The University Of Sheffield.

Advanced Manufacturing Research Centre

BOEING

AMRC Machining Group

Capability directory

CATAPULT
High Value Manufacturing

The University Of Sheffield.

Advanced Manufacturing Research Centre

BOEING

The AMRC Machining Group develops innovative techniques and optimised processes for the machining of high-performance materials.

The aerospace industry is driving the use of high-performance alloys and composites to improve fuel efficiency for a new generation of high-performance aircraft. Components are being produced to tighter tolerances, with more complex geometries, under increasing cost pressures. But the characteristics that make these materials attractive also make them much more difficult to cut and form.

To meet quality standards at an affordable cost, these high-performance materials require high-performance machining. The AMRC's industrial partners look to the Machining Group to apply the latest technology and innovative techniques, to produce and integrate machining solutions that deliver significant improvements in quality and cost.

We use technologies such as dynamic analysis, simulation, advanced fixturing and tool design to solve real business problems. We use a critical path approach to identify the obstacles which stop components being produced efficiently, and trade studies and cost modelling to determine the most cost-effective way to proceed.

We have a strong track record of working with the aerospace industry, and also work with companies in other high-value industries such as marine, energy, automotive, motorsports, and medical devices.

As well as process optimisation, the Machining Group develops new models of machining. The industry drive for higher tolerances is creating a demand for single-operation machining methods. We are integrating technologies and developing multi-task machining methods to significantly reduce manual intervention and downtime.

This document describes the capabilities of our technology and platform teams, and details the major machining resources of the Factory of the Future workshop.

For more information, contact:

Matthew Farnsworth, Head of the Machining Group
m.farnsworth@amrc.couk

Tom McLeay, Head of Research
t.mcleay@amrc.co.uk

The AMRC Machining Group can bring a wide range of capabilities and expertise to bear on machining problems, with dedicated teams focusing on core technologies and component types.

Technology teams

Our technology teams develop the techniques and underpinning science that can deliver significant improvements in machining performance, including:

Click page to jump

Process monitoring and control ..... page 4

Machining dynamics ..... page 5

Machinability ..... page 6

Process modelling ..... page 7

Other teams focus on common processes including:

Grinding ..... page 8

Hole generation ..... page 9

Platform teams

Our platform teams bring together experienced manufacturing engineers to focus on particular component families for our core aerospace partners. The platform teams produce demonstration components which embed the techniques developed by the technology teams into the machining process.

Platform teams include:

Rotatives ..... page 10

Casings ..... page 11

Aerofoils ..... page 12

Structures ..... page 13

To put this expertise into practice, we work with an array of advanced machining centres, located in the main workshop of the AMRC Factory of the Future.

We have a wide variety of machining centres and supporting technologies, many of which are optimised for specific aerospace applications. Our resources are available for collaborative research and development projects, giving companies the capability to develop innovative and optimised machining processes without losing valuable production time on their own machines.

We count many of the world's largest and most innovative machine tool developers and tooling manufacturers among our members, giving us access to the latest models and technologies, and allowing us to push the limits of the state of the art.

The following pages introduce the capabilities, core research areas and resources of the technology and platform teams.

Process monitoring and control

Process monitoring and control systems are the key to lights-out machining, where complex components can be produced without human intervention and with increased productivity and quality.

The AMRC process monitoring and control technology team aims to help UK manufacturers become more competitive by employing the latest monitoring and control tools for intelligent, autonomous manufacturing.

We focus on four essential technologies:

- Low-cost, non-intrusive sensors to obtain physical data from processes.
- Widespread connectivity of manufacturing equipment, machines and facilities.
- Robust computational intelligence for decision making from data.
- Control systems designed to react to process variations and maintain processes at optimum operating conditions.

The process monitoring and control team has a strong background in machining process development, and a wide range of experience in applying on-machine inspection probes for in-process measurement, calibration and machine health checks.

We have a range of specialised equipment tailored to the demands of our industrial partners, including:

- Process measurement systems – sensors, pre-amplifiers and data acquisition hardware including vibration and acoustic emission sensors, directional microphones, current transducers, LVDTs and non-contact displacement sensors, load cells, thermocouples and strain gauge equipment. Zigbee wireless data acquisition equipment is also available.
- Software systems – LabVIEW and Matlab, used for data acquisition, signal processing and computational intelligence. Minitab, MODDE, and SIMCA software, for statistical data analysis, design of experiments and multivariate data analysis respectively.
- ARTIS tool condition monitoring system.
- Machine tool health checks – technologies for testing and calibrating machine tools, including laser trackers, laser interferometers, ball-bar systems and on-machine probes.

Machining dynamics

The AMRC machining dynamics team develops new methods to predict, diagnose and control machining vibrations, and applies these to the machining processes of our industrial partners.

Our research interests include:

- Dynamics of parallel machining.
- Ceramic milling.
- Composite machining.
- Virtual machining.
- Robotic machining.
- Spindle dynamics.

Recent projects include developing process models for the dynamics of parallel machining; surface roughness predictions for milling; and a set-up for rotating frequency response function measurements. We also employ commercial solutions where they are available.

Software resources include:

- Cutpro
- Metalmax TXF
- Matlab
- Ansys
- Machpro
- Labview
- Simulink
- UG NX

Our hardware resources include:

- Tap test kits for experimental modal analysis.
- Set-up for dynamic characterisation of cutting tools in rotating conditions.
- Dynamometers (milling, turning, drilling) for force measurements.
- Laser displacement sensor.
- Laser vibrometer.
- Variety of accelerometers.
- Microphone.
- DAQ boards.
- Piezoelectric patches for shunt damping applications.

Machinability

Machinability research underpins the AMRC with Boeing's machining process work, by developing a better understanding of the essential characteristics of high-performance aerospace materials and cutting tools.

The AMRC machinability team works with a multitude of aerospace materials, focusing on titanium, high strength steel, nickel and aluminium alloys, as well as carbon fibre composites.

We carry out machinability research to support the work of other AMRC groups and industrial partners.

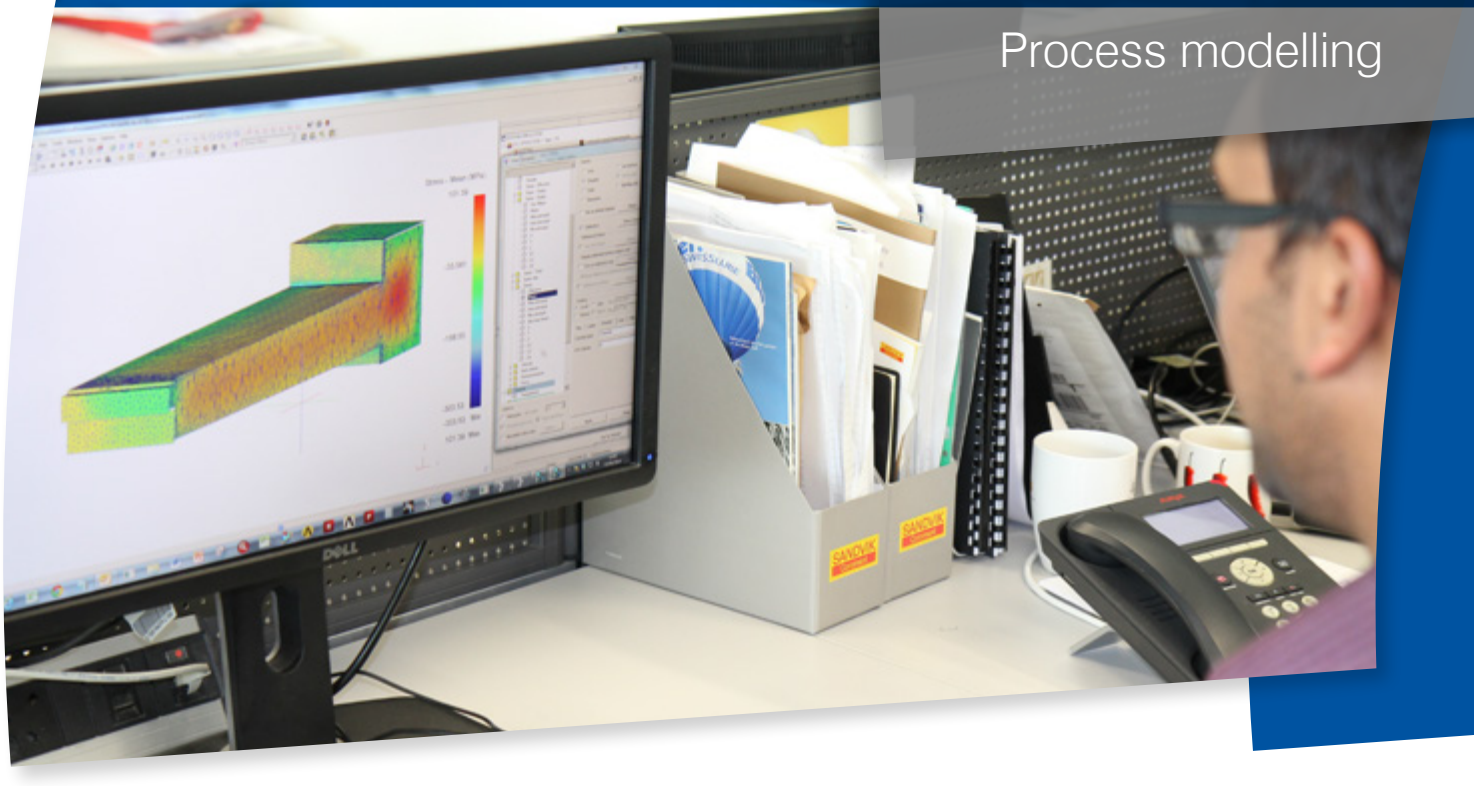
Our core research areas include:

