Aerospace and Automotive Manufacturing – Specific Differences and Trends

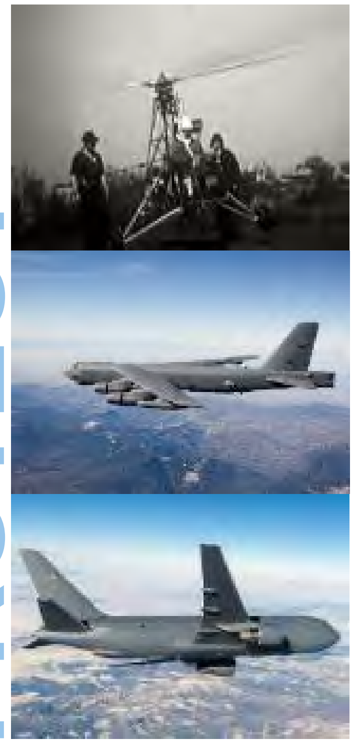
Phil Crothers, PhD
Enterprise Domain Leader – Manufacturing
Boeing Engineering, Test & Technology

Launching Our 2nd Century

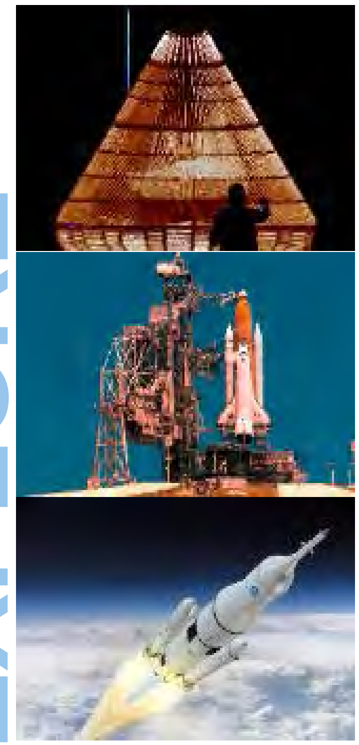
A company and history like no other

CONNECT

PROTECT



EXPLORE



INSPIRE

A century of innovation and human achievement

Boeing: A Global Leader In Aerospace – and Innovation

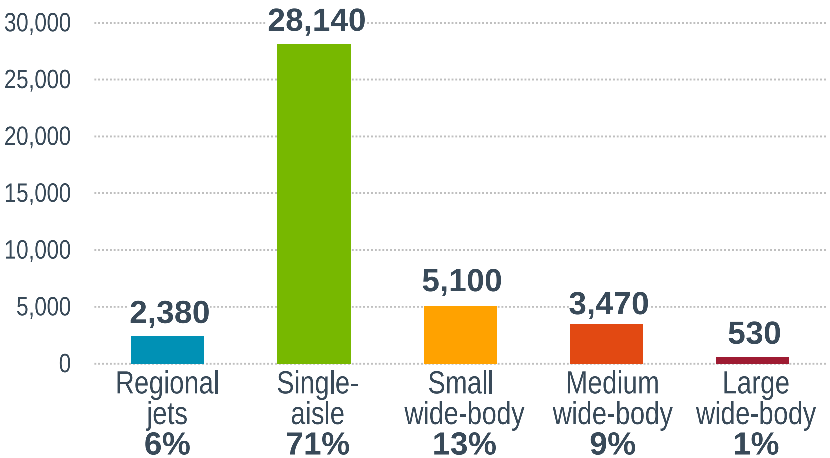
- Products and services support to customers in more than 150 countries
  - Revenue in 2016: $94.6 billion
  - 70 percent of commercial airplane revenue historically from customers outside the United States
- Manufacturing, service and technology partnerships with companies around the world
  - Contracts with more than 20,000 suppliers and partners globally
- Research, design and technology-development centers and programs in multiple countries
  - Maximizes leverage of our R&D investments
  - 2016 R&D investment: $4.6 billion
- More than 150,000 Boeing employees across the United States and in more than 65 countries

Partnering worldwide for mutual growth and prosperity

Airlines will need ~40,000 new airplanes by 2035

Airplane deliveries: 39,620

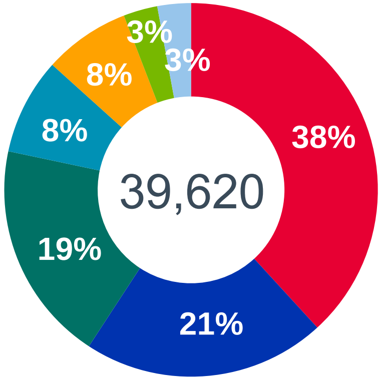
2016 - 2035



New airplane deliveries by region

2016 - 2035

Region	Airplanes
Asia	**15,130**
North America	**8,330**
Europe	**7,570**
Middle East	**3,310**
Latin America	**2,960**
C.I.S.	**1,170**
Africa	**1,150**
World Total	**39,620**



