Should you print it?
A look into Metal AM applications

Boothroyd Dewhurst, Inc.

THE 2019 INTERNATIONAL FORUM on Design for Manufacture and Assembly

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Renishaw Inc.

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Renishaw Corporate Headquarters:
Wotton-under-Edge; UK

- 77 Locations in 35 countries
- 4800+ Employees
- 1,600+ Patents

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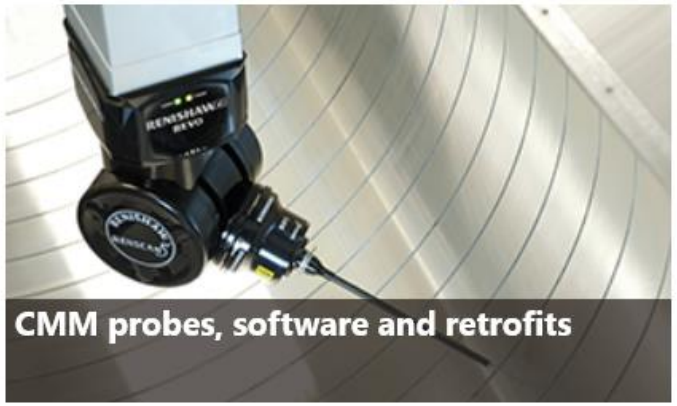
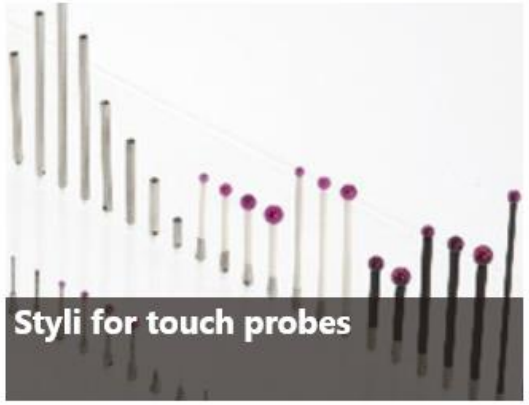
Industrial Metrology

Process control products





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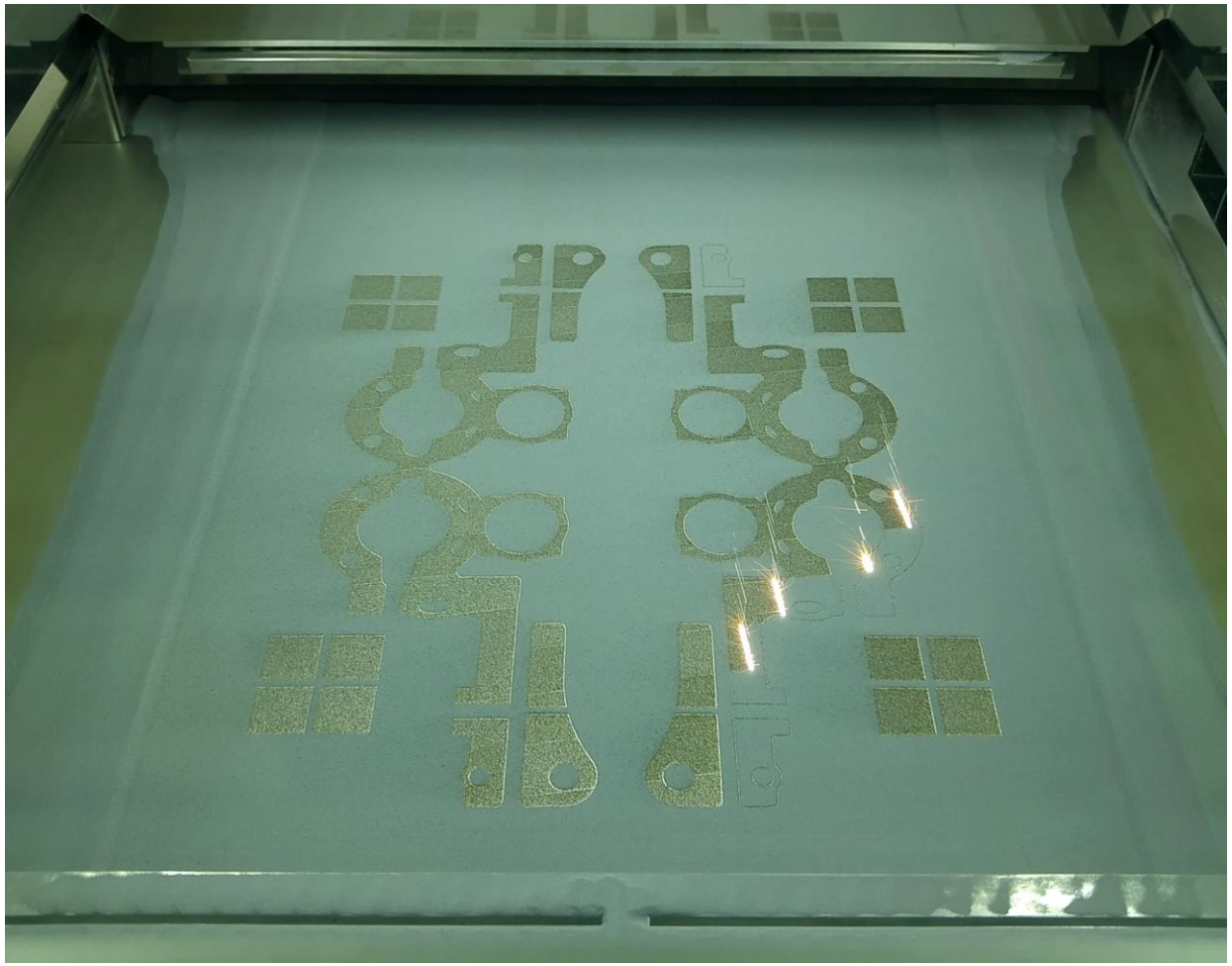
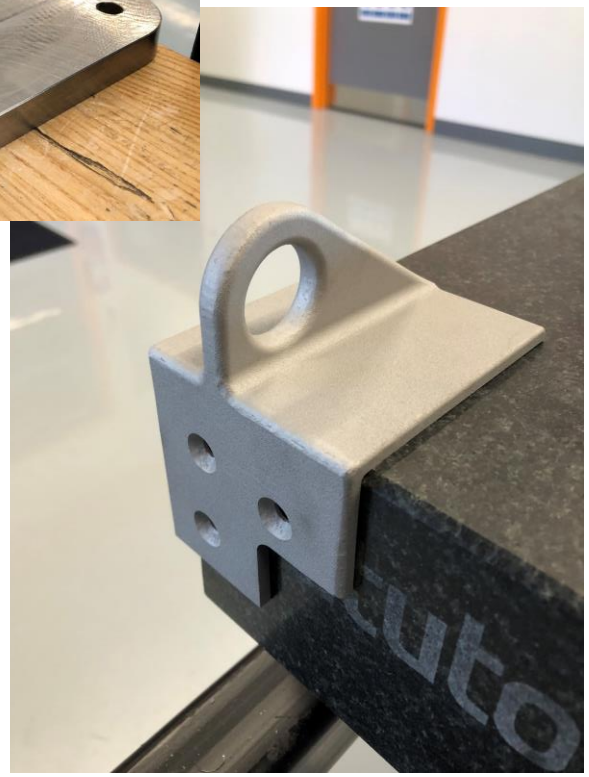
Metal AM – Laser Powder Bed Fusion (LPBF)

RenAM500Q

Should You Print It ???



It Depends ……



Bracket produced by Mark Kirby and Carl Hamann – Renishaw, CN

Chris Tsai's Boat Bracket

- ***Talking points:***
  - Basic geometry, easily fabricated. Why would you print this ??
  - Would sand/die cast or machining from a solid make more sense ? If this is a "production" part all these options would be considered. Key in this conversation would be what "production" equates to.
  - If lead-time is crucial and machine and powder are available…does this change the equation? Sure it does, so "It Depends"

It Depends ……

Water Charge Air Cooler: Automotive

- Benefits:
  - Design provides light weighting
  - Increases vehicle performance
  - Provides part and systems integration
  - Engineered performance in part design opens up opportunities and re-defines how we think about making parts along with providing AfAM / DfAM design opportunities.

HiETA: Case study found online at:
https://www.hieta.biz/casestudies/water-charge-air-cooler/

It Depends ……..

When we say “It Depends” it opens up a world of application and design *opportunities*:

- Do you have design authority ?
- Do you have an understanding of the technology and key process parameters that would inform the decision making process?

- Next we’ll discuss an application and some design talking points that surround most metal additive discussions, some substance behind the **“It Depends”** conversation ……..

Application Discussion

- **Ben Ainslie Racing**
- Land Rover America's Cup Yacht – Team UK
- GC32 Class Catamaran

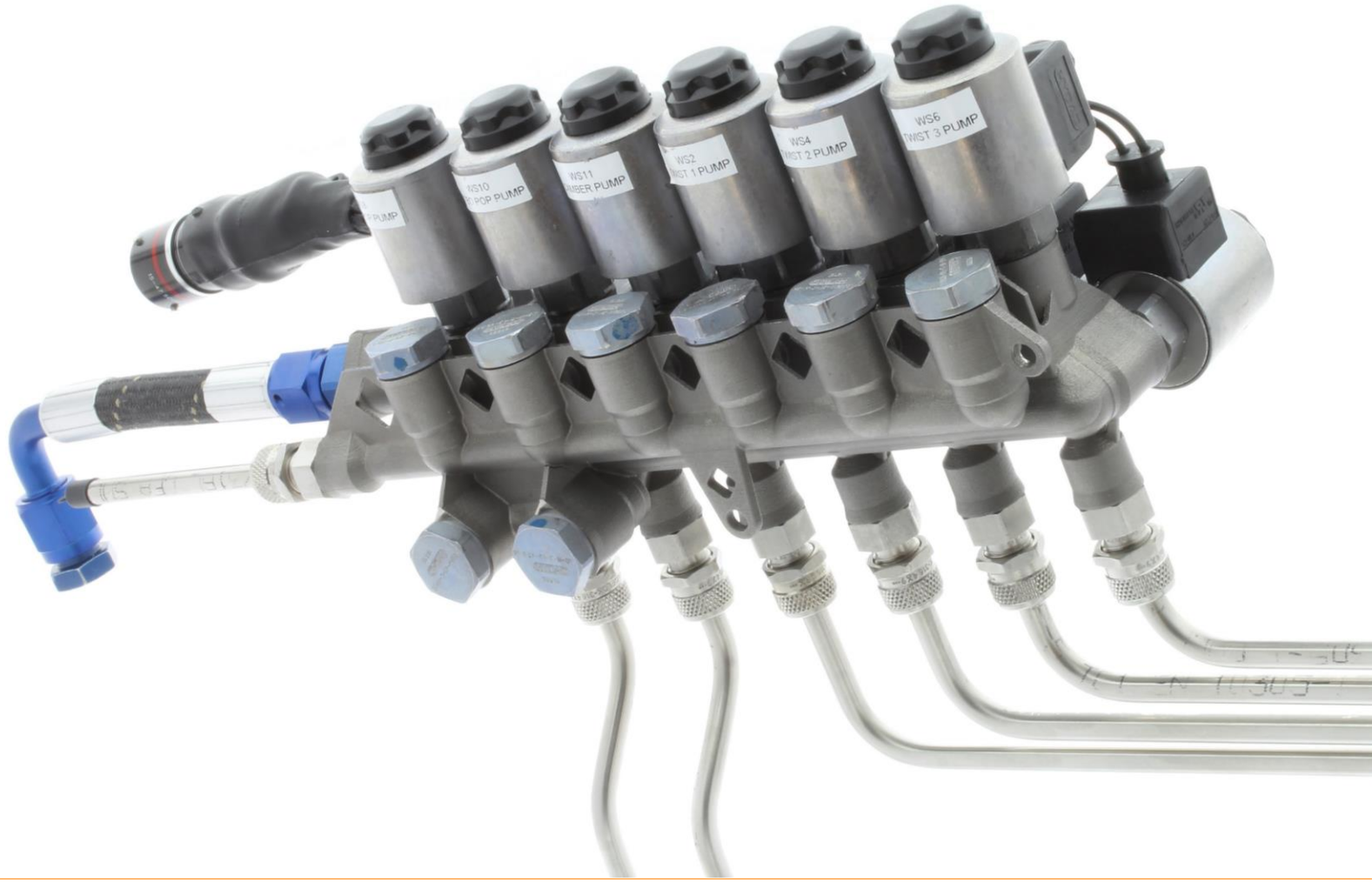
- **Opportunity:**
- Wing / Rudder Manifold; weight reduction, consolidation and performance improvements.

