Overview of Global Aerospace Parts Manufacturing Technologies

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1. Overview of Aerospace Vehicles – Video
2. Current Aviation Market Outlook
3. Overview of Major Components of an Aircraft
4. Major Aircraft Materials and its Classification
5. Major Manufacturing Technology for Aerospace
6. Measurement and Inspection Methods in Manufacturing
7. Research and Development
8. Automation and Innovation in Manufacturing
9. Future Need for Manufacturing
10. Future Aviation
11. Summary
Overview of Aerospace Vehicles - Video
20-Year Forecast: Strong Long-Term Growth

2014 to 2034

World economy (GDP) 3.1%

Number of airline passengers 4.0%

Airline traffic (RPK) 4.9%

Cargo traffic (RTK) 4.7%

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Market Trends

Growth driven by emerging economies

Market much more diverse, balanced

Continued strong replacement demand

New airplanes capabilities opening new markets
Change of Fleet Composition in the Next 20 Years

- Regional jet: 12%
- Single-aisle: 65%
- Small wide-body: 11%
- Medium wide-body: 8%
- Large wide-body: 3%

70% of the demand is for large wide-body, 65% for single-aisle.
What Drives Innovation In Aerospace?

- Economic growth
- Traffic Forecast
- Fuel Price
- Environment
- Market Liberalization
- Transportation
- Infrastructure
- Network Development
- Airplane Capabilities
- Airline strategies & Business models
Beyond the 1st Century of Aerospace Manufacturing

Automated Composite Fab

Additive Manufacturing

Robotic Assembly
Market Challenges – What the Customers Want?

- Safe
- Affordable
- Reliable
- Upgradeable
- Flexible
- Performance
- Environmentally responsible
- Available
Focusing Technology Investments on Future Needs

• **Extreme Affordability** – in development, production, operations and support

• **Breakthrough Performance** – to meet the customer needs (range, payload, speed, mission effectiveness, availability, reliability, etc.)

• **Enduring Sustainability** – to be easy to modify, open system architecture, easy to upgrade

• **Environmentally Responsible** – non-polluting the environment from production (toxic chemicals and other health hazard elements)…to operations (noise and emission) … to end-of-life cycle (recycling)
Overview of Major Components of an Aircraft
(a) Boeing 777 300ER for Thai Airways

(b) Schematic representation of structural and operating system components of an aircraft
**Major Structural Components of an Aircraft**

- **External Shape**
  - Fuselage
  - Wing
  - Stabilizers
  - Undercarriage
  - Keel Beam and Landing Gear
  - Engine Nacelles and Pylon
Major Structural Components of Fuselage Sections

(a) Major components of fuselage structure and their input raw materials for manufacturing

(b) Schematic of three components of fuselage structure

(c) Example of upper lobe section of fuselage
Major Structural Components of Wing

(a) Major components of wing structure and their input raw materials for manufacturing

(b) Schematic representation of a metal wing box

(c) Joining of stringer, skin, and rib of a wing box
Wing Section and Assembly

(a) Schematic of wing section with leading and trailing edge

(b) Pair of wing assemblies, ready to join with fuselage
Major Structural Components of Stabilizers

Schematic of horizontal and vertical stabilizer structure
Major Structural Components of Landing Gear

(a) Major structural components

(b) Schematic of main landing gear major elements
Engine and Cowling Components

(a) Schematic view of an engine components

(b) Engine cowling components
Major Aircraft Materials and its Classification
Major Aircraft Materials

Metal Structure
- Primary Metals
  - Non Ferrous
  - Ferrous
    - Input Raw Materials
      - Melting and Alloy Making
        - Cast Ingots / Billets
      - Fabrication Processes
        - Rolling
        - Extrusion
        - Forging
        - More

Non-metal Structure
- Composite Materials
  - Non-metal Matrix
    - Polymer Matrix
    - Metal Matrix
    - Ceramic Matrix
  - Input Raw Materials
    - Fibers / Fabrics
    - Matrices
      - Prepreg Tow / Tape / Fabric
  - Fabrication Processes
    - Autoclave Molding
    - Vacuum Bag Molding
    - Compression Molding
    - More
Application of Different Materials in a Commercial Aircraft
Examples of structural materials used in various commercial aircrafts – showing gradual increase of composites

- **747**
  - Aluminum (81%)
  - Steel (13%)
  - Titanium (4%)
  - Composite (1%)
  - Misc. (1%)

- **767**
  - Aluminum (80%)
  - Steel (14%)
  - Titanium (2%)
  - Composite (3%)
  - Misc. (1%)

- **777**
  - Aluminum (70%)
  - Steel (11%)
  - Titanium (7%)
  - Composite (11%)
  - Misc. (1%)

