

# Directed Energy Deposition (DED) Serving a Production Role in AM

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Sales Manager

7th Joint EASA-FAA Additive  
Manufacturing Workshop

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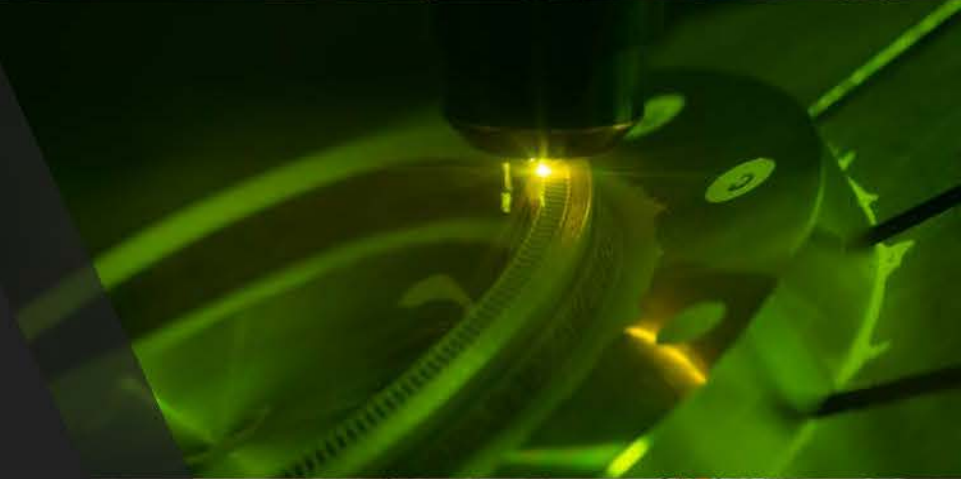


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# Outline

- What is DED
- About RPMI
- Production at RPMI
- FAA/EASA Considerations



# What Is

## **D**irected **E**nergy **D**eposition

- Directed Energy Deposition consists of a high-power laser at a target surface to create a localized melt pool. A stream of metal powder is then delivered to the melt pool and is absorbed, creating a weld bead.
- DED parts are created by converting CAD models into toolpaths. The toolpaths include layer by layer controls to build functional 3D parts to near final shape.
- Rapid cooling rates leave small heat affected zones, minimize part distortion, and provide properties comparable to cast products.





# About RPMI

RPMI is the leader in “Blown Powder” Directed Energy Deposition (DED) which comprises Freeform, Repair and Cladding capabilities. RPMI provides application development, production manufacturing services, repair solutions for its customers and manufactures a complete line of DED Systems which include: Model 222XR and Model 557XR.

## DED Manufacturing Services



- Prototype to production
- 24/7 operation
- Quick Turnaround
- ITAR Registered
- AS9100/ISO9001 certified

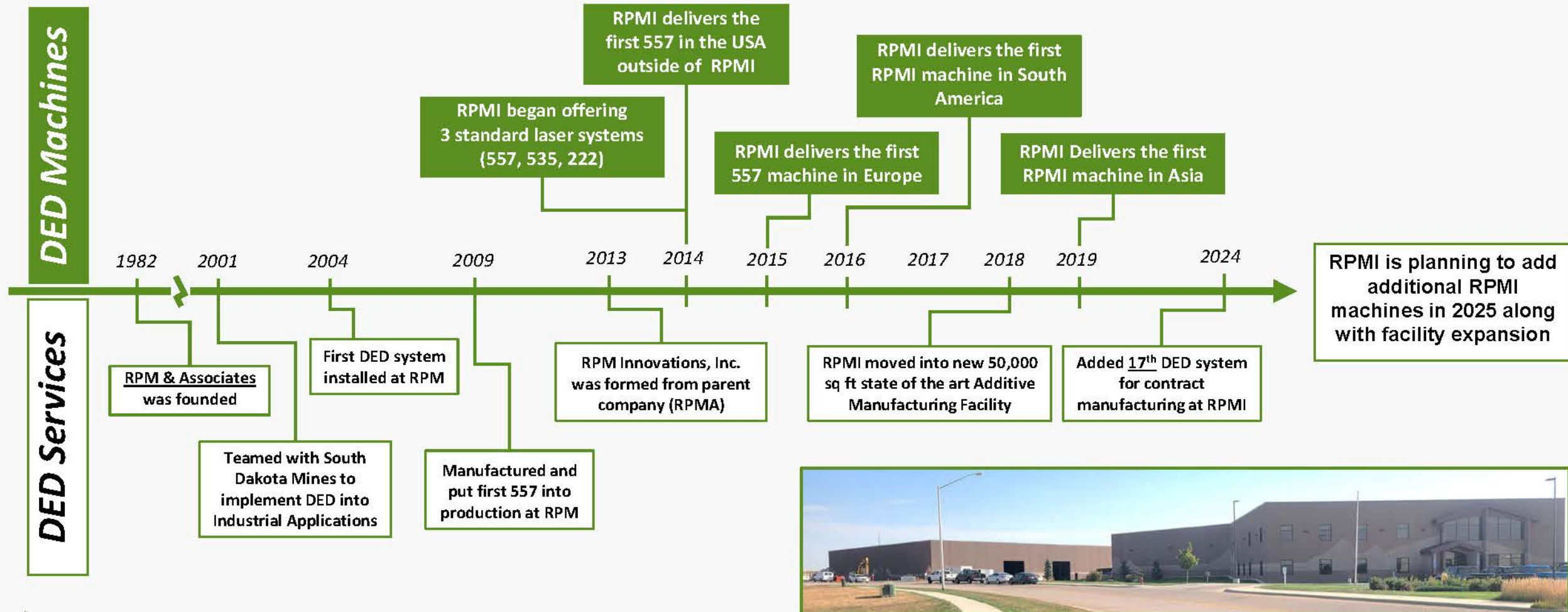
## RPMI Laser Systems



- Work Envelope up to 5 feet x 5 feet x 7 feet
- Process Monitoring and Control
- Inert Environment <10 ppm O<sub>2</sub>
- 5 Axis Control
- Internal Design/Software