Presentation Overview

Design Opportunity
- AfAM or DfAM?
- Wing / Rudder Manifold Attributes

Process Engineering
- Overview of LPBF
- Process parameter basics
- Finding the process “window”
- Multi-laser considerations

Process Monitoring and Control
- Data and Connectivity
- AM process monitoring and control



AfAM vs. DfAM

Adaptation for AM (AfAM):

-The re-design or modification of an existing product design to better suit the design constraints imposed by the additive manufacturing process. This is an area where we can leverage AM specific benefits

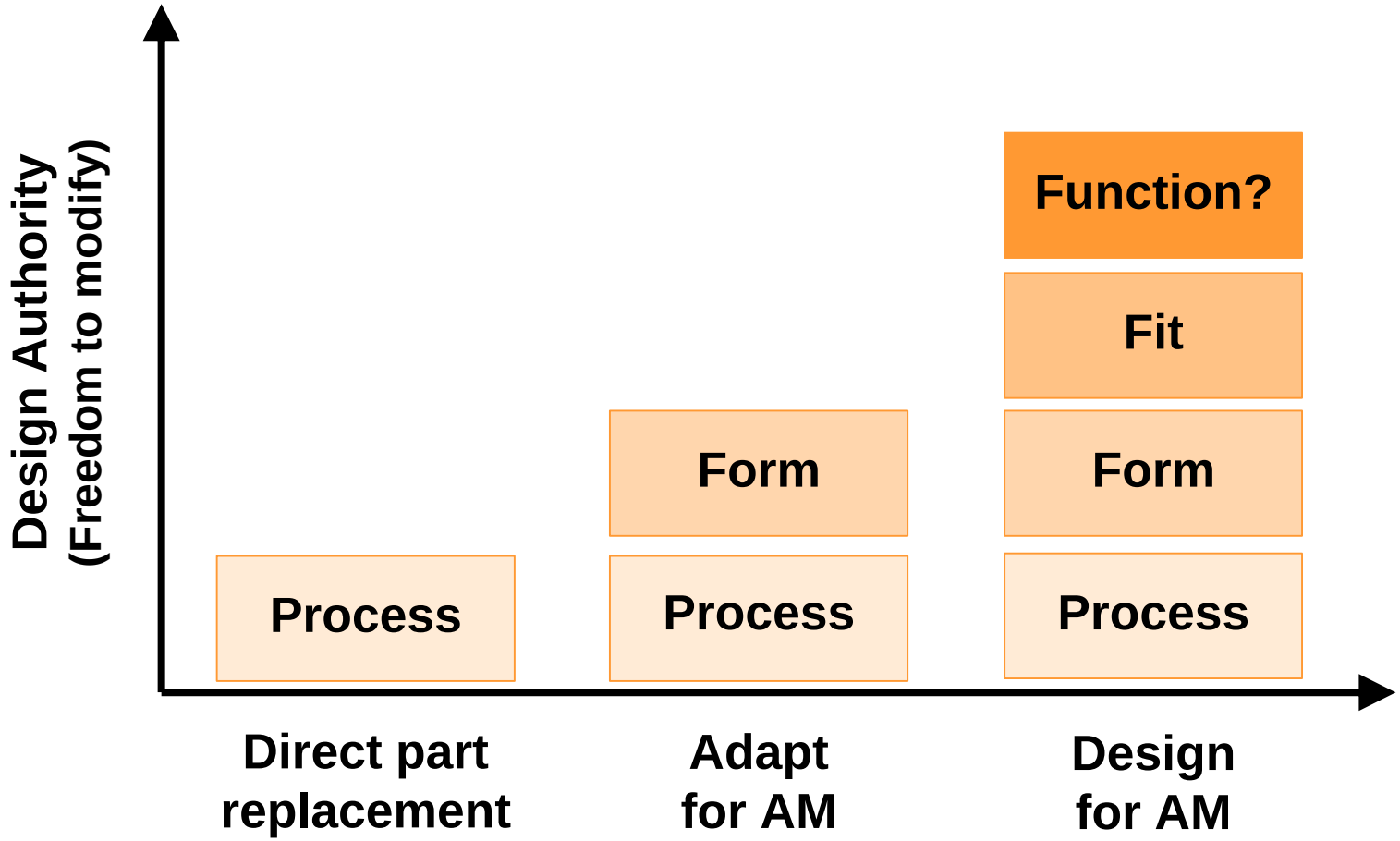
- Existing product design specification and system level design will reduce available ‘design space’.

Design for AM (DfAM):

- The wholesale ‘blank sheet’ design and development of a new product; fully leveraging the opportunities that additive technology provides

- Considerably more open design space and the ability to influence system-level design decisions

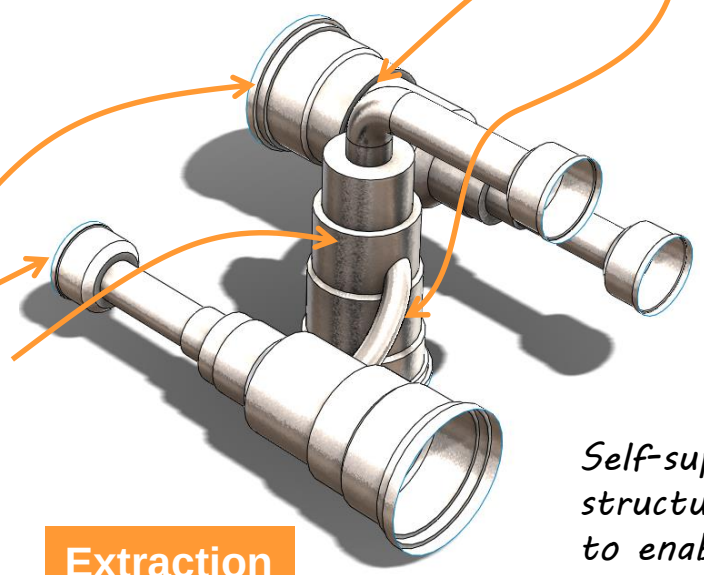
AfAM vs. DfAM – Design Space



AfAM Process flow

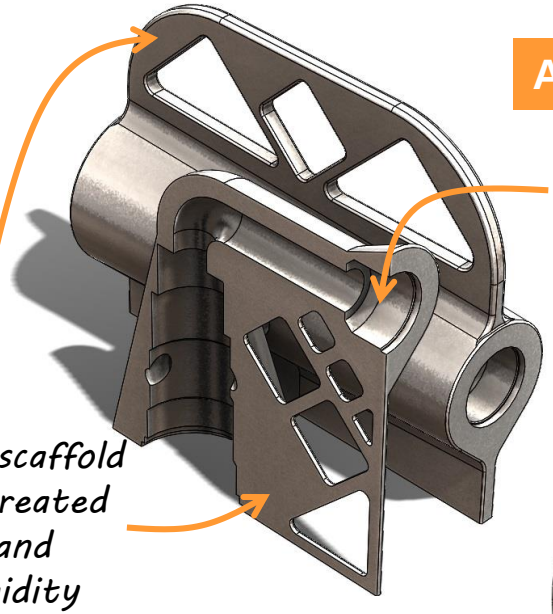
Efficiency reducing cross-drilling replaced with swept pathways

Valve body positioning remains as per original design



Extraction

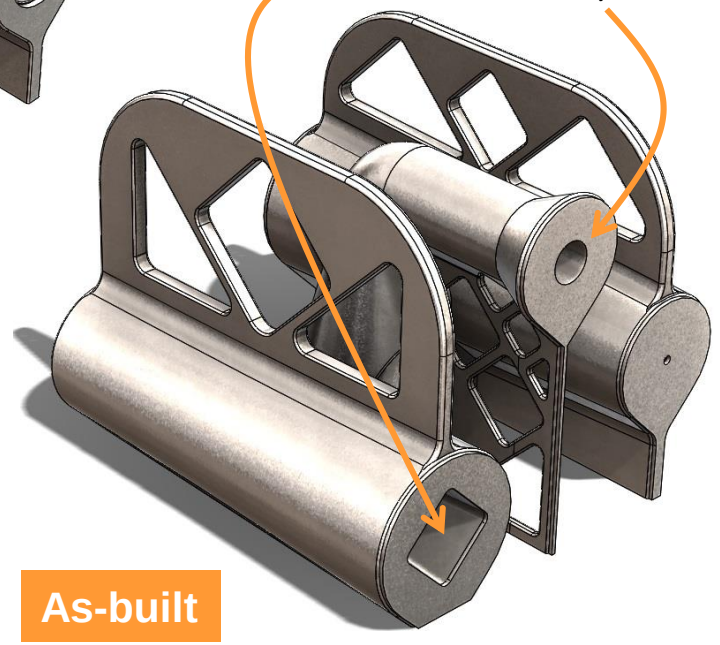
Self-supporting scaffold structures are created to enable build and increase part rigidity



As-finished

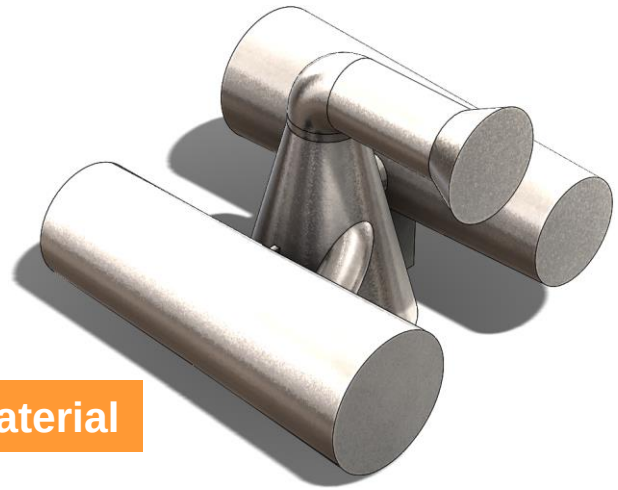
Machined Surfaces are modelled to meet specification

Self-supporting machining stock is incorporated



As-built

Solid material added to meet minimum specified for application through 1D or FEA analysis