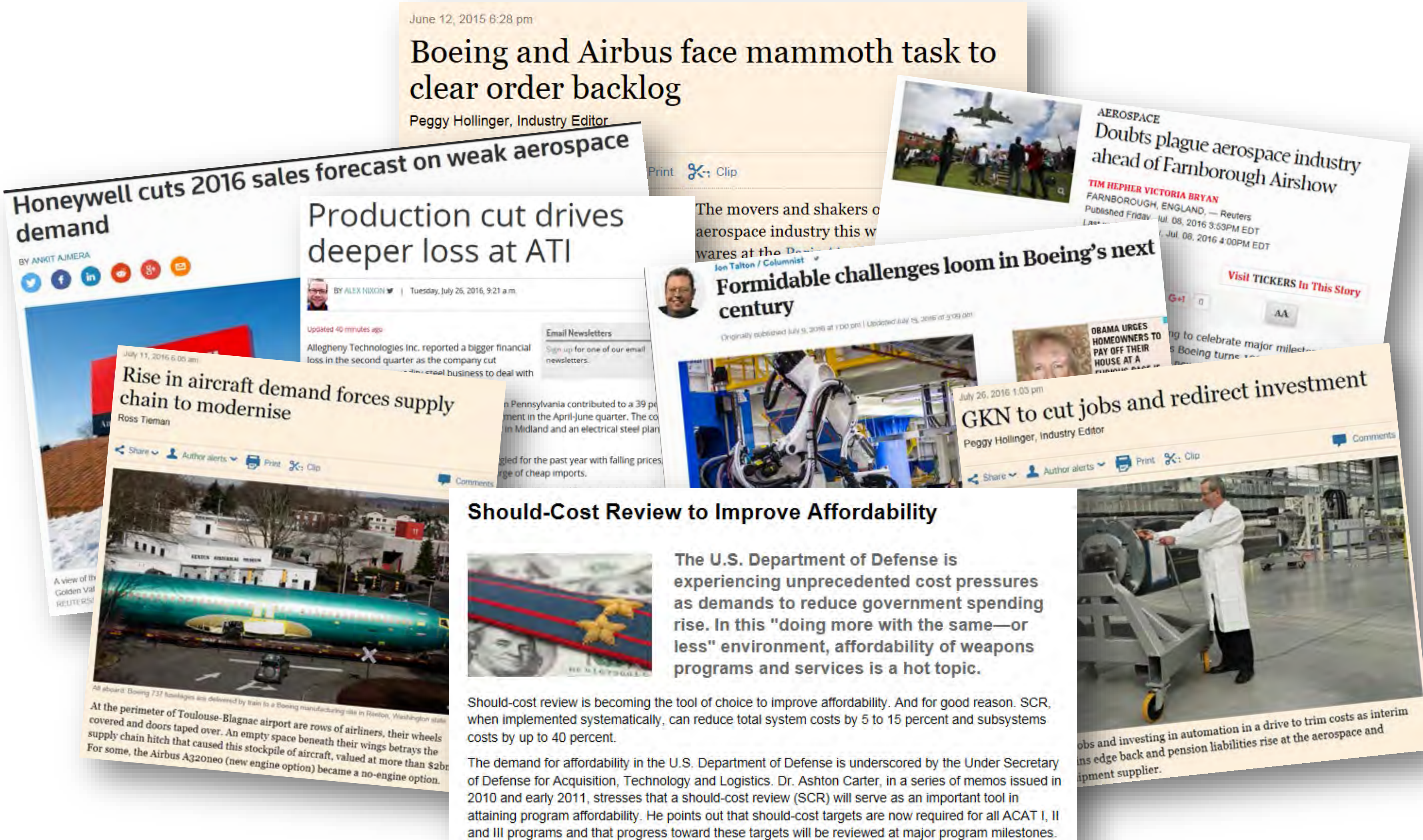
Beyond the 1st Century of Aerospace Manufacturing

Automated Composite Fab

Additive Manufacturing

Robotic Assembly

Industry Realities



Industry customers are demanding more for less

Market Challenges – What the Customers Want

- **Safe**
- **Affordable**
- **Reliable**
- **Upgradeable**
- **Flexible**
- **Performance**
- **Environmentally responsible**
- **Available**

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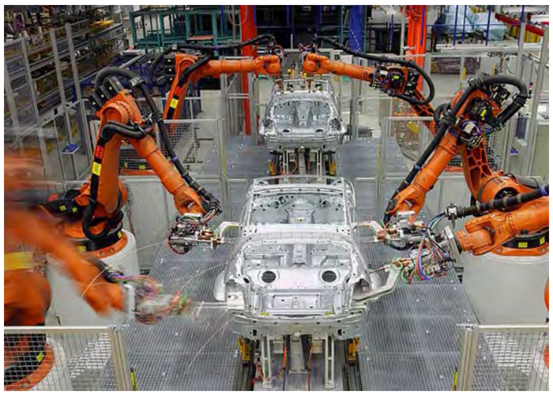
Challenges & Opportunities Ahead

