NLR and Wake Turbulence Separation related research

FSS Wake workshop, Braunschweig, June 2016 | Gerben van Baren, vanbaren@nlr.nl
NLR’s involvement in European research on reduced separation concepts (2000 onwards)

Concept Development → System support → Flight / RTS Simulations → Safety metrics → Safety criteria → Safety Assessment → Safety Case
Highlights of recent research

- Universal Atmospheric Hazard Criteria
- Wake Impact Flight Simulation campaign
- Optimised Runway Delivery Study
- Aircraft performance Model development
- Data analytics & performance monitoring
- FSS P4 Total System Risk Assessment
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What are good metrics and criteria to measure and monitor WVE safety?

How can we support ATC to accurately deliver separation?
UFO – Ultra Fast Wind Sensors
Universal Atmospheric Hazard Criteria

• Wide range of new Lidar/Radar wind sensors for detecting/monitoring/alerting of atmospheric hazards:
  – Wake vortices
  – Wind shear
  – Turbulence
UFO – Ultra Fast Wind Sensors
Why universal criteria?

• UFO system requires consistent assessment of the various hazards:
  ▪ For each atmospheric hazard ideally one specific metric with:
    ➢ Good discriminative power (strong correlation between metric value and severity)
    ➢ Aircraft independent
    ➢ Meaningful
    ➢ Computable (without need for access to proprietary data)
    ➢ Absolute
  ▪ Link to common risk matrix, defining the severity (e.g. minor, major, hazardous, catastrophic) and probability thresholds
UFO – Ultra Fast Wind Sensors
Wind shear

• F-Factor
  – Based on TSO C-117 alerting boundaries
UFO – Ultra Fast Wind Sensors

Turbulence

• **Generalized EDR**
  – Based on PIREP Turbulence Intensity scale
  – In combination with ICAO Annex 3
  – But for Medium sized A/C only
  – Made A/C independent with A/C chord
UFO – Ultra Fast Wind Sensors

Wake vortex -> Dimensionless Equivalent Roll Rate

- Equivalent to RMC
- Meaningful to pilots as it can be interpreted as the angle of attack at the wingtip; wingtip stall criteria can be used for severity rating
- Only few parameters needed: wingspan, airspeed, circulation
- Easy to assess operationally in UFO concept
- Need for ‘real-time’ prediction of airspeed and circulation
- Applied in RECAT-EU
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Wake Impact Severity Assessment (WISA) - Objectives

- Further validate that the RMC as a metric 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.
- In view of RECAT PWS, collect additional evidence for acceptability of WT severity alignment of aircraft types of various size.
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Wake Impact Severity Assessment (WISA)

NLR GRACE Reconfigurable Research Flight Simulator

B744  A332  A320  F100  C550
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Wake Impact Severity Assessment (WISA)

NLR GRACE Reconfigurable Research Flight Simulator

Mixed cockpit configuration
- Fly-By-Wire A320/A330
- Classic Controls B747/F100/C550
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Wake Impact Severity Assessment (WISA) / Experiment set-up

• Two scenario’s
  – Level flight at 3,000 ft altitude
  – ILS approach to EHAM RWY 06 (3500 x 45m)
• Light background turbulence to create realistic environment
• Fixed assumed interception angle of 10 degrees
- The “F65” is a scaled version of the F100 to represent an A/C with a wing span of 20 meters like the E145 which is used as pivot in the Safety Case.
- Final approach speed aligned with RECAT-PWS, based on measurements
- Aircraft at 90% MLW
- Each type is verified in GRACE with type rated pilots
The rolling moment is directly imposed on the aircraft.
- Ensures a predictable and worst case encounter through the core
- Suited for the evaluation of the effect of a WV of certain strength on aircraft of different sizes.
- Avoids undesirable effects of differences in intercept angle and relative position of the aircraft to the vortex core

A shaping function is developed to vary the wake vortex induced rolling moment with time.

Further validated in GRACE simulator with an experienced test pilot involved in WVE flight tests

Participating pilots confirmed realistic behaviour of WVE
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Wake Impact Severity Assessment (WISA) - Configuration of runs

• Altitude 3000 ft (level flight at altitude), 200 & 100 ft (on ILS approach)
• RMC 0.04 / 0.06 / 0.08 / 0.10
  – Broadly covering worst case values that aircraft are exposed to
• Variation in left and right upset
• Random sequence of the runs
• Pilots asked to continue landing and focus on WVE impact and indicate whether or not go-around would have been initiated in an operational setting afterwards
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*Wake Impact Severity Assessment (WISA) - Rating scale*

<table>
<thead>
<tr>
<th>Noticeable disturbance, No or negligible pilot compensation required to maintain desired flight path</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small disturbance</td>
<td>Minor</td>
</tr>
<tr>
<td>Light pilot compensation required to maintain desired flight path</td>
<td>Major</td>
</tr>
<tr>
<td>Large disturbance</td>
<td>Minor</td>
</tr>
<tr>
<td>Moderate pilot compensation required to maintain desired flight path or avoid ground contact. (Safe landing possible)</td>
<td>Major</td>
</tr>
<tr>
<td>Severe disturbance</td>
<td>Minor</td>
</tr>
<tr>
<td>Significant or maximum pilot compensation required to maintain desired flight path or avoid ground contact. (Safe go-around possible)</td>
<td>Major</td>
</tr>
<tr>
<td>Extreme disturbance, Maximum pilot control authority exceeded, inability to maintain desired flight path or avoid ground contact.</td>
<td>8</td>
</tr>
</tbody>
</table>
Topics addressed:

- Preparations sufficient?
- Actual experience on WVE?
- Realism of the simulated encounter?
- Quality of the rating scale?
- Other feedback?

