En Route Traffic Optimization to Reduce Environmental Impact

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Outline

1. Introduction
2. Optimizing a Corridor of Traffic
3. Optimizing Intersection Traffic Flows
4. Conclusions

Introduction

Delays Currently Impact Operations

- $5 Billion Impact [Boeing 2001]

Air Traffic Projected to Grow Significantly

- Up to three times more traffic
- 250% Increase in Delay Hours

Airborne Delays Comprise 24% of all Delay Time [FAA 2000]

Potential benefits of decision-aiding tool to optimally assign flights to available flight levels within a corridor and route traffic in a horizontal plane

- Aircraft performance is dependent on altitude and velocity
- Corresponding emissions and fuel burn savings

Resource allocation problem

Optimizing a Corridor of Traffic

Northeastern United States is a good example of a domestic "corridor" that would benefit from improved altitude and speed assignments

- Severely congested
- Restricted airspace
- Geographical alignment
- Urban density

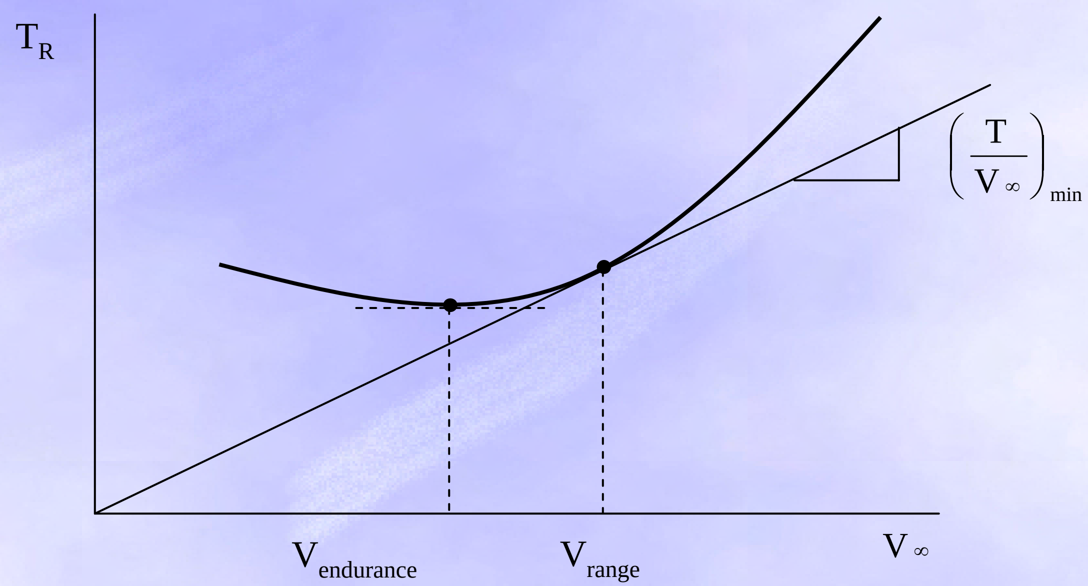
Oceanic tracks are "corridors" that could also benefit from improved altitude assignment as aircraft sometimes get "stuck" behind slower aircraft

- Changes in lateral path restricted

Aircraft Cruise Performance 101

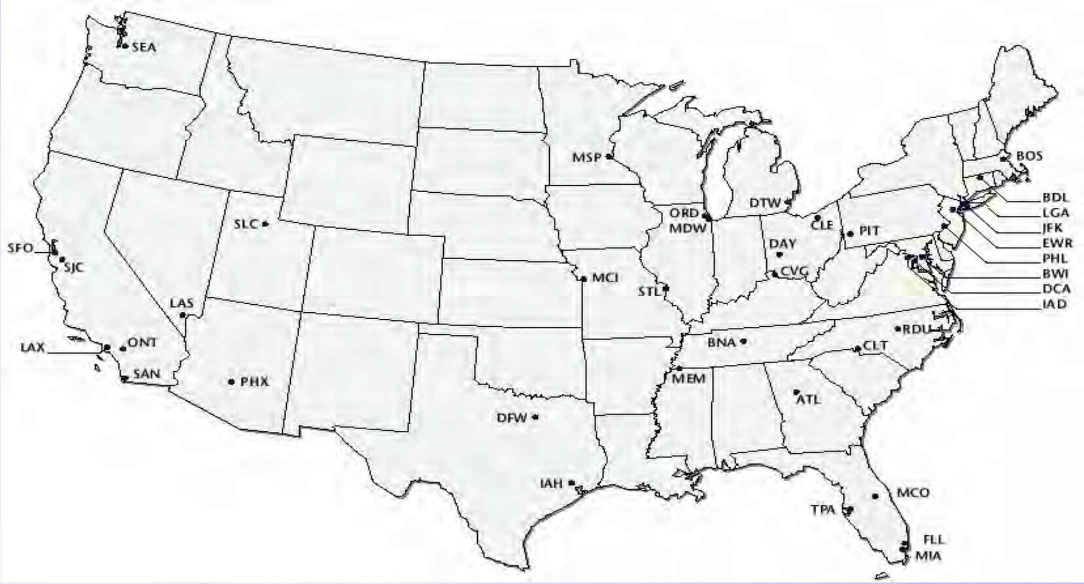
Fuel burn curves have different operating points

