Measurement of Aircraft Wake Vortices Using Doppler 1.5 micron LIDAR

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Contents

- Cooperation for wake vortex research at Sendai Airport
- Doppler lidar at Sendai airport in Japan
- Our research for several years
- Advection database of wake vortices
- Data mining
- Conclusion
Corporative structure of our activity
at Sendai Airport

Wake Vortex Advisory System
Organizer: Japan Aerospace Exploration Agency (JAXA)
Partner: Electronic Navigation Research Institute (ENRI), Tohoku University

Sendai Airport in Japan

**ENRI**
- Development of Doppler LIDAR
- Application to GBAS

**JAXA**
- Evaluation of airplane’s behavior under wake vortices

**Tohoku University**
- Observation
- Simulation (CFD)
Doppler lidar at Sendai airport in Japan

Sendai airport, Japan

Schematic of measurement plane

- Resolution (line-of-sight direction) : 29.9 [m]
- Resolution (Angle) : 0.05 [deg.]
- Range : 2.4 [km]

Template matching method
Our research for several years

Simulation (CFD) considering actual weather condition

Data assimilation (4DVar)

Observation

Advection database of wake vortices

Nested regional numerical weather model

Doppler Lidar at Sendai Airport (By Mitsubishi Electric Corporation)
Advection database of wake vortices

- **Target aircrafts in regular operation at Sendai airport**

<table>
<thead>
<tr>
<th>Model</th>
<th>B767-300</th>
<th>Airbus 320</th>
<th>MD-81/90</th>
<th>Boeing 737-400/-500/-700/-800</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of data</td>
<td>230</td>
<td>145</td>
<td>121</td>
<td>124</td>
</tr>
<tr>
<td>Category</td>
<td>Heavy</td>
<td>Medium</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


- **Measurement and weather conditions in advection database**

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Aircraft size (Strength of wake vortices)</th>
<th>Initial height (vortex position)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weather</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average wind velocity¹</td>
<td>Mean wind direction¹</td>
<td>Humidity²</td>
</tr>
<tr>
<td>Temperature¹</td>
<td>Air density²</td>
<td>Sky condition²</td>
</tr>
<tr>
<td>Visibility²</td>
<td>Showalter stability index (SSI)³</td>
<td>Vertical gradient of potential temp.³</td>
</tr>
<tr>
<td>Static stability³</td>
<td>Richardson number³</td>
<td></td>
</tr>
</tbody>
</table>

¹: JMA database, ²: METAR, ³: MSM-GPV
Advection database of wake vortices

Purpose of advection database of wake vortices
Identify measurement and weather factors that influence behavior of wake vortices

Behavior of wake vortices
1. **Horizontal advection distance**: an advection distance from the center of runway and an advection direction by a residence time
2. **Vertical advection distance**: an advection distance from the initial height by a residence time
3. **Residence time**: an elapsed time until wake vortices disappear from lidar measurements

- Static stability
- Average wind velocity
- Atmospheric pressure
- Richardson number
- Mean wind direction
- Initial height
- Sky condition
- Temperature
- Dew-point temperature
- Air density
- Visibility
- Aircraft size
- The Brunt-Väisälä frequency
- Vertical gradient of potential temp.
- Showalter stability index (SSI)

Horizontal advection distance
Vertical advection distance
Residence time
Advection database of wake vortices

Influence of mean wind direction and average wind velocity on horizontal advection distance

Advection distance of wake vortices depends on averaged cross wind velocity
Data mining

Extraction of cross-correlation from multi dimensional data
✓ Visualization is most simple and most useful method

Less than equal to 3 dimension

More than 3 dimension

Data mining
- Self-Organizing Map
- Parallel Coordinate

SOM is applied to advection database of wake vortices for extraction of the correlations between measurement/weather factors and wake vortex behavior
Data mining
-Self Organizing Map (SOM) -

Neural network (by Kohonen) used as a clustering method

Clustering based on Euclid distance $d$

$$d = \sqrt{\sum_{k} (\tilde{f}_k^i - \tilde{f}_k^j)^2}$$

Multi dimensional layout
(as input to the neural network)

2 dimensional layout
(as output from the neural network)
Data mining
- Horizontal advection distance -

Aircraft size

Average wind velocity

Mean wind direction

Horizontal advection distance

Averaged wind velocity ↓
Horizontal advection distance ↓

Averaged wind velocity ↑ .and. Mean wind direction ↑ (perpendicular to runway)
Horizontal advection distance ↑

Aircraft size ↓ .and. Averaged wind velocity ↑
Horizontal advection distance ↑
Data mining
- Vertical advection distance -

- Initial height
- Temperature
- Average wind velocity
- Vertical advection distance

Temperature ↑
Vertical advection distance ↓

Temperature ↓
Vertical advection distance ↑
Data mining
- Residence time -

Aircraft size ↓
Residence time ↓

Aircraft size ↑ .and. Initial height ↑
Residence time ↓
**Conclusion**

Advection database of wake vortices was constructed based on Lidar measurement.
- Data mining method is applied to the database to understand the cross correlation of multidimensional weather factors.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Averaged wind velocity</td>
<td>↓</td>
</tr>
<tr>
<td>Temperature</td>
<td>↓↑</td>
</tr>
<tr>
<td>Aircraft size</td>
<td>↓</td>
</tr>
<tr>
<td>Aircraft size</td>
<td>↓</td>
</tr>
<tr>
<td>Averaged wind velocity</td>
<td>↑</td>
</tr>
<tr>
<td>Mean wind direction</td>
<td>↑</td>
</tr>
<tr>
<td>(perpendicular)</td>
<td></td>
</tr>
<tr>
<td>Aircraft size</td>
<td>↑</td>
</tr>
</tbody>
</table>

**Future work**

- Extracting more complex correlations from data mining results.
- Extracting correlations between the another factors which are not considering wake vortex prediction model (ex. humidity, sky condition)
Thank you for your kind attention