ITEM 17
Stealth

Stealth

Materials, devices, and specially designed software for reduced observables such as radar reflectivity, ultraviolet/infrared signatures and acoustic signatures (i.e., stealth technology), for applications usable for the systems in Item 1 or Item 2, for example:
(a) Structural materials and coatings specially designed for reduced radar reflectivity;
(b) Coatings, including paints, specially designed for reduced or tailored reflectivity or emissivity in the microwave, infrared or ultraviolet spectra, except when specially used for thermal control of satellites;

Produced by companies in

- Brazil
- China
- France
- Germany
- Israel
- Italy
- Japan
- Netherlands
- Russia
- South Africa
- Sweden
- Taiwan
- United Kingdom
- United States

Nature and Purpose: The need to protect missiles from detection and destruction has led to the development of technologies to reduce their observables; when reduced observables are a primary design goal for a new vehicle, they are often referred to generically as "stealth" technology. Reflections and emissions are reduced or tailored through the use of carefully designed shapes and special materials. Other devices such as low probability intercept radar may be used. The objective is to make the object difficult to detect.

Method of Operation: Emissions and reflections are acoustic or electromagnetic in nature. Emissions are held to a minimum by any of a wide range of techniques such as frequency staggering, vibration isolation, shielding, masking, directing, and dampening.

Electromagnetic emissions and reflections occur in numerous frequency bands, including microwave (radar), infrared (IR), visible, and ultraviolet bands. Because radiation behavior varies significantly between and even within frequency bands, different methods must be applied across the spectrum. Emissions and reflections can be directed away from the observer and/or reduced in amplitude or altered in frequency response with the aid of carefully selected shapes and materials. This reduction is achieved by shaping, material, or devices for controlled emissions, reflectance, absorption, and second surfaces (added insulators and reflectors). These techniques or devices either conceal or disguise the true nature of the object from the observer or allow the vehicle to be detectable only at certain angles and for brief intervals, thereby delaying or avoiding detection and engagement.

Typical Missile-Related Uses: Stealth technology is used to make ballistic missiles, unmanned air vehicles (UAVs), including cruise missiles, and their payloads more difficult to detect, track, identify, and engage by defensive weapon systems. Most design elements of a missile are subject to treatment with stealth technology, including its basic shape, its structural components, its surfaces and leading edges, and its inlets and openings.

Other Uses: Most of the materials used for signature control were originally developed for military aircraft and are found on both fixed- and rotary-wing systems. Modified versions of the materials and treatment techniques are found on some ships, submarines, and ground combat and tactical vehicles. Emission control materials technology also is used to control temperatures in satellites. Several devices can be used with communication gear to reduce detectability. There are commercial uses for some of the low cost, low performance materials for reducing electromagnetic interference and for reducing solar loading.

Appearance (as manufactured): Typical materials for reduced-observable treatments include, but are not limited to, the following categories:

- There are two kinds of conductive fillers: conductive fibers, which look like very light whiskers 2 to 6 mm long, are made of carbon, metals, or conductive-material coated glass fibers; and conductive-material coated particles, which may look like colored sand.

- Sprays include conductive inks or paints, which normally contain silver, copper, zinc, bronze, or gold as the base ingredient. They appear black, metallic gray, copper, bronze, or gold in color.

- Small cell foams, both open and closed, are painted, or loaded, with absorbing inks and paints. These foams resemble flexible foam rubber sheets or air conditioning filters. They can be single-layered or noticeably multi-layered, with glue lines separating the strata. A ground plane, if applied, can consist of a metallic paint, a metallic sheet (aluminum foil or metalized thin plastic), or undetectable sprayed inks. Some manufacturers may mark the front of these foams with lettering saying “front” or with serial numbers if the ground plane is not obvious. Some foams may contain composite fiber to make them more rigid or even structural. Four such foams are shown in Figure 17-1.

