Appendix B.
Fifteen Minutes of Stealth in Aircraft Design

There is no point in considering military aerodynamic configuration development without including stealth. It plays a key role in the configuration layout. Currently, it appears that some government planners want to ignore the fundamental importance of stealth to survivability. This is fanciful and nostalgic thinking. The fact is that missiles are finally becoming reliable, and there is no such thing as too much stealth. Although the details are classified, certain basic principles have been described. Stealth is usually considered to consist of several elements (often referred to as signatures):

- radar cross section, *rcs*
- infrared
- visual
- aural

For aerodynamic configuration design, the key element is radar cross section, *rcs*, with some consideration of infrared, mainly from the back of the aircraft. In the mid 80s I actually took the graduate sequence in Electromagnetic Theory at a local university. Any aerodynamicist working in military configuration design will have to add this topic to his plan for continuing education.

Although complete information on this technology is not available, there are numerous references that define the public information on stealth. To get insight into how stealth emerged to influence airplane design, read the book by Ben Rich.[1] He headed the Lockheed Skunk Works during the development of the F-117. More details on the F-117 design are given by Alan Brown.[2] The B-2 development is described as part of the 1991 Wright Brothers Lecture by Waaland.[3] Explicit discussions of stealth in airplane design have been given by Raymer[4] and Whitford.[5] Somewhat more theoretical treatments of the theory underlying stealth have been given by Ball[6] and Fuhs.[7] The synopsis given here is supported by these references. A good overview of the survivability issues has been given by Patterson,[8] who discusses the question of how much stealth is enough.

How rcs works

(1) A radar site transmits a signal and measures the signal that is returned from the target (in this case an airplane). When the sending and receiving antennas are co-located, the radar is known as *monostatic*. This is the usual case. If the receiving antenna is located somewhere

else, the radar is *bistatic*. Bistatic systems may be able to detect aircraft designed to operate stealthily against monostatic systems. This is a fundamental consideration in stealth. Figure B-1 illustrates the situation.

