39.314'$$

Having determined the characteristics for maximum antenna gain at d_1 = 25.0 miles and h_1 = 4000', we will calculate g (θ) for d_1 = 15.0 miles.

Using equ'n (3)

$$h'_1 = 4000 - \frac{(15)^2}{2} = 3887.5$$

Using equ'n (4)

$$\phi = \cot^{-1} \frac{(5280)(15)}{3887.5} = 2.8^o$$

Using equ'ns (7) and (8)

$$\frac{d_2^{\,2}}{2} + \frac{5280\, d_2}{\cot \psi} - h_2 =$$

$$0.5d_2^{\,2} + \frac{5280\, d_2}{\cot 2.8^o} - 39.314 = 0$$

$$0.5d_2^{\,2} + 259.17d_2 - 39.314 = 0$$

$$d_2 = 0.151 \text{ miles.}$$

(NOTE: The other root for the above equation yields a negative value for d_2 and must therefore be discarded.)

Using equ'n (7)

$$h_2' = \frac{(5280)\,(0.151)}{\cot 2.8^o} = 39.134'$$

$$d = 15 + 0.151 = 15.151 \text{ miles.}$$

Using equ'n (9)

$$D = \frac{1}{\sqrt{1 + \frac{2\,(15)^2\,(0.151)}{(3887.5)(15.151)}}} = 0.9995$$

Using equ'n (5)

$$\Theta = \frac{(1.384 \times 10^{-4})(3887.5)(39.134)(226.8)}{25.151} = 315.4^o$$

From Fig. (2)

$$R\angle\underline{\phi} = 0.382\, \angle\underline{-180^o}$$

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AIRCRAFT:		REPORT No. 71/Systems 1_	
		SHEET No. A8	
		PREPARED BY	DATE
CF-105	ANTENNA EVALUATION PROGRAM CF-105	H. Pollock	July 1957
		CHECKED BY	DATE

Using equ'n (10)

$$g(\theta) = \sqrt{1 + (0.9995 \times 0.382)^2 + 2(.9995)(.382)\cos(315.4+180)}$$

$$g(\theta) = 0.7760$$

The above method was used for calculation of all antenna patterns for this report.

ORM 1318A

REFERENCES

1. Henry R. Reed and Carl M. Russell, "Ultra High Frequency Propagation", John Wiley and Sons, Inc., 1953, pp 58 - 116.

2. Ibid, p. 84.

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AIRCRAFT: CF-105	ANTENNA EVALUATION PROGRAM CF-105	REPORT NO. 71/Systems 13/3	SHEET NO A9
		PREPARED BY H. Pollock	DATE July 1957
		CHECKED BY	DATE