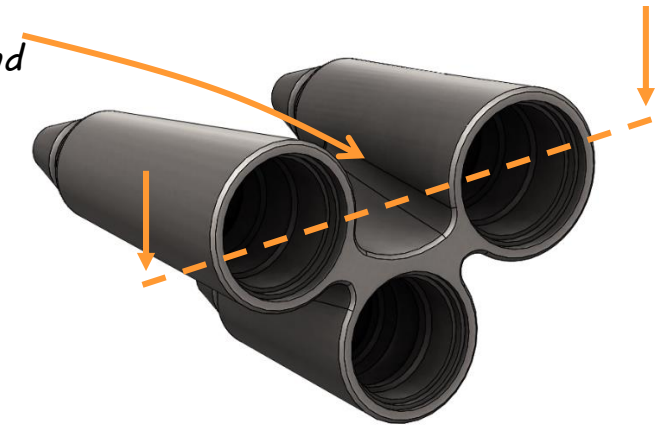
Wall material

DfAM Process flow

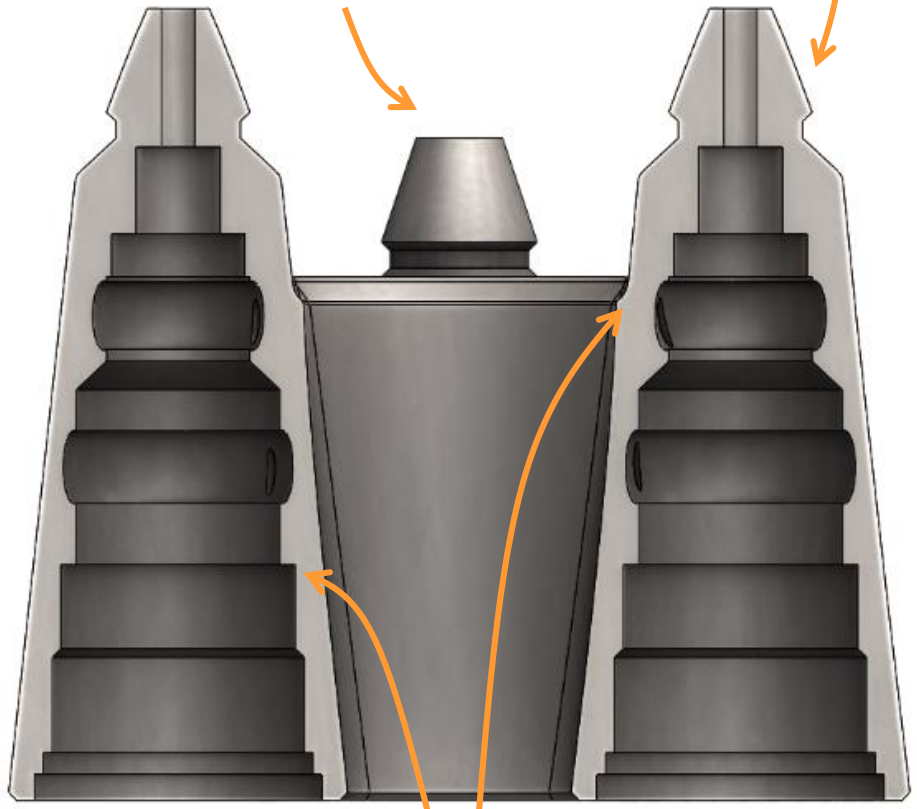
Flow-paths developed to optimise flow performance

Valve bodies orientated co-planar to improve packaging and simplify post-machining

Central "spine" ties together ports, simultaneously shrouding flow paths and increasing rigidity



