

A Complete Guide to Complex Machining and Fabrication for Aerospace Parts

Impro

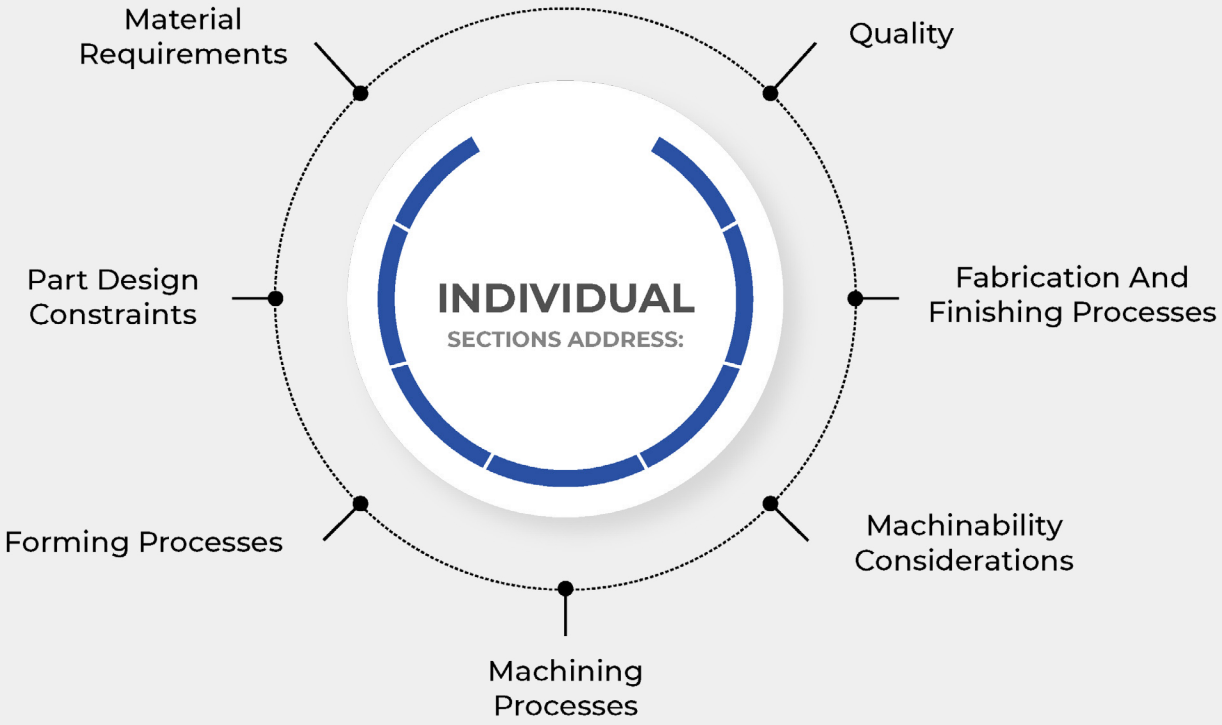
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800-800-9756 | sales@improusa.com

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Minimizing the mass of aerospace parts involves selecting high-strength alloys and eliminating superfluous material. Near-net shape casting methods help, but precision machining is also extremely important.

This eBook describes what it takes to machine and fabricate parts used in aerospace. It discusses the constraints and challenges the alloys impose and the processes used. The goal is to educate and inform anyone looking for complex, precision-machined parts, for aerospace or other applications.



Material Requirements

While the main requirement is high specific strength, corrosion-resistance is also a priority. Furthermore, many gas turbine applications need strength at high temperatures and good creep resistance. Other considerations are machinability and cost.

The preferred alloy for mass reduction is aerospace grade, (7000 series), aluminum. This is used extensively in airframes and interiors and for control mechanisms and undercarriage components. Where higher strength is needed, titanium is usually the alternative, although stainless steel may be chosen for some specific applications.



Gas turbine engine components used downstream of combustion are typically produced from nickel-based superalloys. These provide excellent creep and corrosion resistance, although relatively low melting points require designers incorporate a range of cooling features.

