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HF RADAR ECHOES AND REFRACTION EFFECTS DUE TO WATER AND PROPELLANT RELEASES IN THE IONOSPHERE

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ABSTRACT

High-frequency radar observations of nonburning rockets traversing the ionosphere often yield large range-discrete echoes and ionospheric path perturbations during periods in which the venting of fuel components or fluid ballast takes place. A study of several missile launchings during which such releases occurred has been conducted, and an analysis of the experimental data which takes into account the propagation conditions surrounding each launching is presented.

PROBLEM STATUS

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

AUTHORIZATION

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HF RADAR ECHOES AND REFRACTION EFFECTS DUE TO WATER AND PROPELLANT RELEASES IN THE IONOSPHERE

INTRODUCTION

High-frequency radar observations of missiles traversing the ionosphere often exhibit brief, large echo cross sections during periods in which the rocket engines reportedly are not burning. The appearance of these unexpectedly large echo cross sections commonly occurs during staging or immediately following engine cutoff. It is the purpose of this report to present evidence of the occurrence of ionospheric perturbations and strong hf radar echoes during periods in which there is a reasonable certainty that rocket motors are not burning.

The study was conducted with the NRL Madre radar, a coherent pulse-doppler system possessing receiver rejection filters matched to the usual spectrum of the earth's backscatter. The overall characteristics of the Madre radar are more thoroughly described elsewhere (1-8); a brief review of qualities pertinent to the ensuing discussion follows.

The coherent pulse-doppler system utilizes a comb-filter rejection technique to eliminate the strong earth backscatter signal immediately adjacent to both the center frequency and the pulse repetition frequency (prf) lines. The system possesses a receiver transfer function as shown in Fig. 1(a). Notches are placed within the receiver bandwidth upon the radar carrier frequency and upon each prf sideband. Figure 1(b) shows a detailed sketch of one such rejection notch used in the Madre radar. It can easily be seen that backscatter-associated clutter-to-signal ratios approaching 70 db may be accommodated.

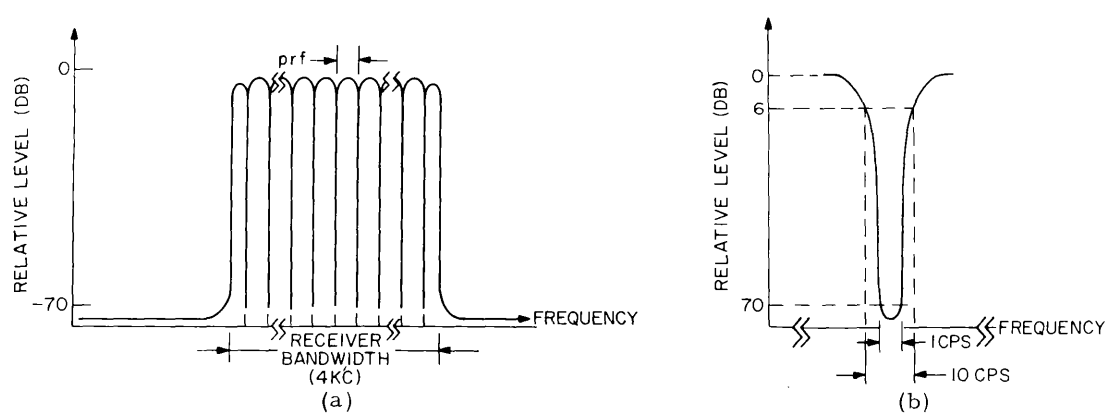


Fig. 1 - (a) Transfer function of Madre receiver utilizing (b) comb rejection filters

Later in the receiver system the target signal is converted to a zero-frequency intermediate frequency by the use of a synchronous detector. Two forms of spectrum analysis then are possible. One of these two analysis processes is illustrated in Fig. 2. The zero-frequency i-f signal is range-gated to exclude the effects of undesired targets, passed through a second comb filter which provides an additional 30 db of backscatter rejection,

and spectrum-analyzed with the aid of a Kay Sonograph. The resultant is a doppler-intensity-time plot of the echo spectrum, with doppler frequency appearing on the ordinate, time on the abscissa, and signal amplitude appearing as the degree of shading (intensity) on the plot. Due to the inherent limitations of a pulse-doppler radar, doppler-shifted traces appear about the prf-induced lines as well as about the center frequency, and hence doppler frequency is unambiguous only insofar as it remains below one-half the prf. The spectrum analysis provides a doppler resolution of 3 cps. The second form of spectrum analysis utilizes a rotating magnetic drum upon which short samples of the coherent echoes are stored and read off sequentially after a 20-second storage period, providing a continually updated time-compressed presentation of the previous 20 seconds of received information. This presentation appears as a range-doppler-intensity plot, with doppler on the ordinate, range on the abscissa, and amplitude appearing as intensity. Both types of spectrum analysis are presented in the following discussion.

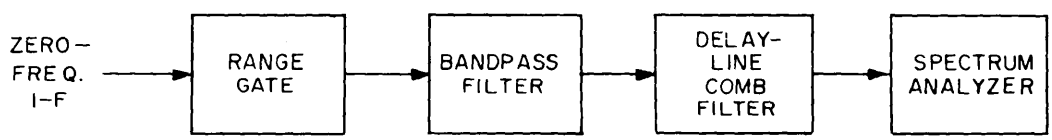


Fig. 2 - Block diagram of a spectrum-analysis system used with Madre radar

DISCUSSION OF MISSILE RELEASE-ASSOCIATED PHENOMENA

During the period from October 1960, until November 1962, four missile launches were carried out at the Atlantic Missile Range (AMR) and the Pacific Missile Range (PMR) which gave rise to path-perturbations and strong hf radar echoes at times when no rocket motors were burning, but when known venting of oxidant or release of fluid ballast was occurring. Upon occasion these path perturbations and radar echoes took on a marked resemblance to the type of effect normally associated with burning rocket motors. The effects detected by the Madre system during each of the four launches are discussed below.

