STEALTH

15 More Minutes…

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WHY STEALTH?

http://www.armysniperassociation.com/52.jpg

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WHY STEALTH?

Basically, something which is stealthy is less likely to be detected than something that isn’t. The idea of stealth does not simply apply to military aircraft, there are many different situations in which humans, and animals for that matter, desire to go undetected by someone or something. For example, the sniper in his ghili suit above needs to get as close to the target as possible without being detected. Often animals, people, and even aircraft which have acquired stealth capabilities have other qualities which would be considered unacceptable otherwise.

The sniper for example, while nearly invisible while sitting still in his ghili suit can be seen better when moving, so he crawls along the ground at an extremely slow speed. However, if he is spotted and has to get up and run quickly, the ghili suit and other equipment not only make him very visible when not in the grass, they slow him down considerably. The same type of things are true of aircraft, the designer is going to have to give up something, be it performance, ordinance loads, communication capabilities, or any number of other things, if the aircraft is to be truly stealthy.

DETECTION TECHNIQUES

1. Visual
2. Acoustic
3. Infrared
4. **RA**dio **D**etection **A**nd **R**anging

DETECTION TECHNIQUES

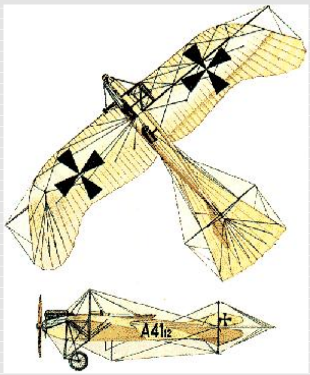
Generally there are four basic means for detecting an aircraft. The most basic of the techniques is visual detection, where detection relies solely on the ability of a human observer to actually spot the incoming aircraft. Acoustic detection similarly relies on an observer to hear the aircraft as it approaches. Infrared detection is much more technical, relying on the ability of some imaging or detection system to pick up the thermal signature of the aircraft. These types of systems are often used for short range missiles. RADAR systems are the best and easiest way to detect a normal aircraft. These systems consist of a transmitter to send radio waves toward an aircraft and a receiver to determine the aircraft's position upon receipt of those waves after they have reflected off of the aircraft.

STEALTH IN NATURE

Stealth is not a new thing, nature has been attempting to decrease the delectability of animals since the beginning of time. Here we see on the left a stick bug, which remains still, clinging on to a branch, until a meal unsuspectingly walks by. On the upper right is a Cryptic Frog which has developed coloring to allow it to blend in with leaves lying on the ground while waiting for a meal. The lower right picture is of a Snowy Owl which has adapted its wings to allow it to fly effectively without any noise, thus allowing it to swoop down on its prey without being heard.

EARLY STEALTH

Etrich Taube



http://www.fiddlersgreen.net/aircraft/WWI/taube/taube_info/taube_info.htm

U-42 Type IX

http://uboat.net/types/ix.htm

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EARLY STEALTH

Aside from camouflage, the first attempt at decreasing the delectability of a military vehicle did not occurred until aircraft emerged on the scene. In the early 1900's Germany experimented with a clear cellulose skin called Emaillit. This skin, along with silver painted internal structures, made the aircraft effectively invisible from the ground when it was over an altitude of 900 ft[1]. The Soviets attempted a similar experiment on their Yakovlev AIR-4 aircraft with a material called Rodoid with very mild success.

The first attempt at reducing the RADAR signature of a vehicle was also done in Germany, this time in World War II. The German U-boats would run just under the surface of the water, so they would not be visible to the human eye, but when doing so they required a snorkel to get air for their diesel engine combustion. Eventually the Allies developed a technique by which anti-submarine aircraft were carrying RADAR equipment and detecting the reflected signatures from the U-boat snorkels. In response, the German navy applied RADAR absorbent materials to the snorkels of several of their U-boats, with great success. The German military never got around to applying these materials to aircraft of surface naval vessels.

The first attempt by the United States at RADAR signature reduction was the application of a RADAR absorbent coating called MX-410 to airplane wings. Though this coating reduced the signature, the amount and thickness needed made the aircraft extremely heavy, usually too heavy for the aircraft to even takeoff with minimal payload.

