INSIGHT

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Introduction

Near net shape (NNS) manufacturing aims for the initial fabrication of a component to be as near as possible, in size and shape, to the finished product. This is with a view to both minimising downstream process steps and reducing the amount of raw materials and energy used. This INSIGHT paper looks at the opportunities and challenges associated with the implementation of near net shape technologies in aerospace.

17 NEAR NET SHAPE MANUFACTURING: *Applications in Aerospace*

EXECUTIVE SUMMARY

This INSIGHT paper looks at the opportunities and challenges associated with the implementation of near net shape (NNS) manufacturing technologies and how the benefits can be recognised across the aerospace manufacturing industry. Recommendations are provided for the civil aerospace sector to develop and exploit disruptive opportunities for NNS technologies that could transform future aircraft platforms. These opportunities are dual use, equally applicable to defence applications as well as to other manufacturing sectors.

Some processes included in the scope of NNS have been or will be explored in further detail in previous or future ATI INSIGHT papers, for example additive manufacturing.

In this INSIGHT, six key topics have been considered to accelerate NNS manufacturing in the UK aerospace sector:

Materials	Design	Process
Understanding the full life cycle of NNS processing, exploring new materials specifically, material modelling and simulation.	Exploring how best to enhance designs for NNS manufacturing - including through topology optimisation, tooling, process design, and factory modelling and simulation.	Develop end-to-end NNS manufacturing processes covering high value design, hybrid manufacturing, post-processing, validation and verification.
Digital manufacturing	**Cost**	**Supply chain**
Ensuring the UK remains a world leader in digital manufacturing through advanced automation, sustaining a digital manufacturing thread, and making best use of through-life data.	Detailing and communicating the recurring, non-recurring and through-life cost implications of using NNS processes in aerospace, including identifying prohibitive costs and potential benefits.	Integrating the UK supply chain and ensuring that it is able to manufacture parts at a competitive price that addresses sector requirements. This involves linking to academia and research organisations.

Aiming for initial fabrication of components that are close in size and shape to the finished product is important for the aerospace sector, offering cost and often lead time reductions over conventional manufacturing processes, potentially also providing opportunities for weight saving.

HIVES (Future Forge) – AFRC, Renfrewshire

The HIVES project is part of a wider investment into the FutureForge project hosted at the University of Strathclyde's Advanced Forming Research Centre.

The £16.5m project establishes a major new advanced engineering facility that will put Scotland at the forefront of the movement to transform one of the manufacturing sector's most traditional and important supply chains.

FutureForge is jointly funded by the ATI, Scottish Enterprise, and the AFRC's High Value Manufacturing (HVM) Catapult funding.

The project will adjoin the world-renowned Renfrewshire-based centre and will revolutionise the global hot forging sector.

NNS processes will be key to sustainable aircraft. Whilst heavily adopted in aero engines today, they are under-utilised in the airframe and offer great opportunity in large civil aircraft manufacture, and future green aviation.

Leading UK aerospace manufacturing organisations were consulted as part of this document's preparation, and all recognise NNS manufacturing as a fundamental part of their future manufacturing strategies.

WHAT IS NEAR NET SHAPE MANUFACTURING?

NNS manufacturing processes aim for the initial fabrication of a component to be as near as possible, in size and shape, to the finished product. This is with a view to both minimising downstream process steps and reducing the quantity of raw materials and energy used. NNS can offer reduced lead time, increased design freedom, and in some cases reduced tooling costs. Although the geometric shape of a NNS component is defined during its fabrication, finished NNS components may require subsequent processes (for example machining, heat treatment or coating) to create a component with the right geometry, surface finish, and material properties for the application.

From a sustainability perspective, NNS manufacturing can lead to reductions in the energy consumption and greenhouse gas emissions from production, transportation, and recycling of wasted material and the broader environmental impacts of materials extraction and refining.

NNS manufacturing is not new; parts have been cast and forged to near final shape for centuries. However, these techniques have evolved over the last thirty years to new levels of capability through the application of engineering science and investment. They also now compete with a whole new range of NNS technologies that have emerged and been developed to offer excellent opportunities for the aerospace sector.

The scope of NNS manufacturing processes is wide, so we have focused on the more applicable ones for aerospace, namely:

- **Forging** (hot, cold, and radial)
- **Forming** (cold sheet, hot sheet, incremental, rotary)
- **Casting** (notably investment, centrifugal)
- **Additive manufacture** (powder based, direct energy deposition)
- **Joining technologies** (fusion and solid state)
- **Hot isostatic pressing**

Other technologies such as cold spraying, bonding, and fastening replacement have not been included in this paper, although the challenges and opportunities mentioned below are also relevant for these. It should also be noted that a more detailed insight into additive manufacturing can be found in ATI INSIGHT 08.

Market opportunity and recent investments

In recent years, there has been large scale investment in additive manufacturing, forming, and joining technologies under the banner of NNS manufacturing. Since 2012, the UK aerospace sector has funded a total of £216m of collaborative research and development (R&D) initiatives focused on NNS technologies. Despite these large investments, there is still a gap to bridge between R&D and more broadly adopting these technologies into aerospace part production, particularly in aerostructures.

£11b opportunity

Global aircraft components which could be manufactured using near net shape processes by **2025**.

Global market opportunity for airframe and engine components to be manufactured using NNS processes

