Machining Processes for High-Temperature Aerospace Alloys

James Donnelly and Chris Wade

Technical Consultants within Autodesk Advanced Consulting

Agenda

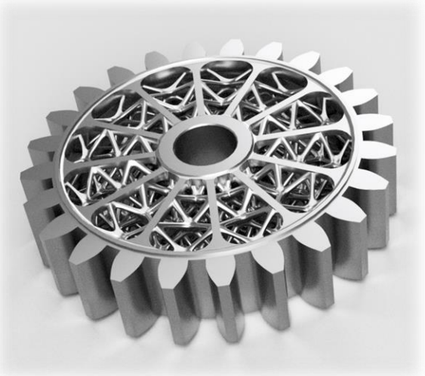
- Who are Autodesk Advanced Consulting?
- An Introduction to Aerospace Materials
- Machining Considerations
- Industrial Case Studies
- James’ Special Surprise

Who Are We?

Who Are We?

- Autodesk Advanced Consulting

AUTODESK.
ADVANCED CONSULTING



- Additive, Subtractive and Composites Manufacturing

- Generative Design, Topology optimization
- Factory Automation & Integration







Materials In The Aerospace Industry

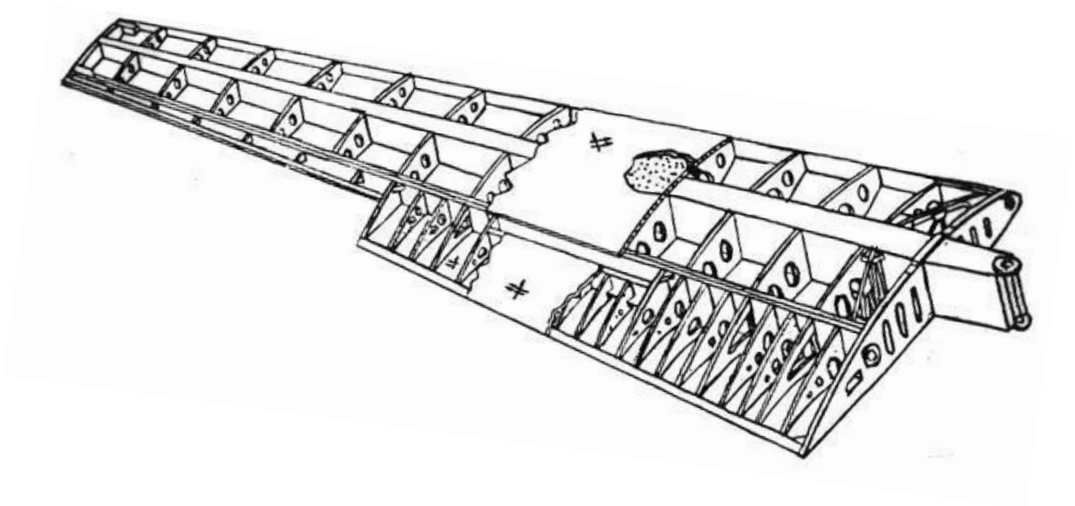
Materials In The Aerospace Industry

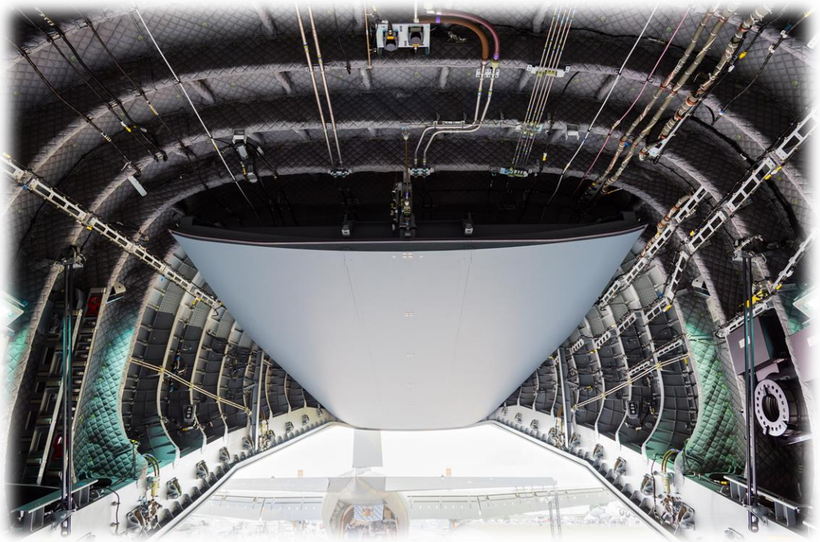
- Material choice and application
- Superalloys and their structure
- Properties of high-temperature alloys
- Machining titanium and nickel alloys

Materials In The Aerospace Industry - Material Choice And Application

- Focus on manufacture for commercial aircraft

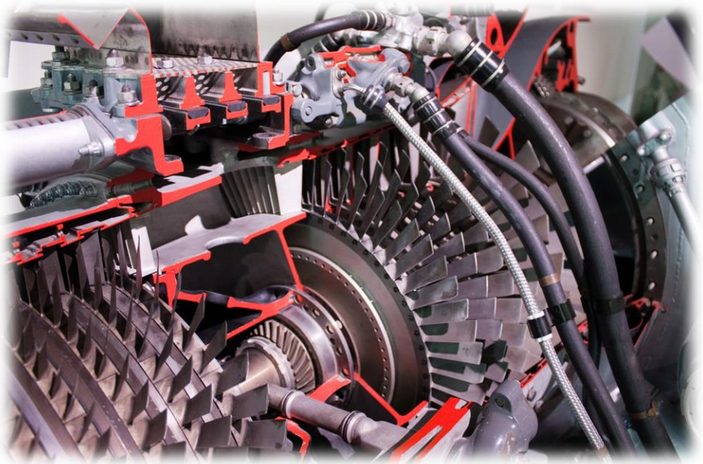
- Need for lightweight materials in aircraft structure





Materials In The Aerospace Industry - Material Choice And Application

- Focus on manufacture for commercial aircraft
- Need for lightweight materials in aircraft structure
- Aircraft engines must be:
  - Able to withstand high forces
  - Able to withstand high temperatures



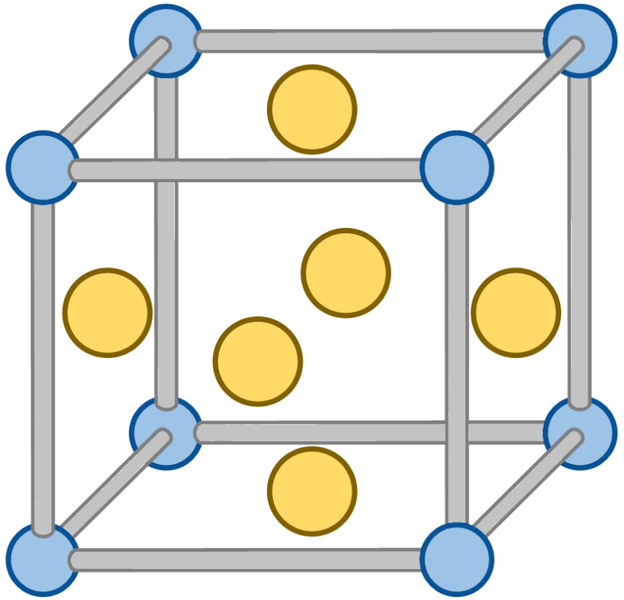
Materials In The Aerospace Industry - Superalloys And Their Structure

- High nickel-content steels and titanium alloys meet these criteria

- These alloys contain a strong crystalline structure

- Nickel

- Aluminium



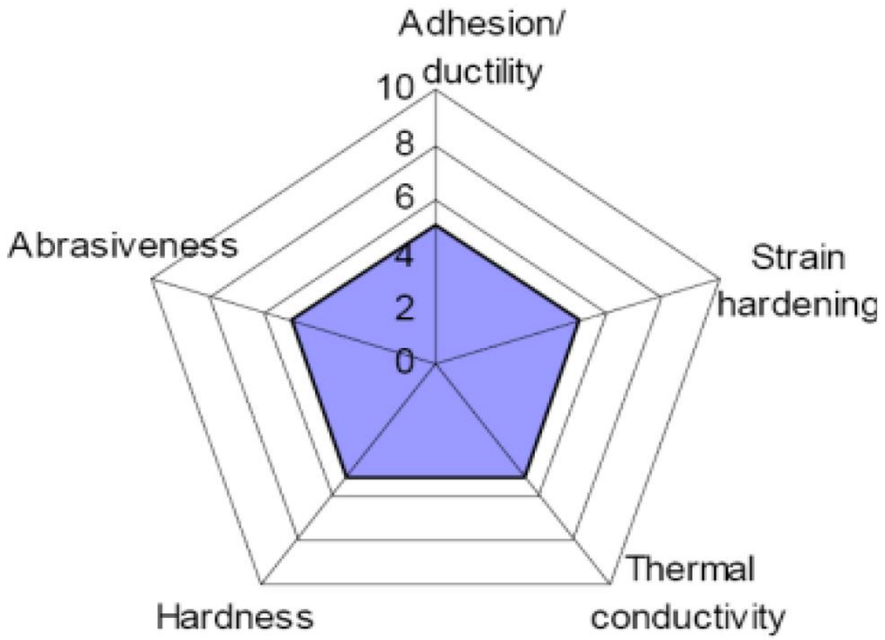
Materials In The Aerospace Industry - Superalloys And Their Structure

- High nickel-content steels and titanium alloys meet these criteria
- These alloys contain a strong crystalline structure
- This structure can change based on how the material was formed

Materials In The Aerospace Industry - Properties of High Temperature Alloys

- A material's properties greatly affect the approach to machining

Machinability properties of the high-grade steel 42CrMo4

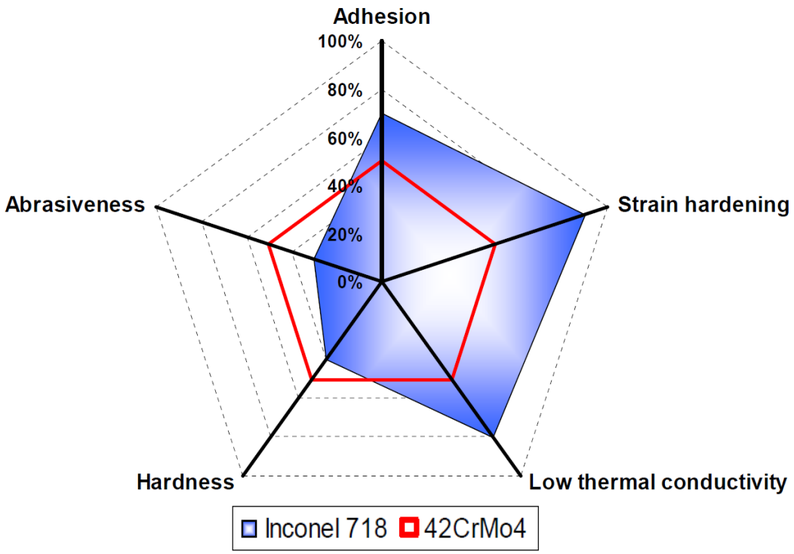


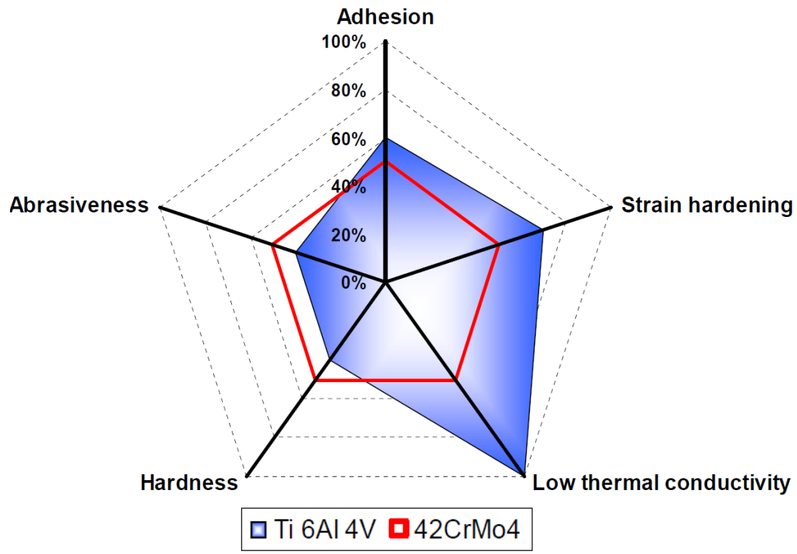
Images courtesy of Seco Tools

Materials In The Aerospace Industry - Properties of High Temperature Alloys

- A material's properties greatly affect the approach to machining

- Compared to steel, superalloys and titanium alloys have:
  - Lower hardness





Images courtesy of Seco Tools

Materials In The Aerospace Industry - Properties of High Temperature Alloys

- A material's properties greatly affect the approach to machining

- Compared to steel, superalloys and titanium alloys have:
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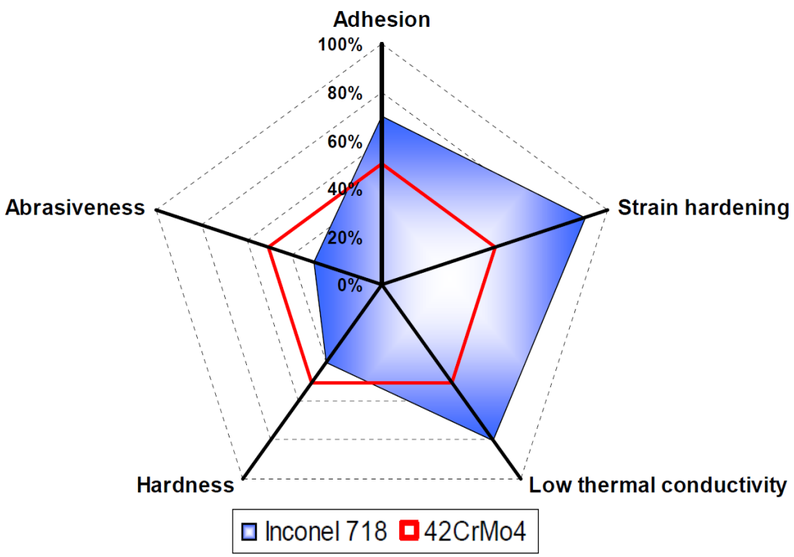
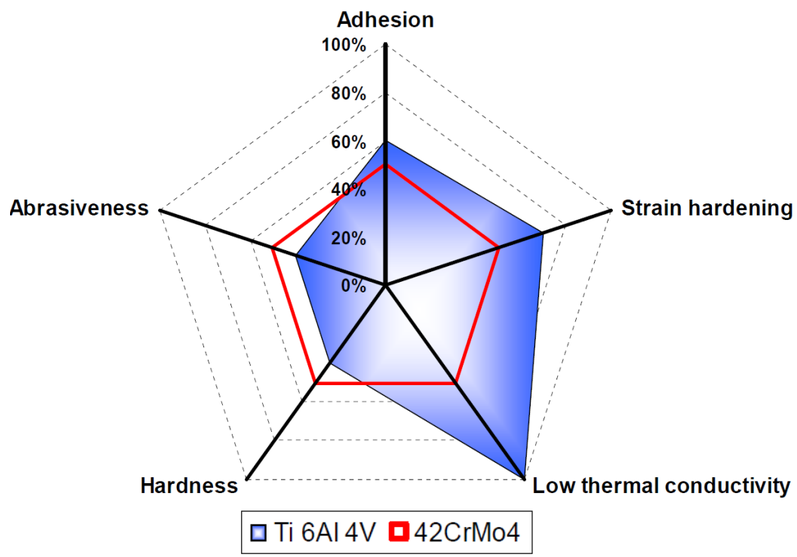
  - Higher resistance to local forces



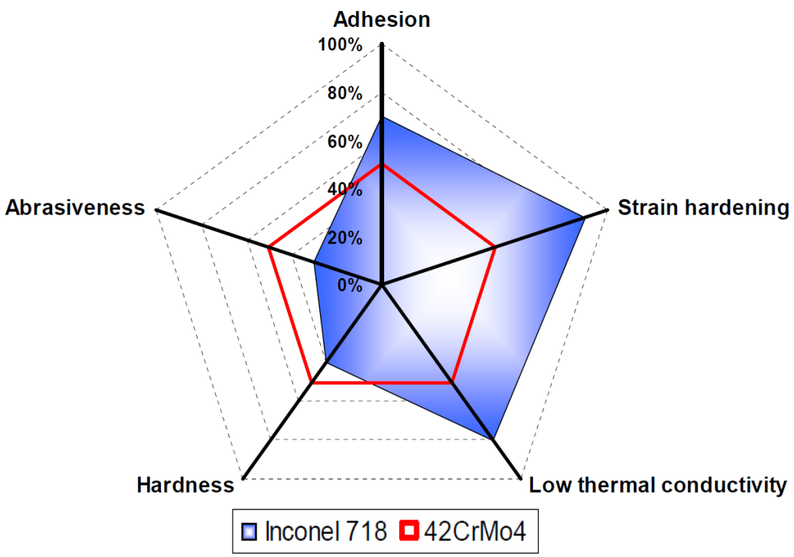


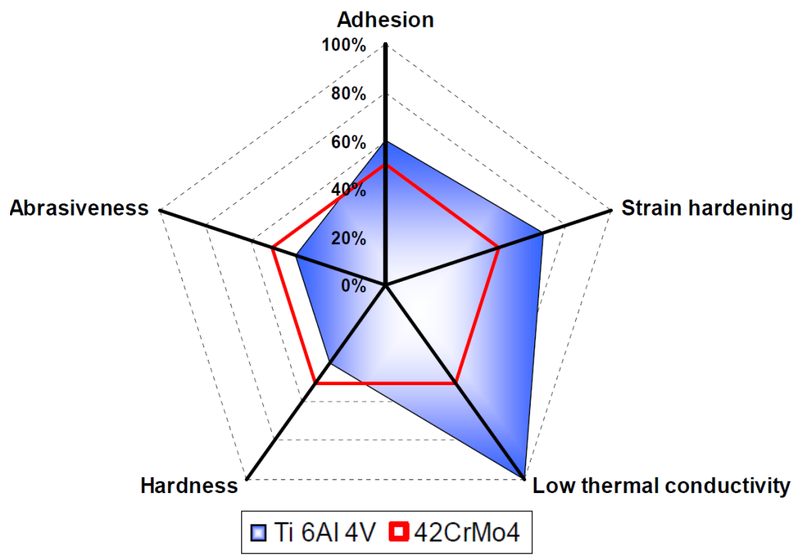
Images courtesy of Seco Tools

Materials In The Aerospace Industry - Properties of High Temperature Alloys

- A material's properties greatly affect the approach to machining

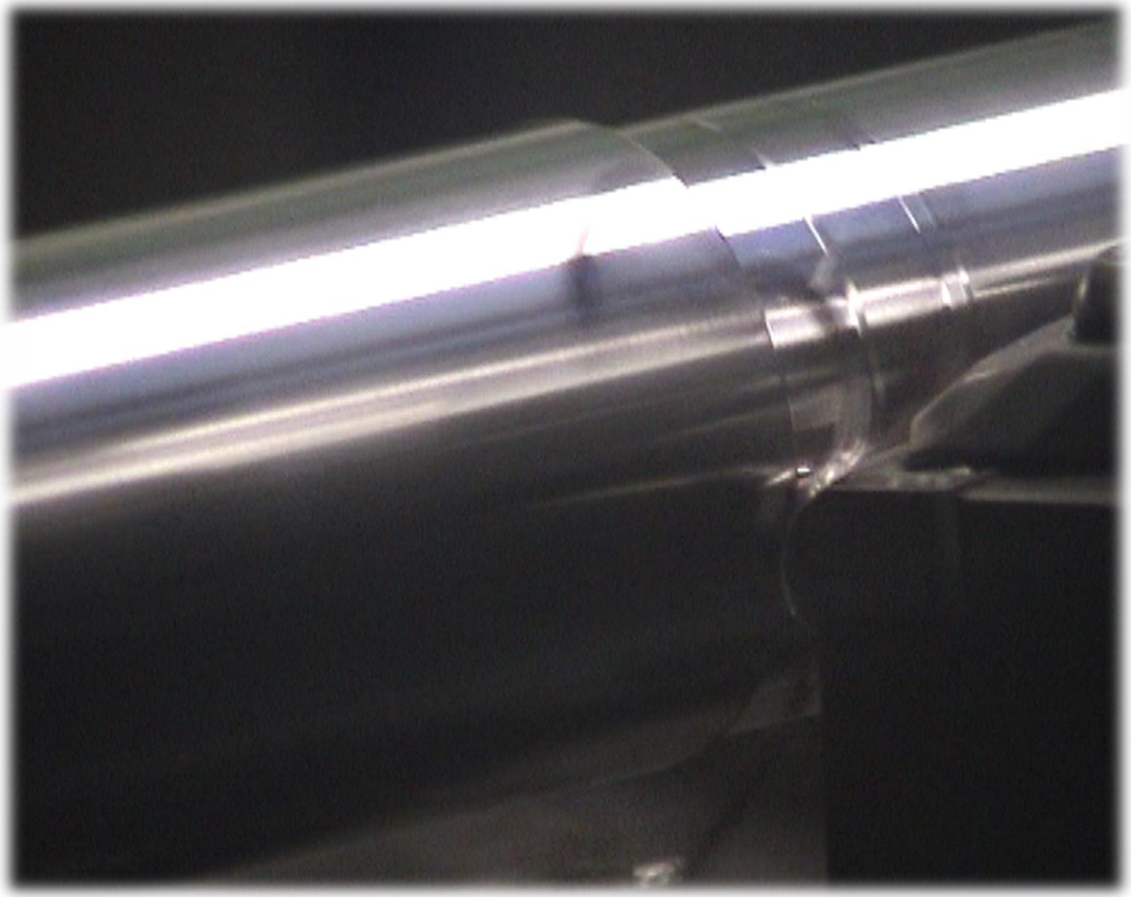
- Compared to steel, superalloys and titanium alloys have:
  - Lower hardness
  - Higher resistance to local forces
  - Lower heat conductivity

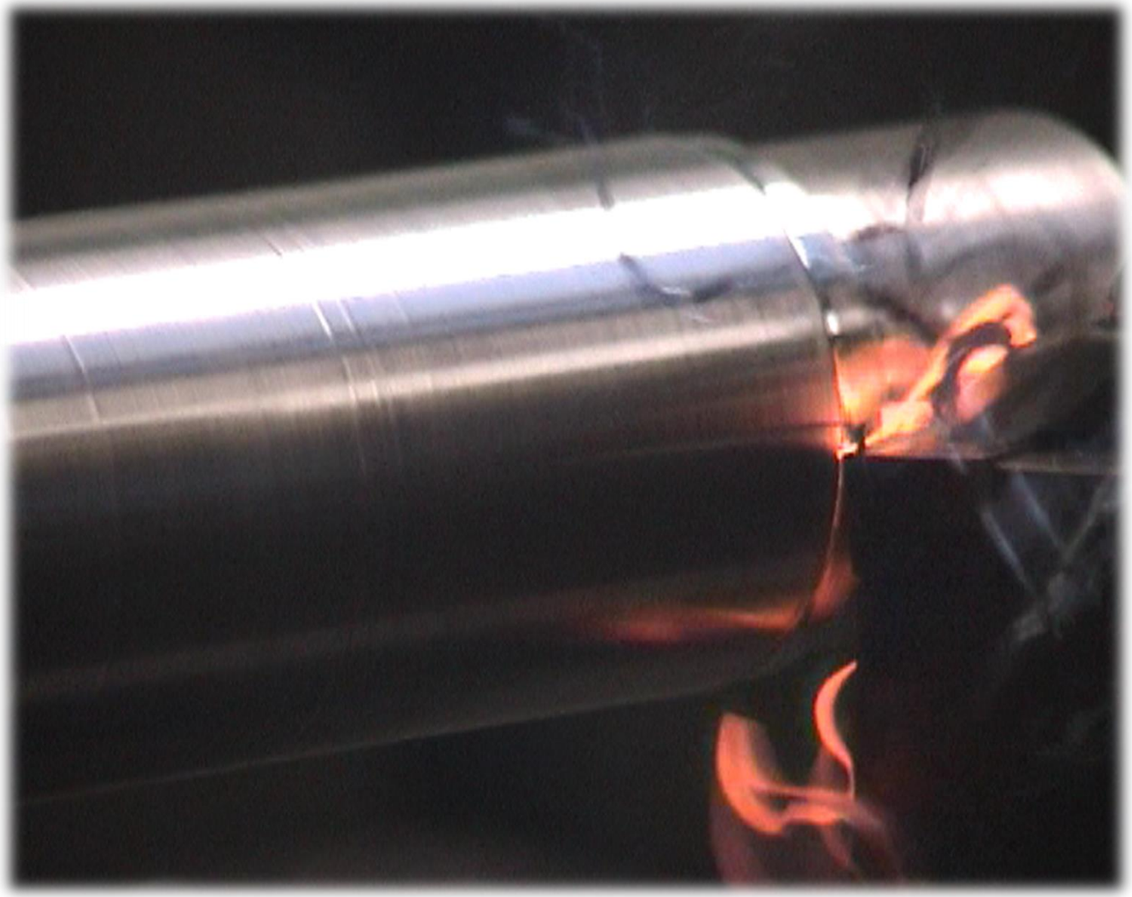




Images courtesy of Seco Toolsc

Materials In The Aerospace Industry - Properties of High Temperature Alloys





Videos courtesy of Dr Richard Hood and Dr Sein Leung Soo
of the Machining Research Group at the University of Birmingham

Materials In The Aerospace Industry - Properties of High Temperature Alloys

- A material's properties greatly affect the approach to machining

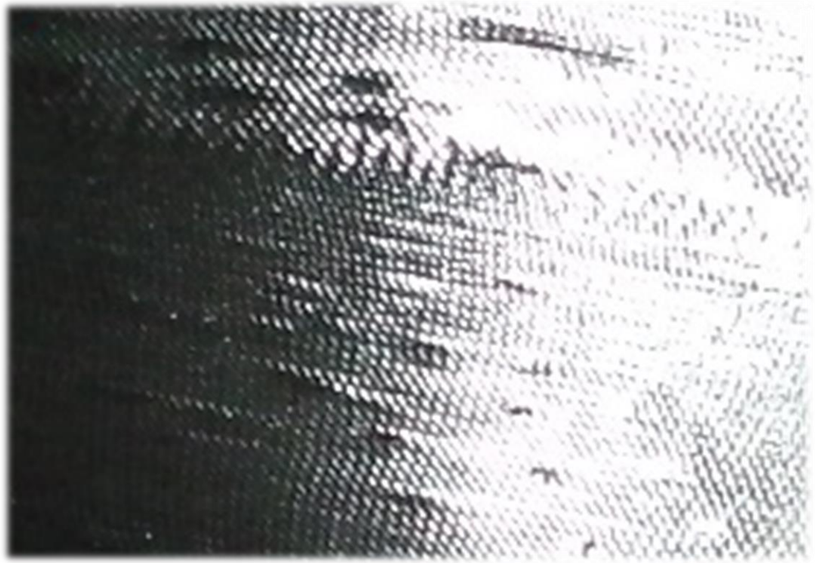
- Compared to stainless steel, superalloys and titanium alloys have:
  - Higher resistance to local forces
  - Lower heat conductivity
  - Lower hardness

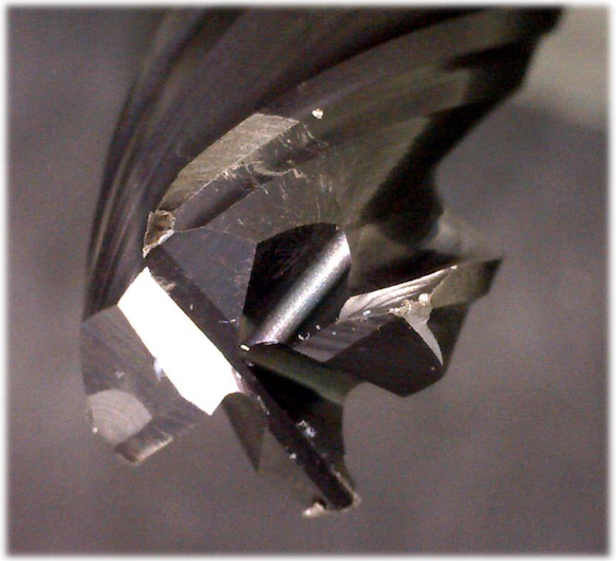
- The approach to cutting must change

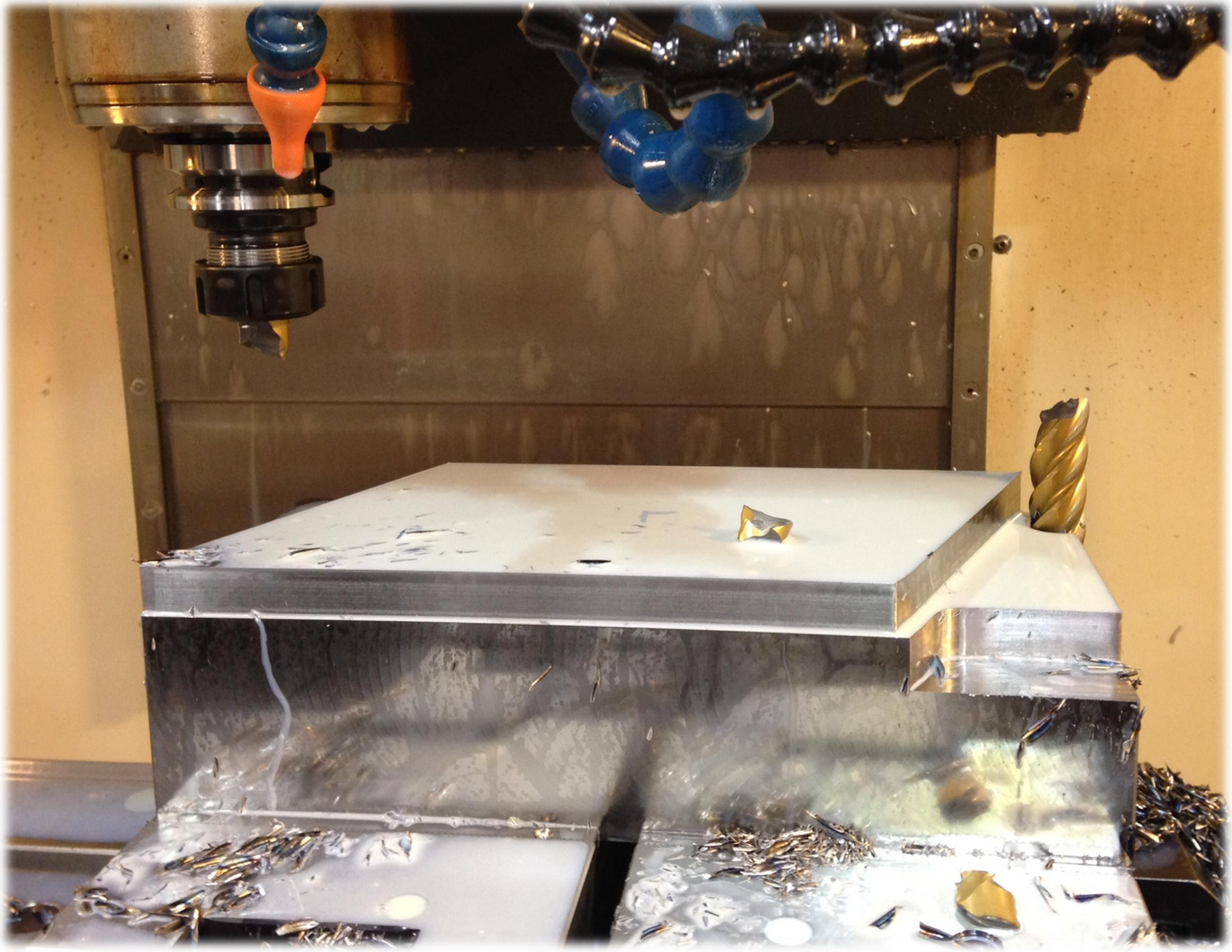
Materials In The Aerospace Industry - Machining Titanium And Nickel Alloys

- Defects or a poor surface finish can drastically reduce efficiency

- Important to use correct cutting tools and machining conditions

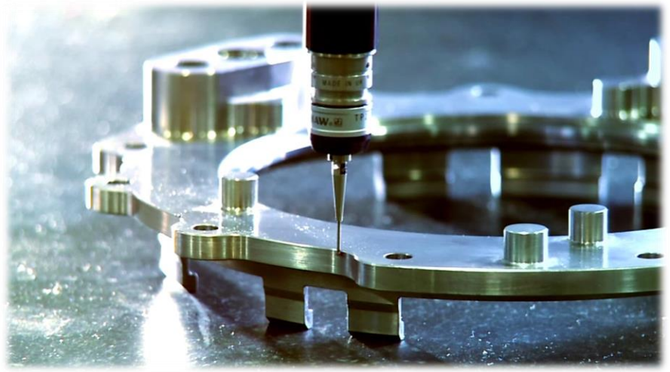


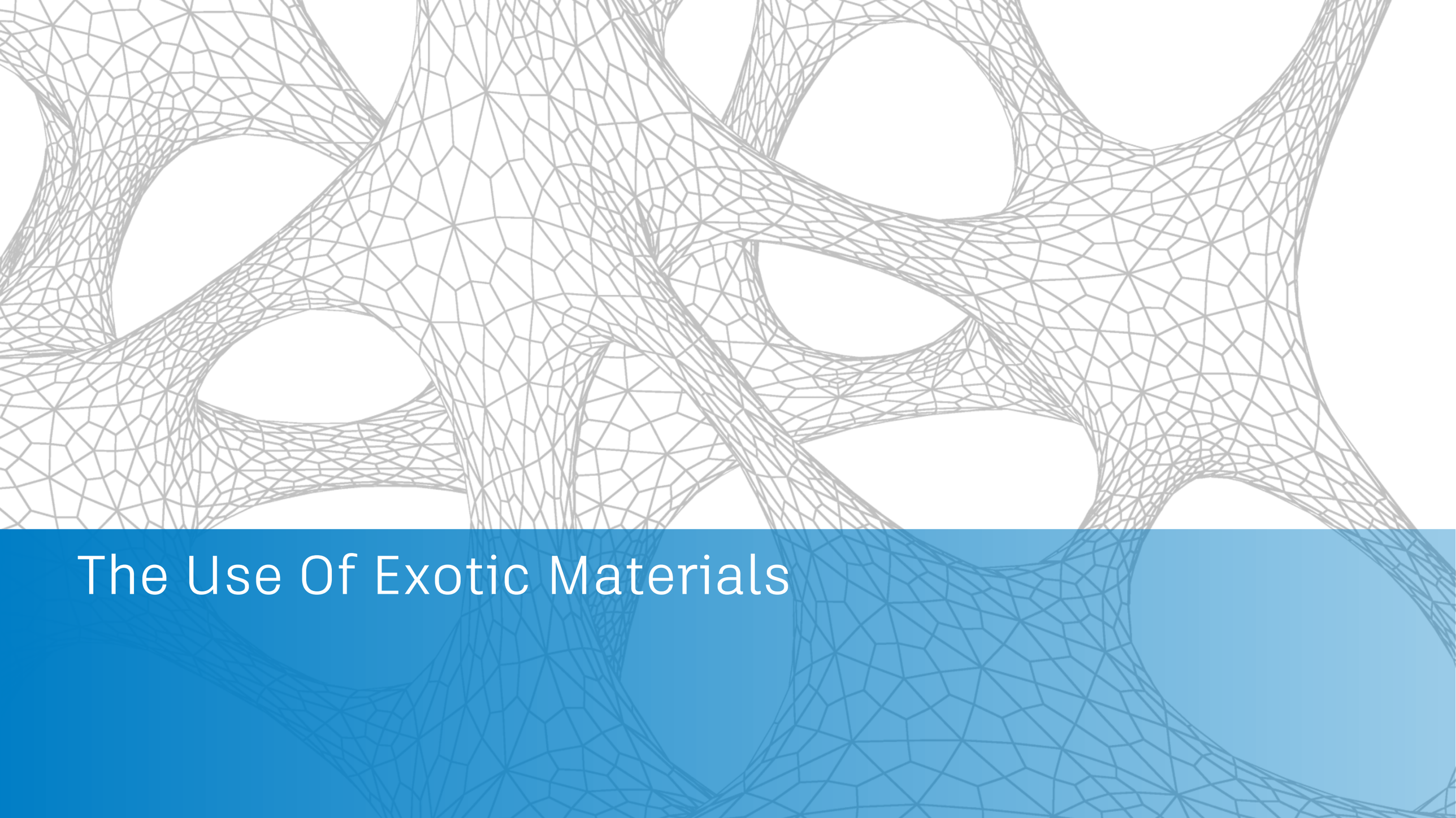




Materials In The Aerospace Industry - Machining Titanium And Nickel Alloys

- Defects or a poor surface finish can drastically reduce efficiency
- Important to use correct cutting tools and machining conditions
- Reducing need for additional processes keeps costs low





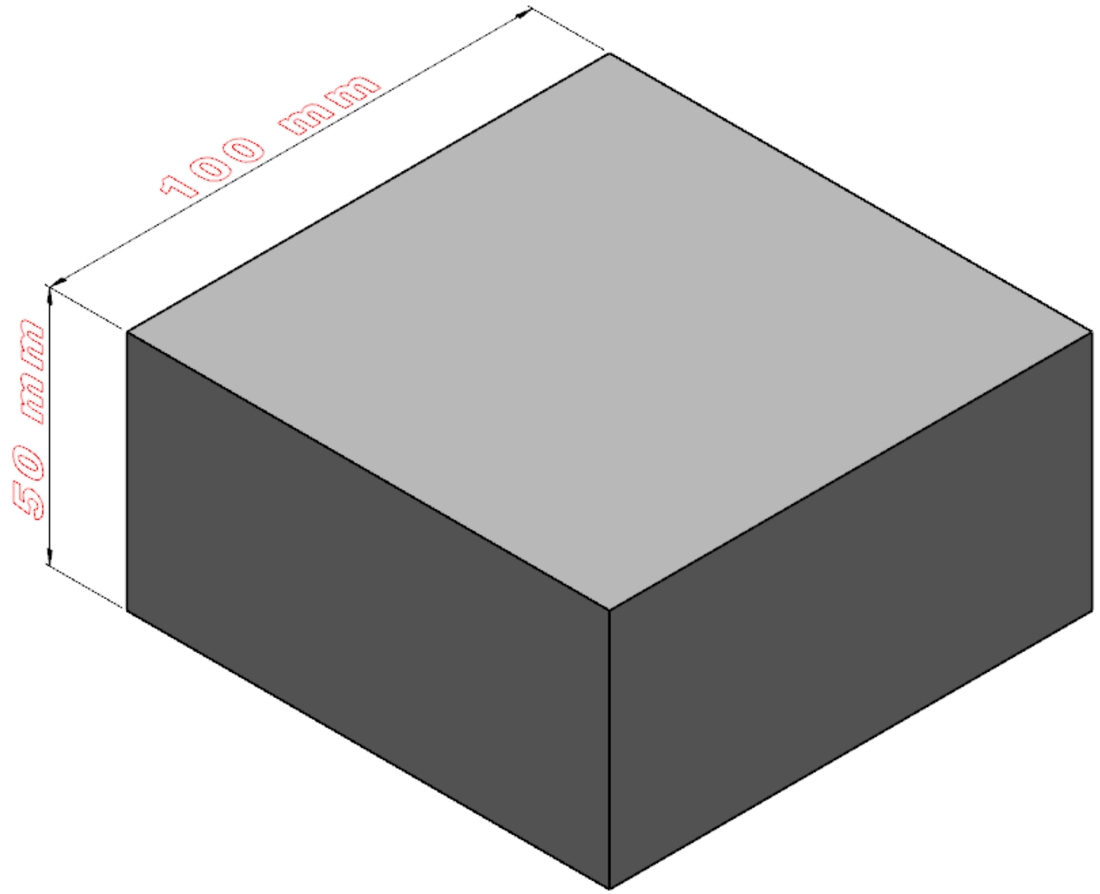
The Use Of Exotic Materials

Cutting Trials – Goals

- How do the materials act with different cutting parameters?
- What effect does the approach have on tool life and surface quality?
- Comparison of the differences in machinability