AMR Test 2508 – Atlas (E)

T_0: 3:15:34 p.m. EDT, 11 Oct. 1960
Frequency: 26.6 Mc
Pulse repetition rate: 180 pps
Pulse duration: 250μ sec
Radiated power: 1.5 kw (average)
Antenna gain: 14 db over an isotrope

Postflight data indicates that the sustainer engine cut off 150 seconds after liftoff and that the vehicle itself exploded 5 seconds later. At this time, 155 seconds after liftoff, the vehicle was at an altitude of 112 km and traveling at 1.5 km/sec. Assuming that the remaining tankage and propellant followed a ballistic trajectory, these should have reached an altitude of 180 km at T_0+240 seconds and should have continued upward to an apogee of 211 km.

The illumination geometry, determined from observation of ground backscatter, and the missile's trajectory are sketched in Fig. 3. This illustration indicates that the ballistic path of the remnants was visible to the Madre radar for altitudes above 180 km.

Figure 4(a) shows the effects of a path perturbation which began at T_0+240 seconds, the time at which propagation conditions indicate that the missile remnants entered the Madre antenna beam. This illustration is a spectrogram of earth backscatter returns

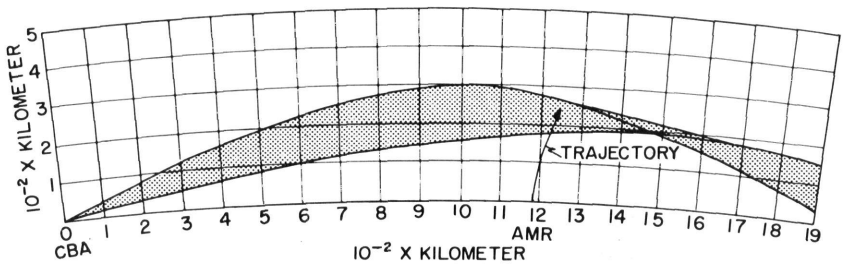


Fig. 3 - Illumination geometry and missile trajectory for AMR Test 2508

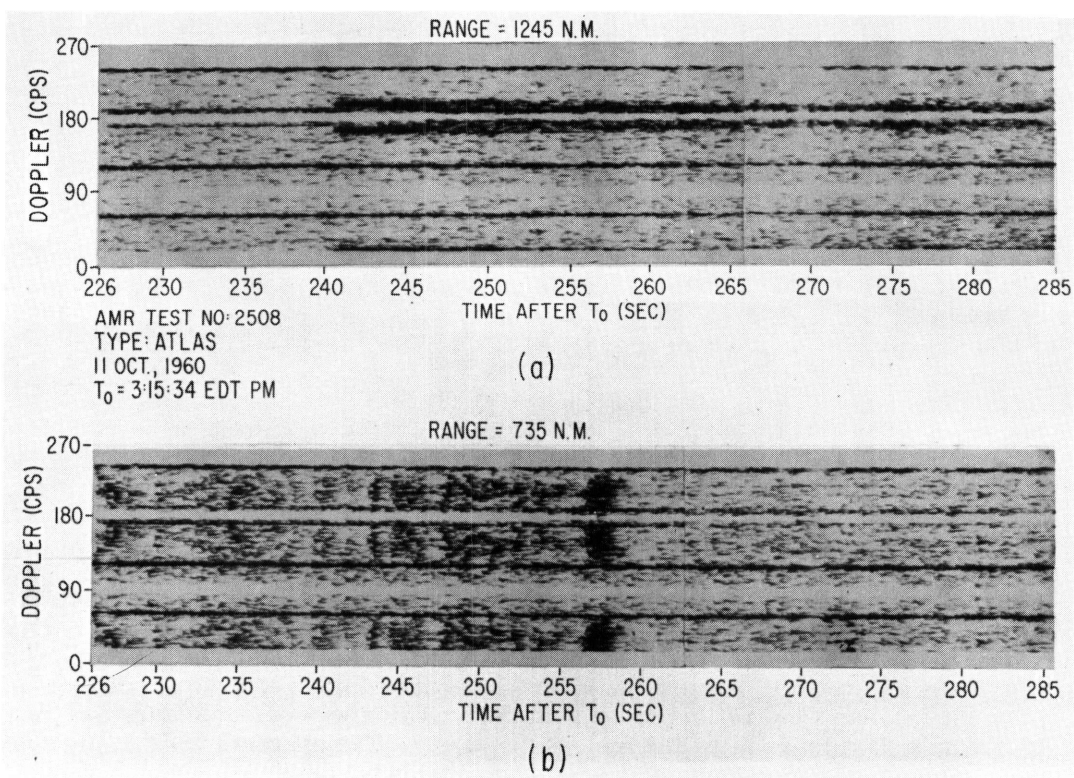


Fig. 4 - Doppler-intensity-time records of (a) path perturbation and (b) diffuse echo associated with exploding missile of AMR Test 2508

driven outside the clutter rejection filters by the path perturbation. Backscatter is driven 20 cps from the 180 cps line at T_0+240 seconds and gradually relaxes to normal over a period approaching one minute. This perturbation was quite similar to the type produced by a missile actually burning through the F-region. Figure 4(b) shows a reflection at T_0+256 seconds which exhibits discreteness in range and diffusion in doppler. This reflection lasts approximately 2 seconds and presumably represents an echo from a charge gradient moving up through the ionosphere at the approximate range of the ballistic missile fragments.

AMR Test 0811 – Jupiter

T_0: 1:17:53 p.m. EDT, 18 Apr. 1962
Frequency: 15.595 Mc
Pulse repetition rate: 180 pps
Pulse duration: 200 μsec
Power: 75 kw (average)
Antenna gain: 11 db over an isotrope

In this flight all missile functions were normal until T_0+153 seconds. At that time fuel depletion was reached due to an excessively fuel-rich propellant mixture, and normal guidance cutoff was not achieved. Oxygen venting is certain to have continued until the supply was exhausted (or until T_0+522 seconds when the guidance computer initiated cutoff procedures). Backscatter coverage ran from 760 to 1250 naut mi in range with a strong peak at 810 naut mi. The coverage suggested by this backscatter distribution is sketched in Fig. 5.