- Characterising materials and tools.
- Understanding and reducing the causes of tool wear.
- Developing the chemistry and application of cutting fluids.
- Understanding the material science behind machinability.
- Developing new experimental methods.

Specialist analytic equipment includes:

- Alicona InfiniteFocus G4 & SL high-resolution 3D scanners – used to check the geometry of cutting tools and investigate the form of finished components, with resolution of 10nm.
- Kistler dynamometers – to measure the cutting forces which dictate regenerative vibration limits, machine power consumption, tool deflection and tool fracture. We have three dynamometers suitable for milling and drilling studies, measuring both forces and torque, and one suitable for turning processes.
- Carl Zeiss and USB toolmaker's microscopes – USB microscopes are useful for rapid on-machine assessment of cutting tools. If significant wear has occurred, we can use the Zeiss microscope to carry out a quantitative flank wear assessment and track tool wear over the time of cutting.

Process modelling



The AMRC process modelling team develops and tests techniques and computer-based models for machining processes.

We investigate metal cutting, composite machining, residual stress/machining distortion, and fatigue life prediction, and validate our models through machining trials and residual stress measurement.

We use computer-based models to investigate alternative machining processes, helping companies make more informed decisions. These models reduce the need for costly shopfloor trials, and shorten the lead time in bringing a new product to market.

We aim to cover all areas of modelling relevant to our industrial partners.

Core capabilities include:

- Prediction of residual stress, machining distortion and feedback loop for tool path optimisation. We can integrate process models and in-process monitoring to investigate and validate the models to develop optimised machining strategies based on part distortions.
- Chip formation analysis in metal cutting and composite machining modelling, to better understand the relationship between the many process parameters and the machining responses. By modelling material removal, we can reduce the cost of experimental tests optimise cutting conditions, and redesign tool geometry.
- Work-holding modelling analysis, using numerical models to investigate the dynamic and static performance of a variety of aerospace components.

We have extensive software resources, including tools for finite element analysis, optimisation analysis, design of experiments and programming. Software providers and packages include Third Wave Systems, Deform, Abaqus, Ansys, Fluent, Nastran, Matlab, Isight, Umetrics and others.

We also have access to the Iceberg high-performance computing cluster at the University of Sheffield.

Grinding

Grinding and surface finishing operations can account for 20-25 per cent of expenditure on all machining operations. Many components are primarily machined using these techniques, while others rely on such processes for final accuracy and precision.

The AMRC grinding and surface finishing team has the capabilities and expertise to improve performance and quality across the range of grinding operations – including stock removal; form and finishing grinding; and component surface finishing – with a particular focus on aerofoil production.

Our research capabilities cover key technologies and techniques in both grinding and surface finishing.

Our current research areas in grinding include:

- Machine tool optimisation.
- Process development.
- Coolant.
- Wheel technology.
- Dressing.
- Grindability of materials.
- Hybrid processes.

Current research in surface finishing includes:

- Mass finishing.
- Surface finishing and blending.
- Deburring.
- Mechanical edge profiling.

Key machining resources include:

- Blohm Profimat MC607 – five-axis grinding capability ‘based in the Design Prototyping and Testing Centre.
- Makino A99 five-axis grinding platform.
- Makino A100e five-axis grinding platform.
- Mori-Seiki NT4250 mill-turn-grind automated cell.
- Mori-Seiki NMV8000 five-axis mill-turn-grind machine.

Hole generation

In aerospace manufacturing, virtually every engineered component features some form of hole – Boeing alone claims to produce around a million holes every day. Every hole has to be precisely positioned and machined, by drilling, milling or eroding. Any error can potentially mean that an expensive part-finished component has to be scrapped.

The AMRC hole generation team is dedicated to improving the performance and quality of hole generation techniques.

We aim to cover all areas of hole generation relevant to our industrial partners.

Our current research areas include:

- Tool geometry, materials and coatings for carbon fibre reinforced composites and composite/metal stacks.
- Robotic systems for the helical generation of holes.
- Orbital drilling.

Many of the CNC machining centres at the AMRC Factory of the Future are capable of producing holes of different kinds.

As well as these generic facilities, specialist equipment includes:

- Novator Twinspin orbital drilling unit – low-torque, air-driven machine capable of producing holes in aluminium and aluminium/composite stacks.
- AIT NCDJ drilling platform – computer-controlled drilling platform, originally designed for Boeing's F18 programme. Our machine has been modified for use as a test platform to investigate parameters such as tool design, workpiece material, cutting forces and coolant application.
- Alicona InfiniteFocus measurement system – optical 3D microcoordinate system for form and roughness measurement, allowing us to assess the effect of different parameters on the hole quality and to study relative tool wear.

Rotatives

The AMRC rotatives team focuses on techniques and tools for machining aeroengine discs and shafts.

These components play a significant role in the efficiency of aeroengines, and can present major challenges for machining and inspection.

With over a decade's experience of solving manufacturing challenges across a range of aerospace components, the rotative team aims to develop high-performance manufacturing strategies for new disc and shaft components.

Key areas of current research include:

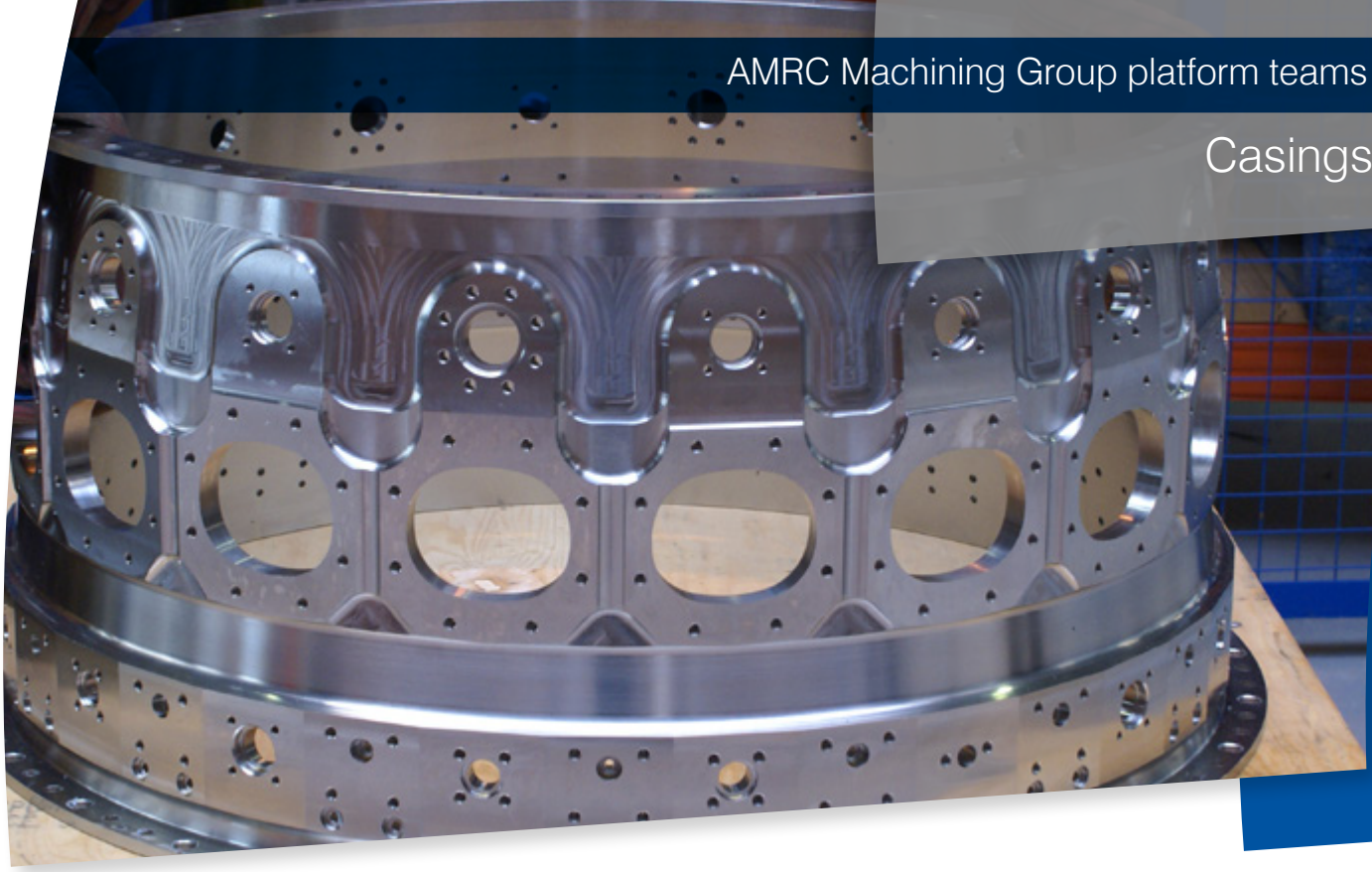
- Fixturing design.
- Tooling strategies.
- Distortion compensation.
- Measurement strategies.

We also lead specific research on critical shaft features to increase metal removal, develop processes for new alloys, and create tooling solutions for complex part geometries.

Key machining resources include:

- WFL M100 turning-boring-milling centre.
- Mori Seiki NT6600 mill-turn.
- Mori Seiki NMV8000 five-axis mill-turn-grind machine.
- Mori Seiki NT5400 five-axis mill-turn.
- Hermle C50 five-axis mill-turn.

Casings



Aeroengine casings have complex geometries and are made from expensive, difficult-to-machine alloys demanded by their increasingly tough operating conditions. Reducing their machining cost while maintaining quality is a critical challenge for many of the AMRC's partners.

The AMRC casings team has researched casing machining since 2005. From our first studies on metal removal rates and vibrational assessment of current industry methods, we have developed a range of novel strategies, tooling and workholding technologies to optimise casing machining.

We have worked with a leading aeroengine partner to combine many of these techniques into a state-of-the-art machining strategy for specific casings which are now in production.

We develop the technology and application processes to create world-class machining solutions for whole casing component development or single feature optimisation.

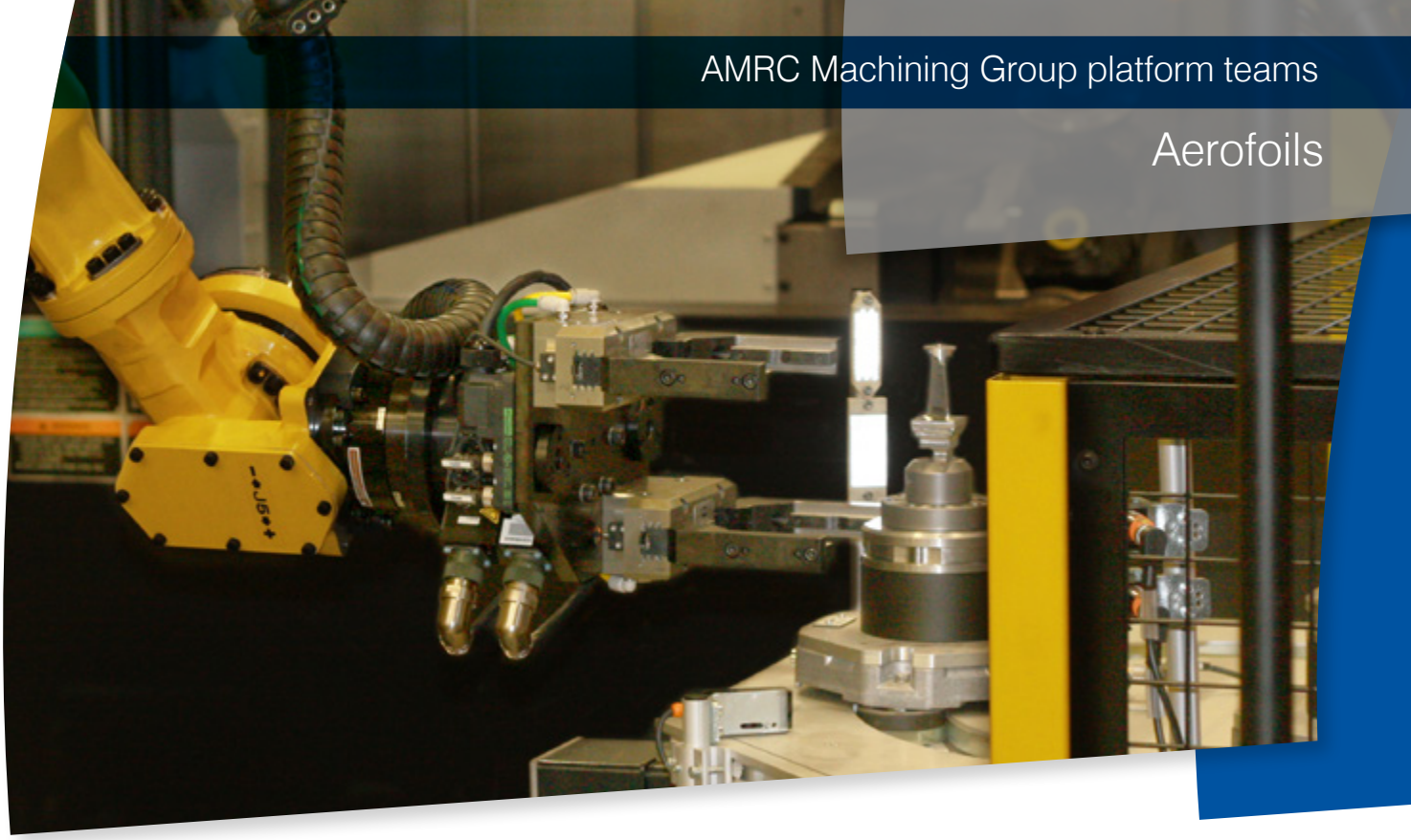
We are currently working in areas such as:

- Metal removal rate improvement.
- Replicating production challenges by producing multiple components simultaneously.
- Reduced material input casing technologies.
- Workholding.
- Feature-specific tooling.
- Design tooling for casing geometries.

Key machining resources include:

- Mori Seiki NVL1350MC vertical lathe.
- Starrag ZT1000 five-axis machining centre.

Aerofoils



Aerofoils are some of the most critical aeroengine components. Their material capability and geometry directly affect engine performance and fuel consumption.

The aerospace industry's constant drive to improve performance and efficiency places increasing demands on aerofoil manufacturing processes. These improvements must be achieved through cost-efficient manufacturing processes which can meet production targets.

The AMRC with Boeing's aerofoils platform team, is dedicated to improving the performance and quality of aerofoil machining techniques.

We aim to cover all single and multi-bladed aerofoil applications for aeroengines and for power generation. We can work with a variety of conditions of supply and machining processes to handle fan, compressor and turbine engine modules.

Our current research areas include:

- Advanced materials and condition of supply.
- Advanced component design and tighter tolerance features.
- Cost-based method of manufacture development.
- Process control, monitoring and modelling.
- Green button manufacturing methods.
- Milling, grinding and surface finishing processes.