Cutting Trials - Materials

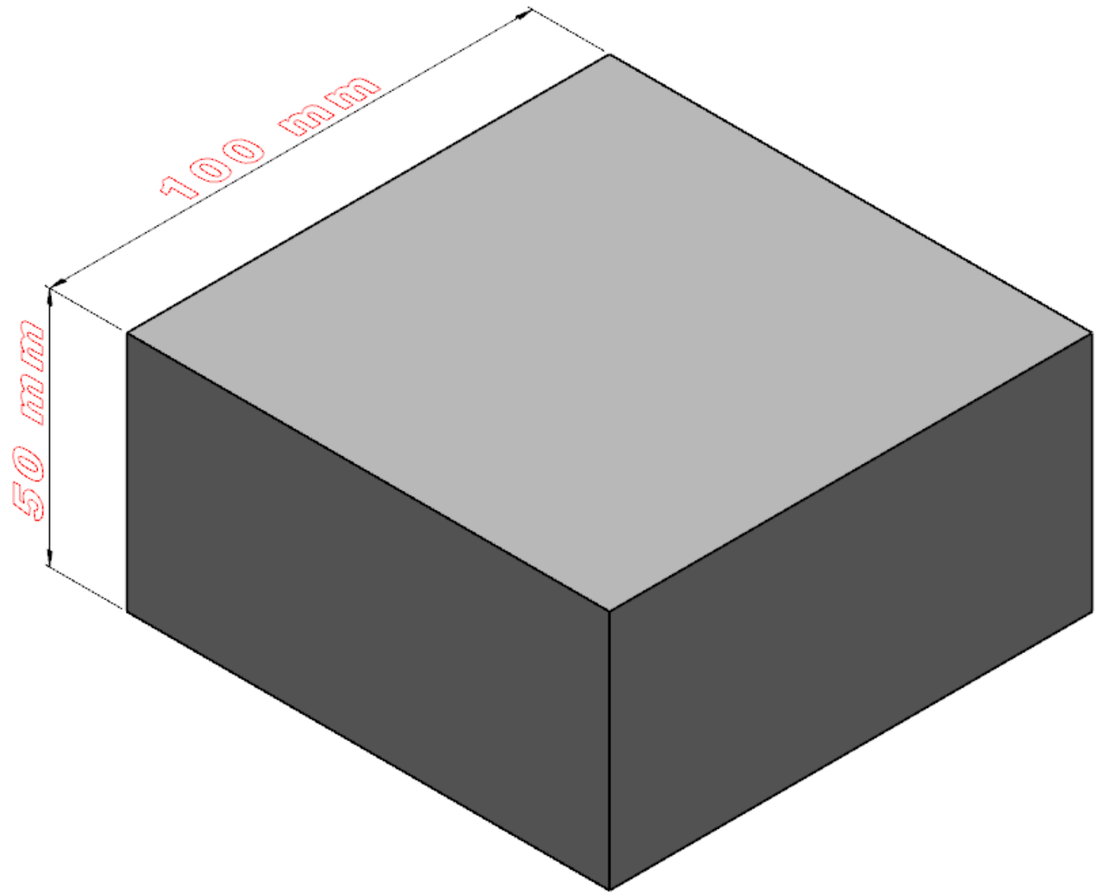
- EN24T Steel



Cutting Trials - Materials

- EN24T Steel
- Titanium Ti6Al4V

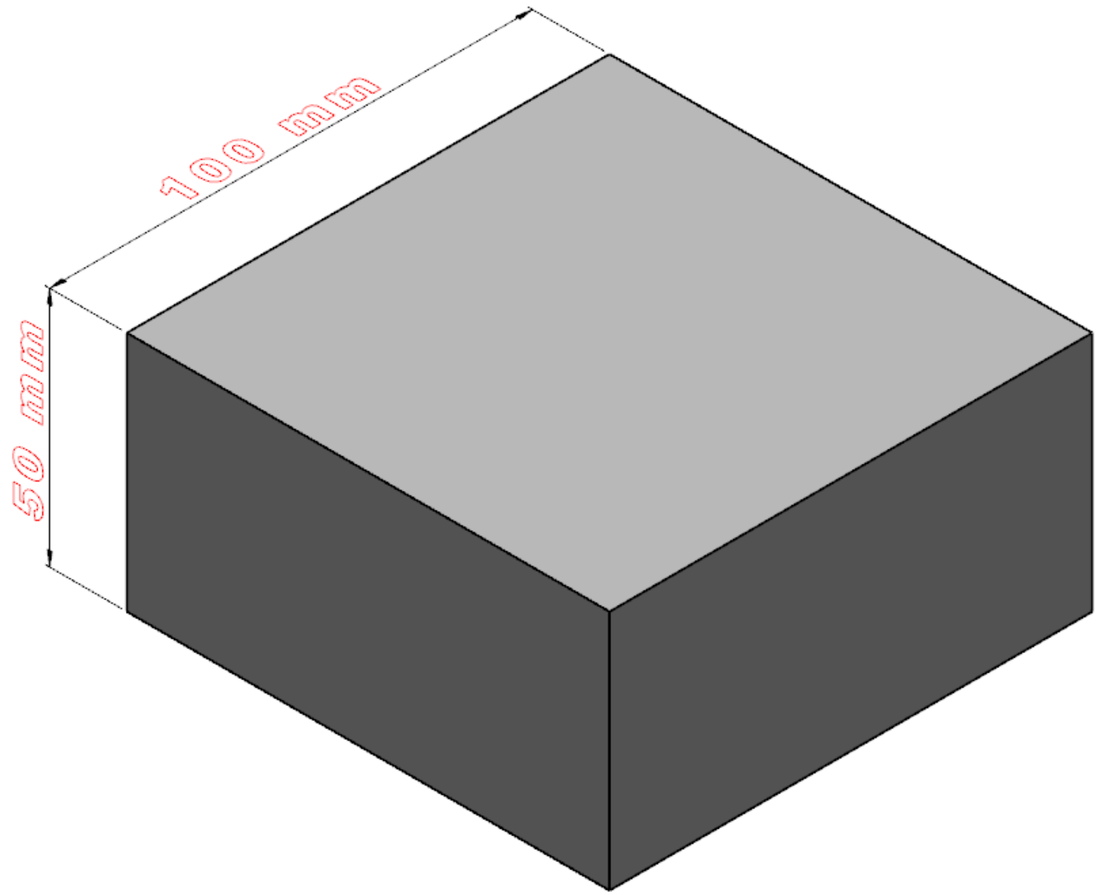
  (6% Aluminum 4% Vanadium)



Cutting Trials - Materials

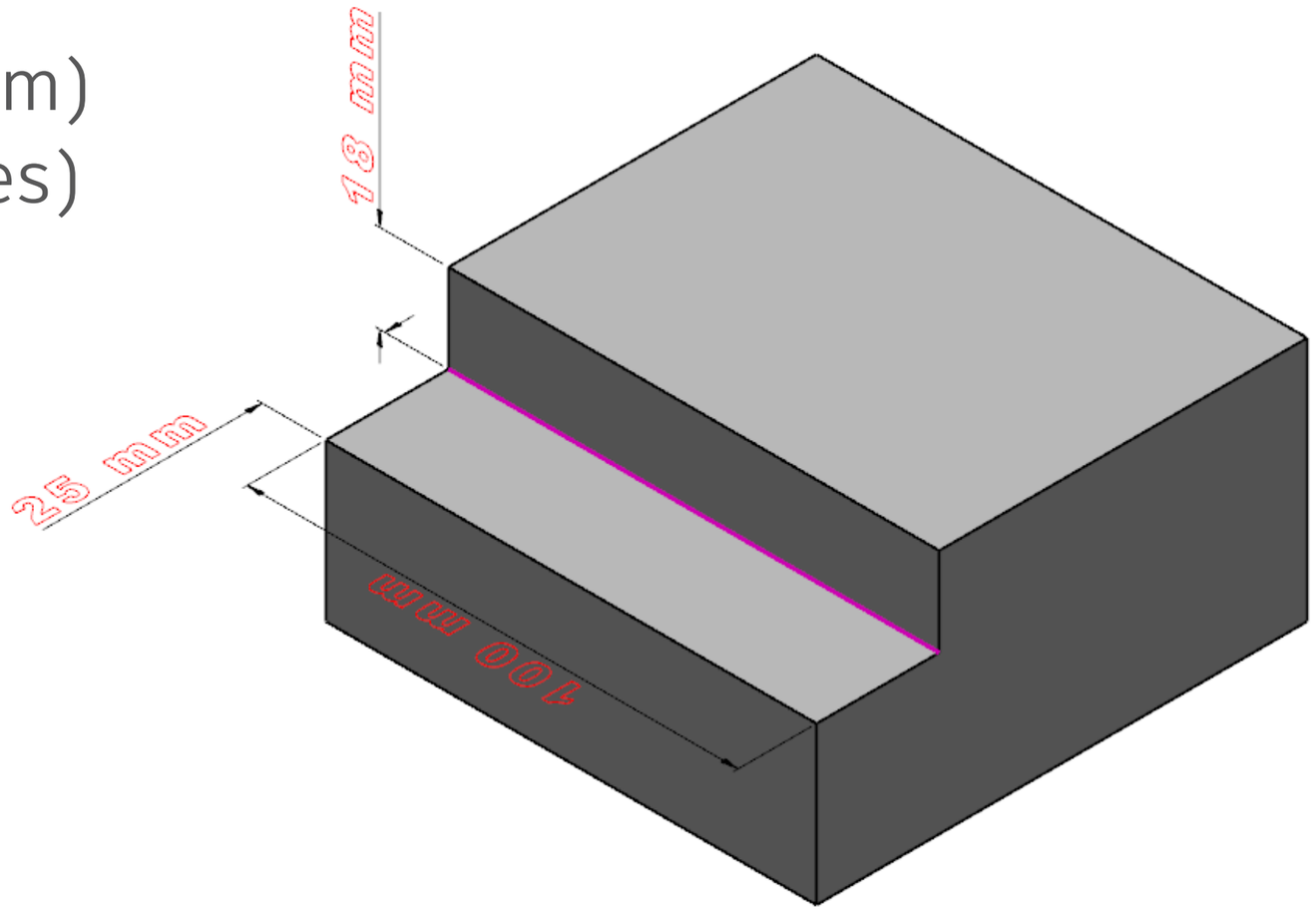
- EN24T Steel
- Titanium Ti6Al4V

  (6% Aluminum 4% Vanadium)
- Inconel 718



Cutting Trials - Method

- Volume - 100 x 25 x 18 (mm)
  - 4 x 1 x 0.7 (inches)



Cutting Trials - Method

- Volume - 100 x 25 x 18 (mm)
  - 4 x 1 x 0.7 (inches)

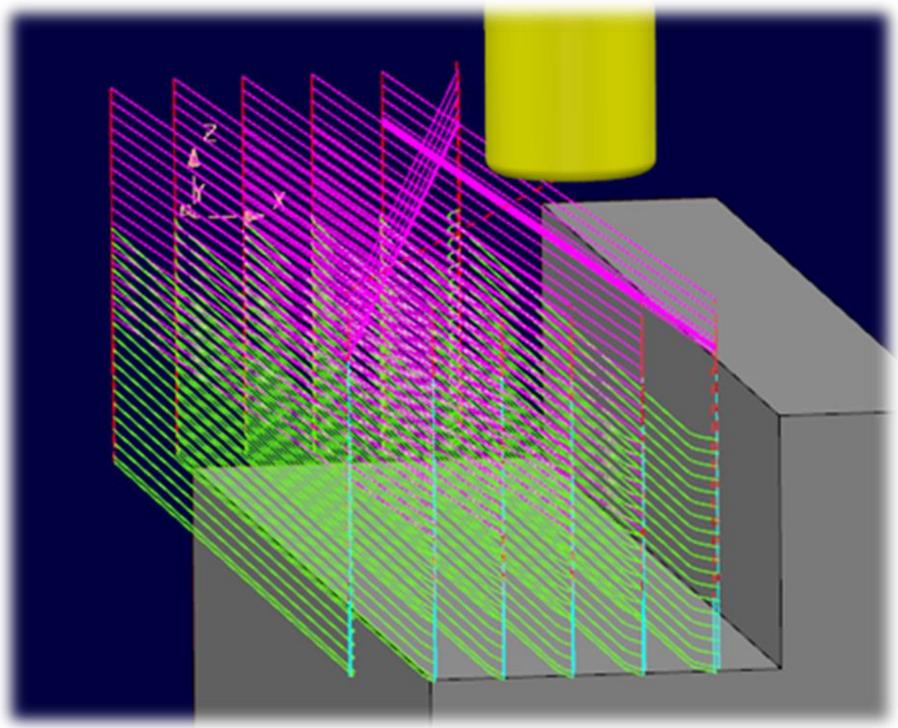
- Tooling – 12mm R1 Z-carb End Mill

Cutting Trials - Method

- Volume - 100 x 25 x 18 (mm)
  - 4 x 1 x 0.7 (inches)
- Tooling – 12mm R1 Z-carb End Mill
- Machine – Huron VX12

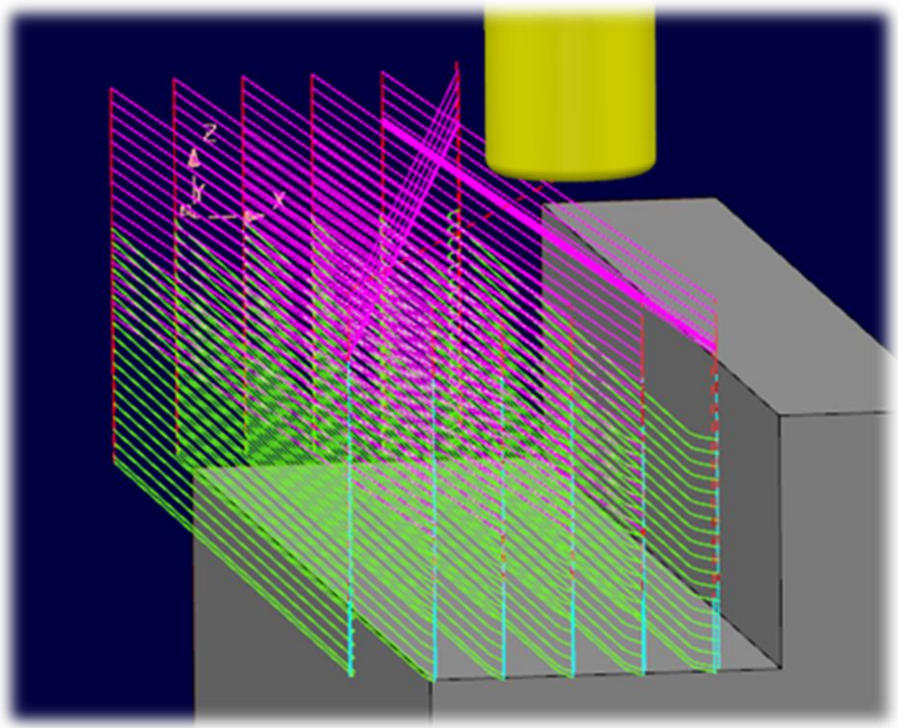
Cutting Trials - Method

- Traditional Method



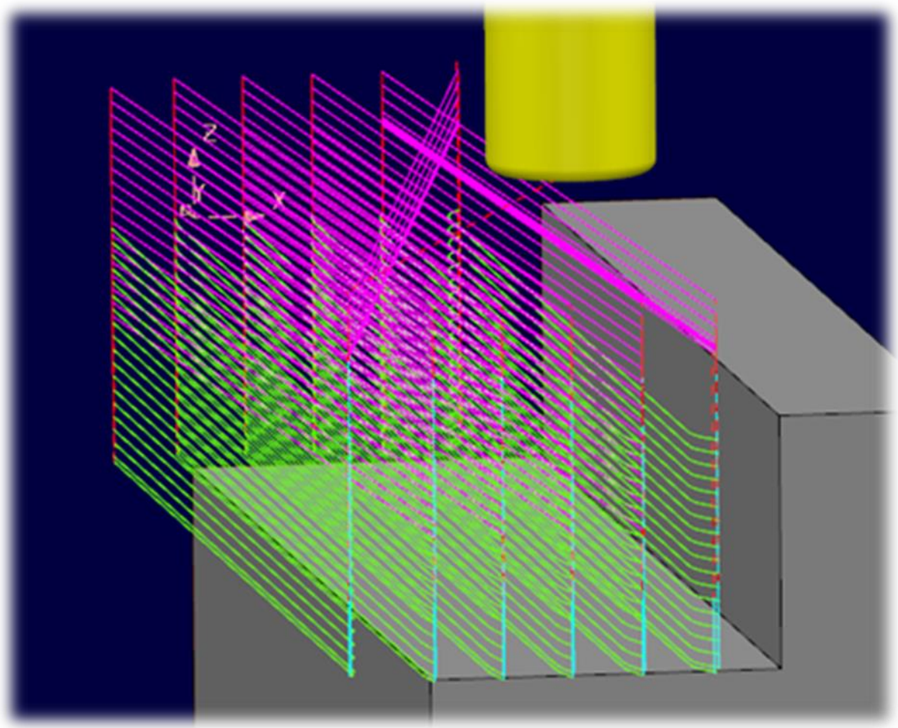
Cutting Trials - Method

- Traditional Method
  - Large Stepover



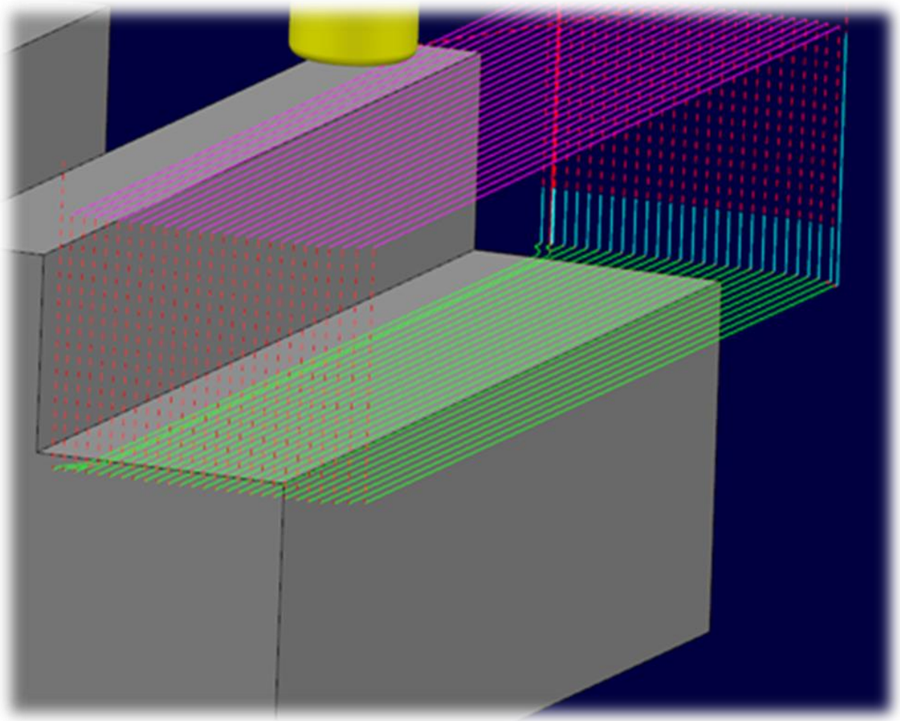
Cutting Trials - Method

- Traditional Method
  - Large Stepover
  - Small Stepdown



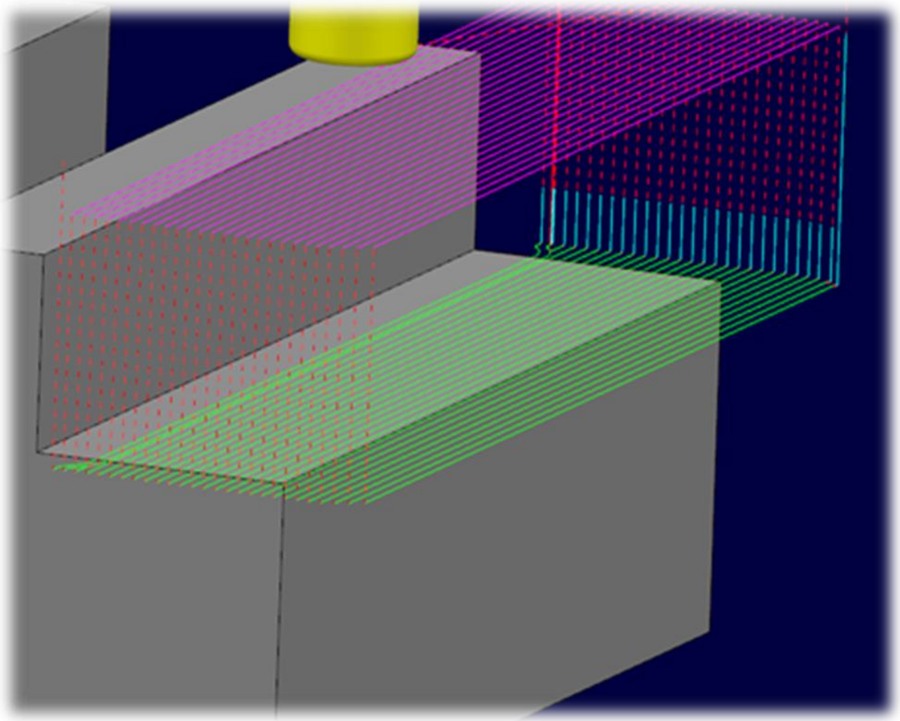
Cutting Trials - Method

- Traditional Method
  - Large Stepover
  - Small Stepdown
- HTA Method



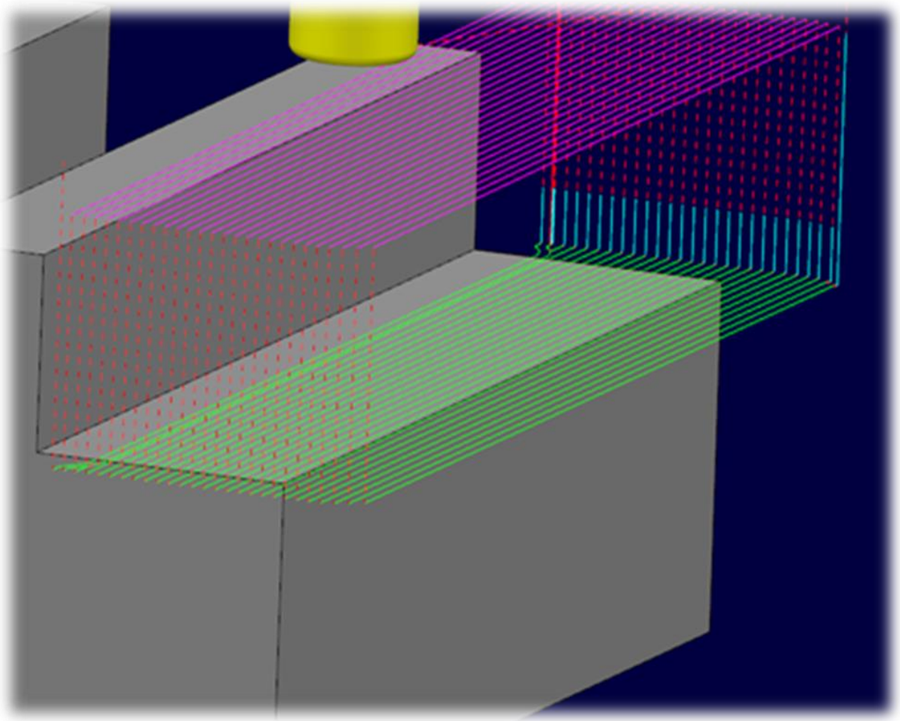
Cutting Trials - Method

- Traditional Method
  - Large Stepover
  - Small Stepdown
- HTA Method
  - Small Stepover



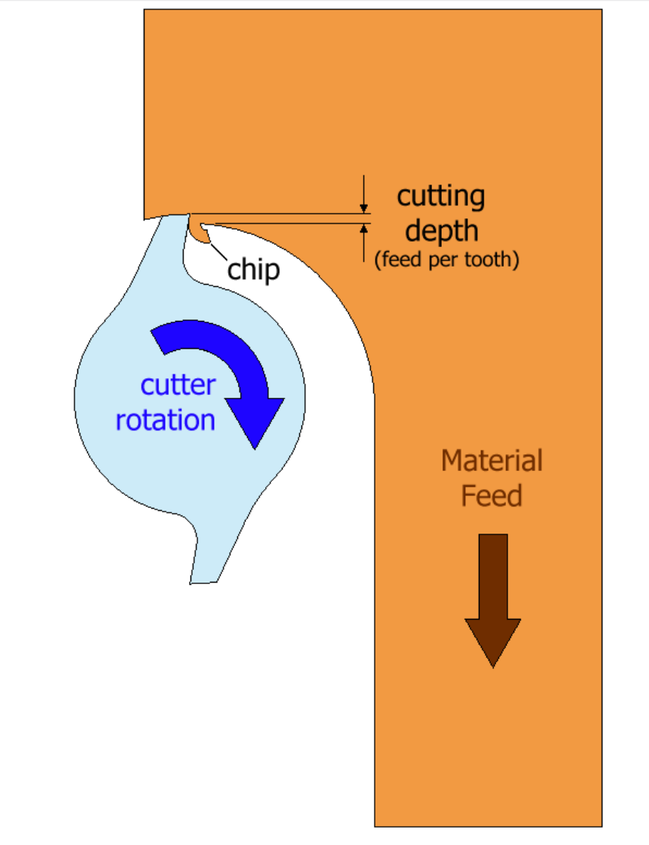
Cutting Trials - Method

- Traditional Method
  - Large Stepover
  - Small Stepdown
- HTA Method
  - Small Stepover
  - Large Stepdown

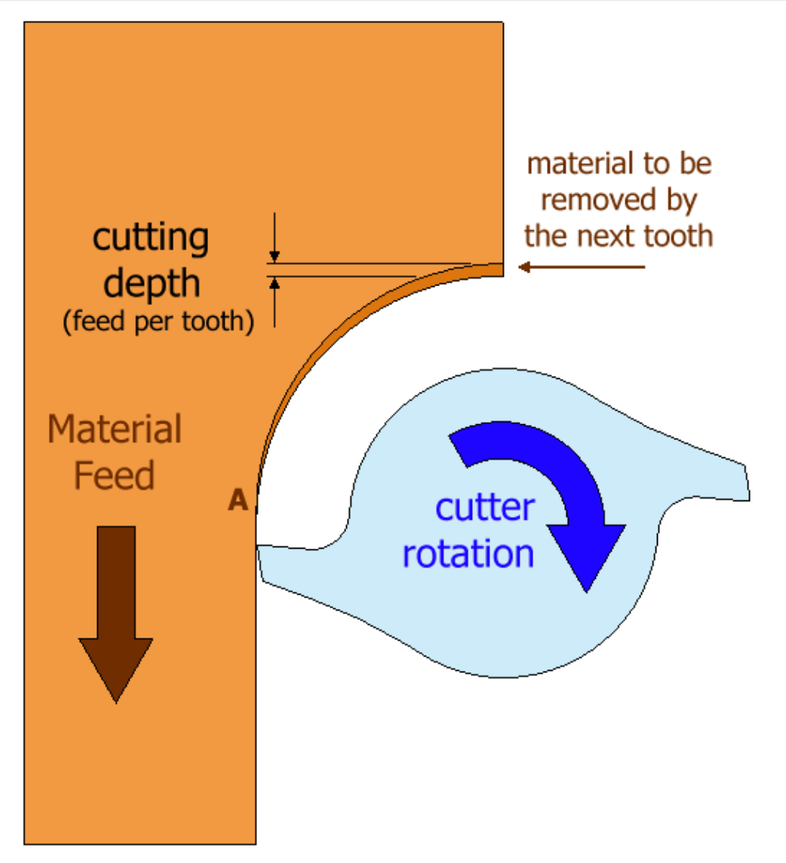


Cutting Trials - Method

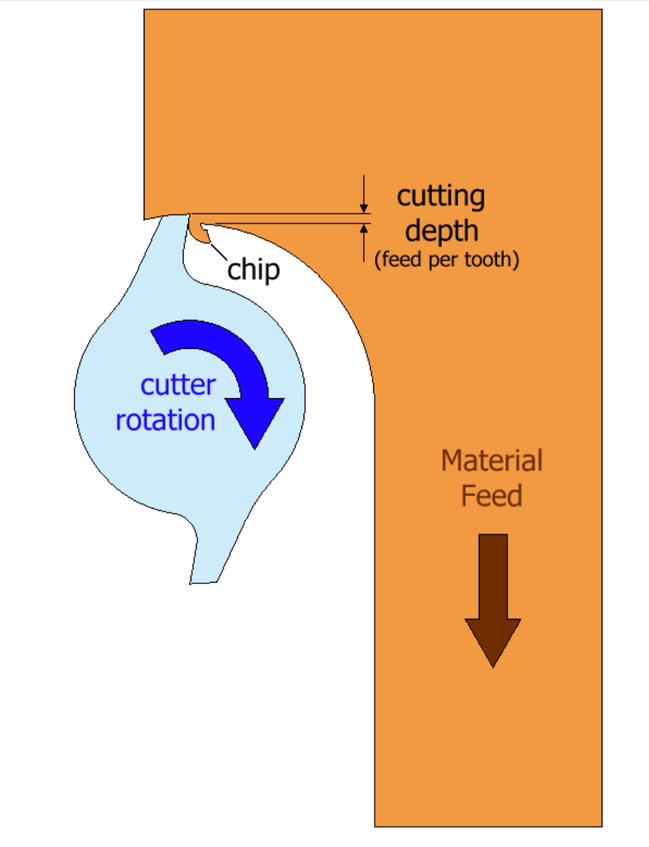
Climb Milling



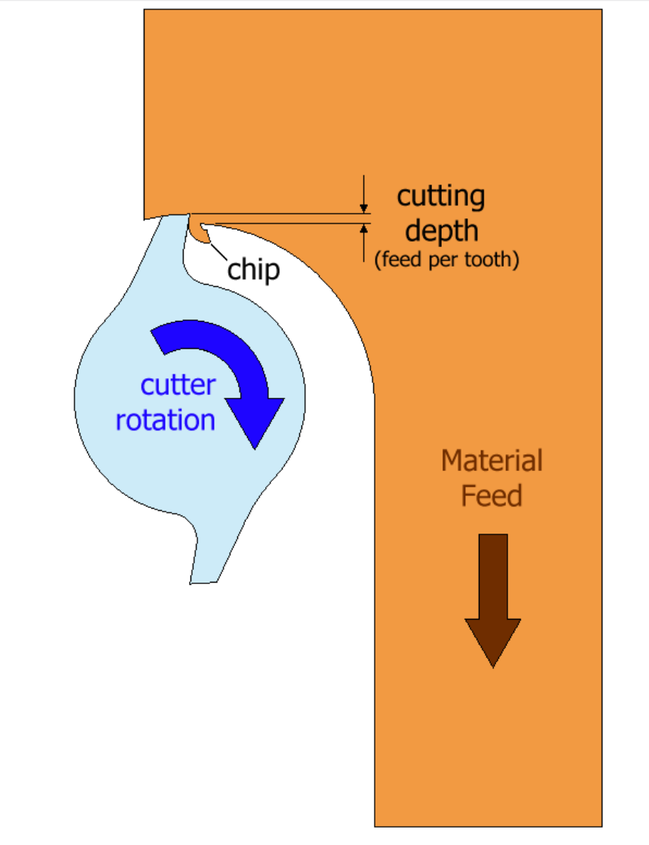
Conventional Milling



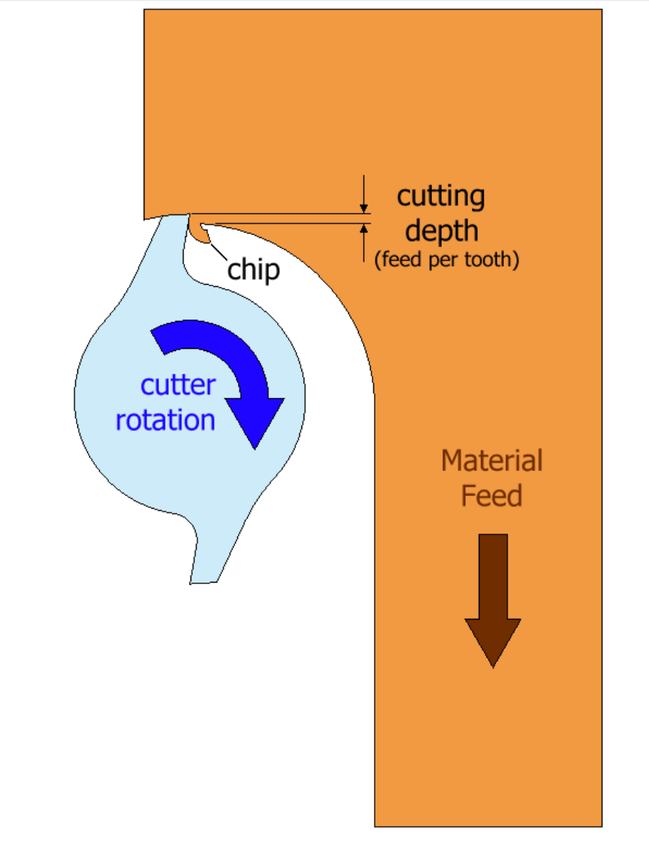
Cutting Trials - Method

Climb Milling	Why?
	

Cutting Trials - Method

Climb Milling	Why?
	• Bigger chips straight away

Cutting Trials - Method

Climb Milling	Why?
	• Bigger chips straight away • Better Swarf Evacuation

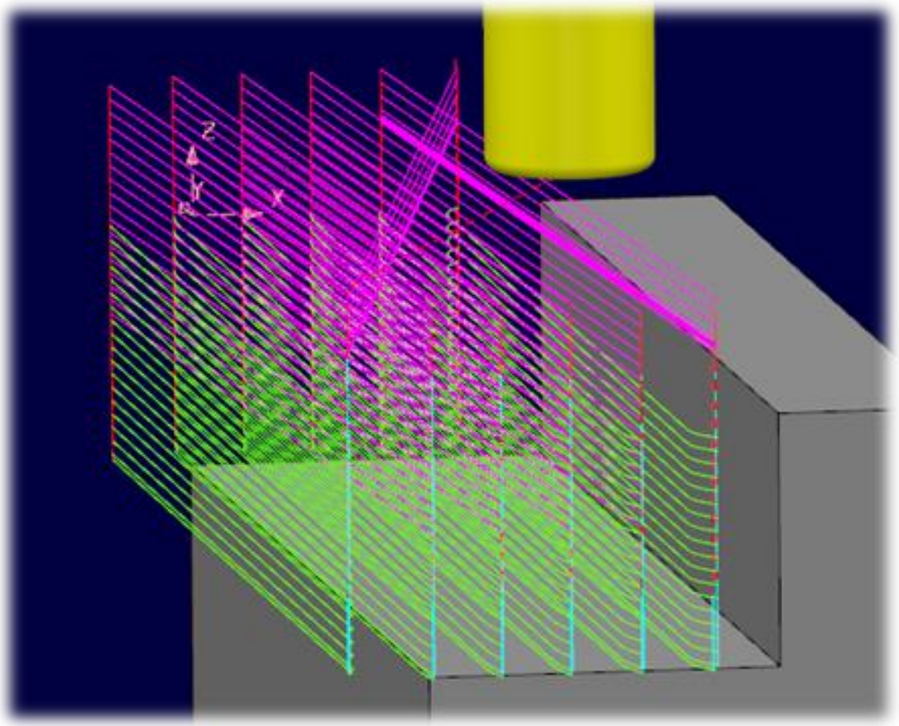
Cutting Trials – EN24T Steel

EN24T Steel

- EN24T Parameters

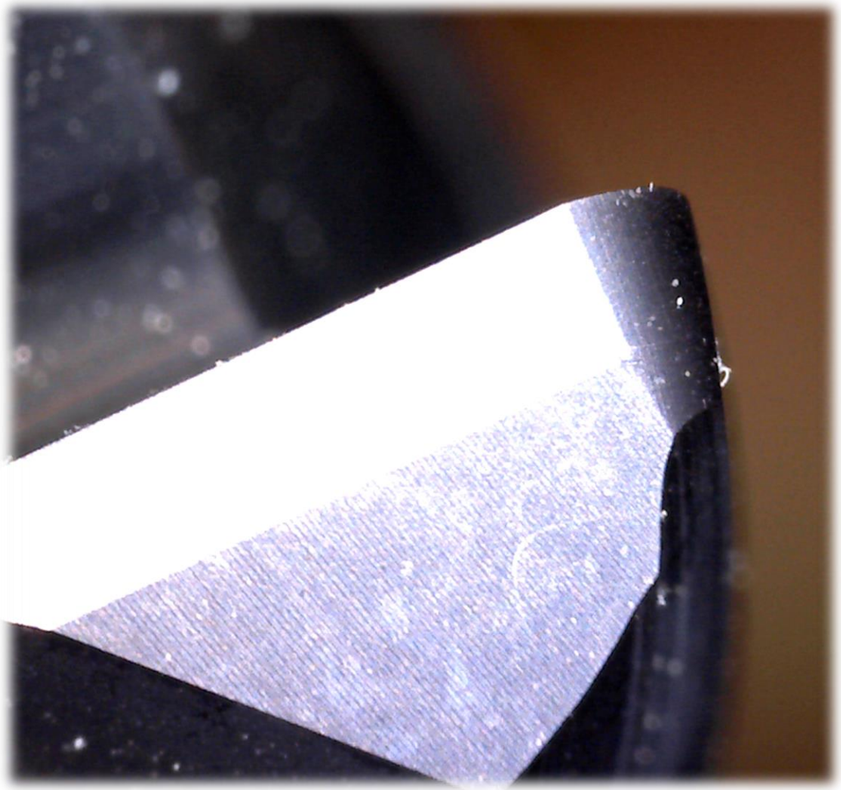
Stepover (mm)	4.8
Stepover (% of Tool Diameter)	40
Stepdown (mm)	1
Stepdown (% of Tool Diameter)	8.3
Feed Rate (mm/min)	1076.0
Spindle Speed (rpm)	4484.0
Approx. Machining Time (mins)	20

