Methods of Aircraft Re-categorizations for Reducing Wake Vortex Separations

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Today’s ICAO separations are based on certificated Maximum Take Off Mass (MTOM) and it includes four categories (i.e HEAVY, MEDIUM or LIGHT) allocating all aircraft into one of them. Because the separations are defined based on the worst case in each category, this leads to over separation in many instances.

<table>
<thead>
<tr>
<th>Leader / Follower</th>
<th>A380-800</th>
<th>HEAVY</th>
<th>MEDIUM</th>
<th>LIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>A380-800</td>
<td></td>
<td>6 NM</td>
<td>7 NM</td>
<td>8 NM</td>
</tr>
<tr>
<td>HEAVY MTOM ≥ 136 tons</td>
<td></td>
<td>4 NM</td>
<td>5 NM</td>
<td>6 NM</td>
</tr>
<tr>
<td>MEDIUM 7 tons ≤ MTOM &lt; 136 tons</td>
<td></td>
<td></td>
<td></td>
<td>5 NM</td>
</tr>
<tr>
<td>LIGHT MTOM &lt; 7 tons</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1: ICAO wake turbulence categories and separation minima
1 Introduction

the new RECAT categories also consider aircraft wingspan and approach speed, providing for a more accurate characterization the risk of wake encounters.
2 Modeling of wake vortex

Wake vortex encountering severity mainly depends on wake strength of leading aircraft, atmosphere conditions, and resistance of following aircraft.

Metrics have been used to reflect flight safe severity include Initial Circulation of Wake Vortex (ICWV), Residual Circulation of Wake Vortex (RCWV), Induced Roll Moment Coefficient (IRMC), required equivalent roll rate (RERR), ...
2 Modeling of wake vortex

2.1 Initial Circulation of Wake Vortex (ICWV)

An aircraft develops lift by imparting momentum to a region of fluid that may be loosely called its wake.

\[ \Gamma_0 = \frac{m \, g}{\rho \, v \, s \, B} \]
2 Modeling of wake vortex

2.2 Residual Circulation of Wake Vortex (RCWV)

various operational models to predict the position and strength of a wake have been developed and validated, including:

Greene’s Decay Model;
Sarpkaya’s Decay Model;
D2P Model;
P2P Model;
3P Model;
....

Which one is the best for us?
2 Modeling of wake vortex

2.2 Residual Circulation of Wake Vortex (RCWV)

For purpose of RECAT research, What we need is:

- Easy to use
- High fidelity
- Common Accepted
- Plenty of Trail campaigns
- Share data
2 Modeling of wake vortex

2.2 Residual Circulation of Wake Vortex (RCWV)

Thanks for many trail campaigns are carried out in EU and US.

* Presentation on Wake Turbulence Re-Categorization Phase I - Methodology and Safety Case, June 20, 2011, TU Berlin, Berlin, Germany
2 Modeling of wake vortex

2.2 Residual Circulation of Wake Vortex (RCWV)

Based on these data, we used a basic liner fitting method to obtain a simple and conservative decay model:

\[ \Gamma^* = 1 - \frac{1}{6} t^* \]
2 Modeling of wake vortex

2.2 Residual Circulation of Wake Vortex (RCWV)

\[ \Gamma^* = 1 - \frac{1}{6} t^* \]

As for RECAT I, we do not need to consider the influence of meteorology condition, Aircraft parameter, and flight data on aircraft category and separation.

It is not necessary to use P2P, APA or other Decay Models. This model is simple but enough.
2 Modeling of wake vortex

2.3 Induced roll moment coefficient (IRMC)

This parameter is a good metric to evaluate the effect of wake vortex on following aircraft.

\[
C_{Rv} = \frac{\Gamma C_L^\alpha}{\pi VB^3 (1 + \lambda)} \int \frac{B}{2} y^2 \left[ B - 2|y|(1 - \lambda) \right] dy
\]

\[
\frac{\pi y^2 \left[ B - 2|y|(1 - \lambda) \right]}{\left( y^2 + r_c^2 \right) dy}
\]
2 Modeling of wake vortex

2.4 Required Equivalent Roll Rate (RERR)

RERR is a simple but effective WVE severity parameter, which means the roll rate in the equilibrium situation where wake vortex induced rolling moment and aircraft roll rate induced rolling moment (damping) are in balance. Therefore, no information on roll inertia is required.

