HOW ADDITIVE MANUFACTURING IS SUPPORTING PRODUCTION OF TITANIUM ALLOY HELICOPTER PARTS – FROM MATERIAL CHARACTERIZATION TO FINAL APPLICATION

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- **This presentation is about**
  - How Bell characterized the properties of the Titanium Alloy Ti6Al4V at the coupon level
    - Properties required to characterize this material
    - Methodology utilized
    - Results
  - How Bell integrated an additively manufactured secondary structure metallic part
    - Design requirements and constraints
    - Parts production : advantages and challenges of the Additive Manufacturing process
    - Final result

INTRODUCTION

- **Why Additive Manufacturing Processes of Metals are Popular in Aerospace Industry?**
  - Weight Reduction – Topology Optimization
  - Reduce Total Cost of Assemblies by Parts Integration
  - Elimination of Tooling
  - Can Reduce Leadtime Compared to Other Legacy Processes
  - Reduce Parts Inventory and Optimize Batch Sizes

But,

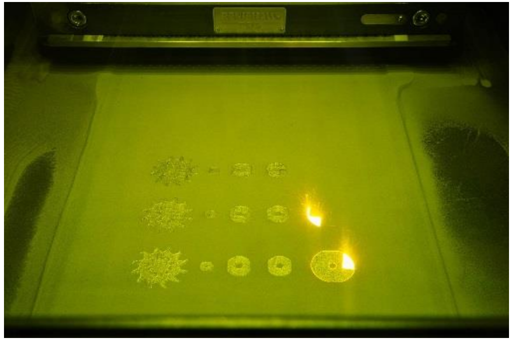
- We must make sure parts produced using these new technologies are meeting design intent for physical and mechanical properties

Description of the 3 different processes utilized

Powder Bed Fusion by Laser

Selectively melts powder using a laser or electron beam.

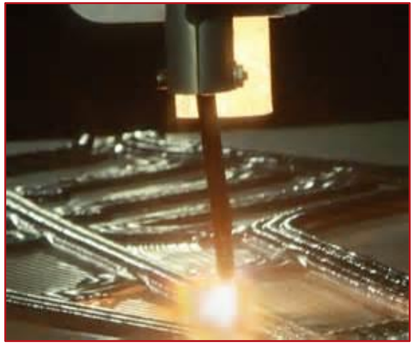
« Growing » the part layer by layer.



Source : www.renishaw.com

Direct Energy Deposition of Wire (Electron Beam)

Moving head deposits molten wire to build linear layers



Sources : www.designnews.com
www.sciaky.com

Direct Energy Deposition of Powder (Laser)

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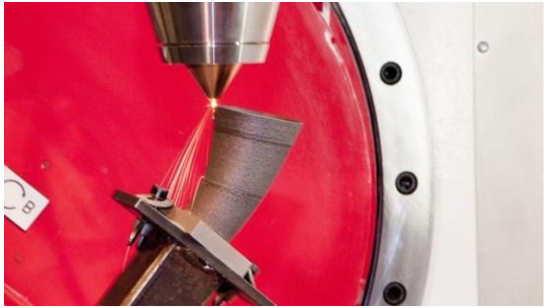


Sources : www.additivemanufacturing.media
www.beam-machines.fr

Description of the 3 different processes utilized (Continued)

Powder Bed Fusion by Laser

Advantages:

- Near net shape
- Good for complex geometry with internal cavities

Disadvantages:

- Limited size
- Small batches
- Relatively slow process

Direct Energy Deposition of Wire (Electron Beam)

Advantages:

- High deposition rate
- Economical
- Large size components

Disadvantages:

- Post-process machining required
- Cannot create internal cavities

Direct Energy Deposition of Powder (Laser)

Advantages:

- High deposition rate
- Large size components
- Limited Post-Process machining
- Can be used for repairs

Disadvantages:

- Limited sources of raw material
- Cannot create internal cavities
- As-Built poor surface finish

- **Properties to be tested**

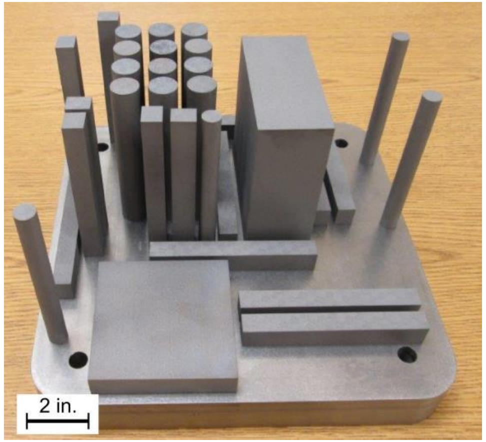
Property	Standard Test Method
Tensile	ASTM E8 / ASTM E21
Microstructure / Density	ASTM B962
Fatigue Crack Growth	ASTM E647
Fracture Toughness	ASTM E399
Axial Fatigue	ASTM E466

