Development of a Greenhouse Gas Emission Inventory and Analysis of Emissions Reduction Strategies for Aviation

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Initial Statements

- I do see the irony in my flying across the country to discuss aviation CO$_2$ emissions
- Acknowledgements:
  - UCTC for their support of this research
  - ATAC Corporation for technical analysis support, data gathering, and enthusiasm for the project
  - Elaine & Irene Kwan and Piu-Wah Lee, 3 dedicated and spirited undergraduate researchers
  - NEXTOR Graduate Students for their ideas, skills, data, and general support while I refine my thesis topic
Aviation & Greenhouse Gas
Reduction: Scenario Analysis

• Scenario: Aircraft operators must reduce CO₂ emissions by a certain percent

• Responses:
  – Purchase offsets/credits from another industry
  – Reduce aviation-related CO₂ emissions

• Purpose of analysis
  – What is the least expensive way to meet this CO₂ reduction target?
  – Does it make sense to reduce CO₂ from aviation?
Domestic CO₂ Emissions Profile

GHG Emissions by End-Use Sector (EPA, 2006)

- Industry: 8%
- Transportation: 30%
- Commercial: 18%
- Residential: 17%
- Agriculture: 27%

Transportation GHG Emissions (EPA, 2006)

- Passenger Cars: 19%
- Light Trucks: 36%
- Heavy-Duty Vehicles: 9%
- Aircraft: 3% (2% each for Boats and Ships, Other, Locomotives)
Research Outline

• Develop high-level aircraft CO₂ emissions model
• Define study corridor and develop baseline CO₂ emissions inventory
• Define a taxonomy of strategies
• Test different scenarios
  – Aircraft swap
  – Mode shift to auto
  – Airport-access mode shift to electric vehicles
• Discuss cost of CO₂ emission reduction
Fuel Burn Model

• Predicts fuel burn for a flight as a function of
  – Stage length
  – Number of seats
  – Average age of type

• Estimated from Form 41 Aircraft Operation Data
Fuel Burn Model

All coefficients significant at 1% level

\[
\ln(\text{fuel burn}) = 7.3687 + 0.8938 \ln\left(\frac{SL}{\text{mean}(SL)}\right) + 0.71742 \ln\left(\frac{SE}{\text{mean}(SE)}\right) \\
+ 0.7963 \left(\ln\left(\frac{SE}{\text{mean}(SE)}\right)\right)^2 - 0.44182 \ln\left(\frac{SL}{\text{mean}(SL)}\right) \ln\left(\frac{SE}{\text{mean}(SE)}\right) \\
+ 0.016388 \times \text{Age} + 0.013588 \times \text{Age} \times \ln\left(\frac{SE}{\text{mean}(SE)}\right)
\]

<table>
<thead>
<tr>
<th>Regression Statistics</th>
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<tbody>
<tr>
<td>Adjusted R Square</td>
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<tr>
<td>Observations</td>
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Fuel Per Flight, Varied Stage Length and Seats per Flight

Minimum fuel per seat at 350 SL: 106 Seats

Fuel per flight (gallons)/Seat vs. Seats

Fuel per flight (gallons)/Seat

#Seats per flight
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Study Network:
The California Corridor

- All flights between these airports on the study days
Emissions Inventory
Methodology

• Use BTS Data to obtain taxi times, stage lengths and tail number for all corridor flights
• Use World Fleet to match tail number with equipment and engine type
• Use ICAO database to obtain fuel flow for taxiing and LTO cycle
• Use fuel burn model and CO\textsubscript{2} conversion factors to predict total emissions from flights in this corridor
• Combine the above to break out total fuel burned for flights in this corridor
CO$_2$ Emissions: Average Flight
Northern CA and Southern CA

- Cruise: 86%
- Take-off/Approach/At Gate: 10%
- Taxi In: 1%
- Taxi Out: 3%
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Taxonomy of CO₂ Emission Mitigation and Reduction Strategies

1. System Efficiency
   - Origin/Destination
   - Network Efficiency
   - Aircraft Activity

2. Aircraft Efficiency

3. Component Efficiency
   - Offsets
     - Pecuniary
     - In-Kind

4. Operational Efficiency
   - Alternative Fuels

5. GHG Emissions
First Strategy: Aircraft Swap

- Replacement aircraft: brand-new 100 seat aircraft
- Perform a capacity-preserving aircraft swap
- Decision rule for swap based on a minimum age for replacement
Percent Reduction in CO$_2$ Emissions From Capacity Preserving 100 Seat Aircraft Swap
Aircraft Swap Strategy Cost