- Traditional Method

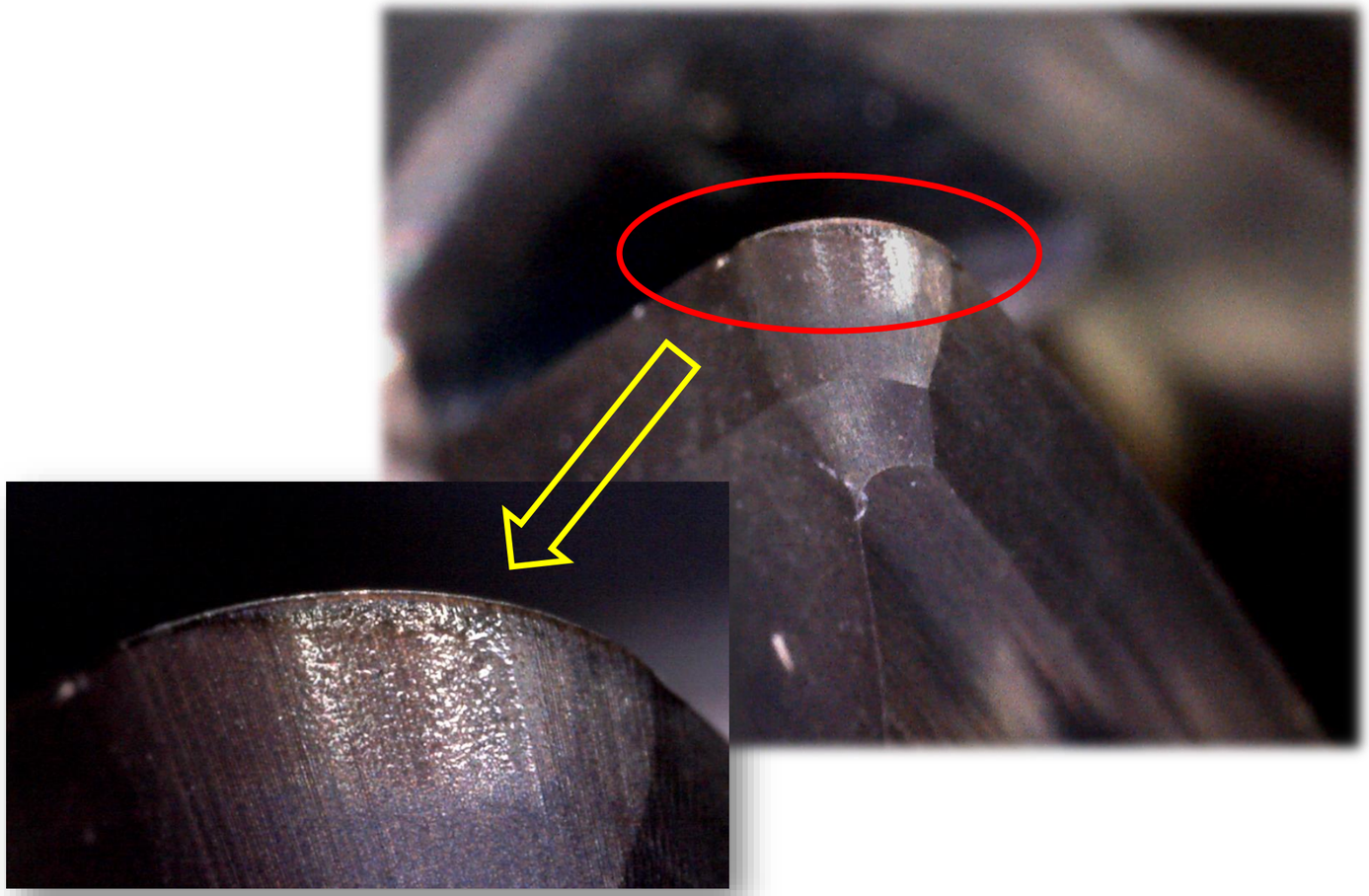


EN24T Steel - Results

- Before

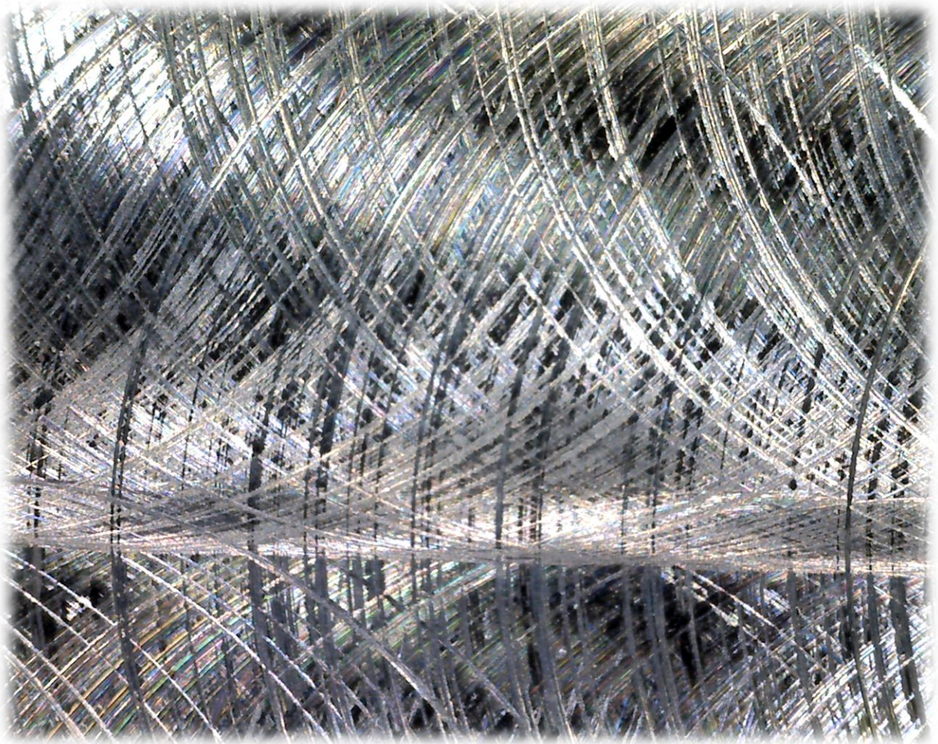


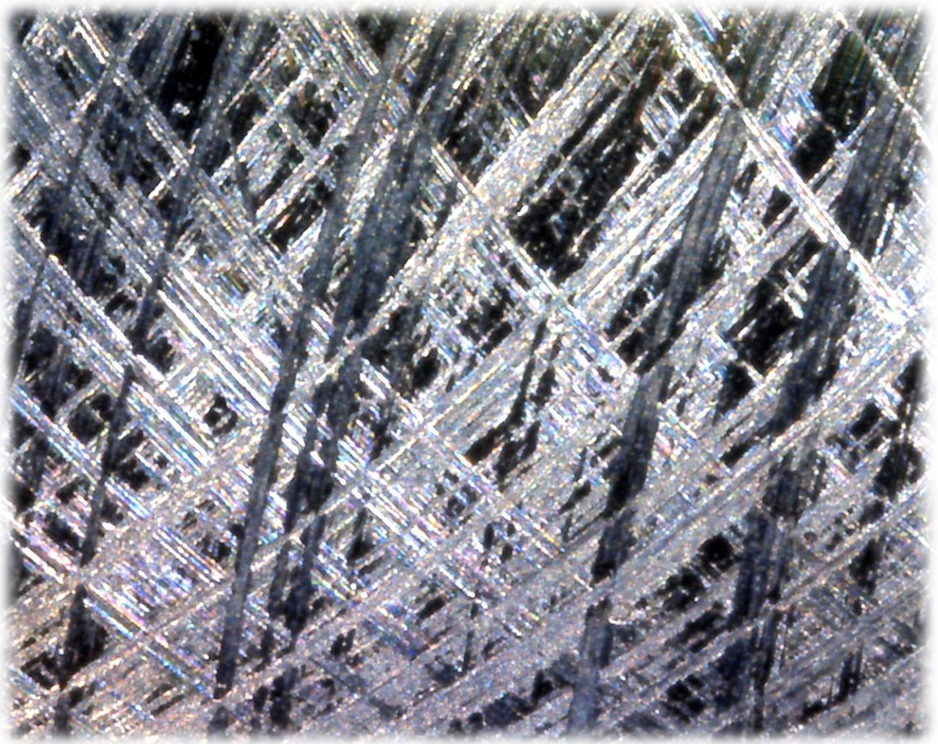
- After



EN24T Steel - Results

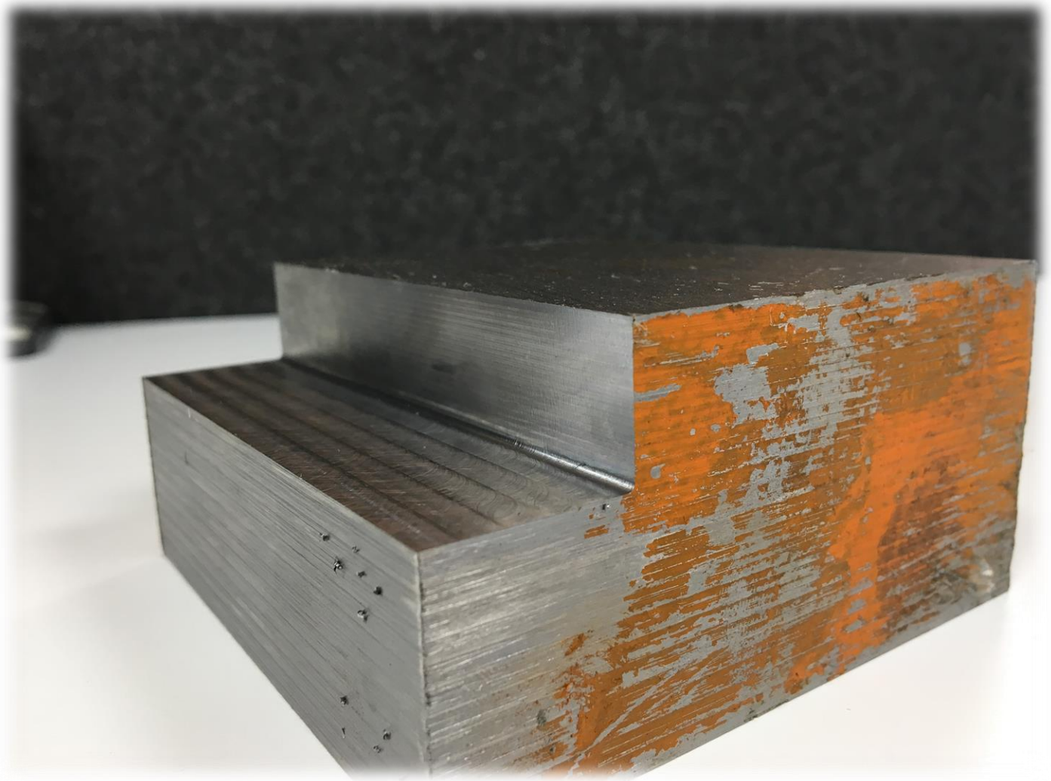
- Surface Quality

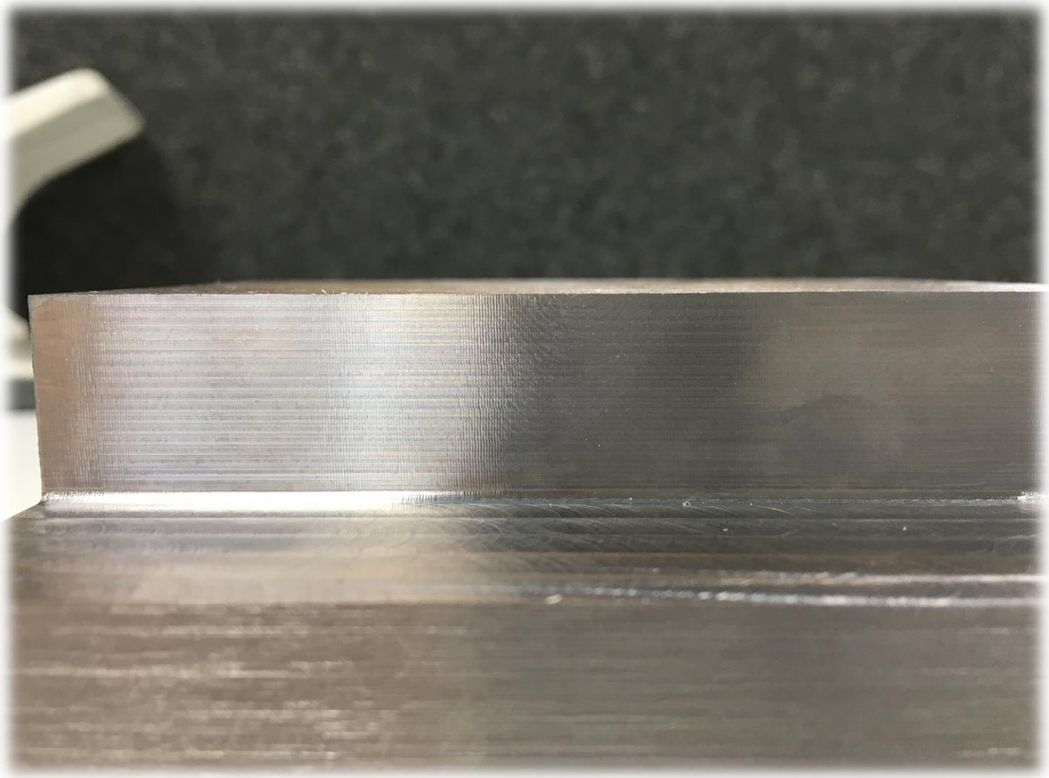




EN24T Steel - Results

- Machined Block





Cutting Trials – Titanium Ti6Al4V

Titanium Ti6Al4V

- EN24T Parameters

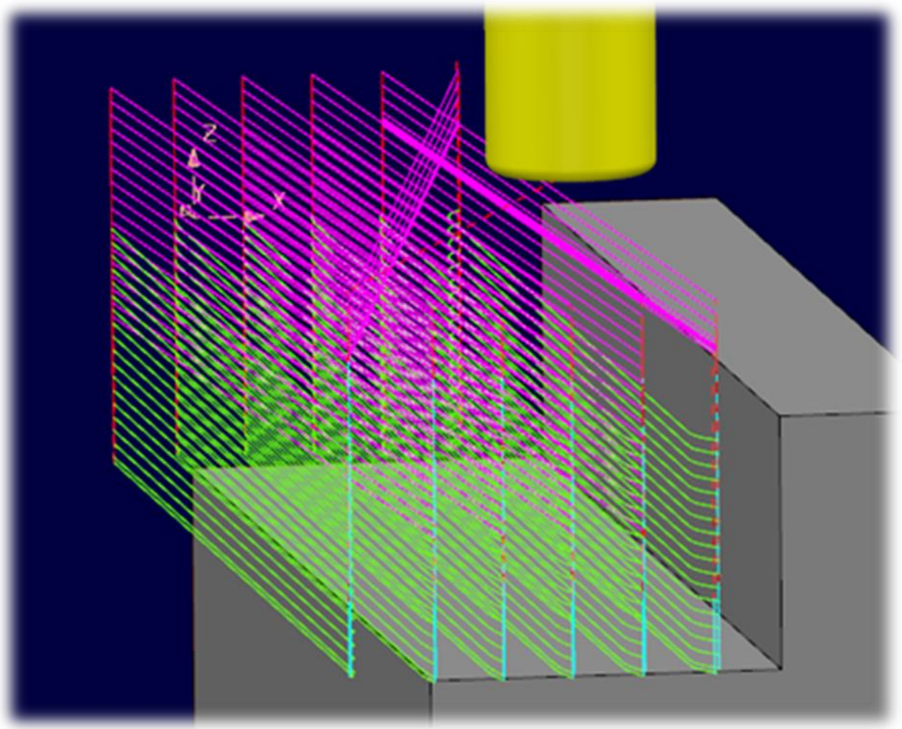
Stepover (mm)	4.8
Stepover (% of Tool Diameter)	40
Stepdown (mm)	1
Stepdown (% of Tool Diameter)	8.3
Feed Rate (mm/min)	1076.0
Spindle Speed (rpm)	4484.0
Approx. Machining Time (mins)	20

- Improved Parameters

Stepover (mm)	1.2
Stepover (% of Tool Diameter)	10
Stepdown (mm)	18
Stepdown (% of Tool Diameter)	150
Feed Rate (mm/min)	217.0
Spindle Speed (rpm)	1737.0
Approx. Machining Time (mins)	16

Titanium Ti6Al4V

- Traditional Method



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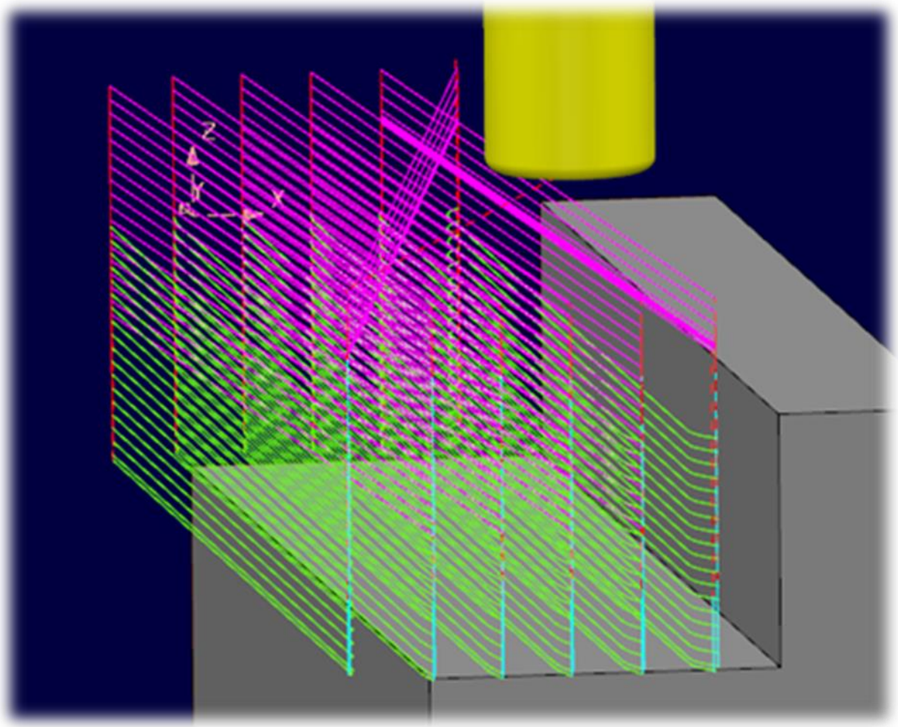
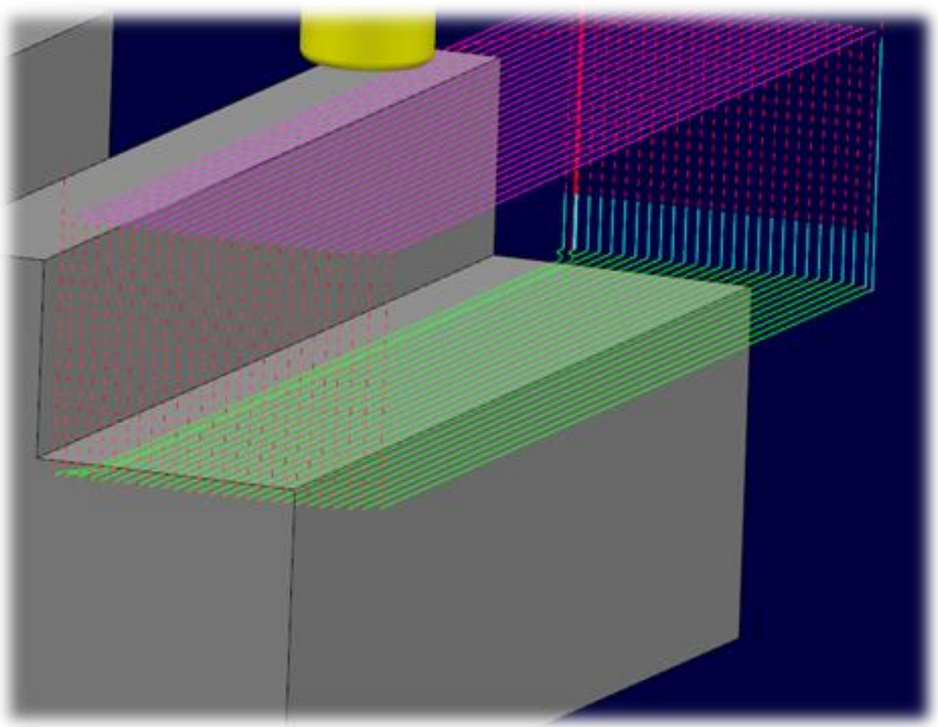
Titanium Ti6Al4V