REFERENCES

1. Henry R. Reed and Carl M. Russell, "Ultra High Frequency Propagation", John Wiley and Sons, Inc., 1953, pp 58 - 116.

2. Ibid, p. 84.

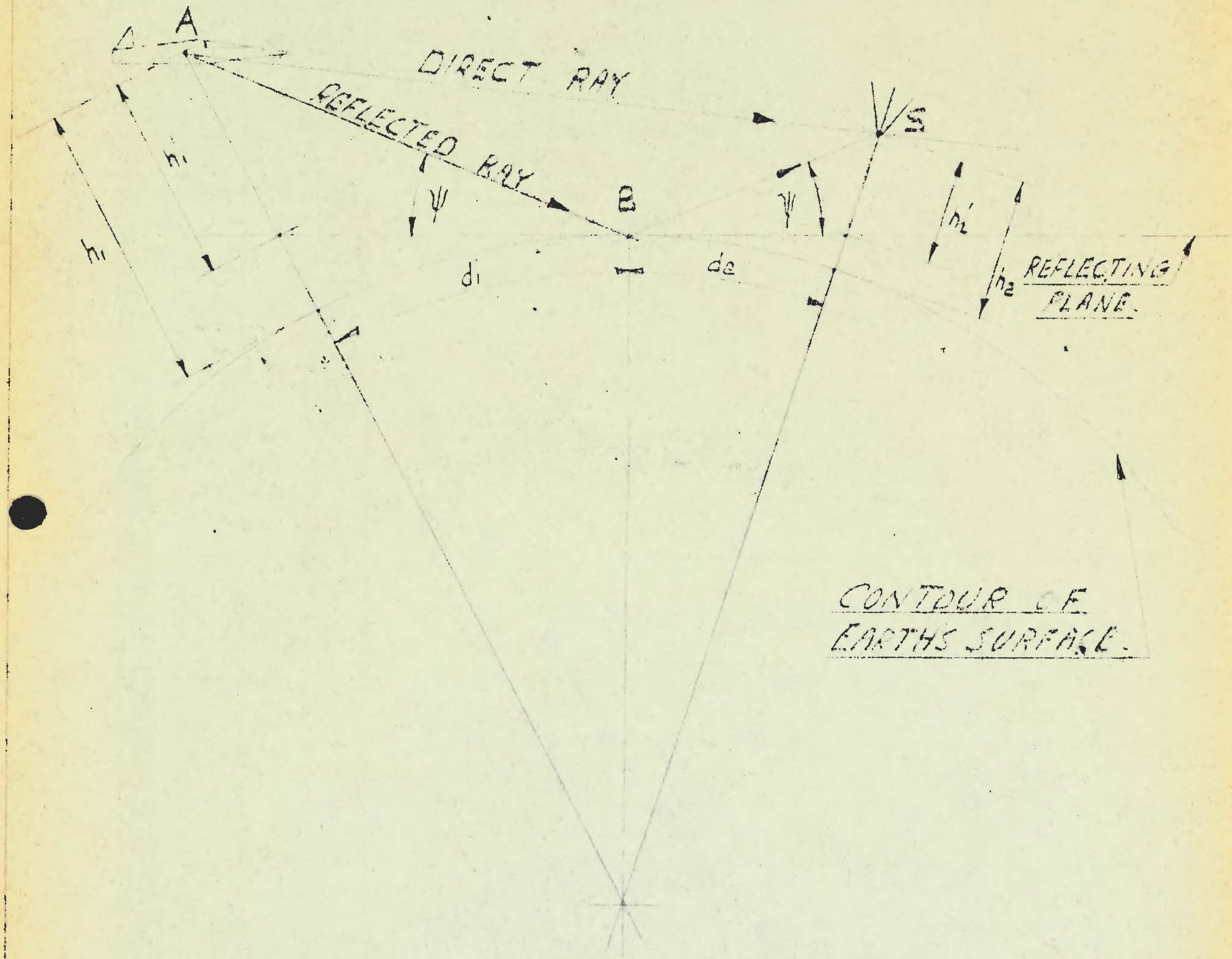
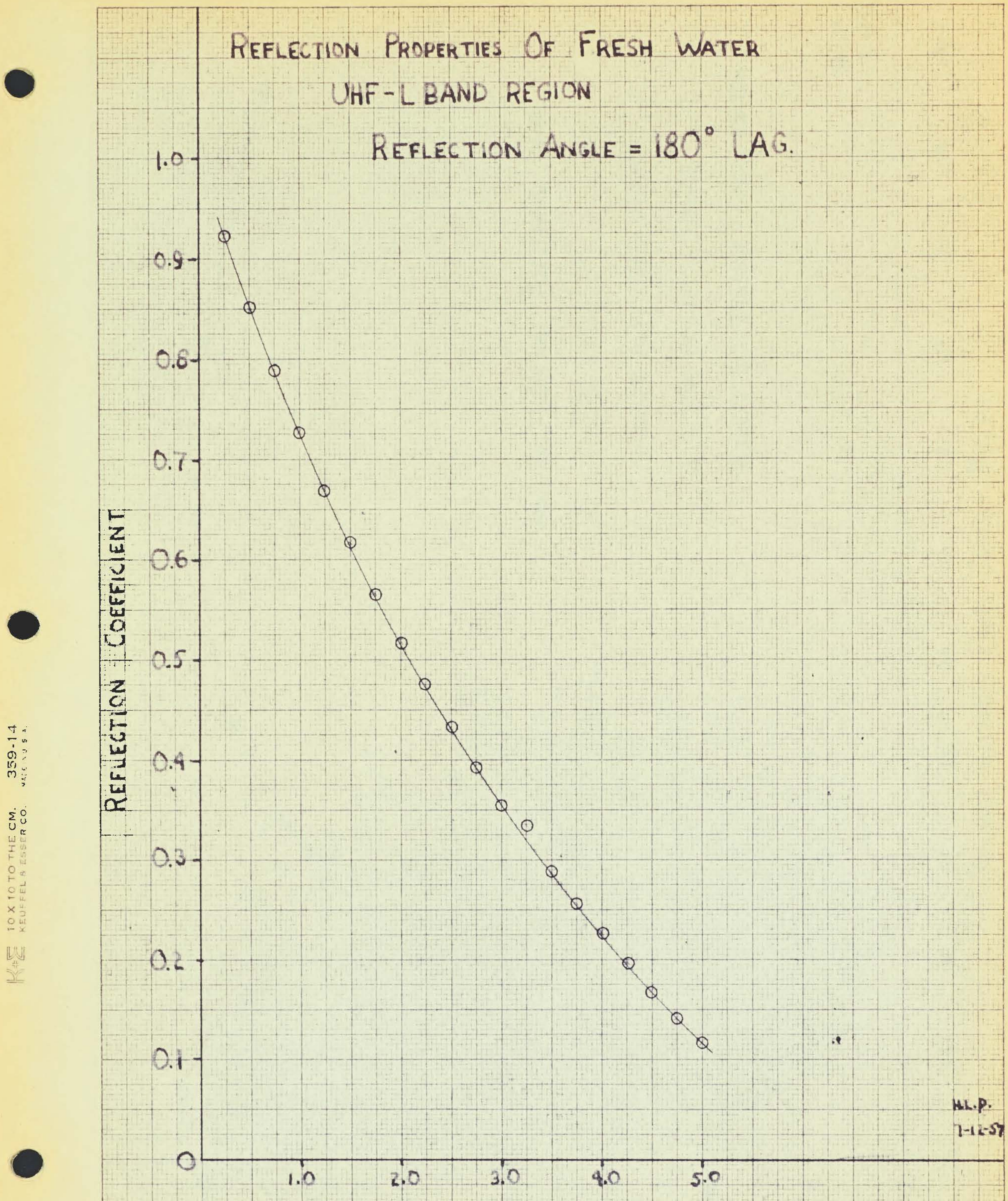