# Our Story

RPM and Associates, Inc. was founded in 1982. RPM then became involved in the application and advancement of Directed Energy Deposition for their customers in 2001. The technology was radically advanced and applied across many platforms. Then on January 1, 2013, RPM Innovations, Inc. was spun-off from RPM and Associates.





# Commonly Used Commercial Alloys

Ni

CP Ni  
IN 617  
IN 625  
IN 718  
IN 722  
IN 909  
Alloy 230  
Alloy 282  
ATI 1700  
Hastelloy X  
Monel K500

Fe

304L  
316L  
410L  
420L  
17-4  
15-5  
13-8  
M300  
Invar 36  
JBK-75  
NASA HR-1  
A36 (1018)

Ti

CP Ti  
Ti-6Al-4V (5)  
Ti-6Al-4V(23)  
Ti-6242  
Ti-5553  
ATI Titan 23

Co

L-605  
Stellite 6  
Stellite 21  
CoCr

Cu

CuNi  
GRCop-42  
GRCop-84  
NiAlBrz

Al

A6061-RAM 2  
AlSiMg  
F357

W

WC-Ni  
WC- Co

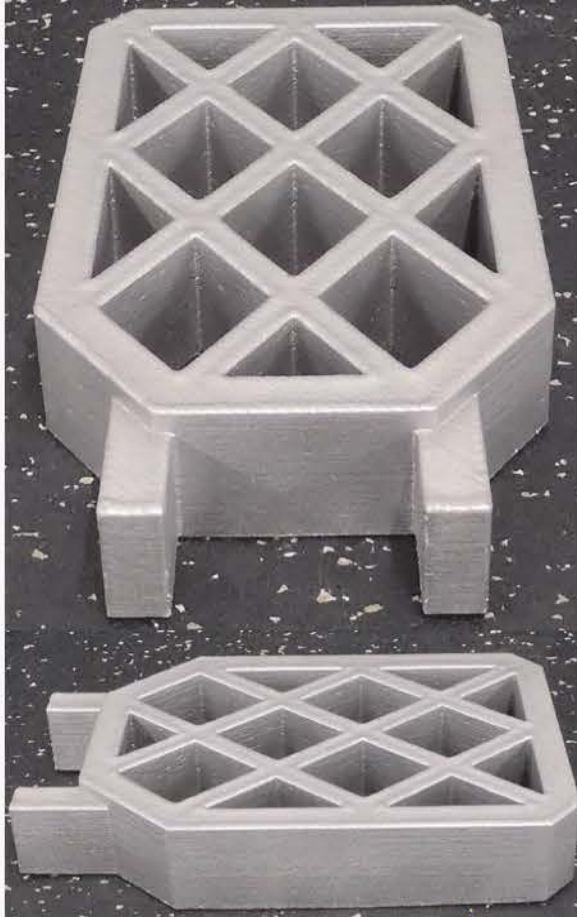
Other

C103  
Vanadium

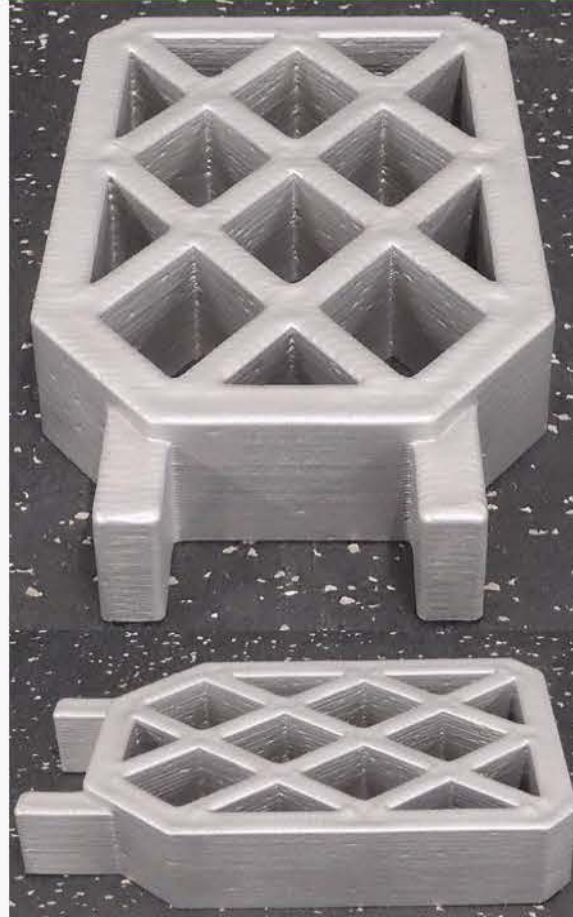
Additional alloys may work with DED, but may not be listed above