- Magnetic Radar Absorbing Material (MAGRAM), as applied to vehicles, may appear in forms such as surface coverings, molded edges, or gap fillers. It consists of very fine grained ferromagnetic or ferrite particles suspended in a variety of rubber, paint, or plastic resin binders. At least one commercially available version uses a silicon-based binder, as shown in Figure 17-2. It may be applied as sprays, sheets, molded or machined parts, or putties. Because of the general colors of typical binders and ferromagnetic particles, the natural colors of MAGRAM range from light gray to nearly black; however, with additional pigments added for other reasons (e.g., visual camouflage or manufacturing/maintenance-aid coding), almost any color is possible. Thin films of plastic or paper material may cover one or both sides of sheets for identification coding or maintaining preapplication surface cleanliness. Sheet thickness may range from less than a millimeter to several centimeters. The density of the material is likely to range from 50 to 75 percent of solid iron.

Figure 17-1: Four radar absorbing material foams, clockwise from upper left: low-dielectric foam (epoxy); lightweight lossy foam (urethane); thermoplastic foam (polytherimide); and sprayable lightweight foam (urethane).

- Resistive Cards (R-Cards) consist of a sheet of fiber paper or very thin plastic covered with a continuous coat of a conductive ink, paint, or extremely thin metallic film. The surface electrical resistivity of the coating may be constant or may vary continuously in one or two directions. The conductive ink versions are likely to be dark gray to black. The metallic coated versions may vary in color depending on both the specific metals used and the thicknesses involved, but black, yellow, green, and gold tints are common. A Kapton R-card is shown in Figure 17-3.

Figure 17-2: A sample of a thin MAGRAM silicone resin sheet.

- Loaded ceramic spray tiles are sprayed-on and fired ceramic coatings heavily loaded with electrically conductive fillers or ferromagnetic particles. They are likely to range from dark gray to black in color. Depending on the specific filler and surface-sealing glaze used, they may range from smooth to abrasive in surface texture. Sprayed-on coatings may range from a few millimeters to tens of centimeters in thickness.

Figure 17-3: A sample of resistive card (R-card) made of metallized Kapton.

Figure 17-4: A sample of radar absorbing honeycomb material.

- Absorbing honeycomb is a lightweight composite with open cells normally 3 to 12 mm in diameter and 25 to 150 mm maximum thickness. It is treated with partially conductive inks, paints, or fibers. The honeycomb core may be shipped without being loaded, in which case it might be indistinguishable from materials used solely for structural purposes. The conductive inks and paints for subsequent loading are likely to come from an entirely different source than the core itself. Absorbing honeycomb is shown in Figure 17-4.

- Transparent RAM (T-RAM) looks like sheet polycarbonate. It is normally 75 to 85 percent transparent in the visible spectrum. Absorbing materials can vary from fibers or spheres spread throughout the material to thin coatings, which look like yellow/green metallic window tinting. A clear sample is shown in Figure 17-5.

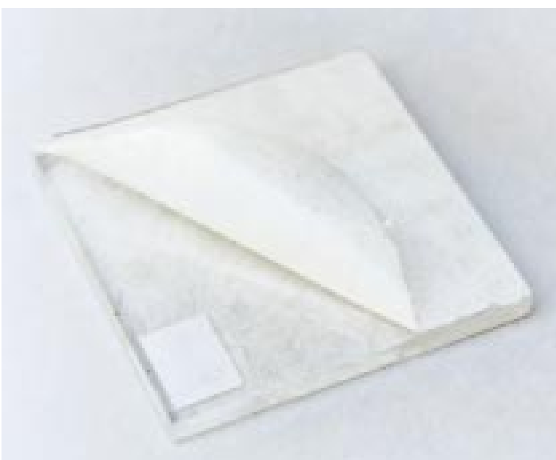

Figure 17-5: A small sample of transparent RAM. Notice the protective covering adhered to the surface.

- Infrared (IR) Treatments usually consist of paints and coatings. Often these coatings are customized to tailor reflectance and/or radiation of IR energy. Because of the wide spectrum (0.8 to 14 microns wavelength) of IR energy and the variety of applications, IR coatings may either be reflective (low emissivity) or designed to absorb (high emissivity). Coatings used for IR treatment include specially designed military paints in camouflage colors or commercial paints designed to reflect solar heat. Some of these products have a noticeable metal content in the paint/binder due to the IR pigments used. Others are designed to have high emissivity and as such, contain pigments that absorb IR. These high emissivity coatings contain carbon-based or other highly emissive particle-based pigments (normally nearly black). In either case, these IR pigments are sometimes shipped separately from the paint/binder.