As roll angular rate can be derived as:

\[
\dot{p} = \frac{M_x}{I_x} = \frac{1}{2} \rho V^2 S_w B \left( C_{Rv} + C_{Rp} p^* - C_{p\alpha} H(t - t_e) \right)
\]

\[
p^* = \frac{C_{Rv}}{C_{Rp}} = \frac{\Gamma C_L^\alpha}{\pi C_{Rp} V B^3 (1 + \lambda)} \int_{-B/2}^{B/2} \frac{y^2 \left[ B - 2 |y| (1 - \lambda) \right]}{(y^2 + r_c^2)} dy
\]
2 Modeling of wake vortex

2.5 Required Actual Roll Rate (RARR)

From this equation we can find that following aircraft’s airspeed has no effect on RARR. For a given following aircraft type, residual circulation of wake vortex is the main variable for RARR.

Relatively to say, we believe that RARR is an ideal metric suitable for evaluating the severity of wake vortex encountering.

\[
p = \frac{2 V p^*}{B} = \frac{2 \Gamma C_L^\alpha \int_{-\frac{B}{2}}^{\frac{B}{2}} \frac{y^2 \left[ B - 2 |y| (1 - \lambda) \right]}{(y^2 + r_c^2)} \, dy}{\pi C_R p B^4 (1 + \lambda)}
\]
3 AIRCRAFT RE−CATEGORIZATIONS

3.1 Problems
In principle, the severity for encountering wake vortex is based on leading aircraft’s residual wake vortex strength (RWVS) and following aircraft’s resistance ability.

Based on MTOW?

Based on Initial Circulation of Wake Vortex (ICWV)?

Which is Better?
3 AIRCRAFT RE-CATEGORIZATION

3.1 Problems

As a matter of fact, this metric (Initial Circulation of Wake Vortex) cannot reflect the leading aircraft’s the actual influence although it is more suitable than MTOW.

For example, a leading aircraft have large numeric of ICWV together with rapid strength decay rate may not cause larger influence on following aircraft than an aircraft with small circulation and slow decay rate.
3.1 Problems
3.2 Required Decay Distance (RDD)

We proposed a metric termed **Required Decay Distance (RDD)** to reflect the actual effect of leading aircraft.
3 AIRCRAFT RE–CATEGORIZATION

3.2 Required Decay Distance (RDD)

Based on the value of RDD, aircraft types can be divided into four categories, 61 types of aircraft are divided into 4 categories in our first step.
3 AIRCRAFT RE-CATEGORIZATIONS

3.2 Required Decay Distance (RDD)

Based on the value of RDD, aircraft types can be divided into four categories, 61 types of aircraft are divided into 4 categories in my first step.

<table>
<thead>
<tr>
<th>threshold values</th>
<th>category</th>
</tr>
</thead>
<tbody>
<tr>
<td>RDD ( \geq 12000m )</td>
<td>A</td>
</tr>
<tr>
<td>12000m &gt; RDD ( \geq 10000m )</td>
<td>B</td>
</tr>
<tr>
<td>10000m &gt; RDD ( \geq 5000m )</td>
<td>C</td>
</tr>
<tr>
<td>RDD &lt;5000m</td>
<td>D, E, F</td>
</tr>
</tbody>
</table>

Strength

Resistance
3 AIRCRAFT RE-CATEGORIZATION

3.3 Wake Vortex Impedance (WVI)

The influences of medium and low aircraft on following aircraft are often slight indeed, due to their relatively small strength of wake vortex.

We proposed that The categorization for these aircraft should consider aircraft’s damping and resistance when encountering other aircraft’s wake vortex instead of wake strength value.
3.3 Wake Vortex Impedance (WVI)

A Metric termed Wake Vortex Impedance (WVI) is proposed to evaluate the characteristic of aircraft when encountering wake vortex.

