Validation Report (VALR) for Time Based Separation (TBS)

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Abstract

Validation of the Time Based Separation (TBS) tool and procedures for Heathrow Approach, including training in the concept and tool, using a real-time ATC simulator at NATS CTC to assess **a)** whether Heathrow Approach Controllers can safely deliver aircraft to TBS minima in all wind conditions using the TBS tool support, **b)** the impact of TBS tool support and operational procedures on the Task and Human Performance of Heathrow Approach Controllers, **c)** the usability of the TBS controller tool support HMI, **d)** the impact of the TBS tool support and operational procedures on the roles and responsibilities of Heathrow Approach Controllers, **e)** the impact of TBS tool support and operational procedures on the arrival runway capacity during strong wind conditions, **f)** the impact of TBS tool support and operational procedures on the efficiency and predictability of operations, and **g)** the impact of TBS tool support and operational procedures on environmental performance of aircraft in the hold and on final approach. This document reports the results of the real-time validation exercises for London Heathrow Approach (VP-303) and Tower (VP-302).

Authoring & Approval

Prepared By - *Authors of the document.*		
Name & Company	Position & Title	Date
[redacted] NATS	[redacted]	23/11/2012
[redacted] NATS		26/10/2012
[redacted] NATS		11/05/2012

Reviewed By - *Reviewers internal to the project.*		
Name & Company	Position & Title	Date
[redacted] EUROCONTROL	[redacted]	20/11/2012
[redacted] NATS		26/10/2012
[redacted] NATS		23/10/2012
[redacted] NATS		23/10/2012
[redacted] EUROCONTROL		23/11/2012

Reviewed By - *Other SESAR projects, Airspace Users, staff association, military, Industrial Support, other organisations.*		
Name & Company	Position & Title	Date
[redacted] EUROCONTROL	[redacted]	20/11/2012
[redacted] EUROCONTROL		20/11/2012
[redacted] Airbus		23/11/2012
[redacted] THALES AIR SYSTEMS		20/11/2012
[redacted] ONERA		20/11/2012

Approved for submission to the SJU By - *Representatives of the company involved in the project.*		
Name & Company	Position & Title	Date
[redacted] EUROCONTROL	[redacted]	20/11/2012
[redacted] EUROCONTROL		20/11/2012
[redacted] EUROCONTROL		20/11/2012
[redacted] Airbus		23/11/2012
[redacted] THALES AIR SYSTEMS		20/11/2012
[redacted] ONERA		20/11/2012

Rejected By - *Representatives of the company involved in the project.*		
Name & Company	Position & Title	Date
N/A	N/A	N/A

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Executive summary

Validation Exercise VP-303 Heathrow Approach

The thirteen day Time Based Separation (TBS) Heathrow Approach validation exercise was run from 11th February 2012 to 5th March 2012 on the LTC real-time simulator at NATS CTC.

The findings from the activity showed that the TBS concept is viable as simulated for Heathrow Approach and could deliver significant benefits in terms of higher aircraft landing rates in stronger wind conditions along with reduced holding and approach times.

Aircraft landing rates were consistently increased with TBS, for the traffic samples and wind conditions simulated: up to 5 additional aircraft per hour were landed, with an average of 2 additional aircraft per hour. Holding times and Stack Entry to Touchdown times were also reduced with TBS with a mean reduction in holding times of 0.9 minutes, and a mean reduction in Stack Entry to Touchdown times of 1.4 minutes.

Separation accuracy for Wake pairs at 4DME shows a clear and statistically significant improvement with TBS, though for Non-Wake pairs the accuracy was the same as DBS. However, overall TBS performed generally better than DBS.

There was no difference in controller workloads with TBS compared with DBS. There was a very slight increase in R/T usage, but this appears linked to the higher aircraft landing rates.

Situation Awareness for the FIN controller was slightly reduced with TBS, though this reduction was not statistically significant. The reduction was evident through a change of focus onto the TBS indicators and away from the flight strips resulting in less awareness of aircraft types, wake vortex categories and the relative position of the lead aircraft.

The percentage of **under-separated** events (<0.5 Nm under Wake / 2.5 Nm) was almost half with TBS compared to DBS showing that, with the TBS indicators, controllers were able to provide improved separation overall. Two **highly under-separated** events (>0.5 Nm under Wake / 2.5 Nm) were recorded with TBS, none were recorded with DBS. One of these resulted from a TBS tool error: the FIN controller did not detect the error due to reduced Situation Awareness.

Several TBS tool issues were observed during the simulation that adversely affected the usability of the prototype tool along with user confidence and trust.

Tactical Enhanced Arrival Mode (TEAM) functionality was unacceptable with unstable not-in-trail indicators, missing in-trail Wake indicators and lateral spacing at 2 Nm being too close. A successful single trial with 2.5 Nm spacing indicated this was an improvement.

Validation Exercise VP-302 Heathrow Tower

The seven day TBS Heathrow Tower validation exercise was conducted on the Heathrow Airport Tower 360° simulator at NATS Heathrow House, London between 11th July 2012 and 24th July 2012.

The findings for the activity showed that the TBS concept is viable as simulated for Heathrow Tower and could deliver significant benefits in terms of higher aircraft landing rates in stronger wind conditions.

The higher aircraft landing rates as delivered by TC Approach with TBS were handled easily by the Tower controller. There was no statistically significant difference in separation accuracy at Runway Threshold between DBS and TBS.

There were no statistically significant differences in controller workload with TBS: 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.

There were no statistically significant differences between the Clearance to Land margins (of 15 seconds or less), Go-arounds, Wake Vortex Advisories or Expedited Runway Vacation Requests issued between DBS and TBS.

Tactical Enhanced Arrival Mode (TEAM) 6 Aircraft per Hour functioned correctly.

1 Introduction

1.1 Purpose of the document

This document provides the Validation Report for the validation exercises EXE-06.08.01-VP-303 and EXE-06.08.01-VP-302 which are defined in the SESAR 06.08.01 document P6.8.1 Validation Plan - Time Based Separation (VALP) [4]. The exercises used the real-time London Terminal Control (LTC) simulator at NATS CTC, Whiteley, Fareham (VP-303) and the Micro Nav BEST 360° real-time Heathrow Airport Tower simulator at NATS Heathrow House, London (VP-302). It describes how the validation exercises were conducted and presents the results of the validation exercises.

The exercise forms part of the Operational Focus Area Time Based Separation within the Operational Package, PAC01 Enhanced Runway Throughput.

1.2 Intended readership

The principal audience of this document are internal P6.8.1 project partners with corresponding system partners P10.4.4 and P12.2.2, but also federating projects sWP6.2 (for bottom up consolidation), sWP6.3 (for integration) as well as transversal projects (WP16, B and C for performance assessments).

1.3 Structure of the document

The document follows the SESAR Validation Report template.

This section provides the scope and background to the validation.

Section 2 describes the context of the validation in terms of concept, and a summary of the validation exercises.

Section 3 describes the conduct of the validation exercises in terms of preparation, execution and deviations from the planned activities.

Section 4 summarizes the validation exercise results, analysis of results and the confidence in results of the validation exercises.

Section 5 presents the conclusions and recommendations drawn from the validation exercise.

Section 6 contains the detailed Validation Exercises reports.

Section 7 contains references for applicable and referenced documents.

1.4 Glossary of terms

'Box and Whisker' Charts – a method of showing the distribution of results through the Median, Upper and Lower first quartile (25^{th} percentile), and the Maximum and Minimum scores recorded for each measure.

Non-parametric Statistical Significance Test – a method to determine if the results of measures obtained from comparable matched exercise runs are statistically significant. Two methods were used for the validation exercises covered by this report: 1) **Wilcoxon Signed-Rank Test** for testing hypothesis to determine if two medians differ between matched exercise runs (the medians are 'ranked' to achieve this, hence the name of the method); 2) **Chi Square Test** for testing hypothesis to determine if there is statistical significance between the populations of comparative measures between matched exercise runs.

Non-Wake Pairs - Arrival Pairs subject to the Spacing Minimum of the Minimum Radar Separation.

Non-Wake Separation - The Spacing Minimum of the Minimum Radar Separation

'Run in Time' – the period of time considered necessary and appropriate to allow a simulation exercise run to build up to normal traffic levels so that measures collected are relevant and appropriate to the validation exercise being conducted; metrics collected during the 'Run in Time' are discounted from analysis. Exercise 'Run in Times' are specified for each validation exercise in Section 6.

Separation Accuracy – a measure of actual delivered aircraft spacing compared with the required spacing, calculated by subtracting the required separation minima (DBS or TBS rules) from the achieved spacing.

1.5 Acronyms and Terminology

Term	Definition
4DME	4 Nm from Distance Measuring Equipment (Runway Landing Threshold)
ACC	Area Control Centre
ACP	Aircraft Control Position
AIR	Airborne aircraft controller
AMAN	Arrival Manager (system)
ANSP	Air Navigation Service Provider
AO	Airport Operations
APS	Air Traffic Project Specialist
ARR	Arrivals controller / position
ASS	Assumption in Table 6
ATA	Actual Time of Arrival
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATM	Air Traffic Management
ATM	Air Traffic Monitor
ATMS	Air Traffic Management System
ATS	Air Traffic Service
BADA	Base of Aircraft Data
BEST	**B**eginning to **E**nd for **S**imulation and **T**raining
CARS	Controller Acceptance Rating Scale
CAT A	Medical flights that are in conflict with the final approach glideslope at Heathrow
CAT B	Police flights that are in conflict with the final approach glideslope at Heathrow
CBA	Cost Benefit Analysis
CDA	Continuous Descent Approach
CFT	Customer Functional Test
CR	Change Request
CROPS	Crosswind Operations
CRT	Criterion
CTC	Corporate & Technical Centre – NATS, Whiteley
CTL	Clearance To Land
CWP	Controller Working Position
DBS	Distance Based Separation
DCX	Digital Exchange
DEP	Departures controller / position
DMAN	Departure Manager (system)
DOD	Detailed Operational Description
DSNA	Direction des Services de la Navigation Aerienne – French ANSP
DTT	Distance To Touchdown
EASA	European Aviation Safety Authority

Term	Definition
E-ATMS	European Air Traffic Management System
EC	European Commission
EC 6FP	European Commission Sixth Framework Project
EFD	Electronic Flight Data
EFPS	Electronic Flight Progress Strips / System
EGLL	ICAO Airfield Identifier for London Heathrow airport
E-OCVM	European Operational Concept Validation Methodology
EU	European Union
EuroBen	European Wake Vortex Mitigation Benefits Study
EVNT	Event
EXE	Validation **Exe**rcise
FAA	Federal Aviation Authority (USA)
FIN	Final Approach Controller (Final Director @ EGLL)
FMS	Flight Management System
FP	Framework Programme (EC)
FSR	Functional Safety Requirements
GND	Ground position in a tower
GS	Group Supervisor
HAZID	Hazard Identification
HF / HP	Human Factors / Human Performance
HMI	Human Machine Interface
IAS	Indicated Air Speed (Knots)
ICAO	International Civil Aviation Organization
ID	Identifier
IFR	Instrument Flight Rules
IGE	In-Ground-Effect
ILS	Instrument Landing System
INT	Intermediate Approach Controller (Intermediate Director North & South @ EGLL)
IP	Implementation Phase (SESAR)
IRP	Integrated Risk Picture
ISA	Instantaneous Self-Assessment
KERMIT	Kerosene Emissions Research Model In the TMA (NATS Tool)
KPA	Key Performance Area
KPI	Key Performance Indicator
LFV	Swedish ANSP
LHR	London Heathrow Airport
LIDAR	Light Detection And Ranging
LP/LD	Low Power/Low Drag
LTC	London Terminal Control
MAYDAY	International distress signal in R/T voice procedure used to signal a life-threatening emergency and requesting immediate assistance; derived from the French *venez* ***m'aider***, which means "come help me".
MNL	Micro Nav Limited
MOps	Method of Operations

Term	Definition
MRS	Minimum Radar Separation
NATS	UK ANSP
NGE	Near-Ground-Effect
Nm	Nautical mile
NOK	Validation objective does not achieve the expectations (exercise results do not achieve success criteria)
OBJ	Objective
OCD	Operational Concept Description
OFA	Operational Focus Area
OGE	Out-of-Ground-Effect
OI	Operational Improvement (SESAR)
OK	Validation objective achieves the expectations (exercise results achieve success criteria)
ORG	**Org**anization – simulator configuration.
OSED	Operational Services and Environment Definition
PAC	Operational **Pac**kages (SESAR)
PAN PAN	International distress signal in R/T voice procedure used to signal urgency on board but no immediate danger to life or to the vessel; derived from the French word ***panne***, nominally referring to a mechanical failure or breakdown.
QoS	Quality of Service
R&D	Research and Development
R/T	Radio Telephony
RESET	Reduced Separation Minima
RNAV	Area Navigation
RTSA	Real-Time Simulation Analysis
RWY	Runway
Rx	Receive
SA	Situation Awareness
SAM	Safety Assessment Methodology
SATI	SHAPE Automation Trust Index
SCN	Scenario
SESAR	Single European Sky ATM Research Programme
SHAPE	Solutions for Human-Automation Partnerships in European ATM project
SID	Standard Instrument Departure Route
SIL	Software/System Integrity Level
SJU	SESAR Joint Undertaking (Agency of the European Commission)
SMP	SESAR Safety Management Plan
SO	Safety Objective
SPO	Safety Performance Objectives
SPR	Safety Performance Requirements
SRS	Scientific Recording System
ST	Safety Target
STAR	Standard Arrival Route
STQ-s	The SHAPE Teamwork Questionnaire (STQ) was originally called SKATE, but was renamed. There is a short version (STQ-s) and a long version (STQ-l).
SUT	System Under Test

Term	Definition
TBS	Time Based Separation
TC	Terminal Control
TCAS	Traffic Alert and Collision Avoidance System
TEAM	Tactical Enhanced Arrival Mode
TMA	Terminal Manoeuvring Area
TST	Time Separation Tool
TWR	Tower
Tx	Transmit
UK	United Kingdom
VALP / VP	Validation Plan
VALR	Validation Report
VALS	Validation Strategy
VFR	Visual Flight Rules
VP-302	Heathrow Tower validation exercise
VP-303	Heathrow Approach validation exercise
WDS	Weather Dependant Separation
WIDAO	Wake vortex independent Departure and Arrival Operation
WP	Work Package
WT	Wake Turbulence
WV	Wake Vortex
WVE	Wake Vortex Encounter

1.6 Acknowledgements

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2 Context of the Validation

The scope/perimeter of the validation in the first phase of the project is limited to the validation of Operational Focus Area Time Based Separation. This OFA along with two other OFAs (Brake to vacate & Dynamic Vortex Separation) contribute to operational sub-package Enhanced Runway Throughput within the Operational Package PAC01.

Operational Package	Operational Sub-Package	Operational Focus Area	DOD Section where problem is described	Complementary description if necessary
PAC01	Enhanced runway throughput	OFA01.03.01 - Time Based Separation	Airport DOD Step 1 Section 2.2 [21] TMA and Approach DOD [22]	P6.8.1, P10.4.4, P12.2.2

Table 1: Scope / perimeter of the Validation

The sWP 6.2 Validation Strategy has identified the following top-down validation objective applicable to S1 TBS phase of P681 validation work:

Identifier	OBJ-06.02-VALS-0010.0015
Objective	Validate if the final approach controller and the tower runway controller are provided with the necessary TBS tool support to respect the minimum radar separation and runway related spacing constraints when applying the TBS rules.

AO-0303: Time Based Separation for Final Approach - Full Concept.

Note that OBJ-06.02-VALS-0010.0013 & OBJ-06.02-VALS-0010.0014 in the sWP 6.2 Validation Strategy apply to Dynamic Vortex Separation and not TBS. Dynamic Vortex Separation is being addressed as a IP1 activity with procedural CROPS for arrivals without separation tool support, and procedural CROPS for departures. The P6.8.1 Phase 2 in 2013 to 2014 is to address Weather Dependent Separation (WDS) for both arrivals and departures with the provision of separation tool support to the controllers.

The enablers of AO-303 Time Based Separation for Final Approach – Full Concept are:

- The TBS tool support for the final approach controller and tower runway controller for:
    - Calculating the TBS distance for i) time-based wake turbulence constrained pair, ii) time-based spacing minimum pairs, and iii) time-based departure gap pairs
    - Calculating the Indicator distance for each arrival pair taking into account all the final approach and runway separation and spacing constraints and specific spacing that apply to each arrival pair
    - Displaying the Indicator distance for each arrival pair i) on the approach radar display to the final approach and intermediate approach controllers, and ii) on the air traffic monitor display to the tower runway controllers
- The TBS tool support dependencies required for calculating each TBS distance, calculating each Indicator distance, and displaying each Indicator to the approach and tower controllers:
    - High integrity and dependable aircraft type and Wake category information for each arrival aircraft
    - High integrity and dependable arrival sequence landing order intent and landing runway intent information including i) timely notification of late tactical sequence landing order intent and landing runway intent, ii) timely removal and re-insertion of missed approach / go-around aircraft, iii) timely update of the runway intent of late runway switch aircraft, and iv) timely restoration of the arrival landing sequence order intent and landing runway intent after an abnormal scenario such as a blocked runway and dispersal of the arrival aircraft, and on resumption after the blocked runway has re-opened. It is envisaged that this is provided through AMAN and the

provision of appropriate interaction support through the intermediate approach and final approach controller electronic interface of the Approach CWP.

- For interlaced / mixed mode operations, high integrity and dependable departure gap requirements in the arrival sequence including timely notification of late tactical changes and the appropriate support for abnormal scenarios. It is envisaged that this is provided through the integrated AMAN / DMAN / Runway Manager and the provision of the appropriate interaction support through the intermediate approach and final approach controller electronic interface of the Approach CWP, and the provision of the appropriate interaction support through the tower runway controller electronic interface of the Tower CWP.
- High integrity and dependable runway-in-use and runway mode information, including timely notification of planned (after an identified arrival) and immediate changes.
- High integrity and dependable information on the final approach separation and runway spacing constants that are to be applied on the final approach of each runway-in-use, including timely notification of planned (after an identified arrival aircraft) and immediate changes. It is envisaged that this is provided through a Separation and Spacing Policy Application for the Approach and Tower Supervisors and the provision of the appropriate interaction support to the Approach and Tower Supervisor CWPs.
- High integrity and dependable requests of specific spacing requests for individual arrival aircraft and between specific arrival pairs, to support for example, PAN PAN arrival aircraft, MAYDAY arrival aircraft, CAT A and CAT B flights impacting final approach, runway inspection procedures, runway crossing procedures, helicopter crossing procedures, RNAV approach procedures and so on. It is envisaged that this is provided through a Specific Spacing Request Application for the Approach and Tower Supervisors and the provision of the appropriate interaction support to the Approach and Tower Supervisor CWPs. There may also be a need to provide appropriate interaction support to the approach controllers and the tower controllers through the Approach CWP and the Tower CWP to facilitate notification of late tactical changes.
- High integrity and dependable final approach glideslope wind conditions profile from at least 12nm from the runway landing threshold to the runway landing threshold, with a wind layer altitude resolution of at least 1nm along final approach, for each runway-in-use. This is used to calculate the TBS distance, and is required to be the wind conditions each arrival aircraft is forecast to experience over the TBS distance to threshold, when the lead aircraft turns on to intercept final approach.
- High integrity and dependable support for displaying and updating the position of each Indicator in synchronisation with the lead aircraft track position update on the approach controller radar display.
- High integrity and dependable support for displaying and updating the position of each Indicator in synchronisation with the lead aircraft track position update on the tower runway controller air traffic monitor display.

The Industrial prototype for the TBS tool support is being developed in P10.4.4.

The Industrial prototype for the final approach glideslope wind conditions service is being developed by P12.2.2 with the forecast wind conditions requirements being addressed in P11.2.

The first phase of the P6.8.1 project intends to define and validate operational concept and procedures to allow controllers to manage the sequence of arriving aircraft with pre-specified fixed time based separations.

This requires, first, to assess the fixed time based separations that will be derived from the existing distance based separations, then to demonstrate that these fixed time based separations are safe under all head wind conditions. For head wind conditions, the use of pre-specified fixed time based separations will lead to a reduction of distance spacing and so to capacity benefits. Safety benefits are also expected by the fixed time based separation increase in the distance spacing in particular headwind condition (e.g. tailwind) presenting the higher risk of sever encounter in today's distance based separation operations.

Once the time based separations are defined, the procedures, the user and high level system requirements to allow the controller to work with these time based separations will be defined and specified.

The spacing delivery aspects will be considered so as to enable the time-based separations to be employed efficiently within the context of the diversity of aircraft speeds employed on final approach.

The operational and system requirements for controller tool provision will be considered across both Wake pairs and Non-Wake pairs so as to address the consistency issues across all pairs from the human factors perspectives for the impacted controller roles.

Both separation support and monitoring functions will be developed to improve delivery across all conditions in close cooperation with the other projects either impacted by or providing input to the envisaged solution.

2.1 Concept Overview

The TBS Concept Overview is described in the 06.08.01 Operational Concept Description (OCD) and Operational Service and Environment Definition (OSED) for Time Based Separation for Arrivals (TBS) [5].

The main objective of TBS validation is to finalise the V3 maturity level – Pre-industrial development and integration. Therefore there are three main generic objectives in this phase:

- Further develop and refine the concept with supporting enablers, in order to achieve their transition from research to a live environment
- Validate that procedures, system and human performance aspects work together coherently and are capable of delivering the required benefits.
- Validate that TBS concept can be integrated into the target ATM system.

One of the most important validation exercises to be conducted in this phase is the "pre-operational validation". It requires integration of pre-industrial prototype in representative system platform to be used in real-time simulation.

The typical activities in V3 are:

- Integration and validation of TBS concept
- Technical specifications and feasibility assessment (prototype to be developed by Sys projects P10.4.4.and P12.2.2)
- Transition feasibility assessment
- Safety, environment, human performance, benefit assessments feeding into the final validation report.

The results and recommendations from the V2 validation activities have been taken as input into this validation plan. The identified validation priorities for achieving V3 maturity have been identified as:

- The Human Performance validation of fixing the TBS distance displayed to the controllers from the lead aircraft turning on to intercept final approach, and validation of the TBS Indicator HMI design improvements recommended in the validation report of the NATS Simulation held in September/October 2010. These recommendations are reflected in the P6.8.1 D05 OCD & OSED for TBS [17]. These are to be validated through the following validation exercises:
    1. EXE-06.08.01-VP-303 – Approach Simulation (Section 4.1)
    2. EXE-06.08.01-VP-302 – Tower Simulation (Section 4.2)

  These are required to be conducted before the industrial prototype of the TBS tool support is available from P10.4.4. The pre-industrial high fidelity prototype of the TBS tool support produced for the NATS 2010 simulation is to be utilised for the VP-303 Approach Simulation and the NATS Heathrow 360° VCR Simulation system supplier pre-industrial high fidelity prototype of the TBS tool support integrated into the emulated runway controller air traffic monitor display commissioned for the VP-302 Tower Simulation.

- Validation of the TBS wake turbulence encounter risk through the safety assessment activities utilising the wake turbulence tracks from the Heathrow NGE/IGE LIDAR data collection campaign conducted from October 2008 to January 2011, and from the Heathrow OGE LIDAR data collection campaign being conducted from January 2011 to December 2012 under the following exercise:
  1. EXE-06.08.01-VP-134 - LIDAR data collection campaign
- Validation of outstanding issues from the VP-303 and VP-302 exercises utilising the industrial prototype of the TBS tool support being developed by P10.4.4 integrated into the NATS approach simulation industrial validation platform. This will be conducted in the timescales of the development and integration of the industrial prototype in 2013 under the following validation exercise:
  1. EXE-06.08.01-VP-136 – System emulator testing using P10.4.4 and P12.2.2 system prototypes

  This is subject to the agreement of the scope and the timings of the validation exercises between P06.08.01 and P10.4.4 and P12.2.2.

Validation Exercise ID and Title	EXE-06.08.01-VP-303: TC Approach Simulation	EXE-06.08.01-VP-302: Heathrow Tower Simulation
Leading organization	NATS	NATS
Validation exercise objectives	See Table 10: Summary of Validation Exercises Results	See Table 10: Summary of Validation Exercises Results
Rationale	See VALP edition 00.01.03 [4]	See VALP edition 00.01.03 [4]
Supporting DOD / Operational Scenario / Use Case	See WP06.02 DOD for Airports [21] See Wp05.02 DOD for TMA and Approach [22] See VALP edition 00.01.03 [4]	See WP06.02 DOD for Airports [21] See Wp05.02 DOD for TMA and Approach [22] See VALP edition 00.01.03 [4]
OFA addressed	OFA01.03.01 -Time Based Separation: See Table 1: Scope / perimeter of the Validation	OFA01.03.01 -Time Based Separation: See Table 1: Scope / perimeter of the Validation
OI steps addressed	See VALP edition 00.01.03 [4]	See VALP edition 00.01.03 [4]
Enablers addressed	See VALP edition 00.01.03 [4]	See VALP edition 00.01.03 [4]
Applicable Operational Context	TMA	Airport
Expected results per KPA	See the Primary and Secondary KPAs in VALP edition 00.01.03 [4]	See the Primary and Secondary KPAs in VALP edition 00.01.03 [4]
Validation Technique	Real-time simulation exercise using the NATS TC Heathrow Approach simulator.	Real-time simulation exercise using the NATS 360° Heathrow airport Tower simulator.
Dependent Validation Exercises	N/A	EXE-06.08.01-VP-303

Table 2: Concept Overview

2.2 Summary of Validation Exercise/s

2.2.1 Summary of Expected Exercise/s outcomes

In summary, the key validation areas are anticipated to be as follows:

- Definition of the time based separations corresponding to the current ICAO distance based wake turbulence radar separations;
- Validation of the defined time based separations as per the application of the E-OCVM and the resulting TBS validation strategy and plan and anticipated associated validation priorities below;
- Assessment of the change in the wake vortex encounter hazard risk associated with the reduction of the distance spacing resulting from applying the pre-specified fixed time based separations under the full range of headwind conditions that are experienced in operations;
- Assessment of the spatial headwind stability along the glide path and the impact that this has on the distance spacing resulting from applying the pre-specified fixed time based separations;
- Assessment of the potential benefits of employing TBS for various airports considering the distribution of their wind conditions throughout the year;
- Definition of the HMI and ATM component requirements and operational procedures enabling the air traffic controllers to apply time based separations;
- Assessment and refinement of the HMI and ATM component requirements and operational procedures enabling the air traffic controllers to apply time based separations;
- Definition of the operational, functional and algorithm requirements of the TBS tool support;
- Assessment of the operational, including functional and algorithm requirements of the TBS tool support;
- Validation that actual delivery to the TBS minima is safe with respect to the wake turbulence encounter, mid-air collision, runway collision, runway accident and the spacing related missed approach ATC tower collision hazard. This should take into account the variability in aircraft landing stabilisation speeds, prevailing wind conditions, spatial wind stability, controller performance and pilot performance on all points on the final approach path;
- Validation that the proposed tool support for the approach controllers and for the tower runway controllers operating in all conditions has an acceptable impact on task performance and safety;
- Validation that the procedural changes for the approach controllers and for the tower runway controllers and aircrew operating in all conditions have an acceptable impact on task performance and safety.

