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A MADRE EVALUATION REPORT

[UNCLASSIFIED TITLE]

J. M. Headrick, B. N. Navid, J. L. Ahearn,
S. R. Curley, F. H. Utley, W. C. Headrick,
and E. N. Zettle

RADAR DIVISION

1 December 1961

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A MADRE ICBM DETECTION
(UNCLASSIFIED TITLE)

7

SOME TRAJECTORY PARAMETER DETERMINATIONS
WHEN EMPLOYING IONOSPHERIC REFRACTION

10

J. M. Headrick, B. N. Navid, J. L. Ahearn,
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RADAR DIVISION

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ABSTRACT

(Secret)

A Mercury-Atlas flight (AMR Test 1254) launched at 14:04:16Z, Sept. 9, 1961 was detected in the launch phase by the NRL Chesapeake Bay Annex Madre radar. The transmitter frequency was 13.7 Mc and its average power was 100 kw. The rotary antenna used had a gain of about 12 db.

The type of signature obtained demonstrated the capability of an "over-the-horizon" radar to measure range and range rate of the missile and its exhaust boundary. The characteristics of the signals detected suggest that information on target identification and trajectory can be extracted.

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

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A MADRE ICBM DETECTION
(UNCLASSIFIED TITLE)
SOME TRAJECTORY PARAMETER DETERMINATIONS WHEN EMPLOYING IONOSPHERIC
REFRACTION
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AMR test 1254, launched at 14:04:16Z, Sept. 9, 1961, gave the first opportunity for observing an ICBM during launch phase with the NRL Chesapeake Bay Annex Madre installation. This test was a Mercury-Atlas flight following a direction slightly north of east (72° T) from AMR and employing a long, nearly horizontal path in the lower F region. The Madre recording and measurement capabilities at test time were incomplete; however, the data taken showed definite promise for determining relative range and velocity during the last two minutes of burn time (T+174 sec to T+300 sec). Due to propagation conditions the missile region was not well illuminated at earlier times.

The radar was a coherent MTI hf system using matched filters, average power was 100 kw, antenna gain about 12 db, and the nominal operating frequency was 13.7 Mc.

An over-the-horizon radar using ionospheric refraction illuminates a large area of the earth. These earth returns (backscatter) are overwhelming when compared with many targets of interest; therefore, early in the receiving system is placed a set of rejection filters matched to the usual clutter that is the earth's backscatter. The received signals are converted to a zero or nearly zero i-f and then sampled. The samples are set as magnetically recorded signals on a drum and continuously read out of the drum storage. This processing gives time compression in a ratio of about 93000:1, with the previous 20 seconds of information stored and always available for analysis. In the case of AMR test 1254, the real-time analysis was of frequency spectrum versus range, with a resolution of one-third cycle per second. Thus the processing is similar to that of a bank of filters matched to targets whose doppler varies less than one-third cycle per second in 20 seconds. This type of analysis did not optimize signal-to-noise ratio for the missile track observed.

In Table 1 some of the pertinent parameters of the flight are given. These were computed with the aid of postflight range data and an assumed 300-km mirror-like ionosphere. In Fig. 1 some of these data are plotted. This plot is of the missile trajectory in the vertical planes containing the radar site and the missile position. The numbers along the dashed missile track give the approximate time in seconds after zero time. The approximate limiting upper and lower rays by which backscatter was received are sketched on the plot; these rays correspond to slant ranges between 800 and 1200 naut mi. This diagram indicates that the missile entered the illuminated region at about 150 sec., skirted along the lower edge until 280 sec., the time of nearest approach, and then receded in the illuminated region.

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In Fig. 2a, 2b, and 2c, Madre display pictures are given for times running from zero time plus 60 sec. through plus 350 sec. The horizontal sweep covers 5555 μ sec, or 450 naut mi. The vertical strobe is located at 200 naut mi for the first 450 naut mi, 650 naut mi for the second 450 naut mi, etc. The vertical ordinate displays 90 cps of doppler frequency, with zero doppler at about midscale and indicated by a heavy, once-broken, horizontal strobe line. Other horizontal lines indicate (undesired) cw signals that have been recorded. Approach dopplers are above the zero line and recede below. For this test it was decided to operate with a 320- μ sec pulse length and a 180-per-second pulse rate. Therefore, successive 450-naut-mi range intervals are overlaid on the display, and the indicated dopplers fold back when greater than 45 cps. Some such compromise between range interval and unambiguous doppler must be made unless a more sophisticated system is used.