Appearance (as packaged):

- Absorbing fibers vary from 2 to 6 mm in length and are usually packaged in plastic bags, vials, or jars. Their weight depends on the materials used. Fibers shipped before being chopped to their functional length may be in the form of conventional spools of textile fibers or in bundles 1 to 2 m in length and 2 to 10 cm in diameter.

- Spray paints and inks are generally shipped in standard size cans. The cans may be in boxes containing desiccants, or the pigments and binders may be shipped separately. Pigments are shipped in jars, plastic bags, or cans, and the binders are shipped in cans or drums. Most are highly toxic or caustic materials until applied and cured.

- Foams come in sheets usually no larger than 1×1 m, ranging from 6 to 200 mm in thickness, and weighing less than 40 g per square meter. They are packaged in cardboard boxes.

- MAGRAM may be shipped in sheets, uncured slurries, and finished parts, or in raw material form (particles, binder, and polymerization-activator all shipped separately). The particles would most likely be shipped in a very fine powder or short fiber form, but possibly also immersed in a hydrophobic fluid to prevent rusting. It may be shipped in sheets up to a few meters in length and width. Sheet thickness may range from less than a millimeter up to tens of centimeters. It may be shipped several layers deep on flat pallets or as a rolled sheet inside a cardboard tube. If shipped as formed parts, it may be in rectangular cardboard or wooden boxes as large as $0.1 \times 0.1 \times 2$ m or as small as $20 \times 20 \times 20$ cm.

- R-Cards are packaged in an envelope or box with a nonabrasive paper sheet between each card. Larger quantities may be shipped in rolls from 0.2 to 1 m in length and 15 cm in diameter, inside desiccated tubes, or in cardboard boxes.

- Loaded ceramic spay tiles are usually bubble wrapped and packaged in cardboard boxes.

- Absorbing honeycomb is shipped in cardboard boxes.

- T-RAM is packaged like sheet polycarbonate or like a window or canopy part. It can have an adhesive protective paper applied to the outside. If shipped in smaller pieces, it can be boxed.

- IR thermal paints and coatings are usually packaged in cans like any paint product. IR paint pigments can be packaged in cans, vials, or plastic bags.

(c) Specially designed software or databases for analysis of signature reduction;

Nature and Purpose: Designing and producing materials for, and systems with, signature reduction normally requires software and databases for analyzing these materials and systems. Software and databases specially designed for analysis of signature reduction are controlled. These databases and software will include data or functions essential to analysis of the signature reduction capability of systems and materials.

Produced by companies in

- France
- Germany
- Israel
- Japan
- Russia
- South Korea
- Sweden
- United Kingdom
- United States

Method of Operation: Because emissions and reflections may take many forms such as acoustic, radio frequency, or infrared energy, software and/or databases containing information or methodologies specially designed for analysis of emissions and reflectance (signatures) are used to evaluate materials for their signature reducing properties. Similarly, software and databases may be used to analyze systems in order to determine effectiveness of the materials and devices already incorporated as well as to determine what areas need improvement.

Typical Missile-Related Uses: These items are used to analyze airframe shape and materials for ballistic missile and UAV, including cruise missiles, applications in order to select signature reducing treatments or identify hot spots (potential areas for improvement). Similarly, these items may be used to evaluate the signature of systems, quantify performance of designs and material choices in systems, and evaluate areas for improvement.

Other Uses: Similar items may be used to analyze signature reduction on many military articles including ground vehicles, manned aircraft, and ships, as well as analysis of effectiveness of energy management systems for satellites and homes. Additionally, passive and active detectors used for security alarm systems also may require analysis using similar technologies.

Figure 17-6: Software in the form of a computer disc, a cassette tape, and written media.

Appearance (as manufactured): Software for signature reduction design tools may be packaged on floppy discs, tapes, and compact discs. A few examples are shown in Figure 17-6. Alternatively, a computer network can be used to distribute software and its documentation electronically.

