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TURBINE SHIELDS AND TOPCOATS

For Lockheed's F-22 and F-35, the need for afterburning engines, supersonic flight and fighter agility, as well as the desire for less maintenance, would require some new approaches. The U.S. stealth fighters use similar IR suppression techniques for internal engine parts, tail structures and airframe coatings. They diverge most noticeably in nozzle design.

The horizontal tails of both aircraft extend well beyond the nozzles, restricting the view of the exhausts and plume core in the azimuthal plane from the side and into the rear quadrant. The engines of both also have stealthy augmenters. Aft of the low-pressure turbine are thick, curved vanes that, when looking up the tailpipe, block any direct view of the hot, rotating turbine components. Fuel injectors are integrated into these vanes, replacing the conventional afterburner spray bars and flame holders. The vanes mask the turbine and contain minute holes that introduce cooler air.

Both aircraft also feature IR-suppressive skin coatings. The final addition to the F-22's low-observable treatment is a polyurethane-based "IR topcoat" precisely sprayed by robots. Such IR topcoats have also been included in the F-16's Have Glass signature reduction program. The F-22 may also use fuel to cool its leading edges.

Despite the RAM fiber mats in the F-35's skin, Lockheed still finishes the aircraft with a polyurethane-based RAM coating applied by a newer robotic system. Program officials have stated this outmost layer possesses anti-friction properties; MWIR imagery of the F-35 suggests low emissivity as well. Both aircraft coatings still exhibit poor wear and temperature resistance and have needed time-intensive recoatings more frequently than desired. In 2015, the U.S. Air Force announced it was testing a new coating for the F-35 with better abrasion and temperature resistance.

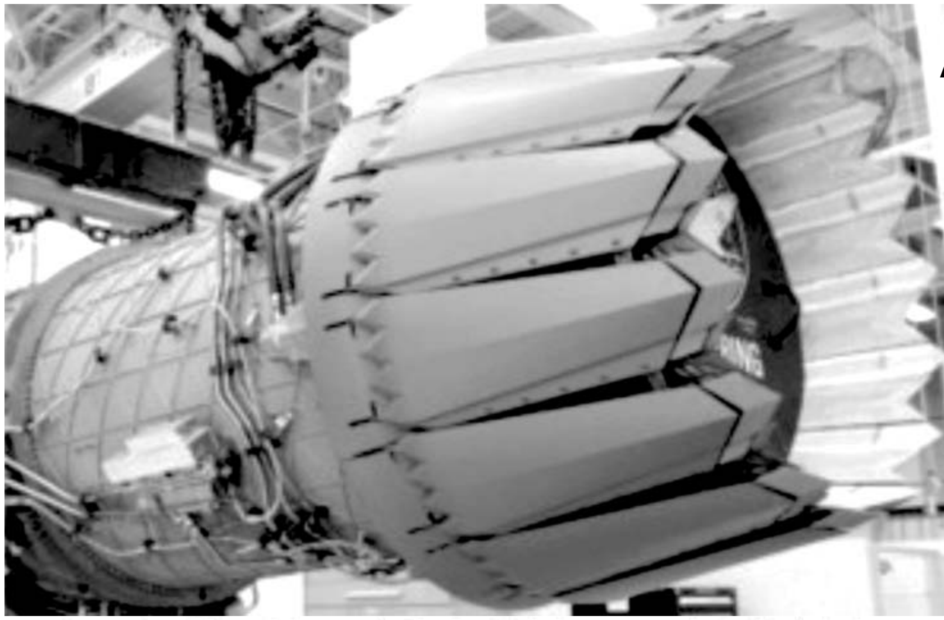
The exact composition of the coatings is unknown, but polyurethane is often used as a matrix material due to its relatively high durability, adhesion and resistance to chemicals and weather. It has a natural emissivity of 0.9, but many fillers have been demonstrated to reduce the emissivity when used in composite materials. Levels as low as 0.07 have been achieved with bronze, although at the expense of higher conductivity and therefore radar reflectivity. Multilayer glass microspheres of 5-500 µm diffused at 50-70% weight can achieve low emissivity at selected wavelengths and would probably be radar-neutral. Unoxidized iron also has emissivity in the 0.16-0.28 range, and its polyurethane-matrix composites have shown emissivity below 0.5.

