Aircraft Technology Modeling and Assessment

Project 10

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Purdue: Daniel DeLaurentis, William Crossley (PIs)
Stanford: Juan J. Alonso (PI)

Overview

Objective: Define range of scenarios that bound the demand for future aviation activity and assess the effects of different fleet composition, mission specification changes, and aircraft technology on fuel burn, emissions, and noise from aviation

- Evaluate broad set of future scenarios out to 2050, showing potential benefits of technology/mission spec. changes on fuel burn, emissions, and noise
- Provide modeling and assessment mechanism for aircraft technology
- Support NextGen Goals Analysis, other analyses

Approach:

1. Developed a set of harmonized fleet assumptions for use in future fleet assessments;
2. Modeled advanced aircraft technologies and advanced vehicles expected to enter the fleet through 2050; while
   - Leveraging, heavily, previous modeling work in CLEEN, NASA programs – and filling gaps as necessary for scenarios developed in (1)
3. Performed vehicle and fleet level assessments based on input from the FAA and the results of (1) and (2).

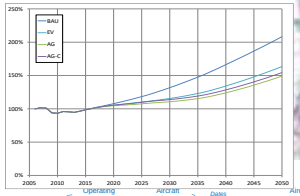
Team Approach to Tasks

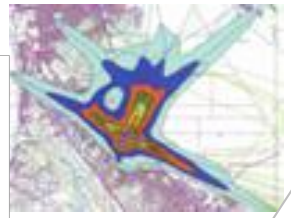
Objectives		Georgia Tech	Stanford	Purdue
1	**Harmonize Fleet Assumptions**	Lead process, coordinate industry, government participation, provide basis for discussion	Support assumptions definition, provide expert knowledge	Support assumptions definition, provide expert knowledge
2	**Advanced Vehicle and Technology Modeling**	Use **EDS** for public domain technology modeling, Provide tech models to Stanford and Purdue	Input into public domain technology modeling	Develop cost, fuel burn, block hour values for aircraft models from Georgia Tech
3	**Vehicle and Fleet Assessments**	Perform vehicle and fleet level assessments using **GREAT** and **ANGIM**	Provide trade factors for mission specification changes using **SUAVE**. Provide tech factors for some tech modeled in (2)	Fleet-level assessments using **FLEET (Fleet-Level Environmental Evaluation Tool)**

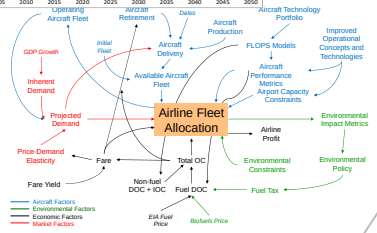
ASCENT-10 Project Focus Areas

Fleet Benefits Assessment

- **Use each university's analysis tools to understand fleet level implications of advanced technology/mission spec. changes on**
  - **Fuel Burn**
  - **Emissions**
  - **Noise**







Ascent 10 Team

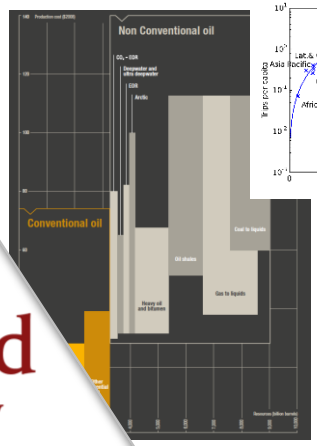
Georgia Institute of Technology

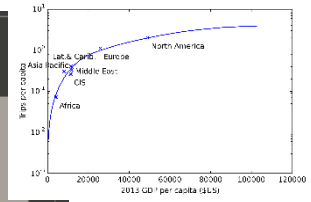
PURDUE UNIVERSITY

Stanford University

Technology Assessment Assumptions Setting

- **Work with broader community to define a standardized set of technology and fleet modeling assumptions for future benefits assessments**





Subsystem Technology Impacts → **Technology Effects on Vehicle** → **Fleet Level Implications**

Project Progression

Fleet Workshop #1

- **Goal: Determine what defines a world view or scenario**
- Feedback on descriptors (variables, ranges, and importance)
- Bring forward initial worldviews for comment

Fleet Workshop #2

- **Goal: Select specific worldviews/scenarios of interest**
- Feedback on technology insertion opportunities and their timing
- Feedback on worldviews and scenarios

Fleet Scenario Definitions Setting

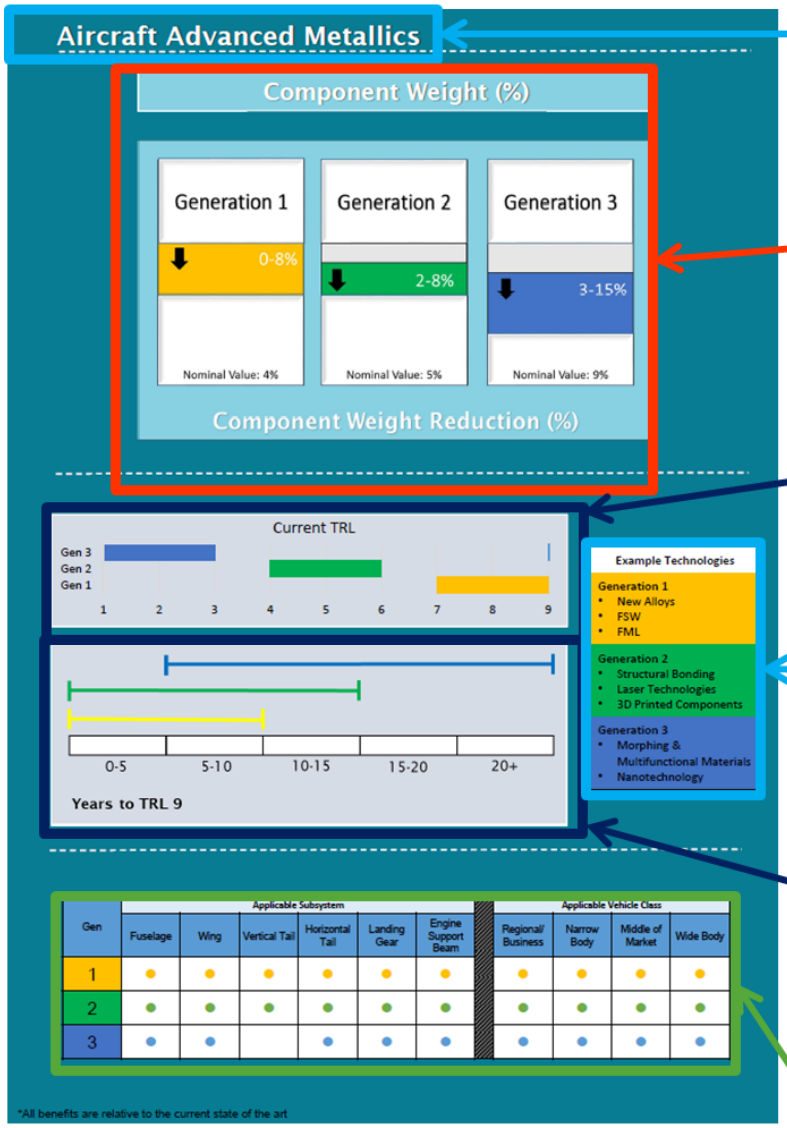
Tech Workshop #1

- **Goal: Identify technology maturation and availability for a broad range of technology areas**
- Feedback on examples of 1st/2nd/3rd generation technologies

Tech Workshop #2

- **Goal: Consensus on technology evolution scenarios**
- Feedback on specific technology impacts and maturation rates

Technology Workshop Outcomes



Technology Area

Technology Impact Area & Impact Ranges

- Top lists technology impact area
- Applicable vehicle class and subsystems
- Generation 1, 2, and 3 impact ranges (three point estimate)