A number of these validation areas are linked. Changes as a result of one validation area may impact another. As the validation process will be iterative it is important that findings are fed back into the TBS operational concept, which may then be used to update the status of other validation areas.

2.2.2 Benefit mechanisms investigated

The benefit mechanisms investigated are detailed in the P6.8.1 Validation Plan for Time Based Separation (VALP) edition 00.01.03 [4].

2.2.3 Summary of Validation Objectives and success criteria

Identifier	Success Criterion	KPA
CRT-06.08.01-VALP-0010-0010	The risk of an ATM related accident due to wake turbulence (WT) on final approach with TBS in all wind conditions shall: • Be reduced as far as reasonably practicable. • Remain acceptable to controllers, ANSP, pilots, airlines and airports; • Not exceed 3.2e-9 per approach (this figure is provisionally derived from EUROCONTROL IRP and subject to revision). • Not exceed the current level when current DBS are applied in low wind conditions. • Be mitigated through controller procedures for monitoring and recovering from time based separation infringement risk on final approach. According to the TBS rule, and for each WT category pairs, the WVE probability distribution of WVE severity (strength) in TBS per 5kts head wind band above 5kts total wind shall always be below an acceptable reference distribution (baseline) in DBS in reasonable worst case conditions.	Safety
CRT-06.08.01-VALP-0010-0015	Assurance that: • High integrity runway-in-use and runway mode, including timely notification of planned and immediate changes, are provided to the TBS tool. • High integrity separation and spacing constraints requirements for each runway-in-use, including timely notification of planned and immediate changes, are provided to the TBS tool. • High integrity arrival final approach landing order, and runway intent for parallel dependent runway operations, including timely notification of tactical changes, are provided to the TBS tool. This includes for a missed approach/go-around, a late runway switch, blocked runway dispersal, resumption from a blocked runway, and so on. • Timely notification of specific special spacing requirements for a specific arrival aircraft or between a specific arrival pair, for example for a PAN PAN or MAYDAY, for providing spacing for CAT A or CAT B aircraft, for providing spacing for runway crossing, for providing spacing for runway inspection, and so on, is provided to the TBS tool. • For interlaced / mixed mode operations, high integrity interlaced departure gap spacing, including timely notification of tactical changes to the departure gap requirements, is provided to the TBS tool. • High integrity and dependable final approach glideslope wind conditions for each runway-in-use supporting packed arrival aircraft, is provided to the TBS tool. • Assurance that the TBS tool algorithms for calculating the TBS distance and the Indicator distance are correctly specified. • Assurance that the TBS tool algorithms for calculating the TBS distance and the Indicator distance have been correctly engineered to the required safety integrity level.	Safety

	• Assurance that the display applications displaying the TBS Indicators to the Approach and Tower ATCOs have been correctly engineered to the required safety integrity level. • Assurance that the TBS tool support for degraded mode operations has been correctly specified. • Assurance that the degraded mode operations support in the TBS tool has been correctly engineered to the required safety integrity level.	
CRT-06.08.01-VALP-0010-0020	The spacing delivered by the controllers under TBS operations in all wind conditions is such that: • The level of under-separation during simulated TBS operations shall be no more than the level of under-separation during simulated current-day DBS operations; • The mean over-separation during simulated TBS operations should be no more than the mean over-separation compared to the level of over-separation during simulated current-day operations; • The Final Approach Controller is observed to employ safe vectoring techniques and standard controller practices during simulated TBS operations; as assessed by a qualified expert; • The TBS tools provide a clear indication of the required spacing constraints.	Safety / Efficiency/ Human Performance
CRT-06.08.01-VALP-0010-0030	The TBS procedures and practices are acceptable and easy to use and: • New procedures and practices are shown to be practical and manageable (suitable and usable); • Changes to existing procedures are shown to be practical and manageable (suitable and usable); • The procedures and practices are shown to be realistic and achievable (suitable and usable); • Any changes to the procedures and practices that impact R/T usage will be acceptable to controllers and pilots.	Safety / Human Performance
CRT-06.08.01-VALP-0010-0040	The Human Performance under TBS will not be negatively impacted compared to DBS in terms of: • Workload; • Controller Trust and Confidence for the operational procedures and technology; • Situational Awareness.	Human Performance
CRT-06.08.01-VALP-0010-0045	The proposed solution is acceptable to the Final Approach Controller, Intermediate Approach Controller, Runway Controller, Approach and Tower Supervisors, and Pilot, and the Human Performance under TBS will not be negatively impacted compared to DBS in terms of: • Dependence on controller tool support; • Controller Skill Levels; • Controller training needs.	Human Performance
CRT-06.08.01-VALP-0010-0050	The utility and usability of the TBS controller tool support will be such that: • The TBS tool support is useful and supports the controllers in their work; • The HMI design is intuitive and easy for the controllers to interpret; • The HMI design (i.e. shape, colour, size and display priority) is acceptable to the controllers; • The HMI design of the indicator shall harmoniously integrate into the final approach controller radar display and the tower runway controller air traffic monitor display	Human Performance

	respectively; • The HMI shall provide mitigation for events that may lead to inappropriate separation scenarios • The required usability of the TBS controller tool support and the harmonised integration with the other approach and runway controller tools is achievable	
CRT-06.08.01-VALP-0010-0060	The allocation of roles and responsibilities will be clear, exhaustive, and acceptable in terms of: • Allocation between Approach Controllers and Runway Controllers; • Allocation between Controllers and Pilots; • Pilot responsibility for maintaining safe operation remaining unchanged.	Human Performance
CRT-06.08.01-VALP-0010-0070	The landing rate under simulated TBS operations in strong headwind conditions shall: • Be shown to increase compared to the landing rate under simulated current day DBS operations in strong wind conditions; • Be shown to increase for all headwinds in excess of the conditions against which the TBS minima have been baselined; • Contribute to a delay saving per flight estimated as a function of the headwind on final approach and traffic mix; this gain shall be positive for all headwinds in excess of the conditions against which the TBS minima have been baselined.	Capacity
CRT-06.08.01-VALP-0010-0080	The TBS tool support and operational procedures shall lead to an improvement in the efficiency of operations in terms of: • the final approach spacing practice with respect to the additional spacing applied with the TBS. • an overall reduction, all else being equal, in the average fuel consumption due to airborne holding. • an overall reduction, all else being equal, in the average level of flight cancellations. • Compatibility with the continued employment of CDAs and LP/LD procedures.	Efficiency
CRT-06.08.01-VALP-0010-0090	The estimated impact of TBS shall demonstrate an overall reduction, all else being equal, in the variability in arrival time due to variability in the headwind conditions on final approach	Predictability
CRT-06.08.01-VALP-0010-0100	The environmental performance under TBS operations will: • Demonstrate an overall reduction, all else being equal, in the average amount of C02 emitted due to airborne holding. • Be within acceptable limits in terms of Leq noise contours. • Be within acceptable limits in terms of Lmax noise.	Environment
CRT-06.08.01-VALP-0010-0110	The potential costs and benefits of TBS deployment have been estimated and indicate that: • Time Based Separation can be deployed in an appropriate and harmonised manner • The operating costs will not be increased, and the implementation costs will be reasonable. • There is a positive benefit-cost ratio for any investment needed for example in weather and wake turbulence sensors, and such as, in improvements in the positioning and design of runway exit taxiways.	Cost Effectiveness
CRT-06.08.01-VALP-0010-0120	The Pilots and Airspace Users are given sufficient information to indicate that, relative to the maturity of the concept: • The TBS concept, rules and procedures will not increase	Acceptability

	risk of severe wake turbulence encounters;
	• There is a clear way for the flight deck to determine and check the time based separation distance spacing that applies in the prevailing wind conditions on final approach;
	• The responsibilities between Pilots and Controllers are clear and acceptable;
	• Pilot responsibility for maintaining safe operation is unchanged;
	• The impact of the time based separation reduced distance spacing on final approach in headwind conditions has no adverse effect on TCAS;
	• Flight Deck Workload will be acceptable;
	• Any changes to procedures, roles and responsibilities will:
	  ○ Be consistent with airline standard operating procedures;
	  ○ maintain existing safety defence barriers;
	  ○ improve flight deck cooperation and anticipation in the traffic flow;
	• Pilot confidence in the time based separation concept is realistic and achievable;
	• Pilot Training needs will be acceptable.	

Table 3: Success Criterion for Validation Objectives and KPAs

2.2.3.1 Choice of metrics and indicators

A mixture of subjective and objective analysis was used to assess the objectives. For this level of maturity, it was appropriate to assess the objectives with an emphasis on objective data whilst still using subjective data (e.g. questionnaires) to provide context to findings. This ensured that controllers had sufficient methods to feedback their opinions of the concept and tools under investigation.

Any quantitative results were combined with results from qualitative sources such as the questionnaires; observations made by experienced observers, controller comments and debrief material.

2.2.3.1.1 VP-303 (TC Approach) metrics and indicators

Qualitative Data

Observations

Observation of the participants was conducted throughout the validation exercises. Particular areas relating to the questionnaires, or any other areas identified through debriefs, were focused on.

End of run and end of exercise questionnaires

Questionnaires were issued at the end of each exercise run and at the end of each validation exercise. They were used to record the opinions and feelings of participants with respect to the impact of the concept. The answers to questions were analysed to assess information provided relevant to the validation exercise objectives. Answers to questions were summarized to give a consensus opinion.

Debriefs

There were debriefs scheduled into the validation exercise timetables. Some *ad hoc* debriefs were conducted when it was deemed appropriate and beneficial. This feedback was used to supplement the questionnaire answers. The information collected supports the relevant objectives.

The questions posed to the controllers evolved slightly over the course of the validation exercise to take advantage of the controllers' increasing knowledge of the concept and tools. Towards the end of the validation exercise the controllers were asked more conceptual questions and there were more questions designed to assess the operational benefit objectives.

Expert Observations

A valid, or recently valid, TC Heathrow ATCO was used as an Expert Observer. They were briefed and provided with a dedicated observation sheet with specific questions for recording observations.

Safety Observations

Any simulation participant (ATCO, observer, project staff) could raise a safety observation if they identified a safety issue or concern during the validation exercises, which they feel could impact upon the safety of the proposed operation. Any observations made were forwarded for consideration in the transversal safety and human performance assessments. The information was used to supplement data collected during debriefs.

Quantitative Data

Task Performance Metrics

Task Performance metrics, namely the Bedford workload scale, China Lakes Situational Awareness scale and CARS User Acceptance scale, were distributed to the controllers with the End of Run questionnaires. These gave the controllers a 10 point scale to rate their task performance in different areas.

Instantaneous Self-Assessment (ISA)

ISA panels were provided on all measured positions so that an ordinal indication of the controllers' perceived mental workload could be obtained. A real-time display of the ISA responses was not available in the simulator room; it had been intended to have this capability. If a controller spent more than 6 consecutive minutes reporting high workload, a post-run debrief would have been conducted to determine the causes; this situation did not occur. At the end of each validation exercise a printout was produced showing the ISA responses throughout the validation exercise; these are included in this report.

SHAPE Questionnaire

The SHAPE STQ-s questionnaires were administered once for each ATCO at the end of their participation; these relate purely to TBS operations.

Madsen-Gregor

The Madsen-Gregor human-computer trust questionnaire was administered once per validation exercise participant. This is an absolute, rating the controller trust in the TBS system.

Data Recording

Standard SRS recordings (R/T, DCX, ACP inputs and track histories) were made for each measured position. All runs using TBS criteria also had data logged from the TST

R/T Utilisation

Details of R/T use was logged and processed to give the number of calls and percentage of time each controller spends using R/T (transmitting and receiving). Data was recorded for each two minute time-slice throughout an exercise run.

Separation Analysis at 4DME

Separation between aircraft at 4DME was calculated by the NATS 'separation at slice' analysis tool. This was based on aircraft track histories collected in the SRS files and the relevant DBS/TBS minima.

Landing Time

Landing time was calculated by the NATS 'separation at slice' analysis tool. This was based on aircraft track histories collected in the SRS files.

Landing Rate

Landing Rate is defined as the number of unique aircraft that cross the landing threshold per hour in each exercise run. A go-around was counted as one landing (despite potentially crossing the landing threshold more than once). This was based on the same data as Separation Analysis.

Loss of Separation Analysis

Details of all losses of separation, involving at least one measured sector, have been presented in tabular form. This was derived from time-stamped aircraft track histories contained in the standard SRS recordings. The separation standards applied were 3 Nm / WV / 1000' for DBS and the time-based separation minimum / 1000', as calculated by the TST, for TBS runs.

Holding Time

Holding Times were based on ACPO instructions (time in and time out of hold) contained in standard SRS logs.

ACP Interventions

Data was collected and analysed relating to all ACP 'Intervention' messages i.e. all inputs that alter an aircraft's flight profile in terms of speed, level and heading.

Aircraft on Frequency

The traffic loading for each measured position, was reported in both tabular and graphic format. The information provided will include the following information:

- Initial number on frequency;
- Number of aircraft joining frequency;
- Number of aircraft leaving frequency;
- Residual number on frequency at end of period;
- Average number on frequency;
- Peak number on frequency;
- Number of aircraft joining per hour;
- Number of aircraft handled per hour;
- Number of aircraft handled for each 15 minute period;
- Graphical display of number on frequency against time.

Environmental Metrics

Fuel burn and CO_2 was derived from standard RTSA logs (track histories and aircraft). From these standard logs it was possible to process NATS KERMIT environmental metrics. No analysis of aircraft noise on approach legs was performed because the required data is not available.

2.2.3.1.2 VP-302 (Heathrow Tower) metrics and indicators

Qualitative Data

Observations

Observation of the participants was conducted throughout the simulation. Particular areas relating to the questionnaires, or any other areas identified through debriefs were focused on.

End of run and end of exercise questionnaires

Questionnaires were issued at the end of each exercise run and at the end of the validation exercise. They were used to record the opinions and feelings of participants with respect to the impact of the concept. The answers to questions were analysed to assess information provided relevant to the objectives. Answers to questions were summarized to give a consensus opinion.

Debriefs

There were debriefs scheduled into the simulation timetables. Some *ad hoc* debriefs were conducted when it was deemed appropriate and beneficial. This feedback was used to supplement the questionnaire answers. The information collected was used to support the relevant objectives.

The questions posed to the controllers evolved over the course of the validation exercise to take advantage of the controllers' increasing knowledge of the concept and tools. Towards the end of the validation exercise the controllers were asked more conceptual questions and there were more questions designed to assess the operational benefit objectives.

Expert Observations

A valid, or recently valid, Tower ATCOs was used as an Expert Observer. They were briefed and provided with a dedicated observation sheet with specific questions for recording observations.

Safety Observations

Any simulation participant (ATCO, observer, project staff) could raise a safety observation if they identified a safety issue or concern during the validation exercises, which they feel could impact upon the safety of the proposed operation. Any observations made were forwarded for consideration in the transversal safety and human performance assessments. The information was used to supplement data collected during debriefs.

Quantitative Data

Task Performance Metrics

Task Performance metrics, namely the Bedford workload scale, China Lakes Situational Awareness scale and CARS User Acceptance scale, were distributed to the controllers with the End of Run questionnaires. These gave the controllers a 10 point scale to rate their task performance in different areas.

SHAPE Questionnaire

SHAPE STQ-s questionnaires were administered once for each ATCO at the end of their simulation participation to assess the Teamwork impact of TBS.

Madsen and Gregor

The Madsen and Gregor questionnaires were administered once for each ATCO at the end of their simulation participation to assess the Trust impact of TBS.

Instantaneous Self-Assessment (ISA)

ISA was not installed at the Heathrow House simulator. However, a mobile ISA version developed by Think Research Ltd was used in its place. This provided an ordinal indication of the controllers' perceived mental workload. If a controller spent more than 6 consecutive minutes reporting high workload, a post-run debrief would have been conducted to determine the causes; this situation did not occur. At the end of each validation exercise a printout was produced showing the ISA responses throughout the validation exercise; these are included in this report.

Data Recording

Data Logging specifications were provided to Micro Nav (MNL). The principal data required was time-stamped aircraft track histories and TST calculations (TBS minima, indicator location). These were essential to determine the separation performance at Runway Threshold.

Separation Analysis at Threshold

Separation between aircraft at the Runway Threshold was calculated based on time-stamped aircraft track histories and DBS / TBS minima. A bespoke analysis tool needed to be developed for this purpose, as no such method already existed for the BEST simulator.

Air Arrival Controller Interventions

The TST log files were analysed to calculate the number of go-arounds and late-runway switches. These were cross-checked against validation and expert observation records.

Other Air Arrival Controller interventions (number of Wake Vortex advisories, number of Expedited runway requests and number of speed instructions issued to controllers before 4DME) were collected manually by a validation team observer with a special observation sheet to record them; it was initially proposed that pseudo-pilots maintain a record of these events, but this was discounted.

Separation Analysis Tool

Separation between each pair of aircraft on final approach (under the control of the Tower) was analysed. A bespoke analysis tool needed to be developed for this purpose. Aircraft separation was compared against the relevant DBS / TBS minima.

Scenario Observations

Validation experts were responsible for recording which scenarios ran during which exercise runs. Dedicated run record and observation sheets were used for this purpose.

Other Validation Observations

Validation experts were responsible for recording go-arounds, late runway switches, wake vortex advisories, expedited runway clearances and speed instructions outside 4DME. Dedicated observation sheets were used for this purpose. Time stamped track histories and log event files were used as secondary source of this information.

2.2.4 Summary of Validation Scenarios

Two key scenarios were used to assess the validation objectives. These were as follows:

ORG0: The reference scenario. This was distance-based separation with the same rules, procedures and practices as today on approach to Heathrow (DBS).

ORG1: The alternative scenario. This was a time-based separation. Controllers operated under time-based separation rules using the time-based separation tool support.

The following Scenario were covered by the validation exercises:

Scenario Identifier	Scenario Title	VP-303	VP-302
SCN-06.08.01-VALP-0010-0010	Normal Wind	YES	YES
SCN-06.08.01-VALP-0010-0020	Challenging Wind	YES	YES
SCN-06.08.01-VALP-0010-0030	Changeable Wind	YES	YES
SCN-06.08.01-VALP-0010-0040	Wake Pairs	YES	YES
SCN-06.08.01-VALP-0010-0050	Non-Wake pairs	YES	YES
SCN-06.08.01-VALP-0010-0060	Distance Spacing Compression caused by varying landing speed stabilization profiles e.g. Slow leader with 4 Nm+ separation to follower, Slow leader with Fast/Medium follower for 3 Nm / 2.5 Nm Non-Wake pairs, Medium leader with Fast follower for 3 Nm / 2.5 Nm Non-Wake pairs	YES	YES
SCN-06.08.01-VALP-0010-0070	Parallel Dependent Runway including segregated mode operations with some arrival aircraft being directed to land on the departure runway e.g. Both runways supporting arrivals at the start of the day or Selected arrivals being directed to land on the departure runway	YES	YES
SCN-06.08.01-VALP-0010-0080	IFR - In-trail minimum radar separation (minimum surveillance separation)	YES	YES
SCN-06.08.01-VALP-0010-0090	IFR - Dependent parallel runway not-in trail minimum radar separation	YES	YES
SCN-06.08.01-VALP-0010-0100	IFR - Minimum spacing	YES	YES
SCN-06.08.01-VALP-0010-0110	VFR - Minimum spacing when applying reduced separation in the vicinity of the airfield	YES	YES

SCN-06.08.01-VALP-0010-0120	TBS operations during abnormal scenarios such as blocked/closed runway, aircraft emergency, equipment failure, radar outage etc.	YES	YES
SCN-06.08.01-VALP-0010-0130	Distance Spacing Compression caused by variation of pilot behaviour	YES	YES

Table 4: Scenarios covered by the Validation Exercises

Within each of the traffic scenarios, other events were scripted; the events were run as individual events, or in combination with other events.

A number of non-nominal events focused on (a) errors that may lead to an incorrect separation indicator being displayed, and (b) ATCO response during abnormal or failure scenarios. The following Scenario Events were covered by the validation exercises:

SCN ID	Identifier	Description	VP-303	VP-302
SCN01	EVNT-06.08.01-0001	Blocked runway. Aircraft are able to establish on the alternate parallel runway at Heathrow. One or two missed approaches as a result.	YES	YES
SCN02	EVNT-06.08.01-0002	Blocked runway. Aircraft are not able to establish on the alternate parallel runway. Multiple missed approaches as a result.	YES	NO
SCN02	EVNT-06.08.01-0021	Missed approach - multiple aircraft. Runway closure with multiple aircraft on final approach. NB covered by Blocked Runway (alternate parallel runway not available) scenario.	YES	NO
SCN03	EVNT-06.08.01-0003A	Emergency Aircraft (Pan Pan).	YES	NO
SCN04	EVNT-06.08.01-0003B	Emergency Aircraft (Mayday).	YES	NO
SCN05	EVNT-06.08.01-0005	Multiple Indicator failure resulting in indicators being removed for all aircraft.	YES	YES
SCN06	EVNT-06.08.01-0028	CAT A Flight.	NO	NO
SCN07	EVNT-06.08.01-0029	CAT B Flight.	NO	NO
SCN08	EVNT-06.08.01-0030	Runway Inspection.	YES	YES
SCN09 (A)	EVNT-06.08.01-0006	Pilot speed non-conformance leads to catch-up on final. Pilot flies higher IAS on joining centreline. Catches and (potentially) infringes WAKE separation.	YES	NO
SCN09 (B)	EVNT-06.08.01-0007	Pilot speed non-conformance leads to catch-up on final. Pilot flies higher IAS on joining centreline. Catches and (potentially) infringes Non-Wake separation.	YES	NO
SCN10 (A)	EVNT-06.08.01-0008	Pilot speed non-conformance leads to catch-up on final. Pilot ignores the 180kt IAS to 160kt IAS speed instruction, catches and (potentially) infringes Wake separation.	YES	YES
SCN10 (B)	EVNT-06.08.01-0009	Pilot speed non-conformance leads to catch-up on final. Pilot ignores the 180kt IAS to 160kt IAS speed instruction, catches and (potentially) infringes Non-Wake separation.	YES	YES
SCN11 (A)	EVNT-06.08.01-0010	Pilot speed non-conformance. Slows very early from 160kt to landing speed. Aircraft behind with Wake separation catches up significantly (if left unnoticed)	YES	YES
SCN11 (B)	EVNT-06.08.01-0011	Pilot speed non-conformance. Slows very early from 160kt to landing speed. Aircraft behind with Non-Wake separation catches up significantly (if left	YES	YES

		unnoticed)		
SCN12	EVNT-06.08.01-0013	Blocked R/T leads to delayed 180kt to160kt IAS instruction.	YES	NO
SCN13	EVNT-06.08.01-0015	TC deliver under-separation for Wake pair to Tower	NO	YES
SCN14	EVNT-06.08.01-0016	TC deliver under-separation for Non-Wake pair to Tower	NO	YES
SCN15	EVNT-06.08.01-0017	Light wind conditions. Separation greater than current-day Wake and Non-Wake separation.	YES	YES
SCN16	EVNT-06.08.01-0018	Extreme catch-up wind conditions. Aircraft need to be spaced at greater than the indicator further out on the ILS to prevent excessive catch-up.	YES	YES
SCN17	EVNT-06.08.01-0019	Pull-away conditions. FIN controller constrained by indicator on turn on to ILS but aircraft subsequently pull-away.	YES	NO
SCN18	EVNT-06.08.01-0020A	Missed approach - single aircraft (short final)	YES	YES
SCN19	EVNT-06.08.01-0020B	Missed approach - single aircraft	YES	YES
SCN20	EVNT-06.08.01-0022	Time Separation Tool calculating separation incorrectly (due error / incorrect wind information) causing too small a separation being displayed for the wind conditions.	YES	YES
SCN21	EVNT-06.08.01-0023	Incorrect TBS sequence causes too small a separation to be displayed by the Time Separation Tool	YES	YES
SCN22	EVNT-06.08.01-0024	Late change of landing runway – aircraft before 4DME	YES	YES
SCN23	EVNT-06.08.01-0025	INTs hand over aircraft in the wrong order to FIN. Results in incorrect sequence order in the AMAN / Electronic Flight Data which further results in incorrect separation if left unnoticed.	YES	NO
SCN24	EVNT-06.08.01-0026	Follower aircraft joins the ILS before the lead aircraft.	YES	NO
SCN25	EVNT-06.08.01-0027	Arrival aircraft on short final. Aircraft joins at minimum distance (8DME for Heathrow)	NO	NO
SCN26	EVNT-06.08.01-0031	Early morning TEAM.	YES	NO
SCN27	EVNT-06.08.01-0032	TEAM 6 aircraft / hour.	YES	YES
SCN28	EVNT-06.08.01-0033	3.0 Nm minimum spacing.	YES	YES
-	EVNT-06.08.01-0004	Arrival aircraft not in the system resulting in indicator failure for a single aircraft.	NO	NO
-	EVNT-06.08.01-0012	Pilot response to turn instruction leads to catch-up on final. Pilot turns late from Base Leg.	NO	NO
-	EVNT-06.08.01-0014	Wrong aircraft takes a Downwind to Base Leg turn instruction	NO	NO
-	EVNT-06.08.01-0015	Wrong aircraft takes a Base to Intercept turn instruction	NO	NO

Table 5: Scenario Events covered by the TBS Validation Exercises

2.2.5 Summary of Assumptions

2.2.5.1 VP-303 (TC Approach) Exercise Assumptions

It was assumed that APS' would be familiar with Heathrow operations;

It was assumed that ATCOs were Heathrow Approach valid;

Despite the reduced fidelity of the TC Approach simulator working positions using paper flight progress strips rather than electronic flight data (EFD), it was still possible to obtain good subjective feedback from Heathrow Approach controllers.

