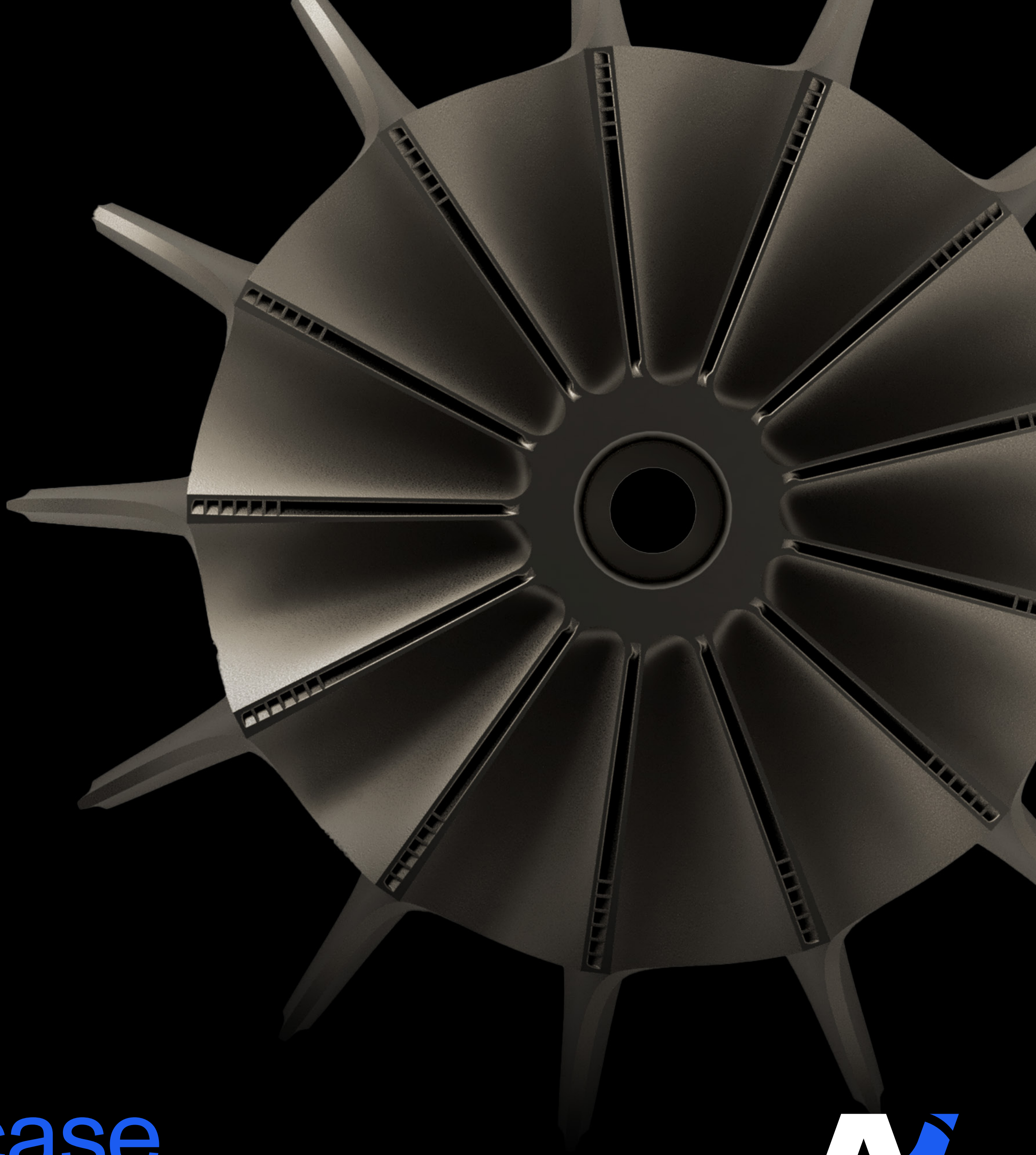

Showcase
Hybrid Manufacturing of a Turbine Impeller with MetalFab

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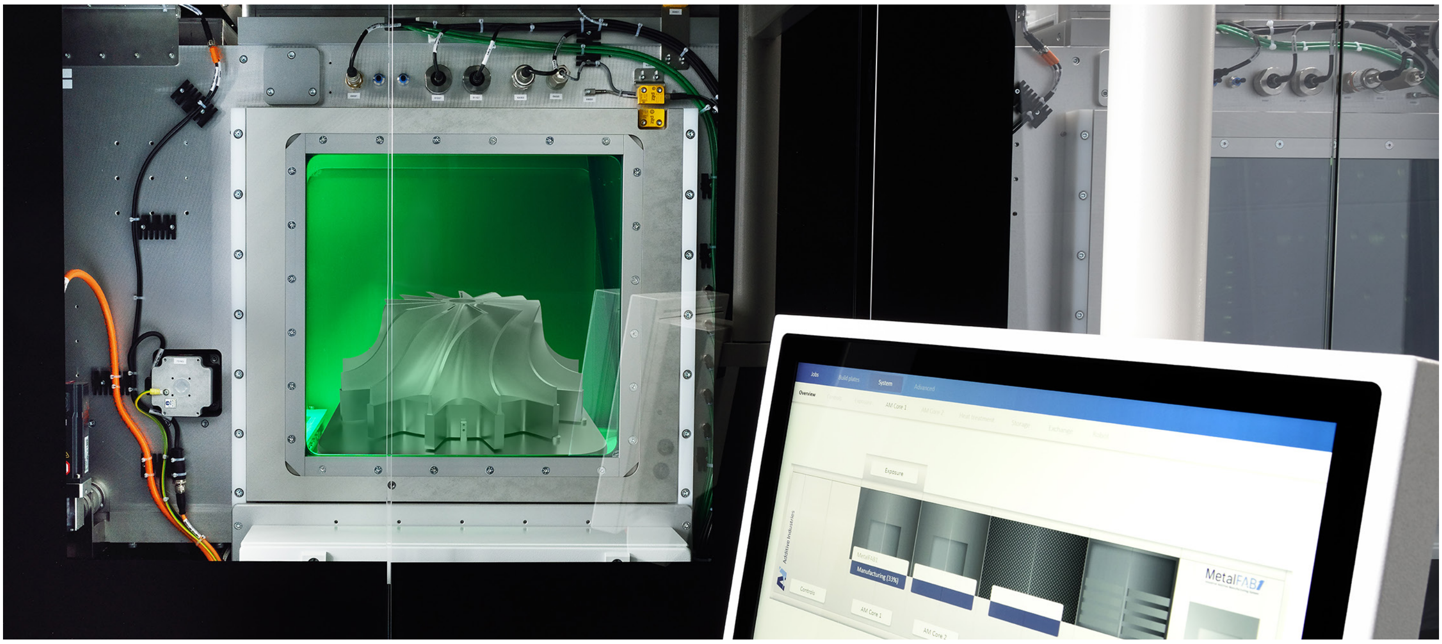
Hybrid approaches within Additive Manufacturing create opportunities to reduce build time, material use and part cost whilst reducing or eliminating post processing. In this Showcase a method of hybrid manufacturing is detailed using the MetalFab technology.



Introduction

The energy, oil and gas sectors offer many opportunities for the introduction of metal additive manufactured (AM) parts, particulary in gas turbines where the freedom of design can be leveraged to unlock improved perfromance in large radial turbine impellers. Through advanced design, analysis and simulation tools a range of functional improvements can be made when compared to the conventional manufacturing routes of casting or miling such components.

However, to unlock this potential and produce AM products in serial production along with a viable business case it is critical to also consider the associated costs of post processing the parts, along with the most efficient way to utilise AM. Through a hybrid manufacturing approach Additive Industries, in collaboration with Makino, have been able to demonstrate a process flow which addresses some of these challenges which can in some cases lead to an unsatisfactory business case, namely:

- **Removal of the conventional AM part seperation** from base plate procedure which eliminates the need for expensive and time consuming wire EDM cutting and base plate resurfacing or consumption.
- **Reduction of AM build time** producing solid or heavy duty support structures which will ultimately be removed from the product as scrap material
- **Reduction of powder material use.**

Part Design

For industrial gas turbine manufacturers which are active in supplying systems into power generation, marine and aerospace industries radial turbine impellers are a critical element of their products, where through optimisation of their design huge performance benefits can be realised.

