Lessons Learnt From The EUROCONTROL Wake Impact Severity Assessment Flight Simulator Campaign

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- Experiment setup
  - The simulator
  - The aircraft
  - The flight crews
  - The scenario’s
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- Conclusions & Recommendations
- Demo Sessions
Separation based on a more efficient schemes: European Wake Re-categorisation

ICAO

HEAVY
- A330
- MD11
- B744
- B763

MEDIUM
- B738
- A320
- E190
- AT45
- SF34
- LJ25

LIGHT

RECAT-EU:
6 wake categories

SUPPER HEAVY
- AN-124
- A380

UPPER HEAVY
- A332
- B744

LOWER HEAVY
- MD11
- B763

UPPER MEDIUM
- B738
- A320

LOWER MEDIUM
- E190
- AT45

LIGHT
- SF34
- LJ35

RECAT2-EU:
Pairwise separations

A320

PWS: 3.5 NM

A343
Safety assessment of RECAT-EU-PWS Separations

Characterisation of wake generation

Characterisation of wake impact

Wake risk assessment methodology
Safety assessment of RECAT-EU-PWS Separations
Characterisation of wake generation

Characterisation of wake generation

Characterisation of wake impact

Wake risk assessment methodology
Safety assessment of RECAT-EU-PWS Separations
Characterisation of wake generation

Characterisation of wake generation

ICAO A380 Working Group
Tarbes (FR) LIDAR campaign (2007)
ICAO State letter (2008)

ICAO B747-8 Working Group
Fresno (CA) LIDAR campaign (2010)
ICAO Guidance (2012)

Characterisation of wake impact

Wake risk assessment methodology
Safety assessment of RECAT-EU-PWS Separations

Characterisation of wake generation

- A343
- A320

350,000+ wake measurements (LiDAR)
Safety assessment of RECAT-EU-PWS Separations
Characterisation of wake generation

![Diagram showing wake vortex generation and dissipation for different aircraft models.](image-url)
Safety assessment of RECAT-EU-PWS Separations
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Wake risk assessment methodology
Safety assessment of RECAT-EU-PWS Separations
Airbus flight test campaign

A346 and A380 as wake generator
Constant track, speed and altitude

A346
A380
A320, A300

A380 and A346 wakes made visible by oil injection

~1,000 ft

4 NM (A300)
5 NM (A300, A320)
6 NM (A320)

~1,000 ft

Follower relative flight path

A320, A300 as encounterer usually horizontally through the wakes at 10°-15° lateral encounter angle
Safety assessment of RECAT-EU-PWS Separations
Measured RMC vs RMC metric

Large variation of the metric for a same RMC value → Increased differences between aircraft pairs that are not observed in the measurements

\[ RMC = \frac{\Gamma_{tot}}{V_f b_f} \]
Safety assessment of RECAT-EU Separations
Measured RMC vs RECAT metric v2 (RECAT-EU-PWS)

\[ RMC = \frac{\Gamma_{tot}}{V_f} \frac{AR}{b_f} F\left(\frac{b_l}{b_f}\right) \]

Best linear fit: 0.98
\( R^2 \) of linear fit: 0.82

Mean deviation: -0.0009
RMS deviation: 0.0226
Safety assessment of RECAT-EU Separations
Wake risk assessment methodology

- Characterisation of wake generation
- Characterisation of wake impact
- Wake risk assessment methodology
Safety assessment of RECAT-EU Separations
Wake risk assessment methodology

Characterisation of wake generation

Characterisation of wake impact

Wake risk assessment methodology
Safety assessment of RECAT-EU Separations
Wake risk assessment methodology

Characterisation of wake generation

Characterisation of wake impact

Wake risk assessment methodology
Safety assessment of RECAT-EU Separations
Wake risk assessment methodology

Characterisation of wake generation

Characterisation of wake impact

Wake risk assessment methodology

Characterised by RMC
Safety assessment of RECAT-EU Separations
Wake risk assessment methodology

Increased $V_f$ and $b_f$ allows to increase acceptable wake strength…

… and consequently to reduce wake age and therefore separation.
Safety assessment of RECAT-EU Separations
RECAT-EU impact on Heavy generator

<table>
<thead>
<tr>
<th>H</th>
<th>M &gt; 15T</th>
<th>M &lt;15T</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper H</td>
<td>Upper M</td>
<td>Lower M</td>
<td>Light</td>
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</tbody>
</table>

Upper H

Lower H

Upper M

Lower M

Light
Safety assessment of RECAT-EU Separations
RECAT-EU impact on Heavy generator

A346 leader

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H | M > 15T | M < 15T | L
---|---|---|---
Upper H | Upper M | Lower M | Light

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A346

Separation [NM]

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RMC

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A310 | AT45 | E145
Safety assessment of RECAT-EU Separations
Wake risk assessment methodology

Characterisation of wake generation

Characterisation of wake impact

Does same RMC leads to same encounter hazard?