# Example Set of DED Parameters

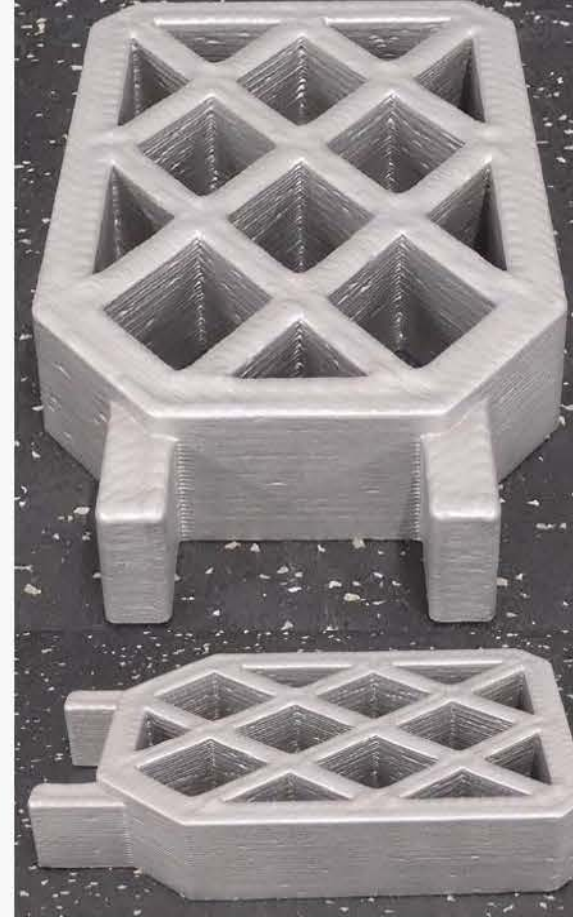
Laser Power:	1070 W
Deposition Rate:	1 in <sup>3</sup> /hr (23 cc/hr)
Deposition Time:	24 hours



Laser Power:	1700 W
Deposition Rate:	2 in <sup>3</sup> /hr (33 cc/hr)
Deposition Time:	16 hours



Laser Power:	2000 W
Deposition Rate:	3 in <sup>3</sup> /hr (49 cc/hr)
Deposition Time:	11 hours



Laser Power:	2620 W
Deposition Rate:	5 in <sup>3</sup> /hr (82 cc/hr)
Deposition Time:	6 hours



