Reduced Wake Vortex Separation Using Weather Information

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Japan’s Plan for Reduced Wake Vortex Separation

Japan civil aviation bureau (JCAB) has compiled the long term vision of the future air traffic system named **CARATS (Collaborative Actions for Renovation of Air Traffic System)** in 2010. In CARATS, JCAB plans to introduce reduced wake vortex separation as follows:

1. Introduction of RECAT (2018-)
2. Dynamic separation taking actual wind data or forecast into account (2022-)
3. Apply actual wake vortex data or forecast from departure or arrival aircraft (2024-)

JCAB has participated in ICAO wake turbulence study group (WTSG) from 2013 to support the standardization of the reduced wake vortex separation.
Japanese Government Organizations Related to Civil Aviation R&D

- MEXT: Ministry of Education, Culture, Sports, Science and Technology
- MILT: Ministry of Land, Infrastructure, Transport and Tourism
- JCAB: Japan Civil Aviation Bureau
- JAXA: Japan Aerospace Exploration Agency
- ENRI: Electronic Navigation Research Institute

R&D organizations
JAXA’s Research Objectives

Establish the following technologies to realize dynamic wake vortex separation:

- Wake vortex advisory system: calculate safe separation based on wake vortex prediction.
- Traffic pattern optimization: optimize separations, take-off/landing sequences, runway allocation and flight paths to increase capacity.

ENRI: Electronic Navigation Research Institute
IFS: Institute of Fluid Science, Tohoku Univ.
1) Wake vortex advisory system

Calculate safe separation based on wake vortex prediction
Concept of Dynamic Separation

1. Define acceptable wake vortex encounter (WVE) risk level within current WVE risks.
   *(Assumption: Current separations are practically safe)*

2. Reduce separations until the expected risk level at the reduced separation reaches the acceptable risk level, or the separation becomes limited by other constraints.
To calculate WVE risk, we use probabilistic models that give probability density distributions (PDDs) of aircraft/wake parameters and hazard area model.

- **Aircraft trajectory model**
  Create JAXA original model based on actual radar track data of target airport and collision risk model (CRM) of ILS approach.

- **Wake vortex prediction model**
  Employ P2P/S2P model developed by DLR.

- **Hazard area model**
  Create JAXA original model based on flight simulation. (Hazard area: Induced roll acceleration > 5degree/s²)

**WVE risk calculation procedures**

1. Divide regions of leading/following aircraft exist into small sections.
2. Calculate probability that wake shed from $RL_j$ exists within the hazard area of following aircraft that exists in $RF_j$ and the following aircraft also exists in $RF_j$.
3. Calculate probability that following aircraft encounters the wake shed from $RL_j$ by repeating the 2nd process for all $RF_j$.
4. Calculate WVE risk by repeating the 3rd process for all $RL_j$.
Example of WVE Risk Calculation

- WVE risks vary largely by surrounding weather conditions.
  ⇒ We can reduce separation at favorable weather conditions.

- WVE risks increase at high altitude (>1500ft) and low altitude (<400ft).
  ⇒ GBAS-based curved approach and dual thresholds may be useful to decrease WVE risks.

WVE risks in successive landings on RWY22 of Tokyo International airport
(about 1000 different weather conditions)

WVE risk: Risk of roll moment excitement over 5 [deg/s²]
Hazard Risk in Separation Reduction

Mainly due to wake vortex prediction errors, the following risks (‘hazard risk’) exist:
✓ ‘TRUE’ WVE risks at reduced separations can exceed the acceptable risk level.
✓ The acceptable risk level can be too high compared to ‘TRUE’ WVE risks at current separations.

We propose to control ‘hazard risk’ by under/overestimating WVE risks considering wake vortex prediction errors.
How to control ‘hazard risk’?

1. Define confidence intervals of probability density distributions (PDDs) of wake vortex parameters to quantify wake vortex prediction errors.
2. **Underestimate** WVE risks at current separations using lower limits of PDD confidence interval.
3. **Overestimate** WVE risks at reduced separations using upper limits of PDD confidence interval.

\[
\text{‘Hazard risk’} = 1 - (1 - P_U)^3(1 - P_L)^3 < 3(P_U + P_L)
\]

Safe Separation Considering
Wake Prediction Errors

By overestimating WVE risk at reduced separations and underestimating WVE risk at current separations, the proposed method can calculate reduced separations whose WVE risks are probabilistically assured to be equal to or lower than the risk at current separations.
Wake vortex Observation

JAXA plans to collect over 3000 wake data for 2 months in FY2013-2014 at New Tokyo international (Narita) airport to improve probabilistic wake vortex prediction.
2) Traffic pattern optimization & expected capacity gain

Optimize separations, take-off/landing sequences, runway allocation and flight paths to increase capacity
Concept of Traffic Optimization

- **Separation**
  Introduce dynamic separation according to weather condition/aircraft pairwise using wake vortex advisory system.