2.2.5.2 VP-302 (Heathrow Tower) Exercise Assumptions

It was assumed that accurate TBS delivery at 4DME could be simulated. The results from EXE-06.08.01-VP-303 combined with the results from the NATS internal TBS simulation in 2010 and extensive operational data was used to inform the ATA calculations required to define the traffic samples.

It was assumed that the BEST 360° simulation could be successfully used for this validation exercise. The BEST 360° simulator had only minimal use for R&D purposes. Development by the developers, Micro Nav (MNL), was required to introduce the TBS tool support and other validation support (such as data logging).

For this reason, an additional dry-run stage was added in 2011 to mitigate against the risks associated with this large scope of developments. The conclusions of this activity have been used to refine the measures and data preparation process for this validation exercise.

Identifier	Title	Type of Assumption	Description	Justification	Flight Phase	KPA Impacted	Source	Values	Owner	Impact on Assessment
ASS-06.08.01-VP303-01	APS familiarity	Human Performance	It was assumed that APS' would be familiar with Heathrow operations.	Required to provide realism	Terminal Area	Human Performance	Expert Opinion	N/A	Primary Project	Medium
ASS-06.08.01-VP303-02	Heathrow Approach valid ATCOs	Human Performance	It was assumed that ATCOs were Heathrow Approach valid.	Required for accurate assessment of Approach	Terminal Area	Human Performance	Expert Opinion	N/A	Primary Project	High
ASS-06.08.01-VP302-01	Accurate TBS delivery at 4DME simulated	Traffic Characteristics	It was assumed that accurate TBS delivery at 4DME could be simulated. The results from EXE-06.08.01-VP-303 combined with the results from the NATS internal TBS simulation in 2010 and extensive operational data was used to inform the ATA calculations required to define the traffic samples.	Required to correlate results with exercise VP-303	Airport	QoS (Capacity, Efficiency, Flexibility, Predictability)	Expert Opinion	N/A	Primary Project	Medium
ASS-06.08.01-VP302-02	BEST 360° simulator suitable for validation exercise	Airport Characteristics	It was assumed that the BEST 360° simulation could be successfully used for this validation exercise. The BEST 360° simulator had only minimal use for R&D purposes. Development by the developers, Micro Nav (MNL), was required to introduce the TBS tool support and other validation support (such as data logging).	Required to enable the validation exercise	Airport	Human Performance	Expert Opinion	N/A	Primary Project	High

Table 6: Validation Assumptions – Prior to Execution

2.2.6 Choice of methods and techniques

Supported Metric / Indicator	Platform / Tool	Method or Technique
Observations	Microsoft Excel	Validation team observations recorded on paper form
Expert Observations	Microsoft Excel	Expert observer paper form with questions for specific objective criterion and hypotheses
Debriefs	Microsoft Word	Structured debriefs focusing on specific Objective Criterion and Hypotheses
Safety Observations	Microsoft Word	Any simulation participant (ATCO, observer, project team) could raise a safety observation
Controller Workload	Microsoft Excel	Bedford Workload Scale – End of Run Questionnaire
Situation Awareness (SA)	Microsoft Excel	China Lakes Situation Awareness scale – End of Run Questionnaire
Situation Awareness (SA)	Microsoft Excel	NATS Picture scale – End of Run Questionnaire
Controller Acceptance	Microsoft Excel	Controller Acceptance Rating Scale (CARS) – End of Run Questionnaire
User Confidence	Microsoft Excel	NATS Confidence Diamond – End of Run Questionnaire
Specific Objective Criterion and Hypotheses Questions	Microsoft Excel	End of Participation Questionnaire
Teamwork	Microsoft Excel	SHAPE STQ-s (Eurocontrol) Questionnaire – End of Participation Questionnaire
Human-computer Trust	Microsoft Excel	Madsen-Gregor human-computer trust questionnaire – End of Participation Questionnaire
Controller Workload	NATS 'separation at slice' analysis tool	Instantaneous Self-Assessment (ISA) – SRS recordings
R/T Utilization	NATS 'separation at slice' analysis tool	SRS recordings (R/T, DCX, ACP inputs and track histories)
Separation at 4DME	NATS 'separation at slice' analysis tool	SRS recordings (R/T, DCX, ACP inputs and track histories)
Landing Times	NATS 'separation at slice' analysis tool	SRS recordings (R/T, DCX, ACP inputs and track histories)
Landing Rate	NATS 'separation at slice' analysis tool	SRS recordings (R/T, DCX, ACP inputs and track histories)
Losses of Separation	NATS 'separation at slice' analysis tool	SRS recordings (R/T, DCX, ACP inputs and track histories)
Holding Times	NATS 'separation at slice' analysis tool	SRS recordings (R/T, DCX, ACP inputs and track histories)
ACP Interventions	NATS 'separation at slice' analysis tool	SRS recordings (R/T, DCX, ACP inputs and track histories)
Aircraft on Frequency	NATS 'separation at slice' analysis tool	SRS recordings (R/T, DCX, ACP inputs and track histories)

Environmental Metrics	NATS KERMIT tool	SRS recordings (R/T, DCX, ACP inputs and track histories)

Table 7: Methods and Techniques

2.2.7 Validation Exercises List and dependencies

Below is a list of validation exercises performed, including details about the dependencies between the different exercises; validation exercises reported in this document are highlighted in **bold text**.

Exercise ID	Title	Year	Dependent Projects
	NATS Planned Spacing Tool Project validation simulations	2004 & 2005	NATS Planned Spacing Tool Project user requirements and concept of operations developed in 2003/2004
	NATS Heathrow Landing Rate Resilience Project workshops and simulation	2004 - 2005	NATS Planned Spacing Tool concept of operations and validations simulations in 2004 & 2005
	NATS Advanced Separation Criteria Project approach speeds behaviour analysis and modelling	2004 - 2006	
	NATS Advanced Separation Criteria Project Wake Turbulence Encounter Safety Analysis and TBS Rules and TBS Tool support proposal for Heathrow	2004 - 2005	NATS Planned Spacing Tool concept of operations and validation simulations in 2004 & 2005.
	EUROCONTROL TBS Preliminary Safety and Benefits Studies	2004 - 2005	EUROCONTROL TBS Project concept specifications developed in 2003 - 2004. NATS Advanced Separation Criteria Project TBS Rules Proposal for Heathrow in 2004 - 2005.
	EUROCONTROL EuroBen CBA Study	2005 - 2006	EUROCONTROL TBS Project Concept of Operations. NATS Advanced Separation Criteria Project TBS Rules proposal for Heathrow further developed in 2005 - 2006.
	EUROCONTROL TBS Validation Simulation	2005	EUROCONTROL TBS Project Concept of Operations and TBS Tool Specifications developed in 2004 -2005
	EUROCONTROL OPS HAZID Workshop at Heathrow	2006	EUROCONTROL TBS Project Concept of Operations and TBS Tool Specifications developed in 2005-2006. NATS Advanced Separation Criteria Project TBS Rules and TBS Tool Support proposal for Heathrow further developed in 2005 - 2006
	EUROCONTROL TBS Validation Simulation	2007	EUROCONTROL TBS Validation Simulation in 2006. EUROCONTROL TBS Concept of Operations and TBS Tool

			Specifications refined from the results of the EUROCONTROL TBS Validation Simulation in 2006.
	EC 6FP RESET Project TBS Validation Simulation at LFV	2008	RESET Project TBS Concept of Operations for 2020 and TBS Tool support developed with EUROCONTROL and NATS contributions.
	EC 6FP RESET Project TBS Safety and Human Factors Assessment	2008 - 2009	RESET Project TBS Concept of Operations for 2020 and the conclusions and recommendations of the RESET Project TBS Validation Simulation at LFV.
	EUROCONTROL project Aircraft Wake Vortex Modelling in Support of the Time-Based Separation project	2007 - 2009	EUROCONTROL TBS Concept of Operations refined from the results of the EUROCONTROL TBS Validation Simulation in 2007.
	NATS/EUROCONTROL NGE/IGE LIDAR Wake Vortex Behaviour Data Collection Campaign at Heathrow	2008 - 2011	To provide NGE/IGE WV track data for the WV safety assessment.
	NATS TBS Approach Simulation	2010	NATS TBS Concept of Operations and TBS tool support based on the NATS Planned Spacing Tool fixed distance Indicator option, and the EC 6FP RESET Project TBS Tool track history option, and incorporating decisions from the NATS TBS User Group workshops in 2009 - 2010.
P06.08.01 VP-134	OGE LIDAR Wake Vortex Behaviour Data Collection at Heathrow	2011 - 2013	To provide OGE WV track data for the WV safety assessment.
P06.08.01 VP-303	**Heathrow TBS Approach Simulation**	**2012**	**NATS TBS Approach Simulation in 2010 incorporating the decisions from the TBS User Group Workshops in 2011.**
P06.08.01 VP-302	**Heathrow TBS Tower Simulation**	**2012**	**VP303 Heathrow TBS Approach Simulation**
P06.08.01	WV Safety Assessment utilising the NGE/IGE and the OGE WV track data	2012	NATS/EUROCONTROL NGE/IGE LIDAR Wake Vortex Behaviour Data Collection Campaign at Heathrow. VP-134 OGE LIDAR Wake Vortex Behaviour Data Collection at Heathrow
P06.08.01 VP-136	System Emulator Test using P10.4.4 and P12.2.2 System Prototype	TBD 2013	P6.8.1 OCD & OSED for TBS P6.8.1 SPR for TBS Conclusions and Recommendations from the VP303 & VP302 Simulations

Table 8: Validation Exercises List and dependencies

3 Conduct of Validation Exercises

Conduct of the Validation Exercise VP-303 (TC Approach) is covered in Section 6.1.2.

Conduct of the Validation Exercise VP-302 (Heathrow Tower) is covered in Section 6.2.2.

3.1 Exercises Preparation

Exercise Preparation for exercise VP-303 (TC Approach) is covered in Section 6.1.2.1.

Exercise Preparation for exercise VP-302 (Heathrow Tower) is covered in Section 6.2.2.1.

3.2 Exercises Execution

The validation activity was conducted as two exercises as listed below:

Exercise ID	Exercise Title	Actual Exercise execution start date	Actual Exercise execution end date	Actual Exercise start analysis date	Actual Exercise end date
VP-303	London Heathrow TC Approach	11/02/2012	05/03/2012	09/03/2012	30/04/2012
VP-302	London Heathrow Tower	11/07/2012	24/07/2012	25/07/2012	07/09/2012

Table 9: Exercises execution/analysis dates

Exercise Execution for exercise VP-303 (TC Approach) is covered in Section 6.1.2.2.

Exercise Execution for exercise VP-302 (Heathrow Tower) is covered in Section 6.2.2.2.

3.3 Deviations from the planned activities

Deviations from the planned activities are covered in Sections 3.3.1 and 3.3.2 below for the two validation exercises conducted.

3.3.1 Deviations with respect to the Validation Strategy

The Validation Plan and this Report conform to the sWP6.2 Validation Strategy [23] and sWP5.2 Validation Strategy [24]; it follows E-OCM and it conforms to the current transversal assessment guidelines (WPB & WP16).

3.3.2 Deviations with respect to the Validation Plan

3.3.2.1 Deviations with respect to Exercise VP-303 (TC Approach)

The P6.8.1 Validation Plan for Time Based Separation (VALP) was revised and new editions issued during the conduct and analysis of exercise VP-303 (TC Approach). Validation exercise VP-303 commenced in accordance with VALP edition 00.01.00 [1]. However, VALP edition 00.01.01 [2] was issued during the Run for Record phase of the validation exercise, which introduced some changes to the objective criterion and hypotheses, including a new question that could not be included in the questionnaires because they were already prepared and in use.

During the analysis and report writing phase of exercise VP-303, further editions of the P6.8.1 Validation Plan were issued for exercise VP-302 (Heathrow Tower), VALP edition 00.01.02 [3], and VALP edition 00.01.03 [4] to incorporate modifications resulting from the Safety Assessment Plan and Human Performance Assessment Plan; this document reports exercise VP-303 (TC Approach) results in accordance to this latest edition of the P6.8.1 Validation Plan. This latest edition of the P6.8.1 Validation Plan introduced a significant number changes to the objectives, criterion and hypotheses which required restructuring the report and some additional analysis to align with the changes in the Validation Plan.

Deviations from the planned activities are covered in Section 6.1.2.3 for exercise VP-303 (TC Approach); this covers deviations from the planned simulation execution (VALP edition 00.01.00 [1]) and deviations from the planned analysis (VALP edition 00.01.03 [4]).

3.3.2.2 Deviations with respect to Exercise VP-302 (Heathrow Tower)

The P6.8.1 Validation Plan for Time Based Separation (VALP) was revised and a new edition issued during the conduct of exercise VP-302 (Heathrow Tower). Validation exercise VP-302 commenced in accordance with VALP edition 00.01.02 [3]. However, VALP edition 00.01.03 [4] was issued during the formal Run for Record phase of the validation exercise, which introduced a significant number changes to the objectives, criterion, hypotheses and in some cases the wording of specific End of Participation questionnaire questions which could not be updated mid-exercise. This document reports exercise VP-302 (Heathrow Tower) results in accordance to this latest edition of the P6.8.1 Validation Plan. Consequently there are some discrepancies between what was actually conducted and the current VALP.

Deviations from the planned activities are covered in Section 6.2.2.3 for exercise VP-302 (Heathrow Tower); this covers deviations from the planned simulation execution (VALP edition 00.01.02 [3]) and deviations from the planned analysis (VALP edition 00.01.03 [4]).

4 Exercises Results

4.1 Summary of Exercises Results

Validation Exercise VP-303 Heathrow Approach

The thirteen day Time Based Separation (TBS) Heathrow Approach validation exercise (VP-303) was run from 11th February 2012 to 5th March 2012 on the LTC real-time simulator at NATS CTC. The measured positions were Heathrow (EGLL) Final Director Controller (**FIN**), Intermediate Controller – North and South (**INT N** & **INT S**) and the Tower Runway Controller (**TWR**) when manned.

The TBS concept is viable as simulated for Heathrow Approach control and could deliver significant improvements and benefits for airport operations in terms of higher aircraft landing rates in stronger wind conditions, and reduced holding and approach times.

Aircraft landing rates were consistently increased with TBS for all eleven matched runs, for the traffic samples and wind conditions simulated; up to 5 additional aircraft per hour were landed with TBS compared to DBS, with a mean of 2 additional aircraft per hour. Holding times and Stack entry to touchdown times were reduced with TBS compared to DBS. The mean reduction in holding times with TBS was 0.9 minutes, with a maximum reduction of 9.4 minutes. The mean reduction in stack entry to touchdown times with TBS was 1.4 minutes, with a maximum reduction of 9.3 minutes.

Aircraft separation accuracy for Wake pairs at 4DME between DBS and TBS shows a clear and statistically significant improvement with TBS compared to DBS for all eleven matched exercise runs analysed; there was no improvement with TBS compared to DBS for Non-Wake pairs. However, overall TBS performed generally better than DBS.

There was no difference in controller workloads (Bedford and ISA) or R/T occupancy with TBS compared with DBS; workloads and R/T were busy but comfortable. A very slight increase was recorded for R/T, but this appears linked to the higher aircraft landing rates.

Two classes of under-separation were analysed using the system log data: **Highly Under-separated** defined as '>0.5 Nm under Wake / 2.5 Nm', and **Under-separated** defined as less than the required separation but <0.5 Nm under Wake / 2.5 Nm. Two highly under-separated events were recorded with TBS during the validation exercise, none were recorded with DBS. One highly under-separated event with TBS in a match run was detected from the TST log data at 4DME. The second highly under-separated event resulted from a TBS tool error which positioned the indicator too close to the Leader aircraft for the wake vortex categories of the two aircraft; the FIN controller did not detect the error due to reduced Situation Awareness. Results from the matched runs shows the percentage of under-separated events was almost half with TBS compared to DBS; this indicates that with the TBS indicators as a visual reference, the controllers were able to provide improved separation overall in TBS operation compared with DBS.

Situation Awareness for the FIN controller was slightly reduced with TBS compared to DBS, this reduction was not statistically significant; the INT N and S roles were generally unaffected with TBS. The reduction in Situation Awareness for the FIN controller was evident through a change of focus onto the Time Separation Tool (TST) indicators and away from the flight strips resulting in less awareness of aircraft types, wake vortex categories and the relative position of the lead aircraft. This indicates the TBS tool needs to be designed to a high level of integrity for accuracy, reliability and robustness, and ATCO training is needed to ensure aircraft types and wake vortex categories are still checked.

Several TST issues and faults were observed during the simulations that affected the usability of the prototype TBS tool and user confidence and trust. Controller trust in the TBS tool was generally low; most of the participants were not confident the tool would provide either the best or correct information. One fault that significantly impacted user confidence was an incorrect calculation of Time Based Separation, which led to one observed loss of Wake separation.

Tactical Enhanced Arrival Mode (TEAM) functionality, particularly early morning TEAM, was unacceptable with unstable not-in-trail indicators, missing in-trail Wake indicators and lateral spacing at 2 Nm being too close; a successful single trial with 2.5 Nm spacing indicated this was an improvement.

In operational service, TBS is planned to be operated with electronic strips, which will overcome the approach sequencing issues. A mature EFD system for Heathrow Approach was not available for the TC Approach exercise; therefore an INT N Support role was needed to assist with agreeing the landing sequence and maintaining the sequence order on the Electronic Flight Data (EFD) display for the TST calculations. This limitation caused some problems with incorrect aircraft sequence order, which resulted in some unusual behaviour of TBS indicators, and affected user confidence in the system.

Validation Exercise VP-302 Heathrow Tower

The seven day TBS Heathrow Tower validation exercise was conducted on the Micro Nav BEST 360° real-time Heathrow Airport Tower simulator at NATS Heathrow House, London between 11th July 2012 and 24th July 2012. A total of 31 exercise runs were completed with a total simulation time of 24½ hours. The measured position was the Heathrow (EGLL) Tower AIR Arrivals (North) controller.

The TBS concept is viable as simulated for Heathrow Tower could deliver significant improvements and benefits for airport operations in terms of higher aircraft landing rates in stronger wind conditions. The TBS Method of Operations was felt to be practical, manageable, realistic and achievable.

The higher aircraft landing rates as delivered by TC Approach with TBS from the VP-303 validation exercise were handled easily by the Tower AIR Arrivals (North) controller. There was no statistically significant difference in separation accuracy at Runway Threshold between DBS and TBS. There were no statistically significant differences in controller workloads (Bedford and ISA) with TBS compared with 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.

It was expected that aircraft spacing would compress between 4DME and Runway Threshold and separation be reduced. There were slightly fewer compressed Wake pairs with TBS compared to DBS (up to 0.5 Nm compression); however there were more highly compressed pairs with TBS (over 0.5Nm compression) – these differences are not statistically significant.

There are no statistically significant differences between the Clearance to Land margins (of 15 seconds or less), Go-around instructions, numbers of Wake Vortex Advisories or Expedited Runway Vacation Requests issued between DBS and TBS. There were no Spacing-related Late Runway Switches during the course of the simulation, and just one instance of a go-around during a TBS Match run; neither result was statistically significant.

Tower AIR Arrivals (North) controllers felt they could accommodate the TBS indicators into their scan; the presence of TBS indicators reduced the need to obtain and process information on aircraft types and wake turbulence categories from the EFPS system. This change of scan indicates that the TBS system needs a high degree of accuracy and reliability because of the high levels of trust placed on correct calculation and display of the TBS indicators.

All scenarios run passed and were 'OK'; scenarios SCN10 (A) & (B), SCN20 and SCN21 were not conducted due to the high turnover of participants and the potentially disproportionate effect that these scenarios may have had on user confidence and trust.

Tactical Enhanced Arrival Mode (TEAM) 6 Aircraft per Hour functioned correctly without any problems using a 2.0 Nm not-in-trail lateral spacing. This is in contrast to the Approach Exercise (VP-303) where errors in the TEAM functionality meant that 2Nm spacing was not possible and instead only a single trial using a 2.5 Nm lateral spacing was conducted.. The in-trail Wake indicators functioned correctly.

The P6.8.1 validation results are provided in the summary table below:

- **OK**: *Validation objective achieves the expectations (exercise results achieve success criteria).*
- **NOK**: *Validation objective does not achieve the expectations (exercise results do not achieve success criteria).*

Exercise ID	Validation Objective ID	Validation Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Validation Objective Status
VP-303	OBJ-06.08.01-VALP-0010-0010	To assess the impact of TBS on the Wake Turbulence Encounter risk on final approach.	CRT-06.08.01-VALP-0010-0010	NOT COVERED - not planned to be assessed.	This Validation Objective is addressed in the LIDAR data collection and analysis report [6].	Not covered
VP-303	OBJ-06.08.01-VALP-0010-0015	To assure that the TBS Indicator displayed to the Approach and Tower controllers shall correctly represent the TBS distance or the most constraining separation or spacing constraint in all wind conditions.	CRT-06.08.01-VALP-0010-0015	NOT COVERED - not planned to be assessed.	Metrics, tools and other resources were not available to address this validation objective	Not covered
VP-303	OBJ-06.08.01-VALP-0010-0020	To assess whether the Final and Intermediate Approach Controller can safely deliver aircraft to TBS minima in all wind conditions using the TBS tool support.	CRT-06.08.01-VALP-0010-0020	The spacing delivered by the controllers under TBS operations in all wind conditions is such that: • The level of under-separation during simulated TBS operations shall be no more than the level of under-separation during simulated current-day DBS operations;	Spacing at 4DME: OK. Aircraft separation accuracy for Wake pairs at 4DME between DBS and TBS shows a clear and statistically significant improvement with TBS compared to DBS for all eleven matched exercise runs analysed; there was no improvement with TBS compared to DBS for Non-Wake pairs. However, overall TBS performed generally better than DBS. NB. TEAM is excluded from separation accuracy comparison because of the issues with TEAM functionality. Losses of Separation: OK. Overall, aircraft separation accuracy at 4DME between DBS and TBS were almost identical for all eleven matched runs analysed. Highly Under-separated: One loss of separation with TBS in a match run (0.25%), no losses with DBS (0%).	**OK** for Single Runway Operation See R2, R4, R5, R6, R7, R8 & R9 in section 6.1.4.2 **NOK** for Parallel Dependent Runways Operation (TEAM) See R2, **R3**, R4, R5, R6, R7, R8 & R9 in section

Exercise ID	Validation Objective ID	Validation Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Validation Objective Status
					Under-separation: OK. There was no statistically significant increase in under-separation between Stack exit and 4DME with TBS (9.25%) when compared to DBS (17.15%). Indeed, TBS performed better than DBS and demonstrates a statistically significant reduction of Wake under-separation events compared to DBS, especially for Easterly operations (Runway 09L).	6.1.4.2
				• The mean over-separation during simulated TBS operations should be no more than the mean over-separation compared to the level of over-separation during simulated current-day operations;	Spacing at 4DME: OK. No statistically significant difference in separation accuracy (over-separation) at 4DME between DBS and TBS exercise runs.	
				• The Final Approach Controller is observed to employ safe vectoring techniques and standard controller practices during simulated TBS operations; as assessed by a qualified expert;	Expert Observer: OK for single runway operations, NOK for TEAM functionality; Recommendation R3. The prototype TBS tool was not fully functional and reliable, e.g. a few faults and an outstanding Change Request (CR) that could not be implemented in time for the validation exercise meant the TST was not acceptable. 23/26 expert observers agreed safe vectoring practices were used 'Always' with TBS. 3/26 replied 'Mostly' or 'Sometimes', but 2 of these refer to TEAM functionality issues.	
				• The TBS tools provide a clear indication of the required spacing constraints.	Questionnaires: Q1.2 & Q1.4 indicate that the Controllers could not reach consensus that they could safely deliver aircraft to TBS minima and effectively monitor separation encroachment. NOK Q3.2 indicated that TBS provided clear spacing indications. OK NATS Confidence Diamond scores indicate the prototype TST software is not sufficiently accurate and	

Exercise ID	Validation Objective ID	Validation Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Validation Objective Status
					reliable enough for safe operation. NOK	
VP-303	OBJ-06.08.01-VALP-0010-0030	To assess the acceptability of the changes to the operational procedures and practices on the Final Approach Controller, Intermediate Approach Controller, Runway Controller, Approach and Tower Supervisors, and Pilot.	CRT-06.08.01-VALP-0010-0030	The TBS procedures and practices are acceptable and easy to use and:	Expert Observer: OK. Results generally favourable for the concept.	**OK** for Single Runway Operation See R5, R6, R7, R8 & R9 in section 6.1.4.2 **NOK** for Parallel Dependent Runways Operation (TEAM) See R2, **R3**, R4, R5, R6, R7, R8 & R9 in section 6.1.4.2
		NB – Approach and Tower Supervisor and Pilot Human Performance not addressed.		• New procedures and practices are shown to be practical and manageable (suitable and usable);	Questionnaires: OK. TBS concept and HMI is generally acceptable, though improvements are required, e.g. tool reliability and TEAM functionality. Debriefs: OK. The TBS concept appears viable. However, there were concerns about maintaining separation with real life variability in wind conditions and pilot non-conformance. CARS: OK. All CARS Mean scores are acceptable. FIN is only just above the lower limit.	
				• Changes to existing procedures are shown to be practical and manageable (suitable and usable);	Questionnaires: OK. Tower and Approach Supervisors were not present during the validation exercise, which introduced some uncertainty in terms of Approach and Tower co-ordinations and procedures. The TBS MOps appear to be suitable and usable with clarity over procedures for 3 Nm and 2.5 Nm spacing. Debriefs: OK. The TBS concept appears viable. However, there were concerns about maintaining separation with real life variability in wind conditions and pilot non-conformance.	