<table>
<thead>
<tr>
<th>Question</th>
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<tbody>
<tr>
<td>1. Was the pilot briefing sufficient for you to prepare for the experiment? (What can we do to improve?)</td>
</tr>
<tr>
<td>2. How many times have you experienced a Wake Vortex Encounter in real life and what was the highest severity? (Could you relate the severity with the proposed severity rating scale?)</td>
</tr>
<tr>
<td>3. Do you consider the behaviour of the simulated aircraft type realistic enough to represent a real Wake Vortex Encounter?</td>
</tr>
<tr>
<td>4. Did you consider the Wake Vortex Encounter scenario’s realistic?</td>
</tr>
<tr>
<td>5. In the event you initiated a go-around or would have initiated a go-around, on what “elements” did you base your decision? (remember we ask you always to try to land, the focus of the experiment is the assessment of the WTE severity)</td>
</tr>
<tr>
<td>6. Could you distinguish the different severity levels of the Wake Vortex Encounters?</td>
</tr>
<tr>
<td>7. Do you think the severity you rated as large disturbance/moderate compensation can be used for separation design for your aircraft type as follower?</td>
</tr>
<tr>
<td>8. Do you have any other feedback or comment? (e.g. on the setup of the experiment …)</td>
</tr>
</tbody>
</table>
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Wake Impact Severity Assessment (WISA) - Experiment execution

• Selected pilots experienced on the type including test pilots (EASA, Airbus, NLR) and airline pilots
• Pilot briefing guide (beforehand) and presentation (on site)
• Experiment runs
• Debriefing and post-experiment questionnaire
• In total 64 hours of simulation time and ~900 runs
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Wake Impact Severity Assessment (WISA) - Collection of data

• For each of the runs:
  – Ratings of the severity by Pilot Flying (PF) and Pilot Not Flying (PNF)
  – PF & PNF indications whether a go-around would have been initiated
  – Recordings of 125 parameters and 30 derived metrics after post-processing
  – Video recordings
• Pilot feedback on post-experiment questionnaire
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Wake Impact Severity Assessment (WISA) - How does it look like?
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Wake Impact Severity Assessment (WISA) - Results

RMC correlates well with WVE severity
Comparison of Level flight versus Approach:
*Correlation best visible at 3000 ft (level flight);
Other effects, causing more variation, play a role close to ground at 200 – 100 ft*
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*Wake Impact Severity Assessment (WISA) - Results*

Safe landing possible up to RMC=0.06 for all A/C and up to RMC=0.08 for M/L.
Highlights of recent research

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- FSS P4 Total System Risk Assessment

What are good metrics and criteria to measure and monitor WVE safety?

How can we support ATC to accurately deliver separation?
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Optimised Runway Delivery Study

Congested airports → Supporting tool → Reduced separation concepts

Current practice? Understanding by data analysis → Forecast capability
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Optimised Runway Delivery Study

Objective:
- Baseline the current practices for separation application throughout Europe
- Understand factors causing variability and compression
- Demonstrate there are today means for going below minima
- To put the SESAR concepts into the right perspective
- New concepts should not be more stringent than current ops

Activities/inputs:
- Observations & Interviews
- Data Analysis
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Optimised Runway Delivery Study – Data analysis

Analysis of flight track and weather data

- Combination of radar/ADS-B data and weather data
- Focus on busy operational hours
- Analysis of:
  - Ground speed
  - Distance and time separation
  - Spacing buffer
- Considering:
  - Headwind
  - Aircraft type / Wake turbulence categories
  - Airport / runway
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Optimised Runway Delivery Study - How does separation delivery work?

Actual separation delivery is combination of:
- Separation minima -> Final Target Distance (FTD)
- Anticipation of compression -> Initial Target Distance (ITD)

Final Target Distance = Initial Target Distance + Spacing Buffer

At 10 NM

• Speed profile follower
• Compression of spacing

At THR

IBE652R H 015 ↓ 160 A343
IBE652R H 009 ↓ 135 A319
EZY475A M 019 ↓ 160 A319

Speed profile leader
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Optimised Runway Delivery Study

Evolution of spacing buffer

- Spacing buffer decreases because of compression
- Close to threshold buffer on average 0.5 NM
- Fraction below minima, justified by e.g., visual separation
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Optimised Runway Delivery Study – More accurate separation delivery

Optimised runway throughput not only requires optimised separation minima, also accurate delivery of separation