RADAR SIGNATURE

Aircraft	RCS (m^2)
Bombers	
B-52	1000
B-1A	100
B-1B	10
B-2	0.000001
Fighters	
F-4	100
F-15	25
F-22	0.5
F-117A	0.1
Cruise Missiles	
ALCM	0.25
ACM	0.001

From Jones, Table 3-1[1]

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RADAR SIGNATURE

The strength of the RADAR signature returned to an enemy instillation by an aircraft is known as the RADAR cross section (RCS). This signal is dependent on several factors, mainly the distance and angle from the RADAR system to the aircraft. Stealth aircraft are generally designed to be very stealthy from certain aspect angles, are always other angles from which the aircraft is always vulnerable. The designer must minimize the number of vulnerable angles and ensure that the aircraft is not at those angles for more than a brief instant. Ideally the RCS of the aircraft will be lower than the wavelength of the enemy RADAR system, in which case the aircraft is basically invisible to the system.

There are three main ways to reduce the RCS of an aircraft:

1. Altering the external design of the aircraft to decrease the number of RADAR spikes. This will require the elimination, or reduction, of surfaces normal to the incoming RADAR signal. Internal structures must also be modified to return a minimal signal strength to the enemy system.

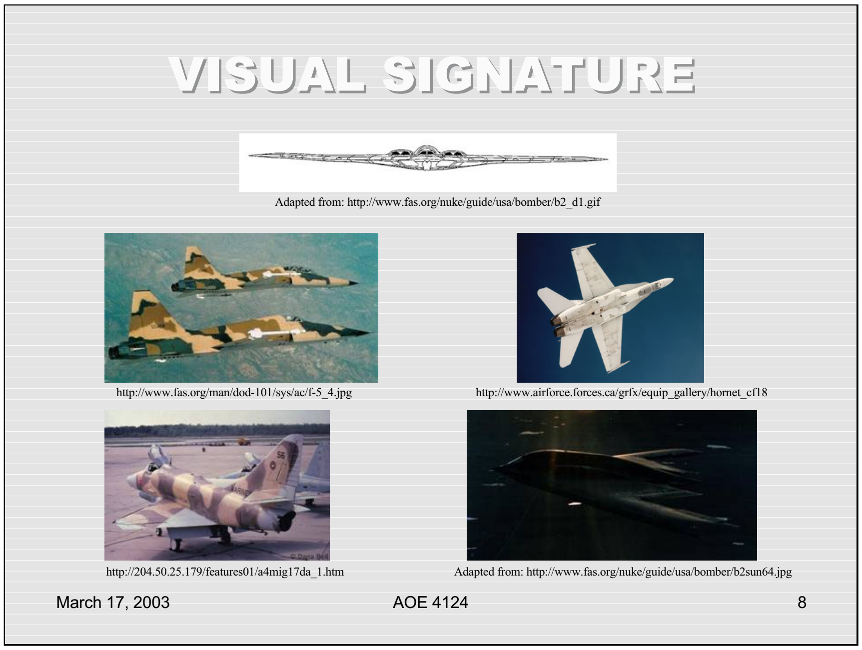
2. Utilize more RADAR-absorbent material on the aircraft. Since the number of surfaces normal to the enemy RADAR system cannot be completely eliminated it is important to coat at least those surfaces with materials which will absorb the energy and reduce the amount returned to the enemy.

3. Increase the use and effectiveness of Electronic Countermeasures (ECMs), both active and passive. A systems ability to fool, or jam, the enemy RADAR increases with the reduction of the aircrafts RADAR cross section. Thus a lower RCS allows for a less effective ECM system to have a better effect than a large system on a non-stealthy aircraft.

INFRAFRED SIGNATURE

Attempting to reduce an aircraft's infrared signature is another important aspect of increasing the aircraft's stealth capabilities. Though these modifications are generally left to the propulsions department, it is beneficial for the configuration aerodynamicist to have some understanding of what must be done. By far the largest portion of the infrared signature is produced by the exhaust from the engines and the nozzle heating produced by the exhaust. One item of consideration for the configuration aerodynamicist is that it is possible to hide the nozzle heat signature from many different aspect angles through extensions of horizontal tails and other structural components. This technique is utilized on the F-22 and F-35 designs. In terms of reducing the exhaust plume temperature, the addition of baffles in the exhaust diffuser causes the flow to separate and cool quicker.

As in the RADAR case there are also infrared jamming systems which consist of devices located near the exhaust nozzle of an aircraft. These devices emit pulses of infrared radiation tailored to confuse infrared tracking systems and missiles. Another consideration is the emissivity of aircraft components. Since the designer attempting to reduce an infrared cross section wants the aircraft to emit the least amount of radiation, the designer also wants the aircraft to absorb the least amount of radiation. Thus, the more environmental radiation which is reflected by the aircraft the better. Low emissivities can be achieved through the use of highly reflective paint and other coatings. Unfortunately, most materials which will reflect infrared waves will also reflect radio waves, thus a compromise between reduction of RADAR signature and the reduction of infrared signature must be sought.



