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BY TECHNICAL EDITOR
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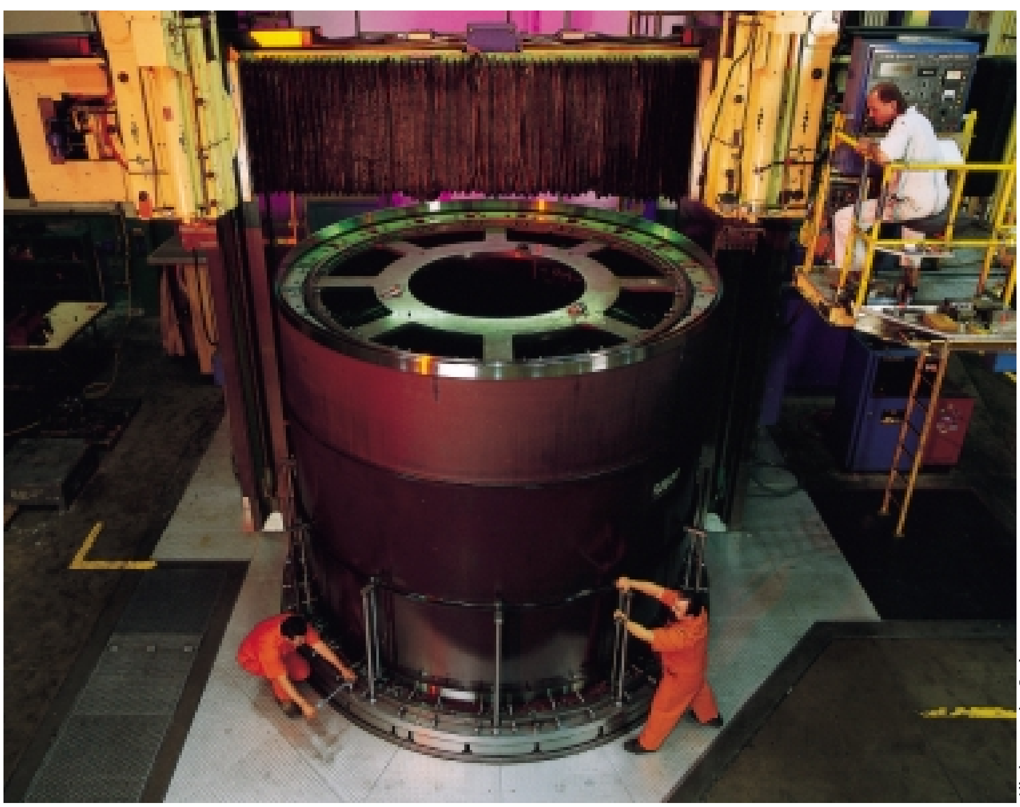
Dimensions of Aerospace

Inside a world-class aerospace manufacturing facility.

On a recent trip to Los Angeles, CTE Technical Editor Chuck Boyles had the opportunity to visit Stadco, a manufacturer of components and tooling for the aerospace industry. Stadco Senior Manufacturing Engineer Bob Wiederrick took Chuck on a tour of the company's plant, which is overflowing with sophisticated equipment. Precision machines were producing close-tolerance, complex parts, tools, jigs, fixtures and molds as 30-ton cranes deftly moved and located 10'- to 30'-dia. parts. Among the staff of approximately 200 are Stadco's engineers, who use CATIA and Auto-Cad software to generate designs. The designs become reality in the hands of highly skilled machinists running huge, multi-axis CNC machines. This article describes some of the projects currently under way at Stadco.



All photographs: Stadco

Machinists prepare a space shuttle rocket motor casing for machining on a 4-axis machining center.

From gigantic molds made of conventional steel to tooling produced from exotic materials like Invar, Stadco has been designing and manufacturing sophisticated components for aerospace manufacturers, defense contractors and high-tech research facilities since the early '40s.

The Los Angeles company is one of the few firms in the world capable of precision-machining large round, curved, cylindrical and convex launch vehicle components, such as nose cones and motor cooling jackets. Its list of customers includes Northrop Grumman, Raytheon, BF Goodrich Aerospace and Boeing. Among the programs Stadco manufactures components for is NASA's Endeavor Space Shuttle.

