Applying Flight-deck Interval Management based Continuous Descent Operation for Arrival Air Traffic to Tokyo International Airport

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Contents

Background and purposes
• Continuous Descent Operation (CDO) to Tokyo International Airport
• Flight-deck Interval Management (FIM)

FIM-based CDO
• Air route design for arrivals to Tokyo International Airport
• Operational goals
• Simulation assumptions

Simulation results
• Time-spacing performance
• Fuel consumption

Concluding remarks
Background and purposes

- Continuous Descent Operation (CDO) to Tokyo International Airport
- Flight-deck Interval Management (FIM)
Continuous Descent Operation (CDO)

• Arrival aircraft continuously descend from cruise to an airport at near-idle thrust
• Environmental-friendly, energy saving arrivals
• Currently doable in low-density traffic
• Applying CDO in high-density operation is the next challenge
Tokyo International Airport (2/2)

- Open 24 hours
- 410,000 movements per year
- 4 runways
- Arrival aircraft land every two mins.

Focus on domestic flights from west and south Japan arriving RW 34L, which is most frequently used in the winter season.
Flight-deck Interval Management (FIM) (1/2)

- One of the applications of Aircraft Surveillance Applications System (ASAS)

ASAS overview
Flight-deck Interval Management (FIM) (2/2)

- Airborne time-spacing by speed control

ATCo decides a sequence of arrivals and time interval $t$ at the runway threshold. Airspeed is controlled in the air following ATCo’s instruction.
Purposes

• Evaluate the performance of time-spacing and fuel consumption when the FIM-based CDO is applied to the Tokyo International Airport

• Build a fast-time simulation environment for FIM-based CDO for arrivals to Tokyo International Airport: “SPICA software”
FIM-based CDO

- Air route design for arrivals to Tokyo International Airport
- Operational goals
- Simulation assumptions
FIM speed control by ASTAR (1/2)

- Combination of trajectory prediction and aircraft speed control
FIM speed control by ASTAR (2/2)

• Air route design
  – Air route is designed as a sequences of waypoints to the runway threshold defined by latitude, longitude, crossing altitude/glide path angle, crossing airspeed, ratio of airspeed, and wind data

• Trajectory generator
  – 4D trajectory is generated to estimate distance/time to the runway threshold (Distance/Time To Go (DTG/TTG))

• Speed controller
  – By using DTG/TTG of the leading/own aircraft, airspeed is controlled to achieve the assigned time-spacing at the runway threshold
  – VNAV/PATH mode, +-10% speed change from the profile
Air route design (1/2)

- Current air route to Tokyo International Airport

Current RNAV route to RW 34L

2.5 degrees path to capturing ILS

Altitude restriction 10,000 ft at a terminal gate ADDUM
Air route design (2/2)

- Designed air routes

**Route A:** No altitude restriction at ADDUM

**Route K/S:** Shortcut crossing Tokyo bay

**Route K/F:** Shortcut merging at OSHIMA(XAC)
Operational Assumptions (1/2)

• FIM execution procedures
  – Initiation
    *ATCo instructs the arrival sequence and time-spacing intervals 10–15 minutes before FIM execution point, SHTLE/FLUTE.
  – Execution
    *Pilot executes FIM to comply with the ATCo instructions.
    *FIM commands are input to FMS
  – Termination
    *FIM is terminated when the leading aircraft arrives at the threshold of RW34L.
Operational Assumptions (2/2)

- Aircraft types and flight scenarios
  - Medium fidelity aircraft model of B777-200 and B737-800 including VNAV/LNAV, engine system, and flight control systems
  - Three pairs of aircraft trailing, a total of four aircraft, in a string according to ATCo comments

<table>
<thead>
<tr>
<th>Case</th>
<th>Aircraft type (Route name)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1&lt;sup&gt;st&lt;/sup&gt; aircraft</td>
</tr>
<tr>
<td>A</td>
<td>B777-200 (Route A)</td>
</tr>
<tr>
<td>B</td>
<td>B777-200 (Route A)</td>
</tr>
<tr>
<td>C</td>
<td>B777-200 (Route K/S)</td>
</tr>
<tr>
<td>D</td>
<td>B777-200 (Route K/S)</td>
</tr>
<tr>
<td>E</td>
<td>B777-200 (Route K/S)</td>
</tr>
</tbody>
</table>
Assumptions on MC simulation

• Wind
  – typical winter seasonal west wind of 100 knots at 40,000 ft decreasing linearly with altitude to 20 knots at RW34L.

• Wind estimation errors
  – wind estimation error is assumed to be 10 knots: actual velocity of the west wind is 10 knots stronger than the estimate.

