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Performance through Innovation

# Validation of the Time Based Separation concept at London Heathrow Airport

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# Introduction to Today's Operations

- Aircraft separated by
  - Wake turbulence separation rules
  - Runway spacing and radar separation rules

- Separation expressed in terms of
  - Time for take-off clearance for departures
  - Distance for arrivals on final approach

- Considered at times over-conservative
  - Fixed regardless of the prevailing meteorological conditions impact on the transport and decay of the wake turbulence

# Headwind Conditions Resilience Issues for Arrivals

- Reduction of the aircraft ground speed on final approach as headwind increases
  - Increases time spacing between each arrival pair
  - Causes a reduction in the landing rate and impacts the stability of the runway throughput
  - Causes a knock-on impact on holding delays

- Impacts
  - Predictability of operations
  - Flying time and fuel efficiency
  - Environment (emissions)

- Causes
  - Service disruption at the network level
  - Knock-on disruption on the other aircraft rotations throughout the day

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# Validation History for Scope (V1) and Feasibility (V2)

- Extensively evaluated refined and partially validated by Eurocontrol (ECTL), NATS and in European 6$^{th}$ Framework Program (EC 6$^{th}$ FP) from 2001 to 2010
  - Model based assessments to quantify the risk of a wake vortex encounter (2008)
  - Model based assessments to quantify costs and benefits (2003, 2005, 2006, 2010)
  - Development, evaluation and initial validation of ATC tools for providing spatial visualization (2004)
  - ECTL & EC 6$^{th}$ FP real-time simulations (2006, 2007, 2010)
  - Development of a detailed concept of operations (2008, 2009)
  - Dedicated wake turbulence LIDAR measurement campaign at in-ground-effect /near-ground effect (IGE/NGE) glideslope elevations (2008 to 2010)
  - TBS user group workshops (2010 & 2011)
  - NATS real-time simulation with Heathrow approach controllers (2010)

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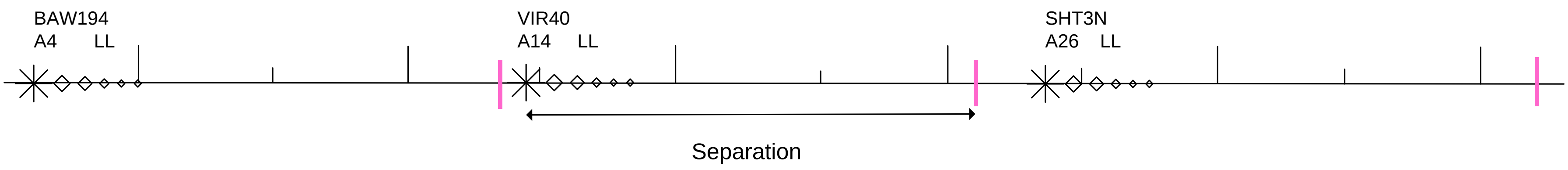
# TBS Concept Objective

- To improve the landing rate resilience to headwind conditions on final approach
- Through recovering the lost landing rate currently experienced when applying distance based separations
- To be achieved by stabilising the time spacings between aircraft on final approach across headwind conditions

| Mean Headwind | Time Spacing Impact |
|---|---|
| 15kn | 6.7% |
| 25kn | 14.3% |
| 35kn | 23.1% |

# TBS Concept Overview

- Change the separation rules on final approach from distance based (DBS) to time based (TBS)
- Facilitate delivery to time based separation constraints by providing separation indicators displayed on the extended runway centre-line of the:
  - Final approach controller radar display
  - Tower runway controller air traffic monitor display
- Change the controller separation/spacing procedures to take into account the use of the separation indicators



# Derivation of the Time Based Separation Rules (1)

- From distance based separation rules taking into account the ground speed profile of aircraft on the final approach glideslope in low headwind conditions
- Complication of the diversity of airspeed profiles flown on final approach
  - Procedural airspeed profiles prior to landing speed stabilisation
  - Airspeed profiles employed during landing speed stabilisation in relation to the aircraft type, landing weight and other factors
  - Results in a multiplicity of time spacing associated with each distance based separation
- Complication managed through the use of a reference airspeed profile to establish the reference time based separations in the low headwind conditions

# Derivation of the Time Based Separation Rules (2)

- Use of a reference airspeed profile to establish the reference time based separations in the low headwind conditions
  - Representative of the local final approach airspeed procedures of the aerodrome
  - Representative landing stabilisation airspeed profile for the follower aircraft type
  - The low headwind conditions proposed is a minimum of 5kn
  - Take into account the local runway elevation and the glideslope angle impact on the true airspeed profile and resulting ground speed profile

# DBS for Heathrow

| Leader | Follower | | | | | |
|---|---|---|---|---|---|---|
| | A380 560T | Heavy More than 162T | Upper Medium 104T to 162T | Lower Medium 40T to 104T | Small 17T to 40T | Light 17T or less |
| A380 (JJ) | 4* | 6 | 7 | 7 | 7 | 8 |
| Heavy (HH) | 4* | 4 | 5 | 5 | 6 | 7 |
| Upper Medium (UM) | * | * | 3 | 4 | 4 | 6 |
| Lower Medium (LM) | * | * | * | * | 3 | 5 |
| Small (SS) | * | * | * | * | 3 | 4 |
| Light (LL) | * | * | * | * | * | * |

**UK Distance Based Wake Turbulence Separation Minima (Nm)**

4* to allow for the runway occupancy time of the lead A380 or Heavy aircraft

* spacing minimum applies (3Nm or 2.5Nm)