Design for Manufacturing –

Aerospace needs to leverage broader industry



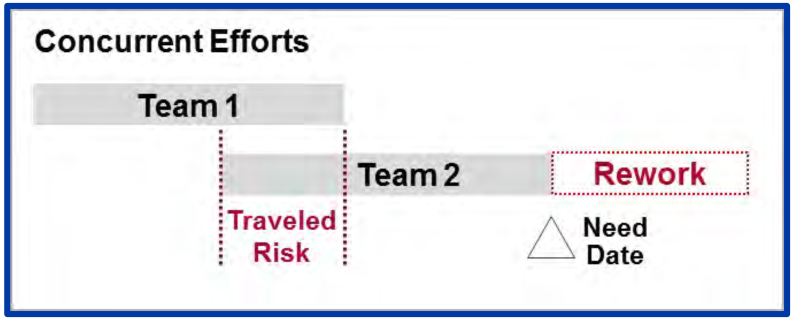
By KUKA Systems GmbH (KUKA Systems GmbH) [CC BY-SA 3.0], via Wikimedia Commons

Speed to Market –

More capability to customers – quicker

Traveled Risk –

Concurrency adds risk of rework



Modularity –

Enables Reuse & Customization

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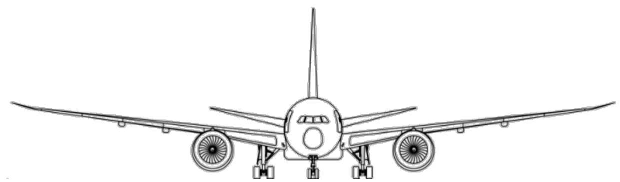
Aerospace and Automotive Comparison

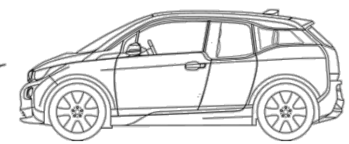
- Engineering
- Material
- Pre-forming Part-forming
- Assembly & Automation
- Sustainability Safety
- Sourcing Strategy

Source: Google Images

Source: bmw.com

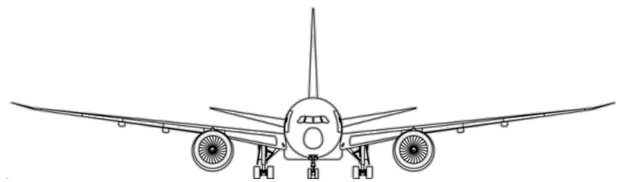
Aviation and Automotive comparison



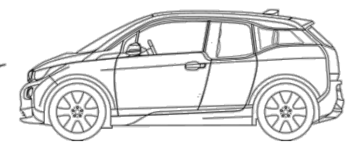


	Boeing 787	BMW i3
Number of passengers	242	4
Total Weight	118.000 Kg	1.195 Kg
Dimensions	60x63x17 m	2,0x3,9x1,6 m
Number of parts	2.300.000	10.000
Development time	89 months	33 months
Production rate	10 units/month	2100 units/month

Aviation and Automotive comparison



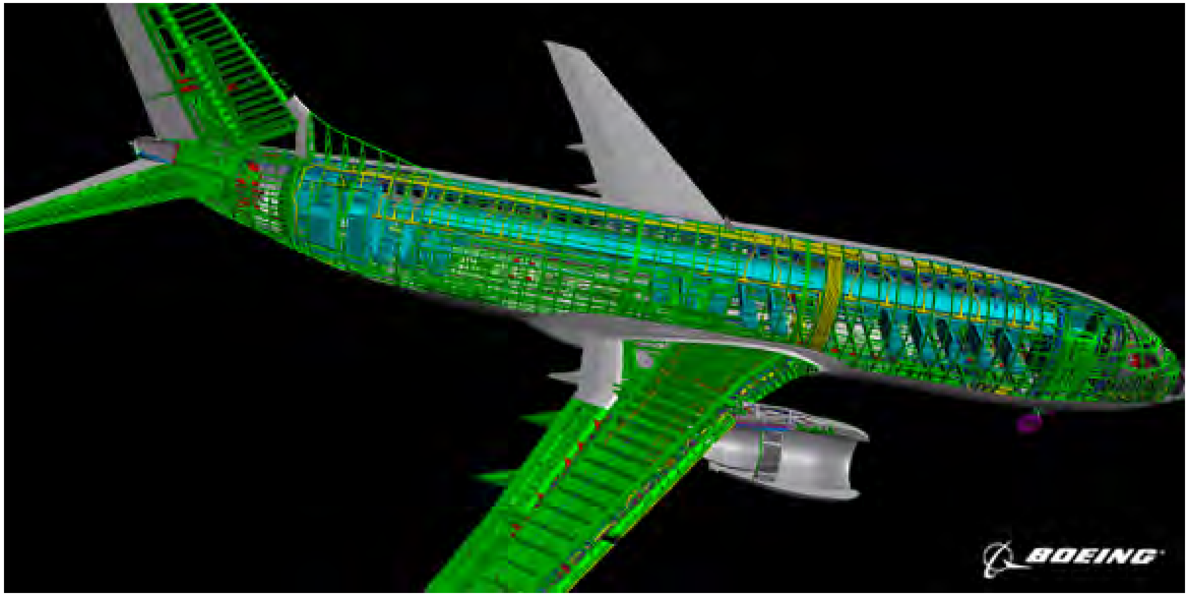
Boeing 787



BMW i3

	Boeing 787	BMW i3	
Number of passengers	242	4	60 x
Total Weight	118.000 Kg	1.195 Kg	100 x
Dimensions	60x63x17 m	2,0x3,9x1,6 m	500+ x
Number of parts	2.300.000	10.000	230 x
Development time	89 months	33 months	3 x
Production rate	10 units/month	2100 units/month	< 210 x