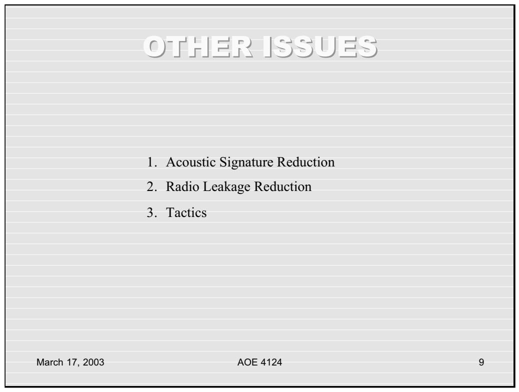
VISUAL SIGNATURE

When all else fails, the human eye still remains a powerful method for the detection of enemy aircraft. Several methods have been utilized to degrade the visual signature of aircraft and other vehicles over the years, camouflage, or the use of some type of coating to make the object blend into the surroundings, is by far the most widely used of these techniques. Aircraft camouflage is created through paint applications on the skin of the aircraft in various mission dependent schemes. For example, an aircraft flying close support missions in jungle surroundings may have jungle colored camouflage painted on the top of the aircraft to blend into the jungle when seen from above, and sky colored patterns painted on the bottom to blend into the sky when viewed from below.

If the aircraft is spotted it is desirable that the spotter either think the aircraft is something it's not or that it's doing something it isn't. For example, one type of visual deception often used on fighter aircraft is in painting the underside of the aircraft to mimic the upper surface, including fake canopies and other main attributes, as seen in the Canadian F/18 above. Another similar technique is to paint an aircraft so that it resembles another aircraft, as in the TOP GUN A-4 in the picture above which is painted to represent a MIG-17. Other coating materials for visual signature reduction include light diffusing paint for night operations, as seen on the B-2 above, and other glint reducing applications for the canopy of an aircraft.

Contrail and smoke emissions from aircraft engines are basically arrows in the sky pointing to exactly where an aircraft is, this is very bad from a stealth perspective. The reduction of smoke emissions is easily achieved through more efficient burning of the engines, but contrail reduction is much more difficult. There are three basic types of contrails: aerodynamic, convection, and engine exhaust. Aerodynamic contrails occur as pressure drops over the surface of an aircraft cause the air temperature to fall bellow the ambient dew point and cause the air to condense. This phenomenon can be reduced through added streamlining of the aircraft, which goes hand in hand with RCS reduction. Convection contrails are caused as warm engine exhaust rises and condenses as it cools to form a vapor trail and engine exhaust contrails form when the exhaust instantly condenses as it enters the cold surroundings, usually this occurs above 30,000 ft. Convection and engine exhaust contrails can be reduced to some extent through the use of certain fuel additives.

One key point to remember is that there are several laser and other long-range optical imaging systems which are capable of effectively racking stealthy aircraft; however, in order to track the aircraft it must be spotted first. Also, as aircraft are tailored more and more towards low RCS signatures, the geometric changes greatly aid in visual signature reduction as well, as is the case of B-2 above. Anything which can be done to make the aircraft look less like an aircraft is a good change in terms of visual signature reduction.



OTHER ISSUES

Acoustic Signature Reduction

An aircraft's aural signature can also become a factor in the detection of the aircraft. The components adding the largest portion of this signature are by far the engines. A great deal of work has been done, with marginal success, in reducing the noise emitted by jet aircraft engines. Some potential changes include the addition of screech liners within afterburners and composite pyramidal skins within the engine to absorb noise. Other changes include the addition of baffles and louvers within the engine in areas where the airflow separates and become more turbulent and thus more noisy. Laminate coating applications on the engine nozzle also help reduce noise emissions, these coatings also helpf for infrared signatures at the same time. Another addition to aircraft noise is noise created as the air flows over the surface of an aircraft. The only reduction possibilities for this problem are increased streamlining. Recent changes in stealth aircraft configurations have move weapons to internal storage bays for the reduction of the aircraft's RCS. When deploying these weapons the weapons bay must open in flight, creating a large recess in the surface and thus a great deal of turbulent and noisy flow through and over the open bay. Several research projects are currently underway in hopes of finding ways to eliminate or reduce this problem through active aero-acoustic suppression.