Additional Information: Each spectrum has its own specific design software. Most countries and defense contractors have developed one-, two-, or three-dimensional computer codes for analysis and design optimization. In the radio frequency (RF)/radar spectrum, any code that can model antennas or radomes can be modified and used as a radar cross-section (RCS) tool. As a rule of thumb, any software code name that includes the letters SIG, RF, or RCS should be regarded as suspect RCS code. Basic codes that run on personal computers can give good fundamental design guidance. When exotic materials and complex shapes come into play, supercomputers and specially designed codes are required.

The key elements of RCS design codes involve the ability to define a vehicle surface profile within an adequate margin (which can be as small as 1/20 of a wavelength of the highest frequency of interest); the ability to represent very small elements of the surface as vectors; and the ability to handle the four real and complex terms associated with magnetic permeability and electrical permittivity. These items indicate the value of general purpose codes and machines capable of rapidly inverting and manipulating very large matrices of numbers.

IR thermal codes are less readily available or mature, but there are commercial codes available that can be used or modified for military applications. These codes include those used for thermal quality control. As in RF, a code capable of vector representation of the size and orientation of surface elements is a critical starting point. Codes estimating the atmospheric transmission of IR radiation at different altitudes, seasons, and types of gaseous environments are used in the design process. Codes for determining heat transfer in aircraft are essential. Codes for determining plume temperature from the volume of combustion products passing through the tailpipe and expanding and dissipating in the atmosphere are typically involved. (This plume modeling often involves engine deck codes but goes beyond their use for determining propulsion performance.) Codes that use material emissivity and bidirectional reflection coefficients of materials as inputs may indicate their potential use in IR signature control design.

Appearance (as packaged): Software on floppy discs, tapes, and compact discs will be packaged in any of a wide variety of packets, pouches, mailers, or boxes. Software may also be packed with related hardware.

(d) Specially designed radar cross section measurement systems.

Produced by companies in

- France
- Germany
- Israel
- Japan
- Russia
- South Korea
- Sweden
- United Kingdom
- United States

Nature and Purpose: RCS measurement equipment has been developed to evaluate, tailor, and reduce the RCS of missile systems in order to reduce detectability by air defense radars. RCS measurement equipment can be used in either indoor or outdoor ranges. Many of the ranges are usable for both military and commercial purposes. RCS measurement equipment can be used for evaluating material samples, missile components, scale models of missiles, and actual rocket systems or UAVs.

Method of Operation: An object under test, often called the target, is positioned or suspended in a test area with a few or no other objects in order to minimize sources of extraneous radar scattering. The target is then illuminated repeatedly by a radar over a select range of radar frequencies of known amplitude, and the reflections are measured. The resulting data are evaluated, and radar reflectivity of the target as a function of frequency and viewing angle is determined.

Typical Missile-Related Uses: This equipment is necessary to determine, tailor, and reduce the radar signature of a rocket, UAV, or payload. These measurement systems also assess computer-modeled performance and ascertain whether the missiles have the desired reduced and tailored observables. Certain RCS equipment is used to characterize radar-absorbing materials.

Other Uses: RCS measurement systems can be used to determine the radar signature of any military vehicle such as land vehicles aircraft, and ships. The