- **Cost Accounting**
  - New Boeing 717 Purchase Price 2004: $37.5 million
    - Daily cost of new B717: $5,991,055
      (20 year useful life, interest rate 15%)
    - 55% of flights per day on unique aircraft, average of 370*55% = 204 aircraft
    - Total cost: $3,348,425/day

- **Daily Reduction**: 332,203,570 lbs (166,100 tons)

- **Cost/Ton**: $3.35 million/166,100 tons = $20.16/ton
Second Strategy: Mode Shift to Surface

- Investigate the possibility of reducing emissions through shifting modes
- Bus mode shift assumes capacity preservation and 40 seats/bus
- Vehicle mode shift assumes 75% load factor per flight and each passenger is shifted to a single vehicle
  - Prius
  - Sedan
  - SUV
CO₂ Emissions Change (Savings) Compared with Baseline For Varying Surface Modes

- Bus: 100.00% increase
- Prius: 80.00% decrease
- FuelEff_1: 60.00% decrease
- FuelEff_2: 40.00% decrease
- FuelEff_3: 20.00% decrease
- Sedan: 0.00%
- SUV: -20.00% decrease
Mode Shift Strategy Cost

- **Cost Accounting**
  - All travelers will drive a Prius to destination airport
    - 2008 price: $24,000, average 31,000 passengers per day
    - 31000 * $24,000 = $744 million in Prius purchases
    - Per day, with 10 year useful life and 15% rate: $406,147/day
  - Value of Time: 4 hr*31000*$50/hr = $6.2 million/day
  - Operating costs: $.40/mile*10.5 million miles/day = $4.2 million /day
    - Daily cost of strategy: $ 10.8 million/day

- **Reduction:** 1,905,917 lbs/day (9,523 tons)
- **Cost of strategy:** $10.8 million/9,523 tons =
In-kind Mitigation: Investments in Clean Airport Access Modes

- Augment baseline CO$_2$ emission inventory to include airport access mode CO$_2$ emissions
- Replace with Electric Vehicle bus (CO$_2$ $\rightarrow$ 0)
- Determine CO$_2$ emission reduction and cost
Aviation Access Mode Network

Walk/Bike
Transit (Rail)
Transit (Bus)
Shuttle Bus
Auto (Single)
Auto (Carpool)

SFO
LAX
SNA
ONT
BUR
SJC

Walk/Bike
Transit (Rail)
Transit (Bus)
Shuttle Bus
Auto (Single)
Auto (Carpool)

NEXTOR
Quantifying Access Mode CO$_2$ Emissions

Northern California

<table>
<thead>
<tr>
<th>Mode</th>
<th>GHG Emissions Operational (g GGE/ PMT)</th>
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<tbody>
<tr>
<td>Sedan</td>
<td>230</td>
</tr>
<tr>
<td>SUV</td>
<td>280</td>
</tr>
<tr>
<td>Urban Bus</td>
<td>330</td>
</tr>
<tr>
<td>BART</td>
<td>230</td>
</tr>
</tbody>
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Mode Share Per Zip Code Per Origin Airport generalizes to sample days

CO$_2$ Emissions for all trips Per Mode Per Zip Code Per Origin Airport
If we broaden our view of aviation-related emissions to include access modes, aircraft operators could save 11% over baseline CO2 Emissions from going to electric vehicles.
**Access Mode Strategy Cost**

- **Cost Accounting**
  - Buy 50 electric buses at $70,000 per bus
    - Cost per day = $559,165
    - Useful life: 20 years, interest rate: 15%
  - Contract Bus Operators & Maintenance
    - 20,000 per year/365 * 50 buses * 2 drivers per bus = $5,480
  - Time Cost = 20*2 min * 31000 pax * $50/hr = $1.03 million/day
  - Daily cost of strategy: $1,597,978/day

- **Reduction:** 702,148 lbs/day (351 tons)
- **Cost/Ton:** $1.6 million / 351 tons = $4,553/ton
Conclusions & Final Thoughts

• Certain reduction strategies are competitive with mitigation costs at projected CO$_2$ emissions prices.

• Lifecycle costs
  – Operations are not the whole story
  – Over the life of an aircraft operational CO$_2$ emissions ~70%

• System-wide impacts
  – Some reduction strategies may require increased airport and airspace capacities (NextGen)
  – Other reduction strategies may require increased road capacity