Engineering – Digital Definition



Source: Google Images

Source: bmw.com

Manufacturing Analytics & Digital Threads

Top Business Outcomes

- Reduce Test & Evaluation / Rework 50%
- Affordable Manufacturing
- First Pass Quality
- Improved Factory Safety

Top Applications

- Optimized Factory Flow
- Manufacturing Process Analytics
- Improved Automation Execution
- Robust Process & Material Specs

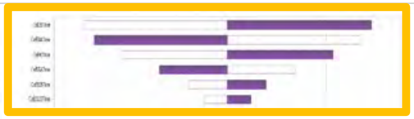
Enablers

- Analytics
- Advanced Modeling & Simulation
- Industry Standards
- Integrated Digital Factory

Production Simulation

Future Factory Concepts

Highest Impact Cells



On-Time Probability

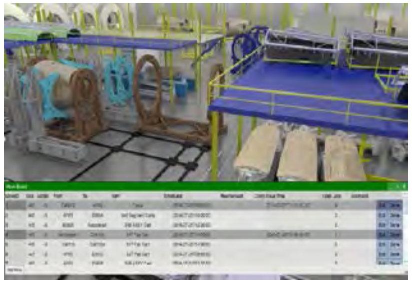
Lateness - Plan		Lateness - Risk Analysis	
Value (Days)	Status	Expected (Days)	OnTime Probability
6.2060	Late	5.0774	21.72%
14.3339	Late	8.7516	21.72%
6.7277	Late	10.9023	21.72%
11.7132	Late	14.2971	21.72%

Integrated Digital Factory

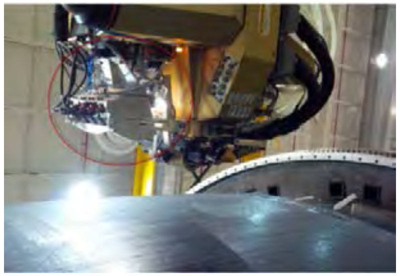
The Complete Picture

Real-Time Predictive Analytics

Process Automation



Computer Vision



Safety Analytics

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Advanced Materials

Top Business Outcomes

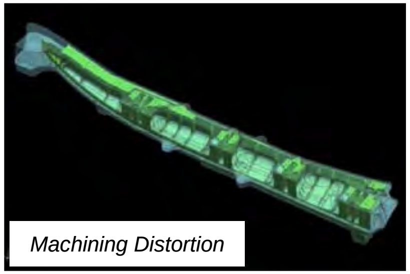
- Safe/Environmental/Ergonomic Processes
- Robust First Pass Quality
- High Rate Capability
- Reduced part count
- Optimized Weight AND Cost

Top Advanced Materials Applications

- Metallic Alloys
- Composites
- Sealants/Paints
- Ceramics

Enablers

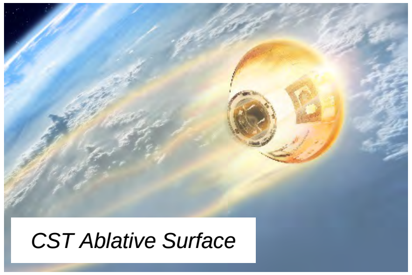
- High rate processes
- Integrated materials modeling, fabrication processing and properties



Computational Materials Models

Reduced Part Count

Robust Seal/Paint

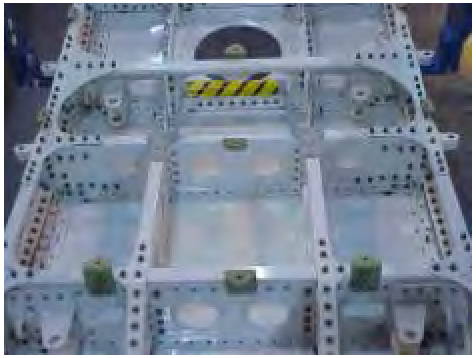
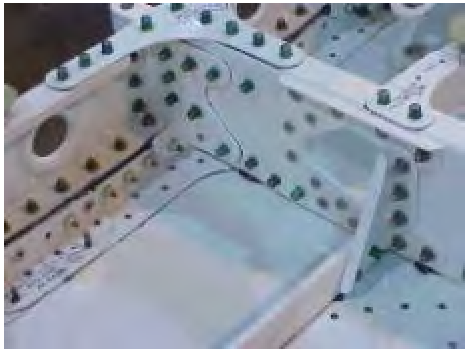