# TBS for Heathrow

| Leader | Follower | | | | | |
|---|---|---|---|---|---|---|
| | **A380** 560T | **Heavy** More than 162T | **Upper Medium** 104T to 162T | **Lower Medium** 40T to 104T | **Small** 17T to 40T | **Light** 17T or less |
| **A380 (JJ)** | 90s* | 135s | 158s | 158s | 158s | 180s |
| **Heavy (HH)** | 90s* | 90s | 113s | 113s | 135s | 158s |
| **Upper Medium (UM)** | 60s | 60s | 68s | 90s | 90s | 135s |
| **Lower Medium (LM)** | 60s | 60s | 60s | 60s | 68s | 113s |
| **Small (SS)** | 60s | 60s | 60s | 60s | 68s | 90s |
| **Light (LL)** | 60s | 60s | 60s | 60s | 60s | 60s |

**Heathrow Reference Time Based Separations**

160kn ground speed conversion of distance based separation rules

90s* to allow for the runway occupancy time of lead A380 or Heavy aircraft

60s to allow for runway occupancy time of the lead aircraft types of spacing minimum pairs

# Derivation of the TBS Distance

- Apply the reference airspeed profile to the prevailing glideslope wind conditions to calculate the TBS distance
- The actual airspeed profile of the follower aircraft will still vary in the same way that it varies today
  - The variation in time spacing under TBS will be no different than that under DBS in the reference low headwind conditions
  - For a particular airspeed profile the time spacing is stabilised across headwind conditions
- The diversity of airspeed profiles employed on final approach is accommodated
  - Without the need to explicitly take into account the airspeed profile intent of each aircraft
- The TBS distance is applied from the follower aircraft merging on to final approach until the lead aircraft crosses the runway landing threshold

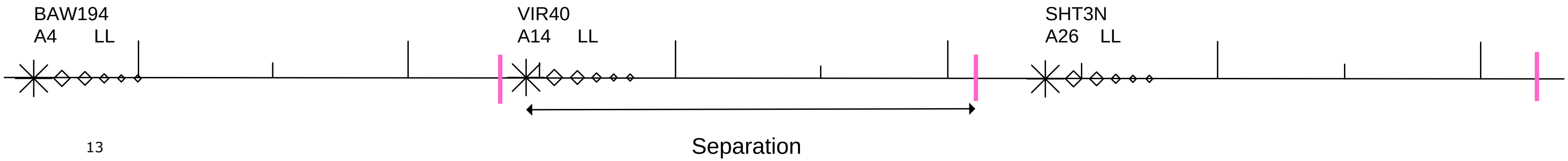
# TBS Distance for Heathrow

- Calculated taking into account the ground speed effect of the prevailing wind conditions on the final approach glideslope over the spacing to 4DME (4Nm from the runway landing threshold)
- The TBS distance is
  - The same as the distance based separation in the reference low headwind conditions used to derive the reference time based separation
  - Less than the distance based separation in stronger headwind conditions
  - More than the distance based separation in light headwind and tailwind conditions

| Mean Headwind | Mean Ground Speed | 90s | 113s | 135s |
|---|---|---|---|---|
| 5kn | 160kn | 4.0Nm | 5.0Nm | 6.0Nm |
| 15kn | 150kn | 3.8Nm | 4.7Nm | 5.6Nm |
| 25kn | 140kn | 3.5Nm | 4.4Nm | 5.3Nm |

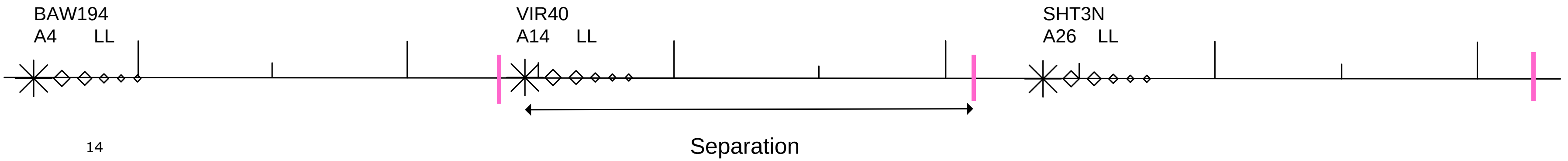
## Separation Indicator Display Requirements for Heathrow

- Clear indication of the required separation between an arrival pair at a glance
  - Shape, size, colour, intensity, display priority
- Stable presentation of the separation indicator distance from a controller perception
  - Separation indicator position to be updated at same time as lead aircraft track position update
- Supporting the turn on decisions for merging the follower aircraft on to the final approach localiser
- Supporting refinement of the spacing set up on the final approach localiser
- Supporting the monitoring of the continued appropriateness of the spacing on final approach
- Support for Heathrow parallel dependent operations
  - Easy to distinguish not-in-trail separation indicator



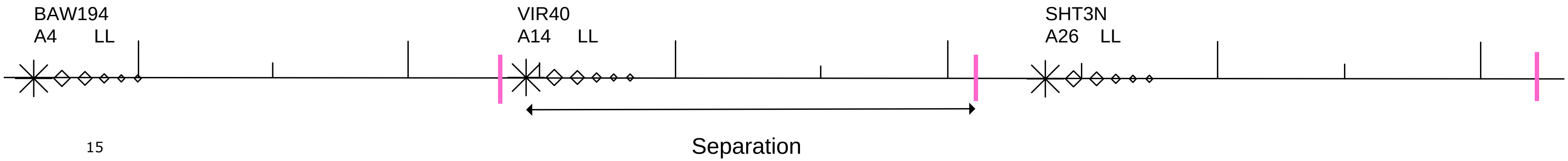
# Controller Procedures (1)

- Separation indicator represents the time based separation on the controller radar display
- The final approach controller is responsible for
  - Efficiently delivering to the radar separation
  - Using the separation indicator as the reference for the separation
  - Turning the follower aircraft on in the zone behind the separation indicator
  - Providing sufficient additional spacing for the distance spacing compression expected to be experienced taking into account
    - The prevailing glideslope wind conditions
    - The anticipated final approach airspeed profiles of both the lead and follower aircraft