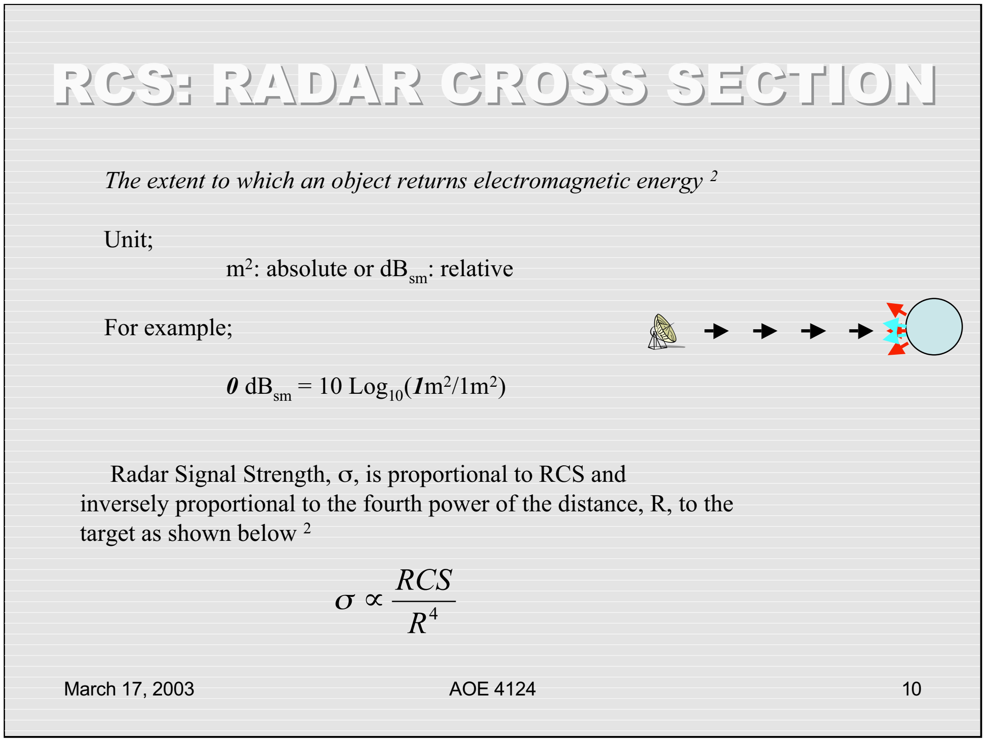
Radio Leakage

As the RADAR signature of an aircraft is reduced the smaller contributors to the signature becoming increasingly more important. One important issue that must be guarded against is leakage of radio waves from various aircraft systems. This simply requires that RAM shielding be placed around any systems which may emit radio waves during a mission where stealth is required.

Tactics

As important as small detection signatures are to a stealth aircraft, the most important variable remaining undetected is still tactics. To this point an aircraft that was completely invisible to all detection systems has never been designed. All aircraft are vulnerable from certain viewing angles or certain situations, it is the job of the designer to minimize these situations. However, it is equally important that the user know when these situations occur and how to avoid them. While this is not directly a designing issue it is still important to know that the aircraft will not always be used in the most stealthy fashion.

A prime illustration for this point lies in the F-117 Stealth "Fighter". While this aircraft is considered to be a highly stealthy aircraft it can't, for example, fly at a large bank angle within the threat zone without exposing it's flat underside to the enemy. Thus the pilot attempts to stay as level and straight as possible throughout the mission. In February 1999 an F-117 was shot down while performing a strike mission in Serbia. This aircraft was not lost due to poor stealth characteristics, or a lucky shot, but instead to poor planning. Tacticians planning the strike missions repeatedly utilized the same flight plan for raids night after night, so that after a strike was carried out an aircraft could be expected to fly over a specific spot a certain amount of time later. And while the Serbian RADAR systems could not get a hard lock on the aircraft they were able to accumulate enough scattered brief sighting of the bombers on their runs that one night they moved a RADAR system directly under the repeated flight path and were able to spot, track, and shoot the F-117 from below.



RCS: RADAR CROSS SECTION

What is RCS? To see the meaning of it, we have to know how a Radar system detects the object. A radar system consists of a transmitter antenna and a receiver antenna. Transmitter discharges a direct beam of electromagnetic radio waves and a receiver gathers the reflected radio waves. During the reflection of radio waves by an object, parts of them are reflected away, parts of them are returned to the receiver with "changed or unchanged" signal.

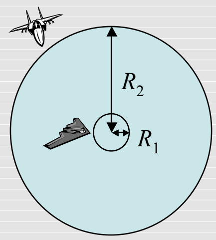
This reflection characteristics are quantitatively defined by RCS, i.e. *the extent to which an object returns electromagnetic energy* is the object's RCS[2]. RCS is measured in square meters or in decibel square meters. Since Radar Signal Strength is proportional to RCS and inversely proportional to the fourth power of the distance, it takes a very substantial reduction in RCS to obtain a meaningful operational benefit[2].

