

# HIGH PERFORMANCE MILLING IN AEROSPACE MATERIALS

*Meeting the Continuous Challenges of  
Machining New Innovative Materials*

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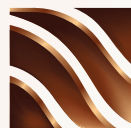
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**Niagara Cutter**

Niagara Cutter relies on 50 years of experience and their Machining Application Process (MAP®) in developing state-of-the-art milling tools that provide solutions to challenges created by the latest aerospace materials. Working closely with key aircraft part manufacturers as well as in-house development and testing leads to better performing and higher efficiency tooling.

Keeping up with the latest machining challenges in the never-ending development of new aerospace materials is at the heart of Niagara Cutter's development efforts.

## THE CHALLENGE: THE GLOBAL AIRCRAFT MARKET

The aerospace market is on a roll. Demand is soaring and the driving force is more fuel-efficient aircraft. This means materials development in aluminum, composites, Inconel, stainless steel, titanium and other aerospace materials that are not only lighter, but stronger. The problem is, often these new wonderful materials, pose very challenging problems in machining efficiency.

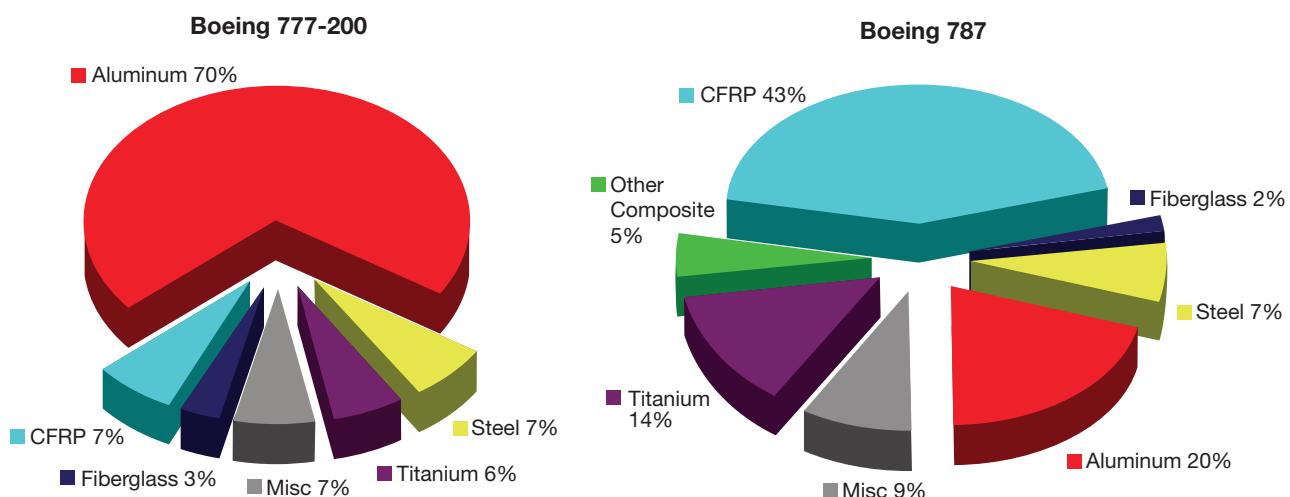
Aerospace technology comprises both air (commercial and military) and space (satellites and exploration) travel. All markets are experiencing substantial growth. The Boeing Company is forecasting a \$2.6 trillion new commercial airplane market over the next twenty years. This represents 27,210 total planes, whereas Toulouse, France-based Airbus is forecasting a similar market value with fewer, 22,700 - - but larger aircraft. These airplanes will be necessary over the next twenty years to accommodate a forecasted 4.9 percent annual increase in passenger traffic and a 6.1 percent increase in air cargo traffic. Much of this growth is being driven by the Mideast and Asian, and in particular the emerging markets such as China and India, where the arrival of low-cost airlines is set to multiply growth in air travel among the expanding middle class. This strong market demand for new airplanes will lead to a world fleet with significantly improved environmental performance – lighter weight – better fuel efficiency.

On the military side, one of the largest aerospace projects is the international Joint Strike Fighter (JSF) a supersonic multi-role stealth fighter led by Lockheed Martin and includes Northrop Grumman, Pratt & Whitney, General Electric, and Rolls-Royce. The JSF will be the most powerful single-engine fighter ever built and will be used to replace aging fighters for both the U.S. and the U.K. More than 2,593 aircraft will be produced in several variations. The concern for fuel efficiency is in the minds of the military. The U.S. Air Force accounts for more than half of all the fuel the U.S. Government consumes. In fiscal 2005, the Air Force used 3.2 billion gallons of aviation fuel or 52.5% of all fossil fuel used by the government. The Air Force bill for jet fuel last year: over \$4.7 billion. Although the federal government and military account for only 1.7% of total national energy consumption, every increase of \$10/ barrel, drives up costs by \$600 million per year.



