Airport Terminal Traffic Simulation Applying Reduced Wake Vortex Separation

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- **MEXT (DOE, DOC)**
  Ministry of Education, Culture, Sports, Science and Technology

- **MILT (DOT)**
  Ministry of Land, Infrastructure, Transport and Tourism

- **JCAB (FAA)**
  Japanese Civil Aviation Bureau

- **JMA (NWS)**
  Japan Meteorological Agency

- **JAXA (NASA)**
  Japan Aerospace Exploration Agency

- **ENRI (FAA Tech. Center)**
  Electric Navigation Research Institute

- **MRI (NOAA, NCAR)**
  Meteorological Research Institute

JAXA (FY2009)
Budget: 193 billion yen (1.7 billion Euro), Staff: 1594

90% goes to space…
Outline

1. Introduction
2. Simulation Environment
3. Simulation Results
4. Conclusion
Tokyo International (Haneda) Airport

Japanese air traffic concentrate on the Tokyo metropolitan area and Tokyo International (Haneda) airport suffers capacity shortage.

Wake vortex separation minima are major impediments to airport capacity increase because:

- ‘Heavy’ aircraft are mainly used at Haneda airport (‘Heavy’ 70%, ‘Medium’ 30%).
- Crossing runway layout causes wake vortex interferences between departures and landings.
Wake Advisory System

Reduce wake vortex separation minima by using the following system:

✓ Wake advisory system: predict wake vortex behavior.
✓ Optimal avoidance path: employing GBAS-based flexible flight paths (dual threshold / curved approach) to avoid wake vortices.

Feasibility Study:
Quantify expected capacity increase at Haneda airport with reduced separations by traffic simulation.

(Still in discussion)

ENRI: Electric Navigation Research Institute
IFS: Institute of Fluid Science, Tohoku Univ.
1. Introduction

2. Simulation Environment

3. Simulation Results

4. Conclusion
Simulation Program Overview

- **Function**
  Reduce wake vortex separation with the same or improved levels of safety.

- **Modules**
  - Meteorological model ⇒ produce realistic weather data
  - Wake vortex prediction model ⇒ predict wake vortex position / strength
  - Aircraft trajectory model ⇒ simulate airport traffic patterns
  - Wake vortex risk calculation ⇒ calculate wake vortex encounter risk
  - Separation scheduling ⇒ minimize wake vortex separation
Meteorological Model / Wake Vortex Prediction Model

Predict wake vortex strength and position according to surrounding meteorological condition using probabilistic wake vortex prediction model (DLR S2P model (Holzäpfel, 2006)) combined with high resolution meso-scale weather prediction model (JAXA SPF model).

Example of probabilistic predictions of wake vortex positions using S2P model.

Example of weather simulation around Haneda airport using SPF model.
Aircraft Trajectory Model

✓ SIDs, STARs of Haneda airport below 2000ft AGL are modeled.
✓ Probabilistic flight path deviation models has been developed based on CREDOS model (for departure) and ILS CRM (for ILS landing).
✓ Aircraft type-specific power settings and airspeed profiles are based on the Aircraft Noise Performance (ANP) model. (currently B747 only)

CRM: Collision Risk Model

<table>
<thead>
<tr>
<th>Altitude [ft]</th>
<th>Range [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal path</td>
<td>1000 ft</td>
</tr>
<tr>
<td>Nominal path + 2σ</td>
<td>2000 ft</td>
</tr>
<tr>
<td>Nominal path - 2σ</td>
<td>3000 ft</td>
</tr>
</tbody>
</table>

Departure trajectory

Path angle = 4.1deg
Path angle = 6deg
Definition of Wake Vortex Encounter

\[ \text{WVE} = \Gamma \geq \Gamma_{\text{thresh}} \]
\[ \quad\land |Y_{\text{AC}} - Y_{\text{wake}}| \leq Y_{\text{thresh}} \land |Z_{\text{AC}} - Z_{\text{wake}}| \leq Z_{\text{thresh}} \]

\( \Gamma_{\text{thresh}} = 100 \text{m}^2/\text{s}, \) \( Y_{\text{thresh}} = Z_{\text{thresh}} = 50 \text{m} \)

✓ Tentative values
✓ Conservative so as not to overlook potential risk
Wake Vortex Encounter Risk

\[ P_{\text{risk}} = \sum_i \left( P(ACL \in RL_i) \cdot P(\Gamma_{Li} \geq \Gamma_{\text{thresh}}) \sum_j P(AC_F \in RF_j) \cdot P(Wk_i \in RFH_j) \right) \]

1. Divide \( R_L, R_F \) into \( N \) sections (\( R_{Li}, R_{Fj}; i, j=1-N, N \approx 30 \))

2. For each \( R_{Li} \), calc. encounter risk due to wake shed from \( R_{Li} \) as follows:
   2-1. Calc. \( Wk_i \) using S2P
   2-2. For each \( R_{Fj} \):
      2-2-1. Set hazard area \( RFH_j \) for \( R_{Fj} \)
      2-2-2. Calc. probability that wake exists within \( RFH_j \) \( \Rightarrow P(Wk_i \in RFH_j) \)
      2-2-3. Calc. probability that follower exists within \( R_{Fj} \) \( \Rightarrow P(AC_F \in RFj) \)
      2-2-4. Calc. encounter risk by multiplying \( P(AC_F \in RFj) \) and \( P(Wk_i \in RFH_j) \)
   2-3. Sum up encounter risks for all \( R_{Fj} (j=1-N) \)
   2-4. Calc. hazardous encounter risk by multiplying probability that circulation exceeds threshold \( (P(\Gamma_{Li} \geq \Gamma_{\text{thresh}})) \)
   2-5. Calc. encounter risk by multiplying probability that leader exists within \( R_{Li} \) \( P(AC_L \in RL_i) \)

3. Sum up encounter risks for all \( R_{Li} (i=1-N) \)

\( R_L: \) Leader distribution,
\( R_F: \) Follower distribution,
\( Wk_i: \) Wake distribution shed from \( R_{Li} \)
\( RFH_j: \) Hazard area of \( R_{Fj} \)
Separation Scheduling

Minimize wake vortex separation without increasing wake vortex hazard.

