The Impact of New Aircraft and Technologies on Fleet-Level Metrics

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## Achieving Emission Goals – NASA SFW

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Noise</td>
<td>-32 dB (cum below Stage 4)</td>
<td>-42 dB (cum below Stage 4)</td>
<td>55 LDN (dB) at avg airport boundary</td>
</tr>
<tr>
<td>LTO NO\textsubscript{X} Emissions (below CAEP 6)</td>
<td>- 60%</td>
<td>- 75%</td>
<td>better than -75%</td>
</tr>
<tr>
<td><strong>Performance:</strong></td>
<td><strong>Aircraft Fuel Burn</strong></td>
<td><strong>Field Length</strong></td>
<td><strong>Exploit metroplex concepts</strong></td>
</tr>
<tr>
<td></td>
<td>- 33%*</td>
<td>- 40%*</td>
<td>- 50%</td>
</tr>
</tbody>
</table>

*An additional 10% may be possible through improved operational capability

These goals are from NASA FAP meeting 2008
The Necessity of an Allocation Tool

• NASA SFW Goals are for *individual aircraft*
• Emission goals are for *entire fleet*
  – How will airlines use new aircraft considering environmental metrics and economic metrics?
  – What impact of new aircraft / new technology in a fleet mix with current aircraft?
• Develop as an allocation problem
  – Minimize fuel burn or DOC of the fleet for a “representative day”
    • Fuel burn is directly proportional to CO$_2$ emissions
    • DOC is a surrogate for profit
  – Meet passenger demand for air transportation
  – Total aircraft flown and under maintenance can not exceed fleet size
  – Decision Variables: Number of aircraft $i$ assigned to route $j$ ($x_{ij}$)
  – Not a scheduling tool
Levels of Abstraction

What actually happened in 2005

What actually happened within WWLMINET 257

What happened within WWLMINET using a/c subset

Simplification Criterion

- Routes amongst WWLMINET

Effect on analysis

- Route & city reduction
- 257 vs. 1000s of airports
- Capture 65% of traffic and 80% of pax that touch US

- Aircraft type reduction from about 100 types to 18 (i.e., only 18 aircraft models needed)

Allocation

- No scheduling of aircraft; all flights are round-trip

- Significant reduction in design variables and constraints
Generic Allocation Problem Formulation

Minimize

Fleet DOC (or Fleet CO₂ Emissions or Fleet LTO NOₓ Emissions)

Subject to

1. \( \sum x_{ij} p_i \geq d_j \) for all routes \( j \)
2. \( \sum x_{ij} (BH_{ij} + TH + MH) \leq 12n_i \) for all aircraft \( i \)

(And could include the following, as appropriate)

- \( CO₂ \leq \kappa CO₂_{2005} \) for total fleet
- \( LTO NOₓ \leq \kappa LTO NOₓ_{2005} \) for total fleet
- \( Noise Area_k \leq \kappa Noise Area_k_{2005} \) for each airport
- \( DOC \leq \kappa DOC_{2005} \) for total fleet

Where

- \( x_{ij} \) = number of aircraft \( i \) on route \( j \)
- \( d_j \) = demand on route \( j \)
- \( BH_{ij} \) = block hours for \( a/c \) \( i \) on route \( j \)
- \( MH \) = maintenance hours
- \( n_i \) = number of aircraft \( i \) available
- \( p_i \) = passengers on aircraft \( i \)
- \( TH \) = turn-around hours
- \( \kappa \) = scaling factor \( \leq 1 \)
Minimizing CO$_2$ from 2005 to 2050

- 2005 to 2050 No New: 114% Increase
- 2005 to 2050 All SFW: 48% Increase
- 2050 Worst to Best: 66% Reduction
- Well short of IATA and ICAO Goals!!

- 2005 to 2050 No New: 3% Reduction
- 2005 to 2050 All SFW: 33% Reduction
- 2050 Worst to Best: 30% Reduction
- Shows promise, but not carbon neutral!