## Groundbreaking Advanced Materials

Boeing's 787 Dreamliner and the Airbus A380 have attracted great attention for the use of groundbreaking advanced materials. The new generation of aircraft will witness the transition from mostly metal structures to new advanced composites in combination with high performance metal alloys. During June of 2006, The Boeing Company began assembly of its latest airplane, the 787 Dreamliner, a mid-size, twin-engine jet that will use 20 percent less fuel than today's mid-size planes. To achieve this goal, new light weight, high strength-to-weight ratio materials are being incorporated into both the airframe and interior components. As much as 50 percent of the primary structure, including the fuselage and wings, will be made of composite materials. Another 15 percent of key components will be titanium, twice the amount used in previous generation aircraft. Titanium and composites resist corrosion, require less maintenance than aluminum, and will help the 787 consume less fuel. In addition, titanium is a better choice than aluminum in some applications because it is more compatible with composites thus avoiding corrosion problems that occur due to galvanic reaction with the carbon fibers in the composite structures.



## CHALLENGES IN MACHINING ADVANCED MATERIALS

New advanced materials impose demanding challenges on current machining systems, particularly on the cutting tools.

### Titanium

Titanium brings tremendous properties to aircraft design and manufacturing – light weight, great stiffness, strength, heat and fatigue-resistance. In the new generation aircraft, the amount of titanium is increasing in high-strength, complex, monolithic components that join composite sections, high-stress landing gear, and high-temperature engine applications. With the anticipated demand,



it is estimated that production will require more titanium-machining capacity than currently exists worldwide! Therefore, there is a critical need to improve machining efficiency.

## New Grade of Titanium to be Used

While Ti-6Al-4V has been the standard for the industry, Ti-5553 (Ti-5Al-5V-5Mo-3Cr) will be used in a number of key component parts. Titanium alloy 5553 is a near-beta alloy that exhibits excellent hardenability characteristics with superior strength combined with high fracture toughness and excellent high cycle fatigue behavior properties compared to Ti-6Al-4V. As a result of these properties, Ti-5553 forgings will be used in highly loaded parts such as flap tracks and pylon or landing gear applications.

### *Comparison of Ti-6Al4V and Ti-5Al-5V-5Mo-3Cr Material Properties*

<b>Material Properties</b>	<b>Titanium 6Al4V</b>	<b>Titanium 5Al5V5Mo3Cr</b>
Heat Treat	Mill Annealed	BASCA ( Beta Annealed Slow Cooling Aged )
Density (lbs/in <sup>3</sup> )	0.16	0.169
Ultimate Tensile Strength (KSI)	134	160
Strength/Density (lbs/in <sup>3</sup> )	838	947
Fracture Toughness	60-85	70
Hardness (Rc)	36	35
Average MRR (Metal Removal Rate) Finishing	1.0 - 19	1.0 - 4
Tool	5 Flute Carbide 45° TiAlN 1"	8 Flute 40° TiAlN 1-1/4" Carbide and ASAP 2030
SFM	190	60-90
Feed (IPM)	13 - 20	5
Axial Depth-Of-Cut	100%	100%
Radial Depth-of-Cut	0.010"	0.005"-0.010"
Tool Life in Minutes	160	120-140
Average MRR (Metal-Removal-Rate) Roughing	29-54	28-50
Tool	4 Flute Carbide Unequal Index TiAlN 1"	8 Flute Cobalt Fine Pitch Rougher TiCN 2"
SFM	160-180	55-60
Feed (IPM)	10	3.0-5.0
Axial Depth-Of-Cut	50-75%	30%
Radial Depth-of-Cut	100%	100%
Tool Life in Minutes	60-120	100-140

