Wake vortex severity criteria

The search for a single metric

The potential of equivalent roll rate

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Contents

• Why do we need a single metric?
• Characteristics of WV severity metrics
• What is used today, pro’s and cons
• What is equivalent roll rate?
• Application to RECAT
• Conclusion & Recommendations
So why?

- Over 20 years of WV R&D has led to few practical benefits!
- Bottleneck: safety assessment; difficult process to prove safety due to absence of widely accepted (universal) metric
- Relative safety assessment approach lead to carry-over of inherent conservatism
- Is a single universal metric a utopian dream?
  - In related areas, such as windshear detection it isn’t!
Good characteristics of Metric

- Strong relation between encounter severity and metric (discriminative power)
- Aircraft independent
- Meaningful
- Easy to be determined for a large range of aircraft, without need for access to proprietary data
- Applicable in an absolute sense
- Thresholds easy to validate
What is used today (basically)

- Wake Vortex Circulation ($\Gamma$), [m$^2$/s]
- Rolling Moment ($l$), [Nm]
- Dimensionless Rolling Moment Coefficient ($C_l$), [-]
- Roll Control Ratio $\frac{C_l}{C_l \delta_a \delta_{a_{max}}}$, [-]
- Roll response (e.g. Tatnall), [deg]
Circulation Strength

Easy to compute, but not very meaningful, not absolute, and aircraft dependent:

Same circulation strength may cause different induced rolling moment, depending on characteristics of generator aircraft.
Rolling Moment

• Strongly related to encounter severity, however…

Dimensional RM:
• Strongly A/C dependent, not very meaningful, not absolute

Non-dimensional RM coefficient:
• Less A/C dependent, not very meaningful, not absolute
Roll Control Ratio

Pro’s:

• Strong relation with encounter severity
• Fairly A/C independent
• Meaningfull
• Absolute

Con’s

• Not that easy to compute, requiring knowledge of roll control authority, roll control surfaces and/or roll control system
Roll Response

Pro’s:

• Good relation with encounter severity
• Fairly easy to compute
• Meaningful
• Absolute

Con’s

• Aircraft dependent
## Metric evaluation

<table>
<thead>
<tr>
<th></th>
<th>Circulation</th>
<th>Rolling Moment</th>
<th>RM coefficient</th>
<th>RC ratio</th>
<th>Response</th>
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<td>Discriminative power</td>
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<td>+</td>
<td>++</td>
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<tr>
<td>Independency</td>
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<td>-</td>
<td>+</td>
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<td>Validation</td>
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<td>-</td>
<td>0</td>
<td>++</td>
<td>O</td>
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</table>
Equivalent roll rate

\[ p \hat{\rho} + \alpha = 0 \Rightarrow P_{\text{equivalent}} = \frac{\hat{\rho}b}{2V} \]

- angle of attack distribution
- nominal lift distribution
- induced lift distribution distribution
- rolling moment distribution distribution
Parameters in Peq Calculation

Given a wake vortex circulation field, parameters are

- Wing Area
- Span
- Velocity
- Lift-curve slope (aircraft dependent, but easy to estimate)
- Lift distribution (aircraft dependent, elliptic assumption, insensitive parameter due to calculation method)
Characteristics of Peq

Equivalent Roll Rate Peq:

• Easy to calculate for any aircraft

• Meaningful parameter, and directly related to:
  ➢ induced rolling moment
  ➢ initial acceleration; \( \dot{p}_0 = \frac{p_{eq}}{\tau_R} \)
  ➢ roll response; \( \varphi(t) = p_{eq} \left( t + \tau_R \left( e^{-t/\tau_R} - 1 \right) \right) \)
  ➢ Non-dimensional eq. Roll rate is equal to roll induced angle-of-attack at the wing tip

• Applicable in an absolute sense (TBD)

• Single, A/C independent, threshold could be potentially valid
Due to increased separation

Due to application of rolling moment metric

RECAT: relative assessment, with basically “WV circulation” as metric
### ICAO and RECAT Separation

