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

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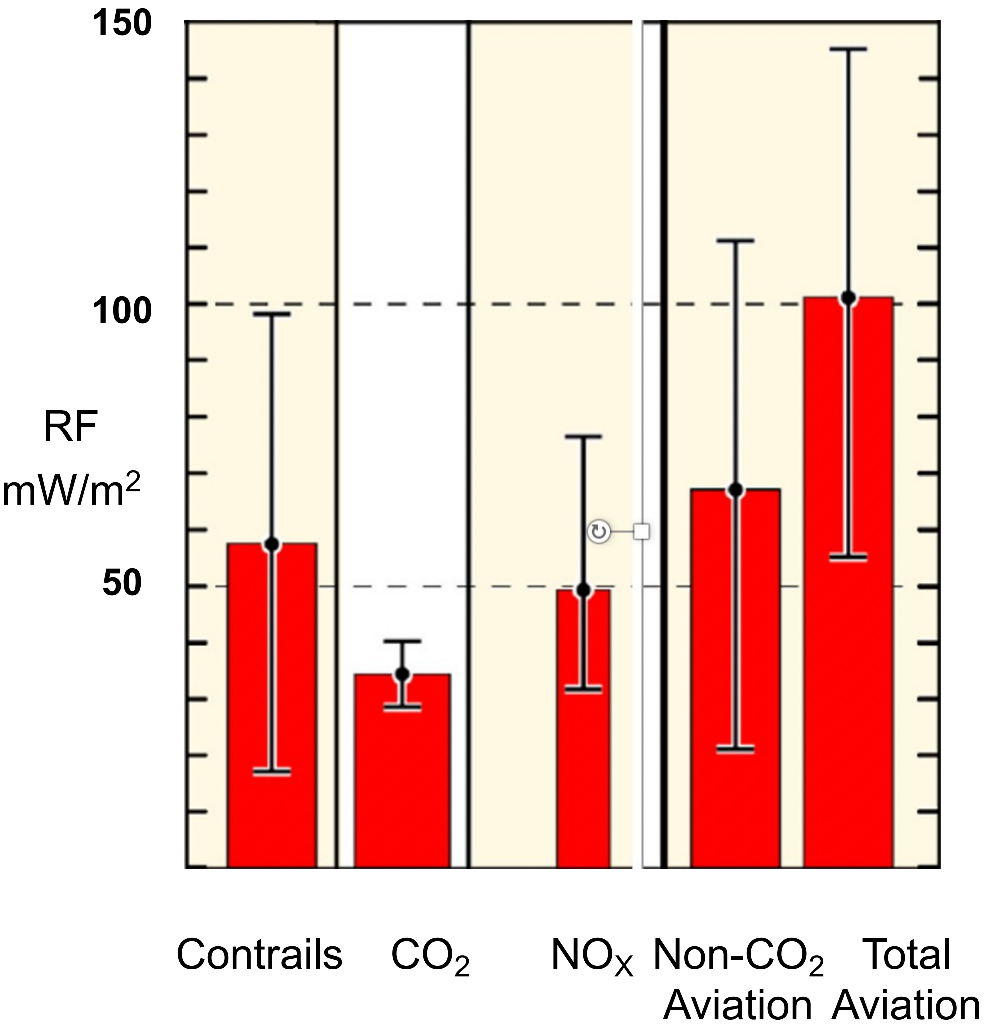
Impact of Aviation on Climate Change*

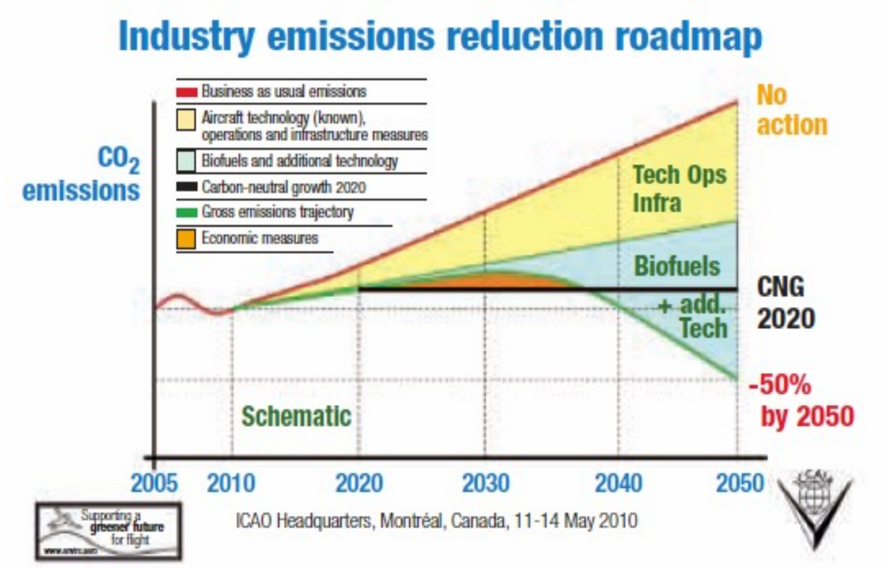
- Aviation responsible for 13% of transportation-related fossil fuel consumption and 2.0% of all anthropogenic CO_2 emissions
  - Direct emissions: CO_2 and water vapor are greenhouse gases (GHG) resulting in a positive Radiative Forcing (RF); Because of its abundance and long lifetime, CO_2 has a long-term 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.



Industry emissions reduction roadmap

ICAO Headquarters, Montréal, Canada, 11-14 May 2010

- 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 ATM Technology Demonstrations (ATD)

- 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

Technology	Focus	Fuel Savings/Flight Annual Savings
EDA	Optimal Descent	110 lbs; $46M
ATD-1	Increased throughput	$300-400M
ATD-2	Increase in departure time conformance (50%); Reduction in departure delay (40%)	$20M 105-130 lbs; $410M
ATD-3	Dynamic Weather Routing Traffic Aware Strategic Aircrew Requests	575 lbs

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