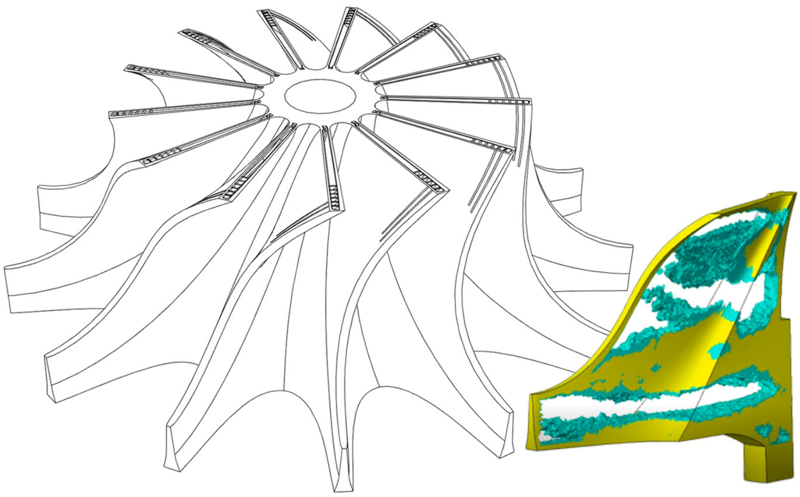


Figure 1. CAD design derived from topology optimisation of turbine blades

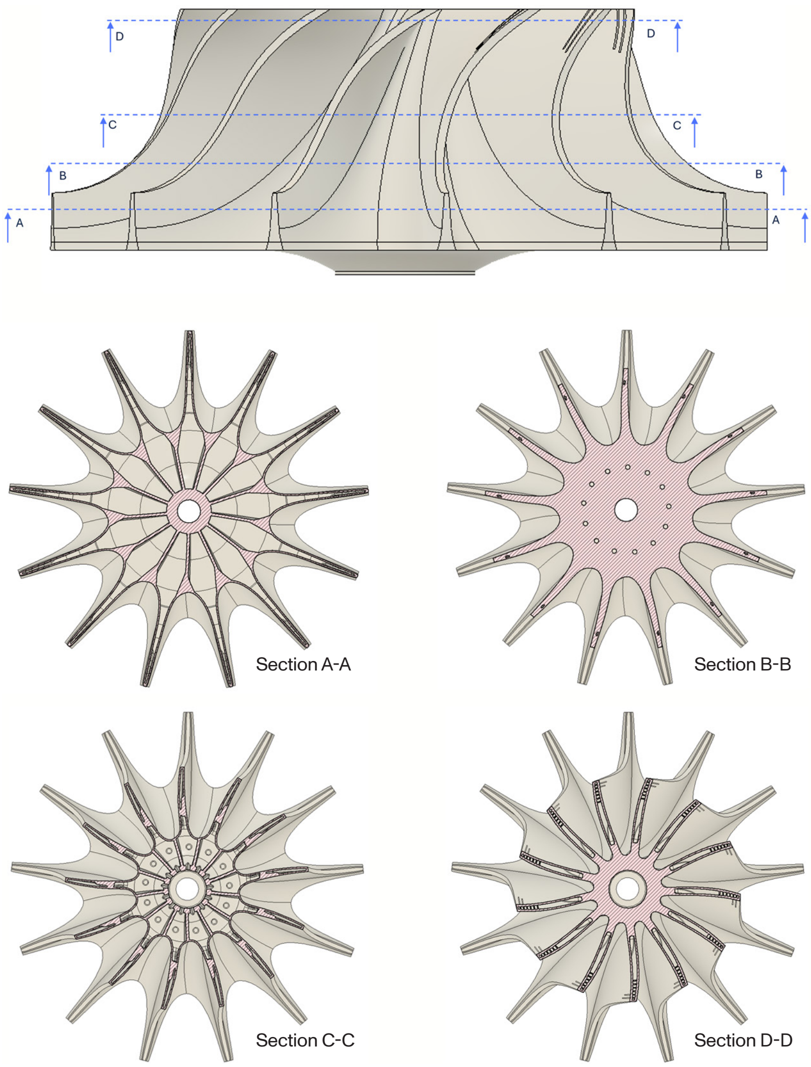


Figure 2. Internal structure within blades at various build heights

This particular case looks at a large impeller which has typically been outside the scope of metal AM production, but with the 420 × 420 × 400 build envelope with 4 x full scan field lasers offered by the MetalFab is now well within scope for such parts.

Required to be manufactured in nickel alloy IN718, the impeller has overall dimensions of 405mm diameter and 150mm height.