FIG I. REFLECTION FROM A SPHERICAL SURFACE



REFLECTION PROPERTIES OF FRESH WATER
UHF-L BAND REGION
REFLECTION ANGLE = 180° LAG.
REFLECTION COEFFICIENT
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.0
2.0
3.0
4.0
5.0
INCIDENT ANGLE - DEGREES
H.L.P.
7-12-57
10 X 10 TO THE CM. 359-14
KEUFFEL & ESSER CO.

FIG. (2)

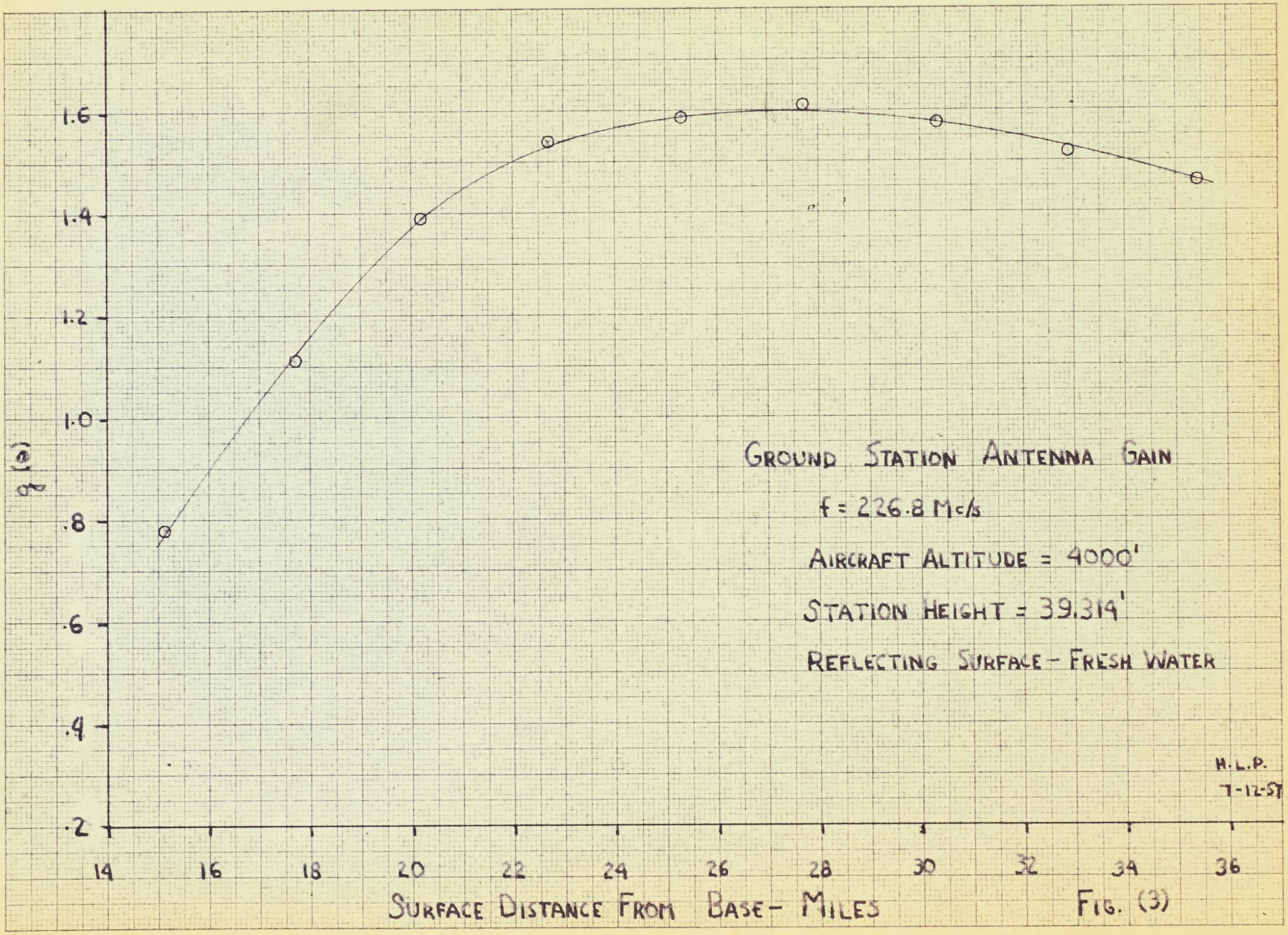
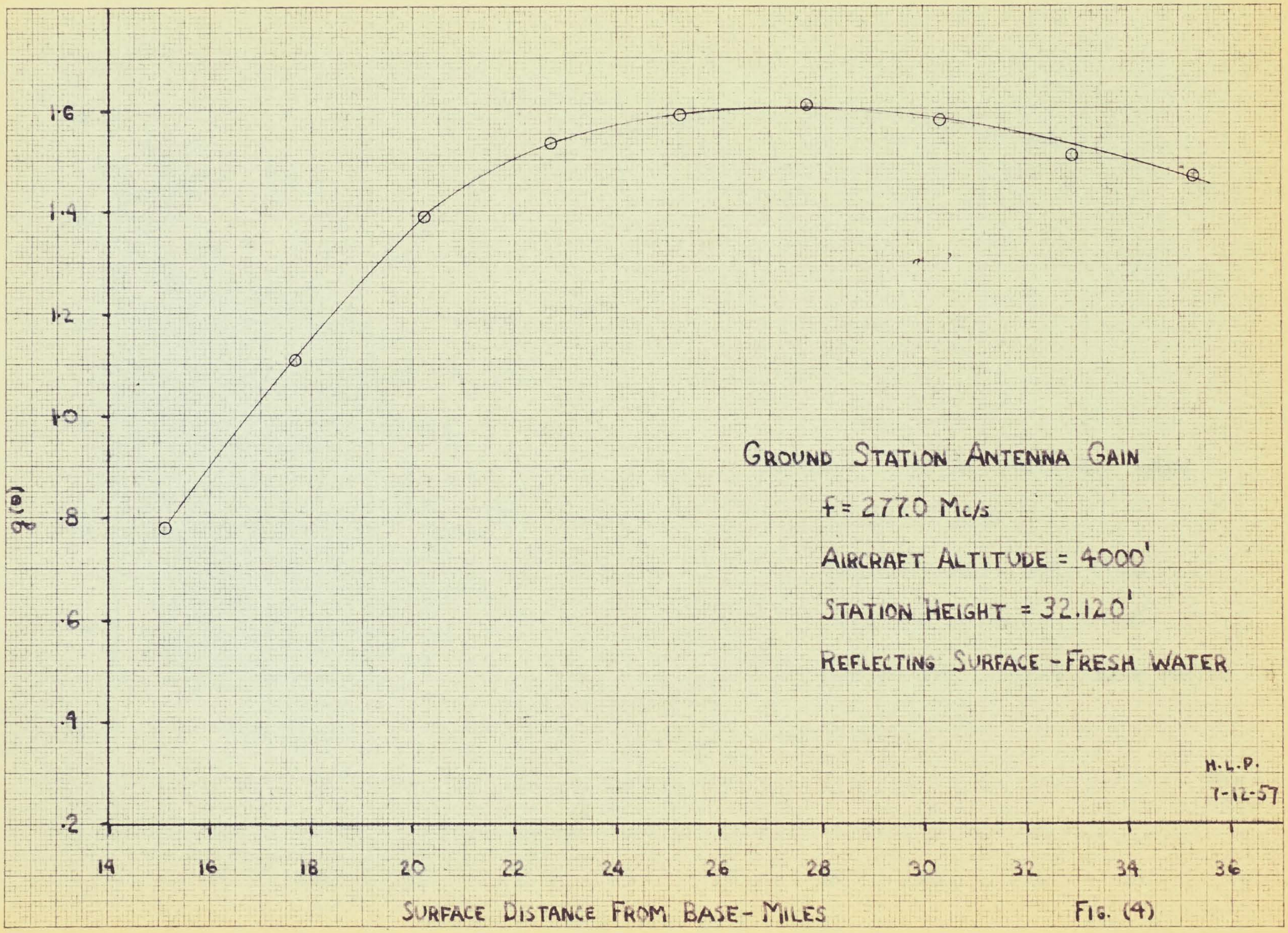

Ground Station Antenna Gain
f = 226.8 Mc/s
Aircraft Altitude = 4000'
Station Height = 39.314'
Reflecting Surface - Fresh Water
1.6
1.4
1.2
1.0
.8
.6
.4
.2
14
16
18
20
22
24
26
28
30
32
34
36
Surface Distance From Base - Miles
H.L.P.
7-12-57

Fig. (3)



1.6
1.4
1.2
1.0
.8
.6
.4
.2
g(θ)
14
16
18
20
22
24
26
28
30
32
34
36
SURFACE DISTANCE FROM BASE - MILES
GROUND STATION ANTENNA GAIN
f = 2770 Mc/s
AIRCRAFT ALTITUDE = 4000'
STATION HEIGHT = 32.120'
REFLECTING SURFACE - FRESH WATER
H.L.P.
7-12-57

Fig. (4)