EFFECTIVE RANGE

To reduce the detectable range of a radar system in an order of tactical significance (***82***%) [3]

$$\frac{RCS_1}{RCS_2} = \left[\frac{R_1}{R_2}\right]^4 = [.18]^4 \approx 0.001$$

we have to reduce the RCS in an order of ***1000***.

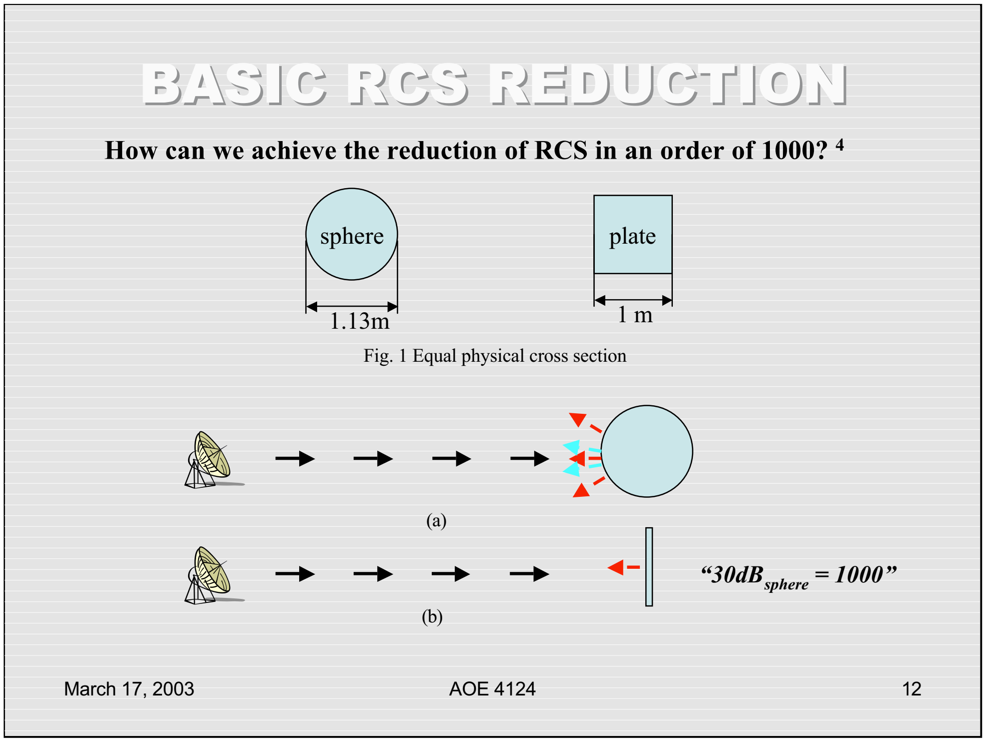


Note: RCS of an aircraft is not a single number [2]

EFFECTIVE RANGE

To reduce the detectable range of a radar system in an order of tactical significance (***82***%)[3] we have to reduce the RCS in an order of ***1000***.

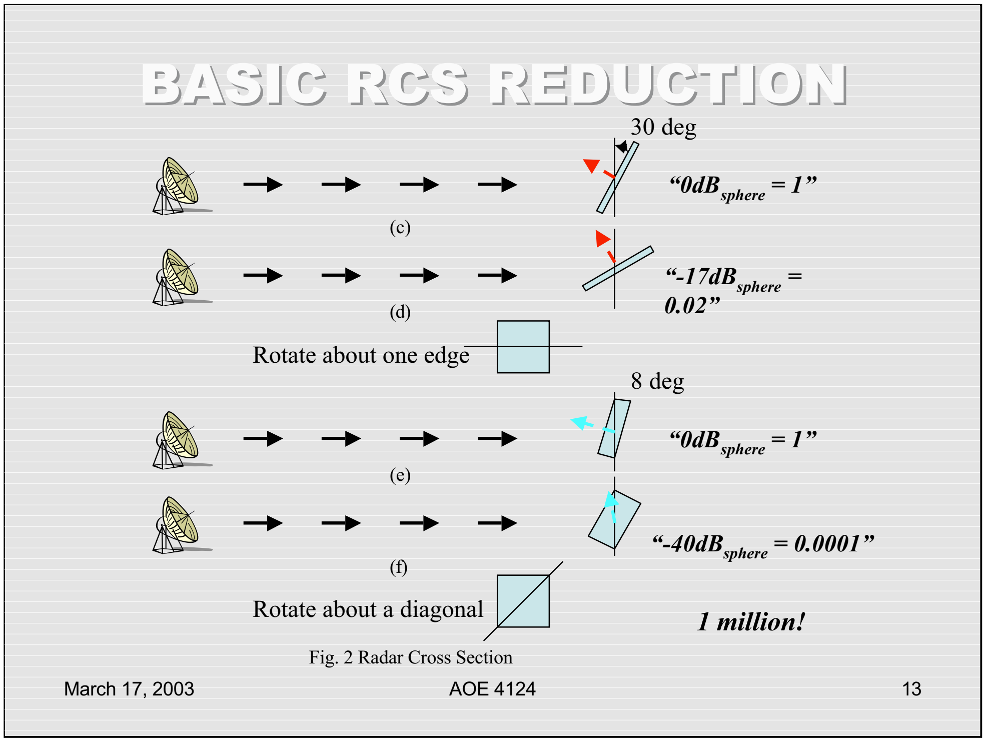
The figure here shows the effect of reduction of RCS. A fighter can approach the target without detection to the distance R_2 but a more stealthy aircraft indicated with a shape of B-2 can approach farther to the distance of R_1 without detection.