Design Optimisation

The goal is to remove mass from the currently solid radial turbine impeller, leveraging the AM design freedoms whilst maintaining the required structure to perform the design intent - the maximum stress constraint. The structural design can then be further optimised to include internal cooling channels within each individual vane. This particular turbine impeller is required to operate with a turbine gas temperature of 900°C and running at a maximum of 22,000rpm.

The baseline CAD model is taken from the solid machined impeller and a single blade is isolated for the optimisation to be carried out on - as the design of the part is cyclic symetric this approach reduced the time to optimise - an example of the topology optimisation output is shown in figure 1.

Once a satisfactory result is obtained the topology is imported into CAD for the building of the 3D model of the final design, taking into account the cooling channel arrangement and the design for AM requirements.

The final design realises many benefits both from a manufacturing perspective, from a part performance persepctive and ultimately a system level performance perspective, they key points being as follows:

- Optimal structural perfromance is achieved - material only present where necessary
- 35% reduction in mass compared to conventional design
- Reduced system running cost due to lower mass
- Increased compenent life
- Reduced environmental impact
- Increased operating efficiency due to internal cooling enabling higher turbine inlet temperatures

Hybrid Manufacturing Approach

The conventional approach to AM manufacturing of the part would require a support structure attached to the underside of the turbine impeller and anchoring it to the base plate. Due to high residual stresses induced by the AM process, particularly with nickel alloys such as IN718, and the tight geometric tolerances required for such a part this support would need to be a signficant amount of material, most likely in a solid form to impart the necessary control on the part. Producing this solid material, which is ultimately scrap, as part of the AM process is expensive and time consuming. Further to this the part is welded to the base plate once manufacturing is complete and will therefore require cutting from the plate by mechanical means, typically by bandsaw or wire erosion (EDM).

With the hybrid approach, only a certain section of the part is produced in the AM process, built directly onto a pre-machined preform with a flat interface which is accruately mounted and located on the base plate ahead of loading into the machine. This approach means that only the complex area of the geometry - in this case the hollow optimised blades - is produced and after manufacturing the hybrid part is lifted from the location plate ready for milling of the final form on the underside of the part. Note that no AM deposited material is milled away. This is shown in figure 3.

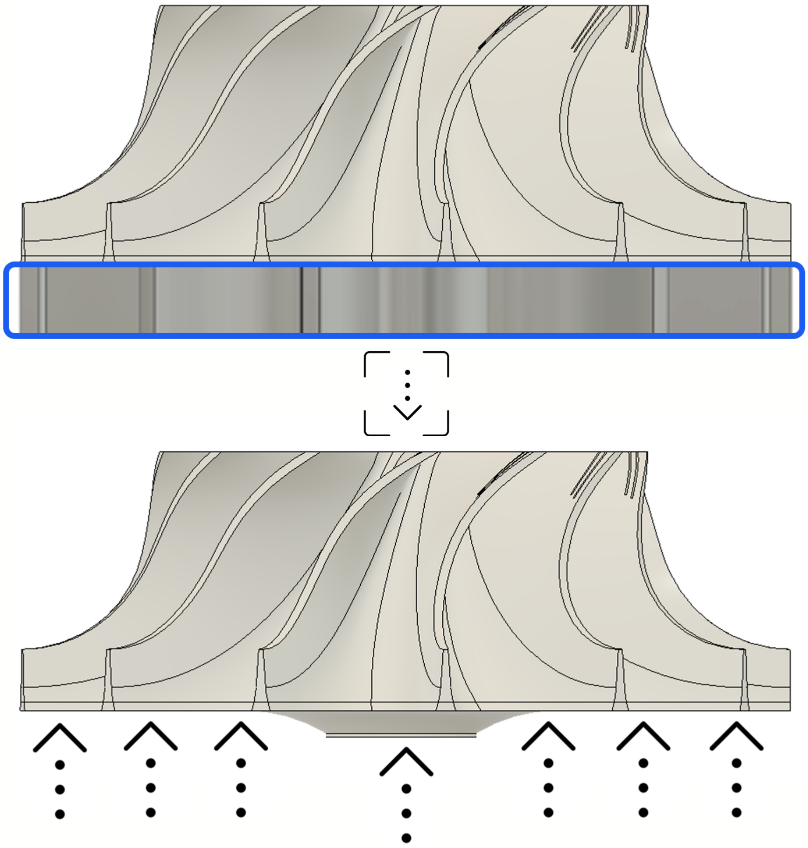


Figure 3. Supported/scrap material versus final milled profile

Hybrid Process Steps

Step 1: A series of location features designed to position, locate and hold the part in place are built onto a base plate. In this case an array of pads have been created to stand the hybrid base/preform clear of the plate surface, then location pins are created to fix the X,Y and rotational position of the hybrid base. An additional tab is added to allow a bolt to fix the position of the base.

