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NATIONAL RESEARCH COUNCIL OF CANADA

RADIO AND ELECTRICAL ENGINEERING DIVISION

THE MZEW RADAR
(EXPERIMENTAL AN/FPS-502 RADAR)

S. G. JONES

OTTAWA

MARCH 1953

ABSTRACT

To assist in the development program of the AN/FPS-502 Radar (an early-warning search equipment based on the A.A. No. 4 Mk.6 Radar) certain studies and investigations were undertaken. An experimental model, designated "MZEW", and incorporating a number of the features of the proposed final equipment, has been constructed by modification of an A.A. No.4 Mk.6 Radar. Flight trials have been conducted to check the performance of the equipment.

The performance to be expected as a result of the various changes in system parameters is outlined. A substantial improvement in performance, in a search role, was predicted, and experimental verification was obtained in the results of the flight trials. Design and performance data on a new, enlarged (21' by 4') antenna are given, and a comparison is made of the operational capabilities of the AN/FPS-3 and the experimental 12-inch A.A. No.4 Mk.6 PPI displays. A description of the flight trials, and details of the results obtained are included. Other aspects, such as tower mounting and mobility of the equipment, are considered.

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THE MZEW RADAR

(Experimental AN/FPS-502 Radar)

INTRODUCTION

Early in 1952, discussions were commenced concerning the feasibility of developing a fixed (and possibly a mobile) early-warning search radar based on the A.A. No.4 Mk.6 (MZPI) radar equipment. The designation "MZEW" was given to the experimental model of the equipment by the National Research Council. The RCAF and USAF designation for the final equipment was "AN/FPS-502".

The MZEW radar was conceived for two applications in the main Air Defence System: as a back-up equipment for the large radars (AN/FPS-3 and AN/CPS-6B), and for gap-filling. Definite requirements for such a radar existed with both the RCAF and USAF. Originally, speed of procurement, and performance per dollar cost were stressed, so the simplest equipment which could fulfill the performance requirements was envisaged. It was to be, in itself, a complete MTI-equipped radar, and in addition, would supply azimuth, range, and IFF information on all aircraft operating within its range, for display on the remote plan position indicators of the principal radars.

It is convenient to refer to the various phases of the development of the MZEW Radar as modifications to the A.A. No.4 Mk.6 equipment. These modifications were to be made by Canadian Arsenals, Ltd., in co-operation with the Radio and Electrical Engineering Division, of the National Research Council. It was agreed that the Directorate of Armament Development (Army) would remain the design authority.

NRC COMMITTMENTS

In addition to the studies and investigations necessary in its role of advisor to the design authority, NRC undertook to do the following:

1. Design, construct, and test an enlarged (21' by 4') antenna, in order to determine if it were feasible to obtain the desired extension of maximum range of the A.A. No.4 Mk.6 in the MZEW equipment.

2. Study the performance of the type AN/FPS-3 Plan Position Indicator when used with the A.A. No.4 Mk.6 Radar.

PROPOSED SYSTEM MODIFICATIONS

When the proposal was made to use the A.A. No.4 Mk.6 as a search radar for air defence purposes rather than as an acquisition radar for anti-aircraft artillery, it was obvious that certain changes could readily be made to increase its usefulness in the new role.

1. High-angle cover could be sacrificed in favour of a narrower beam in the vertical plane (providing higher gain).

2. A longer antenna could be used if mobility requirements could be reduced. Thus, a further increase of gain would be secured, together with a narrower beam in the horizontal plane.

3. The rate of scanning could be reduced from 18 rpm to as low as 3 rpm, since a lower information rate would be acceptable.

4. A proposal to increase the pulse length from 1 to 2 microseconds was already being tried out in the A.A. No.4 Mk.6 Radar, and incorporation of this change in the search model would not be opposed on the grounds of possible loss of range resolution. The increased magnetron duty-cycle was not regarded as likely to cause a significant reduction in magnetron life, as it would be held within safe limits by a simultaneous reduction in pulse recurrence frequency.

No further changes, such as receiver improvements or MTI were considered, since the purpose was to establish the increase in performance over the A.A. No.4 Mk.6 Radar. Any receiver improvements would be equally applicable to the A.A. No.4 Mk.6 and an MTI system would presumably be gated and not used at long ranges. Similarly, possible losses due to sweep compression in the displays were not estimated, because it appeared reasonable to assume that delayed or off-centered sweeps, using the same expansion as in the normal A.A. No.4 Mk.6 Radar, could be utilized. Hence the visibilities would be essentially the same.

On the basis of the above considerations, an estimate of the possible increase in performance was made.

1. The vertical aperture of the antenna could be doubled, giving an increase in gain of 3 db in both transmitting and receiving, or a system gain of 6 db.

2. The horizontal aperture could be increased about 50 per cent, giving an increase in gain of 1.5 db, or a system gain of 3 db.

3. If full advantage could be taken of the increase of pulse length by reduction of receiver bandwidth, a further system gain of 3 db would be obtained.

From these sources alone, therefore, an expected system gain of 12 db or a range increase of 100 per cent would be obtained over the performance of a conventional A.A. No.4 Mk.6 Radar (on which detailed flight trial data was available).

At the time that these proposals were put forward, the predicted increase in performance was left at the above figure. It was recognized that a further 3 db, or 19 per cent increase in range, should be available through reduction of scanning rate. However, it was preferable to hold this increase in reserve, to allow for possible shortcomings in the reduction of receiver bandwidth and in the displays, and for a reduction of pulse recurrence frequency consistent with the increased maximum range.

MZEW ANTENNA

(a) Electrical Design

Since the MZEW antenna reflector was scaled from the A.A. No.4 Mk.6/2 antenna, it was not necessary to change the design of the feed horn. The slotted waveguide array was designed to give as large a gain as possible, consistent with side lobes of about 10 per cent amplitude (20 db down). A 2-1 amplitude taper was chosen, which theoretically, will produce a 6-db beam width of 1.4° from the 247-inch aperture of the MZEW antenna, with maximum side lobe amplitude of 11 per cent. The same type of slot and slot-spacing as was used in the prototype of the A.A. No.4 Mk.6/2 antenna built by Canadian Arsenals, Limited, was used for this array. This was expected to simplify production, and to result in an antenna on exactly the same wavelength band as the A.A. No.4 Mk.6 (10.35 to 11.1 cm.). The slotted-waveguide array, therefore, consists of 68 slots, spaced 3.630 inches from center to center, and a radiating flat load of the type used on the A.A. No.4 Mk.6 antenna.

The radiation patterns and the voltage standing-wave ratios of the slotted waveguide array and horn were measured. The measured beamwidth to half-voltage points was 1.5° , and the side-lobe level was 10 per cent at the design wavelength of 10.7 centimeters. Patterns were considered satisfactory for wavelengths from 10.35 to 11.0 centimeters. The voltage standing-wave ratio was 1.05 at 10.7 centimeters and less than 1.08 at 10.35 to 11.0 centimeters, and 1.2 at 11.1 centimeters. The relatively poor performance for wavelengths greater than 11.0 centimeters was attributed to lack of proper slot covering. It is believed that when the slots are covered with No. 27 Scotch electrical tape, performance will be good over the 10.35 to 11.1 centimeter band. Since the antenna was initially to be used only for wavelengths between 10.65 and 10.75 centimeters, it was decided to cover the slots with No. 27 tape and to proceed with flight trials, postponing further measurements.

Horizontal patterns of the complete antenna were measured in the three beam positions. The patterns for the low beam for representative wavelengths in the band 10.35 to 11.1 centimeters are shown in Figs. 1, 2, and 3. The patterns for the medium and high beams have not been included as the changes produced in the horizontal patterns by changing beam positions are second order effects only. 10-degree sectors of the pattern have been shown as there are no side lobes with amplitude greater than 2 per cent (34 db down) outside this sector.

Vertical patterns were measured on a four-foot section of the antenna reflector. These measurements established the coverage to be expected from this antenna, and the relation between reflector position and the position of the beams in space. The predicted coverage shown in Figs. 4 and 5 was based on these measurements for beams 3°, 6½°, and 14½° above the horizon.