- **Suppliers and Processes**

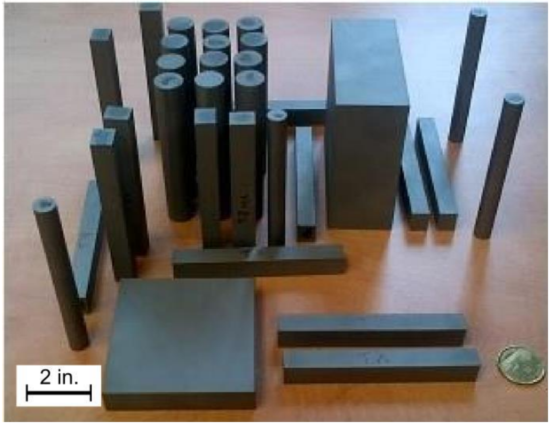
Supplier	Manufacturing Process
Supplier #1	PBFL – Equipment #1
Supplier #2	PBFL – Equipment #2
Supplier #3	PBFL – Equipment #3
Supplier #4	DEDW (Wire)
Supplier #5	DEDP (Powder)

BLOCKS PRODUCED BY POWDER BED FUSION LASER – 3 SUPPLIERS

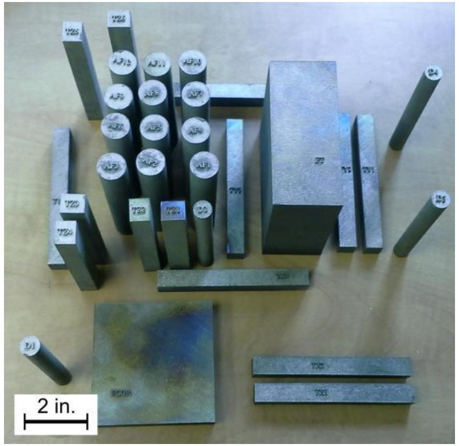
Supplier #1



Supplier #2



Supplier #3



- Tensile and Density Blocks dispersed to investigate influence of location on build platform
- Tensile Blocks also produced vertically and horizontally to investigate influence of building direction
- Axial Fatigue blocks built in vertical direction only
- Fracture Toughness block and one Fatigue Crack Growth Rate block
- Overall surface : 9 in X 9 in (228mm x 228 mm), Volume of powder: 56 in^3 (426 cm^3)
- Weight : 9.8 lbs (4.44 kg)

BLOCKS PRODUCED BY DIRECT ENERGY DEPOSITION (WIRE AND POWDER) - TWO SUPPLIERS

Direct Energy Deposition by Wire (Electron Beam)

Block highly oversized due to lower shape fidelity for small-sized shapes

Direct Energy Deposition by Powder (Laser)

- No need to investigate the effect of location of the blocks on the platform, no fracture toughness coupons built
- Need to investigate the deposition path, tensile blocks in each of the three axes
- Weight 14.9 lbs (6.76 kg) – additional machining required for coupons extraction
- Volume of each build is approx 93.1 in^3 (1525 cm^3)

POST-PROCESSING OF THE BLOCKS

	Powder Bed Fusion Laser	Direct Energy Deposition (Wire)	Direct Energy Depositiion (Powder)
Stress Relieving 1100f (573C) / 2 hours	✓	✓	✓
	❖ Each of the three processes create a thermal cycle different on the first layers than on the last layers. ❖ Last layers are cooling faster than initial ones, creating a variable thermal history and generating thermal residual stresses		
Wire Electrical Discharge Machining (Blocks off the platform)	✓	✓	✓
Hot Isostatic Pressing (HIP) 1650F (900C) / 2 hours / 14750 psi (101.7 Mpa)	✓ to eliminate residual porosities due to powder morphology, distribution and flowability	✓ Wire deposition is considered to create full dense parts but HIP to see if there is a density variation	✓ Powder deposition is considered to create full dense parts but HIP to see if there is a density variation