Core machining resources include:

- Mori-Seiki NT5400 five-axis mill-turn.
- Mori-Seiki NT4250 mill-turn-grind automated cell
- Starrag-Heckert STC1250 horizontal machining centre.
- Starrag-Heckert ZT1000 large five-axis centre.
- Mori-Seiki NMV8000 five-axis mill-turn-grind machine.
- Hermle C50 five-axis mill-turn.

Structures

Structural parts for aerospace present major manufacturing challenges, thanks to the complex nature of their geometries.

Aerostructures can include thin walls and bases, complex webs and difficult-to-reach features, and often have large magnitudes of residual stress movement. These require a detailed understanding of part dynamics and process constraints before the manufacturing method can be optimised.

The AMRC structures team aims to provide step-change productivity improvements in aerospace structural component machining. In one fan disc project with Rolls-Royce, we achieved a 64 percent reduction in machining time and 75 percent reduction in set-up time.

We apply theoretical understanding and novel approaches – including best practice process methodology and tooling selection, complex cutter path generation and unique fixture work holding solutions – to demonstrate improved manufacturing processes and develop them to production readiness. Our work is supported by fundamental machining theory such as machine tool dynamics and stability prediction.

Key projects include:

- Rolls-Royce high-performance fan disc machining.
- Next generation titanium pocketing.
- Mill-turning of prismatic components.

The structures group has access to the world-leading selection of mill-turn machining centres within the AMRC Factory of the Future. This has allowed us to demonstrate optimised manufacturing on alternative and non-standard machining platforms.

Two recently acquired centres offer industry-leading capabilities to develop innovative processes and techniques:

- Scharmann Ecospeed high-speed five-axis machine.
- Starrag STC 1250 horizontal machining centre.

Resources

The following pages give full details for each of our core machining centres, mostly housed in the AMRC Factory of the Future.

Machines by type

Click page to jump

Mill-turn

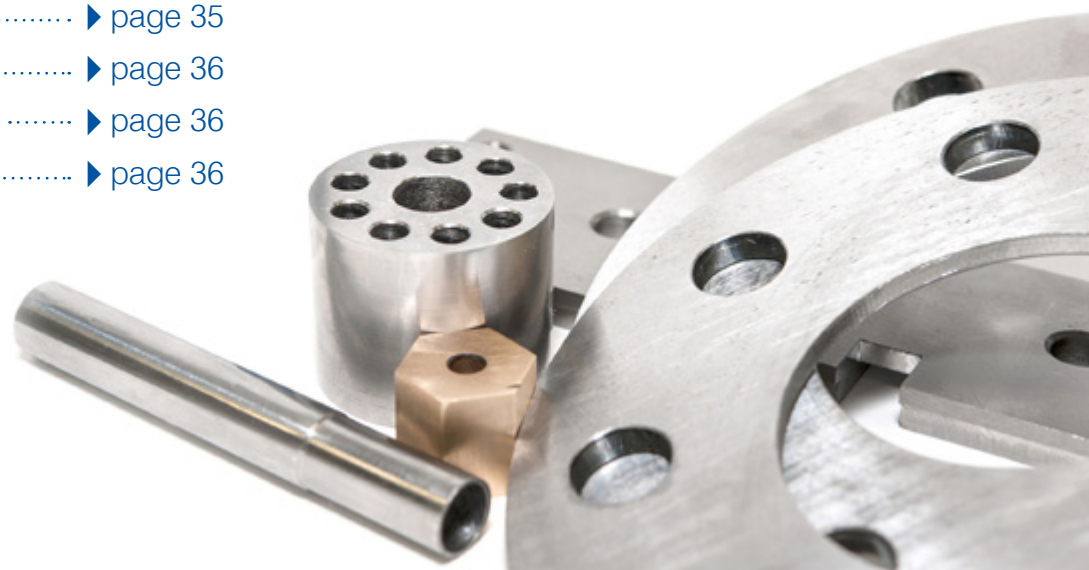
Grinding

Milling

Vertical turning

Waterjet and milling

A final section gives specifications for additional machining resources, mostly housed in the AMRC Knowledge Transfer Centre workshop, including:



The University Of Sheffield.

Advanced Manufacturing Research Centre

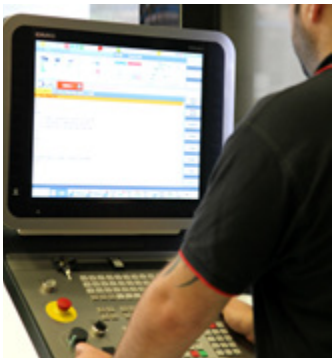
BOEING

DMC 160 FD duoBLOCK

Powerful milling and turning platform, allowing maximum precision with high dynamic stability.

The DMC 160 FD combines milling and turning technology in a single machine. It is designed as a five-axis milling machine with a very powerful milling/turning table with DirectDrive technology and speeds up to 1,200rpm. With a torque of up to 6,200Nm, the table is suitable for a wide variety of milling and turning applications for large and bulky workpieces.

The 160 FD will be available from Q3 2014.



Type	5-axis mill turn
X-axis travel	1,600mm
Y-axis travel	1,400mm
Z-axis travel	1,100mm
A-axis travel	-120° to +10°
B-axis travel	-30° to +180°
Max spindle speed	10,000rpm
Max spindle torque	288Nm
Max spindle power	44kW
Spindle interface	HSK A100
Coolant delivery type	HPC through spindle
Max acceleration, linear axis	6m/s^2
Max acceleration, rotary axis	5m/s^2
Max workpiece size	Ø1,400mm
Max workpiece weight	3,000kg
Additional functionality	Electronic balancing sensor with Siemens 840D solutionline.

The University Of Sheffield.

Advanced Manufacturing Research Centre

BOEING

Hermle C50

Highly flexible five-axis machining centre, capable of a range of cutting operations to high precision.

A highly flexible five-axis mill-turn centre, the C50 is capable of a range of cutting operations to high precision, including blisk, bling and impeller applications.

The C50 can handle workpieces up to 2000kg, and is ideal for difficult-to-machine materials.

Type	5-axis vertical mill turn
X-axis travel	1,000mm
Y-axis travel	1,100mm
Z-axis travel	750mm
Max spindle speed	12,000rpm for milling spindle
Max spindle torque	356Nm
Max spindle power	56kW
Spindle interface	HSKA/T 100
Coolant delivery type	HPC through spindle
Max acceleration, linear axis	6m/s^2
Max acceleration, rotary axis	6m/s^2
Max workpiece size	800mm x 800mm x 500mm
Max workpiece weight	100kg
Additional functionality	Turning capability

The University Of Sheffield.

Advanced Manufacturing Research Centre

BOEING

Mori Seiki NMV8000 DCG

Five-axis milling, turning and grinding machine, equipped with Renishaw scanning probe technology.

Five-axis mill-turn-grind capability for larger diameter components. The NMV8000 allows the development of multi-task machining processes for a variety of component families.

It is one of the most accurate and dynamically stable machine tools at the AMRC, offering an ideal platform for both rotating and prismatic part machining.

Type	5-axis milling with grinding
X-axis travel	1,200mm
Y-axis travel	920m
Z-axis travel	610mm
B-axis travel	+160° to - 180°
C-axis travel	360°
Max spindle speed	10,000rpm
Spindle interface	BT50
Max workpiece size	Ø1,000mm x 500mm
Max workpiece weight	1000kg

The University Of Sheffield.

Advanced Manufacturing Research Centre

BOEING

Mori Seiki NT6600 DCG

Large mill-turn, with world's largest Y-axis travel (330mm) and over five metres of Z-axis.

The NT6600 boasts the world's largest Y-axis travel (330mm) with over five metres of Z-axis, and is ideal for long or large-diameter workpieces.

It combines the powerful NH-series spindle with advanced turning capabilities to deliver outstanding performance on a wide range of applications, from high-speed machining to heavy-duty cutting of complex parts.

Type	Mill-turn
X-axis travel	1,000mm
Y-axis travel	300mm
Z-axis travel	3,100mm
B-axis travel	±120°
Max spindle speed	Milling spindle: 8,000rpm Turning spindle: 1,500rpm
Max workpiece size	Ø1,000mm x 4,000mm

The University Of Sheffield.