Materials for Extreme Environments

Product Performance & Production System Efficiency

Expanding capability for unitized machined components




Advanced modeling/machining technology critical

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Additive Innovation

Top Business Outcomes

- Speed to Market
- Enhance Performance
- Cost Reduction Buy-to-Fly
- Flexible Manufacturing

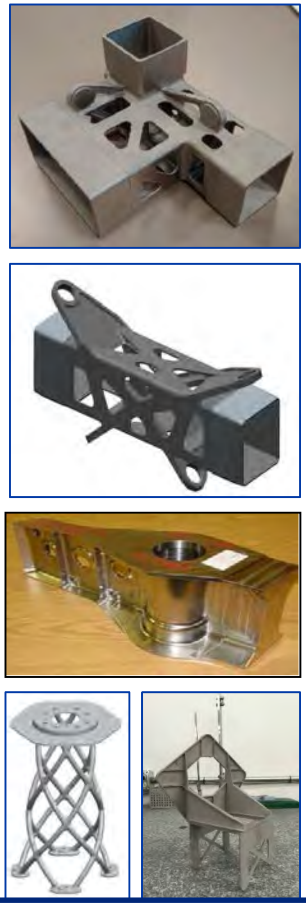
Top Additive Applications

- Prototyping
- Tooling
- Functional Components
- Structural Components

Enablers

- Certification
- In-Process Inspection
- Design for Additive

Tooling

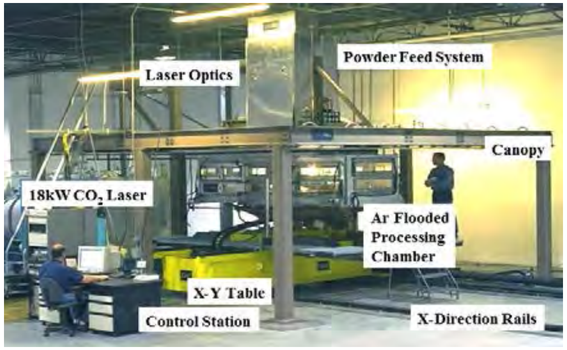


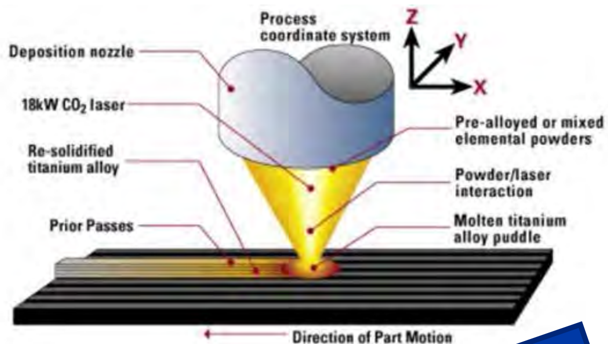
Metals

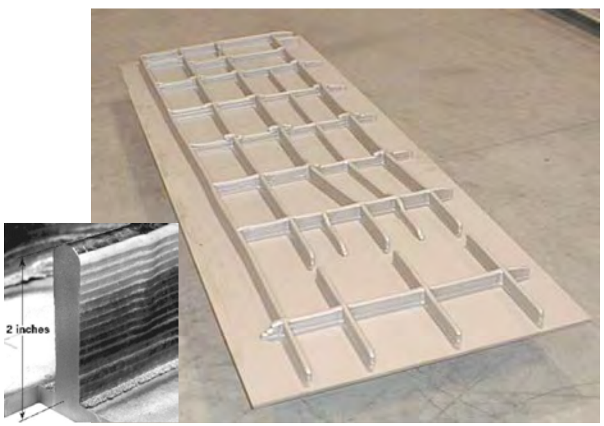
Polymers

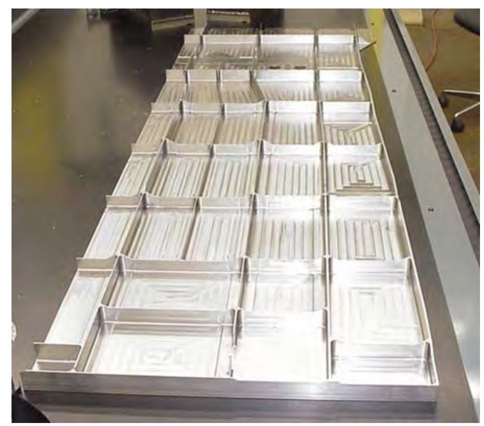
Since 2002 more than 50,000 flyaway parts!

Titanium Additive/Subtractive Innovation









Complex to complex machining will continue to grow!