Wake risk assessment methodology
Objectives

1. Further validate that the RMC scales conservatively with increasing aircraft size: If a given RMC is acceptable for an aircraft, the same RMC will also be acceptable for a larger aircraft.

2. In view of RECAT PWS, collect additional evidence for acceptability of WT severity alignment of aircraft types of various size.

3. Demonstrate to airlines the difference in WTE severity between an encounter under ICAO separation and an encounter under RECAT-EU separation minima.
WISA campaign
NLR- GRACE Flight Simulator

- Reconfigurable Research Flight Simulator
- Different types of aircraft can be used for the evaluations

Mixed cock-pit configuration
- Fly-By-Wire  A320/A330/A340
- Classic Controls  B747/F100/C550
6 different aircraft

B744

A332

A322

F100

E145, CRJ1 (“F65”)

C550
Why these 6 aircraft?

- B744
- A332
- A320
- F100 / “F65”
- C550
6 different flight crews (Airbus, KLM, EasyJet, NLR, EASA, …)
2 different scenarios

**Level flight**
- Aircraft at 3000ft in level flight
- WTE at 3000ft
- No pilot input

**On final approach approach**
- Aircraft at 1000ft on ILS 06 at AMS
- WTE at 100ft and 200ft
- Pilot flies ILS approach and tries to land

**In both scenarios:***
- Aircraft in final approach configuration & approach speed
- No AP, No A/THR
- ISA conditions
- VMC
- Light background turbulence
- Random generated WTE direction & strength
**4 Severity levels and 2 assessments per experiment**

<table>
<thead>
<tr>
<th>RMC values</th>
<th>WISA severity assessment</th>
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<tbody>
<tr>
<td>0.04</td>
<td>PF</td>
</tr>
<tr>
<td>0.06</td>
<td>Acceptable</td>
</tr>
<tr>
<td>0.08</td>
<td>Not acceptable</td>
</tr>
<tr>
<td>0.10</td>
<td>PM</td>
</tr>
</tbody>
</table>
Example of an experiment

- Level Flight - Direct Law
- Airbus pilot

- Level Flight - Normal Law
- Airbus pilot

- RMC 0.06 – 300ft
- Airbus pilot

- RMC 0.06 – 200ft
- Airbus pilot

- RMC 0.06 – 100ft
- Airbus pilot

- RMC 0.06 – 100ft
- ECTL pilot

- RMC 0.08 – 100ft
- ECTL pilot

Acceptable

Not acceptable
### Wake Impact Severity Rating Scale

<table>
<thead>
<tr>
<th>Noticeable disturbance,</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>No or negligible</td>
<td></td>
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<tr>
<td>pilot compensation</td>
<td></td>
</tr>
<tr>
<td>required</td>
<td></td>
</tr>
<tr>
<td>to maintain desired</td>
<td></td>
</tr>
<tr>
<td>flight path</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Small disturbance</th>
<th>Minor 2</th>
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<tbody>
<tr>
<td>Light</td>
<td></td>
</tr>
<tr>
<td>pilot compensation</td>
<td></td>
</tr>
<tr>
<td>required to maintain</td>
<td></td>
</tr>
<tr>
<td>desired flight path</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Large disturbance</th>
<th>Minor 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderate</td>
<td></td>
</tr>
<tr>
<td>pilot compensation</td>
<td></td>
</tr>
<tr>
<td>required to maintain</td>
<td></td>
</tr>
<tr>
<td>desired flight path</td>
<td></td>
</tr>
<tr>
<td>or avoid ground</td>
<td></td>
</tr>
<tr>
<td>contact. (Safe landing</td>
<td></td>
</tr>
<tr>
<td>possible)</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Severe disturbance</th>
<th>Minor 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Significant</td>
<td></td>
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<tr>
<td>or maximum pilot</td>
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<tr>
<td>compensation required</td>
<td></td>
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<tr>
<td>to maintain desired</td>
<td></td>
</tr>
<tr>
<td>flight path or avoid</td>
<td></td>
</tr>
<tr>
<td>ground contact. (Safe</td>
<td></td>
</tr>
<tr>
<td>go-around possible)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Extreme disturbance,</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum</td>
<td></td>
</tr>
<tr>
<td>pilot control authority</td>
<td></td>
</tr>
<tr>
<td>exceeded, inability</td>
<td></td>
</tr>
<tr>
<td>to maintain desired</td>
<td></td>
</tr>
<tr>
<td>flight path or avoid</td>
<td></td>
</tr>
<tr>
<td>ground contact.</td>
<td></td>
</tr>
</tbody>
</table>
Project Plan