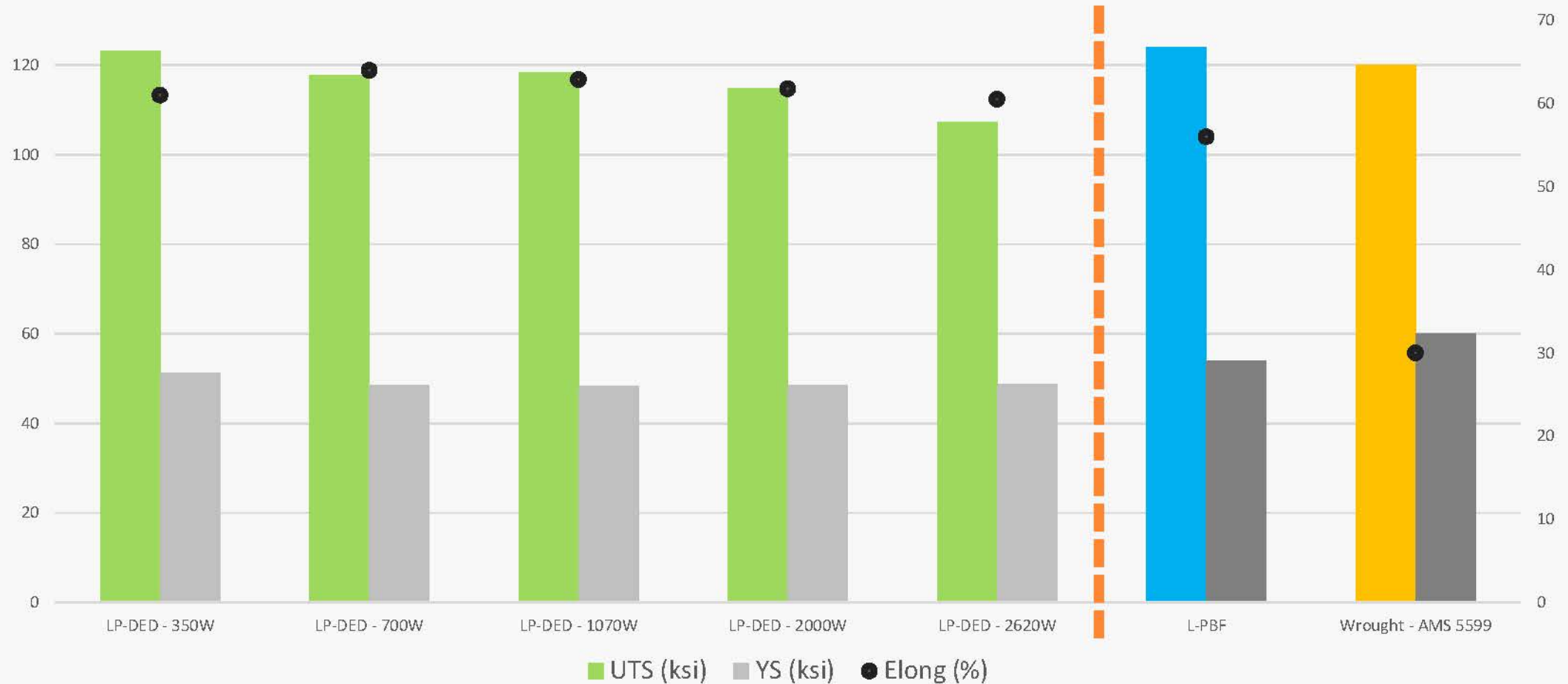
FEATURE RESOLUTION

DEPOSITION SPEED



# IN 625 Mechanical Property Comparisons

IN 625 Properties - LP-DED vs LPBF vs Wrought



LP-DED/LPBF Information Generated by NASA - Rapid Analysis and Manufacturing Propulsion Technology (RAMPT)  
**SR Heat Treatment** 1950 ± 25 °F for 1.5 hrs  
**HIP** 2125 ° F for 3-4 hours at 15ksi per ASTM 3301-18a  
**Solution** 2150 ± 25 °F for 60 minutes, argon gas fan cool at a rate of air cooling or faster to 1200 °F per AMS 7000/AMS27



# Customers and Applications

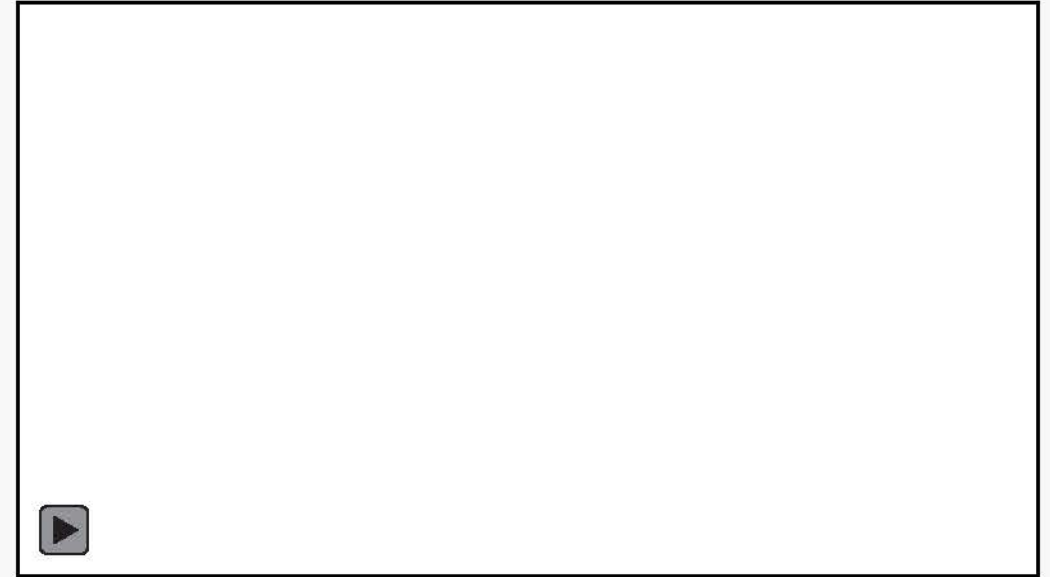
## ■ Customer Sectors:

- 70% Space
  - New Complex/Large Parts
  - Fast turnaround
  - High Value/Low Volume Production
- 25% Aerospace/Defense
  - Replacing conventional techniques
  - Improving lead time/unit costs
  - Material changes/part design improvement
- 5% Other (Industrial/Oil+Gas/Automotive/etc.)
  - Wear improvement
  - Repair
  - Cost/lead time value

## ■ Currently - 8 flight approved applications

- 4 Space (1 performed by RPMI customer)
- 3 Aerospace
- 1 Defense

## ■ Many more nearing approvals

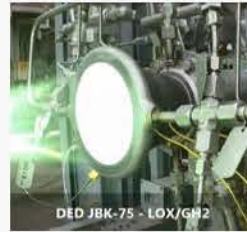
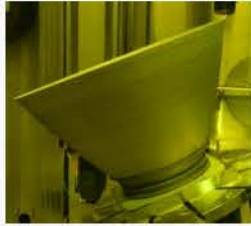


Boeing Eco-Demonstrator Duct

# The Path to Production



America Makes



## Program/ Application Review

- Review Part Applications
- Design for DED
- Product Definition
- Government programs
  - America Makes
  - Public/Private Partnerships

## Prototype

- Print Prototypes
- Coupons
- Initial Testing (including post process steps)

## Inspections/ Testing

- Hot fire
- Flight test
- Load/burst
- C/D Basis Allowables
- Metallography
- Machine Qual
- KPV study
- Dimensional
- CT/X-ray/UT

