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Industry Perspective on Critical AM Applications

Industrial AM Workshop on Metals and Ceramics

25 April 2019

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Agenda

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1	**Oerlikon AM**
2	Applications we are seeing in aerospace
3	What is necessary to realize these applications.
4	What we have been doing internally
5	Where we see need for external support

Oerlikon Group Global Industrial Leader

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Oerlikon Group (FY 2017)

Sales: CHF 2.7B

> 13 700 employees

4% sales invested in R&D

Surface Solutions Segment

oerlikon balzers	oerlikon metco	oerlikon additive manufacturing
Thin film surface solutions and precision coated components	Thick film surface solutions including materials and hardware.	AM metal powders and components

Industries


Aerospace


Automotive

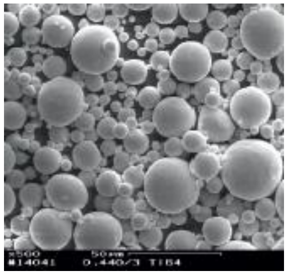

Medical


General Industry


Power Generation

AIRBUS, BMW, GE, ALSTOM, MTU Aero Engines, DAIMLER, CNH, Audi, Rolls-Royce, John Deere, BOSCH, CATERPILLAR, CERN, Continental, ABB, KENNAMETAL, HITACHI, DLR, LAMBORGHINI, Ford, SECO

Oerlikon AM Business Lines



Materials

Plymouth, MI

Troy, MI

Services

Huntersville, NC

Barleben, Germany

Munich, Germany

Medical

Shelton, CT

- **Prototype**
- **Development**
- **Production**

Helping Our Customers Realize the Value of Additive Manufacturing

Building a Global AM Network

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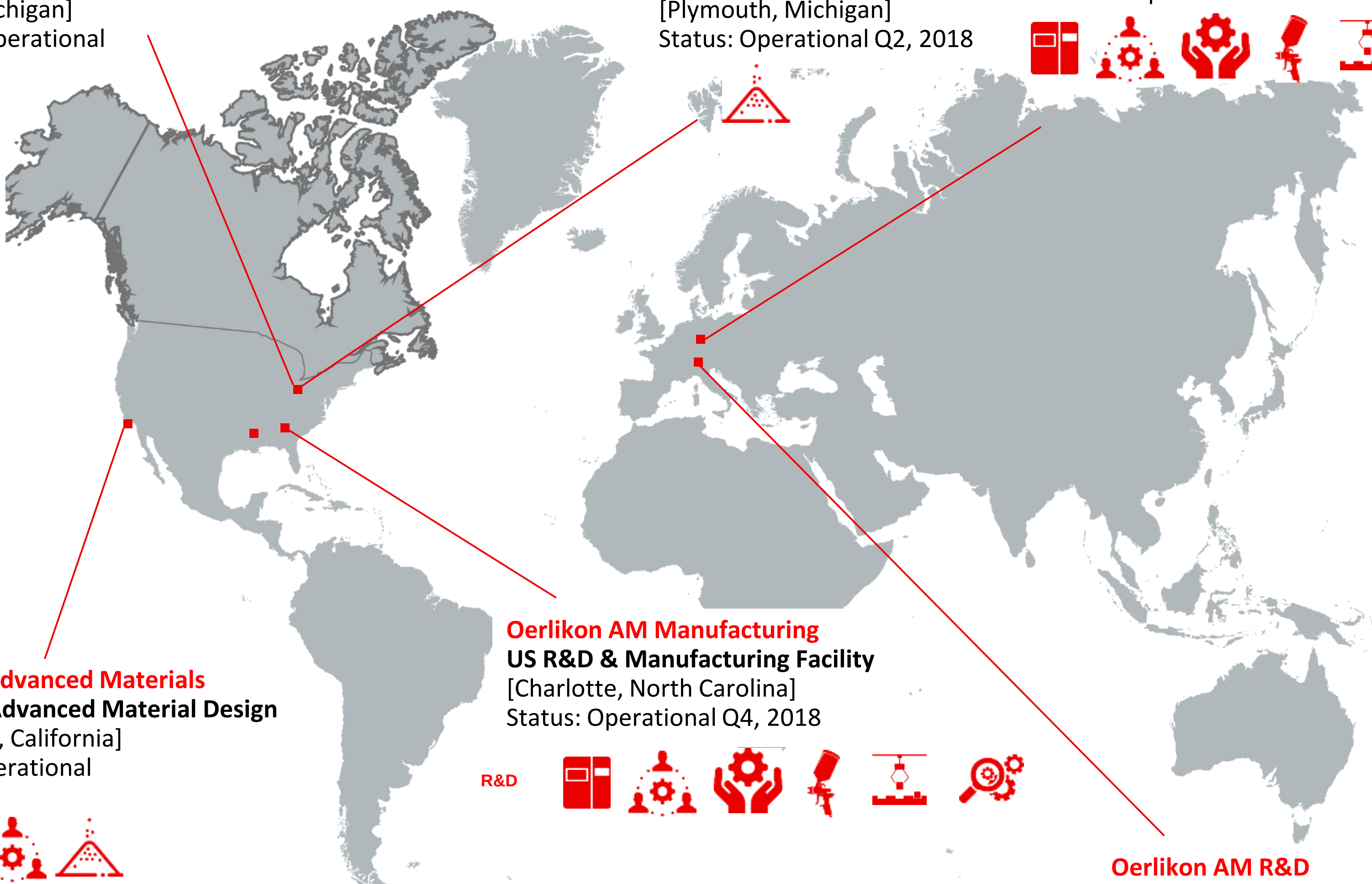
Oerlikon Metco Powder
Powder Atomization Facility
[Troy, Michigan]
Status: Operational

Oerlikon AM Powder
Powder Atomization Facility
[Plymouth, Michigan]
Status: Operational Q2, 2018

Oerlikon AM Manufacturing
European Manufacturing Facility
[Magdeburg, Germany]
Status: Operational



Oerlikon Advanced Materials
Scoperta Advanced Material Design
[San Diego, California]
Status: Operational

R&D

Oerlikon AM Manufacturing
US R&D & Manufacturing Facility
[Charlotte, North Carolina]
Status: Operational Q4, 2018

R&D

Oerlikon AM R&D
Europe R&D
[Munich, Germany]
Status: Operational Q4, 2017

R&D

Aerospace Market Challenges - Optimization of weight and performance in a cost competitive framework

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CHALLENGE

WEIGHT REDUCTION

Weight optimized designs with balanced stress distributions increase fuel efficiency and performance enhancement

Barrier: Weight optimized shapes are prohibitively expensive or impossible to create using conventional techniques.

