Additive Manufactured Titanium for Critical Flight Components

2024 National Conference for Additive Manufacturing

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4:20PM-4:35PM

AM Implementation and Process Background

Northrop Grumman
Additive Manufacturing Journey

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Polymer Rapid Prototyping → Polymer Flyaway Capability


1st SLA Machine at NG

1990


1st FDM Machine at NG

1997


1st SLS Machine at NG

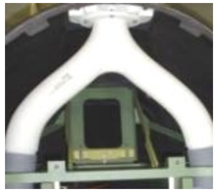
1999


AM Drill Jig Wins Award

2000


1st Place 2001 RP&M World Conference

2001


SLS Nylon 12 Capability

2005 ★


1st Fortus Machine at NG

2012

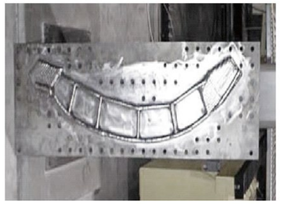

Recyclable LS PEKK Capability

2015 ★


FDM Ultem 9085 Capability

2019 ★

Metals Fly Away Capability


1st Flight Worthy Validation

1999


X-47B Ti-6Al-4V Hot Air Mixer

2007


1st Flight of an AM PBF Titanium Component on a DoD Platform

February 4, 2011 ★


1st ARCAM Machine at NG

2014


1st DMLS Machine at NG

2015


E-Beam Ti. Space Qualification

2017 ★


E-Beam Ti. Air Qualification

2020 ★

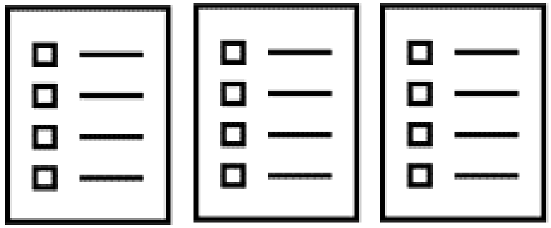

PA-DED Titanium Qualification

2023 ★

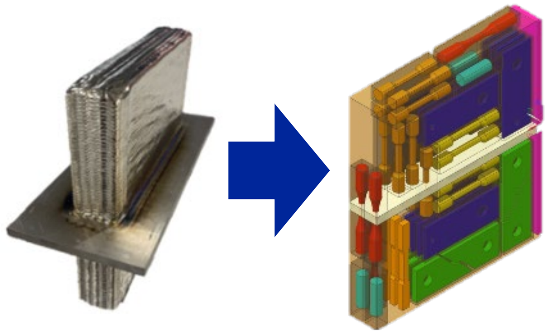
Technology Insertion Milestones ★

AM Implementation Strategy

M&P Specifications