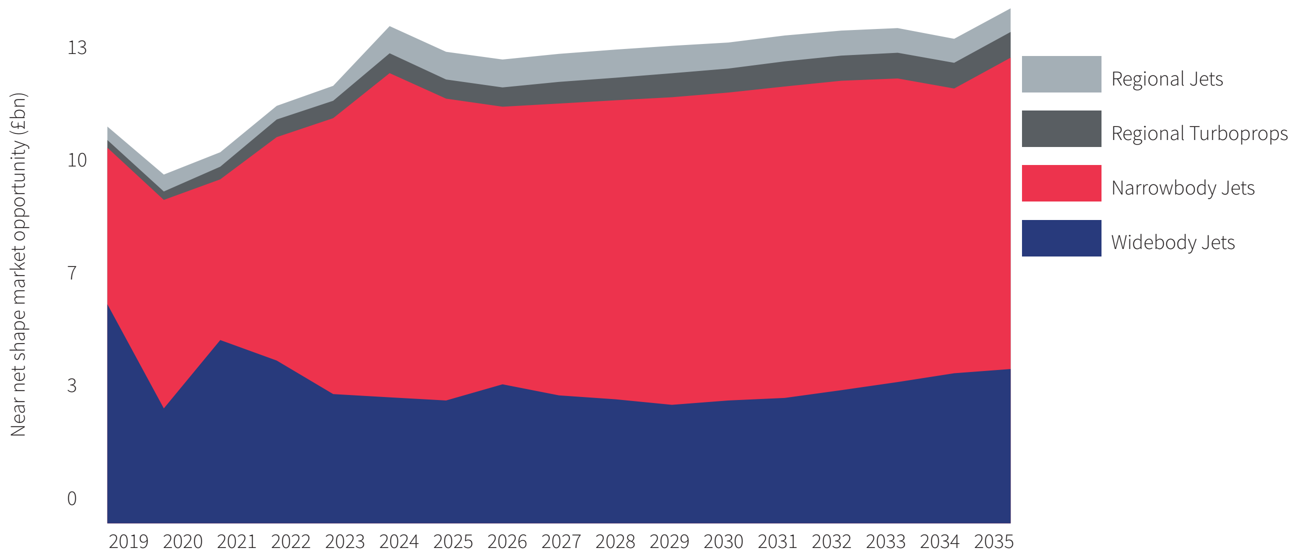


Figure 1: Global market opportunity for airframe and engine components to be manufactured using NNS processes [Source: ATI Market Analysis]

Figure 1 shows the global opportunity to exploit NNS manufacturing in aircraft components. The data is an extract from the **ATI Market Analysis** and illustrates the complete opportunity of metallic components which can be manufactured using NNS manufacturing. There are some intrinsic assumptions made in the data such as the gradual recovery of the market in the wake of Covid-19 and the gradual return to service of the Boeing 737max. The data shows that **by 2025, there is a global market of just over £11b of components which could be re-manufactured using near net shape techniques.**

How has this number been calculated? Using the ATI market model, we identified which metallic components could potentially be redesigned using NNS techniques. By identifying these potential components across the entire aircraft and for different aircraft type, we were able to extrapolate the total global market size. It is important to note that to address the whole market depends wholly on satisfying the business case for each component or family of components on a case-by-case basis.

Split of market opportunity by aircraft type (2020 – 2025)

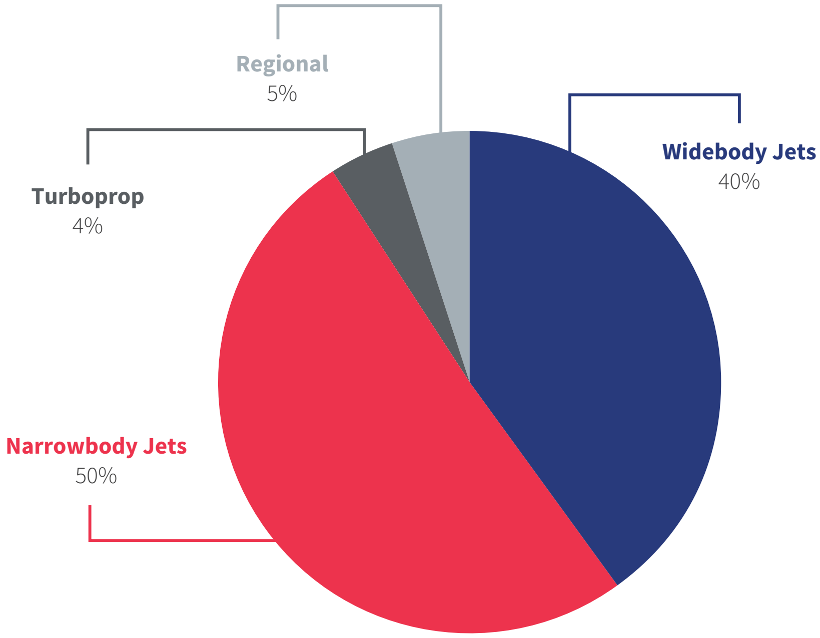


Figure 2: Split of market opportunity by aircraft type (2020 – 2025)

Figure 2 shows opportunity split by aircraft type. The opportunity to exploit NNS manufacturing is greatest in the narrowbody sector, where the A320 and B737 families are predominantly metallic aircraft. Both OEMs continue to look for opportunities to manufacture parts more quickly, cheaply, and efficiently. NNS techniques would allow manufacturers and the supply chain to achieve these objectives.

NNS Techniques would allow manufacturers and the supply chain to achieve these objectives, whilst also potentially de-commoditising products, protecting UK businesses from offshoring or offering opportunities to re-shore manufacturing to the UK.

Looking beyond this timeframe, new platforms such as a next-generation single aisle, and smaller all electric and hybrid aircraft will present further opportunities to rethink manufacturing using some of the methods described in this paper.