Advanced Manufacturing Research Centre

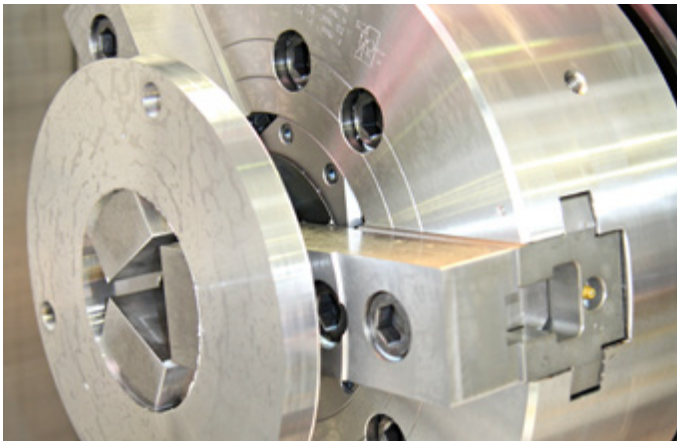
BOEING

Mori Seiki NT5400 DCG

Five-axis milling and turning machine, equipped with Renishaw scanning probe technology.

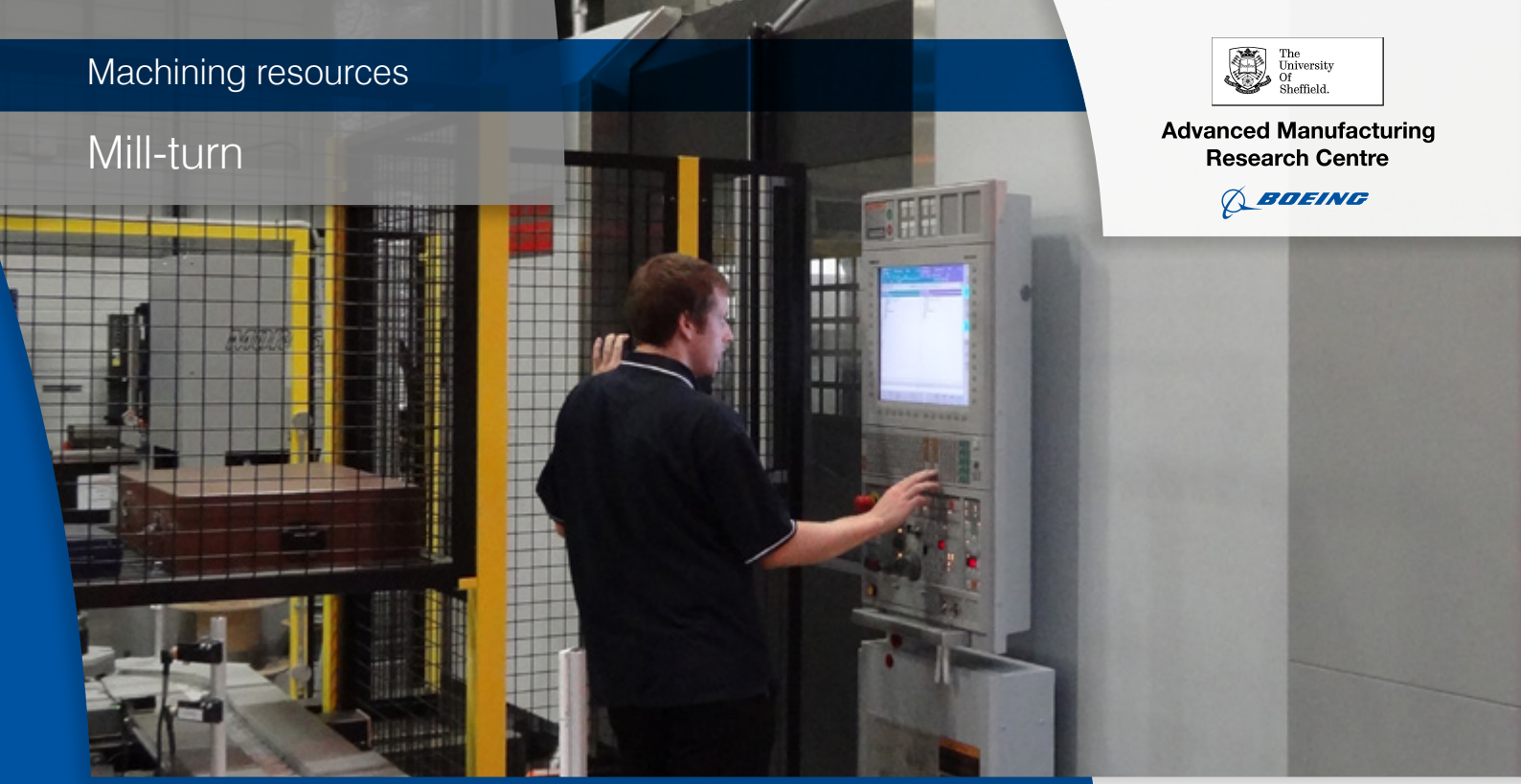
Five-axis milling and turning machine, equipped with the latest on-machine scanning probe technology from Renishaw. The NT5400 has twin chuck capability for green button manufacture, and is capable of parallel turning using a second turret system.

For aerofoils, the NT5400 offers flexible five-axis mill-turn capability for single blade machining, from a range of inputs including forging and bar stock. Twin spindle and lower turret application allow the development of single-hit machining for complex aerofoil geometries.



Type	5-axis horizontal mill-turn-grind
Max spindle speed	Lathe spindles: 2,400rpm Mill spindle: 6,000rpm
Max spindle torque	Lathe spindles: 1,432Nm Mill spindle: 30Nm
Max spindle power	Mill spindle: 30Nm Lathe spindles: 37kW Mill spindle: 5.5kW
Spindle interface	Capto C8
Coolant delivery type:	HPC through tool
Max workpiece size	920mm swing, 1,921mm max length
Additional functionality	SQUAD laser scanning. Spin turning. Involute milling. Pinch/parallel milling capability. Process monitoring system.

Mill-turn



The University Of Sheffield.

Advanced Manufacturing Research Centre

BOEING

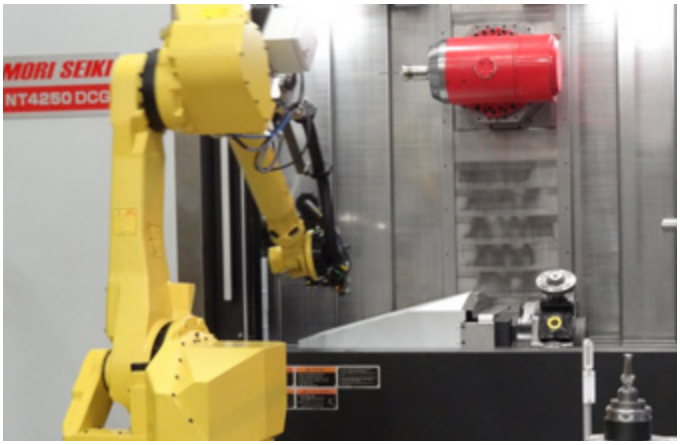
Mori Seiki NT4250 DCG

Five-axis mill-turn-grind centre, integrated into an innovative automated processing cell for aerofoil production.

Flexible five-axis mill-turn-grind capability for component manufacture from a range of input conditions.
The NT4250 is capable of handling a wide range of component handling, component transfer, wheel dressing and coolant applications.

The NT4250 has been integrated into a fully automated processing cell for aerofoil production which combines its machining capabilities with mass finishing techniques (Rösler drag finishing and vibratory bowl) and rapid component inspection.

Type	5-axis mill-turn-grind
Max workpiece size	660mm diameter, 721mm length
Max spindle speed	Mill/grind: 12,000rpm Turn: 3,000rpm turn
Spindle interface	Capto
Additional features of automated cell	Fanuc robot on tracks with Erowa handling unit. Renishaw Equator™ gauging system. Drag finishing unit. Vibratory bowl unit.



The University Of Sheffield.
Advanced Manufacturing Research Centre
BOEING

WFL M100

Large turning-boring-milling centre, capable of machining complex geometries to the highest precision.

Large turning-boring-milling centre, capable of machining complex geometries to the highest precision. The M100 is ideal for working with difficult-to-machine materials, high-volume material removal, and deep ID-machining.

It features a turning length of over five metres, turning spindle speed of 1600rpm and milling spindle speed of 6000rpm.

