Lockheed Martin's

Affordable Stealth

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INTRODUCTION

The F-22 design requirements evolved from a systems analysis study aimed at meeting the U.S. Air Force's requirement for an Air Dominance Fighter. The key elements to providing this capability are: Lethality, Survivability, and Supportability.

These top level requirements were used as the basis for a series of design trade studies that resulted in the development of specific technical design requirements. When implemented, these trade studies result in a weapon system characterized by unprecedented performance capabilities of:

- Stealth (or Low Observables)
- Supercruise (the ability to attain and sustain supersonic speeds with MIL power)
- Agility (the ability to quickly maneuver the aircraft into a shooting position or killing position)
- Advanced Avionics (that provide the pilot 4p steradian situation awareness)
- Supportability (by means of higher reliability and 2 level maintenance)

The design challenge for the F-22 team was to integrate these seemingly conflicting requirements into an affordable aircraft design. Never before have these requirements been integrated into a single aircraft. Conventional fighters are agile, but are not stealthy and cannot supercruise. The F-117 is stealthy, but cannot supercruise and its agility is limited by its low observable design. In the F-22 Raptor a design solution has been reached that provides all of the desired capabilities in a single aircraft.

This paper discusses the techniques and technologies necessary to successfully develop a Low Observable air dominance fighter.

LOW OBSERVABLES DESIGN OVERVIEW

Shape

In order to develop a low observable aircraft, consideration must be given to any part of an aircraft that a radar wave can reach. The first and most critical factor to consider in the design process is the shape of the aircraft. This element has to be designed into the aircraft from the beginning. If the shape is wrong, no amount of material treatments will fix it. This is the fundamental reason that it is impossible to make much progress attempting to retrofit stealth onto a conventional aircraft.

Examination of the F-22 shows that great care has been taken to align all hard edges, i.e., the wing, tail, inlet lip and nozzle edges, so that the maximum radar return from them all point in the same few directions. This results in a few relatively large but narrow signature spikes that are difficult to detect and track. The signature between these spikes is very small. The vertical tails and sides of the aircraft are tilted to avoid a direct reflection back to the radar. Further examination shows that all of the surfaces between the edges are smoothly blended, allowing electrical surface currents to flow over the surfaces without interruption. Any break in the surface causes energy to be reflected back to the radar, raising the aircraft's signature. Any breaks in the smooth surface such as control surfaces or doors are aligned with the wing edges (Figure 1).

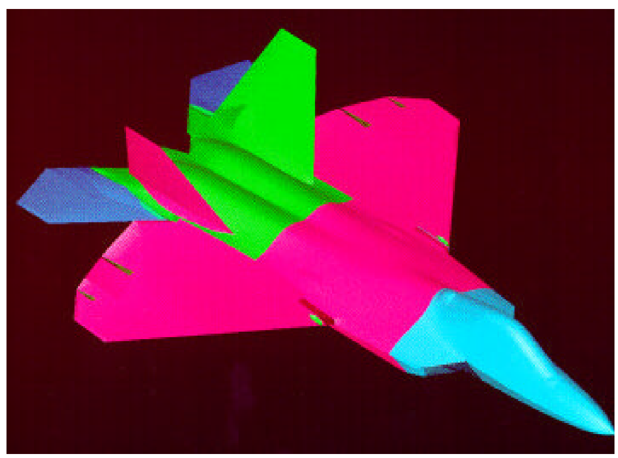

Figure 1: Computer Model

Conductive Surfaces

A common misunderstanding is that composite skins are used to make aircraft stealthy. In reality, many composites are partially transparent to radar, and expose the internal structure, wiring and components to the radar, which is the last thing a low observable designer wants. These components add up to an extremely large signature. In most Low Observable aircraft, the outer surfaces of the aircraft are coated with a metallic paint, so that the radar cannot penetrate into the aircraft (Figure 2).

Figure 2: Full Scale Cockpit Test Model

One of the largest sources of signature on a conventional aircraft is the cockpit. The pilot's head and helmet, the seat and all the various controls and displays in the cockpit contribute to the signature of the aircraft. The most effective way to reduce the cockpit signature is to prevent the radar energy from entering the cockpit. A metallic coating on the F-22 canopy prevents the energy from entering the cockpit, and eliminates the cockpit as a concern. The canopy is smoothly blended into the aircraft's shape to minimize any reflections.

The F-22 Raptor's canopy's transparency features the largest piece of monolithic polycarbonate material being formed today. It has no canopy bowframe and offers the pilot superior optics (Zone 1 quality) throughout. The F-22's canopy is approximately 140 inches long, 45 inches wide, 27 inches tall, and weighs approximately 360 pounds.