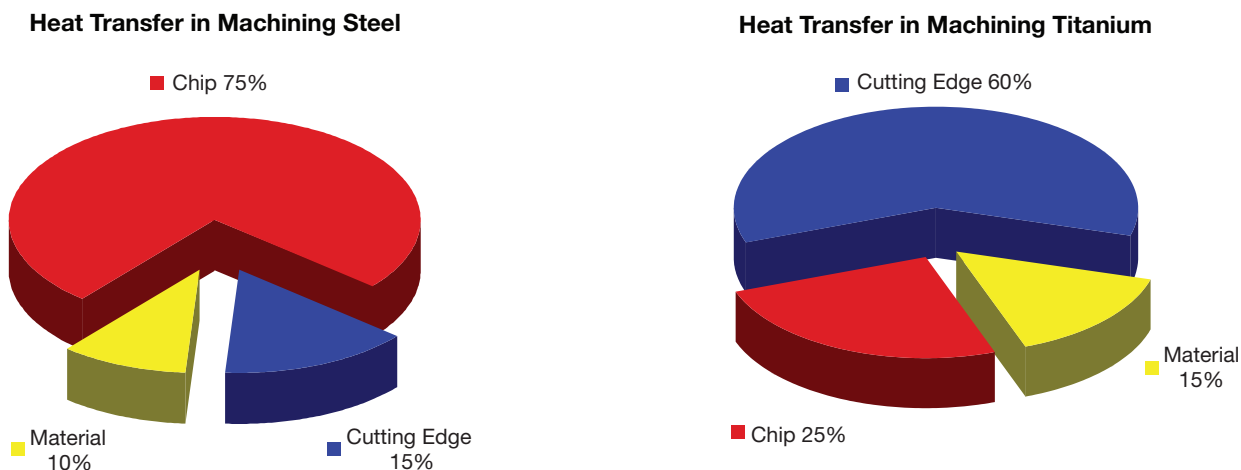
## Machining Challenges

The inherent properties of titanium and the challenges they present for efficient machining have been well documented over the years. Milling titanium is different from other metals because of the risk of heat build-up. Titanium is generally machined at slow speeds and low feed rates with less than 30% radial and low axial depths-of-cut. As a result, the cost of machining titanium can be as high as 10X that of conventional machining of aluminum. As shown in the above material properties chart, while Ti-5553 has superior properties to Ti-6Al-4V, it appears to be more difficult to machine.



### *Thermal Conductivity:*

Titanium is a very poor heat conductor. As the pie charts indicate, thermal conductivity characteristics between steel and titanium differ greatly when comparing the heat imparted to the workpiece versus the chip.



With steel-based components, more than 75% of the heat generated by the cutting process is transferred to the evacuated chip, whereas with titanium-based parts, only 25% of the heat is transferred to the chip, thus creating a greater heat concentration on the cutting edge of the tool. This condition of course leads to more rapid tool failure or diminished productivity due to the slower cutting speeds required to address the heat generation problem. The solution is heat resistant solid carbide and effective coolant.

### *Low Modulus of Elasticity*

Low modulus of elasticity leads to a “springiness” characteristic whereby titanium parts may move under the force of the cutting edge—and then spring back. This condition can lead to accuracy problems. The solution lies in proper tool geometry (primary and secondary relief angles and helix angle) and cutting tool edge preparation.

### *Work Hardening Tendency*

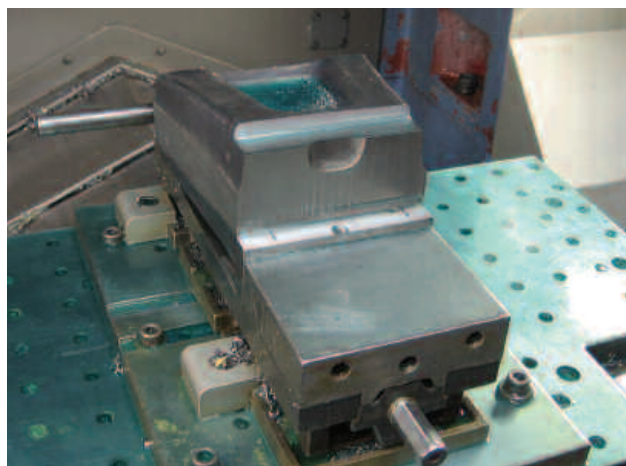
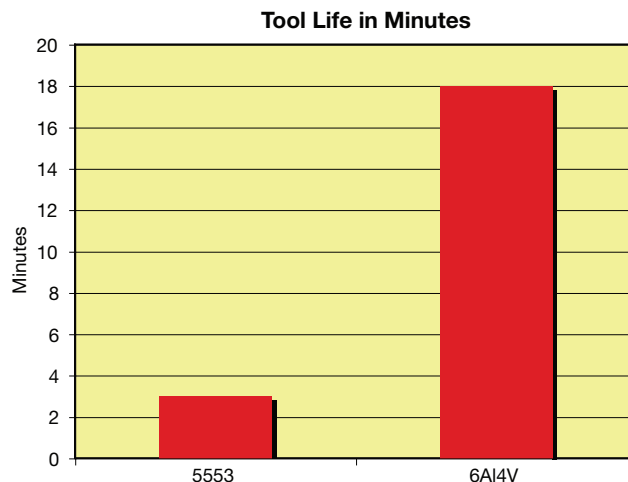
Work hardening tendency in forged parts impose challenges with very hard, at times non-homogeneous surfaces, resulting in high cutting pressures and excessive heat generated. The resulting high cutting pressure, heat generation and undesirable thin, fanfold chips. The solution is machine tool and software capability that eliminates tool dwelling.