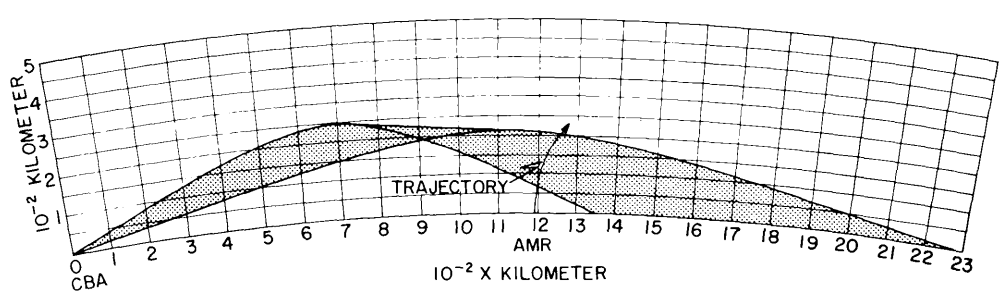


Fig. 5 - Illumination geometry as indicated by backscatter observations at the Madre site, and missile trajectory for AMR Test 0811

Figure 6 is the range-gated doppler-intensity-time record. The first reflections occurred at T_0+162 seconds when the missile was at an altitude of 131 km. It is worthy of note that the backscatter observations represented in Fig. 5 indicate that the burning rocket actually entered the beam of the Madre antenna when it achieved an altitude of 70 km at T_0+130 seconds. No reflection or path perturbation was detected, however, until T_0+162 seconds, 9 seconds after the fuel was depleted. The character of the effect evident at T_0+162 seconds was similar to that associated with a burning rocket traversing the E-layer. This reflection continued until T_0+190 seconds when the missile had achieved an estimated altitude of 200 km. The slope of the doppler envelope apparent near the start

of the signature corresponds roughly to that of the expected missile doppler. The abrupt disappearance of the target at $T_0 + 190$ seconds probably was due to the missile's exit from the radar-illuminated region. The slowly shifting doppler lines near 180 cps are due to aircraft echoes from the range interval under examination.

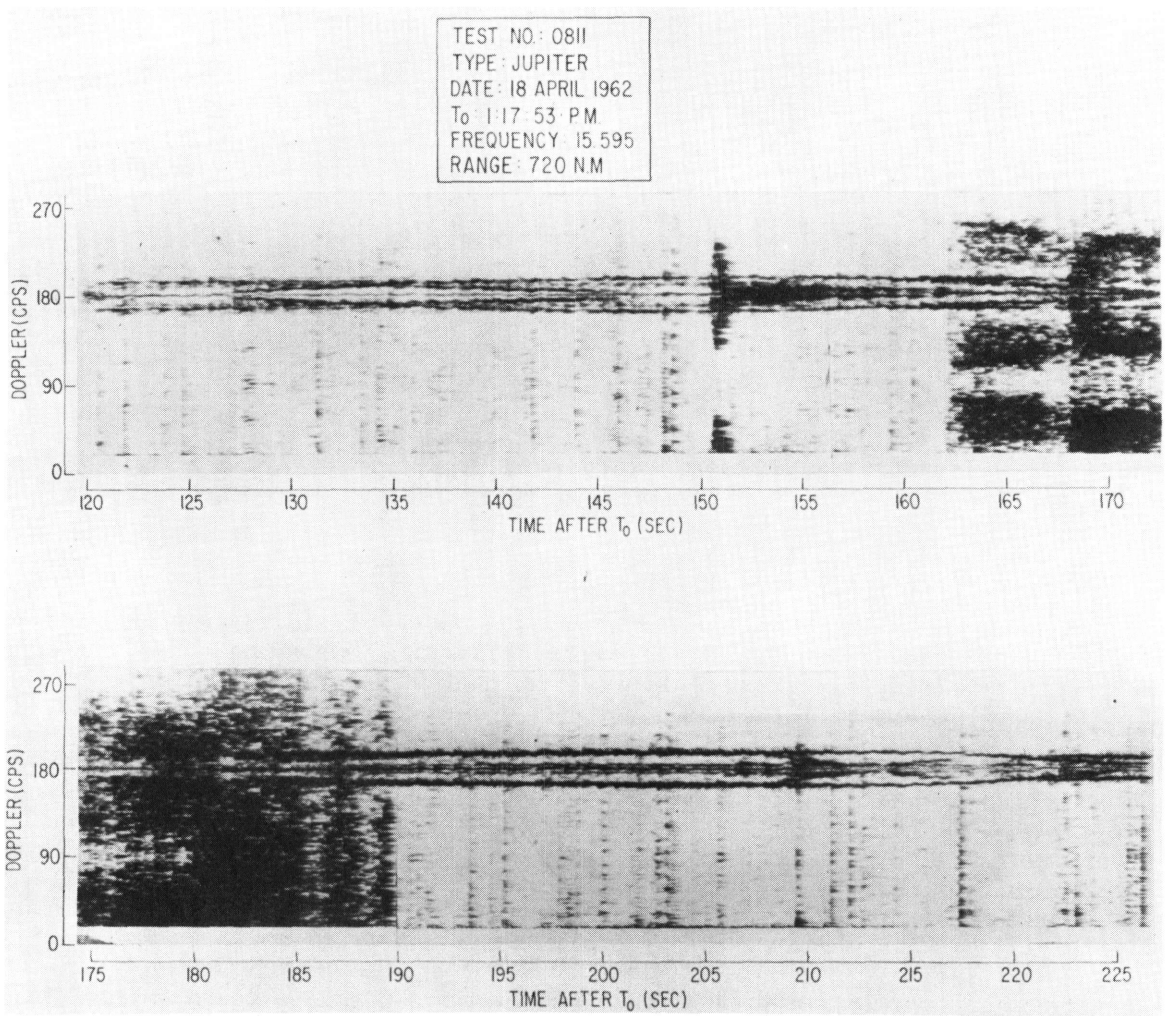


Fig. 6 - Doppler-intensity-time record of diffuse echo due to oxygen venting associated with AMR Test 0811

AMR Test 5051 – Saturn (SA-3)

T_0 : 12:45:02 p.m. EST, 16 Nov. 1962
Frequency: 18.036 Mc
Pulse repetition rate: 90 pps
Power: 75 kw (average)
Pulse duration: 300 μsec
Antenna gain: 12 db over an isotrope

The illumination suggested by backscatter coverage is sketched in Fig. 7. This vehicle was ballistic above 100 km. At $T_0 + 292$ seconds, when the missile reached its apogee of 167 km, 192,528 pounds of water were released into the ionosphere.