This metric we means what large of vortex circulation can be balanced by aircraft’s damping moment for per unit roll rate (radian per second).

\[
\mu = \frac{\Gamma}{P} = \frac{\pi C_{R_p} B^4 (1 + \lambda)}{2 \int_{-\frac{B}{2}}^{\frac{B}{2}} \frac{y^2 \left[ B - 2 |y|(1 - \lambda) \right]}{(y^2 + r_c^2)} \, dy}
\]
3 AIRCRAFT RE-CATEGORIZATION

3.3 Wake Vortex Impedance (WVI), for M&L
### 3.3 Wake Vortex Impedance (WVI)

<table>
<thead>
<tr>
<th>threshold values</th>
<th>category</th>
</tr>
</thead>
<tbody>
<tr>
<td>WVI $\geq 800$</td>
<td>D</td>
</tr>
<tr>
<td>$800 &gt; \text{RDD} \geq 350$</td>
<td>E</td>
</tr>
<tr>
<td>RDD $&lt; 350$</td>
<td>F</td>
</tr>
</tbody>
</table>
What is safety?

We accept the assumptions that ICAO’s current wake vortex separations is sufficiently safe for civil aviation operation.

The minimum acceptable safe level can be obtained by calculating and analyzing metrics for current separation standards.
4 Analyzing current separations

4.1 Induced Roll Moment Coefficient (IRMC)

Based on the liner decay models, the maximum IRMC values for all of the aircraft pairs belong to relative category combination are computed, as are shown in below figure.
4 Analyzing current separations

4.1 Induced Roll Moment Coefficient (IRMC)

IRMC values in some conditions (S-M, H-M, and H-L) are slightly large.

For combinations such as M-S, M-L, L-H, L-M, M-L, and L-L, …

there are some probabilities for reducing separations.
4 Analyzing current separations

4.2 Minimum Acceptable Safe Level (MASL)

The new wake vortex standard should not be worse than ICAO’s current standard.

There are some different criterions for determining the value for RARR in RECAT research.

• Choosing the maximum value among all of the category combinations is a radical method, as it may cause the smallest distance separation together with the largest throughput of air traffic operation.

• choose the smallest value among all of the peak values in above figure is a conservative method. May not reduce separation.
4 Analyzing current separations

4.2 Required Actual Roll Rate (RARR)

RARR is very similar as IRMC.

Can get minimum separation and maximum throughout

Can get maximum separation and minimum throughout
4 Analyzing current separations

4.2 Minimum Acceptable Safe Level (MASL)

We proposed a **pragmatic method** to choose the minimum or maximum one among RARR values in the above figure.

<table>
<thead>
<tr>
<th>Leading aircraft</th>
<th>Following aircraft</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>C</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Max</td>
</tr>
<tr>
<td>F</td>
<td>Equal to minimum Radar Separation</td>
</tr>
</tbody>
</table>
5 REQUIRED SEPARATIONS

5.1 Typical aircraft
In order to reduce the workload of calculation, typical leading aircraft and following aircraft were selected for each type of categories.

<table>
<thead>
<tr>
<th>ICAO’s categories</th>
<th>Leading Aircraft</th>
<th>RDD</th>
<th>Following Aircraft</th>
<th>WVI</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>A380</td>
<td>13862</td>
<td>A380</td>
<td>5287</td>
</tr>
<tr>
<td>H</td>
<td>B744</td>
<td>11685</td>
<td>A306</td>
<td>1426</td>
</tr>
<tr>
<td>M</td>
<td>B752</td>
<td>4751</td>
<td>C650</td>
<td>185</td>
</tr>
<tr>
<td>L</td>
<td>C525</td>
<td>0</td>
<td>C525</td>
<td>143</td>
</tr>
</tbody>
</table>
5 REQUIRED SEPARATIONS

5.1 Typical aircraft
In order to reduce the workload of calculation, typical leading aircraft and following aircraft were selected for each type of categories.

