Product Development – Challenges and Opportunities in Sustainability

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“Our job is to keep everlastingly at research and experiment, to adapt our laboratories to production as soon as practicable, and to let no new improvement in flying and flying equipment pass us by.“

William E. Boeing

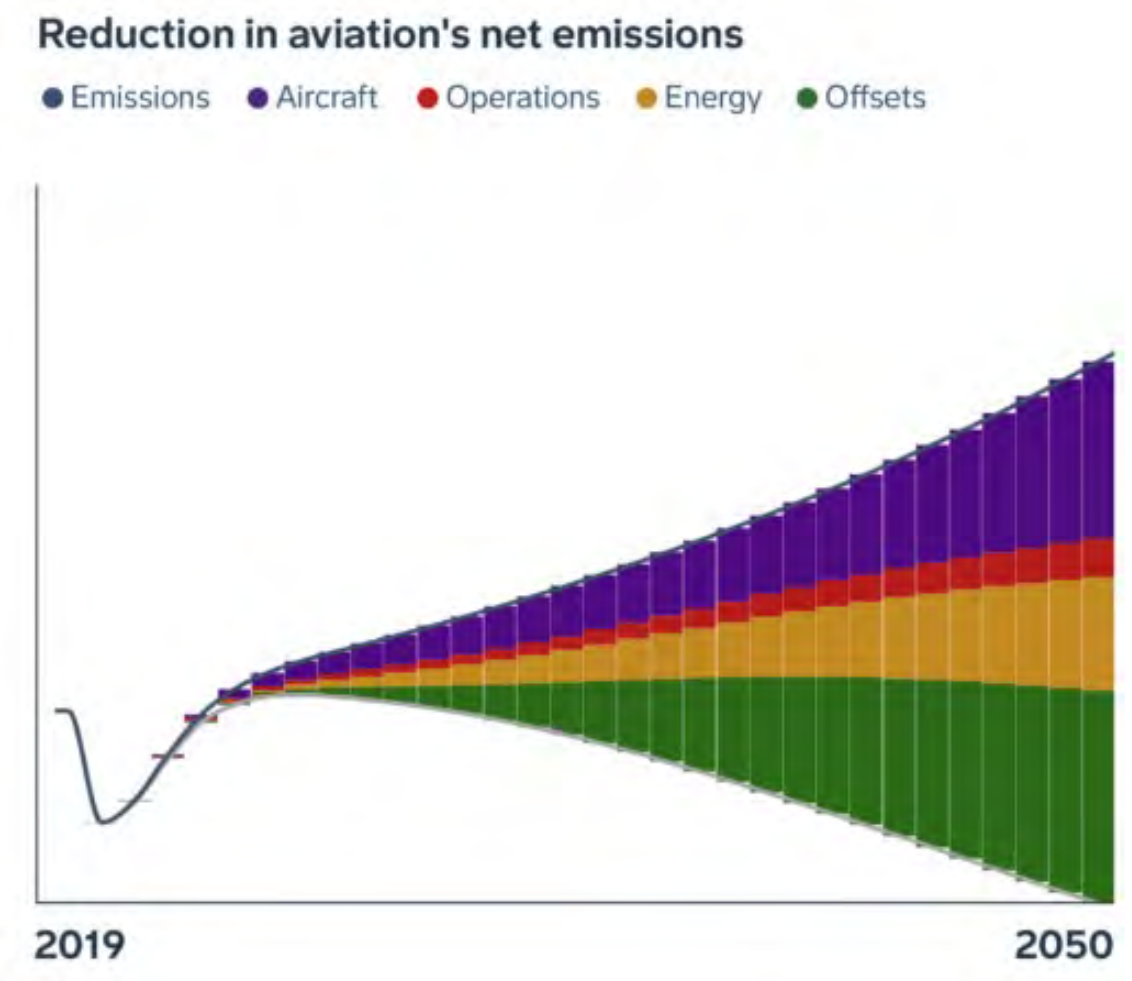


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Aspects of Sustainability Opportunities & Challenges Ahead

- Our Boeing Current Market Outlook (CMO) anticipates:
  - >50,000 fleet by 2045
    - Nearly 44,000 new airplanes
    - Roughly 50/50 split replacement vs growth
  - 3% Annual fleet growth
  - 4% Annual traffic growth

- As Commercial Aviation is a ‘growth’ industry, addressing Sustainability will require a multi-pronged approach.
  - Replacement Aircraft
  - New Aircraft Advancements
  - Improved Operations
  - Alternative Energy & Fuels
  - Non CO_2 Sustainability Challenges



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Levels of efficiency and sustainability expected for new products