- **787**
  - Aluminum (20%)
  - Steel (10%)
  - Titanium (15%)
  - Composite (50%)
  - Misc. (5%)
Examples of composite structural materials used in various locations of 787 commercial aircrafts – the 1st commercial aircraft model introduced by Boeing in 2011
Examples of structural materials used in various military aircrafts – showing gradual increase of composites

- F/A-18 C/D: Aluminum (49%) Steel (15%) Titanium (13%) Composite (10%) Misc. (13%)
- F/A-18 E/F: Aluminum (31%) Steel (14%) Titanium (21%) Composite (19%) Misc. (15%)
- F-22: Aluminum (24%) Steel (10%) Titanium (42%) Composite (24%)
- F-35: Aluminum (27%) Steel (13%) Titanium (20%) Composite (40%)
Usage of Major Wrought Products in a Metal Aircraft

Major Manufacturing Processes of Aluminum Wrought Products:

(a) Rolling sheet/plate
(b) Extrusion
(c) Forging
Major Manufacturing Technology for Aerospace
Fundamentals of Manufacturing Aerospace Parts

Aerospace Part Description

Part Design & Engineering Drawing

Aerospace Materials (Metals and Non-metals)

Research & Development

Aerospace Part Manufacturing

Material and Manufacturing Specifications

Manufacturing Technology

Manufacturing Cost/Quality

Q/A Inspection/Part Acceptance
Major Manufacturing Technology for Metal Parts

Aerospace Metal Parts

Major Metals

Nonferrous

Ferrous

Major Manufacturing Technology

Forming of Various Metal Products
Welding and Joining
Metal Cutting and Machining
Abrasive Metal Removal and Cutting Processes
Chemical Metal Removal and Chemical Processing of Metals
Introduction of Tribology in Manufacturing Technology

(a) Fundamentals of Tribology

(b) Role of Tribology in Major Manufacturing Technology
Forming Technology for Various Metal Products

(a) Cold Forming of Sheet Product
- Current Alloy/New Alloy Sheet Products
  - Brake/Bump Forming
  - Roll Bending
  - Stretch Forming
  - Hydro Press Forming
  - Roll Forming
  - Joggle Forming
  - Deep Draw Hydro Forming
  - Match Die Forming
  - Spin Forming
- Major Forming Technology
- Formability

(b) Cold Forming of Plate Products
- Current Alloy/New Alloy Plate Products
  - Bump Forming
  - Shot Peen Forming
  - Laser Shock Peen Forming
- Major Forming Technology
- Formability

(c) Cold Forming of Extrusion
- Current Alloy/New Alloy Extrusion
  - Stretch Forming
  - Stretch Wrap Forming
  - Roll Contouring
  - Joggle Forming
- Major Forming Technology
- Formability
Bump Forming Technology

(a) Fundamentals of Bump Forming
(Three Point Bending)

(b) Bump Forming of Fuselage Skin Panel

(c) Bump Forming of Wing Skin Panel
Stretch Forming of Flat Sheet Product

(a) Fundamentals of Stretch Forming of Sheet Metal

(b) Forming of Wing Leading Edge

(c) Formed Part
Stretch Forming of Extrusion

(a) 3000T Stretch Forming Press

(b) Forming Process

(c) Formed Heavy Extrusion
Hot Forming of Various Metal Products

- Hot Forming of Flat Sheet, Plate and Extrusion
  - Super Plastic Forming (SPF)
  - Die Forming
  - Brake Forming
  - Stretch Forming
    - Super Plastic Forming (SPF) / Diffusion Bonding (DB)
    - Creep Age Forming (CAF) / Creep Forming / Hot Straightening
Fundamentals of Superplastic Forming (SPF)
SPF Presses

(a) Up-and down-acting Press
(b) Lower Platen Shuttle Press

- Superplastic Forming 1650°F
- Hot Size or Stress Relief 1350°F
**SPF/DB Titanium Parts**

(a) Fine grain 6Al-4V titanium sheet metal parts

(b) SPF/DB sheet metal parts for heat shield

(c) SPF/DB heat shield assembly installed on an airplane
Die Forming of Titanium Sheet

(a) Hot Forming Steel Die Set

(b) Stiffening bead type part for heat shield

(c) Hot die forming part in heat shields installed in an airplane

Typical Hot Forming Temperature for Titanium is around 730°C (1346°F).
Hot Forming of Titanium Plate

(a) Plate on the ceramic die prior forming

(b) Hot formed plate from the ceramic die
Hot Forming of Titanium Extrusion

(a) Stretch Forming  (b) After Forming

(c) Stretched Form Titanium Extrusions
High Energy Forming and Joining

- Explosive
- Electromagnetic

Explosive Forming

(a) Fundamentals

(b) Stainless Steel Sheet Product

(c) Aluminum Plate Product
Electromagnetic forming (EMF)