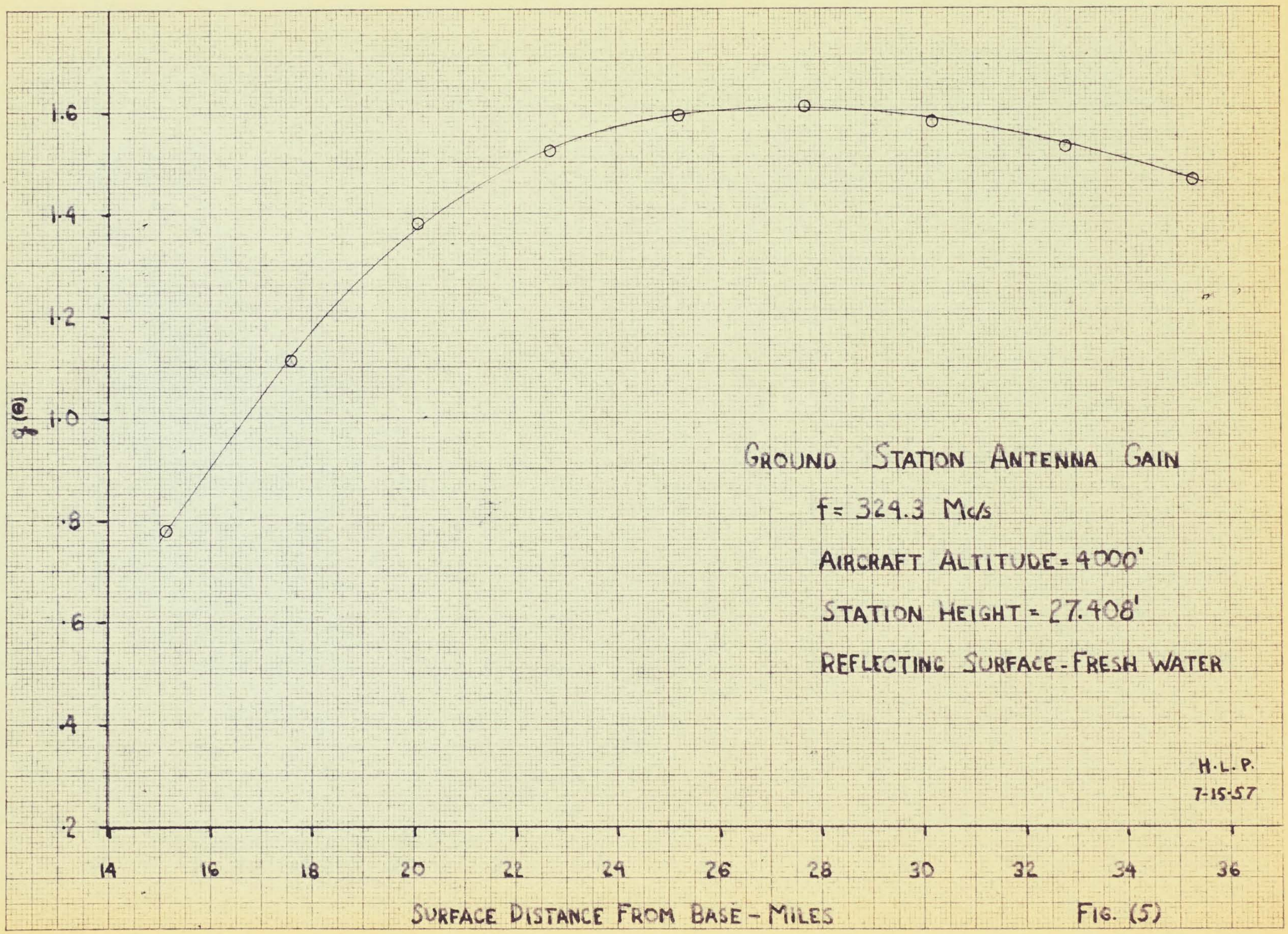

1.6
1.4
1.2
1.0
.8
.6
.4
.2
g(θ)
14
16
18
20
22
24
26
28
30
32
34
36
Surface Distance From Base - Miles
Ground Station Antenna Gain
f = 324.3 Mc/s
Aircraft Altitude = 4000'
Station Height = 27.408'
Reflecting Surface - Fresh Water
H.L.P.
7-15-57

Fig. (5)