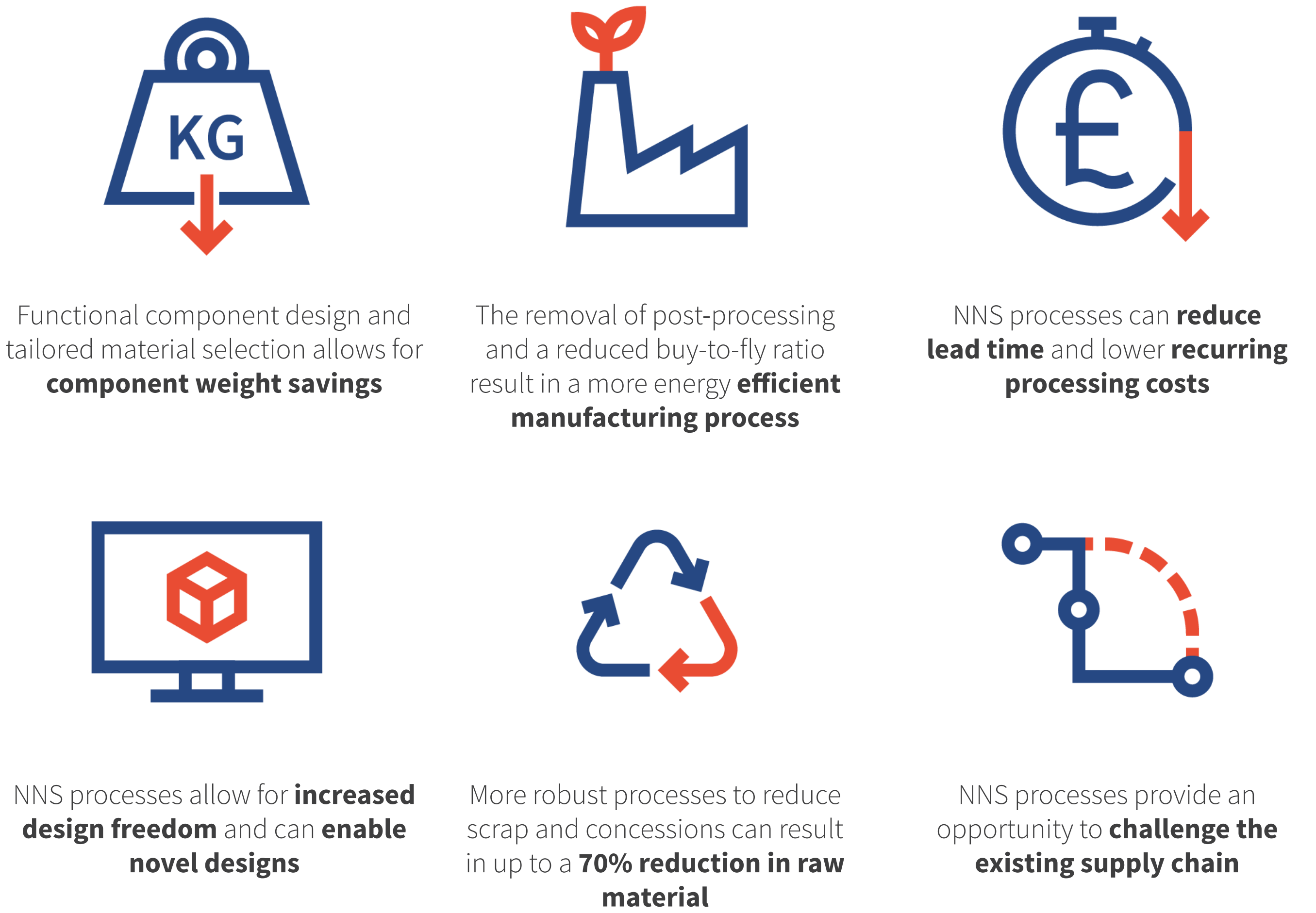


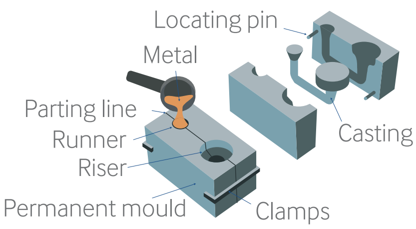
Figure 3: The key benefits of near net shape manufacturing

"OEMs continue to look for opportunities to manufacture parts more quickly, cheaply and efficiently."

MANUFACTURING PROCESSES OVERVIEW

This section provides an overview of the key NNS manufacturing processes, where they are currently used in aerospace, and the challenges and opportunities associated with them.

CASTING



Typical aerospace components

- Hydraulic fluid system components
- Turbine blades
- Interior components
- Landing and braking components
- Bearing cages
- Winglets

Recurring costs - MODERATE
(moulds, material, energy)

Non-recurring cost - HIGH
(capital equipment, specialist facility)

Casting has been used to manufacture components as far back as 4000 BC and it is still extensively utilised in aerospace. Investment casting is regarded as a key precision metal processing process, offering near or net near shape components. Investment castings are primarily in nickel, titanium or aluminium. Specific processes such as centrifugal casting are utilised for producing components with thin walls. Within this process, the inertia forces caused by the rotation of the mould distributes the molten material into the mould cavities. Sand casting and permanent castings are also used for magnesium or aluminium applications. The ATI will publish a castings technology roadmap to provide an insight into how this NNS process will develop to deliver the next generation, high quality, optimised metallic components for future aircraft components.

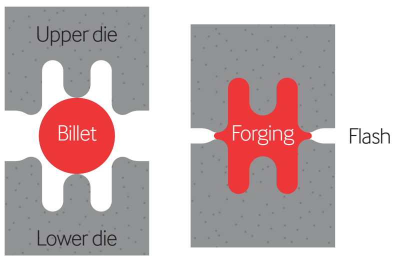
Key opportunities

- Topology optimised castings / Optimised grain structure / Cold formable cast alloys

Key challenges

- Supply chain availability / Perception of technology / Cast quality / Surface finish / Accuracy of features

FORGING – PRECISION FORGING



Typical aerospace components

- Landing gear
- Track ribs
- Compressor and turbine discs
- Compressor aerofoils

Recurring costs - LOW
(tools, material, energy, facility)

Non-recurring cost - HIGH
(capital investment)

Precision forging is a closed die operation, producing a flash-less NNS component with a good quality surface finish. Most aerospace forging operations are undertaken at high temperatures (driven primarily by the materials; titanium, nickel alloys, nimonics) and are not able to achieve full net shape. However, there are specific strands of forging designed to achieve nearer net shape. Precision forging undertaken through reduced temperature (cold forging) is one such technology with potential benefits achieved through reduced energy, reduced material input and reduced post processing operations. However, these are also coupled with high cost for tooling and lower applicability for materials (predominately aluminium).

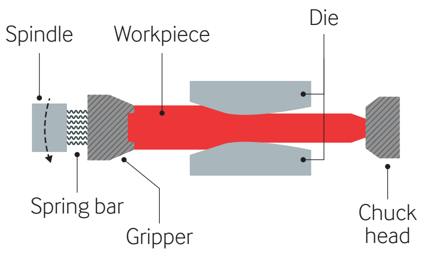
Key opportunities

- Digitisation and I4.0 / Material data and microstructural evolution / Advanced inspection and NDT / Lower temp, higher precision forging

Key challenges

- Lack of investment in new equipment / Historical standards / Perceived as a more traditional and less 'modern' technology

FORGING – RADIAL FORGING



Typical aerospace components

- Turbine blades
- Interior components
- Landing, braking and gearbox components
- Bearing cages
- Drive shafts and actuators

Recurring costs - LOW
(tools, material, energy, facility)

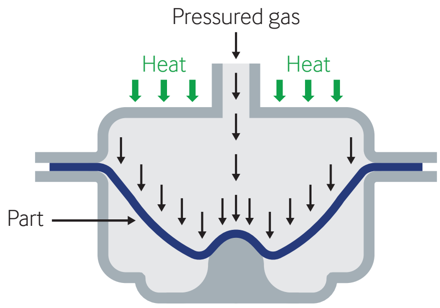
Non-recurring cost - HIGH
(capital investment)

Utilising several high-frequency, radially moving hammer dies to produce axisymmetric components, the radial forging process can be highly automated, with benefits such as cost reduction, material-saving, tight tolerances, and homogenous grains. Technologies of this type have the combined advantage of producing excellent buy-to-fly ratios, and component attributes (cleanliness, flexibility, repeatability) similar to those of machined parts. Radial forging can also be used to manufacture hollow components such as high strength, low weight driveshafts.

