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THE DETECTION OF SCATTERED LIGHT FROM MISSILES BELOW THE HORIZON

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ABSTRACT

Over-the-horizon nighttime measurements of radiation from Atlas and Thor missiles during the boost phase have been made from a distance of 53.5 miles. The detector system was a filter-equipped end-on photomultiplier, sensitive between 0.68μ and 1.1μ, located at the focus of a 24-in., f/1, front-surfaced mirror. The initial detectable signal was at lift-off time. The maximum signal-to-noise ratio was 140 when the meteorological range (visibility) was 10 to 15 miles, and 1400 at 30-mile meteorological range.

PROBLEM STATUS

This problem has been terminated. Additional work will be carried out under problem A02-17.

AUTHORIZATION

NRL Problem N03-05
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THE DETECTION OF SCATTERED LIGHT FROM MISSILES BELOW THE HORIZON
[Unclassified Title]

INTRODUCTION

This report covers a phase of the continuing problem on nighttime investigations into the propagation of light over the horizon by scattering. It has become clear that detectable amounts of radiation can be transmitted in this manner. These observations have led to the conclusion that under many conditions the detection of a high-intensity rocket flame beyond the horizon might be accomplished at night from appreciable distances by means of light scattered in the atmosphere. A previous report* describes the successful detection of a static-fired, 4000-lb-thrust, end burner at a distance of 46.5 mi. The present report deals with the similar detection of large missiles in flight.

TEST CONDITIONS

The test missiles successfully detected were an Atlas (Test 1754), Thor (Test 1003), and Thor-Able (Test 1756) fired from Cape Canaveral, Florida. The observing site was located at the Vero Beach Range Station, 53.5 mi south of the Cape along the coast, about 50 ft inland from the high-tide line. The detector site was about 10 ft above the high-tide point. The elevation of the launch site is not know but believed to be at approximately the same elevation as the detector site. Several miles of viewing path nearest the detector were directly over the breaking surf line. Consideration of the earth's curvature and atmospheric refraction indicates that the detector was about 1100 ft below a line of sight from the launch area. The firings were at night with the moon near full phase. The moonlight produced a large background signal which, in one instance, was several times greater than the signal from the rocket below the horizon.

DETECTION SYSTEM

The detection was accomplished with a Dumont K-1292, end-on, infrared photomultiplier fitted with a Corning 2403 filter. The combination of tube and filter characteristics gave a spectral bandpass between 0.68μ and 1.1μ. This spectral region has proved optimum for much of the over-the-horizon work.

The phototube was used at the focus of a 24-in., f/1, front-surfaced mirror. The system had a 3-1/2-deg-diameter field of view. The line of sight was elevated slightly above the horizon so that an approximate horizon sky field of 2-1/2 x 3-1/2 deg was covered.

The phototube dynode voltages were established by means of high voltage applied to a bleeder resistance network. Voltages between the dynodes were equal and the voltage between cathode and dynode No. 1 was twice the voltage between dynodes. Sensitivity was

*J.A. Curcio, G.L. Knestrick, and T.H. Cosden, "Photoelectric Detection of Scattered Light from a Distant Rocket Engine Firing," NRL Memo Report 927 (Confidential), May 1, 1959.

controlled by adjusting the voltage applied to the network, and the change of sensitivity with network voltage was determined. All signals were normalized to the system sensitivity corresponding to 1000 v across the bleeder network.

Direct current from the photomultiplier was amplified and recorded by a Leeds and Northrup recording microammeter (1-sec response time for full-time deflection). The recording system was operated at a sensitivity of 0.6 μa, full scale. With 1000 v across the bleeder network the dark current was 0.05 μa and the background signal from moonlight, night sky glow, and starlight varied from 0.22 μa to 0.48 μa. Expanded-scale recording was achieved by electrically suppressing the steady dc background signal. Variation in the background appeared as a noise-type fluctuation which, over a one-minute interval a few moments before zero, amounted to 10^{-3} μa for Test 1754 (Atlas), 10^{-2} μa for Test 1756 (Thor-Able), and 4×10^{-3} for Test 1003 (Thor).

Time signals from WWV were recorded on the chart, and test zero or lift-off times relative to WWV were obtained after the shot from the Range post-shot data releases.

APPROXIMATE CALIBRATION

The system used in these preliminary attempts was uncalibrated. In retrospect this seems unfortunate even though lack of calibration does not invalidate the signal-to-background ratio or signal-to-noise ratio. It is possible to get some idea of the system sensitivity in a roundabout way using the measured moonlight background signal. An approximate "calibration" is estimated below, but this is unreliable to perhaps one order of magnitude.