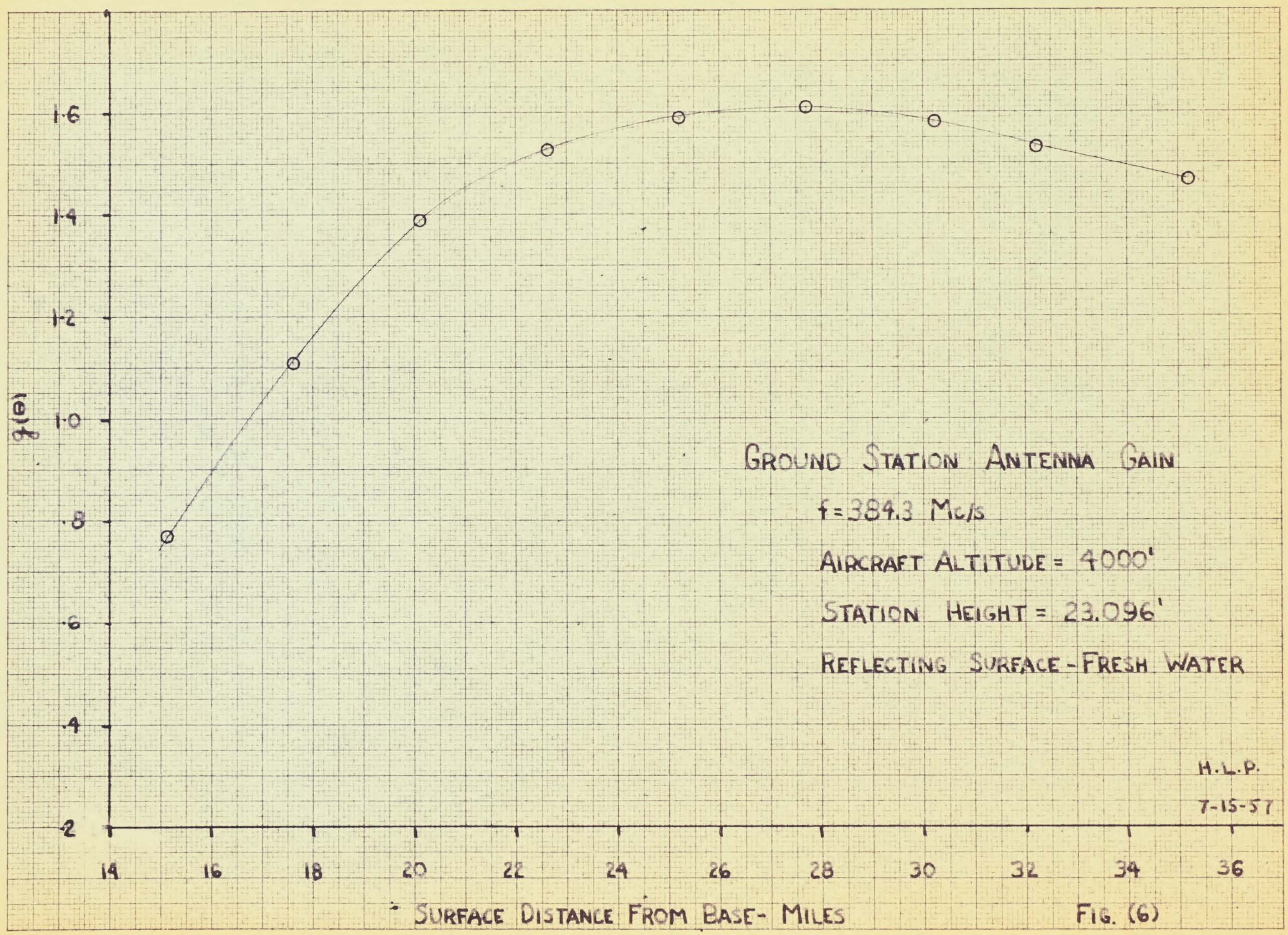
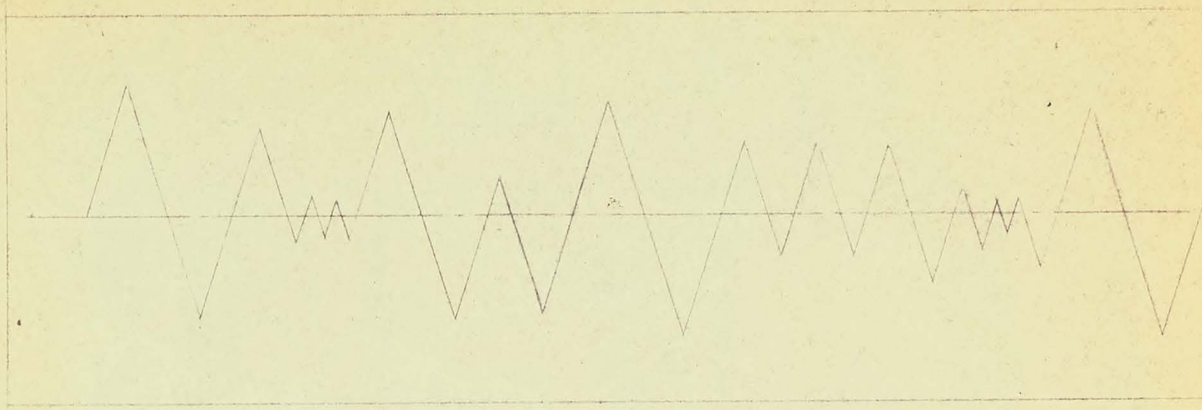
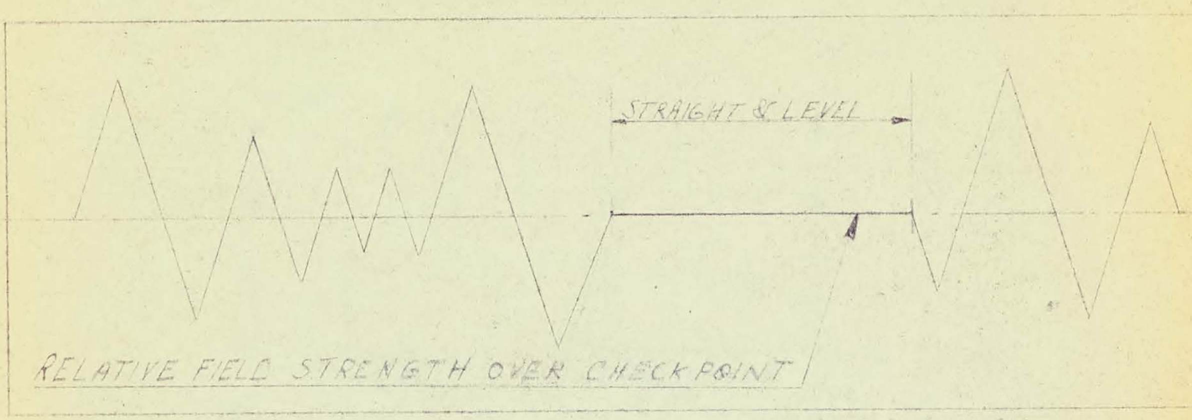