Step 2: The hybrid base/preform which in this case has been cut from an IN718 billet using wire EDM is positioned with the locating fixtures on the base plate. The plate is now ready to be loaded into the system. The kinematic mounting design of the MetalFab build plate interface allows repeatable and accurate positioning in the system relative to the datum (XY accuracy +/-0.1mm). To save time on job setup and reduce powder requirements, volume packing can be added around the hybrid base before loading (the negative billet from the hybrid base can be used as a volume packer).

Step 3: The build job containing the AM section only is prepared and loaded into the system. The job can be started immediately with no adjustment of positioning due to kinematic mounting system. First print layer provides a welded joint to the hybrid base. Once complete the job can be removed immediately from the base plate without any cutting required and sent for post processing steps.

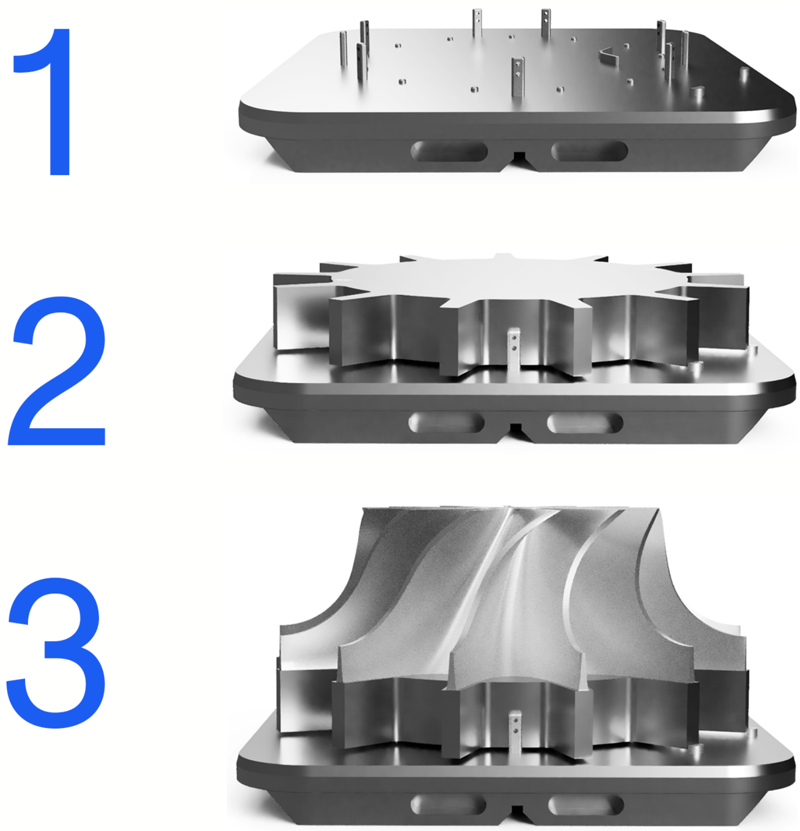
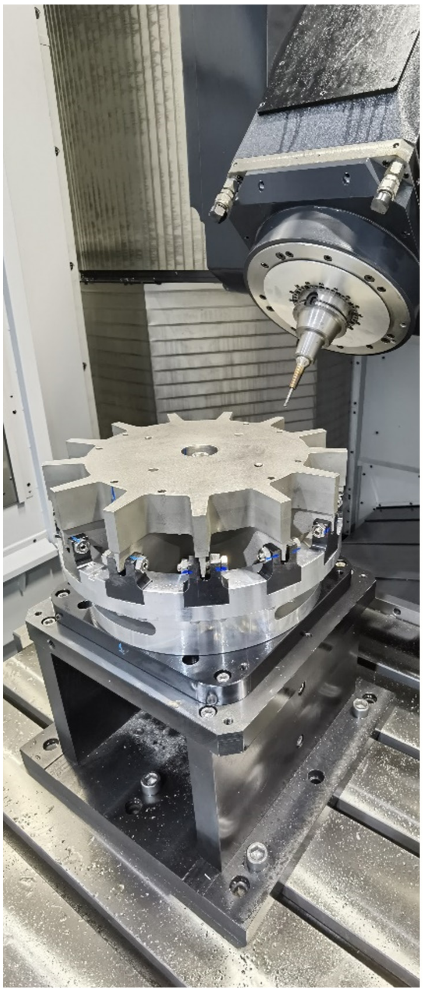