- Traditional Method

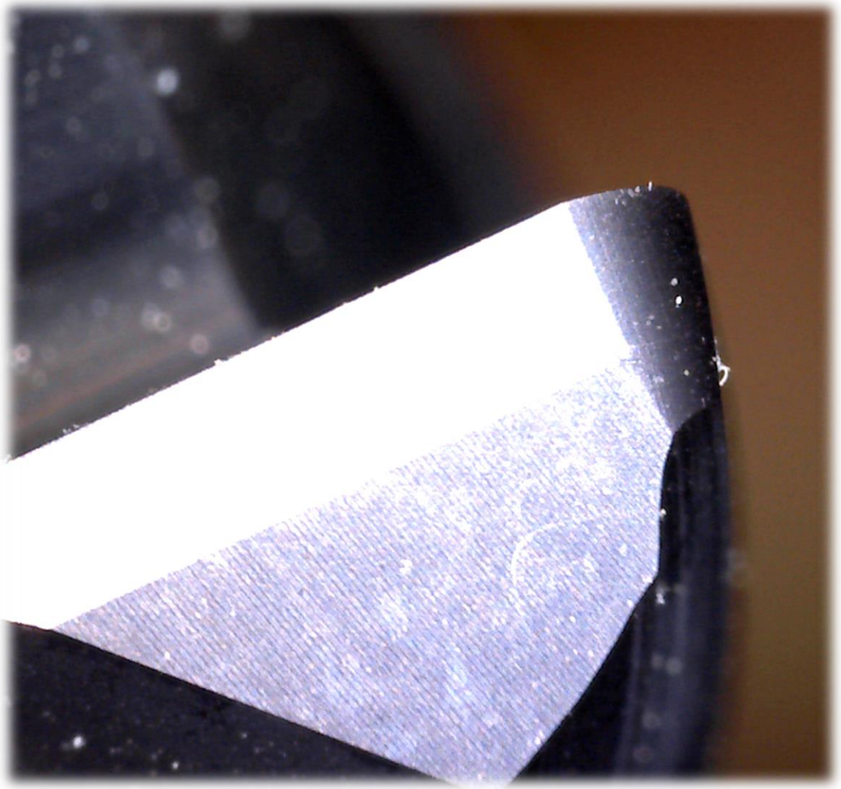


- HTA Method

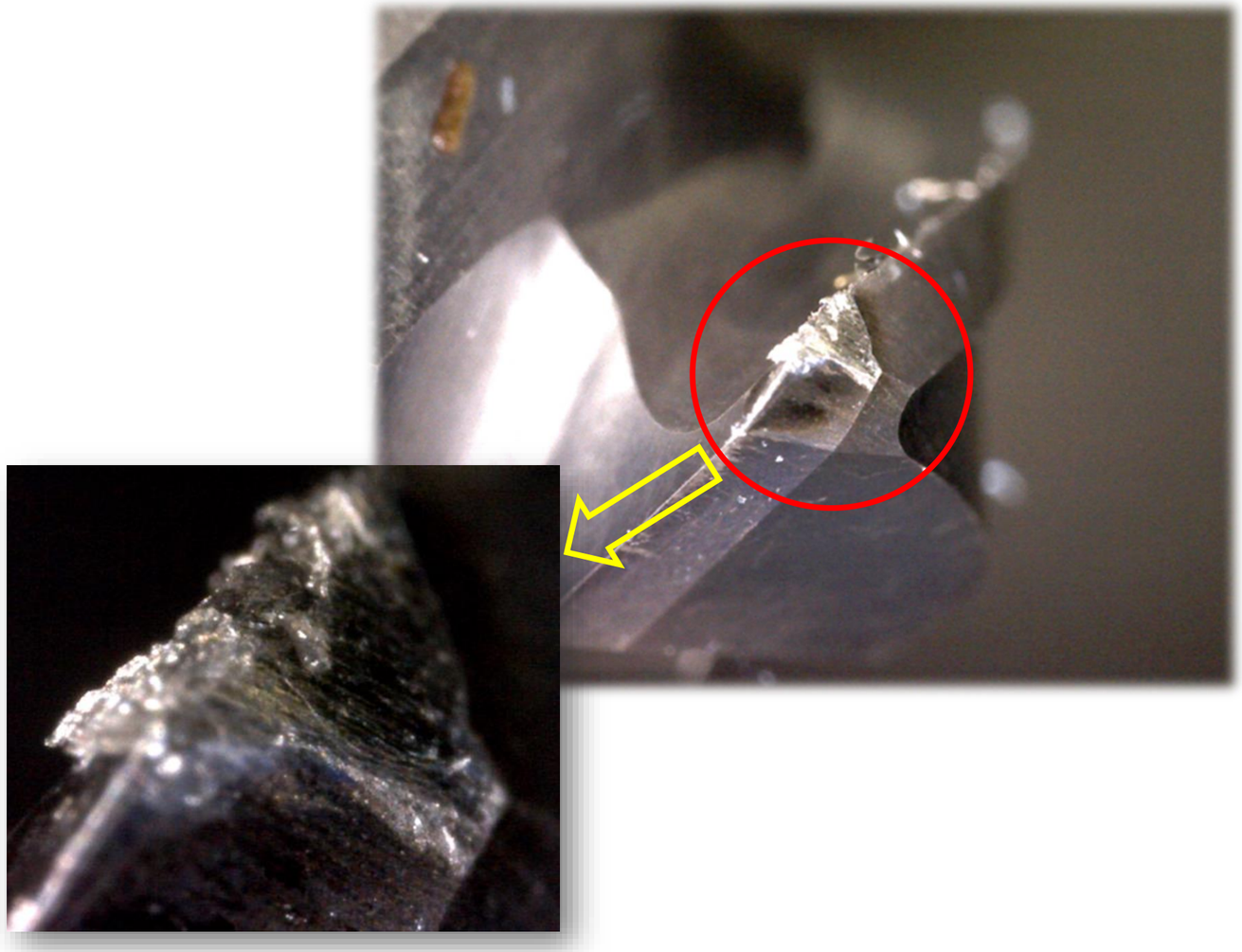


Titanium Ti6Al4V – EN24T Approach Results

- Before

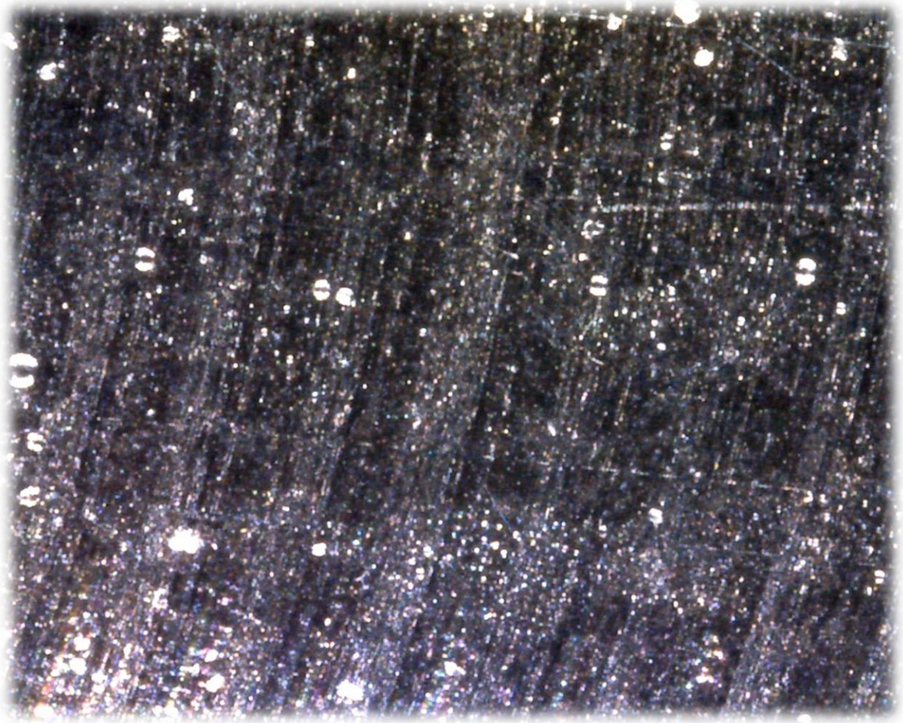


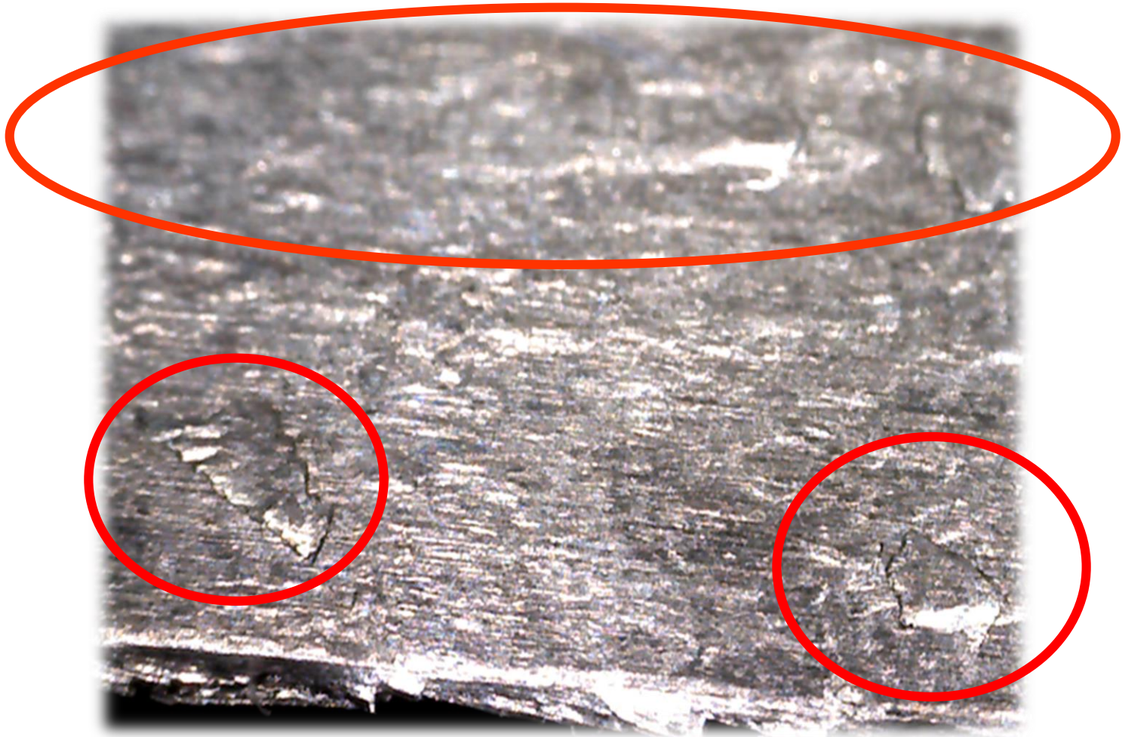
- After



Titanium Ti6Al4V – EN24T Approach Results

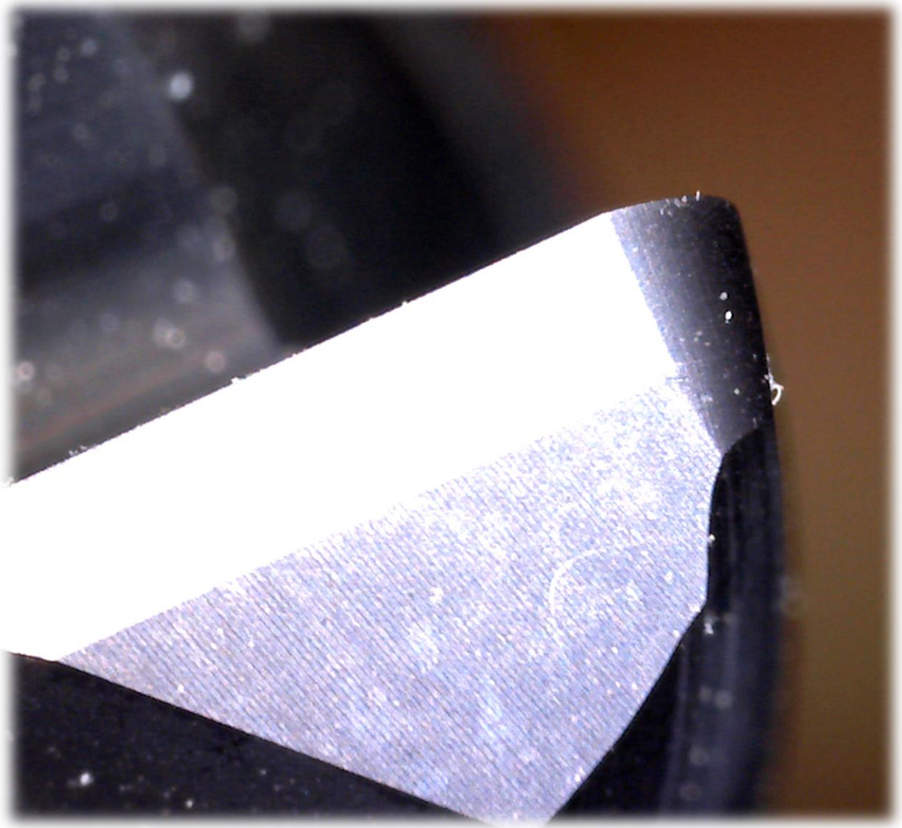
- Surface Quality





Titanium Ti6Al4V - Improved Approach Results

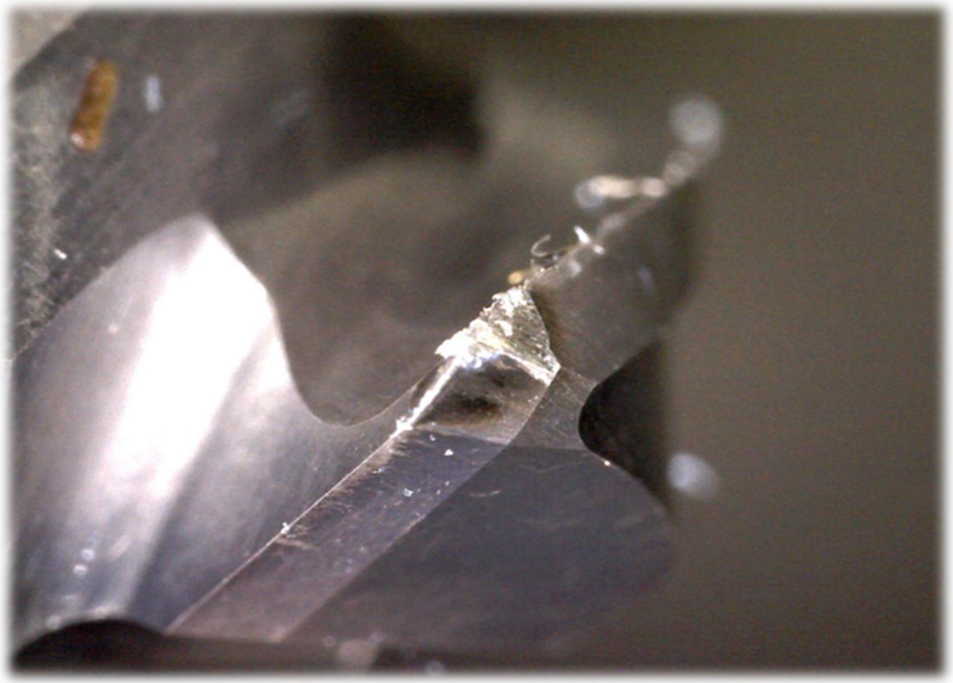
- Before



- After

Titanium Ti6Al4V - Improved Approach Results

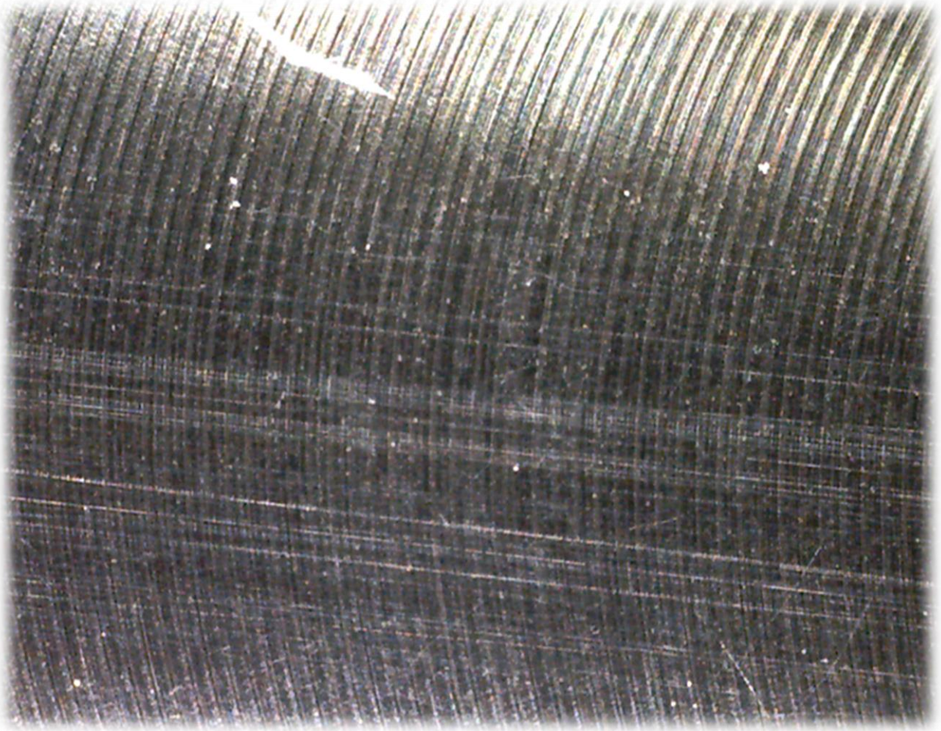
- EN24T Parameters

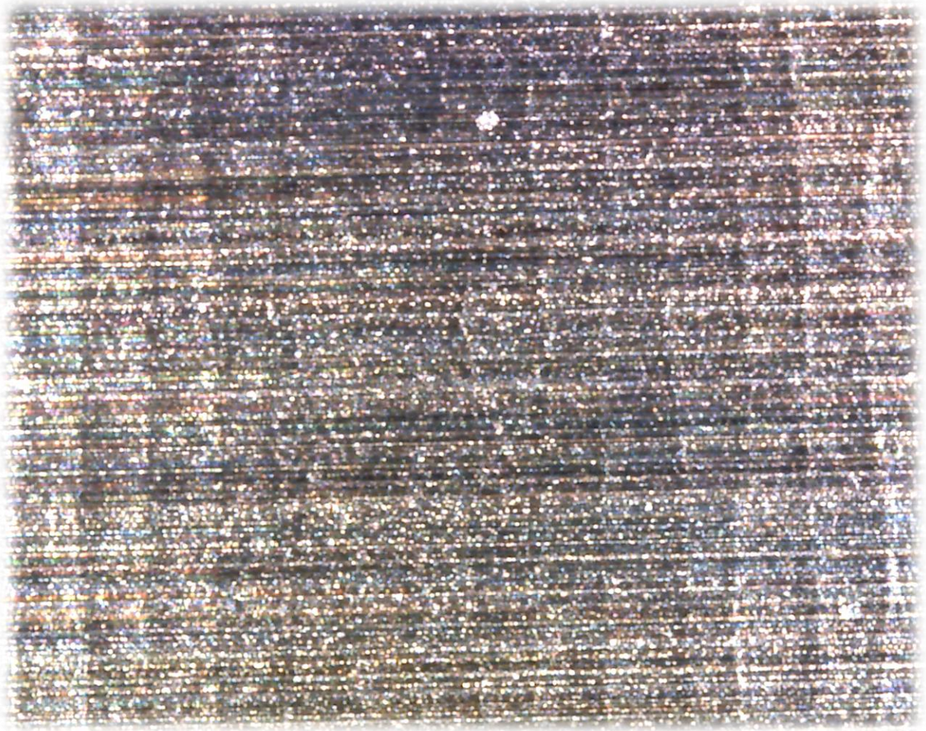


- Improved Parameters

Titanium Ti6Al4V - Improved Approach Results

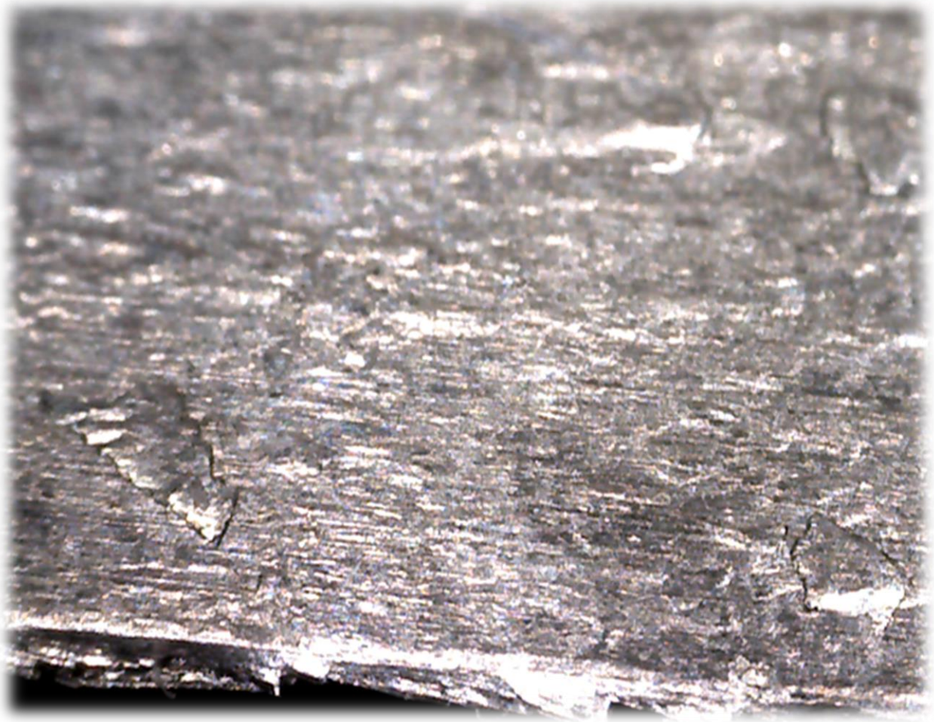
- Surface Quality



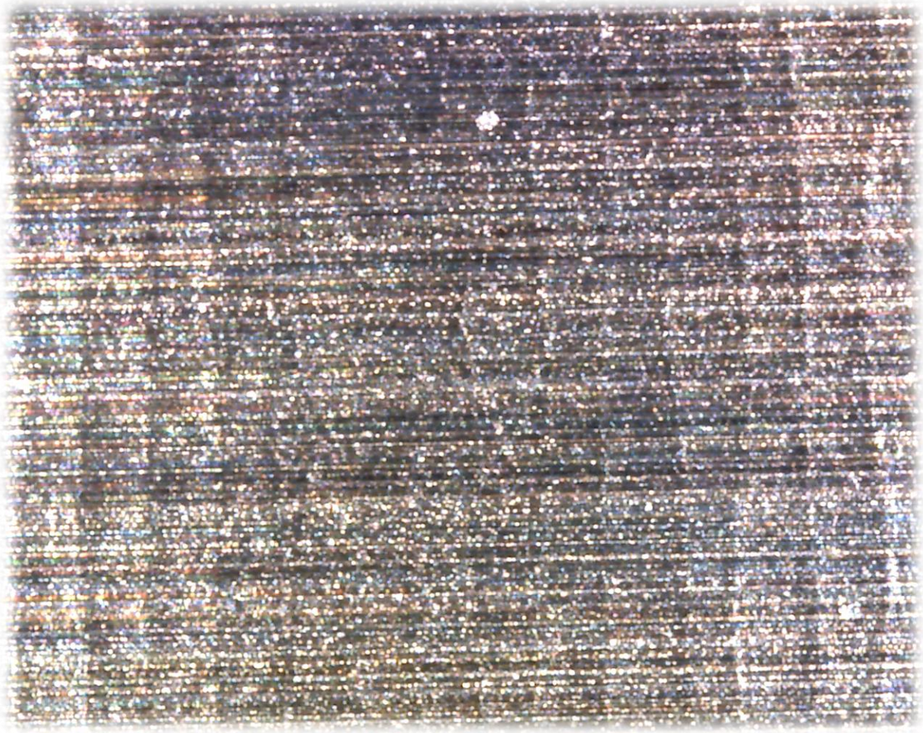


Titanium Ti6Al4V - Improved Approach Results

- EN24T Parameters

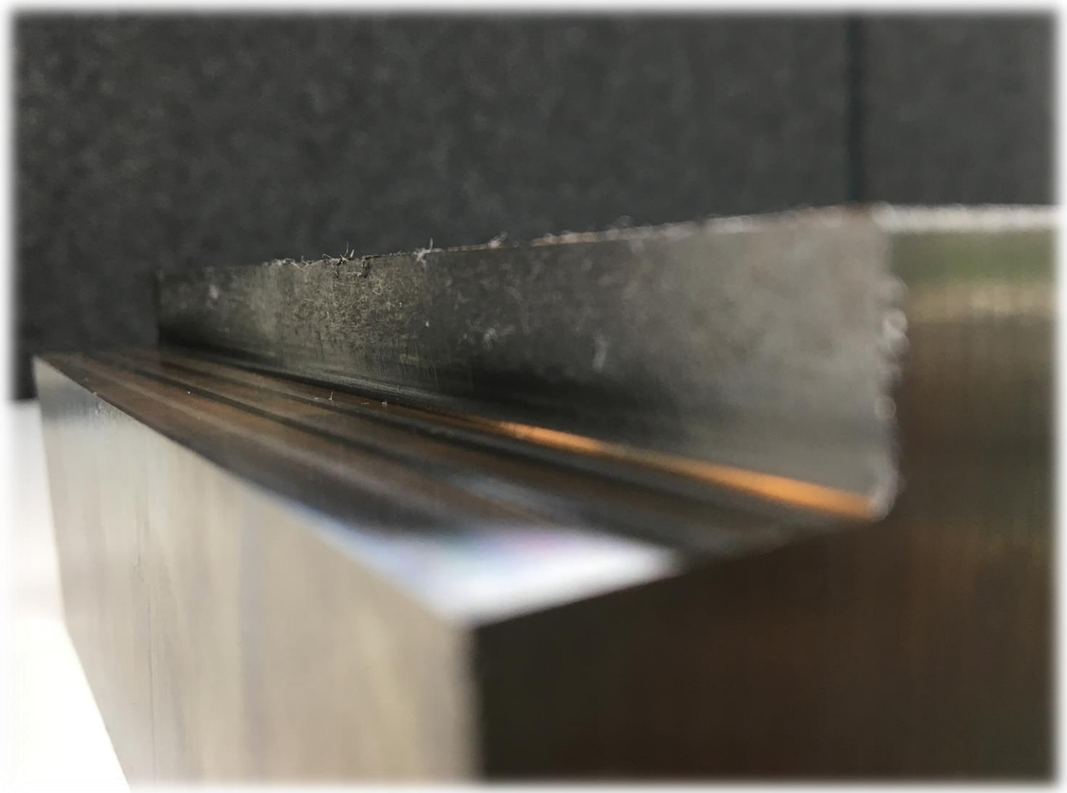


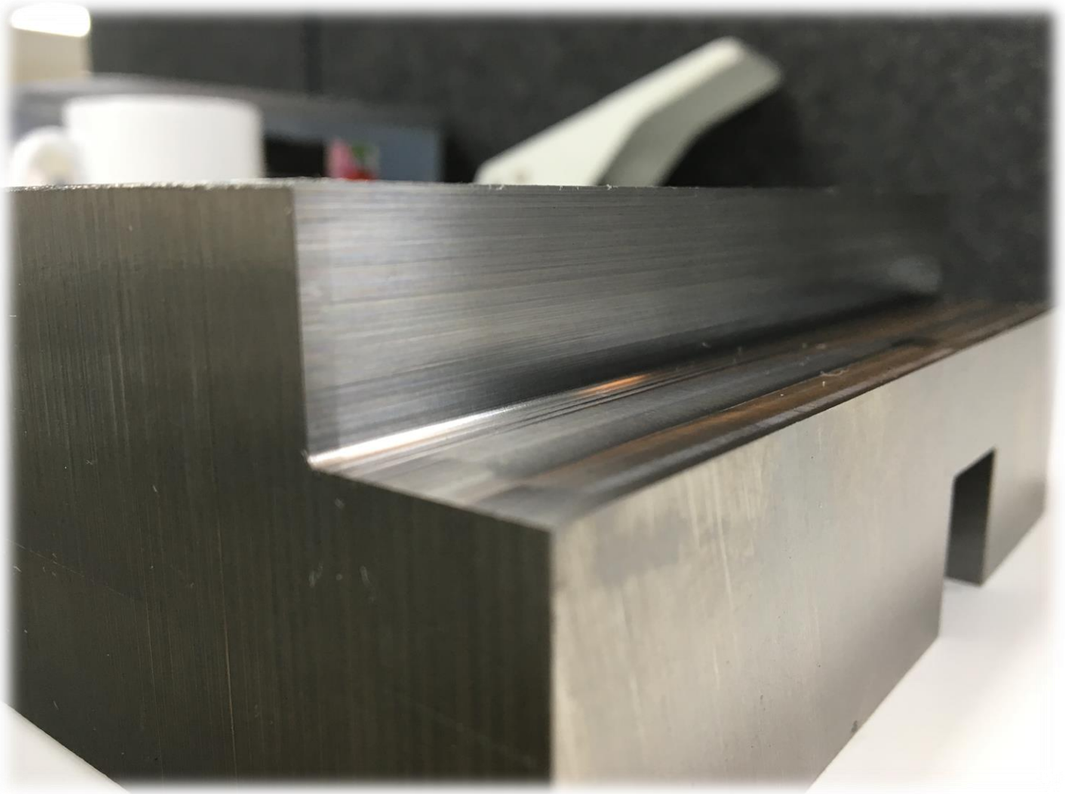
- Improved Parameters

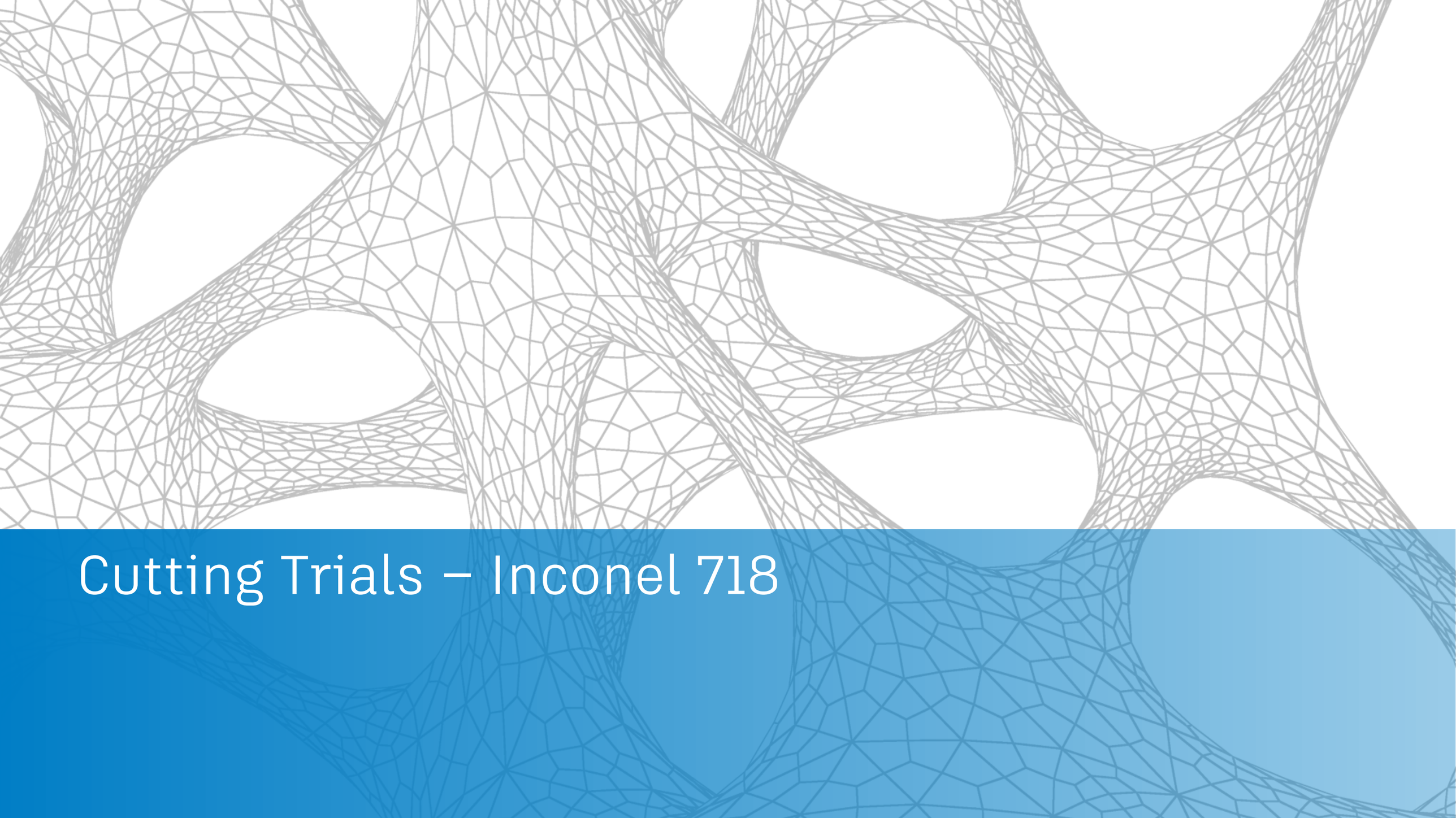


Titanium Ti6Al4V - Results

- Machined Block







Cutting Trials – Inconel 718

Inconel 718

- EN24T Parameters

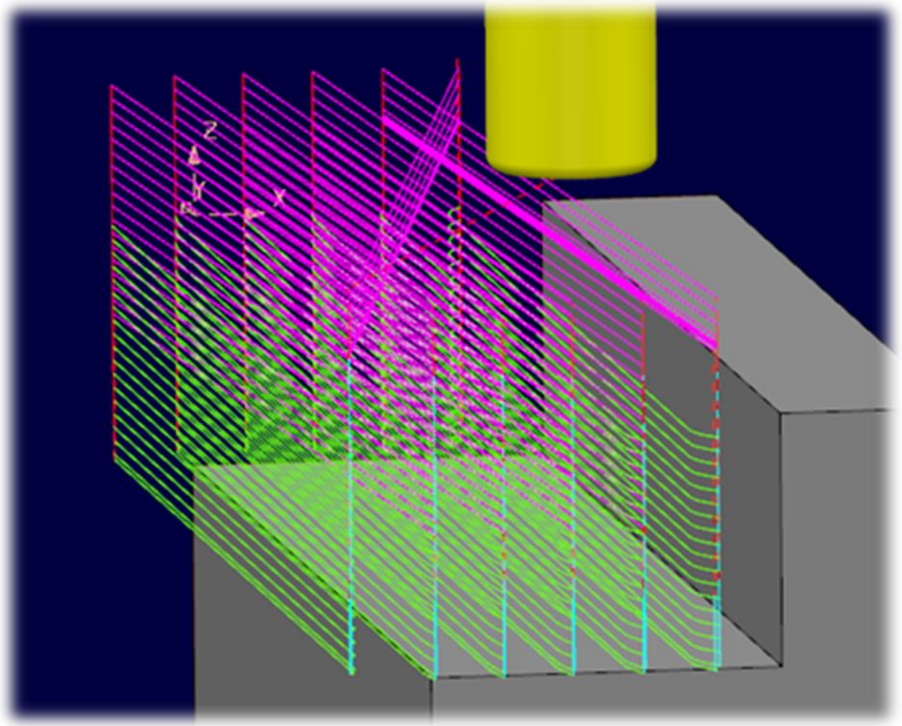
Stepover (mm)	4.8
Stepover (% of Tool Diameter)	40
Stepdown (mm)	1
Stepdown (% of Tool Diameter)	8.3
Feed Rate (mm/min)	1076.0
Spindle Speed (rpm)	4484.0
Approx. Machining Time (mins)	20

- Improved Parameters

Stepover (mm)	1.2
Stepover (% of Tool Diameter)	10
Stepdown (mm)	18
Stepdown (% of Tool Diameter)	150
Feed Rate (mm/min)	**34.0**
Spindle Speed (rpm)	**501.0**
Approx. Machining Time (mins)	**120**

Inconel 718

- Traditional Method

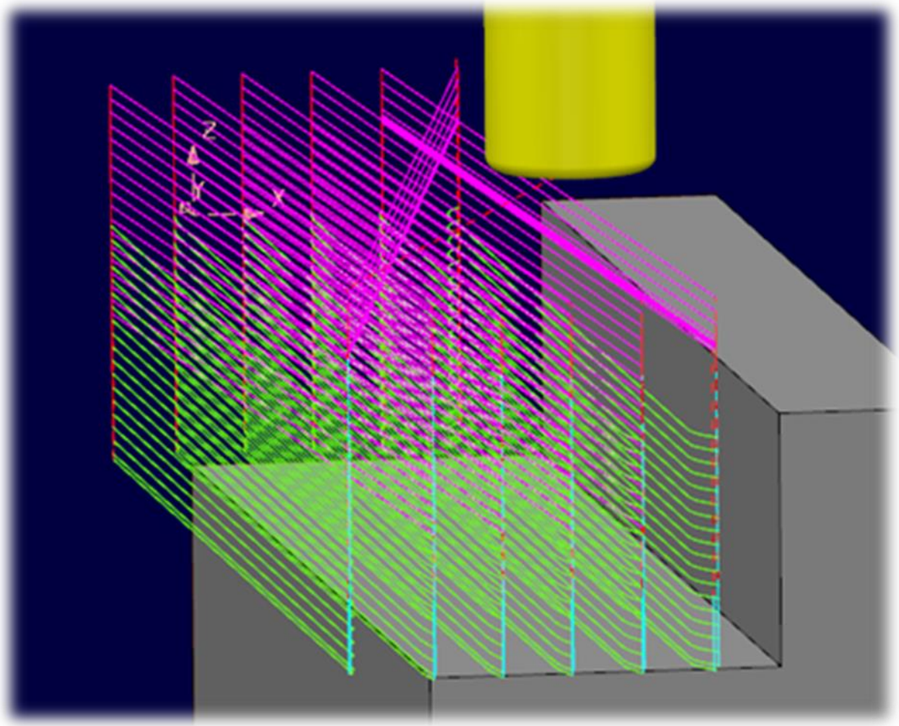


- Improved Parameters

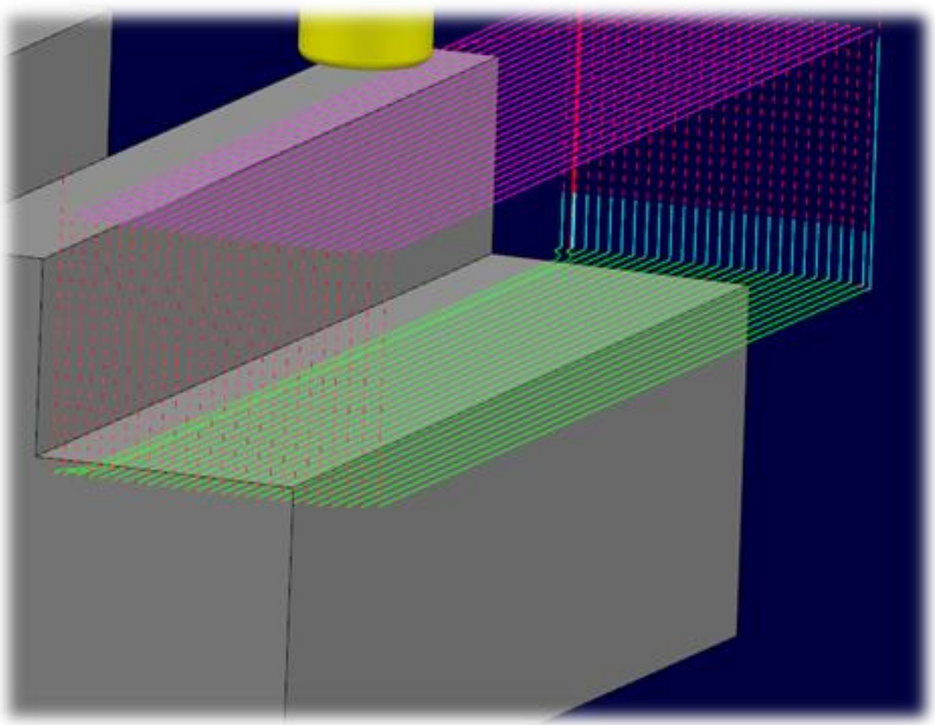
Stepover (mm)	1.2
Stepover (% of Tool Diameter)	10
Stepdown (mm)	18
Stepdown (% of Tool Diameter)	150
Feed Rate (mm/min)	34.0
Spindle Speed (rpm)	501.0
Approx. Machining Time (mins)	120