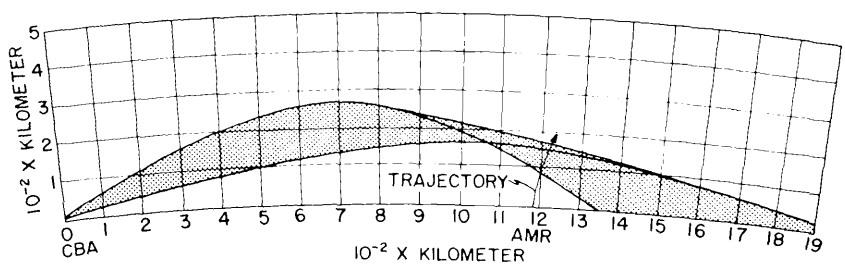


Fig. 7 - Illumination geometry as indicated by backscatter observations at the Madre site, and missile trajectory for AMR Test 5051

Figure 8 is a doppler-intensity-time presentation of echoes from a range gate centered on the missile itself. A large reflection may be seen in this illustration beginning precisely at $T_0 + 292$ seconds, the exact time of the water release. This reflection persisted until $T_0 + 365$ seconds and at its peak displayed an echo cross section of 4×10^8 square meters.

Figure 9 is a doppler-intensity-time presentation of echoes from a range gate centered on the backscatter returns from a one-hop distance at which ionospheric reflection would have occurred in the region in which the ionospheric perturbation took place. An ionospheric perturbation is seen to have begun in Fig. 9 at the water-release time. This perturbation moved rapidly through a distance of 140 naut mi toward the radar site and achieved a maximum doppler spread of ± 18 cps about the 90 pps line. Its duration was approximately 4 minutes.

Figure 10 shows the conventional Madre analysis of the water-release reflections. The doppler frequency scale is on the left, running from 0 to 45 cps. Approximate range is given on the top horizontal scale running from 450 to 900 naut mi. Time after launch is indicated on the counter in minutes and seconds. The echo starts with the available doppler frequencies filled; its maximum doppler decreases with time and occupies about 20 cps at the time of the echo's disappearance.