CHALLENGE

INCREASING EFFICIENCY

New engine concepts for increased fuel efficiency with higher combustion temperatures improve efficiency but require complex components in terms of material and geometry (e.g. cooling channels)

Barrier: Hard to machine high temperature alloys (e.g. Ni-based) and high geometrical complexity due to cooling and combustion features.

AM is helping to drive weight and efficiency optimization and reduce cost in aerospace

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PARTS & MATERIALS

Lightweight – High Performance

- Low cost of complex geometry
- Part consolidation
- Optimized stress distribution through topology optimization
- Complex, optimized internal cooling
- New high-temperature materials (mid-term)

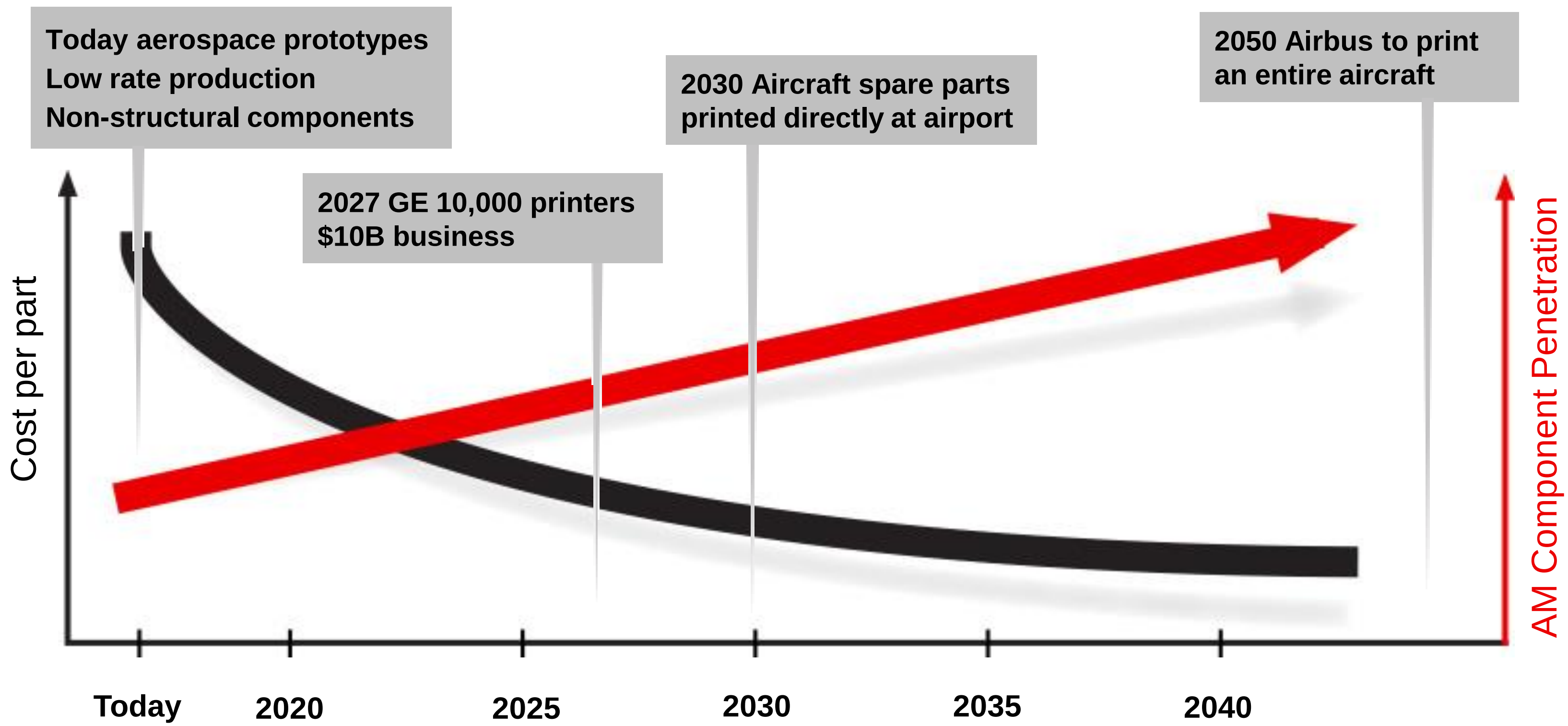
PRODUCTION PROCESS

Streamlined - Efficient

- Reduced development costs
- Reduced part cost
- Reduced inventory
- Reduced logistics
- Shorter lead-times
- Produce spare parts on demand, eliminating some inventory stocks
- Reduce or eliminate assembly activities

AM Technology is rapidly maturing

When does AM become a mainstream manufacturing technology?