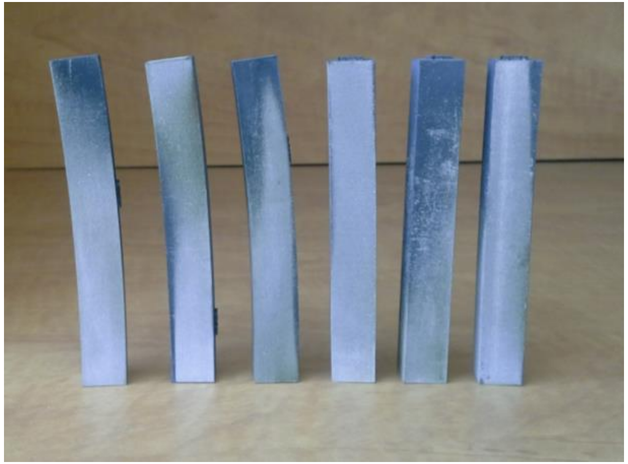
RESULTS AND DISCUSSION - DENSITY

Density – tested using the Archimede principle

	Suppliers				
	#1	#2	#3	#4	#5
Relative Density As built	99.2%	99.8%	92.3%	99.8%	99.8%
Relative Density after HIP	99.4%	99.8%	99.6%	99.8%	99.8%
Volume reduction after HIP	-0.2%	0.0%	-7.3%	-0.0%	-0.0%

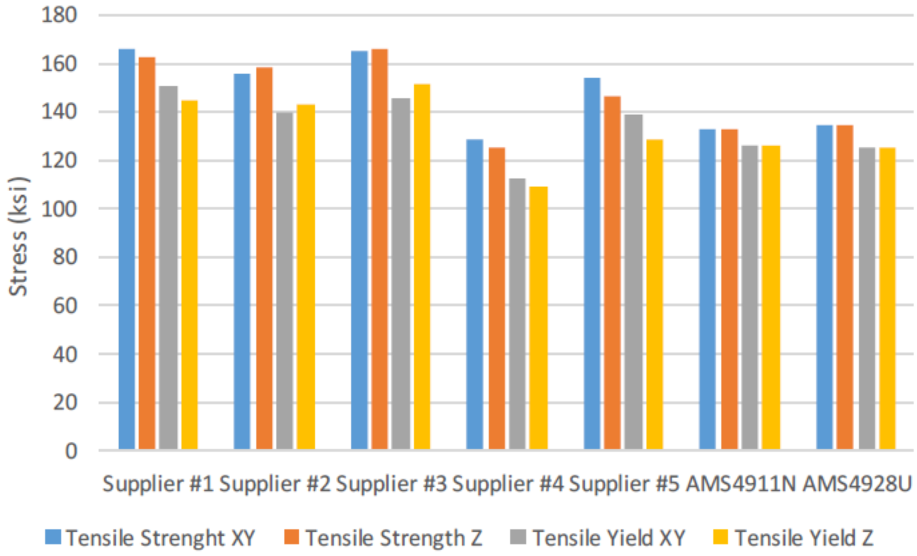
- ❖ As Built >99%, No Impact for HIP on density
- ❖ Supplier #3, HIP produced high volume reduction, creating distorted blocks

Distorted tensile Coupons after HIP



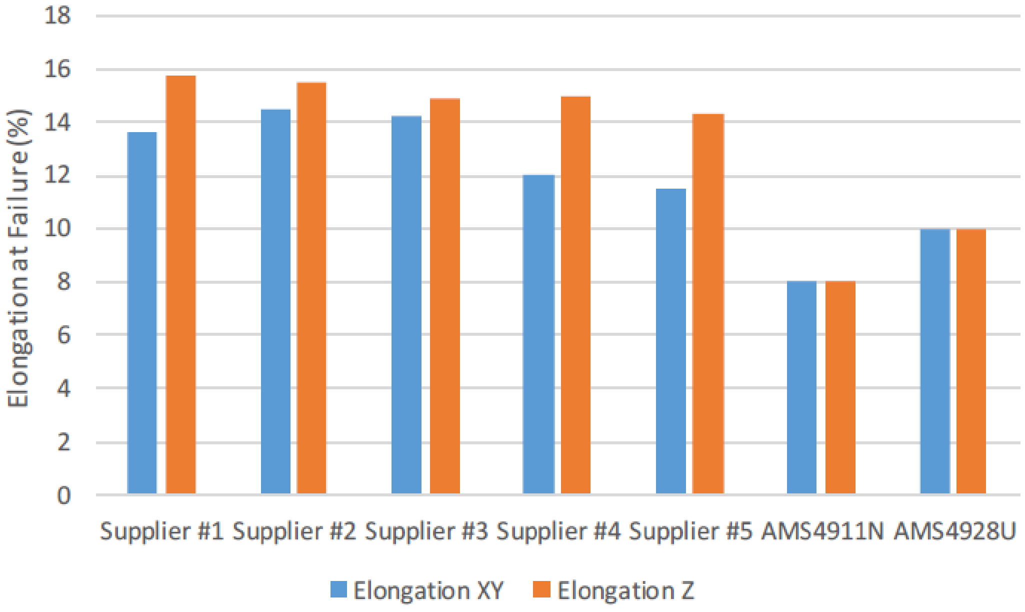
Static Tensile Tests – Tensile Strength and Yield Strength