Current TRL

- Lists current TRL for each technology generation

Example Technologies

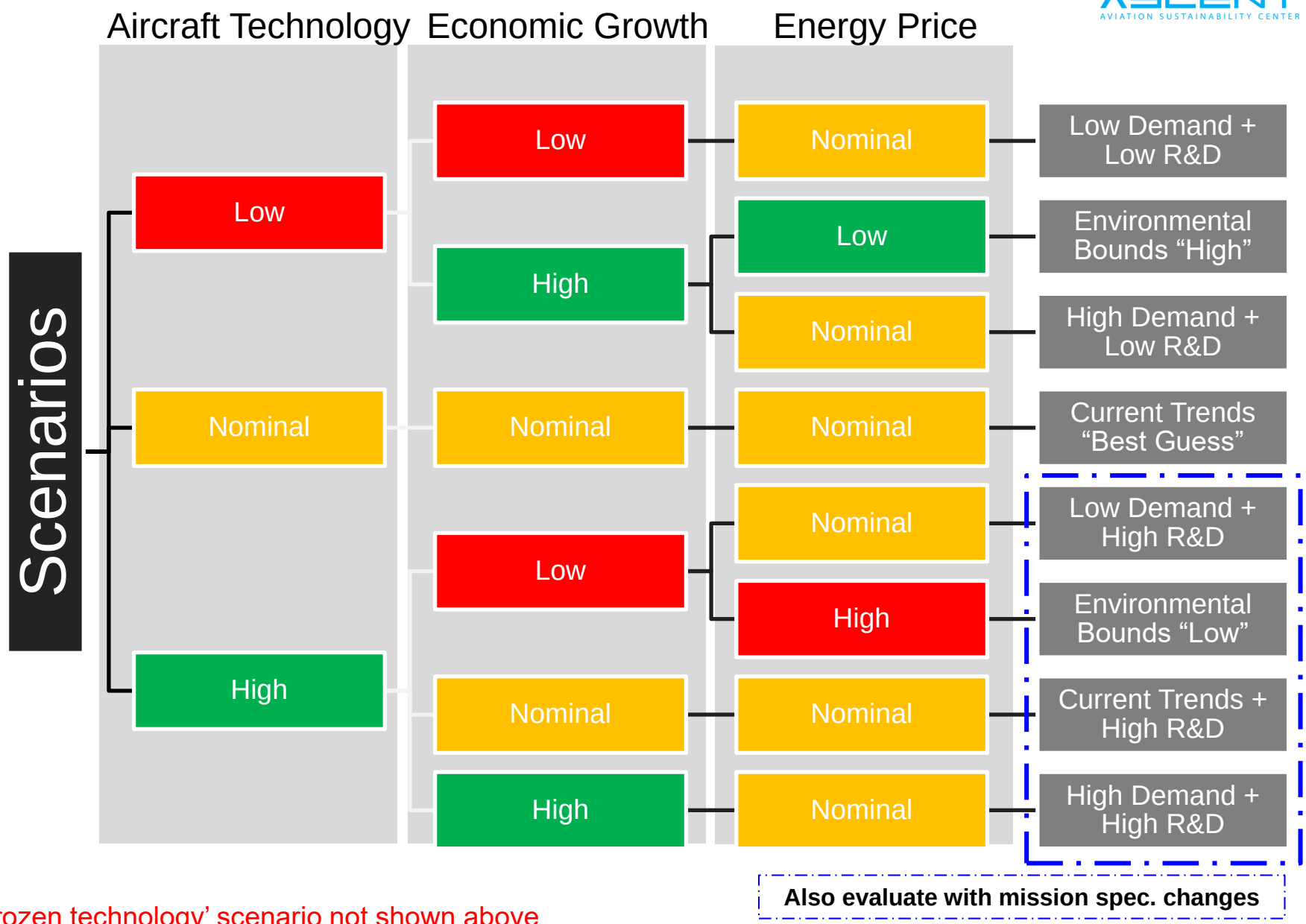
- Lists potential examples of applicable technologies by generation

Time to TRL 9

- Shows high and low estimates on time from present to bring each generation of a technology from the current generation to maturity

Applicable Vehicle Classes & Subsystems

Fleet Workshop Outcomes



* 'Frozen technology' scenario not shown above

World View Scenarios Assumptions

Demand/Economic Factors	Min	Nominal	Max
GDP Growth (%/year)	1.8	2.8	4
Energy Price ($/bbl)	41	77	181
Population Growth (%/year)	0.45	0.58	0.68
International Trade (%/year Asia)	3.3	4.3	5.9
Industry Competetiveness (cent/ASM)	12	12	12
Airport Noise Limitations (% airports noise limited in future)	4	25	95
Cost of CO2 Emissions ($/MT)	0	21	85
Fleet Evolution Factors			
Fleet Evolution Schedule	Single Aisle First	Twin Aisle First	
Aircraft Retirement	Early	Nominal	Late
Production Capacity	Limits	No Limits	
Aircraft Technology Factors			
Amount and Speed of Technology R&D Investment (relative)	0	1.365	1.71
TRL 9 Dates	Early	Medium	High
Benefit Levels	None	Medium	High
Mission Specification Changes		None	Yes (CSR)

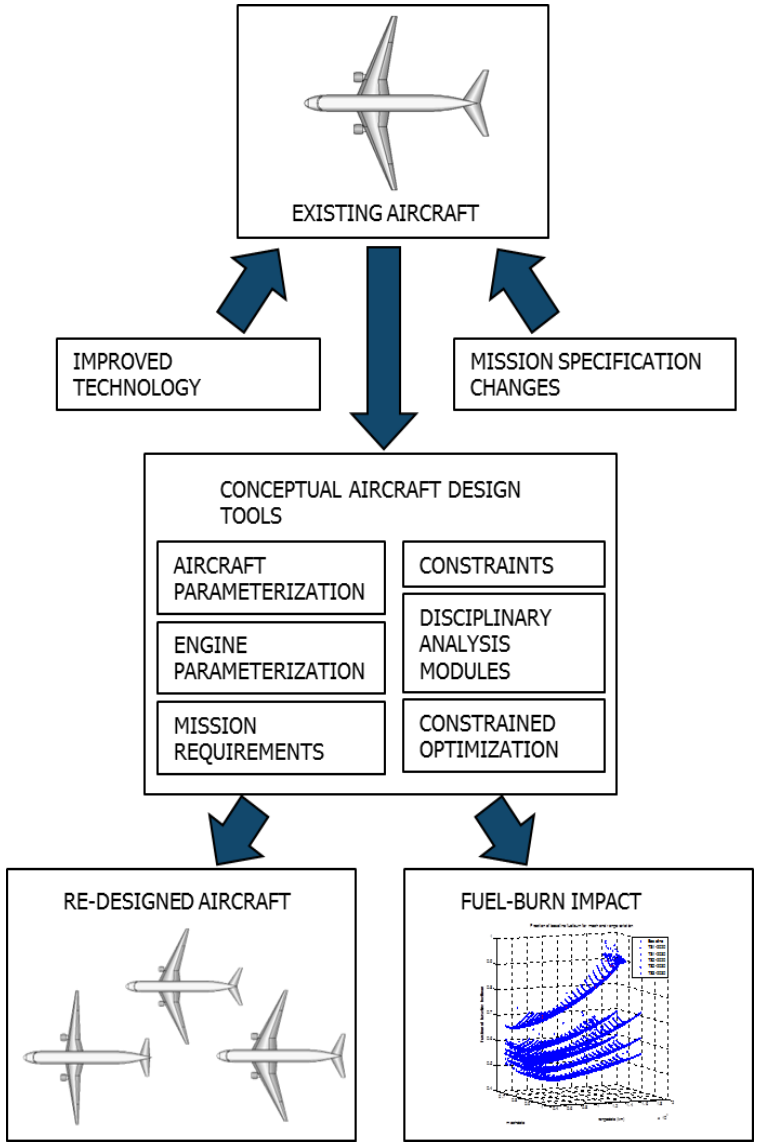
View descriptors become inputs to fleet model

	Demand/Economic Factors							Fleet Evolution Factors			Aircraft Technology Factors			
	GDP Growth (%/year)	Energy Price ($/bbl)	Population Growth (%/year)	International Trade (%/year Asia)	Industry Competetiveness (cent/ASM)	Airport Noise Limitations (% airports noise limited in future)	Cost of CO2 Emissions ($/MT)	Fleet Evolution Schedule	Aircraft Retirement	Production Capacity	Amount and Speed of Technology R&D Investment (relative)	TRL 9 Dates	Benefit Levels	Mission Specification Changes
Current Trends "Best Guess"														
Current Trends + High R&D														
Current Trends + High R&D + Mission Spec.														
Current Trends Frozen Tech - In-Production Only														
Environmental "Bounds" - Low														
Environmental "Bounds" - High														
High Demand (Including Global) + High R&D														
High Demand (Including Global) + Low R&D														
Low Demand (Including Global) + High R&D														
Low Demand (Including Global) + Low R&D														
Very High Demand with Noise Limits - Low R&D														
Very High Demand with Noise Limits - High R&D														

Mission Spec Changes Overview

- Some emerging world views and scenarios in ASCENT 10 (particularly the "High R&D" and "Environmental Bounds" worldviews) call for innovative solutions
- **Mission specification changes are operational improvements**, including aircraft and engine redesign, that can lead to significant fuel savings
  - **Cruise Speed Reduction (CSR)**
  - Changes to Payload/Range capabilities
  - Maximum allowable span
- PARTNER P43, investigated system-level economic implications using our best tools at the time. **CSR was found to be beneficial with all operational costs included.**
- **Improved tools** (SUAVE) and system-level analyses are now available to refine the quality of our predictions