Hydraulic fittings incorporated into the part, consolidating the assembly



Wall thickness is absolute minimum required

Wing Manifold

Conventionally Machined

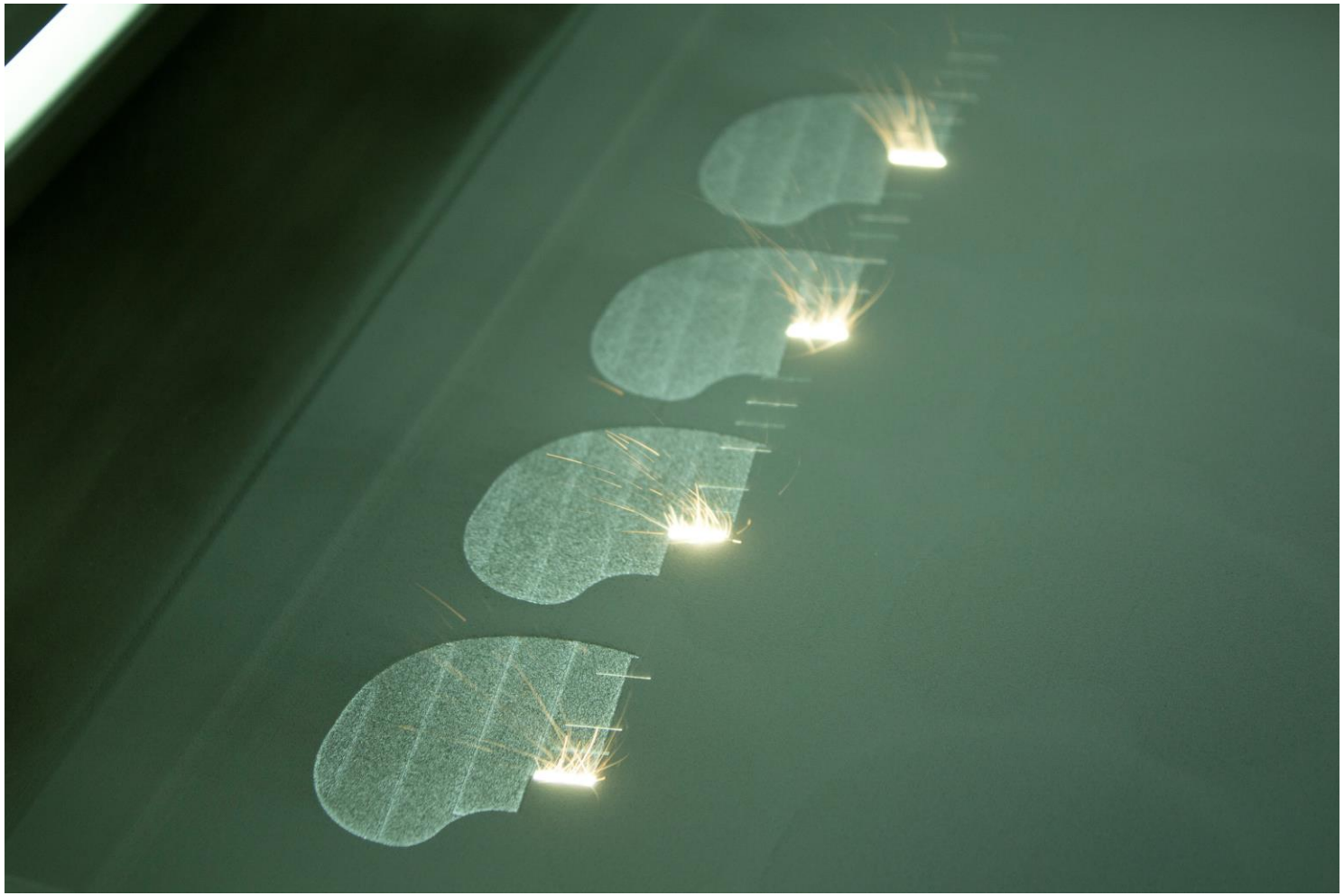
Printed

Wing Manifold

Printed and Machined

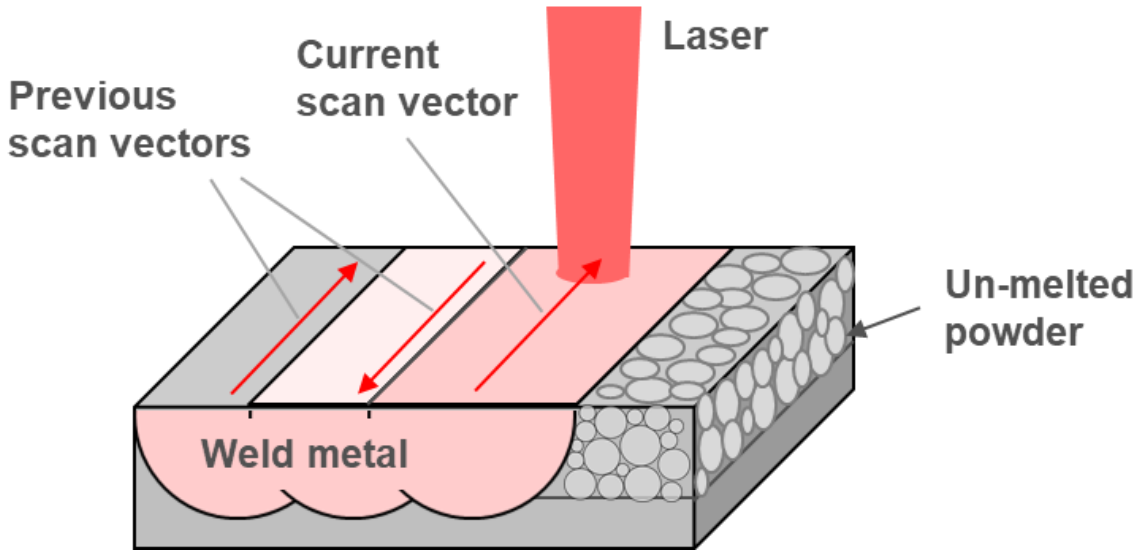
Final Assembly

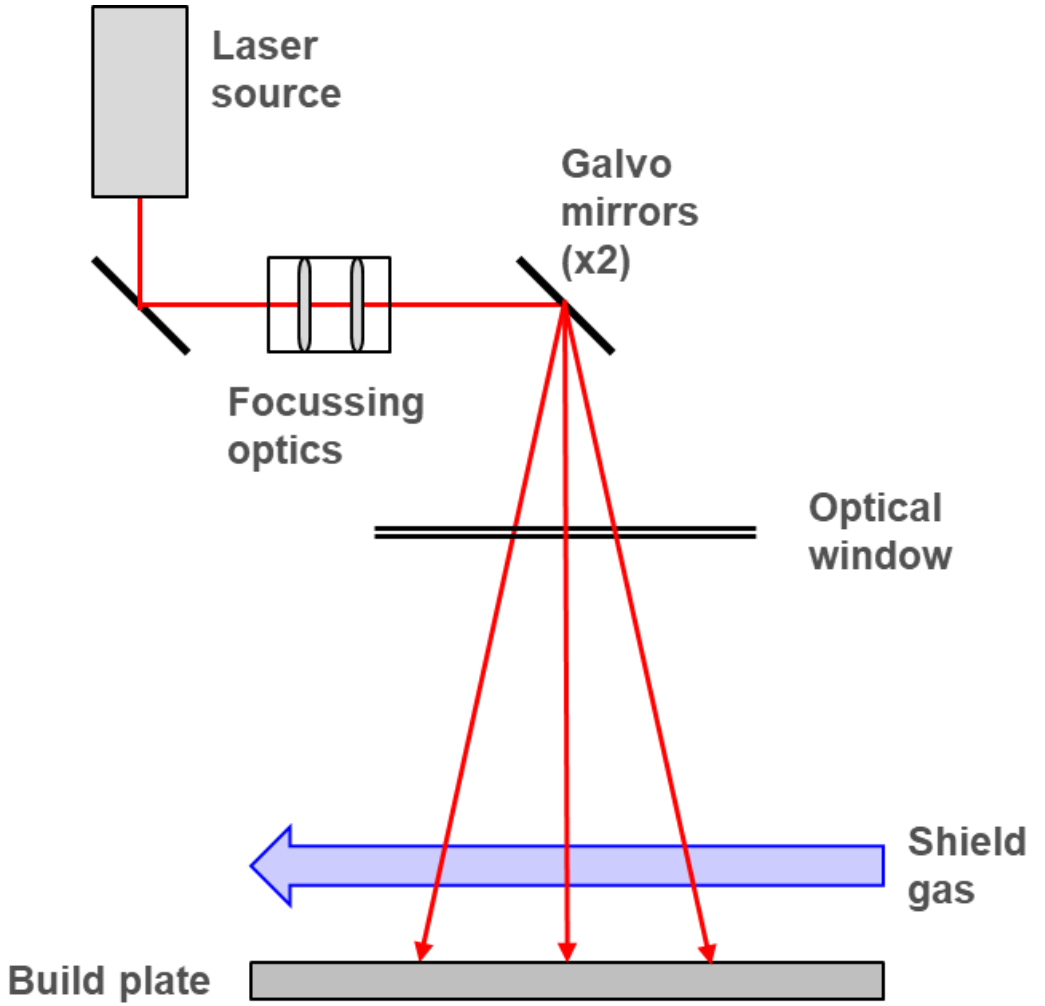
Key Process Parameters



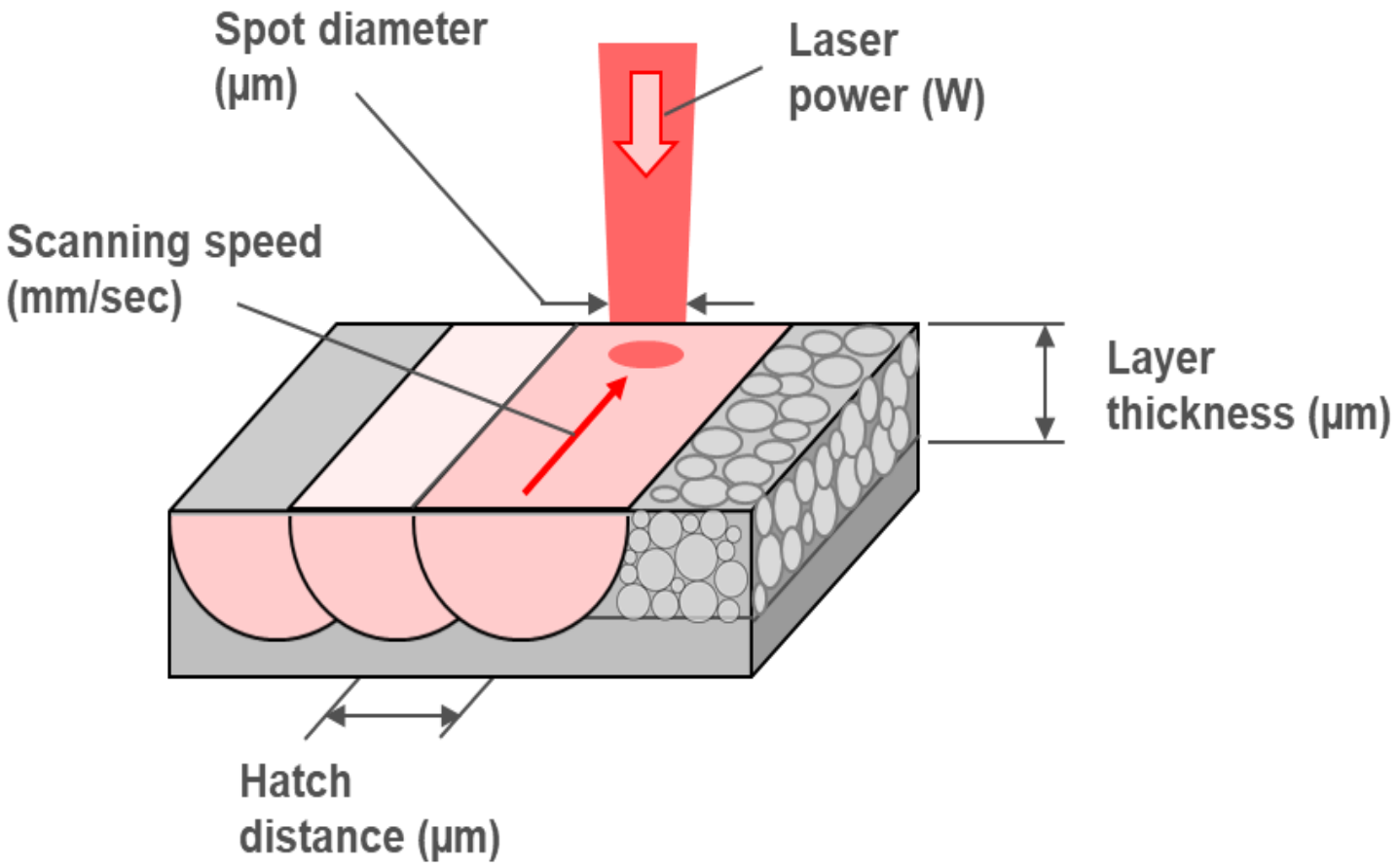
Laser powder bed fusion overview

- Fibre laser focussed to a small spot on the top surface of the powder bed