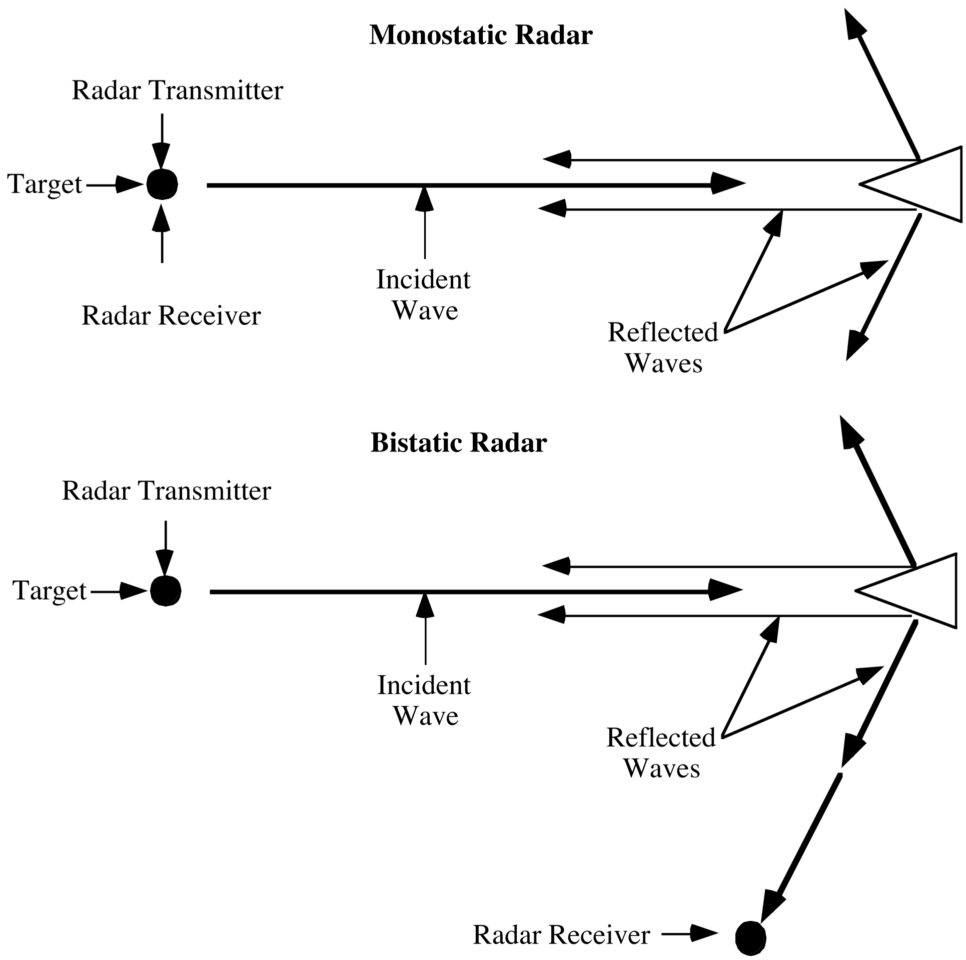

Figure B-1. The basic radar cross-section story. Just about all radars are monostatic.

(2) There is a length scale associated with radar:

$$\underbrace{\lambda}_{\text{wavelength}} \cdot \underbrace{f}_{\text{frequency}} = \underbrace{c}_{\text{speed of light}}$$

The ratio of the wavelength to key length scales on the vehicle,

$$\frac{\lambda}{l_{ref}}$$

is important in understanding the physics of the radar reflectivity. Several different mechanisms exist, and these ratios can be thought of (*very*) loosely as analogous to the Reynolds number and Knudson number for use in aerodynamics, where values of these parameters are used to decide which physical phenomena dominate the flowfield. The wavelength also determines the size of the antenna required.

(3) The signature is expressed as an area. One square meter is the reference area, and the value of the *rcs* is usually expressed as a relative value using decibels,

$$\sigma(db_{sm}) = 10 \cdot \log_{10}\left(\frac{\sigma_{\text{meters}}}{1 \text{ meter}}\right).$$

Some typical values, the magnitude in meters, *db*, and type of vehicle with this *rcs* are given in Figure B-2.

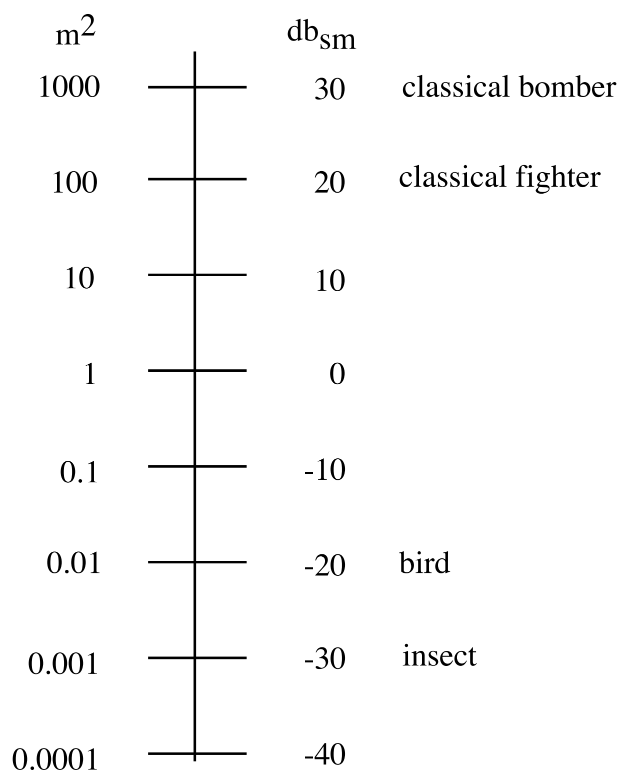

Figure B-2. Typical stealth values.

Ben Rich loved to tell the story of his test range experience, where the operator claimed that the model, a precursor of the F-117, wasn't "on the pole" until a bird landed on the model, and he could pick up a reflection. That should tell you something about the signature level of the F-117.

For a lot of the work in aerodynamic configurations, specular reflection dominates, and physical optics is useful. Figure B-3 is a sketch based on Fuhs notes that illustrates the situation. It is perhaps obvious, but to avoid large radar returns, there should be no surfaces normal to the radar signal.