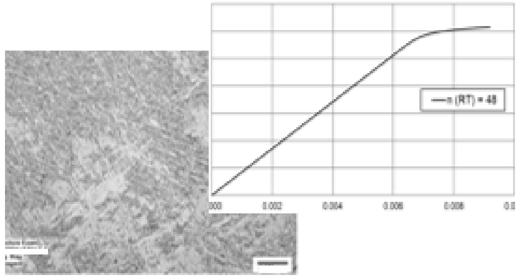


Process Control



Material Property Dataset

Component Level Evaluation



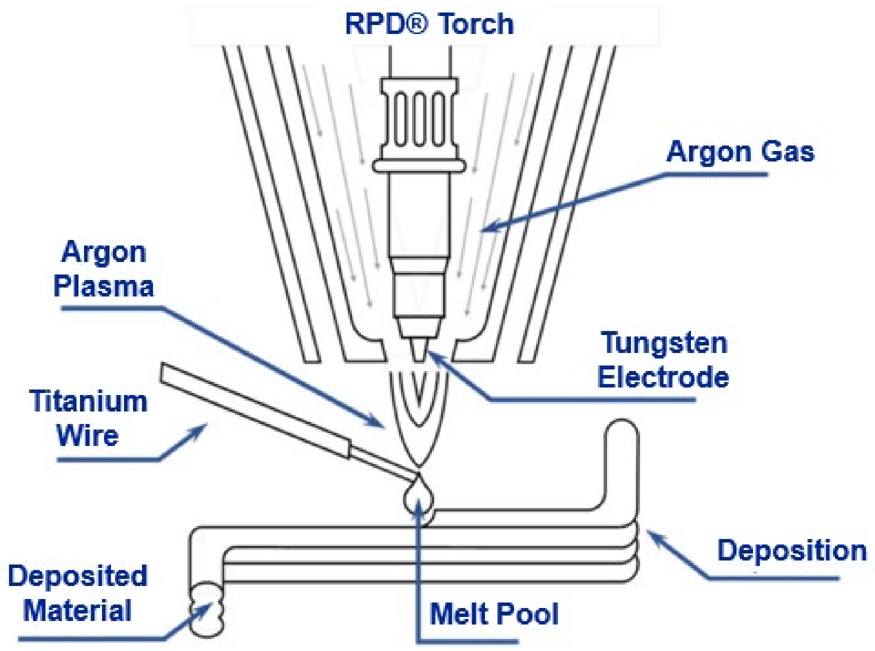
Feasibility Testing

Control and define a quality, repeatable process

Implementation

Plasma Arc Directed Energy Deposition (PA-DED)

- PA-DED (AMS7004™) was developed by Norsk Titanium as their Rapid Plasma Deposition® (RPD®) process
- This is a directed energy deposition process that creates a near-net shape preform that can be quickly machined down to its final dimensions
- Enables the fabrication of large aerospace-quality titanium parts more responsively than many other manufacturing processes
- Northrop Grumman has been working with Norsk since 2019 to qualify this process for defense aerospace applications



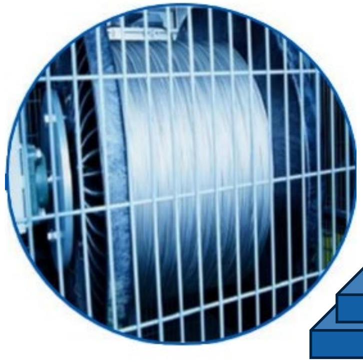
PA-DED/RPD® Process Schematic

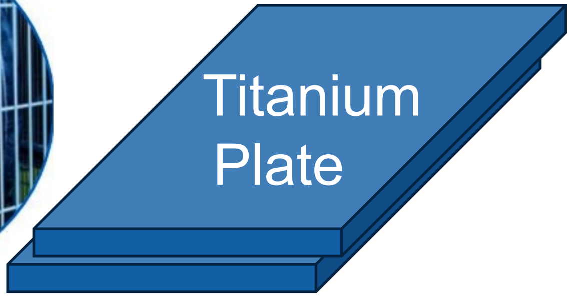
NG Qualified Supplier	Norsk Titanium
Production Location	Plattsburgh, New York
Current Machine Build Volumes	G4B: ~3’ X 2’ X 1’ G4L: ~6’ X 1.5’ X 2’
Deposition Rate	~10-20 pounds/hour
Feedstock Material	Ti-6Al-4V Wire

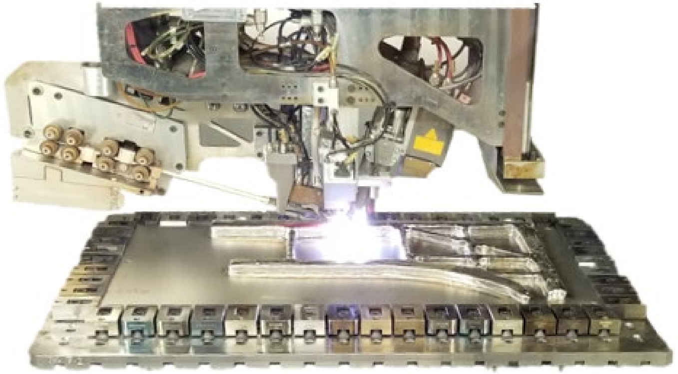
PA-DED/RPD® Process Details

PA-DED Process Overview

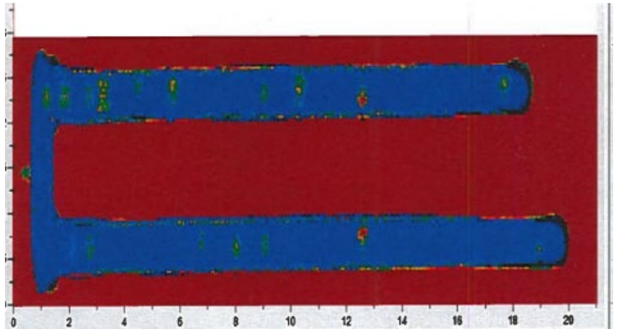
Wire/Substrate → PA-DED Deposition → Thermal Treatment

