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Fundamentals of Low Radar Cross-Sectional Aircraft Design

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Abstract

THERE are two basic approaches to passive radar cross-sectional reduction, shaping to minimize backscatter, and coating for energy absorption and cancellation. Both of these approaches have to be used coherently to achieve required levels over the appropriate frequency range. Design details are extremely important.

Contents

Shaping

There is a tremendous advantage to positioning surfaces so that the radar wave strikes them at close to tangential angles and far from right angles to edges. In Fig. 1, the return from a 1-m² sphere is compared to that from a 1-m plate at different look angles. First consider a rotation of the plate from normal incidence to a shallow angle, with the radar beam at right angles to a pair of edges, then with the radar beam at 45 deg to the edges. The wavelength is about $\frac{1}{10}$ of the length of the plate. At normal incidence, the flat plate acts like a mirror, and its return is 30-decibels (dB) above or 1000 times the return from the sphere. If we rotate the plate about one edge, the cross section drops to that of the sphere when the look angle reaches 30-deg off normal to the plate. As the angle is increased, the return falls by about another factor of 50, for a total change of 50,000.

If we rotate the plate about a diagonal relative to the incoming wave, we see a remarkable difference. Now the cross section drops by 30 dB when the plate is only 8-deg off normal, and drops another 40 dB by the time the plate is at a shallow angle to the incoming radar beam. This is a total change in radar cross section of 10 million!

Multiple reflection complicates the situation. Energy aimed into a closed cavity which is a perfect reflector will bounce back in the general direction of its source, regardless of the shape of the cavity downstream of the entrance. However, the energy reflected from a straight duct will be reflected in one or two bounces, whereas, that from a curved duct will require four or five bounces (see Fig. 2). With care, the number of bounces can be increased without sacrificing aerodynamic performance. If we attenuate the signal with each bounce, there is a significant advantage to a multibounce design. To this ray-tracing approach must be added the backscatter terms resulting from direct return from angled surfaces (see Fig. 1). This generally has to be done on a supercomputer using finite-difference or moment-method techniques.

Coatings and Absorbers

It is clear that although surface alignment is very important for external surfaces, the return from the inside of a cavity is heavily dependent on absorbers. An effective coating should be close to a quarter wavelength thick at the frequency of interest. A typical ferromagnetic absorber will be made of a high dielectric material containing ferromagnetic particles. The dielectric material allows reduced thickness by slowing the wave down, and the ferromagnetic particles absorb the energy. These effects by themselves are insufficient to reduce the scattered energy to the required levels. We must now invoke cancellation as shown in Fig. 3. Incoming energy (E_0) generally penetrates into the coating and most of it is absorbed. Some of the energy reflects from the ground plane and after further absorption, a small part (E_2) escapes, having traveled along an internal path of half a wavelength. The remaining energy reflects off the first surface of the material as E_1. The dependence of path length on angle of incidence is mitigated by having a high index of refraction, which keeps

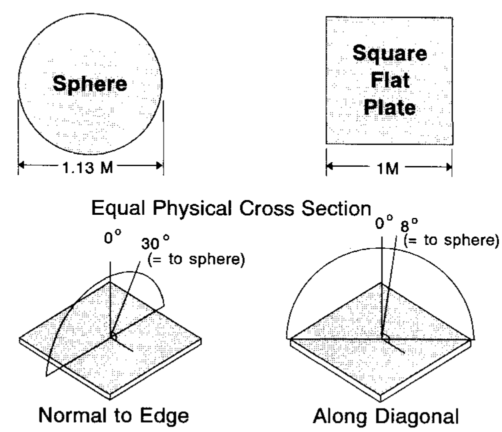

Fig. 1 Radar cross section—square plates.

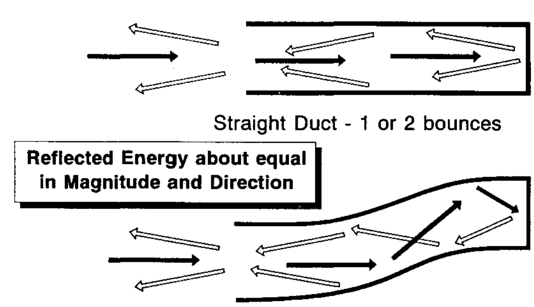

Fig. 2 Energy return from ducts.

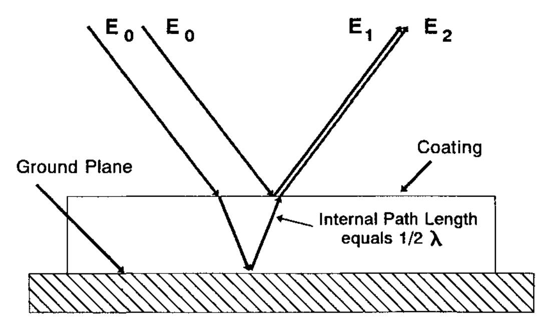

Fig. 3 Attenuation by cancellation.

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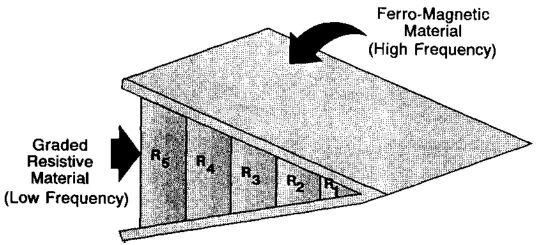

Fig. 4 Typical low observable edge treatment.

the refracted ray close to the normal. This is consistent with a high dielectric constant. It will be seen that not only must the coating be approximately a quarter wavelength thick, but the escaping energy which has passed through the coating must be equal in amplitude to that which bounces off the first surface.

The key dimension of a quarter wavelength can vary in practice from $\frac{1}{2}$ mm to 1 m. Absorbers are needed to cover the required bandwidth. This is shown in Fig. 4 for a typical edge. A low frequency absorber that might be made of loaded glass fiber hex-cell material, is graded from front to back so that the edge is initially electrically soft, and gradually becomes more attenuating as the wave passes through. It is covered by a high frequency ferromagnetic coating, which completes the frequency coverage.

A similar approach is taken to nozzle design, using ceramics as the dielectric materials. Additional issues are thermal expansion, material melting points, and edge brittleness.

Jet Wakes

The driver determining radar return from a jet wake is the ionization present. The strong ion density dependency on gas temperature leads to the conclusion that the radar return from the jet wake of an engine running in dry power is insignificant, although that from an afterburning wake could be dominant. Jet shaping to increase surface mixing is important.

Component Design

When the basic aircraft signature is reduced to a low level, detail design becomes very important. Access panel and door edges, for example, can be major contributors to radar cross section. Conventional rectangular doors and access panels are unacceptable. The solution is not only to sweep the panel edges, but to align those edges with other major edges on the aircraft. On the F-117A, all panel edges are aligned with the trailing edge of the wing so that their signatures are contained inside the basic wing signature.

The pilot's head, complete with helmet and cockpit internals, is a major source of radar return. The cockpit is designed so that its external shape conforms to low radar cross sectional design rules. The glass is plated with a reflective film, which should pass at least 85% of the visible energy, and reflect essentially all of the radar energy.

Aerodynamic measurements and on-board antennae and radar systems are a major potential source of high radar visibility. These must all be designed to have signatures within that of the aircraft envelope.