Exercise ID	Validation Objective ID	Validation Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Validation Objective Status
					CARS: OK. All CARS Mean scores are acceptable. FIN is only just above the lower limit.	
				• The procedures and practices are shown to be realistic and achievable (suitable and usable);	Questionnaires: NOK. TBS concept and HMI is generally acceptable, though improvements are required, e.g. tool reliability and TEAM functionality. Debriefs: OK. The TBS concept appears viable. However, there were concerns about maintaining separation with real life variability in wind conditions and pilot non-conformance. CARS: OK. All CARS Mean scores are acceptable. FIN is only just above the lower limit.	
				• Any changes to the procedures and practices that impact R/T usage will be acceptable to controllers and pilots.	Questionnaires: OK. Occasional and slight R/T increase, but acceptable. Debriefs: OK. Occasional but slight R/T increase. CARS: OK. All CARS Mean scores are acceptable. FIN is only just above the lower limit. R/T Occupancy: OK. All within reasonable working levels and no significant difference. Expert Observer: OK. Slight R/T impact, but acceptable.	
VP-303	OBJ-06.08.01-VALP-0010-0040	To assess the impact of the TBS tool support and operational procedures on the Human Performance of the Final Approach Controller, Intermediate Approach Controller, Runway Controller, Approach and Tower	CRT-06.08.01-VALP-0010-0040	The Human Performance under TBS will not be negatively impacted compared to DBS in terms of: • Workload;	ISA: OK. Scores acceptable between TBS and DBS. Bedford Workload: OK. Workload scores for FIN, INT N & S were almost identical between DBS and TBS. FIN & INT N slightly above the acceptable level, which is indicative of busy traffic samples used. INT S & TWR	**OK** for Single Runway Operation See R2, R4, R5, R6, R7, R8 & R9 in section 6.1.4.2

Exercise ID	Validation Objective ID	Validation Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Validation Objective Status
		Supervisors, and Pilot.			OK. Debriefs: OK. Mixed opinions. A few controllers viewed the TBS indicators as "*clutter*", thus slightly increasing workload.	**NOK** for Parallel Dependent Runways Operation (TEAM) See R2, **R3**, R4, R5, R6, R7, R8 & R9 in section 6.1.4.2
		NB – Approach and Tower Supervisor and Pilot Human Performance not addressed.		• Controller Trust and Confidence for the operational procedures and technology;	CARS: OK. All CARS Mean scores were acceptable. FIN is only just above the lower limit. Debriefs: NOK. Concerns were highlighted with TBS tool accuracy and reliability coupled with the reduction in Situation Awareness. Controller trust was eroded by tool errors and a loss of Wake separation. Madsen & Gregor Trust: Perceived Reliability NOK. SHAPE: OK. Acceptable scores for all roles.	
				• Situational Awareness (SA);	China Lakes Situation Awareness: FIN – NOK. SA Mean scores just below acceptable limit for FIN (including Scenario runs). Reduction in SA for FIN with TBS compared to DBS, but not statistically significant. INT N & S and TWR – OK Debriefs: NOK. SA was reduced with TBS for: aircraft types, wake vortex categories and actual distances between aircraft. Reduced SA contributed to a loss of Wake separation during exercise run TBS121 following a TST indicator error.	
VP-303	OBJ-06.08.01-VALP-0010-0045 NB: New objective with	To assess the acceptability of the TBS tool concept in general by the Final Approach Controller, Intermediate Approach Controller,	CRT-06.08.01-VALP-0010-0045	The proposed solution is acceptable to the Final Approach Controller, Intermediate Approach Controller, Runway Controller, Approach and Tower Supervisors, and Pilot, and the Human Performance under TBS will not be		**OK** for Single Runway Operation See R2, R4, R5, R6, R7,

Exercise ID	Validation Objective ID	Validation Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Validation Objective Status
	edition 00.01.03 of the VALP [4]	Runway Controller, Approach and Tower Supervisors, and Pilot. *NB – Approach and Tower Supervisor and Pilot Human Performance not addressed.*		negatively impacted compared to DBS in terms of: • Dependence on controller tool support;	Debriefs: OK. Good training and experience with different wind conditions is needed to learn how best to use TBS. Madsen & Gregor Trust: Perceived Reliability NOK. SHAPE: OK. Acceptable scores for all roles.	R8 & R9 in section 6.1.4.2 **NOK** for Parallel Dependent Runways Operation (TEAM) See R2, **R3**, R4, R5, R6, R7, R8 & R9 in section 6.1.4.2
				• Controller Skill Levels;	Not explicitly covered by validation exercise, deferred to HP assessment.	
				• Controller training needs.	Not explicitly covered by validation exercise, deferred to HP assessment.	
VP-303	OBJ-06.08.01-VALP-0010-0050	To assess the utility and usability of the TBS controller tool support.	CRT-06.08.01-VALP-0010-0050	The utility and usability of the TBS controller tool support will be such that: • The TBS tool support is useful and supports the controllers in their work;	Debriefs: OK. Results indicate the TBS tool is very useful to the Final Director Controller (**FIN**) and essential for the TBS concept to be implemented. However, TBS is not so useful to the Intermediate controllers North & South (**INT N & S**).	**OK** for Single Runway Operation See R2, R4, R5, R6, R7, R8 & R9 in section 6.1.4.2 **NOK** for Parallel Dependent Runways Operation (TEAM) See R2, **R3**, R4, R5, R6, R7, R8 & R9 in section 6.1.4.2
				• The HMI design is intuitive and easy for the controllers to interpret;	Debriefs: OK. Overall, the behaviour of the indicators was considered to be intuitive. However, TBS indicators require interpretation as references rather than targets; the degree of interpretation varied by individual controller. In some situations controllers felt they struggled to "*see through*" the indicators to understand the situation. A few of the controllers perceived the TBS indicators as "*clutter*", thus slightly increasing workload.	
				• The HMI design (i.e. shape, colour, size and display priority) is acceptable to the controllers;	Questionnaires: OK. HMI design shape, colour, size & display priority all acceptable. Debriefs: OK. No specific comments about the HMI	

Exercise ID	Validation Objective ID	Validation Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Validation Objective Status
					design.	
				• The HMI design of the indicator shall harmoniously integrate into the final approach controller radar display and the tower runway controller air traffic monitor display respectively;	CARS: OK. All CARS Mean scores are acceptable. FIN is only just above the lower limit. Debriefs: NOK. The production TBS tool needs to address the functionality, accuracy, reliability and stability issues highlighted in this report. The key issues are integration with Electronic Flight Data (EFD) in operation to provide a reliable landing sequence order, and resolving the TEAM usability issues. Questionnaires: OK. Questionnaire evidence not available because the question "*The separation indicator did not distract from my tasks as FIN controller*" was not asked – questionnaires were prepared to the VALP issued prior to the validation exercise (edition 00.01.00 [1]. However, from debrief comments it can be deduced that the majority of controllers felt the TBS indicators did not distract from their tasks as FIN controller.	
				• The HMI shall provide mitigation for events that may lead to inappropriate separation scenarios;	CARS: OK. All CARS Mean scores are acceptable. FIN is only just above the lower limit. Debriefs: NOK. Controller reliance on the TBS indicator support means that tool errors may not to be noticed leading to a potential loss of separation. The production TBS tool needs to be more accurate and reliable than the prototype used for the simulations. Questionnaires: OK. However, there was a wide spread of views to whether TBS helped identify potential losses of separation; 4 of the 6 controllers responded TBS did help, 1 responded neutrally and 1 responded that TBS did not help.	
				• The required usability of the TBS	NOT COVERED - Not planned to be explicitly covered	

Exercise ID	Validation Objective ID	Validation Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Validation Objective Status
				controller tool support and the harmonised integration with the other approach and runway controller tools is achievable.	by the validation exercise; metrics, tools and other resources were not available to address this validation objective	
VP-303	OBJ-06.08.01-VALP-0010-0060	To assess the impact of the TBS concept and operational procedures on the roles and responsibilities of the Final Approach Controller, Intermediate Approach Controller, Runway Controller, Approach and Tower Supervisors, and Pilot.	CRT-06.08.01-VALP-0010-0060	The allocation of roles and responsibilities will be clear and acceptable in terms of: • Allocation between Approach Controllers and Runway Controllers;	Debriefs: NOK. Clarification of roles and responsibilities is required for Approach (FIN) & Tower runway controllers; this was highlighted as a result of the absence of Approach and Tower Supervisors during the validation exercise, which caused some uncertainty with required spacing delivery in different wind conditions. Questionnaires: FIN & TWR – NOK, INT N & S – OK. Clarification of roles and responsibilities is required for FIN, INT N/S & TWR controllers in TBS operation. SHAPE: OK. Acceptable scores for all roles. Debriefs and Questionnaires: FIN & TWR – NOK, INT N & S – OK. End of Participation results indicate that some clarification is needed for roles and responsibilities between FIN and Tower Runway controllers, e.g. clarity over operating procedures for 3 Nm and 2.5 Nm spacing. Note, Approach and Tower Supervisors were not present during the validation exercise, which introduced some uncertainty in terms of Approach and Tower co-ordinations and the procedures.	**NOK** See R4 & R5 in section 6.1.4.2
		NB – Approach and Tower Supervisor and Pilot Human Performance not addressed.		• Allocation between Controllers and Pilots; *NB - Criteria not totally covered by validation exercise (requires pilot input).*	Debriefs and Questionnaires: FIN & TWR – NOK, INT N & S – OK. Clarification of roles and responsibilities is required for FIN controllers and pilots; the main factor is pilot conformance to speed instructions. Controllers felt confident at delivering 2.5 Nm spacing. However, the FIN controllers are reliant on prompt and correct pilot conformance to instructions to assure separation, which with the higher landing rates with TBS reduced the contingency distance to allow for pilot non-conformance	

Exercise ID	Validation Objective ID	Validation Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Validation Objective Status
					without initiating a go-around.	
				• Pilot responsibility for maintaining safe operation remaining unchanged.	NOT COVERED - Not planned to be explicitly covered by the validation exercise; metrics, tools and other resources were not available to address this validation objective	
VP-303	OBJ-06.08.01-VALP-0010-0070	To assess the impact of TBS tool support and operational procedures on the arrival runway capacity during strong wind conditions.	CRT-06.08.01-VALP-0010-0070	The landing rate under simulated TBS operations in strong headwind conditions shall: • Be shown to increase compared to the landing rate under simulated current day DBS operations in strong wind conditions;	Landing Rates: OK. Statistically significant increase with TBS up to +5 additional aircraft per hour, with a mean of 2 additional aircraft per hour.	**OK**
				• Be shown to increase for all headwinds in excess of the conditions against which the TBS minima have been baselined;	Landing Rates: OK. Statistically significant increase with TBS up to +5 additional aircraft per hour, with a mean of 2 additional aircraft per hour.	
				• Contribute to a delay saving per flight estimated as a function of the headwind on final approach and traffic mix; this gain shall be positive for all headwinds in excess of the conditions against which the TBS minima have been baselined.	Landing Rates: OK. Statistically significant increase. Landing Times: OK. Statistically significant reduction in holding times, and hold entry to touchdown times. Mean reduction in holding times with TBS was 0.9 mins, maximum reduction of 9.4 mins. Mean reduction in stack entry to touchdown times with TBS was 1.4 mins, maximum reduction of 9.3 mins.	
VP-303	OBJ-06.08.01-VALP-0010-0080	To assess the impact of TBS tool support and operational procedures on the efficiency of operations.	CRT-06.08.01-VALP-0010-0080	The TBS tool support and operational procedures shall lead to an improvement in the efficiency of operations in terms of: • The final approach spacing practice with respect to the additional spacing applied with the TBS;	Spacing at 4DME: OK. No statistically significant difference in separation accuracy.	**OK** See R6 in section 6.1.4.2 for DTT advisories
				• An overall reduction, all else being	Holding Times: OK. Statistically significant reduction in holding times. Mean reduction in holding times with TBS	

Exercise ID	Validation Objective ID	Validation Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Validation Objective Status
				equal, in the average fuel consumption due to airborne holding;	was 0.9 mins, maximum reduction of 9.4 mins. Hold to Touchdown: OK. Hold entry to touchdown times were slightly reduced with TBS. Mean reduction in stack entry to touchdown times with TBS was 1.4 mins, maximum reduction of 9.3 minutes.	
				• An overall reduction, all else being equal, in the average level of flight cancellations;	Landing Rates: OK. Statistically significant increase up to +5 a/c per hour, mean of 2 additional a/c per hour. Landing Times: OK. Statistically significant reduction in holding times, and hold entry to touchdown times.	
				• Compatibility with the continued employment of CDAs and LP/LD procedures.	Questionnaires: NOK. Controllers did not all agree they could issue accurate DTT advice using TBS; 2 of the 6 controllers reported not using TBS for DTT, they based DTT on DBS Wake Vortex requirements. Expert Observer: NOK. Controllers did not reach consensus that they could issue accurate DTT advice using TBS. DTT advisories can be misinterpreted and need to be improved.	
VP-303	OBJ-06.08.01-VALP-0010-0090	To assess the impact of TBS tool support and operational procedures on the predictability of operations.	CRT-06.08.01-VALP-0010-0090	The estimated impact of TBS shall demonstrate an overall reduction, all else being equal, in the variability in arrival time due to variability in the headwind conditions on final approach.	Landing Rates: OK. Statistically significant increase with TBS up to +5 additional aircraft per hour, with a mean of 2 additional aircraft per hour. Consistent increase with a variety of wind conditions.	**OK**
VP-303	OBJ-06.08.01-VALP-0010-0100	To assess the impact of TBS tool support and operational procedures on environmental performance of aircraft in the hold and on final approach.	CRT-06.08.01-VALP-0010-0100	The environmental performance under TBS operations will: • Demonstrate an overall reduction, all else being equal, in the average amount of C02 emitted due to airborne holding;	Holding Times: OK. Statistically significant reduction in holding times. Landing Times: OK. Statistically significant reduction in hold times and hold entry to touchdown times. Hold to Touchdown: OK. Hold entry to touchdown times	**OK**

Exercise ID	Validation Objective ID	Validation Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Validation Objective Status
					were slightly reduced with TBS. Fuel burn and CO_2 emissions: OK. Statistically significant fuel burn and CO_2 reduction of 5.77% with TBS compared to DBS (sample size of 383 aircraft across 11 matched exercise runs).	
				• Be within acceptable limits in terms of Leg noise contours;	Metrics, tools and other resources were not available to address this validation objective.	Not covered
				• Be within acceptable limits in terms of Lmax noise.	Metrics, tools and other resources were not available to address this validation objective.	Not covered
VP-303	OBJ-06.08.01-VALP-0010-0110	To assess the benefit-cost ratio for any investment needed for the deployment of TBS.	CRT-06.08.01-VALP-0010-0110	NOT COVERED - not planned to be assessed.	Metrics, tools and other resources were not available to address this validation objective.	Not covered
VP-303	OBJ-06.08.01-VALP-0010-0120	To assess the acceptability of the TBS concept, rules and procedures to Flight Crew and Airspace Users.	CRT-06.08.01-VALP-0010-0120	NOT COVERED - not planned to be assessed.	Metrics, tools and other resources were not available to address this validation objective.	Not covered
VP-302	OBJ-06.08.01-VALP-0010-0010	To assess the impact of TBS on the Wake Turbulence Encounter risk on final approach.	CRT-06.08.01-VALP-0010-0010	NOT COVERED - not planned to be assessed.	This Validation Objective is addressed in the LIDAR data collection and analysis report [6].	Not covered
VP-302	OBJ-06.08.01-VALP-0010-0015	To assure that the TBS Indicator displayed to the Approach and Tower controllers shall correctly represent the TBS distance or the most constraining separation or spacing constraint in all wind conditions.	CRT-06.08.01-VALP-0010-0015	NOT COVERED - not planned to be assessed.	Metrics, tools and other resources were not available to address this validation objective.	Not covered

Exercise ID	Validation Objective ID	Validation Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Validation Objective Status
VP-302	OBJ-06.08.01-VALP-0010-0020	To assess whether the Final and Intermediate Controller can safely deliver aircraft to TBS minima in all wind conditions using the TBS tool support.	CRT-06.08.01-VALP-0010-0020	The spacing delivered by the controllers under TBS operations in all wind conditions is such that: • The level of under-separation during simulated TBS operations shall be no more than the level of under-separation during simulated current-day DBS operations; Note: When the lead aircraft is under the control of the Tower Runway Controller inside of 4DME, this is the level of compression; compressed (up to 0.5Nm compression) and highly compressed (more than 0.5Nm compression).	Spacing at Threshold: OK. Aircraft separation accuracy at Threshold between DBS and TBS were almost identical for all 8 matched runs: the differences are not statistically significant. Number of go-arounds (due to spacing): OK. There was only one go-around during a Match run, which was during a TBS run; this is not statistically significant. Late runway switches (due to spacing): OK. There were no late runway switches due to spacing. Wake Vortex Advisories issued to aircraft: OK. More Wake Vortex Advisories were issued to aircraft during TBS runs – TBS (12), DBS (9). The differences are not statistically significant. Expedited Runway Requests (due spacing): OK. There were more expedited runway requests for TBS than for DBS runs – TBS (17), DBS 11). The differences are not statistically significant. Speed interventions before 4DME: OK. No speed interventions were issued during any of the Matched exercise runs. Clearance to land: OK. TBS results are all slightly lower than those for DBS. However, the differences are not statistically significant	**OK**
				• The mean over-separation during simulated TBS operations should be no more than the mean over-separation compared to the level of over-separation during simulated current-day operations;	N/A	
				• The Final Approach Controller is observed to employ safe vectoring techniques and standard controller	N/A	

Exercise ID	Validation Objective ID	Validation Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Validation Objective Status
				practices during simulated TBS operations; as assessed by a qualified expert;		
				• The TBS tools provide a clear indication of the required spacing constraints.	Questionnaires: OK. Overall, feedback indicates that aircraft can safely and clearly be delivered by Heathrow AIR Arrivals controllers using TBS.	
VP-302	OBJ-06.08.01-VALP-0010-0030	To assess the acceptability of the changes to the operational procedures and practices on the Final Approach Controller, Intermediate Approach Controller, Runway Controller, Approach and Tower Supervisors, and Pilot.	CRT-06.08.01-VALP-0010-0030	The TBS procedures and practices are acceptable and easy to use and:	Expert observation: OK. All questions responded to as 'Always' in the majority of cases, which indicates they are all acceptable. Question 1 (*Tower Arrivals Controller employs safe techniques and standard controller practices*) was unanimously answered positively. CARS: OK. CARS results indicate that TBS is acceptable for the Heathrow Tower controllers – very good scores considerably above the acceptable limit.	**OK**
		NB – Runway Controller only.		• New procedures and practices are shown to be practical and manageable (suitable and usable);	Questionnaires: OK. Q2.1 results for Heathrow Tower controllers indicate that the TBS concept and HMI is practical and manageable, with only minor reservations. Debriefs: OK. The impact of different spacing minimum values (2.5 Nm or 3.0 Nm at 4DME) and policies (low visibility, TEAM) and the way in which these will be input into the tool and by whom are areas for development. Expert Observer: OK. Q3 for new procedures and practices was responded to as 'Always' in the majority of cases, which indicates these are acceptable.	
				• Changes to existing procedures are shown to be practical and manageable (suitable and usable);	Questionnaires: OK. Q2.1 results for Heathrow Tower controllers indicate that the TBS concept and HMI is practical and manageable, with only minor reservations. Debriefs: OK. It was not felt to significantly change the way AIR Arrivals operates or the way they interact with other actors in the system (most notably TC FIN and aircrew) and is consistent with existing practices and procedures.	

Exercise ID	Validation Objective ID	Validation Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Validation Objective Status
					Expert Observer: OK. There was no specific question for changes to existing procedures. However, all the other questions including Q3 for new procedures and practices were responded to as 'Always' in the majority of cases, which indicates this is acceptable.	
				• The procedures and practices are shown to be realistic and achievable (suitable and usable);	Questionnaires: OK. Q2.1 results for Heathrow Tower controllers indicate that the TBS concept and HMI is realistic and achievable, with only minor reservations. Debriefs: OK. Generally acceptable for routine operations, though there are areas for development for the way in which spacing minimum will be input into the tool and by whom. Procedures for emergency scenarios need to be defined, e.g. runway closures and whether TST indicators should be turned off during such events. Expert Observer: OK. All questions responded to as 'Always' in the majority of cases, which indicates procedures and practices are acceptable.	
				• Any changes to the procedures and practices that impact R/T usage will be acceptable to controllers and pilots.	Questionnaires: OK. Specific question not included in End of Participation questionnaire. However, Expert Observer and Debrief feedback indicates R/T usage was acceptable during the validation exercise. Debriefs: OK. R/T usage acceptable. Expert Observer: OK. R/T usage under TBS operations was acceptable.	
VP-302	OBJ-06.08.01-VALP-0010-0040	To assess the impact of the TBS tool support and operational procedures on the Human Performance of the Final Approach Controller, Intermediate Approach Controller,	CRT-06.08.01-VALP-0010-0040	The Human Performance under TBS will not be negatively impacted compared to DBS in terms of: • Workload;	ISA: OK. Scores for the 8 matched runs indicate normal working levels of 'Very Low' (1) and 'Low' (2) for the majority of the validation exercise runs with very little difference between TBS and DBS. There was no	**OK**

Exercise ID	Validation Objective ID	Validation Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Validation Objective Status
		Runway Controller, Approach and Tower Supervisors, and Pilot. *NB – Runway controller only.*			statistically significant difference between DBS and TBS ISA scores. Bedford Workload: OK. The Bedford Workload measures for the DBS Match, TBS Match and all TBS runs were all comfortably below the acceptable upper limit. There was no statistically significant difference between DBS and TBS Bedford workload results. Debriefs: OK. Controllers commented that the traffic samples did not include departures, runway crossers and helicopters, thus the actual equivalent operational workload would be slightly higher, though still comfortably acceptable.	
				• Controller Trust and Confidence for the operational procedures and technology;	Debriefs: OK. AIR Arrivals controllers quickly placed a lot of trust in the tool to display the correct separation minimum between aircraft on the ATM. Madsen & Gregor Trust: OK. The Madsen & Gregor Trust scores were acceptable for all categories. NATS Confidence Diamond: OK. All results are above the acceptable lower limit.	
				• Situational Awareness;	China Lakes Situation Awareness: OK. Results for the DBS and TBS matched runs, and all TBS runs, are comfortably above the acceptable limit. NATS Picture Scale: OK. All results above the acceptable limit. Debriefs: OK. Minor concerns by a few participants that the TST indicators present extra clutter on the Radar display. Overall, TBS was considered an improvement for Situation Awareness through being able to visualize compression throughout final approach quicker than is currently available.	
VP-302	OBJ-06.08.01-	To assess the	CRT-06.08.01-	The proposed solution is acceptable to		**OK**

Exercise ID	Validation Objective ID	Validation Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Validation Objective Status
	VALP-0010-0045	acceptability of the TBS tool concept in general by the Final Approach Controller, Intermediate Approach Controller, Runway Controller, Approach and Tower Supervisors, and Pilot. *NB – Runway controller only.*	VALP-0010-0045	the Final Approach Controller, Intermediate Approach Controller, Runway Controller, Approach and Tower Supervisors, and Pilot, and the Human Performance under TBS will not be negatively impacted compared to DBS in terms of: • Dependence on controller tool support;	Debriefs: OK. Tower AIR Arrivals (North) controllers quickly placed a lot of trust in the tool to display the correct separation minimum between aircraft on the ATM. As with TC, it was not considered certain that they would detect errors in the tool should an incorrect separation be displayed (and delivered by TC). SHAPE STQ-s: OK. Responses to all questions were very favourable with only slight doubt relating to questions 1, 4 and 5; these refer to team-working aspects which are not so relevant to Tower AIR Arrivals (North) controllers.	
				• Controller Skill Levels;	N/A. Not explicitly covered by validation exercise, deferred to HF assessment.	
				• Controller training needs.	N/A. Not explicitly covered by validation exercise, deferred to HF assessment.	
VP-302	OBJ-06.08.01-VALP-0010-0050	To assess the utility and usability of the TBS controller tool support.	CRT-06.08.01-VALP-0010-0050	The utility and usability of the TBS controller tool support will be such that: • The TBS tool support is useful and supports the controllers in their work;	Debriefs: OK. All controllers agreed TBS was either 'essential', 'very useful' or 'useful'; no controller reported TBS as 'not useful' or 'caused problems'.	**OK**
				• The HMI design is intuitive and easy for the controllers to interpret;	Questionnaires: OK. Q3.4 All of the participants either agreed or strongly agreed that the TBS tool was intuitive and easy to use and interpret. Debriefs: OK. Controllers commented that TBS was quick to understand and use, typically becoming comfortable with the tool with just 10 minutes use.	