Inconel 718

- Traditional Method

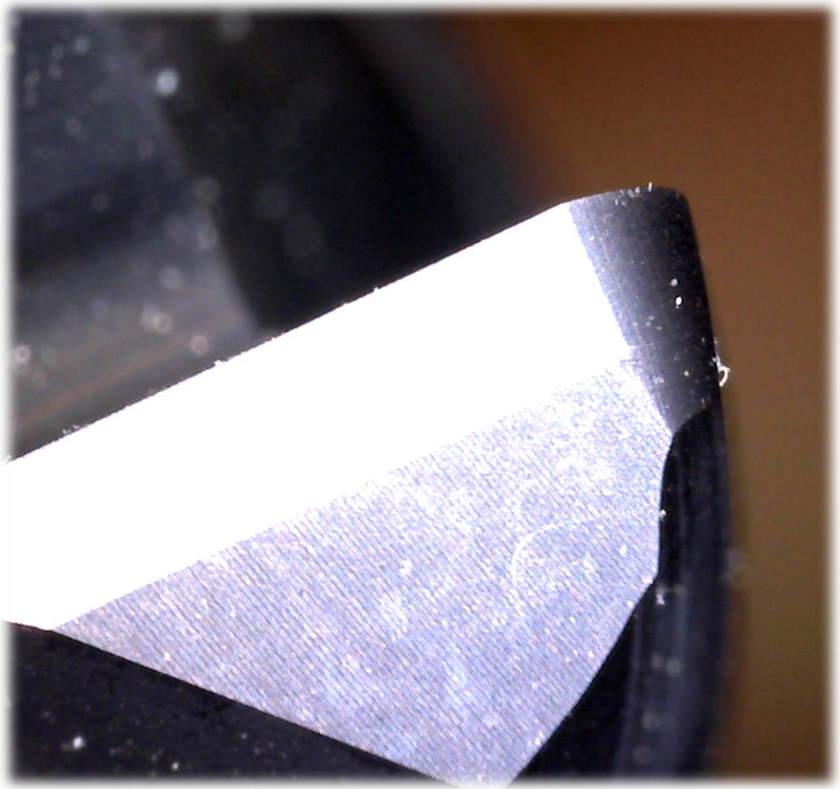


- HTA Method

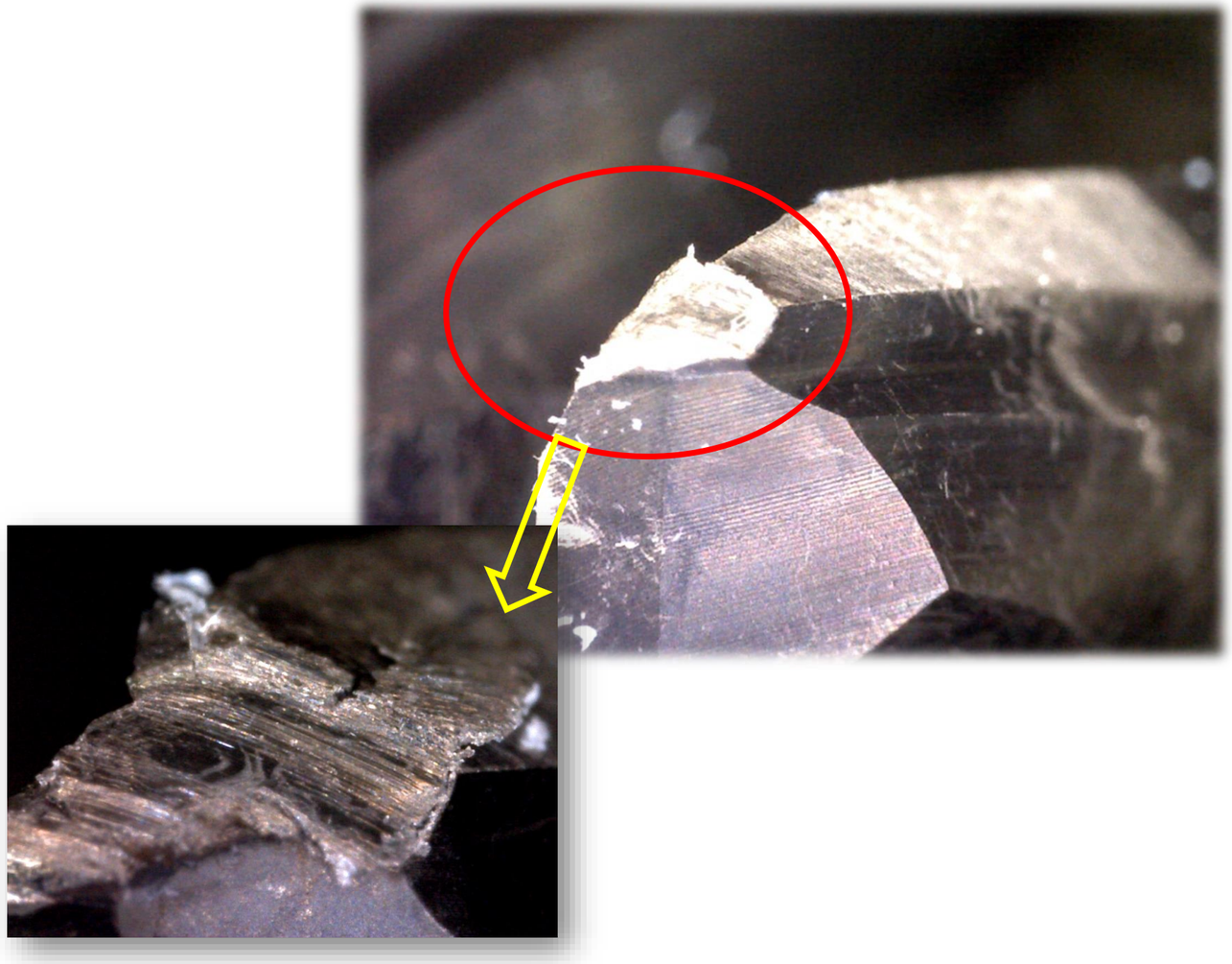


Inconel 718 – EN24T Approach Results

- Before

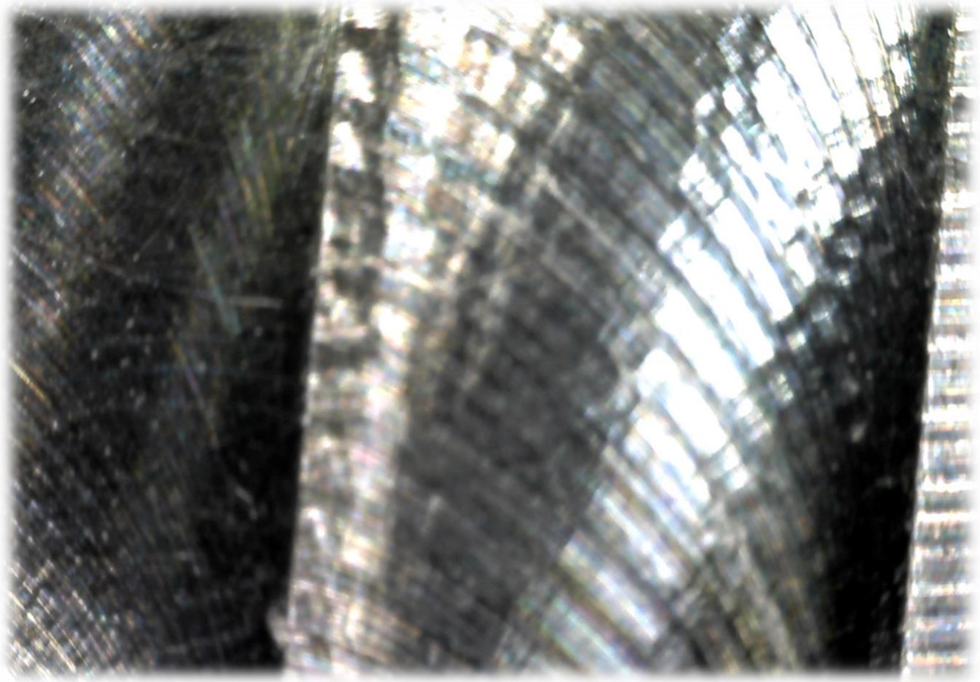


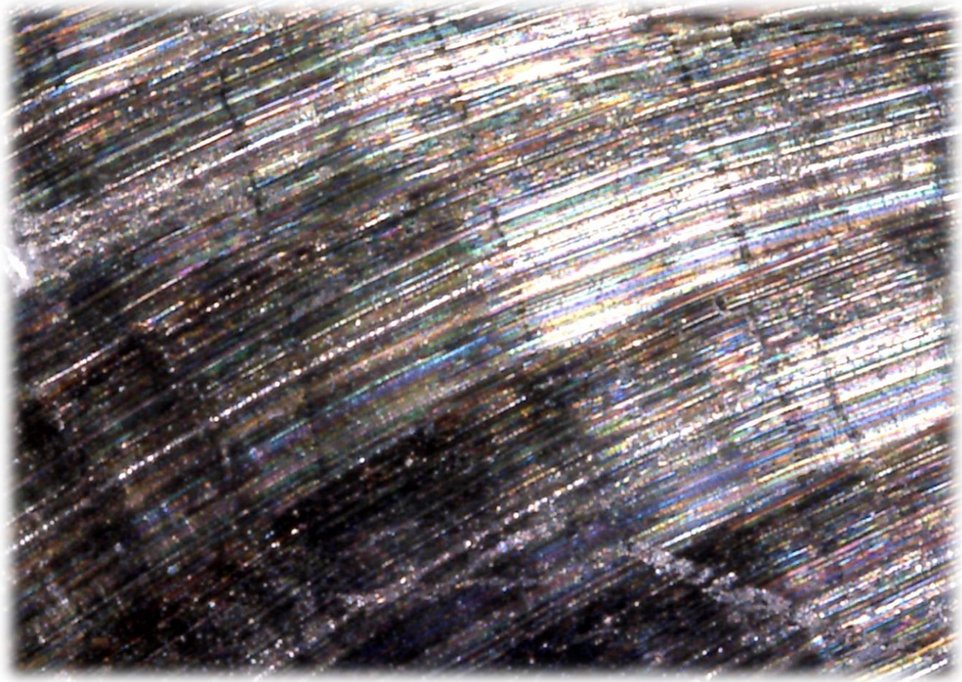
- After



Inconel 718 – EN24T Approach Results

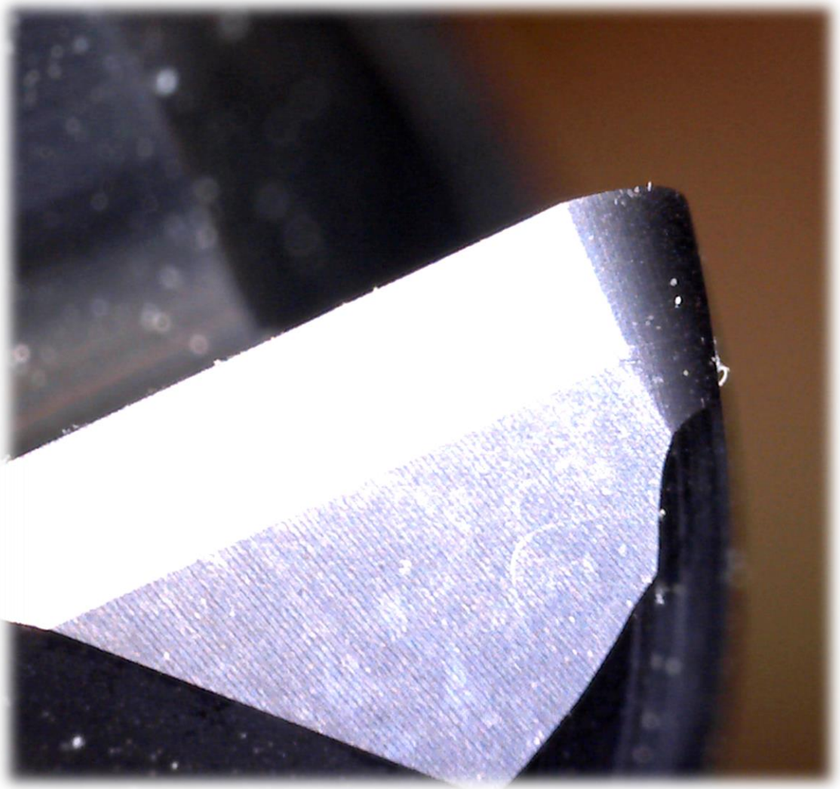
- Surface Quality



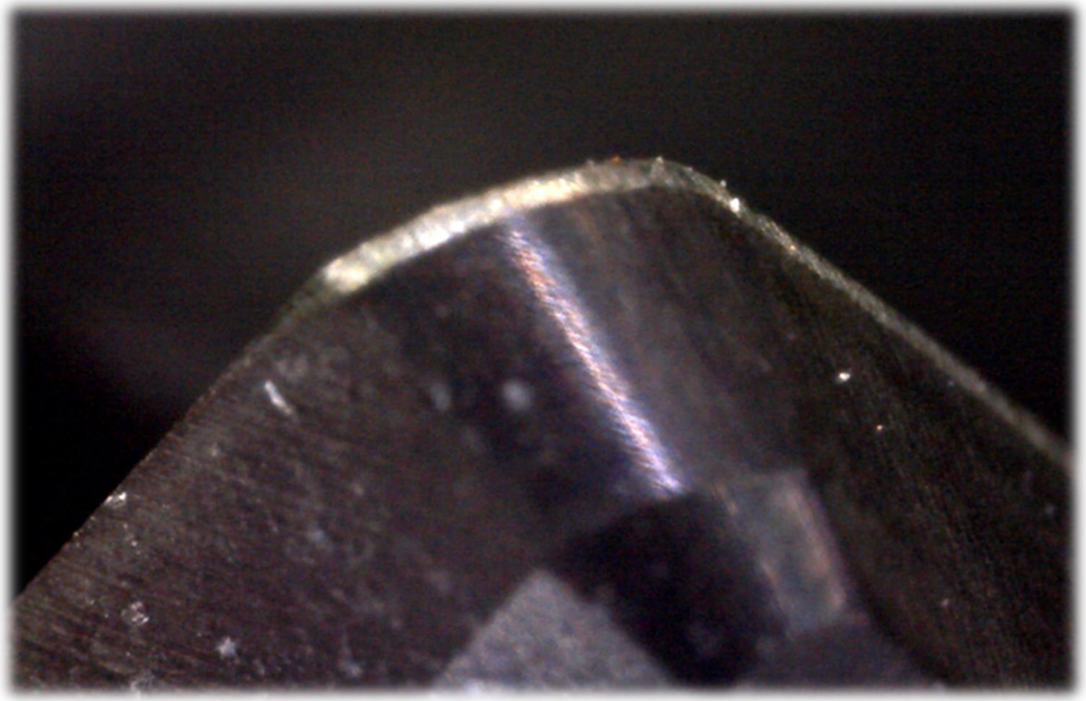


Inconel 718 – Improved Approach Results

- Before

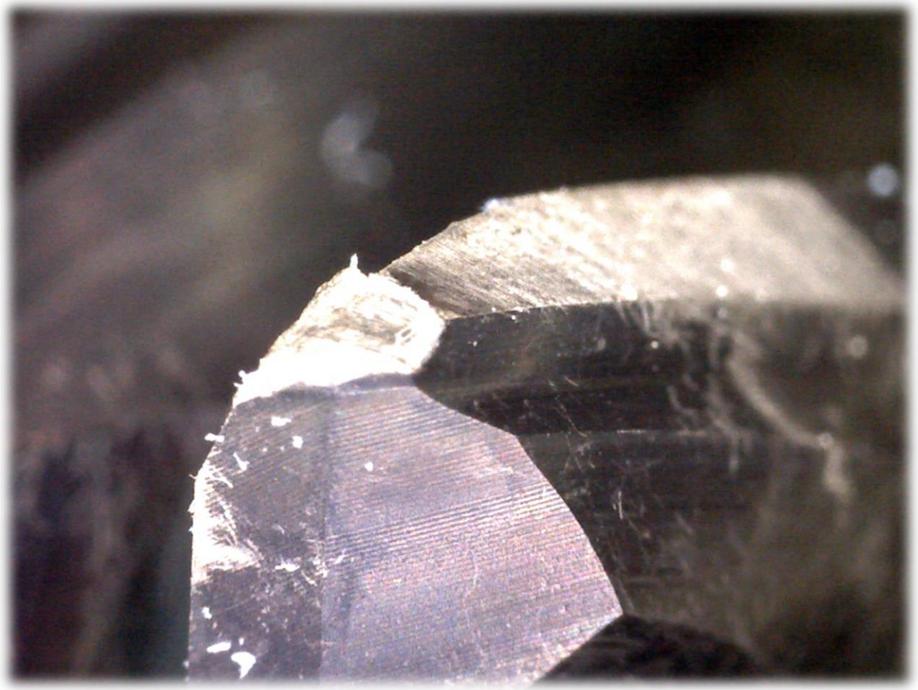


- After

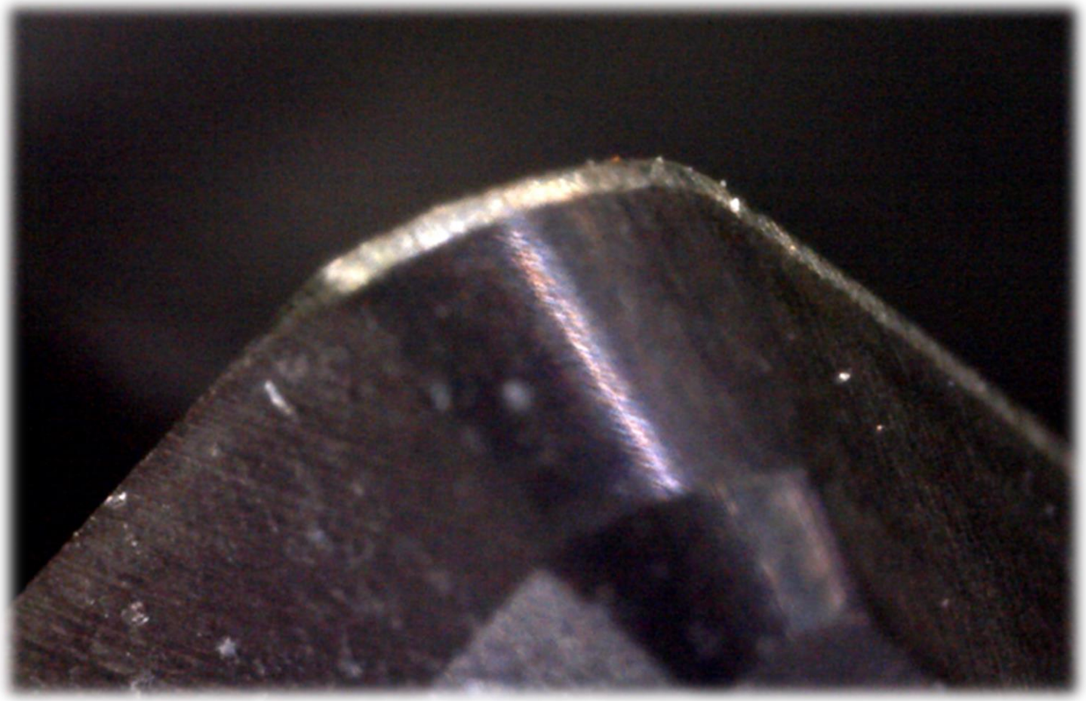


Inconel 718 - Improved Approach Results

- EN24T Parameters

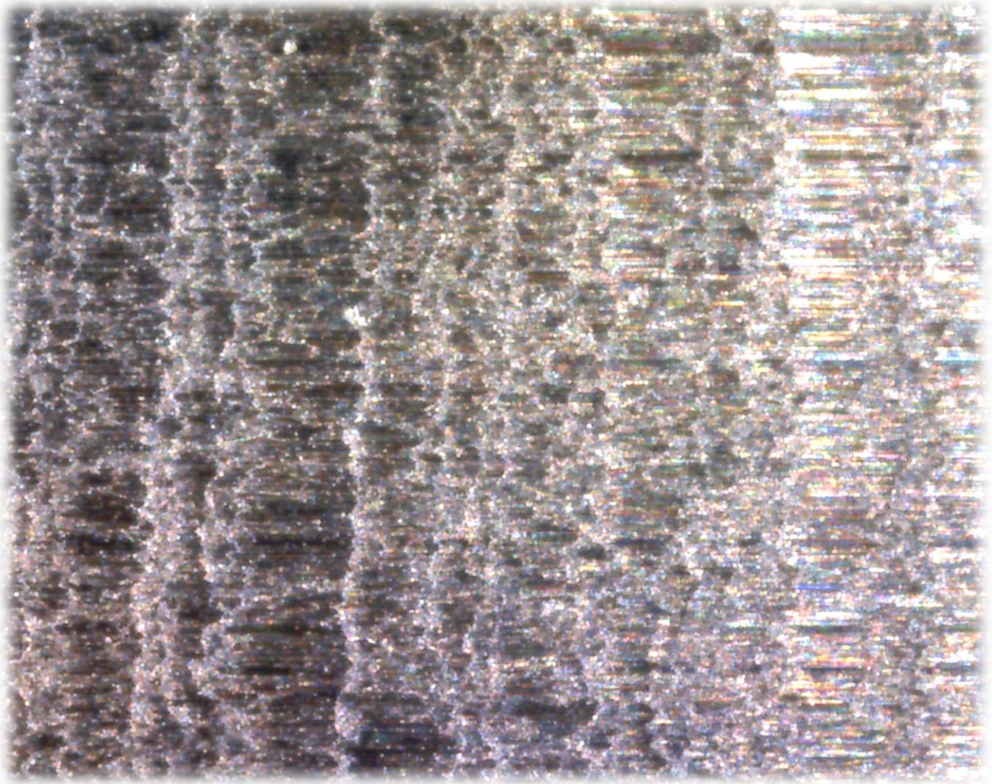


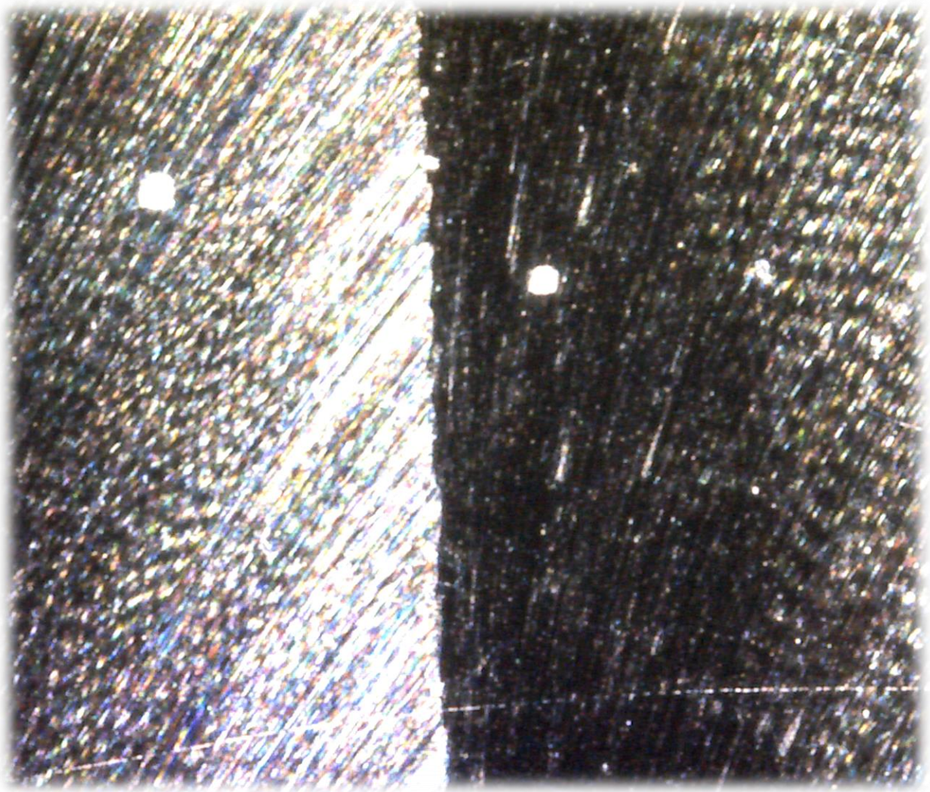
- Improved Parameters



Inconel 718 - Improved Approach Results

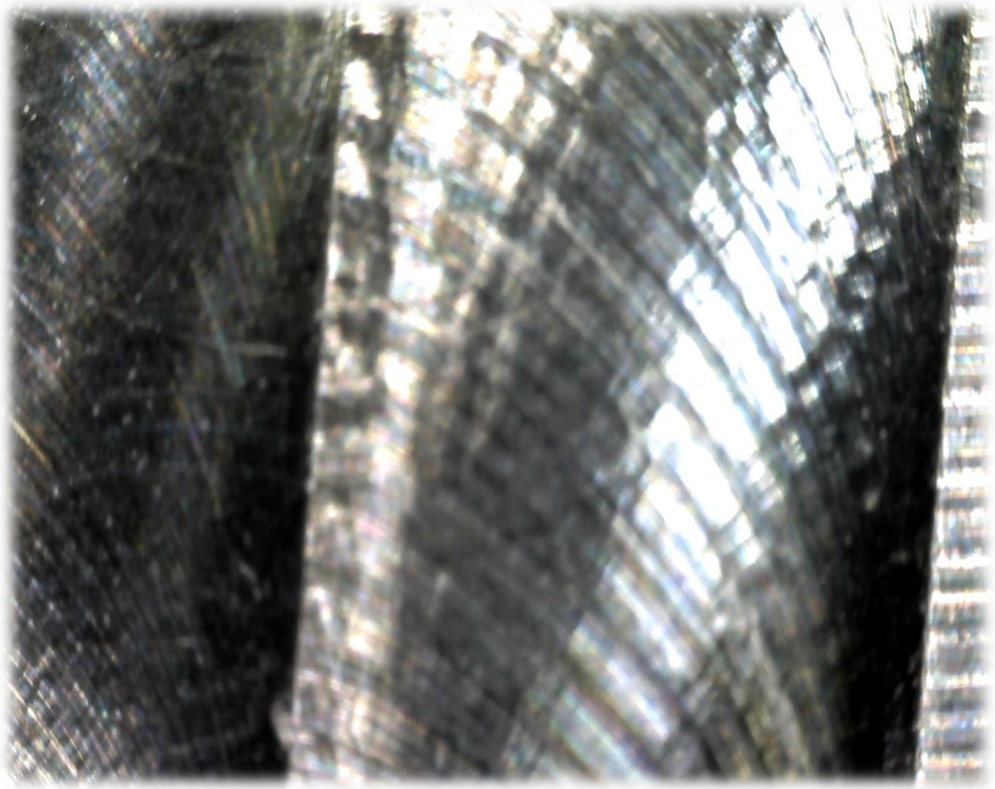
- Surface Quality



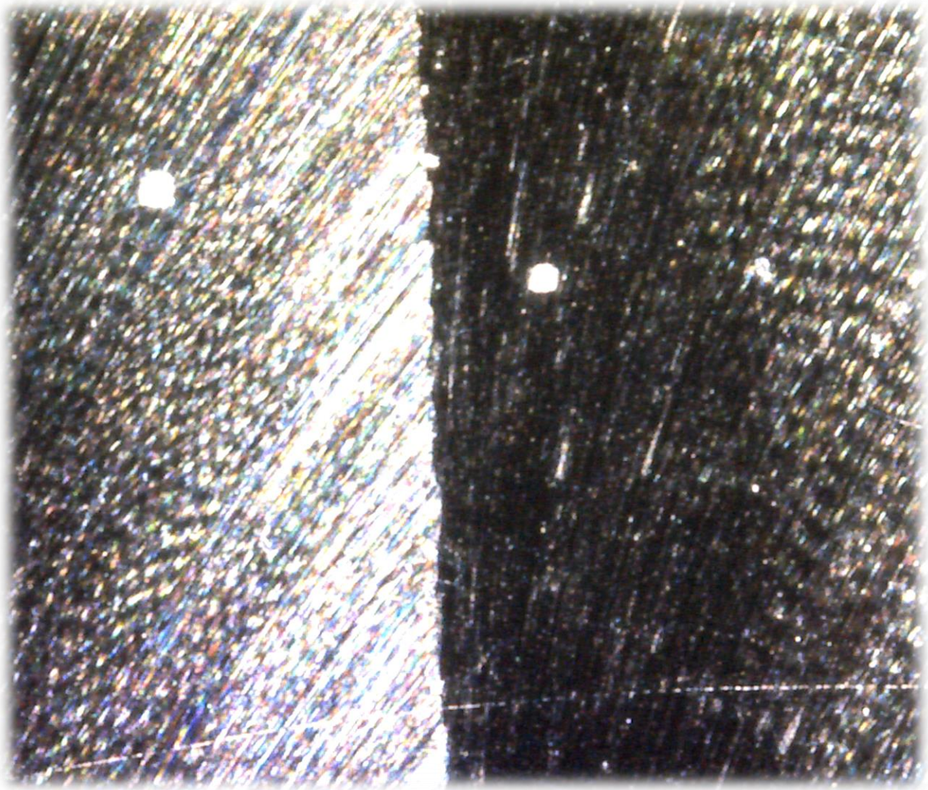


Inconel 718 - Improved Approach Results

- EN24T Parameters

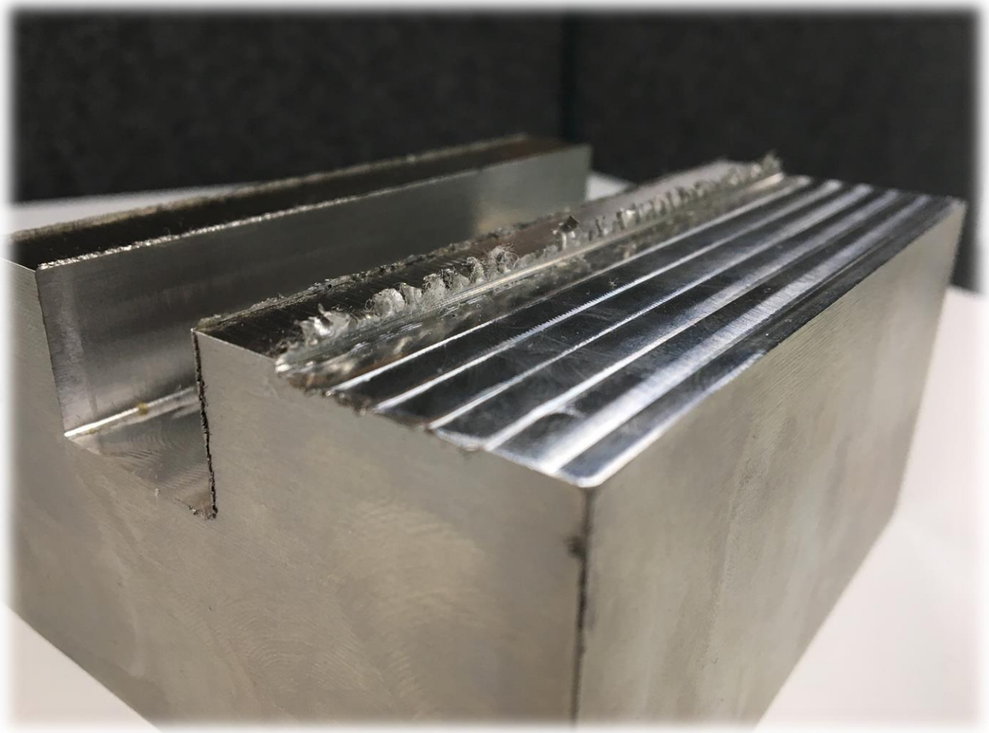


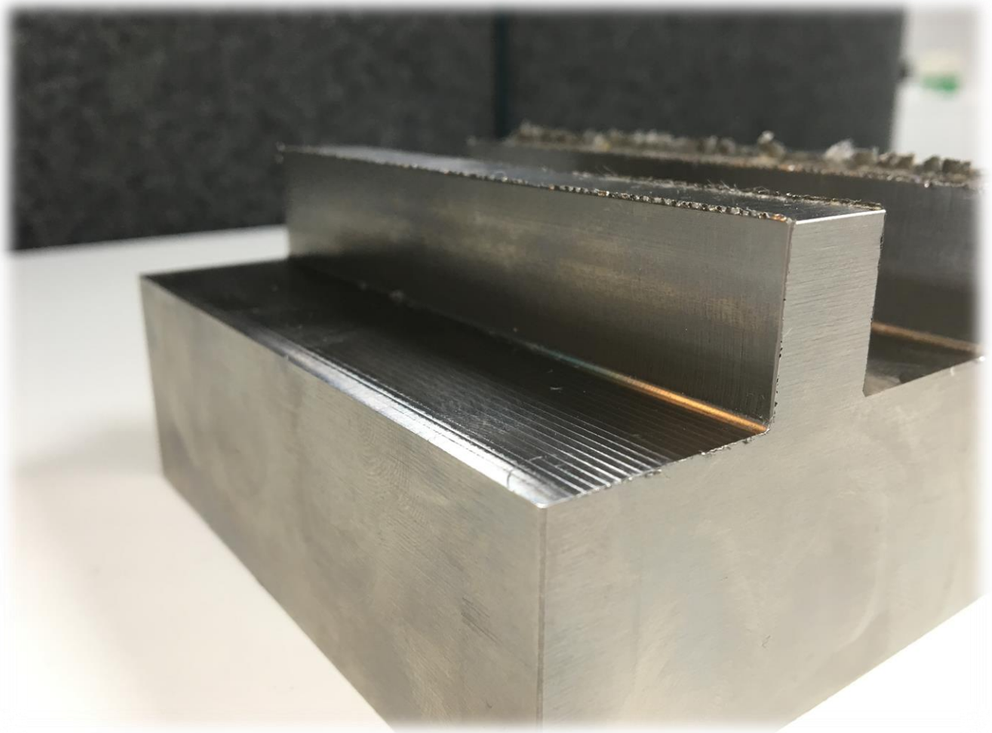
- Improved Parameters



Inconel 718 - Results

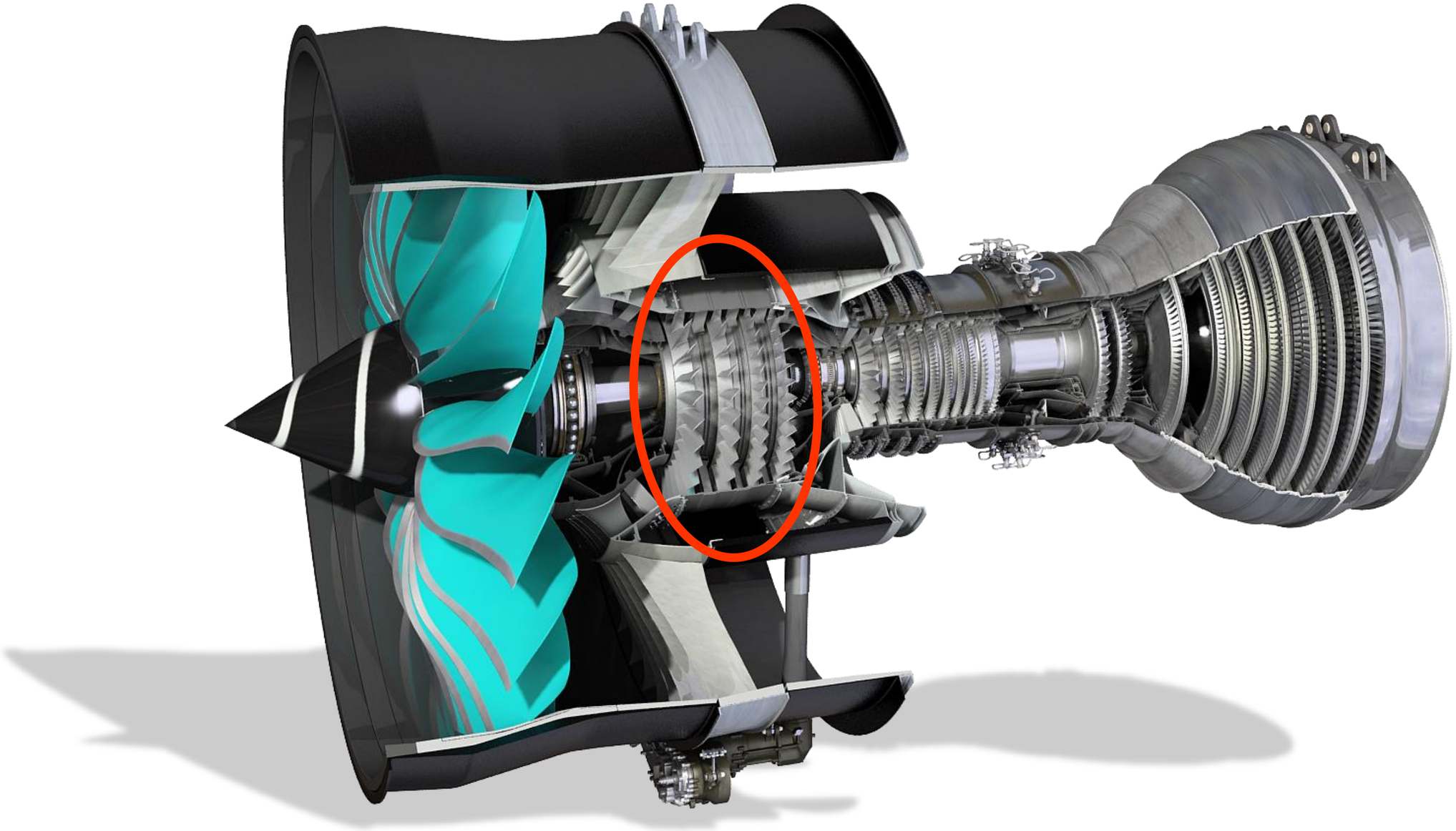
- Machined Block



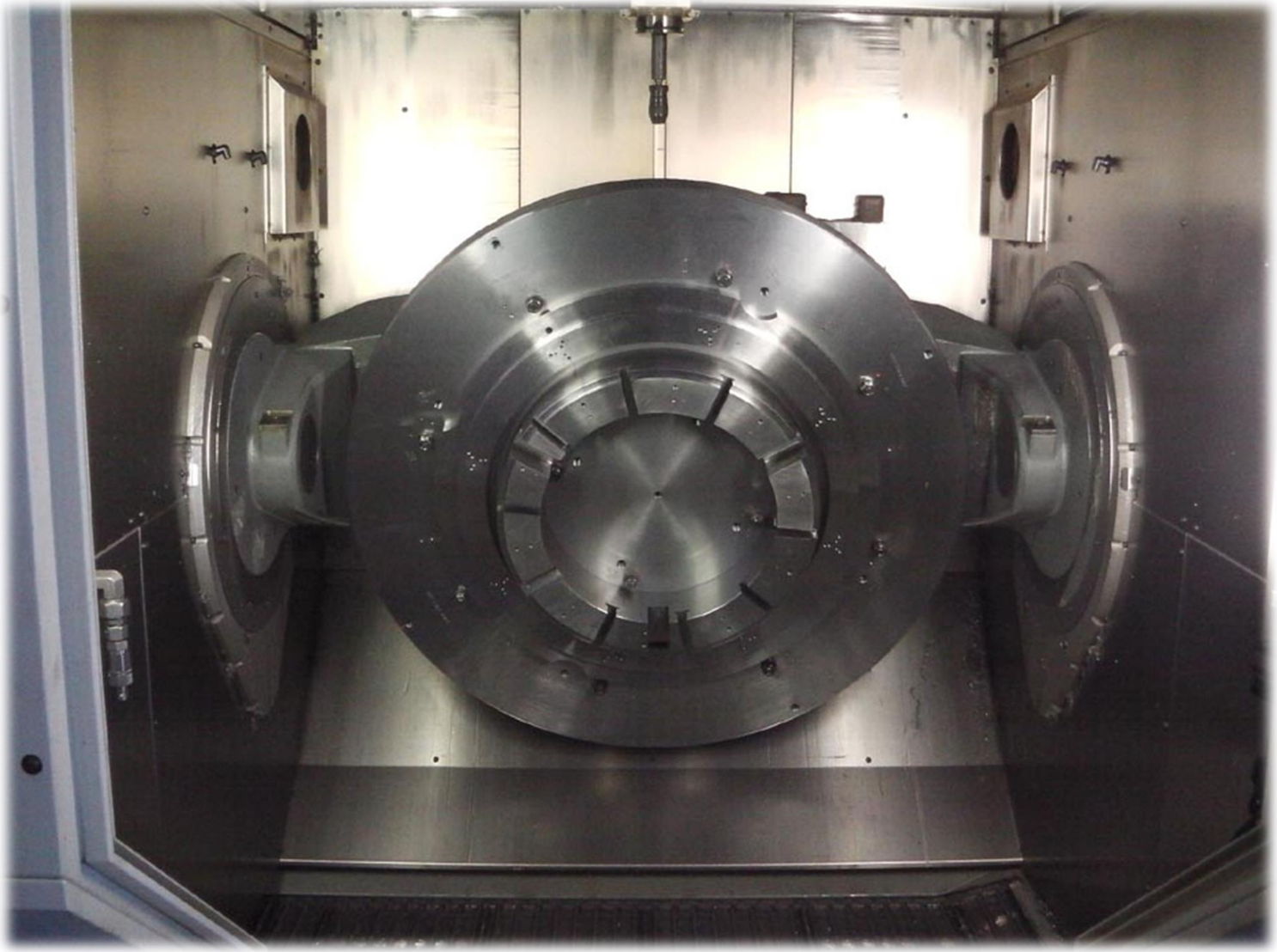


Manufacturing The Advance3 Blisk

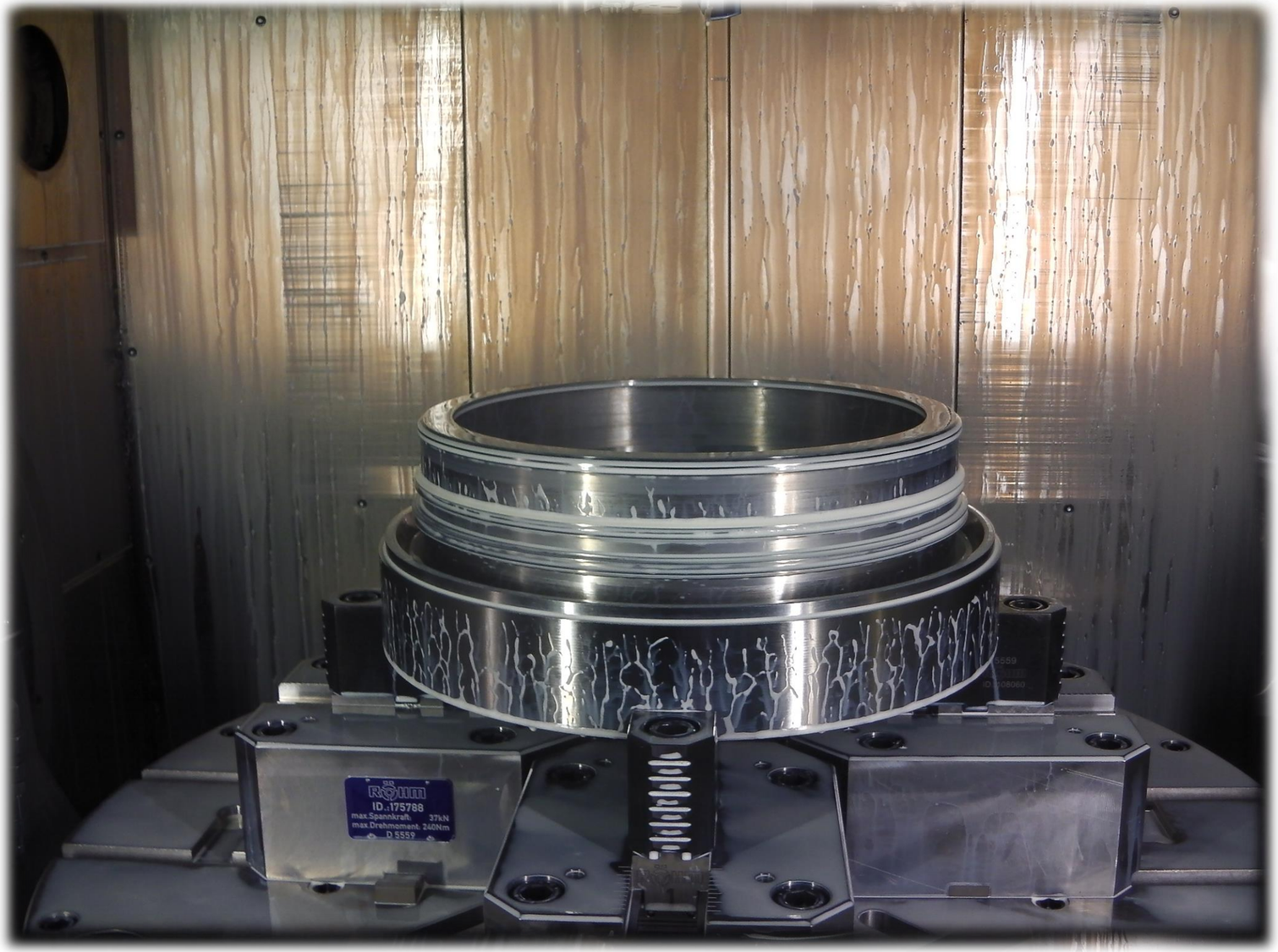
Manufacturing The Advance3 Blisk

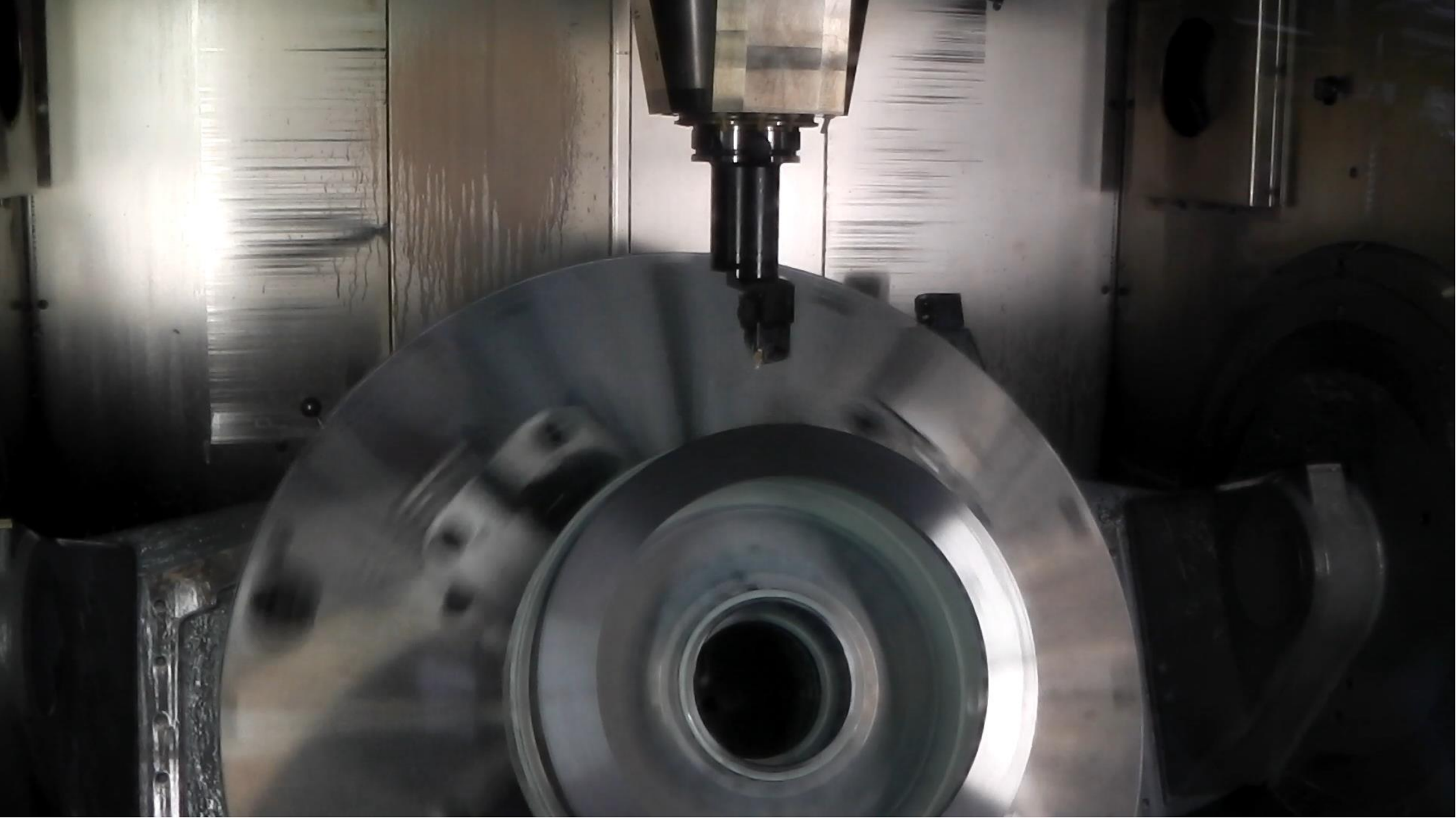


Manufacturing The Advance3 Blisk

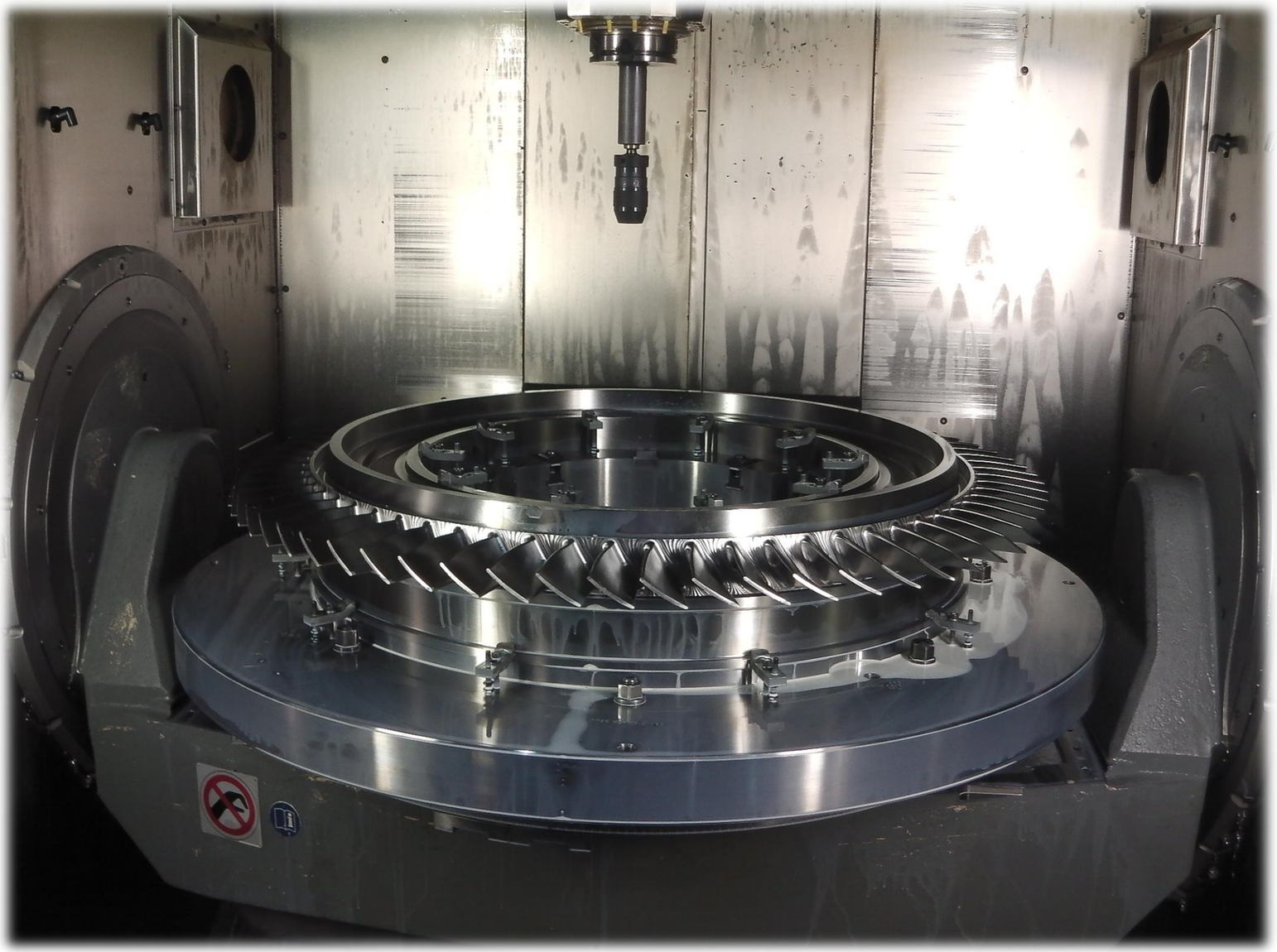


Manufacturing The Advance3 Blisk





Manufacturing The Advance3 Blisk



Manufacturing The Advance3 Blisk

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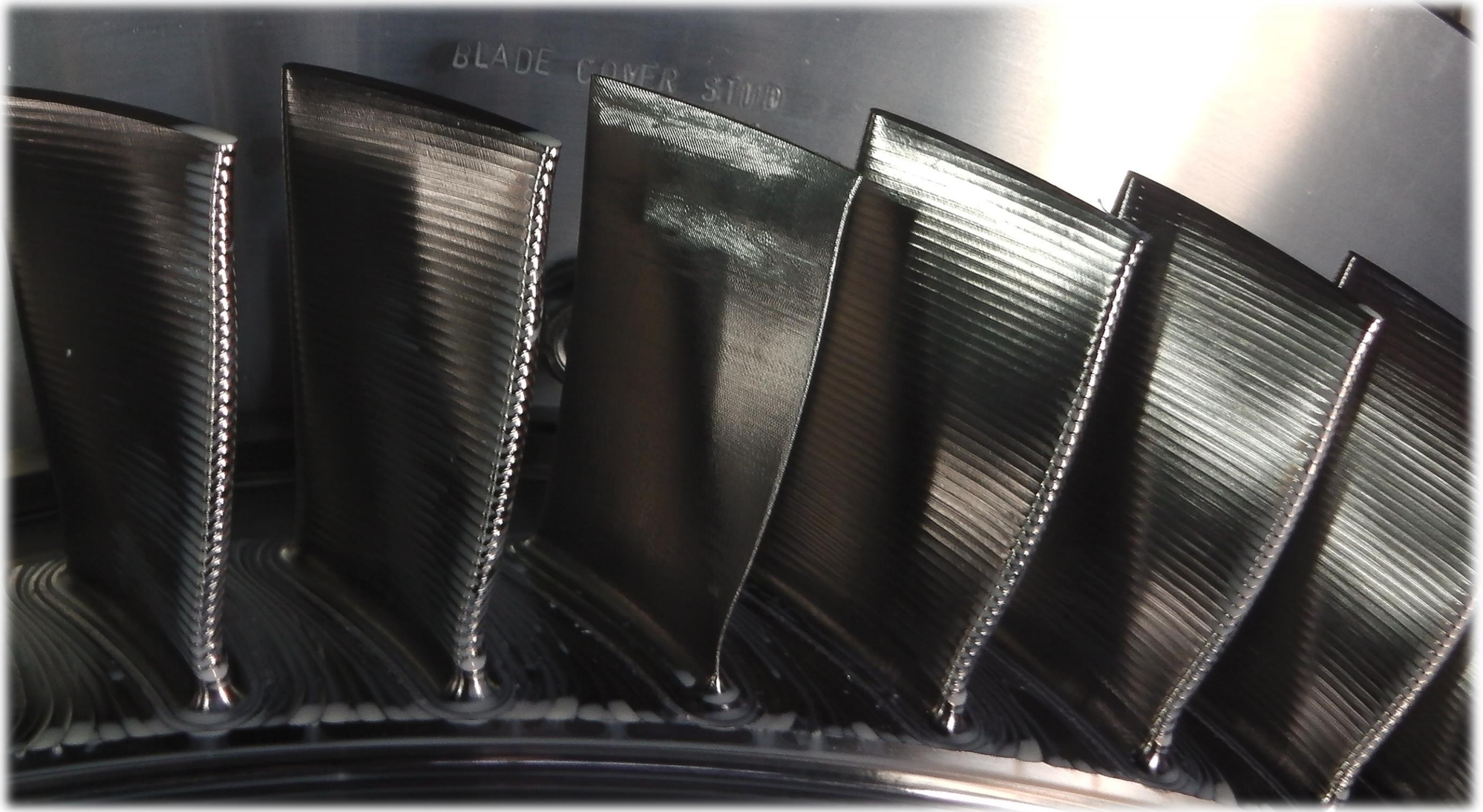
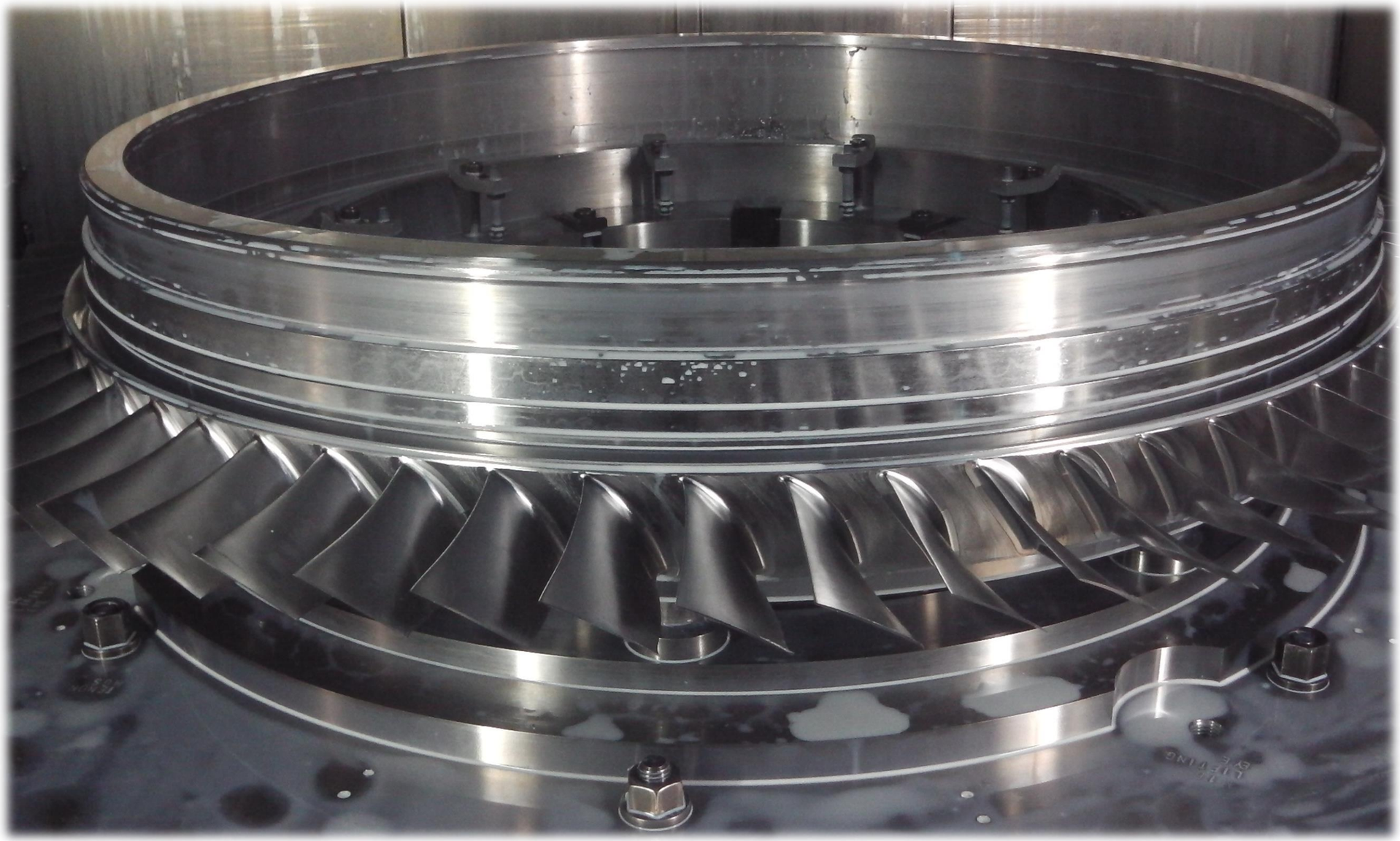
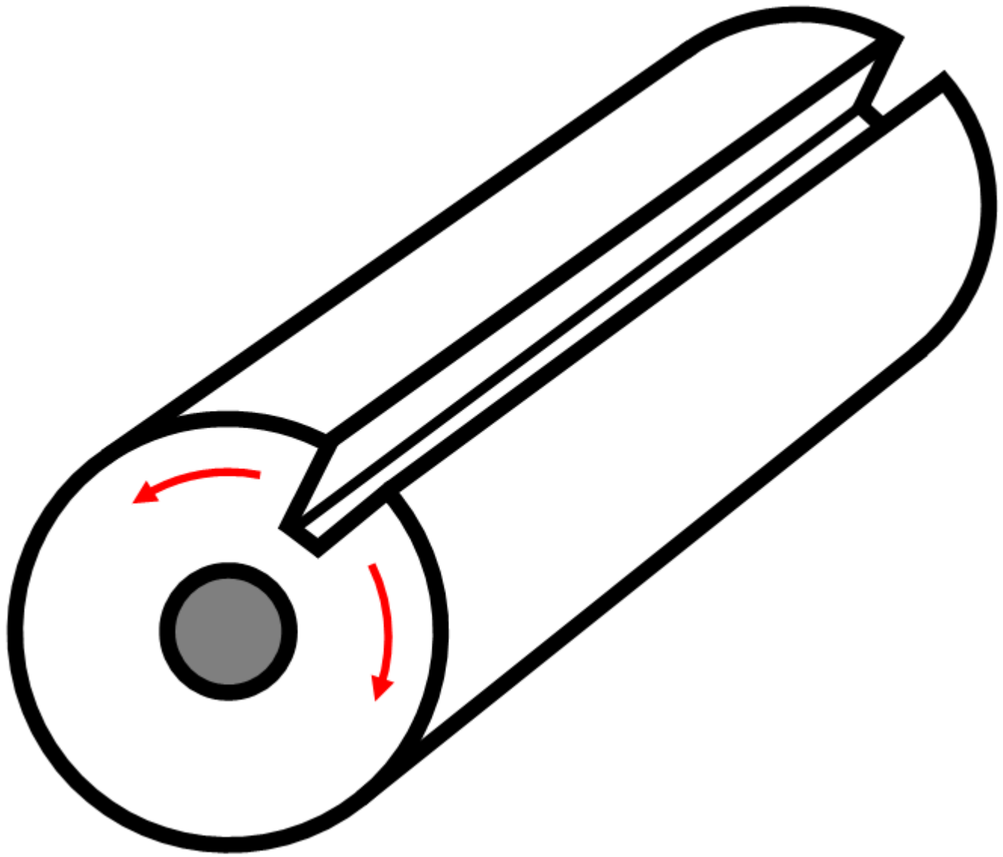


Manufacturing The Advance3 Blisk



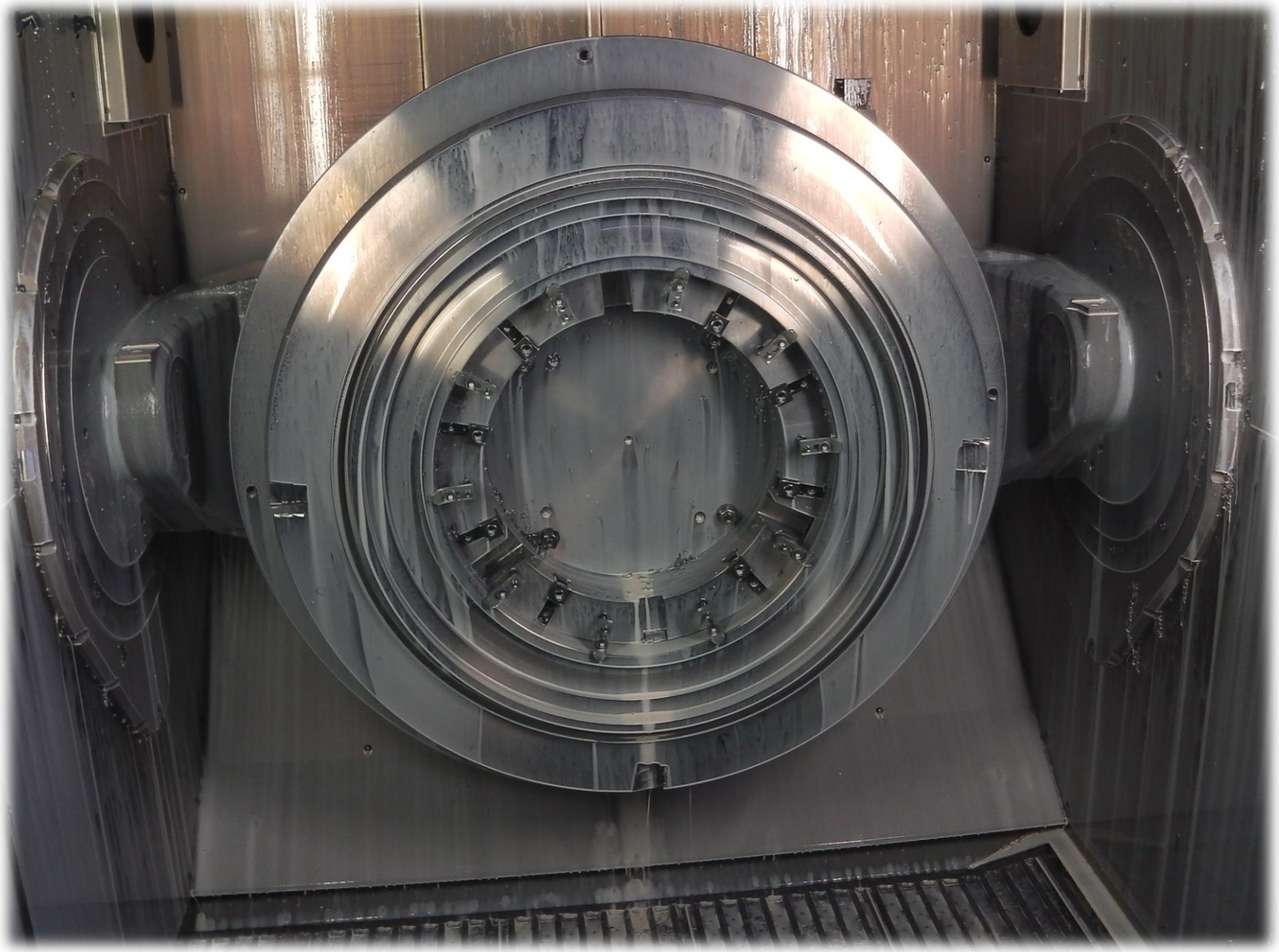
Manufacturing The Advance3 Blisk - Knowledge Gained