Sustainability
Safety

Aircraft CFRP components recycling

CFRP Recycling – growing importance

- Each Boeing 787 carries approximately **18,144kg** of salvageable carbon fiber
- Carbon fiber can be recycled at approximately **70% of the cost to produce virgin fibers** ($8-12/lb vs. $15-30/lb), using **less than 5% of the electricity required** (1.3-4.5kWH/lb vs. 25-75kWH/lb)

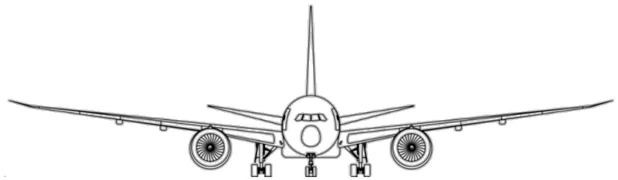
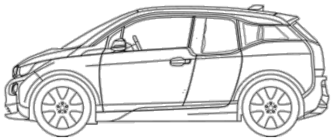
Example of aircraft reclaimed carbon fiber through pyrolisis application:

Reclaimed carbon fiber from an F-18 fiber's stabilator

The preform, made from the F-18 recyclate

The finished part: A Chevrolet Corvette wheelhouse, made by Molded Fiber Glass Co
Source: Materials Innovation Technologies

Aviation and Automotive comparison

	 **Boeing 787**	 **BMW i3**
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Total Weight	23 million parts per month	21 million parts per month
Dimensions		
Number of parts	**2.300.000**	**10.000**
Development time	**89 months**	**33 months**
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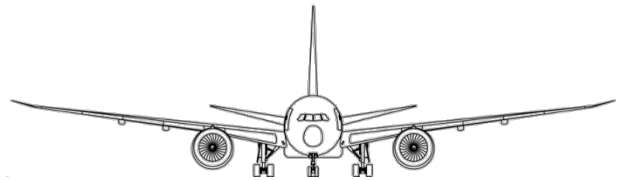
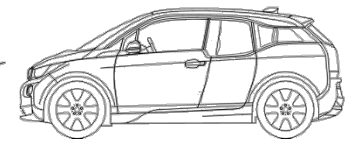
Assembly & Automation

Aviation and Automotive comparison





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Source: Boeing, BMW, Wikipedia

Mass customisation

Automation Innovation

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

777 Fuselage Flex Tracks

737/787 Heatshield Line

787 Aft Robotic Drill/Fill

Innovative, Simple, Robust & Cost Effective

Monumental Aerospace

Approx $10M per machine

50+ AFP/ATL machines globally

60x63x17 m

Source: Ingersoll

Reach equivalent to $1/5^{th}$ size

Source: Composite World

Pre-forming
Part-forming

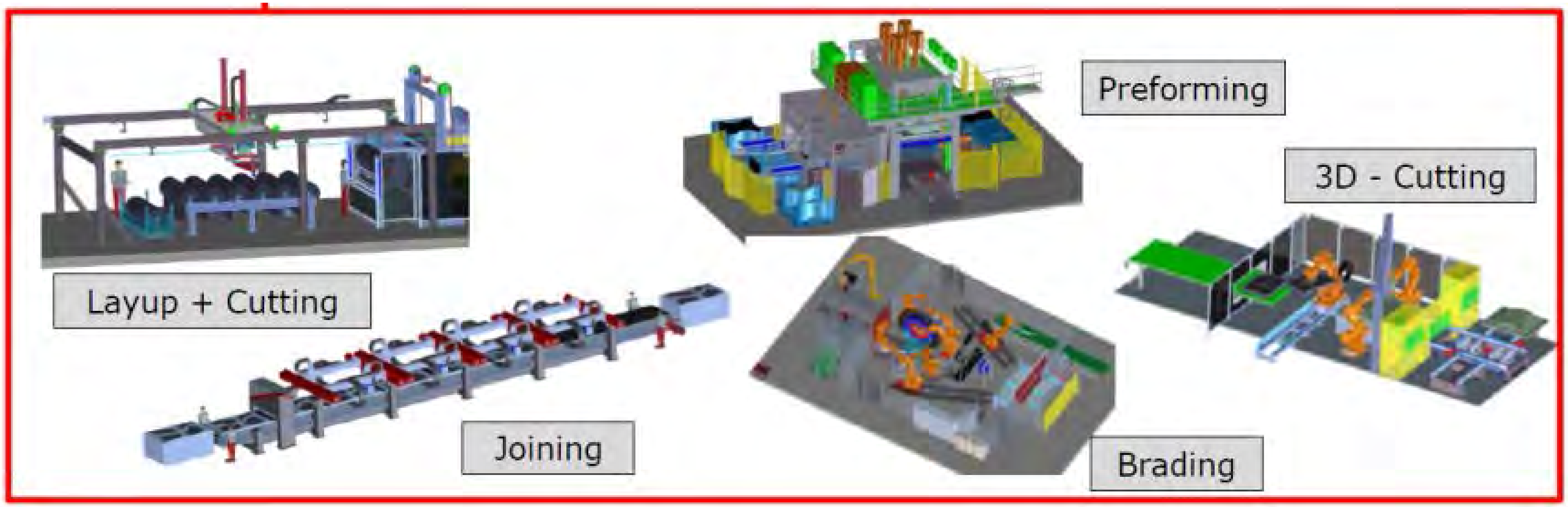
Automotive composite fabrication

Highly automated process & transfer lines

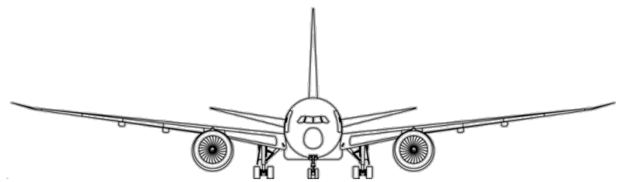
Monumental structure

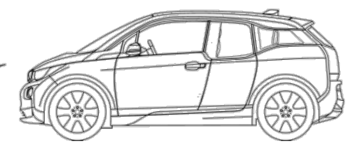
- Equivalent to press lines
- Large energy usage
  - renewable

