An Algorithm for Estimation Wake Vortex Parameters from Lidar Lateral RHI

Eiichi Yoshikawa and Naoki Matayoshi
Japan Aerospace Exploration Agency (JAXA),
Tokyo, Japan
Outline

1. Introduction
   - Background –omitted
   - Observation in Narita

2. Methodology
   - Traditional Methods
   - Key Ideas
   - Principle
   - Algorithm flow

3. Statistical evaluation
   - Algorithm specifications
   - Detail of Statistical evaluation
   - An example of observed WV behaviors

4. Summary
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4. Summary
Introduction

Observation in Narita

Zoomed map

Narita airport
Introduction

◆ Lidar and Scanning Strategy

➢ Lidar
   ✓ Windcube200S, Leosphere
   ✓ Pulsed-Doppler Type
   ✓ Wavelength: 1543 nm
   ✓ Max power: 5 mW
   ✓ Pulse Repetition: 20 kHz
   ✓ Digital Sampling rate: 250 MHz
   ✓ Measurement: CNR, radial velocity, velocity dispersion, Doppler spectrum, range, gazing angle, and time.

➢ FAST Scanning Strategy
   ✓ RHI: 0 – 40 deg for landing aircrafts
         (20 – 60 deg for take-off aircrafts)
   ✓ Scan duration: 6 sec (+1-2 sec to reset)
   ✓ Range sampling: Every 5 m; 100 – 885 m
         (physical range resolution: 48 m)
   ✓ Elevation sampling: Every 0.2 deg
   ✓ Velocity sampling: Every 3 m/sec; -30 – 30 m/sec
Introduction

◆ RHI data sample
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Algorithm Specifications

◆ Probability of detection
  - Step 1; in 100% of flights, a WV is detected
  - Step 2; in 76.2% of flights, WV parameters are obtained (converged)
    - A better initial solution (closer to the optimum) could improve POD of Step 2.

◆ Estimation accuracy (Step 2)
  - $\Gamma_m$ estimation; Mean of 13.3 and Std of 22.9 ($m^2 / sec$)
  - $y$ estimation; Mean of -1.1 and Std of 6.0 (m)
  - $z$ estimation; Mean of -1.7 and Std of 2.7 (m)
    - Depending on lidar specifications and operation settings

◆ Computation
  - Mean of 82 and Std of 22 (sec / vortex pair)
    - CPU; Intel Xeon E5-2697v2; 12core (24thread) / 2.7GHz / L3cache 30MB
    - Memory; 64 GB; 8GBx8 / DDR3 SDRAM / 1866 MHz / ECC Registered
    - A better initial solution (closer to the optimum) reduces the computational cost.

See following slides in detail!
## Statistical Evaluation

- **Results – total**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Radii-averaged circulation, $\Gamma_m$ (m$^2$/sec)</th>
<th>Horizontal range, $y$ (m)</th>
<th>Height, $z$ (m)</th>
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<tbody>
<tr>
<td>$b_{\text{LDR}}$</td>
<td>13.3</td>
<td>-1.1</td>
<td>-1.7</td>
</tr>
<tr>
<td>$\sigma_{\text{LDR}}$</td>
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<td>6.0</td>
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<td>$\sigma_{\text{QAR}}$</td>
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<td>2.2</td>
<td>0.8</td>
</tr>
<tr>
<td>$\mu_{\text{prg}}$</td>
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WV estimation accuracy by our lidar and algorithm
Statistical Evaluation

Results – total

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Error in the theoretical equation, $\Gamma_0 = \frac{Mg}{\rho sBV}$, including measurement error of QAR data
Statistical Evaluation

◆ Results –total –Γm

➢ Cross evaluation

\[ \Gamma_{m_{\text{LDR}}}(t) - \Gamma_{0_{\text{QAR}}} \text{ (m}^2/\text{sec)} \]

➢ Self evaluation

\[ \Gamma_{m_{\text{LDR}}}(t) - \Gamma_{m_{\text{LDR}}}(t_0) \text{ (m}^2/\text{sec)} \]
Statistical Evaluation

- Results – total – y
  - Cross evaluation
  - Self evaluation

\[ y_{LDR}(t) - y_{QAR}(m) \]

\[ y_{LDR}(t) - y_{LDR}(t_0)(m) \]
Statistical Evaluation

- Results –total –$z$

  - Cross evaluation
  - Self evaluation

$$z_{LDR}(t) - z_{QAR} (m)$$

$$z_{LDR}(t) - z_{LDR}(t_0) (m)$$
Statistical Evaluation

Example of Estimated WV Behavior

Wakes of B773ER (mass = 203 tons, true airspeed = 143kts)

- Normalized Circulation
  - $\Gamma_0 = 433 m^2/s$

- Circulation

- Runway centerline

- Aircraft altitude

- Horizontal Position

- Altitude
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Summary

◆ An algorithm to detect a WV and estimate its parameters is developed.
◆ Motivation is to achieve high estimation accuracy even in a low CNR condition to obtain knowledge of WV characteristics with a large number of observations and to use it in real-time operations.
◆ Key ideas: 1) assuming a WV model to express a WV with few parameters, 2) optimization to fit the WV parameters to Lidar measurements, 3) Utilizing all the components of Doppler spectra, and 4) optimization on Bayesian scheme.
◆ Two statistical evaluation approach, cross evaluation with QAR data and self evaluation in lidar data, were carried out. The results indicated that…
  ➢ Vortex center is accurately estimated with bias and standard errors of -1.1 and 6.0 m in y, and -1.7 and 2.7 m in z.
  ➢ Radii-averaged circulation is estimated with bias and standard errors of 13.3 and 22.9 m²/sec.
  ➢ Interestingly, a standard error of the theoretical equation relating root circulation to aircraft and atmospheric parameters is also derived by 17.3 m²/sec. This could contribute to understand the generation process.
Future Plan

◆ Step 1 (detection part) can be replaced with another better algorithm.
   - It’s important for the detection part to give a better initial solution to the optimization of Step 2.
   - Update of Step 1 could reduce the number of miss-convergent cases and the computational cost of Step 2.
   - Looking for other promising detection algorithms (We will NOT improve this part anymore by ourselves.) How about Leosphere’s one…?

◆ An error structure model
   - An error structure model offers statistical properties of WV parameters which are INDEPENDENT on characteristics of measurement such as lidar specifications, observation mode and setting, and estimation algorithm. This could give significant features to develop a world-wide large database.
   - We would do some more about this. Scientific conversation or cooperation about this is very welcome.