At the time of AMR 1254, the magnetic-tape recording system for the Madre analysis data was inoperative, and the pictures of Fig. 2 were taken at the time of the test. Apologies are made for the cluttered appearance of the displays. A desire to miss nothing resulted in record, playback, and display levels being initially set rather high. Observer concentration, admiration, and marveling at the tremendous returns from the missile and trail allowed no time for readjustment during the test. In this series of display pictures the computed missile slant range and doppler are plotted (starting at T+154) as large dotted line crosses. The multitude of targets to the left of the vertical line are local aircraft targets (less than 200 naut mi) plus their harmonics (due to high levels employed); the doppler targets close to zero at all ranges are for the most part echoes from meteor trails.

Study of the displays suggests that missile returns are seen intermittently starting prior to T+100. However, the large indications of the missile effect start at about T+170, the last picture of Fig. 2a, as the start of a smear in the recede doppler half at about 660 naut mi. This smear varies in position with time approximately as does the computed missile position. That is, initially as the smear decreases in doppler frequency so does the computed missile position and similarly when the smear increases. Moreover the same statement applies to the respective ranges. The high record level coupled with display of the past 20 sec. of information makes the pictures a bit confusing; however, it can be seen that ranges and range rates go through gyrations similar to those computed for the missile with an idealized ionosphere. All big returns fade shortly after burnout at about 300 sec.

Attention is invited to the returns, starting at T+231 sec. and continuing thereafter, with small recede dopplers and indicated 400 to 450 naut mi range (probably at 850 to 900 naut mi); this patch is probably earth's backscatter that came around the rejection filters due to missile-induced flutter in the ionosphere.

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In addition to the pictorial record of the Madre primary analysis display, a magnetic-tape record of a clutter-filtered zero-frequency i-f was made. This record was spectrum analyzed with a Kay Missilizer (approximately 2-cps bandwidth) and a range gate approximately 30 miles wide. The results with the gate centered on 620 naut mi are given in Fig. 3a and 3b. Here doppler frequency is given on the vertical, time after zero on the horizontal, and density roughly proportional to intensity. The spectrograph was allowed to scan through 360 cps, and therefore the 90-cps available doppler range is plotted against zero frequency, both sides of the repetition frequency 180 cps, and against 360 cps. The computed folded doppler as given in Table 1 is plotted against zero as a dotted line. This dotted line can readily be compared with the 90-cps range above 180 cps, in addition to the data it overlays.

It is felt that low-level missile returns are in evidence even before 150 sec; however, the big missile effect is first noted at 173 sec. and although the doppler is diffused in frequencies there is a clear intensification around the computed doppler. There is a fading in level until 210 sec. when a rather sudden intensity increase starts. The frequencies at which the most intense signals occurred follow the computed doppler until the signal level and frequency diffusion have increased so that no predominant frequency can be picked at 255 sec. From about 280 sec. to burnout, near 300 sec., the frequencies of greatest intensity can be seen to correspond to the computed doppler. A search for times after burnout revealed no returns that could be definitely attributed to the missile.

The large missile echoes, described here, are almost certainly returns from a gradient in the charge density caused by the rocket exhaust. In past observations with the low-powered Madre and preceding Music radar, similar returns have been noted from the missile regions. In these past cases, due to operating-frequency restrictions, only the upper F layer was illuminated, and the returns were rather short lived and of small amplitude. It was not possible to establish whether range rate or doppler information could be extracted in these earlier tests. The test 1254 results are very encouraging, since the big returns from the missile region have recognizable doppler components that correspond to the missile relative velocity, and the change in slant range corresponds to that for the missile itself. The evidence is good that the missile was detected for some time prior to the large-amplitude returns, even though it must have been poorly illuminated. Attention is invited to the fact that the signals displayed in Figs. 2 and 3 were initially immersed in the earth's backscatter, plus strong multichannel teletype interference. The only thing critical about frequency selection and consequent propagation path is that the target be illuminated.