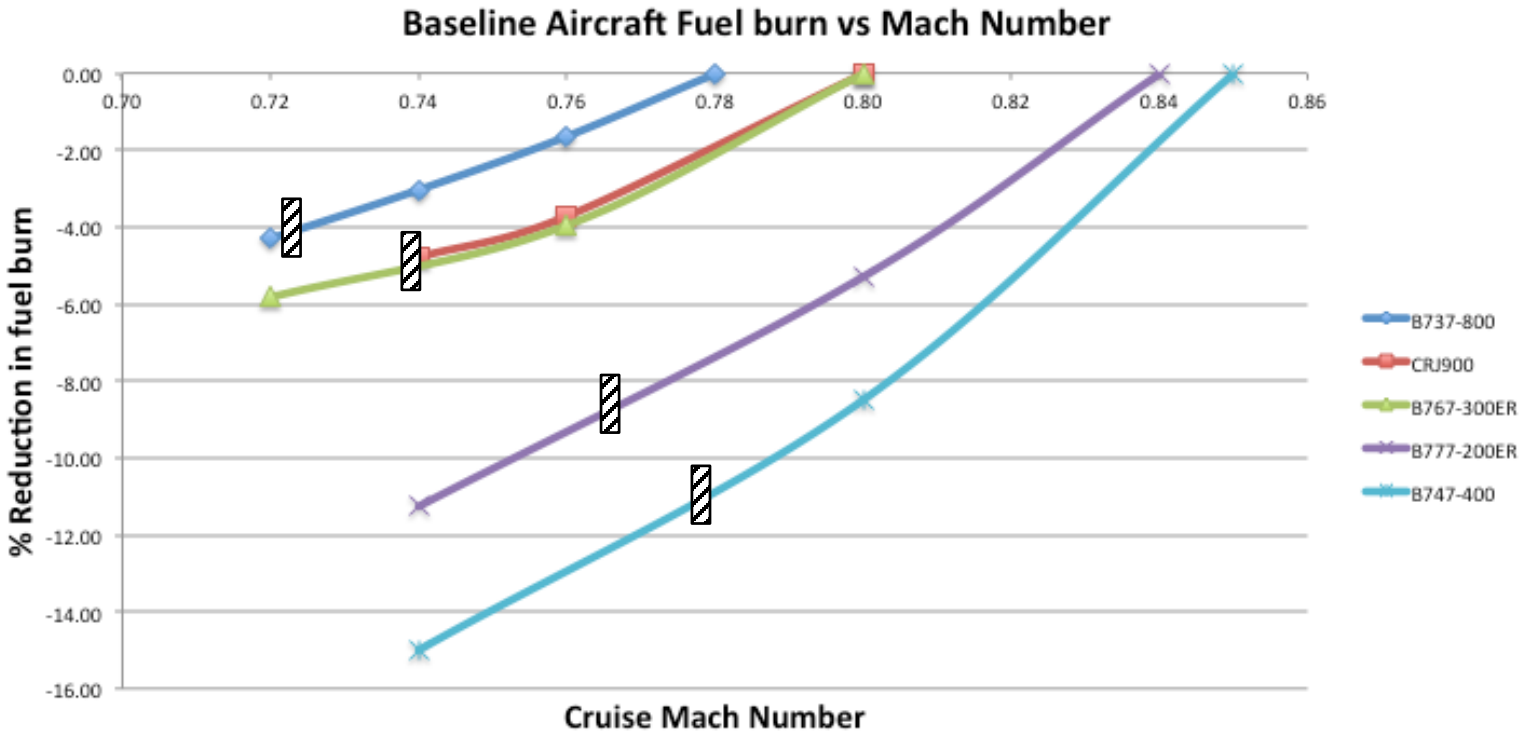
SUAVE



Mission Spec Changes Results

- Completed detailed analyses and re-designs for **all five aircraft classes**:
  - RJ: CRJ900
  - SA: B737-800
  - STA: B767-300ER
  - LTA: B777-200ER
  - VLA: B747-400
- **Factors** (% decrease in fuel burn over baseline) have been used in fleet-level simulations including **all aircraft types** and **different payload/range combinations**
- **Similar trends observed in all aircraft classes** (smaller wing area, engine params against bounds, de-sweeping / increased t/c).
- **Decreased fuel burn due to CSR varies by aircraft class** with long range vehicles showing larger benefits (4%-15%)
- Fleet-level savings depend on the fraction of new aircraft redesigned with CSR

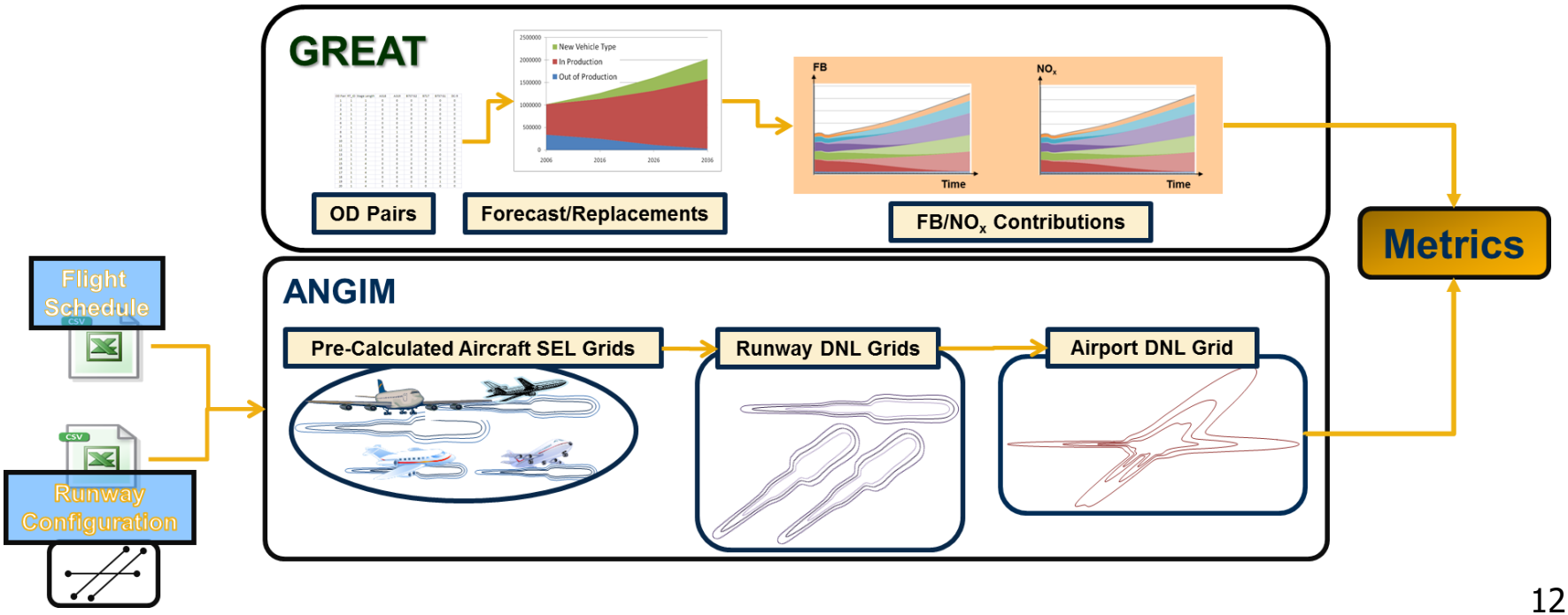
CSR Impact on Fuel Burn



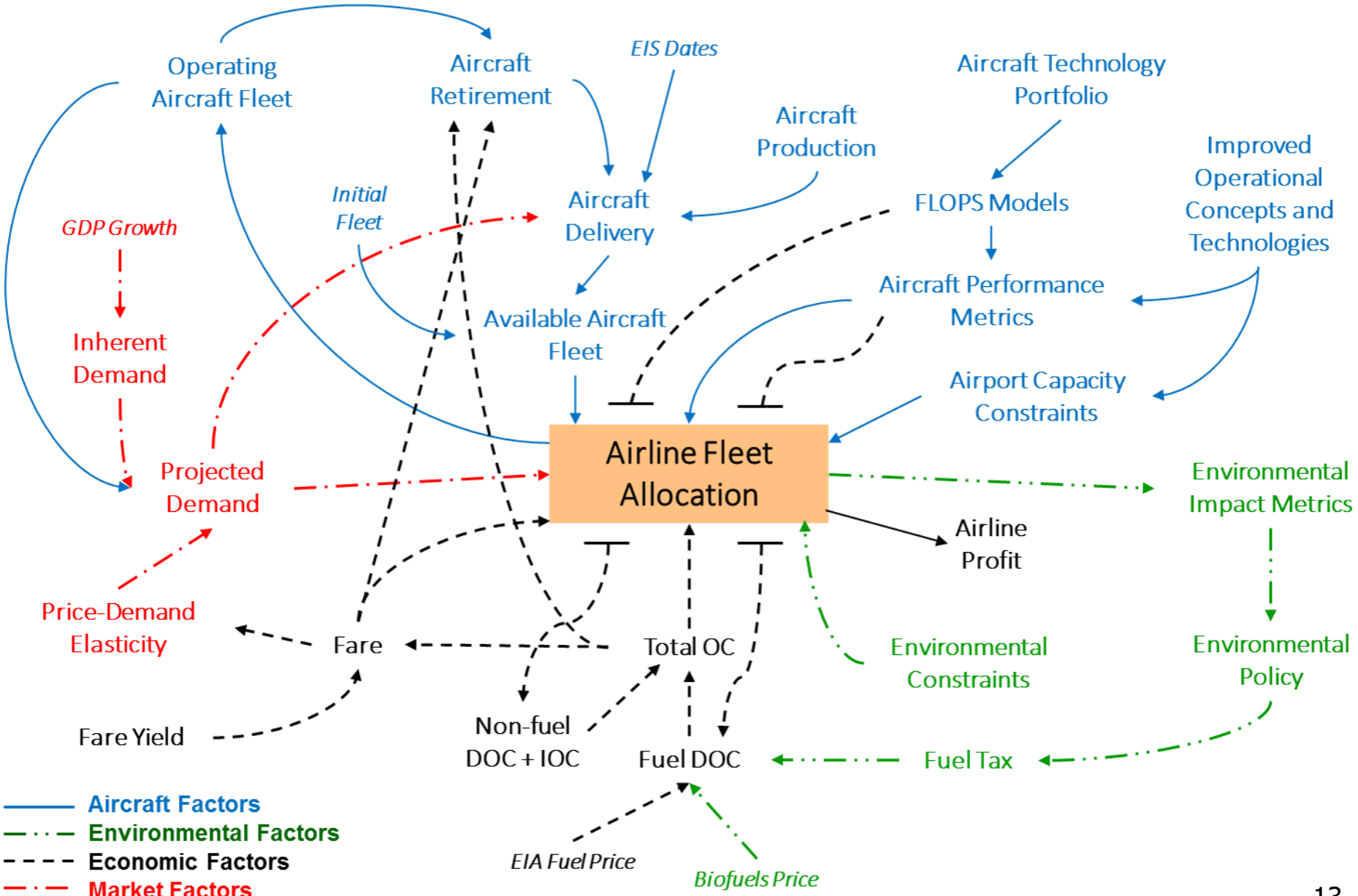
- Block fuel burn of re-designed aircraft is smaller by 4-15% depending on aircraft class and selected cruise Mach number
- In these re-designs the wing span is constrained to be no larger than the baseline aircraft value
- For each aircraft, the economically-viable CSR is typically around 8-10% of the baseline value (indicated with ▨ on the plot)