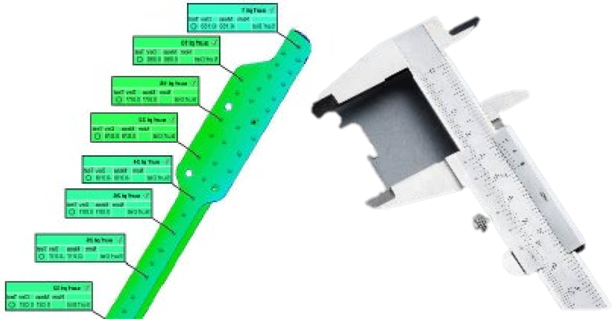






Non-Destructive Inspection → Finish Machining → Dimensional and Final Inspection





Ti-6Al-4V PA-DED Process Overview

Specification Controlled

Material Requirements

- **Wire/Substrate**
  - Ti-6Al-4V wire certified to requirements of Northrop Grumman internal material specification and substrate certified to AMS4911

Process Requirements

- **PA-DED**
  - Plasma Arc Directed Energy Deposition using qualified process and build schedule on certified machine per Northrop Grumman process specification
- **Post-process**
  - Post DED thermal treatment of PA-DED preforms per AMS 7004
- **NDE & Testing**
  - Rough machine of inspection surfaces and ultrasonic inspection of PA-DED preforms per AMS 2631
  - Quality and material conformance inspection and testing

Drawing and Design Requirements

- **Final Machine**
  - Final machine all surfaces of the preform to drawing
- **Final Inspection**
  - Dye Penetrant inspection and dimensional inspection

Northrop Grumman Development Timeline

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2019-2020

- ✓ Northrop Grumman DED industry evaluation
- ✓ Completed initial feasibility testing of Norsk Titanium

2021-2022

- ✓ Material and process specification release
- ✓ Static and dynamic dataset development
- ✓ Completed component level testing

2023

- ✓ Approval for implementation on first critical subsystem and initial structural applications

2024+

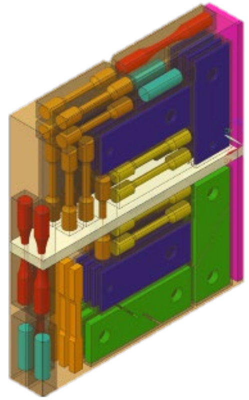
- ❑ Qualification of larger PA-DED machine(s)
- ❑ Broad structural implementation across multiple Northrop Grumman aircraft

Allowables Development

- **Testing Overview**
  - Full allowables for multiple preform geometries
  - Coupons have been tested from the X and Z direction in addition to the plate/DED interface region
  - Over 1000 static and 100 dynamic coupons tested to date
- **Completed Allowables Testing**
  - Static: Tension (RT/ET), compression, shear and bearing
  - Dynamic: Stress life fatigue and crack growth
- **In-Progress/Planned Testing**
  - Fracture toughness and additional dynamic testing
  - Delta qualification testing of larger PA-DED machine(s)

