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MADRE EVALUATION IV

[UNCLASSIFIED TITLE]

J. M. Headrick, J. L. Ahearn, S. R. Curley, E. W. Ward,
F. H. Utley, and W. C. Headrick

Radar Techniques Branch
Radar Division

June 27, 1962

DEPARTMENT OF THE NAVY · OFFICE OF NAVAL RESEARCH

NAVAL RESEARCH LABORATORY
Washington, D.C.

SECRET

MADRE EVALUATION IV

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A LOW ALTITUDE ATLAS DETECTION AT LONG RANGE

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ABSTRACT

(Secret)

On a PMR Atlas test the launch site and up to 50 km altitude was illuminated by second hop energy radiated from the Madre radar. Weak missile plus exhaust boundary echoes were obtained while the missile was at low altitudes. Analysis of the returns shows the character to be typical of exhaust boundary reflections with promise of extractable doppler information.

PROBLEM STATUS

This is an interim report on one phase of the problem; work is continuing on this and other phases.

AUTHORIZATION

NRL Problem R02-23
Project RF 001-02-41-4007

Manuscript submitted June 19, 1962

MADRE EVALUATION IV
(UNCLASSIFIED TITLE)

A LOW ALTITUDE ATLAS DETECTION AT LONG RANGE
(SECRET)

INTRODUCTION

The Madre HF Radar Project is intended to demonstrate the possibility of over-the-horizon detection and track parameter determination of aircraft and missiles. Some idea of the early lines of development that led to the present research system can be obtained from NRL Secret Report 5023 (by F. E. Wyman and E. N. Zettle, titled "Magnetic Drum Storage Crosscorrelation Radar," and dated 14 Nov. 1957). A description of the Madre installation at the NRL CBA site has been given in short summary form in NRL Secret Memorandum Reports 1251 and 1287 (each titled "Madre Evaluation" and dated respectively 1 Dec. 1961 and 2 Jan. 1962). In brief, the Madre radar is a coherent doppler research system of considerable flexibility and under continuous development. It has the following basic attributes:

1. Up to 100 KW average power generation (10 - 27 mc).
2. A 23 to 17 db (27 to 13.5 mc) gain over an isotrope slewable antenna viewing the North Atlantic.
3. A 16 to 11 db (27 to 13.5 mc) gain over an isotrope antenna rotatable to any bearing.
4. Receiver clutter rejection filters matched to the usual ground backscatter.
5. Sampling and packing of received signals (time compression of 83,000 to one) with the prior 20 seconds of signal information available in each 1/180 second.
6. Doppler versus range signal processing and display (1/3 cps filters matched to constant velocity targets).
7. Magnetic tape storage of the clutter filtered received signals and several techniques of after the fact analysis.

BACKGROUND

The use of the equipment herein described has disclosed several capabilities of such a system and the following are listed:

1. ICBM induced ionospheric flutter can be detected with good certainty, even with low radiated power (one KW average) for AMR launches.
2. Using ionospheric refraction, missile exhaust boundary reflections can be obtained such that rough track parameter determinations are possible. For AMR launches the lowest altitude of detection so far has been about 70 kilometers.

3. On AMR launches, missile skin tracks can be obtained above the horizon and fragmentary skin echoes have been obtained over the horizon. If the missile is under thrust the large exhaust boundary echoes tend to hide the skin at ionosphere altitudes.

4. Aircraft on transatlantic flights have been detected and tracked via an ionospheric path at ranges from 490 to 1800 nautical miles.

5. Round-the-world signals have been circulated on east-west paths at all times of the day with received levels high enough for spectrum analysis.

The success with over-the-horizon aircraft tracking and with above-the-horizon missile tracking indicate that missile launches should be detectable starting at very low altitudes. The lower frequency limitation of the Madre rotatable antenna has prevented illumination of the AMR launch site at any time that a large missile has been fired and so the low level skin tracking possibilities have yet to be demonstrated. During the approaching summer propagation via the E-layer may afford AMR launch site illumination.

Missiles fired from PMR would appear to offer an opportunity for low altitude track study. During nine PMR launches, attempts have been made to obtain missile and exhaust reflections. Four of these were Atlas missiles and the rest were Discoverers. In the case of only one firing was the radar mode of use sufficiently well matched to existing propagation conditions for even fair two-hop illumination of the launch site. Such a showing needs a little explanation. On four observations efforts were aimed at obtaining one ionospheric hop illumination or coverage right after the first ground reflection. Getting appreciable energy transmitted through the region of the predicted missile path proved to be difficult and was never achieved at the time of a missile firing. On the other PMR observations an operating frequency was selected such that the launch site and beyond was illuminated by energy descending from the second ionospheric bounce. Although this operating condition was achievable, it was still obtained at launch time in only one case and in this hardly optimum. Most PMR firings occur at a time when the propagation path from NRL is changing rapidly; PMR countdowns frequently include holds of unspecified length near T_0; and the Madre complex of components is not designed for really quick frequency change. Thus the failures in securing desired illumination are not due to any inherent limitation; however, they emphasize the need for instant frequency flexibility when a certain area is to be covered.