The canopy has to be resistant to chemical/biological and environmental agents, and has been successfully tested to withstand the impact of a four-pound bird at 350 knots. It also protects the pilot from lightning strikes. The design challenge was to balance the low observables, optics (both visual transmissivity and reflection) erosion, durability and structural requirements, including jettison.

The combination of shape and conductive materials lets the LO designer work with a known, well controlled outer surface.

Inlets

The signature of the inlet and engine combination on conventional fighters is usually one of the dominant contributors to the aircraft's signature. The engine is the primary signature source, followed by the inlet edges, and any variable geometry control surfaces used for adjusting airflow (Figure 3).

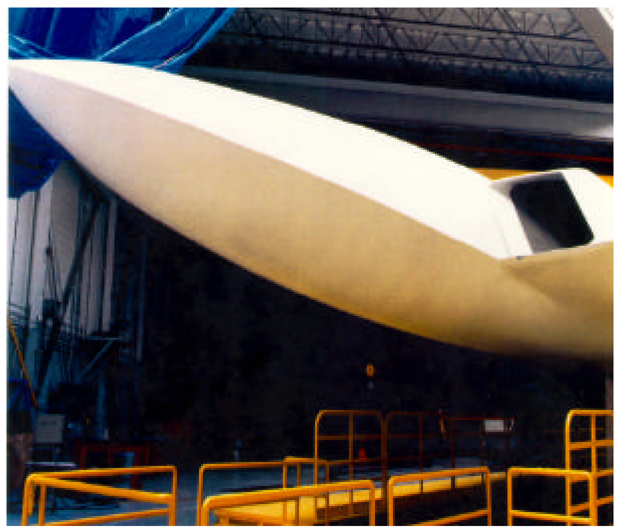

Figure 3: Full Scale Inlet Test Model

The F-22 design reduces the engine signature by hiding the engine behind a serpentine inlet duct; a technique referred to as line-of-sight blockage. One hundred percent line-of-sight blockage means that the front of the engine cannot be viewed from outside the aircraft. The Raptor's engine inlet design is based on many hours of wind tunnel testing. The Raptor has a fixed ramp external compression inlet with internal boundary layer porous bleed off-takes. The long diffuser duct (l/D = 6.35) provides excellent low distortion characteristics. The inlet has no variable geometry devices; inlet stability characteristics and variable bypass provide stable airflow over the entire flight envelope with no throttle or maneuver restrictions. The inlet edges are designed to reduce signature and align with the wing leading edges.

Engine Exhaust Nozzle

The aircraft's engines are major signature contributors in the rear of the aircraft. The F-22 uses two Pratt & Whitney F119 engines coupled with 2D thrust vectoring exhaust nozzles. Integration of these powerful, high-temperature engines into the airframe was an extremely difficult design challenge. The rear end of the engine is largely exposed to radar. The multi-bounce effects caused by the nozzle cavity and nozzle flaps, and the large gaps required for thermal expansion and for nozzle movement complicate the situation. An extensive test program was conducted on a full-scale twin nozzle model to make design trades and to generate a final design (Figure 4).

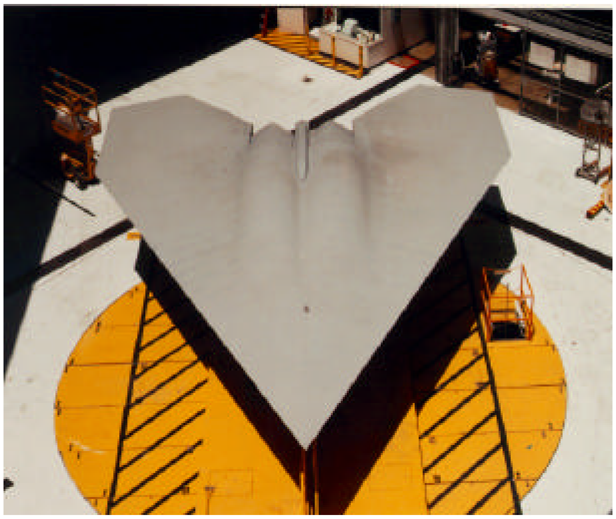

Figure 4: Full Scale Dual-Engine Test Model

Radar/Radome

An aircraft's radar is usually a very significant contributor to an aircraft's signature. The F-22 design significantly reduces the radar's signature using a combination of a bandpass resonant radome and low signature radar. The F-22 radome is one of the most complex structural components on the F-22.

