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Environmental Effects on Airborne Radar Performance

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***Abstract* – A radar is designed to meet customer specifications of range performance, angle accuracy, etc. However, an airborne radar must operate in an environment which may be different from the assumptions used in writing the performance specification. In an aircraft installation, the radar antenna is protected from the atmospheric environment by a radome which may introduce distortions and reflections of the radar energy. In some installations, such as AWACS, the aircraft may intrude into the near-field of the antenna, with subsequent distortions and reflections. The atmosphere between radar and target introduces diffraction effects which frequently cause fluctuation of the received target signal. The surface of the Earth acts as a large, complex target. Modern pulse Doppler radars use range-Doppler processing to separate airborne targets from the backscatter from the Earth (dubbed clutter). The antenna is designed with low side-lobes to minimize "side-lobe clutter" and with adequate system frequency stability to handle "main-beam clutter." The forward scatter from the Earth frequently causes the radar to see a mirror reflection of the desired target, apparently below the Earth's surface. This may cause undesired effects in tracking the target. This paper discusses these environmental effects revealed in flight testing of two Westinghouse radars.**

***Index Terms* – Airborne Radar, Radar Detection, Radar Tracking**

I. Introduction

The AN/DPN-53 radar was designed by Westinghouse for installation in the nose of the BOMARC B (IM99-B) interceptor missile, shown in Fig. 1, built by Boeing. The antenna was mounted in the nose and covered with a radar-transparent radome. Pulse-Doppler techniques permitted the radar to detect low-flying targets against a ground-clutter background. The missile was flown at a constant altitude until the desired target was detected, then dove to intercept the target. A major problem, described below was found during missile flights against drone targets over the Gulf of Mexico.

Fig. 1. BOMARC Missile – IM99-B

The AWACS (Airborne Warning and Control System) is comprised of a Boeing 707 (E-3A or Sentry), shown in Fig. 2, configured to carry a long-range surveillance radar, the AN/APY-1, supplied by the Westinghouse Defense and Electronics Center (now Northrop Grumman Electronic Systems) and associated command and control equipment.

Fig. 2. AWACS aircraft – USAF version – E-3 Sentry

The radar antenna is installed in a rotating "rotodome" with a radome over the radar antenna supported by two pylons above the fuselage, shown in Fig. 3, thus obtaining 360 degree azimuth coverage. Details of the radome multilayer construction are shown in Fig. 4. To obtain target altitude information the radar beam is electronically scanned vertically. The rest of the radar is installed in the fuselage.

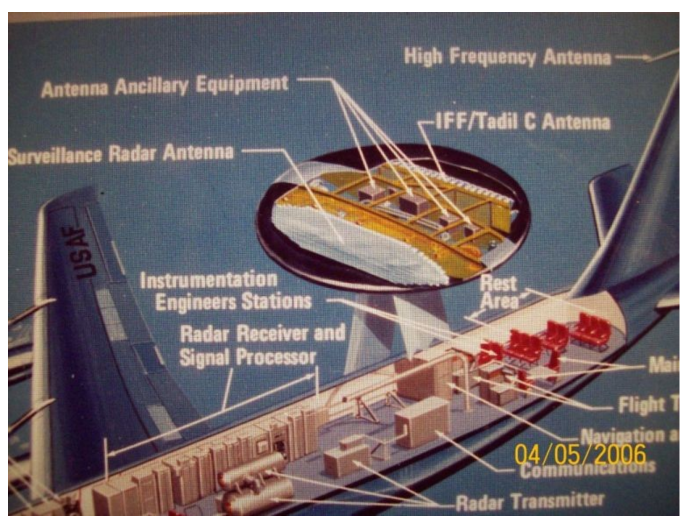

Fig. 3. AWACS Rotodome on pylons (Brassboard installation).

Again, pulse-Doppler is used to separate targets from clutter. A Brassboard "fly-off" in the Seattle area in the summer of 1972 between Westinghouse and Hughes versions of the AWACS radar revealed several problems described below.

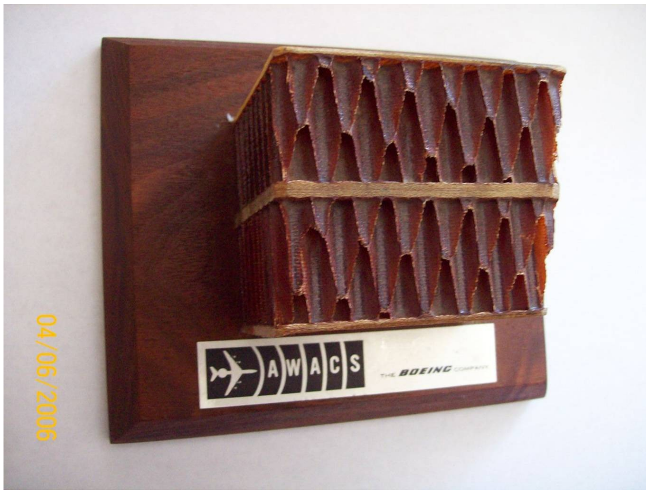

Fig. 4. AWACS Radome multilayer construction

Below we will discuss the effects on radar performance of the following environments:

1) Radome
2) Aircraft
3) Atmosphere
4) Surface of the Earth

II. Radome Effects

The AWACS radar antenna is a planar array which is covered by a radome to protect it from the airstream, shown in Fig. 3. The radome is a complex fiberglass structure, roughly 30 feet wide and 6 feet tall that is bolted to a central structure. Monocoque construction is used to avoid support structure in front of the antenna. The radome is constructed with several layers of sheet fiberglass, separated by honeycomb to provide adequate strength against airstream and gravity loads, as shown in Fig. 4. In the early design phase a one-seventh scale antenna was tested in a scale radome to evaluate radome structural effects on the antenna pattern and provide guidance for the final radome design. In initial flights of the "Brassboard" radar at Seattle in 1972, the antenna/radome performed reasonably well However; there were several areas of concern. Diffraction by the radome appeared to deform the main beam so that height-finding using elevation beam scanning was degraded. Also, the nose of the radome caused strong downward radiation as illustrated in Fig. 5.

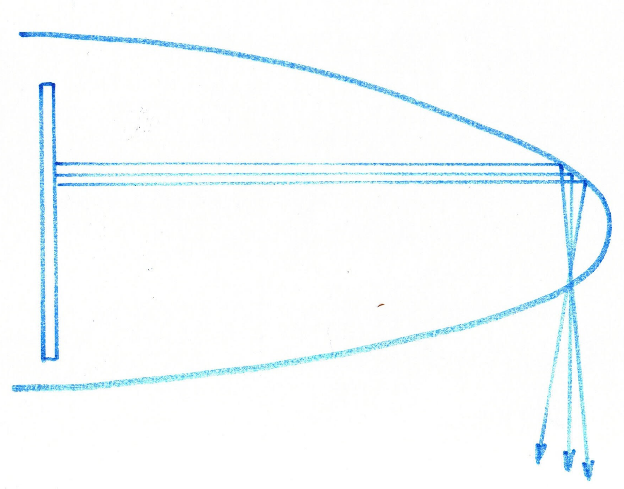

Fig. 5. Downward lobe from radome nose reflection

This caused a large radar signal due to relative closeness of the Earth and the strong back-scatter at normal incidence. The first return from the ground is from the ground directly below the aircraft, called the "Altitude Line." To reduce this signal and minimize beam shape distortion, part of the inside layer of the radome near the nose was removed with the desired improvements.

III. Aircraft Effects

Contrasted with the nose installation of the BOMARC radar, the AWACS antenna radiation can impinge on the aircraft structure. In the 1972 flight tests several occurrences were noted, referring to Fig. 2. The most significant problem occurred when scanning over the vertical stabilizer and rudder. Reflections from the metallic surface caused multiple lobes in azimuth which sometimes caused a single target to appear as several targets at different azimuths. Since the Air Force and Boeing vetoed the application of radar absorber on the tail surfaces, no solution was found except to attempt to fly patterns so that the tail pointed away from the expected target direction(s). A smaller, similar problem was found that when looking for low-flying targets over the nose and wing tips of the aircraft. During aircraft banks, such as occurs at the ends of a race-track station-keeping pattern, the wing tip may hide targets momentarily.

IV. Atmospheric Effects

Although the Earth's atmosphere is quite transparent to radar waves at the microwave frequency used by AWACS, its diffraction effects are typically modeled as if the atmosphere were a weak lens with a power that varies with altitude. If this were true, the only effect would be that target elevation measured by the radar would appear higher due to the curvature of the radar to target path. Unfortunately, the atmosphere is generally turbulent so that the index of refraction varies in a chaotic manner so the rays are bent in different directions along this path. Since both radar and target are moving, the bending effects vary over time so that the target return signal also varies chaotically over time. In the 1972 flight test, test targets were frequently observed to experience "drop-outs" over several scans. Initially this was attributed to normal target scintillation. At one point Air Force observers thought the problem was unique to the Westinghouse radar and concluded our design suffered from an "X mile hole problem." To isolate the problem, the Air Force provided an aircraft with a steady or non-scintillating target (Doppler repeater) which experienced similar signal variations as real aircraft targets, thus strongly suggesting that the atmosphere was the cause of the problem. The history of the signal strength vs. time or range is shown in Fig. 6. Wide variation is seen in the S/N.