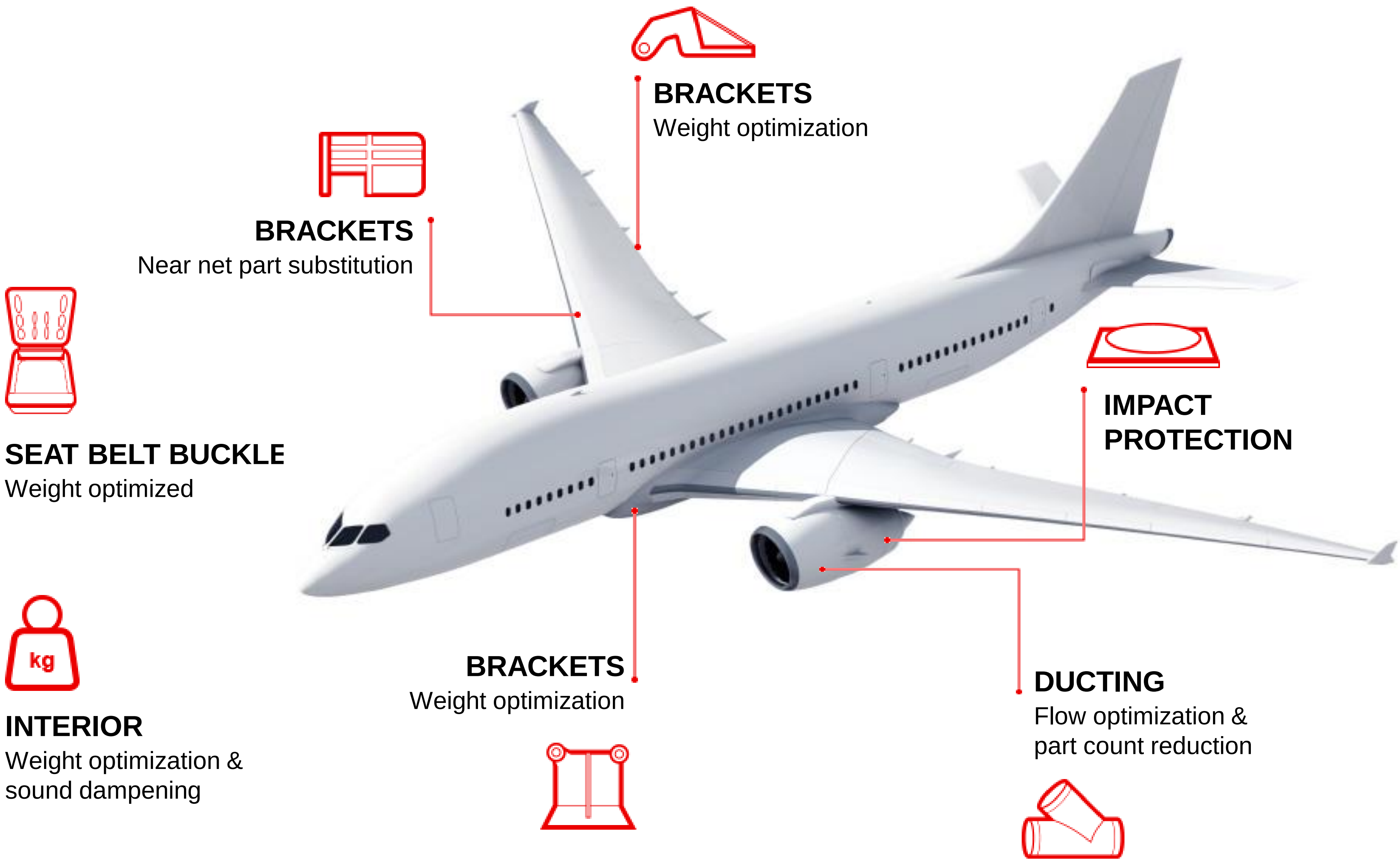


Cost Reduction Drivers

Near term drivers:
- Machine cost down 30%
- Increased build factor of 10
- Part cost down 90%

Medium term drivers:
- Powder cost down 30%
- Machine cost down 30%
- Increased build factor of 30
- Process automation
- Part cost down 98%

Aircraft Applications



Aero Engine Applications

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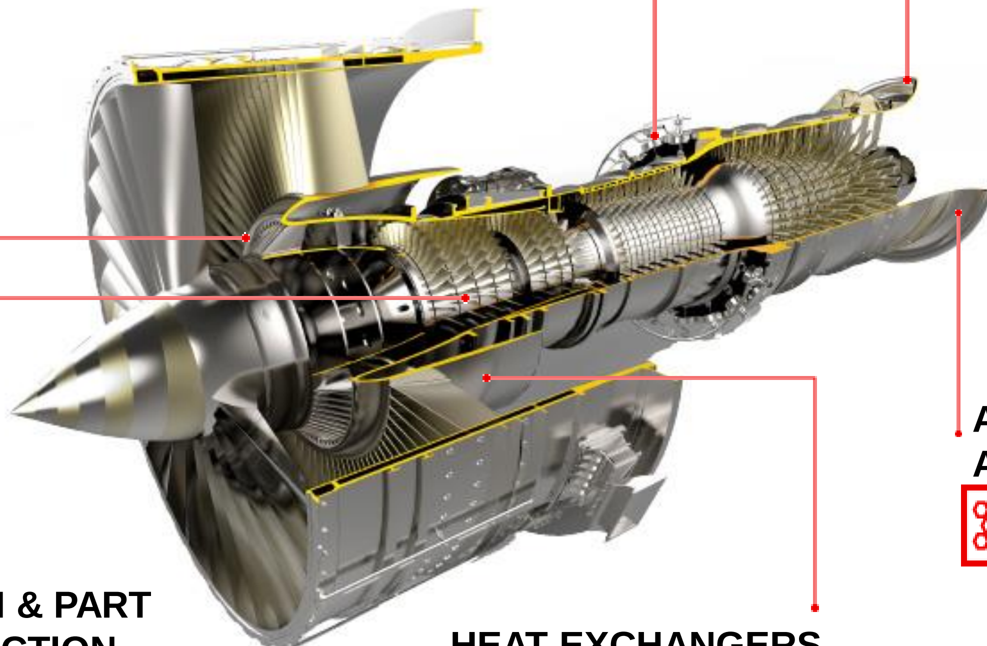
DIFFUSER