Average WVE risk with current wake vortex separation minima is used as acceptable risk.

WVE Risk

- WVE risks with current wake vortex separation minima at various weather conditions
- Average risk $\Rightarrow$ acceptable risk
- Cases where separation minima can be reduced
# Considered Separation Limits

In addition to wake vortex separations, the following separation limits are considered in separation scheduling.

<table>
<thead>
<tr>
<th>Situation</th>
<th>Separation minimum</th>
<th>Reason for separation</th>
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<tr>
<td>1) between successive departures from the same runway</td>
<td>95 sec.</td>
<td>runway occupancy time</td>
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<td>115 sec.</td>
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<td>3) From: take-off clearance from RWY16L</td>
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<tr>
<td>To: a departing aircraft from RWY16L flies over RWY23</td>
<td></td>
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<td>4) From: take-off clearance from RWY16R</td>
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<td>5) From: a departing aircraft from RWY16L flies over RWY23</td>
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<td>radar separation minimum (2NM)</td>
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<td>To: a landing aircraft on RWY23flies over RWY23 threshold</td>
<td></td>
<td></td>
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<td>6) From: a departing aircraft from RWY16R flies over RWY23</td>
<td>29 sec.</td>
<td>radar separation minimum (2NM)</td>
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<td>To: a landing aircraft on RWY23flies over RWY23 threshold</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7) From: a landing aircraft on RWY23flies over RWY23 threshold</td>
<td>25 sec.</td>
<td>landing confirmation</td>
</tr>
<tr>
<td>To: take-off clearance from RWY16R/L</td>
<td></td>
<td></td>
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<td>8) time required for take-off clearance from RWY16R</td>
<td>15 sec.</td>
<td>engine blast avoidance</td>
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For Haneda airport (at southerly wind condition)
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Simulation Scenario

- Operations at southerly wind (simulated typical 946 weather conditions occurred in 2009)
- All aircraft are B747 (Heavy).
- Three major bottlenecks due to wake vortex separations:
  1) b/w successive departures from RWY16L/R
  2) b/w successive landings on RWY22
  3) b/w RWY16L departure and RWY23 landing

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WVE Risk vs. Altitude

1) b/w successive departures on RWY16L/R
2) b/w successive landings on RWY22
3) b/w RWY16L departure (leader) and RWY23 landing (follower)

Incidence rate of altitudes where WVE risks become maximum

- Curved app.
- Dual threshold

Wake does not descend
Deviation increases & RoC decreases
Deviation increases
Separation Scheduling

1) b/w successive departures on RWY16L/R

Average WVE risk: $3.2 \times 10^{-4}$
Capacity increase (incidence): +2 Dep. & +2L/D (32%)
+1 L/D (7%)

Total capacity increase

Average: +2.2 Dep. & +1.9 L/D (5% capacity increase)
Maximum: +6 Dep. & +5 L/D (14% capacity increase)

2) b/w successive landings on RWY22

Average WVE risk: $1.4 \times 10^{-3}$
Capacity increase (incidence): +1 L/D (50%)

3) b/w RWY16L departure (leader) and RWY23 landing (follower)

Average WVE risk: $2.5 \times 10^{-6}$
Capacity increase (incidence): +6 Dep. & +4L/D (13%)

Average WVE risk: $1.4 \times 10^{-3}$
Capacity increase (incidence): +6 Dep. & +4L/D (28%)
Separation Scheduling with weather information uncertainty

Wake parameters’ PDF spread and peak probability decrease due to weather information uncertainty. (Holzäpfel, 2010)

Comparison b/w WVE risks calculated by different uncertainty is difficult.

Use PDF envelope to calculate WVE risk.

Evaluated influence of cross wind uncertainty to airport capacity increase in 136 cases out of 946 cases

Capacity increase drops from 4.1% to 2.4% with realistic cross wind uncertainty of 3m/s.
Conclusions

- Developed simulation program that quantify expected airport capacity increase with reduced wake vortex separations.
- Demonstrated that 2.4% improvement in airport capacity can be gained at Haneda airport (southerly wind ops.) by introduction of reduced separation considering realistic weather information uncertainty (3m/s standard deviation of cross wind).

Future Plan

- Introduce flight path optimization such as curved app. & DT ops. and quantify their effects.
- Quantify weather information uncertainty by comparing weather prediction data with aircraft observation data (ACARS).
- Conduct wake vortex observation campaign using LIDAR to make wake vortex behavior database.
Wake vortex observation campaign

- Collect wake behavior data for 2 weeks on each season (total 2 months) in FY2013 to establish PDF (probability density function) of wake vortex parameters used in S2P.
- Plan to use lidar as a wake vortex sensor and flight data to get weather data along flight paths.