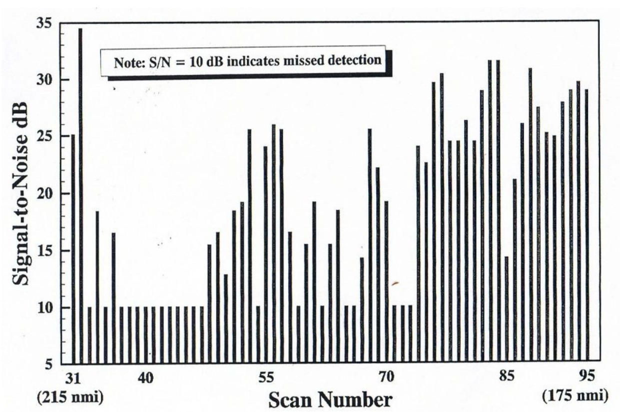

Fig. 6. Doppler Repeater S/N vs. Range and Scan Number

To show how this variation was possible, atmospheric refractivity vs. altitude from balloon-borne radiosonde data was used in a computer program to create ray traces for a variety of ray angles at the radar. Fig. 7 shows the results where voids indicate low S/N and crossing rays high S/N. This effect is commonly called "atmospheric multipath."

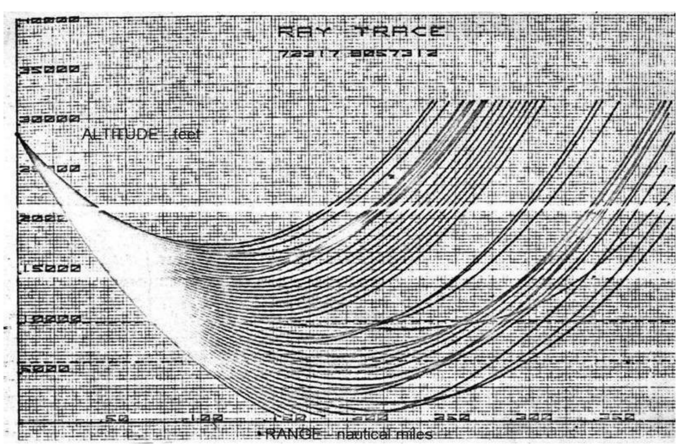

Fig. 7. Ray Trace - Radiosonde atmospheric data

V. Earth's Surface Effects

Both the BOMARC-B and AWACS radars were designed to handle clutter returns, or backscatter from the Earth's surface and separate this clutter from targets using pulse-Doppler processing. However, forward scatter is also present and must be dealt with. In fact, the Grumman Hawkeye surveillance radar uses the bounce (specular reflection) from water, along with measured radar range, to calculate target height. Fig. 8 shows direct and bounce paths.

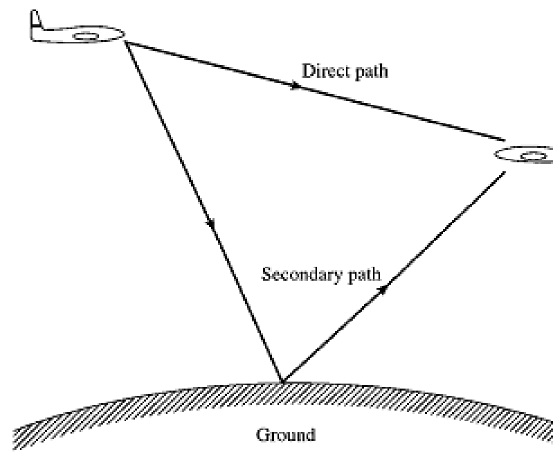

Fig. 8. Radar to Target Paths

The true target return is created by energy propagating on the direct path from radar to the target and returning on the same path. Two "ghost" targets are created by energy propagating via the bounce point. The first return after the true target is from energy propagating from radar to target to bounce to radar, and also the reverse. These two returns are identical and reinforce the received return. The 2nd return is from energy propagating from radar to bounce to target to bounce to radar and is generally the smallest signal. However, the three returns fluctuate independently due to changing angle of incidence on the target and varying atmospheric multipath effect on the different paths. Each return has a different Doppler shift and also a different apparent altitude.

When the Air Force tested the BOMARC-B radar (pulse-Doppler version) against live drone targets over the Gulf of Mexico the "bounce" caused a problem. The BOMARC missile normally flies at a constant altitude until a target is detected at which time it dives on a collision course with the target so the warhead will explode close to the target. However, in these tests the missile frequently dived into the Gulf ahead of the target. This was traced to the radar switching the target track from the direct radar-target path to the radar to reflected target path. Modifications were made to later radars to minimize this switching.

Because of the smaller forward-scatter coefficient over land, this effect was considered negligible for AWACS. However, flights in the Overland Technology Program (ORT) that preceded AWACS design showed that a weak "trailer" sometimes appeared over land. It was dubbed “trailer” because the bounce path is longer than the direct path from radar to target. The trailer appeared in the AWACS flight tests, but the measurement of target height, not available in the BOMARC, aided the target tracker in tracking the direct path.

VI. Conclusion

Flight testing of the Westinghouse BOMARC-B and AWACS radars showed that there were “surprises” due to environmental effects that needed to be explained and compensated for wherever possible. My hope is that the next generation of radar designers will benefit from this exposé of the problems these Westinghouse radars encountered.

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http://SkillmansofAmerica.com/AWACHIST.pdf
Original B/W pictures now in color.

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