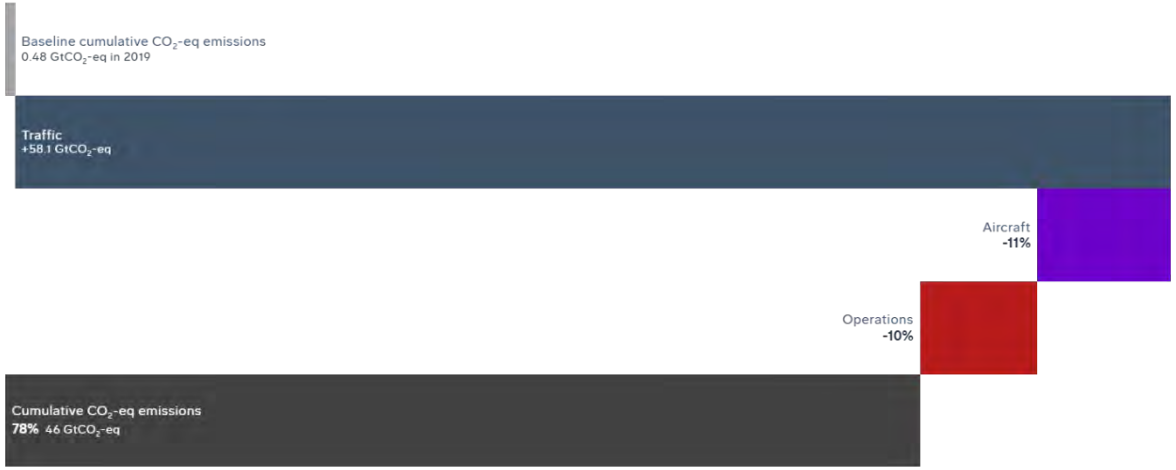
	737 MAX	787	777X	777-8F
REDUCTION IN FUEL AND CO_2	20% Reduction	25% Reduction	20% Reduction	30% Reduction
NOISE FOOTPRINT	50% Smaller	50% Smaller	40% Smaller	60% Smaller
REDUCTION IN CAEP/8 NOx	10% Reduction	40% Reduction	50% Reduction	50% Reduction
	Compared to original Next-Generation 737	Compared to 767-300ER	Compared to 777-300ER	Compared to 747-400F

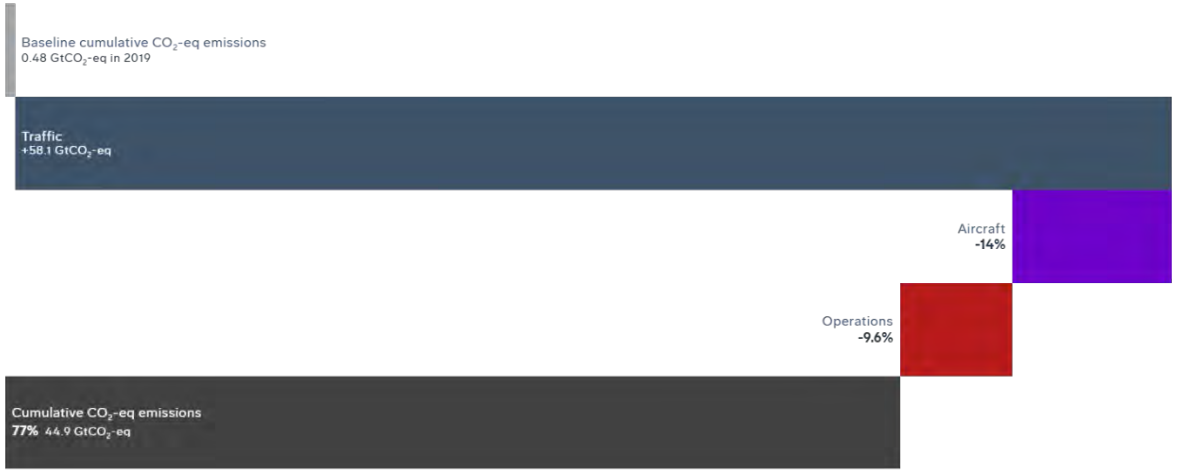
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Timing: Is it better to enter service sooner, or wait, if it meant higher efficiency?

Comparing cumulative single aisle fleet emissions by entry-into-service timing, in Cascade

Cumulative emissions from aircraft and operations of the single aisle fleet, gigatonnes of carbon dioxide equivalent emissions (Gt CO_2-eq)





Entering service in **203X**, with an airplane **15% more efficient** than today's best in class: **46 Gt CO_2-eq** cumulatively.

Entering service **five years later**, with **1.5% per annum** efficiency improvement over the five years: **44.9 Gt CO_2-eq** cumulatively.

Even starting five years later, the more efficient airplane produces lower cumulative emissions — its efficiency outweighs the late start.