## First Article

- Create PCD
  - AMS 7010
  - NASA 6030
  - AWS D20.1
- FAI
- Lock Process

## Production Approved

- NADCAP for DED – in progress

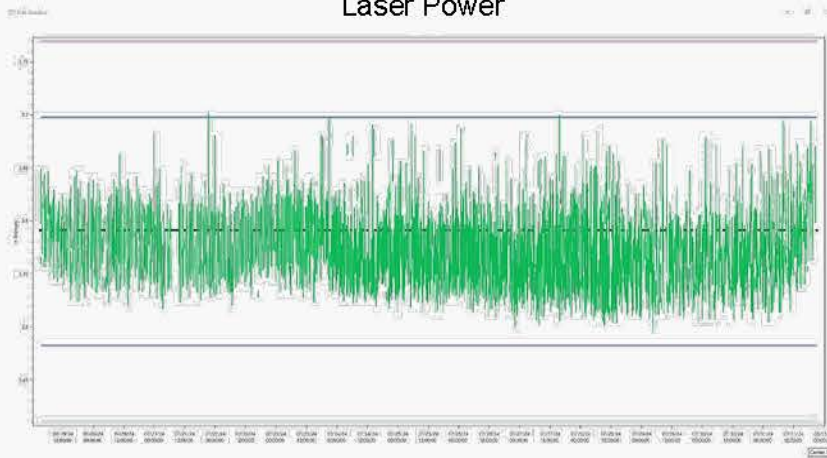
# DED Production

- Begins with a detailed and proven QMS System (AS9100/ISO9001) to meet standards and customer specifications
  - Feedstock Handling Plan
  - Environmental Controls
  - Training/Documentation
  - Data Management
  - Inspections
- Machine OEM role directly supports into production improvements
  - Machine Design - In situ powder removal to internal cavities, automation
  - Software – tool code generation/control access
- Process Monitoring/Control is vital to DED production
  - Longest single part print – 7 months (24/7)
  - Production parts at 30 day print times per part

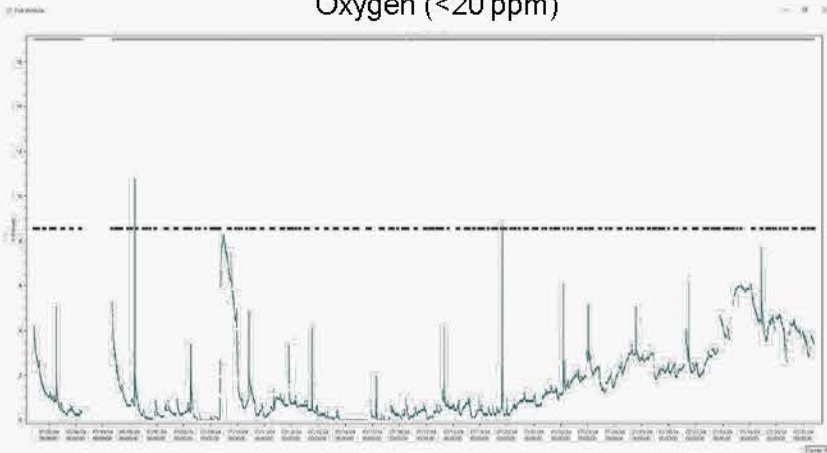


# Process Monitoring and Controls – Key Process Variables

Laser Power



Oxygen (<20 ppm)