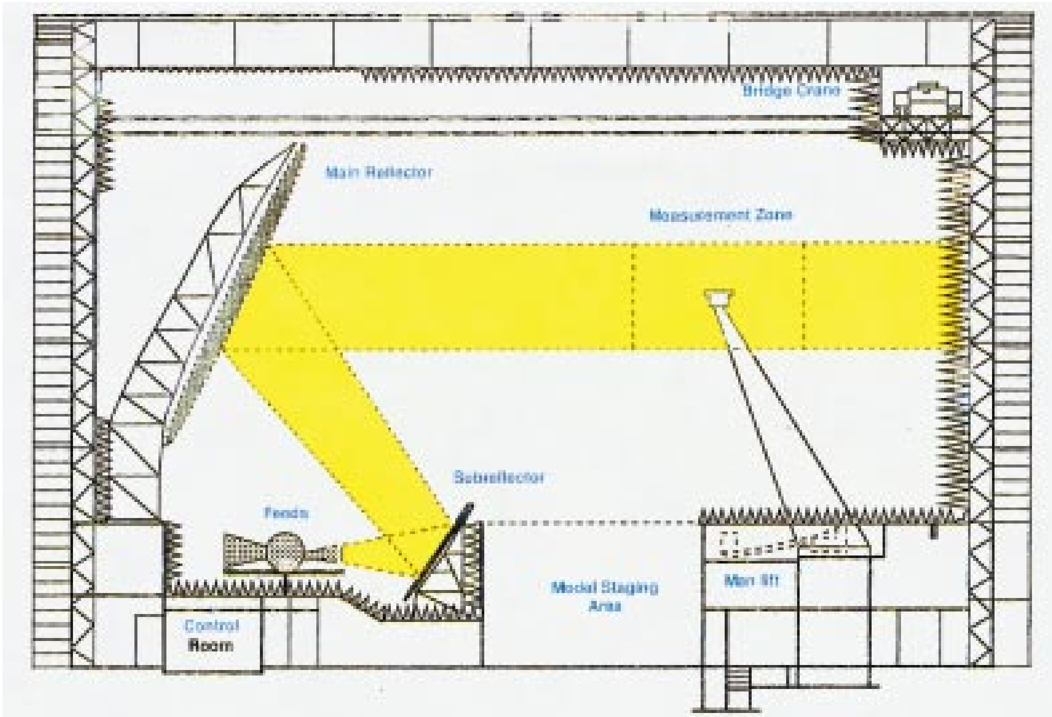

Figure 17-7: Schematic of a typical Cassegrain indoor RCS measurement range.

measurements provide information that aids in tailoring or reducing the RCS. Indoor RCS measurement ranges can be adapted to measure antenna performance patterns for various commercial applications such as cell phones, automobile antennas, and satellite dishes.

Appearance (as manufactured): The basic elements of an indoor RCS test range are explained below and shown in Figure 17-7.

- *Radar Source Equipment:* RF equipment is a rack-mounted collection of electronic equipment that, when assembled, occupies the space of a filing cabinet and is used in all types of RCS measurement systems. Up/down converters with feed horns provide radar illumination. To provide a wide range of frequencies, the conical feed horns vary in diameter from 1 to 100 cm in internal width. The feed horn length is generally two and a half times the internal width. They are metal lined and have provisions for attaching a coaxial cable or waveguide on the rear end. In RCS measurement systems, radar feed sources can be replaced by a radar source from a commercial radar system (e.g., marine radar). Network analyzers can measure absorption and reflection, and are commonly used commercially to develop antennas and electromagnetic interference shielding materials. RF cabling is low-loss coaxial cabling and is required for connecting the components. These cables vary in length but are normally 1 to 2 cm in diameter and have a metal mesh outer surface.

- *Dual Reflectors:* Cassegrain measurement systems use two large plates or dishes of different dimensions as reflectors; they can be circular, elliptical, or rectangular. The plates may have calibration marks on several portions of the surfaces and may be painted. Reflectors may be assembled from pieces and may have rolled or serrated edges. For measuring the RCS of a typical cruise missile, the two reflectors are 2 to 5 cm in thickness, and their major axes are 4 m and 5 m in length. These reflectors create a measurement "sweet spot" 2 m in diameter. A typical RCS dual-reflector measurement system is shown in Figure 17-8. This type of system is almost invariably used for indoor measurements. It should be noted that a measurement system could be devised using a single reflector.

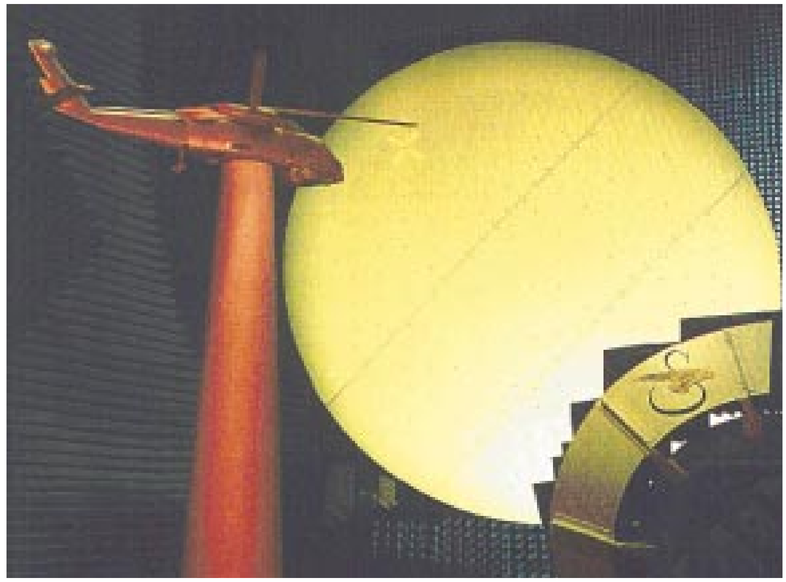
Photo Credit: Sikorsky Aircraft

Figure 17-8: RCS measurement equipment using a dual reflector system.