Note: Emissions are measured against a latest-generation fleet baseline, the meaningful reference for timelines beyond 2050. The earlier airplane is modeled at best-in-class in-production efficiency; the later entry reflects 1.5% per annum efficiency improvement applied over the five additional years, relative to the earlier airplane. Operational improvements are modeled separately and held constant. Model horizon extended to 2075.
Source: Boeing Cascade Climate Impact Model | **Emission scope**: Well-to-wake

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What it Takes To Launch a New Commercial Product



Market Readiness

- ❑ Customer fleet stability & timing
- ❑ Competitive product positioning
- ❑ Macroeconomic environment



Technology Readiness

- ❑ Sufficient, balanced overall airplane operating benefits
- ❑ Production enablers & supply chain readiness
- ❑ Safe & Reliable product in service



Boeing Readiness

- ❑ Team and culture built to execute
- ❑ Financial health and a compelling business plan
- ❑ Tools and processes ready to certify and deliver on time

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Accelerating Innovation

250+ technologies
50+ partnerships
13 years



- Sustainable Aviation Fuel
- Operational Efficiency
- Community Noise
- Replacement of Hazardous Materials
- Reduction in Fuel Usage
- Customer Support
- Circular Life Cycle Technologies
- Advanced Aerodynamics

Building Blocks for Efficiency






Aerodynamics

Minimize cruise Drag, While Addressing Low Speed Performance

Propulsion

Advanced engines – Fuel, noise and emissions efficiency Reliable Time on Wing

Systems

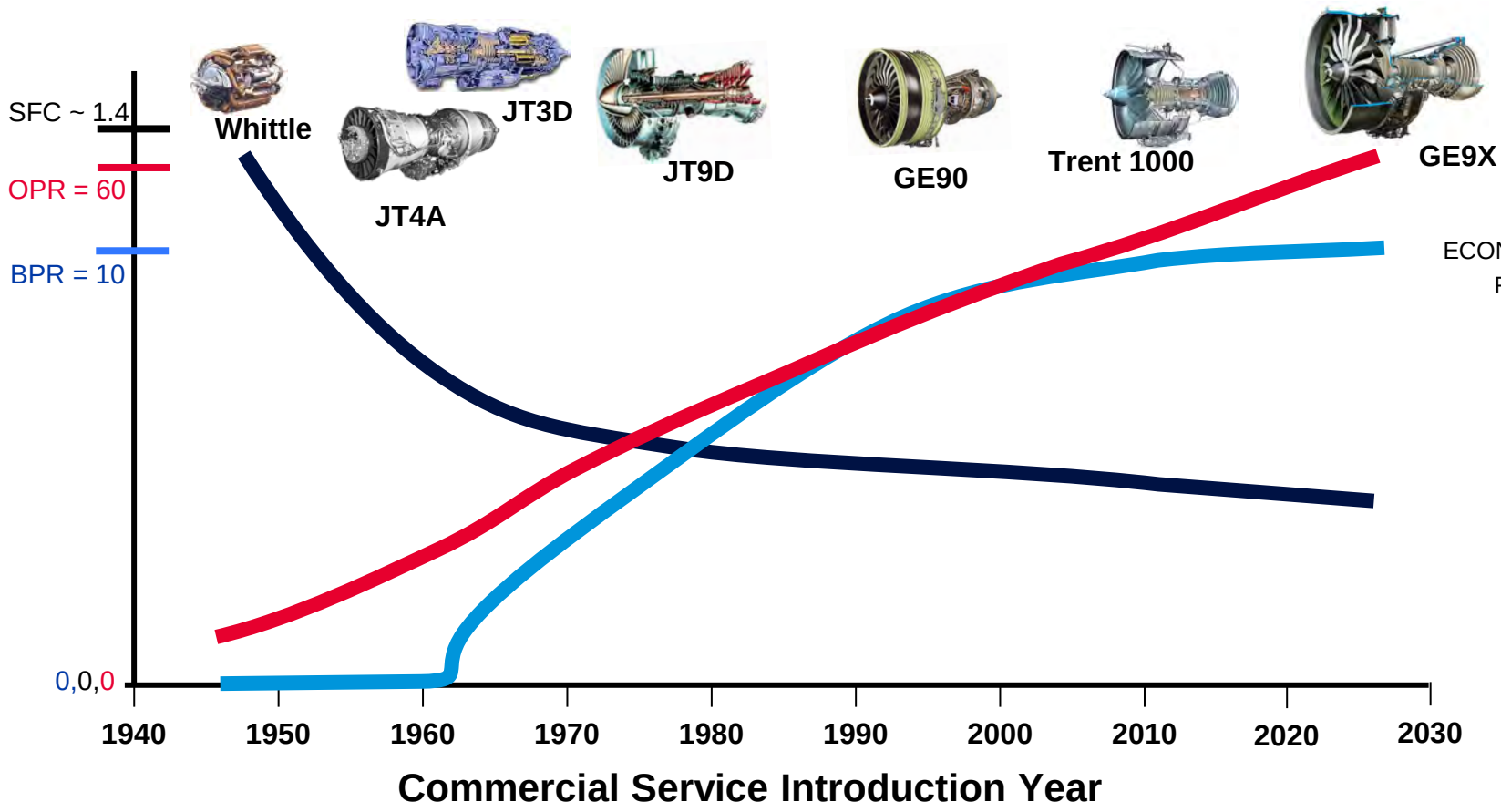
Safety oriented, appropriate automation, Tech insertion for value

