First approach to wake vortex predicting and detecting integrated fusion filters

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Outline

• motivation/current situation
• state-of-the-art approaches
  – prediction models
  – measurement technologies
• collaboration approach
• excursus filter technologies
• conclusions
Wake vortices
-
general motivation
Wake vortices as capacity limiting factors

- today: separation rules based on worst-case-scenario
  - assumed calm atmosphere, no lateral wind
    ➔ long wake vortex lifetime
- unnecessarily limiting capacities in favorable conditions
- but: separation reduction only possible while preserving safety level
- two approaches:
  - propagation of wake vortices by assessed models
  - detection and monitoring of wake vortices by dedicated sensors
  - operating quasi separately
Motivation for closer collaboration of model and sensor

• benefit from using complementary characteristics for the operational (real-time) use
• allows the use of different measurement input sources, e.g. airborne sensor AND information coming from ground
  ➔ ground/board interaction
• close collaboration model / sensor at different scanning patterns
• allows observation of not-measured quantities through observability to some extent, e.g.
  – fast changing met-conditions
  – a/c-weight
  – a/c-speed
• helps decision making
• on-time reduction of model uncertainties through sensor measurements could result in capacity gain
The Propagation
State-of-the-art approaches - prediction

- propagation of wake vortex behaviour
- models: P2P (DLR), PVM (UCL), AVOSS-PA (NASA)
  proven in several projects
- real-time prediction of:
  - turbulence strength (circulation)
  - vortex trajectory in y and z
  - uncertainty bounds
Prediction model: input parameters

- aircraft configuration
  - weight, span, speed

- weather conditions
  - wind profile
  - stratification
  - turbulence
  - wind shear

- ground proximity conditions

uncertainties
unknown or varying

lack of adequate spacial and
temporal resolution
measurement and forecasting
constraints
The Measurement
**State-of-the-art approaches - detection**

- wake vortex monitoring
  - measurement of wind velocities
  - focus on LIDAR (also X-band RADAR is a possibility)
  - research activities in several projects

- real-time measurement of:
  - turbulence strength (circulation)
  - vortex trajectory in y and z
  - range \( r \) and bearing \( \theta \) of the sensor
**Complementary attributes of prediction and detection**

<table>
<thead>
<tr>
<th>Model</th>
<th>Sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>good knowledge of vortex behaviour</td>
<td>limited field of view/difficulties in flow field identification</td>
</tr>
<tr>
<td>forecast ability</td>
<td>no information about vortex state between measurements or due to loss of track</td>
</tr>
<tr>
<td>short term stability</td>
<td>limited accuracy/noise</td>
</tr>
<tr>
<td>high prediction update rate</td>
<td>low measurement update rate</td>
</tr>
<tr>
<td>no real-time information update through measurement</td>
<td>physical wake detection</td>
</tr>
<tr>
<td>no update of changed meteorological conditions</td>
<td>updated information of vortex state</td>
</tr>
<tr>
<td>increasing uncertainty bounds due to model or met input uncertainties</td>
<td>decreased uncertainties on measurement update</td>
</tr>
</tbody>
</table>

- Typical example of two complementary systems
- Taking advantage by using only the positive characteristics of each system
Using complementary attributes

**fused** uncertainty bounds could be extracted from filters covariance

**current** uncertainty bounds relatively large

measurement-updates
Fusion filter concept
for
model / sensor collaboration
Collaboration approach

Model / Prediction

Measurement

Model / Prediction

Measurement

[www.cerfacs.fr]

[www.eurocontrol.be]
Collaboration approach

- two steps:
  - a time update - system state is predicted based on current state
  - a measurement update - performed when new sensor data are available

\[ x_0, P_0 \]
Some illustrating examples
Example with simplified model

- constant velocity
  - measurements at low frequency
  - short time accurate information between measurements

\[ x_k^- = x_{k-1}^+ + \dot{x}_{k-1}^+ \cdot \Delta T_s \]

New position = old position + old velocity * sample Time

Estimated Position corrected by difference model <-> measurement
Example with specific model

- tracking object example: cannon-launched projectile tracking
  - model of movement exists (e.g. gravity, drag)
    ➔ high frequent prediction
  - low frequent measurement updates model
Back to collaboration
Fusion Filter concept for collaboration

**Time-update**
- **State**: WV traffic, MET, LIDAR-angles
- **Model state transition**: ~ established prediction models
- **Covariance**: ~ uncertainty bounds in current models, decreased by measurement

**Measurement-update**
- **State**: WV traffic, MET, LIDAR-angles
- **Covariance**: ~ uncertainty bounds in current models, decreased by measurement
- **Measured quantities**: position, strength, range, bearing, TBD)
- **Error/uncertainty-feedback**

$x_0, P_0$

**Update on new prediction**
**Update on new measurement**
Uncoupled

LIDAR / RADAR → processing → \( \Gamma, x, y, z \)

A/C data, MET data → WV-model → \( \Gamma, x, y, z \)

current status
Loose coupled approaches

- LIDAR / RADAR
- Processing
- Fusion Filter error state
- A/C data
- MET data
- WV-model
- Output

\[ \Gamma, x, y, z \]

\[ \Delta \Gamma, \Delta x, \Delta y, \Delta z \]

Model and sensor independent, but collaborative output
Loose coupled approaches

- LIDAR / RADAR → processing → Fusion Filter error state
- A/C data, MET data → WV-model → Fusion Filter error state

Output:
- $\Gamma, x, y, z$
- $\Delta \Gamma, \Delta x, \Delta y, \Delta z$

Model accepts and processes corrections from collaboration
Loose coupled approaches

LIDAR / RADAR → processing → \( \Gamma, x, y, z \) → integrated collaborative prediction and measurement system

A/C data
MET data → output

fully collaborative system
Conclusions

- model predictions and measurement are complementary
- taking advantages by collaboration of both
- first implementation results show proof-of-concept
  - keeping in mind, that the WV behaviour is not modelled within the filters yet
    ➔ results show that fusion approach is applicable for future WV prediction and detection systems
  - integration of prediction model should be proposed
- further applications
  - enhance detection ability of sensors
    ➔ involve processing of sensor into collaborative system
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Thank you for your attention!

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