- For each supplier, Tensile Strengths are very similar in the XY and the Z Direction
- Also, for each supplier, Yield Strengths are very similar in the XY and the Z Direction
- All suppliers had results higher than the minimum of both wrought products AMS Specifications, except Supplier #4 (DEPW)
- These results are not statistically significant and shall not be used for design purposes (Not A or B-basis)



Static Tensile Tests – Elongation

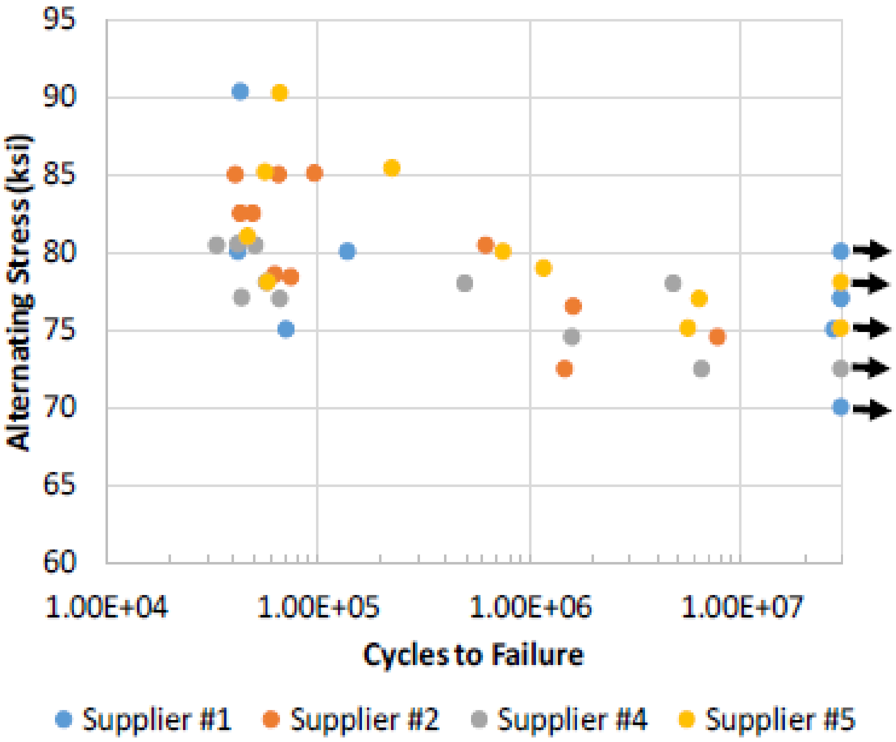
- ❖ Elongation is higher in the Z-Direction for all builds
- ❖ These results are not statistically significant and shall not be used for design purposes (Not A or B-basis)



Fatigue Tests

- Tests performed in Tension-Compression mode
- Supplier #3 test blocks were distorted, therefore no test coupons could be manufactured and tested
- Fatigue strength at 30M cycles is similar for each supplier and around 75ksi (comparable to wrought products)
- Supplier #4 (DEDW) had lower mean lives in the low cycle regime
- Scatter in results is high
- Most cracks initiated at sub-surface defects (per literature : porosities and unmelted particles)

- **These results are not statistically significant and shall not be used for design purposes (Not A or B-basis)**