The radome's primary design considerations were:

- In-band radar performance
- Low Observables
- Structural loads including bird strike integrity
- Rain Erosion
- Maintainability, and
- Lightning strike integrity (Figure 5)

The Raptor's radar is an active element array which is tilted back to reduce direct reflection. Element manufacturing emphasizes accuracy and repeatability across the large number of radar array elements. Key manufacturing processes for circulator, radiator, and T/R module assembly have been automated to ensure affordability.

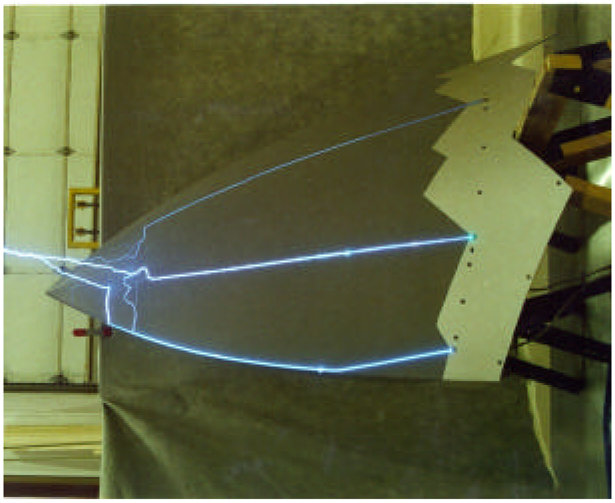

Figure 5: F-22 Radome Undergoing Lighting Strike Testing

Antenna Apertures

The F-22 Raptor's antenna suite includes a large number of embedded and conformal antennas. Antennas are designed to receive and radiate energy, which is often directly contrary to the LO designer's goals. These antennas signature must be significantly reduced to achieve LO goals, while simultaneously maintaining satisfactory gain performance. The final designs, arrived at by extensive analysis and test, represent the best balance between antenna performance and signature.

Materials

Several special materials are used on the F-22, including Radar Absorbing Materials (RAM), Radar Absorbing Structure (RAS), and Infrared (IR) Topcoat. RAS is used to minimize scattering from hard edges, while RAM is used to reduce scattering from surface breaks. IR Topcoat is used to reduce the infrared signature, and ensure that the radar and infrared signatures are balanced. Early LO programs made extensive use of RAM and RAS, resulting in substantial weight impacts. Improvements in analysis and design tools, combined with extensive testing, have been used to minimize the use of RAM on the F-22 while maintaining a low signature. The result is that the F-22 uses far less material than previous generations of LO aircraft, resulting in significant weight and cost savings.

Design for Maintainability

The F-22 is designed to be significantly more reliable than the aircraft it will replace, and it requires significantly less support resources (Figure 6).

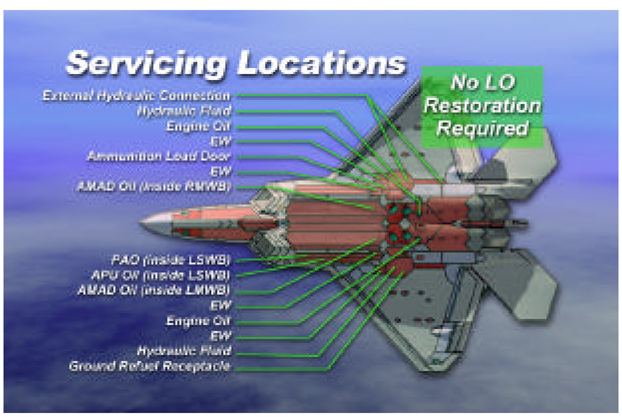

Figure 6: Aircraft Servicing Locations

The Raptor panel configuration has been carefully designed to facilitate the maintainer in accessing the Raptor's subsystems while meeting low observables requirements. Access is achieved through almost 300 aircraft surface locations that include actuated doors and quick access panels. Over 95% of all maintenance actions based on a 30 day deployment are performed without any LO restoration.

For the remaining 5% of maintenance actions that require LO restoration, repair processes and materials have been developed to minimize the amount of time necessary to perform a maintenance action. The repair processes have been developed with the direct involvement of Air Force maintainers to ensure that the processes are robust and can be implemented in the field. The processes are being validated during a three-phase program that proceeds from laboratory testing, to signature testing of actual repairs performed by USAF maintainers on representative test fixtures, to final verification in the field on aircraft at Edwards Air Force Base. The first two phases are complete, and the final phase is in work.

The Integrated Combat Turn is the military equivalent of a pit stop in auto racing — the aircraft is refueled, rearmed, and sent back into combat. The F-22 allows for simultaneous gun ammunition and missile reloading, a process that normally goes in sequence only. The Raptor has single-point refueling and a single-point consumables (oil, chaff, flares, etc.) status check point. The Raptor has been designed so that Integrated Combat Turn can be accomplished without having to restore LO characteristics.