# Controller Procedures (2)

- Ideally sufficient spacing is set up after initial spacing refinement such that there is no need for further intervention action
- In the event of unanticipated distance compression the final approach controller and tower runway controller are required to take active steps to preserve the separation and to recover separation
- System support can be provided
  - For monitoring and alerting for aircraft employing abnormal airspeed profiles on final approach
  - For monitoring and alerting for infringement scenarios resulting from unanticipated distance spacing compression



# Airspace User Procedures

- Flight deck multi-media awareness briefings on the TBS concept
  - Incorporated into the pre-departure briefing
  - Incorporated into the top-of-descent briefing
- Notification to the flight deck that TBS procedures apply through the airport air traffic information service
- On first call to Approach ATC, pilot is require to provide
  - Confirmation of aircraft type
  - Notification of approach airspeed non-conformances against the procedural airspeed profile published in the AIP
  - Optionally notification of the intent to employ an abnormally slow or an abnormally fast landing stabilisation airspeed profile for the aircraft type

# Consideration of all the other Separation and Spacing Constraints that apply on Final Approach

- The wake turbulence time based separations are to be applied in the context of all the other separation and spacing constraints on final approach
  - Minimum radar separation constraints
  - Runway spacing constraints appropriate for the runway visual conditions
  - Runway spacing constraints appropriate for the runway surface braking conditions and exit taxiway positioning and serviceability
  - Scenario specific spacing requirements such as for a runway inspection or for accommodating crossing traffic
  - Departure gap spacing requirements for interlaced mode operations
- The separation indicator is required to clearly represent the maximum separation or spacing constraint to be applied between the arrival pair

# Enabling Dependencies

- Provision of dependable runway-in-use, runway mode, final approach separation and runway spacing constraints
- Provision of arrival sequence order and aircraft landing runway intent information, including late tactical changes
- Provision of the scenario specific spacing and interlaced departure gap requirements
- Provision of a glideslope wind conditions service

# Validation towards Pre-Industrialisation Development (V3) maturity in SESAR

- Identified key validation objectives
  - Definition of the time based separations
  - Definition, assessment and refinement of the HMI and ATM component requirements and operational procedures enabling controllers to apply time based separations
  - Definition and assessment of the operational, functional and algorithm requirements of the TBS tool support
  - Assessment of the change in wake vortex encounter risk from applying time based separations
  - Validation that the proposed tool support and the procedural changes for TBS have an acceptable impact on task performance and safety
  - Validation that the actual delivery to the time based separations is safe with respect to wake turbulence encounter, mid-air collision, runway collision and runway accident risk

# Validation Exercises

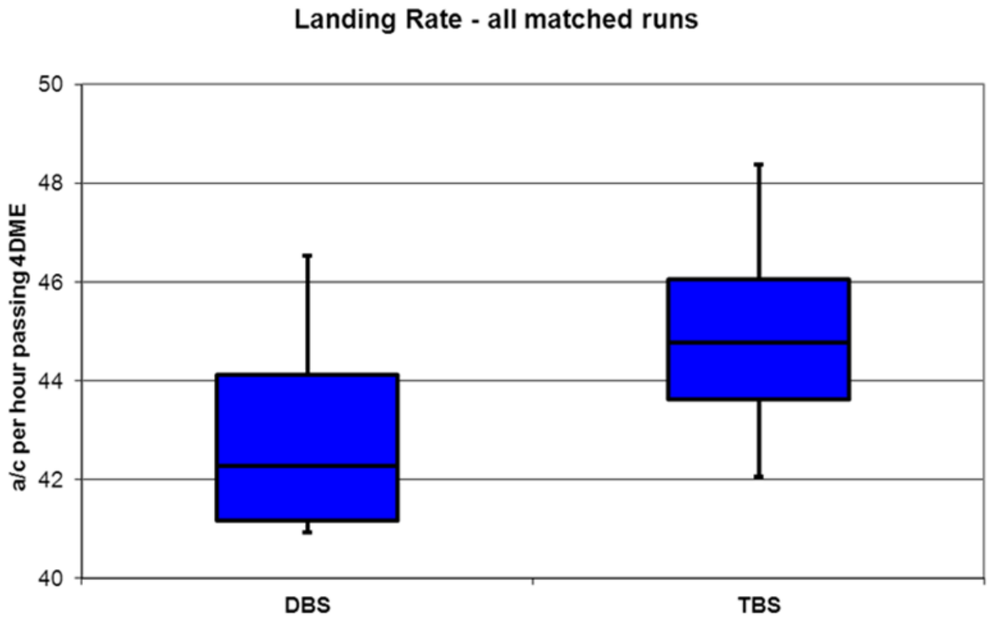
- To cover the key validation objectives the following main validation exercises have been defined
  - Real-time simulations
    - For Approach ATC
    - For Tower ATC
  - Wake turbulence risk assessment
  - Safety assessment
  - Human performance assessment
  - Business benefit assessment
  - Environment assessment

# Heathrow Approach Validation Exercise

- 13 day TBS Heathrow Approach validation exercise
  - 11th February 2012 to 5th March 2012
  - Heathrow approach real-time simulator at the NATS Corporate Technical Centre
- Measured positions
  - Final approach controller
  - Intermediate approach controllers, north and south
  - Tower runway controller when manned
- 51 simulation runs completed
  - 6 training runs
  - 13 DBS runs for comparison to the matched TBS runs
  - 38 runs, including scenario exercise runs, using TBS
- Good number and good mix of controllers with extensive operational experience to assess TBS