PMR 355201 OBSERVATIONS

On February 28, 1962, an Atlas-E, PMR Test 355201, was launched at 7:14:09 EST (00:14:09 Zulu). 100 KW average power was radiated to the west by the Madre radar at a 90 pps rate, 700 μs pulse length, on 18.036 mc. Figures 1 and 2 give earth's backscatter amplitude versus range at 30 minutes prior to and 6 minutes after launch. These were obtained by reducing the repetition rate to 22-1/2 pps and thus the displayed range is 0-3600 n.m. The backscatter maximum levels averaged at 3 mv peak to peak

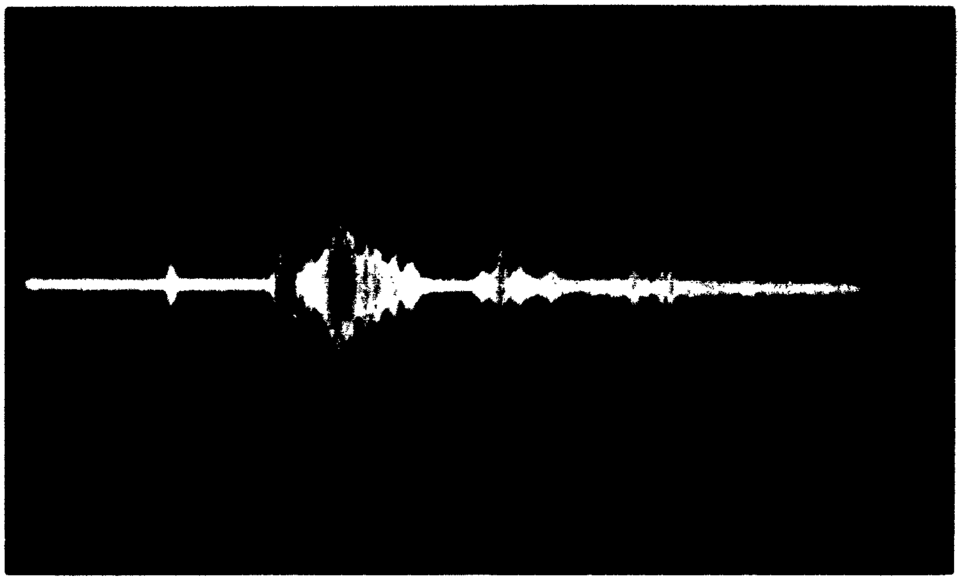

Fig. 1 - Backscatter amplitude at a 500 kc I-F on the vertical versus slant range in nautical miles on the horizontal. Time of picture is about thirty minutes prior to launch.

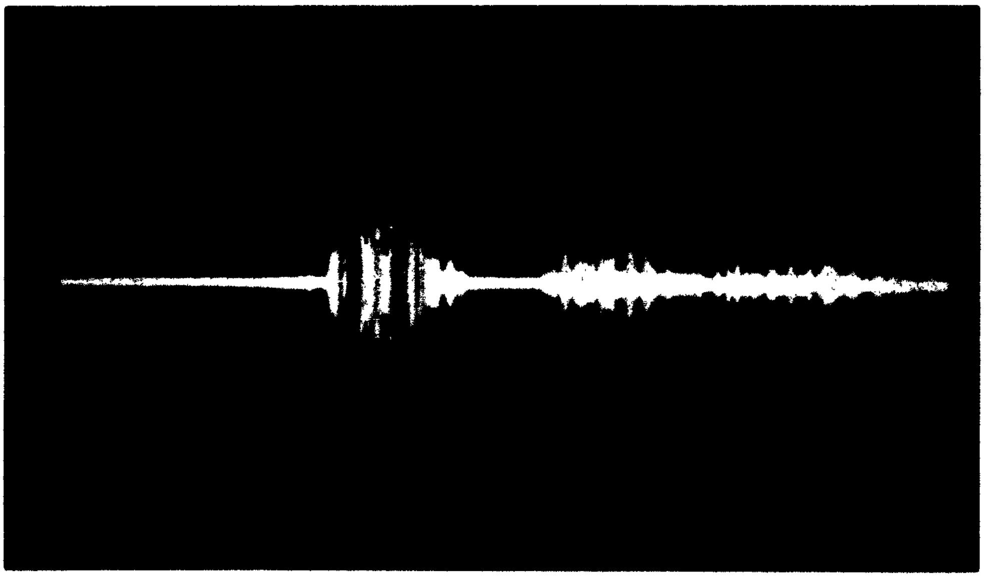

Fig. 2 - Backscatter amplitude at a 500 kc I-F on the vertical versus slant range in nautical miles on the horizontal. This picture was taken five minutes after launch.

for 1 hop and 1 mv peak to peak for 2 hop at the receiver input (50 ohm impedance level). Figure 3 sketches the estimated limiting paths by which the higher level 2 hop backscatter was received. This assay of the situation indicates that good illumination of the missile track runs from 0 to 50 KM in altitude. In order to eliminate nearby aircraft and meteor trail returns the receiver was gated on for only even multiples of 450 n.m. Considering the propagation path this means that any targets detected come from slant ranges greater than 1350 n.m. with the exception of meteor trails that are seen direct at around 500 n.m. The open gate intervals are indicated in Figure 3.