- **64h** total simulation time

**Main Experiments**
- Level Flight: \( 6 \text{ A/C} \times 4 \text{ RMC} \times 4 \text{ repeats} \times 2 \text{ pilots} = 192 \text{ runs} \)
- Approach 200ft: \( 6 \text{ A/C} \times 4 \text{ RMC} \times 2 \text{ repeats} \times 2 \text{ pilots} = 96 \text{ runs} \)
- Approach 100ft: \( 6 \text{ A/C} \times 4 \text{ RMC} \times 6 \text{ repeats} \times 2 \text{ pilots} = 288 \text{ runs} \)

\[= 576 \text{ runs} \]

**Reference Experiments (2 pilots doing all A/C types)**
- Approach 200ft: \( 6 \text{ A/C} \times 4 \text{ RMC} \times 1 \text{ repeats} \times 2 \text{ pilots} = 48 \text{ runs} \)
- Approach 100ft: \( 6 \text{ A/C} \times 4 \text{ RMC} \times 2 \text{ repeats} \times 2 \text{ pilots} = 96 \text{ runs} \)

\[= 144 \text{ runs} \]

**Demo sessions**
- **16h** simulation time with participating airlines: Air France, easyJet, Emirates and Netjets
Input for the flight simulation

Wake Vortex Encounter geometry

- 1 leader span altitude
- Max impact encounter angle

![Diagram of wake vortex encounter geometry with labels for input parameters: wingspan alt, 10 deg, and 1 leader span altitude.](image)
Input for the flight simulation

Induce rolling moment function:
- Calibrated on real measurement
- Verified by airbus test pilot
Sanity check of the Results
Is there a difference between assessed severity by PF and PM?
Comparison of ratings PF (○) and PM (■)

Differences less than granularity of the scale = 1
Comparison of ratings PF (o) and PM (■)

*Differences less than granularity of the scale = 1*
Is there a “learning effect” during the repetitions?
Exp A and B (ex. B747_A) @100ft
Small effect visible for B747, F100 and C550.
Exp A and B (ex. B747_A) @100ft
Small effect visible for B747, F100 and C550.
Does RMC correlates well with WVE severity as rated by the pilot?
RMC correlates well with WVE severity
Correlation best visible at 3000 ft (level flight); Other effects, causing more variation, play a role close to ground.
Severity for same RMC compares well for Medium

Larger Medium (A320) can be compared to smaller Medium ("F65")
Severity for same RMC compares well for Medium
Larger Medium (A320) can be compared to smaller Medium ("F65")
Severity for same RMC compares well for Medium Larger Medium (A320) can be compared to smaller Medium ("F65")
Severity for same RMC compares well for Heavies

Larger Heavy (B744) can be compared to smaller Heavy (A332)
Severity for same RMC compares well for Heavies

Larger Heavy (B744) can be compared to smaller Heavy (A332)
Severity for same RMC compares well for Heavies

Larger Heavy (B744) can be compared to smaller Heavy (A332)
For Heavy (B744) vs Medium (A320), acceptability is not properly captured by RMC only.
For Heavy (B744) vs Medium (A320), acceptability is not properly captured by RMC only
For Heavy (B744) vs Medium (A320), acceptability is not properly captured by RMC only.
Severity in RECAT-PWS rated as acceptable Absolute interpretation of results
Recovery Technique - Guidance
Recovery Technique – lateral interception – Free Flight

- Maintain the autopilot
- If no autopilot engaged or automatically disconnects:
  - Release the controls
  - Let aircraft stabilise
  - Do not use the rudder
  - Roll wings level
  - Re-establish initial flight path and engage autopilot
Recovery Technique – longitudinal interception – on approach