- Galvanometer mirrors move the laser across the powder bed in a series of scan vectors
- Melt pool width typically 2 – 3 times spot size





Process parameter basics



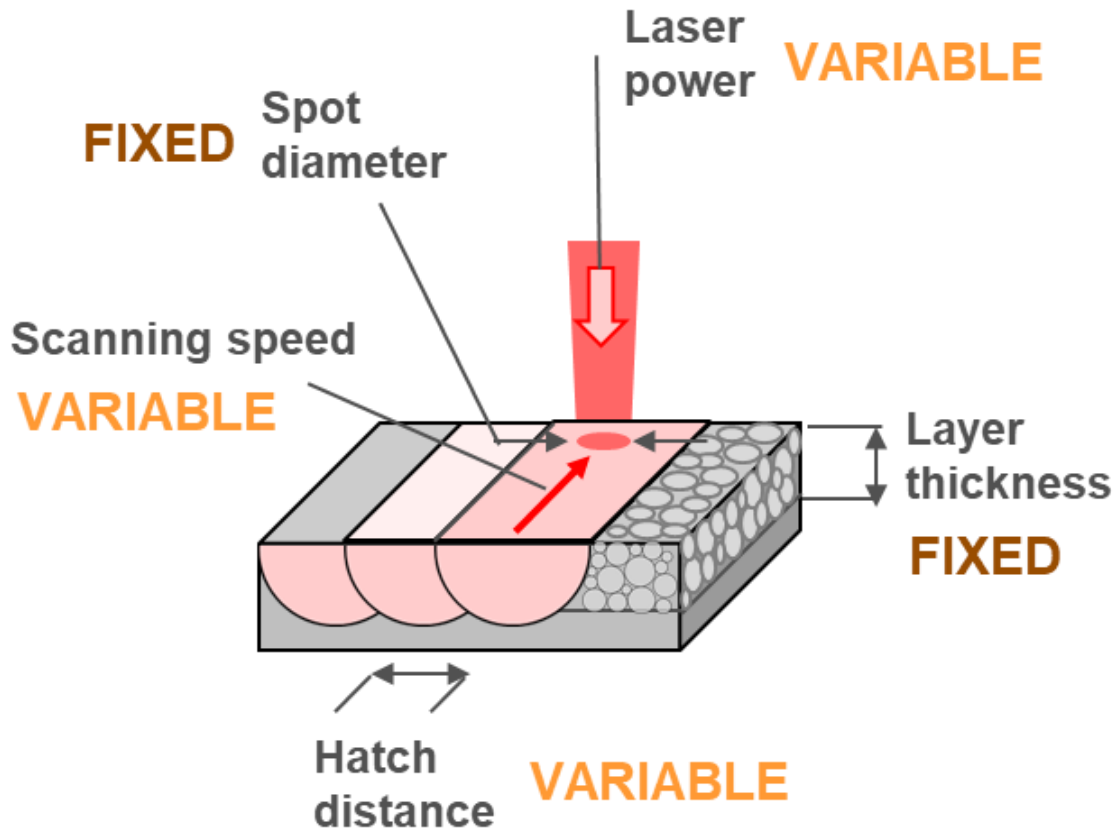
Finding the ‘Process Window’

First objective is to achieve good density…

- Porosity will weaken the material, reduce strength, ductility and fatigue / creep performance

Simplify the optimization task

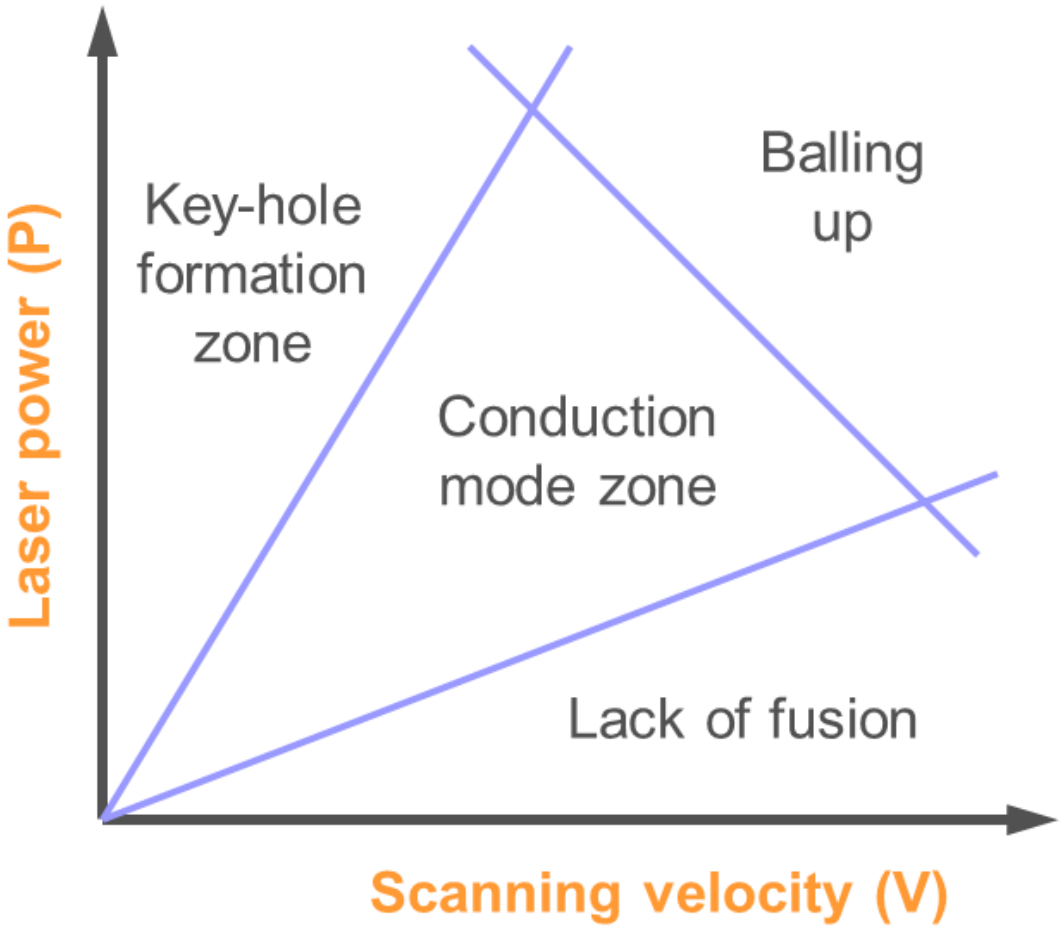
- Fix key variables – spot size and layer thickness
- Laser power, scanning speed and hatch distance remain variables



