

Optimizing Titanium Component Machining

NC Program Analysis Using Physics-Based Modeling

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INTRODUCTION

Delivery and cost pressures for titanium components continue to increase, but with access only to conventional machining resources, engineers and CNC programmers cannot make process improvements without the risk of adversely affecting delivery target dates. These engineers recognize the need for technology that promotes faster, high performance machining and NC program optimization; however, with no time to halt current production it is critical that this technology integrate with current resources. NC program analysis technology that interfaces seamlessly with conventional computer-aided design/manufacturing (CAD/CAM) systems would enable aerospace manufacturers to reduce part machining times without disrupting current manufacturing activities.

Third Wave Systems' AdvantEdge Production Module software has been demonstrated to reduce machining cycle times by 20-30% during initial application. With increased software familiarity and machining expertise, users can implement additional modifications to cutting tool geometries and toolpath trajectories that realize 40-70% cycle time reductions. By incorporating this physics-based modeling software into the production cycle for titanium components, aerospace manufacturers can produce new parts, and improve existing parts, more affordably and efficiently than ever before.

BUSINESS CHALLENGE

The machining of titanium alloys and other high temperature aerospace metals poses various challenges to engineers due to the material's low thermal conductivity, high specific cutting energy and high hardness. Despite being complicated, toolpath analysis during the process design can yield a wide range of benefits in many different areas. When attempting to optimize cutting conditions and improve machining processes, the ability to model the process using computer-aided engineering (CAE) tools is critical. The use of modeling technology allows for different scenarios to be tested in a virtual environment to reduce the amount of on-machine testing needed to implement machining improvements. With the help of a validated toolpath analysis model that can predict forces across the entire toolpath, cycle times and scrap can be reduced, and machine breakdown can be avoided, all through off-line analysis. Productivity and process efficiency can be improved through simulation, drastically reducing the amount of spindle cutting time.

As the current market practice, the on-machine testing of process improvement proposals has three principle drawbacks:

1. It is very expensive to run the tests
2. The time needed to run tests prevents operators from using the machine for production
3. The number of machine test iterations is restricted

The use of CAE modeling software reduces the need for as many machining tests and allows engineers to examine potential areas for machining problems or possible improvements in a cost-effective environment.

SOLUTION DESCRIPTION

Third Wave Systems' CAE software, AdvantEdge Production Module, allows engineers and CNC programmers to simulate their machining processes before commencing physical tests, optimizing process parameters with consideration for existing equipment and tool and workpiece limitations – further reducing overall production times. Material physics-based optimization features within the software apply high performance machining (HPM) methods to existing processes with proprietary methods for attaining optimum manufacturing parameters (Figure 1).

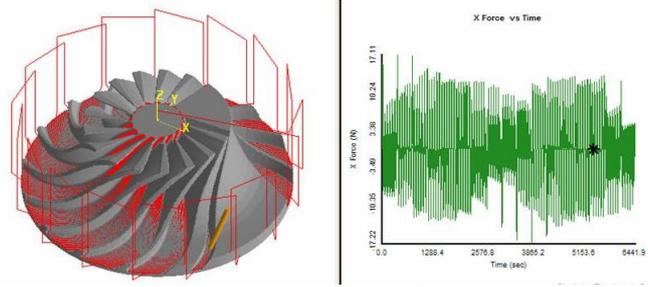


Figure 1. AdvantEdge Production Module can be used to calculate exerted forces using tool, workpiece material, machine dynamics, and toolpath parameters. Red lines indicate cutting toolpath along the impeller.

This technology does not require staff to halt production, nor spend valuable dollars on new equipment; instead, the software interfaces with industry-leading CAD/CAM packages for seamless integration with current design cycle processes. Instead of requiring that users manually determine an optimization strategy based on trial-and-error testing and experience, the technology automatically suggests parameter improvements with consideration for material properties, cutting tool geometries, toolpath approach, and calculated tool forces and temperatures. Technology users ultimately gain machining expertise and make the most of their program's current resources without sacrificing finished part strength, quality, weight, or fatigue.

Utilizing this software at a baseline level typically realizes machining cycle time reductions of 25%. As the user becomes more familiar with the software's capabilities, additional modifications to cutting tool geometries and toolpath trajectories can result in 40-70% cycle time reductions. These gains can be used to not only reduce the total labor content of the individual part, but also reduce the need to invest large amounts of capital in new machine tools to increase capacity.