Stadco's senior manufacturing engineer, Bob Wiederrick, said, "Production at Stadco can involve any quantity, from a prototype to a full production run."

A large rocket engine serves as an example of its prototyping capabilities. Stadco did most of the prototype work and all the testing of the engine. Many of its components are nickel alloys, such as Inconel 625 and 718. A bearing support, for example, is made of Inconel 625—a workhardenable alloy containing nickel, chromium, molybdenum, niobium and iron.

These large, and often intricate, parts require highly specialized knowledge of the application. Usually, the "starting" speed for milling Inconel 625 in its aged condition is 5 to 15 sfm. Feed per tooth is between 0.001" and 0.004", depending on the particular milling operation. In addition, system rigidity—including the fixture, workpiece, cutting tool, toolholder and machine tool—is critical for maintaining tolerances. Since Inconel 625 is workhardenable, sharp cutting tools are imperative.

Another part made of Inconel 718 for the same rocket engine has volutes on the inside. Stadco holds these tolerances to 0.001".

This 25'-high x 27'-dia., dome-shaped mold was produced at Stadco. Machining tolerances were held to 3-millionths of the diameter.

Understanding Space

One of the more critical tasks in preparing aerospace castings for machining—the setup work—requires defining spatial relationships. A large casting being set up during CTE's visit illustrates how Stadco accomplishes this.

The casting has hubs at both ends and required internal machining of multiple surfaces at different angles and levels. A pallet was set up for qualifying—finding the datum points—of the casting. Then a toolmaker found the exact center of the hubs on both ends, and determined exactly how much stock—the machining or finish allowance—was available on each face. (Machining allowances vary as a function of casting length.) After qualification, surfaces are machined in relation to the datum.

Beginning with the known table width, blocks were used to center the datum relative to the table edge. Once centered, the casting was balanced with side jacks so it sat on four corner blocks. Then the toolmaker measured across a hub to obtain the hub radius. Next, he measured down to the tabletop and adjusted the hub's centerline to the table centerline. When the casting is blocked and aligned, he can secure it to the pallet.

During the process, the machinist located the datum points inside the casting that must be held. Also, the tabletop and a point on the hub face become additional datums. The same procedure was repeated for the hub on the other end and for the other features.

When the datums were located and defined, then a programmer set zero points for machining. This process ensures every feature can be machined and that there is adequate material allowance in the casting for machining. Thus, the casting is qualified.

For production runs, Stadco's engineers design hard tooling that makes the setup process less complicated.

Domed Configuration

One project at Stadco represents the artistry and sophistication customers have come to expect from the company. The requirements called for a 25'-high × 27'-dia., dome-shaped mold made of 0.475"-thick A-36 steel.

Wall thickness cannot vary more than ±0.100" from top to bottom and, when set on its side, the mold cannot collapse more than 0.100". The inside profile cannot vary more than ±0.030" on the 27' diameter (3×10^{-6}, or 3-millionths of the diameter). Wiederrick described these tolerances as "interesting, for something this size."

Fixturing was critical to ensuring dimensional stability. Development of the correct machining fixture was based on Stadco engineers' understanding of the dynamics of the geometric sections—that is, side support controls roundness at the rim. Domes act like conical paper cups. If you push or pull the side of a cone, the rim distorts to an out-of-round condition.

Therefore, if the dome is supported during a turning operation by individual point supports on the sides, it distorts and tolerances cannot be met. However, if the cone rests in a perfectly flat ring, the rim will be round—a self-fixturing arrangement generating a self-fulfilling prophecy. Thus, a large, flat, circular tooling fixture keeps the mold round. Using a laser tracker to monitor and control fixture tolerances by establishing datum points, Stadco ensures conformance to the specifications.

As a welded structure, the mold bottom is composed of a 10'-dia. domed piece and 12 gore plates—triangular steel plates with their apexes cut away to conform to the domed section. The plates are 0.750"-thick stock, hot-formed at 1,650° F. Each segment was roughed and then evaluated by digital photogrametry, a process in which the actual surfaces are compared to a master model.

