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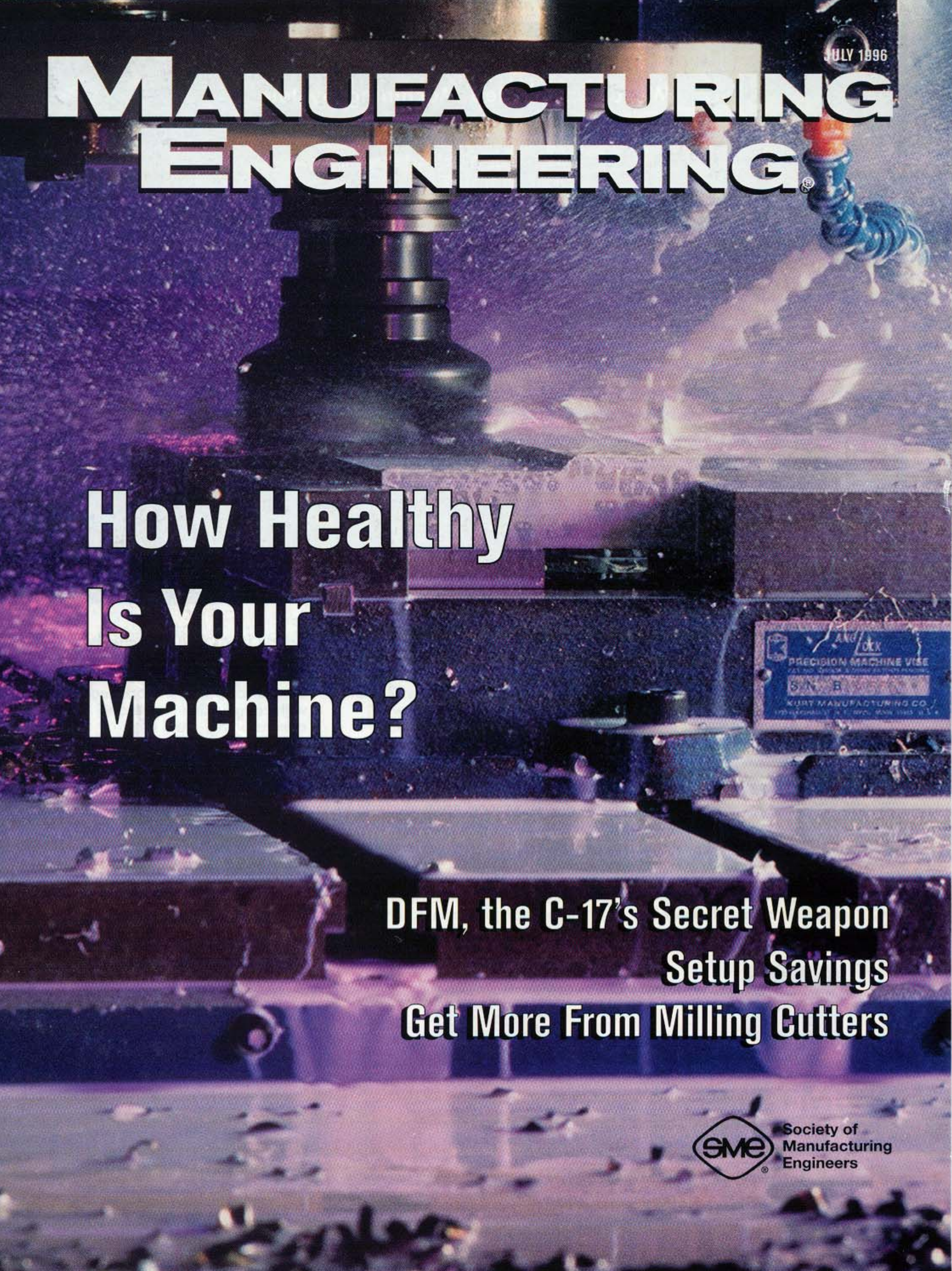

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DFM THE C-17's SECRET WEAPON

An aggressive design for manufacturing program helped make this bird the most sophisticated heavy-equipment transport plane in the world

A maximum gross weight of 585,000 lb (263,250 kg) at takeoff might also make the US Air Force's McDonnell Douglas C-17 Globemaster III one of the heaviest transport planes in the world, but don't let that statistic fool you. This aircraft is no Spruce Goose.