- **Take-off / landing sequence**
  Optimize sequence to increase the opportunity of successive take-offs/landings of the same category aircraft.

- **Runway allocation**
  Optimize runway allocation to reduce interferences between runways.

- **Flight path**
  Introduce dual thresholds and curved approach to reduce separations by changing flight paths between leading and following aircraft.
Target airport and operation

Runway operations for southerly winds at Tokyo International (Haneda) airport is chosen because wake vortex separations limit the airport capacity.

<table>
<thead>
<tr>
<th>Situation</th>
<th>Wake vortex separation without</th>
<th>Wake vortex separation with</th>
</tr>
</thead>
<tbody>
<tr>
<td>Successive landings on RWY22</td>
<td>115 sec.</td>
<td>120 sec.</td>
</tr>
<tr>
<td>Successive take-offs from RWY16L/R</td>
<td>95 sec.</td>
<td>120 sec.</td>
</tr>
<tr>
<td>Take-off from RWY16L and landing on RWY23</td>
<td>47 sec.</td>
<td>102 sec.</td>
</tr>
</tbody>
</table>

Simulation conditions

- Only aircraft operations below 2000ft are considered. Cruise-phase and airport surface operation are not considered.
- Approximately 1000 weather conditions where southerly winds prevailed are chosen.
- Two different accuracy levels of available weather information are considered. The poor accuracy of weather information leads to the poor performance of wake vortex prediction.

<table>
<thead>
<tr>
<th>Item</th>
<th>Errors (1σ) case 1 (current)</th>
<th>Errors (1σ) case 2 (ideal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EDR [m²³/s]</td>
<td>0.05</td>
<td>0.025</td>
</tr>
<tr>
<td>Brunt–Väisälä freq. [1/s]</td>
<td>0.005</td>
<td>0.0025</td>
</tr>
<tr>
<td>Wind [m/s]</td>
<td>3.0</td>
<td>1.5</td>
</tr>
</tbody>
</table>
Expected Capacity Gain (2/2)

- Major factors affecting capacity gain
  - Acceptable risk level
    Higher acceptable risk level brings larger separation reduction.
  - Weather information accuracy
    Fine accuracy of available weather information increases separation reduction. To improve weather information accuracy is a good tool to reduce separation.

- Expected capacity gain
  We obtained the 4.5% capacity gain with the following assumptions:
    - Employ 90% cumulative risk level as acceptable risk level and ideal accuracy level of weather information.
    - Consider airport operating condition at the most congested time period (8–9 AM) of the target airport.
      The ratio of heavy to medium category aircraft was almost one to one.

  In addition, the capacity gain increased up to 14.5% when we optimized the take-off/landing sequences.

Next step: optimize runway allocation and introduce dual thresholds / curved approach.

<table>
<thead>
<tr>
<th>Situation</th>
<th>Weather information accuracy</th>
<th>Acceptable risk level (cumulative risk level at current separations)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulated separation reductions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Averaged over approximately 1000 different weather conditions</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>50%               70%         90%</td>
</tr>
<tr>
<td>Successive landings on RWY22</td>
<td>Current</td>
<td>0 sec.            0 sec.       2 sec.</td>
</tr>
<tr>
<td></td>
<td>Ideal</td>
<td>0 sec.            1 sec.       3 sec.</td>
</tr>
<tr>
<td>Successive take-offs from RWY16L/R</td>
<td>Current</td>
<td>3 sec.            5 sec.       10 sec.</td>
</tr>
<tr>
<td></td>
<td>Ideal</td>
<td>4 sec.            7 sec.       13 sec.</td>
</tr>
<tr>
<td>Take-off from RWY16L and landing on RWY23</td>
<td>Current</td>
<td>0 sec.            1 sec.       7 sec.</td>
</tr>
<tr>
<td></td>
<td>Ideal</td>
<td>1 sec.            7 sec.       16 sec.</td>
</tr>
</tbody>
</table>
Conclusions

- Japan has a plan to reduce wake vortex separations.

- To realize dynamic wake vortex separations, JAXA has conducted various research activities (DREAMS project) to establish wake advisory system and traffic pattern optimization.