- Relieving hoop stress



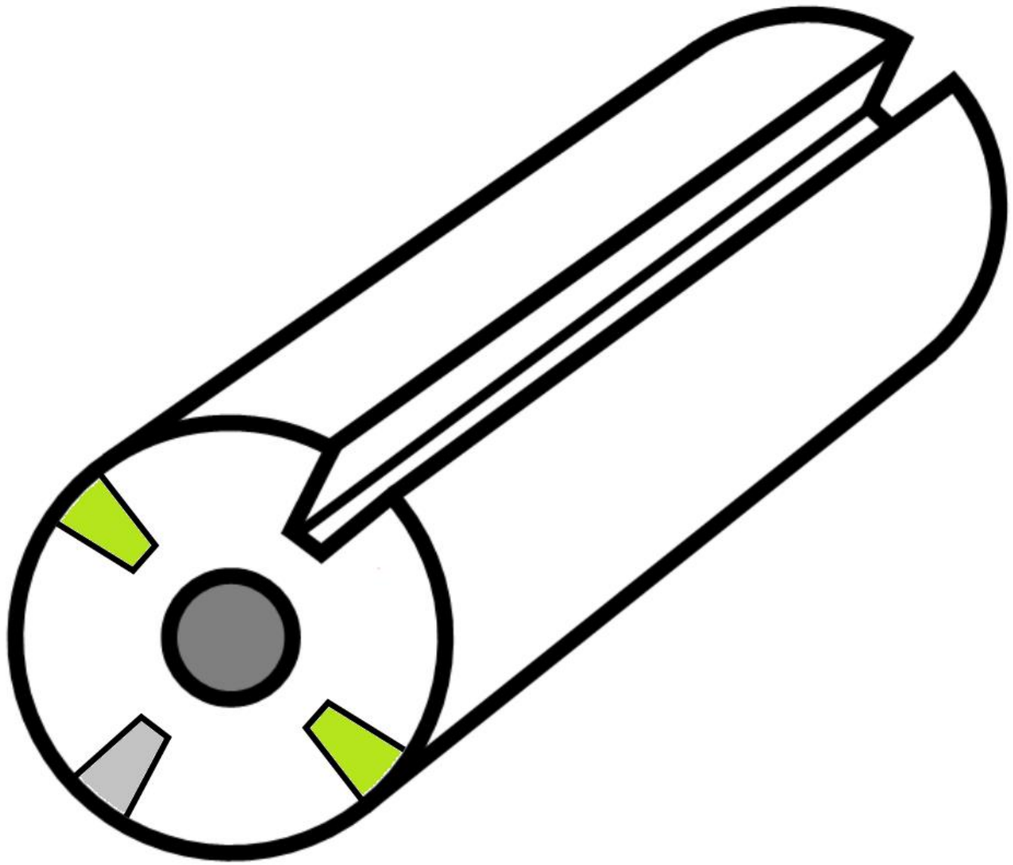
Manufacturing The Advance3 Blisk - Knowledge Gained

- Relieving hoop stress



Manufacturing The Advance3 Blisk - Knowledge Gained

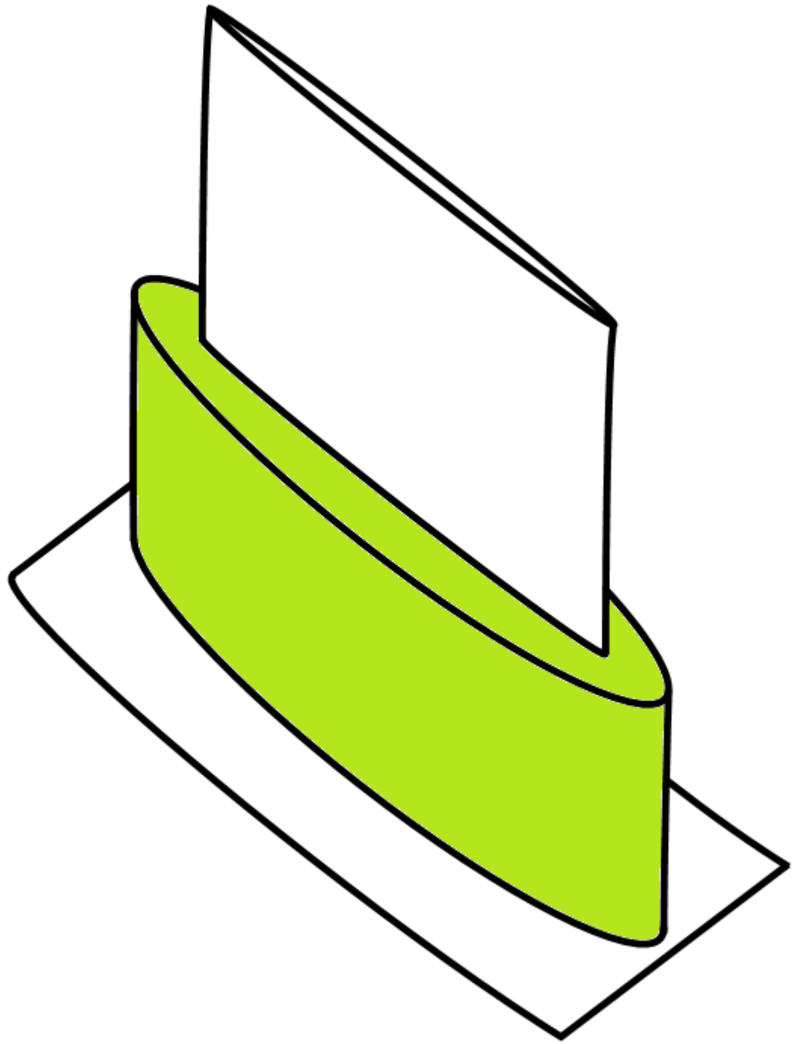
- Relieving hoop stress



Manufacturing The Advance3 Blisk - Knowledge Gained

- Relieving hoop stress

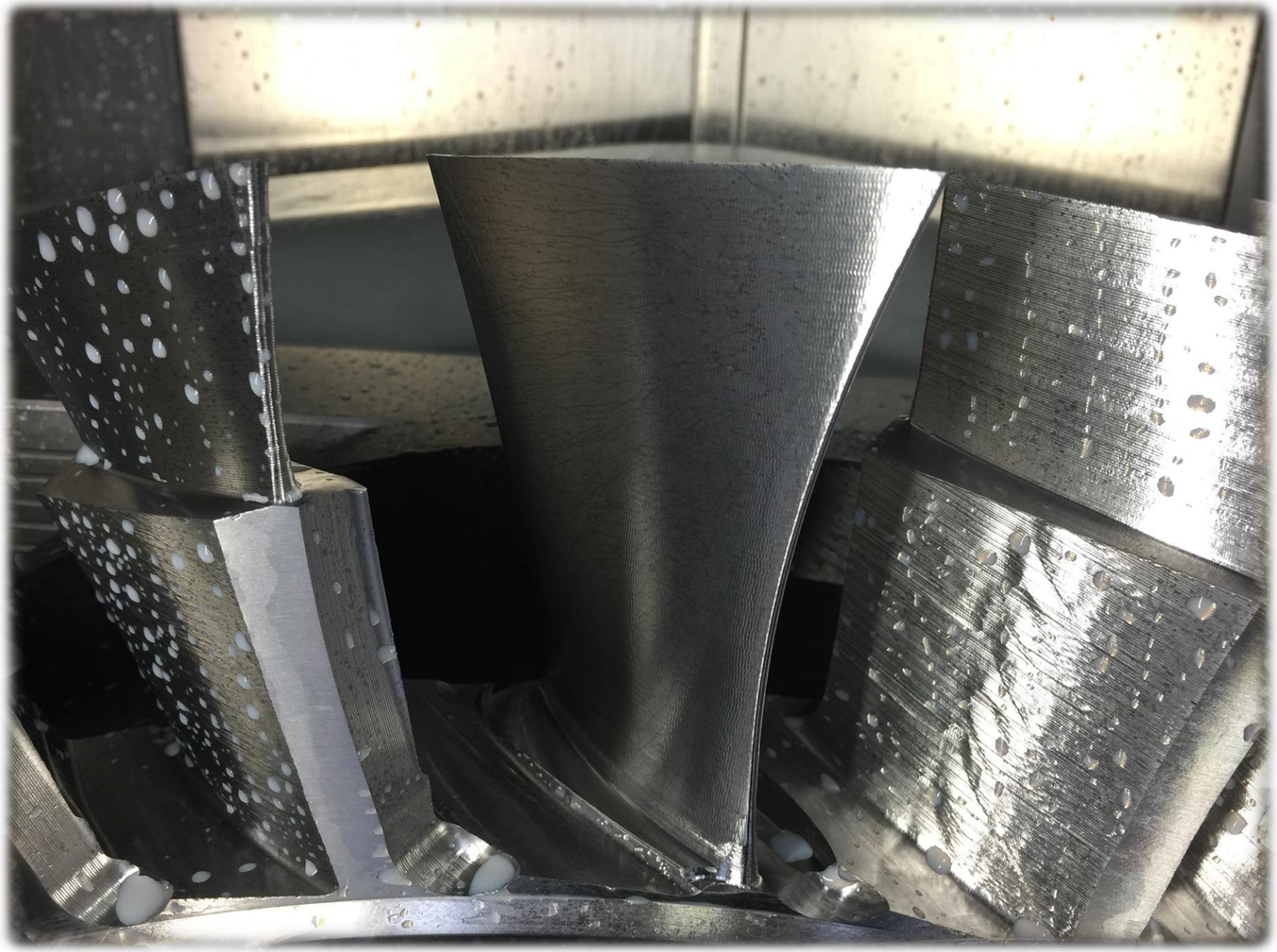
- Use of blade monoliths



Manufacturing The Advance3 Blisk - Knowledge Gained

- Relieving hoop stress

- Use of blade monoliths

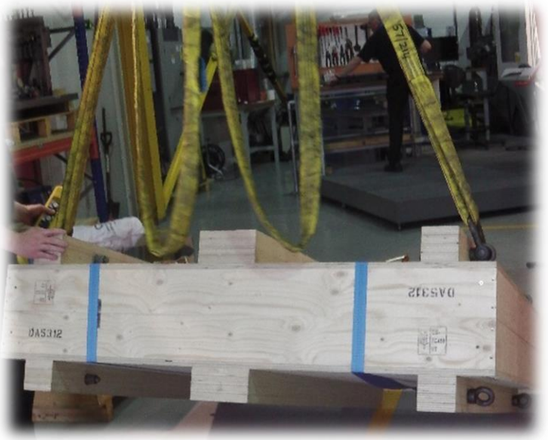


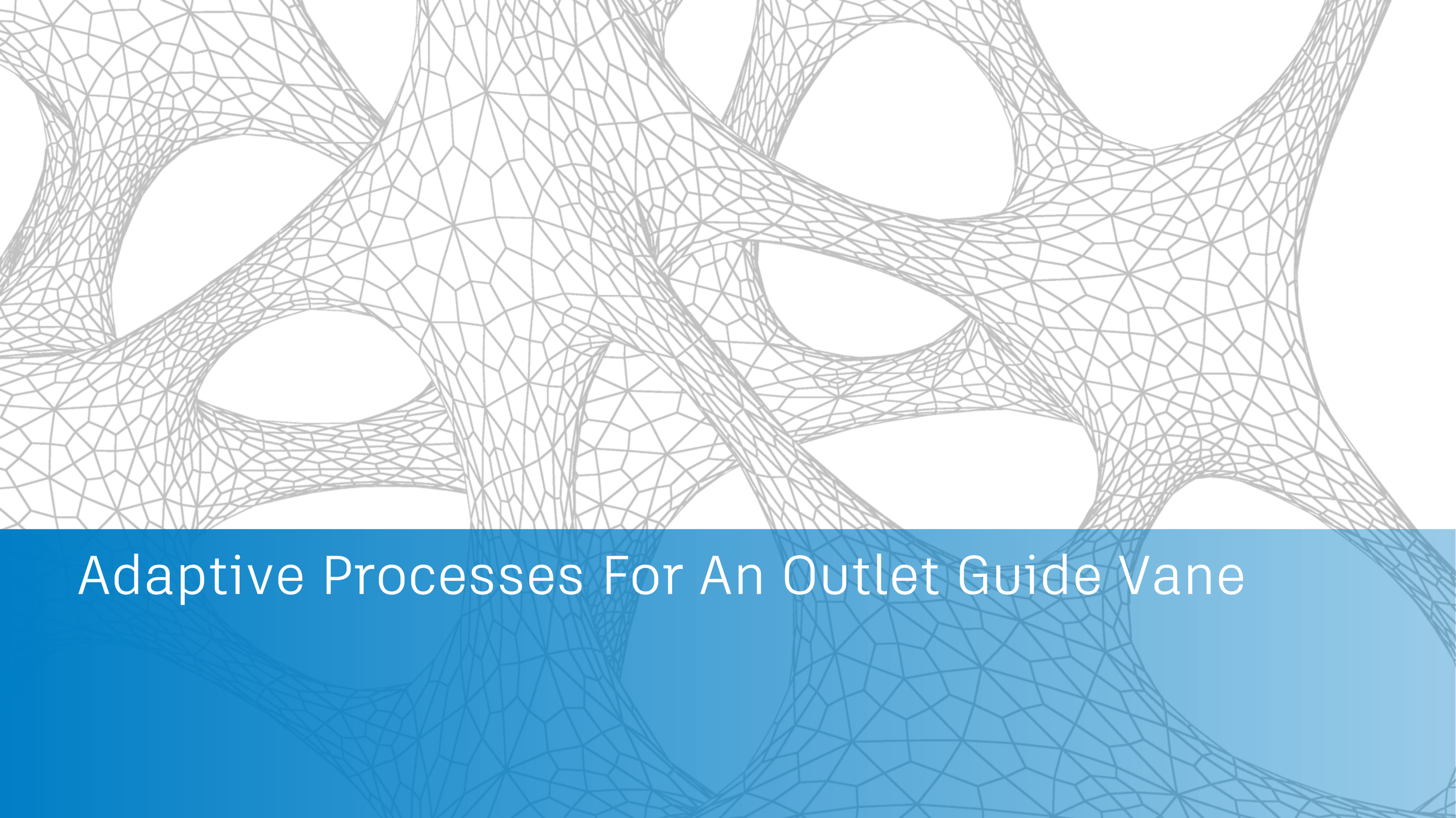
Manufacturing The Advance3 Blisk - Knowledge Gained

- Relieving hoop stress
- Use of blade monoliths
- Using test blocks

Manufacturing The Advance3 Blisk - Knowledge Gained

- Relieving hoop stress
- Use of blade monoliths
- Using test blocks
- Safe part handling

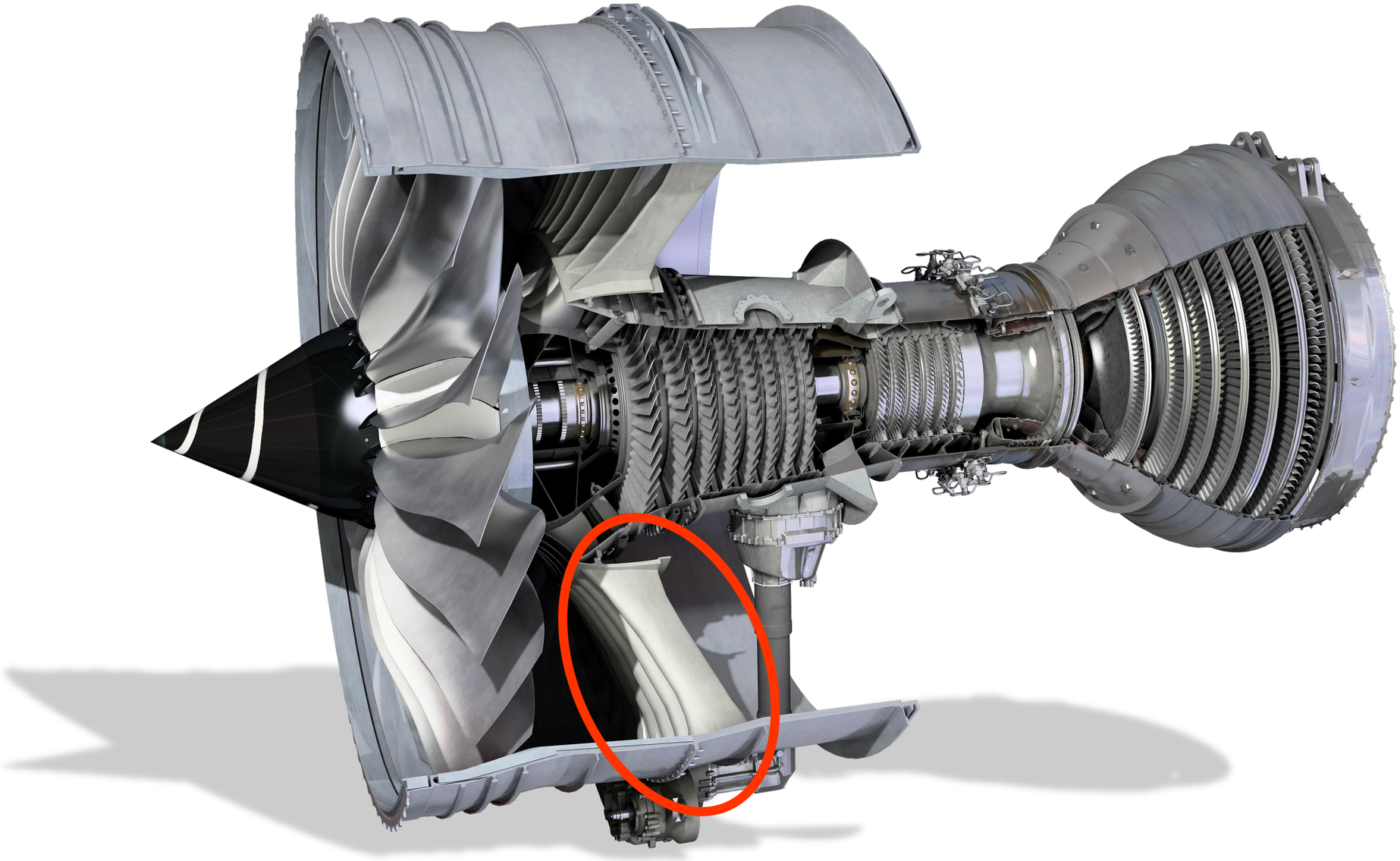




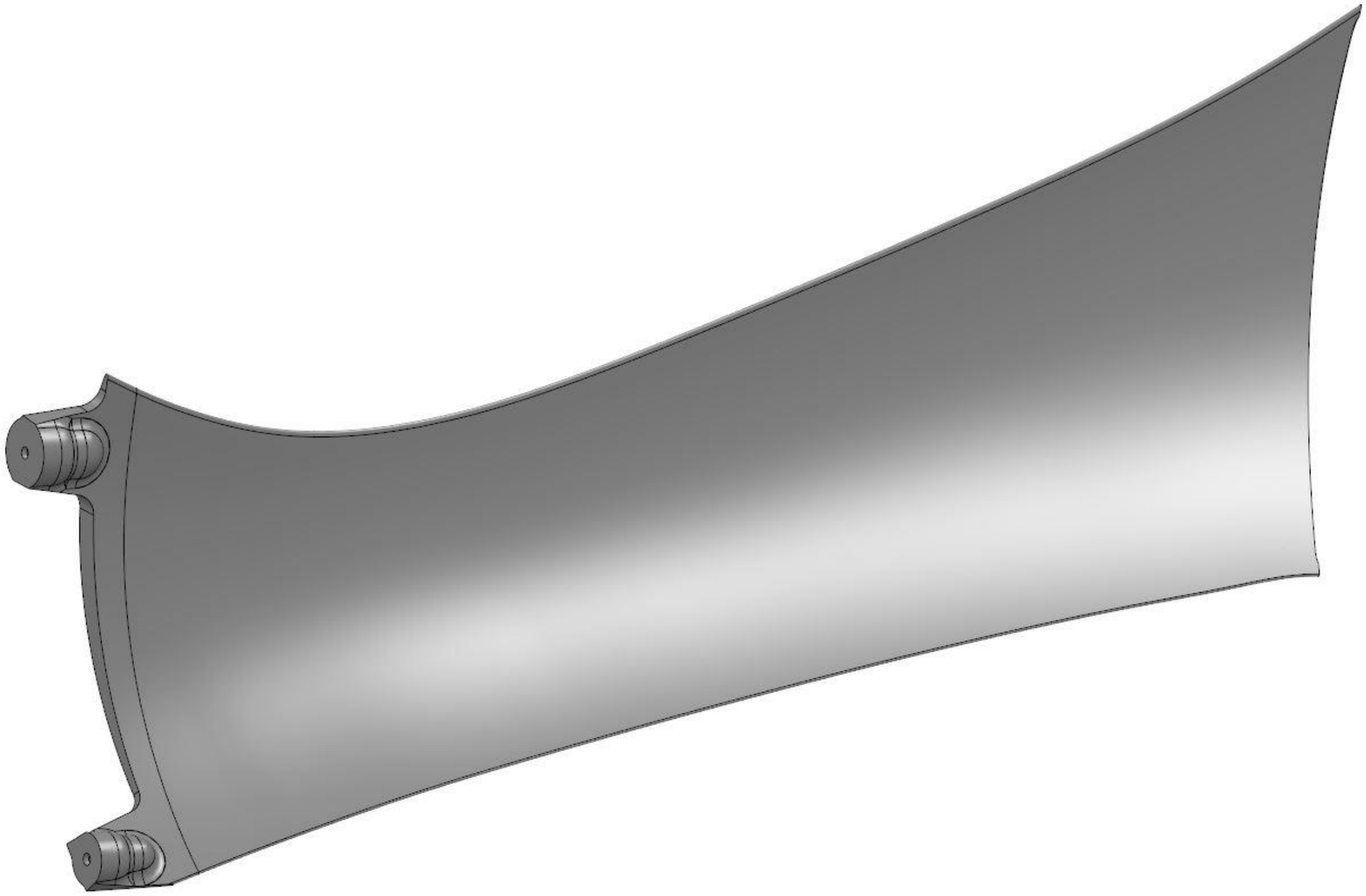
Adaptive Processes For An Outlet Guide Vane

Adaptive Processes for an Outlet Guide Vane

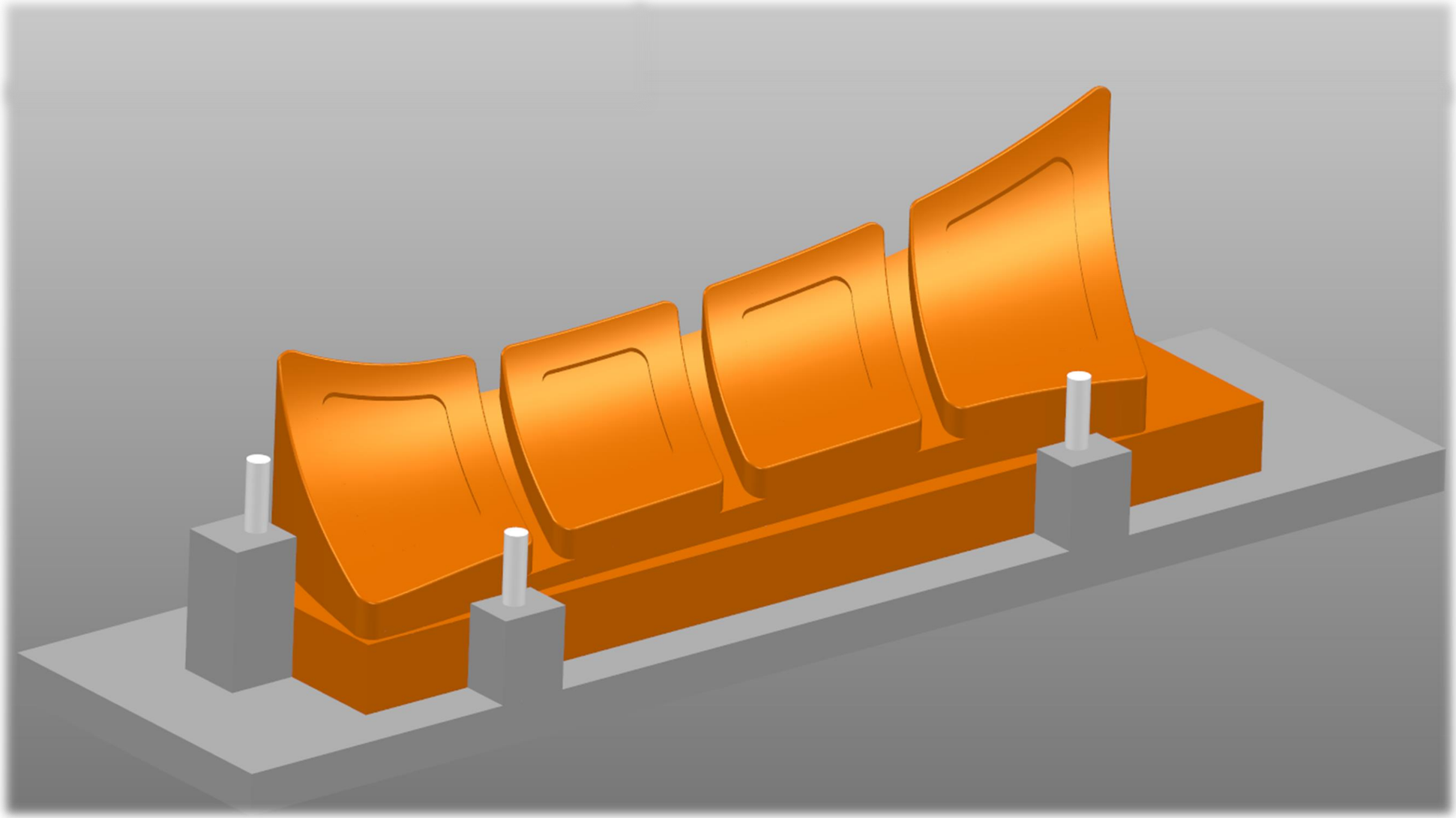
Adaptive Processes for an Outlet Guide Vane



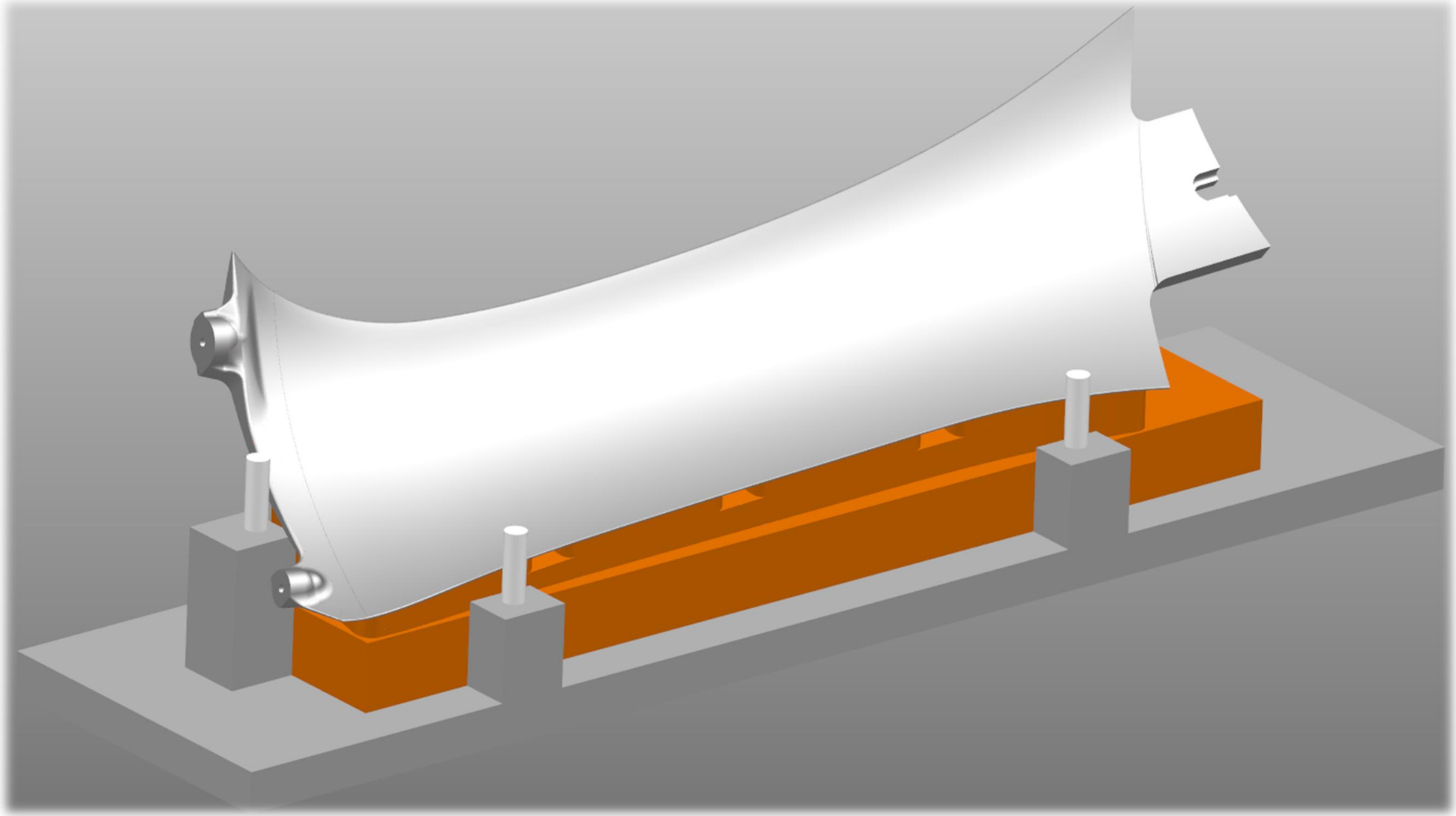
Adaptive Processes for an Outlet Guide Vane



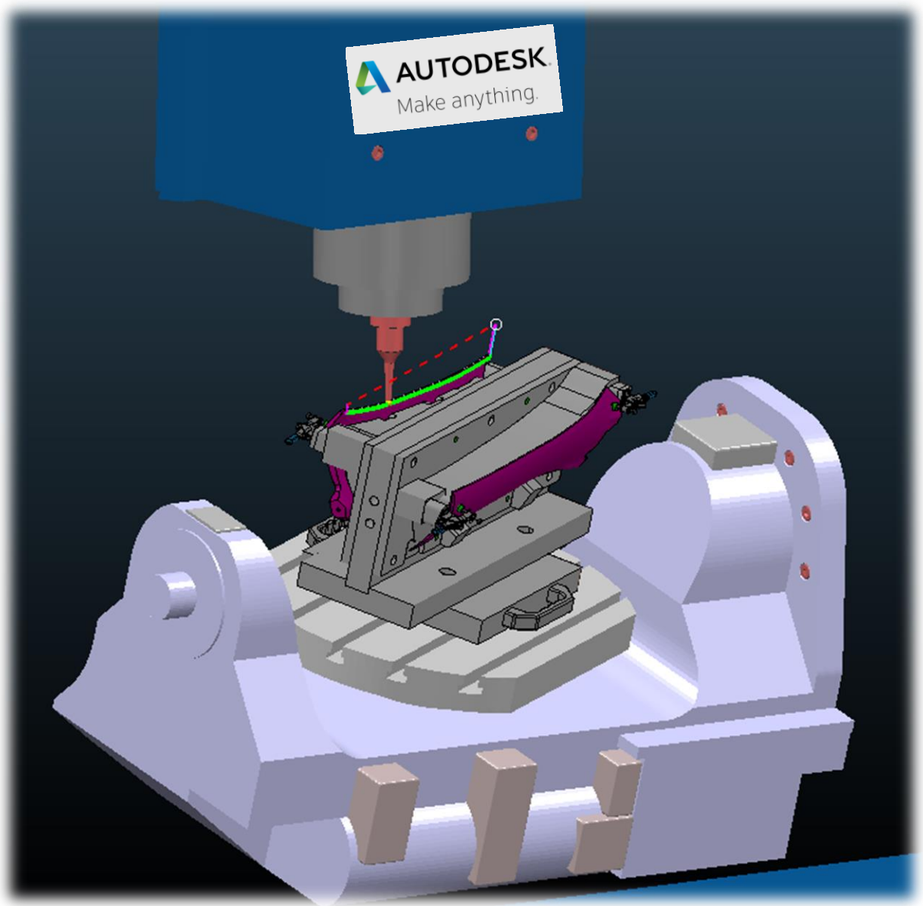
Adaptive Processes for an Outlet Guide Vane

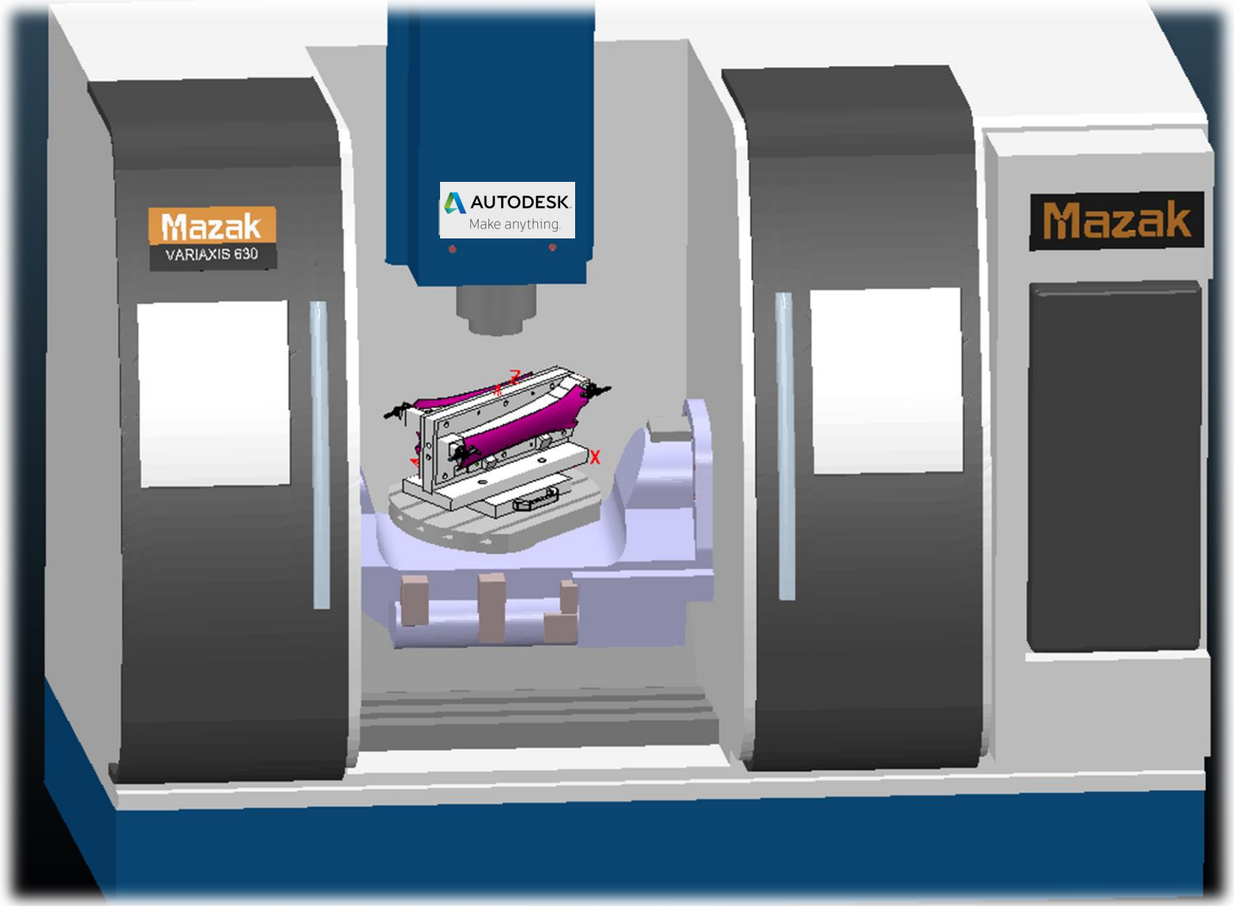


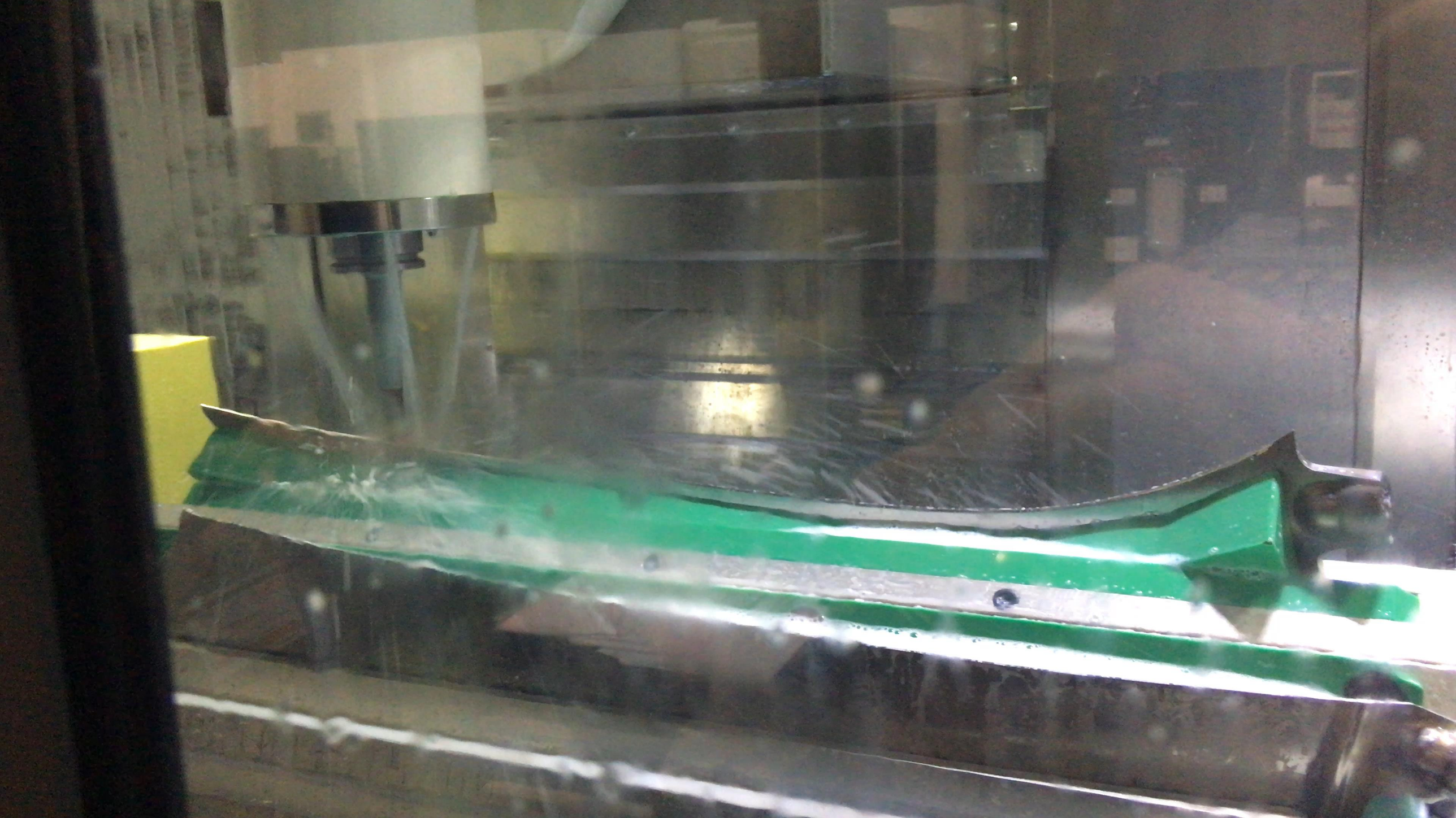
Adaptive Processes for an Outlet Guide Vane



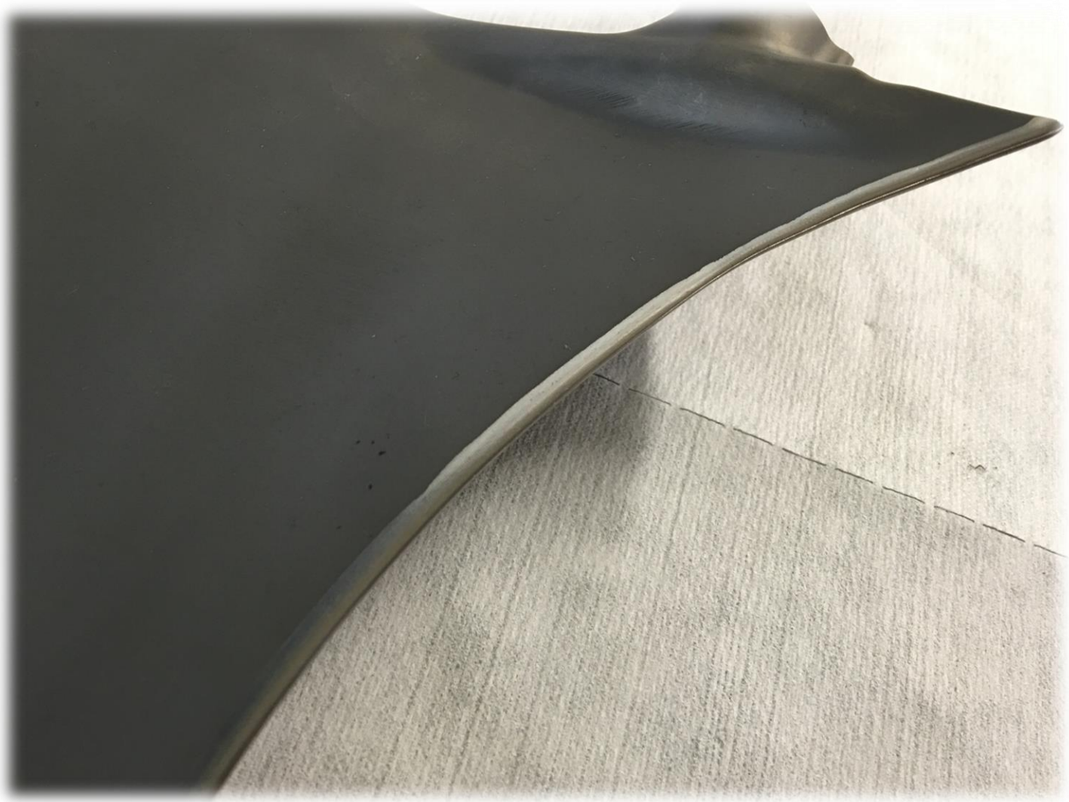
Adaptive Processes for an Outlet Guide Vane