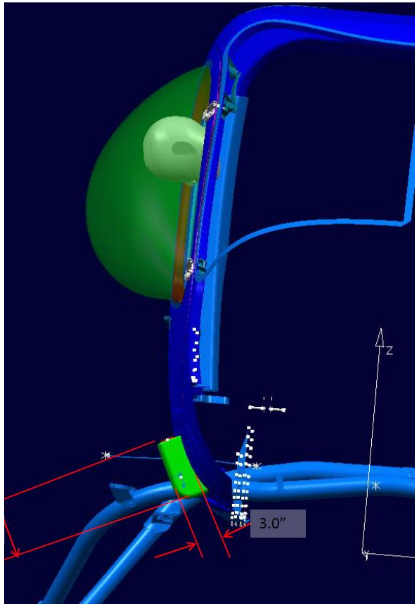
CONCLUSIONS OF THE MATERIAL CHARACTERIZATION

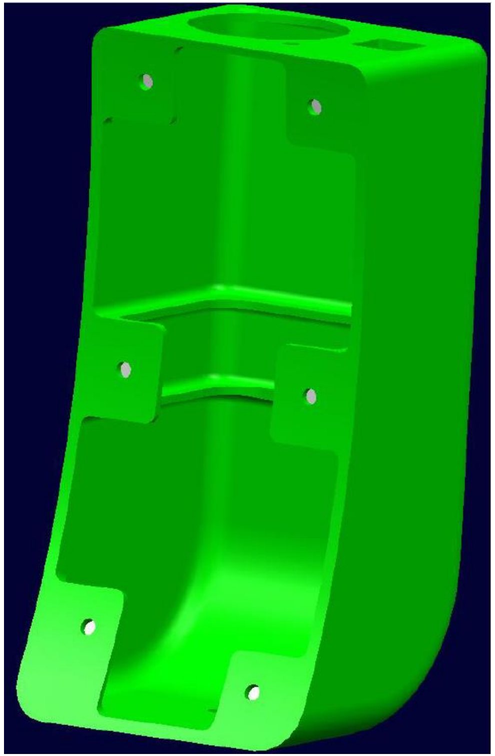
- Three Additive Manufacturing processes compared
- All builds manufactured to address all impact of coupon orientation and location on the platform
- All blocks stress relieved and Hot Isostatic Pressed to make it as much as possible comparable to wrought products
- Microstructures are predictable and comparable to other product forms when post-processes are performed.
- Powder Bed Fusion Laser coupons produced in this preliminary study indicated slightly better mechanical properties than Direct Energy Deposition
- This development test showed that 4 out of 5 Suppliers had mechanical properties above wrought product minimum requirements

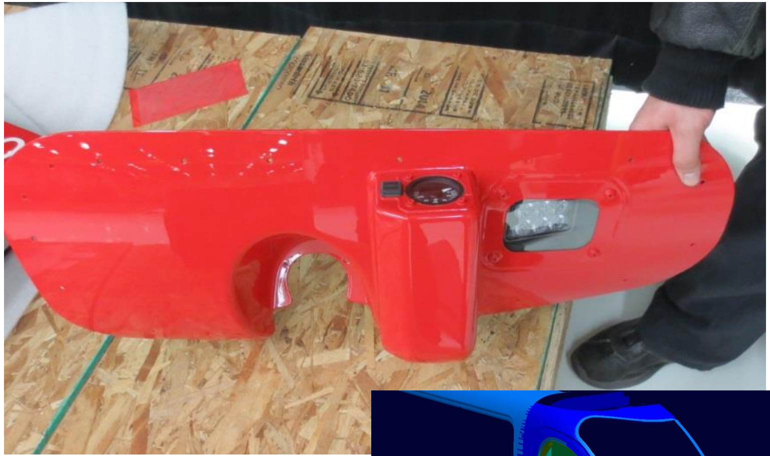
CONCLUSIONS OF THE MATERIAL CHARACTERIZATION

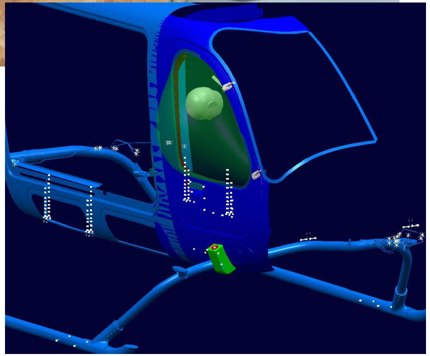
- **Equipment of Supplier #3 showed parts produced with unacceptable porosity content**
- **Direct Energy Deposition development test showed good mechanical properties with a slight advantage to Powder deposition compared to Wire deposition**
- **Position and orientation of the blocks within each build showed insignificant differences – except for elongation at failure in the Z direction which was noticeably larger than in the XY plane.**