- Minimum delay (i.e. max. cruise speed)
- Minimum fuel burn rate
- Minimum total fuel burn

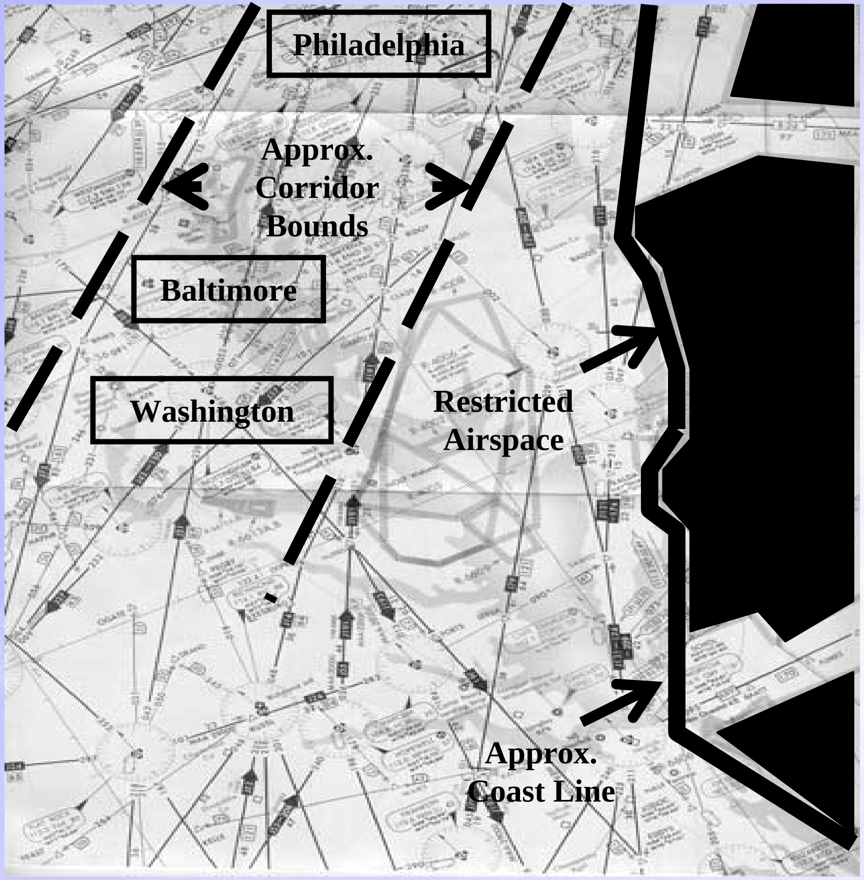


Northeastern US in Focus

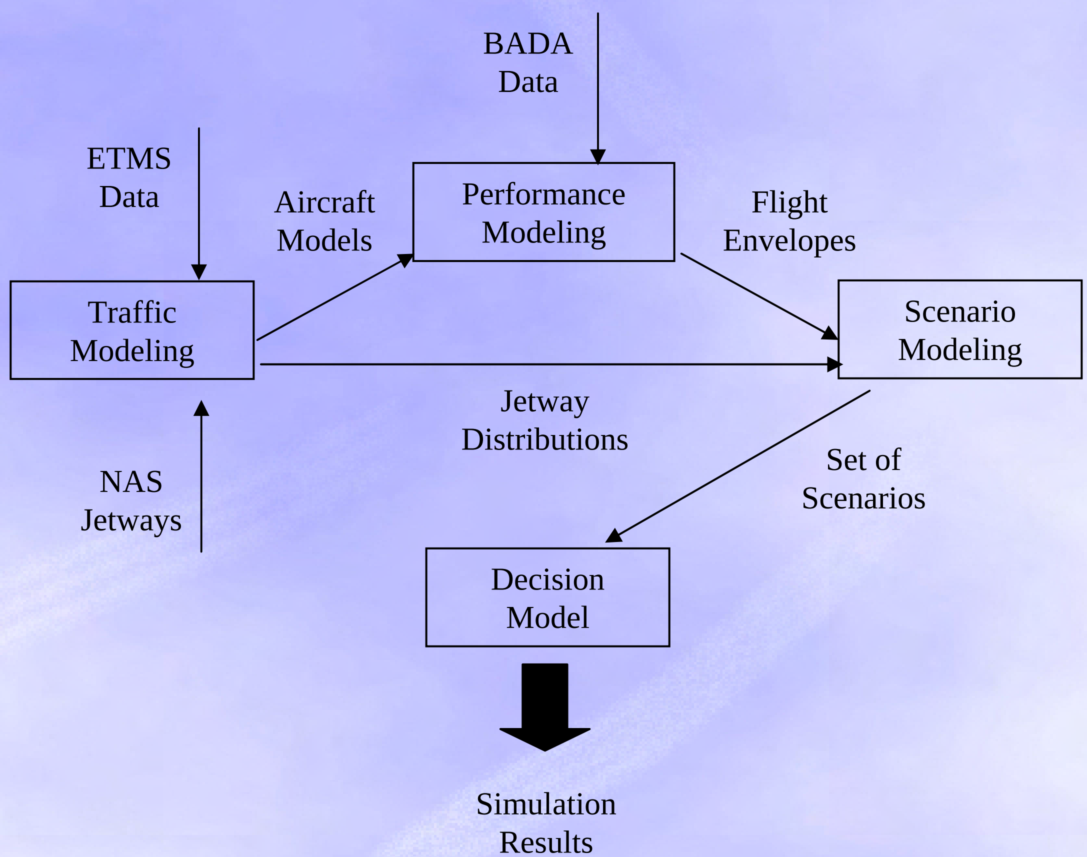
Airports with 20,000+ Hours of Annual Delay



Airspace Restrictions



Analysis of Northeastern US



Scenarios

Baseline (Single Jetway)

- Provides estimate of optimization benefits

Reduced Vertical Separation Minimum (RVSM)

- Provides more capacity overall

Optimization Algorithm

$\max \sum_{i \in N} x_i$ or $\min \sum_{i \in N} f_i$	**Objective**

$subject\ to:$

$Tv_i = x_i - x_{0_i}, \forall i \in N$ $Ta_i = v_i - v_{0_i}, \forall i \in N$	**Kinematics**