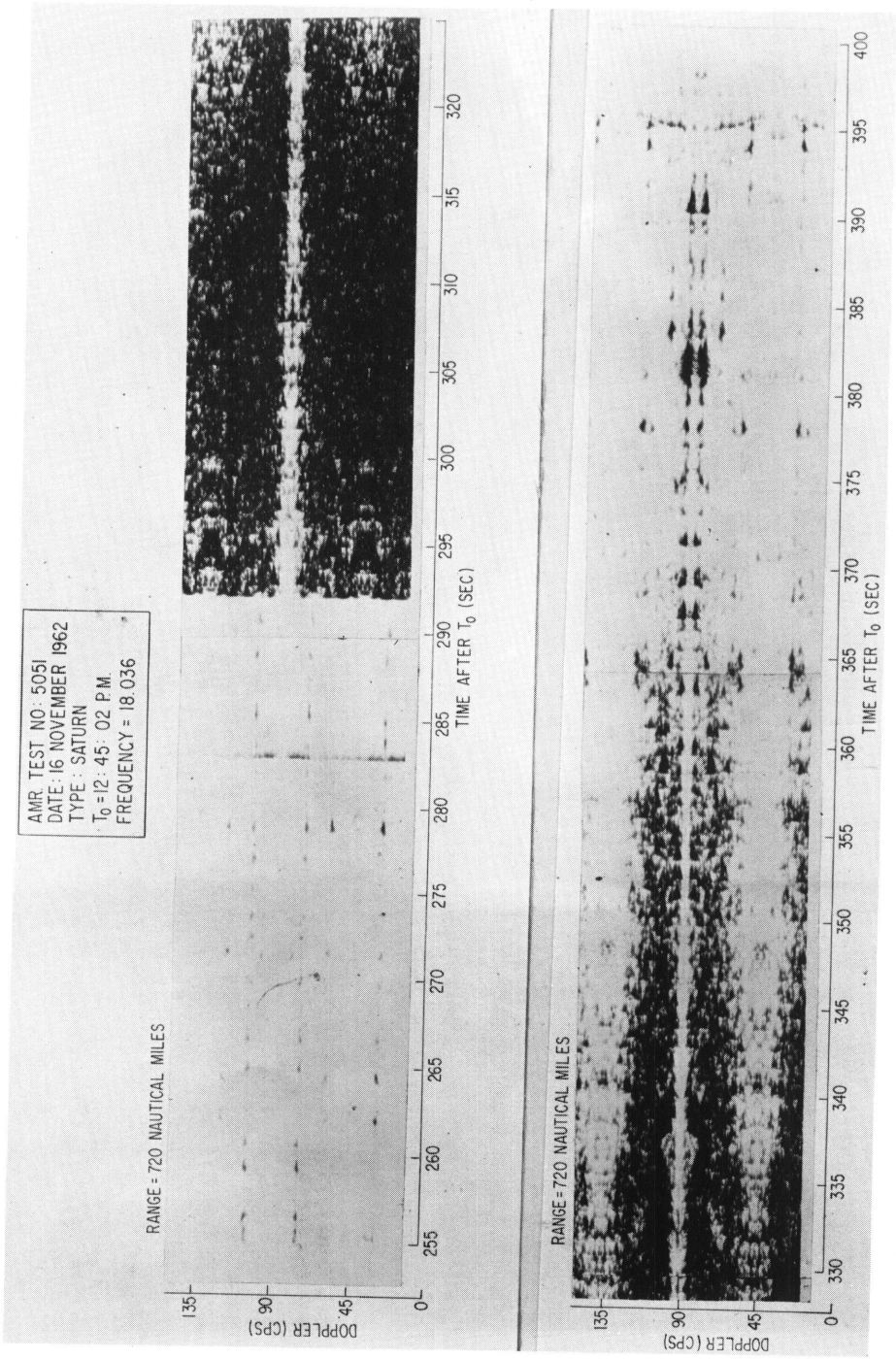
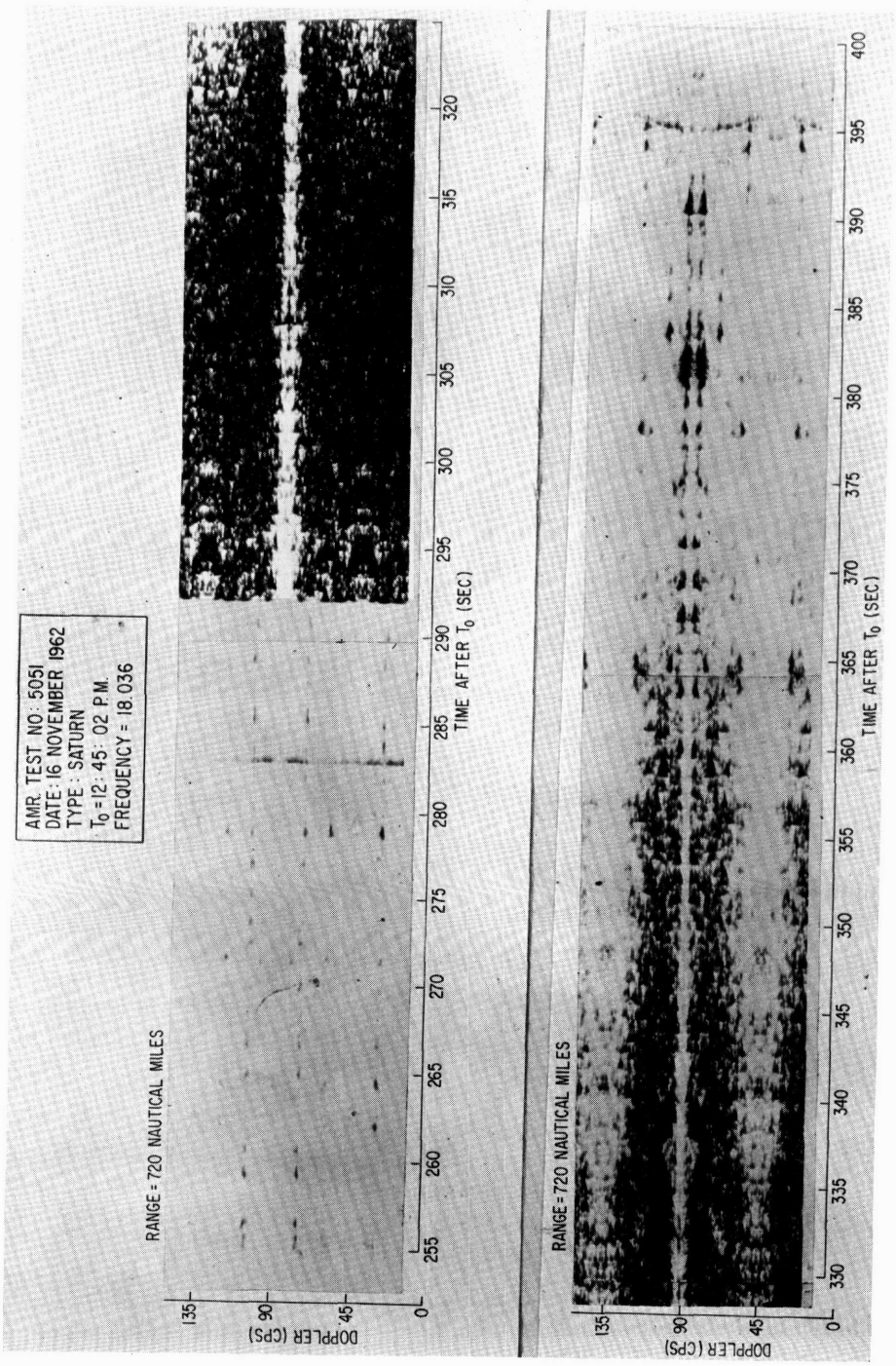


Fig. 8 - Doppler-intensity-time record of diffuse echo due to water release associated with AMR Test 5051; range gate centered on missile



