

General principles of passive radar signature reducing – stealth technology and its applications

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Abstract

The paper presents passive radar signature reducing principles and technologies and discusses the ways to implement stealthy characteristics in general vehicle design. Stealth is a major requirement to all current-generation military vehicle designs and also a strong selling point for various aircraft and UAVs.

Introduction

Stealth technology is currently being incorporated in the great majority of the newest airframe and vehicle designs in response to an ever increasing range of high performance radar guided missiles and interceptors on the modern battlefields.

Reducing an aircraft radar signature is a problem as old as the RADAR system itself- and has been studied since the early 40's when the Nazi Germany tried to delay the detection of its bombers and fighters as they crossed the English Channel in the battle for Britain. The revolutionary Gotha/Horten 229 incorporated stealth characteristics and advanced aerodynamic solutions in its design such as drag-rudders and blended wing-body configuration that ensured a minimal radar cross-section. In fact, the much bigger Ho 229 had the same radar signature as a typical Me109 fighter (up to four times smaller than the physical cross-section area).

Anti-radar solutions on this early stealth fighter/bomber included surface blending, flying wing design, masked air intakes and jet exhausts, absence of any vertical stabilizers and use of non metallic (wooden) parts for the outer wing sections, as well as laminated wood surfaces with strongly conductive graphite mixed glue especially in the forward section (leading edges and engine intake cones). The pioneering design is presented in Fig. 1.

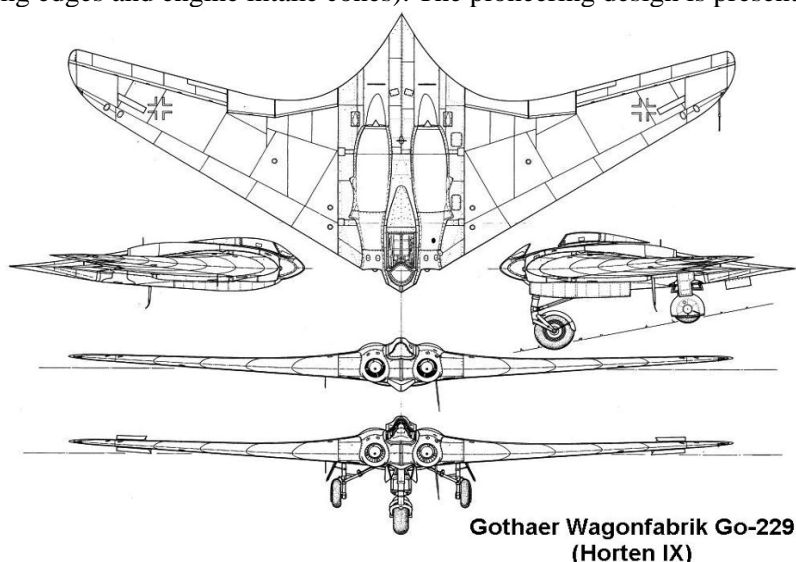


Fig. 1 The Horten-Gotha 229 prototype-the first stealth aircraft (1943). [1]

The Gotha 229 prototype completed some hundreds of flights before an engine failure caused it to crash. The testing concluded it was an excellent design surpassing contemporary jet and propeller aircraft, and was rushed into production. An accurate aerodynamic analysis states:” The Ho-229's design employed a thoroughly modern wing shape far ahead of its time. The wing had a twist so that in level flight the wingtips (and thus, the ailerons) were parallel with the ground. The center section was twisted upwards, which deflected air in flight, and provided the majority of its lift. Because of this twist in its shape, if the pilot pulled up too suddenly, the nose would stall (or, lose lift) before the wingtips.

This meant that the craft's nose would inherently dip in the beginnings of a stall causing the plane to accelerate downwards, and thus it would naturally avoid a flat spin. A flat spin is difficult to recover from, and many rookie pilots have crashed from this condition. Horten also noticed in wind-tunnel testing that in the beginnings of a stall, most airfoil cross-sections began losing lift on their front and rear edges first. Horten designed an airfoil cross-section that developed most of its lift along the centerline of the wing. Since the center line had high lift and the front and rear edges had low lift, it was called a "Bell-Shaped lift curve". The wings were also swept back at a very modern and optimum angle (his gliders from the 1930's used this sweep long before it became popular) which enhanced its stall-resistance, and also lowered its wind-resistance which helped its top speed. This made the Ho-229 easy to fly and very stall-resistant in all phases of its operation.”[1]. Nevertheless only three were completed, one being taken to the US and tested after the war, currently being in storage at the National Air and Space Museum.