Source: FILL



Aviation and Automotive comparison





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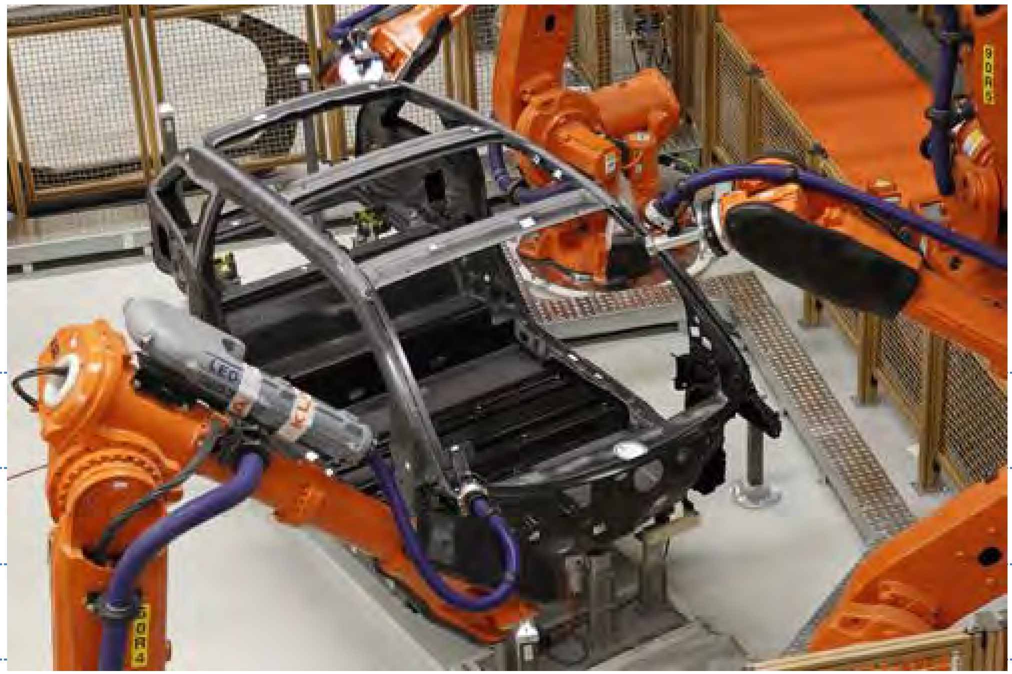
Source: Boeing, BMW, Wikipedia

Same no. of seats / interiors

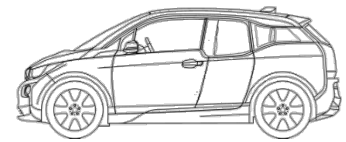
40,000 + / year^

40,000 + / year

Automotive efficiency of scale



Source: BMW



BMW i3

4

1.195 Kg

2,0x3,9x1,6 m

10.000

33 months

Reach equivalent to car size

1,25M robots currently in industry

40% of industrial robots in automotive

Approx 60K for robot

1.130 robots per 10.000 employees

Assembly & Automation


Sources: Boeing

	Everett	Leipzig
Area	**399.480 m²**	**500.000 m²**
Employees	**15.000**	**6.000**
Robots / machines	**15+**	**500+**


Sources: BMW

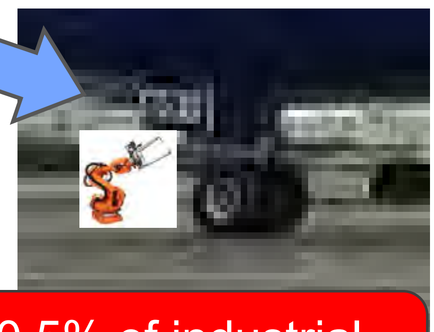
Aerospace problems of scale

60x63x17 m

Source: Broetje

Component manufacturing

Source: BAA

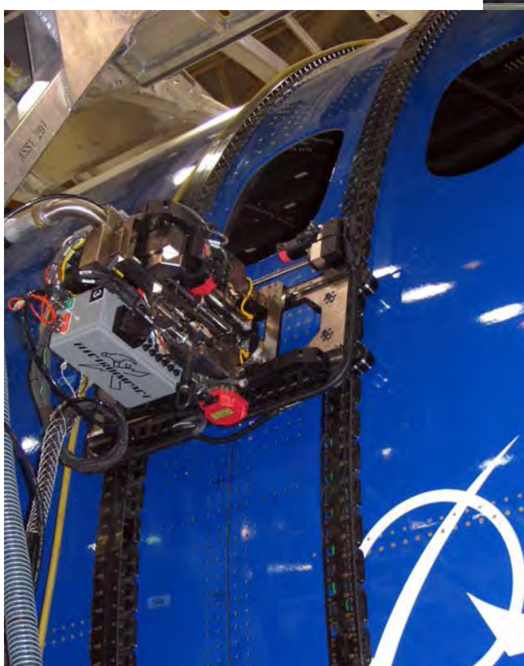


0.5% of industrial robots in aerospace

Aerospace "right size machines"

Dedicated machines

60x63x17 m



Source: Electroimpact

Flextrack & crawlers
$1M per machine

Source: M Torres

Standard Families of Aerospace Automation

How can we create a standard family of automation for aerospace?