DUCTING
Flow optimization & part count reduction

COMPRESSOR VANES



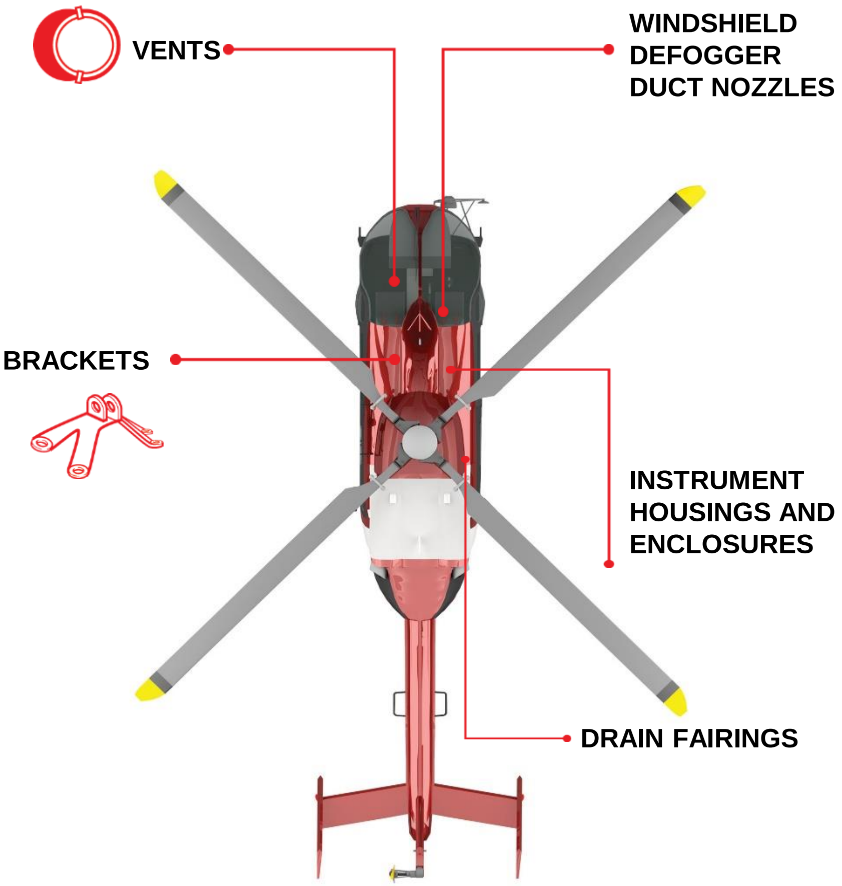
ACOUSTIC ATTENUATION

SYSTEM INTEGRATION & PART COUNT REDUCTION

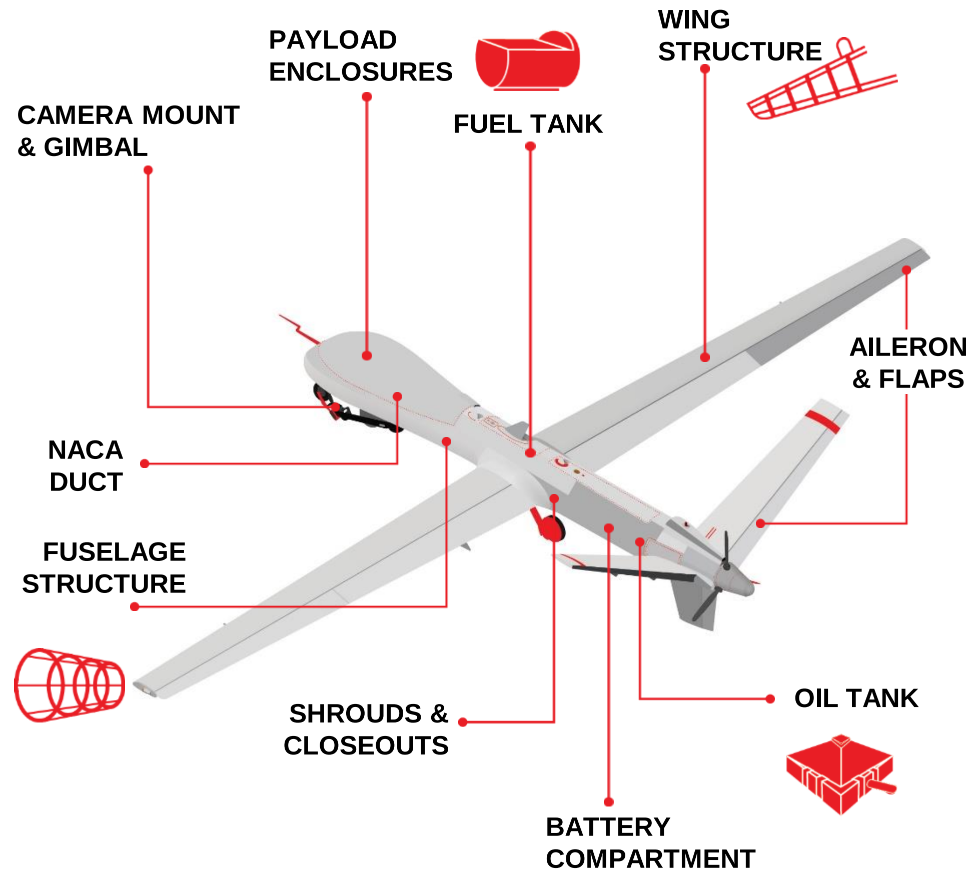
HEAT EXCHANGERS

Rotorcraft Aand Defense Application

Helicopter



UAVs



Basic Requirements for AM Success

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Quality

ASTM/ISO/AS

NADCAP

Work Instructions

Material Knowledge

Powder performance

Printed/Heat treated material performance

Robust Processes

Key Performance Variables

Stable Platforms

Stable Processes

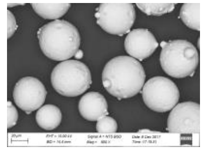
Design Data

Varies by industry

Primarily Conventional Alloys

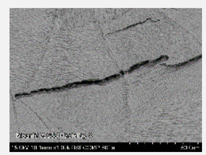
High quality, complex, primary, secondary, and functional components

Oerlikon AM's view for achieving aerospace production?