Exercise ID	Validation Objective ID	Validation Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Validation Objective Status
				• The HMI design (i.e. shape, colour, size and display priority) is acceptable to the controllers;	Questionnaires: OK. Q3.3 All 12 controllers considered the HMI design acceptable with a minor change in size range. The only exception was one comment about display priority of the TST indicator as follows: "*Was masked by a SSR return directly over it.*" Debriefs: OK. The consensus was that the current 'Large' indicator size should be set as Medium with a 50% increase / decrease value used for 'Large' and 'Small'. A potential issue was identified with the colour of the TST indicators: day-time mode ATM has a blue background with white centreline; night-time has a black background with red centreline. Pink TST indicators are fine for day-time mode, but pink may not contrast well with the night-time mode.	
				• The HMI design of the indicator shall harmoniously integrate into the final approach controller radar display and the tower runway controller air traffic monitor display respectively;	CARS: OK. CARS results indicate that TBS is acceptable for the Heathrow Tower controllers – very good scores considerably above the acceptable limit. Debriefs: OK. Potential issue with the colour of the TST indicators in night-time mode – pink on a red centreline.	
				• The HMI shall provide mitigation for events that may lead to inappropriate separation scenarios	CARS: OK. CARS results indicate that TBS is acceptable for the Heathrow Tower controllers – very good scores considerably above the acceptable limit. Debriefs: OK. A wider discussion was whether TST indicators are required at all during runway closure scenarios; TBS becomes a low priority in these situations.	
				• The required usability of the TBS controller tool support and the harmonised integration with the other approach and runway controller tools is achievable	N/A. Not explicitly covered by validation exercise, deferred to HF assessment.	

Exercise ID	Validation Objective ID	Validation Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Validation Objective Status
VP-302	OBJ-06.08.01-VALP-0010-0060	To assess the impact of the TBS concept and operational procedures on the roles and responsibilities of the Final Approach Controller, Intermediate Approach Controller, Runway Controller, Approach and Tower Supervisors, and Pilot.	CRT-06.08.01-VALP-0010-0060	The allocation of roles and responsibilities will be clear and acceptable in terms of:	Questionnaires: OK. Q2.1 All 12 of the participants either agreed or strongly agreed that they understood their roles and responsibilities when using TBS.	**OK**
		NB – Runway controller only.		• Allocation between Approach Controllers and Runway Controllers;	Debriefs: OK. It was not felt to significantly change the way Tower AIR Arrivals (North) controller operates or the way they interact with other actors in the system (TC FIN) and is consistent with existing practices and procedures. Questionnaires: OK. Q1.2 All 12 participants agreed the division of responsibility between Approach and Runway controllers will be acceptable. Q3.2 11 participants agreed the indicators helped detect losses of separation.	
				• Allocation between Controllers and Pilots;	Debriefs: OK. It was not felt to significantly change the way AIR Arrivals operates or the way they interact with other actors in the system (aircrew) and is consistent with existing practices and procedures. Questionnaires: OK. Q1.3 All 12 participants agreed the division of responsibility between controllers and pilots will be acceptable. *NB – Objective not totally covered by validation exercise.*	
				• Pilot responsibility for maintaining safe operation remaining unchanged.	N/A. Not explicitly covered by validation exercise.	
VP-302	OBJ-06.08.01-VALP-0010-0070	To assess the impact of TBS tool support and operational procedures on the arrival runway	CRT-06.08.01-VALP-0010-0070	The landing rate under simulated TBS operations in strong headwind conditions shall:		**OK**

Exercise ID	Validation Objective ID	Validation Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Validation Objective Status
		capacity during strong wind conditions.		• Be shown to increase compared to the landing rate under simulated current day DBS operations in strong wind conditions;	Go-arounds (due spacing): OK. There was only one (not statistically significant) instance of a go-around during a matched run. No comments were specifically recorded pertaining to the go-around. Workload scores were low and Situation Awareness high. Late runway switches (due spacing): OK. There were no Spacing-related Late Runway Switches during the course of the Heathrow Tower exercise.	
				• Be shown to increase for all headwinds in excess of the conditions against which the TBS minima have been baselined;	Go-arounds (due spacing): OK. There was only one (not statistically significant) instance of a go-around during a matched run. Late runway switches (due spacing): OK. There were no Spacing-related Late Runway Switches during the course of the Heathrow Tower exercise. Landing Rate: OK. The traffic samples reflected the increased aircraft landing rates with TBS that had been evident during the Approach activity.	
				• Contribute to a delay saving per flight estimated as a function of the headwind on final approach and traffic mix; this gain shall be positive for all headwinds in excess of the conditions against which the TBS minima have been baselined.	N/A. Not explicitly covered by validation exercise. Deferred to the Business Case.	
VP-302	OBJ-06.08.01-VALP-0010-0080	To assess the impact of TBS tool support and operational procedures on the efficiency of operations.	CRT-06.08.01-VALP-0010-0080	NOT COVERED - not planned to be assessed.	Metrics, tools and other resources were not available to address this validation objective.	Not covered
VP-302	OBJ-06.08.01-VALP-0010-0090	To assess the impact of TBS tool support and operational procedures on the predictability of operations.	CRT-06.08.01-VALP-0010-0090	NOT COVERED - not planned to be assessed.	Metrics, tools and other resources were not available to address this validation objective.	Not covered

Exercise ID	Validation Objective ID	Validation Objective Title	Success Criterion ID	Success Criterion	Exercise Results	Validation Objective Status
VP-302	OBJ-06.08.01-VALP-0010-0100	To assess the impact of TBS tool support and operational procedures on environmental performance of aircraft in the hold and on final approach.	CRT-06.08.01-VALP-0010-0100	NOT COVERED - not planned to be assessed.	Metrics, tools and other resources were not available to address this validation objective.	Not covered
VP-302	OBJ-06.08.01-VALP-0010-0110	To assess the benefit-cost ratio for any investment needed for the deployment of TBS.	CRT-06.08.01-VALP-0010-0110	NOT COVERED - not planned to be assessed.	Metrics, tools and other resources were not available to address this validation objective.	Not covered

Table 10: Summary of Validation Exercises Results

4.1.1 Results on concept clarification

The main objective of TBS validation was to finalise the V3 maturity level – Pre-industrial development and integration; see Section 2.1 Concept Overview for full details.

4.1.2 Results per KPA

Validation results per KPA for VP-303 (TC Approach) are described in Section 6.1.3.1.2 Table 13: Results by KPA (VP-303).

Validation results per KPA for VP-302 (Tower) are described in Section 6.2.3.1.2 Table 37: Results by KPA (VP-302)

4.1.3 Results impacting regulation and standardisation initiatives

N/A

4.2 Analysis of Exercises Results

The measured positions, measures and how the analysis was performed, including any assumptions and limitations during analysis, for VP-303 (TC Approach) is detailed in Section 6.1.3.2.1.

The measured positions, measures and how the analysis was performed, including any assumptions and limitations during analysis, for VP-302 (Heathrow Tower) is detailed in Section 6.2.3.2.1.

4.2.1 Unexpected Behaviours/Results

Unexpected behaviours and results for VP-303 (TC Approach) are described in Section 6.1.3.2.12.

Unexpected behaviours and results for VP-302 (Heathrow Tower) are described in Section 6.2.3.2.12.

4.3 Confidence in Results of Validation Exercises

4.3.1 Quality of Validation Exercises Results

Quality of validation exercise results for VP-303 (TC Approach) is detailed in Section 6.1.3.3.1.

Quality of validation exercise results for VP-302 (Heathrow Tower) is detailed in Section 6.2.3.3.1.

4.3.2 Significance of Validation Exercises Results

Statistical and operational significance of the validation exercise results for VP-303 (TC Approach) are detailed in Section 6.1.3.3.2.

Statistical and operational significance of the validation exercise results for VP-302 (Heathrow Tower) are detailed in Section 6.2.3.3.2.

5 Conclusions and recommendations

5.1 Conclusions

Evidence from the Time Based Separation (TBS) Heathrow Approach and Tower validation exercises (VP-303 and VP-302) indicates that the TBS concept is viable and could deliver significant improvements and benefits for maintaining aircraft landing rates in stronger wind conditions.

However, issues with the prototype TBS tool software and changes in controller scanning focus resulted in slight but perceivable reductions in controller situation awareness; this was most apparent during the Heathrow Approach validation exercise (VP-303).

The most significant problems encountered were with the implementation of Tactical Enhanced Arrival Mode (TEAM) functionality, which affected the Heathrow Approach validation exercise (VP-303) to the extent where TEAM is not viable without faults being corrected and functional changes implemented. TEAM performed much better during the Heathrow Tower validation exercise (VP-302) as a result of experience gained from the Heathrow Approach validation exercise and fixes implemented to the prototype tool prior to the validation exercise.

The causes of the NOK validation results related to Parallel Dependent Runway Operations are understood and easily resolvable through small changes to the TBS tool functionality. These will be addressed through the V4 and V5 maturity steps.

Situation Awareness was slightly reduced with TBS compared to DBS, with the mean Situation Awareness scores for FIN being slightly below the acceptable lower limit. This will be addressed through the V4 and V5 maturity steps.

All aspects are sufficiently mature for transitioning to the V4 and V5 maturity steps.

Specific conclusions are detailed in Section 6.1.4.1 (VP-303) and Section 6.2.4.1 (VP-302).

5.2 Recommendations

Specific recommendations are detailed in Section 6.1.4.2 (VP-303) and Section 6.2.4.2 (VP-302).

6 Validation Exercises reports

6.1 Validation Exercise VP-303 (TC Approach) Report

The objective of this exercise was to validate the application of time based wake turbulence radar separation rules on final approach (TBS), so as to aid towards stabilizing the overall time spacing between arrival aircraft. The Heathrow Final Approach controller and the Tower runway controller (when available) were provided the necessary TBS tool support to enable consistent and accurate delivery to the TBS rules on final approach. The minimum radar separation and runway related spacing constraints were respected when applying the TBS rules.

6.1.1 Exercise Scope

See the Concept Overview in Section 2.1 in accordance with P6.8.1 Validation Plan for Time Based Separation (VALP) edition 00.01.03 [4]

6.1.2 Conduct of Validation Exercise

6.1.2.1 Exercise Preparation

The V&V platform used for the simulation was the real-time London Terminal Control (LTC) simulator at NATS CTC, Whiteley, Fareham. The positions indicated with yellow workstation numbers (see the figure below) were allocated to the TBS simulation. The measured positions were workstations R11, R12 and R13 for Heathrow (EGLL) INT S, FIN and INT N respectively. Heathrow Tower Air was positioned on workstation R7 on the days a tower controller was available.

Figure 1: TBS Approach Simulation Room Floor Plan

The secondary displays on three workstations (R7, R9 and R14) were used for Electronic Flight Data (EFD) display; this was essential for the Heathrow (LL) INT N Support position (R14) to enter and maintain the approach sequence for the Time Separation Tool (TST) to generate the TBS indicators. The INT N Support role was a simulation specific role and not representative of operations; the role was necessary because the simulation was paper operation rather than electronic as it would be in service. Paper strips were used by all measured control positions, including the TMA feeds and Heathrow Tower Air.

Radar recordings were captured on workstation R30 marked "RECORD". A visitor position (R9) was provided along with a Tower Air secondary display and partitioned from the measured positions to minimize visitor distraction to the measured controllers.

It had originally planned for the measured positions to be utilizing EFD displays, with the FIN EFD panel providing the sequence order into the TBS tool. However, due to the EFD programme delays this became an unviable option and had to revert to the measured positions using their familiar paper flight strips.

6.1.2.2 Exercise execution

The thirteen day TBS Heathrow Approach validation exercise was conducted from 11th February 2012 to 5th March 2012 on the LTC simulator at NATS CTC. A total of 51 simulation exercise runs were completed, of which six were for training; total simulation time was 46 ½ hours. Thirteen exercise runs were DBS as baselines for the matched TBS exercise runs; the remaining 38 exercise runs, including scenarios, were using TBS. Match runs were pairs of exercise runs with the same traffic samples with the same wind conditions and same controllers in the same measured positions, but conducted with DBS for reference and TBS for direct comparison; the first exercise run of the pair was alternated between DBS and TBS to mitigate any influence of running one method before the other. Daily timetables are provided in Appendix B.

Nine different traffic samples were used during the validation exercise (six westerly and three easterly samples). Details of the nine traffic samples, including the number of times run, are provided in the table below:

Traffic Sample Name	Anticipated Flow Rate (/hr)	Start Time	Traffic Mix Values (%)						Number of Runs
			J	H	UM	LM	L	S	
TBS1W	51	07:00	0	41	0	53	4	0	11
TBS2E	54	14:00	0	26	0	70	2	2	5
TBS3W	53	14:00	0	25	0	62	8	6	9
TBS4W	58	15:00	3	31	0	50	7	7	6
TBS5W	52	10:00	0	29	0	63	6	2	3
TBS6E	48	06:00	0	35	0	54	6	4	4
TBS8E	44	08:00	2	39	0	45	9	0	4
TBS9W	54	14:00	2	20	0	78	0	0	6
TBS11W	48	06:00	0	27	0	67	4	0	3

Table 11: Traffic Samples and number of times run – Easterly traffic samples shaded

Note: during the Customer Functionality Test (CFT) it was discovered that 'UM' wake category aircraft were being recognized by the prototype TST as 'LM' category, thus leading to incorrect wake vortex separation calculations. Because this could not be rectified in the TST in time for the Run for Record simulation, the 'UM' wake category aircraft were removed from the traffic samples.

The traffic samples were combined with 14 different wind scenarios ranging from light wind conditions to extremely challenging winds including headwinds, tailwinds, crosswinds and changing winds.

Wind	Type	Description	No. of Runs	Spacing Minimum
EC2	Easterly	Extreme Catch-Up - Tailwind at 3-4,000 ft.	2	2.5 Nm
EC3	Easterly	Easterly Pull-Away (Leader pulling away from Follower)	2	2.5 Nm
EC4	Easterly	Pull-Away Effect - Headwind backing to Crosswind	1	3.0 Nm
EN1	Easterly	Normal - Medium Wind Profile	5	2.5 Nm
EN3	Easterly	Normal - Medium Wind Profile	1	3.0 Nm
EV2	Easterly	Variable Decreasing Headwind - Strong Easterly headwind changing to medium crosswind.	2	2.5 Nm
WC1	Westerly	Westerly Pull-Away (Leader pulling away from Follower)	7	3.0 Nm
WC2	Westerly	Westerly Pull-Away (Leader pulling away from Follower)	3	2.5 Nm
WC3	Westerly	Strong Westerly Headwind - Catch-Up between Follower and Leader	7	2.5 Nm
WC4	Westerly	Tailwind	1	3.0 Nm
WC4*	Westerly	Tailwind - winds were multiplied by 2.5 to represent extremely strong crosswinds during turning on and the approach.	1	3.0 Nm
WN1	Westerly	Normal - Medium Wind Profile	11	2.5 Nm
WN2	Westerly	Still and Light Wind	1	3.0 Nm
WN3	Westerly	Normal - Medium Wind Profile	5	2.5 Nm
WV2	Westerly	Variable Decreasing Headwind - Strong Westerly headwind changing to medium crosswind	2	2.5 Nm

Table 12: Wind Profiles used – Easterly traffic samples shaded

The spacing minimum for each wind scenario was agreed with an operational Heathrow Tower controller prior to the start of the simulations; the agreed spacing minimum is shown in the table above.

Twelve matched runs were planned, with each matched pair to use the same traffic samples with the same controller seating in DBS exercise run and TBS exercise run for comparison; these exercise runs were scheduled as a priority and were completed on day 10 leaving three days as a reserve and for the remaining non-matched TBS scenarios. Eight different controllers were sat in the FIN position for the twelve matched runs to provide as wide a range of exposure and views as possible.

Nineteen specific scenario exercise runs were completed, which included seven exercise runs with Heathrow Tower manned and scenarios with the Tower controller. In summary, scenarios included the following: extreme catch up, pull away and crosswind conditions, light wind conditions, aircraft speed non-conformances, 3 Nm spacing, controller handovers, Tactical Enhanced Arrival Mode (TEAM – early morning and 6 aircraft per hour), runway inspections, blocked runways, missed approaches, aircraft emergencies, incorrect approach sequences and TBS indicator failure. Scenario coverage is listed in Appendix C.

A total of ten Heathrow Approach Controllers from LTC and one Heathrow Tower Controller were involved in the validation exercise simulations. Of the ten Heathrow Approach Controllers, four were only able to attend for one day because of operational commitments; these four controllers were not requested to complete the end of participation questionnaires because one day was considered insufficient exposure to TBS and the different positions (FIN, INT N and INT S). However, the four controllers who attended only one day fully contributed in every other respect, including End of Run questionnaires, expert observer forms and debriefs. Of the six other Heathrow Approach Controllers who attended for two or more days, one was non-operational having recently retired from operations, one other is a Group Supervisor (GS) Air and operational but no longer working on Heathrow Approach and has been closely involved with TBS through previous workshops and simulations. Both these controllers have extensive experience on Heathrow Approach and were deemed appropriate to include by the NATS ATC lead. Overall, the simulations had a good number and good mix of controllers and operational experience to assess TBS.

The figure below shows the Standard Arrival Routes (STARs) and Standard Instrument Departure (SIDs) for London Heathrow airport. This validation exercise focused on standard Westerly (runway 27R) and Easterly (runway 09L) approaches as the primary landing runways, with some TEAM exercise runs conducted with these as the main landing runways.

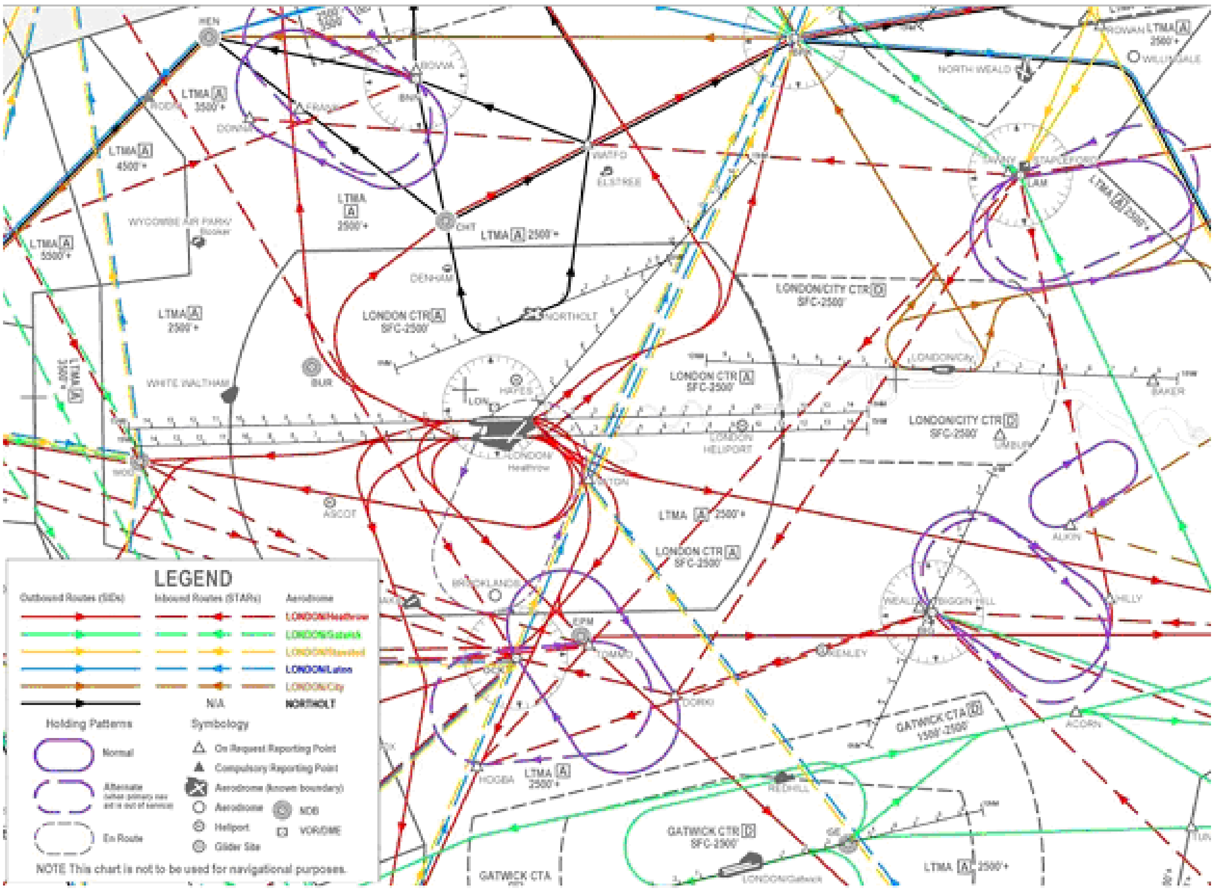


Figure 2: Airspace Information – EGLL Standard Arrival & Instrument Departure Routes

6.1.2.3 Deviation from the planned activities

Deviations from Planned Simulation Execution

Of the twelve planned matched runs (DBS vs. TBS), one matched pair (Match 1) needed to be re-run because of unrealistic aircraft behaviour early in the simulations on 12th February, which compromised the fidelity of that particular pair of exercise runs; 'Match 1' was rescheduled and successfully re-run on 29th February. The problem with unrealistic aircraft behaviour resulted from attempts to recreate aircraft non-conformance – unfortunately it proved extremely difficult to fully replicate realistic aircraft behaviour and non-conformance in the simulator and was not fully achieved (See **SCN09**) in Section 6.1.3.2.6 (OBJ-06.08.01-VALP-0010-0050).

The wind for scenario exercise run TBS123 was increased to present a very strong crosswind effect during the approach. From debriefs, it was commented that the participants had not assessed TBS with very strong crosswinds, which are experienced reasonably often in live operations. A tailwind profile with a crosswind (WC4) was modified during the simulation start up by multiplying the wind speeds by 2.5 to give crosswinds up to 59 knots at 4,000 feet during the approach.

The opportunity was taken to assess handovers at the Final Director Controller (FIN) position, which was not originally planned; TBS handovers were performed on exercise runs TBS082, TBS131 and TBS132.

Deviations from the Planned Analysis

During the simulation it was recognized that 'Match 4' TBS exercise run experienced significant problems with the TEAM functionality, which compromised the run (see TEAM scenarios **SCN26** and **SCN27** in Section 6.1.3.2.6); it was decided to exclude 'Match 4' from the analysis. Therefore, all matched run analysis was for single runway operations only.

The Madsen & Gregor Trust questionnaire was included as part of the end of participation questionnaire and analysis; this was not specifically stated for validation objective OBJ-06.08.01-VALP-0010-0040 in the Validation Plan, though it was decided and agreed before the simulation exercise to include it as an additional measure of trust in the TBS tool.

Handovers during TBS exercise runs meant that the analysis had to allow for the changeover of FIN controllers. Each FIN controller was provided an End of Run questionnaire, which meant for some exercise runs there were two FIN scores available. One match run (Match 1) had handovers at exactly the same time into the validation exercise run (35 minutes) for the DBS and TBS exercise runs; the separate FIN End of Run questionnaire scores were used in the analysis as they increased the data set.

The RTSA data did not permit fuel burn and CO_2 calculations for aircraft in the hold or from hold entry to touchdown. The calculations were conducted on aircraft pairs between DBS and TBS exercise runs from their point of origin in the validation exercise run to the point of touchdown on the runway at 80 feet above sea level. This covers the whole approach phase for each aircraft including any holding, if the aircraft was held, and CDA if feasible.

6.1.3 Exercise Results

6.1.3.1 Summary of Exercise Results

See *Table 9: Exercises execution/analysis dates* in Section 3.2 and *Table 10: Summary of Validation Exercises Results* in Section 4.1 for validation objectives, success criterion and hypotheses results.

6.1.3.1.1 Results on concept clarification

The main objective of TBS validation was to finalise the V3 maturity level – Pre-industrial development and integration; see Section 2.1 Concept Overview for full details.