Process parameter impact on laser melting outcomes

For a given material, spot size and layer thickness…

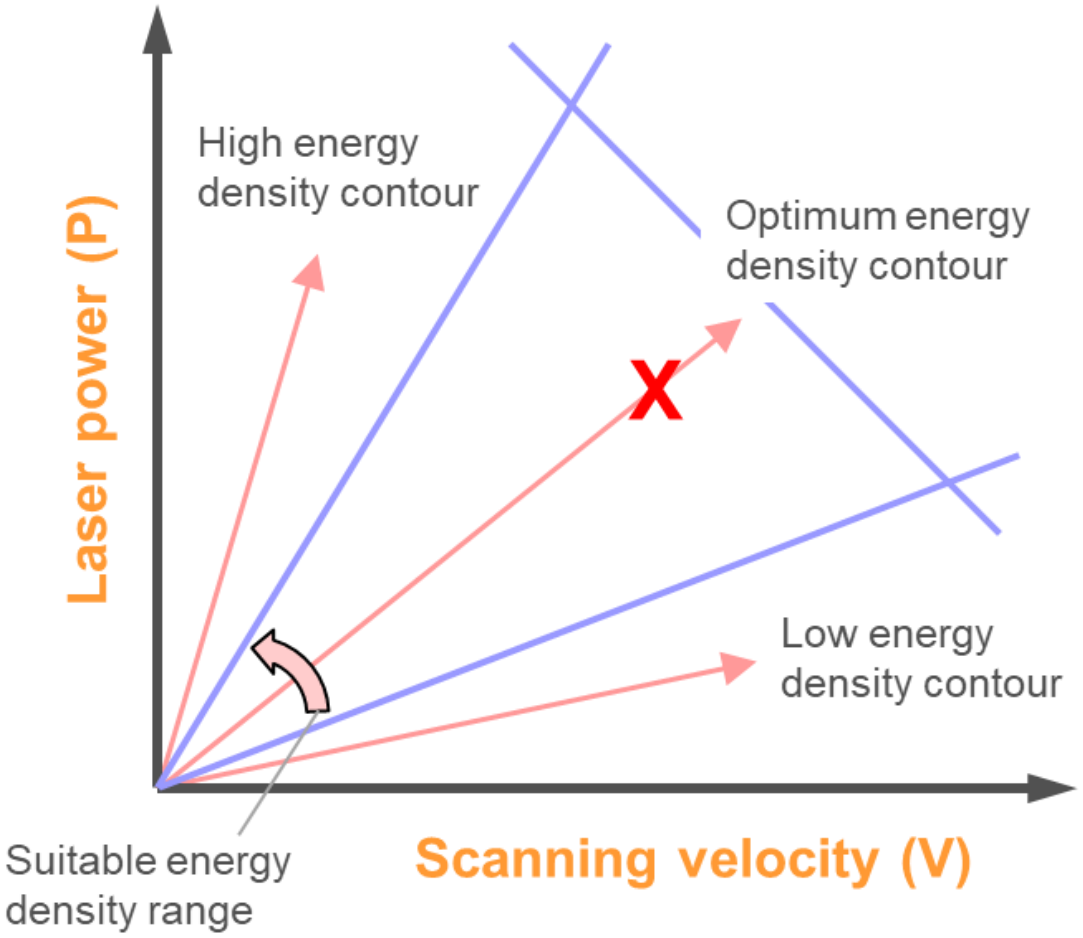
- Insufficient power results in **lack of fusion**
- Too much power leads to **keyhole** formation
- Too much power and speed combined leads to break-down of the weld pool – '**balling up**'
- **Conduction mode zone** where full melting occurs without keyhole formation



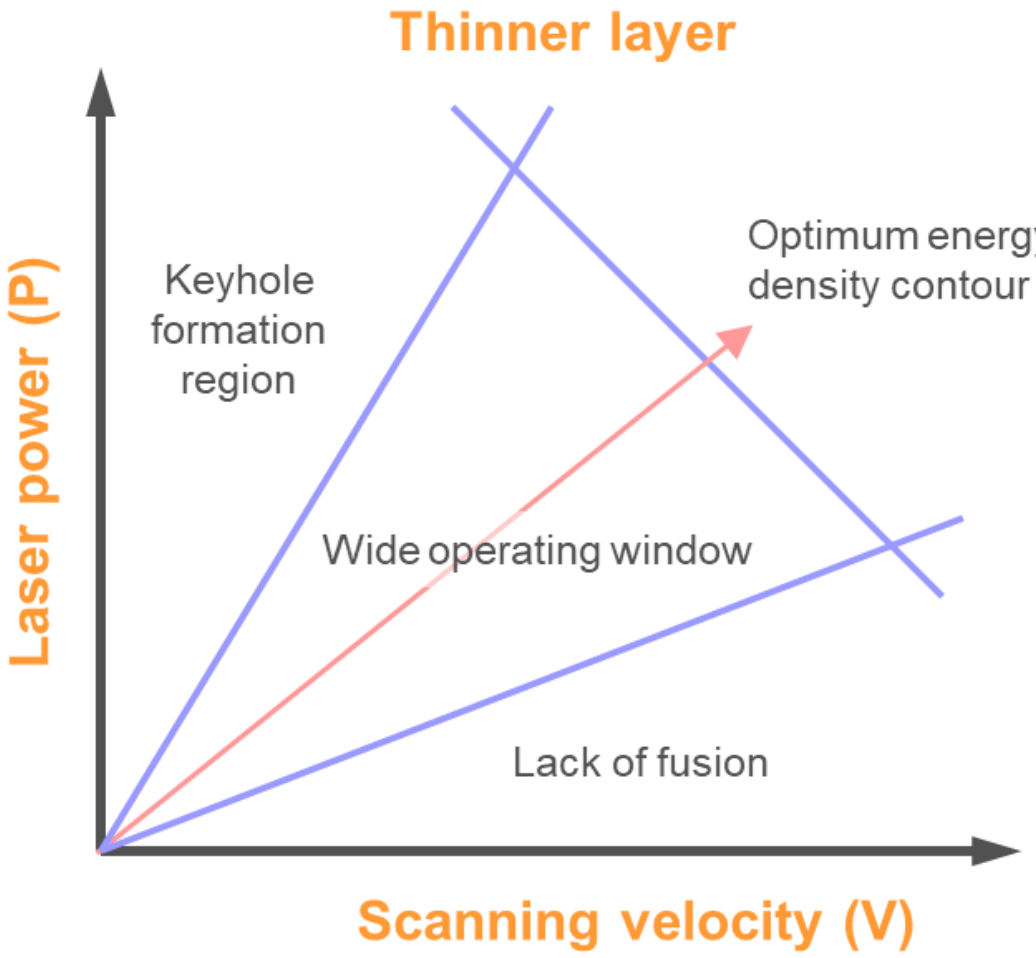
X-Marks The Spot

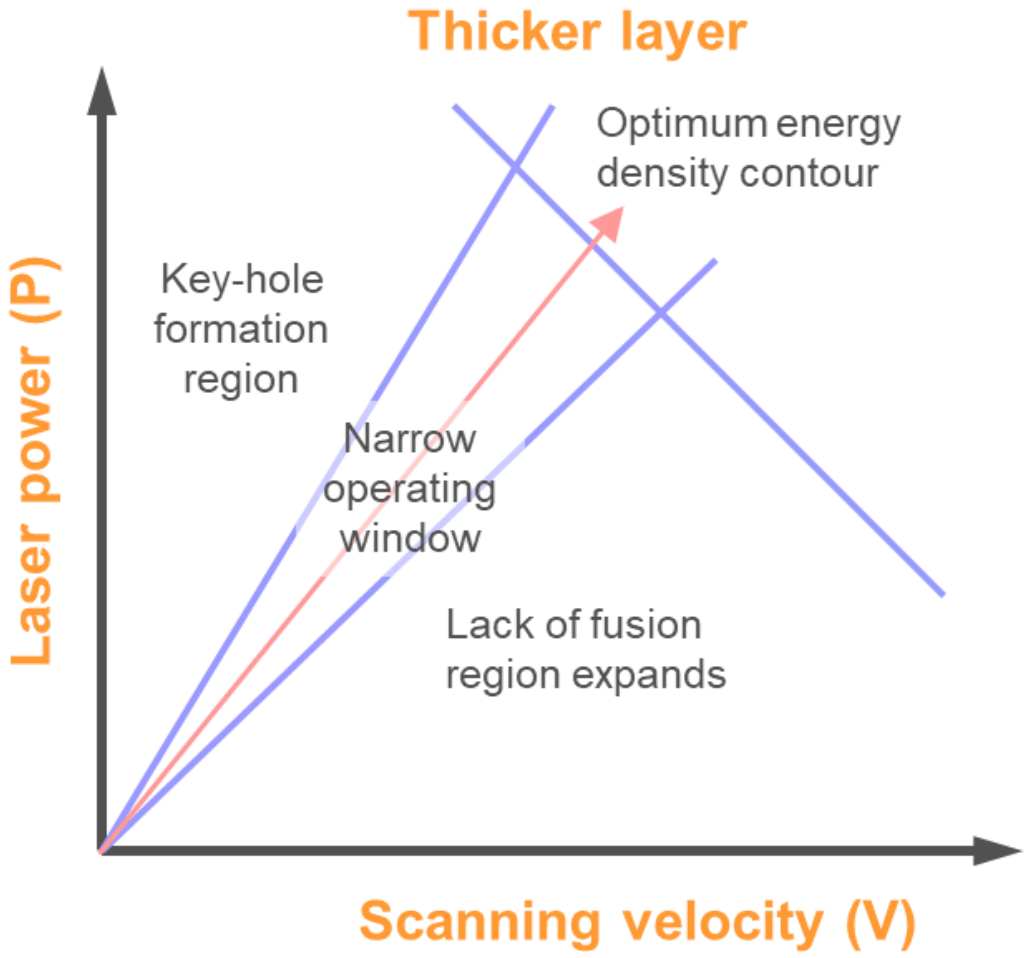
Energy Density (heat flux)

- Amount of energy applied per unit volume
- Energy density contours radiate from the origin in P-V space
- Each material will have a range of energy densities that it can absorb
- An optimum contour provides efficient processing and will deliver the best material properties
- **X** is the ‘Ideal’ processing point