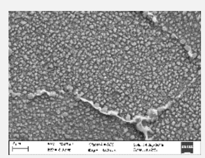
Powder

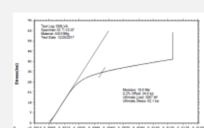
"Powders that work"



Material

"tailored, controlled mechanical performance"





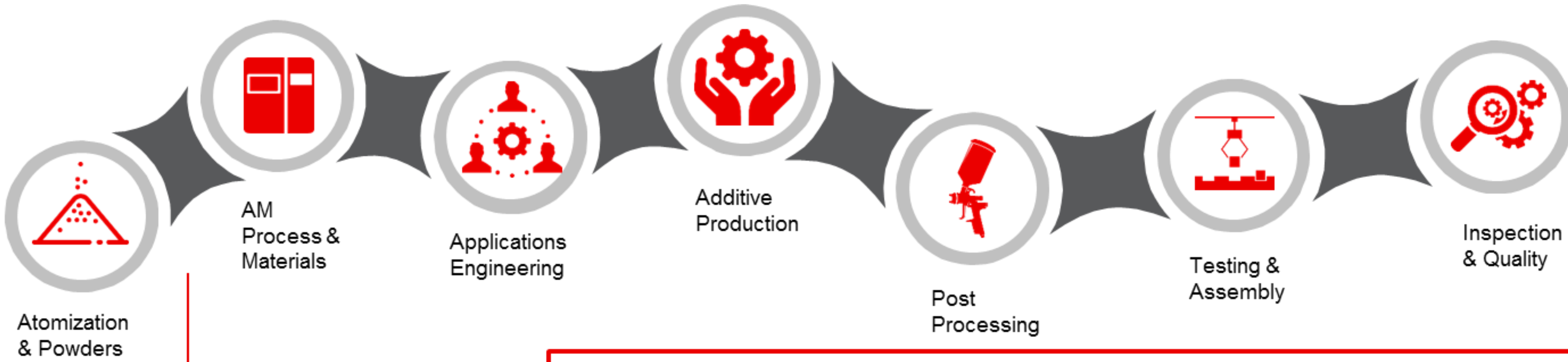
AM Production & Post Processing

"End-to-end Advanced stable Component Manufacturing"

Applications Engineering & Design

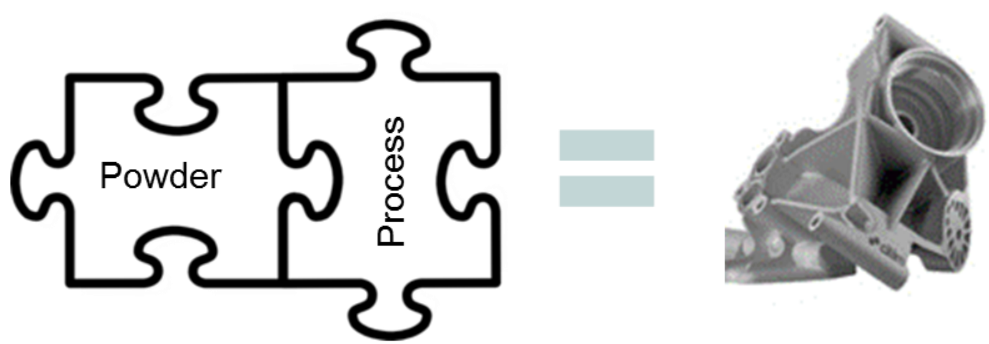
"Deep vertical and domain knowledge for optimal customer solutions"

Integration of AM Value Chain to Realize Additive Manufacturing



The "AM Equation"

{Powder + Process} = {Material / Shape}



INNOVATION & ADVANCED COMPONENT PRODUCTION
CHARLOTTE, NC (US)

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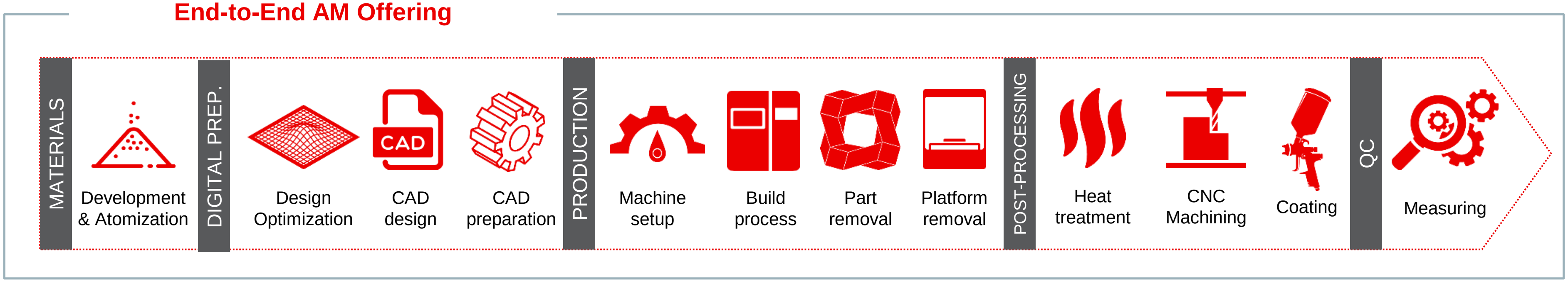
Key facts

- ~125,000 ft^2 facility, plus future expansion possible
- End-to-End engineering, manufacturing and R&D center
- Capacity for >50 AM systems and post processing

Key equipment

- Powder management and QA
- AM systems: 18 PBF-L; 6 PBF-EB (Shelton, CT)
- Post processing: 2 Wire-EDM, 1 vacuum furnace, 1 HIP, 1 mill/turn CNC, 5-axis milling, grit blasting, vibratory finishing, polishing,
- Comprehensive QA equipment and R&D laboratories for AM (metal powder lab and materials testing)

End-to-End AM Offering



R&D (including material)

Why vertically integrate?