# Aircraft Landing Rate Comparison

- Aircraft landing rates were consistently increased with TBS compared to DBS for the eleven matched runs for the traffic samples and wind conditions simulated
  - Up to 5 additional aircraft per hour
  - Mean of 2 additional aircraft per hour
  - Increased aircraft landing rates are statistically significant

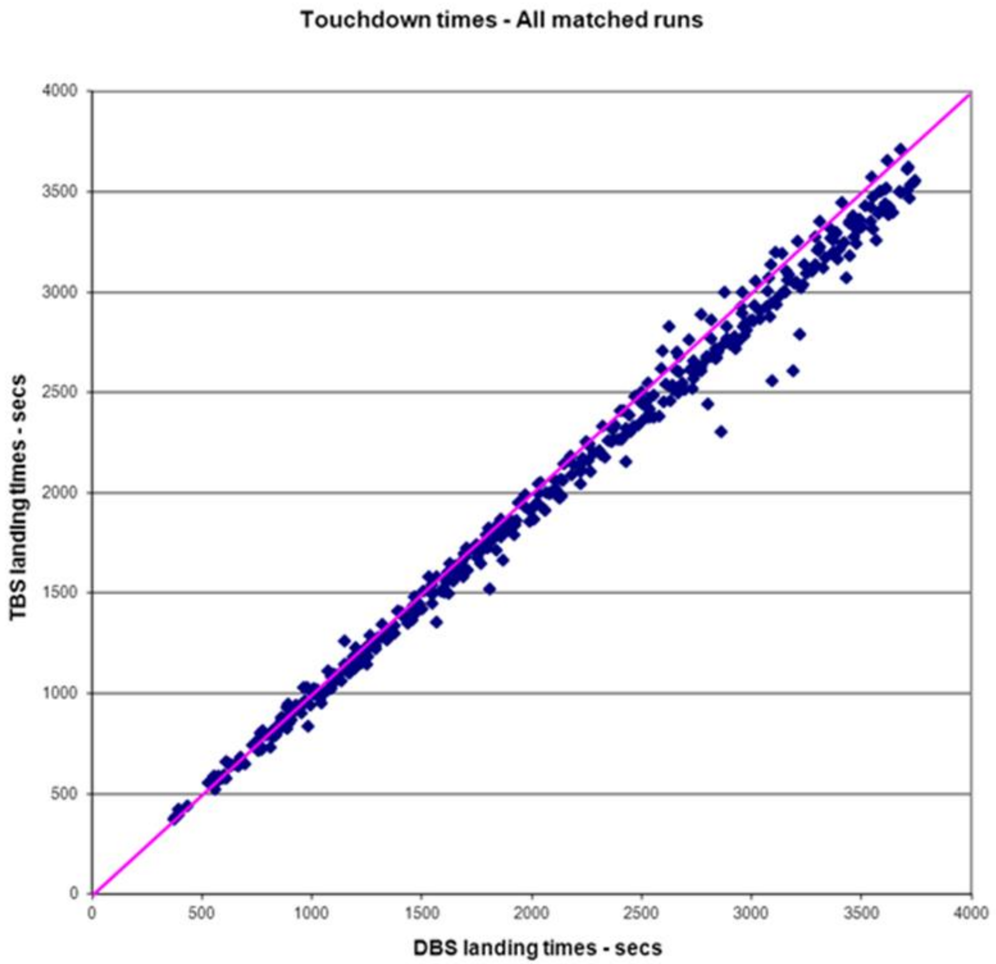


# Separation Accuracy and Workload

- Separation accuracy at 4DME (TBS v DBS)
  - Wake pairs shows a clear and statistically significant improvement with TBS
  - Same accuracy with spacing minimum pairs
  - Overall TBS performed generally better than DBS
  - The percentage of under-separation with TBS was almost halved
- Workload (TBS v DBS)
  - The was no difference in controller workloads
  - Workload measures indicated busy but comfortable normal operating levels
  - Slight increase in R/T usage of the final approach controller appearing to be linked to the higher aircraft landing rates achieved with TBS