The C-17 has set a total of 22 world records, including those for payload to altitude, time to climb, and short takeoff and landing. One C-17 took off in less than 1400´ (427 m), carrying a 44,000-lb (19,800-kg) payload to altitude and landing in less than 1400´ (427). With a 160,000-lb (72,500-kg) payload, the plane can take off from a 7600´ (2316-m) airfield, fly 2400 nautical miles, and land on a small airfield in 3000´ (914 m). Its maximum payload is 171,000 lb (77,500 kg).

The high-wing, four-engine, T-tailed aircraft is 174´ (53-m) long and 55.1´ (17-m) high, and has a 169.8´ (52-m) wingspan. Hanging from pylons ahead of and below the wing's leading edge, each of the four Pratt & Whitney PW2000 series turbofans produces 40,700-lb (181-kN) thrust. The engines have directed-flow thrust reversers that can deploy in-flight. The powered-lift system directs the engine exhaust through double-slotted flaps to produce the extra lift force necessary for steep, low-speed final approaches and short runways.

The Defense Dept. has approved procurement of 120 C-17s, and, so far, has placed orders for 40 from McDonnell Douglas, the prime contractor. As of February, the Air Force received 25 of the versatile cargo planes, some of which are now providing critical support for Operation Joint Endeavor in Bosnia and landing on runways inaccessible to other heavy equipment transports.

The flyaway cost is $325 million/plane for the first 40 aircraft, but will drop to less than $175 million/plane for the next 80. How has McDonnell Douglas been able to cut those costs by nearly half? By rethinking its manufacturing processes and streamlining the design and manufacture of key assembly structures.

Landing-Gear Pod Redesign

Over the last two years, the defense contractor has put considerable effort into improving the C-17 production line. A critical assembly benefiting from this effort is the main-landing-gear pod, which is longer than the F-15 fighter. Attaching this assembly to the aircraft has been problematic from the beginning. Assembling the pod, basically an aerodynamic covering for the landing gear, occurs in St. Louis, but the operation mating it to the C-17 fuselage is at a Long Beach, CA, facility. The procedure consumed an excessive number of hours in assembly, rework, and repair, which is why the pod became a prime candidate for review using design for manufacturing, then a relatively new technique for McDonnell Douglas.

Targeted for revision were the large bulkheads around the gear, which engineers redesigned to allow high-speed machining. Per bulkhead, the ability to hog out work material fast allowed engineers to produce more-complex large single-piece components in an adequate time frame. Before, they had to machine several smaller sections and

High-Speed Machining Cuts Costs

McDonnell Douglas engineers report high-speed machining is the key to a number of production improvements made on the C-17. Instead of building up assemblies, the process allows them to produce monolithic large parts. The first high-speed machining application was on bulkheads in the cargo door, and the company has since adopted the practice for other sections of the aircraft.

An example is a landing gear bulkhead machined at McDonnell Douglas Aerospace (St. Louis) on a Giddings and Lewis five-axis gantry mill. The machine has an 8 × 35′ (2 × 11 m) bed and opposing spindles that can run two jobs independently. This size machine was necessary to accommodate the raw work material, which was a 9 × 12.5′ (3 × 4 m) 3.5″ (89 mm)-thick 7050-T7351 aluminum alloy plate pocketed on both sides.