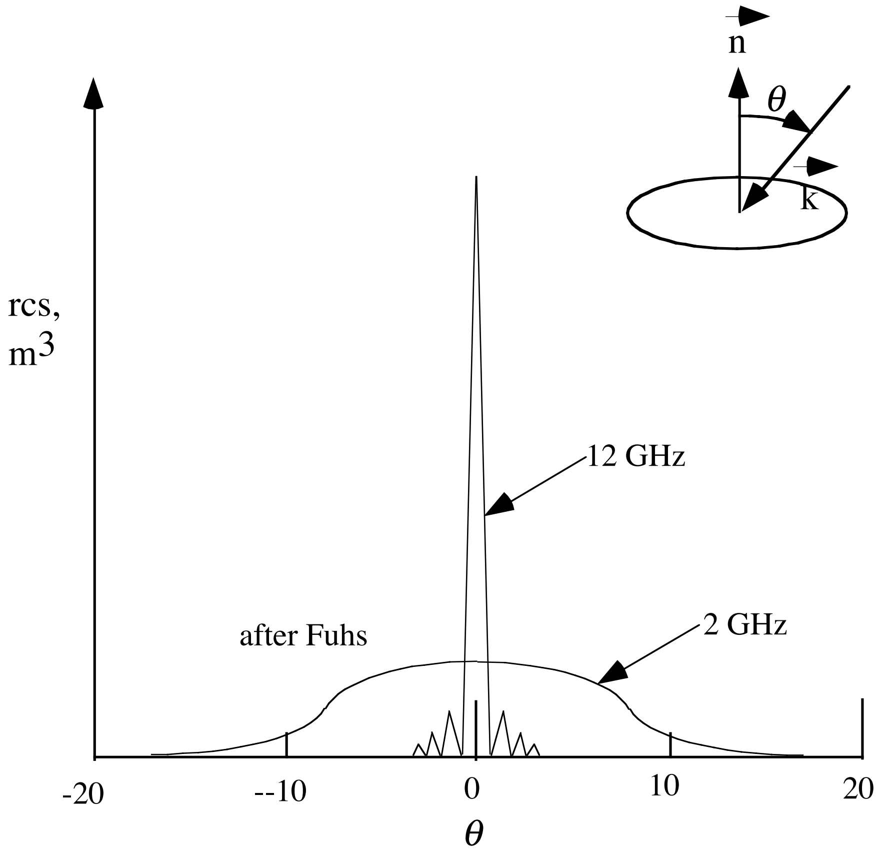

Figure B-3. Radar return from a circular plate

Clearly, flat surfaces normal to the incoming waves are bad, and reflect strongly back to the transmitter, thus surfaces should be angled to reflect the waves in other directions, *i.e.*: examine Figure B-4.

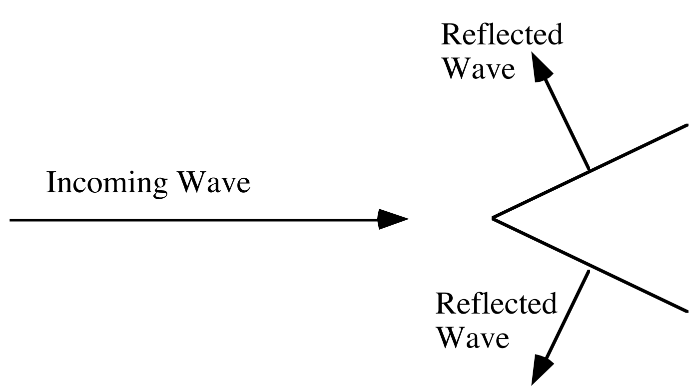

Figure B-4. A way to reduce radar returns.

Designers work to different *rcs* target values (levels) in different sectors. A typical division is show here in Figure B-5.