In Figure 4 a sequence of Madre displays are pictured. Time after launch is given on a counter located at the bottom of each picture; time is in the form of hours, minutes, and seconds. The 90 pps repetition rate allows 45 cps of resolvable doppler. This doppler is on the vertical ordinate and is scaled in cycles per second on the left of each picture. The 450 n.m. length of the displayed range interval is scaled across the bottom horizontal ordinate. Thus actual slant ranges will be the indicated distances from zero added to 450, 1350, 2250, etc. In all the pictured displays meteor trail returns may be seen from 0 to 50 on the abscissa and smeared out around 12 on the ordinate. Where these meteor returns extend or repeat at much higher dopplers, they are harmonics generated where the signal level exceeds the linear range of the processing system. The meteor trail returns are from distances of about 450+50 or 500 n.m. Some aircraft returns are in evidence in most pictures and they show a fading character. One aircraft return can be noted at T+9 sec and coordinates 225, 10: it fades but is quite strong again at T+2 min 22 sec and coordinates 200, 10. This is considered to be an aircraft at 1350+200 or 1550 n.m. slant range with a relative doppler of about 10 cps. At the times of these pictures a 0.3 µv peak to peak target signal at the receiver terminals was discernable on the display.

The first missile associated returns can be seen at T+39 sec and are manifested by the faint vertical trace that runs from coordinates 240, 35 to 240, 45. The picture fails to reproduce some of the signal, which at the time was noted to run down to nearly zero doppler. Remnants of this return are visible at T+43 seconds but it is fading. At T+1 minute 15 seconds the missile associated returns reappear running from 240, 5 to 240, 45 and continuing until they fade at T+2 minutes 7 seconds. (Actual slant range 2250+240 = 2490 n.m.) Identification of these echoes as missile associated returns is based on the diffuse doppler filling the 45 cps available at one very discrete range; these are the characteristics of echoes from a missile exhaust boundary and in NRL experience are not associated with natural phenomena.

The zero frequency, clutter filtered, IF recording was repeatedly replayed and by knowing at what time and range to look the missile echoes could be identified. At their strongest the echoes were measured as having about 1 µv peak to peak amplitude at the receiver terminals. Assuming no absorption or reflection loss, this indicates a radar cross section of about 2500 square meters. The range was quite discrete.

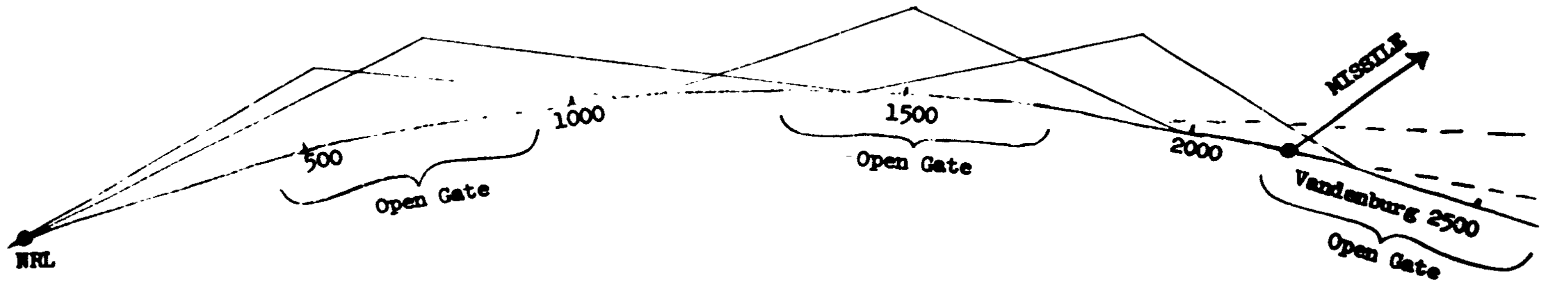

Fig. 3 - A sketch of the limiting paths by which 2nd hop backscatter of high level was received. Range is given in nautical miles.