$v_i \le C(1 - z_i^k) + v_{max_i}^k, \forall i \in N, k \in M$ $v_i \ge -C(1 - z_i^k) + v_{min_i}^k, \forall i \in N, k \in M$ $a_i \ge a_{min} = 2\ fps, \forall i \in N$ $a_i \le a_{max} = -2\ fps, \forall i \in N$	**Performance**
$\sum_{k \in M} z_i^k = 1, \forall i \in N$ $y_{ij} + y_{ji} = 1, \forall i \in N,\ \forall j \in N \mid i \ne j$ $y_{ii} = 0, \forall i \in N$	**Sequencing**
$x_j - x_i \ge -C(3 - z_i^k - z_j^k - y_{ij}) + s, \forall i \in N, \forall j \in N, \forall k \in M$	**Separation**
$f_i \ge -C(1 - z_i^k) + a_{i1}^k v_i + b_{i1}^k, \forall i \in N$ $f_i \ge -C(1 - z_i^k) + a_{i2}^k v_i + b_{12}^k, \forall i \in N$ $f_i \ge -C(1 - z_i^k) + a_{i3}^k v_i + b_{i3}^k, \forall i \in N$ $f_i \ge -C(1 - z_i^k) + a_{i4}^k v_i + b_{i4}^k, \forall i \in N$	**Fuel Burn**