Test Program

Throughout the EMD program the F-22's signature has been verified by an extensive test program. Radar Cross Section (RCS) Testing at Lockheed Martin's Helendale Measurement Facility started in the fall of 1991. All models used in this program were full scale, a lesson learned from previous programs where problems were encountered when attempting to "scale-up" results from sub-scale models. The test program began with the construction and test of a full-scale inlet model, followed by a full-scale dual engine exhaust model, a radar/radome model, a wing model, a large flattop model for door, panel and antenna testing, and numerous other component models. Program risk was greatly reduced by the use of full-scale aircraft component models.

The EMD test program culminated in the construction and test of the EMD Full Scale Model, which is an extremely high fidelity representation of the F-22. The model includes all significant signature drivers and includes numerous production components. The model includes a radar and radome; the antenna suite; inlet and engine front frame and first two stages; highly detailed engine exhaust model including the turbine and turbine exhaust case, augmentor section and convergent and divergent nozzles; production edges; access and in-flight actuated doors, air data systems, screens, seals, missile launch detector windows, pylon access covers, remote control actuation of control surfaces and engine components, and lights (Figure 7).

Figure 7: F-22 Raptor Full-Scale Test Model

EMD FLIGHT TEST

The final verification of the F-22 Raptor's RCS signature will be conducted in-flight, and will begin in late 2000. Tests will be conducted on five EMD aircraft, with repeated tests on certain aircraft to verify that the aircraft's stealth properties do not degrade in the field (Figure 8).

Figure 8: Final F-22 Signature Testing Performed In-Flight

MANUFACTURING

The successful manufacture of a LO aircraft requires the aircraft to be built to tolerances that are tighter than conventional aircraft. Dimensional accuracy, surface finish and surface waviness are key elements in the manufacture of the F-22. Components of the F-22 are manufactured in virtually every state in the U.S., and these parts have to fit precisely. The F-22 program has used Computer Aided Design tools to design parts and tooling that meet these requirements (Figure 9).

Figure 9: F-22 Assembly Station

Also key to the LO characteristics of the F-22 is the application of its finishes, i.e., conductive coatings, RAM and IR topcoat. The robotics coating facility has been developed to accurately apply these finishes. The robotics coating facility features an environmentally controlled, secure, state-of-the-art robotic coatings hangar and subassembly paint booth with track mounted coatings robot (Figure 10).

Figure 10: Robotic Coating Facility

PRODUCTION SIGNATURE VERIFICATION

The F-22 program has developed an indoor RCS measurement facility for production verification of the aircraft's signature. The RCS test hangar is 150' x 210' and includes an anechoic chamber for antenna testing. The RCS facility contains a turntable to slowly rotate the test aircraft while suspended from the ceiling. The 50,000 square feet facility has been in operation since July, 1997. This test will eventually be used to accept the aircraft, rather than performing airborne testing used by previous programs. The cost of performing an indoor test is a small fraction of the cost of an airborne test, resulting in significant reductions in aircraft production costs. Because of the uniqueness of the facility, testing will be performed using both the indoor and airborne tests on several EMD aircraft. The back-to-back tests will be used to build confidence in the indoor tests (Figure 11).

Figure 11: Indoor Signature Test Facility

SUMMARY

The F-22 Raptor represents a revolutionary leap forward as the first Low Observable air dominance fighter. The Raptor has successfully blended the unprecedented performance characteristics of stealth, supercruise, agility and advanced avionics to dramatically improve fighter lethality, survivability and supportability. Low Observables designers were and continue to be key contributors, by advancing the-state-of-the-art, to the success of the F-22 Raptor.

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Brett Haisty is currently the manager of the F-22 Special Technology Department and the F-22 Observables Integrated Product Team. In this role, he is responsible for the overall management of the Low Observable (Stealth) signature of the F-22, and Low Observables Program management and technology development at LM Aeronautics Company, Marietta, GA.

Brett joined the Fort Worth Division of General Dynamics (currently Lockheed Martin Aeronautical Systems – Fort Worth) in 1987, as an Engineering Specialist in the Advanced Methods Department. He was assigned to develop improved signature design and analysis tools and methods. He supported signature design efforts on several classified programs until joining Lockheed Martin as the F-22 Signature Analysis Group Lead in 1991. In 1997, he was promoted to Department Manager for the F-22 Special Technologies Department and Integrated Product Team Manager for F-22 Observables.

Brett received his Bachelor's, Master of Science degree, and Ph.D degrees in Mechanical Engineering from the University of Arkansas in 1983, 1984 and 1986 respectively. Brett is married and has four children.