Custom Tools Achieve F-35 Stealth Characteristics While Lowering Assembly and Operating Cost

by Robert Jones - Author and Aerospace Consultant

Manufacture of the stealthy Lockheed Martin F-35 Lightning II has two important precision machining activities: (1) edge routing of the wing skins and forward fuselage panels and (2) drilling of holes in the machined parts to assemble the wings and forward fuselage. All external structural surfaces are made of carbon-epoxy (one of many CFRPs) with some carbon-bismaleimide panels in highly heated regions. Problems were encountered with machining the edges and drilling holes in carbon-epoxy composite material panels fastened to aluminum and titanium substructures. Previously existing tools wore out quickly, and the machined surfaces were not acceptable. Those problems are solved with the use of AMAMCO diamond-coated carbide compression routers and drills in special machines for composite materials.

Two main issues override the technical problems, solutions, and procedures, namely (1) the use of effective tools to achieve a stealthy aircraft with fewer processes than previous stealth aircraft (hence less costly to initially produce and, perhaps more important, to maintain over the life of the aircraft) and (2) the cost reductions, fewer part rejections, and higher production rates that are achieved when using advanced machining and drilling tools.

Stealth characteristics have been obtained with radar-absorbent coatings that are expensive and time-consuming to apply (and that must be applied during routine maintenance after every flight with the F-117A, B-2, and F-22). Alternatively, if the aircraft external structural parts are precisely machined to fit together with exceptionally close tolerances, then the stealth requirements can be more easily fulfilled. That is, reduction and near-elimination of gaps between structural parts is highly desirable in achieving stealth characteristics of an aircraft. No gaps between the outer surfaces of structural parts means there is far less routine maintenance to be performed after each flight leading to lower maintenance costs over the life of each aircraft. Previous stealth aircraft require stripping and reapplication of radar- absorbent material in the gaps on the outer surface that opened up after every flight.

Current aircraft composite materials are generally quite abrasive to machine, and hence require more durable cutting tools than are used for machining metals, especially aluminum. Moreover, the laminated character of aircraft composite materials such as carbon-epoxy introduces yet another difficulty for machining because some machining operations inherently cause delamination of a part with resulting rejection of that part for service. During manufacturing with diamond-coated carbide tools, significant cost reductions result from longer tool life and elimination of part damage and hence scrappage as well as the lessened cost of stealth creation and long-term maintenance than with conventional tools.

The most significant problem in machining carbon-epoxy composite structural skins and panels to fit closely together is precision routing the edges. The top and/or bottom surfaces of each panel are delaminated with conventional carbide routers resulting in a very high scrappage rate, a totally unacceptable result. The AMAMCO diamond-coated carbide compression router in Figure 1 is used to mill the composite material away from each surface of the laminated composite material toward the center of the panel thickness. That is, the laminated material is compressed from the top as well as the bottom of the laminate so that it cannot delaminate. Note the opposing handedness of the flutes that converge to a neutral point or overlap region near, but not at, the end of the tool. That neutral point is usually centered on the thickness of the panel. The flutes direct the cut carbon-epoxy material in the form of dust up and away from the edge in the coolant flow. This tool is an advanced version of the bit used to rout the edges of laminated kitchen countertops. A comparative study sponsored and directed by Lockheed Martin through NCDMM [Reference] demonstrated that the diamond-coated carbide compression router is both very much longer lived and produces a more reliable surface than competitive tools without scrappage. Only two routers are used for each wing skin, one to rough cut and one to finish cut.

Figure 1
AMAMCO Compression Router

The compression router has therefore been adopted as the tool of choice for composite laminate edge routing and is used for F-35 wing skins and forward fuselage panels as well as other composite panels. A significant part of the accuracy requirement for edge routing is met by mounting each panel on a shaped tooling fixture to which the panel is vacuum mounted while being routed in the Flexible Overhead Gantry (FOG) machining center. The FOG is a CNC (computer numerically controlled) five-axis precision milling machine with various tools to machine parts to very tight-tolerance accuracy. The FOG is in a large room that is vibration isolated from the surrounding factory by installation on a deep concrete foundation with surrounding vibration-absorption materials. Shaped tooling fixtures with parts on them are moved into the FOG room on a pallet large enough to accept a full-width F-35 wing from tip to tip (although currently each wing in made in two parts, left and right). The position of the part and its shaped tooling fixture on the pallet is accurately measured in an adjacent calibration room. Then, the pallet is moved to the FOG room where the measurements are used to automatically machine the part. For example, a wing skin is shown on its tooling fixture on a pallet ready to move into the FOG room in Figure 2.