Type	Turn-bore-mill
X-axis travel	900mm
Z-axis travel	5,700mm
Max spindle speed	Turning: 1,600rpm Milling: 6,000rpm
Max spindle torque	Turning: 5,290Nm Milling: 315Nm
Max spindle power	Turning: 71kW Milling: 30kW
Max workpiece size	Turning length: 5,200mm Centre distance: 500mm

The University Of Sheffield.

Advanced Manufacturing Research Centre

BOEING

MAG Mega 5

Five-axis horizontal machining centre for high-torque cutting of tough materials or high-speed processing of aluminium.

The MAG Mega 5 is built for power and speed. The AMRC's machine is fitted with a high-torque spindle for the processing of tougher materials such as titanium or 300M.

A two-pallet automatic workchanger accommodates machining centre loads weighing up to 2,200kg.

Type	5-axis milling
X-axis travel	1,400mm
Y-axis travel	1,300mm
Z-axis travel	1,200mm
A-axis travel	+60° to -120°
B-axis travel	360°
Max spindle speed	6,500rpm
Max spindle torque	1146Nm
Max spindle power	45/37kW
Max workpiece size	Ø1,300mm x 2,000mm
Spindle interface	HSK 100
Max workpiece weight	2,200kg

The University Of Sheffield.

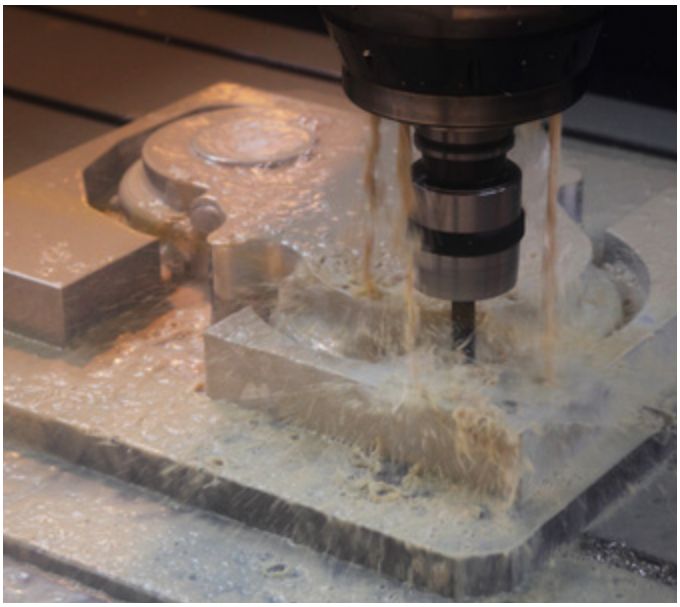
Advanced Manufacturing Research Centre

BOEING

MAG Cincinnati FTV5-2500

Flexible five-axis vertical machining centre capable of working range of metals.

The FTV5 provides a flexible vertical machining platform capable of cutting a wide range of materials from aluminum to today's hardest metals, particularly titanium alloys. The large table size allows us to work on larger structural components or multiple smaller test pieces at the same time.



Type	5-axis milling
X-axis travel	2,500mm
Y-axis travel	1,000mm
Z-axis travel	800mm
A-axis travel	±95°
C-axis travel	360° contouring
Max spindle speed	18,000rpm
Max spindle torque	130Nm
Max spindle power	27kW
Spindle interface	HSK 63
Max acceleration, linear axis	1m/s^2
Max workpiece size	2,500mm x 1,000mm
Max workpiece weight	8,000kg

The University Of Sheffield.

Advanced Manufacturing Research Centre

BOEING

MAG Cincinnati H5-800

Flexible five-axis horizontal machining centre for multi-function and high-efficiency processing.

The H5-800 integrates five-sided processing and five-axis contouring into a single agile platform.

The machine features a 180° A-axis tilt spindle sweep at 60° above horizontal and 120° below horizontal. The table is capable of continuous rotation. All axes work together to provide full five-axis capability.

Type	5-axis milling
X-axis travel	1,500mm
Y-axis travel	1,200mm
Z-axis travel	1,200mm
A-axis travel	180°
B-axis travel	Continuous
Max spindle speed	6,000rpm
Max spindle torque	11,390Nm
Max spindle power	30kW
Spindle interface	BT 50 taper
Max acceleration, linear axis	1m/s^2
Max workpiece size	800mm x 800mm x 1,350mm

The University Of Sheffield.

Advanced Manufacturing Research Centre

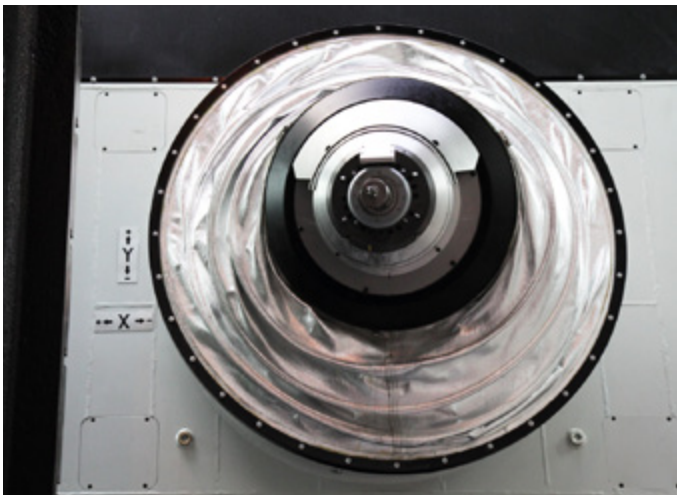
BOEING

Scharmann Ecospeed

High-speed five-axis machining of monolithic aerostructures, and wet cutting of carbon fibre composites.

The Ecospeed is designed for high-speed five-axis machining of monolithic aluminium and composite aerostructures.

It features the Z3 parallel kinematic head, which can follow any path within a conical working envelope of ±40°, mounted on a column with 3.8 metre X and 2.5 metre Y-axis travel. Our machine is also specified for wet cutting of carbon fibre composites.



Type	5-axis high speed machining
X-axis travel	3800mm
Y-axis travel	2500mm
Z-axis travel	Spindle horizontal: 670mm Spindle ±40°: 370mm In A-/B-axis, conical work envelope ±40°
Max spindle speed	30,000rpm
Max spindle torque	83Nm
Max spindle power	120kW
Spindle interface	HSK 63A-63/80
Max acceleration, linear axis	1g
Max acceleration, A/B-axis	685°/sec^2
Max jerk move	50 m/s^3
Coolant delivery type	Dual: HPC and MQL
Max workpiece size	3,800mm x 2,500mm x 370-670mm
Max table load	3,000kg
Additional functionality	Z3 PKM head for rapid 5-axis moves. Specified for wet cutting of carbon fibre reinforced polymer.

The University Of Sheffield.

Advanced Manufacturing Research Centre

BOEING

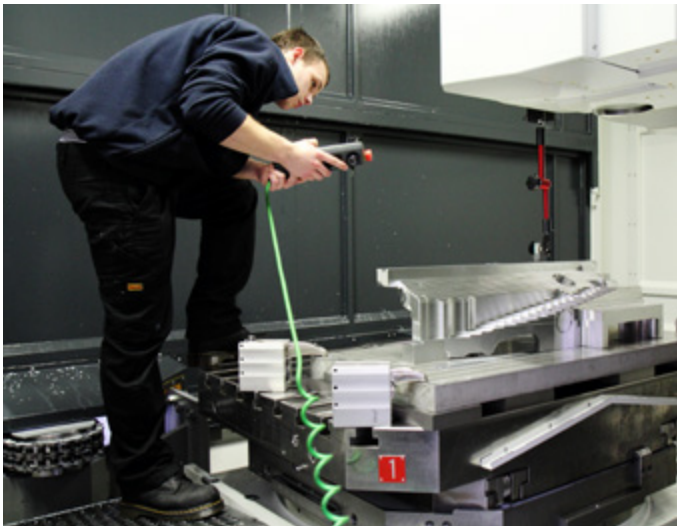
Starrag STC 1250

Flexible five-axis machine for cutting complex structural components from titanium and other high strength metals.

The STC 1250 is a flexible five-axis machine, ideal for cutting complex structural components from titanium and other high strength metals in a single set-up.

The STC modular design allows for the rapid integration of new capabilities and features, while its excellent static and dynamic characteristics provide high process stability.