BASIC RCS REDUCTION

In Fig. 1, the return from a 1-m^2 sphere is compared to that from a 1-m^2 plate at a different look angle.

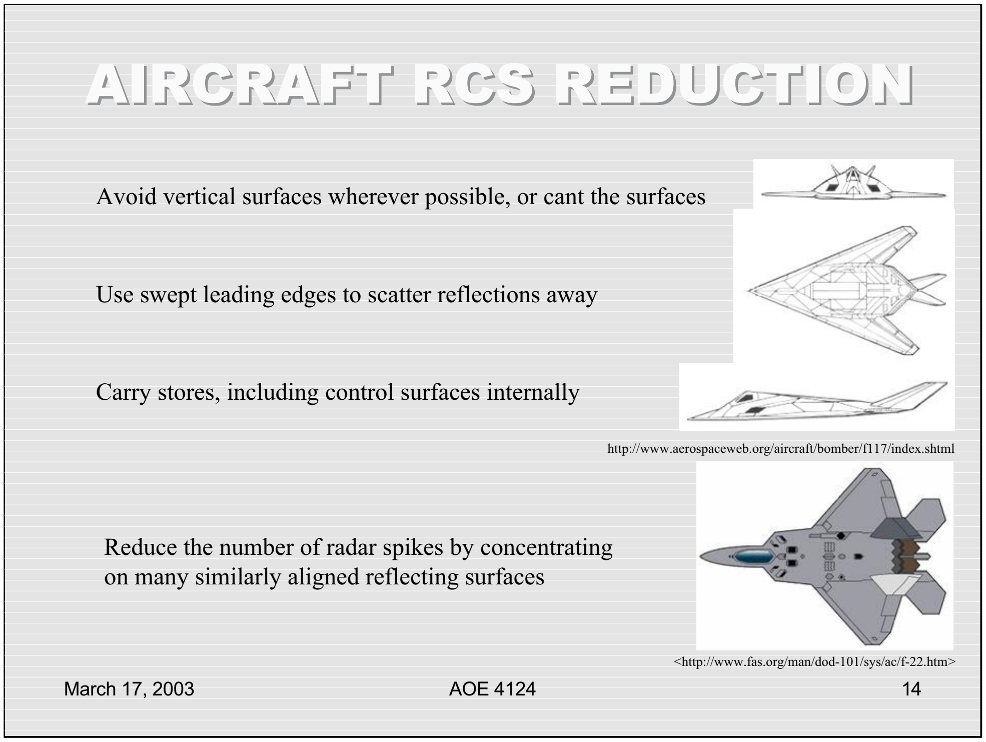
At normal incidence shown in Fig. 2(b), the flat plate acts like a mirror and its return is 30 dB above the return from the sphere.



BASIC RCS REDUCTION

If we rotate the plate about one edge, the cross section drops to that of the sphere when the look angle reaches 30-deg shown in fig. 2(c). As the angle is increased near parallel to the direction of a radar beam, the return falls by about another -17 dB in Fig. 2(d), i.e. a total return is 50,000 times less than the one from the normal plate.

If we rotate the plate about a diagonal relative to the incoming wave, the cross section drops by 30 dB with 8-deg off normal in Fig. 2(e) and drops another 40 dB with the plate at a shallow angle to the incoming radar beam in Fig. 2(f), i.e. a total return is 1,000,000 times less than the one from the normal plate.



AIRCRAFT RCS REDUCTION

How to reduce RCS in Aircraft Design?[3]

There are two different approached to shaping. Firstly as shown in the previous page, a faceted configuration can be used to minimize normal reflection. This led to F-117A design. Secondly, a compact, smoothly blended external geometry can be employed to achieve a continuously varying curvature as shown in designs of B-2A and F-22A.