Part Design Constraints

Smaller factors of safety than used in other applications result in aerospace parts being more complex. Typically, they will feature:

- Pockets, where material not contributing strength is removed
- Complex contours to put strength where it is needed
- Radii that minimize stress concentrations
- Smooth surface finishes

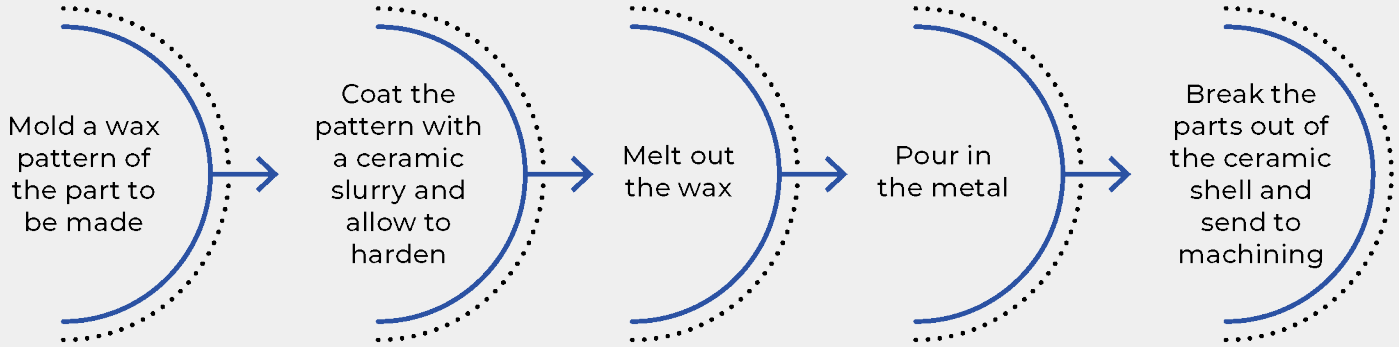
Tolerances are typically tighter than 0.0002” (0.005mm) and high repeatability is required to aid assembly and replacement and minimize stress concentrations.

Manufacturability is also an important consideration, especially given that production quantities are usually relatively low. This can render some near-net shape forming processes uneconomic, so putting greater emphasis on machining and fabrication.

Forming Processes

Many aerospace parts are produced by investment casting. Forging is also an option for some geometries, especially those where high strength is paramount. However, for parts needed in smaller quantities it can be less expensive to machine from billet or bar stock, (which also reduces production lead time.)

Aerospace alloys are generally well-suited to investment casting. This multistep process entails:



Machining Processes

The major challenge in machining aerospace parts is achieving the high metal removal rates necessary to drive floor-to-floor times down to economic levels. This is important because, as noted previously, these parts, especially when produced from billet, typically need large volumes of metal cutting away.

The primary metal removal process for aerospace parts is CNC milling. This is performed on castings, forgings and also billet material. Historically, milling was carried out on machines with three orthogonal axes, but today manufacturers like Impro are making increased used of 4 and 5 axis milling.

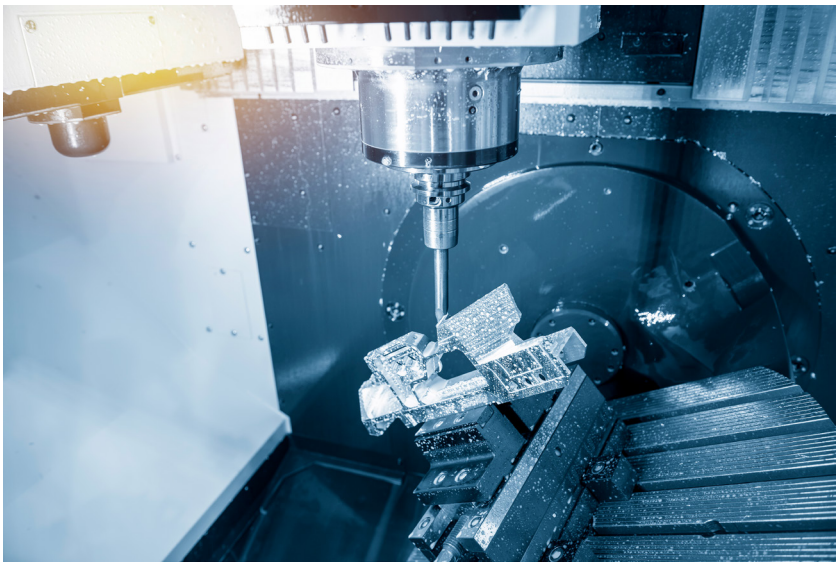




These additional axes make it possible to move the workpiece relative to the cutting tool. This enables milling surfaces and pockets and drilling holes at angles other than 90° in a single setup. (Combining operations into a single setup also improves part-to-part repeatability.)