Tools: GREAT/ANGIM

- Methods developed to enable *rapid analysis* of fleet-level environmental impacts
  - **G**lobal and **R**egional **E**nvironmental **A**viation **T**radeoff (**GREAT**)
    - Metrics: Fuel-Burn, NO_x
  - **A**irport **N**oise **G**rid **I**nterpolation **M**ethod (**ANGIM**)
    - Metrics: Grids of DNL values, DNL contours (measures areas & shape metrics), and population exposure



Tools: Fleet Level Environmental Evaluation Tool (FLEET)



Aircraft Models In FLEET

Aircraft Types in Study				
	Representative-in-Class EIS 1983-2001	**Best-in-Class EIS 1996-2007**	**New-in-Class EIS 2017-2025**	**Future-in-Class EIS 2030-2040**
SRJ	Canadair RJ200/RJ440	Embraer ERJ145		
RJ	Canadair RJ700	Canadair RJ900	GT Gen1 DD RJ (2020)	GT Gen2 DD RJ (2030)
SA	Boeing 737-300	Boeing 737-700	GT Gen1 DD SA (2017)	GT Gen2 DD SA (2035)
STA	Boeing 757-200	Boeing 737-800	GT Gen1 DD STA (2025)	GT Gen2 DD STA (2040)
LTA	Boeing 767-300ER	Airbus A330-200	GT Gen1 DD LTA (2020)	GT Gen2 DD LTA (2030)
LQ	Boeing 747-400	Boeing 777-200LR	GT Gen1 DD LQ (2025)	GT Gen2 DD LQ (2040)

SRJ – Small Regional Jet
RJ – Regional Jet
SA – Single Aisle
STA – Small Twin Aisle
LTA – Large Twin Aisle
LQ – Large Quad

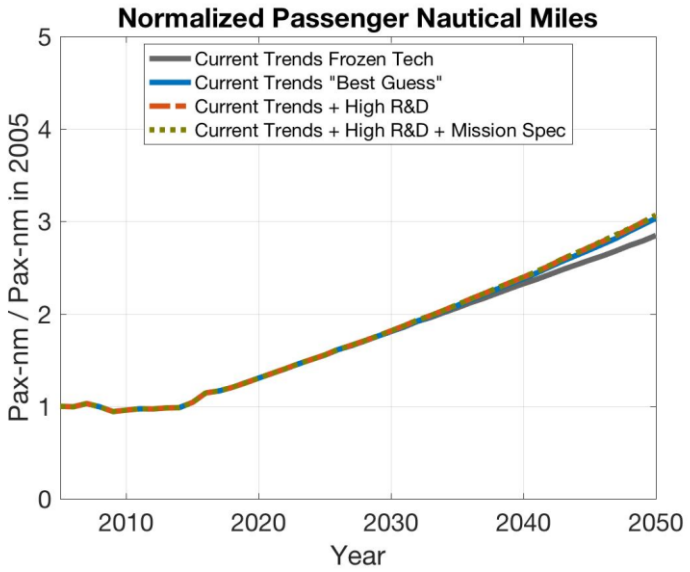
Tools: Major Differences in Modeling Approaches

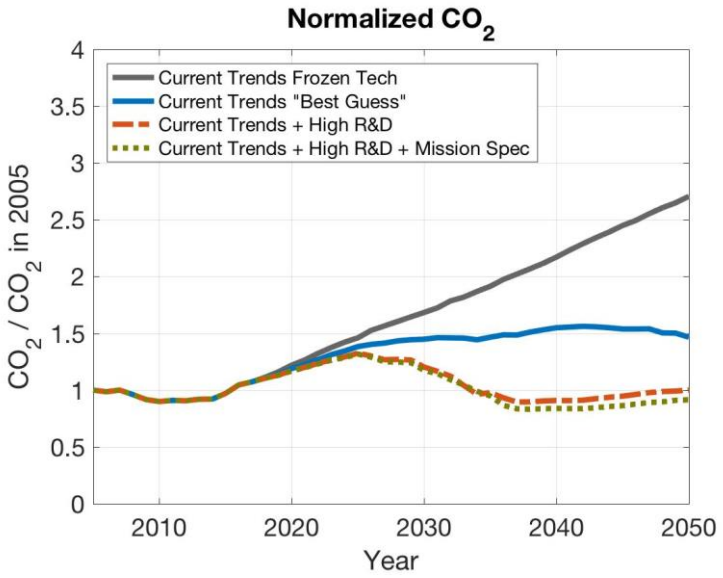
Category	FLEET	GREAT
Demand	Year-to-Year (Bottom-up)	Forecast driven (Top-down)
Evolution of Fleet Composition	Accommodates up- or down-gauging	One-for-one size replacement
Aircraft Retirement	Driven by airline NPV	Retirement curves
Aircraft Replacement Choice	Driven by airline NPV	Set schedule
Aircraft Replacement Availability	Fixed category	Year-to-year schedule
Noise Limit	65 dB DNL area cap decreased linearly (starting in 2020) to 50% of 2005 total DNL area by 2050	65 dB DNL area not allowed to exceed 2010