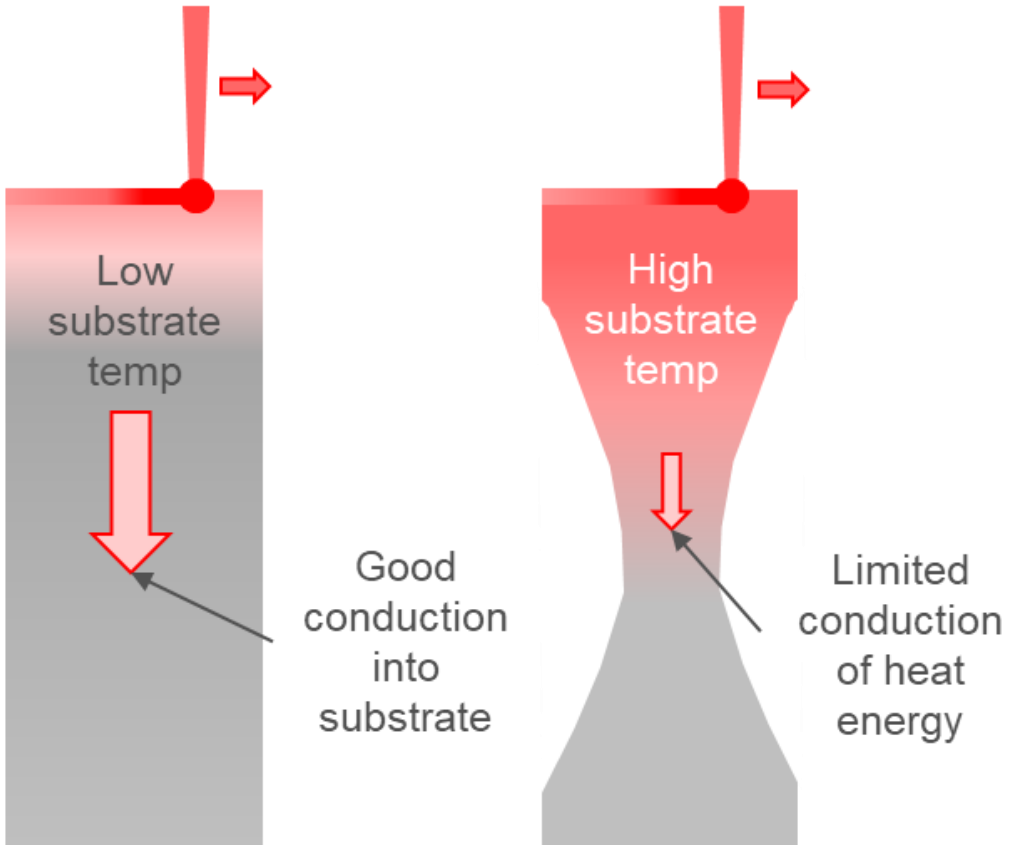
Changing Layer Thickness



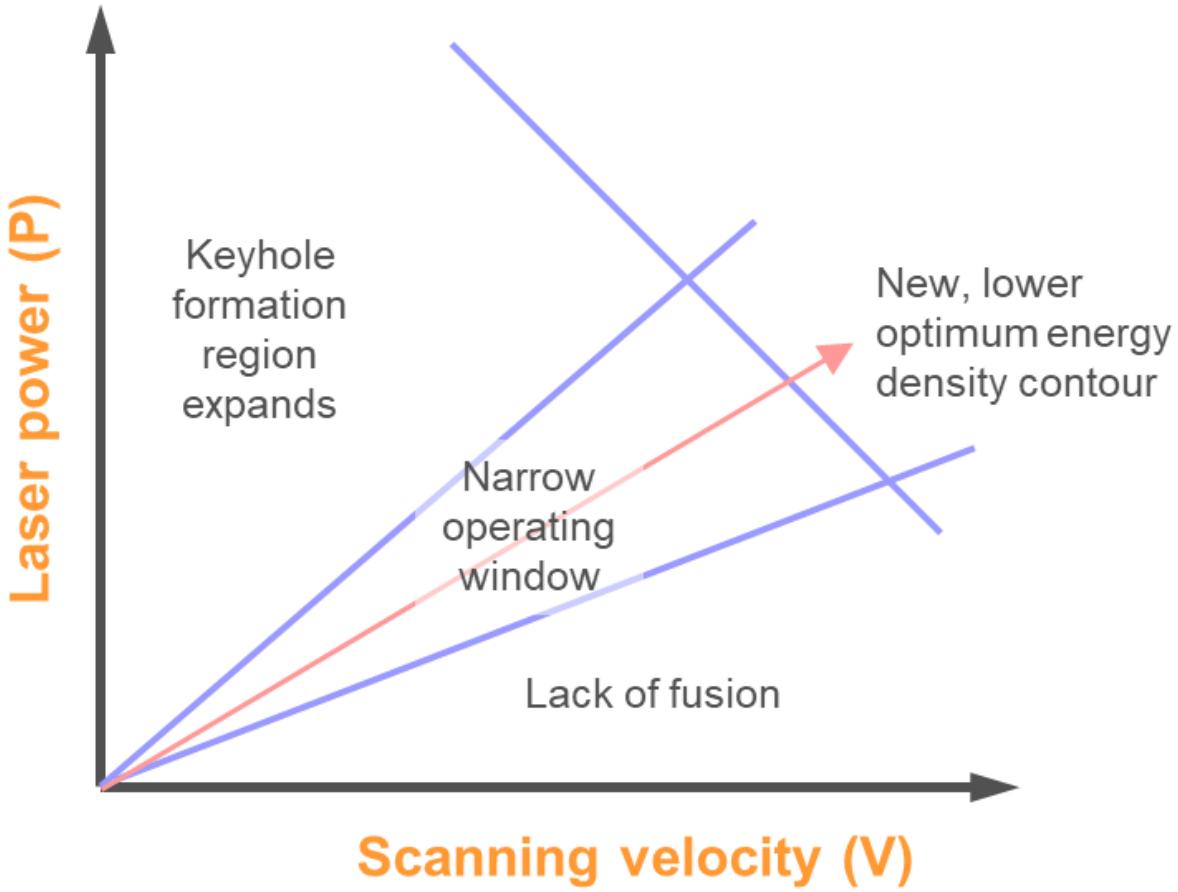


Importance of Design Safety Factors

Geometry impact on retained heat

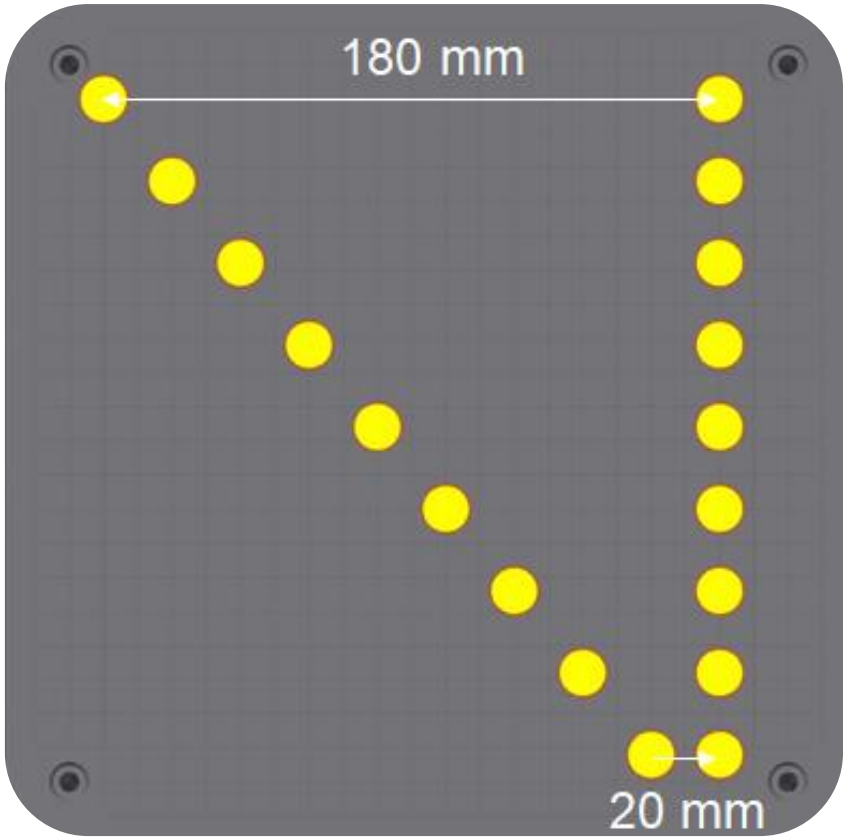


Hotter substrate

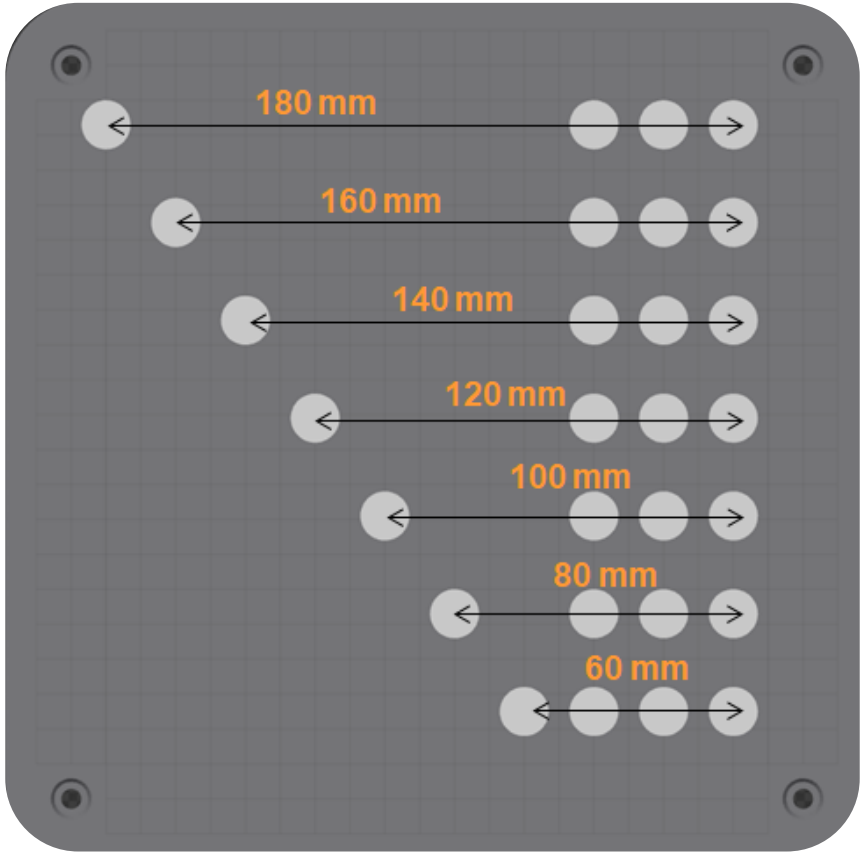


Multiple Lasers

One upwind

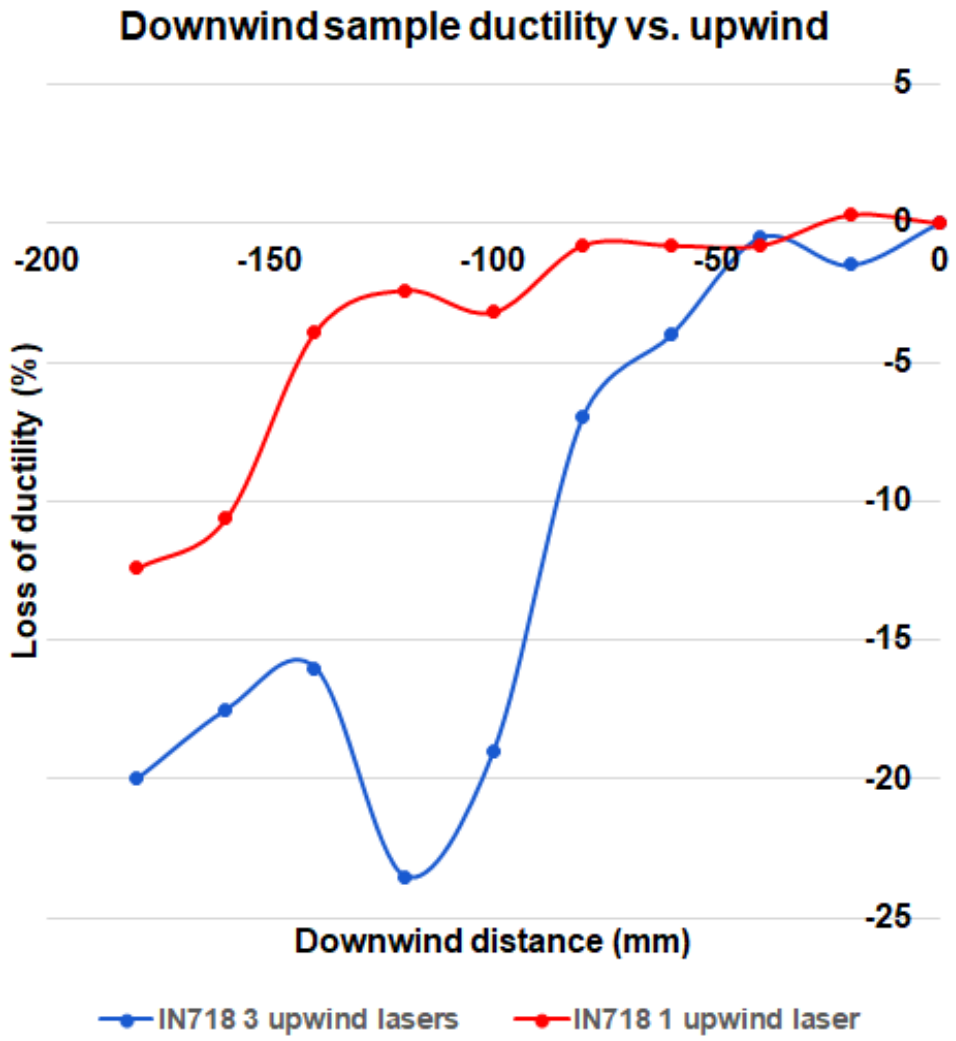


Three upwind



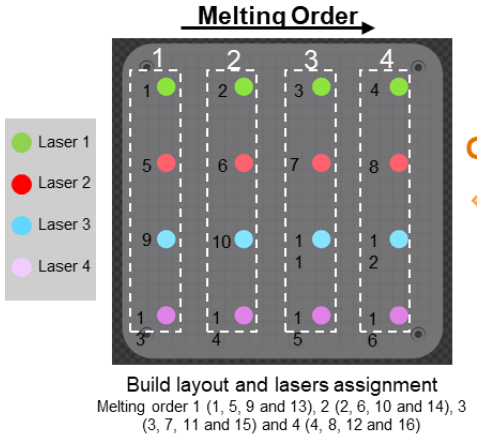
Gas flow direction

The number of upwind laser interactions matters



Impact of “multiple-lasers per part” strategy

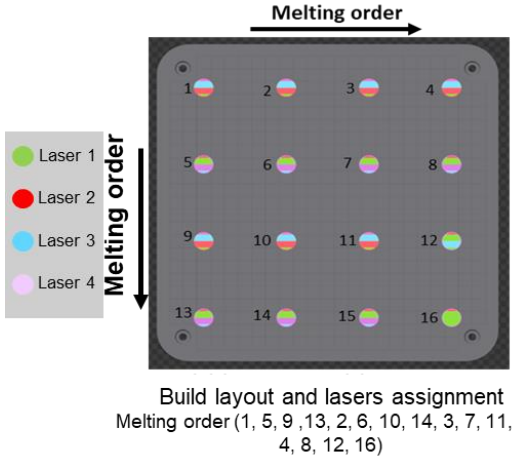
- 1 laser per part and 4 lasers per part show similar mechanical properties (Inconel 625)
- Part quality is not affected when lasers are closer.



Build layout and lasers assignment
Melting order 1 (1, 5, 9 and 13), 2 (2, 6, 10 and 14), 3 (3, 7, 11 and 15) and 4 (4, 8, 12 and 16)

Gas flow

	Mean	STDev
UTS	892	8
Yield	586	6
Elongation * (measured under tensile load)	61.2	0.8

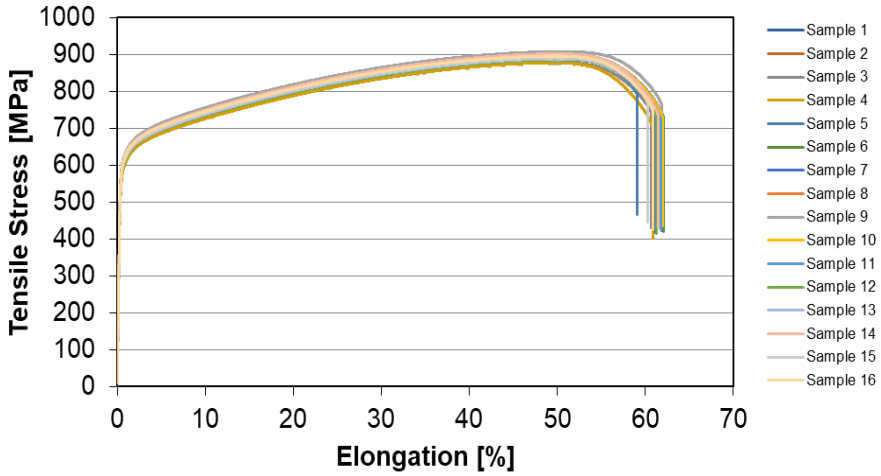


Build layout and lasers assignment
Melting order (1, 5, 9 ,13, 2, 6, 10, 14, 3, 7, 11, 15, 4, 8, 12, 16)

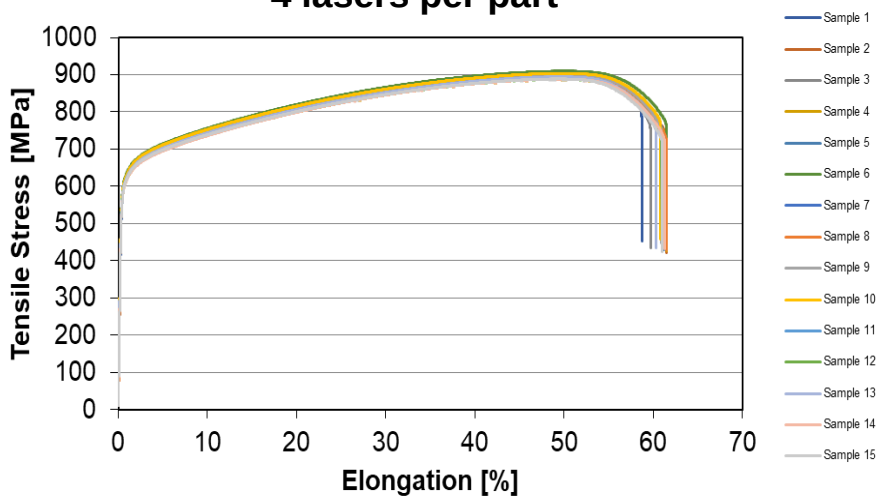
Gas flow

	Mean	STDev
UTS	896	7
Yield	589	5
Elongation * (measured under tensile load)	60.8	0.8