### High Chemical Reactivity

High chemical reactivity can lead to chemical reaction and an undesirable diffusion reaction at the tool/workpiece interface leading to premature tool wear. The solution is the use of thin film coatings that act as a heat barrier.

### IN-HOUSE TESTING

To develop optimum tools and operating parameters to machine Ti-5553, extensive testing at Niagara Cutter's machining laboratory located in the Reynoldsville, PA production facility has taken place on actual forging samples. This project started last year and is currently an ongoing development project.



*Ti-5553 Forging Sample; showing "skin" and as fixtured in Mazak milling machine for machinability testing*



*Mazak milling machine with Dennis Noland (Tool Designer), Yair Bruhis (Application Engineer) and Kevin Harriger (Machining Testing Laboratory Technician) discussing testing operating parameters.*



*Ti-5553 Machinability Testing; Determining Range of Operating Parameters*



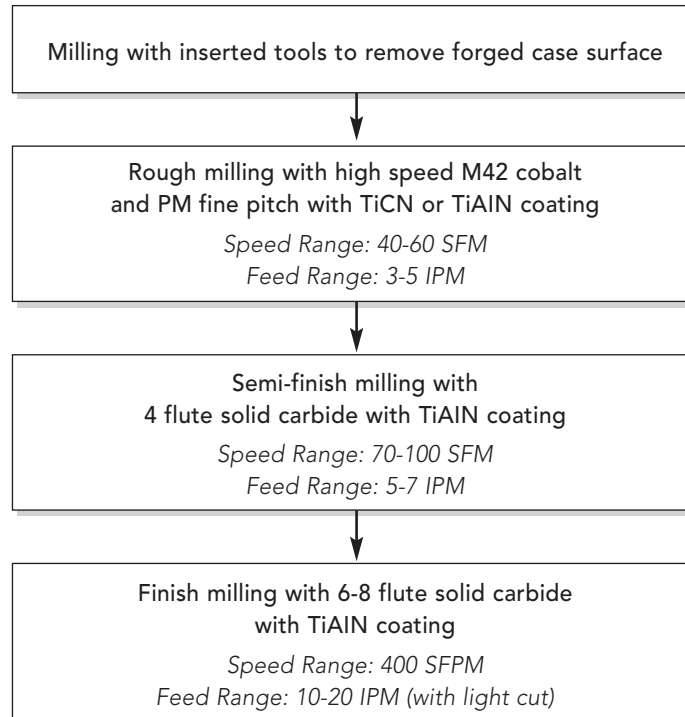
*Yair Bruhis Monitoring Tool Wear During Machining Tests*



## RESULTS TO DATE:

As a result of both in-house and on-site customer evaluations, the following are the early stage results on how best to machine the new generation of Ti5553 components:

### *Process Flow Diagram for Machining Forged Ti5553 Components*



## MACHINING APPLICATION PROCESS (MAP®)

Some of the factors Niagara Cutter considers during the MAP® for new application challenges such as Ti5553 are:

### *Tool Geometry Design*

When it comes to the design of the cutting tool for machining Titanium both the Low Heat Transfer Rate and the Low Modulus of Elasticity must be taken into consideration. To combat these constraints, High Shear Geometry must be incorporated. Both Higher Helix and Radial Rake angles combine to create a Higher Effective Cutting Rake or shear plane. This Higher Effective Cutting Rake generates a Higher Chip Forming Deformation Plane, which will reduce the pressure required to make a chip. This reduced pressure will lead to reduced temperature generated and less pushing of the Titanium part while machining.



Since most aircraft parts made from titanium are large structural parts, large amounts of material must be removed to get to the finished part size and weight. This dictates that a large part of the machining process is dedicated to rough machining, with large tools, to remove this excess material. This can be done cost effectively with the use of large diameter fine pitch cobalt roughing end mills with TiAlN coating. The fine pitch configuration leads to a more narrow but thicker chip being generated. This thicker chip retains more of the heat generated in the chip itself, thus helping the tool maintain a longer operating life. By increasing the helix angle and the radial rake angle, greater efficiency can be realized. Even though the tools run at a much slower speed, large amounts of tool engagement can be employed due to the shock resistance of the HSS cobalt substrate.