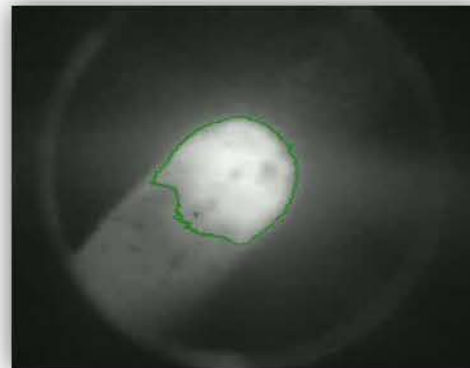


## ■ Process Controls

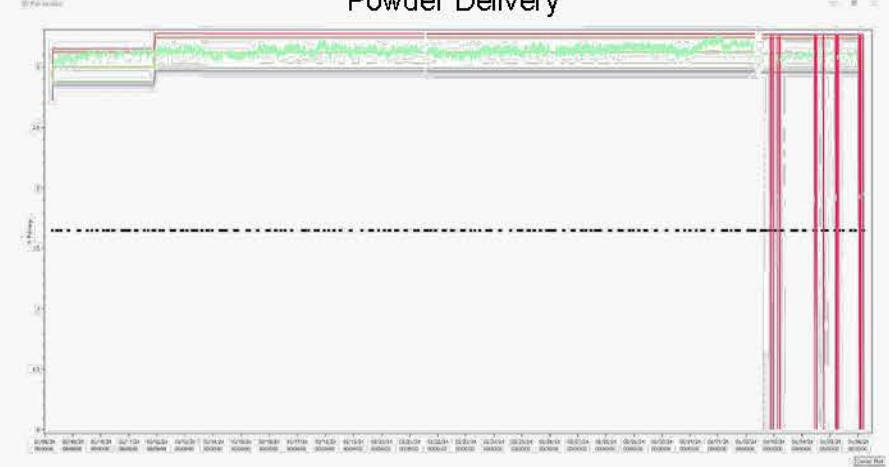
- Warning Limits
- Alarm Limits

## ■ Monitor and Log KPV's

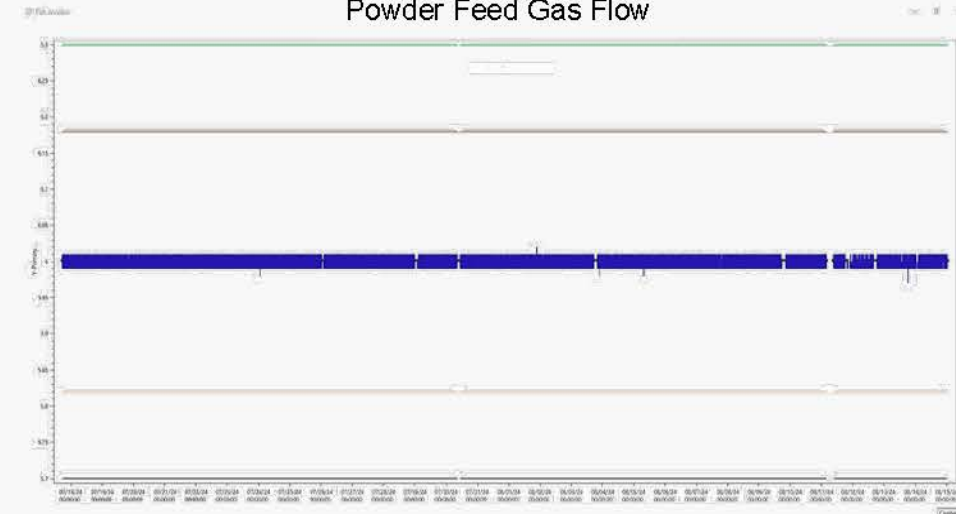
- Laser Power
- Melt Pool Size
- Moisture Content
- Oxygen Content
- Gas Flow Rates
- Process Pressures
- And others...



Powder Delivery



Powder Feed Gas Flow

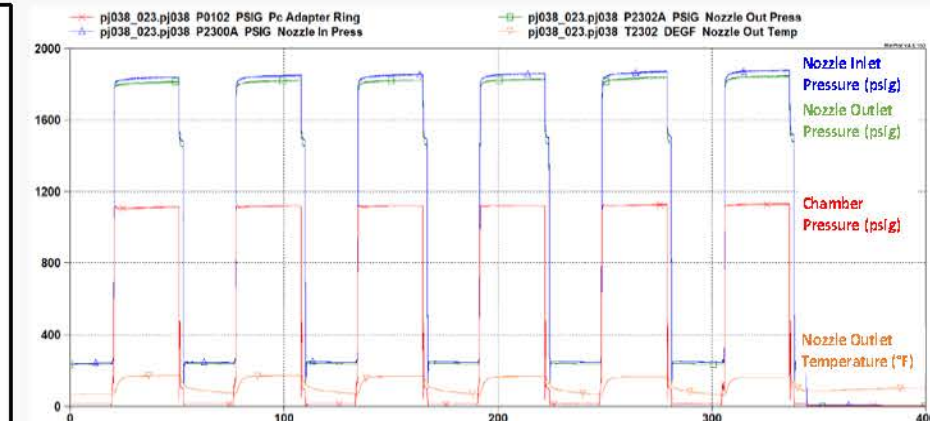
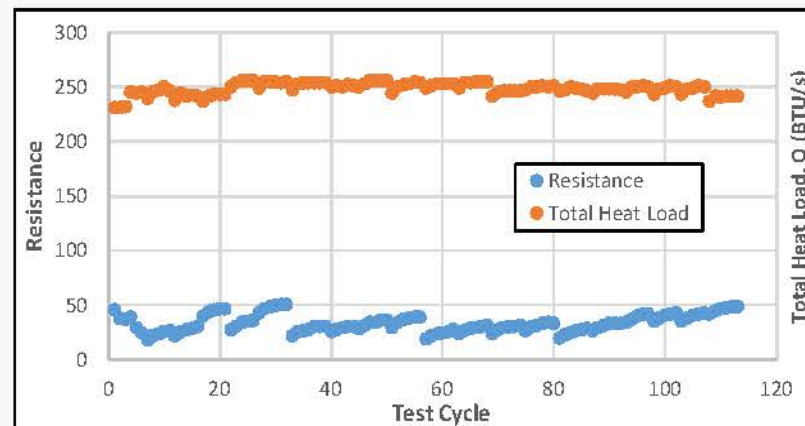


# NASA - Rapid Analysis and Manufacturing Propulsion Technology

2017-2018



- 1.2K Nozzle (1.5 Day build)
- Built in JBK-75 and IN 625
- 6 in diameter – Aft end
- Hot fired 114 times
- Near 1.5 hour of run time on a single nozzle