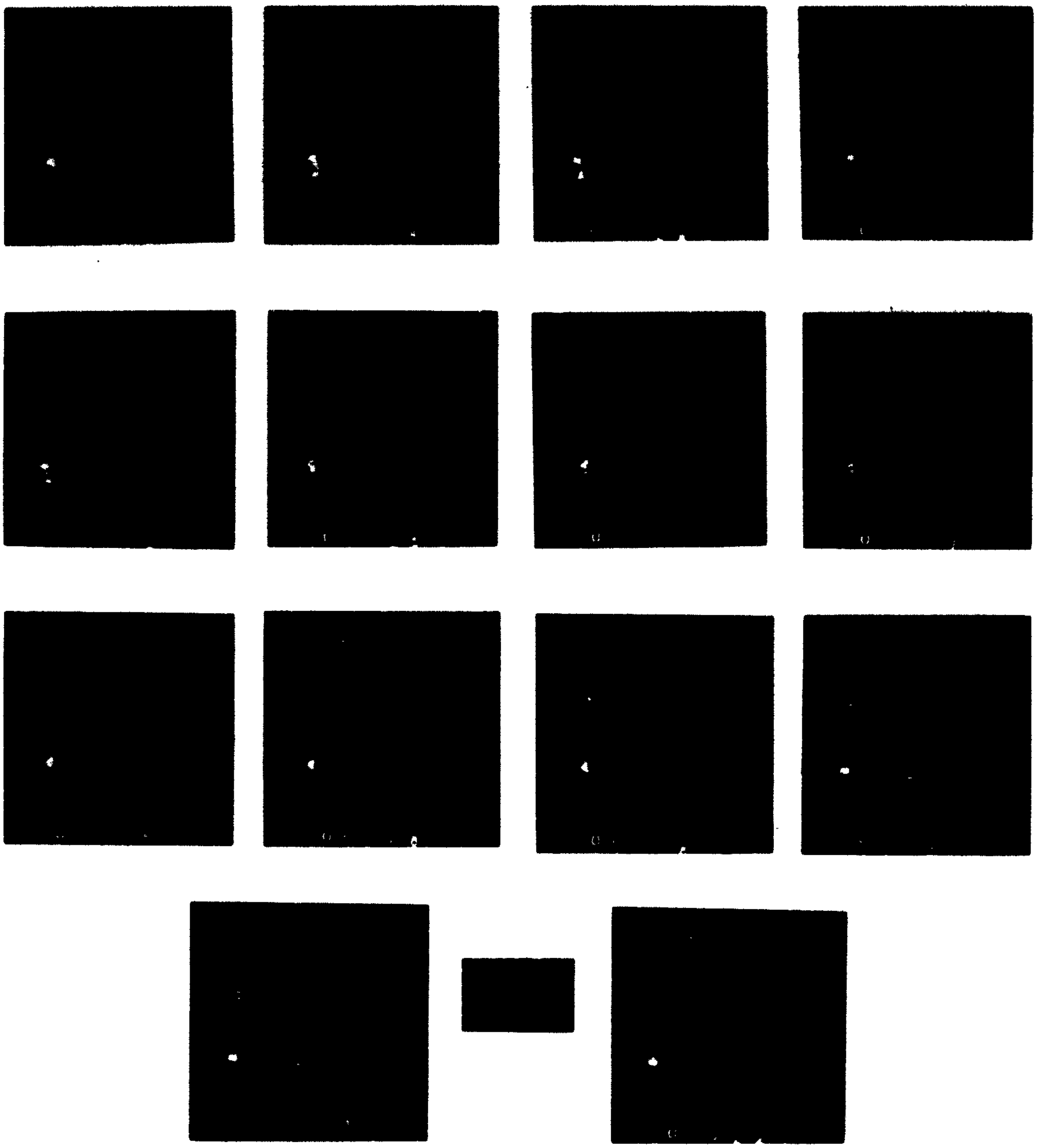

Fig. 4 - Pictures of the Madre display taken after missile launch. Times are given in the form of hours, minutes, and seconds. The vertical ordinate has 45 cps available for target doppler. The horizontal ordinate gives a 450 naut. mi. range interval.