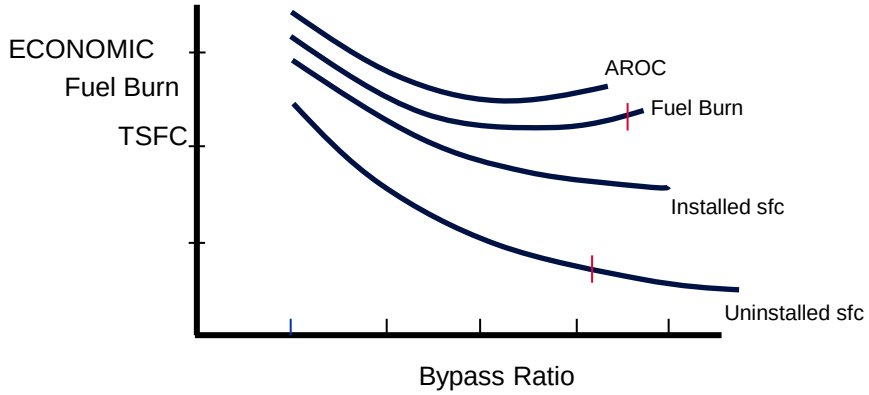
Structures

Advanced CFRP wing and fuselage, producible and maintainable

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Propulsion | Improvements with Time





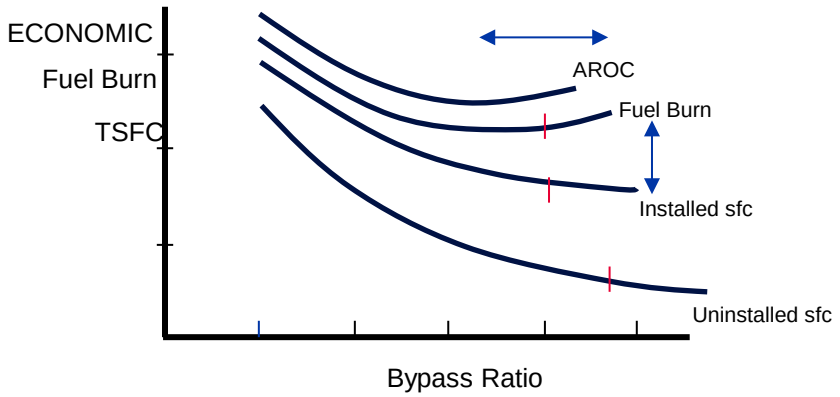
AROC – Airplane Related Operating Costs, includes ownership, maintenance, crew pay, fuel, etc.
Installed includes inlet, nozzles, bleeds, HP extraction, etc.

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Propulsion | Looking Forward

New engine architectures:

- Are assessed on comparative timelines
- And to consistent vehicle requirements for ‘apples to apples’ trades

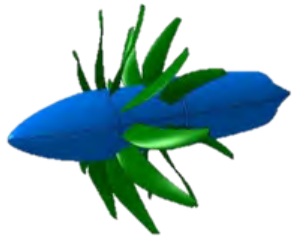




Ducted engines

- Harder working cores
- Trending up in BPR, increases nacelle weight and drag
- Direct drive vs Geared (and what type) engine architectures

Or



Open Rotor Concepts

- Harder working cores
- Greater engine to airframe, airframe to engine interactions (thrust drag bookkeeping)
- Different engine installation challenges
- Noise challenges
- Certification differences

Or

Increased Electrics

- Power the ‘utility’ systems on the airplane
- Used for managing turbine efficiently
- Used to provide propulsive thrust

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Boeing SAF Milestones

Viewed from the standpoint of fuel composition

SUSTAINABLE AEROSPACE TOGETHER

2008
First biofuel test flight with Virgin Atlantic

2011
Led research approval of HEFA pathway

2018
First commercial airplane test on 100% SAF (FedEx)

2021
100% SAF flight with Rolls-Royce

First 100% SAF passenger flight with United Airlines, one engine

2023
First 100% SAF transatlantic commercial flight with Virgin Atlantic, dual engine

100% SAF flight with Emirates on 777 – one engine only

2008 | 2010 | 2012 | 2014 | 2016 | 2018 | 2020 | 2022 | 2024

In 2008, Virgin flew a demo flight with a blend of jet fuel and biofuel created from coconut oil.