Its working envelope measures 2.2 x 1.9 x 2.1 metres.



Type	5-axis machining centre
X-axis travel	2,200mm
Y-axis travel	1,900mm
Z-axis travel	2,100mm
A-axis travel	+60° to -100°
B-axis travel	360° continuous min 5.5rpm
Max spindle speed	8,000rpm
Max spindle torque	940Nm
Max spindle power	37kW
Spindle interface	HSK A100
Max acceleration, linear axis	0.3g
Max acceleration, A-axis	1 rev/s^2
Max acceleration, B-axis	0.8 rev/s^2
Coolant delivery type	High pressure through-spindle coolant at 100bar, 70 litres/min
Max workpiece size	1,250mm x 1,250mm
Additional functionality	Monitoring software and sensors.

The University Of Sheffield.

Advanced Manufacturing Research Centre

BOEING

Starrag ZT 1000

Five-axis machining centre with large working envelope, ideal for precision milling of casing components.

With simultaneous five-axis machining and a large working envelope, the ZT1000 is ideal for precision milling of casing components.

The twin-pallet design offers great versatility and a working area of 2 x 1.6 x 1.6 metres. Up to 50 tools can be stored ready for use, while a choice of standard or high-speed A-axis head attachments offers maximum spindle speeds of 6000rpm or 24000rpm respectively.

Type	5-axis milling
X-axis travel	2,000mm
Y-axis travel	1,600mm
Z-axis travel	1,600mm
A-axis travel	160°
B-axis travel	Continuous
Max spindle speed	Spindle 1: 6,000rpm Spindle 2: 24,000rpm
Max spindle torque	Spindle 1: 1270Nm Spindle 2: 43Nm
Max spindle power	Spindle 1: 37kW Spindle 2: 40kW
Spindle interface:	HSK A100/HSK63
Max workpiece size	1,000mm x 1,000mm

The University Of Sheffield.

Advanced Manufacturing Research Centre

BOEING

Starrag LX 051

High-performance five-axis centre designed for milling turbine blades.

The LX 051 is a single-spindle, five-axis machining centre that has been specifically designed for the high-performance milling of free-form surfaces such as gas turbine and compressor blades of varying shapes and sizes.

It can machine all types of blades with one jig, thanks to an innovative and flexible fixturing system. The AMRC's machine includes a cryogenic cooling system using liquid CO2, capable of achieving surface temperature of -50°C.

The LX 051 will be available from Q3 2014.

Type	5-axis turbine blade/impeller/blisk milling centre
X-axis travel	650mm
Y-axis travel	650mm
Z-axis travel	650mm
A-axis travel	360° continuous
B-axis travel	-100° to +40°
Swing diameter	350mm
Max feed rate/traverse	50,000mm/min
Max spindle speed	18,000rpm (milling spindle)
Max spindle torque	181Nm (milling spindle)
Max spindle power	28kW (milling spindle)
Max workpiece size	490mm length
Max workpiece weight	50kg
Additional functionality	Siemens Sinumerik 840D CNC. Cryogenic cooling to -50°C.

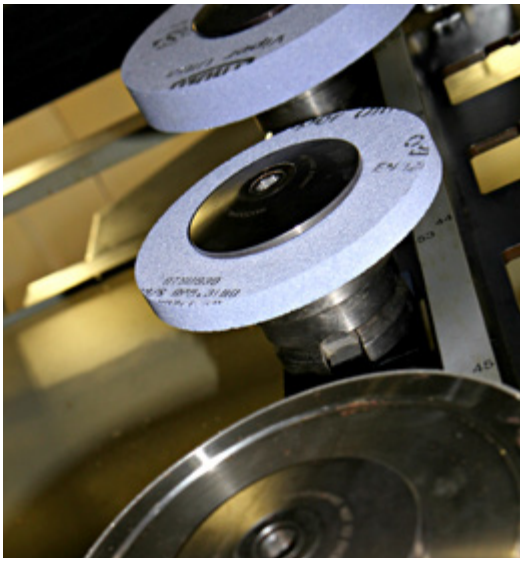
The University Of Sheffield.
Advanced Manufacturing Research Centre
BOEING

Makino A99

Continuous dress five-axis Viper grinding platform.

Continuous dress five-axis Viper grinding platform, with proven capability for stock removal and finish and form grinding of aerospace components.

The platform has also been used to develop on-machine polishing strategies to support advanced component surface finishing techniques.



Type	5-axis milling with continuous dress grinding capability
X-axis travel	1,200mm
Y-axis travel	800mm
Z-axis travel	1,200mm
A-axis travel	Continuous
B-axis travel	270°
Max spindle speed	Spindle 1: 12,000rpm Spindle 2: 8,000rpm
Max spindle torque	Spindle 1: 268Nm Spindle 2: 18.8Nm
Max spindle power	Spindle 1: 55kW Spindle 2: 11kW
Spindle interface	Big Plus BT 50 taper/HSK63A (BT-50 Flange)
Max acceleration, linear axis	4.9m/s^2
Max workpiece size	320mm x 320mm x 900mm
Max workpiece weight	220kg
Additional functionality	Has the ability to continuously dress grinding wheels and operate with Viper grinding capability.

The University Of Sheffield.
Advanced Manufacturing Research Centre
BOEING

Makino A100e-5XR-A320S-CD

Universal horizontal machining centre with creep-grinding.

The Makino A100e is a universal five-axis horizontal machining centre with an advanced creep-grinding function including Viper and continuous dressing.

It provides cutting feed rates and rapid traverse rates of up to 50m/min. Its 30 tonne weight ensures stability for high-performance machining requirements, and its 0.4G acceleration is exceptional for a machine of this size.

The A100 will be available from Q4 2014.

Type	Horizontal machining centre with creep-grinding capability.
X-axis travel	1,700mm
Y-axis travel	1,050mm
Z-axis travel	1,400mm
B-axis travel	270° (table)
C-axis travel	360° (rotary workhead)
Max spindle speed	Spindle 1: 12,000rpm Spindle 2 (CD): 8,000rpm
Max spindle torque	Spindle 2 (CD): 18.8Nm
Max spindle power	Spindle 1: 50kW Spindle 2: 11kW
Spindle interface	Spindle 1: Big-plus BT50 Spindle 2: CD HSK63A (BBT50 flange)
Max acceleration, linear axis	4m/s^2
Max workpiece size	ø 1,900mm x 1,500mm
Max workpiece weight	3,000kg
Additional functionality	Makino Pro 3 control system. Able to continuously dress grinding wheels. Viper grinding capability.

The University Of Sheffield.

Advanced Manufacturing Research Centre

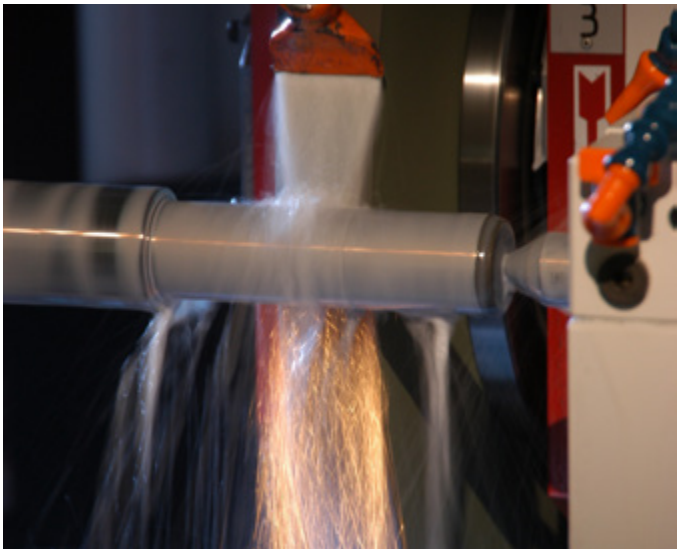
BOEING

Studer S41

Universal machine for complex grinding of large components.

The Studer S41 is an advanced universal cylindrical grinding machine. It boasts a range of technical features, including the StuderGuide guideway system, high-precision axis drives with linear motors, extremely fast direct drive of the B-axis, and an even larger selection of grinding head variants.

The S41 will be available from Q4 2014.