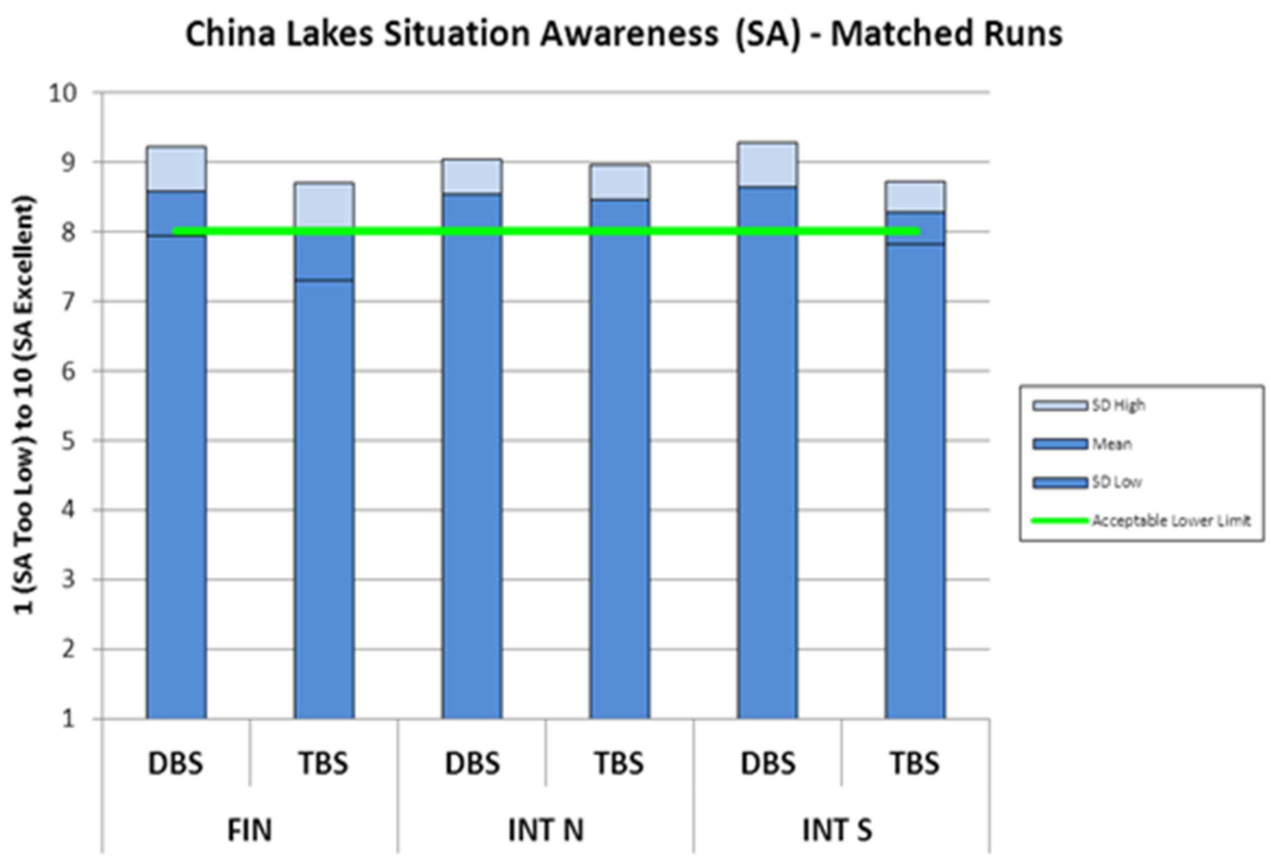
# Aircraft Landing Times Comparison

- Holding times and stack entry to touchdown times were reduced with TBS
- Mean reduction of 0.9mins and 1.4mins respectively



# Situation Awareness Comparison

- Situation awareness for the final approach controller was reduced with TBS
- Change of scan focus to the separation indicators
  - Away from the flight progress strips
  - Away from the lead aircraft target position



# Heathrow Tower Validation Exercise

- 7 day TBS Heathrow Tower validation exercise
  - 11th July 2012 to 24th July 2012
  - Heathrow tower 360° VCR real-time simulator at NATS Heathrow House
- Measured position
  - Tower runway controller
- 31 simulation runs completed
  - 8 DBS runs for comparison to the matched TBS runs
  - 23 runs, including scenario exercise runs, using TBS
- Good number and good mix of controllers with extensive operational experience to assess TBS
  - 12 Heathrow tower runway controllers
- Matched runs were pairs of exercise runs derived from the same traffic samples and the same wind conditions from the Heathrow Approach Validation Exercise

# Heathrow Tower Validation Exercise Results

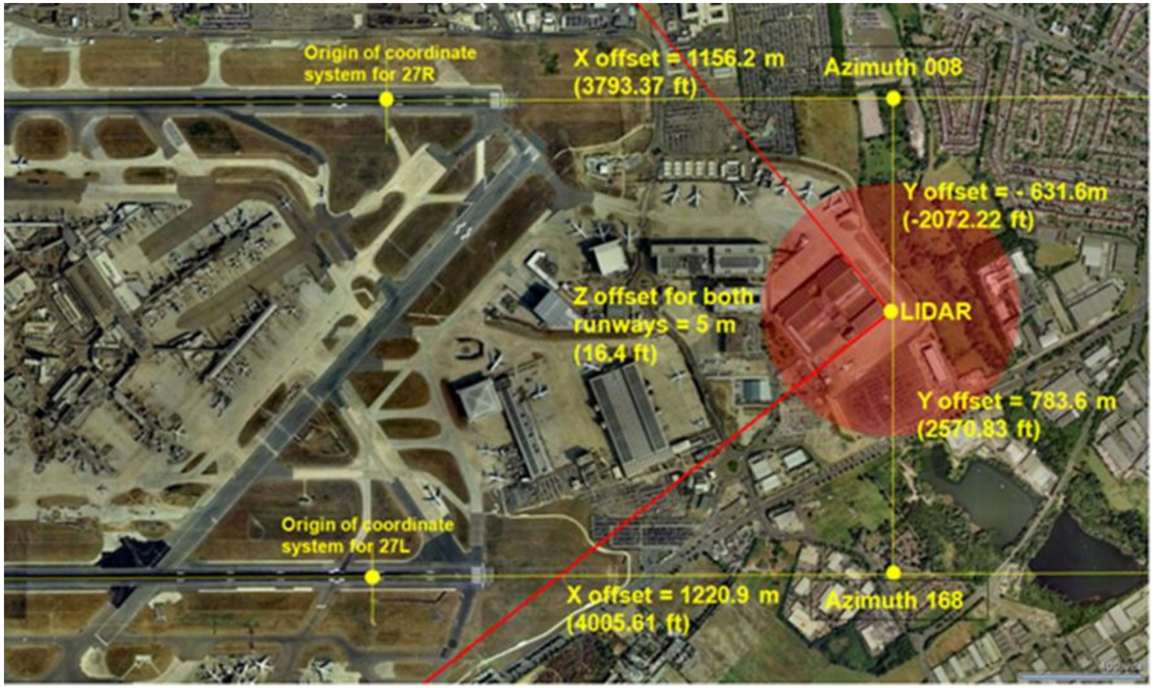
- The higher landing rates as delivered in the Heathrow Approach Validation Exercise with TBS were easily handled by the Tower controller
- There was no statistical difference in separation accuracy at the runway threshold between DBS and TBS
- There was no statistically significant differences in the controller workload with TBS compared to DBS; all were found to be acceptable
- Situation awareness remained high and comfortably above the acceptable limit at all times; there were no statistically significant differences between TBS and DBS
- There were no statistically significant differences between the clearance to land margins (of 15 seconds or less), the number of go-around instructions, the number of cautionary wake vortex advisories, or the number of expedited runway vacation requests issued between DBS and TBS
- The Tower runway controllers indicated that they could accommodate the separation indicators into their scan

