Aircraft Technology Modeling and Assessment
Project 10

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Opinions, findings, conclusions and recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of ASCENT sponsor organizations.
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

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

Technology Assessment Assumptions Setting

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

Ascent 10 Team

Subsystem Technology Impacts
- Technology Effects on Vehicle
- Fleet Level Implications
Project Progression

**Fleet Workshop #1**
- **Goal:** Determine what defines a worldview 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

**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

**Fleet Scenario Definitions Setting**
Technology Workshop Outcomes

Aircraft Advanced Metallics

- Component Weight (%)
  - Generation 1: 0-8%
  - Generation 2: 2-8%
  - Generation 3: 3-15%
  Nominal Value: 4%, 5%, 9%

Component Weight Reduction (%)

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

*All benefits are relative to the current state of the art.*
Fleet Workshop Outcomes

Aircraft Technology  | Economic Growth  | Energy Price

Low  | Low  | Nominal  | Low Demand + Low R&D
Low  | High | Nominal  | Environmental Bounds “High”
Nominal  | Low  | Nominal  | High Demand + Low R&D
Nominal  | High | Nominal  | Current Trends “Best Guess”
High  | Low  | Nominal  | Low Demand + High R&D
High  | High | Nominal  | Environmental Bounds “Low”
Nominal  | Low  | Nominal  | Current Trends + High R&D
High  | High | Nominal  | High Demand + High R&D

* ‘Frozen technology’ scenario not shown above

Also evaluate with mission spec. changes
# World View Scenarios Assumptions

## Demand/Economic Factors

<table>
<thead>
<tr>
<th>Factor</th>
<th>Min</th>
<th>Nominal</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDP Growth (%/year)</td>
<td>1.8</td>
<td>2.8</td>
<td>4</td>
</tr>
<tr>
<td>Energy Price ($/bbl)</td>
<td>41</td>
<td>77</td>
<td>181</td>
</tr>
<tr>
<td>Population Growth (%/year)</td>
<td>0.45</td>
<td>0.58</td>
<td>0.68</td>
</tr>
<tr>
<td>International Trade (%/year Asia)</td>
<td>3.3</td>
<td>4.3</td>
<td>5.9</td>
</tr>
<tr>
<td>Industry Competetiveness (cent/ASM)</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Airport Noise Limitations (% airports noise limited in future)</td>
<td>0</td>
<td>25</td>
<td>95</td>
</tr>
<tr>
<td>Cost of CO2 Emissions ($/MT)</td>
<td>0</td>
<td>21</td>
<td>85</td>
</tr>
</tbody>
</table>

## Fleet Evolution Factors

<table>
<thead>
<tr>
<th>Factor</th>
<th>Single Aisle First</th>
<th>Twin Aisle First</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fleet Evolution Schedule</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aircraft Retirement</td>
<td>Early</td>
<td>Nominal</td>
</tr>
<tr>
<td>Production Capacity</td>
<td>Limits</td>
<td>No Limits</td>
</tr>
</tbody>
</table>

## Aircraft Technology Factors

<table>
<thead>
<tr>
<th>Factor</th>
<th>Early</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amount and Speed of Technology R&amp;D Investment (relative)</td>
<td>0</td>
<td>1.365</td>
<td>1.71</td>
</tr>
<tr>
<td>TRL 9 Dates</td>
<td>Early</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Benefit Levels</td>
<td>None</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Mission Specification Changes</td>
<td>None</td>
<td>Yes (CSR)</td>
<td></td>
</tr>
</tbody>
</table>

## Current Trends "Best Guess"

- Current Trends "Best Guess"
- Current Trends + High R&D
- 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

View descriptors become inputs to fleet model.
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
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 a mark on the plot).
Tools: GREAT/ANGIM

- Methods developed to enable *rapid analysis* of fleet-level environmental impacts
  - **Global and Regional Environmental Aviation Tradeoff (GREAT)**
    - Metrics: Fuel-Burn, NO$_x$
  - **Airport Noise Grid Interpolation Method (ANGIM)**
    - Metrics: Grids of DNL values, DNL contours (measures areas & shape metrics), and population exposure
Aircraft Models In FLEET