FAIRING OF A VERTICAL REFERENCE INDICATOR



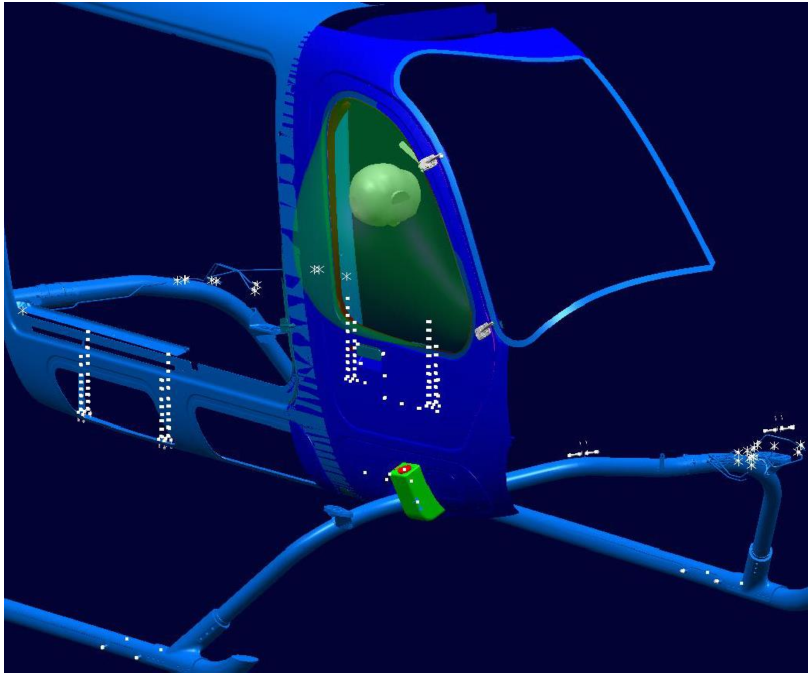






Casing for externally installed Instrument

- Usage : Engine torque indicator during load transportation using the cargo hook



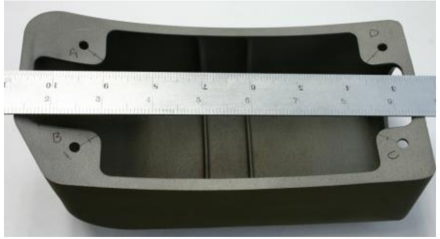
Casing for externally installed Instrument

- **Usage : Engine torque indicator during load transportation using the cargo hook**

Design parameters influencing the choice of Ti6Al4V AM part

- Design constraint due to the restrained footprint for attachment of the part to the structure
- Material compatibility with surrounding carbon composite material
- Requirement for conductivity with instruments
- Low production run (qty of 15 required)
- Requirement for durability due to location of the device:
  - Outside (temperature and other environmental threats)
  - Located under pilot door (risk of impacts and damage)

- **Other aspects and challenges encountered during this project**
  - Development of the supply chain
  - Understanding the limitations of dimensional tolerances of AM process
  - Defining the design requirements by using available limited data
  - Establishing achievable requirements for
    - Level of involvement in the production of the parts
    - Non-Destructive and Destructive Testing
    - Mechanical properties
    - Surface finish
    - Surface treatment



SPECIFIC CASE STUDY – CANADIAN COAST GUARD AIRCRAFT

- **Other aspects and challenges monitored during this project**
  - Cost of a part – presently can be from 2 to 3 times more expensive than an equivalent machined part – when a machined part can be produced
  - Better freedom of design
  - Surface treatments applied on the conventionally processed parts can be utilized on these parts
  - Possibility of combination of details to reduce assembly time and weight (less hardware and reduction of galvanic corrosion protection for dissimilar materials)
  - Parts can be built faster than some conventional processes (casting and forging) and require less fabrication steps

What are the future challenges?

- Develop a ‘’Design for AM’’ mindset
- Aquire a better knowledge of the potential defects inherent to this process and their potential impact on the final product
- Apply in a more efficient way the conventional non-destructive inspection methods
- Acquire a better knowledge of a larger variety of metallic materials
- Looking at how this process can be used for the spare parts market and its impact on certification process

Special thanks to Ghislain Auger and Walter Faessler for their support by providing useful information and pictures

QUESTIONS?