<table>
<thead>
<tr>
<th>New RECAT</th>
<th>Leading Aircraft</th>
<th>WVES</th>
<th>Following Aircraft</th>
<th>WVI</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>A380</td>
<td>13862</td>
<td>A380</td>
<td>5287</td>
</tr>
<tr>
<td>B</td>
<td>B744</td>
<td>11685</td>
<td>A343</td>
<td>2912</td>
</tr>
<tr>
<td>C</td>
<td>MD11</td>
<td>7964</td>
<td>A306</td>
<td>1426</td>
</tr>
<tr>
<td>D</td>
<td>B752</td>
<td>4751</td>
<td>A320</td>
<td>868</td>
</tr>
<tr>
<td>E</td>
<td>B722</td>
<td>3706</td>
<td>SF34</td>
<td>361</td>
</tr>
<tr>
<td>F</td>
<td>E145</td>
<td>991</td>
<td>C525</td>
<td>143</td>
</tr>
</tbody>
</table>
## 5 REQUIRED SEPARATIONS

### 5.2 Calculation cases

<table>
<thead>
<tr>
<th>factor</th>
<th>Data range</th>
<th>Step value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>ISA-20 C ~ISA+30 C</td>
<td>10(^\circ)C</td>
</tr>
<tr>
<td>Flight Altitude</td>
<td>300m~1800m</td>
<td>300m</td>
</tr>
<tr>
<td>Airspeed plus for leading aircraft</td>
<td>10knots~20knots</td>
<td>5knots</td>
</tr>
<tr>
<td>Weight ratio for leading aircraft</td>
<td>0.80~0.95</td>
<td>0.05</td>
</tr>
<tr>
<td>Airspeed plus for following aircraft</td>
<td>-10knots~20knots</td>
<td>5knots</td>
</tr>
<tr>
<td>Weight ratio for following aircraft</td>
<td>0.80~0.95</td>
<td>0.05</td>
</tr>
</tbody>
</table>
5 REQUIRED SEPARATIONS

[Software interface showing parameters and data tables for analysis]
### 5 Required Separations

#### 5.3 Required Minimum Distance Separations

<table>
<thead>
<tr>
<th>Leading aircraft</th>
<th>Following aircraft (NM)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>A</td>
<td>2.5</td>
</tr>
<tr>
<td>B</td>
<td>2.5</td>
</tr>
<tr>
<td>C</td>
<td>2.5</td>
</tr>
<tr>
<td>D</td>
<td>2.5</td>
</tr>
<tr>
<td>E</td>
<td>2.5</td>
</tr>
<tr>
<td>F</td>
<td>2.5</td>
</tr>
</tbody>
</table>
5. REQUIRED SEPARATIONS

5.3 Required Minimum Distance Separations
5 REQUIRED SEPARATIONS

5.3 Required Minimum Distance Separations

As is shown in this figure, the separation for our new RECAT is larger than RECAT-I and RECAI-EU in some cases, such as A-E, A-F, B-E, and B-F. While for medium and low type aircraft, the separation may be decreased.
5 Required Separations

5.4 Severity analysis

RARR for different combinations (RECAT NEW)
5 Required Separations

5.4 Severity analysis

RARR for different combinations (RECAT-I)
5 REQUIRED SEPARATIONS

5.4 Severity analysis

RARR for different combinations (RECAT-EU)
5 Required SE

5.4 Severity analysis

More equilibrium!
Many Thanks!
Biography

WEI Zhiqiang (1979.9-) is Associate Professor and Master Tutor in college of air traffic management, Civil Aviation University of China. He graduated from CAUC, achieved Bachelor’s degree of traffic transportation in 2001, and Master’s Degree of traffic transportation planning and management in 2008. His research interests are aircraft flight performance and wake vortex.

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魏志强（1979.9-），中国民航大学空管学院，副教授，硕士生导师。2001年毕业于中国民航大学交通运输专业（工学学士）；2008年毕业于中国民航大学交通运输规划与管理专业（工学硕士）。研究方向：飞机性能与尾流建模仿真。