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- Manage the external and internal powder supply chain
- Shared technical resources (manufacturing, materials, design) to develop and deliver solutions capable of replacing conventional manufacturing
- Reduce lead times from non-printing supply chain
- AM specific:
  - Heat treatment
  - Finishing
  - Inspection

Technical Roadmap Themes - US

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Technical Area	2018 Foundation	2019 Stabilize	2020+ Grow
Powder Ensure powder that can be used internally and externally; expand materials palate	▪ 6 new alloys; 18 total ▪ PLY requalification ▪ Implement powder management strategy	▪ Launch of 4 alloys (22) ▪ PLY requalification ▪ Establish powder reuse limits	▪ y-TiAl, NiTi, ▪ Refractory metals ▪ Amorphous alloys/FGM/SMA ▪ Ceramic powder
Printing Processes Enable stable printing processes that unlock current and future markets	▪ Printing process readiness to capture customers ▪ Establish SPC for Services.	▪ Process windows ▪ Customer driven application development ▪ Multi-Laser Readiness	▪ Adv. Process Control ▪ DED ▪ Simulation tools
Materials Use structure/property/process knowledge to enable data driven expansion of AM applications	▪ Generate "quick" data for existing powders and processes ▪ Establish HT practices	▪ HS Aluminum ▪ Optimized HT (Including HIP) ▪ Impact of flaws	▪ A/B Basis Data ▪ AM Specific Alloys ▪ Designed microstructure
Post Processing Deliver finished components to customers, in-house to realize lead times and low vol savings	▪ Initial equipment online ▪ Establish external supplier base ▪ Cross-BU support	▪ 80% capability in-house ▪ Recipes established. ▪ Begin exploring differentiating capability	▪ Integrate surface solutions ▪ Differentiating post process capability in house.

Highlights – Powder Management Strategy

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Challenge:

- Implement a fully traceable and efficient powder management strategy servicing critical applications.

Solution:

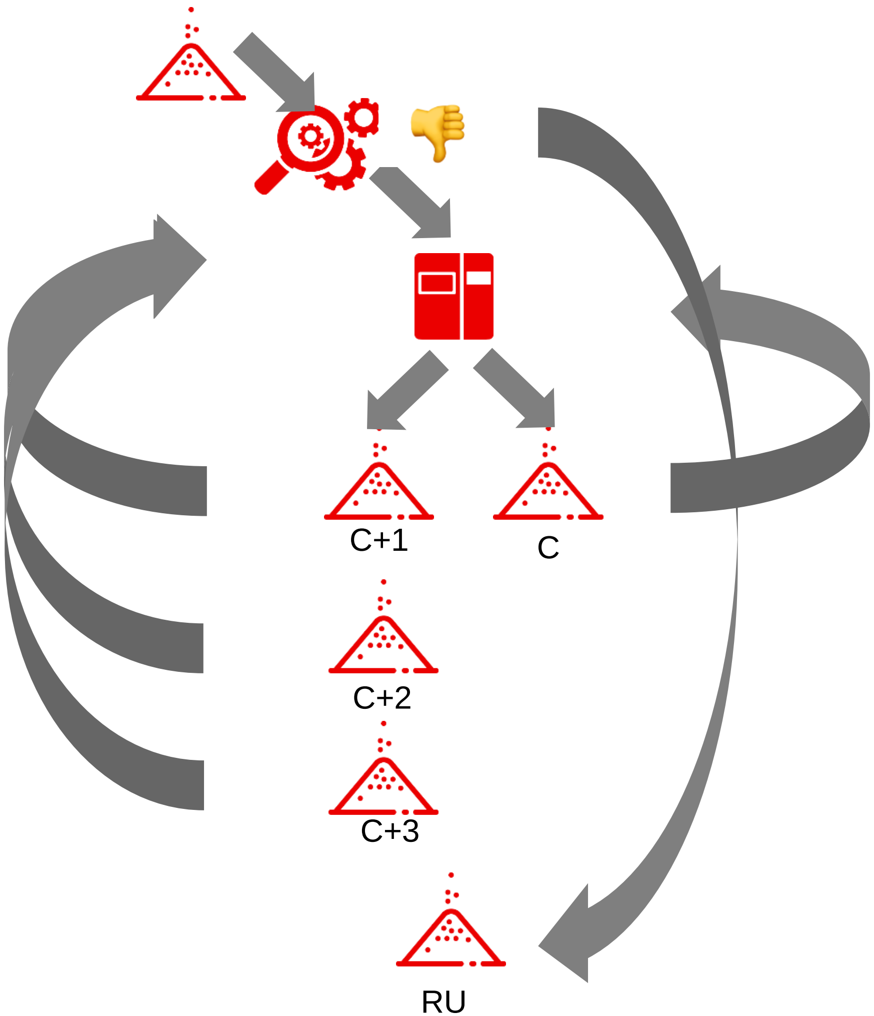
- Maintain lot and cycle count
- Verify re-used powder in-spec

Current Status:

- Tracking all powder in shop
- Equipment installed
- Building Quality database

Result of Project:

- Process control
- Customer confidence



Highlights - Powder Launch Strategy

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Challenge:

- Nickel Alloy H-X cracks when printed. (started 7/16)

Solution:

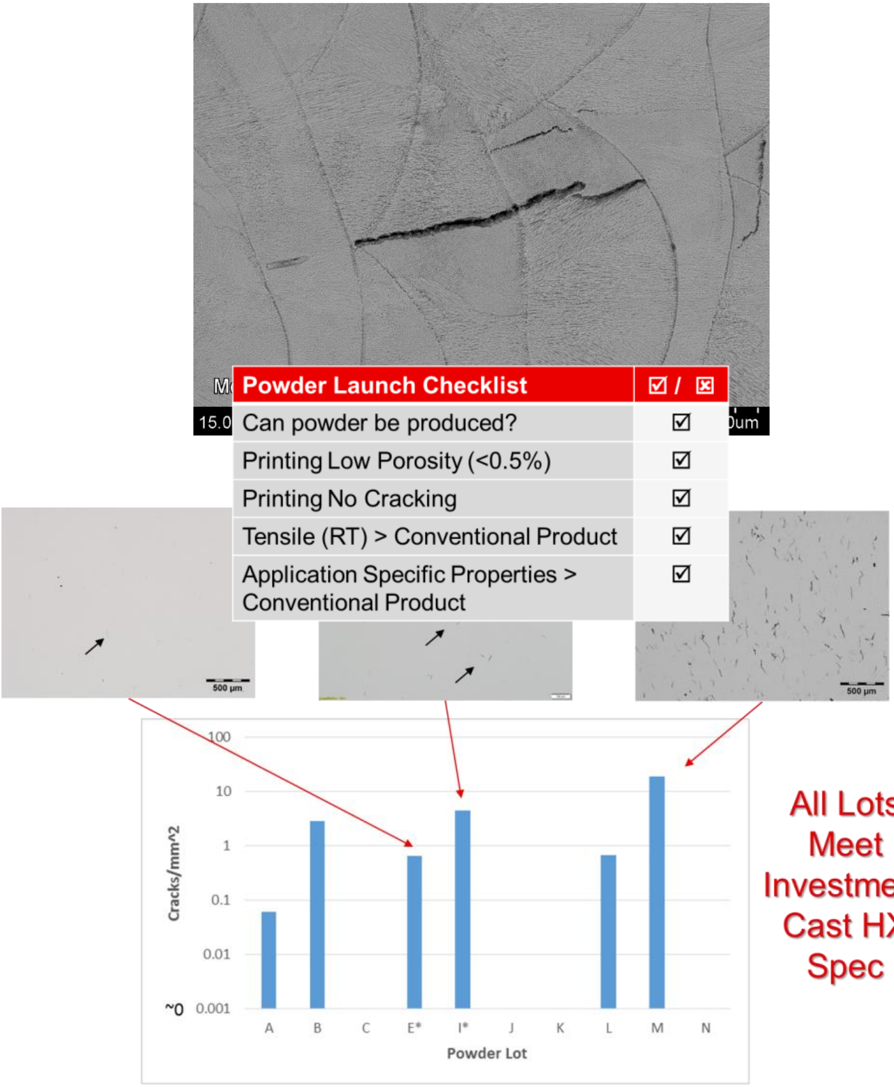
- Identify crack-free chemistry

Current Status:

- Re-Launch of H-X
- Customer pre-production in progress

Result of Project:

- Established powder launch procedure for H230, 738, MARM509, H188, etc
- Ongoing work with customer to supply powder and enter series production



Powder Launch Checklist	☑ / ☒
Can powder be produced?	☑
Printing Low Porosity (<0.5%)	☑
Printing No Cracking	☑
Tensile (RT) > Conventional Product	☑
Application Specific Properties > Conventional Product	☑

All Lots Meet Investment Cast HX Spec

Highlights – Materials “Quick” Data Generation

Challenge:

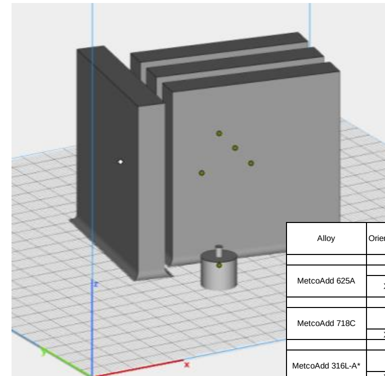
- Existing MetcoAdd alloys launched with limited data.
- Difficult to convince customers to switch to MetcoAdd powders.

Solution:

- “QDG” Project to generate datasheets for 9 alloys using stock machine parameters.
- Completed in 2.5 months.

Result:

- Established benchmark for performance.
- Identify need for HT optimization.



Alloy	Orientation	Data generated in the QDG project								
		Printed using EOS M290			Printed using SLM 125HL			Printed using CL M2		
		YS(MPa)	UTS(MPa)	%E	YS(MPa)	UTS(MPa)	%E	YS(MPa)	UTS(MPa)	%E
MetcoAdd 625A	Z	409±3	891±3	61±1	403±3	846±51	43±11	445±5	889±5	60±2
	XY	419±10	914±6	58±1	412±3	899±4	54±3	462±3	926±11	54±1
MetcoAdd 718C	Z	1172±6	1379±7	19±1	1190±9	1439±37	11±2	1186±18	1415±16	17±3
	XY	1237±27	1491±28	15±1	1209±23	1455±21	10±2	1258±46	1522±10	15±1
MetcoAdd 316L-A*	Z	500±3	609±2	59±1	456±12	537±30	11±7	491±4	635±9	44±8
	XY	562±12	677±7	45±3	536±16	658±13	42±3	548±15	670±2	45±2
MetcoAdd C300-A	Z	1980±7	2027±9	8±1	1389±207	1389±208	2±1	2023±15	2104±15	5±3
	XY	1996±18	2050±17	9±1	1967±18	2034±22	5±1	1982±30	2064±25	5±2
MetcoAdd 17-4PH-A	Z	1316±5	1434±5	10±1	985±460	993±466	0	1310±3	1431±4	8±2
	XY	1304±5	1430±5	12±0	1291±7	1421±6	8±2	1297±11	1425±6	11±1
MetcoAdd 15-5PH-A	Z	1235±5	1354±4	12±0	1101±182	1120±197	1±0	1206±5	1334±2	12±1
	XY	1224±4	1349±5	14±1	1204±11	1340±5	8±1	1205±12	1337±9	14±1
MetcoAdd H13-A	Z	1538±31	1903±12	11±1	1465±9	1807±19	2±1	1510±14	1886±16	10±1
	XY	1531±37	1899±7	11±1	1466±13	1826±15	3±1	1512±14	1894±12	10±1
MetcoAdd 76A	Z	598±2	1215±7	46±3	582±4	1057±59	25±5	590±17	1206±17	44±3
	XY	604±4	1225±10	42±2	593±12	1124±19	30±3	598±6	1209±15	40±3
MetcoAdd 78A	Z	504±6	1162±5	44±1	493±5	791±85	10±4	503±6	1131±42	40±7
	XY	514±9	1188±6	40±2	506±6	1117±7	32±1	514±7	1144±35	40±7