It is not possible to give a good reflecting cross-section estimate for the target of test 1254. Some uncertainties about the vertical antenna pattern and the absence of a suitable reference level discourage estimation of echoing area; however, the big echoes were from a huge

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target. These echoes certainly are of the same nature as the excellent examples that ACF and NATC have reported, in which earth's backscatter was arranged to start at a slightly greater range than the missile trajectory.

The observations made on test 1254 give some indications of very early detection of a missile launch. It was demonstrated that the large reflecting area that accompanies the burning rocket in the F region contains significant and recognizable characteristics that allow relative range rate and range to be measured simultaneously over the horizon. This is encouraging, since the NRL objective is not restricted to detection but is aimed also to include target recognition and trajectory determination.

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Table 1
Calculated Flight Parameters

Time (sec)	Doppler true (cps)	Doppler folded (cps)	Doppler Madre indicated (cps)	Slant Range		Ground Range (naut mi)	Altitude (km)
				(naut mi)	(km)		
150	157a	23	23r	676	1250	1130	81
160	156a	25	25r	667	1230	1110	98
170	153a	27	27r	658	1220	1100	107
180	150a	30	30r	649	1200	1080	116
190	146a	34	34r	640	1190	1070	124
200	142a	39	39r	631	1170	1050	131
210	138a	46	44r	623	1150	1030	137
220	136a	54	36r	615	1140	1020	143
230	115a	65	25r	608	1130	1010	148
240	101a	79	11r	601	1110	990	151
250	84a	84	6a	596	1100	980	155
260	63a	62	27a	591	1100	980	157
270	36a	35	36a	588	1090	970	159
280	2a	2	2a	587	1090	970	160
290	40r	40	40r	588	1090	970	160
300	87r	87	3r	591	1100	980	160
310	132r	48	42a	599	1110	990	160
320	174r	6	6a	608	1130	1010	160
330	214r	34	34r	619	1150	1030	159
340	251r	71	19r	633	1170	1050	159
350	261r	81	9r	650	1200	1080	159

Note: The letter "a" refers to advancing targets; the letter "r" to receding targets.

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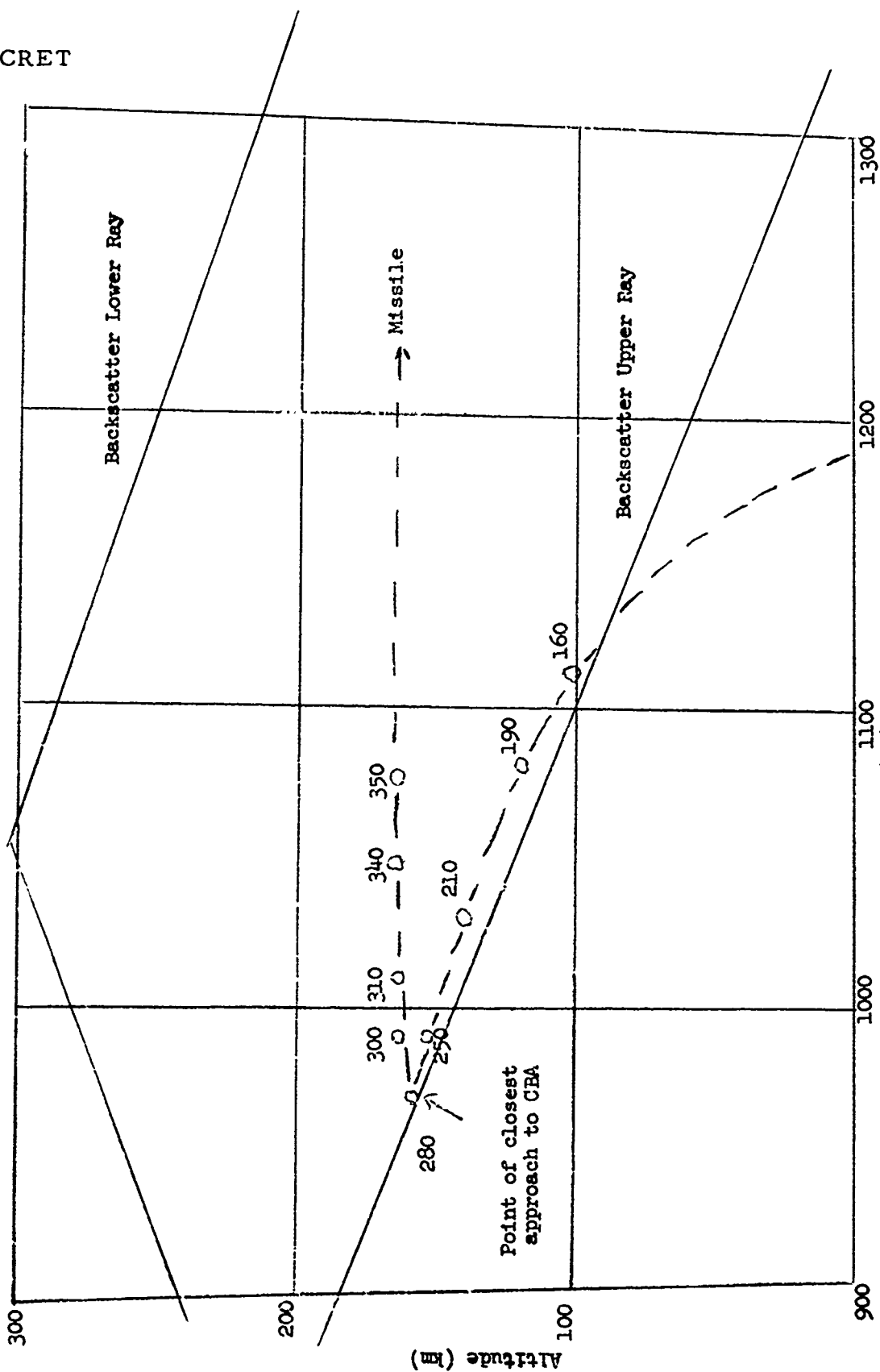