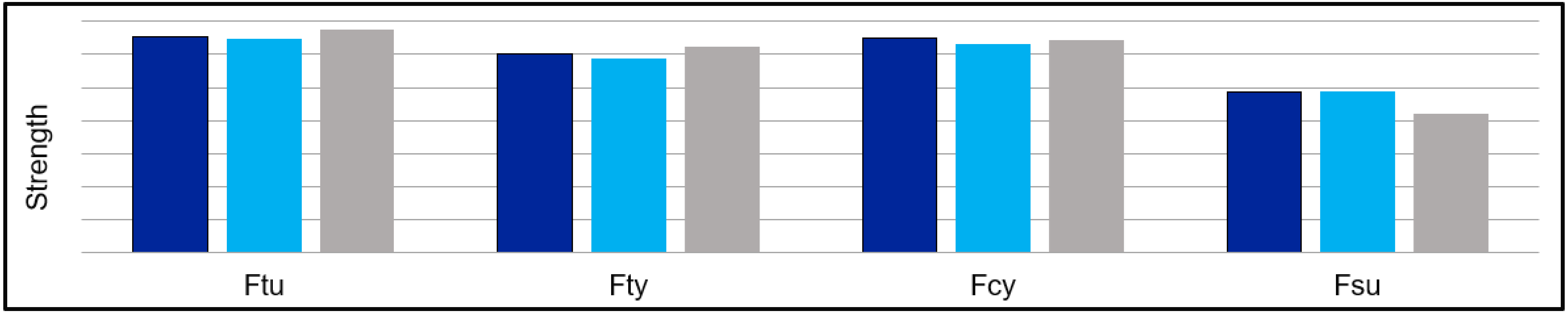
As-Deposited Preform

Machined and Inspected Preform

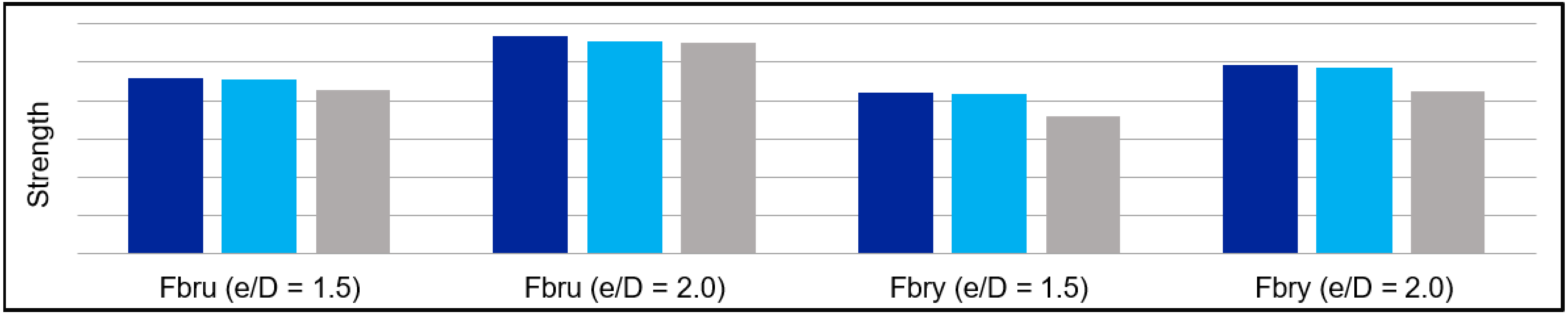


Test Coupon Layout

PA-DED Allowables Comparison

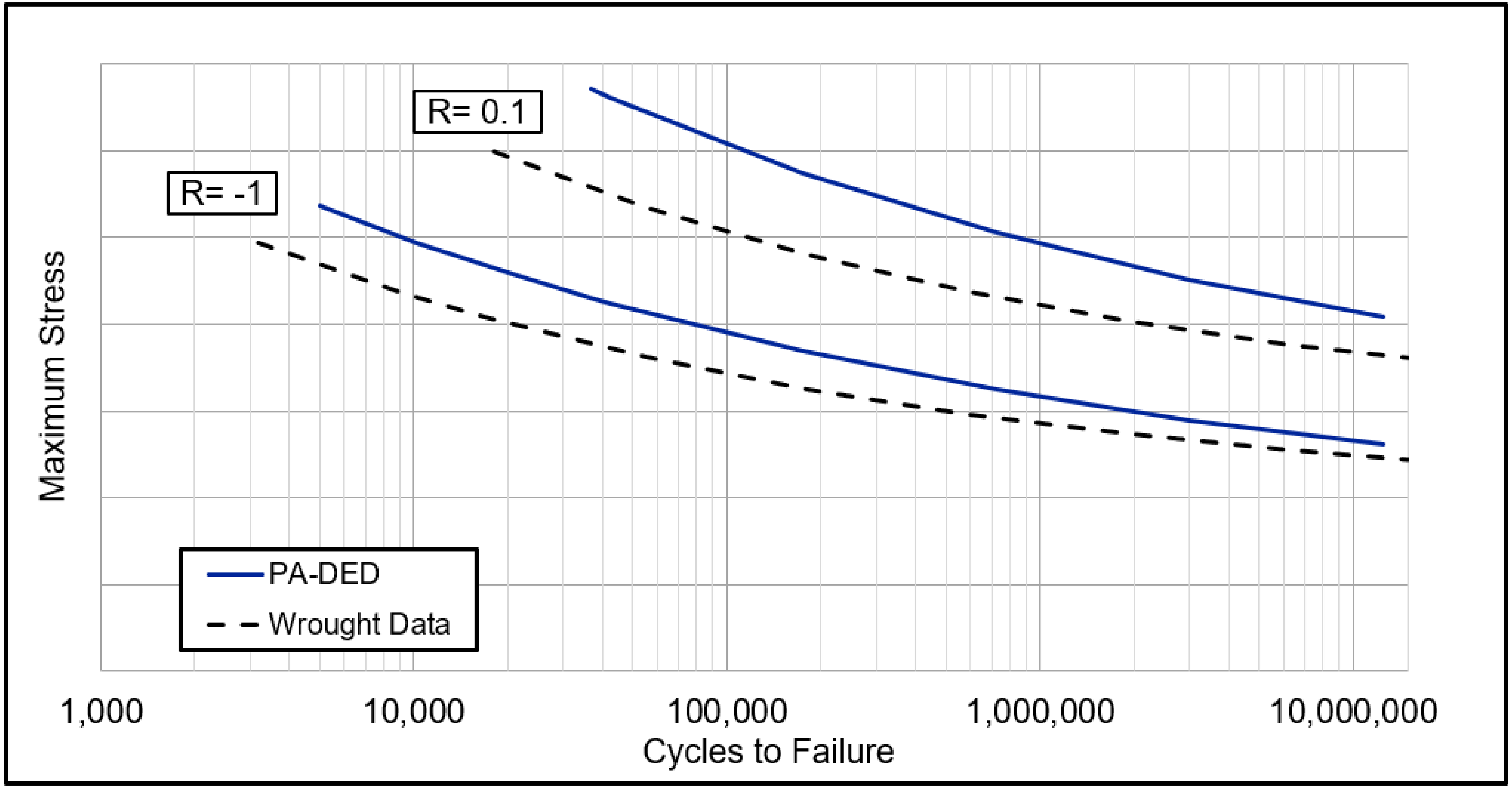


PA-DED (X) PA-DED (Z) Ti-6Al-4V Plate (L)