(red)	Values are below EOS datasheet indicated range
(green)	Values are within or above the EOS datasheet indicated range
-	No comparable materials/materail with heat treatment condition with EOS

ASTM E8 round specimens. Average of 10 samples for each orientations. Values are rounded to nearest whole number.

Highlights – Process Qualification

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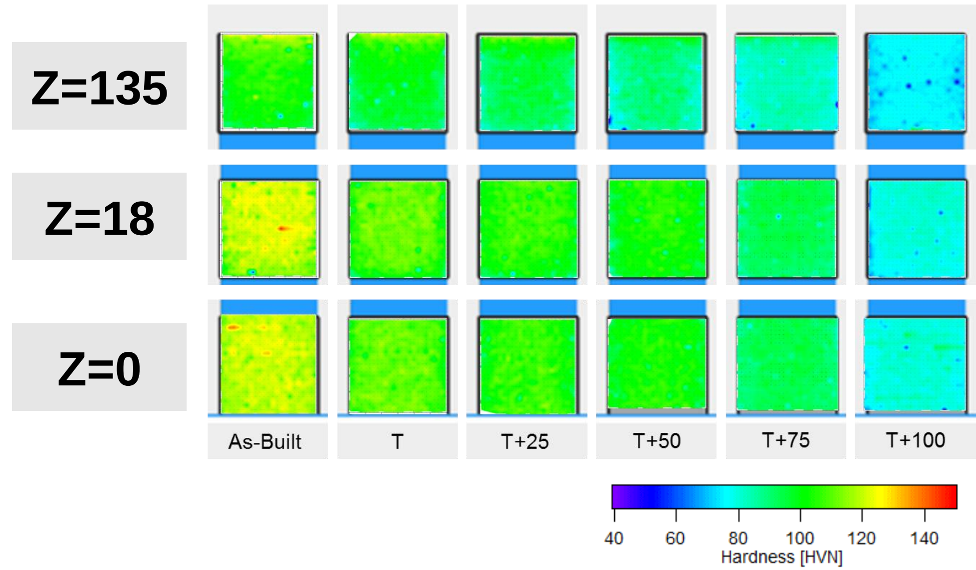


Challenge:

- Doubling speed would significantly open the AM viable part envelope (AlSi10Mg)
- Properties and heat treatment response depend on layer thickness

Solution:

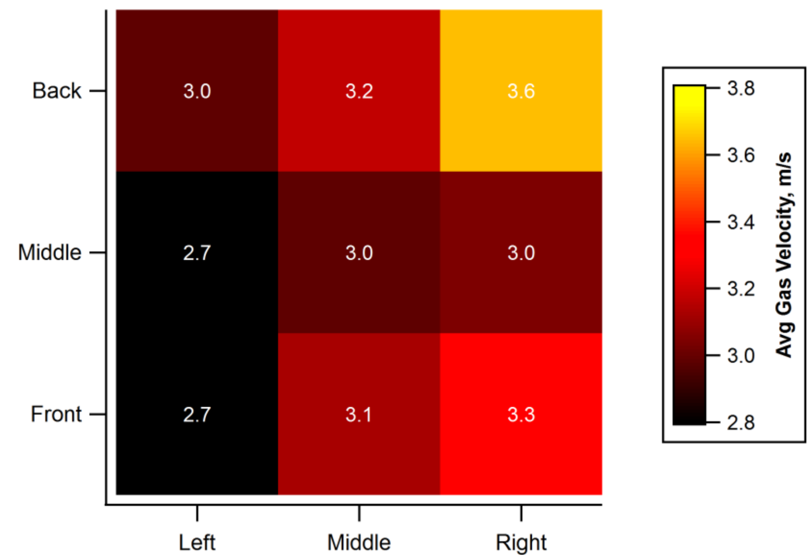
- 8 month machine stabilization and heat treatment optimization study.
- Preliminary data met requirements.

Current Status:

- confirmation of properties at different build locations and height.
- Stabilize process

Result:

- Expand parameter set to 2x and 3x layer thickness, define HT mod.



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Greatest industry needs

- Stable repeatable printing equipment and process understanding:
  - In process inspection
  - Billion dollar facility in a million dollar machine

- How to rapidly identify material performance:
  - without creating $500k test programs
  - Across different printers/features/process parameters/alloy chemistries

- Future items:
  - New AM specific alloys
  - Harnessing structure property and processing relationships
    - alloy design,
    - microstructure design
    - Heat treatment design

Thank you.

Questions?

Oerlikon AM Portfolio

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- Currently Offer 14 alloys that have been printed on multiple machines and are at various stages data generation
- Developing 8 additional products for launch by 4Q18-1Q19

Alloy Base	Current Portfolio
Ni-based	718
	625
	HX
	H230
Co-based	75A, 76A
	78A, 78-1A
Fe-based	17-4PH
	15-5PH
	316L
	C300
	H13 H11

Alloy base	Development Pipeline
Al-based	AlSi10Mg
Co-based	Haynes/Udimet 188
	MAR-M-509
Ni-based	Inconel 738LC
	CM-247LC (Rene 108)
	Alloy 939
Fe-based	Alloy 904L
Ti Alloys	Ti-6Al-4V Gr 5 and Gr 23; TBD