Fig. 1. Radar-Illuminated Portion of Missile Trajectory. (The Azimuthal Component is not presented).

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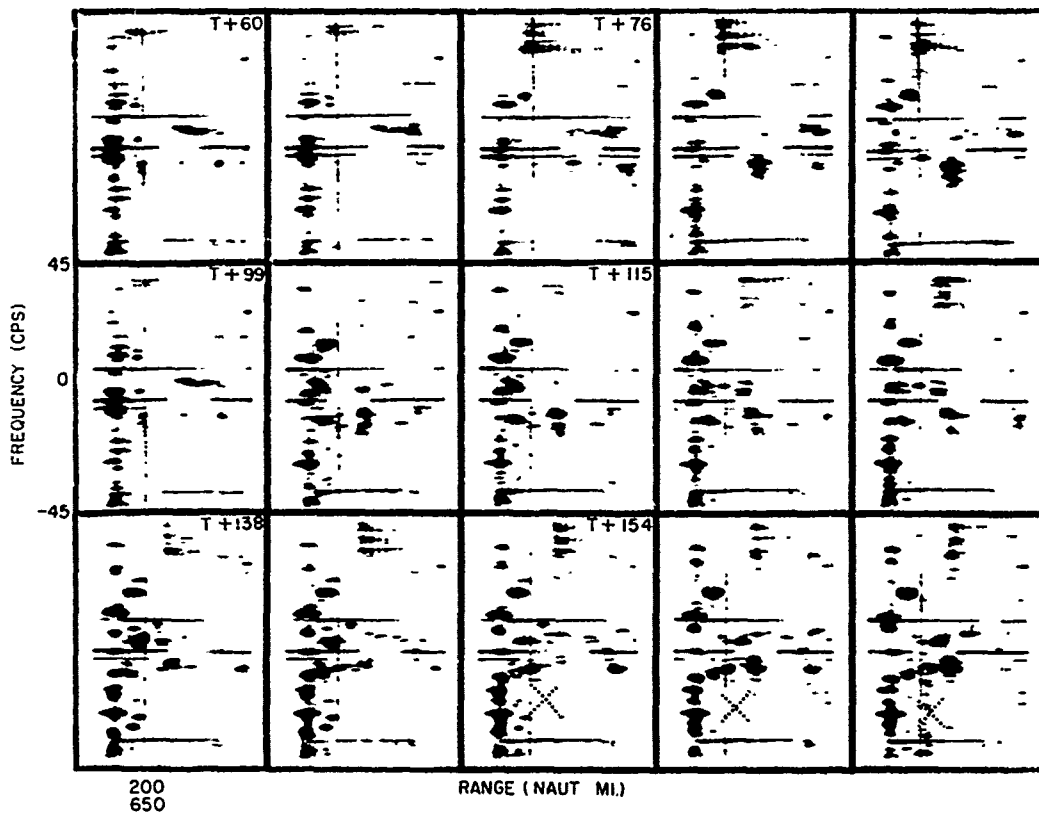