6.1.3.1.2 Results per KPA

KPA	Success Criterion ID	Indicators	Validation Status
Safety	CRT-06.08.01-VALP-0010-0010	NOT COVERED - not planned to be assessed.	**OK** for Single Runway Operation **NOK** for Parallel Dependent Runways Operation (TEAM)
	CRT-06.08.01-VALP-0010-0015	NOT COVERED - not planned to be assessed.	
	CRT-06.08.01-VALP-0010-0020	Spacing at 4DME: OK. Losses of Separation: Generally OK. However, there was one Highly Under-separated aircraft pair with TBS in a match run compared to no losses with DBS. Under-separation: OK. No statistically significant increase in under-separation between TBS and DBS. Expert Observer: OK for single runway operations, NOK for TEAM functionality. Questionnaires: NOK. Controllers could not reach consensus that they could safely deliver aircraft to TBS minima and effectively monitor separation encroachment.	
	CRT-06.08.01-VALP-0010-0030	Expert Observer: OK. Questionnaires: OK. Debriefs: OK. CARS: OK. R/T Occupancy: OK.	
Human Performance	CRT-06.08.01-VALP-0010-0020	Spacing at 4DME: OK. Losses of Separation: Generally OK. However, there was one Highly Under-separated aircraft pair with TBS in a match run compared to no losses with DBS.	**OK** for Single Runway

		Under-separation: OK. No statistically significant increase in under-separation between TBS and DBS. Expert Observer: OK for single runway operations, NOK for TEAM functionality. Questionnaires: NOK. Controllers could not reach consensus that they could safely deliver aircraft to TBS minima and effectively monitor separation encroachment.	Operation **NOK** for Parallel Dependent Runways Operation (TEAM)
	CRT-06.08.01-VALP-0010-0030	Expert Observer: OK. Questionnaires: OK. Debriefs: OK. CARS: OK. R/T Occupancy: OK.	
	CRT-06.08.01-VALP-0010-0040	ISA Workload: OK. Bedford Workload: OK. CARS: OK. Madsen & Gregor Trust: Perceived Reliability NOK. SHAPE Teamwork (STQ-s): OK. China Lakes Situation Awareness: FIN – NOK, INT N & S and TWR – OK. NATS Confidence Diamond: OK. However, concerns were raised with the suitability, accuracy and reliability of the prototype TST software. NATS Picture Scale: OK. Debriefs: NOK. Situation Awareness was reduced with TBS for: aircraft types, wake vortex categories and actual distances between aircraft. A few controllers viewed the TBS indicators as "*clutter*", thus slightly increasing workload.	
	CRT-06.08.01-VALP-0010-0045	Debriefs: OK. Good training and experience with different wind conditions is needed to learn how best to use TBS. Madsen & Gregor Trust: Perceived Reliability NOK. SHAPE: OK. Controller Skill Levels and Training Needs not explicitly covered by validation exercise; deferred to HP assessment.	
	CRT-06.08.01-VALP-0010-0050	Questionnaires: OK. HMI design shape, colour, size & display priority all acceptable. CARS: OK. Debriefs: NOK. Overall, the indicators were considered to be intuitive and very useful to the Final Director Controller (**FIN**). However, the production TBS tool needs to address the functionality, accuracy, reliability and stability issues highlighted in this report. The required usability of the TBS controller tool support and the harmonised integration with the other approach and runway controller tools was not planned to be explicitly covered by the validation exercise.	
	CRT-06.08.01-VALP-0010-0060	Debriefs: NOK. Clarification of roles and responsibilities is required for Approach (FIN) & Tower runway controllers; highlighted due to the absence of Approach and Tower Supervisors during the validation exercise. Questionnaires: FIN & TWR – NOK, INT N & S – OK. Clarification of roles and responsibilities is required for FIN, INT N/S & TWR controllers in TBS operation. SHAPE: OK. Pilot responsibility for maintaining safe operation remaining unchanged was not planned to be explicitly covered by the validation exercise.	
Efficiency	CRT-06.08.01-VALP-0010-0020	Spacing at 4DME: OK. Under-separation: OK. No statistically significant	**OK** for Single

		increase in under-separation between TBS and DBS. Expert Observer: OK for single runway operations, NOK for TEAM functionality.	Runway Operation
	CRT-06.08.01-VALP-0010-0080	Spacing at 4DME: OK. Holding Times: OK. Statistically significant reduction in holding times. Hold to Touchdown: OK. Hold entry to touchdown times were slightly reduced with TBS. Landing Rates: OK. Statistically significant increase up to +5 a/c per hour, mean of +2 a/c per hour. Landing Times: OK. Statistically significant reduction in holding times, and hold entry to touchdown times. Questionnaires: NOK. Controllers did not all agree they could issue accurate DTT advice using TBS for continued employment of CDAs and LP/LD procedures. Expert Observer: NOK. Controllers did not all agree they could issue accurate DTT advice using TBS.	**NOK** for Parallel Dependent Runways Operation (TEAM)
Capacity	CRT-06.08.01-VALP-0010-0070	Landing Rates: OK. Statistically significant increase up to +5 a/c per hour, mean of +2 a/c per hour. Landing Times: OK. Statistically significant reduction in holding times, and hold entry to touchdown times.	**OK**
Predictability	CRT-06.08.01-VALP-0010-0090	Landing Rates: OK. Statistically significant increase up to +5 a/c per hour, mean of +2 a/c per hour.	**OK**
Environment	CRT-06.08.01-VALP-0010-0100	Holding Times: OK. Statistically significant reduction in holding times. Landing Times: OK. Statistically significant reductions in hold times and hold entry to touchdown times. Hold to Touchdown: OK. Hold entry to touchdown times were slightly reduced with TBS. Fuel burn and CO_2 emissions: OK. Statistically significant fuel burn and CO_2 reductions with TBS compared to DBS. Be within acceptable limits in terms of Leq noise contours was not planned to be explicitly covered by the validation exercise. Be within acceptable limits in terms of Lmax noise was not planned to be explicitly covered by the validation exercise.	**OK**
Cost Effectiveness	CRT-06.08.01-VALP-0010-0110	NOT COVERED - not planned to be assessed.	N/A
Acceptability	CRT-06.08.01-VALP-0010-0120	NOT COVERED - not planned to be assessed.	N/A

Table 13: Results by KPA (VP-303)

6.1.3.1.3 Results impacting regulation and standardisation initiatives

N/A

6.1.3.2 Analysis of Exercise Results

Validation Exercise results summary is provided in Section 4.1 Table 10: Summary of Validation Exercises Results.

6.1.3.2.1 Measured Positions, Measures and Analysis

The measured controller positions for all 'Run for Record' exercises runs were as follows:

- Heathrow (EGLL) Final Director Controller (**FIN**);
- Heathrow (EGLL) Intermediate Controller – North (**INT N**);
- Heathrow (EGLL) Intermediate Controller – South (**INT S**);
- Heathrow (EGLL) **Tower** Runway Controller (**TWR**) when manned.

Note: measures were not collected for pseudo pilots because they were not trained aircrew, did not have representative cockpit equipment and acted as multiple pilots for the different aircraft to make any measures viable in terms of assessing pilot performance. The only metric collected from the pilot perspective was R/T occupancy (Rx - Receive) as a measure of workload on the frequency.

After each exercise run for record exercise, every participant on each measured position completed an End of Run questionnaire for all measured TBS and DBS exercise runs. End of Run questionnaires provide evidence for validation objectives OBJ-06.08.01-VALP-0010-0030, 06.08.01-VALP-0010-0040, 06.08.01-VALP-0010-0050. The End of Run questionnaires collected evidence for Workload (**Bedford Workload** scale), **Situation Awareness (China Lakes scale**) and the **NATS Picture Scale** during the validation exercise run. The questionnaires also included a box for comments or clarification of scores.

Controller Acceptance Rating Scale (CARS) and the **NATS Confidence Diamond** questionnaires were completed by controllers at the measured positions for all TBS exercise runs. The CARS and the NATS Confidence Diamond questionnaires provide evidence for validation objectives OBJ-06.08.01-VALP-0010-0030, 06.08.01-VALP-0010-0040 and 06.08.01-VALP-0010-0050.

Expert Observations of the Heathrow Final Director Controller (FIN) role were obtained for 26 individual TBS exercise runs with 8 different Heathrow Approach controllers as FIN. The expert observer questionnaires asked seven specific questions, each directly linked to validation objectives, and space was provided for comments and clarifications. The results from expert observations provide evidence for validation objectives OBJ-06.08.01-VALP-0010-0020, OBJ-06.08.01-VALP-0010-0030 and OBJ-06.08.01-VALP-0010-0080.

Structured Debriefs were conducted after every individual exercise run, with a more detailed debrief at the end of the day; a debrief checklist was used to ensure coverage of the key items. Debrief information provides evidence for validation objectives OBJ-06.08.01-VALP-0010-0020, OBJ-06.08.01-VALP-0010-0030, 06.08.01-VALP-0010-0040, 06.08.01-VALP-0010-0045, 06.08.01-VALP-0010-0050, 06.08.01-VALP-0010-0060 and OBJ-06.08.01-VALP-0010-0080.

Two types of **End of Participation questionnaire** were prepared and used – one for the Heathrow Approach controllers (FIN, INT N & INT S) and the other for Heathrow Tower Runway controllers. The End of Participation questionnaires were specifically tailored to address the validation objectives with direct and indirect questions relating to the validation objectives. End of Participation questionnaires provide evidence for validation objectives OBJ-06.08.01-VALP-0010-0020, OBJ-06.08.01-VALP-0010-0030, 06.08.01-VALP-0010-0040, 06.08.01-VALP-0010-0045, 06.08.01-VALP-0010-0050, 06.08.01-VALP-0010-0060 and OBJ-06.08.01-VALP-0010-0080.

The **Madsen & Gregor (M&G) Trust questionnaire** was included in the End of Participation questionnaires. The results from this questionnaire provide evidence for validation objectives OBJ-06.08.01-VALP-0010-0045 and OBJ-06.08.01-VALP-0010-0060. The Madsen & Gregor Trust questionnaire was completed by six Heathrow Approach controllers and the one Heathrow Tower Runway controller.

The **SHAPE Teamwork (STQ-s) questionnaire** was included in the End of Participation questionnaires. The results from this questionnaire provide evidence for validation objectives OBJ-06.08.01-VALP-0010-0045 and OBJ-06.08.01-VALP-0010-0060. The SHAPE Teamwork (STQ-s) questionnaire was completed by six Heathrow Approach controllers and the one Heathrow Tower Runway controller; the scores are combined.

All system data analysis excludes the '**run in time' of 10 minutes** – this was decided before the simulation and confirmed as the appropriate 'run in period' during the simulations. The 'run in time' is the time taken for the landing sequence to stabilize on the final approach, i.e. to achieve a steady and established approach sequence as experienced in operations.

All separations were measured at the point the lead aircraft crossed 4DME and measuring the distance between the lead aircraft and the follower aircraft. **Separation Accuracy** was calculated by subtracting the required separation minima (DBS or TBS rules) from the achieved spacing.

Analysis was undertaken using the comparative DBS and TBS data from eleven matched runs. Two methods of comparative analysis were used:

1. **'Box and Whisker' charts** showing the Median, Upper and Lower first quartile (25^{th} percentile), and the Maximum and Minimum scores recorded for each measure. The Upper and Lower first quartiles with the Median are shown as blue boxes on the charts in this document.
2. **Wilcoxon Signed-Rank Test for Statistical Significance**. The Wilcoxon Signed-Rank Test is a non-parametric statistical test for testing hypothesis to determine if two medians differ for match runs. The tests were conducted at the 95% significance level. No charts or tables for this analysis are provided within this report, statistical significance is reported in the supportive text to the 'Box and Whisker' charts to indicate the importance of the results.

Not all 'Box and Whisker' charts have been included in this report; the reason for this is in most cases the comparative results between DBS and TBS are identical and there would be little value in including these charts. This report focuses on the measures that demonstrate differences between DBS and TBS and endeavours to explain these differences and their significance.

6.1.3.2.2 Safe Delivery of Aircraft to TBS Minima

OBJ-06.08.01-VALP-0010-0020 This section presents the results for the objective: "*To assess whether the Final and Intermediate Approach Controller can safely deliver aircraft to TBS minima in all wind conditions using the TBS tool support.*"

Summary: Aircraft separation accuracy for Wake pairs at 4DME between DBS and TBS shows a clear and statistically significant improvement with TBS compared to DBS for all eleven matched exercise runs analysed; there was no improvement with TBS compared to DBS for Non-Wake pairs. However, overall TBS performed generally better than DBS. One Highly Under-separated event was recorded with TBS in a match run (0.25%), no Highly Under-separated events with DBS (0%). There was no statistically significant increase in under-separation between Stack exit and 4DME with TBS (9.25%) when compared to DBS (17.15%). Indeed, overall TBS performed better than DBS. Expert Observer results indicate TBS is acceptable for single runway operations, but not acceptable for Parallel Dependent Runway operation (TEAM) functionality. Controllers could not reach consensus that they could safely deliver aircraft to TBS minima and effectively monitor separation encroachment, primarily because of the change in scanning focus onto the TST indicators and away from the flight strips, which affected Situation Awareness. However, results indicate that the TST indicators provided clear spacing indications. Overall, the results indicate the TBS concept is viable, but the prototype TST software highlighted the need for high levels of tool accuracy and reliability for safe operation.

Spacing at 4DME

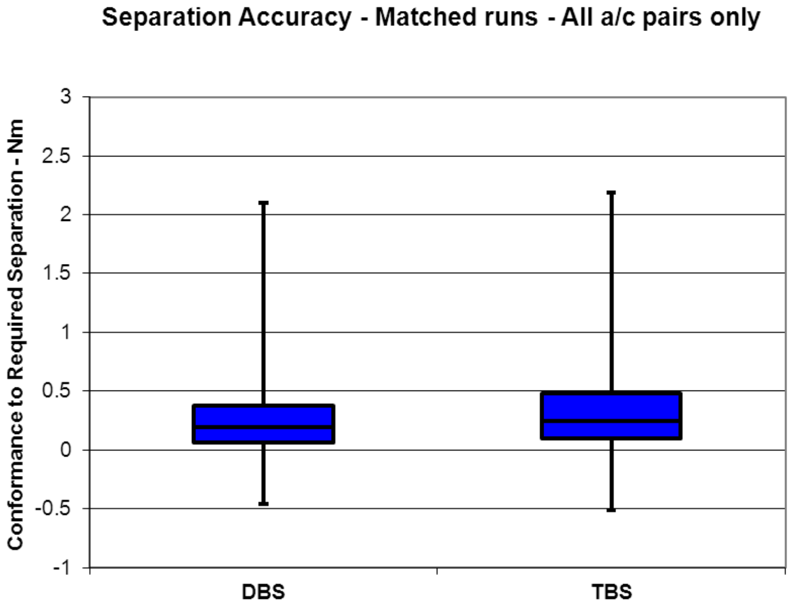


Figure 3: Separation Accuracy at 4DME – All Matched Runs

Aircraft separation accuracy at 4DME between DBS and TBS were almost identical for all eleven matched runs analysed (Match 4 excluded); see the 'Box and Whisker' chart above. Separation accuracy was analysed using the DBS separation rules and TBS calculated minimum separation (indicator position). The Medians are almost identical, though there is a slightly wider spread with the first quartile (25^{th} percentile) and the maximum and minimum separations with TBS, indicating less consistency with separation accuracy. Using the Wilcoxon Signed-Rank Test, the differences in separation accuracy are not statistically significant.

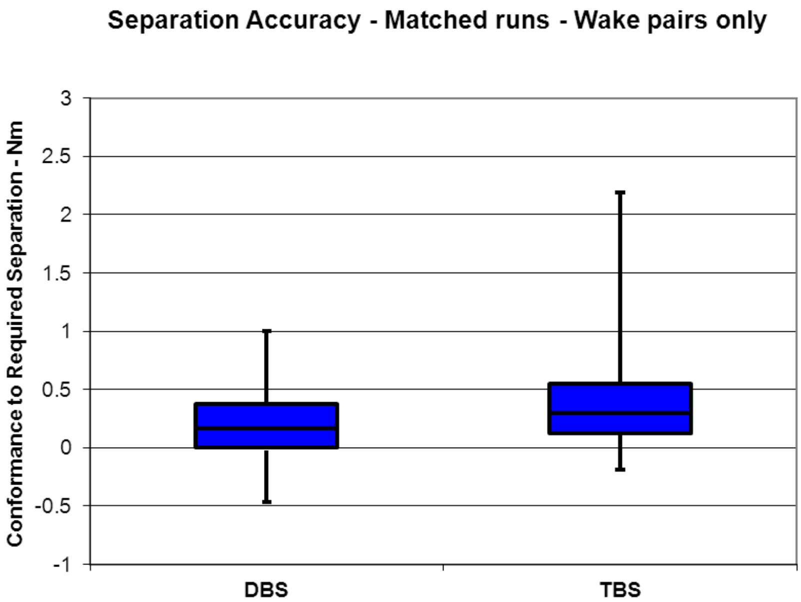


Figure 4: Separation Accuracy at 4DME – Wake Pairs

Aircraft separation accuracy at 4DME between DBS and TBS for Wake pairs only shows a clear and statistically significant improvement with TBS compared to DBS; there were fewer under-separation events with TBS. However, the spread of separation accuracy was wider with TBS, particularly for over-separation with some aircraft pairs over 2 Nm over-separated.

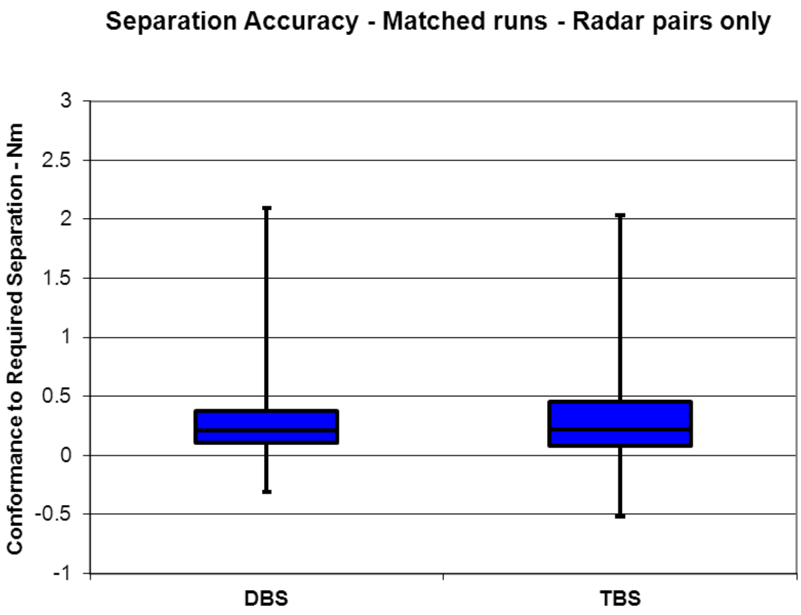


Figure 5: Separation Accuracy at 4DME – Non-Wake pairs

Aircraft separation accuracy at 4DME between DBS and TBS for Non-Wake pairs only were similar with no statistically significant differences.

Losses of Separation

Time Separation Tool (TST) Measured Separation – One Highly Under-Separated Pair

Only one measured highly under-separated aircraft pair on approach was recorded with TBS during all the formal measured exercise runs; a highly under-separated pair is defined as '*>0.5 Nm under Wake / 2.5 Nm*' (Validation objective OBJ-06.08.01-VALP-0010-0020). Loss of separation was analysed by measuring the separation between Leader and Follower aircraft as the Leading aircraft passes 4DME and comparing with the required minimum separation as calculated by the Time Separation Tool (TST); either 2.5 Nm or 3 Nm as set for the wind conditions, or Wake separation as per the wake vortex for the Leader and Follower.

The loss of separation occurred during TBS Match run 7 (Run ID. TBS073) and was only just over the >0.5 Nm limit. Charts of Separation Accuracy Passing 4DME are provided in Appendix D and includes TBS Match run 7.

The Final Director Controller (FIN) noted the following comments after the validation exercise run: "*Felt more 'uncomfortable' than the DBS run. Took a while to work out the best technique to employ. Less monitoring of the actual lateral separations / WV gaps required.*" Note: the DBS exercise run was run before the TBS exercise run in this instance.

The Expert Observer noted the following while observing the FIN controller on TBS Match run 7: "*Tendency to be less aware of lateral distance between aircraft than would be the case with DBS. Also less aware of aircraft types or vortex categories. In short, less situational awareness than when using DBS.*"

The FIN controller scored slightly high on Bedford Workload (4) and slightly low on both China Lakes Situation Awareness (7) and CARS User Acceptance (7). The FIN controller also scored mid-scale on all five NATS Confidence Diamond questions, indicating lower confidence in the system.

It can be concluded from the evidence that the cause of the loss of separation on approach during the validation exercise was the result of reduced Situation Awareness and a slightly higher workload caused by uncertainty over the best technique to employ with TBS. This was the controller's third run with TBS as Final Director Controller (FIN) and from the comments it is evident that they were still learning and determining the best technique to use with TBS.

DBS Matched Runs – No Highly Under-Separated Pairs

No highly under-separated aircraft pairs on approach were recorded or observed during the DBS exercises for the matched runs; some events were recorded for joining the ILS centreline, but not once established on ILS – see **Wake Separation during ILS Join** below.

Wake Separation – One Observed Highly Under-Separated Pair

In addition to the Time Separation Tool (TST) log calculated loss of separation during a matched run; there was one additional observed highly under-separated aircraft pair through being under wake vortex separated; TBS scenario exercise run (Run ID. TBS121) – see the explanation of the causal error in **Time Separation Tool (TST) Observed Faults** 'Incorrect Calculation of Time Based Separation' in Section 6.1.3.2.12. The main analysis was reliant on TST accuracy in terms of the TST having calculated the correct minimum separation between Leader and Follower aircraft, including Wake separation. For further information about the scenario see 'Usability of the TBS Controller Tool Support HMI' Section 6.1.3.2.6 Scenario **SCN20**. In this instance with 2.5 Nm Separation between two heavy category aircraft, resulting in an under-separation of approximately 1.0 Nm on the Time Based wake vortex separation. To mitigate the risk of incorrect separation displayed by TBS, controllers need to be provided the means to quickly check the credibility of the indicated spacing for the aircraft types and vortex categories and the wind conditions; this needs to be incorporated into training and procedures and may require some system modifications to more clearly highlight the aircraft types/vortex categories.

Percentage Under-Separation at 4DME

Two classes of under-separation were analysed using the system and TST log data: Highly Under-separated defined as '*>0.5 Nm under Wake / 2.5 Nm*', and Under-separated defined as less than the required separation but <0.5 Nm under Wake / 2.5 Nm. Results from the matched runs are shown in the table below as percentages of under-separation for all aircraft in the match runs, in accordance with the validation objective.

	TBS	DBS
Under-Separated	9.75%	17.15%
Highly Under-Separated	0.25%	0.00%

Table 14: Under-Separation Percentages for TBS and DBS

As illustrated in the table above, although there was one highly under-separated event with TBS and none with DBS, the percentage of under-separation was almost half with TBS compared to DBS. This indicates that with the TBS indicators as a visual reference, the controllers were able to provide improved separation overall in TBS operation compared with DBS.

Analysing Wake and Non-Wake under-separation events further, the results demonstrate a statistically significant reduction of Wake under-separation with TBS compared to DBS; with TBS there were 11 Wake under-separation events (2.76%) compared to 43 with DBS (11.35%). A significant proportion of the Wake under-separation events with DBS were during matched runs 10, 11 and 12 which were the only three Easterly operations matched runs conducted; matches 10 and 11 had different traffic samples with the same wind EN1. These three Easterly operations matched runs had a large impact on the statistical significance of the results, which would not be statistically significant if their results were of a similar nature to the Westerly operations matched runs. Non-Wake under-separation events varied between matches but were overall similar and not statistically significant in the differences.

In conclusion, the use of TBS indicators demonstrates a statistically significant reduction of Wake under-separation events compared to DBS, especially for Easterly operations.

Separation during the Approach Phase – Stack Exit to 4DME

To address the objective "*The number of losses of separation on approach when using TBS shall not show a statistically significant increase when compared to DBS operations*", conflict analysis was carried out. The tool compares the tracks of the aircraft and determines if there was breach of the relevant separation rule. The rule applied in this case was a lateral separation of 2.5 Nm, with a vertical separation of 1,000 feet.

The analysis was intended to assess any losses of separation during the phase of flight from approximate stack exit to base leg. As such, therefore, the results were filtered to include any conflicting pairs of aircraft below 7,000 feet but above 1,300 feet (as approximations of stack exit to 4DME). The results are presented in the table below:

Altitude limits: >1300 ft and < 7000 ft		
Run Type	**DBS**	**TBS**
Match1	1	0
Match2	1	2
Match3	5	0
Match5	4	2
Match6	6	4
Match7	9	9
Match8	0	3
Match9	2	8
Match10	1	1
Match11	3	3
Match12	0	1
Totals:	**32**	**33**

Table 15: Conflict Analysis with 2.5 Nm and 1,000 feet Separation – Stack Exit to 4DME

The results indicate that although there are some variations in separation between DBS and TBS matched runs, the total 'conflicts' measured between approximate Stack exit and 4DME are almost identical. However, the change in total 'conflicts' is not statistically significant; tested using the Wilcoxon Signed-Rank Test. This indicates there is no statistically significant increase in losses of separation between Stack exit and 4DME with TBS when compared to DBS operations.

Wake Separation during ILS Join

Analysis of highly under-separated events of Wake aircraft pairs joining the ILS indicates that TBS performed very slightly better than DBS; however this is not statistically significant because there is insufficient data for a statistical significance test. Five highly under-separated Wake events were recorded during the 11 Matched exercise runs; 3 events with DBS and 2 with TBS. Details of these events are provided in the table below:

Leader	Follower	Mode	ILS Join Separation	Separation Minima	Separation Accuracy	Exercise ID	System Time	Wind
BAW114	BAW72	TBS	3.08	3.9	-0.77	TBS051	07:26:53	WC1
ETD017	UAE3	TBS	3.26	3.9	-0.59	TBS052	14:16:36	WC1
MAS4	BMA448	DBS	4.49	5	-0.51	TBS071	14:42:20	WC3
ANA201	SHT3L	DBS	4.42	5	-0.58	TBS091	14:28:24	EN1
ACA858	BAW853	DBS	4.43	5	-0.57	TBS092	07:52:28	EN1

Table 16: Highly under-separated Wake events in Matched exercise runs – Joining ILS

Each highly under-separated Wake event on joining ILS occurred during a separate exercise run. Notably, the two TBS events occurred with the same wind scenario WC1 with Westerly Pull-Away conditions. Two of the DBS events occurred with the same wind scenario EN1, which were normal Medium wind profiles; the third DBS event occurred with wind scenario WC3, which was a strong Westerly headwind giving catch-up between follower and leader aircraft. Overall, comparison of highly under-separated events of Wake aircraft pairs joining the ILS is inconclusive in terms of establishing any difference between DBS and TBS.

Expert Observations

The expert observer questionnaires asked seven specific questions, each directly linked to validation objectives, and space was provided for comments and clarifications. Questions relating to this section are shown in the table below.

Question	Always	Mostly	Sometimes	Rarely	Never
Q.1 Final Approach Controller employs safe vectoring techniques and standard controller practices.	23	2	1	0	0

Table 17: Expert Observation Results Summary – Safe Delivery of Aircraft to TBS Minima

As can be seen from the table above, Question 1 was primarily responded to as 'Always'. Significantly, there were scored no 'Rarely' or 'Never' responses from any expert observer and only one 'Sometimes' recorded, indicating there are no fundamental problems with either the TBS concept or the tool. However, in terms of answering the question in this section for safe delivery of aircraft to TBS minima, the responses were not a unanimous 'Always', which indicates there are some issues to resolve.