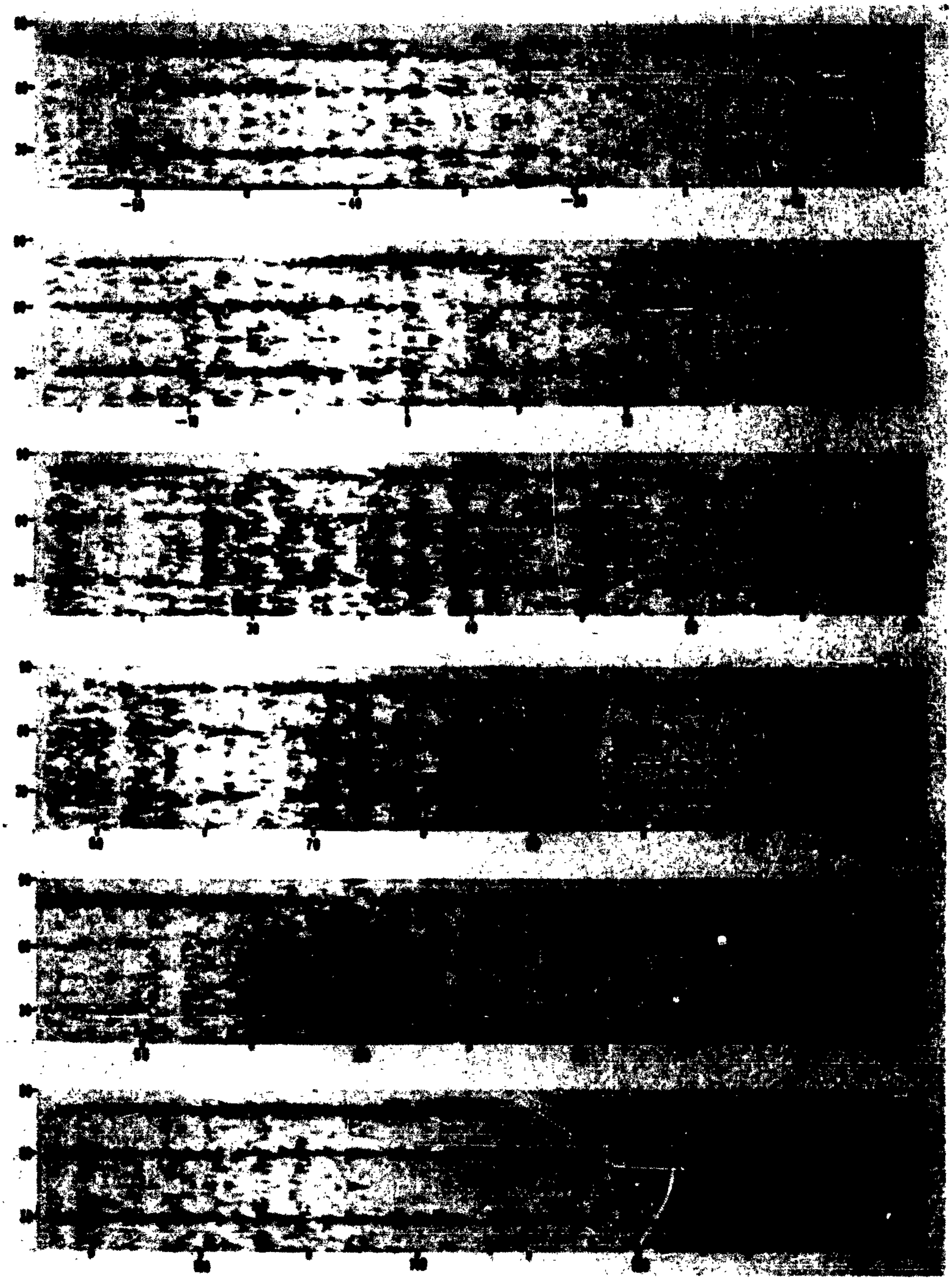

Fig. 5 - An intensity and doppler frequency versus time plot of the range gated, zero frequency I-F. Time after launch (accuracy ±2 seconds) is given in seconds along the horizontal. Frequency in cycles per second is given on the vertical.