The most sophisticated 5 axis CNC milling machines can move the workpiece while the tool is in-cut. This enables machining of complex contours, which contributes to mass reduction.

Some castings may need turning as well as milling, although 5-axis machines are increasingly capable of producing accurate cylindrical geometries. For aerospace parts turned from bar stock Impro has a range of CNC lathes. Many of these have secondary or subspindles for finish turning the back end (previously held in the chuck) or milling flats and drilling cross-holes.



Cylindrical outer surfaces and bores may be brought to size and roundness by grinding. However, the poor machinability of many aerospace alloys makes this difficult to do while achieving satisfactory production rates and surface finishes.

Machinability Considerations

Maximizing output from CNC machine tools means cutting as fast as possible. However, the hardness and other properties of aerospace alloys pose some challenges, as detailed below.

7000 Series Aluminum

The addition of zinc raises tensile strength but at the same time makes machining more difficult than for other aluminum series. The major problem is that at low speeds material adheres to the cutting edge, creating “built-up edge” (BUE). This degrades surface finish and can affect dimensions while requiring more power from the machine.

The solution is to cut at the highest possible feed rates, preferably at least 6,000 sfm. With smaller cutters, as are needed for pocket milling, this can require spindle speeds of 30,000 rpm.

Titanium

This alloy, available in a wide range of grades, is notoriously “gummy”, sticking to the cutting insert and forming significant BUE. In addition, low thermal conductivity means much of the heat from cutting goes into the tool rather than the chips and workpiece. Complicating matters further, the chips are tough and abrasive, which accelerates tool wear.

Superalloys

These combine toughness with hardness, so machining requires rigid and powerful machine tools. In addition, alloys like Inconel tend to work-harden. Recommended cutting speeds are in the region of 100 sfm.

Fabrication and Finishing Processes

Few parts are finished after machining. Most will be incorporated into assemblies, which may need welding or brazing, and almost all will undergo some form of surface treatment.

At Impro welding is mostly done by electron beam. This uses an electron “gun” similar to a cathode ray tube to generate a very small diameter high energy beam. This puts more energy into a smaller area than is possible with a laser, which results in a high depth-to-width ratio. This means less time at temperature, shrinking the heat affected zone, which results in less expansion and distortion and less impact on material properties.

Welding can have undesirable effects when used on metals with a number of alloying elements. In particular, the different melting points can lead to segregation, reducing strength and other properties.

Brazing is a lower temperature alternative to welding where the parent metals are not melted. Instead, a lower melting point filler alloy, selected for its bonding ability, is introduced between the two parent pieces. Brazing can join dissimilar metals, providing the filler bonds to both.

Brazing under vacuum prevents oxidation effects and results in higher quality and greater consistency.

Two finishing processes applied to aerospace parts are anodizing and passivating.