• Initial time-spacing intervals
  – ± 15 second deviation from a standard two-minute landing interval: $t_{min} = 105 \ sec$, $t_{max} = 135 \ sec$, given by uniform density
Simulation results

- Time-spacing performance
- Fuel consumption
Time-spacing performance (1/7)

- Does FIM achieve good performance in time-spacing?
- Does the time-spacing performance depend on aircraft types/route design?
- Is FIM feasible under the wind effects and wind estimation errors?
Time-spacing performance (2/7)

• Route A:
  Case A (B777-B777-B777-B777)

Wind estimation errors

Route A

Case A 1st pair
- goal: 125, var: 0.400

Case A 2nd pair
- goal: 125, 225, var: 0.005

Case A 3rd pair
- goal: 124, 257, var: 0.173

Spacing time
Time-spacing performance (3/7)

- **Route A:**
  - **Case A** (B777-B777-B777-B777)
  - **Case B** (B777-B737-B737-B777)

**Wind estimation errors**

**Spacing time**

![Route A diagram](image-url)
Time-spacing performance (4/7)

- Route K/S:

  Case C (B777-B777-B777-B777)

Wind estimation errors

Route K/S

V3R3 (B772 B772)

Case C 1st pair

- Goal
- Start

ave: 118
var: 0.695

V3R3 (B772 B772)

Case C 2nd pair

- Goal
- Start

ave: 112
var: 0.591

V3R3 (B772 B772)

Case C 3rd pair

- Goal
- Start

ave: 109
var: 0.763

Spacing time
Time-spacing performance (5/7)

- Route K/S:
  Case C (B777-B777-B777-B777)

- Route A
  Case A (B777-B777-B777-B777)

Wind estimation errors

Route K/S

Route A

Spacing time

V3R3 (B772 B772)

Case C 1st pair

- goal
- start
- ave: 118.695
- var: 0.791

Case C 2nd pair

- goal
- start
- ave: 112.591
- var: 0.521

Case C 3rd pair

- goal
- start
- ave: 109.763
- var: 0.453

V3R2 (B772 B772)

Case A 1st pair

- goal
- start
- ave: 125.400
- var: 0.000

Case A 2nd pair

- goal
- start
- ave: 125.225
- var: 0.005

Case A 3rd pair

- goal
- start
- ave: 124.257
- var: 0.173
Time-spacing performance (6/7)

- Route K/S, K/F:
  - Case D (B777-B777-B777-B777)
  - Case E (B777-B737-B737-B777)

![Spacing time graphs for Case D and Case E](image-url)

- Case D:
  - Spacing time: goal (113.824 seconds), start (average 14.530 seconds)

- Case E:
  - Spacing time: goal (111.358 seconds), start (average 20.234 seconds)
Time-spacing performance(7/7)

- FIM time-spacing performance depends on characteristics of the designed air route.
- Combinations of aircraft types influence on time-spacing performance depending on the air route design.
- Further simulations are required based on air routes designed for FIM-based CDO.
- The effect of the wind estimation errors is one of the potentials to deteriorate the time-spacing performance.
Fuel consumption (1/3)

- Simulated B777-200 fuel consumption from Top Of Descent (TOD) on Route K/S

1st aircraft

2nd aircraft

3rd aircraft

4th aircraft

Route K/S
Fuel consumption (2/3)

- Comparison of simulated B777-200 fuel consumption and time from TOD with actual data

![Graph showing fuel consumption comparison]

- AC0: 1\textsuperscript{st} aircraft
- AC1: 2\textsuperscript{nd} aircraft
- AC2: 3\textsuperscript{rd} aircraft
- AC3: 4\textsuperscript{th} aircraft
Fuel consumption(3/3)

• FIM-based CDO realizes energy-saving arrivals.
• The variances of average fuel consumption and required time from TOD for each of the four aircraft in the simulated data are significantly smaller than the variances in actual data.
• Applying FIM-based CDO has a potential to achieve assigned time spacing while reducing fuel consumption for all traffic, not just for specific aircraft.
Concluding remarks
Conclusion

• Implemented FIM-based CDO with a medium-fidelity aircraft model including VNAV and LNAV autopilot modes, an engine system, and TECS, in a fast-time simulation via SPICA software.

• Estimated the effectiveness of the FIM-based CDO to Tokyo International Airport based on the time spacing performance and fuel consumption.
Future works

• Further simulation studies to evaluate the effect of combinations of air route design, wind effect, wind estimation errors, including more aircraft types via SPICA software
• Consider mixed equipage situation
• Analyze how to harmonize with the ground operation
• Estimate FIM off-nominal events
Thank you!
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