Solution Technical Details

AdvantEdge Production Module allows users to compute cutting force across entire toolpaths. Force modeling through the toolpath trajectory provides the data necessary to pinpoint opportunities to raise low forces and reduce force spikes. This load-leveling approach is made possible by algorithms within the Production Module software that automatically adjusts the cutting feed rate based on user constraints from the initial force model. Changes in cutting tool loads that result in force peaks and valleys are common to all machined structure components.

To achieve the necessary complex geometries in modern aerostructures, cutting tool engagement will vary greatly throughout the course of the toolpath. For example, if the cutting tool for a common rectangular pocket is programmed to machine the pocket with a radial step-over of 25% of the cutter diameter, the tool will only have that step-over on the side pocket wall. As the cutting tool approaches the corner of the pocket, the effective radial step-over of the cutting tool engaged in the material will increase significantly. This motion is repeated over and over to create the necessary geometry of the machined components. This constantly-varying geometry represents a perfect opportunity to level the cutting forces using Production Module.

Toolpaths used to mill intricate titanium components commonly contain tens of thousands of lines of numerical control (NC) code. For optimization of such complex codes to be viable for machining suppliers, the optimization must be automated to reduce engineering labor. After analyzing the initial force model, Production Module users define a set of parameters that are incorporated into the software's algorithms. Production Module 3D then automatically adjusts the toolpath feed rate values based on the force model and input optimization data, and suggests a new, optimized toolpath for use on the machine.

TECHNOLOGY DEMONSTRATION

To demonstrate the capability of the Production Module software to significantly reduce cycle times while not adversely affecting tool life, Third Wave Systems (TWS) partnered with a respected airframe supplier on a Department of Defense (DoD) program. A representative titanium airframe component was selected for the demonstration (Figure 2) due to its commonality with most titanium airframe structures: more than 95% of the stock material is removed through milling operations. This part contains web and pocket floor thicknesses in the 1-1.5 mm range, and its size fits within the capacity of most machining facilities.

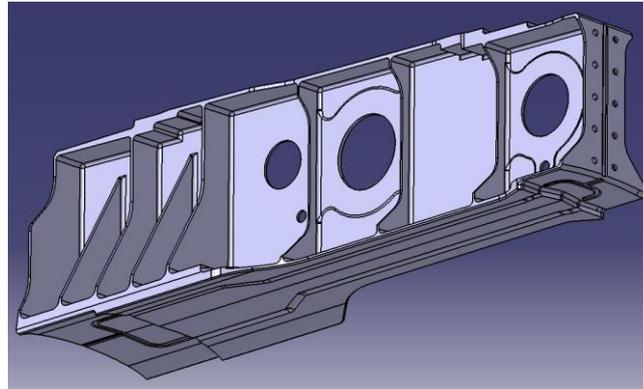


Figure 2. CAD picture of the candidate titanium airframe for optimization demonstration.

For the project, TWS provided Production Module training to the supplier's manufacturing engineer and NC programmer. After receiving an initial orientation to the software, the supplier completed the physics-based model of the titanium structure. The supplier then utilized Production Module to calculate the cutting forces and temperatures of the component, and then based on the model, optimized the feed rates to minimize machining time.

Figure 3 shows a Production Module plot highlighting the load-leveling feed rate optimization approach used by the supplier. Shown in the figure is tangential cutting force plotted against time, both before (red) and after (green) feed rate optimization. After original forces were computed, the supplier sought to apply force boundaries on the cutting tool. A minimum and maximum force value

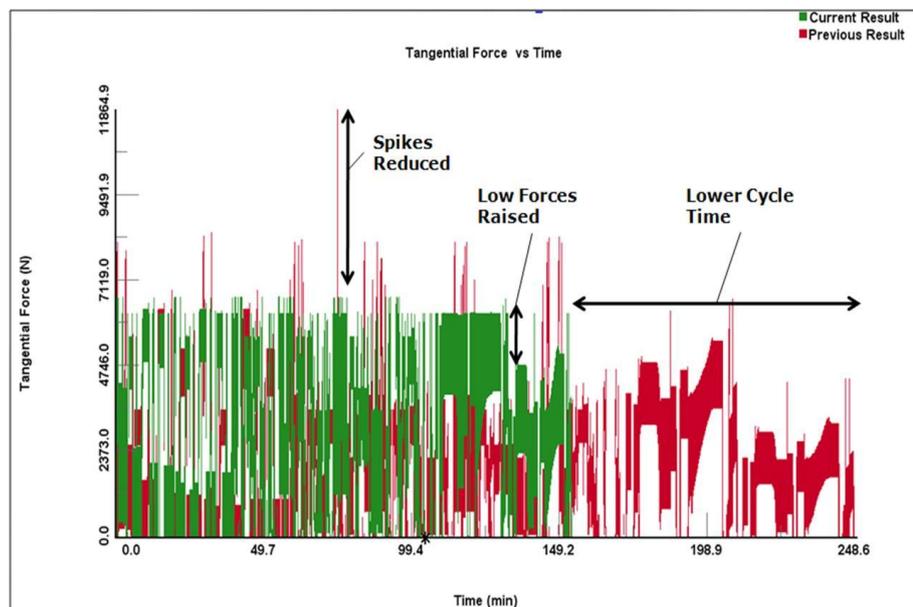


Figure 3. Before and after load-leveling optimization results.