The spectral radiant emittance of the northern horizon for a cloudless sky and near-zenith sun was measured at 0.66μ with a telephotometer and found to be 2.5×10^{-3} w/cm^2 per 2π steradian per 0.1μ. At 0.80μ, which is the region of peak detector sensitivity, the radiant emittance was estimated, from solar spectral intensity data, to be about 1.8×10^{-3} w/cm^2 per 2π steradian per 0.1μ. Applying a sun-to-moon brightness factor of 10^6 gives an estimate of the moonlight horizon radiant emittance at 0.8μ as 1.8×10^{-9} w/cm^2 per 2π steradian per 0.1μ. Using 0.35μ for the detector spectral bandpass gives an estimate of 2.0×10^{-9} w/cm^2 per steradian for the effective moonlight horizon radiance. A 1-1/2-in. detector at the focus of a 24-in. f/1 collector should have received 1.6×10^{-8} w. The blocking filter will reduce this to 1.3×10^{-8} w. This situation occurred for Test 1003 when there was a high full moon and clear sky which gave a horizon background signal of 0.45 μamp for 1000 v across the bleeder network. The approximate calibration then is 1 μamp = 3×10^{-8} w incident on the tube for 1000 v across the tube.

RESULTS

Atlas Test 1754 (May 18)

The signal as a function of time for Test 1754 is shown in Fig. 1. Below-the-horizon signal was received for 26 sec, from plus 2 sec after zero time to plus 28 sec. The large signal fluctuations below the horizon are presumed to have been caused by the missile going through several low, thin, cloud layers. High off-scale signals were received when the missile was in the field of view from plus 29 sec to 45 sec. The missile detonated at plus 66 sec at a point 5 deg out of the detector's field and strong signals were received from plus 66 sec to plus 75 sec.

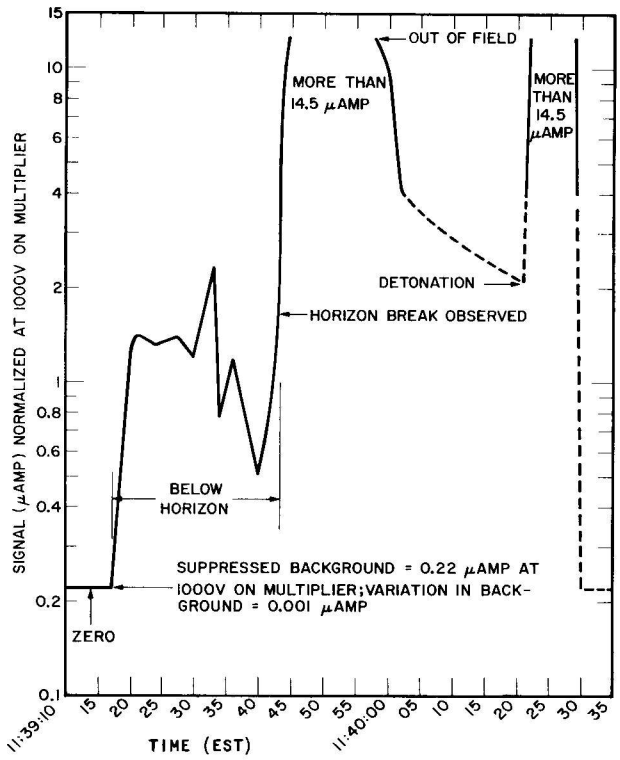

Fig. 1 - Signal as a function of time for Atlas Test 1754

The average below-the-horizon signal of 1.4 μamp is about 6.5 times the electronically suppressed background signal of about 0.22 μamp whose moonlight component was 0.17 μamp. The maximum below-the-horizon signal-to-noise (peak to peak) ratio is estimated to be 1400. Using the approximate calibration figure of 1 μamp = 3×10^{-8} w of moonlight gives an average below-the-horizon signal equivalent of about 4×10^{-8} w on the phototube.

The surface meteorological range at the detector site was estimated at 30 mi, with 80 percent overcast and the moon at near-full phase. Atmospheric transmission for 53.5 mi was estimated to be 10^{-2} at 0.7μ and 4×10^{-2} at 1.0μ. Assuming that the atmosphere attenuation varies exponentially with distance, the maximum distance for below-the-horizon detection is estimated to be at least 150 mi with the above atomspheric conditions.