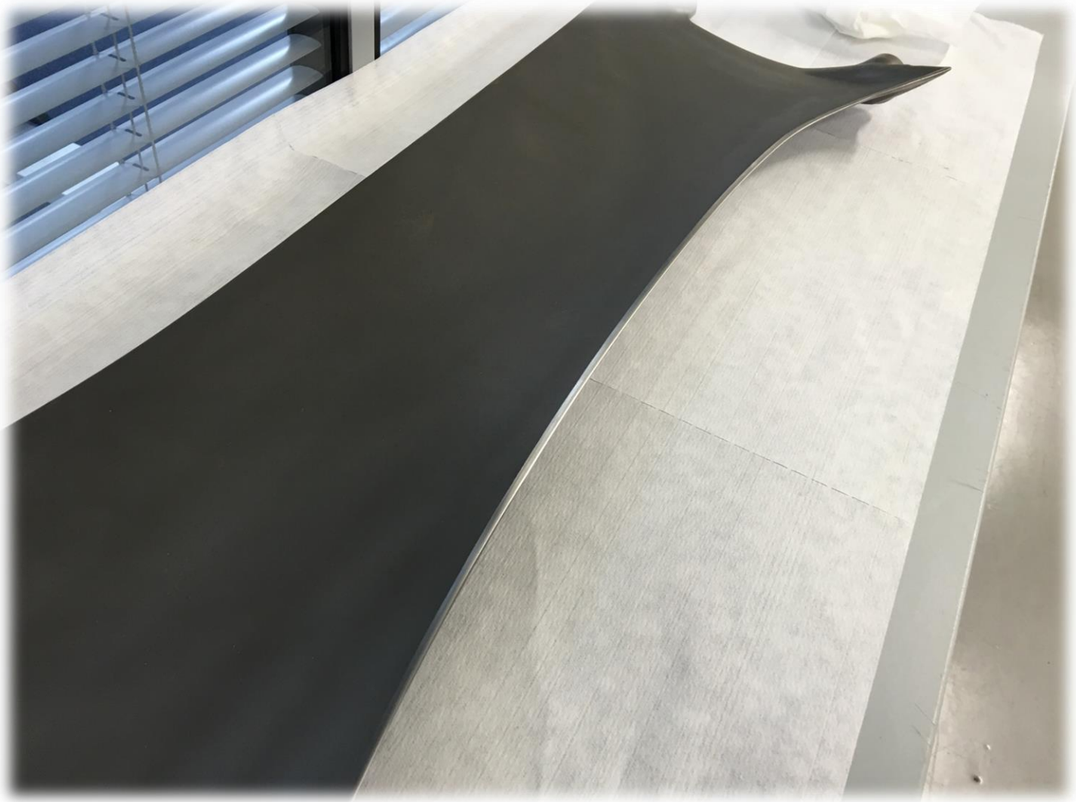


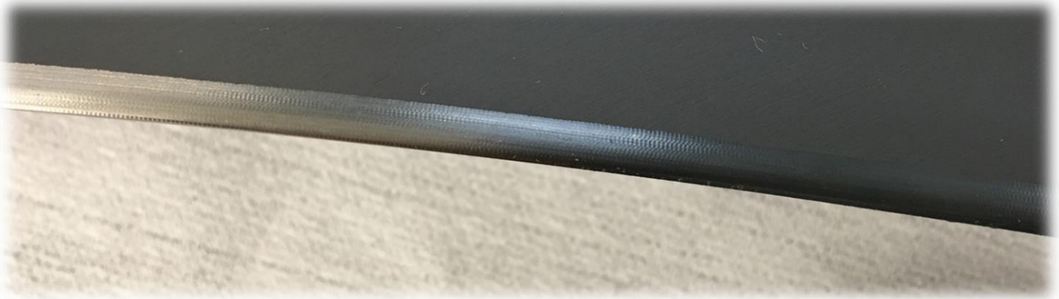




Adaptive Processes for an Outlet Guide Vane

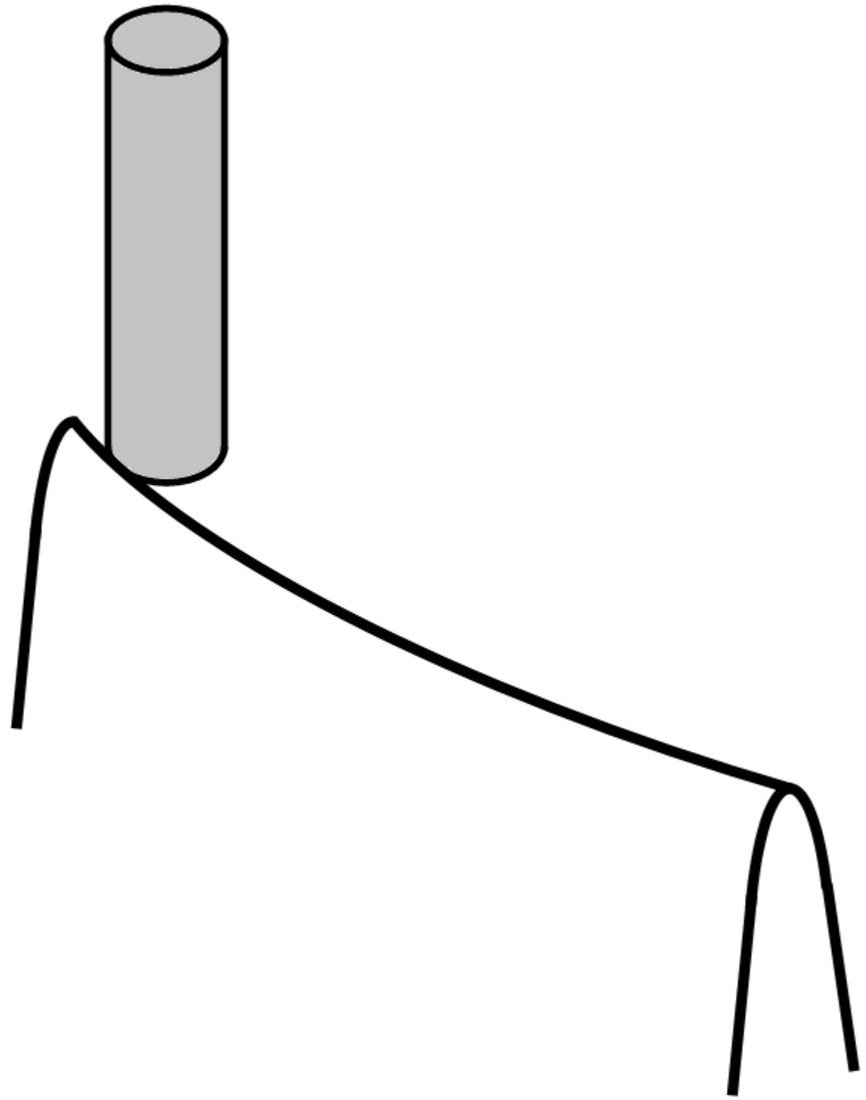






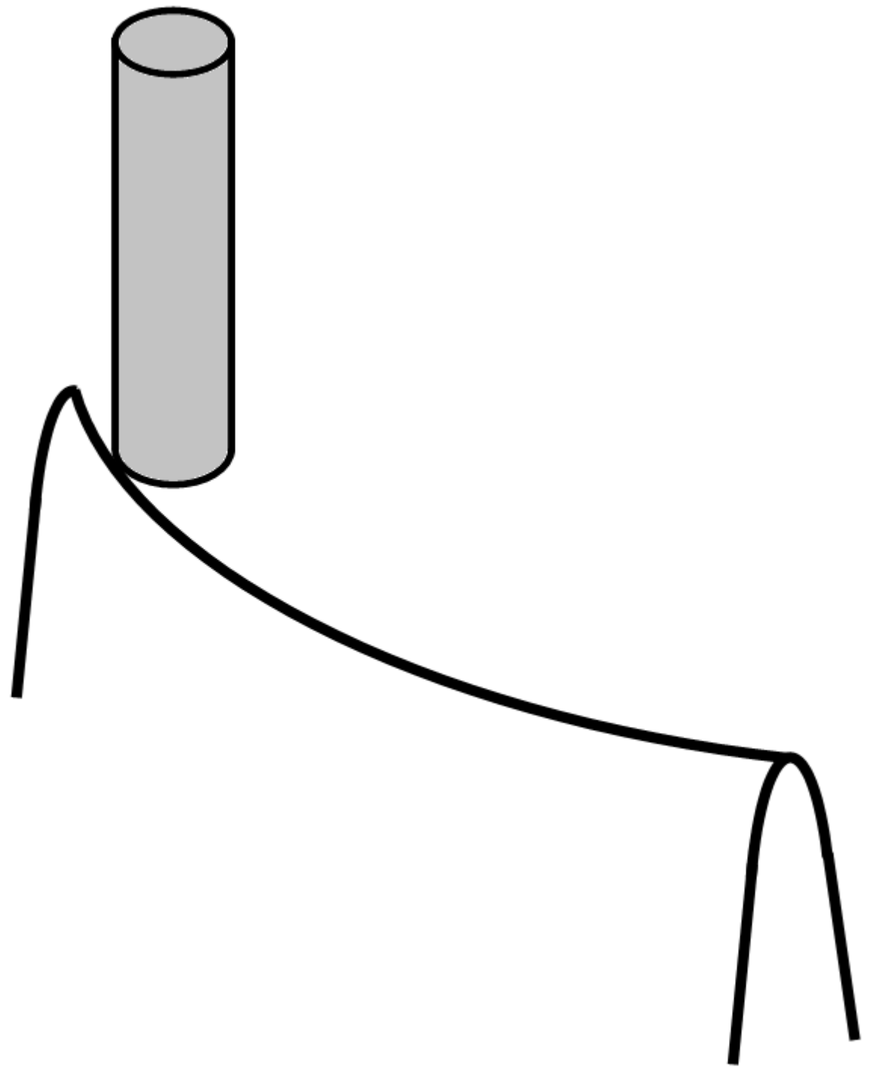
Adaptive Processes for an Outlet Guide Vane - Knowledge Gained

- Adapting toolpaths



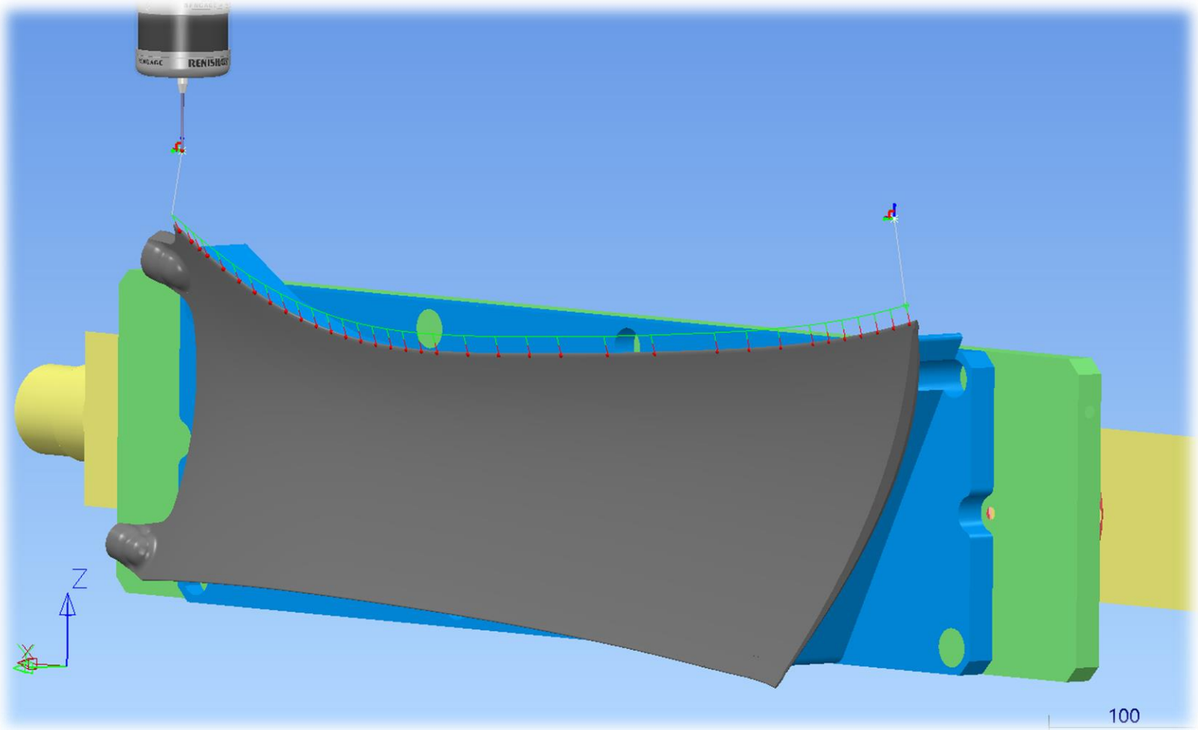
Adaptive Processes for an Outlet Guide Vane - Knowledge Gained

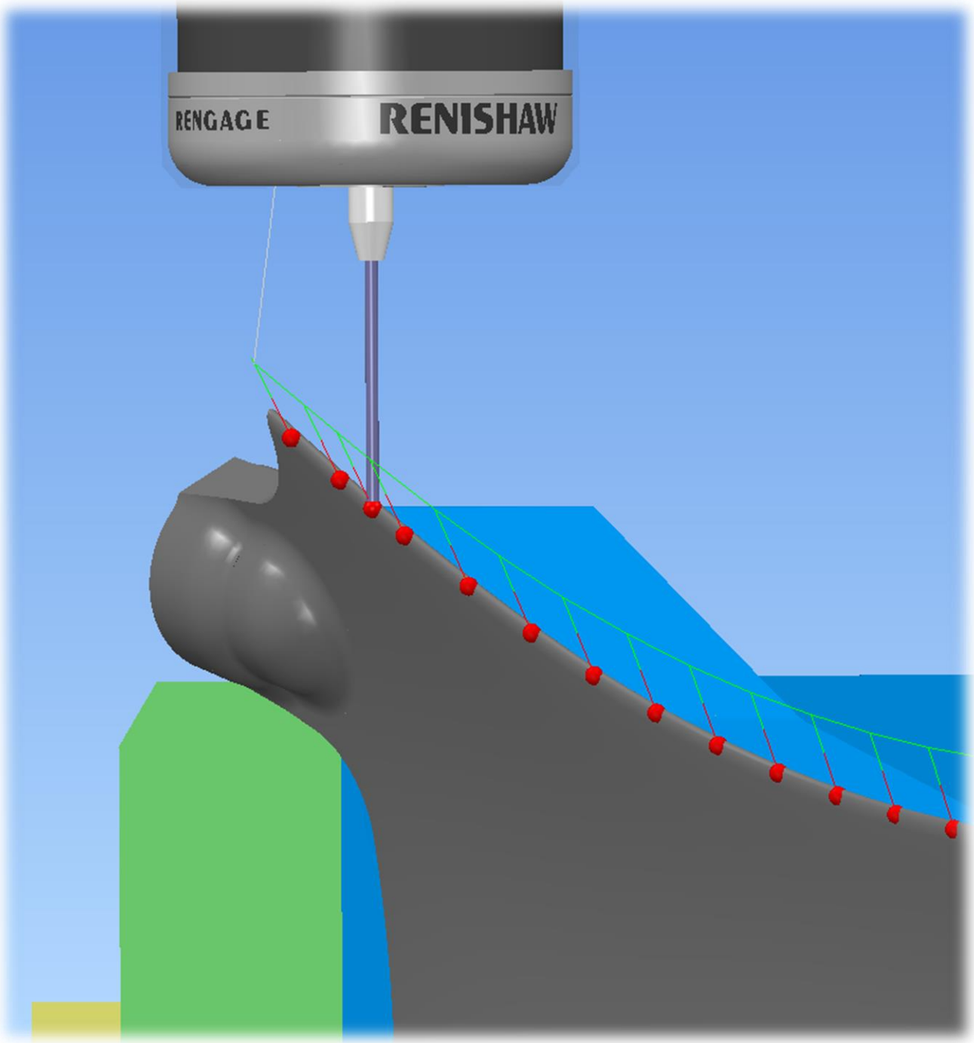
- Adapting toolpaths



Adaptive Processes for an Outlet Guide Vane - Knowledge Gained

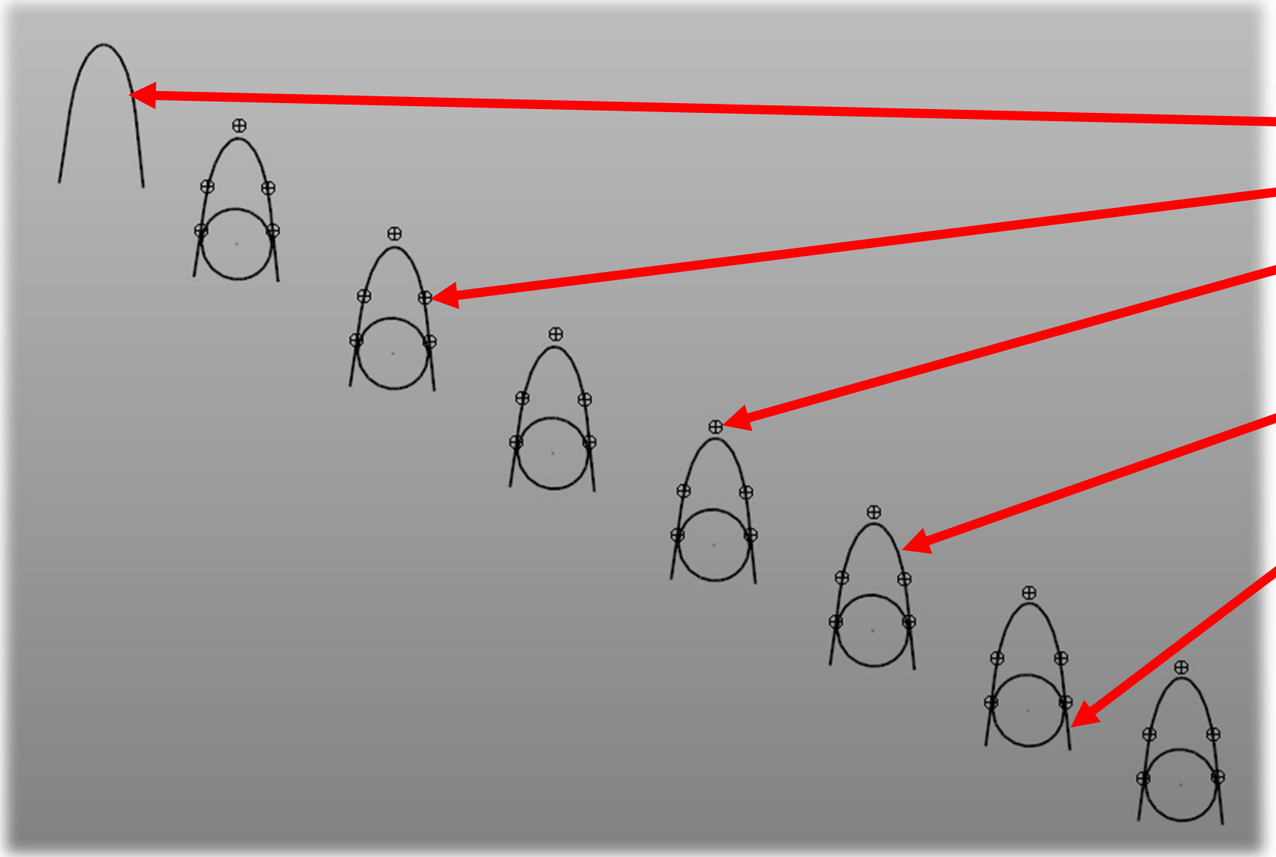
- Adapting toolpaths





Adaptive Processes for an Outlet Guide Vane - Knowledge Gained

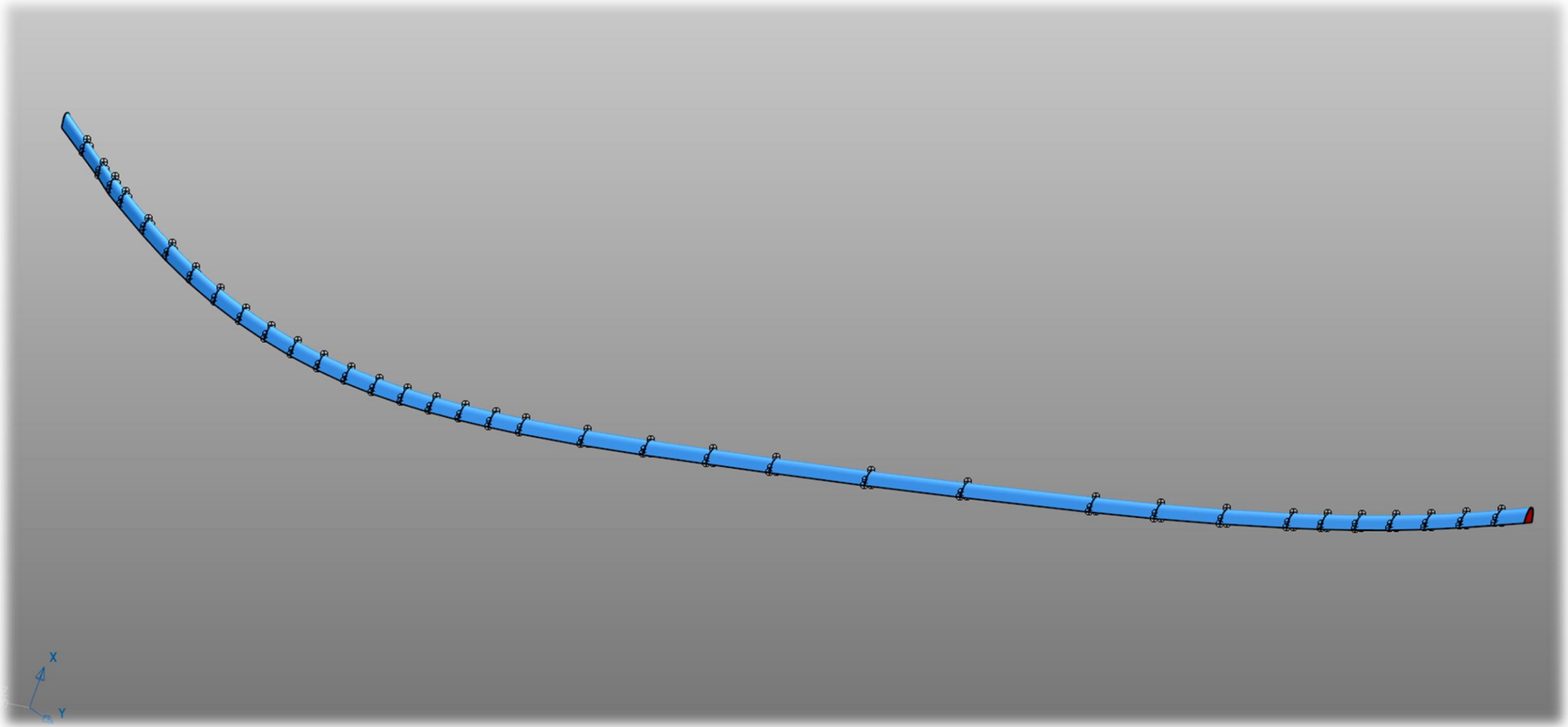
- Adapting toolpaths



1. Cloned extension section
2. Side measurements
3. Leading edge measurements
4. Elliptical comp. curve section
5. Pig Tail flare

Adaptive Processes for an Outlet Guide Vane - Knowledge Gained

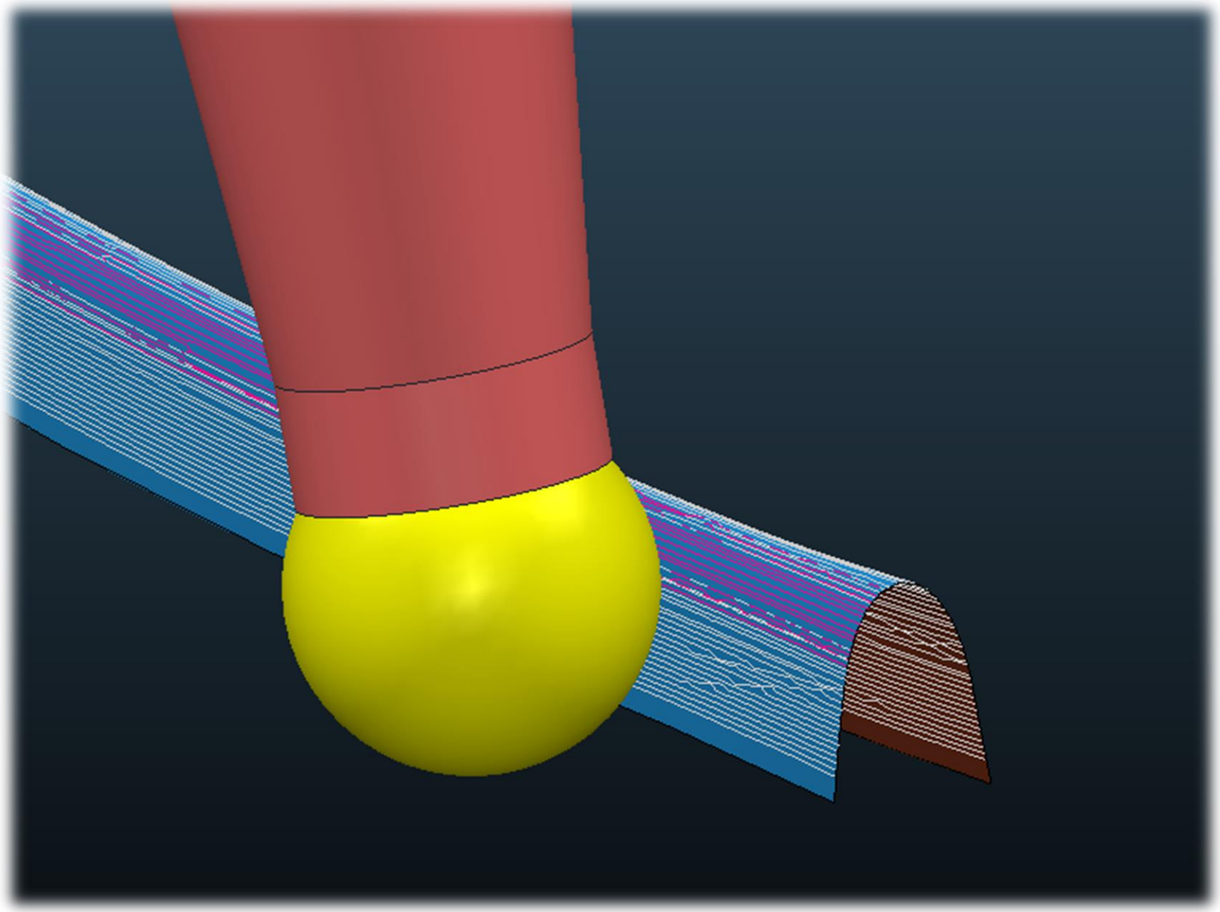
- Adapting toolpaths



Adaptive Processes for an Outlet Guide Vane - Knowledge Gained

- Adapting toolpaths

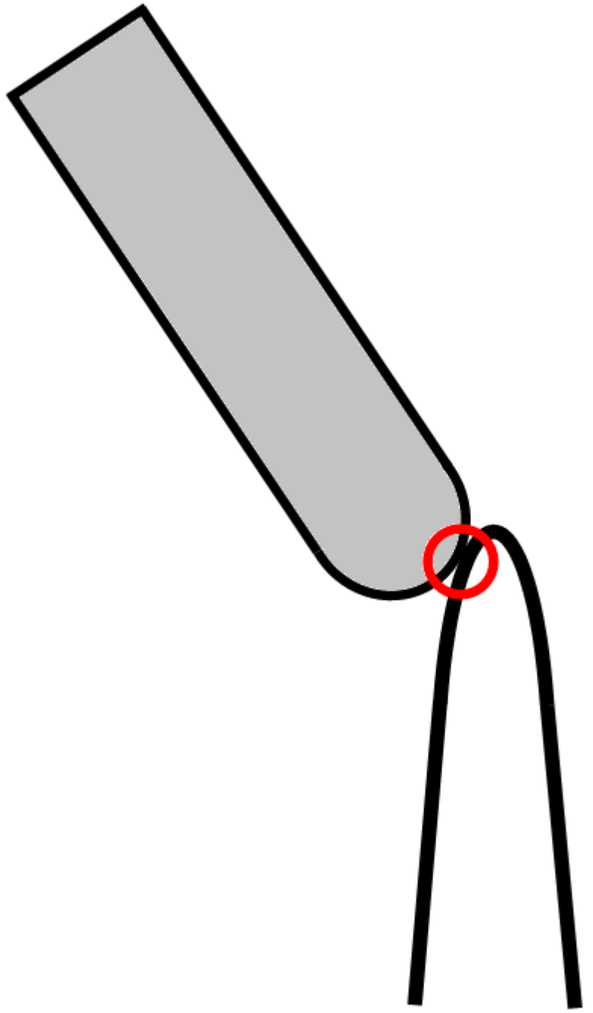
- Proper use of cutting tools



Adaptive Processes for an Outlet Guide Vane - Knowledge Gained

- Adapting toolpaths

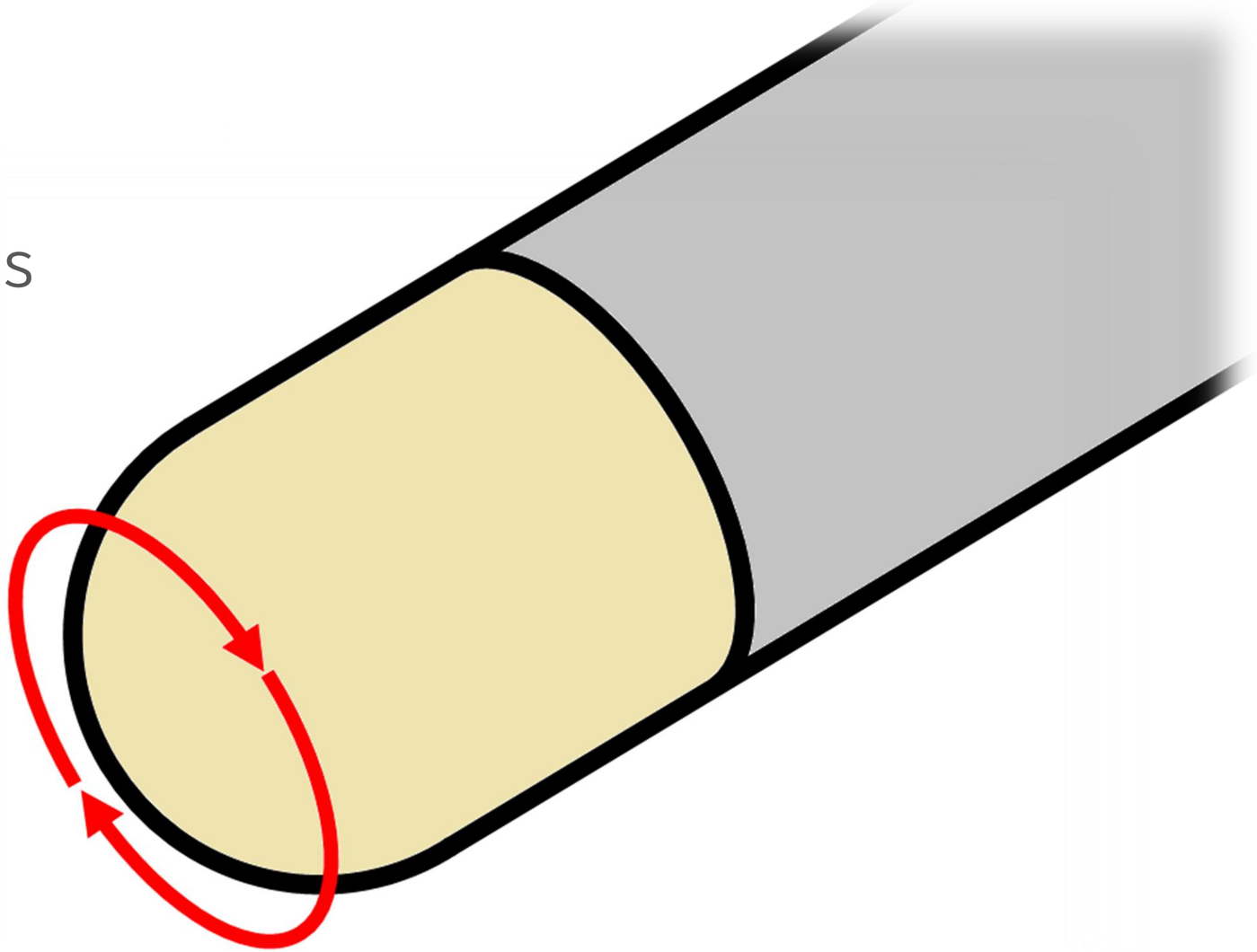
- Proper use of cutting tools



Adaptive Processes for an Outlet Guide Vane - Knowledge Gained

- Adapting toolpaths

- Proper use of cutting tools



Adaptive Processes for an Outlet Guide Vane - Knowledge Gained

- Adapting toolpaths

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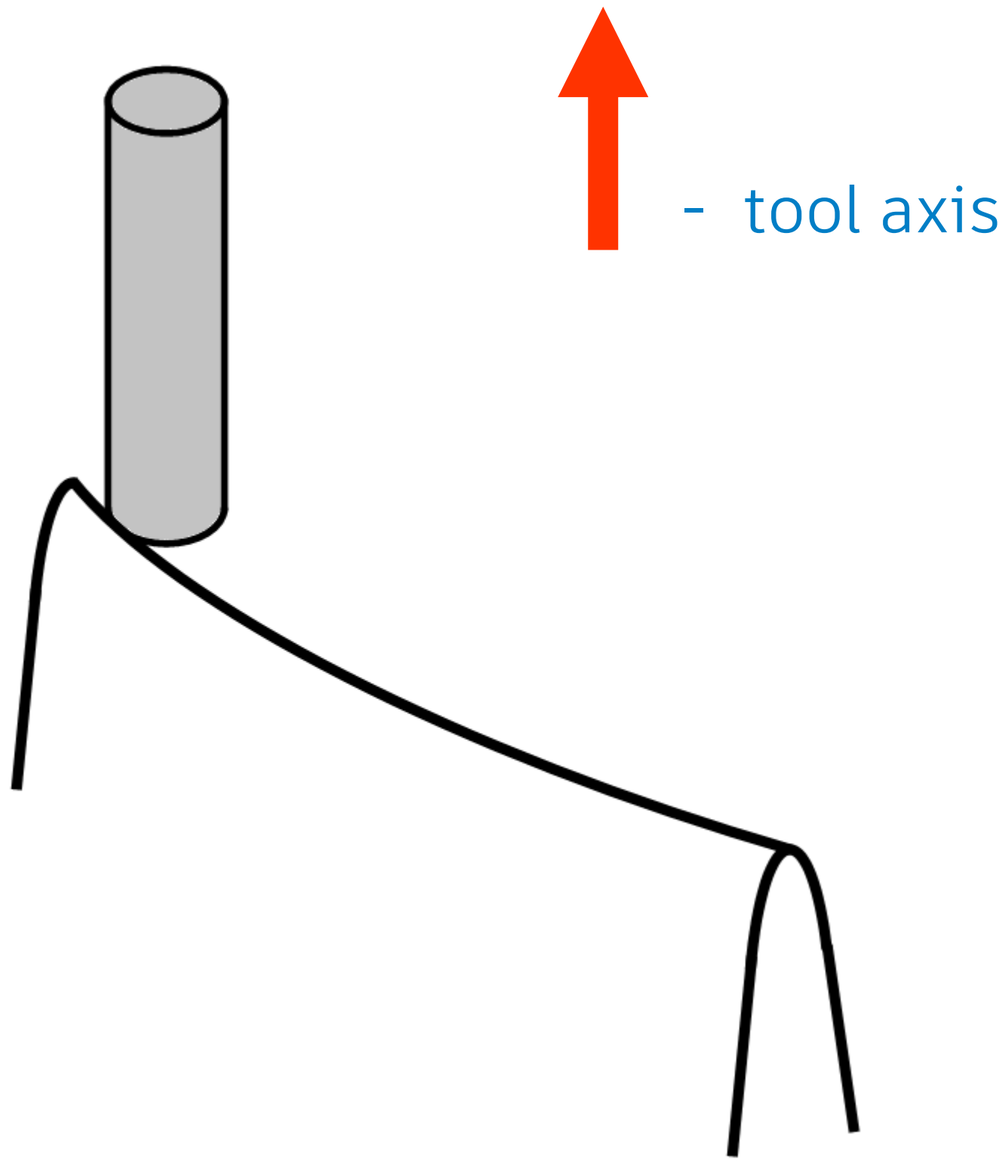
Adaptive Processes for an Outlet Guide Vane - Knowledge Gained

- Adapting toolpaths
- Proper use of cutting tools
- Machine tool selection

Adaptive Processes for an Outlet Guide Vane - Knowledge Gained

- Adapting toolpaths
- Proper use of cutting tools
- Machine tool selection



Adaptive Processes for an Outlet Guide Vane - Knowledge Gained

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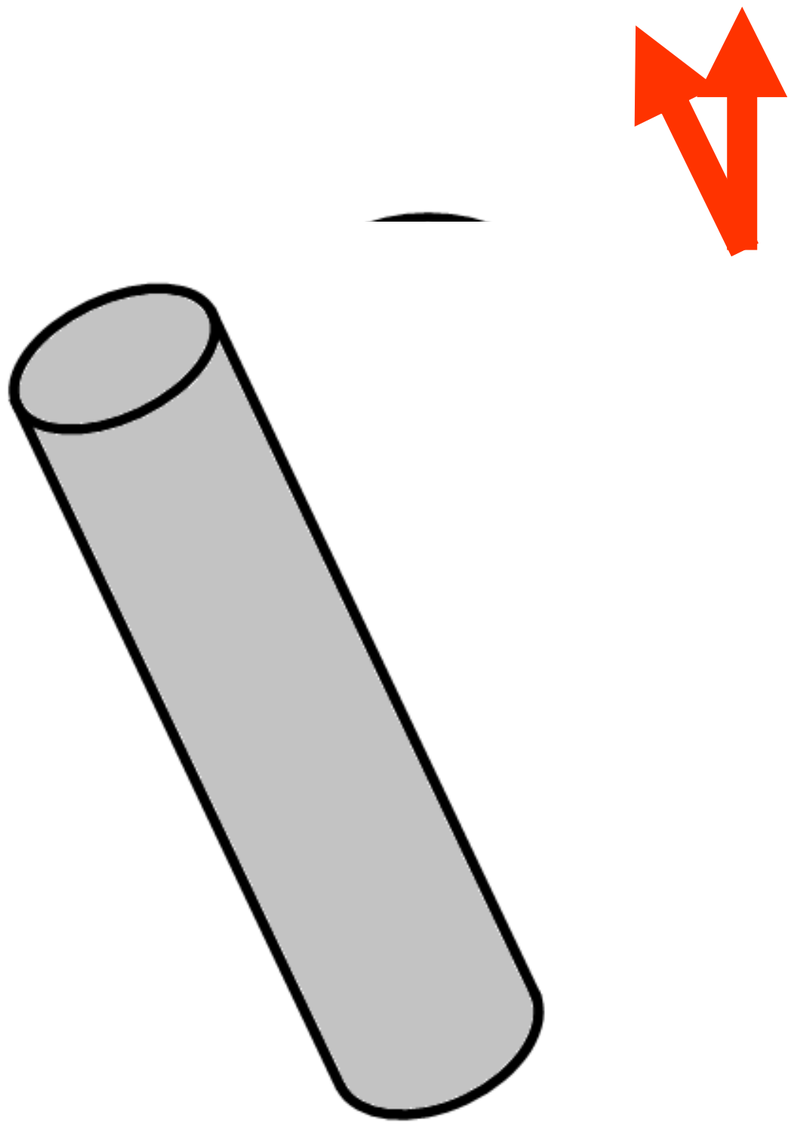

