Global Air Traffic Modeling for Climate Assessment of Routing Strategies

Leading Graduate School Program on Global Safety
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Hiroshi Yamashita,
Volker Grewe, Patrick Jöckel, DLR-Oberpfaffenhofen
Martin Schaefer, Bundesministerium fuer Verkehr
Florian Linke, DLR-Hamburg
Daisuke Sasaki, Kanazawa Institute of Technology
Shigeru Obayashi, Tohoku University
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Global Air Traffic in 24 hours

https://www.youtube.com/watch?v=G1L4GUA8arY
Evolution of World Air Traffic 1940 to 2008

- World annual air traffic growth + 5 %/yr
- Air traffic will be double in the next 15 years

How to Reduce Climate Impact of Aviation Emissions?

• **Technological approach**
  - Aerodynamic changes
    - Blended body aircraft, Laminar flow control
  - More efficient engines
  - Alternative fuels
    - Liquid hydrogen, Bio-fuels

• **Operational approach**
  - Efficient ATM
    - Reduced time holding, More direct flight
    - NextGen(USA), SESAR(EU), CARATS(JP)
  - Efficient flight-profile
    - Continuous descent approach
  - **Climate-optimized routing**
Recent Studies on Climate-optimized Routing (1/2)

- "Wind-optimal routes reduce average fuel burn of actual routes by 4.4 % on Dec. 4, 2010."
  
  H. K. Ng, et al. 2011

- "Almost 45 % decrease in global contrail coverage is achieved by 6,000 ft down-shift of cruise altitude. However 6 % increase in Fuel burn"
  
  C. Fichter, et al. 2005
Recent Studies on Climate-optimized Routing (2/2)

• “…a reduction of cruise altitude will results in increased fuel consumption (CO2), counteracting the benefits gained by contrail avoidance and reduction of NOx impact.”

K. Gierens, et al. 2008

• “…the sole minimization of CO2 (fuel burn) does not lead to the minimum (total) climate impact.”

K. Alexander, et al. 2011
Practical Issues on Climate-optimized Routing

• What is the optimum route for total climate impact reduction?
  – Great circle: min. flight distance
  – Wind optimum: min. flight time
  – Min. CO2 (Fuel-use)
  – Min. NOx
  – Contrail avoidance
  – Etc…

• How effective is the selected strategy for total climate impact reduction?
Research Objectives

• Develop new assessment platform: AirTraf
  - Global airtraffic model coupled to Climate-chemistry model

• Simulate global air traffic on routing strategies
  - Trajectory optimization (horizontally and vertically)
  - Local atmospheric conditions
  - Long-term simulation

• Clarify the reduction potential on aviation climate impact
Overview of AirTraf Chemistry

Base Model
Climate Chemistry Model EMAC
P. Jöckel 2010

Submodels
Aviation data base:
- ICAO engine emission
- BADA aircraft model
- One day flightplan

Optimizer:
- Genetic algorithms
  J. H. Holland 1975, D. Sasaki, 2009

Emissions:
- Total energy model
- DLR fuel flow method

Emis sions  Optimizer  GA
AirTraf
Air traffic simulation

Contrails
Potential impact
P, T, ρ, Wind, etc.
Chemistry

Aviation data base

EMAC
Atmospheric Chemistry Model

- Flight trajectories
- Global emission fields
  (NOx, H2O, fuel use, flight distance)
Flow Chart of AirTraf (1/2)

- Flight plan inputs
  - City pairs, timetable, aircraft/engine
- Decomposition of trajectories
- Departure check
  - Calculate trajectory
  - Calculate emissions along trajectory
  - Fly aircraft
  - Gather global emission fields
- Arrival check

Trajectory optimization

Options
0: Great circle (min. distance)
1: Wind (min. flight time)
2: NOx
3: H2O
4: CO2 (Fuel-use)
5: Contrail avoidance
6: Climate cost functions

Genetic algorithms

Flow Chart of AirTraf (1/2) Trajectory optimization

Init. memory

Time loop

Wind

GC

NOx

Arr.

Dep.
Flow Chart of AirTraf (2/2)

Init. memory

- Flight plan inputs
  - City pairs, timetable, aircraft/engine
- Decomposition of trajectories
- Departure check
  - Calculate trajectory
  - Calculate emissions along trajectory
  - Fly aircraft
  - Gather global emission fields
- Arrival check

Time loop

Emission calculation
- NOx, H2O, Fuel use

Total Energy model
- DLR Fuel Flow method
Geometry Definition of Trajectory

- Control points consist of design variables: **location: 6, altitude: 5**
- Control points express arbitrary trajectories for city pairs
- Evaluate flight time along trajectories (if wind optimum case)

Example: MUC to JFK
One Day Test Simulation

EMAC/AirTraf
ECHAM5 Resolution : T21/L19
Calculation term : 1 day (JAN.01.1978–JAN.02.1978)
Waypoints : 61
Options : GC, Wind optimum
Flight altitude : FL290, 330, 370, 410 (GC)
               FL290 – 410 (Wind optimum)

Aviation data base
Flight plan : 1,840 (FRA/MUC)
Aircraft type : A330-301
Engine type : CF6-80-E1-A2 Jet Engine×2
Flight speed : M = 0.82

Optimizer
Design variables : 6 (location), 5 (altitude)
Generation : 50
Population : 50
Comparison of Flight Trajectories

GC with winds, FL330

Wind optimum, b/w FL290-410

FRA/MUC
Trajectories Explored through Optimization (MUC to JFK)

50 population × 50 generation = 2500 traj.

Wind optimum, b/w FL290-410
Comparison of Wind Fields and Trajectories (MUC to JFK)

- **u [m/s]**
  - FL290: Wind
- **v [m/s]**
  - FL290: Wind

- gc(FL330)
- gc(FL290)

- JFK
- MUC

- Latitude, deg
  - Range: 20° to 80°
- Longitude, deg
  - Range: -100° to 100°
Comparison of Flight Time (MUC to JFK)

Flight time, s

- Wind opt
- GC290
- 330
- 370
- 410

(12.5 min)

End

50 population × 50 generation
= 2500 evaluations

Number of function evaluations

Flight time, s

27000
27500
28000
28500
29000

27600
27800
28000
28200
28400

0 500 1000 1500 2000 2500
Flight Time Reduction by Wind-optimum Option (Global, One Day)

Positive values Max +106 s

<table>
<thead>
<tr>
<th>GC290</th>
<th>330</th>
<th>370</th>
<th>410</th>
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<td>−0.4 %</td>
<td>−2.6 %</td>
<td>−3.3 %</td>
<td>−3.7 %</td>
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Fuel Usage of One-day Global Air Traffic

Kg(fuel)/box/s
Comparison of Total Flight Time, Fuel, NOx, H2O (Global, One Day)
Summary

• New assessment platform AirTraf is under development to simulate global air traffic and assess routing strategies

• AirTraf can simulate global air traffic correctly with gc/wind optimum options

• One day test simulation was implemented
  - Optimizer could find superior trajectories in most city pairs
  - 0.4 to 3.7 % total flight time reduction by wind optimum option
  - Trade-off between total flight time and total fuel usage (= total NOx, H2O emissions)