Delay & Fuel Burn Benefits

Baseline

- Up to 8.5 minutes delay savings per aircraft
- Up to 160 gallons of fuel per aircraft

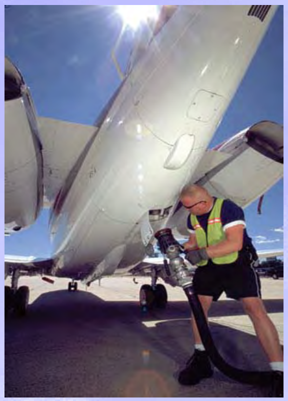
RVSM

- 45% additional delay reduction
- No additional fuel burn reduction

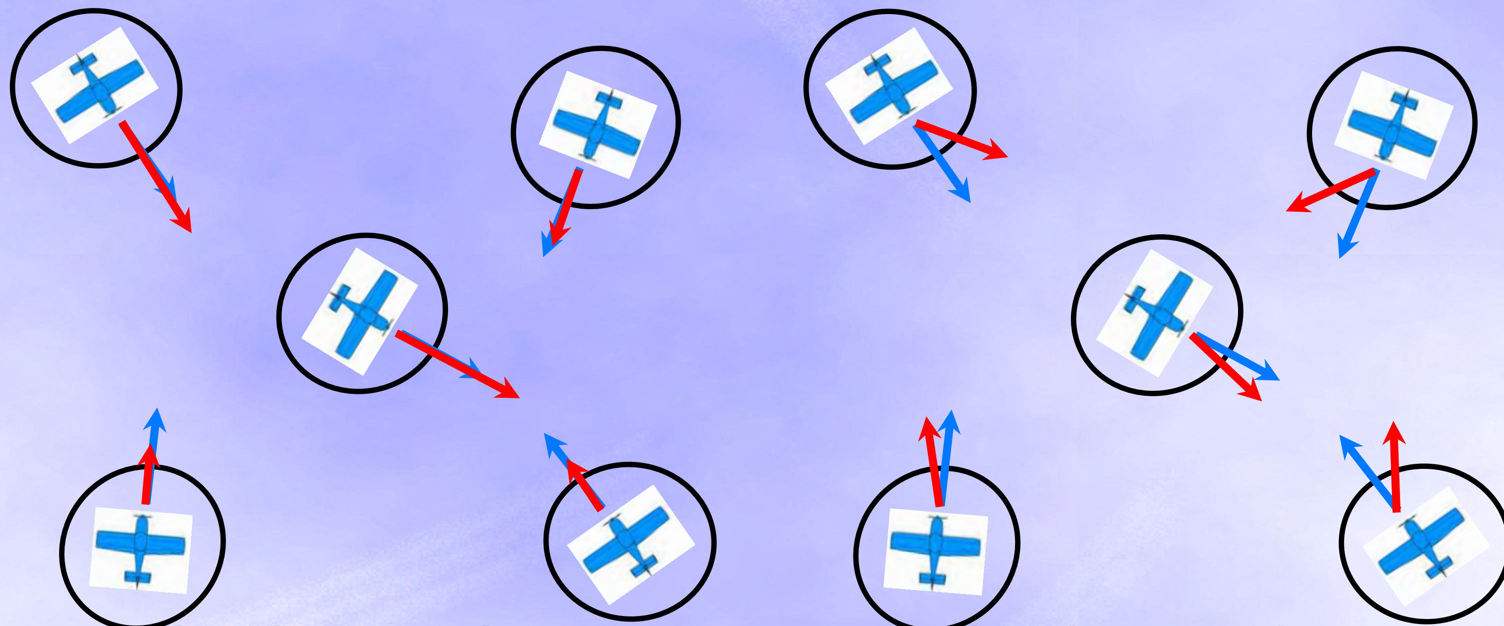
Optimizing Intersection Traffic Flows

- Ensure safety
- Satisfy transfer constraints between sectors
- Avoid obstacles

- Minimize deviation
- Reduce fuel costs



Changing Trajectories to Avoid Conflicts and Minimize Cost (e.g. Fuel Burn)