PA-DED static allowables are comparable to plate

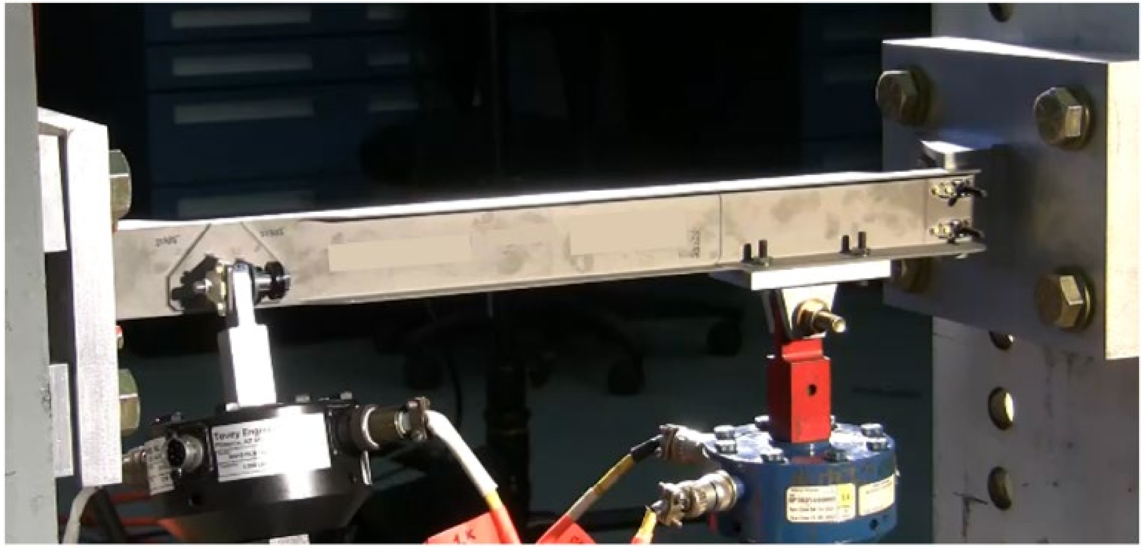
PA-DED Fatigue Performance



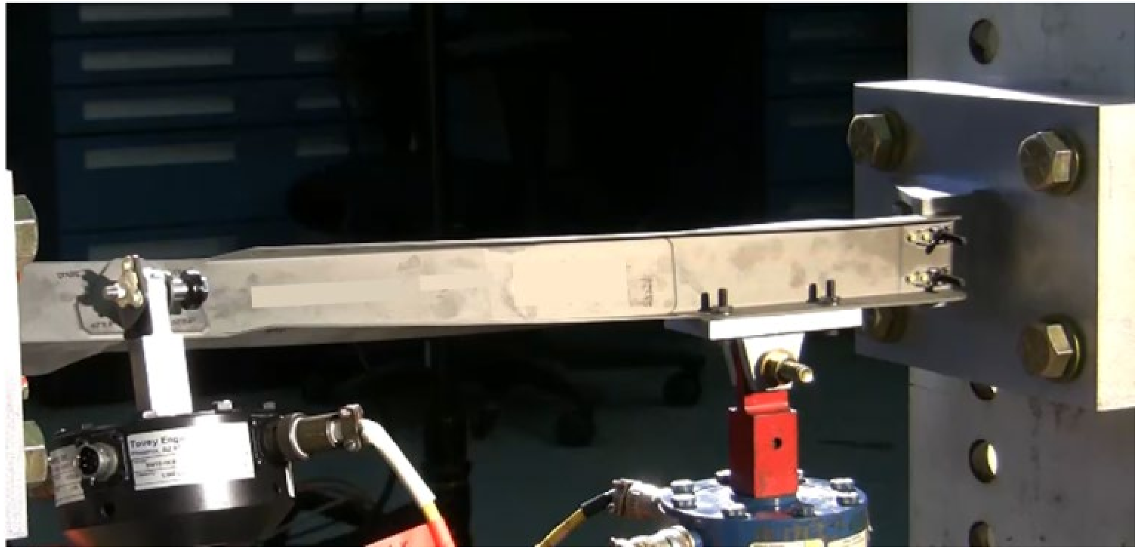
PA-DED fatigue properties are similar to or better than wrought material