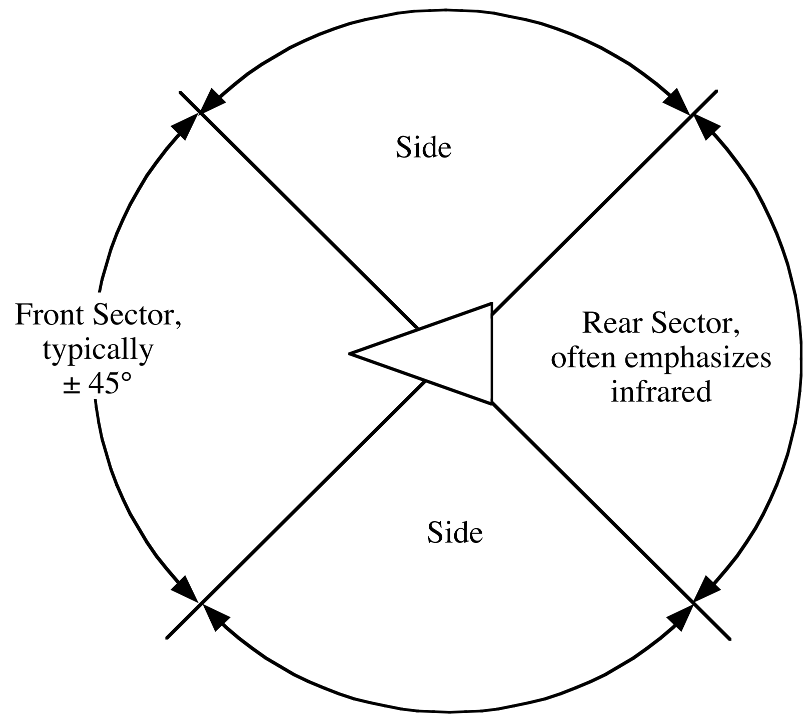

Figure B-5. Typical divisions of radar returns around an airplane.

The front sector typically has the lowest allowable value of *rcs*. This means that wings are swept, and cavities are bad. The worst case is the inlet and engine front face.

The F-14 and F-15 turned out to have terrible inlets from a stealth point of view. This was ironic. The designers had worked hard to design these intakes, since they were excellent aerodynamically. Figure B-6. illustrates this situation.

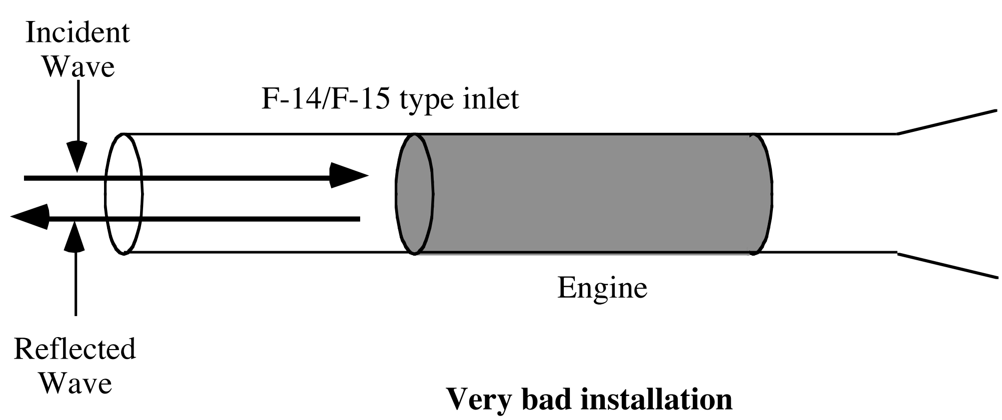

Figure B-6. Example of the inlet situation on some modern fighters.

Instead, the engine front face has to be shielded by an offset inlet, as shown below. Observe the extreme effort devoted to hiding the engine in the F-117 and B-2. This also provides an opportunity to take full advantage of *rcs* absorbing material treatments in the duct. Thus modern military inlets use *s*-shaped inlets. Figure B-7 provides an example. More recently, more information and new approaches to inlet design appeared in Aviation Week.[9]