Boeing led efforts to test HEFA, which can be used up to a 50/50 blend

99% of the SAF in use today is HEFA

2018 100% SAF flight was on 100% HEFA with no aromatics

2021 flights were on a blend of 80% HEFA with 20% synthetic aromatics created from biomass

2023 Virgin flight on a blend of 88% HEFA with 12% synthetic aromatics created from biomass

2023 Emirates flight on a blend of 80% HEFA with 20% synthetic aromatics created from biomass

Boeing has committed its commercial airplanes will be 100% SAF-compatible by 2030

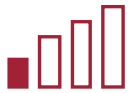
Boeing has a long history of thought leadership on fuel composition and in recent years has been at forefront of efforts to get to 100% SAF, including through the use of synthetic aromatics

Primary work streams:

- *Working with ASTM Intl to enable use of 100% SAF in today's aircraft through approval of synthetic aromatics*
- *Evaluating in-production aircraft to understand what is possible in terms of changing the fuel specification*
- *Conducting measurements to understand impact of fuel composition on persistent contrails*

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SAF State of Play

Feedstock	*Fats, Oils, & Greases*	*Sugars & Starches*	*Solid Wastes, Residues, and Novel Energy Crops*	*Power to Liquid / E-Fuels*
Examples	Used Cooking Oil, Soybean Oil; Palm Oil	Sugar Cane; Corn starch	Municipal solid wastes; Forestry Residues; Corn Stover; Rice Straw; Energy Grasses	Low carbon electricity, H_2O, Captured CO_2
Conversion Process ASTM Approved	HEFA	Alcohol-to-jet (ATJ)	Fischer-Tropsch (FT) Alcohol-to-jet (ATJ)	Fischer-Tropsch (FT) Alcohol-to-jet (ATJ)
Carbon Intensity	**Low to High** Depends on land use	**Low to High** Needs carbon capture	**Low** Depends on organic fraction of MSW	**Low** Requires green hydrogen
Feedstock Cost	**High**	**High**	**Low**	**High**
Production Cost Compared to Fossil Jet	**$$**	**$$$**	**$$$$**	**$$$$$$$**
Potential Supply Compared to 2050 Jet Fuel demand				
Competition	Diesel Engines	Gasoline Engines	-	Data Centers

CONTINUE DEPLOYMENT
but not sufficient to replace petroleum

FIND COST EFFECTIVE MEANS OF UTILIZATION

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SAF Emissions and Contrail Testing

2023 Boeing ecoDemonstrator Explorer 737-10

- Testing Objectives & Partners

- Study how a low-soot engine (GE LEAP-1B) and SAF affect contrails and non-CO2 emissions
- NASA, FAA Ascent, GE, DLR, and United Airlines

- Conclusions

- Early signs of improvement from fuel chemistry and lean burn combustion
- Relative humidity impacts on the formation of the contrail
- Potential opportunity to mitigate contrails through advanced satellite data and humidity sensors



2023 Explorer: 737-10

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Demonstrating Operational Efficiency



Boeing ecoDemonstrator Explorer 787-10 – Multi-Regional Trajectory Based Operations

Demonstrated how coordinating navigation across global airspace jurisdictions can improve operational efficiency

Leveraged existing equipment

Flight tests from Seattle to Tokyo, Singapore, and Bangkok in 2023

Optimized Air Traffic Management
can reduce emissions up to 10% (Eurocontrol data) and could help mitigate climate impact from persistent contrails

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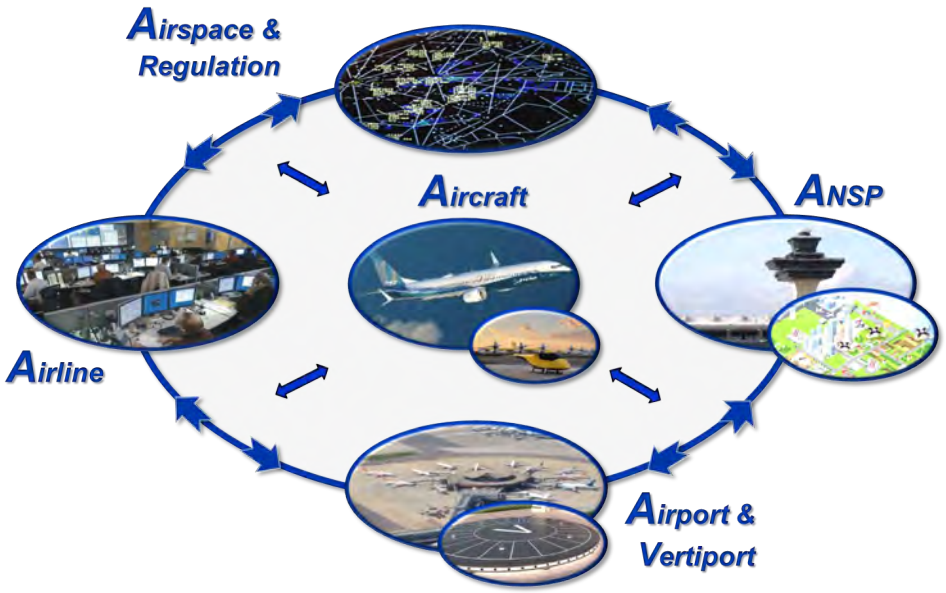
Airspace Operational Efficiency and Safety

Vision: Global widespread trajectory-based operations using digital services



Enabling Technologies

- Connected aircraft
- System wide information management
- Time-based traffic flow management
- Traffic management automation
- Data-driven services for airlines
- Collaborative decision making
- High-performance navigation
- Flight and Flow Information for a Collaborative Environment