PA-DED Subsystem Test Overview

- PA-DED subsystem brackets were tested in both static and dynamic conditions (multiple lifetimes) representative of service conditions
- No cracking or plastic deformation was found in any component after completion of the testing



Unloaded Component in Test Frame

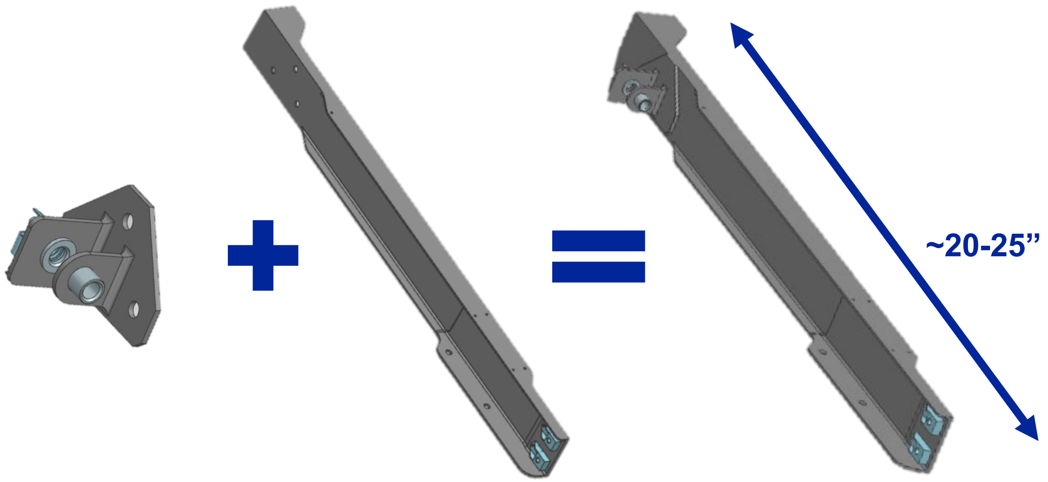


Component Loaded to Max Stress in Frame

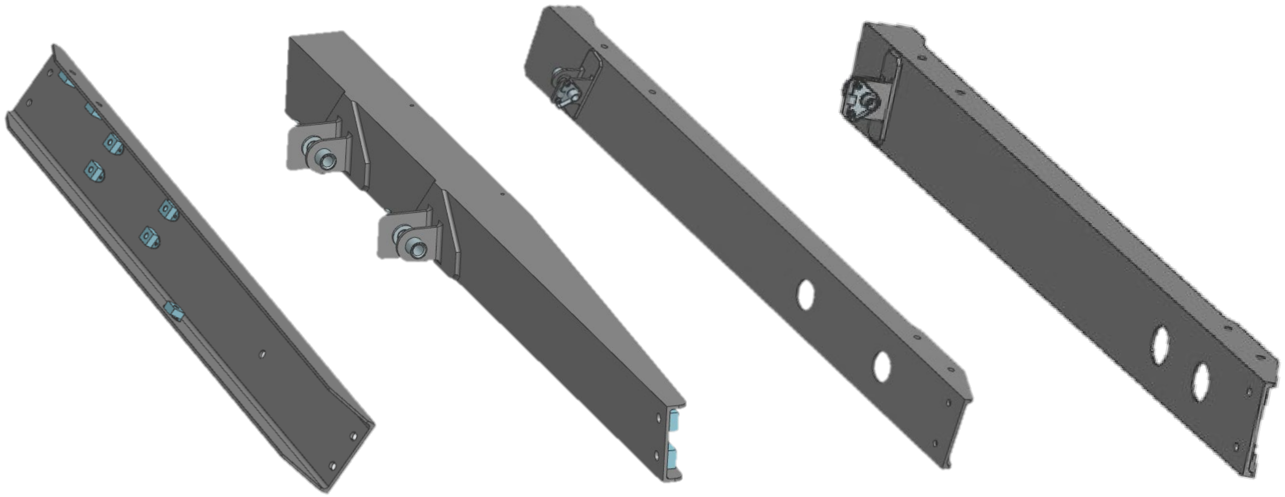
PA-DED Implementation at Northrop Grumman