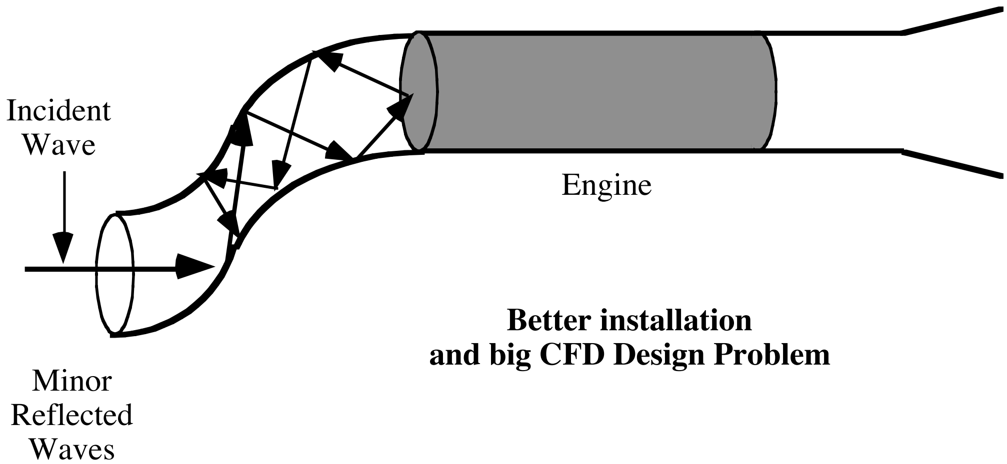

Figure B-7. Inlet design to reduce radar return.

Cockpits and radomes are also bad. They pass the electromagnetic waves through to the surfaces inside them, which are often huge reflectors. Thus special design procedures and materials are required to reduce the radar cross section.

From the side, vertical surfaces are eliminated, introducing canted tails and chine-sided fuselages. However, corner reflectors are terrible, so the angle shown in the front view is only acceptable if it doesn’t line up in the side view. Figure B-8 illustrates this situation.

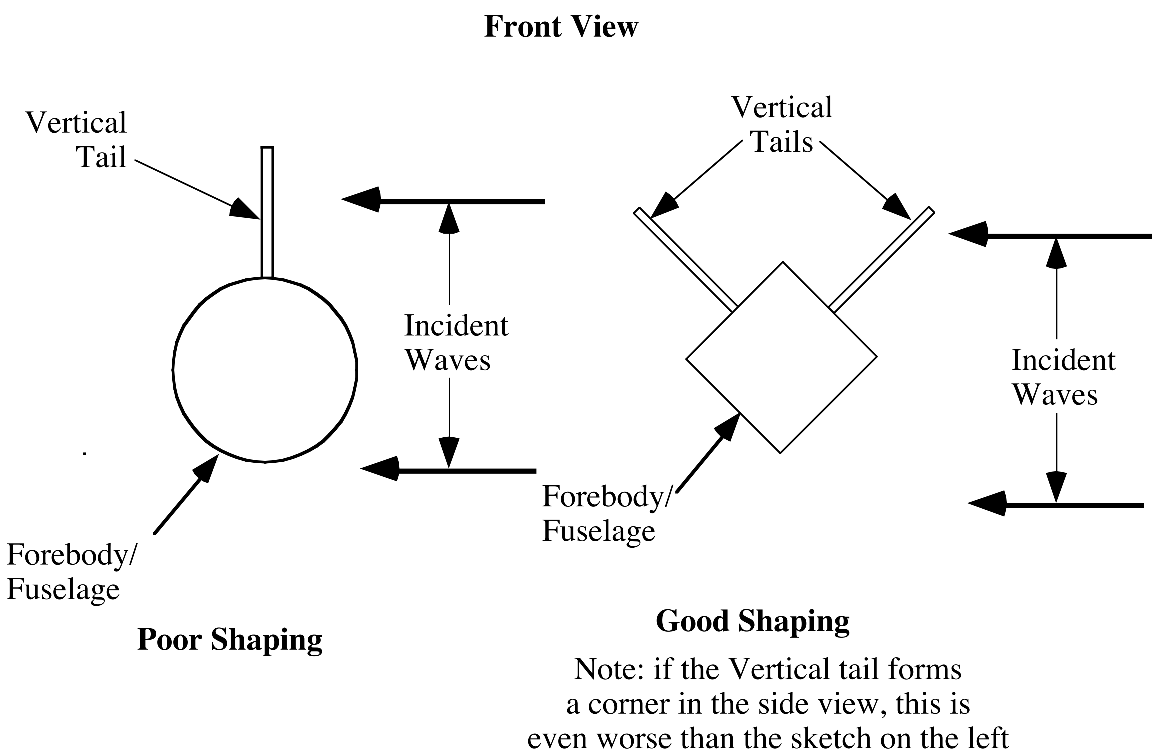

Figure B-8. Shaping practice to reduce radar returns.