(b) Mechanical Design

As an initial experiment, a four-foot section of the reflector was made up, together with a four-foot array. Vertical radiation patterns were taken, and on the basis of the results achieved, it was decided to proceed with a full-scale model. A composite wood and aluminum reflector, 21 feet by 4 feet was, therefore, designed and fabricated. This was mounted on the A.A. No.4 Mk.6 trailer, together with a 21-foot array and horn. The resulting structure was far from perfect mechanically, but sufficed to conduct initial tests on range, operating characteristics, etc.

For the first tests, the A.A. No.4 Mk.6 drive pulleys were changed to reduce the rotational speed from 16 rpm to 10½ rpm. After the initial tests, the drive was further modified by addition of a primary gear reduction to provide a 3-rpm rotation speed.

To check the power required to rotate this larger antenna, a 1/8 scale model of the antenna and trailer was made in the shops. This model was then tested in the N.A.E. #3 wind tunnel. The torque about the rotational axis of the antenna was measured for an azimuth angle range of 360°, and three positions of the trailer relative to the wind. The position of the trailer with respect to the wind did not alter the torque values appreciably. The tests indicate that the maximum torque load induced by a 100 mile an hour wind at standard sea level conditions would be 11,500 pound-feet on the full-scale antenna.

DISPLAY ON AN/FPS-3 INDICATOR

The provisional specification for the AN/FPS-502 Radar suggests that, if possible, a type AN/FPS-3 Indicator be used in the equipment. The remote indicators which the set would feed are also of this type, or almost identical to it. In order to compare the quality of picture obtainable on this display with that produced by the A.A. No.4 Mk.6 experimental 12-inch display (with fluoride-screen cathode-ray tube), both displays were operated simultaneously from the A.A. No.4 Mk.6 Radar which was fitted with the larger (MZEW) antenna. A 2-microsecond pulse was used, but the bandwidth of the receiver was unchanged. Video information, range markers, and trigger pulses of the correct amplitude and polarity were supplied to the AN/FPS-3 Indicator from the A.A. No.4 Mk.6 Radar through an adapter unit and twenty-foot lengths of cable. The following table gives details of the interconnections:

TABLE I

SIGNALS	From A.A. No.4 Mk.6		To FPS-3 Indicator	Adapter Unit Function
	Amplitude and Polarity	Location	Amplitude and Polarity	
Video	2.5 - 10 volts (unlimited) positive	Cathode V_5, Unit 56 (or Term. 13, Unit 68)	1.5 - 2.5 V. Positive	Video Limiter and Cathode-follower Amplifier
Range Markers	17 volts Negative	Test Point SK-5, Unit 74	15 - 40 V. Positive	Inverter-Amplifier
Trigger Pulses	145 volts Negative	Terminal No. 12, Unit 74	25 - 30 Volts Positive	Inverter-Amplifier

FLIGHT TRIALS

Flight trials were conducted with Sabre (F-86) and Mustang (P-51) aircraft to determine coverage, and with North Star and B-29 aircraft to check the range of the radar.

Figs. 4 and 5 show the results of Sabre, Mustang, and North Star trials. It is seen that the coverage is approximately what was expected, but that the beams were directed lower than desired. Since the antenna was a "lash up" model this was not too surprising. With a properly engineered antenna, it would be relatively easy to set the beams very close to the positions shown in Figs. 4 and 5. (For a more complete report covering this part of the flight trails see Reference 2).

For the B-29 flight trials, the speed of antenna rotation was reduced from 10.5 rpm to 3 rpm, the type-1N21B crystal was replaced by type-1N21C, a faulty joint in the antenna feed system was corrected, and the system properly matched. The improvement in performance resulting from these changes was estimated to be 3½ db. In addition, a type-FPS-3 Indicator was installed in an adjacent trailer, and this display was operated simultaneously with the A.A. No.4 Mk.6 experimental 12-inch display (with fluoride-screen cathode-ray tube). Records of target detection on each of these displays were obtained, and the operators were interchanged at various times during the trials in an attempt to minimize the effect of differences in individual operators. Identical sweep expansions were employed on the two displays (i.e., 100,000 yards, 200,000 yards, 200,000 yards with 100,000 yards delay in the start of the sweep) out to 150 nautical miles. This was the normal limit of the A.A. No.4 Mk.6 display, but it was possible to display considerably greater ranges (at reduced expansion) on the FPS-3 display. The results of the flight trials with B-29 aircraft are shown in Figs. 6 and 7.

RESULTS AND CONCLUSIONS

The detailed results of the MZEW flight trials are shown in Figs. 4, 5, 6, and 7. It is considered that these data constitute the very minimum necessary to assess the capabilities of such an equipment. Much more data would be required before a firm statement of the performance under varying conditions of site, target, etc., can be made. However, considerable data is available on the performance of the A.A. No.4 Mk.6 Radar, and all predictions for the MZEW Radar were made relative to the capabilities of the A.A. No.4 Mk.6. It would seem only reasonable, therefore, to state the results and conclusions in terms of the comparative performance of the two radars.

Reference (1) sets forth the results obtained in flight trials of the A.A. No.4 Mk.6 Radar conducted in 1950 from an almost identical adjacent site, with target aircraft flying over areas which, while not identical, have similar topographical features. Different aircraft were used, but allowance can be made for this on the basis of equivalent echoing areas. It is proposed to set forth a comparison of the performance of the MZEW Radar relative to the A.A. No.4 Mk.6 equipment, using the data obtained in the present field trials on Sabre aircraft and those obtained in the 1950 trials on Vampire aircraft. The equivalent echoing areas of these aircraft are such that an increase of 6 per cent in range would be expected for the Sabre over that obtained for Vampire aircraft. The approximately 1-decibel improvement to be expected by the reduction of the antenna rotation speed from 16 to 10.3 rpm, is just offset by a deterioration in overall receiver noise figure (as measured during the Sabre trials) from about 10.4 db. to 11.5 db.

As outlined above, a system gain of 9 db., or a range increase of 68 per cent was expected because of the larger antenna. A receiver of narrower bandwidth, to take full advantage of the increase in pulse length from 1 to 2 microseconds, was not used. Therefore, only a portion of the predicted 3-db improvement due to this change is applicable. It would appear, then, that the range performance of the MZEW Radar relative to the A.A. No.4 Mk.6 Radar should be greater than 168 per cent, but less than 200 per cent. (This, of course, assumes that the operational condition of the basic radar, and the abilities of the operators, were equal in the two sets of flight trails. It is considered that such an assumption is reasonable.) Comparative study of the results of the data obtained in the two sets of flight trails indicates that the relative range performance of the MZEW Radar is about 186 per cent (ranges on the "nose" of the low beam were compared). This constitutes good experimental verification of predicted performance. It must be kept in mind that this is not a measure of the ultimate performance to be expected of the MZEW Radar, but merely that which could be expected, and which was actually obtained, under the conditions existing during the flight trials with Sabre aircraft. The relative performance when all the proposed changes are made should be at least 200 per cent.

On the basis of experience of various American laboratories, the equivalent echoing area of a B-29 aircraft is such that an increase in range of detectability by a factor of between 2 and 2.5 over that of Sabre-type aircraft can be expected. In the B-29 trials, for ranges in excess of 120 nautical miles, the aircraft was always below the "nose" of the beam, and the lower edge of the beam was not too well defined in the Sabre flight trial data. On the basis of the data which is available, and assuming the above range increase factor to be applicable, it would be reasonable to assume that returns from a B-29 aircraft flying at 30,000 feet will be visible at ranges up to at least 160 nautical miles, if the lower beam were in the same position and had the same shape that it had for the Sabre trials. Figs. 6 and 7 show experimental verification of this. However, use of this range figure should be treated with extreme caution, as it is based on a meager quantity of data. Such factors as poorer site, deterioration in radar performance, operators with less experience or ability, or poor meteorological conditions, could reduce the figure considerably.

A comparison of the data obtained with the A.A. No.4 Mk.6 experimental 12-inch display and the AN/FPS-3 Indicator would appear to show a small performance difference in favour of the A.A. No.4 Mk.6 display. It is considered that this is due, entirely, to the smaller spot diameter and better viewing properties of the fluoride-screen cathode-ray tube, with its higher accelerating voltages, and the absence of the bright blue flash of the type P-7 phosphor screen. The modification of the type FPS-3 Indicators to permit the use of a CV.429, or similar type of cathode-ray tube, is suggested for slightly increased visibility and decreased operator fatigue. However, quite satisfactory performance is obtained when the type AN/FPS-3 Indicator is used in conjunction with the A.A. No.4 Mk.6 Radar.