Implementation on Critical Subsystem Parts

- Approved to replace mission critical aircraft components using PA-DED AM processes
- Implementation will result in an estimated 20-35% cost savings
  - Labor savings were also realized through part unification on multiple components
- This initial implementation will be used as a stepping-stone to enable use of PA-DED AM onto a larger number of subsystem and structural components in the future



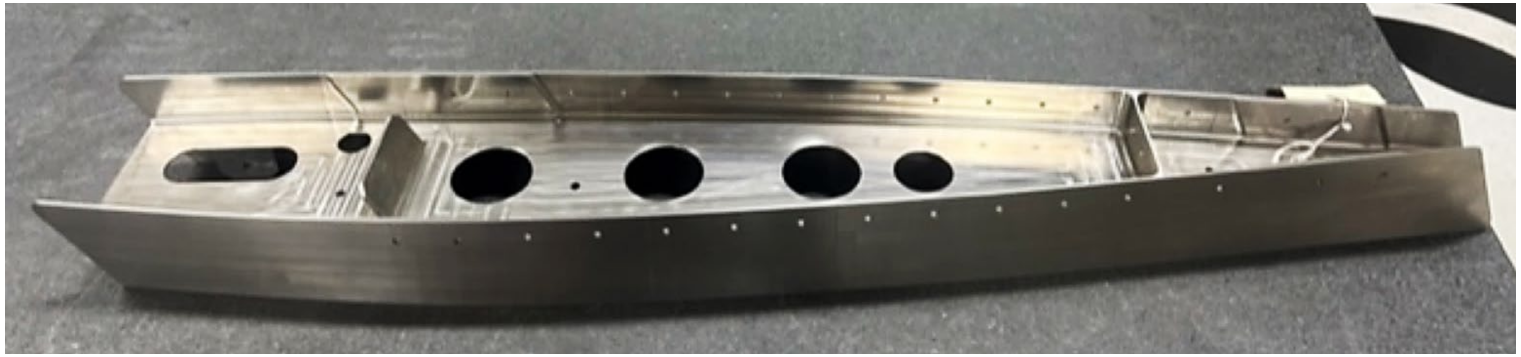
Unification of Two Brackets for PA-DED Design



Approved Mission Critical PA-DED Flight Components

Structural Implementation at Northrop Grumman

- PA-DED structural wing tip rib to be integrated as structural component manufactured using the PA-DED process to fly on a Northrop Grumman air vehicle



Top and Bottom of Machined PA-DED Component

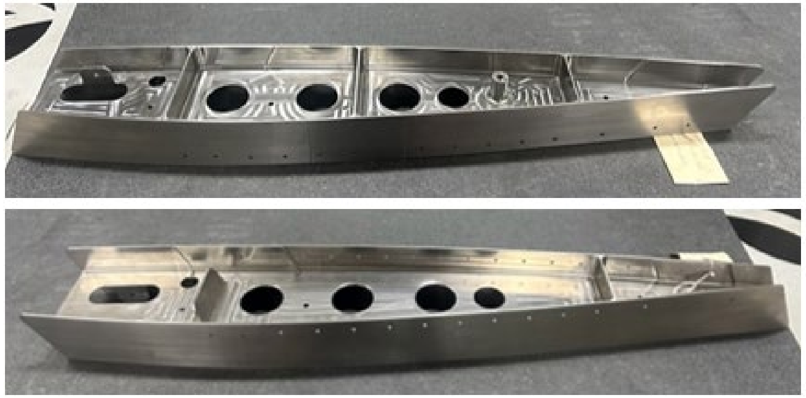
Roadmap to Broad PA-DED Implementation

- **2023:** Initial implementation of PA-DED at Northrop Grumman
- **2024:** Continue implementing components and work towards expanding size and criticality
- **2025/2026+:** Enable responsive and disruptive manufacturing of critical titanium aircraft structure with broad implementation on Northrop Grumman aircraft

2023

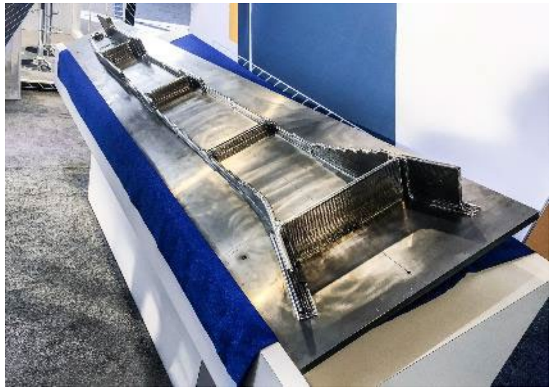
Subsystem up to 3’