This also explains the sawtooth landing gear doors and access panels as shown in Figure B-9.

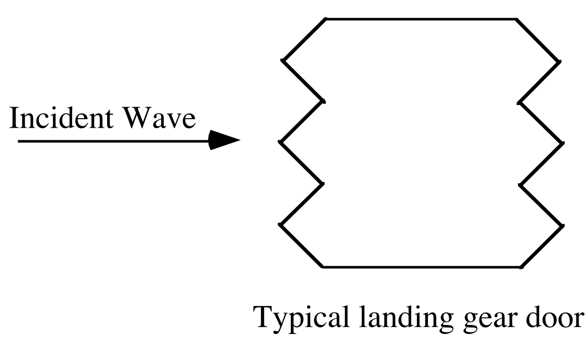

Figure B-9. Example of doors used on stealth airplanes showing no edges normal to the incident wave.

Finally, in addition to shaping, the vehicles are treated with coatings and special materials to reduce the radar return.

Computations

The recently updated reference by Ball provides some sources to start making *rcs* estimates. There is also a website with a Matlab code that can be used: http://aces.ee.olemiss.edu/, look under software for POFACETS. In 2006 a Google Search leads to many other sources of information.

References

[1] Ben R. Rich and Leo Janos, *Skunk Works*, Little, Brown, and Co., 1994. This book tells the story of stealth configuration development at the Skunk Works. Not particularly technical, but a good read. Gives good insight into aircraft development programs. Rich succeeded Kelly Johnson, and passed away much too soon.

[2] Alan Brown, "Fundamentals of Low Radar Cross-Sectional Aircraft Design," *Journal of Aircraft,* Vol. 30, No. 3, May-June 1993, pp. 289-290, and "Stealth Design of the F-117A." This second paper supports the synoptic that appeared in the AIAA *Journal of Aircraft* cited first. This paper covers much more than the aerodynamic configuration issues.

[3] Irv Waaland, "Technology in the Lives of an Aircraft Designer," 1991 Wright Brothers Lecture. Describes Northrop experience, including the B-2 development, along with many other programs. The author received the AIAA Aircraft Design Award for the B-2.

[4] Dan Raymer, *Aircraft Design: A Conceptual Approach*, 3rd Ed., AIAA, Washington, 1999. The section on RCS is contained in pages 191-201. Infrared, Visual and Aural aspects of stealth are discussed in the following sections, pp. 201-203. This is a good direct unclassified source of accurate shaping information.

[5] Ray Whitford, "Designing for Stealth in Fighter Aircraft (Stealth from the Aircraft Designer's Viewpoint)" SAE Paper 965540, October 1996. This paper is very good. A version of this material is also contained in Whiford's "Fundamentals of Fighter Design, Part 10 - Stealth," *Air International*, Sept. 1997, and his recent book, *Fundamentals of Fighter Design*, Airlife, 2000.

[6] Robert E. Ball, *The Fundamentals of Aircraft Combat Survivability Analysis and Design, Second Edition*, AIAA, Washington, 2003.

[7] Allen Fuhs, *Radar Cross Section Lectures*, AIAA, but there is no date or copyright. These are handwritten charts from lectures by Prof. Fuhs developed in 1982. They help the designer get some insight into electromagnetic theory.

[8] John Patterson, "Overview of Low Observable Technology and Its Effects on Combat Aircraft Survivability," *Journal of Aircraft,* Vol. 36, No. 2, March-April 1999, pp. 380-388.

[9] David A. Fulghum, "Stealth Engine Advances Revealed in JSF Designs," *Aviation Week*, March 19, 2001, pp.90-99.