Method 1: Change Airspeed of each Aircraft

Method 2: Change Heading of each Aircraft

Method 3: Change both Airspeed and Heading of each Aircraft

Optimization Formulation

$$
\begin{aligned}
\min \quad & f_0(x) \\
\text{s.t.} \quad & f_i(x) \leq 0 \\
& Ax \leq b \\
& Fx = g
\end{aligned}
$$

<u>Cost Function</u>

Evaluation Criteria

<u>Constraints</u>

Equalities: Define variables

Inequalities: Allowable regions

Cost Function

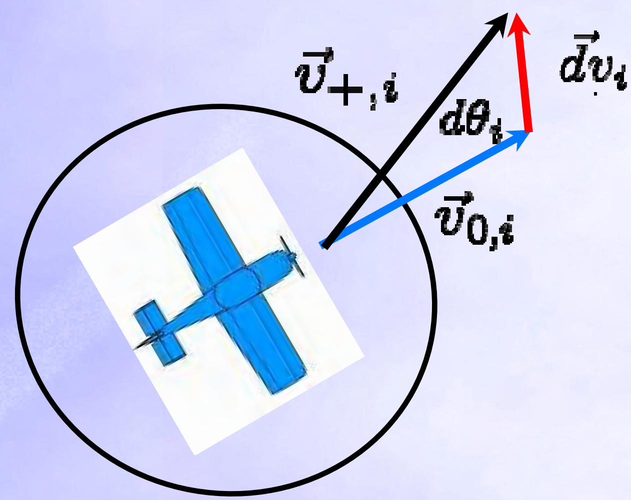
$$f_0 = \sum_{i=0}^{n} [g_{1,i}(||\vec{v}_i||) + g_{2,i}(\theta_i)] + ||g_1(||\vec{v}||)||_\infty + ||g_2(\theta)||_\infty$$