After the war, a number of essays have been made along these lines, along with the independent-and unintentional- discovery made by John K. Northrop, that a low aspect ratio flying wing configuration has stealth characteristics, his experimental XB-35 bomber prototype experiencing radar detection problems when tracked from ground-based radar during maneuverability assessment trials.

The final decision in favor of reduced radar observability came after a spy U2 plane flying at very high altitude was shot down using a radar-guided missile and the pilot, Gary Powers, was captured. Stealth technology was to be used for any special mission aircraft designed since. As radar systems became more portable, and with the development of small systems containing radar-directed weapons firing and guidance, any newly designed military aircraft is currently expected at least to have „reduced” observability if not be of a fully stealth design.

Current European projects such as the Eurofighter and the Rafale are low observability design having „stealthy features” but not true stealth, lacking the needed geometric design to ensure a multi-lobed radar scatter that is desirable to disable the weapons locking systems by presenting conflicting radar images (two or more apparent targets moving at various speeds and different directions using reflections from angled and rigorously parallel surfaces and sharp edges).

Let us analyze the main features of some of the currently flying, declassified stealth objects (Fig.2). It is obvious that all have faceted, low profile shapes with minimal frontal cross-sections and various curves that change the radius across the shape on more than one direction. In addition, some show a coating of absorbing material ensuring both a scatter and a strong attenuation of the radio waves that get to the metallic construction underneath. It is also common to use composites as much as possible on the leading edges and front sections, as a part or as a coating of a metal part to ensure further reduction of the reflecting front section. Nose cones and wing main panels in lighter aircraft and drones are entirely composite.

The guiding principles of radar detection avoidance are: a minimal frontal cross-section to delay the detection until the aircraft is near the antenna, and aligned features parallel to two or more directions to produce a strongly lobed reflection that can misguide the radar to interpret as multiple targets moving on different directions (as it is the case with a flock of birds for example). The curved surfaces that constantly change curve radius function as well as flat surfaces in producing lobed reflections, making target speed and direction assessment more difficult in the event of a radar lock-on.

First generation designs were strongly angular and had to sacrifice performance to improve stealth, as seen in the F-117 a Nighthawk bomber, the Tacit Blue airborne radar platform, the Senior Prom cruise missile project and the stealth demonstrator and precursor to f-117, the Have Blue experimental airplane or even the German Lampyridae stealth demonstrator. Except for the latter and the SR-71/A-12 they were subsonic and very poor-handling aircraft that were useless as interceptors or proper fighter roles.

The second generation of stealth aircraft was designed to make a compromise between aerodynamics and stealth, and such they incorporated a mix of flat angled surfaces and curves –the B-2 bomber and most of the drones from the X47 family and derivatives, the AGM 137 missile and X36, the T3 minus Dark Star drone ,etc.

The third and current generation of stealth objects blend advanced aerodynamics and stealth characteristics by using non-standard control surfaces and layout that favors both maneuverability performance and low and scattered radar signature. An example of such a craft is the Boeing Bird of Prey, the X-36 flying model and the YF-23.



Fig. 2 Some of the full-stealth design planes, helicopters and drones.

The analysis of the effect of a shape (and coating) for an aircraft can be carried out quite simply, by analyzing the radar reflection (or, if you will, secondary emission considering the plane to be a radio wave antenna). As radar frequencies vary, I will simulate a simple stealth configuration that is under the scope of a K-band radar (12, 5-18 GHz to 26, 5-40 GHz, omitting the resonating frequency of water vapors, 22,2GHz). K-band radars are the typical fire control radars used throughout the world and thus a typical range of frequencies to look out for when designing radar-proof aircraft [2].