Figure 4. Workflow to set, mount and build hybrid geometry



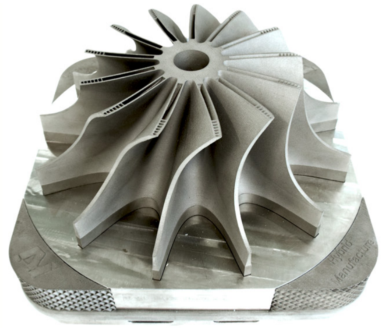


Figure 5. Completed hybrid part

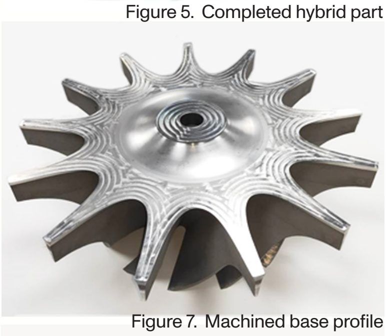


Figure 7. Machined base profile

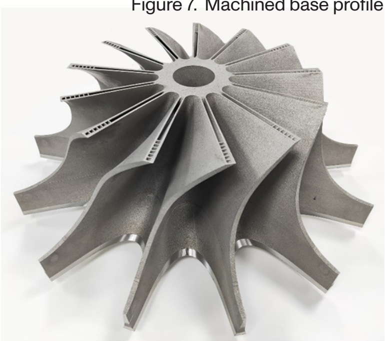


Figure 6. CNC machining base profile

Figure 8. Final part

Part Production

As previously outlined the accurate repeatable location made possible with the MetalFab allows for a seamless job start and successful 'right first time' production of the hybrid part. The part is shown in figure 5 immediatly after production with volume packers in place, ready for the limted subsequent post processing steps to be undertaken as follows:

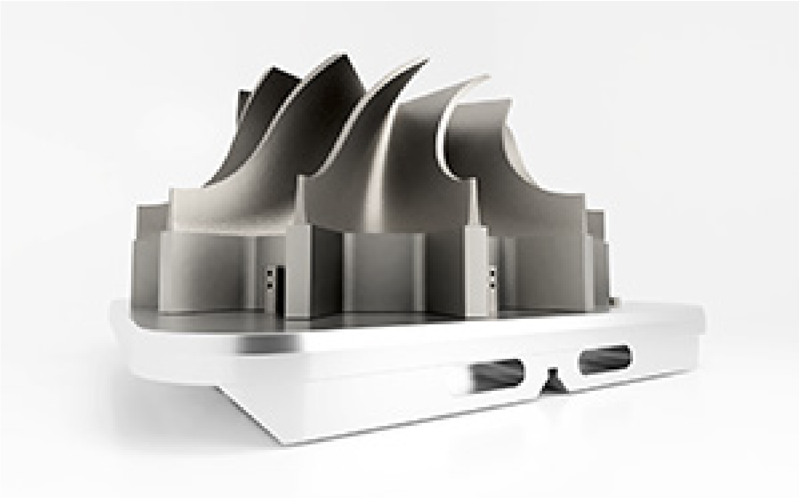
- Standard heat treatment process for IN718 material carried out - solution treatment + 2-stage ageing
- CNC machining of base profile on Makino 5-axis T1 machine tool - hybrid base is blended into part, blade tips are machined to balance wheel (see figure 6 & 7)
- Abrasive blasting for final finish (figure 8)

Automation with MetalFab

The capabilities of the MetalFab series can take hybrid manufacturing to the next level and into automated serial production when needed.

By adding a Storage Module (STM), Exchange Module (EXC) and Robot (ROB) - all in-field upgrade options to base MetalFab systems - the MetalFab can run continuous production of back to back jobs without any system downtime. This is illustrated in figure 9 - plates with pre-mounted preform bases are loaded into the STM in preperation for manufacturing, completed parts are moved from the build chamber to the STM by the ROB which in turn takes a new plate from the STM and loads it ready for the next job.