WEDGES AND TAIL FEATHERS

The F-22's "non-axisymmetric," or 2D, thrust-vectoring nozzles have upper and lower surfaces ending in wedges with blended central edges. These nozzles further mask the engine hot parts while flattening the exhaust plume and generating vortices. Minute holes are evident on their inner surfaces, likely providing bypass air for enhanced cooling.

The wedge nozzles are believed to be effective in signature reduction, but they are a major driver of the Raptor's maintenance cost and workload (nozzle internal flaps are one of the most often replaced parts even on conventional fighters). Thus, when designing the Joint Strike Fighter (JSF), engine and airframe manufacturers looked for a more cost-effective approach.

In late 1996, while the JSF competition was still ongoing, the two engine competitors tested axisymmetric designs aiming to rival the wedge nozzle's signature while beating it on cost. Pratt & Whitney tested the Low-Observable Asymmetric Nozzle (LOAN) on an F-16C, which demonstrated significant reductions in RCS and IRSL. The LOAN was known to incorporate shaping, special internal and external coatings and "an advanced cooling system" that was expected to more than double the life of the nozzle flaps.



In designing the nozzle of the F135 engine that powers the F-35 Joint Strike Fighter, Pratt & Whitney aimed to rival the F-22's wedge nozzles in signature while beating it on maintenance costs. The nozzle flaps incorporate minute holes to supply cooling air, like those on the F119, and overlap to create a sawtooth trailing edge, which introduces shed vortices to the exhaust and shrinks the plume. Their interior and exterior surfaces are likely composed of low-emissivity, radar-absorbent ceramics.

Pratt & Whitney's F119 engines use a number of techniques to shrink their plumes and limit the IR signature of the Lockheed Martin F-22 Raptor. Just visible in this photograph are the end of the curved vanes which block direct view of the low-pressure turbine and contain minute holes that inject cooler air to the exhaust. The "wedge" nozzles also flatten the exhaust, which shortens the plume by mixing it with ambient air as well as narrowing it from the side.

In early 1997, GE tested a similar Low-Observable Axisymmetric (LO Axi) exhaust system on an F-16C, achieving its signature goals. GE stated LO Axi included overlapping diamond shapes, coatings and slot ejectors inside the nozzle to provide aircraft bay cooling air. The engine-maker said improvements in RCS design and material technology allowed axisymmetric nozzles to match the signatures of 2D exhausts while weighing half and costing 40% as much.

The nozzle on the Pratt F135s that power the F-35 descends from these approaches. It comprises two overlapping sets of 15 flaps, offset so outer flaps are centered on the gaps between the inner flaps. The inner flaps are thin, have metallic exteriors and straight sides and terminate in inverted "Vs." The sides create rectangular gaps between them with the nozzle fully diverged.

The outer flaps, which Pratt calls "tail feathers," are thicker and covered in tiles with blended facets. They terminate in chevrons that overlap the ends of the inner flaps to create a sawtooth edge. Toward the fuselage, the tiles end in four chevrons and are covered by additional tiles that terminate fore and aft in chevrons and interlock with adjacent tiles in sawtooth-fashion.

The F135 nozzle likely suppresses IR signature through multiple methods. The trailing-edge chevrons create shed vortices, shortening the plume, while their steeper axial angle likely directs cooler ambient air into the exhaust flowpath. The inner surfaces of both sets of flaps are white and incorporate minute holes similar to those on the F119, which might supply cooling air. Some reports suggest the presence of ejectors between the tail feathers and chevrons to provide even more cooling air. The tiles and inner flap surfaces are likely composed of low emissivity, RAM composites. The trailing edge of the central fuselage also terminates in small chevrons, possibly further increasing airflow vorticity.

It is hard to quantify the success of these IR suppression efforts. Periodically, IR cameras will record stealth aircraft flying at air shows, but at ranges so close the images belie the suppressive effects of atmospheric absorption. Following the start of F-22 IR signature testing in 2000, Air Force officials stated the Raptor would exhibit a "low all-aspect IR signature under sustained supersonic conditions." Some images captured by IR-sensor manufacturer FLIR of the F-35 at the Farnborough Airshow in 2016 suggest effective suppression of engine airframe heating and nozzle emissions. Undoubtedly, IR sensors are advancing, but they are also being met with initiatives to suppress IR signature.

Gallery *See more on reducing IR signatures on the F-117, B-2, F-22 and F-35:* **AviationWeek.com/SOS-Part-5**