$\begin{align*}
2005 \text{ CO}_2 &= 8.63 \times 10^8 \text{ lb} \\
2005 \text{ CO}_2/\text{pax-mi} &= 0.374 \text{ lb/mi}
\end{align*}$
Improving Fuel Burn Technology and Varying Passengers Served

• Under current assumptions, IATA goals unattainable
• How can the 2050 Fleet attain 50% of 2005 CO$_2$ emissions?
  – Three possibilities explored:
    1. Increase fuel burn efficiency of N+1/N+2 concepts
    2. Decrease passengers served with the same fuel burn efficiency
    3. Various combinations of passengers served and fuel burn efficiency
  – Assume: Fuel burn improvement ranges from 0% to 95%
  – Vary: Passengers served from 25% to 200% of 2050 projections
• Creates contours of acceptable passengers served and fuel burn improvements
To achieve IATA goal when all aircraft are New-in-Class:

1. Reduce fuel burn by 70% at 2050 demand (e.g. aircraft meet NASA SFW N+3 goal)
2. Serve up to 86% more passengers than original projection, but requires high reduction in fuel burn (95%)
3. Any combination of passengers served and fuel burn reduction in white area

Ex: 150% projected 2050 demand with 20% fuel reduction = 4× IATA Goal
Impact of Discrete Technology

- Aviation Partners estimates that blended winglets for 767-300ER will save up to 6.5% on fuel consumption
  - Estimate only valid for operations on longest routes and highest utilization
- Performed two studies to minimize fuel burn
  1. Rep-in-Class 4 (Boeing 757-200) retrofitted with winglets
  2. Rep-in-Class 5 (Boeing 767-300) retrofitted with winglets
- Fuel burn savings varied from 0% (baseline) to 7% in 1% increments
- Reveals what impact has larger impact on fleet-level metrics and how optimal allocation changes
- Note: Non-fuel DOC not adjusted and aircraft not resized
Impact of Retrofitted Winglets

<table>
<thead>
<tr>
<th>Winglet Fuel Improv.</th>
<th>Fleet ΔCO₂ (%)</th>
<th>Fleet ΔDOC (%)</th>
<th>ΔCO₂ per A/C (lb)</th>
<th>ΔDOC per A/C ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rep Class 4 (1130 Aircraft)</td>
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</tr>
<tr>
<td>– 1%</td>
<td>-0.53%</td>
<td>-0.28%</td>
<td>-4,112</td>
<td>-491</td>
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<tr>
<td>– 3%</td>
<td>-1.20%</td>
<td>-0.38%</td>
<td>-9,309</td>
<td>-680</td>
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<tr>
<td>– 5%</td>
<td>-2.06%</td>
<td>-1.04%</td>
<td>-16,024</td>
<td>-1,857</td>
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<tr>
<td>– 7%</td>
<td>-2.72%</td>
<td>-1.21%</td>
<td>-21,179</td>
<td>-2,155</td>
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<tr>
<td>Rep Class 5 (830 Aircraft)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– 1%</td>
<td>-0.19%</td>
<td>-0.25%</td>
<td>-1,998</td>
<td>-611</td>
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<tr>
<td>– 3%</td>
<td>-0.77%</td>
<td>-1.15%</td>
<td>-8,121</td>
<td>-2,785</td>
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<tr>
<td>– 5%</td>
<td>-1.55%</td>
<td>-2.56%</td>
<td>-16,453</td>
<td>-6,222</td>
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<tr>
<td>– 7%</td>
<td>-2.24%</td>
<td>-2.75%</td>
<td>-23,759</td>
<td>-6,686</td>
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</tbody>
</table>

Baseline (No winglets)
- Fleet CO₂: 8.80 × 10⁸ lb
- Fleet DOC: $2.01 × 10⁸

Key Trends
- Class 4 greater % ΔCO₂
- Class 5 greater % ΔDOC
- Class 5 greater DOC savings per aircraft

• Class 5 aircraft fly up to 84% more total miles → Longer routes
• Class 4 aircraft fly up to 2% more total miles → Higher frequency
Decomposing the Allocation Problem

- Adding more aircraft models and airlines increase problem size and complexity
  - Current max variables: 592,128, Current max constraints: 33,019
- Decomposing the one large problem into smaller problems that can be solved quickly will allow additional aircraft and airlines to be modeled
- Two proposed decompositions:
  1. Each airline is a separate problem
  2. Each route is a separate problem