(a) Fundamentals

(b) Hydraulic Joint

(c) Torque Tube joint

(d) EMF Torque tube in a wing flight control system
Tube and Duct Forming

(a) Tube and duct forming processes

(b) Bend tube, pullout and joint

(c) Isostatic bulge formed part

(d) Axial bulge formed part

(e) Rotary swaged part
Welding Technology in Aerospace
Linear Friction Welding (LFW)

(a) Oscillating object 1 is brought in contact with object 2
(b) Welding takes place with flash
(c) Example of LFW of engine fan blade


**Rotary Friction Welding (RFW)**

(a) Rotating object 1 is brought in contact with stationary object 2  
(b) Develops flash in forging  

(c) Example of RFW of cylindrical shaped product
Friction Stir Welding (FSW)

- FSW was invented in 1991, used extensively in aluminum alloys
- Solid state weld, no melting
- Retains, or produces, fine grained microstructure
- Low occurrence of defects (cracking, porosity, etc.)
- Exceptional properties (static and fatigue)

(a) Tool plunged into the work-piece
(b) FSW begins
Friction Stir Welding Combined With SPF

(a) FSW blank

(b) SPF setup

(c) SPF of FSW blank
SPF inlet lip skin having six friction stir welds that cannot be seen after abrasive polishing.
Metal Cutting and Machining Technology

(a) Wing Rib from Aluminum Forging  
(b) 15-5 Stainless Steel Flap Track
Uses of Titanium at Various Location of an Aircraft

Example of a Machined Landing Gear Beam from Titanium Forging
Airframe Fabrication is Machining Intensive

Typical Buy-To-Fly Ratios

- Plate, Hog-Out: 30:1
- Extrusion: 12:1
- Die Forged: 6:1
- Welded: 2:1
- Additive: 1.2:1
Monolithic Aluminum Example Part

Current Configuration, Sheet Metal Assembly

Machined Monolithic Part
Abrasive Metal Removal and Cutting Processes

(a) Abrasive metal removal and cutting processes

(b) Tribological model of an abrasive wear process
(a) Belt type grinding, polishing and deburring machine

(b) Turbine blade processed with this machine
(a) Schematic representation of Abrasive Water Jet (AWJ) cutting

(b) AWJ cutting machine

(c) AWJ cut titanium plate for part manufacturing
Chemical Metal Removal and Chemical Processes

Chemical Metal Removal and Chemical Processing of Metals

- Chemical Milling
- Chemical Cleaning/Coatings
- Plating

Aluminum Alloys
- Cleaning
- Conversion Coating

Hard Metals
- Stainless Steel, Titanium
- Cleaning
Chemical Milling

(a) Fundamentals of chemical milling process

(b) Aluminum fuselage skin panel having chemical mill pockets
Manufacturing Processes of Composite Materials

(a) Typical applications of composites in an aircraft
Major Manufacturing Processes of Composite Materials

Prepreg Layup
  - Hand
  - Machine

Liquid Composite Molding
  - Resin Transfer Molding
  - Resin Film Infusion
  - Pultrusion

Filament Winding
Tape Lamination
Fiber Placement
Drape Forming
(a) Automated Tape Lamination (ATL) of horizontal stabilizer skin

(b) Large Horizontal Automated Fiber Placement (AFP) of fuselage barrel

(c) Composite fuselage structure made by AFP technology
Measurement and Inspection Methods in Manufacturing
**Measurement Methods/Testing**

- **Manufacturing of Aerospace Parts**
  - Input Raw Materials
  - Manufacturing Processes
    - Measurement Methods
      - Manual Bench
      - Computer Assisted
        - Machine Driven CMM
        - Functional Check Fixtures
    - Testing/Inspection
      - Destructive
      - Non Destructive
        - Hand Driven Devices
          - Guided
          - Non Guided
Manual Bench

(a) Precision measurement tools

(b) Standard gages

(c) Check fixture
**Computer Assisted**

(a) Bridge Type CMM

(b) Hand-Driven Guided Metrology System

(c) Non-Guided Laser Tracker System
Major Elements for Aircraft Design and Manufacturing

1. Airline Customers Needs
   - Aircraft Design Configuration
     - Passenger Capacity
     - Flying Range
     - Fuel Efficiency

2. Materials Research and Development
3. Engineering Design Need
4. Manufacturing Research and Development
5. Aircraft Manufacturing Cost/Performance
6. Quality and Safety
R&D Model for Material Development