- Pilot needs to maintain approach flight path
  - Needs to maneuver to maintain flight path due to atmospheric turbulence
  - This constant maneuvering might increase or decrease the WVE effect

- Needs to react immediately to WVE to maintain approach flight path
  - possibly aggravate the perturbation
  - possibly result in larger bank angle
  - Will it still be safe:
    - to continue to land
    - to execute a safe go-around
### Bank Angles in Approach at 100ft & 200ft @RMC=0.06

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>B747</td>
<td>6</td>
<td>14</td>
<td>22</td>
</tr>
<tr>
<td>A330</td>
<td>10</td>
<td>15</td>
<td>21</td>
</tr>
<tr>
<td>A320</td>
<td>8</td>
<td>11</td>
<td>14</td>
</tr>
<tr>
<td>F100</td>
<td>13</td>
<td>19</td>
<td>30</td>
</tr>
<tr>
<td>F65</td>
<td>13</td>
<td>18</td>
<td>24</td>
</tr>
<tr>
<td>C550</td>
<td>16</td>
<td>25</td>
<td>31</td>
</tr>
</tbody>
</table>

**Note:** 83% flights continued to safe landing
17% flights initiated a safe go-around
@RMC 0.06 or lower: no “8” rating assigned by test pilots
### Average Bank Angle – at ICAO and RECAT-EU separation

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>B747</td>
<td>0.0313</td>
<td>0.0400</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>A330</td>
<td>0.0367</td>
<td>0.0470</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>A320</td>
<td>0.0471</td>
<td>0.0590</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>F100</td>
<td>0.0532</td>
<td>0.0530</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>F65</td>
<td>0.0622</td>
<td>0.0620</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>C550</td>
<td>0.0617</td>
<td>0.0520</td>
<td>26</td>
<td>22</td>
</tr>
</tbody>
</table>
Go-around observations
Go-Around decision versus lateral deviation from centerline

Wisa acceptable
Go-Around decision versus lateral deviation from centerline

Wisa acceptable
Pilot Training - Guidance
**Aeroplane upset.** An airplane in flight unintentionally exceeding the parameters normally experienced in line operations or training, normally defined by the existence of at least one of the following parameters:

a) pitch attitude greater than 25 degrees, nose up; or  
b) pitch attitude greater than 10 degrees, nose down; or  
c) bank angle greater than 45 degrees; or  
d) within the above parameters, but flying at airspeeds inappropriate for the conditions.
Decision 2015/012/R affecting PART DEF & ORO (EU) 965/2012

GM1 ORO.FC.105 (b)(2) Route and aerodrome knowledge

ENVIRONMENTAL KNOWLEDGE RELATED TO THE PREVENTION OF AEROPLANE UPSETS

The knowledge should include understanding of:

(a) the relevant environmental hazards, such as:
   – Clear Air Turbulence (CAT),
   – Intertropical Convergence Zone (ITCZ),
   – thunderstorms,
   – microbursts,
   – wind shear,
   – icing,
   – mountain waves,
   – wake turbulence, and
   – temperature changes at high altitude;

(b) the evaluation and management of the associated risks of the relevant hazards in (a); and

(c) the available mitigating procedures for the relevant hazards in (a) related to the specific route, route area, or aerodrome used by the operator.
Proposal to include in Recurrent Training

- Safety benefit could be obtained for Aircraft Operators (AO) operating at:
  - large busy airports
  - airports using specific separation procedures

- Could include in recurrent training (3-yearly cycle)
  - Basic theoretical knowledge on Wake Vortex physics and hazards
  - Simulator training on:
    - Recognition: wake vortex signature (feeling)
    - Avoidance: scenario based
    - Recovery: maneuver based
Demo Sessions

- Demonstrate to airlines the difference in WTE severity between an encounter under ICAO separation and an encounter under RECAT-EU separation minima.

- Invited major airlines operating at LFPG: Air France, easyJet, Emirates and Netjets.

- The selected aircraft pairs were relevant to their fleet.

- Helped to increase the buy-in from airlines operating at CDG.
Conclusion

- RMC demonstrated as a suitable metric for separation design
- RECAT reduced separations shown as acceptable through flight simulation sessions
- Wake encounter training recommended for safety improvement
Questions?