Fleet Turnover

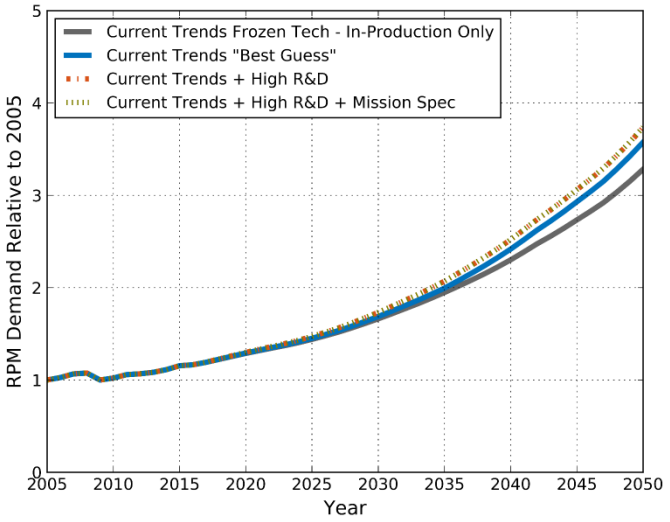
Current Trends Technology Effects

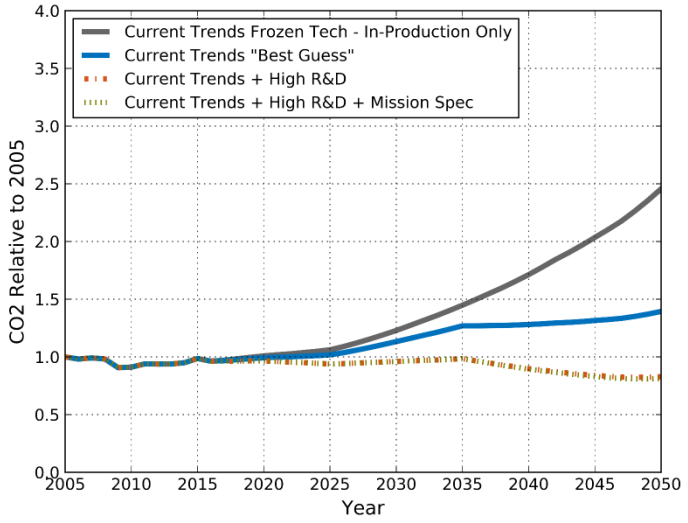
FLEET





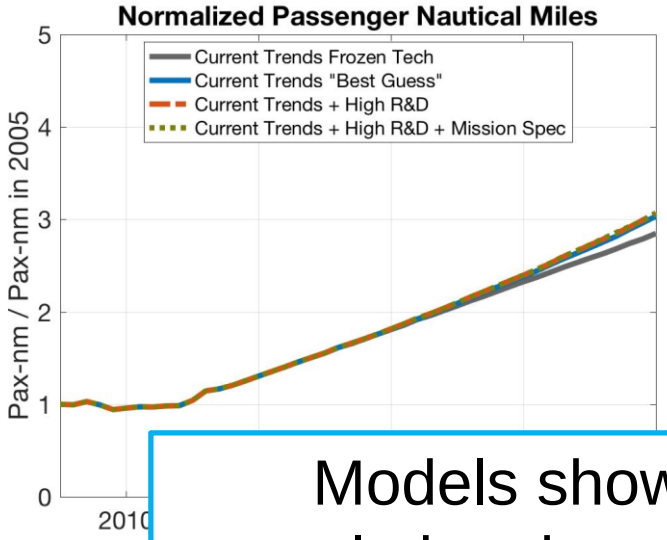
GREAT



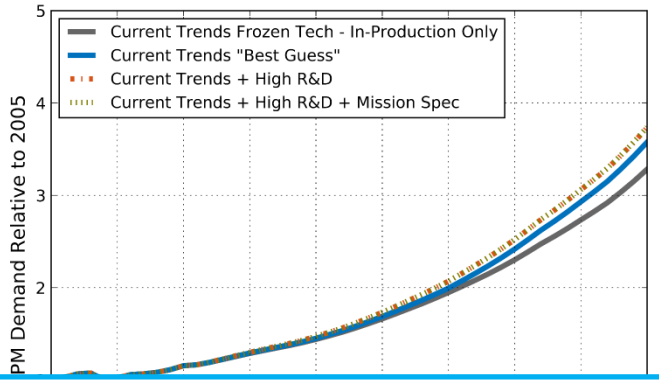


Current Trends Technology Effects

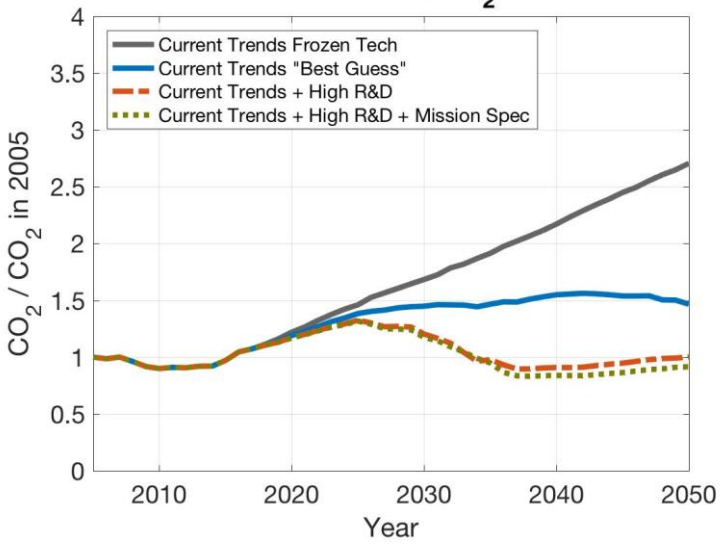
FLEET

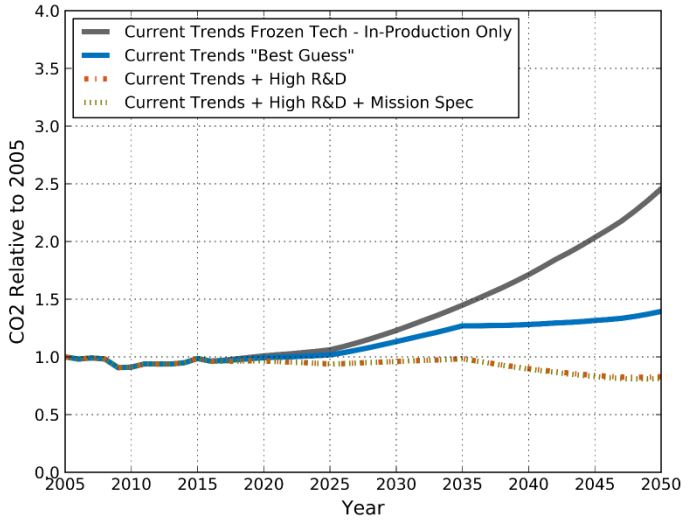


GREAT



Models show different pax-nm and CO_2 evolution, but similar CO_2 outcomes in 2050

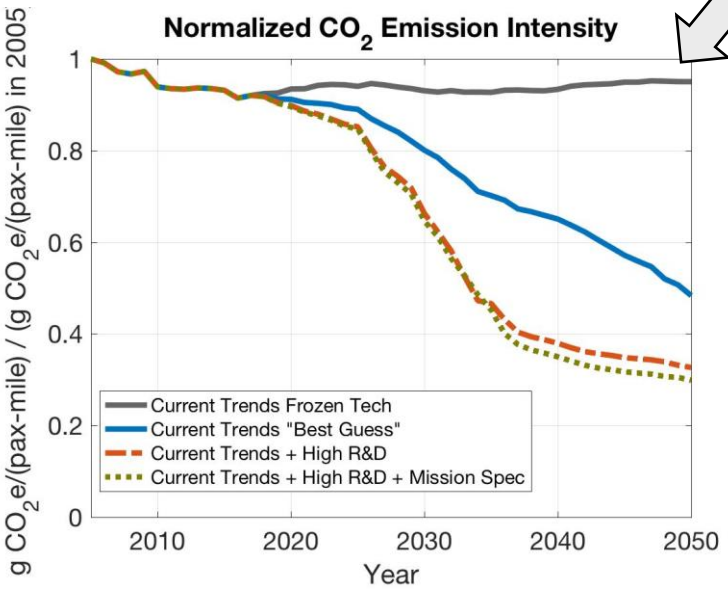




Current Trends: Normalized CO_2 Emission Intensity

Implementation of Frozen Technology scenario is slightly different

FLEET



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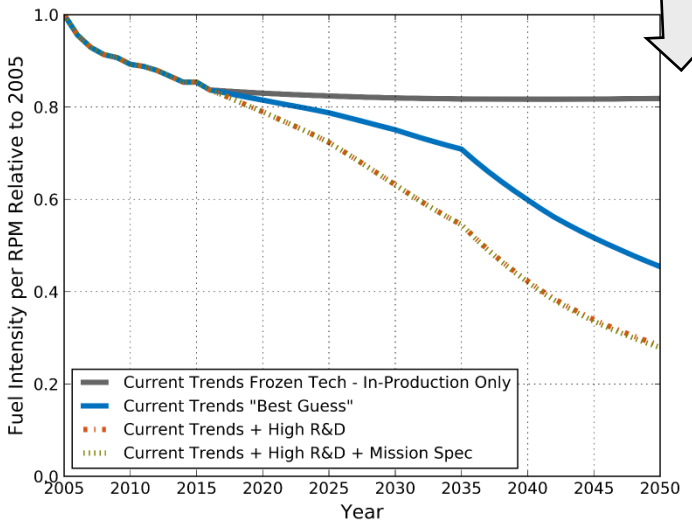
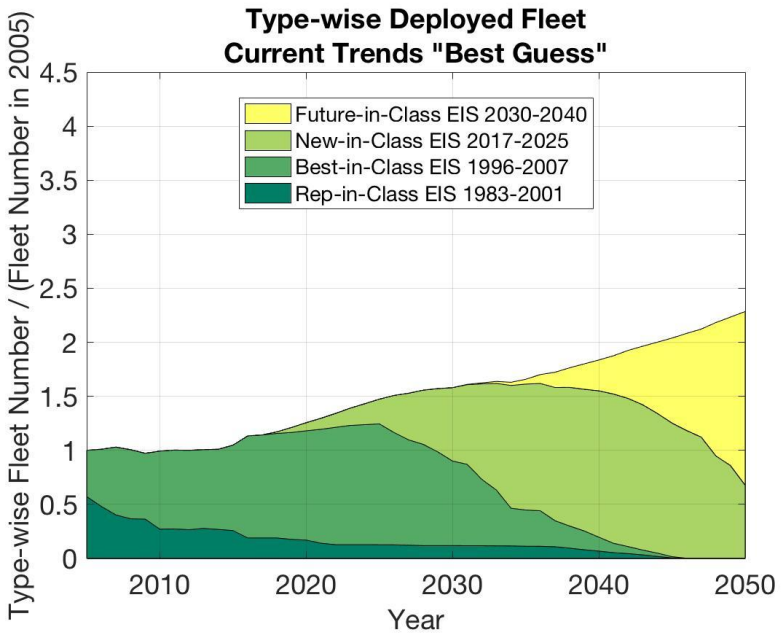