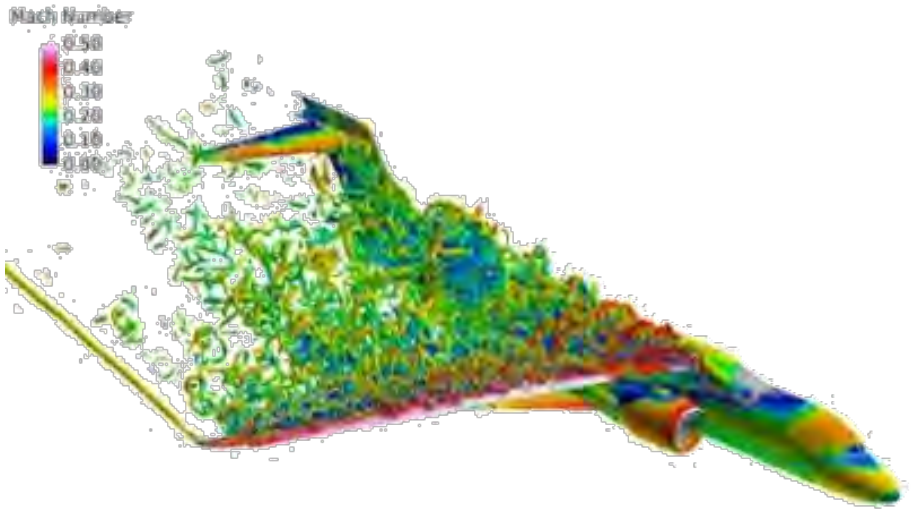


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Airframe Challenges & Opportunities

- Material **Systems**
- Aerodynamics





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Challenges – Optimizing for the next generation

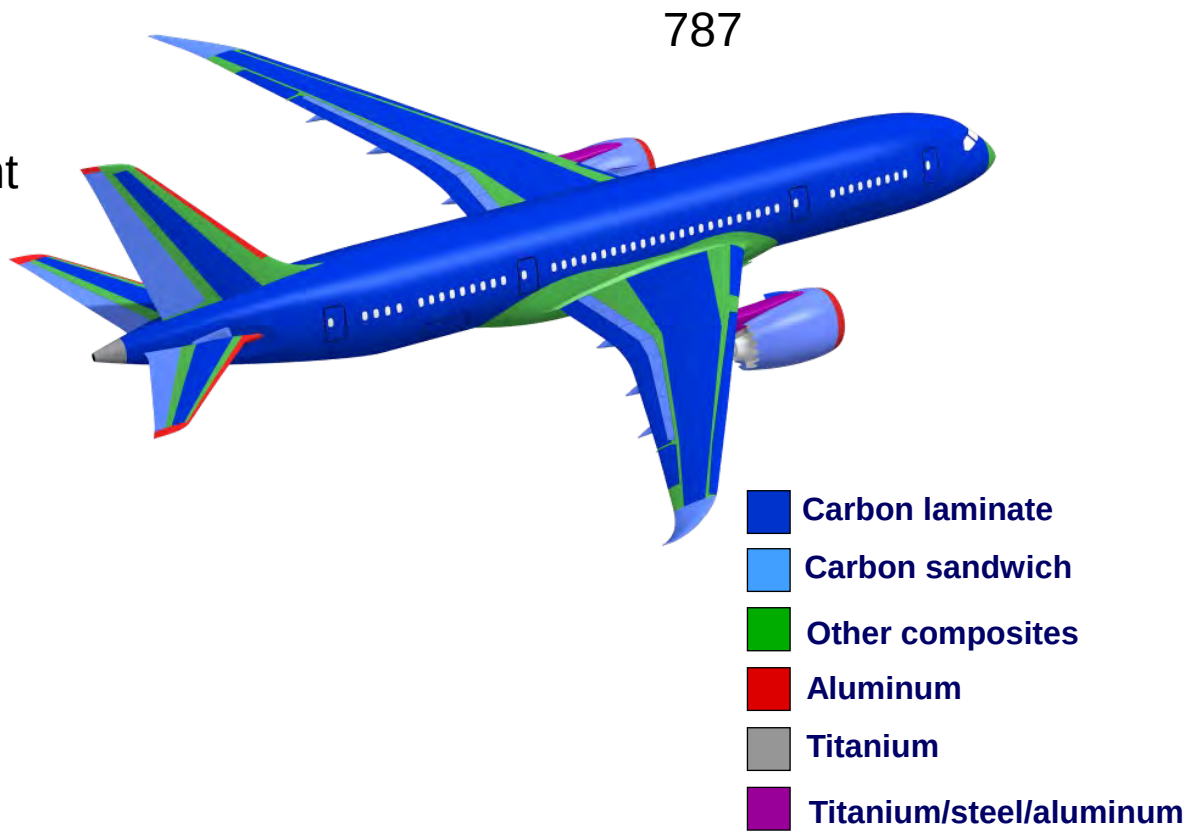
Opportunity:

- Continue the legacy of Structure and Material System advancements from our last two major products
- Progress our research and technology initiatives (Flight Sciences, airframe propulsion integration, Systems design) to align the overall TRLs to the new airplanes timing

Challenge:

The need to tailor the above for differences in requirements (e.g. single aisle vs long range twin aisles)

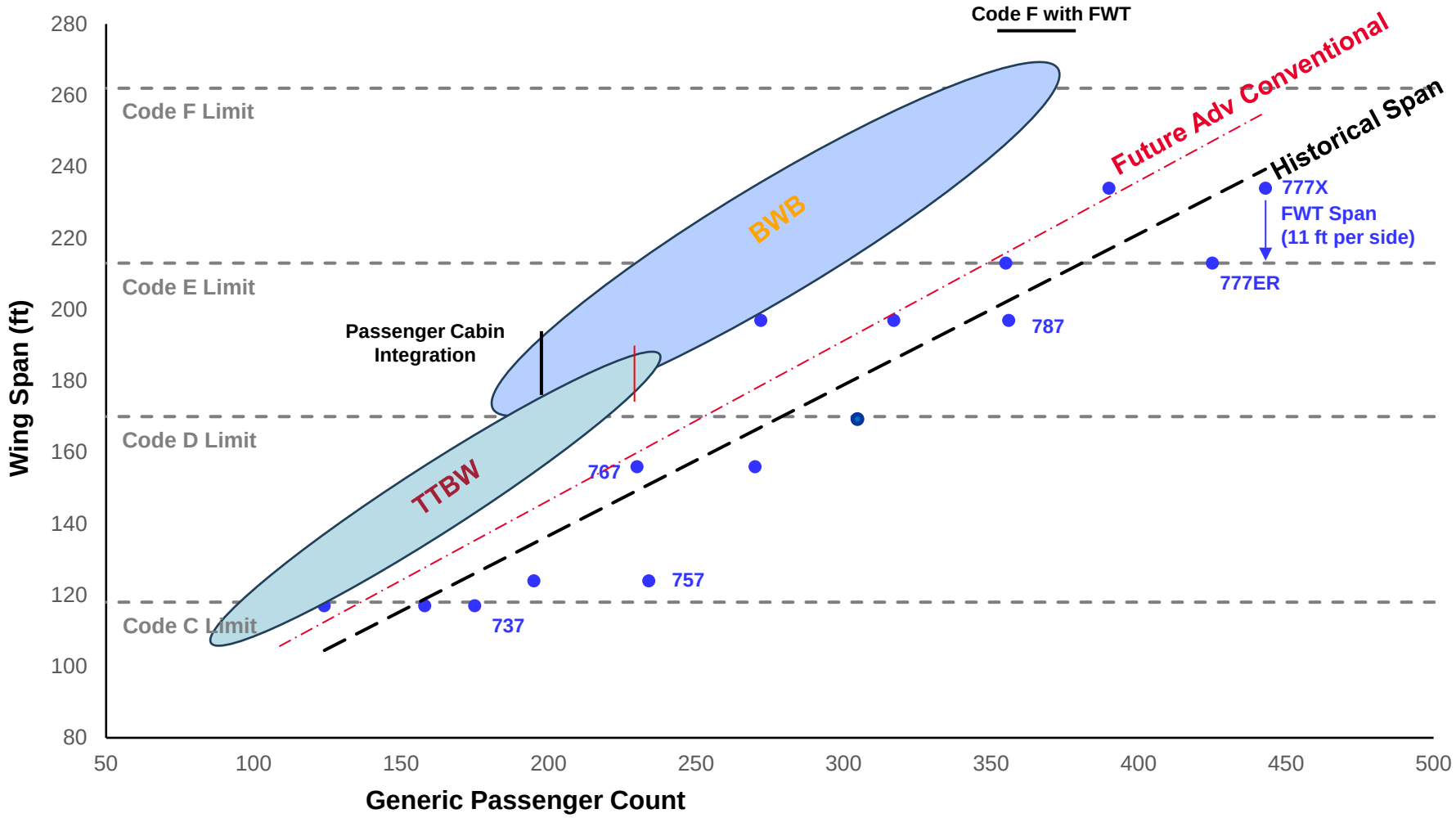
- Production rates
- Build processes
- Utilizations (economic missions, daily frequencies, reliability and maintainability, etc.)
- Diversity of operators, networks, airport locations
- Etc



