Airspace System Efficiencies Enabled by PNT

John-Paul Clarke
Associate Professor, Aerospace Engineering and Industrial and Systems Engineering
Director, Air Transportation Laboratory
Georgia Institute of Technology
Motivation (1)

- Air transportation is a critical component of the “backbone” of the global economy
  - Strong correlation with gross domestic product
  - Air cargo is a leading indicator of economic activity
  - Significant number of direct, indirect, and induced jobs
  - Air transportation provides a basis for economic activity in regions with poor surface and water access
- Future economic growth will require significant efficiency improvements and/or capacity increases
Motivation (2)

• Development of air traffic control in the six decades since WWII has been driven by...
  • Technologies (e.g. Radar, VOR, ILS, RNAV) that brought new or significantly improved operational capabilities
  • Accidents precipitated mandates for technologies that were “on the shelf” (e.g. TCAS) but “could not buy their way into the system”

• Air transportation system still prone to frequent disruption and delays (mostly weather-based) despite over 50 year of all-weather operations
Motivation (3)

• Recent shift towards higher precision navigation and timing
  • Cockpit-focused Area Navigation (RNAV) with Required Navigation Performance (RNP)
  • GPS-based Automatic Dependent Surveillance - Broadcast (ADS-B)
• What can we do with PNT to improve efficiency?
  • Metering of Arrival Flows
  • Regulation of Departure Flows
Metering of Arrival Flows
Motivated by Near-Term Benefits

<table>
<thead>
<tr>
<th>Optimized Profile Descent</th>
<th>2018 ESTIMATES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MIA</strong></td>
<td>Reduce Delays</td>
</tr>
<tr>
<td>50 Gallons Fuel Saved*</td>
<td>21%</td>
</tr>
<tr>
<td>1,000 Pounds Emissions Reduced*</td>
<td></td>
</tr>
<tr>
<td><strong>ATL</strong></td>
<td>Reduce CO₂ Emissions</td>
</tr>
<tr>
<td>38 Gallons Fuel Saved*</td>
<td>14M Tons Cumulative</td>
</tr>
<tr>
<td>800 Pounds Emissions Reduced*</td>
<td></td>
</tr>
<tr>
<td><strong>LAX</strong></td>
<td>Reduce Fuel Use</td>
</tr>
<tr>
<td>26% Reduction of Average Level Flight (ALF) Time</td>
<td>1.4B Gallons Cumulative</td>
</tr>
<tr>
<td>5.2% Reduction of Fuel Use</td>
<td></td>
</tr>
</tbody>
</table>

*Per Flight in May 2008

© John-Paul Clarke | Stanford PNT Symposium 15 November 2013
Optimized Profile Descent (OPD)*

- Aircraft actively controlled during descent from cruise (top-of-descent) to transition altitude
- Minimal intervention below transition altitude

* OPT = Continuous Descent Arrival (CDA)
OPD Trajectories (2004 Flight Trial)

Vertical Profile to SDF 35L

- B767 CDA on Sep 22
- B757 CDA on Sep 15
- B767 STD on Sep 08
- B757 STD on Sep 28

Altiude (1000 ft) vs. Distance Flown (nm)
OPD Trajectories (2004 Flight Trial)
OPD Trajectories (2004 Flight Trial)
Challenge

- Ability to achieve these benefits without sacrificing throughput is primarily a function of the accuracy with which aircraft can be metered
  - Intervention required if aircraft are too closely spaced
  - Throughout lost if aircraft are too widely spaced
TASAT*
Variability in Threshold Spacing

Required separation at runway

Target spacing at transition point

Range of spacing at runway for a given target spacing at transition point;

Shaded area equal to confidence that descent to runway can be completed without controller intervention;

Shape of distribution depends on target spacing.
Observation

- TASAT nominally provides conditional probability density function (PDF) for the spacing between aircraft when the lead aircraft is over the threshold
  - PDF conditional on the metering being perfect
- Actual probability density function will depend on metering accuracy
  - Actual PDF will be a convolution of the conditional PDF and the PDF for the metering accuracy
- PNT is thus the key to optimizing arrival operations
Regulation of Departure Flows
Background

- Most OEP airports have closely spaced parallel runways (CSPRs)
  - 20 out of 35 OEP airports have CSPRs
  - 27 sets of CSPRs in total at these airports (i.e. some airports have multiple sets of CSPRs)
- Departures typically wait for arrivals to “cross the threshold” or “touchdown” before commencing their takeoff roll
Nominal Departure Process (1)