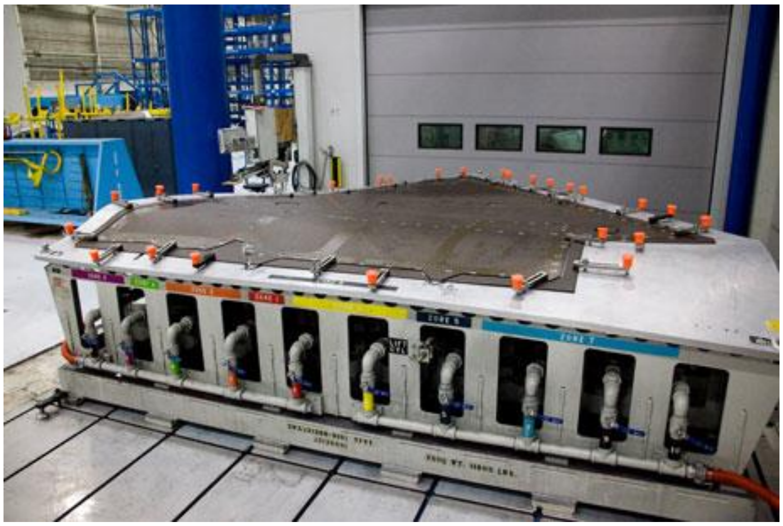

Figure 2
Wing Skin on Tooling Fixture on Pallet in Front of FOG Room

The carbon-epoxy forward fuselage panels are surface routed in the FOG to create their Inner Mold Line (IML) during which composite material is removed except where the panel is to be fastened to the substructure as in Figure 3. That removal is accomplished with a polycrystalline diamond ball-head router, and the unrouted material is covered with a glass-epoxy layer to isolate the carbon-epoxy panel from the aluminum substructure to avoid galvanic corrosion. Then, the panels are edge routed with a compression router and have a limited number of holes drilled in them for fastening to the aluminum substructure. The panels are mounted on the substructure with fasteners in the limited number of holes whereupon the remaining holes are drilled and fasteners installed. The holes in the stacked carbon-epoxy panels on the aluminum substructure are drilled at the same time in both materials. However, because of differences in drilling resistance of the two materials, the automated drilling machines adjust feed and speed parameters at the transition from carbon-epoxy to metal to ensure quality results and an efficient process. The resulting forward fuselage is shown in Figure 4.

Figure 3 Routed Forward Fuselage Panel Interior Mold Line

Figure 4
Completed Forward Fuselage

The carbon-epoxy wing skins are quite large and require an enormous number of holes to fasten them to the titanium substructure (i.e., internal structure) of each wing as in Figure 5. Those holes are drilled with an AMAMCO diamond-coated carbide tapered drill as in Figure 6 when the wing skins are mounted on a large jig that holds both the left and right wing skin along with the underlying substructure. Note the very clean-cut hole produced with the drill. Then, holes are drilled through the wing skin holes into the substructure and fasteners are installed. The stack of carbon-epoxy skin and titanium substructure must be carefully kept in contact (compressed) to avoid chips from the titanium undercutting the carbon-epoxy panels (similar to a countersink on the backside of the hole). An epoxy shim material is usually applied between the carbon-epoxy and the metal substructure to aid in maintaining that contact. At this stage, the wing is not complete because many fixtures and assemblies inside the wing must be installed. Thus, the wing skin and substructure must be disassembled (and holes deburred), the interior installation completed, and then the wing is reassembled and ready for final installation on the F-35 assembly line in Figure 7. There, note the many holes for fasteners for the wing skins, forward fuselage, and other panels on an F-35B (STOVL) for the Marines.

Section of F-35 wing part, showing high number of precision drilled holes.

Figure 5
Wing Skin with Many Holes

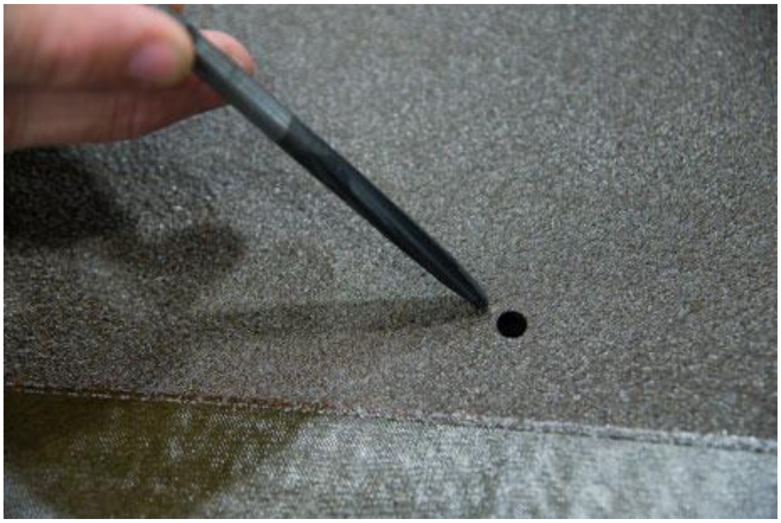

Figure 6
AMAMCO Tapered Drill with Clean Hole in Carbon-Epoxy

Figure 7
Final Assembly of the F-35

In summary, diamond-coated carbide routers and drills enable effective manufacture and assembly of carbon-epoxy wing skins and the forward fuselage of the F-35. The resulting structure has very significantly narrower gaps between structural panels than previous stealth aircraft and hence is far less costly to create and to maintain stealth characteristics in long-term service. Moreover, all machining is done with efficient tools to significantly save production costs.

Reference:
F-35 Composite Edge of Part Machining, Project Number 05005602, 2005, National Center for Defense Manufacturing and Machining, www.ncdmm.org, 2005.