SYSTEM INTERCONNECTIONS

Considerable study has been given to the system interconnections between the AN/FPS-502 Radar and the AN/FPS-3 or AN/CPS-6B Radars. Originally, as has been pointed out previously, the simplest equipment which could fulfill the performance requirements was envisaged. It was, therefore, assumed that any useful portions of the primary radar video systems, such as range and angle mark generators, calibrators, interference blankers, and line amplifiers could be made use of in the AN/FPS-502 role. The present conception of the radar is more ambitious in scope, with complete paralleling of facilities, except for the actual PPI displays, primary power supply, and, presumably, communications.

The exact nature of the arrangements to be made here are still under discussion amongst the various agencies interested in this equipment.

TOWER MOUNTING AND MOBILITY

Although the AN/FPS-502 equipment was conceived as a fixed radar, it is apparent that it could also be readily converted into a mobile unit. The standard A.A. No.4 Mk.6 trailer can accommodate the transmitter, receiver, including M.T.I., I.F.F. equipment, and one display unit (possibly not a full size AN/FPS-3 indicator) together with the simplified range and angle mark generators developed in the USA for later models of the AN/FPS-3 equipment. It is questionable whether any spares cabinet could be provided, and the de-humidifier unit, if used, must be mounted externally. It is doubtful if a plotting board similar to that in the standard A.A. No.4 Mk.6 trailers could be provided in a position where it would be of any real utility.

With the possibilities of fixed and mobile uses in mind, the MZEW antenna was designed as shown in Figs. 8 and 9 so that it could be folded down on top of the standard A.A. No.4 Mk.6 trailer in transit, with the addition of brush guards, and a lengthened tow-bar to avoid damage should the truck-trailer combination be "jack-knifed" in a sharp turn. The reflector would overhang the trailer by two feet at each end, while the waveguide feed would extend considerably farther unless it were arranged as in the radome model (Fig. 10).

For fixed service, the design of the antenna allows use of an RCAF type-30 tower with a 22-foot (base diameter) radome, as illustrated in Fig. 10. In order to give an adequate safety factor against radome distortion caused by wind loading, about 6-inches of the top corners of the reflector would have to be cut off. This can readily be done with the present mechanical design, and will not result in any significant alteration in its electrical characteristics.

* * * * * * * *

ACKNOWLEDGEMENT

Personnel from various Sections of the Division collaborated in the MZEW project. The additional task of preparing and correlating the material for publication was assigned to the author, who desires to acknowledge with thanks the considerable contributions made by F.V. Cairns and R.S. Rettie of the Microwave Section, H.E. Parsons of the Engineering Design Section, and W.C. Brown of the Army Section.

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2. Cairns, F.V. "Flight Trials of MZEW (AN/FPS-502) Radar". Report ERA-241 (Secret), Radio and Electrical Engineering Division, National Research Council.

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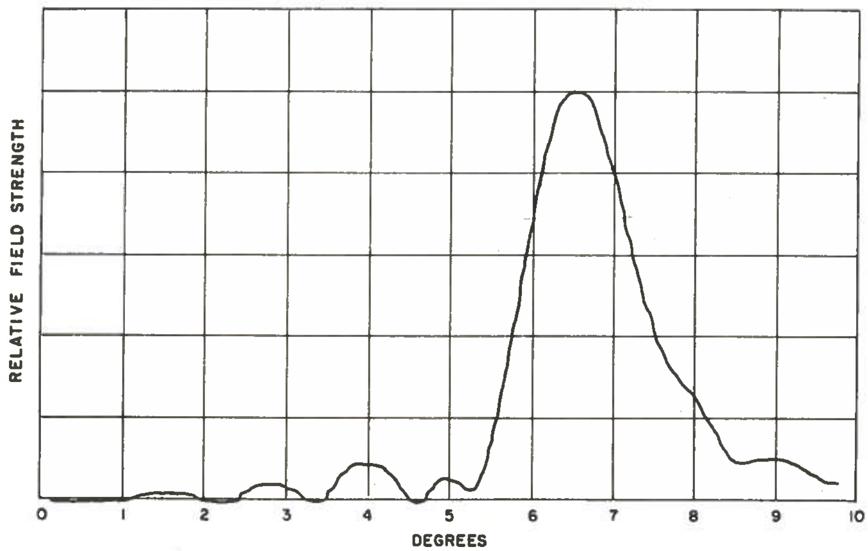
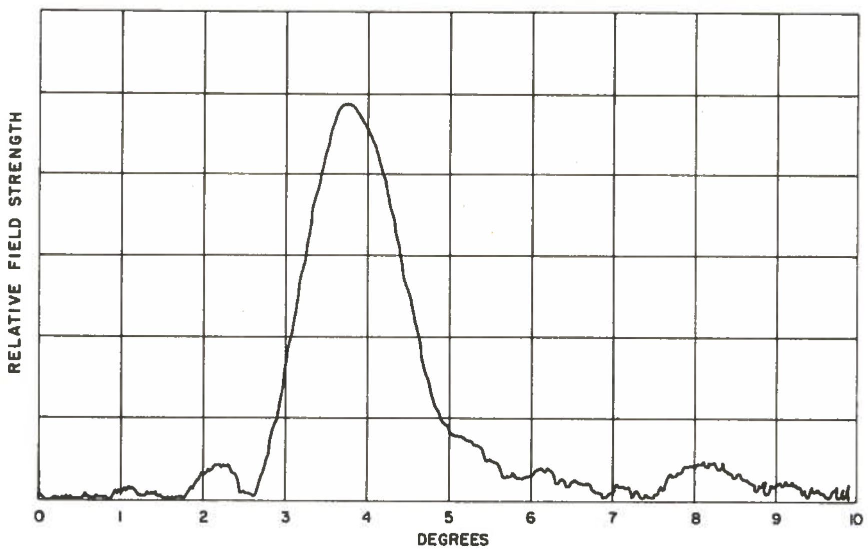


HORIZONTAL PATTERN OF SLOTTED WAVEGUIDE ARRAY AND HORN

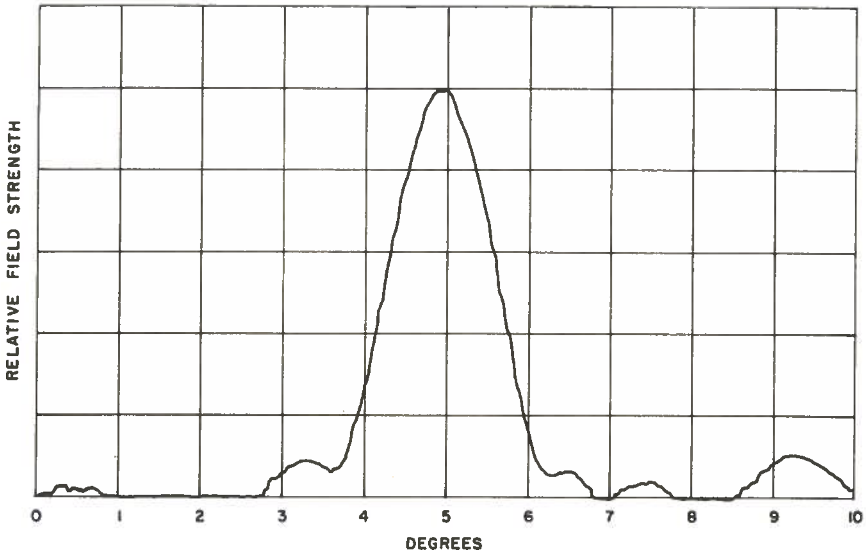
(λ = 10·7 CM)