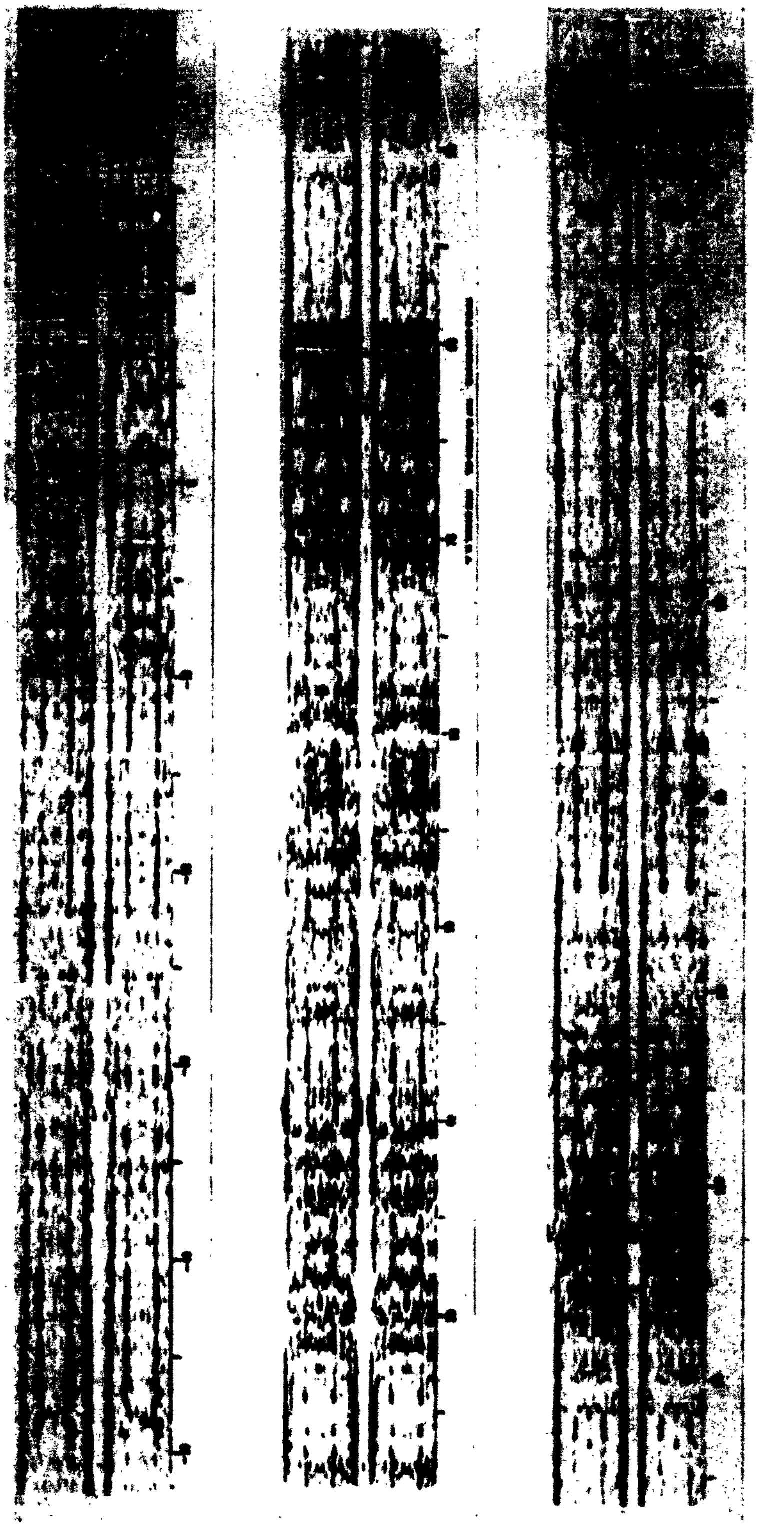

Fig. 6 - An analysis similar to that displayed in Fig. 5 except that the vertical frequency scale runs up to 180 cps. The horizontal scale gives time after launch in seconds (accuracy ±2 seconds).

A narrow 30 n.m. range gate was placed on the echo range and an intensity and frequency versus time spectrum analysis performed. This analysis is given in Figure 5 starting at T-50 seconds and running through T+160. Frequencies displayed run from 15 to 90 cps. Target dopplers read direct from zero frequency and as 90 cps minus the doppler frequency with the fold point at 45 cps; thus the undesired power line 60 cps appears as lines at 30 and 60 cps. The aircraft echoes that fall in the analysis gate and which can be noted to fall between 10 and 15 cps doppler on the Madre display (Figure 4) can be seen between 90-10 and 90-15 cps. The highest level missile echoes can be seen to come in from T+28 to T+40, T+70 to T+82 and T+95 to T+110. The ambient noise level is illustrated for times prior to zero and after T+120. The signals are not much higher than the noise, and they fill the available 45 cps doppler in the manner characteristic of exhaust boundary echoes. In Figure 6 the data of Figure 5 is presented in slightly different form. The spectrum analyzer has been allowed to scan on through 180 cps and the frequency scale compressed. The redundancy of information has been doubled as this aids in noting the frequency structure in the signature. If one will look down the time axis so that the line of vision intercepts the paper at a small angle, some of this structure becomes apparent. For example, between T+105 and T+110 an intensification around a changing velocity line is seen. It would have been interesting to check this velocity curve with the expected missile relative velocity, however, detailed and accurate missile track data were not available.

NATURE OF THE EXHAUST

The Naval Research Laboratory has extensively studied rocket exhaust ionization and growth as a function of altitude using small scaled versions of large engines operating in a controlled low pressure chamber. For example, see NRL Confidential Report 4866, by J. L. Ahearn, et al, titled "Interaction Between Electromagnetic Waves and Flames, Part 3, Absorption Loss Through Rocket Exhausts as a Function of Altitude," and dated May 1, 1957. Scaled models of the Atlas engines with appropriate fuel and oxidizer have been extensively operated and studied at simulated altitudes up to 50 kilometers and the following statements can be made:

1. At the engine's exit plane the fraction ionized is quite small. The ionization density runs from 10^{10} to 10^{14} electrons per cc for currently employed propellants.

2. The ionized portion of the exhaust closely coincides with the visible exhaust. The boundary is sharp and the gradient steep.

3. Below 50 KM, ionization down the visible exhaust increases due to afterburning. This includes the fuel reaction both with incompletely used propellant oxygen and with atmospheric oxygen.