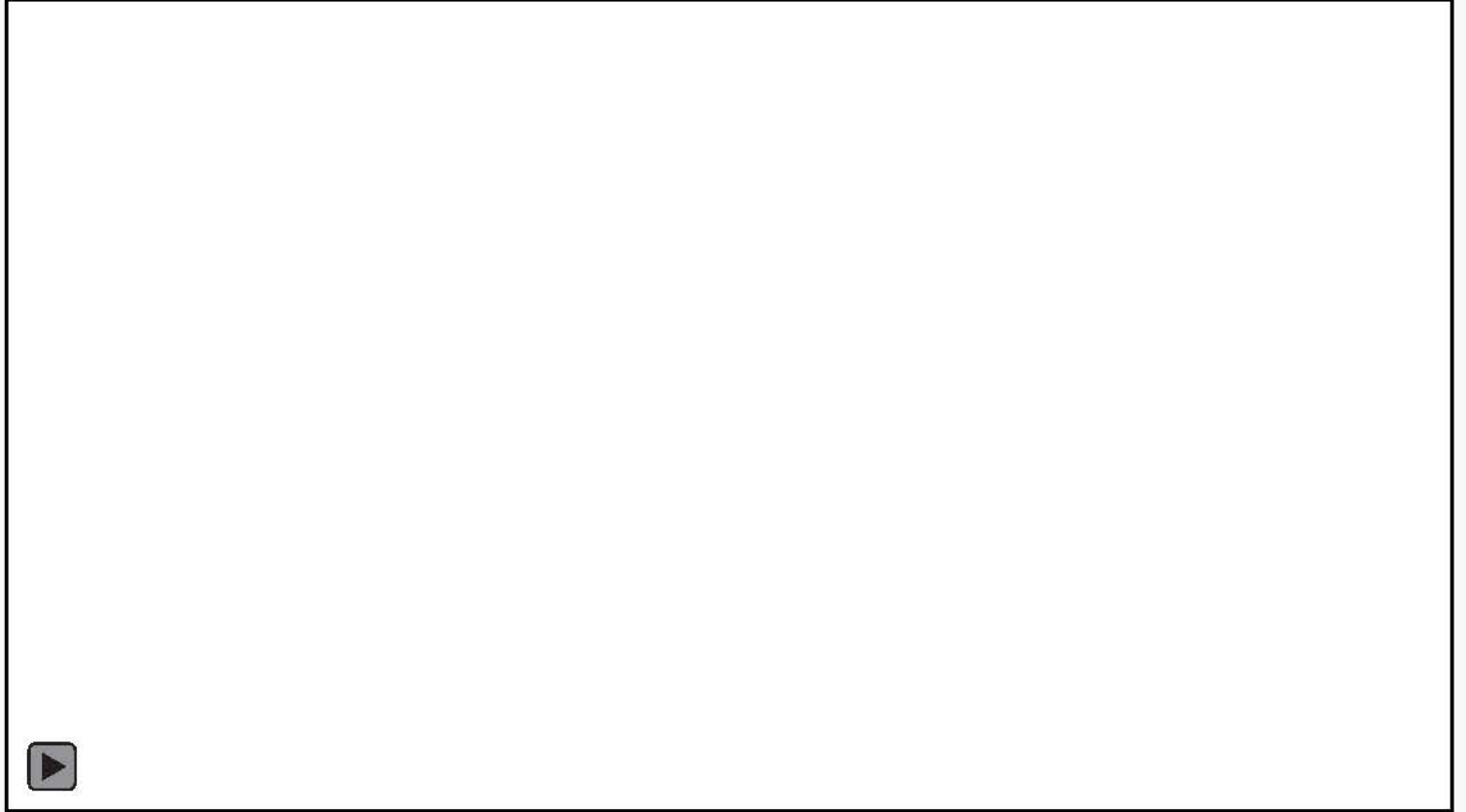


# NASA - Rapid Analysis and Manufacturing Propulsion Technology

## 2019



- 35K Nozzle (14 Day build)
- Built in HR-1
- 24 diameter – Aft end
- Single nozzle tested 207 starts – 6756 seconds
- Program reaching hot fire testing 488 times and over 16,000 seconds



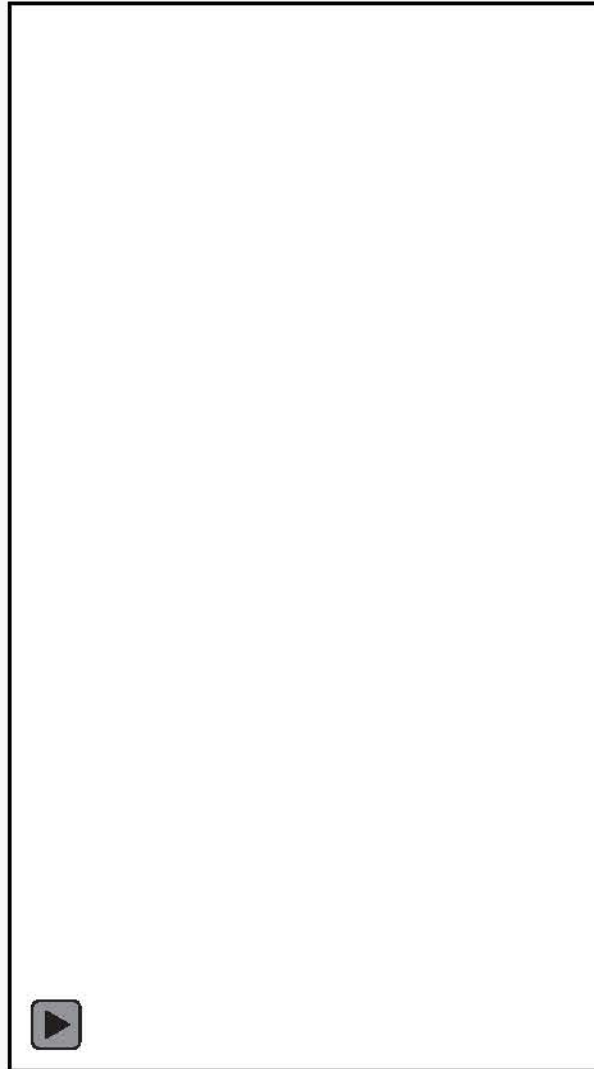


# NASA - Rapid Analysis and Manufacturing Propulsion Technology

2020-2021



- 65% Scale RS-25 Engine (90 Day build)
- Built in HR-1
- Wall thickness of 0.04" (1 mm)
- 72" tall x 60"OD (1.83 m tall x 1.5 m OD)
- >900 channels throughout nozzle profile
- Substantiated Planned Interruptions throughout build
- Over 60% cost and lead time reduction to conventional