Key opportunities
- Accurate and repeatable / Material data and microstructural evolution / Lower temp, higher precision forging / Flexible tooling

Key challenges
- Awareness and perception of technology / UK supply chain availability / Designing for radial forged manufacture

FORMING – SUPER PLASTIC FORMING



Typical aerospace components

- Engine fan blades
- Outer guide vanes
- Exhaust structures
- Canard wings
- Fuselage panels
- Wing leading edges.

Recurring costs - LOW
(tools, material, energy, facility)

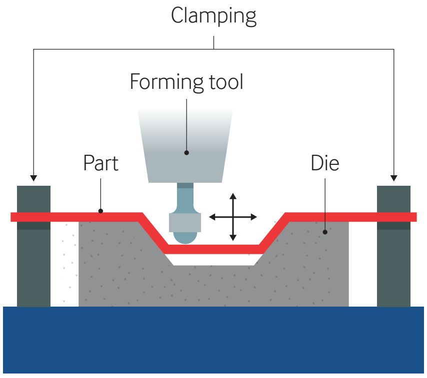
Non-recurring cost - HIGH
(capital investment)

Super plastic forming (SPF) is a highly specialised NNS process involving heating of the material to its superplastic state and then applying forming techniques such as vacuum forming, gas forming or thermoforming to shape the component within a closed die set. The process is used extensively for titanium fan blade production and complex lightweight panels across the aircraft structure. SPF is an energy intensive process based both on the required processing temperature and long forming cycle times. It also requires bespoke, expensive equipment.

Key opportunities
- Low-cost tooling and equipment / More effective part heating solutions / Automated part handling at temperature

Key challenges
- Long forming cycles (low production rate) / Significant processing cost / Limited surface finish quality

FORMING – INCREMENTAL FORMING



Typical components

Flow forming
- Thrust strut, air guide tubes, nose cones, accumulator housings, nozzles and shafts

Shear forming
- Combustor liners, shields and seals, vanes,
- heat shields and bearing housings

Metal spinning
- Lip skins, combustor liners and shields, nozzle assemblies and bearing housings

Recurring costs – LOW to MODERATE

(preforms, tooling, energy usage, lubricants)

Non-recurring cost - HIGH

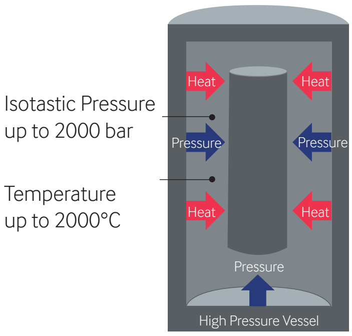
(capital investment and equipment)

Incremental bulk cold forming processes (flow, shear and spin forming) were originally developed in the early twentieth century and were adopted for manufacture as it became clear that large deformations can be achieved with substantially less press load and power than for conventional forging and pressing processes. The processes are based on the principle of incremental deformation achieved through a relatively small contact area between the tool and parts which transcend over many rotations or increments. This fundamental capability to operate with reduced load means that incremental processes can process material at room temperature, with benefits in refined and homogeneous grain structures, accuracy of the finished form, and superior surface finish over hot forming processes.

Key opportunities
- Reduction in forgings and machining operations / Higher strength, lower weight components / Reduced part count and number of welds

Key challenges
- High capital cost / UK supply chain and knowledge / Material preparation (pre and post) / Metal spinning: predominately light gauge materials

HOT ISOSTATIC PRESSING (HIP)



Typical aerospace components

- Large titanium components
- High temperature superalloy turbine and compressor discs
- Pylon
- Pintle fittings
- Landing gear
- Gear ribs

Recurring costs - MODERATE

(material, energy, facility)

Non-recurring cost - HIGH

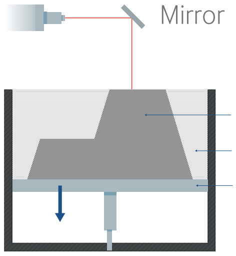
(capital investment and equipment)

Hot isostatic pressing (HIP) is a process used to consolidate cast, sintered or printed metal components. The process uses a combination of high pressure (around 150 MPa) and high temperatures (around 1000°C) to consolidate or 'densify' the green component. The gas pressure acts uniformly in all directions to provide isotropic properties and maximum consolidation of the component. HIP provides an alternative to conventional processes such as forging, casting and machining in many applications. HIP can also be used as a post process for AM parts to reduce void content and can also be used to consolidate and sinter titanium or steel powder in a canister, producing a refined grain structure for superior material properties over billet and forgings.

Key opportunities
- Qualified process in aerospace /Complementary to other powder metallurgy processes /Reduction of post processing / Relieves residual stresses

Key challenges
- Requires high integrity containers and equipment / Slow cycle times

ADDITIVE MANUFACTURING – POWDER BED (LASER AND ELECTRON BEAM)



Typical aerospace components

- Heat exchangers
- Ducting
- Vanes
- Fuel nozzles
- Mounting brackets

Recurring costs - MODERATE
(metal powder, energy, facility, post-process)

Non-recurring cost - HIGH
(capital investment and equipment)

Powder bed AM involves using a high energy heat source such as a laser or an electron beam to melt and fuse material powder particles together.
The process involves spreading a uniform layer of powder material over a build platform. The heat source fuses the first cross-section of the build from this layer, before the machine spreads another layer of powder on top and the process repeats for the next cross-section of the build. Un-fused powder remains in position but is removed during post processing. A more detailed insight into the laser metal powder bed process can be found in ATI INSIGHT 08 . The DRAMA project led by the MTC looks at developing AM within the aerospace supply chain.