Of the three not-'Always' responses, all three were reported for different FIN controllers and by three different expert observers; consequently there is no correlation to the individuals involved. Two of the responses relate to TEAM functionality, which from other measures is known to be problematic. One expert observer noted the following during one of the TEAM exercise runs: "*Easy to miss vortex as concentrating on the chevrons. Comments of 'It feels like a computer game'*." Another expert observer noted the following during the other TEAM exercise: "*Very uncomfortable going for the TBS-displayed minimum for TEAMers. (Esp. crossing TEAM). NJE533G TBS indicator briefly flipped onto 27R before reverting to 27L*."

The third not-'Always' response, which was from a TBS Match run for single runway operations, had the following comments noted by the expert observer: "*The 'indicator' seemed to be quite distracting. There also seemed to be a tendency to 'catch' the indicators if slightly behind it, which could lead to keeping aircraft unrealistically fast. This may lead to unstable approach*." Note: this was the Expert Observer's first exposure to TBS and therefore an early opinion while they were still learning how TBS works in practice.

Overall the Expert Observation results are favourable for TBS operations with single landing runway operation. Parallel Dependent Runway operation (TEAM) functionality needs to be resolved to address the concerns highlighted by the expert observers and the other measures.

Questionnaires

End of Participation Questionnaires

Summary tables for Heathrow Approach controllers and Heathrow Tower Runway controllers are provided below:

Question	Yes	Possibly (with improvements)	No
1.2 As a Final Director could you safely deliver aircraft to TBS minima using the Time Separation Tool?	3	3	0
1.4 As FIN, were you able to monitor for separation encroachment when using TBS?	3	2	0

Question	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
3.2 The required spacing between aircraft was clear to me when using TBS.	0	0	1	5	0

Table 18: Heathrow Approach Controllers End of Participation – Safe Delivery of Aircraft to TBS Minima

Six of the ten Heathrow Approach controller participants completed the End of Participation questionnaire; four controllers only attended one day, which was considered insufficient exposure to TBS and the measured positions to contribute.

The End of Participation results for Heathrow Approach controllers indicate that the TBS concept and HMI is generally acceptable, though improvements are required. Overall there were mixed views in response to the three questions related to this objective, indicating that some controllers felt that improvements were required to safely deliver aircraft to TBS minima using the prototype TBS tool, or effectively monitor separation encroachment. The controllers mostly agreed that TBS clearly indicated the required spacing between aircraft, therefore Question 3.2 is acceptable.

The following controller comments were received in the End of Participation questionnaires for Questions 1.2 and 1.4, for which the majority of controllers could not reach consensus. There were several very positive responses to the questions. However, to understand the areas for improvement only the specific responses identifying issues encountered are listed below:

Question 1.2 "*As a Final Director could you safely deliver aircraft to TBS minima using the Time Separation Tool?*"

- "*Yes, it is possible to deliver to TBS minima (which is 2.5nm?) as at present, but it relies again on adequate speed adherence by aircrews; and trust in the TBS tool. On one exercise, I vectored H-H* (Heavy to Heavy) *2.5nm apart without hesitation which caused me to re-evaluate my trust in the tool.*"
- "*I feel there is an overall reduction in situational awareness particularly of separation between aircraft and of aircraft types and hence characteristics, all of which have safety implications*."
- "*Issue of clutter on the screen. Also feel that even with training there still may exist a misconception with what the tool provides, for example, where the FIN still needs to compensate for excessive compression within 4DME*."

Question 1.4 "*As FIN, were you able to monitor for separation encroachment when using TBS?*"

- "*You started to disregard (not notice what separation was) and just look at what the marker wanted you to get. If you were looking at actual separation, it was too cluttered!*"
- "*I did feel that any under-separation was noticed particularly whilst at circa 8 - 15 DME, but further down the approach I was less aware.*"
- "*With TEAM aircraft and 2.5 nm Non-Wake pairs especially I felt it was easy to lose awareness of separation between aircraft particularly when one or both were on intercept headings, and also when one established and the follower on base leg*."

In summary, there are some important issues to address from the End of Participation results: **Situation Awareness** of aircraft types and wake categories and correct separation between leader and follower aircraft; **Controller Trust** in the TBS tool through providing a highly accurate and reliable tool yet still providing controllers the means to detect incorrectly displayed spacing; **Training** to address the impressions of 'clutter' with the TBS indicators, the change in scanning focus onto the TST indicators and away from the flight strips affecting Situation Awareness, and the means and capacity to monitor under-separation inside 8DME.

Question	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
3.2 The required spacing between aircraft was clear to me when using TBS.	0	0	0	1	0

Table 19: Heathrow Tower Runway Controller End of Participation – Safe Delivery of Aircraft to TBS Minima

Only one Heathrow Tower Runway controller was available for the simulations, during which they attended two days. The Heathrow Runway controller role will be specifically assessed during forthcoming simulations with exercise 06.080.01 VP-302.

The End of Participation results for Heathrow Tower Runway controller suggest that the TBS concept is generally useful and acceptable.

End of Run Questionnaires

The following sections report results for metrics from the End of Run questionnaires.

NATS Confidence Diamond

The NATS Confidence Diamond has five scales with separate questions, the fifth scale asking for an overall confidence rating for the TBS system. The five questions were as follows:

1. I am comfortable with the procedures and policy of use associated with this system;
2. I feel well trained in the use of this system;

3. I am sure I can work well with my team when using this system;
4. I believe that the software supporting this system is suitable for my job and tasks;
5. Please rate your overall confidence in this system as a whole.

The results from these scales are presented in two charts in the two figures below. The first reports on scales/questions 1 to 4 (grouped by question for each of the four measured roles), the second chart presents the overall confidence in this system for each measured role. The acceptable lower limit for each scale is 7.

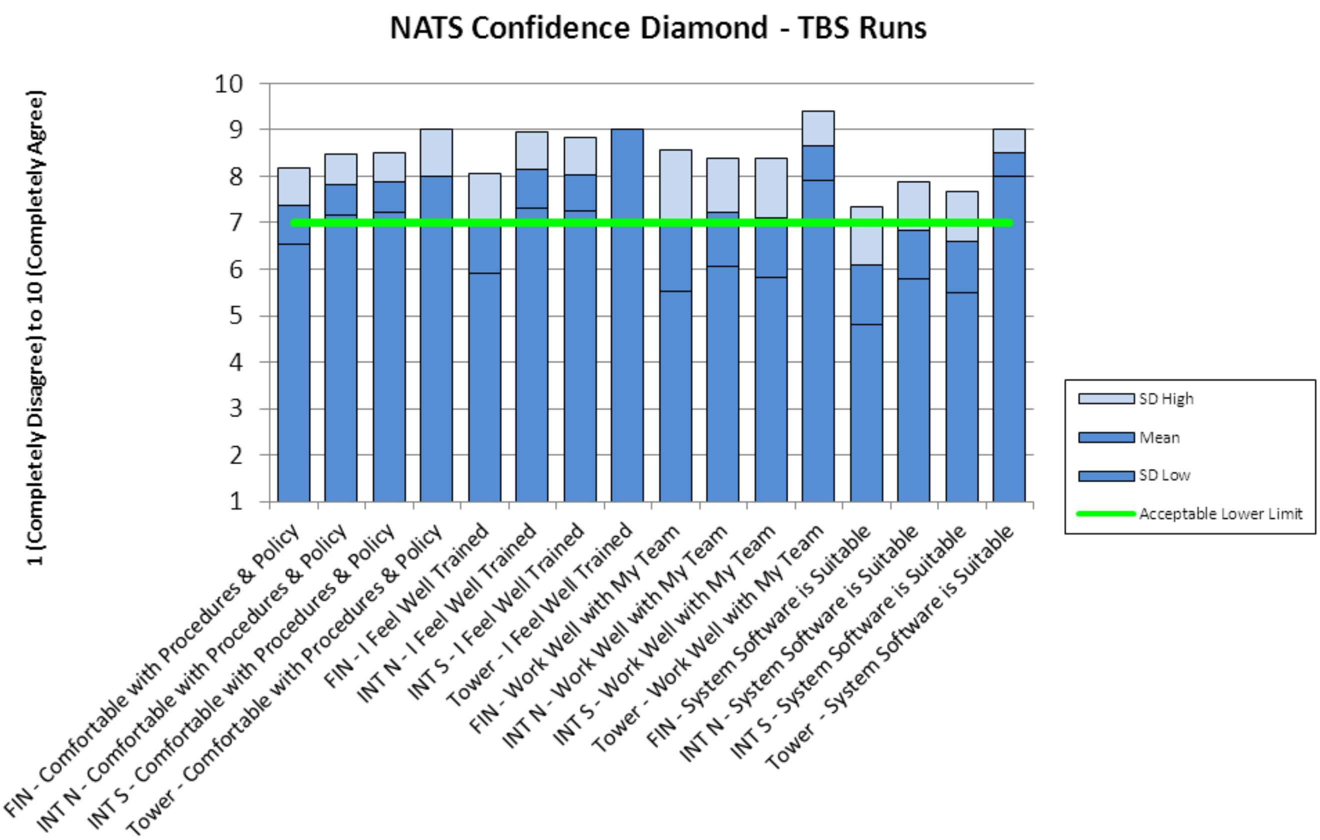


Figure 6: NATS Confidence Diamond Questions – all measured exercise runs for each role

Results for scales/questions 1 to 4 indicate that most scales are above the acceptable lower limit. However, three scales/questions fall below the acceptable lower limit, all three concerning the suitability of the supporting TST software for the FIN, INT N and INT S roles respectively. From the End of Run questionnaires there is a correlation between lower team working scores and confidence in the simulation prototype TST software and the TBS system overall; i.e. when the controllers felt the TBS tool had not performed so well then in addition to scoring low on software and the TBS system overall they also scored lower for team working.

From debriefs and questionnaires the controllers had already highlighted TST and simulation concerns as follows:

- A number of occurrences of incorrect aircraft approach sequences causing TBS indicators to be displayed in the wrong order;
- A TBS "*Tool error showing Heavy - Heavy gap as 2.5 Nm*" whereas it should have been about 3.5 Nm in the wind conditions (4 Nm with current DBS operation);
- TEAM functionality for 2 Nm not-in-trail lateral separations worked as specified. However, the validation exercise revealed that 2 Nm lateral separations were insufficient to allow for compression and that 2.5 Nm was a more appropriate distance. In addition, the not-in-trail

TBS indicators (chevrons) were sometimes momentarily observed to jump runway centrelines instead of switching runways and remaining on the correct runway centreline.

- The display of in-trail Wake separation for TEAM did not work as specified; in-trail Wake indicators were not displayed when they should have been.

Four scales/questions are border-line for acceptability. The first concerns the FIN controller feeling well trained in the use of the TBS system. From debriefs and questionnaires it is believed this relates to human intuition to use the TBS indicators as a 'target' rather than a reference; the phrase "*if it looks like a target, I'll use it like a target*" was used repeatedly. This aspect needs to be specifically addressed with training in the use of spacing practice with TBS indicators in a variety of wind conditions to become used to how TBS performs with different winds.

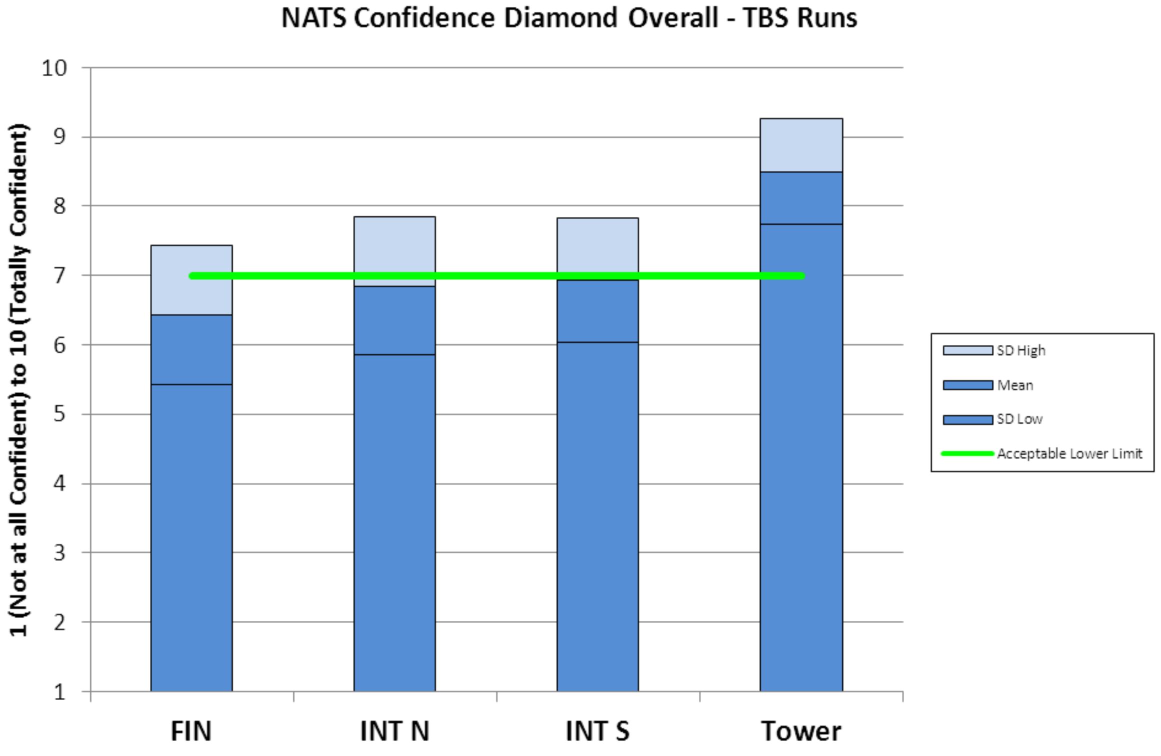


Figure 7: NATS Confidence Diamond Overall – all measured exercise runs for each role

Results for overall confidence in the TBS system show that the FIN controller role falls just below the acceptable lower limit. The INT N and INT S roles are border-line for acceptability.

The Heathrow Tower controller role is acceptable. It should be noted that only one Tower participant was involved in the validation exercise, the aim was to add more realism to the Approach controllers on FIN, INT N and INT S. A separate validation exercise will be undertaken to assess the impact upon tower performance and roles and responsibilities.

China Lakes Situation Awareness

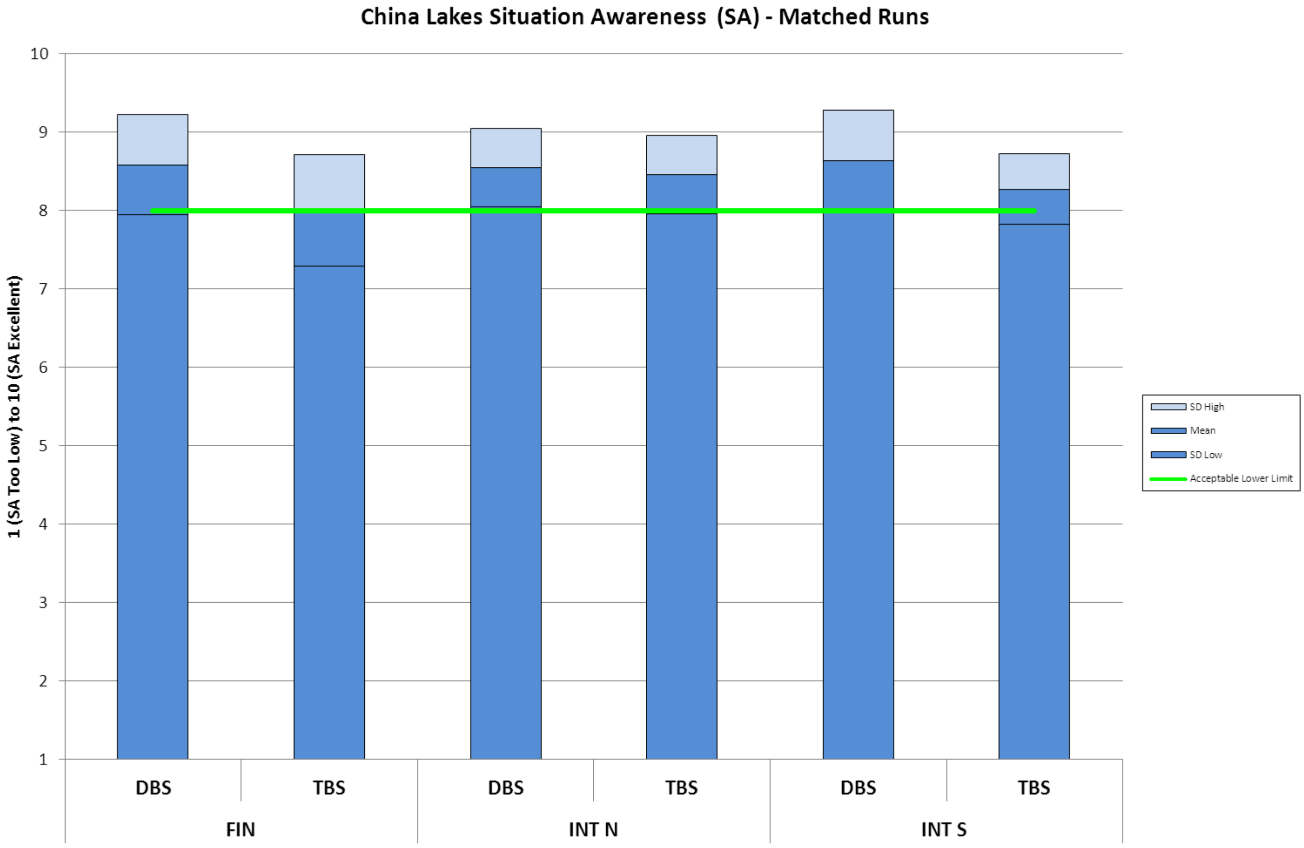


Figure 8: Situation Awareness (SA) – Matched exercise runs for Approach Controllers

The results from the matched exercise runs for China Lakes Situation Awareness indicate that all roles are comfortably above the acceptable limit except for the Final Director Controller (FIN), which is exactly on the lower limit. The Situation Awareness for FIN was reduced with TBS compared to DBS, which corresponds to other metrics. The INT N and S roles were generally unaffected with TBS.

Definitions of the China Lakes Situation Awareness scale higher scorers are provided below:

9 My SA with respect to the task was very good. I was able to perform the task well all of the time.

8 My SA with respect to the task was good. I was able to perform the task well most of the time.

7 My SA with respect to the task was not complete. I was able to perform the task, but not satisfactorily.

Comparative DBS and TBS Situation Awareness scores for the Final Director Controller (FIN) indicate a slight but not statistically significant reduction in Situation Awareness using the Wilcoxon Signed-Rank Test. Comparative DBS and TBS Situation Awareness scores for the INT N and S roles were identical.

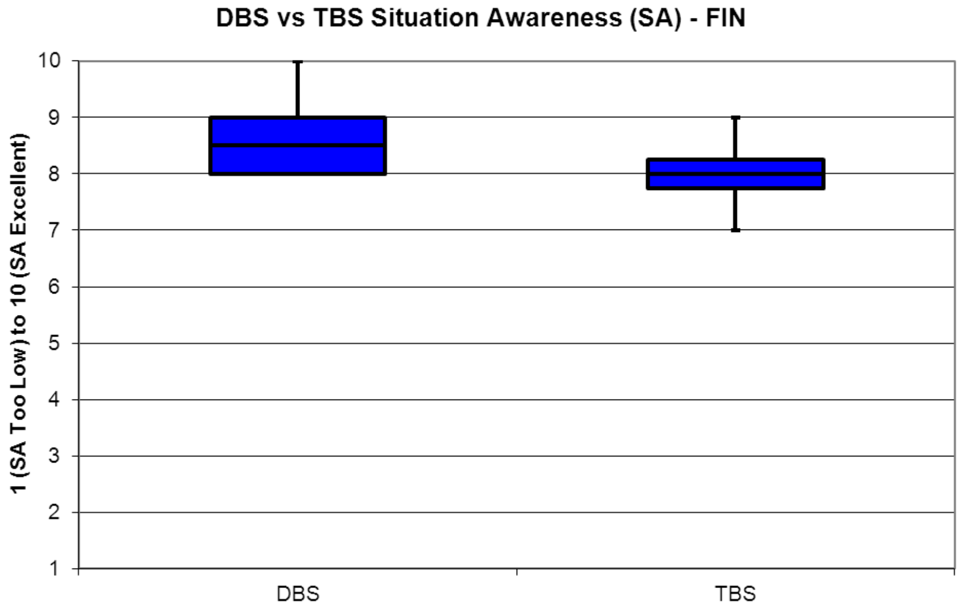


Figure 9: China Lakes Situation Awareness Scores for FIN

Situation Awareness was slightly reduced with TBS compared to DBS; see the 'Box and Whisker' chart above. With TBS, the Median was reduced from 8.5 to 8 (the acceptable lower limit) and the first quartiles (25^{th} percentile) were closer to the Median. The maximum and minimum scores were reduced by 1 between DBS and TBS. However, testing for statistical inference concludes that there is insufficient evidence to conclude that Situation Awareness is different in TBS than DBS.

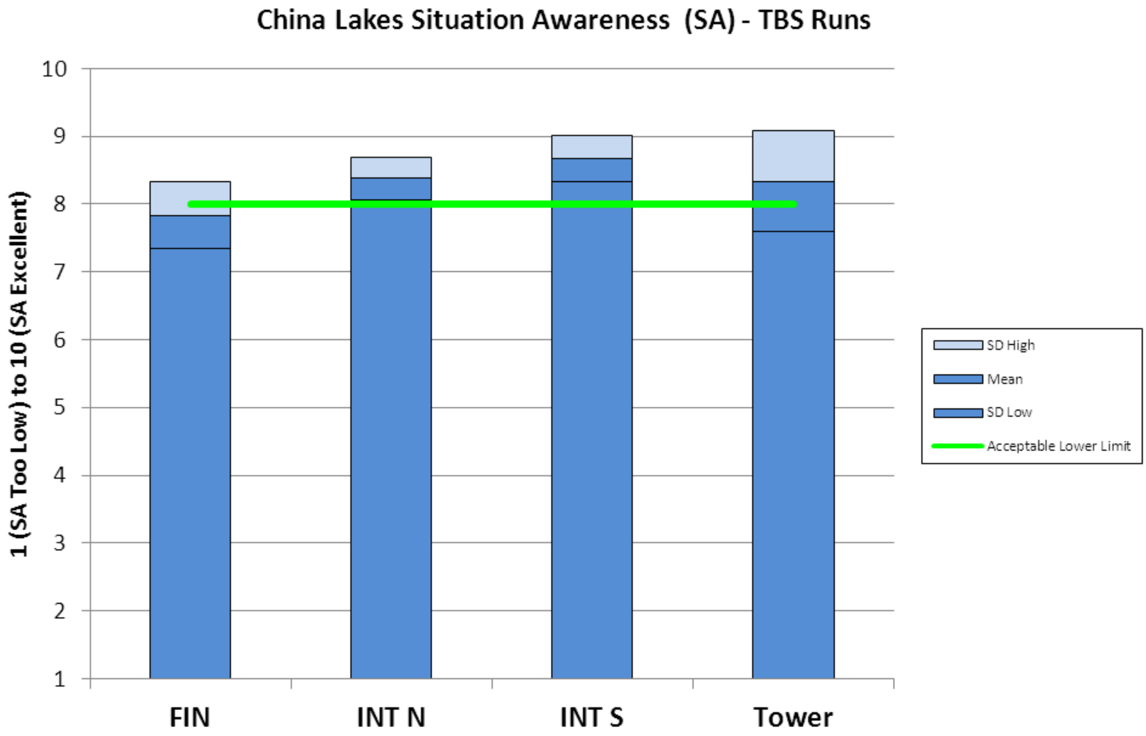


Figure 10: Situation Awareness (SA) – All measured TBS exercise runs for each role

The overall Situation Awareness results for all TBS exercise runs (excluding 'Match 4') indicate that all roles except for the FIN controller are above the lower limit; the mean Situation Awareness scores for FIN are slightly below the acceptable lower limit. This indicates that beyond the 11 matched exercise runs where the FIN scores were on the lower limit, the 21 scenario exercise runs experienced a further reduced Situation Awareness.

Controllers reported that they tended to focus on the following aircraft and TST indicator, rather than the leader and follower as they do today with DBS; this change in scanning focus also resulted in less scan attention on the flight strips. These scanning changes reduced comprehension of the relative distances and positions between aircraft along with the aircraft types and wake vortex categories. Training and operational procedures will need to address these changes in Situation Awareness with TBS to ensure safety is maintained. The following comments from controllers are relevant to explaining the reduced Situation Awareness:

- "*A couple of concerns resulting from reduced awareness. I find focus is mostly on the indicators causing reduced awareness of separation (particularly on base leg when spacing 2.5 Nm), and also reduced awareness of aircraft type, which could be significant with respect to aircraft performance.*"
- "*Tendency to be less aware of lateral distance between aircraft than would be the case with DBS. Also less aware of aircraft types or vortex categories. In short, less situational awareness than when using DBS.*"
- "*Again training is key. I feel there is an overall reduction in situational awareness particularly of separation between aircraft. and of aircraft types and hence characteristics, all of which have safety implications*."
- "*Also feel the lines clutter the screen and I noticed a reduction in my situational awareness.*"
- "*With TEAM aircraft and 2.5 Nm Non-Wake pairs especially I felt it was easy to lose awareness of separation between aircraft particularly when one or both were on intercept headings, and also when one established and the follower on base leg*."

NATS Picture Scale

The NATS Picture Scale asked four questions relating to performance experienced during TBS exercise runs, the four questions were as follows:

1. 'Feeling of being behind' to 'Comfortably ahead of the game';
2. 'Poor understanding of the traffic situation' to 'Full understanding of the traffic situation';
3. 'Lost control of the RT' to 'In full control of the RT';
4. 'Aircraft call you and you have to hunt to recall them' to 'Aware of aircraft coming into your sector before they call you'.