Impact of mission specification changes secondary to technology

Fleet Evolution – Current Trend Best Guess

FLEET



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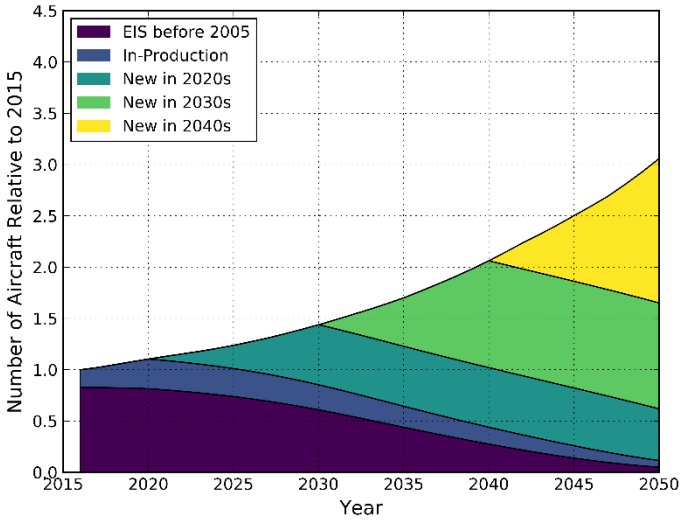
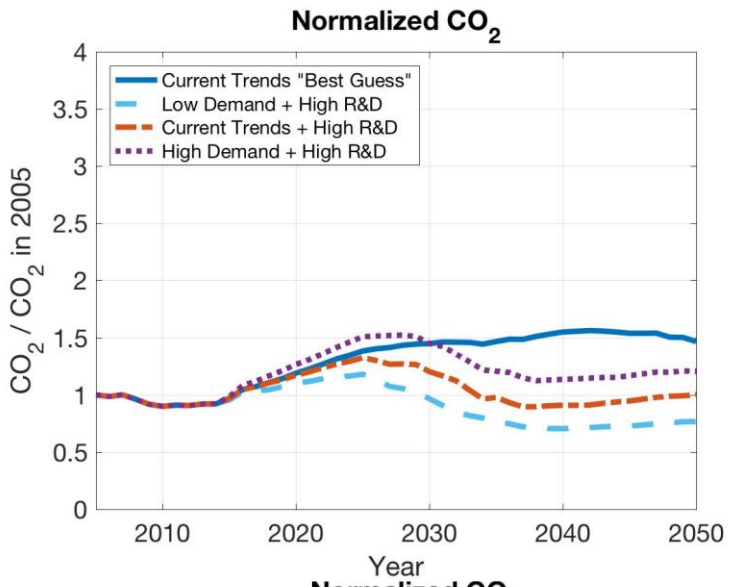
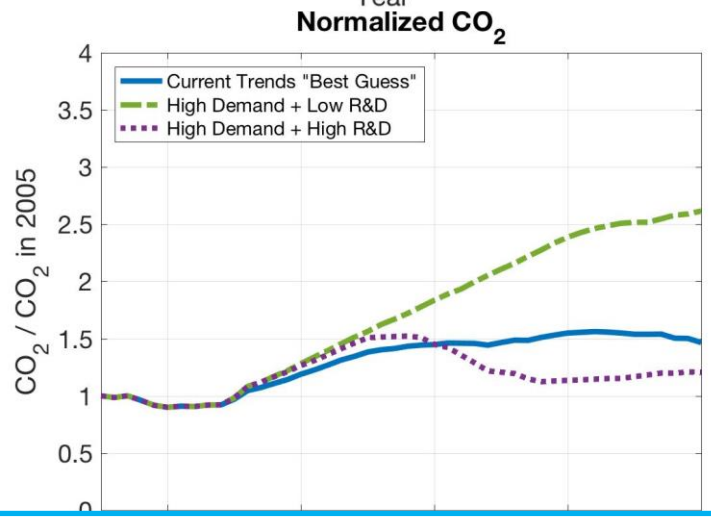


Similar trends, but with some differences due to differing retirement, acquisition, and allocation strategies.

CO2 by Demand Variation (Upper) & Technology Variation (Lower)

FLEET





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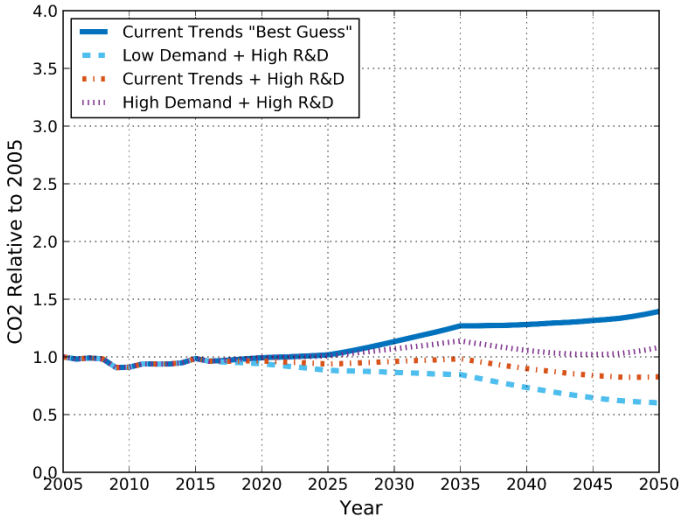
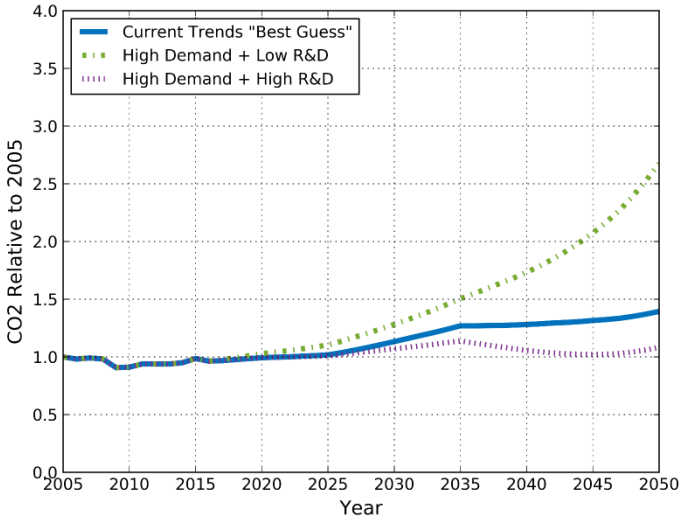


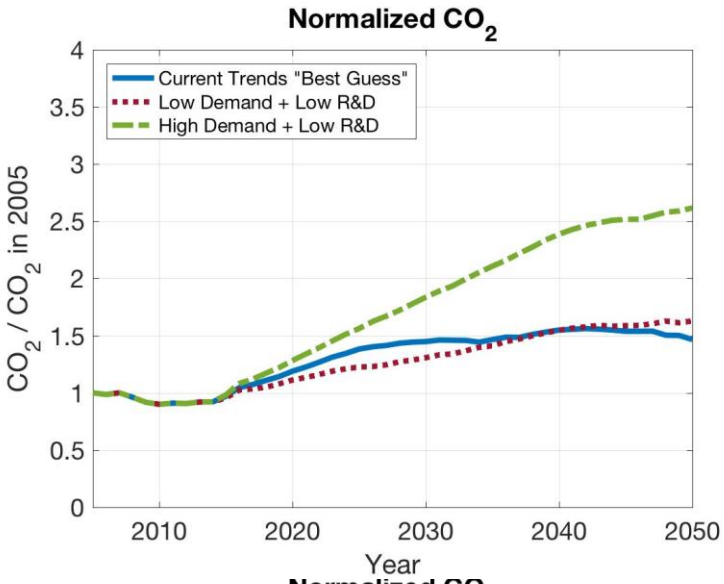


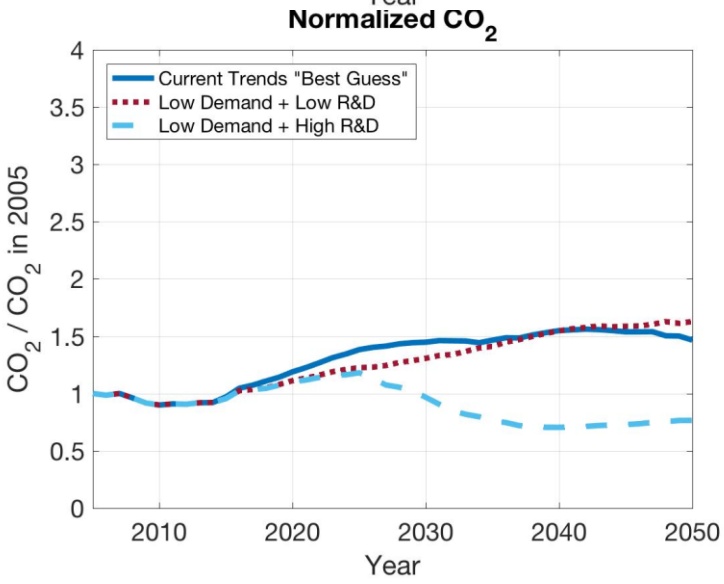
Increased demand makes it difficu
goals, even with advanced technology

CO2 by Demand Variation (Upper) & Technology Variation (Lower)