Fig. 2a - Madre Primary Display at Successive Times (T+60 to T+170 sec.)
The dotted crosses represent computed positions of missile.

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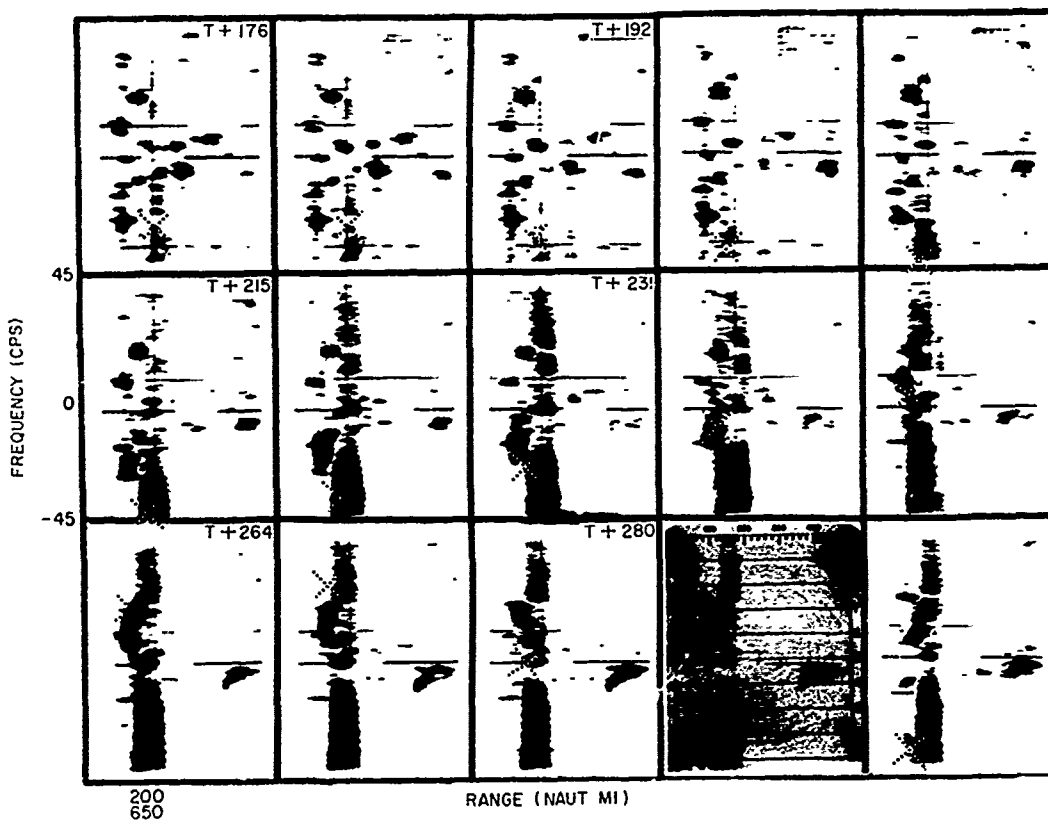


Fig. 2b - Madre Primary Display at Successive Times (T+176 to T+286 sec.)
The dotted crosses represent computed positions of missile.