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>SRJ</td>
<td>Canadair RJ200/RJ440</td>
<td>Embraer ERJ145</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RJ</td>
<td>Canadair RJ700</td>
<td>Canadair RJ900</td>
<td>GT Gen1 DD RJ (2020)</td>
<td>GT Gen2 DD RJ (2030)</td>
</tr>
<tr>
<td>SA</td>
<td>Boeing 737-300</td>
<td>Boeing 737-700</td>
<td>GT Gen1 DD SA (2017)</td>
<td>GT Gen2 DD SA (2035)</td>
</tr>
<tr>
<td>STA</td>
<td>Boeing 757-200</td>
<td>Boeing 737-800</td>
<td>GT Gen1 DD STA (2025)</td>
<td>GT Gen2 DD STA (2040)</td>
</tr>
<tr>
<td>LTA</td>
<td>Boeing 767-300ER</td>
<td>Airbus A330-200</td>
<td>GT Gen1 DD LTA (2020)</td>
<td>GT Gen2 DD LTA (2030)</td>
</tr>
<tr>
<td>LQ</td>
<td>Boeing 747-400</td>
<td>Boeing 777-200LR</td>
<td>GT Gen1 DD LQ (2025)</td>
<td>GT Gen2 DD LQ (2040)</td>
</tr>
</tbody>
</table>

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

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

FLEET

Normalized Passenger Nautical Miles

- Current Trends Frozen Tech
- Current Trends "Best Guess"
- Current Trends + High R&D
- Current Trends + High R&D + Mission Spec

Year
2010 2020 2030 2040 2050
Pax-nm / Pax-nm in 2005
0 1 2 3 4 5

Normalized CO₂

- Current Trends Frozen Tech
- Current Trends "Best Guess"
- Current Trends + High R&D
- Current Trends + High R&D + Mission Spec

Year
2010 2020 2030 2040 2050
CO₂ / CO₂ in 2005
0 0.5 1 1.5 2 2.5 3 3.5 4

GREAT

RPM Demand Relative to 2005

- Current Trends Frozen Tech - In-Production Only
- Current Trends "Best Guess"
- Current Trends + High R&D
- Current Trends + High R&D + Mission Spec

Year
2005 2010 2015 2020 2025 2030 2035 2040 2045 2050
0 1 2 3

CO₂ Relative to 2005

- Current Trends Frozen Tech - In-Production Only
- Current Trends "Best Guess"
- Current Trends + High R&D
- Current Trends + High R&D + Mission Spec

Year
2005 2010 2015 2020 2025 2030 2035 2040 2045 2050
0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
Current Trends Technology Effects

FLEET

Normalized Passenger Nautical Miles

- Current Trends Frozen Tech
- Current Trends "Best Guess"
- Current Trends + High R&D
- Current Trends + High R&D + Mission Spec

GREAT

Normalized CO₂

- Current Trends Frozen Tech - In-Production Only
- Current Trends "Best Guess"
- Current Trends + High R&D
- Current Trends + High R&D + Mission Spec

Models show different pax-nm and CO₂ evolution, but similar CO₂ outcomes in 2050
Current Trends: Normalized CO₂ Emission Intensity

Implementation of Frozen Technology scenario is slightly different

Impact of mission specification changes secondary to technology
Fleet Evolution – Current Trend Best Guess

Similar trends, but with some differences due to differing retirement, acquisition, and allocation strategies.
Increased demand makes it difficult to achieve carbon neutral goals, even with advanced technology.
CO2 by Demand Variation (Upper) & Technology Variation (Lower)

**FLEET**

Normalized CO2

- Current Trends "Best Guess"
- Low Demand + Low R&D
- High Demand + Low R&D

**GRFAT**

Normalized CO2

- Current Trends "Best Guess"
- Low Demand + Low R&D
- High Demand + Low R&D
- Very High Demand with Noise Limits - Low R&D

Year

CO2 Relative to 2005

2010 2020 2030 2040 2050

0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0

Year

CO2 Relative to 2005

2005 2010 2015 2020 2025 2030 2035 2040 2045 2050

0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0

ASCENT AVIATION SUSTAINABILITY CENTER
Scenarios bound environmental outcomes
FLEET and GREAT Noise Analysis

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

![Relative CO2 vs. Technology Level](image)

Rapid technology introduction required to reduce CO2 in 2050
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.
• 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