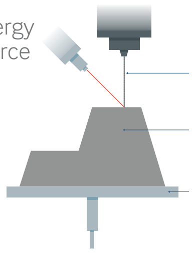
Key opportunities

- Topological optimised parts / Digital end-to-end AM process / Development of AM certification and standards / Enhancement of AM supply chain

Key challenges

- High costs of AM systems / UK skills and expertise / Product quality (voids, surface finish) / Component size limitation

ADDITIVE MANUFACTURING - DIRECT ENERGY DEPOSITION (DED)



Typical aerospace components

- Brackets
- Enclosures
- Ribs
- Engine casings
- Bulkheads

Recurring costs - LOW
(metal powder/wire, energy, facility, post-process)

Non-recurring cost - HIGH
(capital investment and equipment)

Direct energy deposition is typically used for larger scale builds. The process combines a metal-depositing nozzle with a high energy heat source such as a laser mounted on a multi-axis arm. The nozzle deposits metal powder or wire and the heat source melts the deposited material onto the build below it. The arm allows metal to be deposited from many directions. As with powder bed fusion, the component is built up in layers. Similarly, wire-arc additive manufacturing (WAAM) is a processing route whereby using an electric arc as the heat source, a metal wire, when melted, is extruded in the form of beads on the substrate. As the beads stick together, they create a layer of metal material. The process is then repeated layer by layer, with a robotic arm, until the metal part is completed. The Welding Institute's OAAM project (supported by the ATI and funded through UKRI's Industrial Strategy Challenge Fund) looks at developing a wide range of DED processes and tools.

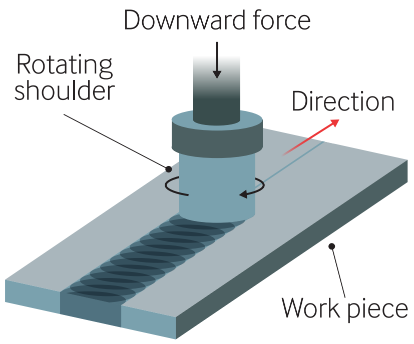
Key opportunities

- Larger scale components / Can be included in hybrid manufacturing processes / Topological optimised parts / Digital end-to- end AM process

Key challenges

- Material limitations / High costs of AM systems / UK skills and expertise / Accuracy and repeatability

SOLID STATE JOINING



Friction stir welding (pictured above) is one of several solid state joining processes.

Typical aerospace components

Friction stir welding

- Fuselage sections, fuel tanks, panel joints

Linear friction welding

- Bladed disk (blisks, see *Figure 5*), rib web to rib feet, structural flanges and brackets (see front cover)

Rotary friction welding

- Compressor disks, turbine shafts, piston rods, copper-aluminium electrical connections, tubular transition joints

Recurring costs -
LOW to MODERATE
(material, energy, facility dependant on process)

Non-recurring cost - HIGH
(capital investment and equipment)

Solid state joining includes processes such as friction stir welding (pictured above), linear, and rotary friction welding. The process uses friction between two moving surfaces to generate heat which softens the region between the two parts. When the oscillation or rotation stops, the parts cool to form a mechanically superior diffusion bond. In most cases, the strength and material properties of the join is superior to the properties of the adjoining materials.

Why do we consider this as NNS? Although not producing a component in a single step, solid state joining allows net shape sub-components to be joined so that the final component benefits from some of the advantages of the upstream NNS manufacture. As an example, the billet from which a metallic wing rib is machined is constrained by the width of the rib foot. Up to 98% of the billet can be wasted upon manufacture. Using linear friction welding as an example, the rib foot can be joined on to the web, significantly reducing the required billet width.

Key opportunities

- High-strength and high-quality joins / Lower cost of equipment / Cost effective quick changeover of tooling

Key challenges

- OEM application identification and qualification / Adaptable tooling

CHALLENGES

This section explores some of the more general challenges for the adoption of NNS technologies.

Awareness, understanding and perception

Many NNS manufacturing processes are perceived to be high-cost, low-volume processes (e.g. superplastic forming and additive manufacturing) which is a key barrier to adoption. R&D investment in NNS across the UK aerospace network has brought many NNS technologies up to TRL 4 or even 6 in some applications. In some cases, these are limited applications or where a sufficient volume of suitable parts is required to make the business case viable. This is where collaborative working can help build the case for UK investment.

In recent years, primes and OEMs have often struggled to make the business case for introducing NNS manufacturing into their serial production. This has largely been due to the risk and cost of introducing novel technologies. Although reduced production cycle times, materials wastage, and logistics are desirable, cost savings need to be focused around developing lower capital cost solutions, processing routes, and lower cost and lead time tooling; these are where most of the benefits can be achieved and must be taken into consideration from initial part design.

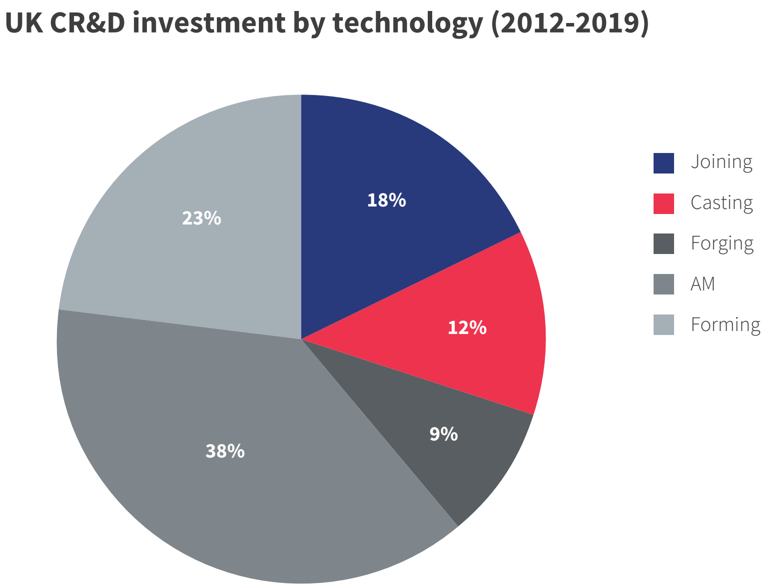


Figure 4: ATI funded near net shape projects by technology (2012 – 2019)

The same is true in the wider supply chain. A challenge for designers is that there is no effective 'design for manufacture trade tool' to compare NNS and conventional manufacturing methods. This would help designers, manufacturing engineers and businesses work out the best solution for a part or family of parts. To reap the full benefits of NNS manufacture, components must be optimally designed for such processes. This includes topological optimisations and other novel design methods which are yet to be widely adopted.