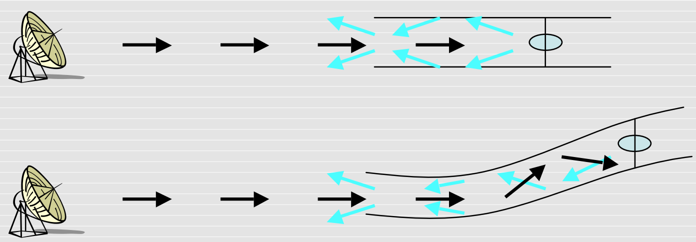
Many physically small and apparently insignificant features of an aircraft generates radar returns that are still quite detectable.

Therefore a very low RCS must be designed into an aircraft from the outset, with rigorous attention paid to all three elements: overall configuration of the aircraft and its components, special detail design treatment, and RAM.

Here a few conceptually important techniques are introduced.

AIRCRAFT RCS REDUCTION

Give the inlet duct an S or double S shape to hide the compressor face
and to force multiple reflection on the RAM-lined duct



Detail designs such as door, access panel, radar, control surfaces, cockpit, etc, are very important. In addition to shapes, RAM material should be used effectively

STEALTH MATERIALS

- Materials in Stealth design
- Options for Retrofit stealth
- Structures considerations for Stealth

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STEALTH MATERIALS

In addition to a stealthy configuration, materials and structures can be made to enhance the stealthiness of a vehicle. Materials can be added to the initial structure of a plane or the plane can be retrofit with special paint or tiles to enhance its stealth characteristics. Stealth factors can also influence the internal structures of the airplane.

RADAR ABSORBENT MATERIALS (RAM)

- DiElectric RAM
  - Addition of carbon products introduces electric disturbances and changes the electrical properties.
  - Bulky and fragile
- Magnetic RAM
  - Iron ferrites dissipate Radar waves and absorb Radar energy
  - Good against high frequency radar (modern fighters)

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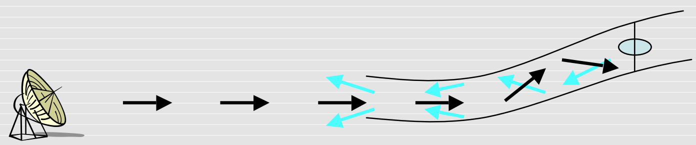
RADAR ABSORBENT MATERIALS (RAM)

Radar Absorbent Material (RAM) is any material that can dissipate or absorb radar energy. There are two main types of RAM, dielectric RAM and magnetic RAM. Dielectric RAM is the addition of carbon-based materials to an insulating material which effectively changes the electrical properties of the material and alters the radar signal. Dielectric RAM is usually too bulky to be used in most practical applications. Magnetic RAM is the addition of iron based products like iron ferrites or iron oxides to the coating of a vehicle. These iron products dissipate radar energy and thereby reduce the radar waves returned to the radar station. Magnetic RAM can be used in paint and sprayed onto the plane or it can be embedded in tiles and glued to inlets or other areas.

RETROFITTING FOR STEALTH

- Paint
  - Magnetic RAM, iron based paints
- Stealth Tiles
  - Placed on engine inlets and nozzles



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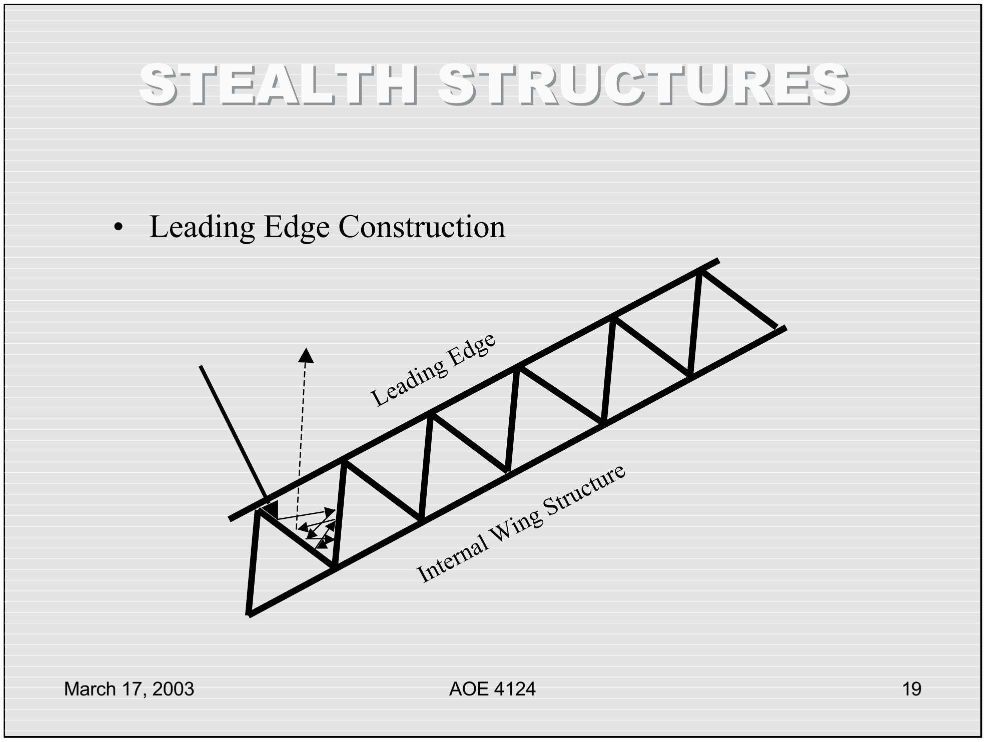
RETROFITTING FOR STEALTH

