Sustainable Aviation Operations and the Role of Information Technology and Data Science: Background, Current Status and Future Directions

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Impact of Aviation on Climate Change*

- Aviation responsible for 13% of transportation-related fossil fuel consumption and 2.0% of all anthropogenic CO$_2$ emissions
  - Direct emissions: CO$_2$ and water vapor are greenhouse gases (GHG) resulting in a positive Radiative Forcing (RF); Because of its abundance and long lifetime, CO$_2$ has a long-term effect on climate change.
  - Indirect effects: NO$_x$ affecting distributions of Ozone and Methane has a short-term effect on climate change.
  - Condensation trails (Contrails) are clouds that are visible trails of water vapor made by the exhaust of aircraft engines.

*D.S. Lee et al, Atmospheric Environment, 2021
International Civil Aviation Organization (ICAO)
Strategies for Reducing Impact

• ICAO established global aspirational goals in 2010
  – 2% annual fuel efficiency improvements through 2050
  – Carbon neutral growth from 2020 onwards.

• Three-pronged approach
  – Improvements in aircraft technology,
  – Improvements in operations and
  – Development and market-based approach to the use of alternative aviation fuels.
Global Efforts to Improve Operations

• Led by ICAO to improve operations by Aviation System Block Upgrade

• Gradual introduction of new technologies, procedures and operational concepts
  – Block 0 (2013), Block 1 (2019), Block 2 (2025), Block 3 (2031)

• Fuel efficiency goals and achievements
  – 1999: Inter-governmental Panel on Climate Change (IPCC) estimates fuel efficiency can be increased to 82-92%
  – 2006: U.S fleet efficiency 92-93% with a 2026 goal 93-96%
  – 2008: Civil Air Navigation Services Organization (CANSO) estimated global fuel efficiency between 92% and 94%

• Next Generation Air Traffic Management (NextGen) in US, Single European Sky ATM Research (SESAR) in Europe, and Collaborative Actions for Renovation of Air Traffic Systems (CARATS) in Japan
NextGen Implementation: Technologies

• ADS-B: Surveillance information over oceanic and remote airspace
  – Aircraft need to be equipped with ADS-B Out by Jan 2020 to operate in U.S. Airspace A,B,C and E

• Area Navigation (RNAV) and Performance Based Navigation (PBN)
  – RNAV equipped aircraft can travel directly between points in the airspace
  – Required Navigation Performance (RNP) is a navigation accuracy requirement that RNAV capable aircraft can monitor and comply with during flight

• Weather
• Data Communications
• Decision Support Systems
NextGen Implementation: Operations

• Improvements in all phases of flight
  – Reduced separation, more efficient flight profiles and tailored arrivals
  – Wind-optimal routes
  – Surface and Taxi operations

• Global Harmonization: Demonstration Flights
  – Asia and Pacific Initiative to Reduce Emissions (ASPIRE), a collaboration between the FAA and ANSPs in Australia, New Zealand, Singapore, Japan, and Thailand.
    • Series of flights in 2008-2011 to successfully demonstrated the potential for fuel and emissions savings in the region.
  – Atlantic Interoperability Initiative to Reduce Emissions (AIRE)
    • During 2010-2011, the FAA, the European Commission, several European ANSPs and 40 European airlines participated in the demonstration of NextGen and SESAR capabilities on transatlantic flights.
    • Produced fuel savings ranging from 200 to 300 gallons per flight.
NASA conducted research exploring many concepts to different levels of maturity in all aspects of aviation operations and some of the matured concepts were field-tested and transferred to the FAA for further integration in operations.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Focus</th>
<th>Fuel Savings/Flight Annual Savings</th>
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<tbody>
<tr>
<td>EDA</td>
<td>Optimal Descent</td>
<td>110 lbs; $46M</td>
</tr>
<tr>
<td>ATD-1</td>
<td>Increased throughput</td>
<td>$300-400M</td>
</tr>
<tr>
<td>ATD-2</td>
<td>Increase in departure time conformance (50%); Reduction in departure delay (40%)</td>
<td>$20M 105-130 lbs; $410M</td>
</tr>
<tr>
<td>ATD-3</td>
<td>Dynamic Weather Routing Traffic Aware Strategic Aircrew Requests</td>
<td>575 lbs</td>
</tr>
</tbody>
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Newly Emerging Class of Vehicles

- **Unmanned Air System (UAS) Traffic Management (UTM)**
  - UAS vehicles weighing less than 20 kg used for goods delivery, infrastructure surveillance, search and rescue, and agricultural monitoring.
  - NASA (2015-2018) in collaboration with the FAA, industry and academic partners conducted a series of increasingly complex flight tests to develop requirements for a system.
  - FAA registered about 860,000 drones (32% commercial and 68% recreational)

- **Urban Air Mobility (UAM)**
  - Movement of goods and people in a regional environment using electrically powered Vertical Take-Off and Landing (eVTOL) vehicles

- **Extensible Traffic Management (xTM)**: Vehicles operating in Upper E-class airspace
  - Commercial Space Traffic, High Altitude Long-Endurance (HALE) aircraft providing communications services
Common Features of Emerging Class of Vehicles

• No established infrastructure to enable and safely manage the widespread use of low-altitude airspace and UAS operations
• Higher levels of automation to reduce operational costs
• Distributed services provided by several organizations meeting FAA rules and regulations
• Communications over open networks
• Provides greater role for machine learning
Green Aviation Challenge

• Next phase of SAO: Look beyond reducing the CO$_2$ emissions

• Key findings from earlier research
  – Changing altitude is an efficient way of achieving contrail reduction
  – Short flights (less than 500 miles), although half the number of flights in the National Air Space, contribute a small amounts of contrails (about 7%) due to their altitude profile
  – Contrail reduction beyond a certain amount may not be environmentally friendly due to the use of extra fuel and the emission of additional amount of CO$_2$
  – Effect of contrails becomes less important as the decision-making horizon is increased
    • Effect of NO$_x$ negligible except for a small impact around 25 years

• Address the effects of other emissions and Contrails

• Higher levels of uncertainty and difficult trade-off and policy decisions
Machine Learning (ML) and Sustainable Aviation Operations (SAO)

• ML has an important role in SAO
  – Providing information for decision making from different and conflicting databases covering different spatio-temporal scales (Seconds to decades, sectors to global airspace) from several disciplines (aviation, weather, atmospheric science, communications, socio-economic data)
  – Understanding the collaboration between automation and users
  – Developing standards and training of workforce

• ML Challenges
  – Role of ML in critical safety related decisions
  – Trust in AI systems
  – More transparency about the performance of ML algorithms and conditions under which it was developed
  – Better explanation of ML decisions
Concluding Remarks

• More details in the paper
• Lot of progress in reducing the effect of aviation CO$_2$ emissions on the environment
• Next phase of SAO should consider other emissions and contrails
  – Difficult trade-offs and Policy decisions
• New class of vehicles depend on more automation and need to take advantage of Machine Learning