HORIZONTAL PATTERN OF MZEW ANTENNA

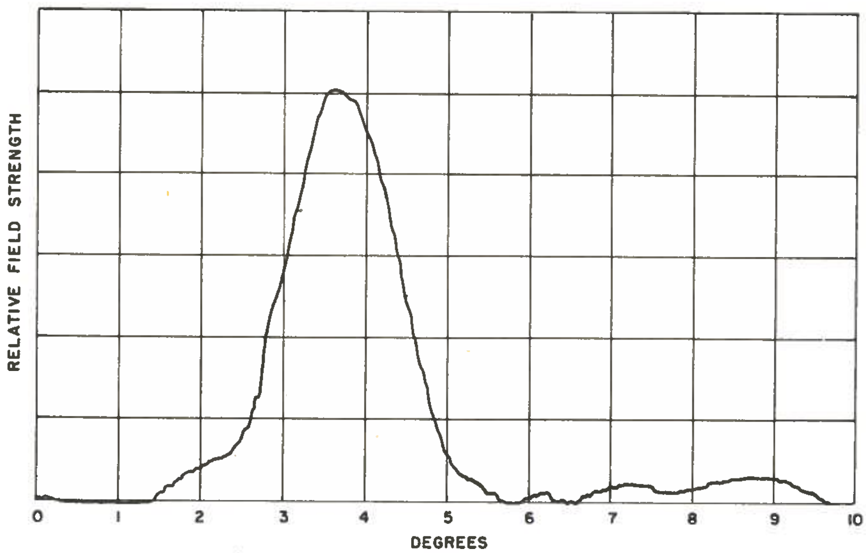
(λ = 10·35 CM)

FIG. 1



HORIZONTAL PATTERN OF MZEW ANTENNA

(λ = 10·5 CM)



HORIZONTAL PATTERN OF MZEW ANTENNA

(λ = 10·7 CM)

FIG. 2

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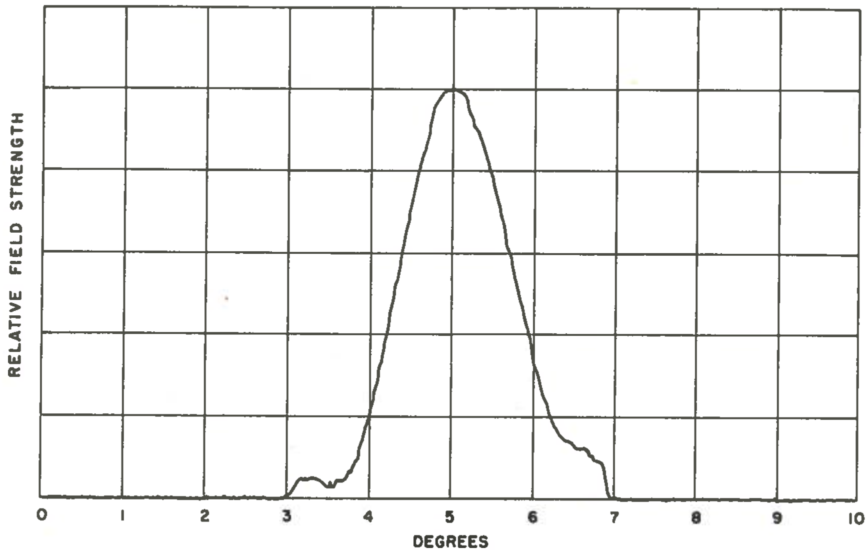
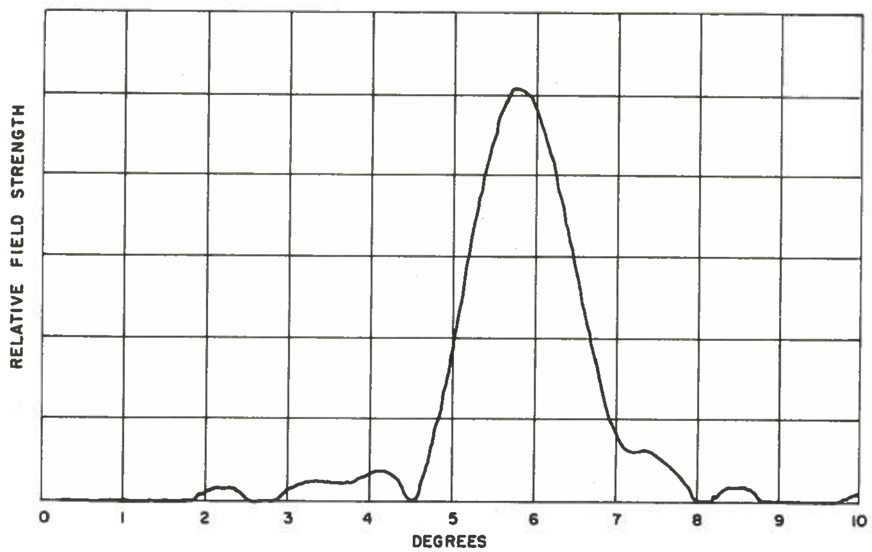


HORIZONTAL PATTERN OF MZEW ANTENNA

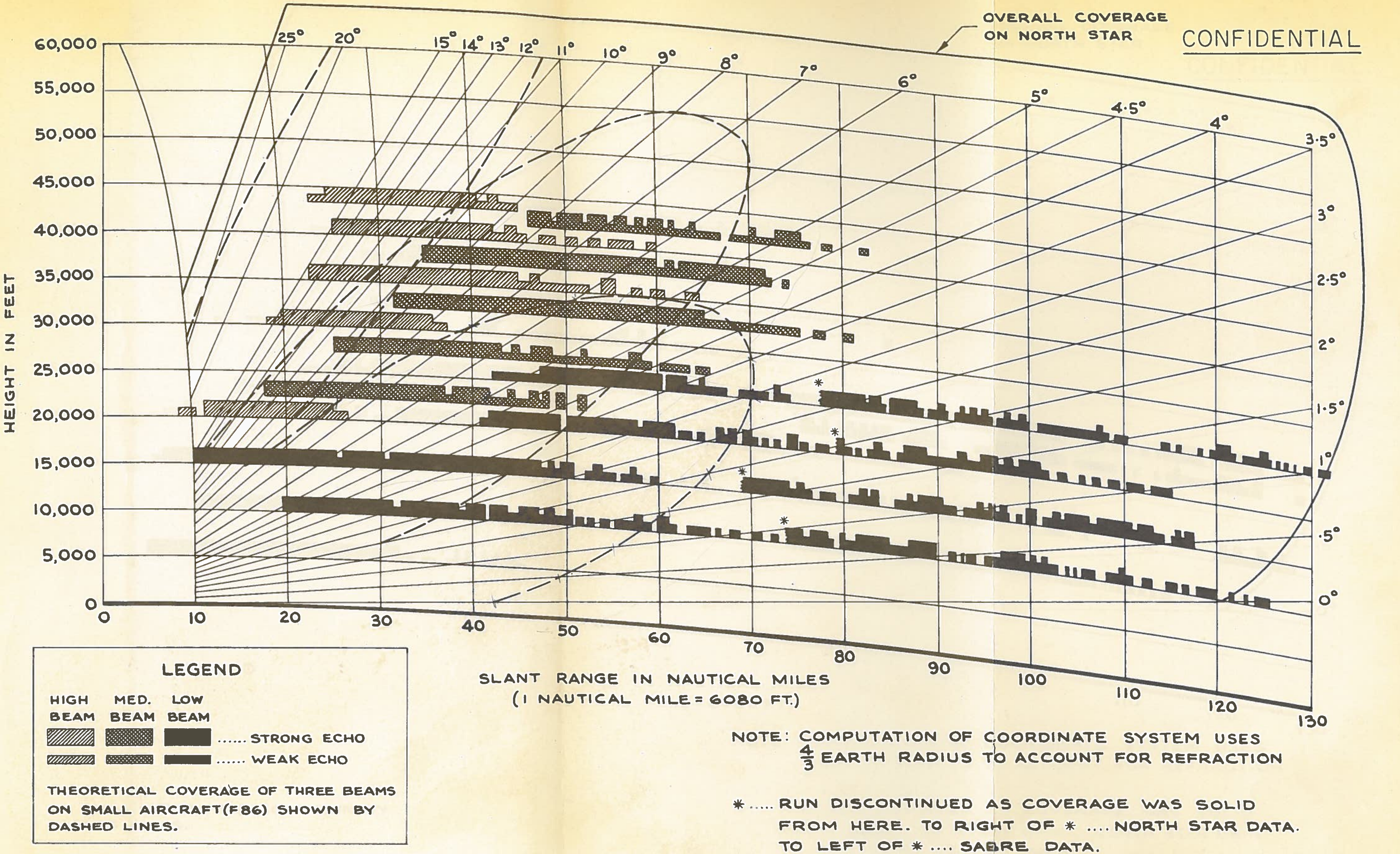
(λ = 10·9 CM)