ASCENT
AVIATION SUSTAINABILITY CENTER

FLEET





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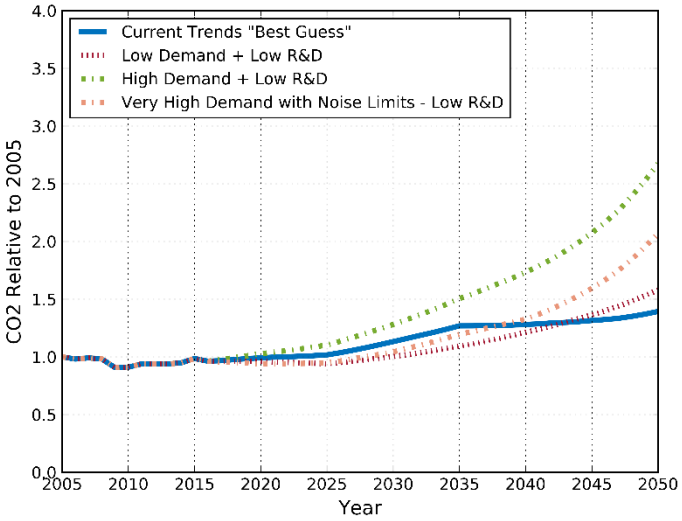
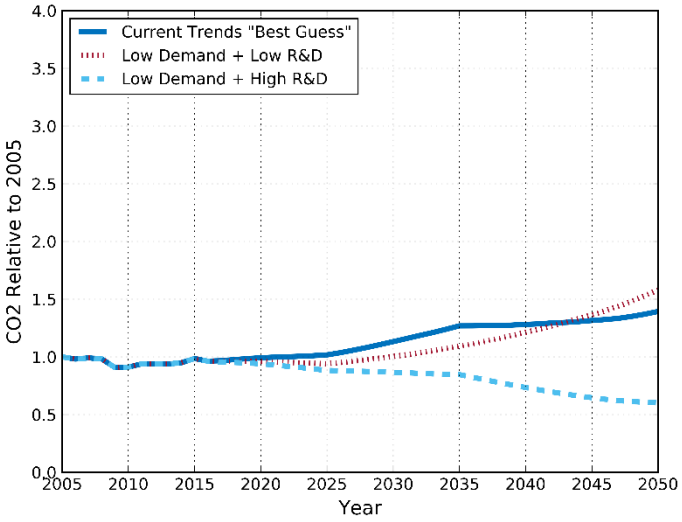
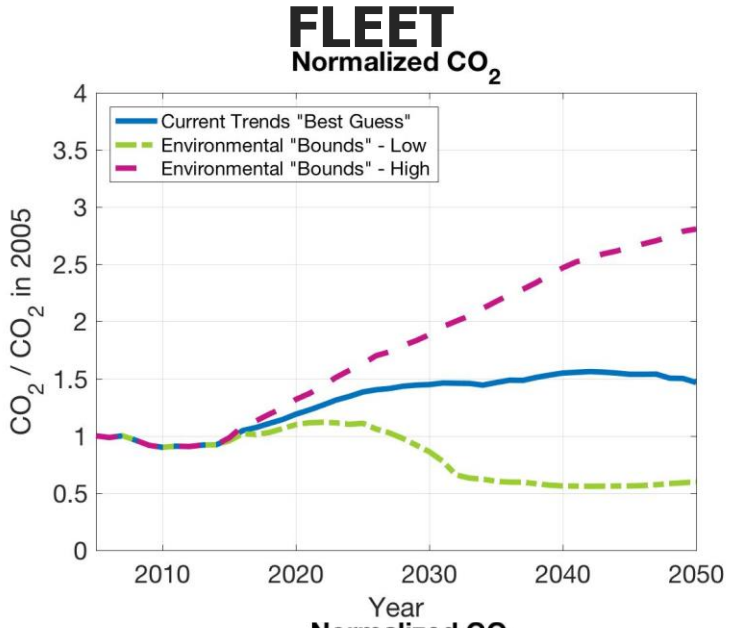
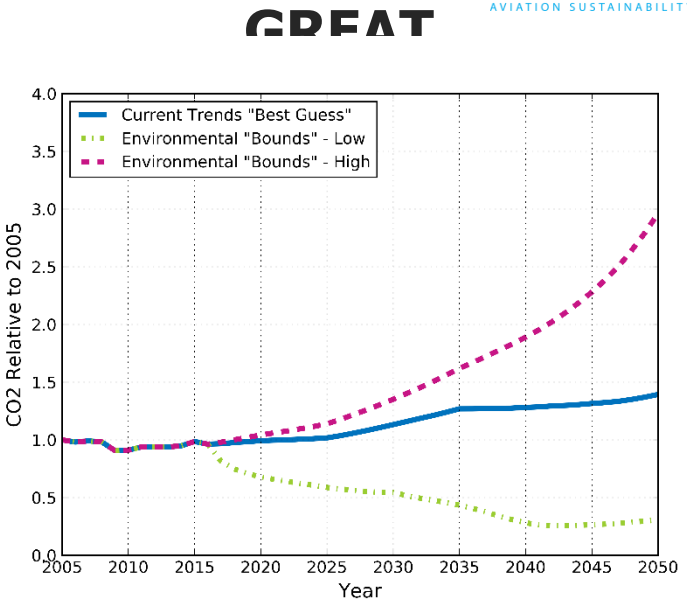
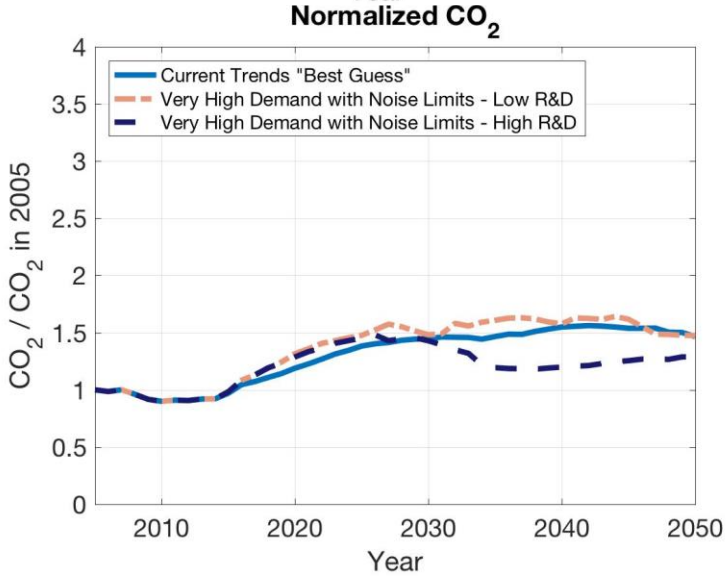