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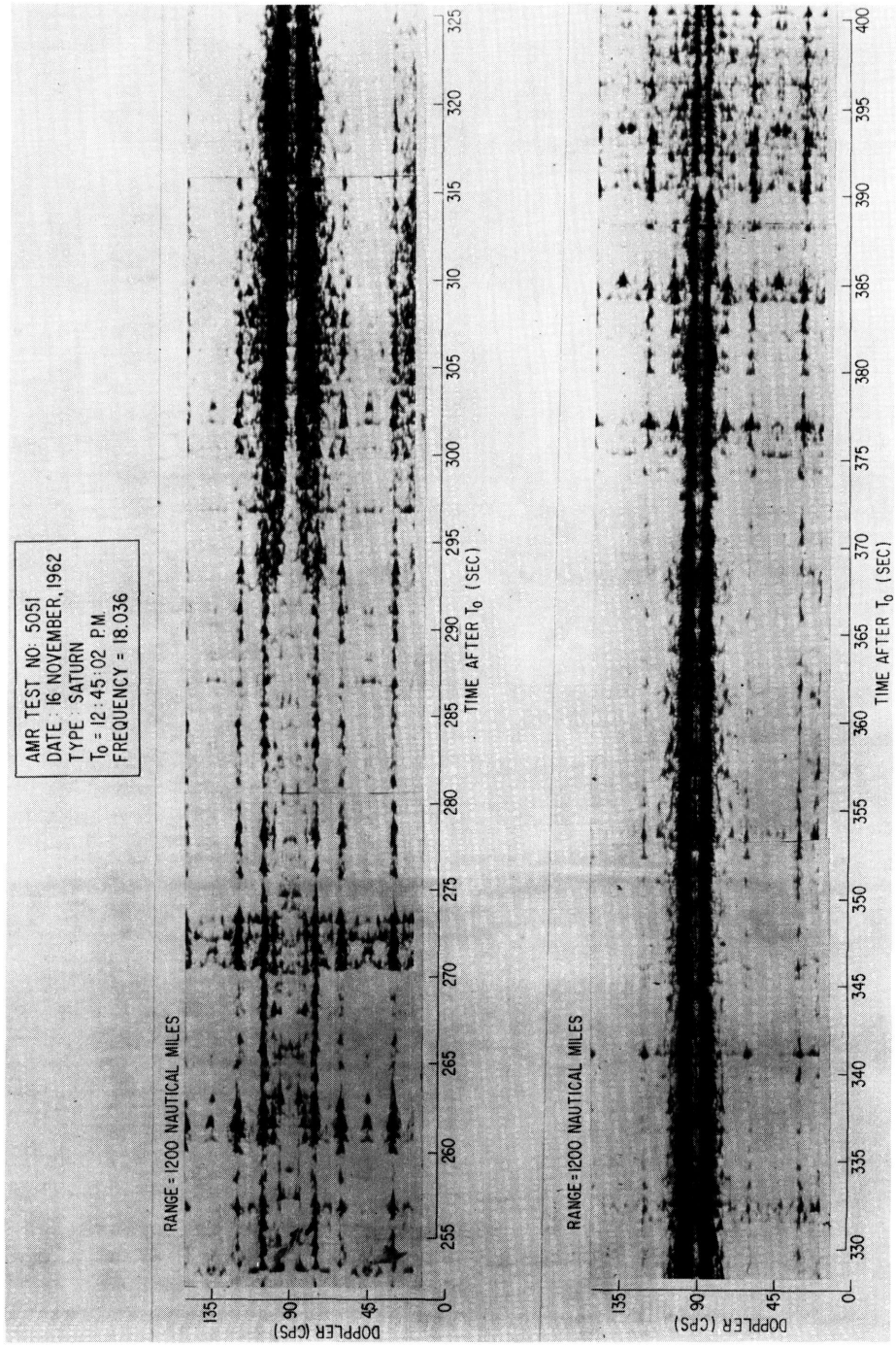

Fig. 9 - Doppler-intensity-time record of path perturbation due to water release associated with AMR Test 5051; range gate on one-hop distance backscatter returns