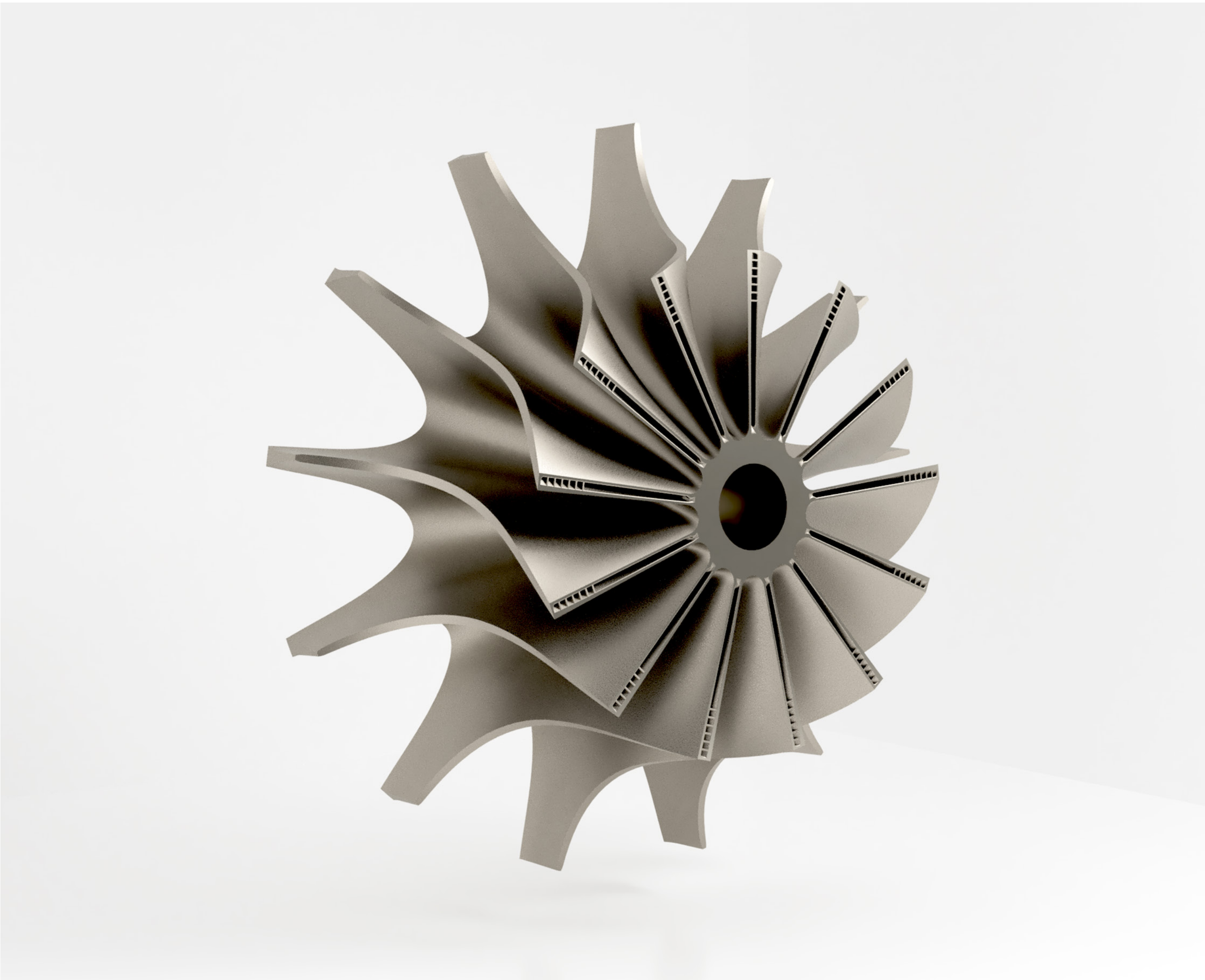
Figure 9, MetalFab modularity enabling continuous production



Summary

This case shows the potential for additive manufacturing to work in combination with conventional manufacturing processes in a hybrid fashion to harness the design freedom possible and already well understood with AM whilst being conscious of cost and lead time when manufacturing turbo machinery parts.

Furthermore, this methodology can be applied to various applications in other industries where aspects of a part may be suited to the benefits of AM, but large areas of the part would not make commercial sense - an example here being large mold tool and die inserts with conformal cooling channels at their upper surfaces.



At Additive Industries, our objective is the success of our customers in achieving the lowest cost per part at market leading part quality.

We pride ourselves on our flexibility to work with our MetalFAB users in achieving their industrial goals.

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