The model uses a simplified geometry of such a craft, namely it is based loosely on the Boeing design, Bird of Prey- a stealth technology demonstrator using advanced aerodynamics.

Basic modeling assumes that around a scaled aircraft a 1 V/m electric field radiates in all normal directions to the plane's surfaces, modeling the scatter of a radar beam aimed at the aircraft; the plane is considered to be made of aluminum (no refracting coating applied) and a working volume of about ten times its length is considered (an air sphere). The model is shown in pictures 3 and 4.

The aim of the model is to determine the shape and intensity of the reflection pattern measured as the electric field is projected onto the spherical control volume.

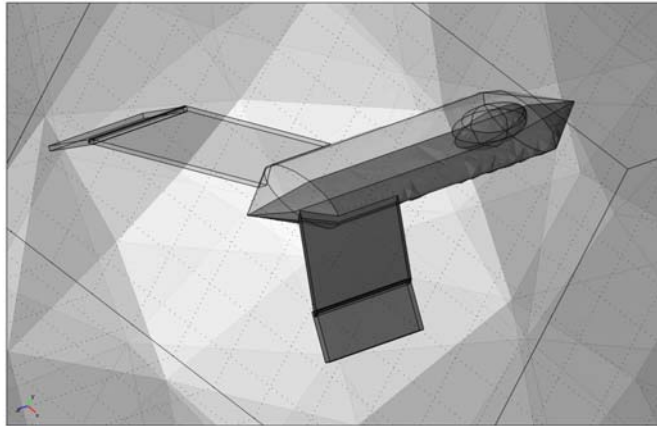


Fig. 3 The stealth configuration that will be tested.

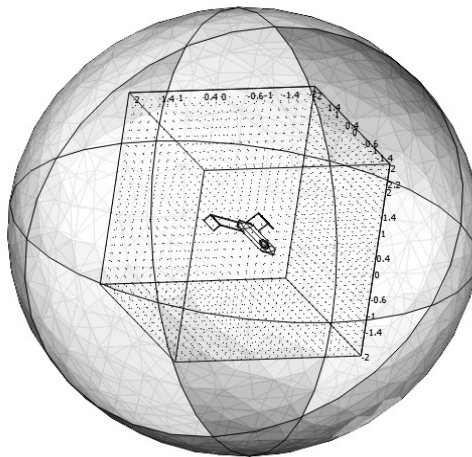


Fig.4 The air sphere and the stealth plane contained within.

Results of the test show a peculiar distribution of the electrical scattered field (fig. 5 and 6) having a minimum below the aircraft and a two lobed appearance along the sides, generating two radar targets moving independently, minimizing the speed and direction detection precision to the point, where simple radar guided missiles cannot lock on the target.

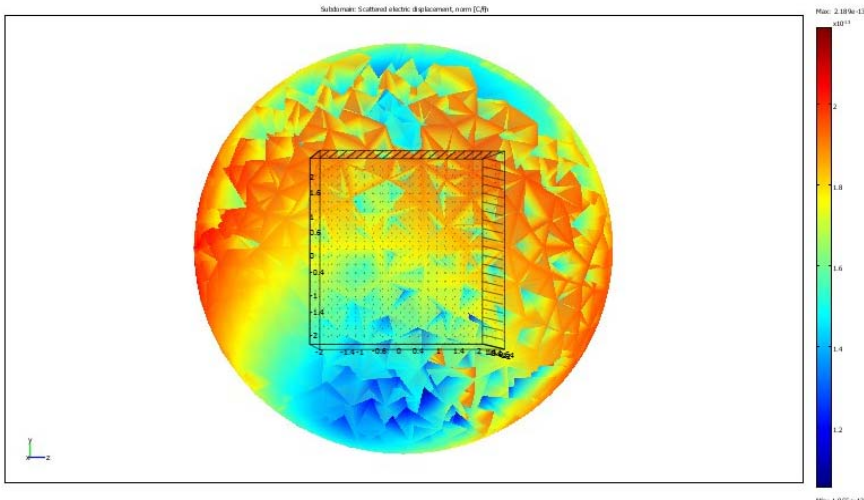


Fig.5 Radar wave (electric field) scatter on the profile, showing in red the “lobes” of the maximal reflection, appearing as other targets on the radar screen.