# Summary Findings of the Heathrow Approach and Tower Simulations

- TBS concept is viable as simulated for Heathrow approach and could deliver significant improvements and benefits for airport operations
  - Increased aircraft landing rates in stronger headwind conditions
  - Reduced holding and approach times
- TBS tool needs to perform with a high degree of accuracy and reliability
  - Because of the high level of trust placed on the correct calculation and display of the separation indicators
  - Indicated by the change of scan focus to the separation indicators and from the flight progress strips and the lead aircraft target position

# Heathrow Wake Turbulence Measurement Campaign

- Wake turbulence at Heathrow has been measured using a Lockheed Martin WindTracer® LIDAR
  - In-Ground/Near Ground Data from October 2008 to December 2010, ~220ft above the ground
  - Measuring wake vortices generated by aircraft on westerly approaches to Heathrow
  - Measures the movement of particles in the air to estimate the circulation strength and location of a vortex



# Heathrow Wake Turbulence Data

- The following data has been collected
  - Aircraft data
  - LIDAR data
    - Wake vortex data
    - Wind data
  - Runway anemometer data
  - METAR data
- 104,201 LIDAR tracks, where each LIDAR track can contain up to two wake vortex tracks
  - Following detailed data cleaning

| | | Follower | | | | | |
|---|---|---|---|---|---|---|---|
| | | **JJ** | **HH** | **UM** | **LM** | **SS** | **LL** |
| **Leader** | **JJ** | 11 | 316 | 9 | 360 | 9 | 2 |
| | **HH** | 341 | 24159 | 606 | 20528 | 430 | 81 |
| | **UM** | 22 | 2289 | 243 | 1588 | 80 | 4 |
| | **LM** | 163 | 10231 | 2122 | 37685 | 2332 | 245 |
| | **SS** | 1 | 77 | 25 | 220 | 13 | 4 |
| | **LL** | 0 | 1 | 0 | 2 | 1 | 1 |

# Wake Turbulence Risk Assessment

- Analysis of the IGE/NGE LIDAR data to understand how the likelihood of vortex persistence will change under a TBS regime
- Primary metric is the probability of vortex persistence, for a given circulation strength or greater, after a defined time period
  - Vortex circulation strength is measured in metres squared per second ($m^2/s$)
  - Time period reflects the time spacing for the modelled aircraft pair at the LIDAR scan plane
  - This metric is expressed as a Complimentary Cumulative Distribution Function (CCDF)
- It is accepted that analysis of the data cannot provide an absolute answer to the severity of an encounter that may occur
  - Comparative analysis is used to make a relative assessment of the probability of the persisting vortex strength
  - Comparison of TBS CCDFs with baseline (DBS) CCDFs

# Wake Turbulence Risk Assessment Safety Criteria

- The assessment is performed by addressing the following safety criteria established through apply the SESAR safety assessment methodology
  - Is the probability of persisting vortex strength, considering “all wind conditions”, under a TBS separation regime no more than 5 percentage points greater than today, i.e. current DBS operations?
  - Is the probability of persisting vortex strength in “any wind conditions” under a TBS separation regime no greater than today under “low wind conditions”, or no greater than today in the same wind conditions?
  - Is the probability of persisting vortex strength in “any wind conditions” under a TBS separation regime with separation infringement no greater than today with an equivalent separation infringement under “low wind conditions”, or no greater than today in the same wind conditions?

# LIDAR Data Analysis Assumptions

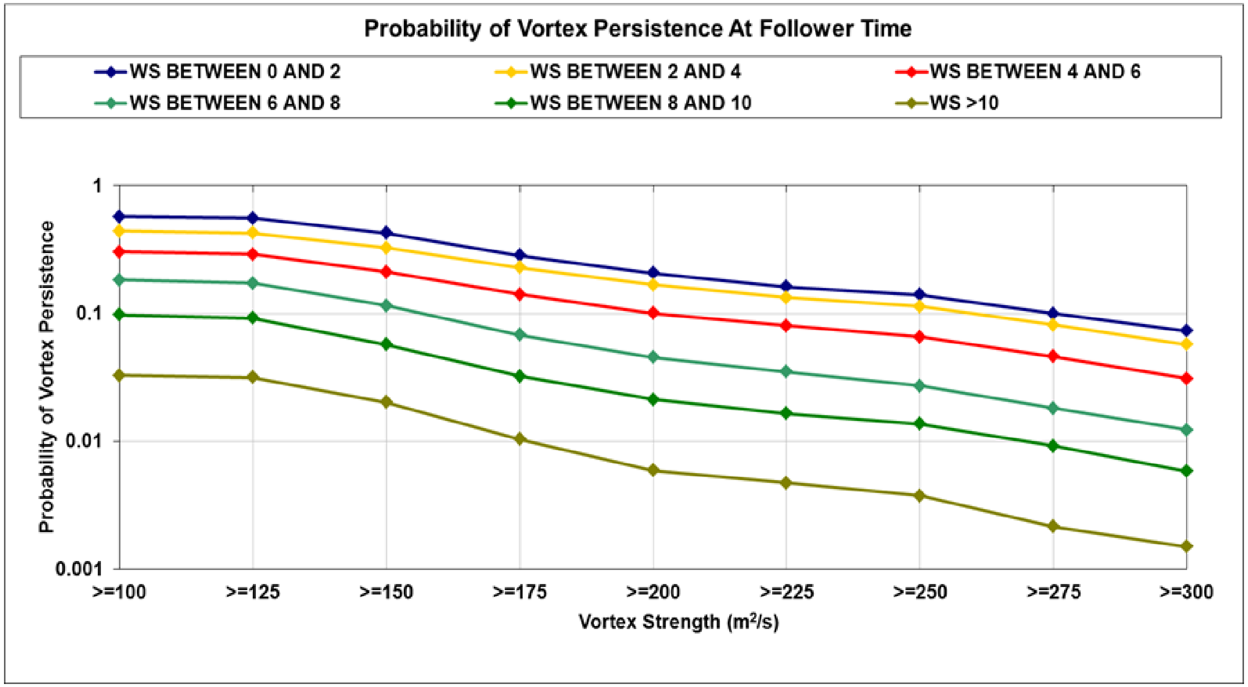
- For each safety criteria, a TBS scenario is compared to a DBS baseline (reflecting “today”)
- The LIDAR data analysis makes no assumptions as to how controllers may actually deliver separations
  - The assessment is made at exactly the defined separation minima for the separation regime being modelled
- The following assumptions have been made
  - “All wind conditions” considers all vortex tracks measured by the LIDAR, irrespective of the associated wind conditions
  - “Low wind conditions” is assumed to be where the total wind speed associated with the vortex track is between 0kn and 5kn, and represents reasonable worst case conditions with respect to vortex persistence
  - “Any wind conditions” focuses on analysing tracks in 2kn pure headwind bands; pure headwind being defined as when the crosswind is less than 2kn