Radar Absorbing Paint (RAP) is an application of magnetic RAM that can be used to coat any vehicle surface. Specifics about the composition of the paint are classified but it is thought to be a polyurethane based coating. RAM tiles can be used in situations such as inlets and nozzles where high temperatures might be present. The jet exhaust nozzle is an important area to be aware of in stealth design. Modern stealth fighters use ceramics or stealth tiles to absorb and dissipate as much of the heat from the engine as possible.



STEALTH STRUCTURES

An important structural consideration for stealth is the inside of the leading edge of the wing. Some frequencies of radar penetrate the wing skin and in a normal plane would bounce right off a spar or another major structural member. The above illustration is an example of what can be done to reduce the strength of the waves reflected by the internal structure of the wing. Placing a structure as shown above inside the leading edge of the wing reduces the strength and alters the direction of the returning radar wave.

CONCLUSIONS

25 m^2

http://www.fas.org

0.5 m^2

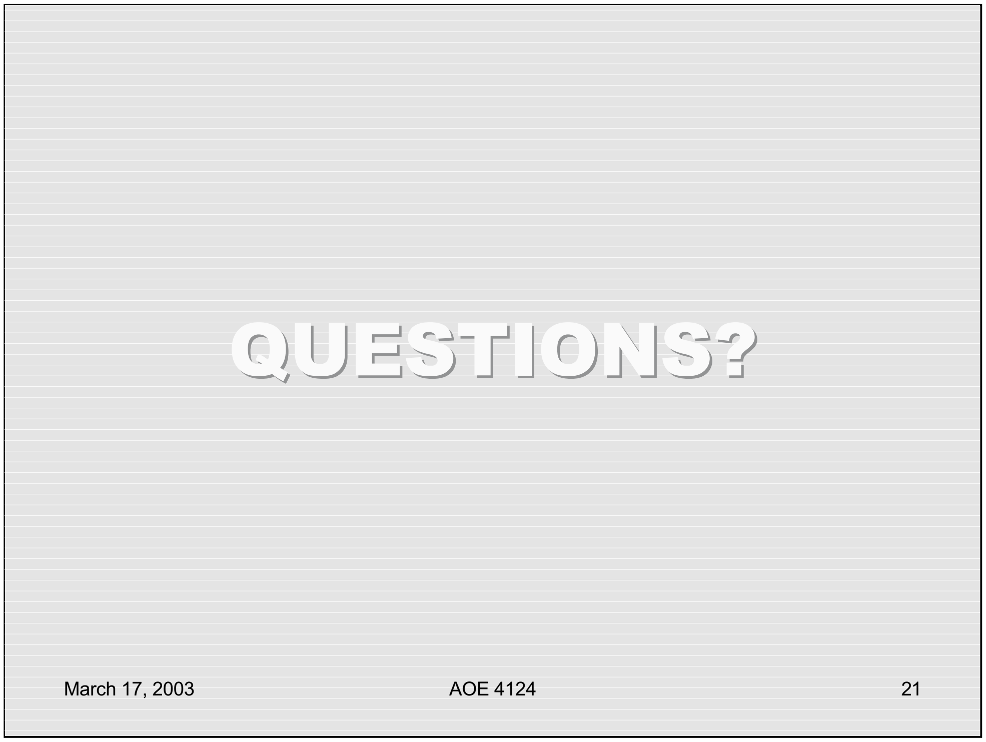
http://www.fas.org

http://www.fas.org

1000 m^2

http://www.fas.org

0.000001 m^2



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