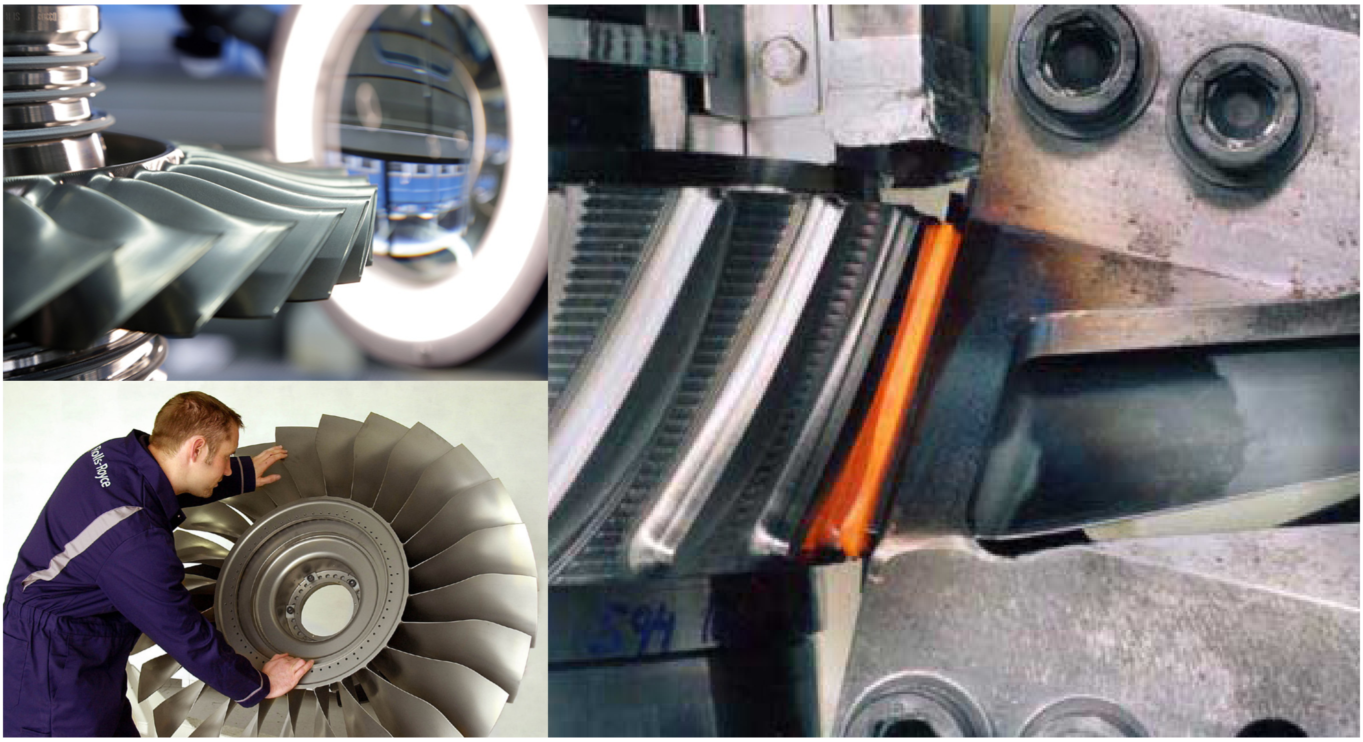


Figure 5: An example of linear friction welded bladed disks or 'blisks' used in the compressors of turbofan engines

Technology limitations

Although there are significant benefits to adopting NNS technologies, there are also various technical limitations.

Pre- and post-processing

Current standards and process specifications do not always accommodate NNS processes and their associated downstream requirements such as heat treatment, inspection, and testing. Today's standards and process specifications are more suited to established processing routes such as machining, and therefore have not been optimised for NNS. This inevitably leads to customer reluctance to changing the manufacturing solution, especially where there is existing in-house knowledge and established testing strategies for conventional processes. Furthermore, long development lead times, process qualification, and extensive quality controls make it difficult to change an approach once a product is in the market, unless there are immediate cost or performance advantages.

Modelling and simulation

The modelling and simulation of the physics, chemistry and metallurgy of NNS processes is critical in enabling the success of NNS. Further research is required focusing on improved modelling of NNS processes and the creation of new standards and best practices for designs that use NNS.

Materials

Most aerospace materials are applicable to NNS processes, however current applications are focused on expensive, hard to process materials such as titanium, nickel, and aluminium-lithium alloys. There is a desire to move towards lower cost materials with greater applicability, such as aluminium and steel alloys. Additionally, research is being undertaken on how to carry out NNS techniques at lower temperatures to reduce the overall manufacturing cost (examples include cold spray additive manufacturing and low temperature solid state joining). Whilst there are barriers, there are opportunities for material producers to work collaboratively to create new alloys specifically for NNS processes, leading to the wider adoption of NNS. Conversely, the drive towards sustainability and developing a circular economy in aerospace for recycling end-of-life components may lead to prioritisation of fewer alloys to simplify the logistics and strengthen the economic case for re-introducing back into the supply chain.

Hybrid manufacture

There is also the possibility to create multi-material components through the solid state joining of dissimilar materials. Figure 6 below shows a TRENT XWB intermediate compressor casing manufactured by GKN. The final assembly is fabricated from two different titanium alloys and the main body is cast with features being added through DED additive manufacture.

Figure 6: Hybrid NNS engine casing, courtesy of GKN

Commercial and supply chain availability

The UK has many strengths in NNS process technologies, including hot forging, fusion and friction welding, additive manufacturing, hot isostatic pressing and casting. However, this knowledge and expertise sits mostly in other sectors or in academia and research centres, rather than in the aerospace supply chain.