Current



Structure up to 6’

2025/2026+



Critical Structure over 10’

Magnitude of savings increase with part size and complexity

Conclusion

- Northrop Grumman continues its tradition of leading AM adoption by using PA-DED Titanium in critical subsystem and structural applications
- As AM technologies mature, the lessons learned from these implementations will be incorporated into the evolving Northrop Grumman qualification process and leveraged to expand future adoption

1st Flight of an AM PBF Titanium Component on a DoD Platform

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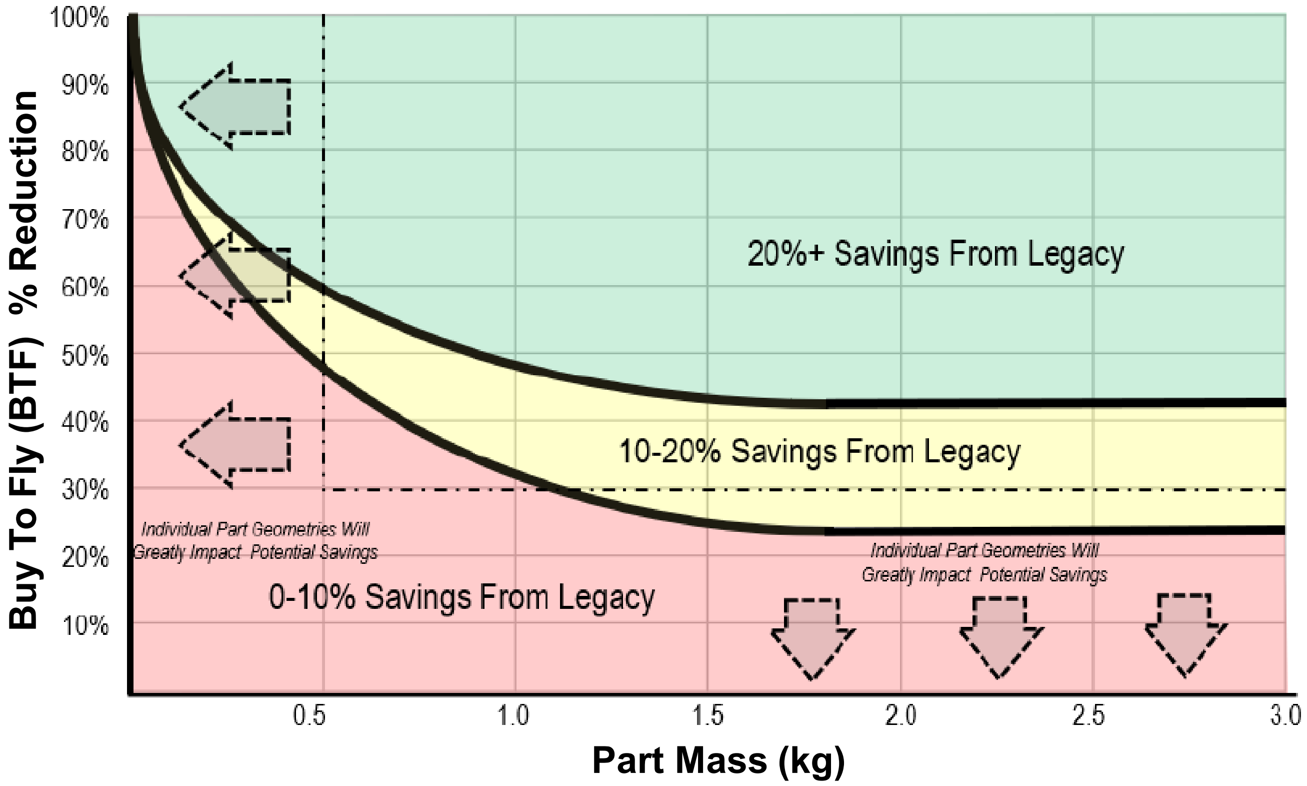
Candidate Parts for Implementation

- Targeted titanium components are often parts that are machined thick plate or forging with long flat sections
- Parts with positive cost trades are normally over 2” thick with parts 4” thick often trading exceptionally well
- Part unification/BOM reduction can also increase part trade by reducing assembly count and touch time
- Lead time and cost savings greater than 30% have been seen for candidate components



Estimated Savings Correlation Between Mass and BTF Reduction