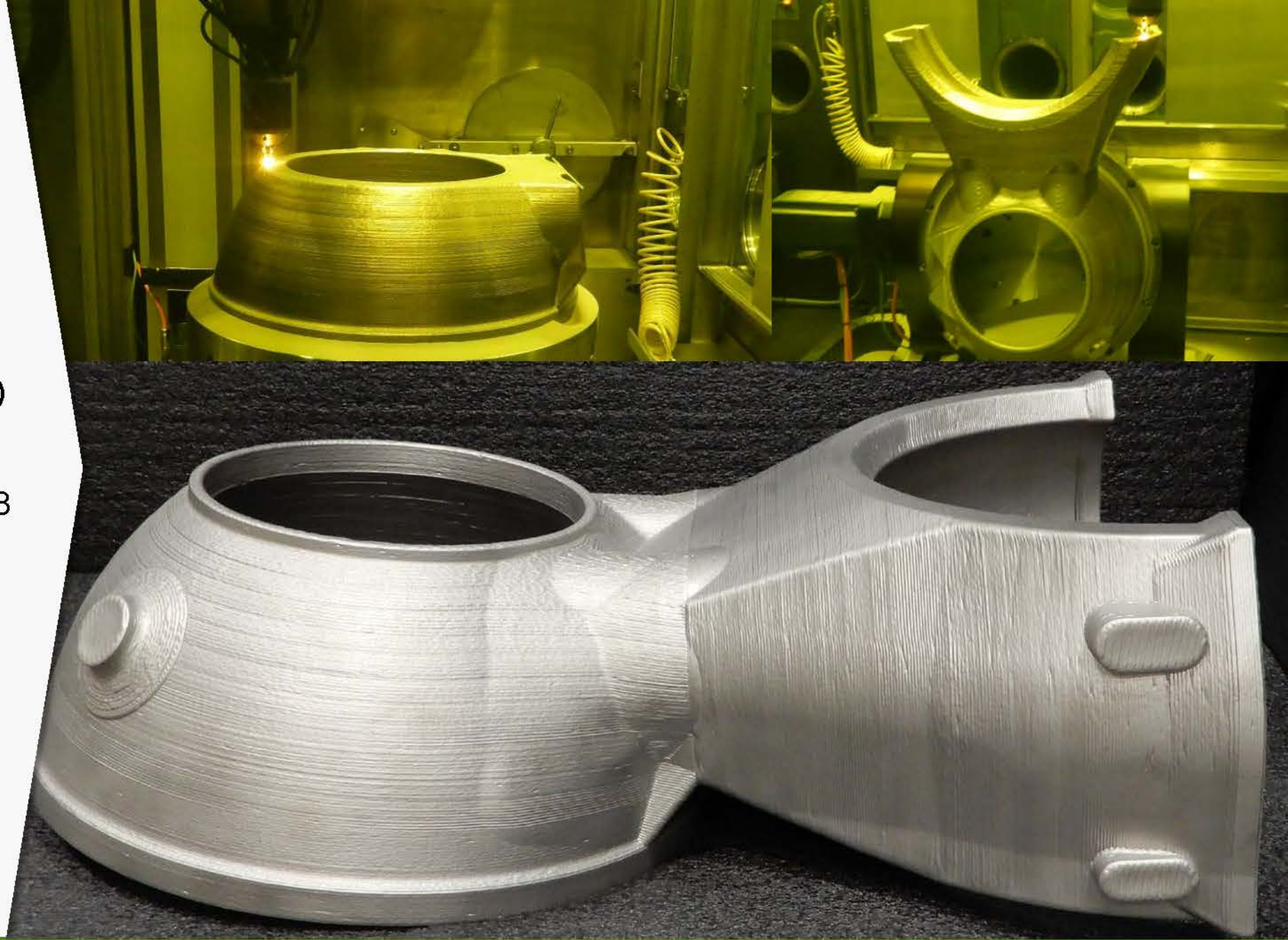




# RS-25 Powerhead

Inconel 718

- 36" l x 25" w x 12" h  
(0.91 m x 0.64 m x 0.30 m)
- Lead times – exceeding 12-18 months
- Build time - **9 days**
- Improved properties over casting





# Part Repair

Ti-6Al-4V

- Machining errors
- Forgings delivered undersized
- Repairs various parts including:
  - IBR
  - Blisk
  - Airfoil
  - Case
  - Ducting





# Support from FAA/EASA

- Customers look to governing bodies/standards for “Path-To” OR “Qualification Procedures”
  - AMS/ASTM/AWS standards primarily point to the means of defining the process
  - MMPDS allowables/process is hefty cost to a new user
- Considerations:
  - Repair vs Freeform
  - Flight Critical vs Non-critical Part
  - **DED ≠ PBF ≠ Conventional**
- Additive manufacturing in flight approved parts is only a piece of the question
  - Post heat treat (solution/HIP/Age-Harden)
  - Post processing (chem mill/machining/etc.)
  - Inspections (UT, CT, etc.)
  - Part Size (DED now introduces other large part applications not previously considered)

# Opportunities for FAA/EASA

- Generate DED Design Data - AMERICA MAKES – Generation of Additive Material Allowables for Ti-64 (GAMAT)
  - Statistically based bulk material properties for print/post processing of material
  - Generation of public Process Control Document (for future applications to establish from)
- Public Data
  - Generate applicable end case applications for public information
  - Data to lay groundwork for common application needs (ducting, frame, engine, etc.)

# THANK YOU!



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