Engineers rough-machined the bulkhead with a 2″ (51 mm) cutter at 200 sfm (61 m/min) and 10,000 rpm. The final machining process used a 3/4″ (19 mm) cutter at 150 sfm (46 m/min) and 13,500 rpm, and then a 1/2″ (12 mm) cutter at 100 sfm (30 m/min) and 13,500 rpm.

Machining one side of the bulkhead took four shifts, the other side two in a three-day period. McDonnell Douglas machining experts estimate the high-speed technique made the overall machining time 15× faster than conventional machining. Accuracy also was high. Out of the first 20 tryout parts, engineers determined 17 were accurate enough for installation on the aircraft.

McDonnell Douglas officials attributed the smooth transition to high-speed machining to the use of Integrated Product Teams. In one case, a team received a piece of raw material that was too small. Because the McDonnell Douglas personnel involved were working closely with the material supplier, the team obtained new material in hours, instead of days.

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assemble them. The redesign reduced detail parts from 72 to 2 and fasteners from 1720 to 35.

The redesign also changed the pod from a three-piece composite-skinned assembly to one unit. Key to reducing assembly time was the step revising the attachment method. Engineers replaced the existing shear clip attachments and multiple fasteners with a clevis and drag-link arrangement. Instead of riveting a skate angle to the assembly's perimeter and to the aircraft fuselage, production workers now install blade seals that need no attachment to the fuselage, which reduces the number of holes they must drill through the fuselage and makes it easier to complete the assembly's interior work, such as installing insulation.

Before the redesign, pod sections arrived from St. Louis with composite cover panels installed. In Long Beach, workers had to remove the panels to install the required lighting and hydraulic systems. They then had to reassemble the panels. Now, workers in St. Louis install the lighting and hydraulics systems. Mating the landing gear pod assembly to the fuselage takes less time, and the whole structure has more rigidity and a better fit.

The project showed the importance of McDonnell Douglas's Integrated Project Team system, which the company put in place to ensure that all necessary groups, from accountants to suppliers and maintenance staff, provide input about design and process changes. The landing-gear pod redesign project, for instance, involved both St. Louis and Long Beach personnel from structural and systems engineering, and tooling production, as well as suppliers and the product maintenance support organization.

Since the redesign project involved teams in both cities, a better way to communicate was essential. The solution involved developing a CAD model of the development fixture previously used to mockup the assembly and verify fit of all components. Engineers in both St. Louis and Long Beach could then work with the same electronic fixture model and receive automatic updates of approved design changes. This electronic design and verification eliminated the need to build two development fixtures, which helped reduce variation.

The cost estimate for implementing the improvements is $41 million. The results have led to major procedural changes that have cut manufacturing time by 10 days and that will save more than $100 million on the remaining aircraft to be delivered to the Air Force.

Eliminate Those Fasteners

Another redesign that saved time was a project revising the original aircraft ceiling structure of matrixed aluminum hat-section beams. In the first planes off the assembly lines, engineers attached panels to the structure using 24 adjustable rods. Fitting and trimming them around the ducts, electrical power centers, and avionics racks was time-consuming. The redesign eliminated the ceiling structure, using existing aircraft components like the ventilation ducts and fluorescent light fixtures as support. Instead of using a hard attachment around the panel edges, engineers attached Velcro-type Dual Lock strips to allow fast attachment and removal of panels and eliminate trimming.

Cost of making the changes was just over $400,000, but the cost avoidance with the new cockpit ceiling is an estimated $1,750,000 in the 120-aircraft program. Moreover, the Air Force will require less maintenance time over the next 20 years with the redesign. Other results were that part count dropped from 687 pieces to 75 and that the fastener count is now about 400 instead of 2450. The redesign saved 25 lb (11 kg), and installation time fell from 230 hr to less than 75 hr.

More than 27,000 workers nationwide are involved in the building of C-17s.