#### ICAO

<table>
<thead>
<tr>
<th></th>
<th>A380 Follower</th>
<th>Heavy Follower</th>
<th>Medium Follower</th>
<th>Light Follower</th>
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<td>A380 Leader</td>
<td>6 NM</td>
<td>7 NM</td>
<td>8 NM</td>
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<td>5 NM</td>
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<td>Light Leader</td>
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#### RECAT

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<th>Leader</th>
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<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
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<td>6.0NM</td>
<td>7.0NM</td>
<td>7.0NM</td>
<td>8.0NM</td>
<td>7.0N+1,+2</td>
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<tr>
<td>B</td>
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<td>4.0NM</td>
<td>5.0NM</td>
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<td>-1.5+1</td>
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<tr>
<td>D</td>
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<td>-4.0N</td>
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</tbody>
</table>

**Separation Reduction**

**Separation Increase**
Max Peq under ICAO

![Graph showing Equivalent Roll Rate vs. AC nr](image)

- **Peq [deg/s]**
- **Peq*b2v [-]**

- **AC nr**
- **Equivalent Roll rate**
- **Max encountered at ICAO separation**

- **A380**
- **Heavy**
- **Medium**
- **Light**

**Dimensional Eq. Roll rate**

**Non-Dimensional Eq. Roll rate**
Peq max @ ICAO separation

Maximum encountered eq. roll rate at ICAO separation as function of wingspan

- **Light**
- **Medium**
- **Heavy**
- **Super**

Light Medium A/C violate criterion

A380 followed by A380 A/C violates criterion

Suggested threshold ~2.8

Room for separation reduction

Wingspan [ft]

Non-dimensional equivalent roll rate $P_{eq} \frac{b^2/2V}{[.]}

NLR Air Transport Safety Institute

29-2-2012
Peq max @ RECAT separation

Maximum encountered at RECAT separation as function of wingspan

Non-dimensional equivalent roll rate $P_{eq} \cdot b/2V$ [-]

- Separation increase light-Medium A/C
- No separation reduction for Medium
- Separation decrease Heavy A/C

Suggested threshold ~2.8

A380?

D/E
D/F
D/E
C/D
B/C
A/B

Separation increase light-Medium A/C
Separation decrease Heavy A/C

ICAO separation
RECAT separation
Peq max @ adjusted RECAT separation

Maximum encountered at adjusted RECAT separation as function of wingspan

Suggested threshold ~2.8

-0.5 NM separation reduction
Medium-Heavy

+1 NM separation increase A380-A380

Non-dimensional equivalent roll rate $\frac{P_{eq} \cdot b}{2V}$ [-]

Wingspan [ft]

ICAO separation
RECAT separation
Adjusted RECAT
Peq max @ optimised RECAT separation

Maximum encountered at optimised RECAT separation as function of wingspan

Suggested threshold ~2.8

-.75 NM separation reduction
Cat D/E boundary shifted from 90 to 100 ft

Non-dimensional equivalent roll rate $P_{eq} \cdot b/z/V [\text{[-]}$

Wingspan [ft]

D/E
E/F
D/E
C/D
B/C
A/B

ICAO separation
RECAT separation
Adjusted RECAT
Optimised RECAT
Conclusions

Equivalent roll rate appears to have very good potential for a WV severity metric:

- Strong correlation with encounter severity
- Only dependent on a few aircraft parameters
- Has a physical meaning and therefore easy interpretable
- Easy to compute
- Provides an absolute, aircraft independent, metric (to be validated)

Preliminary research suggests:

Peq < 2.8 provides equivalent safety as ICAO separation

Preliminary application to RECAT

- provides suggestions for optimisation in RECAT categories
  - A380 behind A380 may need +1 NM separation
  - Cat D behind B could be reduced with -.5 NM
  - Cat D behind B could be reduced to approx -3/4 NM, when Cat D/E boundary is changed from 90 ft to 100 ft wingspan
Recommendation

Equivalent Roll Rate with upper bound of 2.8 needs further validation.

Recommended to:
- Give it some thought, and ..
- Re-process existing data to verify Equivalent roll rate concept and associated threshold
- Piloted simulations with various aircraft type to validate concept