- To get to low cost found in automotive

What does it look like

- Light
- Modular
- Work with humans
- Mobile or transportable
- Useful payload / force
  - What is the right payload/force?

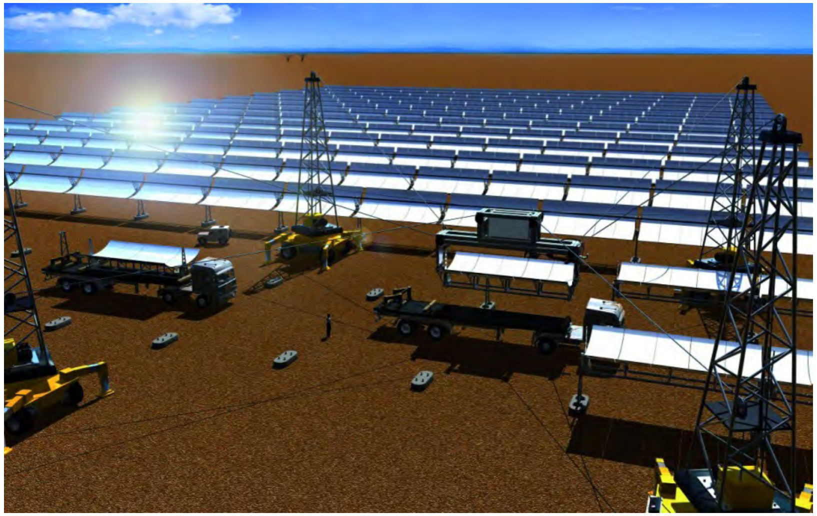
Source: Alfred T. Palmer - October 1942 - Library of Congress

How did we get from this to this?

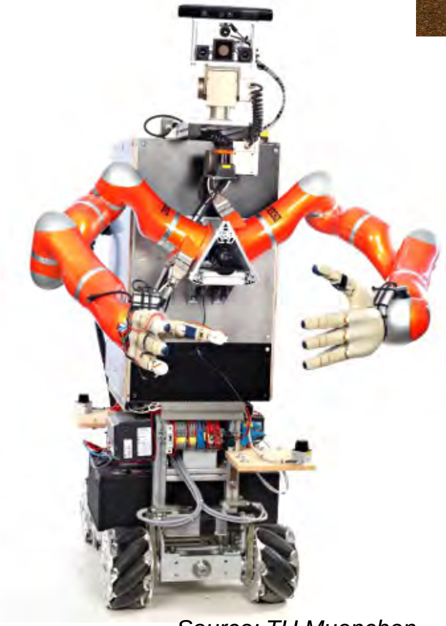
Format? Next steps?

Source: Universal Robotics

Source: Fraunhofer



Source: KUKA

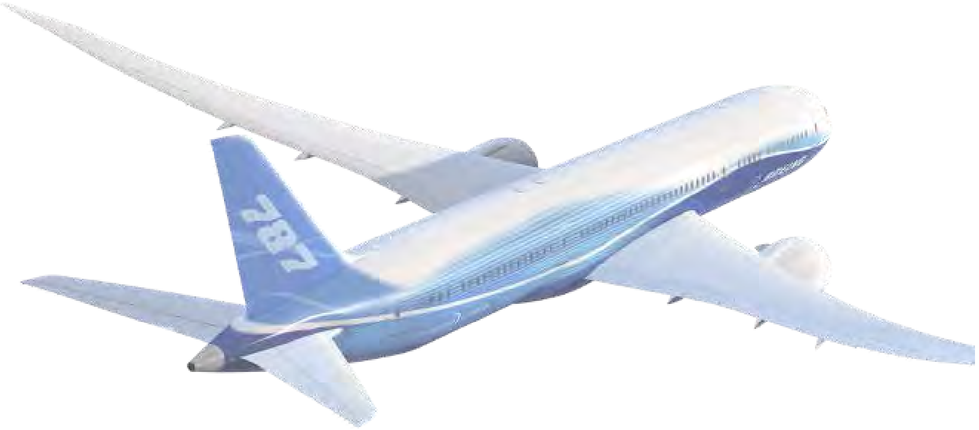


Source: TU Muenchen

Source: ABB

Summary

- **Market challenges and industry realities are driving changes in the way the aerospace industry designs and builds products**
  - Cost
  - Speed to market
  - Performance
  - Environment



- **Advances in materials, automation, additive/subtractive manufacturing, and data analytics are leading the changes for the 2nd century of the aerospace industry**