Materials Research and Development

Introduce New Materials

Product Shape/Form → Material Cost

Materials Properties and Applications

Part Producibility → Cost of Manufacturing

Meets all Cost and Performance Considerations

Implementation

No → Yes
Manufacturing R&D Model

Manufacturing Research and Development

- Input Material

Manufacturing Technology Development

- Explore New Technology
- Part Geometry
- Improve Existing Technology

Automation

Manufacturing Process Flow

- "Lean" Approach

Production Rate

Part Cost

Part Quality
Automation and Innovation in Manufacturing
Introducing Automation to the Manufacturing Technology

Top Business Outcomes
- Workplace Safety
- Product and Process Quality
- Flexibility / Factory Optimization
- Standardization / Replication

Top Automation Applications
- Drill/Fill
- Paint & Seal
- Composite Fabrication
- Material Movement

Enablers
- Networked Enabled Manufacturing
- In-Process Inspection
- TRL AND MRL

Innovative, Simple, Robust & Cost Effective
Additive Innovation

Top Business Outcomes
- Speed to Market
- Enhance Performance
- Cost Reduction Buy-to-Fly

Top Additive Applications
- Tools
- Interiors
- Structural Parts

Enablers
- Certification
- In-Process Inspection

Since 2002 more than 50,000 flyaway parts!
## Metal Additive Manufacturing Processes

<table>
<thead>
<tr>
<th>WIRE FEED DEPOSITION</th>
<th>POWDER FEED DEPOSITION</th>
<th>LASER POWDER BED</th>
<th>EB POWDER BED</th>
<th>INDIRECT POWDER BED</th>
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<td><img src="image2" alt="Laser weld wire &amp; powder" /></td>
<td><img src="image3" alt="Laser powder sintering" /></td>
<td><img src="image4" alt="EB powder sintering" /></td>
<td><img src="image5" alt="Binder-powder sintering" /></td>
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<td>50 in³/hr (8 lbs/hr)</td>
<td>12 in³/hr (2 lbs/hr)</td>
<td>Highly net-shape</td>
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<td><img src="image7" alt="Tubes and Ducts" /></td>
<td><img src="image8" alt="Intricate complex shapes" /></td>
<td><img src="image9" alt="Complex shapes" /></td>
<td><img src="image10" alt="Small to medium, complex shapes" /></td>
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<td><img src="image17" alt="Small chambers" /></td>
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<td>3D Nested parts</td>
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Future Need for Manufacturing?
Material Development

Advanced Aluminum – Will offer Substantial Weight Savings At Lower Risk

Advanced Titanium Alloys – Will Reduce Processing Costs & Structural Weight

Corrosion Resistant Steels – Can Reduce Maintenance Costs Over High Strength Steels

Specialty Alloy Development – Is Critical For Materials-Driven Systems and Subsystems

Computational Alloy Design – Enables Rapid Certification & Advanced Hybrid Concepts
Technology Development

Physics-based Machining – Creates Value In The Supply Chain & Enables Advanced Designs

Advanced Joining Technologies – Provide Low Buy-to-Fly & Low Cost Tailored Blanks

New Forming Technologies – Produce Lower Buy-To-Fly & Rapid Cycle Times

Advanced Wrought/Cast/Powder Products – Reduce Material and Component Costs

Revolutionary Processes – Allow Direct Manufacturing & Innovative Hybrid Structures
Future Aviation

- Blended Wing Body (BWB), Aerodynamics
- Non-circular Pressure Vessel
- Advanced Composites (Materials)
- Autonomous Flight (Potentially Pilotless)
- Increased Monolithic Structure
- Increased Additive Process
- Increased Robotic and Touch Time Reduction.

NASA Boeing ERA (Environmentally Responsible Aviation)
Summary

- Market challenges and industry realities are driving changes in the way the aerospace industry designs and builds products
  - Cost, Speed to market, Performance and Environment
- Aircraft is an integration of many large, medium and small metal and nonmetal structural, nonstructural and operating system components made with millions of parts
- Cost effective efficient materials with lower density, higher strength, stiffness and excellent fatigue characteristics are needed for developing fuel efficient aircraft
- Manufacturing cost and quality of a part is directly related to the manufacturing technology involved
- Measurement and inspection methods are key to maintain the highest quality in manufacturing aerospace parts
- Role of R&D is very critical in aerospace industry for continuous improvement in productivity, reduced cost of manufacturing, quality, and safety performance of an aircraft
- Advances in materials, automation, additive/subtractive manufacturing, and data analytics are leading the changes for the 2\textsuperscript{nd} century of the aerospace industry
- Material and technology development is important to meet manufacturing need for future aviation
Thank You For Your Attention