- Taxi into position and hold
Nominal Departure Process (2)
Nominal Departure Process (3)
Nominal Departure Process (4)
Nominal Departure Process (5)
Nominal Departure Process (6)
Nominal Departure Process (7)
Nominal Departure Process (8)
Nominal Departure Process (9)
Nominal Departure Process (10)
Nominal Departure Process (11)
Runway Regulator – Objective

- For each set of
  - Closely spaced parallel runways
- Decide
  - When to issue automated takeoff clearance/advisory
- Given
  - Position of arrival (e.g. from ADS-B)
  - Potential future trajectories of all aircraft
  - Probabilities that landing will be completed
  - Probability successful response to missed approach
Runway Regulator – Logic Flow

- Departure aircraft given clearance by ATC to:
  - taxi into position and hold
  - await automated departure clearance
- Automated departure clearance/advisory issued when:
  - Next arrival descends below decision height
  - There is sufficient separation between previous departure
- Automated abort clearance/advisory issued if:
  - Arrival executes a missed-approach
Separation w/Prev. Departure

Arrival more than 2 miles from runway end

Arrival Below Decision Height

Departure Clearance

Missed Approach

Abort Clearance

Departure Stop
Track and Field Analogy (1)

- The 4x400m
  - Handoff occurs at low speed
  - Relay time approximately equal to sum of individual times
Track and Field Analogy (2)

- The 4x100m
  - Handoff occurs at high speed
  - Relay time less than sum of individual times
Nominal Departure Process

Distance from Threshold

Time

1st Arrival

2nd Arrival

Pilot Response

Communication

Controller Response

Departure

Required Inter-Arrival Gap without Regulator

$S_{ij}$
Regulated Departure Process

Diagram showing the regulated departure process with labels for Pilot Response, Communication, Controller Response, Distance from Threshold, Decision Height, Departure, 1st Arrival, 2nd Arrival, and Required Inter-Arrival Gap with Regulator.
Regulated Departure Process (1)

- Taxi into position and hold
- Await automated clearance
Regulated Departure Process (2)
Regulated Departure Process (3)
Regulated Departure Process (4)
Regulated Departure Process (5)
Regulated Departure Process (6)
Regulated Departure Process (7)
Regulated Departure Process (8)
Regulated Departure Process (9)
Implementation Options

• Options for Automated Clearance:
  • Audio clearance via computer generated voice message
  • Visual clearance via lights (similar to drag racing)

• Option for Automated Advisory:
  • Audio and visual cue to controller who then issues clearance as normal
Simulation

• Overview:
  • Models arrivals and departures on a set of CSPRs
  • Varies arrival rate
  • Finds maximum departure rate

• Inputs:
  • Fleet Mix
  • Flight Conditions

• Output:
  • Pareto Frontier
Simulation Results

Automated Clearances

Automated Advisories

© John-Paul Clarke | Stanford PNT Symposium
Observations (1)

- As expected... Slope of Pareto Capacity Curve is shallower with runway regulator
  - Probability of finding a large enough gap in the arrival stream is increased so more departures are allowed
Observations (2)

• Surprisingly... Slope of Pareto Capacity Curve reverses and starts to increase at large arrival rates
  • Counter to the nominal situation where the slope continually decreases
  • Mode of operation changes from “finding a gap in the arrival stream to fit a departure” to “finding the next arrival with which to synchronize a departure”
  • Akin to “driving system near resonance”
• Up to 34% increase in throughput possible!
Robustness Issues

• What happens when the arrival executes a missed-approach?
Regulated Missed-Approach (1)

Decision Height

- Taxi into position and hold
- Await automated clearance
Regulated Missed-Approach (2)
Regulated Missed-Approach (3)
Regulated Missed-Approach (4)
Regulated Missed-Approach (5)
Regulated Missed-Approach (6)
Regulated Missed-Approach (7)
Regulated Missed-Approach (8)
Regulated Missed-Approach (9)
How could this be fielded?

- Dedicate set of CSPRs to ADS-B equipped aircraft
  - Consistent with best equipped-best served paradigm
- Phase 1: Install underlying sensing and processing systems and validate their performance
  - Address expected system operating curve issues
- Phase 2: Install automated advisory tool in tower
  - Requires the least change on the part of controllers
  - Enables controllers to build confidence in system
- Phase 3: Install automated clearance capability