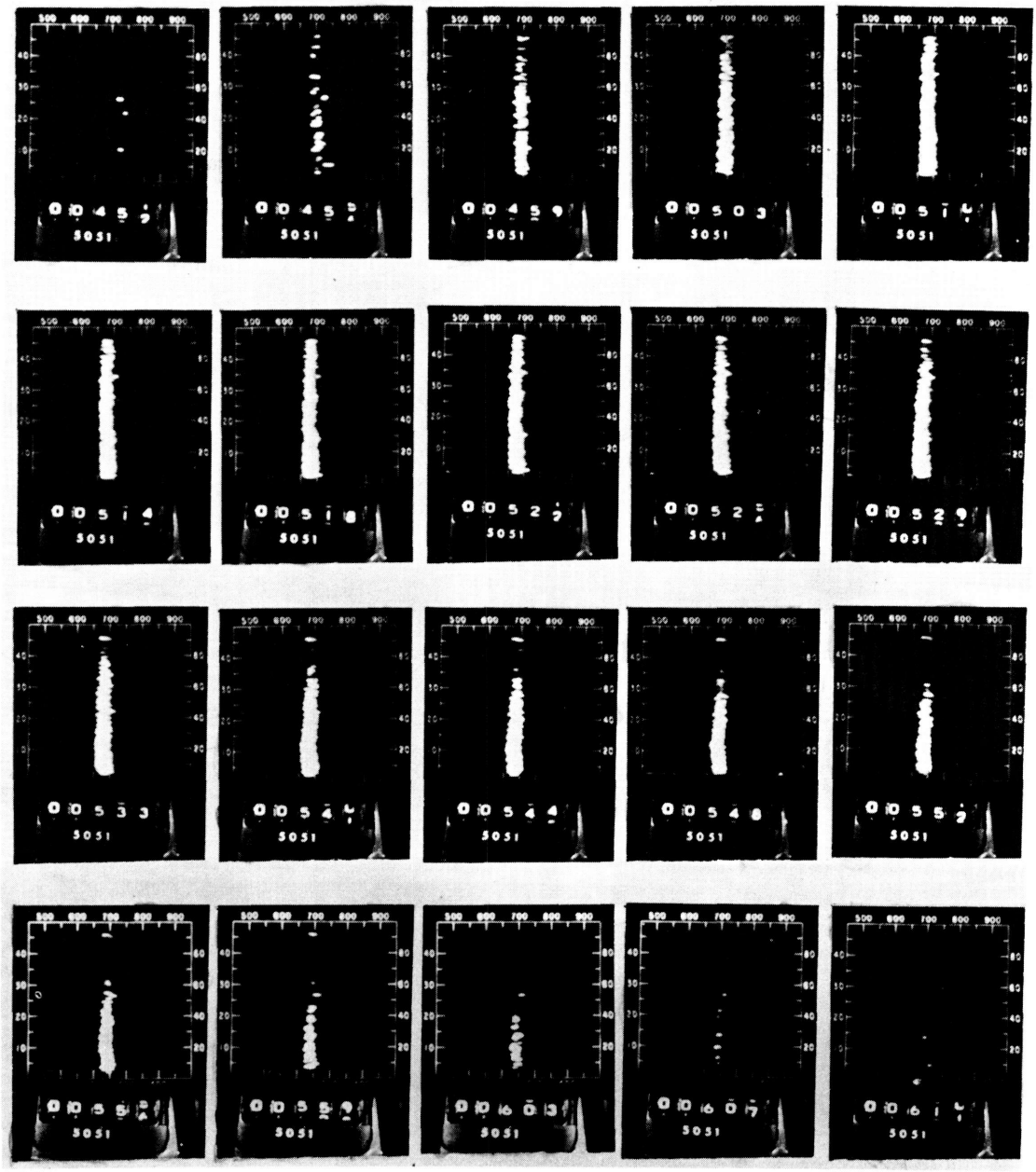

Fig. 10 - Conventional Madre record of doppler-intensity-range for the diffuse echo due to water release associated with AMR Test 5051

PMR Test 291201 – Thor-Agena

T_0: 12:14:39 p.m. EST, 26 Oct. 1962
Frequency: 18.036 Mc
Pulse repetition rate: 90 pps
Pulse duration: 300 μsec
Power: 75 kw (average)
Antenna gain: 12 db over an isotrope

In this test, propellant depletion was allowed to determine first-stage thrust termination. Stanford Research Institutes furnished information indicating that 10 pounds of liquid oxygen remained at main engine cutoff (MECO) and it appears likely that this excess oxidizer was vented. Although ten pounds of liquid oxygen seems a small quantity, a well-defined reflection typical of rocket exhausts and releases was noted.

Backscatter distribution and ionosonde data indicate an illumination geometry as sketched in Fig. 11. Signals from a transponder at Point Arguello showed only two-hop coverage of the launch site.

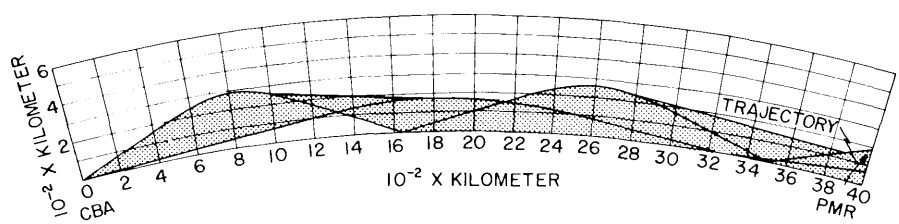

Fig. 11 - Illumination geometry, as indicated by backscatter distribution and ionosonde data, and missile trajectory for PMR Test 291201

Figure 12 shows the conventional Madre display. The 45-cps available doppler is scaled on the left side of each picture. Range intervals for which the receiver was unblanked were 350-800, 1250-1700, and 2150-2600 naut mi, and in these superimposed 450-naut-mi intervals, the range runs from left to right along the abscissa. The time after launch is given in minutes and seconds on the counter below each frame. Numerous meteor trail returns appearing on the photographs at low doppler frequencies partially obscured the display throughout the test. The echo in the pictures taken at 002:48, 002:52, 002:56, and 003:00 minutes, appearing at about the center of the range display and having a continuum of dopplers up to 25 or 30 cps, had the characteristics typical of a missile exhaust. This echo's slant range was 2350 naut mi, about 65 naut mi farther than that of the transponder.

A range-gated doppler-intensity-time analysis of the event is shown in Fig. 13. The target, which shows on this display from T_0 +160 to T_0 + 180 seconds, did indeed have the character of an exhaust or release. No echo was seen during Agena burn period, and it is doubtful that illumination of the missile was obtained during that period.