The UK supply chain has evolved through the long history of aerospace in the UK and is strongly aligned to the current generation of products and product architectures. As novel product concepts are developed, in parallel the UK must further evolve its domestic manufacturing supply chain. This can be achieved through using the UK's extensive High Value Manufacturing Catapult (HMVC) network to accelerate the introduction of novel NNS manufacturing methods. Furthermore, the UK must continue to increase its uptake of automation and development of digital manufacturing through the latest technology developments, use of research and technology organisations (RTOs) and ATI funding to allow the UK to compete with other economies who provide extremely cost competitive alternative methods.

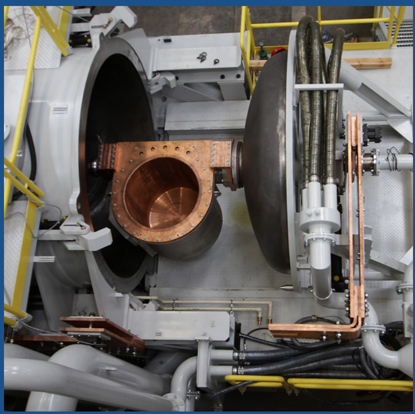
Cost and business case

The costs of capital equipment, tooling and infrastructure to support NNS manufacturing can often be prohibitive. The 'manufacting processes overview' section of this report shows that for nearly every NNS process, the non-recurring cost is high. Equipment such as additive manufacturing machines or forging presses require high initial capital expenditure. However, the recurring costs for these processess can usually be significantly lower so an effective NNS cost modelling is required to demonstrate the longevity and return on expensive equipment.

Aerospace manufacturers who effectively model the through-life cost of a NNS component would be able to build a more robust business case to enable its adoption. Traditional manufacturing routes such as machining have been highly cost optimised, which means generating a business case for some NNS processes to invest the high initial investment costs can be difficult, particulalry for low volume production. De-risking the development of the technology through collaborative ATI-funded programmes can allow technologies to be matured for businesses to sign off on large investments with confidence, and a route to market.

Titanium castings (AMRC) - £15.4m

The ATI have supported the UK's capability to produce large scale titanium aerospace parts. The Castings Technology International (CTI) furnace will enable the UK to compete on a global scale, producing some of the biggest titanium aerospace castings in the world. The new furnace will be capable of melting 1000kg of titanium, the amount required to make a 500kg casting and has three interchangeable crucibles. The furnace can produce castings which are suitable for the largest aeroengine cases and structural aerospace components.



TECHNOLOGY ROADMAP

As part of this study, a 2020-2035 NNS technology roadmap, shown below, was created based on the key findings and opportunities identified through this study. The roadmap includes:

Market drivers

The top-level market drivers link to the market and technological drivers in ATI's Accelerating Ambition. In the case of the NNS roadmap, the focus is on areas such as increased energy efficiency, reduction in operating costs, and the holistic sustainability required from future products.

Design and analysis

This area focuses on some of the key upstream processes involved with NNS manufacturing. This includes better modelling of NNS processes and the creation of new standards and best practices for designing specifically for NNS. Post-processing validation methods also need to be improved including the development and implementation of key industrial standards, and the development of test and validation strategies for NNS.

Processes

Current NNS processes still require significant capital expenditure. Strategies for lower cost, more adaptable tooling, and cheaper materials could enable greater opportunities for adoption. Many current manufacturing specifications were created and aligned to established processing routes such as machining, and therefore are not optimised for NNS - this leads to additional testing and quality controls. Finally, there are opportunities to move towards hybridised processes to reduce lead times and costs, including the use of additive manufacturing and joining techniques to add smaller features.

Materials

There is a desire to use lower cost materials in NNS processes with applicability for structural components across the aircraft - specifically steel and nickel alloys. This presents an opportunity for material producers to design, create, and test novel alloys specifically for use within the NNS processes. For high strength materials, lower temperature processing technologies may be required to reduce cost.

Cross-cutting enablers

Cross-cutting enablers apply to all the processes mentioned in this INSIGHT (increased collaboration, ease of access, connected supply chains, improved training, and more recognised NNS standards and processes).

Primarily, there is a need to focus on developing and enhancing the UK supply chain. In many cases these collaborations will include research organisations, some SMEs, and other supply chain partners. With lower cost economies providing extremely cost competitive alternative methods, there needs to be evidence of a significant advantage for UK supply chains to move away from traditional processing routes and adopt more advanced NNS manufacturing processes. This includes the seamless flow of parts and manufacturing data from raw material to finished part for robust, high volume, and highly competitive aerospace component production.

National Centre for Net Shape and Additive Manufacturing - £14.2m

This project was funded through the ATI Programme. It was undertaken by the MTC to establish the National Centre for Additive manufacturing. The aim of the centre is to develop production-ready additive manufacturing processes, to overcome barriers to wide-scale adoption, and to work on legislative and standardisation issues for this emerging activity.

The Centre has delivered over 100 projects for companies across the supply chain, including the manufacture of a flight-test front-bearing housing for the Trent XWB-97 engine. The project resulted in a 30% improvement in lead time and led to the largest aero engine structure to fly, incorporating AM components.

DRIVERS

Vehicles: Replacing existing fleet with models that are more fuel-efficient to have a reduced environmental impact
Aerostructures: Improved structural efficiency, high strength-to-weight ratios, efficient manufacturing processes and reduced production energy
Propulsion: Alternative sources for traditional products that deliver equal or better performance at lower costs
Systems: Improved product design, durability and dependability through light-weighting and functional design

TECHNOLOGY PRIORITIES

DESIGN & ANALYSIS

- Process and cost modelling to inform design know how
- Redesign of existing components using NNS
- Component integration and design methodology
- Future platforms designed around NNS processing
- New and novel NDT and inspection processes
- Integrated design, test and simulation toolsets integration
- Design for NNS processes embedded within new product architectures
- Fully optimised configurations and deployment
- Enhanced simulation and modelling development
- Accurate predictive modelling capability for NNS
- Multi-scale modelling to ensure design optimises manufacture
- System design solutions enabled by NNS process adoption

PROCESSES

- Low cost tooling and material input
- Stable, consistent NNS processing routes adopted within platforms
- Significant reduction in testing and validation for NNS
- Significant reduced supply chain costs and lead times
- Development of routes to process materials at lower temperature
- Focus on low power/ low resource processes
- Combining processes to optimise manufacturing route
- Fully hybridised NNS process routes adopted by supply chain
- Novel NNS routes for lower cost alloys and materials
- Design of low cost, modular equipment for NNS applications
- Industry 4.0 - rapid reconfiguration, automation & digital manufacturing