# LIDAR Data Analysis Methods

- Two methods have been employed; a Eurocontrol method and a NATS method
- The Eurocontrol method addresses the generic case, using default ICAO separation regimes
  - Examining four major European airports by applying local traffic mixes and local profiles
  - Applies a technique to extrapolate vortex tracks in order to maximise data usage
- The NATS Pairwise method addresses the Heathrow case, using the UK specific aircraft wake turbulence categories and their associated separation rules and procedures
  - Only considers observed arrival aircraft pairs in the Heathrow LIDAR data
  - For a given separation regime determines the actual time spacing across 4DME taking into account the follower aircraft's observed speed profile over the spacing to 4DME
  - Takes into account the time spacing changes from 4DME that were observed in the radar data to derive the time spacing at the LIDAR scan plane

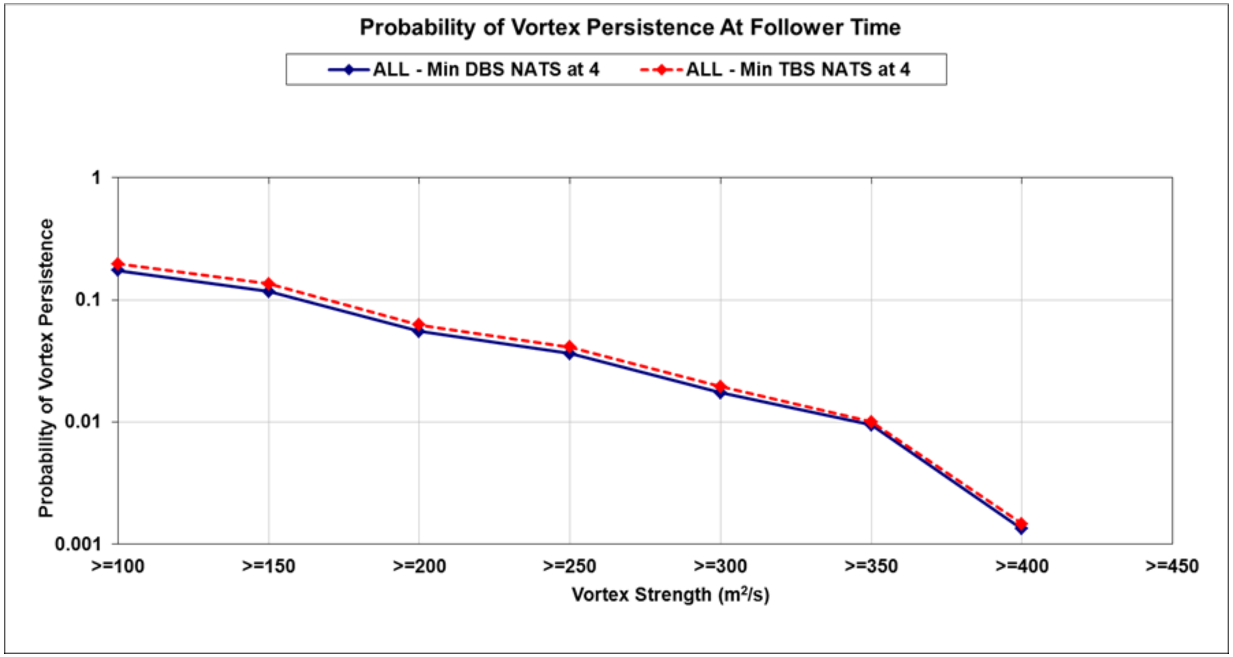
# Heathrow LIDAR Data Analysis Results (1)

- A key result is to understand whether the probability of persisting vortex strength changes as wind speed increases
- Under a TBS separation regime, the probability of persisting vortex strength still decreases as the wind speed increases