Thor-Able Test 1756 (May 21)

The signal as a function of time for Test 1756 is shown in Fig. 2. Below-the-horizon signal was received for 13 sec, from plus 3 sec to plus 16 sec. The missile was in the field of view for about 18 sec. The average below-the-horizon signal of 0.14 μamp is about 0.3 times the supressed background signal of 0.48 μamp whose moonlight component

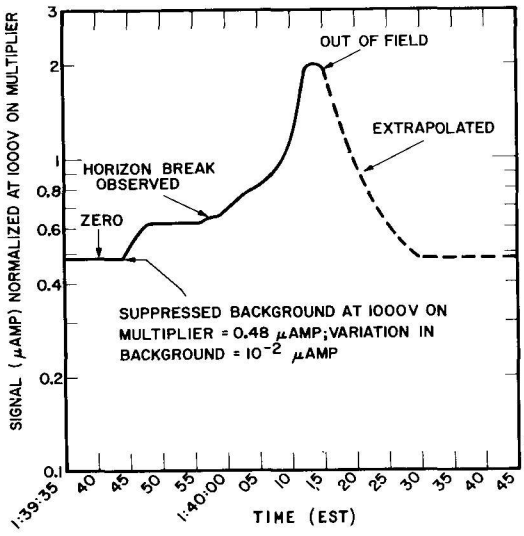

Fig. 2 - Signal as a function of time for Thor-Able Test 1756

was 0.43 μamp. The maximum below-the-horizon signal-to-noise ratio is estimated to be 140. Using the approximate calibration figure of 1 μamp = 3×10^{-8} w of moonlight gives an average below-the-horizon signal equivalent of about 4.3×10^{-9} w.

The surface meteorological range at the detector site was estimated at 10 to 15 mi, with 50 percent overcast and the moon 2 days from full phase. Transmission for 53.5 mi was estimated at 10^{-6} at 0.7μ and 2×10^{-4} at 1.0μ. The maximum range for below-the-horizon detection is estimated to be at least 75 mi with the above atmospheric conditions.

Thor Test 1003 (May 22)

The signal as a function of time for Test 1003 is shown in Fig. 3. Below-the-horizon signal was observed for 15 sec from lift-off. The recorder trace indicates that the missile was apparently in the field for 27 sec. This time is long compared to Tests 1756 and 1754 and may be the result of an error in the voltage changes which were necessary to keep the signal on scale at the recorder. It appears that the missile broke through a low haze layer just as it was leaving the detector field of view. Scattered radiation from the out-of-field missile by the in-field low haze would explain the high signal level beyond plus 35 sec.

The average below-the-horizon signal of 1.12 μamp is about 2.8 times the moonlight background. The maximum below-the-horizon signal-to-noise ratio is estimated to be 1100. Using the approximate calibration figure of 1 μamp = 3×10^{-8} w of moonlight gives an average below-the-horizon signal equivalent of 3.5×10^{-8} w.

The surface meteorological range at the detector site was estimated at 30 mi, with clear sky and full moon. Transmission for 53.5 mi was estimated at 10^{-2} at 0.7μ and 4×10^{-2} at 1.0μ. The maximum range for below-the-horizon detection is estimated to be at least 140 mi with the above atmospheric conditions.

CONCLUSIONS

Very satisfactory nighttime detection of large missiles was accomplished at a range of 53.5 mi with both source and detection system near sea level. It is believed that the first signals occur at lift-off time. Radiation prior to this time is probably attenuated by local obscurations at the launch site. The signal builds up to a maximum in several seconds and remains constant until the missile breaks over the horizon some 15 to 25 sec after the initial signal. The below-the-horizon signal-to-noise ratio varied from 140 when the meteorological range was 10 to 15 mi to 1400 when the meteorological range was 30 mi.

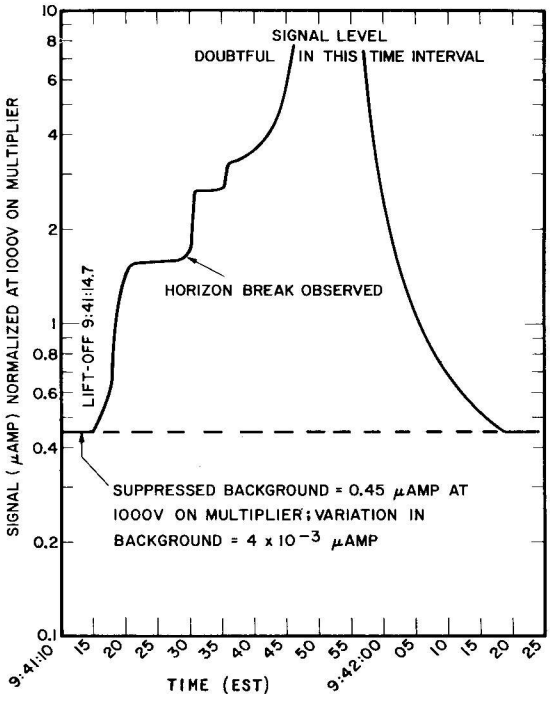

Fig. 3 - Signal as a function of time for Thor Test 1003

The maximum detection ranges given have been computed by the conventional exponential method $T = \exp(-\alpha X)$ where T is path transmission, α is attenuation coefficient, and X is path length. It appears that this technique may not be directly applicable to below-the-horizon signals when, for example, a change in surface path transmission of 1000 times produces a signal change of only 10 times. This phase of the problem requires further study with adequate monitoring of atmospheric conditions along the test path.

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