g(θ)
1·6
1·4
1·2
1·0
·8
·6
·4
·2
14
16
18
20
22
24
26
28
30
32
34
36
SURFACE DISTANCE FROM BASE- MILES
GROUND STATION ANTENNA GAIN
f = 384.3 Mc/s
AIRCRAFT ALTITUDE = 4000'
STATION HEIGHT = 23.096'
REFLECTING SURFACE - FRESH WATER
H.L.P.
7-15-57

FIG. (6)



(a) AIRCRAFT APPROACHING CHECK POINT AT ATTITUDE OTHER THAN STRAIGHT & LEVEL. (REJECT READING)



(b) AIRCRAFT IN STRAIGHT & LEVEL FLIGHT OVER CHECKPOINT

FIG 7 GROUND STATION RECORDER INDICATION

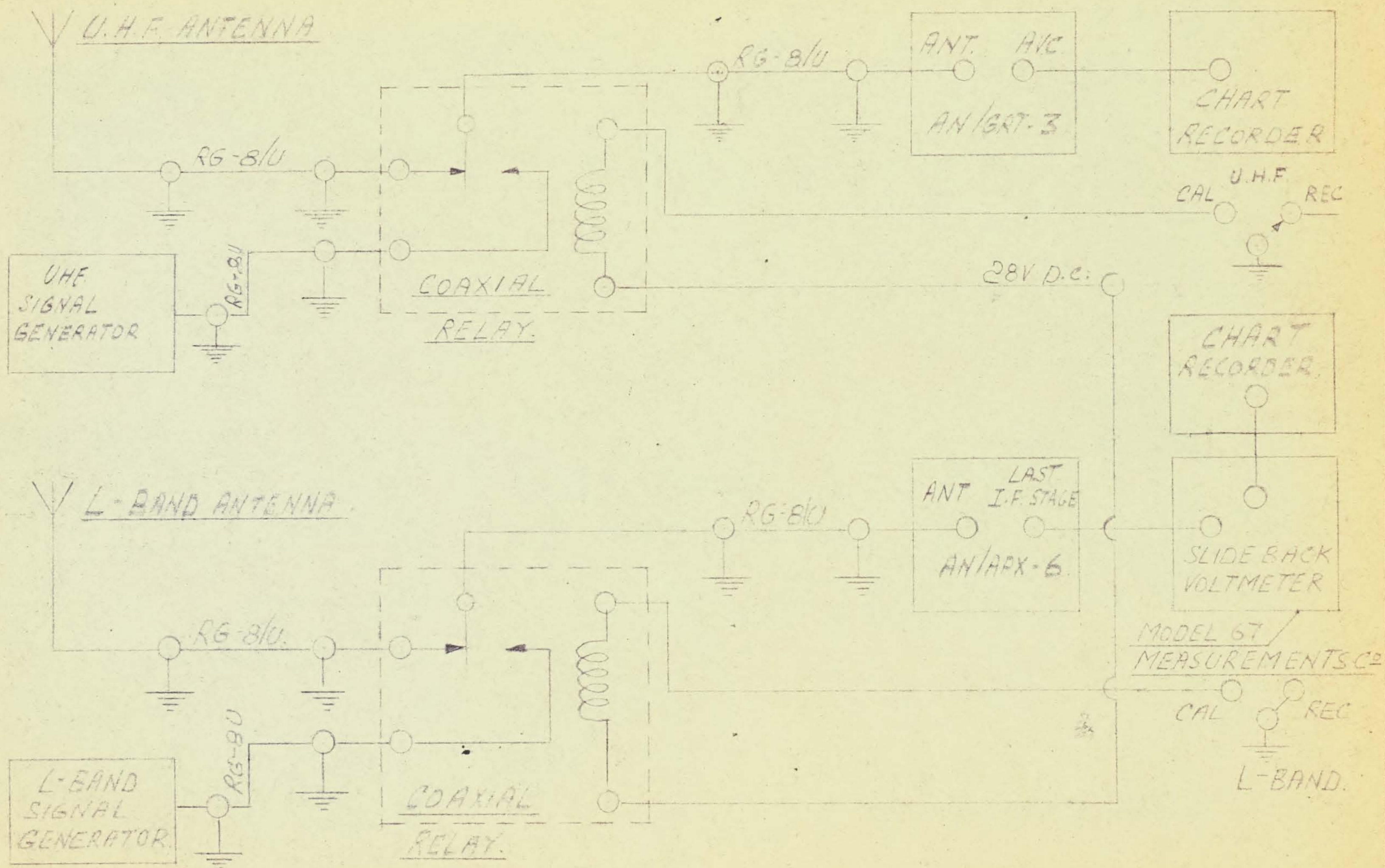


FIG 8 GROUND STATION SYSTEM

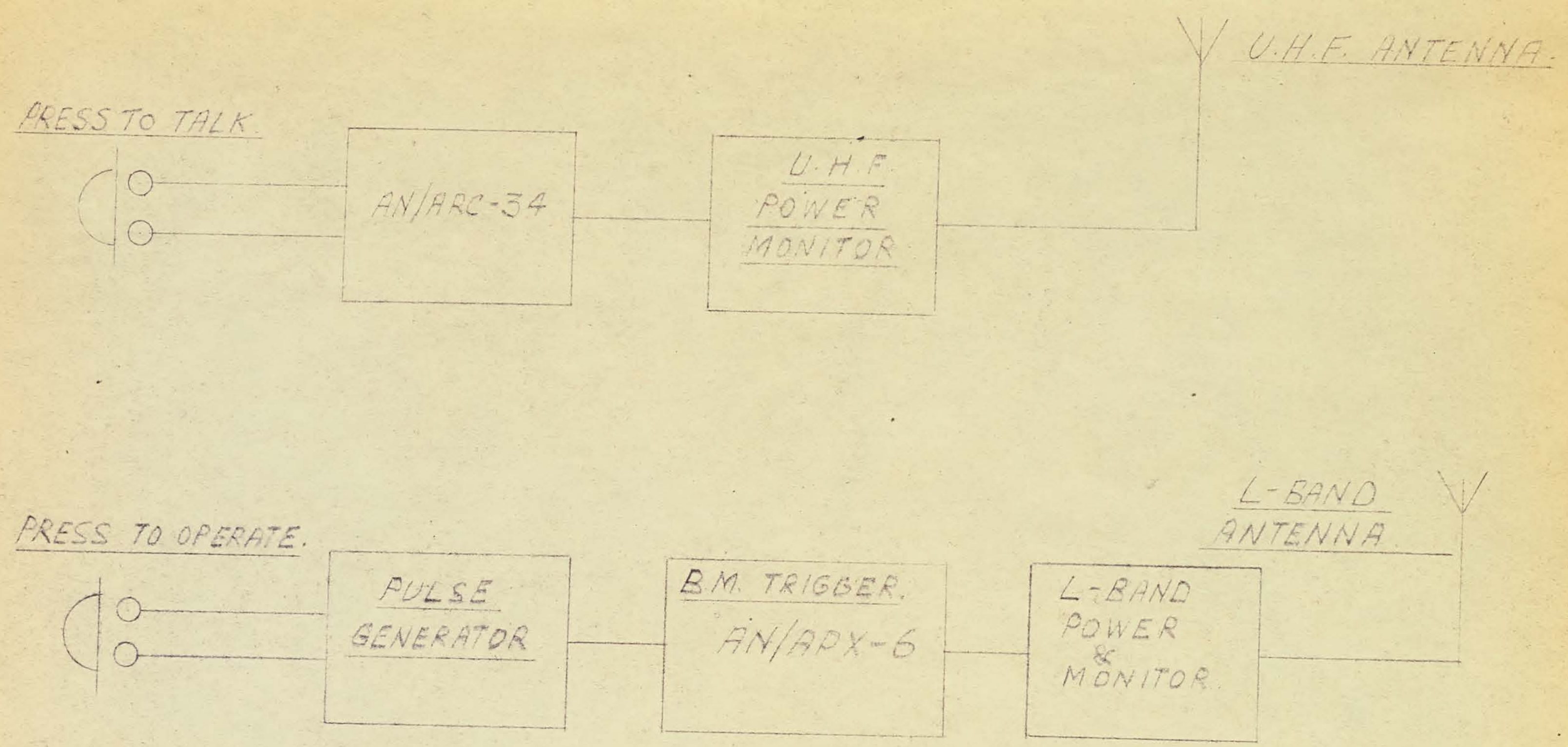


FIG. 9. AIRBORNE SYSTEM