Reduced distribution of spacing buffer close to threshold
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Aircraft Performance Model – Prediction of airspeed / time to fly

- More accurate spacing? => Develop capability to predict aircraft speed and time-to-fly on final approach

**Time/ distance separation minimum**

**Actual conditions:**
- A/C type
- Airline
- Wind
- Traffic pressure

**Predicted speed profile from data driven model**

**Initial and final targeted spacing indicators to support ATCo**
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Aircraft Performance Model - Prediction of airspeed / time to fly

Time separation converted into FTD/ITD using aircraft speed/T2F profile

IAS profiles from data

Time to fly profiles from data
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Aircraft Performance Model – Headwind dependent model

Ground speed and Time-to-fly per segment of 0.5 NM and headwind condition at altitude

<table>
<thead>
<tr>
<th>Headwind condition [kts]</th>
<th>10</th>
<th>9</th>
<th>8</th>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
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<tr>
<td>&gt;20</td>
<td>180</td>
<td>176</td>
<td>171</td>
<td>167</td>
<td>164</td>
<td>161</td>
<td>158</td>
<td>156</td>
<td>152</td>
<td>149</td>
<td>144</td>
</tr>
<tr>
<td>15 - 20</td>
<td>180</td>
<td>176</td>
<td>171</td>
<td>167</td>
<td>164</td>
<td>161</td>
<td>158</td>
<td>156</td>
<td>152</td>
<td>149</td>
<td>144</td>
</tr>
<tr>
<td>10 - 15</td>
<td>187</td>
<td>182</td>
<td>180</td>
<td>175</td>
<td>173</td>
<td>169</td>
<td>166</td>
<td>162</td>
<td>159</td>
<td>156</td>
<td>150</td>
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<tr>
<td>5 - 10</td>
<td>193</td>
<td>188</td>
<td>183</td>
<td>180</td>
<td>175</td>
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<td>170</td>
<td>167</td>
<td>164</td>
<td>160</td>
<td>154</td>
</tr>
<tr>
<td>0 - 5</td>
<td>198</td>
<td>194</td>
<td>190</td>
<td>186</td>
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<td>179</td>
<td>176</td>
<td>172</td>
<td>169</td>
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<tr>
<td>-5 - 0</td>
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<td>191</td>
<td>186</td>
<td>183</td>
<td>179</td>
<td>176</td>
<td>174</td>
<td>169</td>
<td>164</td>
<td>158</td>
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<tr>
<td>&lt; -5</td>
<td>207</td>
<td>205</td>
<td>200</td>
<td>197</td>
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<td>184</td>
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<td>172</td>
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</table>

<table>
<thead>
<tr>
<th>Distance to threshold [NM]</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
</tr>
<tr>
<td>-----------------------------</td>
</tr>
<tr>
<td>103</td>
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<tr>
<td>93</td>
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<td>83</td>
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<tr>
<td>73</td>
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<tr>
<td>63</td>
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</tbody>
</table>

A320 GS model

A320 T2F model
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Aircraft Performance Model – How to use it?

- Model build based on historic data
- Assume a specific headwind profile
- Identify the associated model cells
- Resulting in an average T2F profile ...
- ... and uncertainty band due to variation within a cell
- To account for uncertainty in the headwind profile itself ...
- ... another uncertainty band may be added

- Model can learn taking into account new data, resulting in smaller variations
NLR own research – Data analytics & performance monitoring

• **Potential application in view of WT research:**
  – To support monitoring and accurate delivery of separation after deployment of a new separation concept
• NLR cross-domain and multidisciplinary working group of performance experts, data scientists, IT engineers
• Development of own big data base, combination of ADS-B data, weather data, safety data ...
• Development of (regression, machine learning) techniques to predict indicators based on combination of historical and actual data
• Looking at performance of the ‘whole picture’: final approach + runway + taxi ways + TMA + take-off
• Real-time information for tactical monitoring & predictions
• Frequent updates for strategical monitoring
NLR own research - Data analytics & Performance monitoring, Dashboard development to visualise safety / performance data
Future Sky Safety Project 4 – Total System Risk Assessment

- Development of Prototype Risk Observatory
  - Combining safety data from abroad the sector
  - Integration with risk models
  - Potential for integration of WVE safety information
Conclusions

• Research has been important to build up knowledge and create the tools to deploy reduced separation concepts
• For optimizing runway throughput:
  + Optimized separation minima
  + Optimized – more accurate – delivery of separation
• Requires accurate prediction of aircraft speed & time to fly
• Future work focus on:
  – Accurate prediction of aircraft performance and weather/wind
    • More advanced data analytics and Machine Learning techniques
    • Broader, larger, and more accurate data sets
  – Extension to departures
  – Integration of reduced separation in broader scope of the airport runway throughput operation
  – Monitoring: separation performance, WVE metrics
Fully engaged
Netherlands Aerospace Centre

NLR Amsterdam
Anthony Fokkerweg 2
1059 CM Amsterdam

p ) +31 88 511 3113  f ) +31 88 511 3210
 e ) info@nlr.nl  i ) www.nlr.nl