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was entered - for the sequence shown in Figure 3, the maximum force was 6500 Newtons (N) and the minimum force was 6000N – and Production Module automatically lowered any feed rates resulting in forces higher than 6500N and raised any feed rates resulting in forces lower than 6000N. Consequently, force spikes detrimental to tool life were reduced, while under-utilized areas of the cutting tool that lengthened machining times were improved. The optimization process was completed by the supplier with support from TWS for 75% of the component’s original machining time. The remaining 25% is primarily drilling operations for fixturing and orientation of the component.

After optimization, the component’s roughing, semi-roughing, and finishing operations required 25% less machining time (Figure 4).

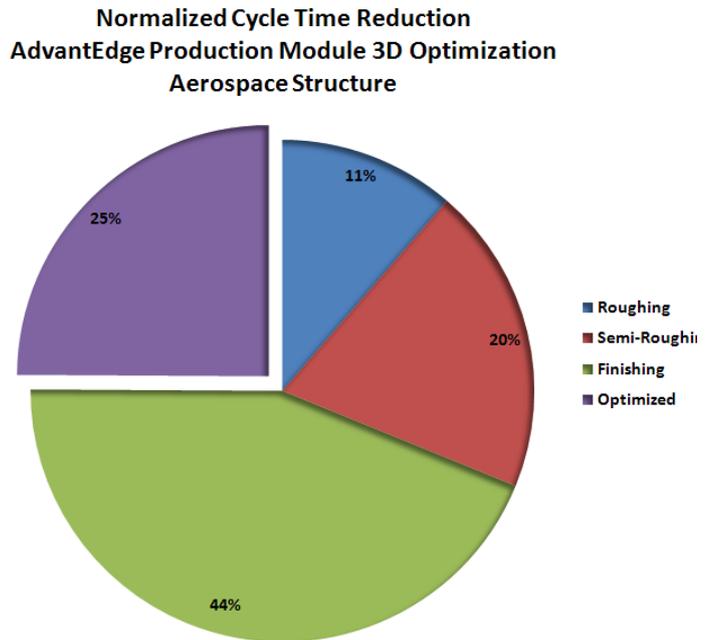


Figure 4. Overall machining time reduction.

MACHINING TRIALS

As part of production requirements for the selected component, the supplier also conducted a machining trial of six individual setups and toolpaths (Table 1) to help foster confidence in Production Module’s optimization results (Figure 5).

The first machining trial, Operation 30, was conducted using a conservative optimization approach and realized a 13% machining time improvement. After the first setup was completed, more moderate optimization parameters were selected to reduce the machining time of an identical process setup,

Operation 40, which resulted in a 21% machining time reduction. Following the second successful trial, the supplier began to implement optimization strategies that fully utilize the capabilities of the load-leveling approach; as a result, Operations 70 and 75 realized machining time reductions of 34% and 35%, respectively. To ensure that surface finish met part specifications, it was important that the supplier not be overly aggressive with modifying finishing operation toolpaths – Operations 80 and 90. Still, these processes achieved significant reductions (up to 25%) without compromising surface finish.

Table 1. Machining trial operation descriptions.

Trial	Operation	Machining Description
1	30	Pocket Roughing
2	40	Pocket Roughing (Alternate Side)
3	70	Pocket Semi-Roughing
4	75	Pocket Semi-Roughing (Alternate Side)
5	80	Pocket & Peripheral Feature Finishing
6	90	Pocket & Peripheral Feature Finishing (Alternate Side)