HORIZONTAL PATTERN OF MZEW ANTENNA

(λ = 11·1 CM)

FIG. 3



FLIGHT TRIALS OF M.Z.E.W. ANTENNA

AIRCRAFT RECEDING

Fig. 4

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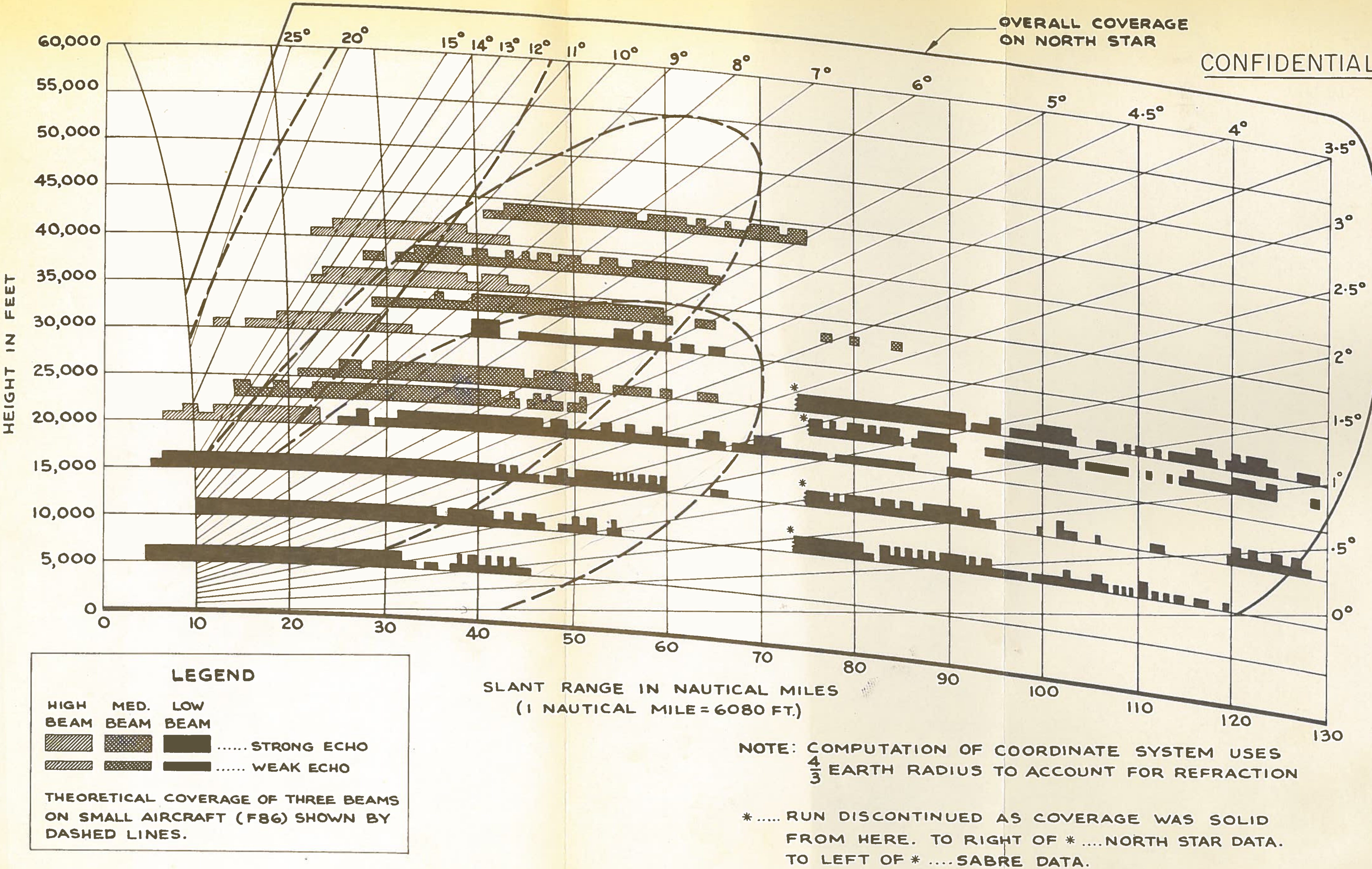
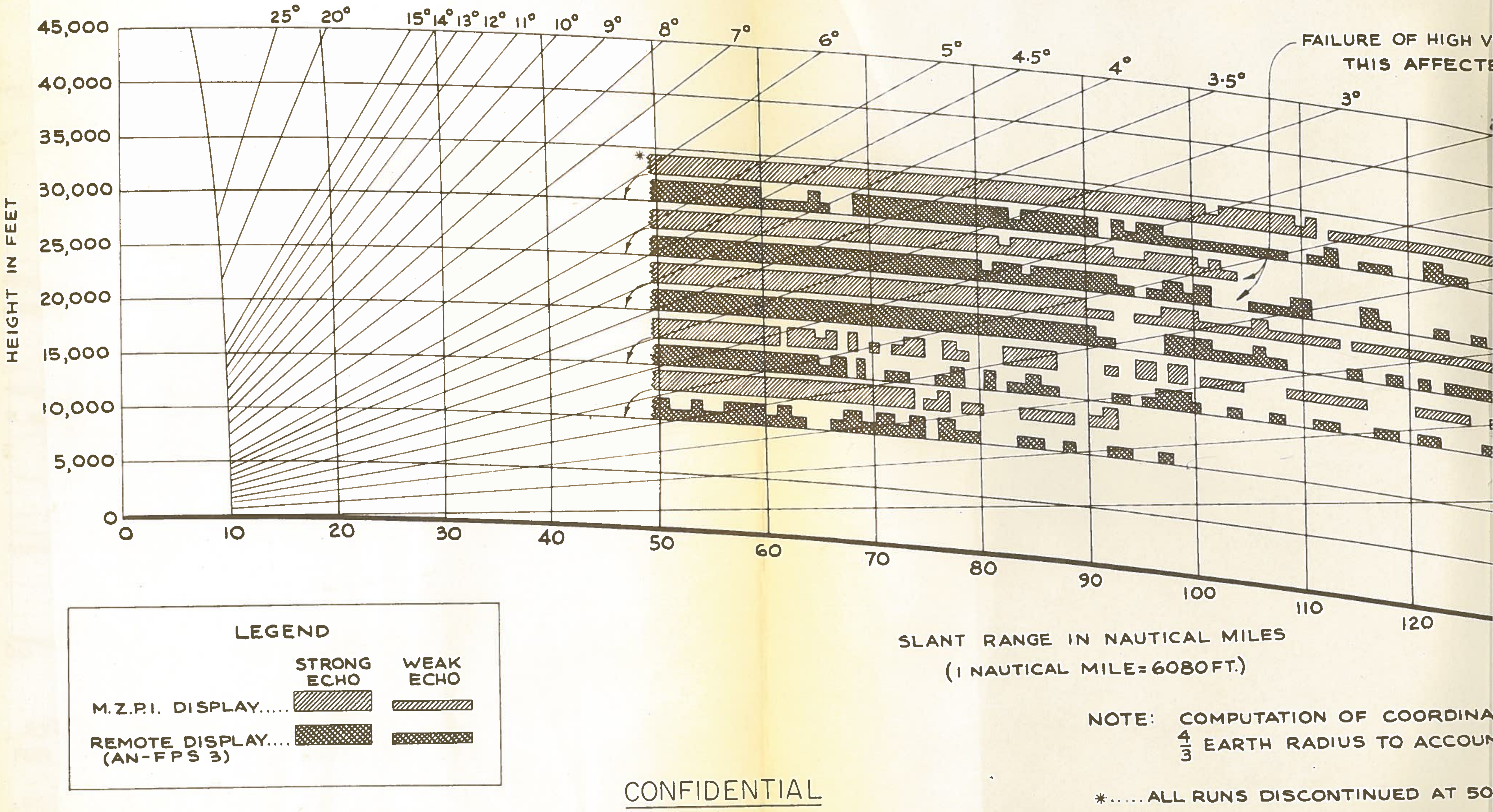