MATERIALS

- Lightweight materials with higher strength to weight ratios
- Replace existing materials with lower cost materials through NNS processing
- New alloys specifically for use within the NNS processes
- Material production/ supply developed in line with NNS
- Preparatory treatments to allow materials to be NNS 'formable'
- Increased adoption of NNS driving material production
- Multi-material components through hybrisided processing routes
- Multi-material components & systems manufactured to NNS
- Material models and testing standards for NNS
- Ful life-cycle analysis of materials processed through NNS
- Low cost high strength lightweight alloys
- Optimised material structures for novel structures and propulsion systems

ENABLERS

Collaboration: Collaborative R&D through the entire supply chain (Primes, OEMs, Tier 1s & below, RTO Networks and academia)
Access: Lower cost access to equipment and knowledge
Supply Chain: Development of joint ventures and collaborations throughout the supply chain
Skills: Training and skills development in NNS processing routes
Standards: Incorporation of NNS processing routes within OEM standards

2020-2025 | 2025-2030 | 2030-2035+

NEXT STEPS FOR THE ATI

The ATI will work with OEMs and key aerospace stakeholders to identify suitable opportunities around the topic of NNS manufacturing that generate technology impact and economic benefit for the sector. From the ATI's consultation, different parts of the NNS supply chain are at varying levels of development and adoption. The focus will be on the formation of suitable technology projects, coordination of activities and the dissemination of insights to people in organisations positioned to deliver these requirements.

To exploit the large market opportunity in the coming years, the ATI has identified four key steps to develop NNS technologies in the UK aerospace supply chain.

Material development

The ATI will create and support wider collaborative programmes to include material producers to design, create, and test new alloys specifically for use within the NNS processes. The ATI will work alongside the materials and manufacturing aerospace working group to achieve this. The ATI will also support projects which aim to rationalise the use of metal alloys for easing material segregation and recycling.

Design

The ATI will support the development of R&D programmes or projects which focus on upstream design (topology, tooling and process optimisation as well as manufacturing modelling) and downstream validation and verification activity (in-process monitoring, post-processing and NDT). This will lead to an optimisation of the entire value chain and factory system for flow of material and parts to finished part ready for assembly.

Supply chain

The ATI will continue to support and develop open access NNS technology capability and infrastructure in the UK. This will provide platforms for UK manufacturers and OEMs to develop new technologies through collaborative R&D projects. The ATI will also encourage NNS skills through the AGP and other working groups.

Cost optimisation

The ATI will support programmes with a drive for cost optimisation using NNS technology. This includes working with equipment vendors to develop novel low-cost equipment and tooling solutions.

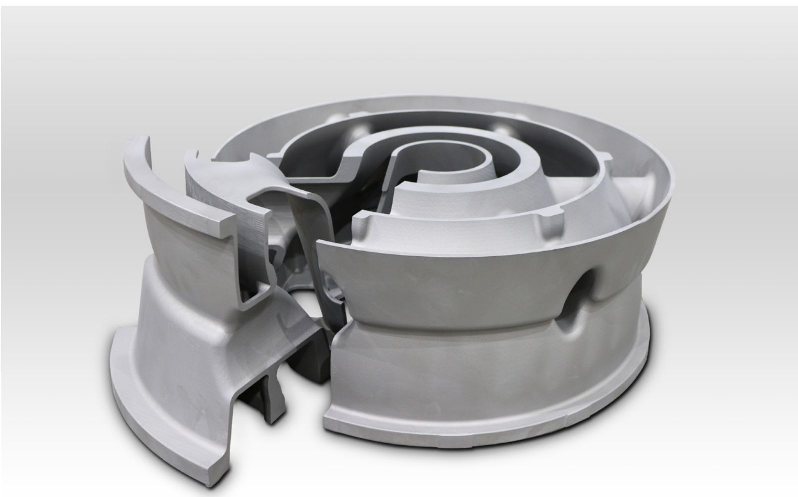


Figure 6: An example of a centrifugally-cast engine casing, courtesy of CTI

FEEDBACK AND DISCUSSION

This INSIGHT paper has been authored and compiled by Nour Eid. The ideas in this INSIGHT paper are intended to provide guidance and strategy to the sector whilst also provoking discussion and feedback. If upon reading this INSIGHT, you have an idea for a project or comments on the content, please get in touch with us to discuss further: info@ati.org.uk

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Thank you to TWI for providing the image for the front cover of this paper. The image shows linear friction welded titanium stanchion demonstrators, produced on project TiFab.

GLOSSARY

AFRC	Advanced Forming Research Institute
AGP	Aerospace Growth Partnership
AMRC	Advanced Manufacturing Research Institute
AM	Additive manufacture
ATI	Aerospace Technology Institute
CBM	Confederation of British Metalforming
CTI	Castings Technology International
DED	Direct energy deposition
DRAMA	Digital Reconfigurable Additive Manufacturing facilities for Aerospace (led by the MTC)
FSW	Friction stir welding
HIP	Hot isostatic pressing
HIVES	High Integrity Validated Engineering Space (part of the AFRC's FutureForge project)
HVMC	High Value Manufacturing Catapult
ISCF	Industrial Strategy Challenge Fund
LFW	Linear friction welding
MRO	Maintenance, repair and overhaul
MTC	Manufacturing Technology Centre
OEM	Original equipment manufacturer
NDT	Non-destructive testing
NNS	Near net shape
OAAM	Open Architecture Additive Manufacturing (led by TWI)
R&D	Research and development
RFW	Rotary friction welding
RTO	Research and technology organisations
TRL	Technology readiness level
TWI	The Welding Institute
SPF	Super plastic forming
WAAM	Wire & arc additive manufacturing

WHO WE ARE

The **Aerospace Technology Institute** (ATI) is an independent not-for-profit company at the heart of aerospace research and development in the UK. Our mission is to raise UK ambitions and lead technology in air transport to maximise the UK's full economic potential. We do this by providing objective technical and strategic insight, maintaining a UK aerospace technology strategy, and together with Industry and Government, direct match-funded research investments – set to total £3.9bn between 2013 and 2026.

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