Titanium Usage on Bombardier Aircraft: Present and Challenges for the Future

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Bombardier – Evolution Of Mobility

The World’s Only Manufacturer of Trains and Planes

INNOVATION IS PART OF OUR DNA
Bombardier Overview

Bombardier Transportation

- Customers in more than 60 countries
- Presence in 40 countries\(^1\)
- Employees: 39,400\(^2\)
- Headquarters in Berlin, Germany

Bombardier Aerospace

- Customers in more than 100 countries
- Presence in 29 countries\(^1\)
- Employees: 31,200\(^2\)
- Headquarters in Montréal, Canada

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1. Defined as countries with BT or BA employees
2. As of December 31, 2015
We Offer A Broad Business Aircraft Portfolio...

**LEARJET family**
- Learjet 70
- Learjet 75

The Learjet family of aircraft features exceptionally fast cruise speeds, high climb rates and operating ceilings, along with competitive operating costs. ¹

**CHALLENGER family**
- Challenger 350
- Challenger 650

The Challenger family of aircraft features productivity-enhancing business tools, with the most comfortable cabins in their category. ¹

**GLOBAL family**
- Global 5000
- Global 6000
- Global 7000²
- Global 8000²

The Global family of aircraft offers a balance of performance, comfort and productivity for long-range missions. ¹

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¹ Under certain operating conditions, when compared to aircraft currently in service. See aircraft program disclaimer at the end of this presentation.
² Currently under development.
...And A Broad Portfolio Of Commercial Aircraft In The 20- To 149-Seat Categories

**Q SERIES**
- Market category: 60- to 90-seat turboprop
- Models: Q400, extra capacity, combi

**CRJ SERIES**
- Market category: 70- to 100-seat regional jets
- Models: CRJ700, CRJ900 and CRJ1000

**C SERIES**
- Market category: 100- to 150-seat mainline single-aisle jets
- Models: CS100 and CS300
Bombardier is continually evolving its product platforms to maintain its leadership in the industry and to offer products and services that exceed its customers’ expectations.
Performance Driven for new aircraft design:

• Fuel efficiency
  • Lower structural weight of components
  • Higher strength, lower density materials
    • Composites, hybrid structures

• Lower maintenance costs
  • Increased inspection intervals
  • Fatigue resistant, damage tolerance materials
  • Corrosion resistant materials
  • Impact resistant materials

• Cost
  • Acquisition cost
  • Operating cost
  • Disposal cost
    • Material recycling

• New innovative aircraft require optimized material solution
Material Selection for Aircraft – Titanium Alloys

Advantages:
• Low density (~2/3 density of steel) high strength
• Excellent specific strength
• Excellent fracture toughness
• Excellent corrosion resistance
• Excellent fatigue resistance
• Conductive
• Recyclable

Disadvantages
• Cost
  • Raw material cost and processing costs
• Processing
  • Heat treatment, machining, forming
Titanium – Focus

Reduction in BOM
  • Better Buy to Fly Ratio
  • Pre-cut near net shape raw material
    • More processing closer to the mill

Fewer Parts
  • Machining, forgings, castings

Larger Parts
  • Less joints / fasteners

Less operations due to near net shape
  • Greater use of die forgings
  • Introduction of Additive manufacturing
Titanium Usage on Business Aircraft

- **Alloys**
  - Ti-6Al-4V most widely used
  - CP Commercially Pure grades
  - Ti-3Al-2.5V

- **Forms**
  - Bar
  - Sheet & Plate
  - Forging
  - Tubing

**Applications:**

- High strength components
  - Wing attachments
  - Flap track components

- High temperature components
  - Firewalls
  - Pylon structure
  - Leading edge components

- Hydraulic Lines
To Reduce The Cost

From Plate to Die Forging

From Hand Forging to Die Forging
To Reduce The Cost

From Plate / Bar to Die Forgings

<table>
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<tr>
<th>Center Wing Box</th>
<th>Mid Fuselage</th>
<th>Wings</th>
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<td><img src="image2" alt="Mid Fuselage" /></td>
<td><img src="image3" alt="Wings" /></td>
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To Reduce The Cost

From Forgings to Extrusions
To Reduce The Cost

From Plate to Casting: Adequate static, corrosion durability and damage tolerance properties demonstrated
Introduction of Additive Manufactured (AM) Components on Global 7000

• Evaluation of AM technology
  • Pre-production evaluation through joint industry-governent programs (CRIAQ) to validate proof of concept
  • CRIAQ projects completed in 2014
• Substitution of existing titanium components in order to save weight and cost
  • Several potential components evaluated
• Part Categories / Type
  • Secondary Structure
  • Low criticality Primary Structure (no fatigue)
  • APU goose neck fitting selected for first component
APU Goose Neck Design

APU Door Hinge
- APU Hinge used on Global 5000/6000/7000/8000
- Initial material- Titanium 6Al-4V per AMS 4928
- Currently manufactured from bar stock
  - Very high buy/fly ratio
- Manufactured using laser based system
  - EOS 280/290 powder fed laser fusion
- Final design is currently undergoing qualification & certification testing
- Optimized final design provides both cost & weight savings
Certification of new materials and processes for civil aircraft is controlled by regulatory authorities:

- FAA – (MMPDS) Federal Aviation Authority (Metallic Material Properties Development & Standardization)
- MMPDS Working group, Emerging Technology Working Group (ETWG) tasked with developing handbook guidelines for the introduction of new technologies. BA as well as other OEM’s input to guidelines

Guidelines for Emerging Materials & technologies:

- Detailed report outlining the procedures and guidelines for the development of statistically based allowables from new technologies focused on additive manufacturing.
- Inputs from FAA specialists & Battelle
- Reference ASTM F2792 for general process & definitions
- Focuses on Powder Bed Processes and Direct Deposition (e.g. EB processes)
- Importance of Non-Destructive testing challenges
Certification of Titanium Additive Manufactured (AM) Components

Conclusions

- Significant variability with the numerous Additive Manufacturing (AM) processes which do not warrant the inclusion of design values with the MMPDS handbook on a general basis.
- FAA will currently only consider “Point Design” for the certification of AM produced parts.
- FAA has released an Issue Paper – AMN-113/AMN-115 titled “Additive Manufacturing Material Allowables Test Program”
  - Defines process for certification of AM part
  - Focuses on variability of material properties
  - Allows for the use of special factors (25.619) to account for variability where “due to quantity of tests needed or difficulty in extracting test specimens from representative parts due to part geometry”
  - Allows for the use of “casting factors” per 25.621
- FAA strongly recommends a building block approach to certification of components.
  - Basic simple coupons
  - Structural details
  - Sub-component
  - Full-scale component
- Degree of testing would be dependent upon size and criticality of the part
Conclusion

• Titanium remains a material of choice in aerospace
• Cost reduction efforts from titanium manufacturers will help promote its use
• Near net shape titanium forms will replace standard plate, bars and hand forging
  – Improvements in machining thick plate & die forgings is required
• Additive manufacturing is attractive
  – Best suited to replace complex parts with high buy to fly ratios
  – Deposition maturity needs development to reach an adequate Manufacturing Readiness Levels (MRL) for larger structural components
  – Qualification/Certification of parts is a concern
    > Providing a high level of confidence in the structural integrity of components built with additive technology will require extensive testing, demonstration, and data collection
    > There is a need for a concerted co-operative approach in order to increase the Aerospace Industry use of Additive Manufacturing for structural parts
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