FLIGHT TRIALS OF M.Z.E.W. ANTENNA

AIRCRAFT APPROACHING

Fig. 5

10 R.P.M.



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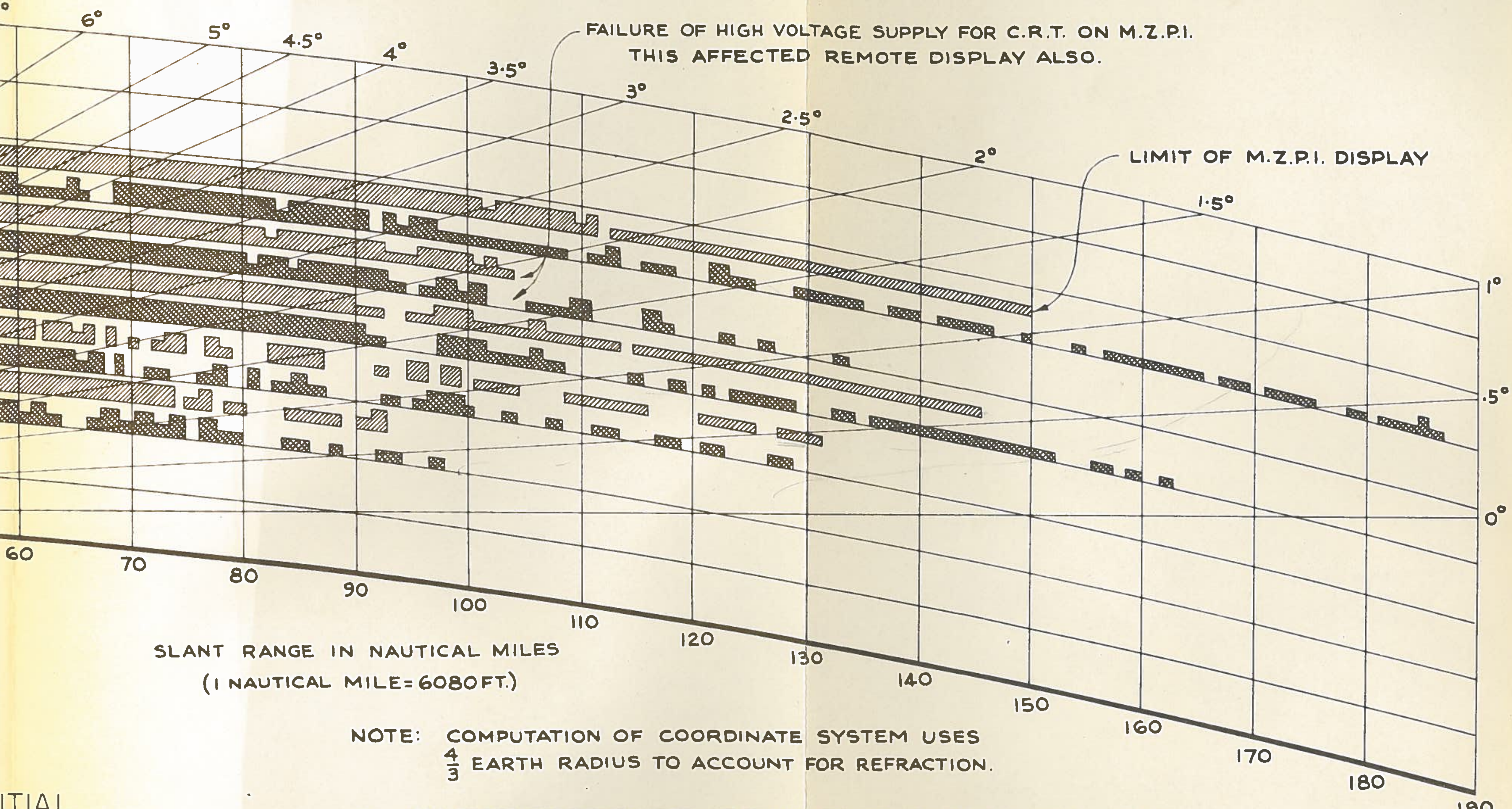
FLIGHT TRIALS OF M.Z.E.W. ANTENNA

B29 AIRCRAFT RECEDING

FIG. 6



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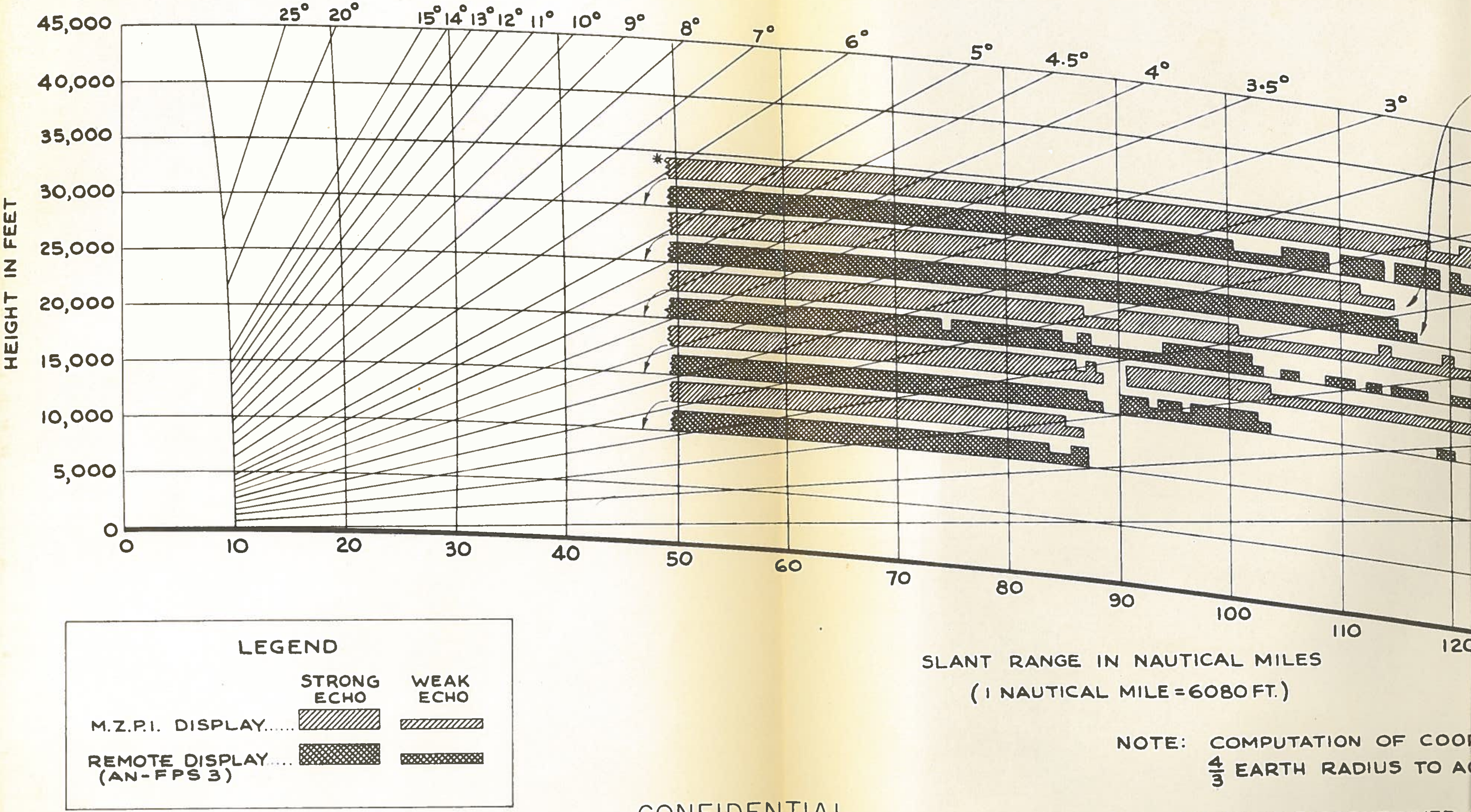
*..... ALL RUNS DISCONTINUED AT 50 MILES AS COVERAGE WAS SOLID.