Fuel and heading cost for each plane

Max fuel and heading cost for all planes

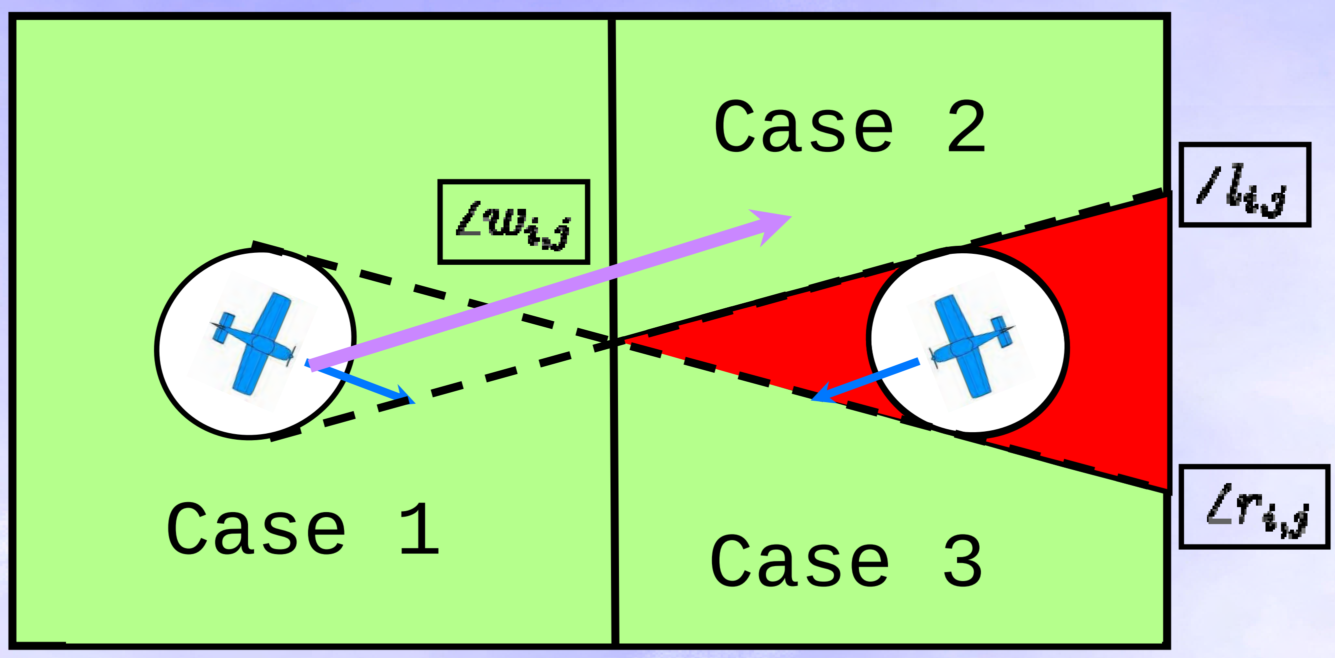
Decision variables are

$\vec{v}_{+,i}$ $\vec{v}_{0,i}$ $\vec{dv}_i$



Safety Constraints

Safety regions defined using relative velocity vector



$\angle r_{i,j}$ and $\angle l_{i,j}$ given from initial conditions

Example: Baseline (No Changes)

- Initial Trajectory
- **Desired Trajectory**

Example: Airspeed and Heading Changes

- Initial Trajectory
- Desired Trajectory
- Optimal Trajectory

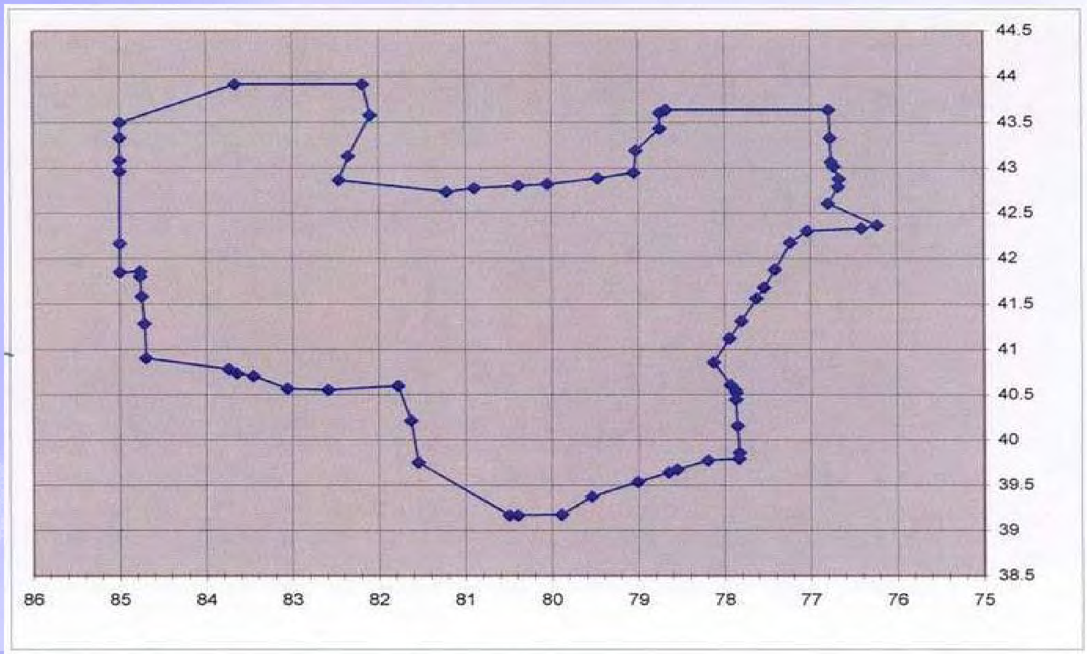
QuickTime™ and a
H.264 decompressor
are needed to see this picture.

Cleveland Center Study

- Cleveland ARTCC subject of case-study
  - Center is defined by a collection of latitude,longitude boundary fixes
  - Sector is non-convex so it has been partitioned into a complimentary and comprehensive set of convex regions

- Currently developing simulation to
  - Evaluate algorithm performance
  - Study fairness implications

- Will develop enhanced algorithm that considers fairness while optimizing traffic flow



Conclusions

Preliminary results suggest that there are significant emissions and fuel burn savings to optimally…

- Assign aircraft to amongst available altitudes with a traffic flow
- Reroute traffic flows to prevent conflicts (with other aircraft, weather, terrain)

Algorithm framework provides means for rerouting aircraft around other aircraft, weather, and terrain at minimum cost in terms of emissions and fuel burn

- Potential to reroute around super saturated air masses to avoid contrail formation

Further research needed to take ideas to a working prototype