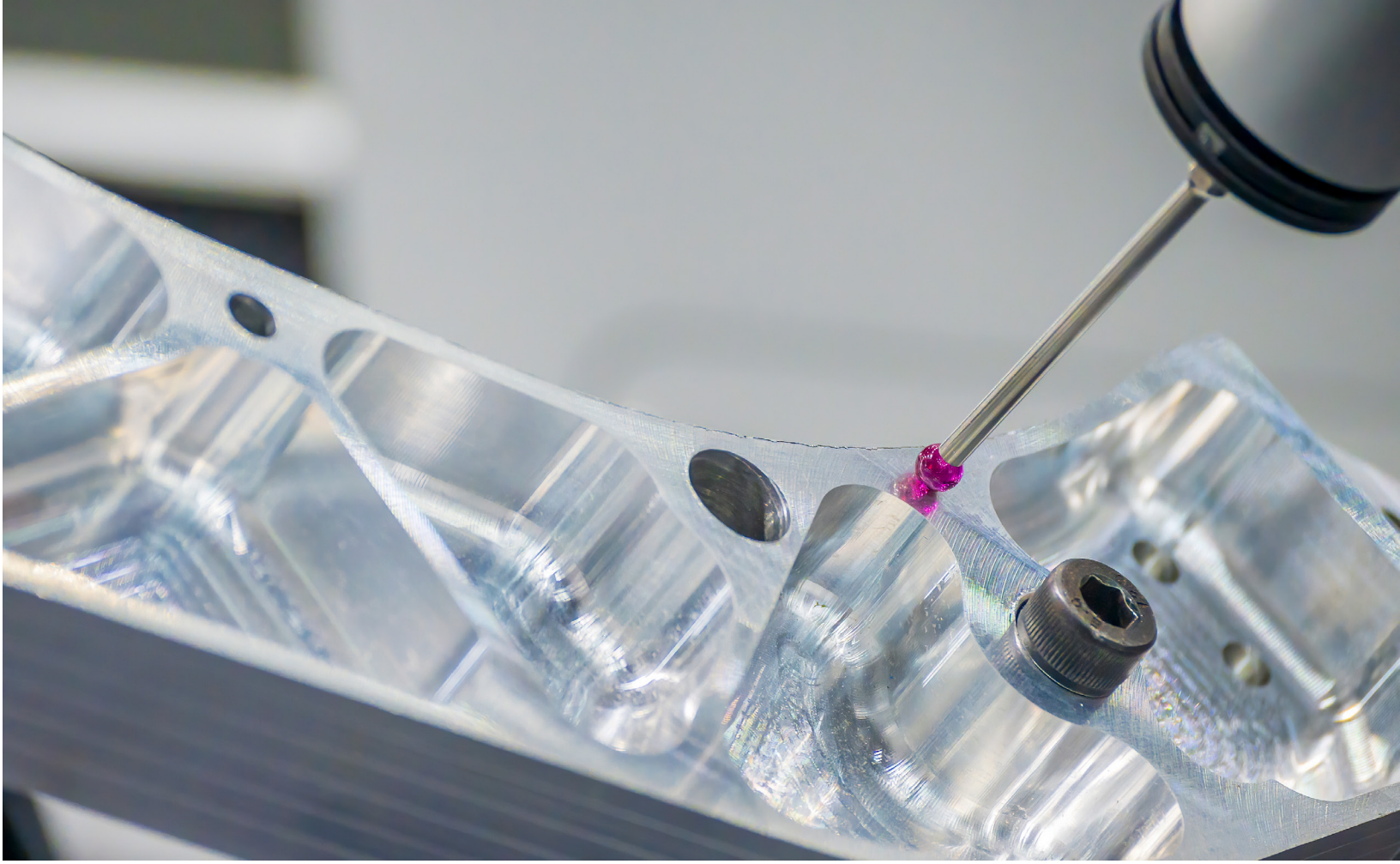
Anodizing is a method of enhancing the oxide layer on the surface of aluminum. This increases hardness and wear-resistance and can also be used to impart colors.

Passivating is used to clean up stainless steel surfaces. Using a mild acid, it removes loose ferrous particles that would otherwise initiate corrosion.

Quality

Quality is of the highest importance when producing aerospace parts. The two approaches taken to ensuring defect-free production are part inspection and operation of a rigorous Quality Management System.

Inspection methods include coordinate measuring machines (CMMs) for dimensional verification, plus nondestructive flaw detection techniques such as x-ray and fluorescent particle detection.



The accuracy and repeatability of measurement equipment like CMMs is assured through regular calibration, as dictated by the QMS. Leading manufacturers like Impro have their QMS's audited and certified by external authorities to verify fitness for purpose. In aerospace parts manufacturing the principal certification is AS9100.

Additional certifications under the NADCAP umbrella are evidence of effective control of specific processes such as welding and heat treatment. Competence in welding is further assured by certification to ISO 3834-2, the international Standard defining quality requirements for fusion welding of metallic materials.

Specialized Expertise Required

Aerospace parts, by their very nature, feature complex geometries and are made from difficult-to-machine alloys. Weight is minimized through extensive machining. When these parts need joining, special care is required to avoid creating any defects that could lead to premature failure.

As a leader in precision machining and aerospace parts manufacturing, Impro combines a deep understanding of product requirements with a high level of manufacturing mastery. To learn more about what it takes to produce these parts, or to discuss your specific machining and fabrication needs, contact us to schedule a conversation.

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