Type	Universal cylindrical grinding
X-axis travel	350mm (cross slide)
Z-axis travel	1,750mm (longitudinal slide)
B-axis travel	-45° to +225°
X-axis travel speed	0.001-20,000mm/min
Z-axis travel speed	0.001-20,000mm/min
Max spindle speed	Spindle 1: 10,000rpm Spindle 2: 4,500rpm
Max spindle power	Spindle 1: 30kW Spindle 2: 15kW
Max workpiece size	1,600mm (centre distance) x 350mm (centre height)
Max workpiece weight	250kg
Additional functionality	StuderGuide guideway system with linear drive.

The University Of Sheffield.

Advanced Manufacturing Research Centre

BOEING

Mori Seiki NVL1350

Two-axis high-precision vertical lathe with milling capability, designed for machining flanged casings.

A two-axis high-precision vertical lathe with milling capability, the NVL is specifically designed for machining flanged casings.

The combination of an octagonal ram construction (ORC) design with a large, wide working envelope (max turning diameter of 1600mm, and 1300mm Z-axis travel) ensures high rigidity in both turning and milling applications.

Type	Vertical turning lathe
X-axis travel	1,900mm = 0.135 ARC travel
Z-axis travel	800mm
Max spindle speed	Turning tool: 400rpm Rotary tool: 3,000rpm
Max spindle torque	Turning tool: 20,000Nm Rotary tool: 525Nm
Max spindle power	30kW
Spindle interface	BT50
Max workpiece size	Ø1,600mm x 1,100mm
Max workpiece weight	8,000kg

The University Of Sheffield.

Advanced Manufacturing Research Centre

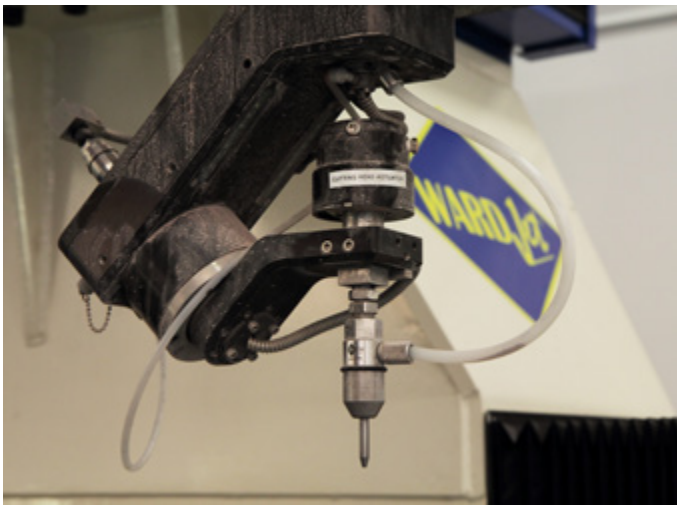
BOEING

WardJet GCM

Large gantry-style waterjet milling centre with range of advanced features.

The G-series composite milling (GCM) waterjet combines WardJet's proven waterjet technology with high-speed five-axis machining, providing highly efficient and flexible cutting of composites and metals.

With over 1.5 metres of vertical travel for the cutting head and four metres of cross-beam travel, it is one of the world's largest combined waterjet-machining centres.



Type	5-axis waterjet and milling centre
Working area	Tank: 4,000mm x 2,000mm x 900mm Floor: 4,000mm x 9,000mm x 1,500mm
Max spindle speed	24,000rpm
Waterjet pump	4136 bar
Max spindle power	15kW
Coolant delivery type	MQL
Additional functionality	Two heads for 5-axis water jet and 5-axis milling. Option of machining over tank or floor mounted.

Additional machining resources

We also have a range of smaller machining centres, mostly housed in the AMRC Knowledge Transfer Centre, used for routine machining tasks, technology demonstrators and training.

Manual machinery

Lathes:

- Huvema HU410 x 1000 (two)
- Huvema HU460 x 1500
- Colchester Student 2500

Surface grinder:

- Seedtec YSG-52AIS

Saws:

- Huvema HU450BMSY bar saw
- Huvema KV100 vertical band saw

Milling machines:

- Huvema HU18VS (two)
- Huvema HU24EVS

Cylindrical grinder:

- Jones & Shipman 1305

Oven:

- Vecstar MRF4: max temp 1,200°C, 205mm high x 305mm x 460mm

Three-axis milling

Haas VF-6/50

Type	5-axis milling (with trunion table)
X-axis travel	1,600mm
Y-axis travel	800mm
Z-axis travel	700mm
Max spindle speed	7,500rpm
Max spindle torque	610Nm
Max spindle power	22.4kW
Spindle interface	BT 50
Max workpiece size	1,600mm x 800mm
Max workpiece weight	1,814kg

Haas TM-1P

Type	3-axis milling
X-axis travel	700mm
Y-axis travel	300mm
Z-axis travel	400mm
Max spindle speed	6,000rpm
Max spindle torque	45Nm
Max spindle power	5.6kW
Spindle interface	CT 40
Max workpiece size	Table length: 1200mm Table width: 200mm
Max workpiece weight	450kg

Haas MM

Type	3-axis milling
X-axis travel	400mm
Y-axis travel	300mm
Z-axis travel	200mm
Max spindle speed	6,000rpm
Max spindle torque	45Nm
Max spindle power	5.6kW
Spindle interface	CT 40
Max workpiece size	Table length: 900mm Table width: 300mm
Max workpiece weight	227kg

Mori-Seiki SV-500/40

Type	3-axis milling
X-axis travel	800mm
Y-axis travel	500mm
Z-axis travel	500mm
Max spindle speed	10,000rpm
Max spindle torque	1139Nm
Max spindle power	22kW
Spindle interface	NC 5
Coolant delivery type	External flood coolant
Max workpiece size	1,100mm x 600mm x 600mm

Mori-Seiki NV5000a1

Type	3-axis milling
X-axis travel	800mm
Y-axis travel	500mm
Z-axis travel	500mm
Max spindle speed	14,000rpm
Spindle interface	BT40
Max workpiece size	Table length: 1,300mm Table width: 600mm
Max workpiece weight	1,200kg

MAG CFV 550i

Type	3-axis milling
X-axis travel	500mm
Y-axis travel	500mm
Z-axis travel	500mm
Max spindle speed	8,000rpm
Max spindle torque	177Nm
Max spindle power	22kW
Spindle interface	BT 40 taper
Max workpiece weight	700mm x 500mm

Turning

Haas SL40

Type	Haas SL40
X-axis travel	400mm
Z-axis travel	1,000mm
Max spindle speed	2,400rpm
Max spindle torque	1898Nm
Max spindle power	29.8kW
Max workpiece size	Cutting diameter: 600mm Cutting length: 1,100mm

Haas TL-1

Type	Haas TL-1
X-axis travel	200mm
Z-axis travel	700mm
Max spindle speed	2,000rpm
Max spindle torque	136Nm
Max spindle power	5.6kW
Max workpiece size	Cutting diameter: 400mm Cutting length: 700mm

MAG Hawk 300 Lathe

Type	Lathe
X-axis travel	200mm
Z-axis travel	1,000mm
Max spindle speed	3,000rpm
Max spindle power	45/37kW
Coolant delivery type	External flood coolant
Max workpiece size	400mm x 600mm
Additional functionality	External HP coolant system available

Electro-Discharge machine

Mitsubishi FA30-S Advance

Type	Submerged technology (EDM)
X-axis travel	700mm
Y-axis travel	500mm
Z-axis travel	400mm
A-axis travel	±100mm
B-axis travel	±100mm
Max workpiece size	1,300mm x 1,000mm x 400mm

Sliding head machine

Star SR-20RIII

Type	Sliding head lathe
Machining diameter	20mm
Drilling capacity	10mm
Milling capacity	10mm
X-axis travel	20mm
Z-axis travel	200mm
Max spindle speed	10,000rpm
Max spindle power	2.2/3.7kW
Spindle interface	12mm x 100~135mm
Max workpiece size	Ø20mm
Additional functionality	Fitted with external bar feed system

AMRC with Boeing
Advanced Manufacturing Park
Wallis Way
Catcliffe
Rotherham
S60 5TZ

e: enquiries@amrc.co.uk
t: +44 (0)114 222 1747
w: amrc.co.uk

CATAPULT
High Value Manufacturing

EUROPEAN UNION
Investing in Your Future
European Regional
Development Fund 2007-13