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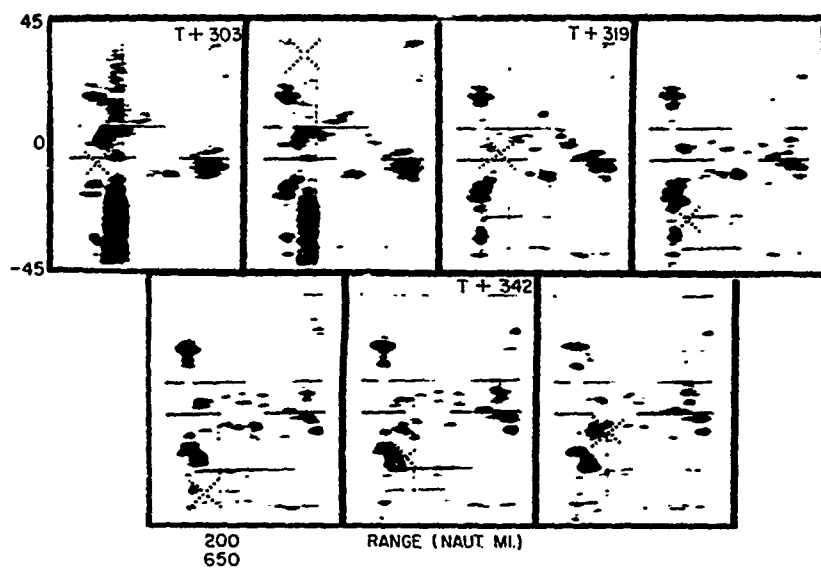


Fig. 2c - Madre Primary Display at Successive Times (T+303 to T+350 sec). The dotted crosses represent computed positions of missile.

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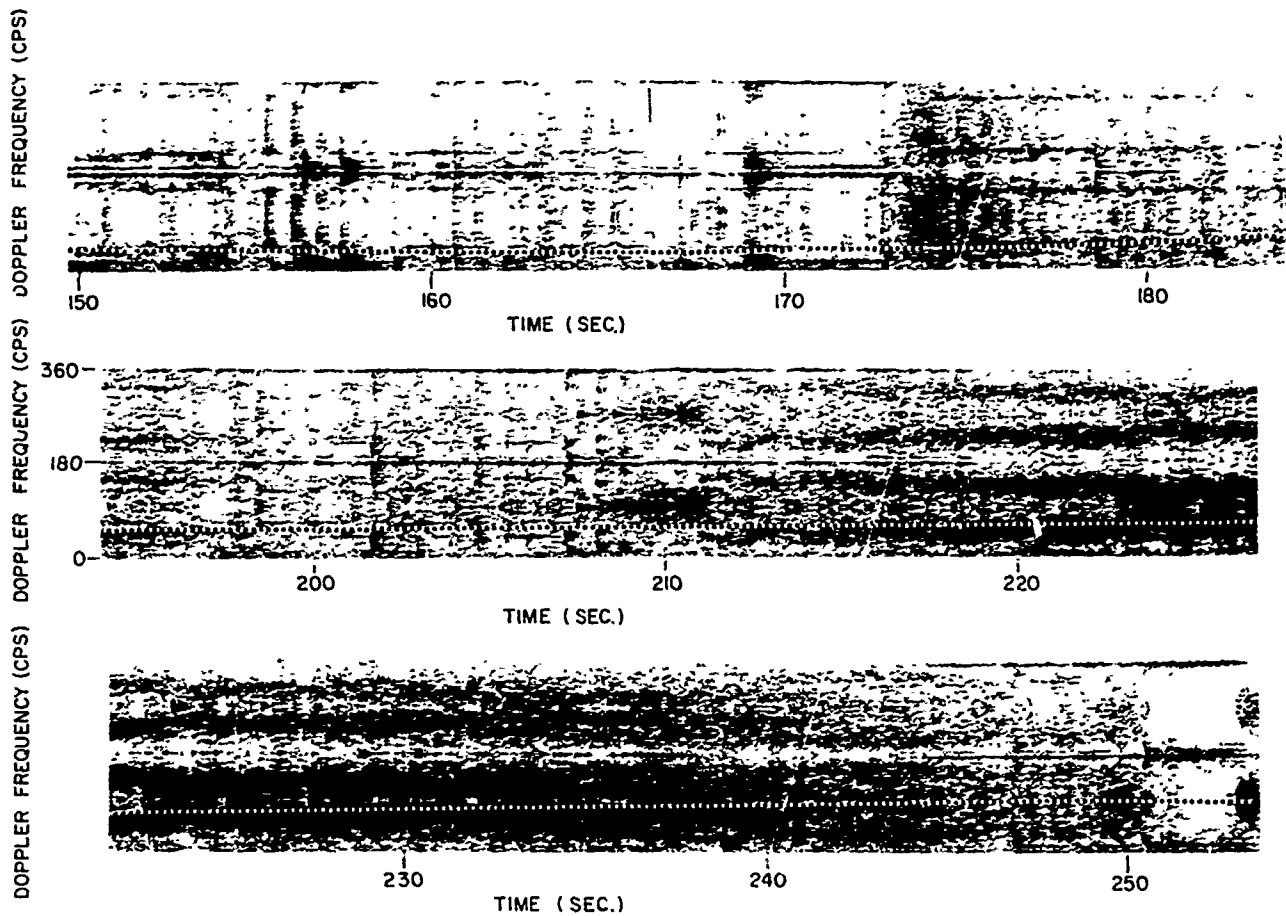