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Spans want to be Increasing

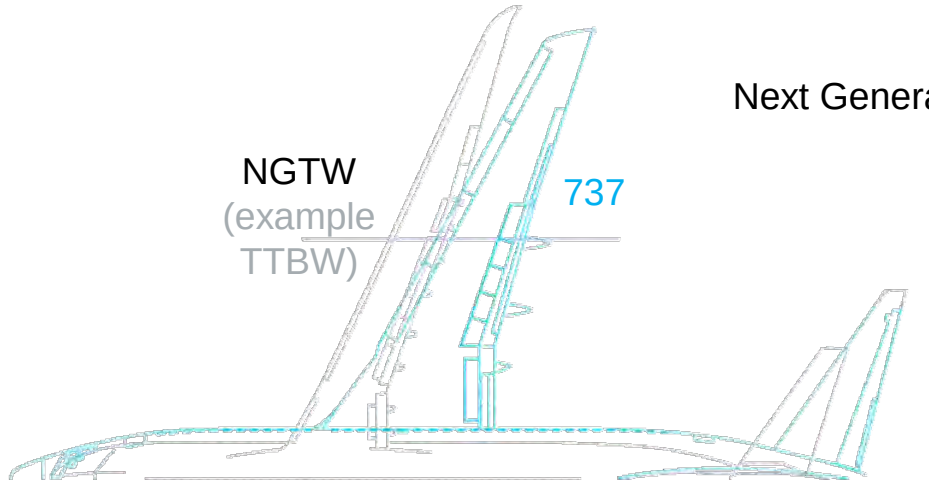


Trend with Technology

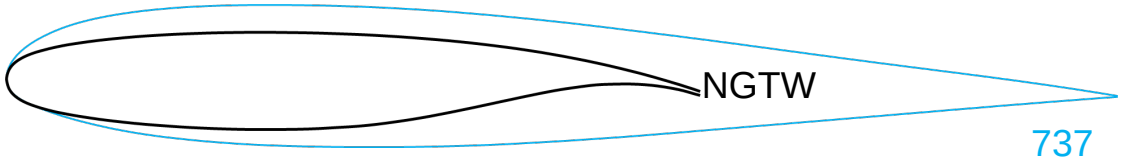
Trend market forces
(payload/range sizing)

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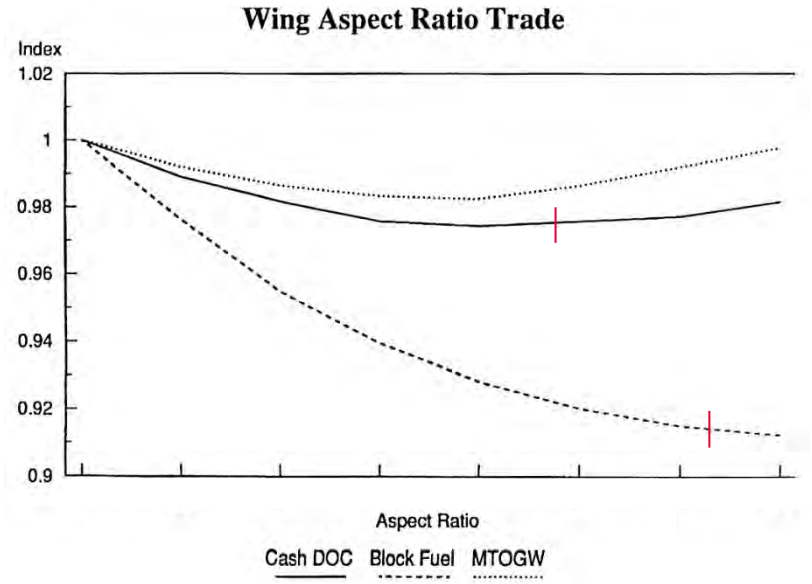
Opportunity Example – Optimizing for the next generation wings



Next Generation Thin-Wing (NGTW) comparison to 737
Illustrative purposes only



- Higher span, thinner wing designs are anticipated to minimize drag, improve efficiency, reduce emissions and potentially produce weaker wake vortices.
- However, as with any new airplane, the ‘sweet spot’ will ultimately be a trade-off of a particular airplanes value metrics.



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Build sustainably



100% renewable electricity
at manufacturing facilities

Novel partnership
to recycle excess carbon fiber

Zero
Waste to Landfill since 2011

End of service possibilities

Second lives as freighters

- Boeing converted freighter (BCF) fleet renewal
- Passenger-to-freighter programs provide airlines an economical way to replace less efficient, older-generation freighters

Used serviceable material (USM) offerings

- Recertified used parts from retired aircraft
- Boeing manages recertification, ensuring quality

Disassembly and materials recovery

- Boeing is a founding member of Aircraft Fleet Recycling Association (AFRA)
- Newer aircraft include higher amounts of carbon composite materials
- Boeing is collaborating with the industry on recycling carbon composite materials at the end of service



Carrying it Forward

- Addressing the sustainability challenges of commercial aviation is integral to all phases of our business, from research, design, build, support and after market.
- Our objectives are to find balanced, integrated solutions with all the relevant design considerations. Strive for ‘AND’.
- The next new airplane is still ahead of us, and we are at an exciting time of possibilities.
- Our developments and learnings will, in Bill Boeing’s words, be “Adapted to production…as soon as practical” Be it for new airplanes, derivatives and improvements on our current products.
- Stay tuned.





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