Adaptive Processes for an Outlet Guide Vane - Knowledge Gained

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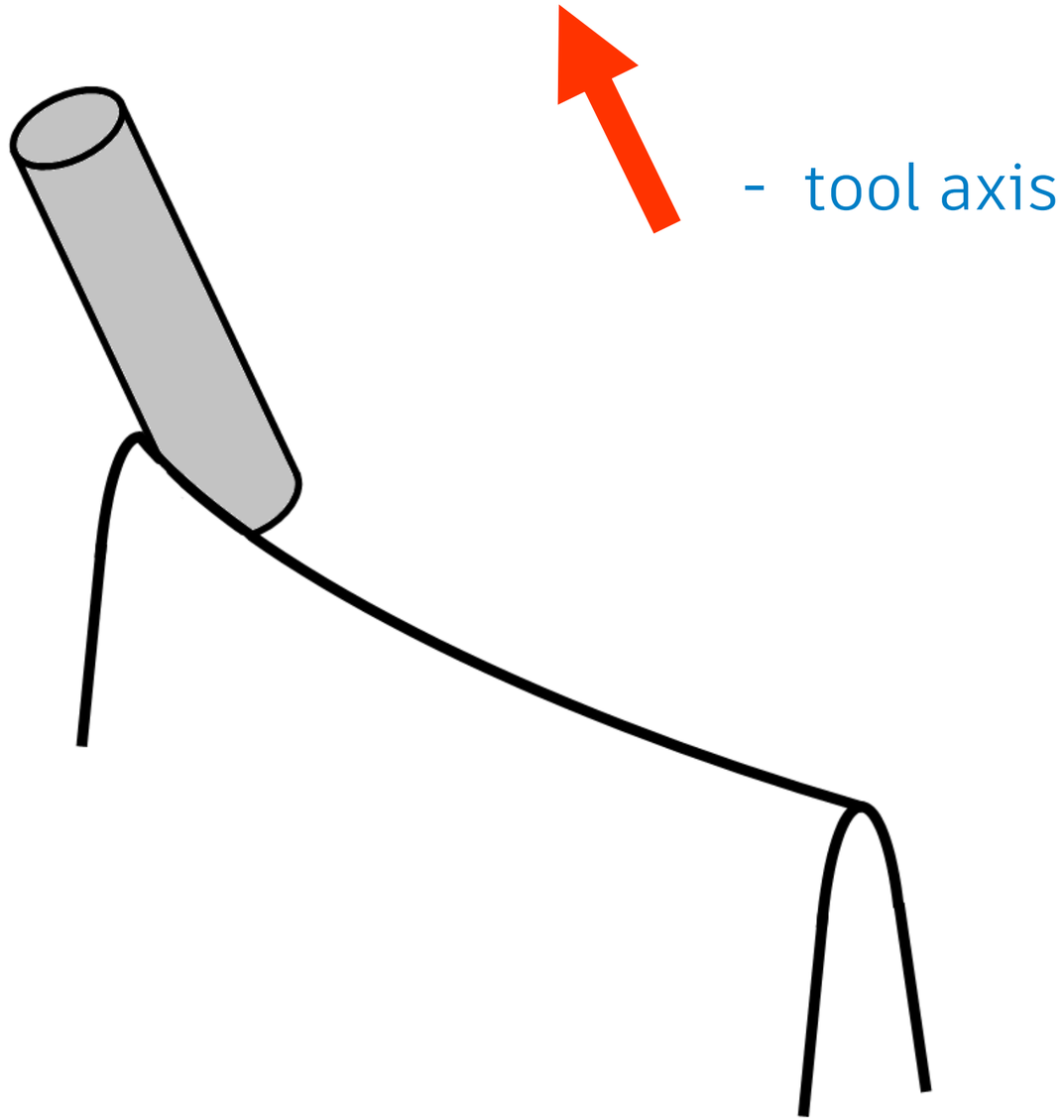

Adaptive Processes for an Outlet Guide Vane - Knowledge Gained

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Adaptive Processes for an Outlet Guide Vane - Knowledge Gained

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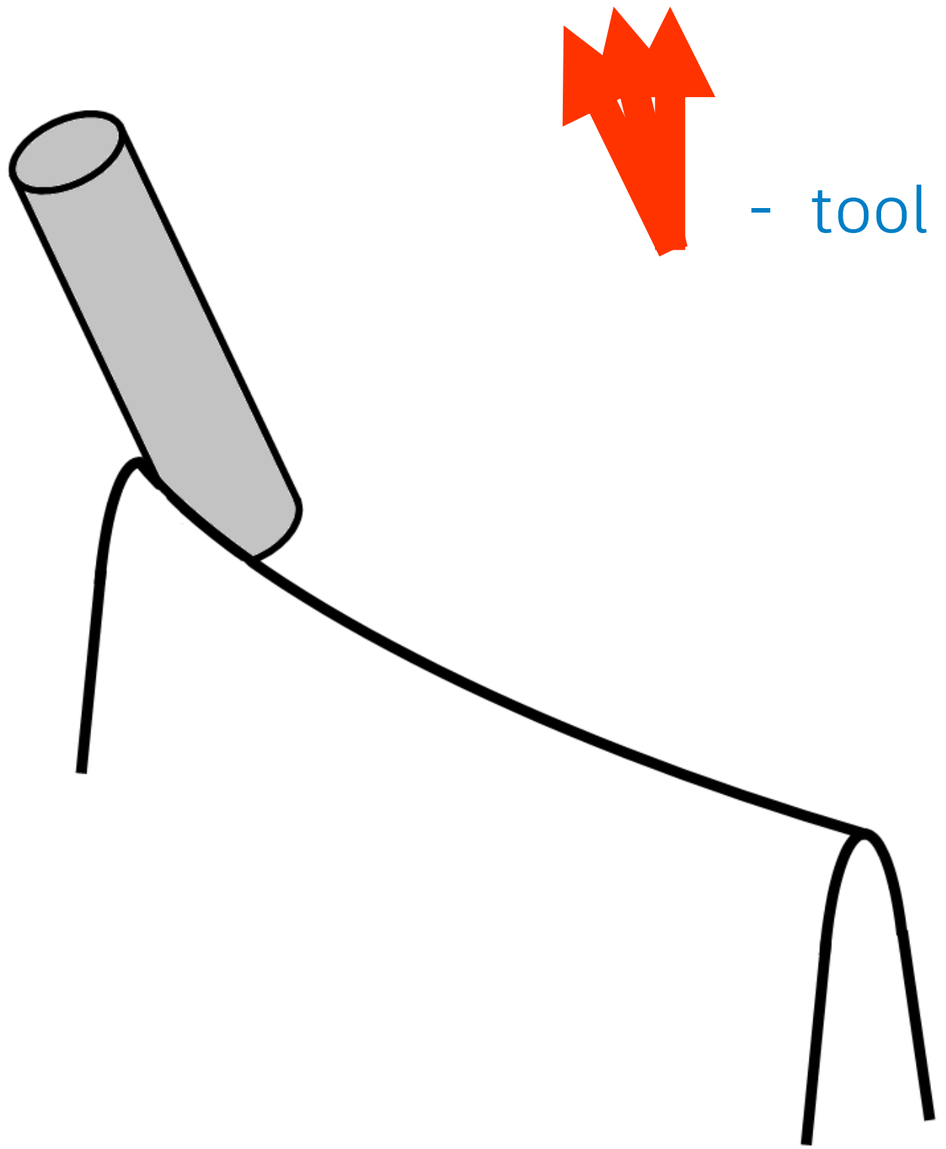
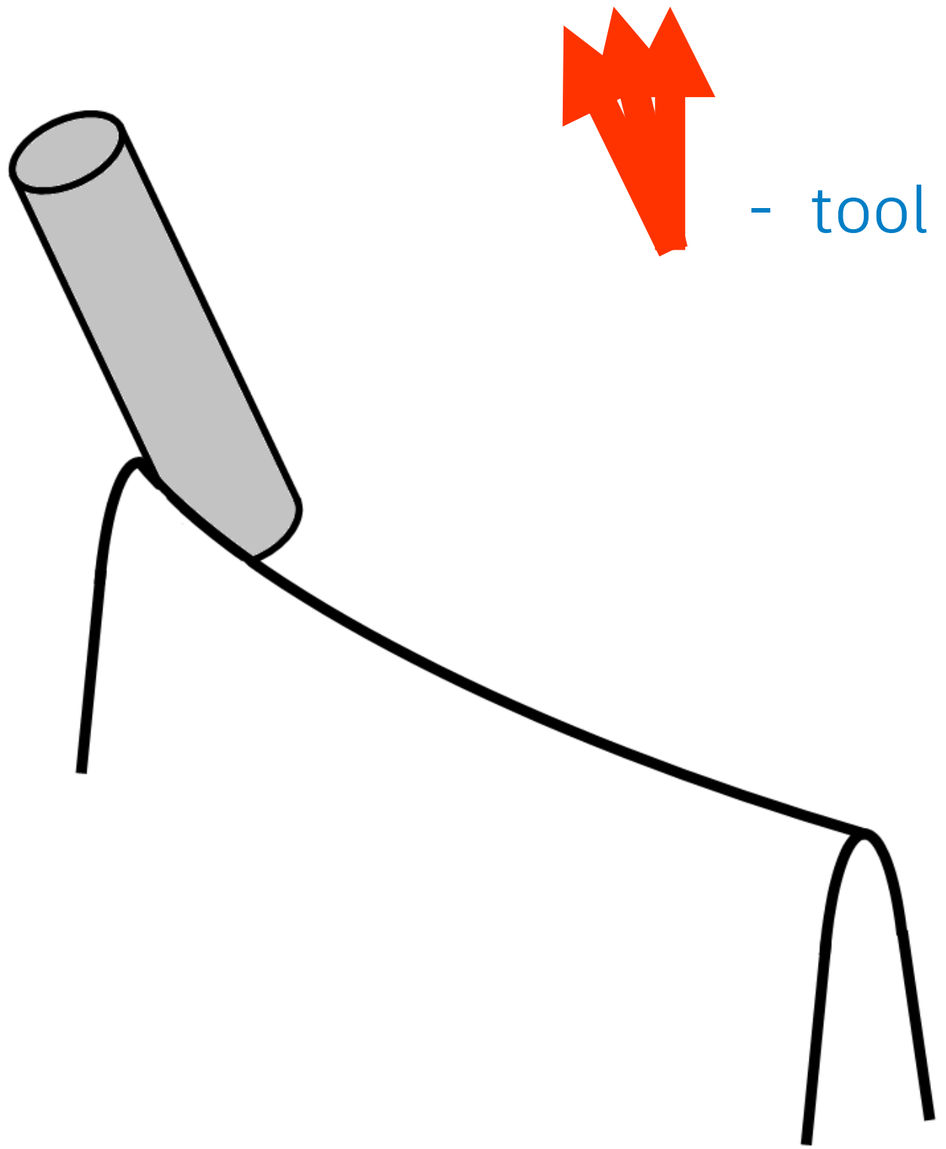


- tool axis

Adaptive Processes for an Outlet Guide Vane - Knowledge Gained

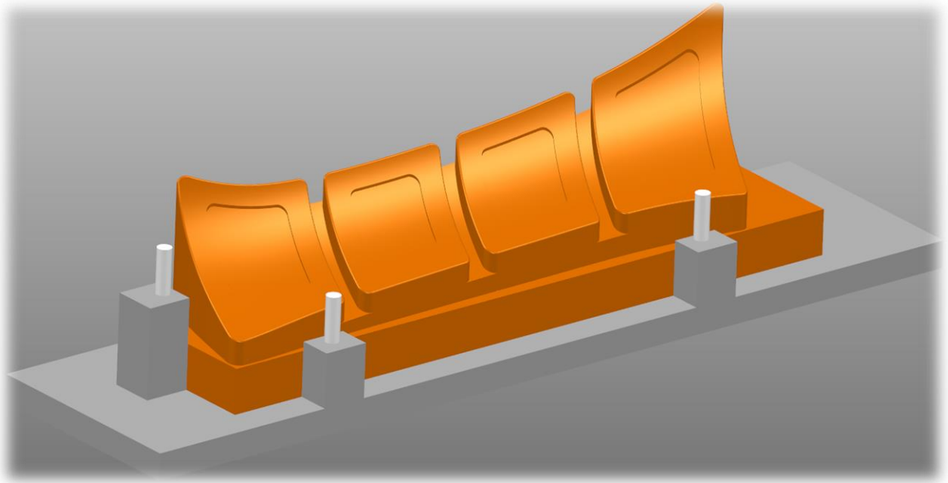
- Adapting toolpaths
- Proper use of cutting tools
- Machine tool selection

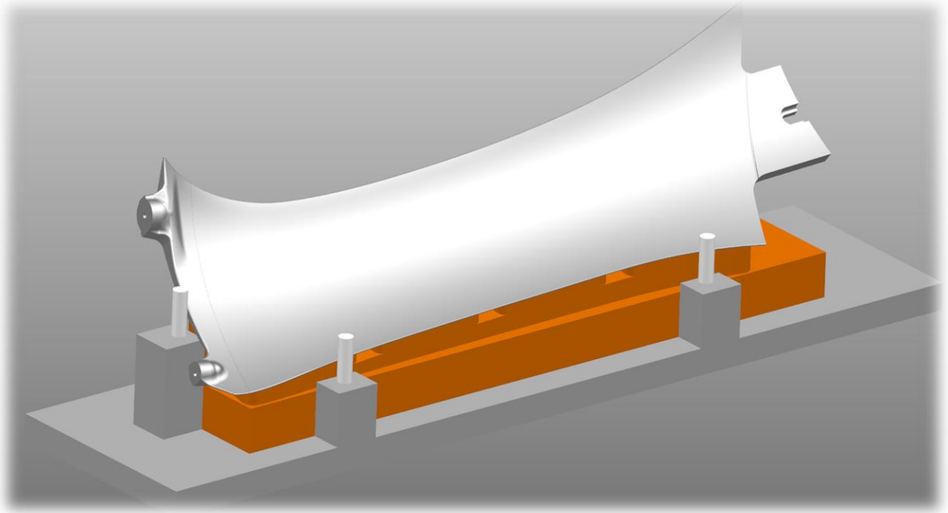


- tool axis

Adaptive Processes for an Outlet Guide Vane - Knowledge Gained

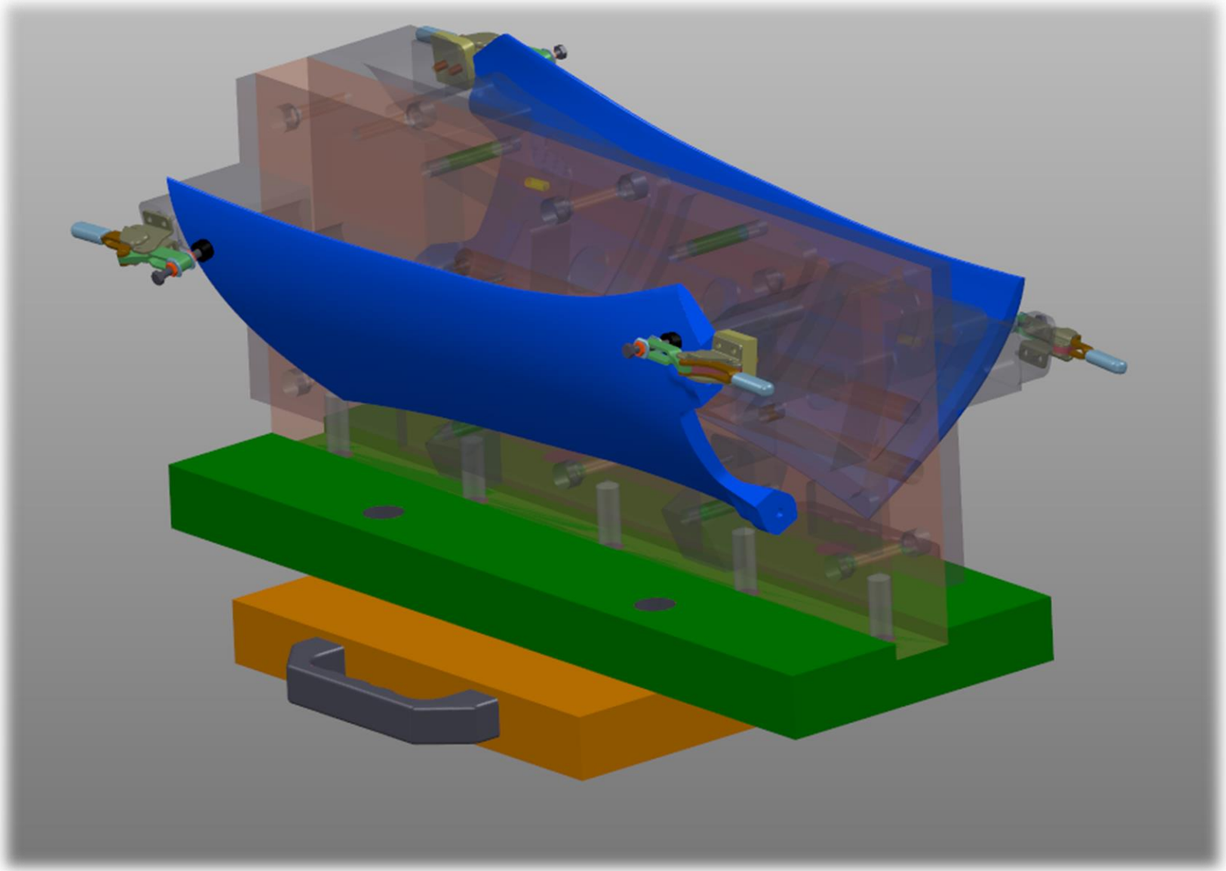
- Adapting toolpaths
- Proper use of cutting tools
- Machine tool selection
- Fixture design





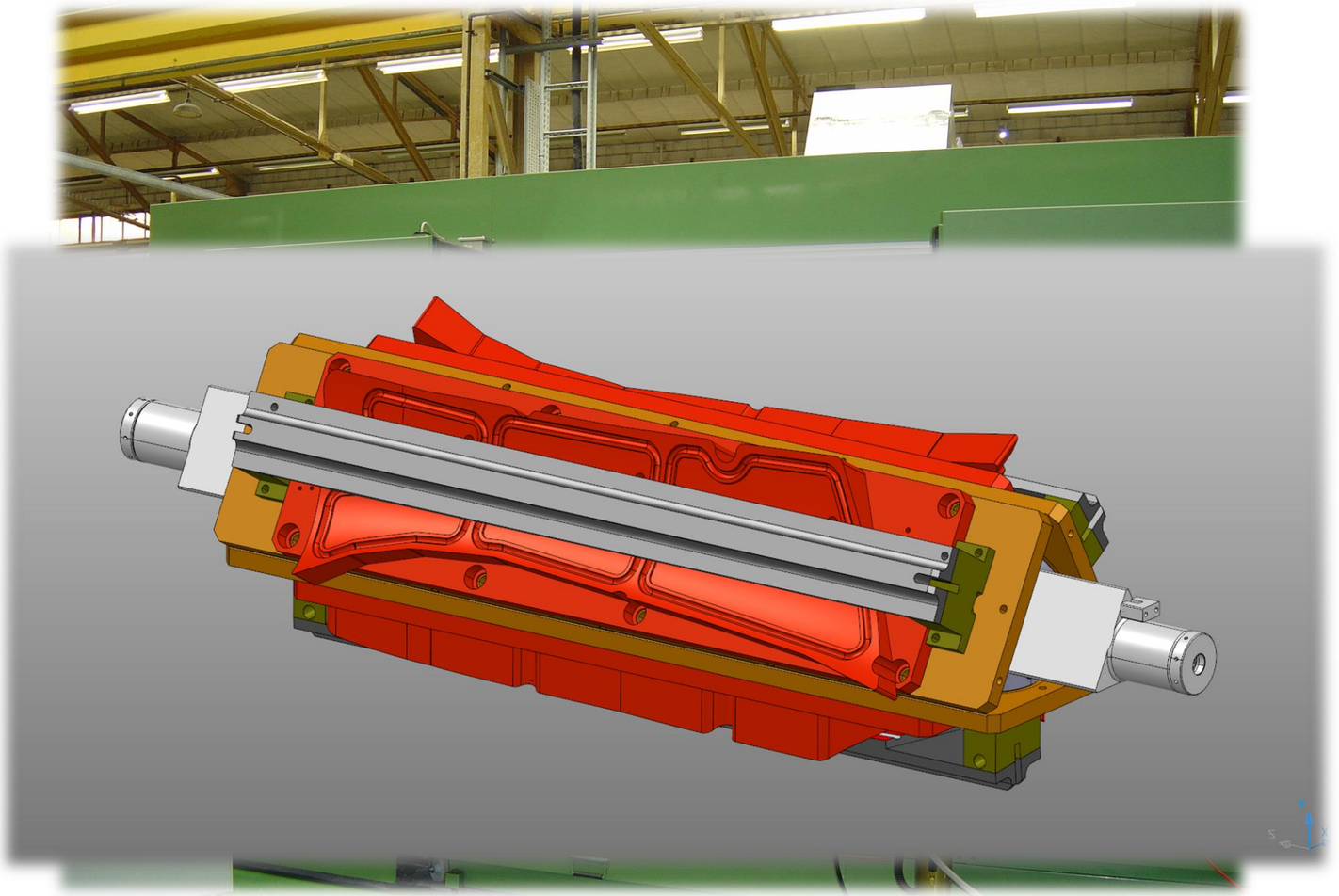
Adaptive Processes for an Outlet Guide Vane - Knowledge Gained

- Adapting toolpaths
- Proper use of cutting tools
- Machine tool selection
- Fixture design



Adaptive Processes for an Outlet Guide Vane - Knowledge Gained

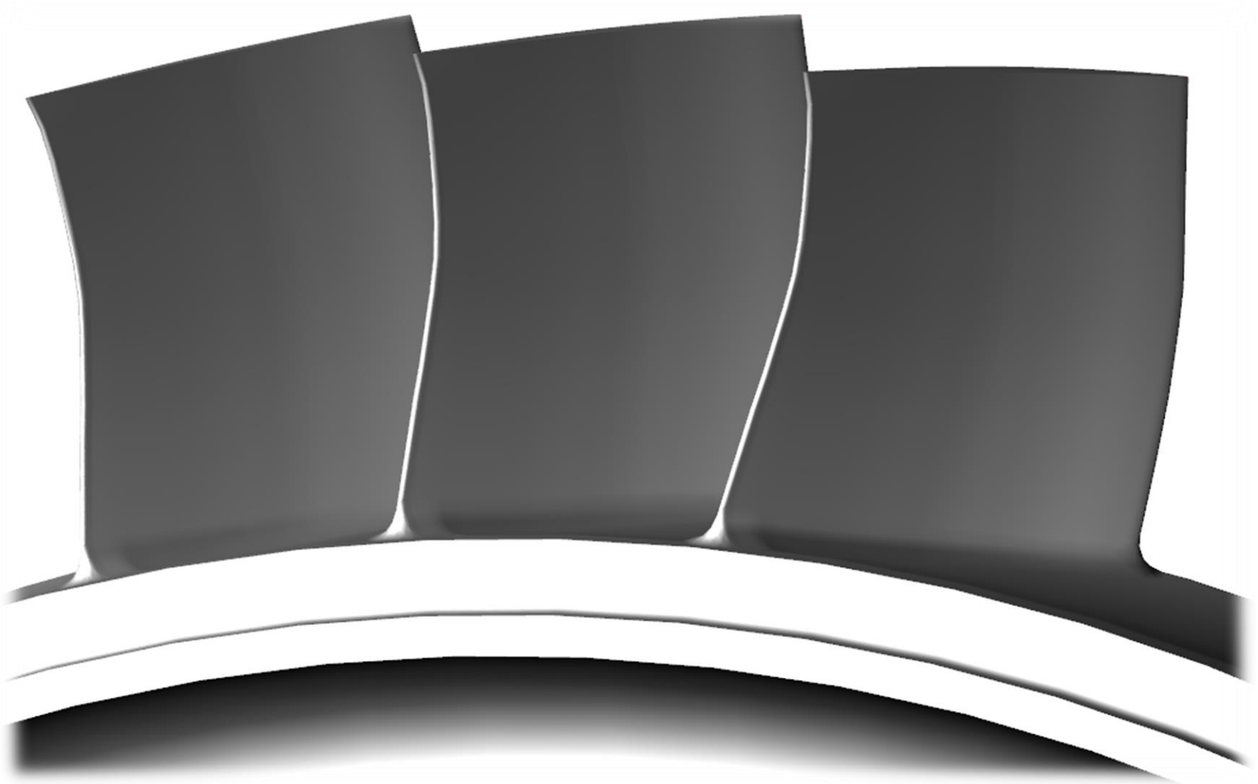
- Adapting toolpaths
- Proper use of cutting tools
- Machine tool selection
- Fixture design



Exploring The Future, With James Donnelly

HTA Blisk Case Study

- Design & Manufacture of Blisk



HTA Blisk Case Study

- Design & Manufacture of Blisk

- Adaptive Tip Repair

Project: RECLAIM

HTA Blisk Case Study

- Design & Manufacture of Blisk

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Project: RECLAIM

HTA Blisk Case Study

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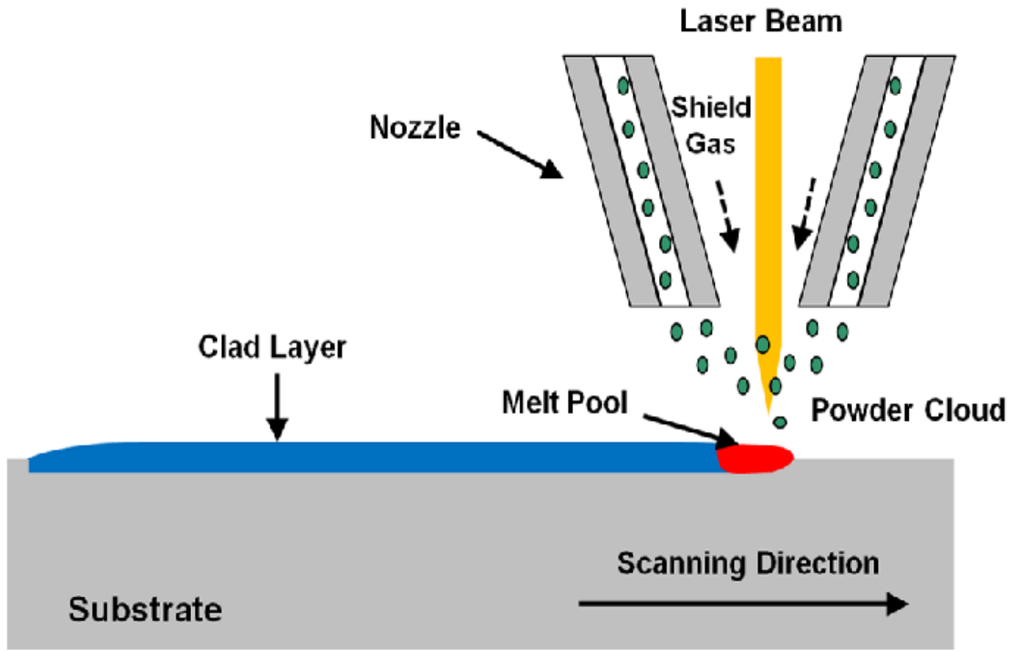
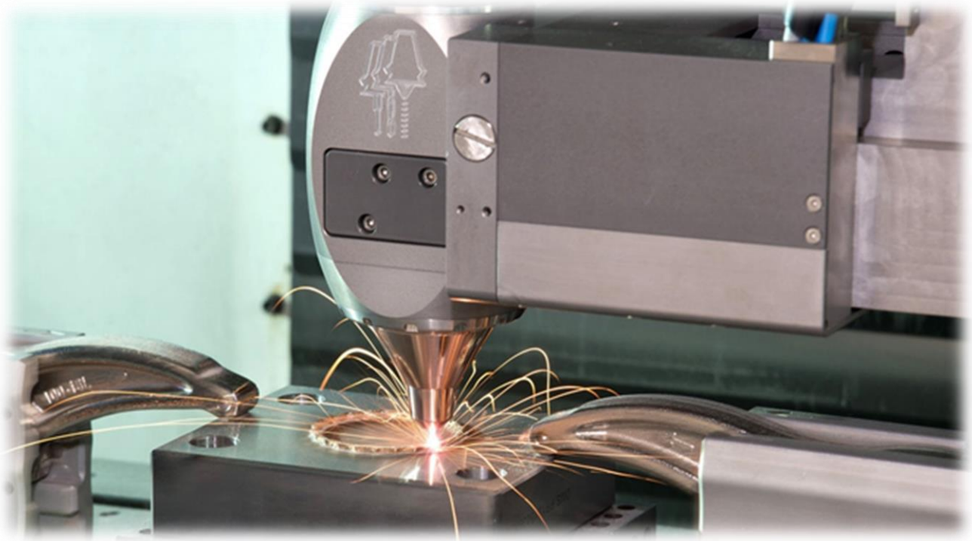
Project: RECLAIM

HTA Blisk Case Study

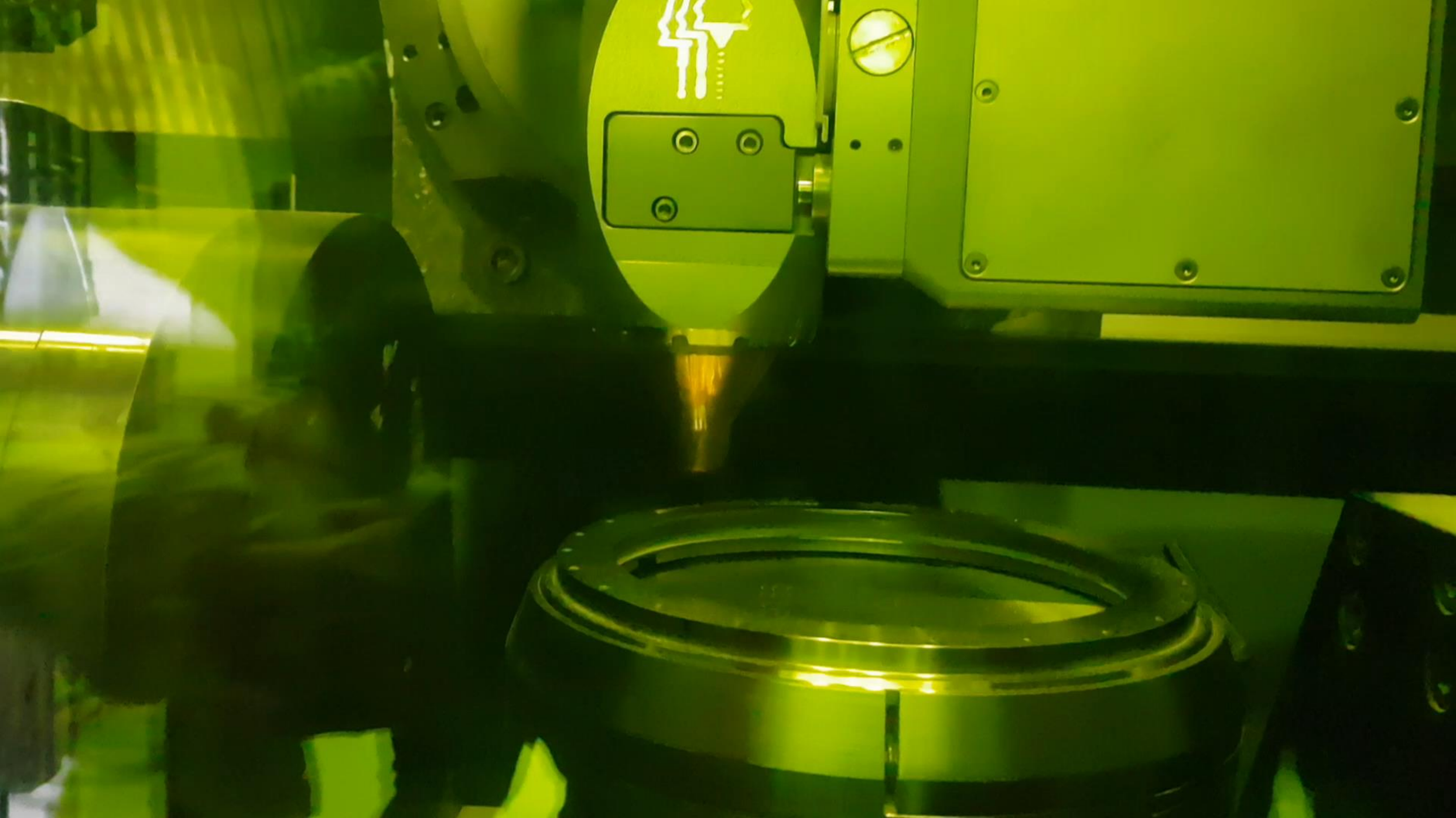
- Design & Manufacture of Blisk
- Adaptive Tip Repair
- Additive Blade



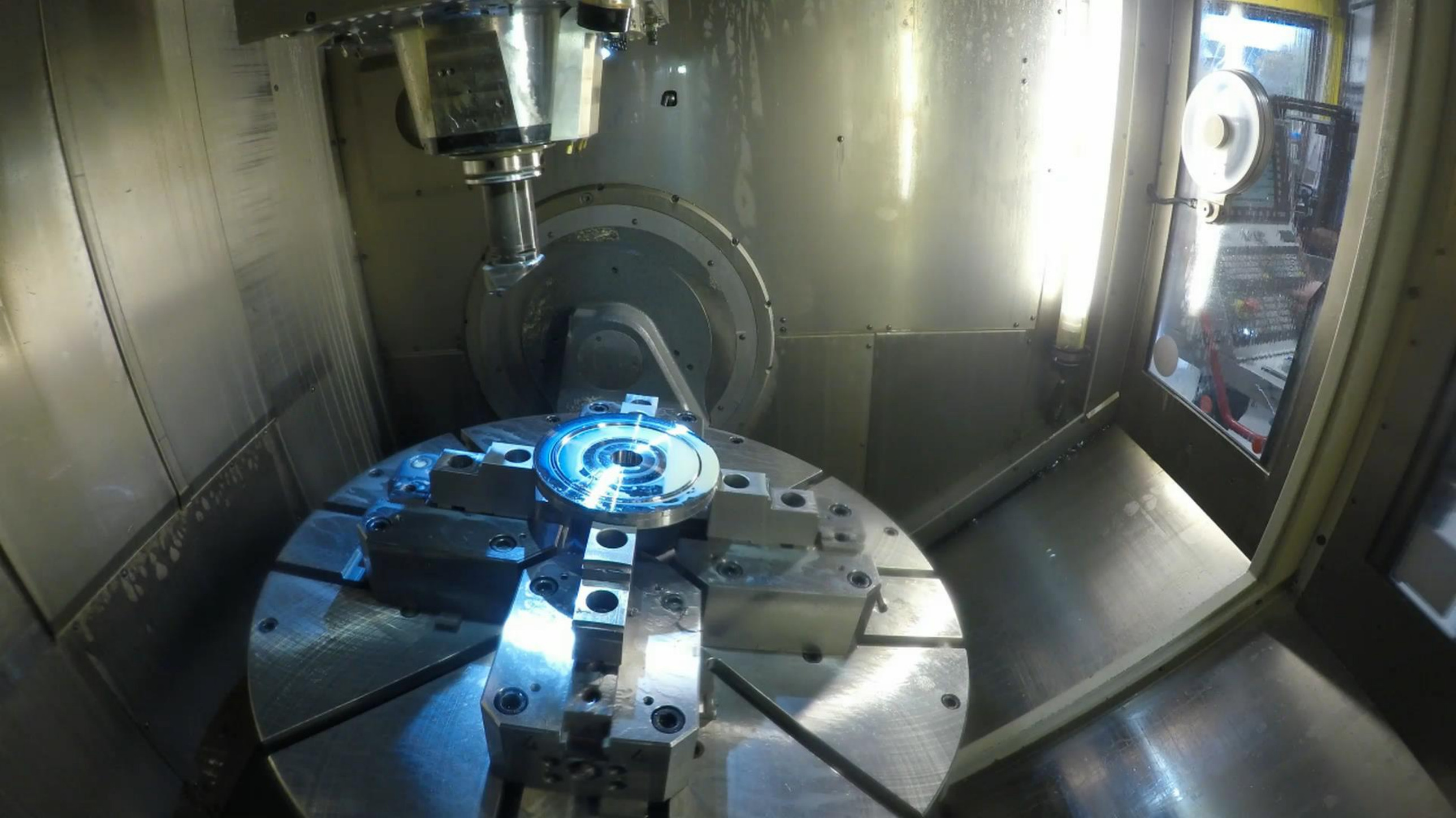


HAMUEL REICHENBACHER
A member of the SCHERDEL group

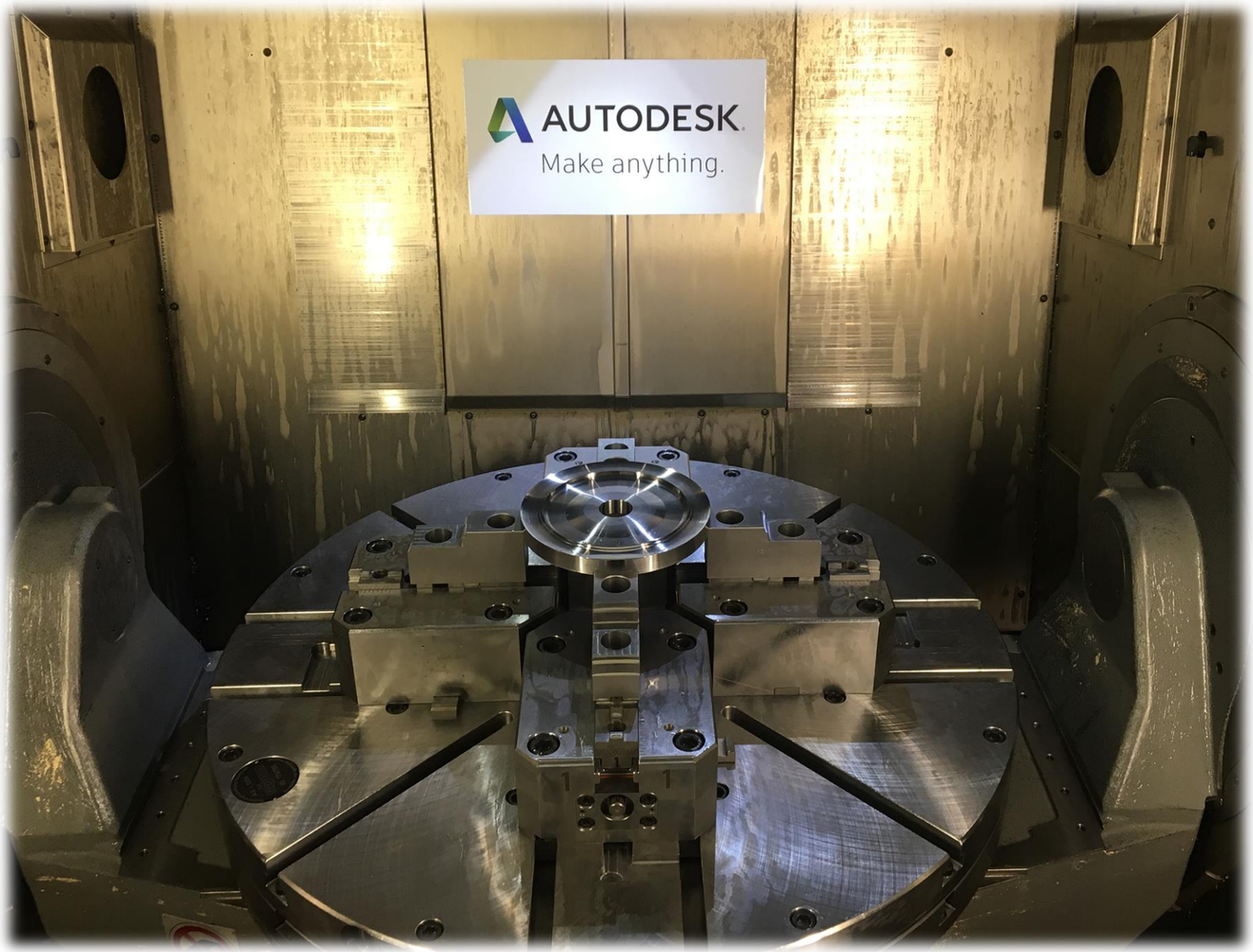
HYBRID MANUFACTURING TECHNOLOGIES

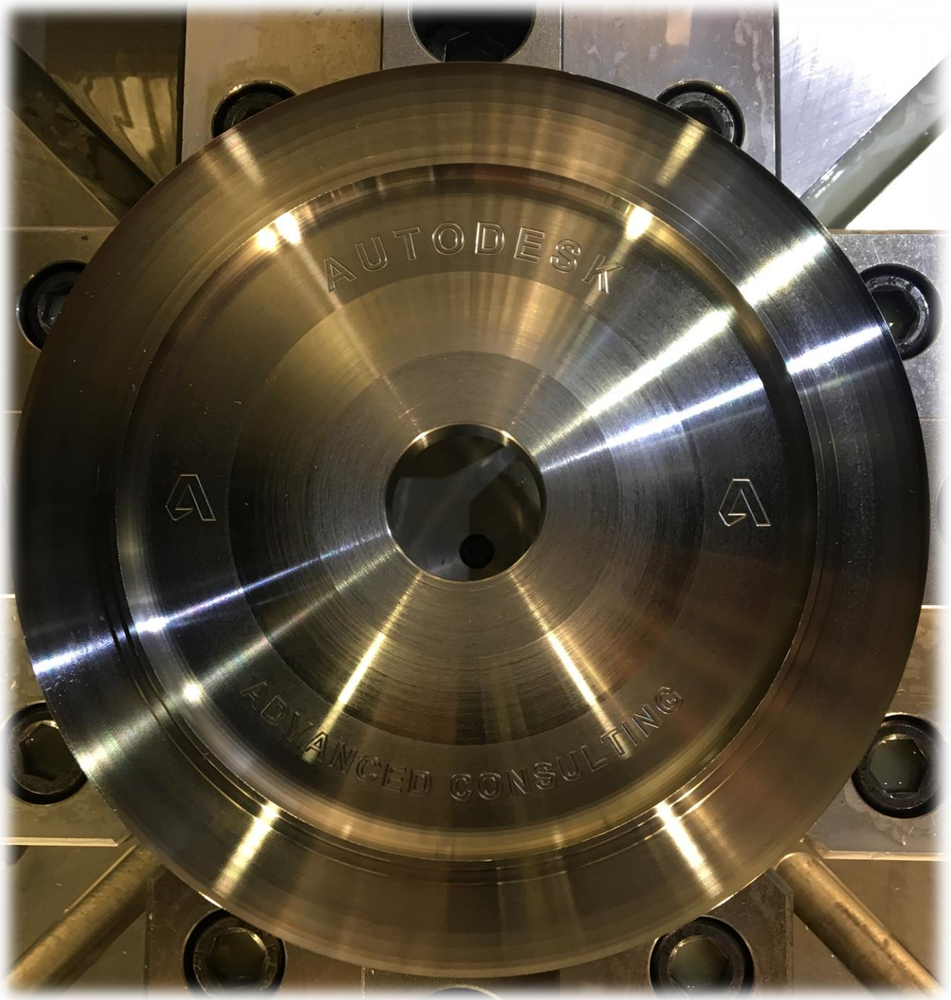


HTA Blisk Case Study – Progress So Far



HTA Blisk Case Study – Progress So Far





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