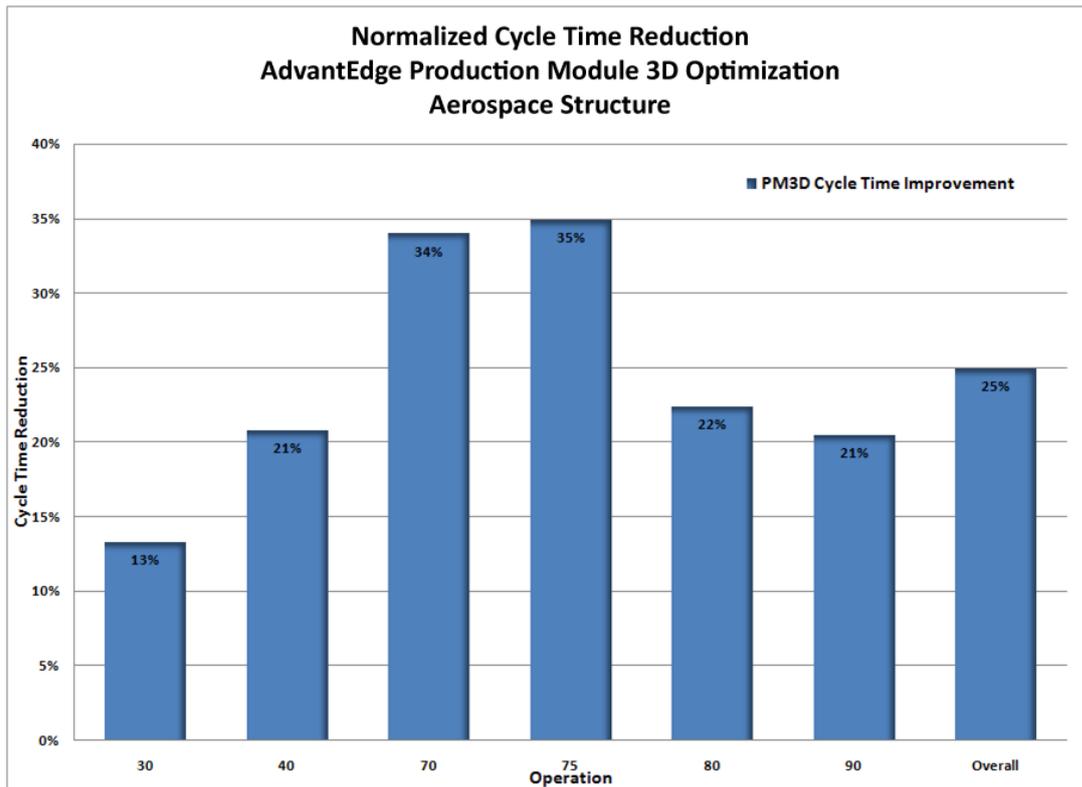


Figure 5. Machining test cycle time reductions by operation.

The overall result of these machining trials added up to a 25% reduction in machining time for the applicable operations. This final result is a composite of individual operation improvements shown in Figure 5; however, if the more aggressive optimization approaches utilized in Operations 70 and 75 had been applied to earlier operations, the composite number could have been increased to 28%. It is also important to note that these numbers represent only gains made by using existing cutting tools with the baseline, load-leveling Production Module approach. If new cutting tools were to be applied in conjunction with a new optimization to further improve finish pass optimization, these numbers could feasibly increase to a 40% machining time reduction, if not more.

Following the tape trials that reduced machine time by 25%, the titanium component was inspected and approved for shipment to the prime contractor. This seal of approval indicates that through utilization of Production Module and its load-leveling process, a 25% reduction in titanium component machining time can be achieved without adversely affecting surface finish or part geometry. By demonstrating that a new part can be machined to market standards with just one on-machine attempt, this trial indicates that the improvement of machining processes can be significantly more affordable through a virtual elimination of dedicated trial-and-error tests, and reduced operator intervention during production.

While this effort was the supplier’s first experience with Production Module, the company’s general manager is pleased with the technology demonstration and the potential for even higher results as his staff gains expertise.

“All things considered, we believe this demonstration yielded very positive results. We felt our baseline program was solid to start with, and still we achieved marked improvements. Technology advances like these – that are production worthy – are just what we need to ensure success.”

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SUMMARY

The ability to model machining processes using predictive CAE tools is important to machining titanium components affordably and efficiently. It is possible to minimize expensive machine testing while maintaining cutting tool life and surface finish to keep costs down and production levels up. Third Wave Systems' Production Module software has been demonstrated to reduce machining cycle times by at least 25%. With increased software familiarity and machining expertise, users can implement additional modifications to cutting tool geometries and toolpath trajectories that realize 40-70% cycle time reductions. These gains can be used to not only reduce the total labor content of the individual part, but also reduce the need to invest large amounts of capital funding in new machine tools to increase capacity.

ACKNOWLEDGEMENT OF SUPPORT AND DISCLAIMER (MAY 1995)

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