Engineers also were able to use DFM techniques to eliminate fasteners and rethink the manufacturing of a series of fuselage panels. The project combined three fuselage panels on the bottom of the aircraft to make one 10×17′ (3×5-m) panel. The new method also included more chemical milling of the skin to produce thicker skin around the maintenance hatch opening to the aircraft bilge. Using one panel eliminated doublers, longeron splices, and fasteners at the points where panels met, as well as the need to install doublers around the maintenance hatch.

The change in method and sequence put more work back at the original panel buildup area, where it was easier to work. Aiding the redesign was a new supplier that could make larger skins than previously available. Now, workers can fabricate the single-skin panel in about the same time previously required for just one of the three panels. Estimated savings for the remainder of the planned 120 aircraft are about $12 million.

On every DFM project, engineers examined even the smallest details. Consider fasteners. No project could completely eliminate them. The C-17 still has some 1.4 million fasteners. Military specifications require defense contractors to install each fastener with a wet sealant. The mechanic must get fasteners and sealant from stock, apply sealant to both the hole and fastener, install the fastener, check for squeeze-out of the sealant, and clean off the excess sealant with solvent. To streamline the process and maintain corrosion protection, a team of McDonnell Douglas engineers and production experts developed a process to bake on a dry sealant that completely covers the fasteners.

Extensive testing of corrosion, fatigue, and stress showed that these precoated sealants have superior corrosion protection to the wet-sealant fasteners and provide increased joint fatigue life. Testing also showed that the coating reduces the force necessary to install the fasteners and reduces operator fatigue.

Implementation for the two-phase precoated fastener program is beginning with about 600,000 titanium interference fit fasteners, which will save about $150 million over the 120-aircraft program. Phase II, which covers more than 800,000 aluminum rivets and other fasteners, will save another $260 million. This will translate to an estimated total cost reduction per aircraft of nearly $4 million.

A DFM Doubleheader

Sometimes, engineers performed two redesign projects in concert. One example involved modifying the wing-box assembly fixture and the wing pylon stub subassembly, where variables in the front wingspar affected installation of the pylon stub.

Workers assemble each wing half while it is in a vertical position and then install the pylon stub on the front spar. The problem with the initial wing box tooling was that it supported the 95′ (29-m)-long front spar at only four points, which meant the spar could sag up to 0.3″ (8 mm) during assembly. It also meant that the wing skin panel required trimming in the fixture to ensure a good fit. Because of the variability in the front spar location, it was difficult to install the pylon stub without a lot of rework. Operators also had to assemble the pylon stub, with its more than 100 detail parts, on the wing to eliminate the problems caused by variability. They also had to remove supports to install the upper skin panels, and then reassemble them.

The tool modification replaced the four supports with a large truss arrangement that supported the front spar at 17 points, which reduced sag to less than 0.010″ (0.3 mm). In addition, workers now have access to a dedicated internal crane system to load upper skins into the tool without removing the support. The truss also prevents workers from using the front spar as a convenient work platform.

Reducing variation made it easier to assemble the pylon stub off the wing with separate tooling and then install it as one piece. A subcontractor aided the cost reduction effort by machining the countersinks for fasteners in the titanium upper doubler using a five-axis machine tool, which eliminated a manual operation.

The two projects combined saved time in later positions on the assembly line, cutting the need to shim the fixed leading edges that attach to the front spar and facilitating a fitting operation around the pylon stubs. The projects also changed many workers' attitudes: they no longer feel as though they have to make due with inadequate tools. ■

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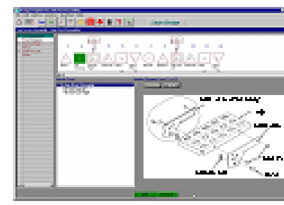
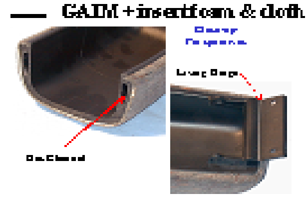


First redesign-molded plastic



C-17 *Lean Design*™ Successes