Fig. 3a - Missilyzer Analysis of Clutter-Filtered
Zero-Frequency I-F (150 to 250 sec)

Notes: Dotted line represents computed missile frequency. Data repeats every 180 cps, starting at 0 cps. Moreover data folds over at 90 and hence also at 270 cps.

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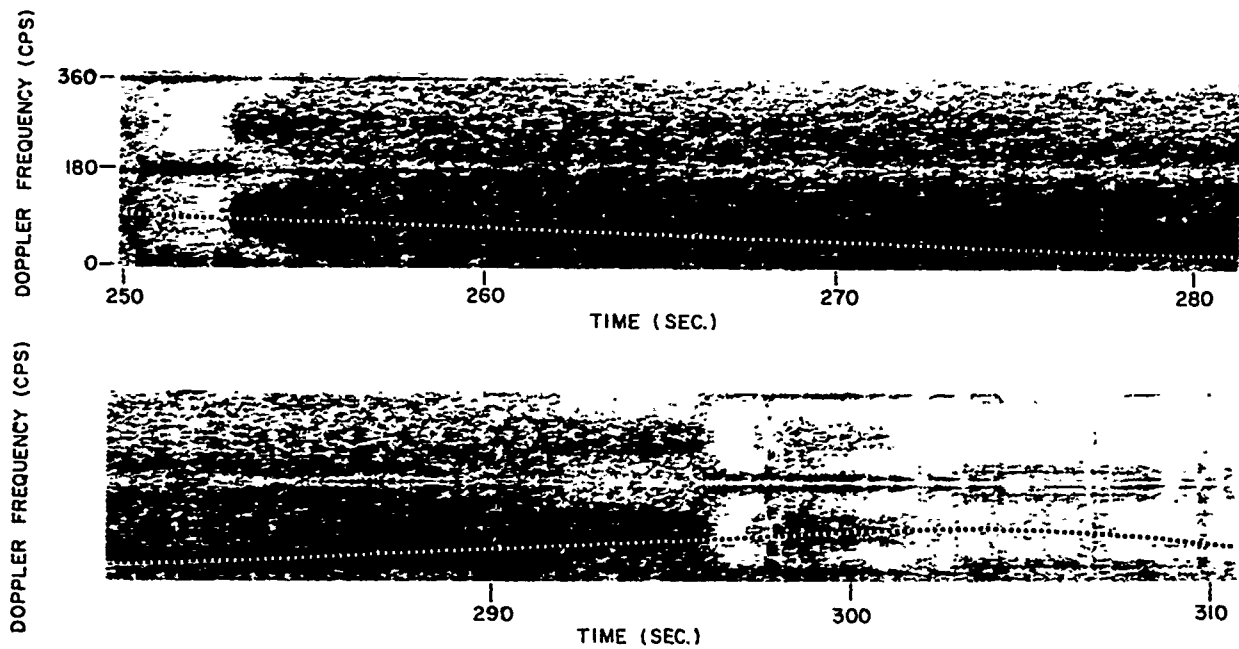


Fig. 3b - Missilyzer Analysis of Clutter-Filtered
Zero-Frequency I-F (250 to 310 sec)

Notes: Dotted line represents computed missile frequency. Data repeats every 180 cps starting at 0 cps. Moreover data folds over at 90 and hence also at 270 cps.

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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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