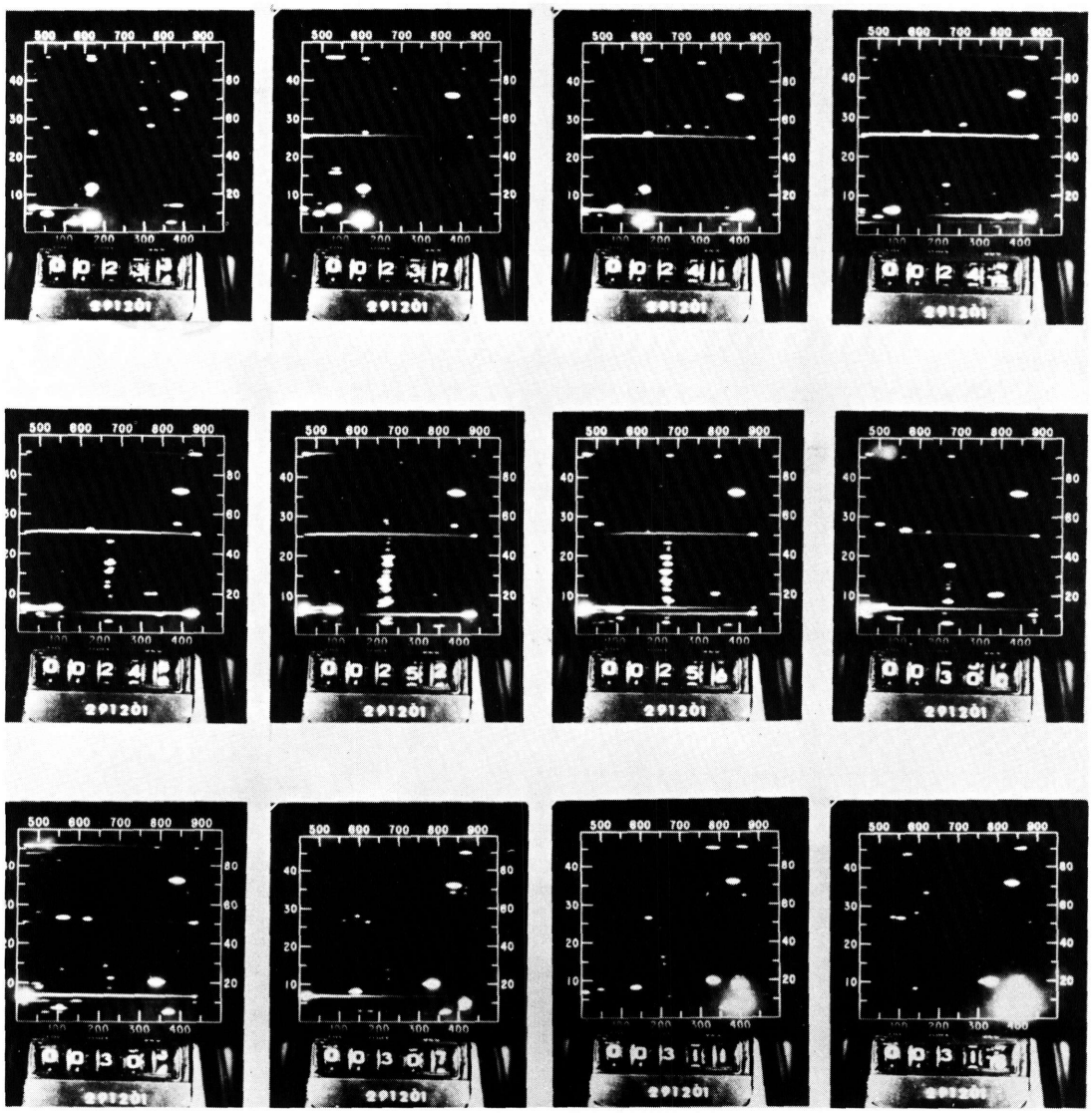

Fig. 12 - **Conventional Madre** record of doppler-intensity-range for the diffuse echo due to oxidizer release associated with PMR Test 291201

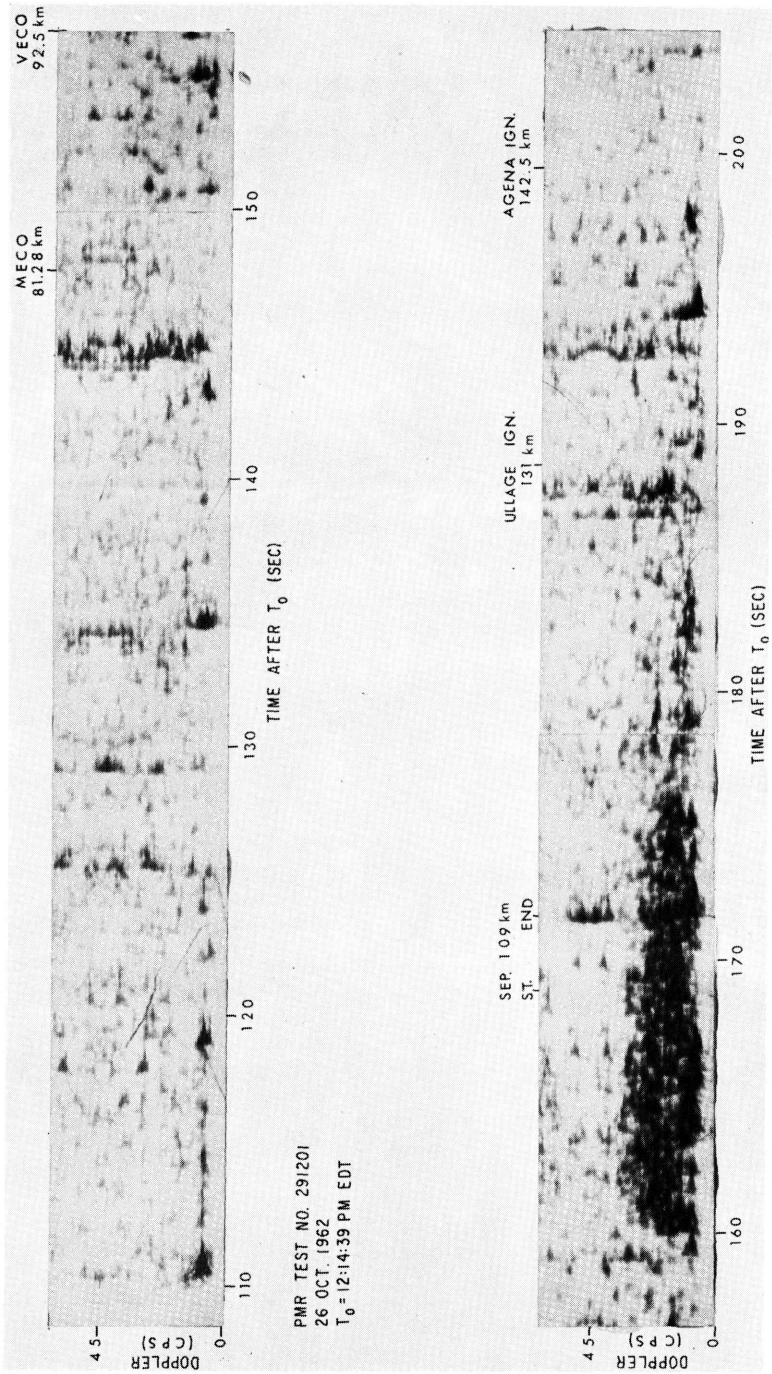

Fig. 13 - Doppler-intensity-time record of diffuse echo due to oxidizer release associated with PMR Test 291201

CONCLUSION

During each of these four missile launches the Madre facility was able to detect hf radar echoes at the approximate range of the vehicle at a time when its rocket motor was not burning. In three cases the missile itself had achieved E-layer altitude when the effects set in, and in all four events the character of the echoes bore a close resemblance to the effects normally associated with burning rockets traversing the ionosphere. In two cases an ionospheric path perturbation, usually detected when a burning rocket passes through the F-layer, was discerned when nonburning debris approached F-layer height.

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