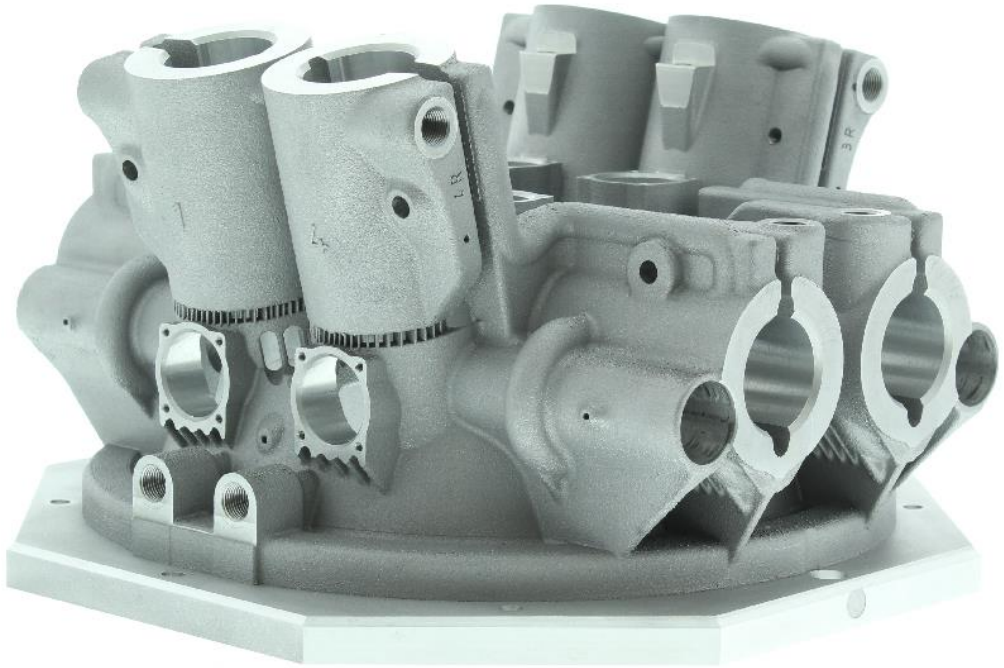
1 laser per part



4 lasers per part



Multi-Laser Produced Part
- 500Q Galvanometer Block

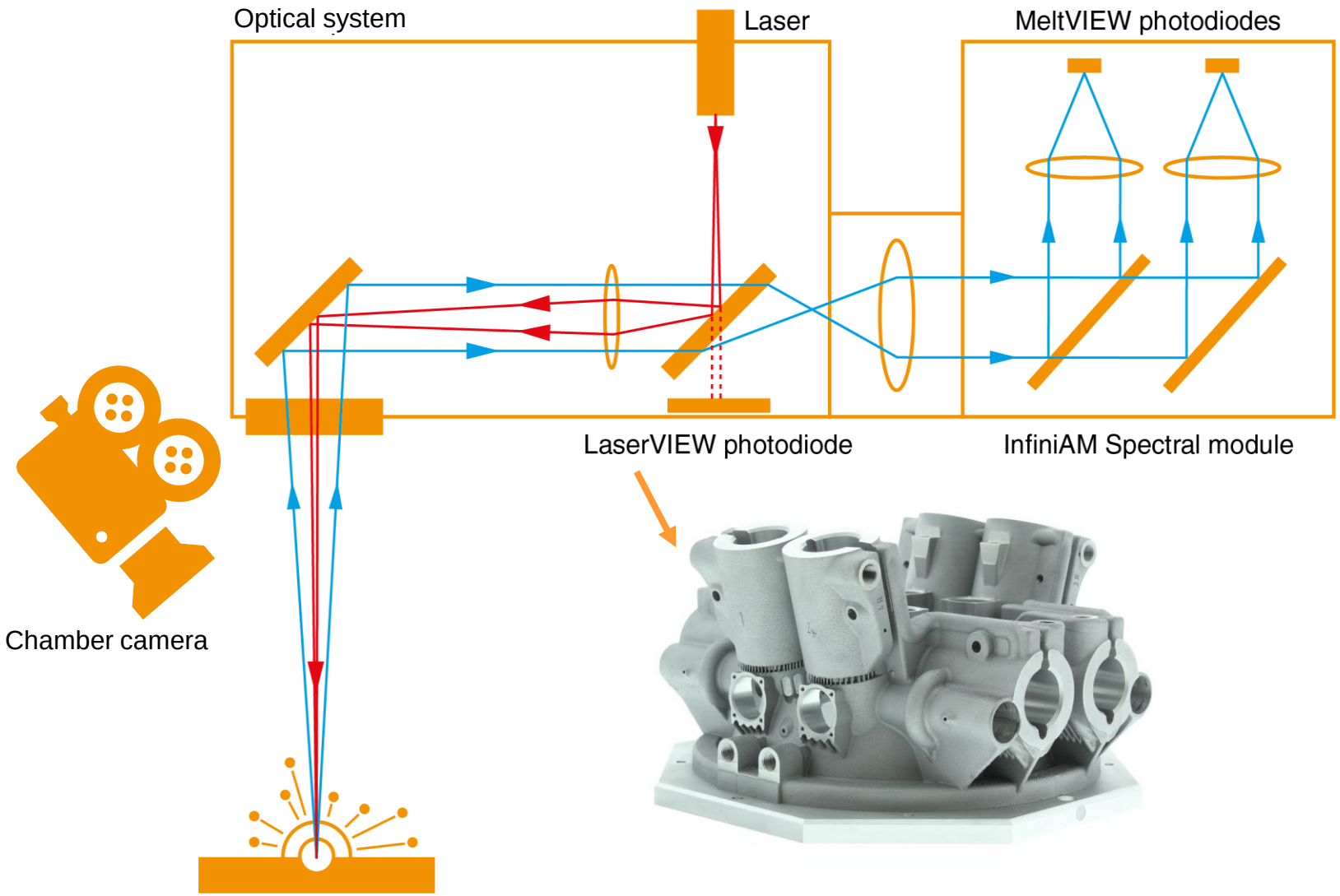


- Heart of the system
- Tightly packed and integrally mounted galvo assemblies improve system performance and accuracy.
- Conformally cooled to optimize performance
- Designed for AM process

Process Monitoring and Machine Reporting

- Provides near real time documentation/logging of process
- Provides confidence in comparing finished parts to in-process data
- Informs ongoing manufacturing and design process
- Provides central monitoring and reporting capabilities which are key to serial AM production operations.

Process Monitoring: The Hardware



InfiniAM Spectral / MeltVIEW

- Twin photodiodes sampling at 100kHz
- Plasma emissions @ 700 to 1050nm
- Melt-pool emissions @ 1080 to 1700nm
- Integration with RenAM system controller to synchronize sensors with motion control

InfiniAM Spectral / LaserVIEW

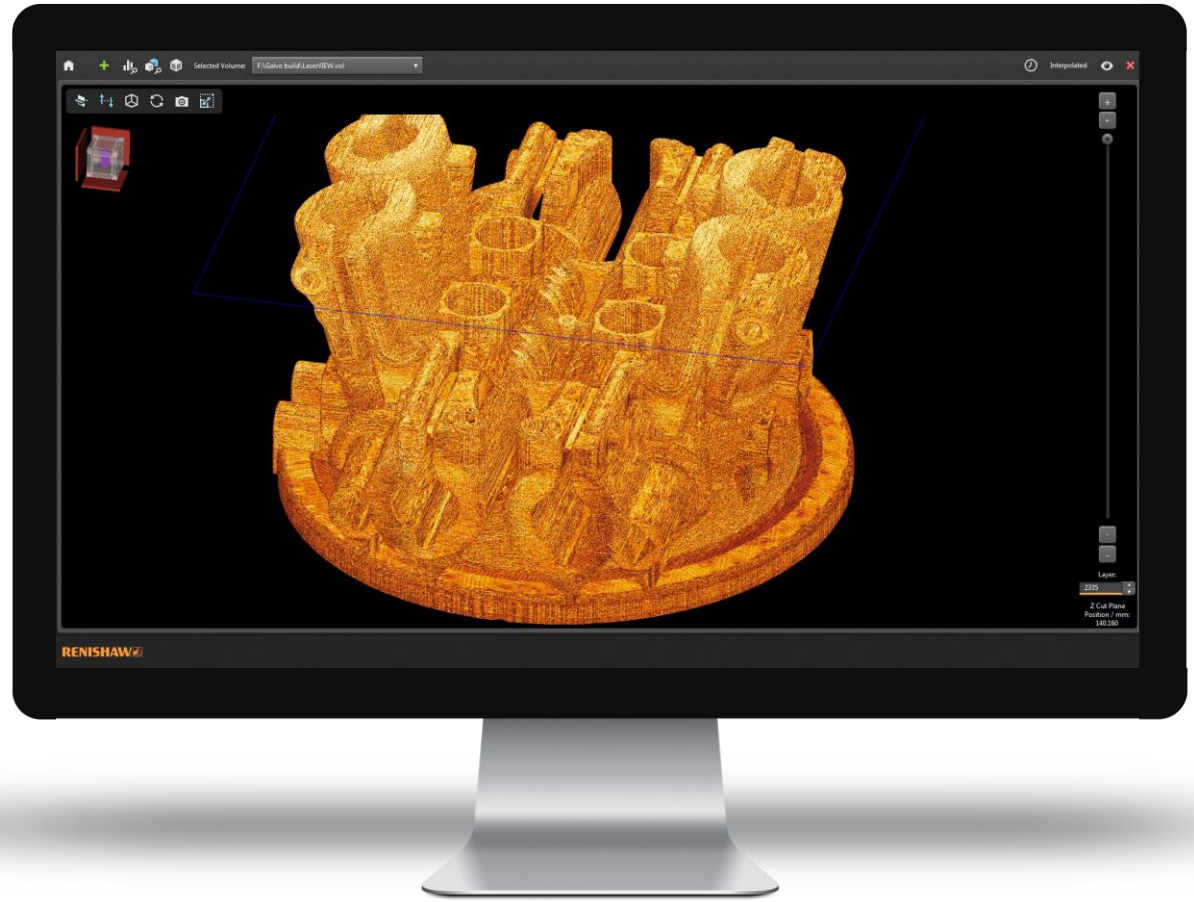
- Captures sample of laser energy during every pulse
- Samples at up to 2MHz
- Relative measurement of laser power for comparison to calibration data

Chamber camera

- Images taken after each dose
- Can be used to aid build failure analysis

Process Monitoring: The Software

Near real-time 2D image viewing



Post-build 3D rendering of data captured voxel by voxel

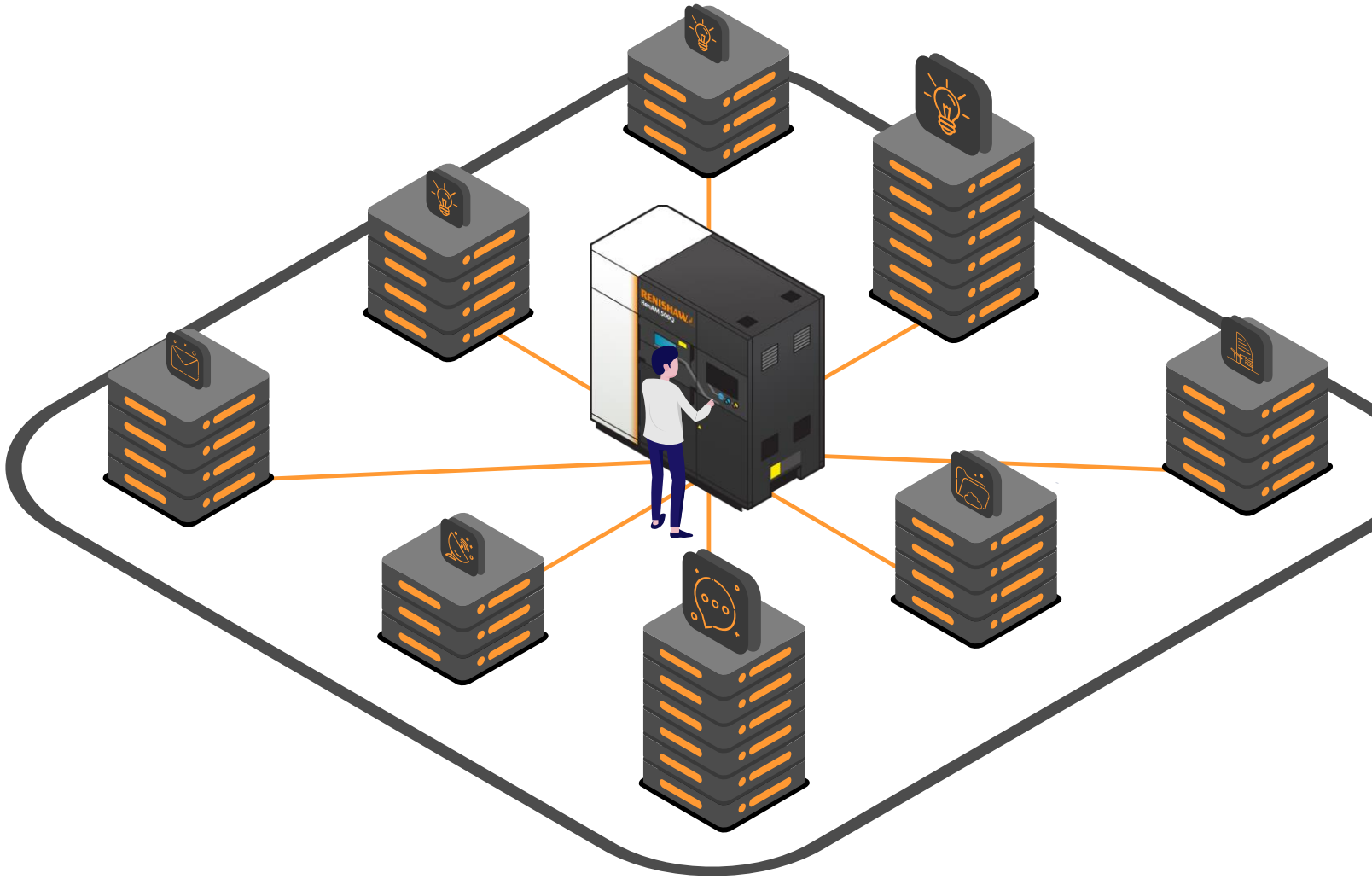
Process monitoring and control

InfiniAM Central

- Machine productivity and status monitoring
- Real-time performance monitoring
- Post-process data harvesting

InfiniAM Spectral

- Camera analysis
- LaserVIEW
- MeltVIEW
- DataHUB



InfiniAM Central

Taking a global over-view of machine variables

Taking an in-depth view of a single layer

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Thank you!

Keith Brady

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