Machine time for each segment was about a week. After assembly, both mold and fixture were turned to hold the required 0.475" wall thickness. After turning, wall thickness and roundness were again verified with a laser tracker.

After assembly, the mold was stress-relieved by means of a vibratory process. This was necessary since any residual stresses from the manufacturing processes could lead to mold failure. Mass and configuration determine the stress-relieving frequencies, which can be identified as maximum energy-consumption levels. Accelerometers attached to the object sense the vibration levels. As the object vibrates at the stress-relieving frequency, mechanical stress dissipates and energy consumption, represented as a spike on a graph, approaches a minimum level.

In the final analysis, the mold, when positioned horizontally, collapsed in the neighborhood of 0.075", well below the specified 0.100".

Space Shuttle Parts

Stadco builds and refurbishes space shuttle booster casings. These casings, made of D-6 AC—an aircraft-grade 4340 steel—go on the sides of the main fuel tank. Each of the casings is 13' high, 13' in diameter and weighs 1,200 lbs. Their hardness value is about 32 HRC.

After a number of flights, the booster casings tend to mushroom at the ends and must be reconfigured. In some cases, if the casings are exposed to seawater, corrosion sets in and must be removed, too.

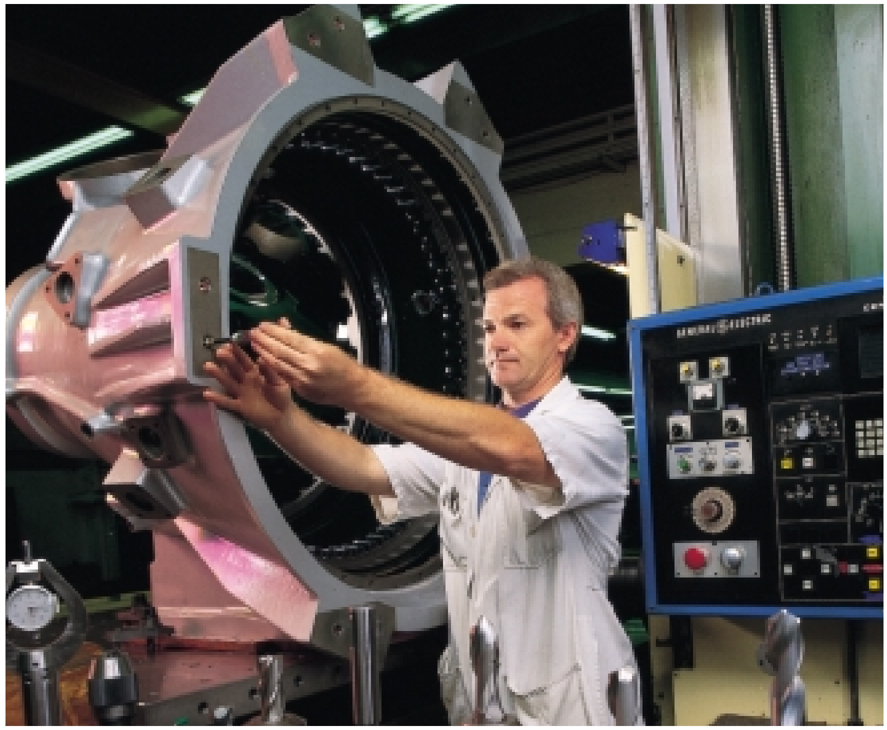
Stadco also remachines the O-ring grooves and brings the casings back into specification, holding tolerances at ±0.002" to ±0.003" on everything except the O-ring grooves. The O-ring grooves call for ±0.001"—that is, 6×10^{-6} of the radial dimension—with a 32 R_a finish on the bottoms of the grooves.

Rotary Equipment Carriage

An aluminum casting for a rotary equipment carriage, nominally 8' in diameter, is typical of the parts Stadco machines. The carriage attaches to a platform, which rotates on a pedestal. Precision is critical because the carriage must rotate at high speed.