4. The exhaust ionization has a random variation with time containing frequencies up to several kilocycles.

In Figure 7 a very approximate plot of Atlas exhaust ionization density versus altitude is drawn based upon NRL experience up to 50 kilometers and extrapolated to higher altitudes. An estimate of ambient ionization density is sketched. In Figure 8, exhaust approximate dimensions for an Atlas engine are given versus altitude based on observations up to 50 kilometers and extrapolated to higher altitudes by using a simple expansion theory. Considering the sharp ionization boundary it seems reasonable to expect the exhaust to materially add to the HF radar reflecting area at 50 kilometers. By taking the product of the diameter and length as given in Figure 8, a cross section of 27,000 square meters is obtained.

DISCUSSION

The missile exhaust echoes displayed here are not as spectacular as some from AMR; it is unfortunate that the missile track was not well illuminated in the E and F regions so that some large cross section could have been demonstrated. However, it is very encouraging that skin plus exhaust returns can be obtained at altitudes below 50 kilometers and at long distances and that these returns exhibit evidence of having extractable doppler information. That the echo magnitudes come within an order of magnitude of that predicted is good agreement considering all of the indeterminacies.

The velocity gate form of the Madre analysis and display was not primarily designed for detection of missiles. However, its presentation of target frequency spectrum versus range affords an excellent means for detecting and recognizing missile exhaust echoes. Some other form of display such as acceleration gates, tracking filters or frequency time is desirable for extracting fast changing doppler information. Two of these facilities are to be added to the Madre complex in the near future.

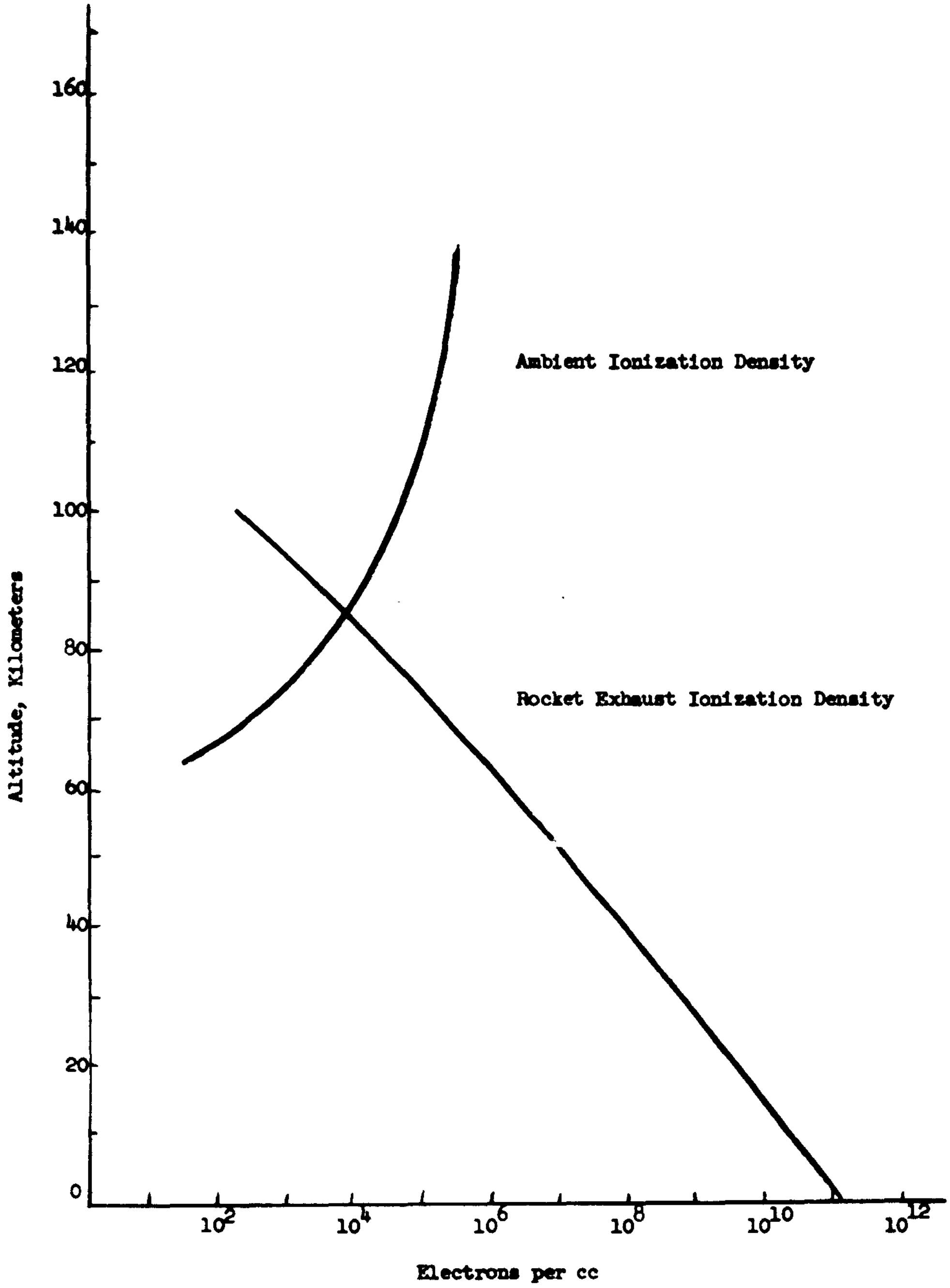

Fig. 7 - Ambient and Atlas exhaust ionization density approximations versus altitude