FLIGHT TRIALS OF M.Z.E.W. ANTENNA

B29 AIRCRAFT RECEDING

FIG. 6

3 R.P.M.



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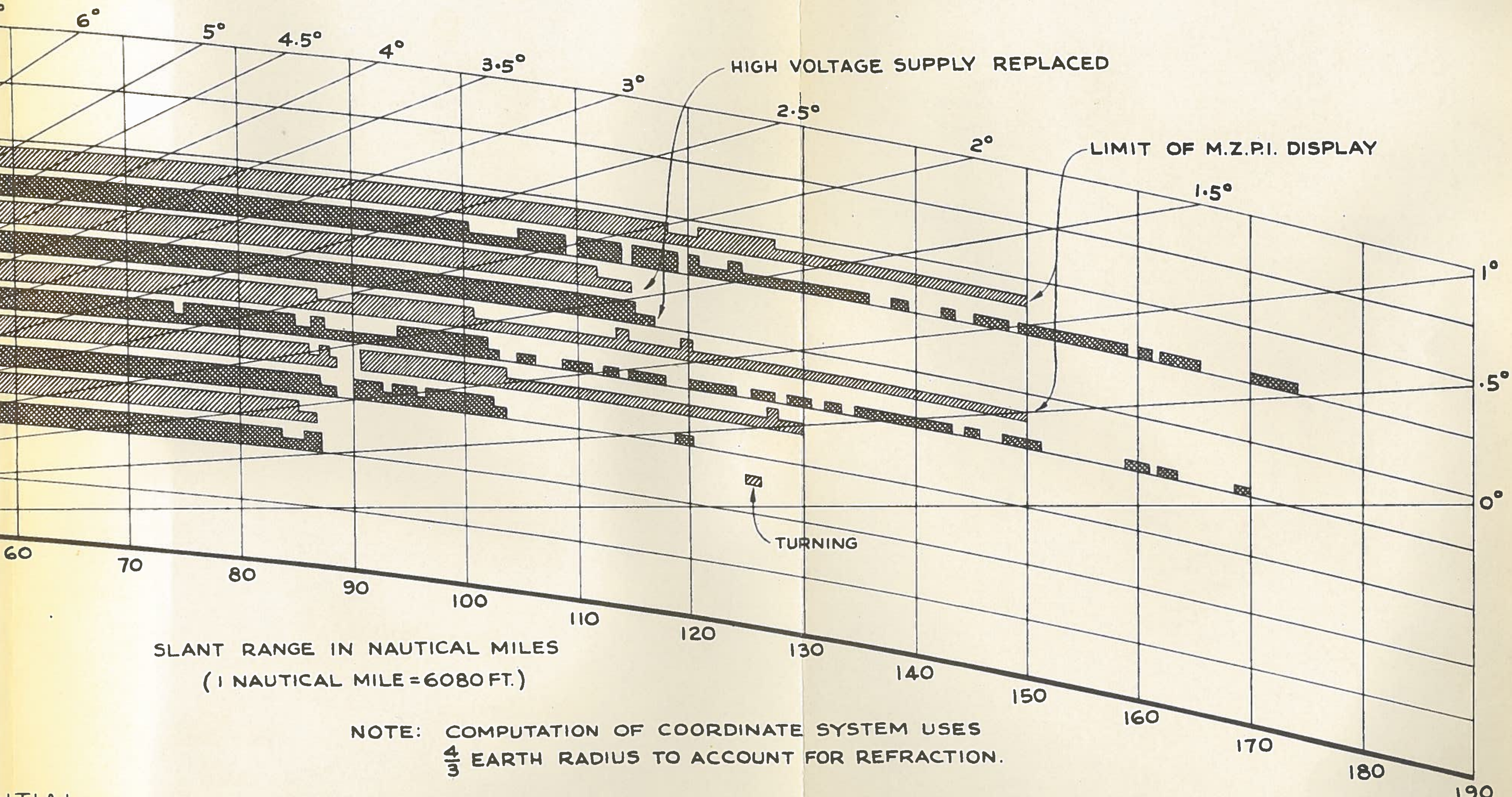
FLIGHT TRIALS OF M.Z.E.W. ANTENNA

B29 AIRCRAFT APPROACHING

FIG. 7



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* ..... ALL RUNS DISCONTINUED AT 50 MILES AS COVERAGE WAS SOLID.