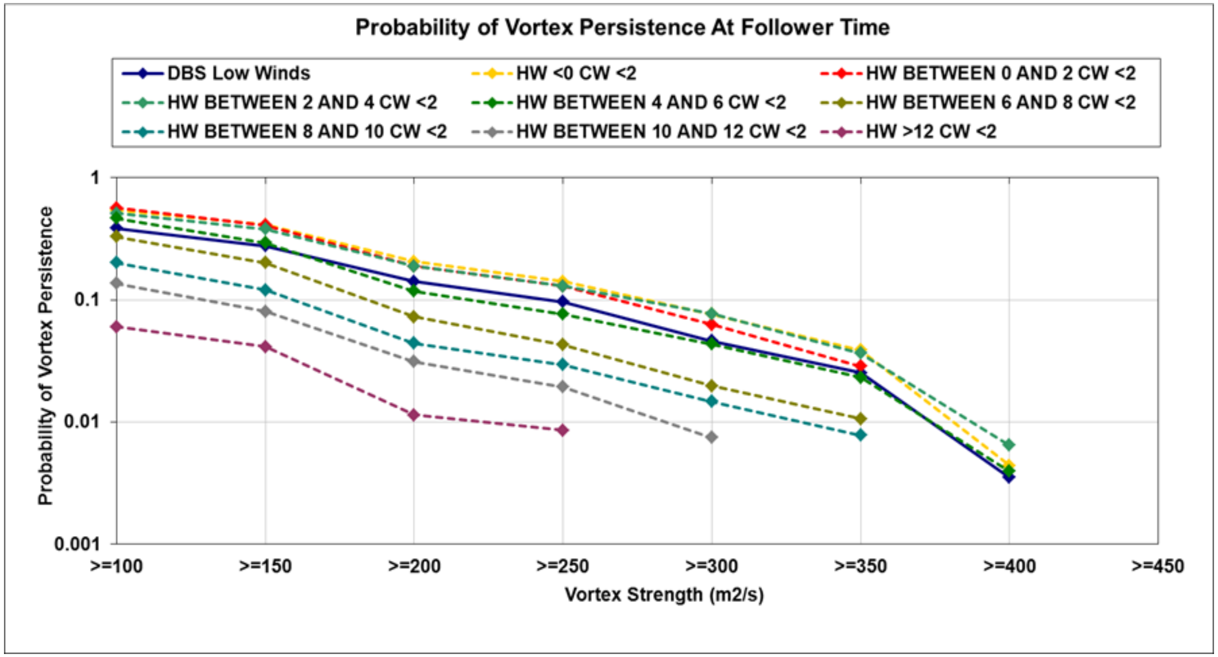
# Heathrow LIDAR Data Analysis Results (2)

- The probability of persisting vortex strength under TBS rules in all winds (red dashed line) is no more than 5 percentage points greater than under DBS rules in all winds (solid blue line)
  - The maximum measured increase across all analysed UK wake turbulence category pairs was 3.9 percentage points



# Heathrow LIDAR Data Analysis Results (3)

- The comparison of 2kn pure headwind bands under TBS rules versus DBS under low wind conditions (total wind between 0kn and 5kn) shows
  - For moderate and strong pure headwind bands the probability of vortex strength under TBS is less than the DBS low winds baseline
  - For the lower pure headwind bands the probability under TBS is greater than the DBS low winds baseline



# Heathrow LIDAR Data Analysis Results (4)

- For the lower pure headwind bands the probability of vortex strength under TBS is no greater than DBS for the same pure headwind band for all but a single instance
- There is a single instance only where the assessment criteria are not met. This is for UK Heavy-Heavy pairs in 4-6kn pure headwind, where the circulation strength is less than 150m²/s
  - For Heavy followers, circulation strengths below 200m²/s are deemed moderate and therefore from a qualitative perspective the assessment criteria are still met

| | Comparison to DBS Minima Low Wind Baseline | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| WT Category Pair | <0kts | 0-2kts | 2-4kts | 4-6kts | 6-8kts | 8-10kts | 10-12kts | >12kts |
| JJ-HH | Pass | | Pass | | | | | |
| JJ-LM | Pass | | | | | | | |
| HH-JJ | Pass | | Pass | Pass | Pass | | | |
| HH-HH | Pass | Pass | Pass | Pass | Pass | Pass | Pass | Pass |
| HH-UM | Pass | Pass | Pass | Pass | Pass | | | |
| HH-LM | Pass | Pass | Pass | Pass | Pass | Pass | Pass | |
| HH-SS | | | Pass | Pass | | | | |
| UM-UM | | Pass | Pass | Pass | Pass | | | |
| UM-LM | Pass | Pass | Pass | Pass | Pass | Pass | Pass | |
| UM-SS | Pass | | | | | | | |
| LM-SS | Pass | Pass | Pass | Pass | Pass | Pass | Pass | Pass |

# Heathrow LIDAR Data Analysis Conclusions

- The LIDAR data analysis for the local Heathrow case, using the NATS Pairwise method, has shown that
  - The probability of persisting vortex strength in all wind conditions under TBS is not more than 5 percentage points greater than under DBS in all wind conditions
  - In moderate and strong wind conditions the probability of persisting vortex strength under TBS is less than measured in low wind conditions under DBS
  - In low wind conditions, the probability of persisting vortex strength under TBS is not statistically greater than DBS in the same wind conditions
  - The same conclusions can be reached when a separation infringement of 0.5Nm and 1Nm is applied equally to the TBS scenarios and DBS baseline
  - Under strong wind conditions TBS rules still provide a lower probability of persisting vortex strength compared to low wind conditions

# Overall Conclusions

- The results of the Heathrow Approach and Tower Validation Exercises and the Heathrow and Generic LIDAR Data Analyses have been used to provide evidence against the issues addressed in the Safety Assessment, the Human Performance Assessment, the Business Benefits Assessment and the Environment Assessment
- These assessments have concluded that the TBS concept is viable from a safety and human performance assessment perspective; and could deliver significant benefits in terms of recovering the reduction in landing rate currently experienced with DBS in headwind conditions, with the resulting beneficial impact on the environment and the predictability and efficiency of operations
- The TBS concept has achieved the pre-industrial development maturity and is now ready to begin the Heathrow local industrialisation and deployment project phase

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