Also note that the profile presents a minimum scatter direction towards the largest surfaces (sides) of the aircraft. The aircraft is in the center of the sphere, facing left. The cube visible here is the same as in fig.4 containing the aircraft.

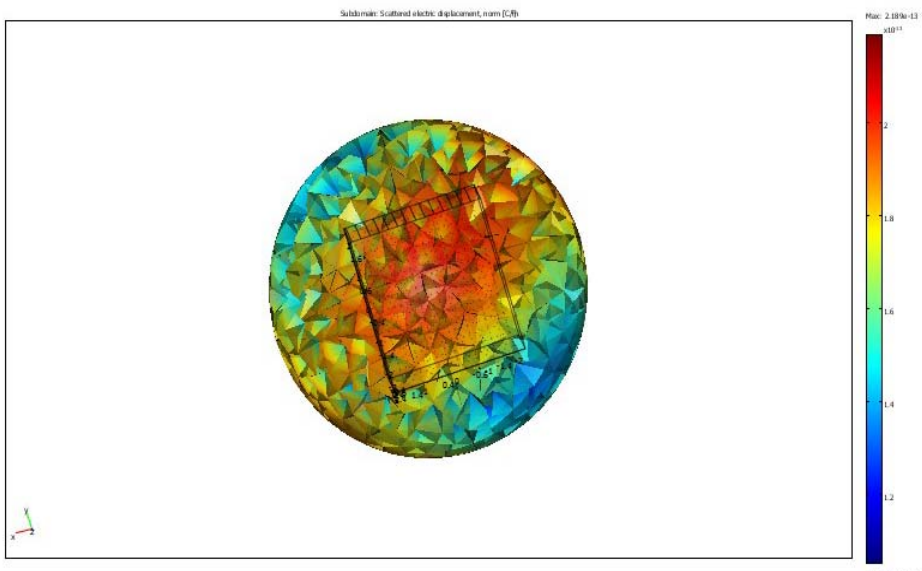


Fig.6 The frontal wave scatter. Plane faces the viewer, inclined at 45degrees to the left.

Conclusions

The frontal area of the stealth aircraft remains the most visible and directionally precise no matter the configuration of the angles. The cross-section is crucial here because it is the direction the plane is most vulnerable, generating the biggest radar reflection of all the surfaces.

Our model used a simplified geometry and simplifying hypotheses such as: the absence of an absorbing/ micro scattering coating on the aircraft, the entire aircraft skin made of aluminum, absence of parasitic scatter from the cockpit interior (a major source of radar beam reflection in real aircraft), and arbitrary scaled power for radar and control air volume sizes. The results should be seen as an analysis of the effect that a particular shape has on the radar reflection and its consequences on detection and ranging using radio waves. In reality, the reflections are much lower due to the use of coatings and materials that absorb and dissipate, or otherwise re-route the electric field lines (special high-frequency high-loss dielectrics mixed with resin and microspheres or prisms of highly-reflecting metals). Testing of radar-avoiding passive means is made by placing a 100% scale mock-up of the plane on a pillar and aiming a special radar at it, then measuring the response (reflections) along a large frequency domain.

The special coating along with underlying composites achieve the reduction in intensity of the scattered field and the particular shape of stealthy objects arranges the direction of the maximum scattered reflection on conflicting directions or ensures cancelling of reflections by interference if the surface arrangement needed for this effect is also aerodynamically acceptable. Using such means, the radar reflection can be either too weak to interpret correctly and impossible to range, or, as the target approaches and the reflections become important –totally unusable for targeting as the lobes confuse the weapons firing radar on the target direction and speed that seem to change in large and sudden steps.

The concept being sufficiently simple and technologies at least partly known by all the major weapons manufacturers I consider an appropriate study of the matter is in order.

REFERENCES

- [1] <http://greyfalcon.us/The%20Horten%20Ho%20229.htm>.
- [2] PEYTON Z. PEEBLES jr., *Radar Principles*, John Wiley & Sons Inc, 1998.