The casting has qualifying bosses to position it on a vertical turning lathe (VTL) fixture, where the bottom side is turned first. Then the machined features on the bottom position it for further machining, which includes producing side faces and bearing mounts on the inside and bearing bores. One position serves as a datum for milling and another for turning on the VTL while holding ±0.001" to ±0.002" under the coordinate measuring machine's (CMM) program control.

Then the fixtured casting is fitted to an indexable rotary table on a 4-axis CNC machining center, where cutting tools are applied to the faces for the bearing bores and liners.



Competent people are the primary reason tolerances are met and quality is maintained in every machining program.

When boring large bearing settings, tolerances are held to ±0.0002".

Transmission Housing

A cast transmission housing for a large helicopter is another example of the precision work done at Stadco. The manufacturing process began with a setup that positioned the casting based on the foundry's tooling points, which are references for initial bores.

After the initial bores were made, they became tooling references for another family of tools to complete the other features.

The casting has at least a dozen different surfaces, including gasket surfaces that require milling, drilling and tapping—just from one aspect. When the part was rotated to the next position, there were more surfaces. Some internal features required a tool reach of over 30".

Tweaking Equipment

Engineers at Stadco do not limit themselves to machining parts. They also modify machine tools to meet customer parts' requirements and design and build timesaving devices for internal use.

For example, one small device—a swing indicator—is the brainchild of Bob Wiederrick. It allows a programmer to read high points on a surface so he knows exactly how much stock should be machined away. The swing indicator is now a standard tool used by aerospace manufacturers.

Another example is Stadco's custom-made, air-indexable rotary table that allows machinists to index both the table and part into position. Using air pressure—like an air-hockey table—machinists can rotate a large part or casting before locking it into a new position for machining.

For another application, Stadco elevated and extended a large missile-maker lathe. The additional height allows Stadco to position and machine heavier and larger-diameter parts. Also, the faceplate diameter was hardened and fitted with rollers so workpiece weight does not overload the bearings.

A similar configuration is at the opposite end where rollers support the faceplate. The lathe easily accommodates a shaft over 8' long and 36" in diameter. After machining, the shaft will accept a split bearing with a tolerance of ±0.001".

Similarly, on a Jo'Mach 5-axis CNC gantry mill, Stadco engineers redesigned the table, which is normally at floor level. They dropped the work surface down an additional 5' to accommodate larger parts. Now the mill can handle workpieces up to 255"×157"×59". Machinists also can elevate the table to its original level, should it be necessary.

The most recent addition to Stadco's manufacturing capacity is the largest electron-beam-welding chamber in the U.S. Designed and built in Seattle, the welding chamber is being set up on the main factory floor while the control system is being configured on an upper level of the plant.

Stadco's People

Stadco, like every company, is made up of people. A distinguishing quality of Stadco's people is their ability to understand the dynamics of aerospace manufacturing and spatial relationships. Through an eclectic blend of talent, creativity and innovation, Stadco identifies the most cost-effective approach to manufacturing.

There's a great deal of interaction among the people at Stadco. Wiederrick said, "It's primary to capture everyone's thoughts, since any thought process that is not recorded seems to evaporate. And, it behooves us to record those thoughts and pass that information onto the people who do the work."

That's what happens in the beginning stages of a new program. The first step is to create models of the components to be manufactured. Then programmers review the models before the machinists present their views on how to best approach the job. Ultimately, the machinists will have ownership of the work.

Empowering employees in this way builds loyalty. It should come as no surprise that there is very little turnover at Stadco. The average employee's tenure is 17 years.

Whether it's an Invar mold, an aluminum thrust reverser for a commercial jet, a titanium or magnesium casting, or an Inconel component for a rocket engine, Stadco's people have the ability to discern the combinations of processes that transform manufacturing from function to elegance. The company has successfully integrated its knowledge of technology, machines and machining, material properties, spatial relationships and the behaviors of geometric configurations to manufacture an ever-increasing array of aerospace tools and components.

"We at Stadco essentially build and machine everything," noted the company's vice president, Steve Hardwick.