FLIGHT TRIALS OF M.Z.E.W. ANTENNA

B29 AIRCRAFT APPROACHING

FIG. 7

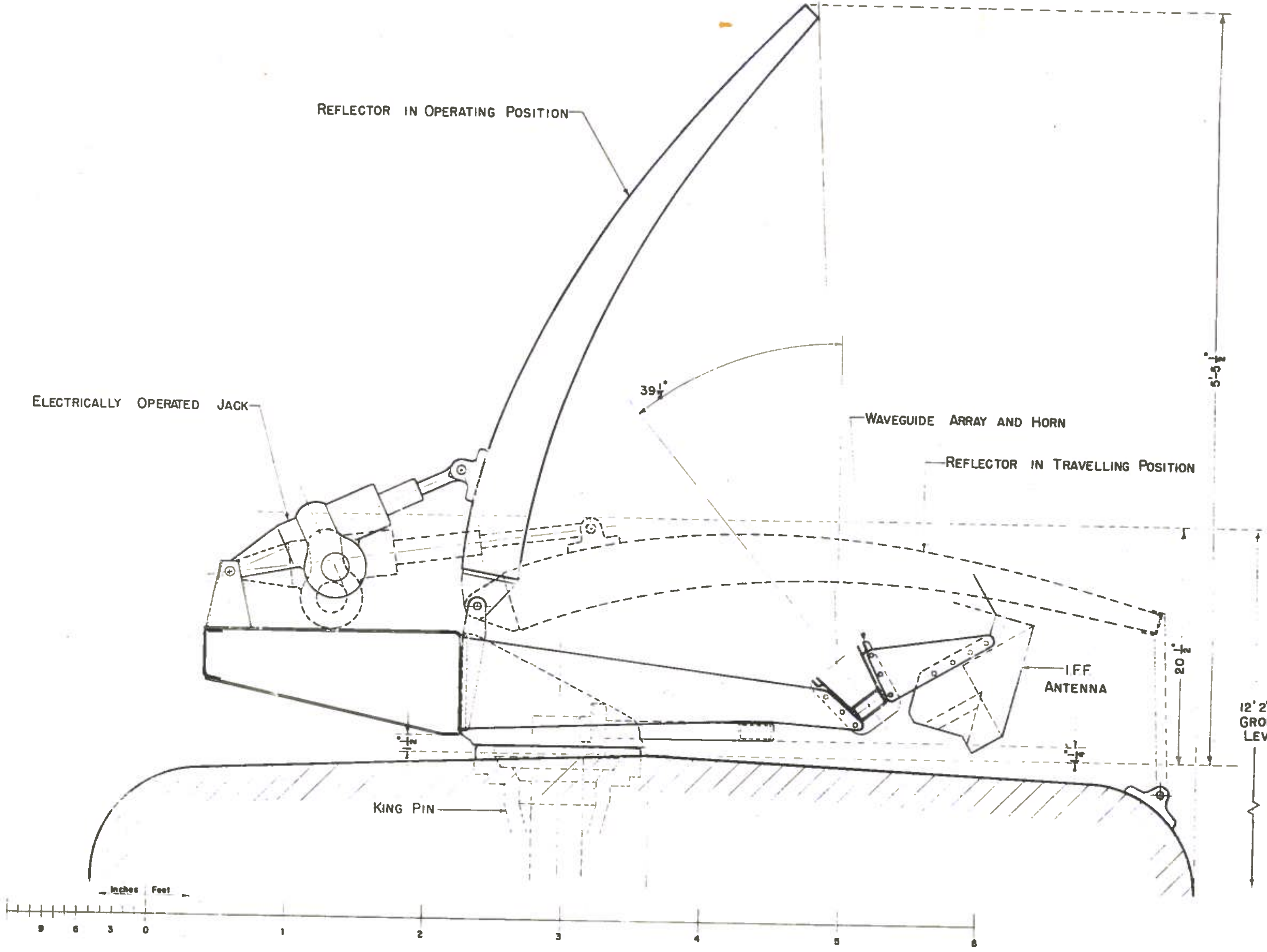

FIG. 8
SKETCH OF MZEW ANTENNA POSITIONED ON TRAILER TOP
END VIEW

RESTRICTED

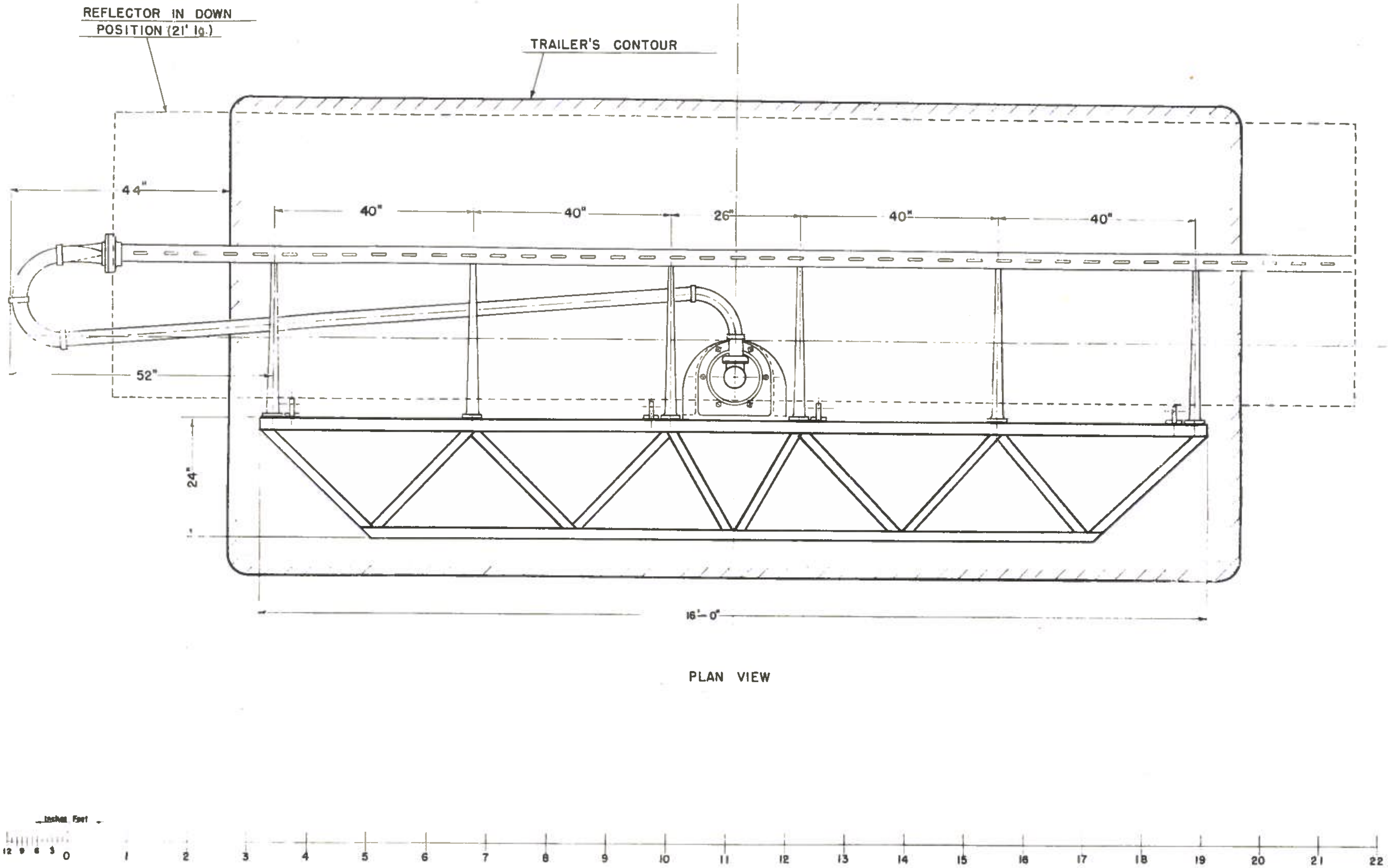

FIG. 9
SKETCH OF MZEW ANTENNA POSITIONED ON TRAILER TOP
PLAN VIEW

RESTRICTED

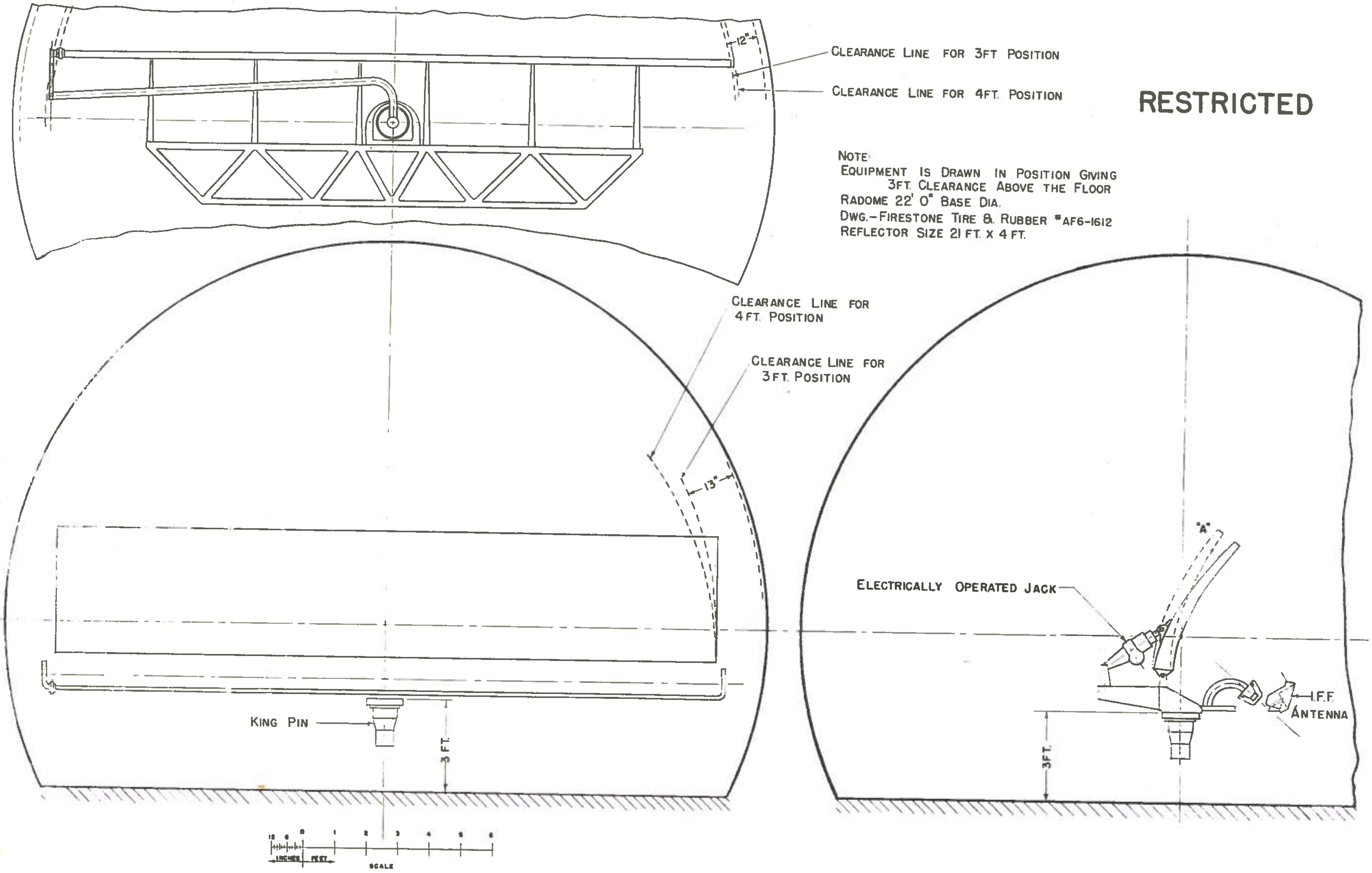

FIG. 10
SKETCH OF MZEW ANTENNA POSITIONED INSIDE RADOME

MZEW RADAR (A.A. No 4 MK VI WITH AN/FPS-502 ANTENNA)

RESTRICTED