- *Target Support Devices:* These devices hold the target off the floor or ground and in the radar illumination; they need to be as imperceptible to radar as possible. Styrofoam columns, metal blades coated with radar absorbing material (RAM), and puppet strings from overhead mounts are common methods of supporting and suspending targets to be measured. The Styrofoam columns may range from 2 m in height and 0.5 m in diameter to 5 m in height and 2 m in diameter. Their horizontal cross-section may be round (with or without taper), square, triangular, or diamond-shaped; Figure 17-8 shows a truncated-cone column. The metal blades, or pylons, may range from 2 to 40 m in length and be 5 × 30 cm at the top; short pylons are 50 × 90 cm at the bottom, and tall pylons are 2 × 8 m at the bottom. Both Styrofoam columns and pylons can be mounted on a mechanism that tilts them forward. Rotating interfaces can also turn the Styrofoam column and target. Sets of three to five Styrofoam columns mounted on a common turntable can be used to support and rotate a target. Some pylons also have a rotating interface with the target at the top.

- *Bidirectional Arches:* Another approach to measuring missile RCS is to use a bidirectional arch, which can be made out of plywood, fiberglass, or metal. An electric motor drive system is used to relocate the feed horns along the arch, as shown in Figure 17-9. Custom cabling links the arch to a control computer (normally a PC with a keyboard and monitor) and the feed controls. A test article, with its surface perpendicular to the plane defined by the arch, is placed at the center of the arch. The articles are typically 0.3 to 1.0 m on a side. The calibration reference is a flat, smooth metal plate the same size as the test article.

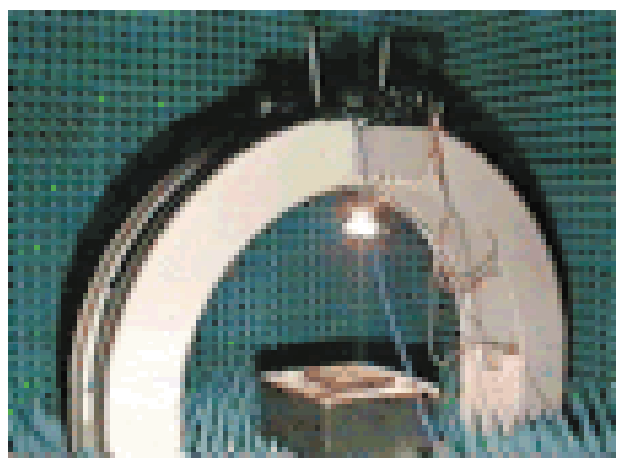
Photo Credit: Sikorsky Aircraft

Figure 7-9: Bidirectional reflectance arch.

Appearance (as manufactured): Transmission/reflection tunnel RCS measurement systems look like large, sheet metal, air vent ducting. They have two matching metal feed horns with coaxial cabling or waveguides leading to the radar source and detector measurement electronics. They are controlled by a computer that looks like any PC with a keyboard and a monitor. There may be radar-absorbing foam (normally medium blue or black in color and spiked on the surface) inserted in portions of the ducting. Direct illumination indoor systems and bounce range outdoor systems use conventionally shaped, parabolic radar reflectors ranging in size from a few centimeters up to 10 m in diameter.

Appearance (as packaged): Radar ranges are seldom shipped as one piece; rather, they are assembled onsite from many components. There are no unique packaging requirements for this equipment beyond those of the industry standard for rack-mounted electronics and commercial computer components. Some of the components (such as the Cassegrain reflectors) can be fairly large and require special crates. Styrofoam target supports are delicate and must be packaged to prevent denting.