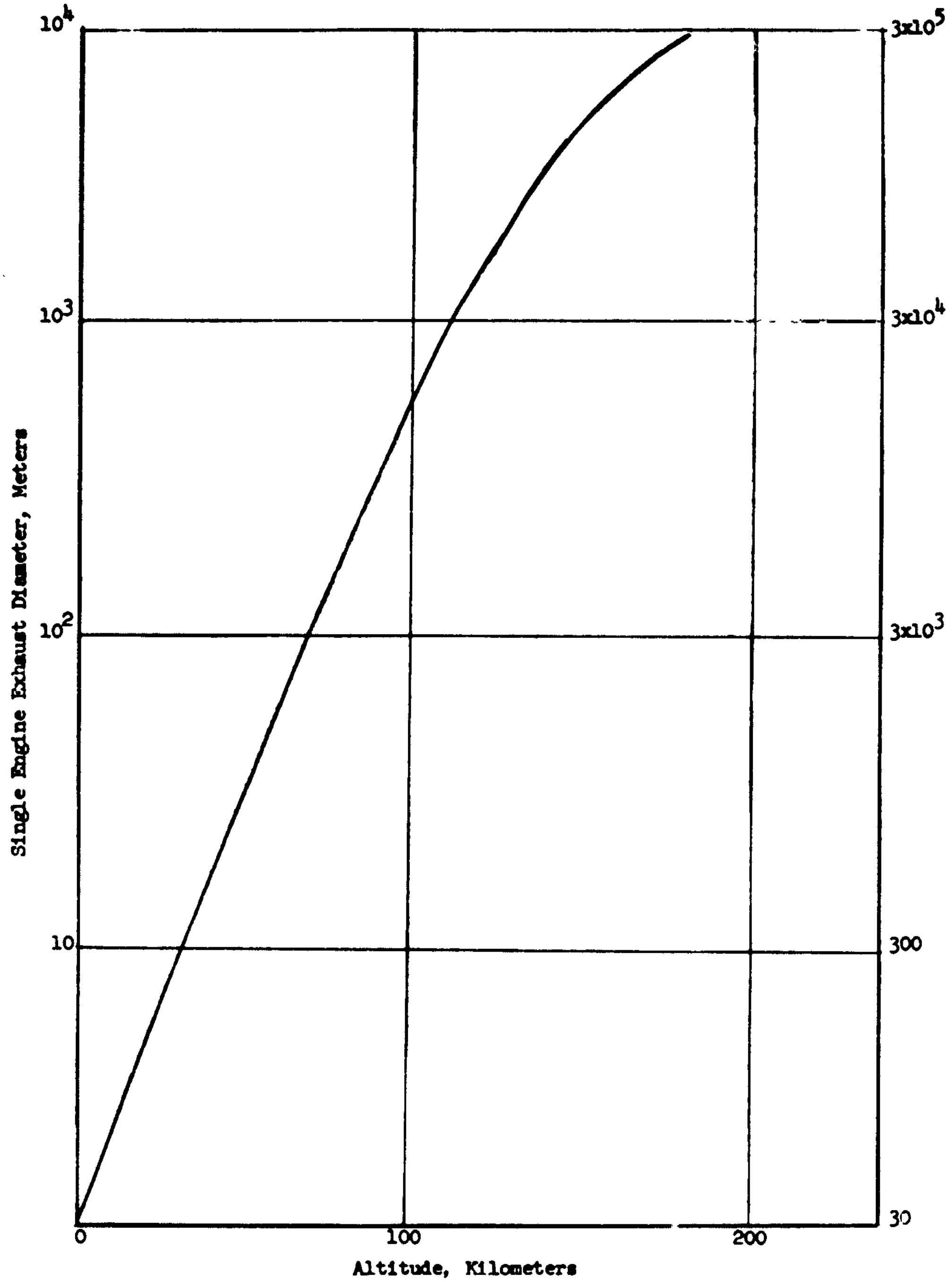

Fig. 8 - Approximate dimensions of the region of exhaust ionization for an Atlas engine versus altitude

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20 February 1997

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Memo: 1251, 1287, 1316, 1422, [redacted], 1500, 1527, 1537, 1540, 1567, 1637, 1647, 1727, 1758, 1787, 1789, 1790, 1811, 1817, 1823, 1885, 1939, 1981, 2135, 2624, 2701, 2645, 2721, 2722, 2723, 2766. Add 2265, 2715.

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2. The above reports are included in the listings of enclosures (b) and (c) and were selected because of familiarity with the contents. The rest of these documents very likely should receive the same treatment.

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