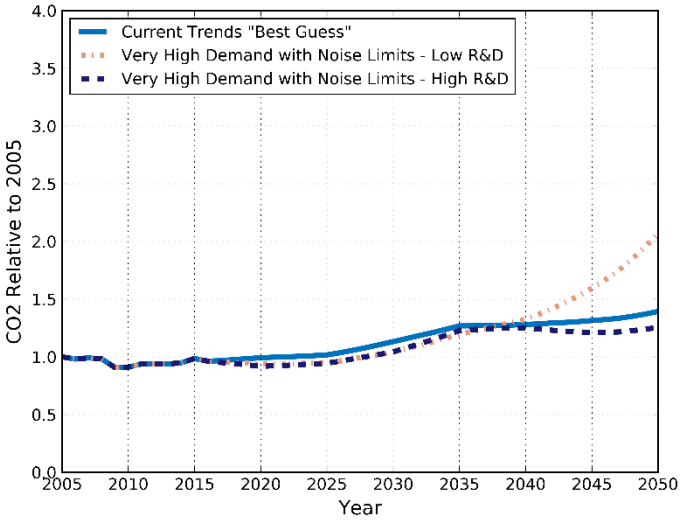


Environmental Bounds and Noise Limits





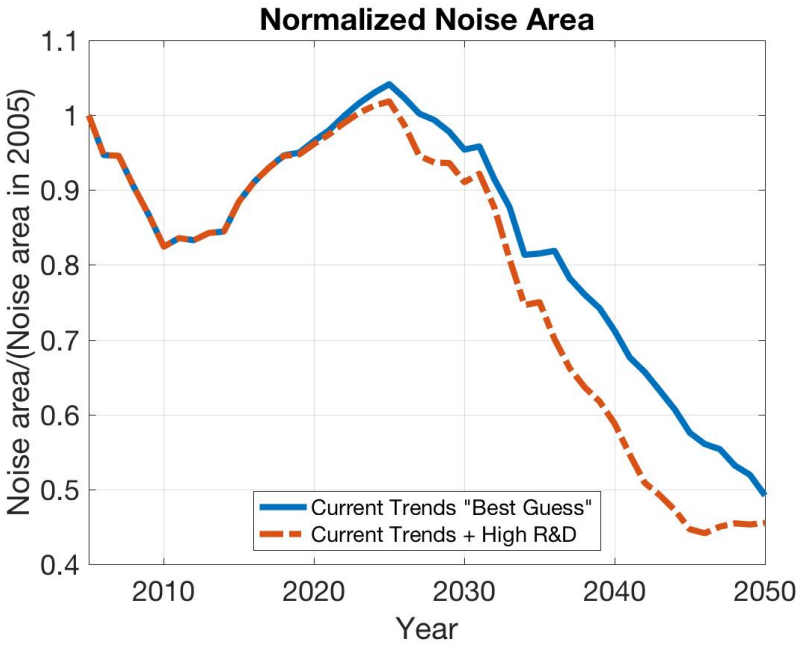




Scenarios bound environmental outcomes

FLEET and GREAT Noise Analysis

FLEET



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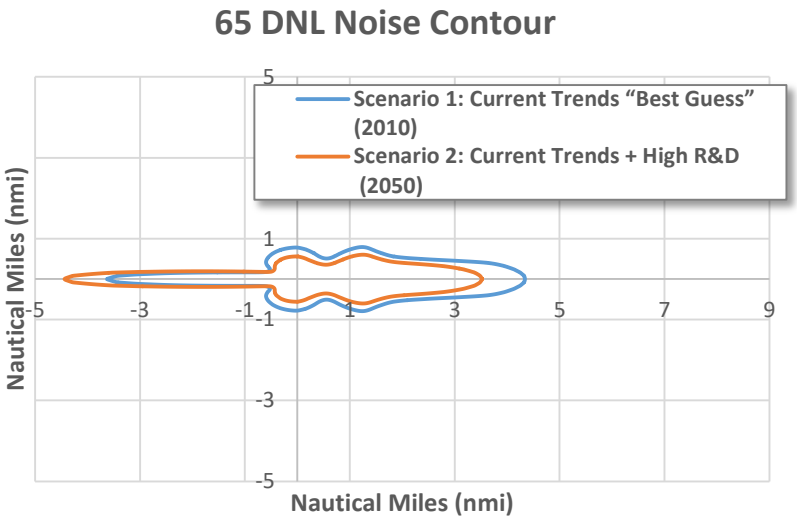
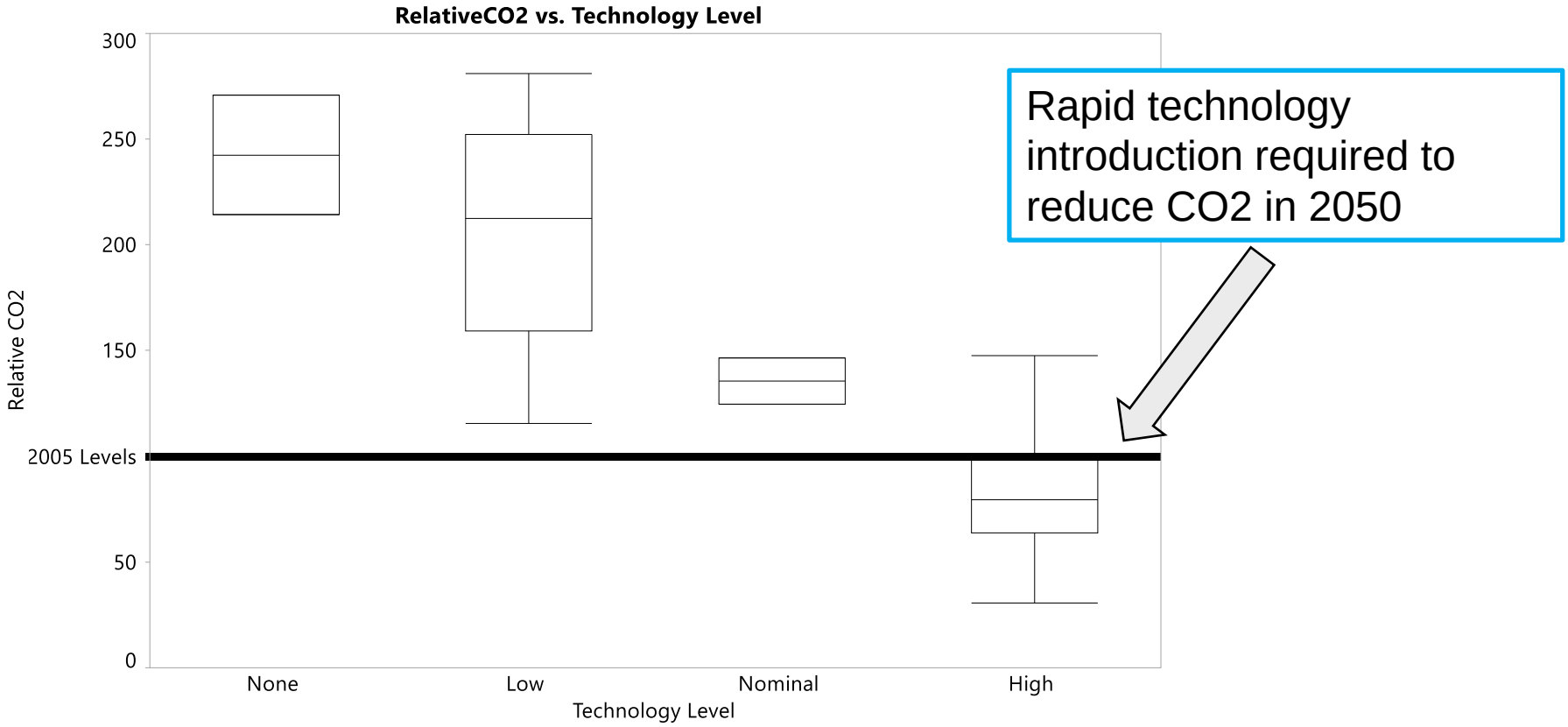


FLEET: Noise area results influenced by introduction of new technology aircraft
GREAT/ANGIM: Single Runway, Unidirectional Flow, Representative Fleet Mix

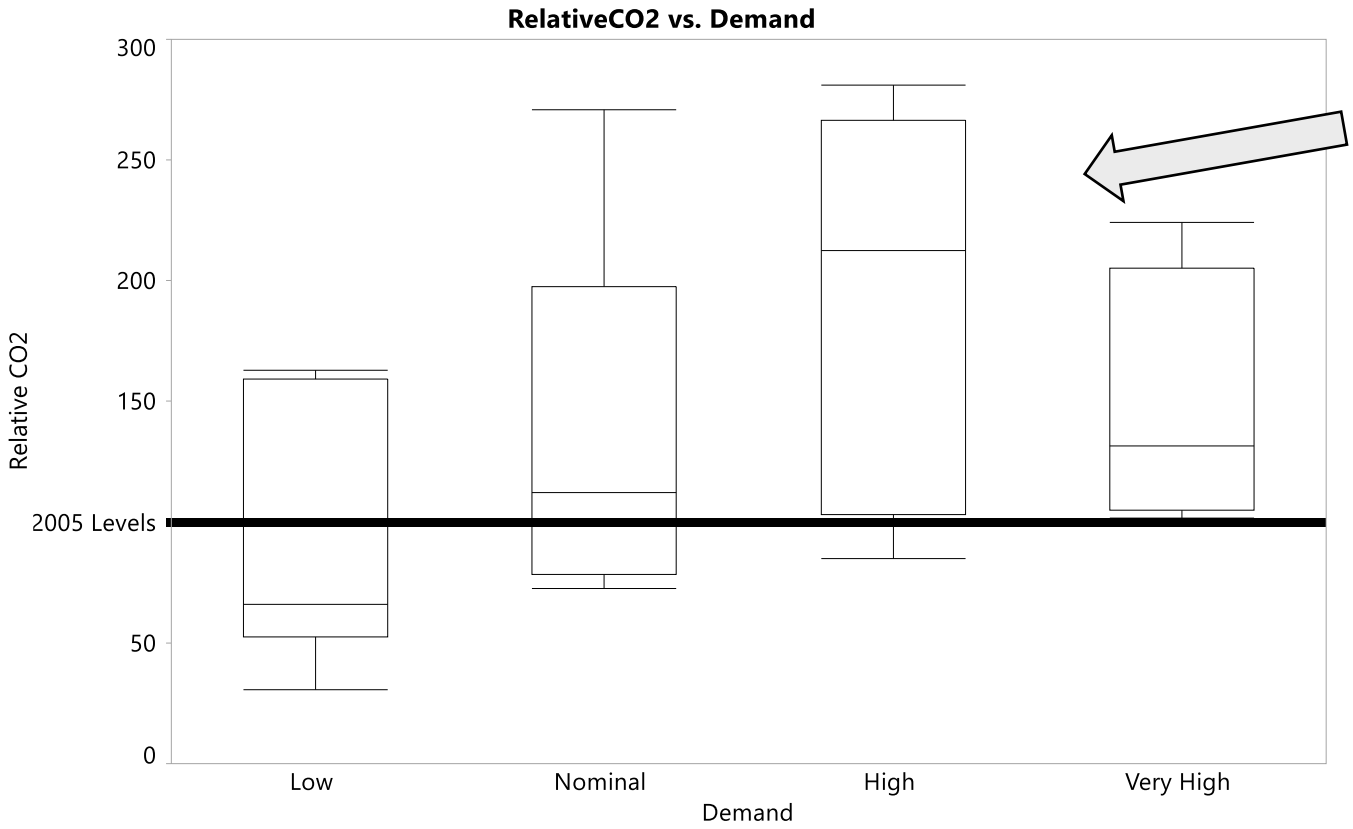
Technology Impact On 2050 CO2

- Examined variability introduced by fleet demand and technology at the macro level
  - Grouped as **'high'** (greater impact, more rapid introduction) or **'low'** (less impact, delayed introduction) **technology** relative to baseline
- Variation in 2050 CO2 caused by demand assumptions for given technology level



Demand Impact On 2050 CO2

- Examined variability introduced by fleet demand and technology at the macro level
  - Grouped as **'high' or 'low' demand** relative to baseline
- Variation in 2050 CO2 caused by technology assumptions for given demand



Increased demand makes it difficult to achieve carbon neutral goals, even with advanced technology

Summary

- Successfully completed project 10 initial intent
- Project outcomes
  - Suggested Fleet Scenario inputs for future assessment activities
  - Technology evolution scenarios for future assessment activities
  - Conducted long term technology assessment for defined fleet and technology scenarios
  - Understand bounding of technology and demand on future fleet-wide environmental impacts
  - Comparison of similarities and differences using multiple fleet evaluation tools (FLEET and GREAT)
- Provided framework for deeper investigation of sensitivities to demand and technology drivers
- Wrapping up final ASCENT report