#### *HSS, HSCO vs Carbide Tool Substrate Material*

Because Titanium has a very Low Heat Transfer Rate, heat resistance becomes a major concern when developing tooling designs for machining applications. Starting with the selection of the base substrate material for the cutting tool, heat resistance is of primary concern. As in most materials technologies, trade-offs in properties comes into play. HSS substrates, which contain Cobalt, provide excellent heat resistance. In addition, Particle Metallurgy (PM) offers more uniform heat and wear resistance and can add to the machining run time of the cutting tool. Carbide substrates give much higher heat and wear resistance; however they are susceptible to shock because of their high hardness. For finishing operations, carbide substrate is the material of choice. In finish machining there is only a small amount of material to be removed. Because of this the chips will be shorter and very thin and not have enough mass to retain the heat generated. End mills with carbide substrates can withstand much higher temperatures than end mills with HSS Cobalt, but they are more susceptible to shock. This dictates that the carbide finishing tool be of a high shear design typically in the 40 to 45 degree helix range. The higher helix will lead the cutting edge into the work piece at a higher plane reducing the impact shock. It also increases the Chip Forming Deformation Plane reducing pressure and heat generation. Newer variable geometry tool designs like the Niagara Stabilizer HT™ Series Carbide End Mills allow for greater engagement into the work piece while reducing vibration and shock.

#### *Cutting Edge Considerations – Preparation*

Considerable progress has been made during the last few years on further understanding the impact of preconditioning the tool cutting edge prior to the coating operation. The proper cutting edge geometry can aid in providing a more predictable break-in period with reduced chatter. Special cutting edge preparation, to slightly round off the sharp edge, can be key in reducing chipping of the carbide due to the shocks encountered during the machining process.



### *The Significant Impact of PVD Coatings*

For over twenty years Niagara Cutter has applied highly engineered PVD and CVD coatings in-house to obtain the numerous benefits that have been widely documented in the literature. Coatings greatly increase the performance of cutting tools by providing a wear resistant, low friction, non-reactive barrier to the challenges of machining operations with difficult to machine workpiece materials. The coatings can serve as an inert surface to reduce chip welding and act as a thermal barrier to reduce heat transfer. The typical coatings used for machining Titanium are: TiAlN, AlTiN, and a newer AlCrN coating. Each has excellent heat resistance and thermal stability.

### *Coating Surface Enhancement*

A relatively new development has been the significant improvement in coated tool performance by further treating the coated tool surface. The unique technology Niagara Cutter utilizes provides for better chip flow characteristics with resulting improvements in workpiece surface finish and tool life.

### **Stainless**

Improved stainless steel materials, such as Custom 465 and Project 70+15C5-5Ni are being used in structural components such as flap tracks, slat tracks, engine mounts, and landing gear hardware. Custom 465 has higher strength and better corrosion resistance than PH17-4, 15-5, and 13-8. Niagara Cutter is also currently performing machining tests on this material and results will be reported in a future article.

### **CRPF (Carbon Reinforced Polymer Fiber)**

Unlike any other commercial aircraft, almost 50% by weight of the 787 structure is made of advanced composite materials. Carbon composite materials are extremely strong yet lightweight and very corrosion resistant. They are resistant to fatigue that eventually causes metal structures to weaken and crack. However, milling CRPF is difficult. The material is tough and abrasive. This material is also undergoing machining analysis by Niagara Cutter. The best way to machine this material is with a unique tool geometry with a CVD diamond coating. Again, this development work will be reported on in a future article.



## NIAGARA CUTTER UP TO THE CHALLENGE

*A problem-solving partner to the aerospace industry*

Since 1954 N. C. Industries, Inc. has been providing innovative solutions to the latest machining challenges. Based in Amherst, New York with Niagara Cutter plants in Reynoldsville, PA, Athol, MA and a subsidiary, Diamond Tool Coating, in North Tonawanda, NY, the company fully utilizes their Machining Application Process (MAP®) to provide specific solutions to particular workpiece materials and required machining operations. This means, tool design with optimum geometries, engineered tool substrate materials with pre and post coating surface preparation and finishing techniques, unique in-house thin film wear resistant PVD and CVD coatings, and specific operating parameters are combined to offer the best "system" solution to a specific machining application.

The process optimization begins with machining studies on actual workpiece samples at the machining laboratory in the Reynoldsville, PA tool manufacturing facility, followed by on-site testing by Application Engineers at the customer's facility. The defined tooling system process is then transferred to the customer through intensive application specific training sessions.

To contact N.C. Industries view their Web site at [www.niagaracutter.com](http://www.niagaracutter.com) or call 814-653-8211 and ask for the Application Engineering Department.