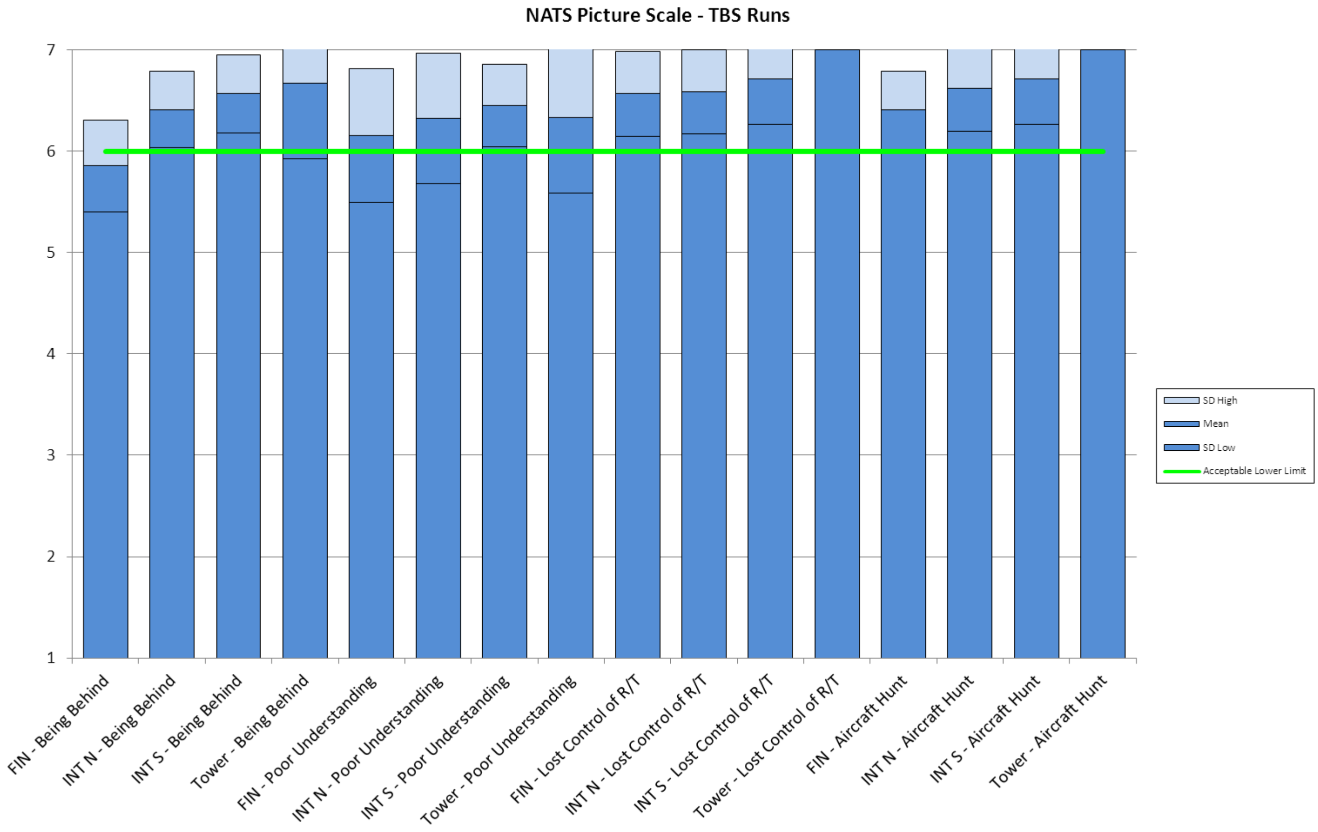


Figure 11: NATS Picture Scale – all measured TBS exercise runs for each role

Results for the NATS Picture Scale are presented in the figure above. All four roles (FIN, INT N, INT S and TWR) are grouped together for each question in turn for comparison. The only question and role that falls below the acceptable lower limit (6) is FIN for being 'Comfortably ahead of the game'; this indicates that the FIN experienced times when they felt slightly behind. Although the mean score was above the target acceptable limit, the FIN also experienced slightly reduced understanding of the traffic situation. These scores align with the Situation Awareness results presented for FIN, indicating reduced understanding of the traffic situation with TBS.

Debriefs

Safety – by the end of the simulation, controllers understood how the TBS indicators behaved and that they represented a reference and not a target. The controllers learned how to use the TBS indicators as a reference in different wind and traffic conditions by allowing varying compression distances between the indicator and the following aircraft. However, it is important to highlight specific safety related scenario events that were raised during the simulations. These all relate to situations where the position of the TBS indicators could be misleading and result in a loss of separation if followed precisely; these relate to TST failure scenario events. The scenario events were **SCN20**, **SCN22** and **SCN26 & SCN27** and are discussed in detail in Section 6.1.3.2.6 under 'Scenario Events'.

Controller reliance on and trust in the TBS indicators illustrates the need for a high degree of accuracy and reliability of the TBS tool; a greater degree of accuracy and reliability than seen in the simulations.

6.1.3.2.3 Task Performance of Heathrow Approach and Tower Controllers

OBJ-06.08.01-VALP-0010-0030 This section presents the results for the objective: "*To assess the acceptability of the changes to the operational procedures and practices on the Final Approach Controller, Intermediate Approach Controller, Runway Controller, Approach and Tower Supervisors, and Pilot*." Note: Approach and Tower Supervisor and Pilot Human Performance were not assessed because the pseudo pilots were not sufficiently representative.

Summary: Expert Observer and CARS results were generally acceptable for the TBS concept. However, the prototype TBS tool was not fully functional and reliable, e.g. TEAM functionality. All CARS mean scores are acceptable, though FIN is only just above the lower limit. During debriefs concerns were raised about separation conformance with real life variability in wind conditions and pilot non-conformance with higher landing rates and more precise separation delivery in TBS operations; these concerns could be addressed through an operational trial. The HMI is generally acceptable, though improvements are required for tool reliability and TEAM functionality.

Expert Observations

The expert observer questionnaires asked seven specific questions, each directly linked to validation objectives, and space was provided for comments and clarifications. Questions relating to this section are shown in the table below.

Question	Always	Mostly	Sometimes	Rarely	Never
Q.2 Task performance for the Final Approach Controller is acceptable when using TBS.	15	9	2	0	0
Q.3 New procedures and practices for the Final Approach Controller are practical and manageable.	15	7	4	0	0
Q.4 TBS Method of Operations are practical and manageable.	14	7	5	0	0
Q.5 TBS Method of Operations are realistic and achievable.	9	13	4	0	0
Q.6 Any changes to the procedures and practices that impact R/T usage are acceptable to controllers and pilots.	19	5	1	0	0

Table 20: Expert Observation Results Summary – Task Performance

As can be seen from the summary table above, the majority of the questions were responded to as 'Always', which indicates these aspects these are all acceptable. The exception is with Question 5; 'TBS Method of Operations are realistic and achievable', which was responded to primarily as 'Mostly' followed by 'Always', indicating improvements are needed.

Significantly, none of the questions were scored 'Rarely' or 'Never' by any expert observer, and only a small number of 'Sometimes' were recorded, indicating there are no fundamental problems with either the concept or the tool. However, in terms of answering the question in this section (objective) for task performance, the number of 'Mostly' and 'Sometimes' indicates improvements are needed.

TEAM functionality was highlighted as an issue by FIN controllers and expert observers. The pink not-in-trail 'chevrons' were set to 2 Nm lateral spacing, which proved to be too close as the following comments illustrate: "*Easy to miss vortex as concentrating on the chevrons*" and "*very uncomfortable going for the TBS-displayed minimum for TEAMers*". The feedback prompted an increase in the TEAM spacing from 2 Nm to 2.5 Nm for the pink 'chevrons'; this was tested with a patched software build on the final exercise run of the validation exercise (Run TBS134). End of Run feedback from this final modified exercise run was as follows: "*2.5 Nm lateral between aircraft and following indicator for TEAM aircraft seemed much more appropriate.*"

Subsequently to the validation exercise it was realized that the display of in-trail Wake separation for TEAM had not worked as specified; in-trail Wake indicators were missing as they were not displayed when they should have been. This suggests that if the TEAM in-trail Wake indicators had worked as intended, the 2 Nm lateral spacing would probably have been acceptable because in-trail Wake indicators would have highlighted Wake separation issues and indicated the appropriate spacing to the controller.

Overall the Expert Observation results are generally favourable for TBS operations. Areas for improvement are clarification of some responsibilities and ensuring the TBS tool is fully functional and reliable, e.g. TEAM functionality.

Questionnaires

End of Run Questionnaires

Controller Acceptance Rating Scale (CARS)

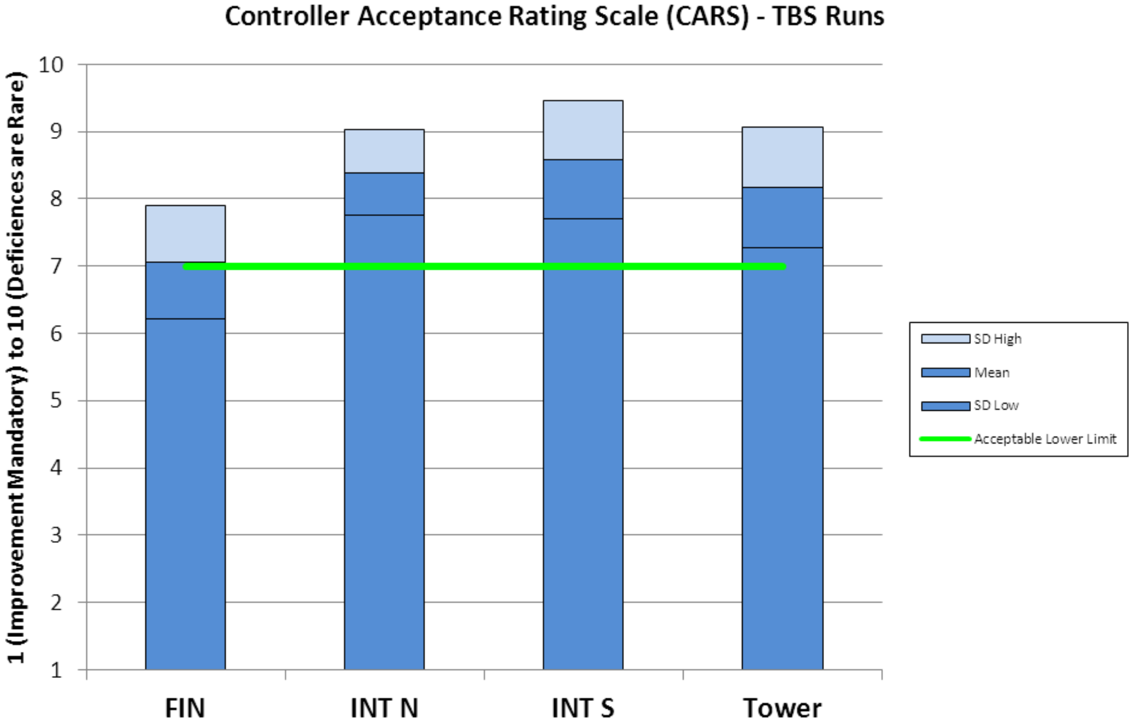


Figure 12: Controller Acceptance Rating Scale (CARS) – all measured exercise runs for each role

The CARS results indicate that TBS is acceptable for all four measured positions from the Heathrow Approach exercise. However, the mean scores for the Final Director Controller (FIN) are only just above the acceptable lower limit (7), which indicates for FIN, TBS has 'Minor but Annoying Deficiencies'. The mean scores for INT N, INT S and TWR controllers are each above 8, which indicates for these roles there are only 'Mildly unpleasant deficiencies' and the system is acceptable with minimum compensation needed to achieve desired performance.

Wake Constrained Pairs – Wake only Indicators

Two exercise runs were conducted with Wake Constrained Pairs, i.e. only Wake indicators were displayed by the TST; these exercise runs were TBS113 and TBS132. The End of Run questionnaires indicates that the controllers were not comfortable operating with Wake only indicators and found it confusing, potentially leading to mistakes; they would prefer full TBS functionality rather than partial with only Wake indicators. Both CARS and NATS Picture Scale scores were particularly low and unacceptable for these exercise runs. The following comments were made by the participants:

- "*It was a little disconcerting not seeing TBS markers all the time*."
- "*MAS4 taken through the localiser for spacing, this caused the subsequent indicator for a vortex H-H* (Heavy vs. Heavy) *to disappear for several sweeps at a crucial time causing me to revert to DBS decision making. The displaying of wake vortex indicators only caused no noticeable further complications, although did require a little extra thought at first*." Note: this event was an unintended TST error and a limitation of the emulation.
- "*Not sure whether wake vortex pair indicators only are a benefit*."
- Expert Observer comment: "*The first of a pair of heavy aircraft does not have a marker which I found to be disconcerting, although logical in the circumstances. A consequence of the operation seems to be that markers appear between some non-vortex pairs after they are*

localiser established. This does impact and distort any conclusions that are deduced. Overall I would prefer to show all the markers rather than selected ones based on vortex wake. It can be misleading when identifying occasional markers with specific aircraft as there is the possibility to wrongly attach them until it become obvious."

- Expert Observer comment: "*Personally, I have to concentrate more in this mode of operation, especially where there is a mixture of traffic being sequenced, some of which have indicators attached and some which don't. Additionally in this exercise an additional indicator appeared when there were no vortex issues associated. In my view this method of operation has the potential to be confusing, it should be all or nothing. In a scenario where heavy traffic was taken through the localiser, on an initial closing heading, the indicator associated with the following heavy traffic did not compensate until the first traffic was approximately 2 miles south of the centreline. At this point the indicator disappeared completely only to reappear once the first traffic was closing the localiser once more. If the indicator had been referenced just before it has disappeared then vortex separations would have been compromised*." Note: the disappearing indicator event was an unintended TST error and a limitation of the emulation.

End of Participation Questionnaires

Summary tables for Heathrow Approach and Tower Runway controllers are provided below:

Question	Yes	Possibly (with improvements)	No
1.1 Is Time Based Separation, as simulated, viable at Heathrow?	2	4	0
1.3 As FIN, did you change your controlling method or technique when delivering aircraft to TBS minima?	3	1	2
1.5 As INT, did FIN delivery to TBS minima change the way you delivered aircraft to FIN?	0	0	6

Question	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
2.1 The TBS Method of Operations are practical and manageable.	0	1	1	3	1
2.1 The TBS Method of Operations are realistic and achievable.	0	1	2	2	1
3.2 R/T usage under TBS operations was acceptable.	0	0	0	5	1

Table 21: Heathrow Approach Controllers End of Participation – Task Performance

Six of the ten Heathrow Approach controller participants completed the End of Participation questionnaire; four controllers only attended one day, which was considered insufficient exposure to TBS and the measured positions to contribute.

The End of Participation results for Heathrow Approach controllers indicate that the TBS concept and HMI is generally acceptable, though improvements are required, one notable aspect being TEAM functionality. The TBS Method of Operations tends towards being practical, manageable, realistic and achievable. However, improvements are required on the TBS Method of Operations to resolve some issues; e.g. clarification of responsibilities and ensuring the TBS tool is fully functional and reliable.

Aircraft/pilot non-conformance to speed instructions was a recurrent concern highlighted throughout the simulations because it has a large impact on TBS operations; this is discussed in more detail as a limitation of the simulation in Section 6.1.3.2.12.

One comment from the End of Participation questionnaires provides a possible explanation for the R/T usage (Question 3.2): "*An occasional R/T increase as there is a tendency to use 150kts more often to achieve correct spacing*." However, subsequent analysis of speed instructions revealed this comment was a perception because from the Matched exercise runs there were fifteen 150 Knots speed instructions with DBS compared to eleven 150 Knots speed instructions with TBS; i.e. there were actually fewer 150 Knots speed instructions with TBS.

Question	Yes	Possibly (with improvements)	No
1.1 Is Time Based Separation, as simulated, viable at Heathrow?	0	1	0

Question	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
2.1 The TBS Method of Operations are practical and manageable.	0	0	0	1	0
2.1 The TBS Method of Operations are realistic and achievable.	0	0	0	1	0

Table 22: Heathrow Tower Runway Controller End of Participation – Task Performance

Only one Heathrow Tower Runway controller was available for the simulations, during which they attended two days. The Heathrow Runway controller role will be specifically assessed during forthcoming simulations with exercise 06.080.01 VP-302.

The End of Participation results for Heathrow Tower Runway controller suggest that the TBS concept and HMI is generally useful and acceptable, though some clarifications are required, e.g. "*Clarity over operating procedures 3Nm / 2.5Nm spacing etc*." in response to question 1.1; Note, Tower and Approach Supervisors were not present during the validation exercise, which introduced some uncertainty in terms of Approach and Tower co-ordinations and the procedures. The TBS Method of Operations appears to be practical, manageable, realistic and achievable with clarity over procedures for 3 Nm and 2.5 Nm spacing as already mentioned. The TBS tool appears neutral in terms of assisting the identification of losses of separation.

Debriefs

Safety debrief results are presented in section 6.1.3.2.2 above.

Training and Familiarization – all participants were briefed in the TBS concept and provided a training and familiarization period. The MOps were clearly described: in particular the use of the TBS indicators as a reference and not as a target. In practice, it became apparent that the natural inclination was for the controllers to use the TBS indicators as a target despite the briefing and training; the phrase "*if it looks like a target, I'll use it like a target*" was used repeatedly. Over time, more (but not all) of the participants were able to switch their technique to using the TBS indicators as a reference.

Non-Wake Separation – The controllers raised a number of concerns regarding TBS, which appeared to be linked to the use of 2.5 Nm separations. These concerns are discussed below:

1. The display of TBS indicators at 2.5 Nm in certain winds can appear too tight. There was a feeling that the display of indicators at 2.5 Nm could lead controllers to put aircraft too close together as they join the ILS, particularly in catch-up wind conditions. Note: Each exercise run was assessed prior to the validation exercise for appropriate separation delivery; therefore effectively a Supervisor had agreed the required spacing prior to the validation exercise run. In operations this would remain a Tower Supervisor's decision as per current operations.

2. In certain wind conditions (spacing pull-away or no catch-up) it can be difficult to conform to radar separation on Base Leg when merging with 2.5 Nm spacing. Controllers felt a temptation to '*go for the indicators*' without considering the radar separation requirements. This issue and the previous issue are training related, but nevertheless reflect some conflict between controllers' natural inclination when presented with indicators and what they are told the indicators represent.

3. Controllers felt more pressure to deliver to the separation minima when TBS indicators were presented compared to current DBS operations. A loss of 2.5 Nm between aircraft is a loss of separation against the Non-Wake separation minimum. The controllers did not feel the same level of pressure for Wake constrained pairs as they were able to take active steps to recover separation by 4DME.

4. While controllers felt able to deliver aircraft tight to the indicators in the simulation, there was concern that real life variability in wind conditions and pilot non-conformance could result in

infringements of 2.5 Nm. With the introduction of TBS indicators, any under-separation would be more apparent to FIN, the approach operation overall and management.

5. Delivery to 2.5 Nm is difficult in operations today. There was uncertainty as to whether 2.5 Nm today means delivery to 2.5 Nm, or an allowance to deliver to less than 3.0 Nm. The controllers said that some FIN controllers are reluctant to go under 3.0 Nm even if 2.5 Nm is agreed with the Tower. The majority of wind conditions simulated were based on a 2.5 Nm minimum, so controllers experienced this in most exercises.

6. It is also possible that the 60s basis for Non-Wake minimum pairs meant controllers were using 2.5 Nm in conditions they would not do today; this may have added to the sense of unease, however this would be initiated by the Tower Supervisor (not present during most exercise runs) as per current DBS operations. In the changeable wind exercises (decreasing wind speed over time) the reversion to 3.0 Nm spacing minimum was always conducted before the TBS distance for 60s time spacing increased to 3.0 Nm.

R/T Occupancy

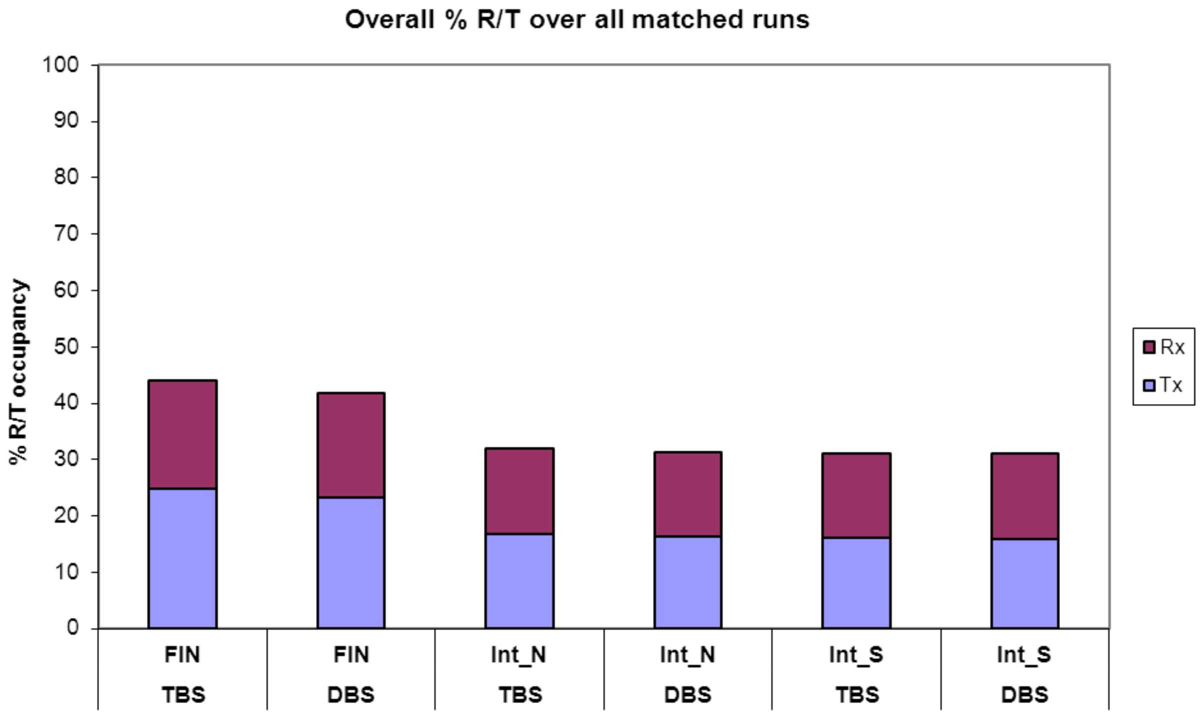


Figure 13: R/T Occupancy – All Matched exercise runs

Note: these figures exclude the 'run in time' of 10 minutes.

As can be seen from the combined R/T occupancy chart above for the matched exercise runs, there is negligible difference between TBS and DBS on all three positions – FIN, INT N and INT S. The R/T occupancy for both transmit (Tx) and receive (Rx) is just over 40% for FIN, which is a busy but comfortable working level.

For FIN, there was a very slight increase in R/T occupancy with TBS, which probably corresponds with the increased aircraft landing rates measured. One comment from the End of Participation questionnaires provides another explanation for the slight increase in R/T: "*An occasional R/T increase as there is a tendency to use 150kts more often to achieve correct spacing*." However, subsequent analysis of speed instructions revealed this comment was a perception because there were actually fewer 150 Knots speed instructions with TBS (11) than DBS (15).

The INT N and INT S had slightly lower R/T occupancy levels of around 30% with no difference in levels between TBS and DBS.

The R/T occupancy data is consistent with the ISA scores described above and the Bedford workload scores, indicating a busy but comfortable working level for all three measured positions.

6.1.3.2.4 Impact of TBS Operations on Human Performance

OBJ-06.08.01-VALP-0010-0040 This section presents the results for the objective: "*To assess the impact of the TBS tool support and operational procedures on the Human Performance of the Final Approach Controller, Intermediate Approach Controller, Runway Controller, Approach and Tower Supervisors, and Pilot.*" Note: Approach and Tower Supervisor and Pilot Human Performance were not assessed because the pseudo pilots were not sufficiently representative.

Summary: The ISA scores were acceptable between TBS and DBS. Bedford Workload scores for FIN, INT N/S were almost identical between DBS and TBS; the FIN and INT N scores were slightly above the acceptable level, which is indicative of the busy traffic samples used. The INT S and TWR Bedford Workload scores were acceptable. There were mixed opinions during debriefs with a few controllers viewing the TBS indicators as "*clutter*", thus slightly increasing their workload. Concerns were highlighted during debriefs with TBS tool accuracy and reliability coupled with the reduction in Situation Awareness. Controller trust was eroded by tool indicator errors which once lead to a loss of Wake separation as the tool displayed the incorrect minima**.** CARS scores were acceptable for all roles. China Lakes Situation Awareness scores were below the acceptable limit for FIN but were acceptable for all other roles. Situation Awareness was reduced with TBS for aircraft types, wake vortex categories and actual distances between aircraft; this contributed to a loss of Wake separation during exercise run TBS121 following a TST indicator fault. The identified primary cause for the reduction in Situation Awareness was a change in scanning to focus more on the displayed TST indicators and follower aircraft and less scan attention on the flight strips.

Instantaneous Self-Assessment (ISA) Workload

The Instantaneous Self-Assessment (ISA) Workload scale rates from Very Low (1) to Very High (5). ISA scores were collected via the touch screen communications panel, which prompted the controllers for their workload score every two minutes; this was done visually with the ISA screen appearing on their communications panel simultaneously with a notification 'beep' in the headset. If the controller did not submit a score after the initial prompt, the controller would be prompted with further 'beeps' every 10 seconds until the ISA screen timed out and was removed at which point a 'no press' blank score would be recorded.

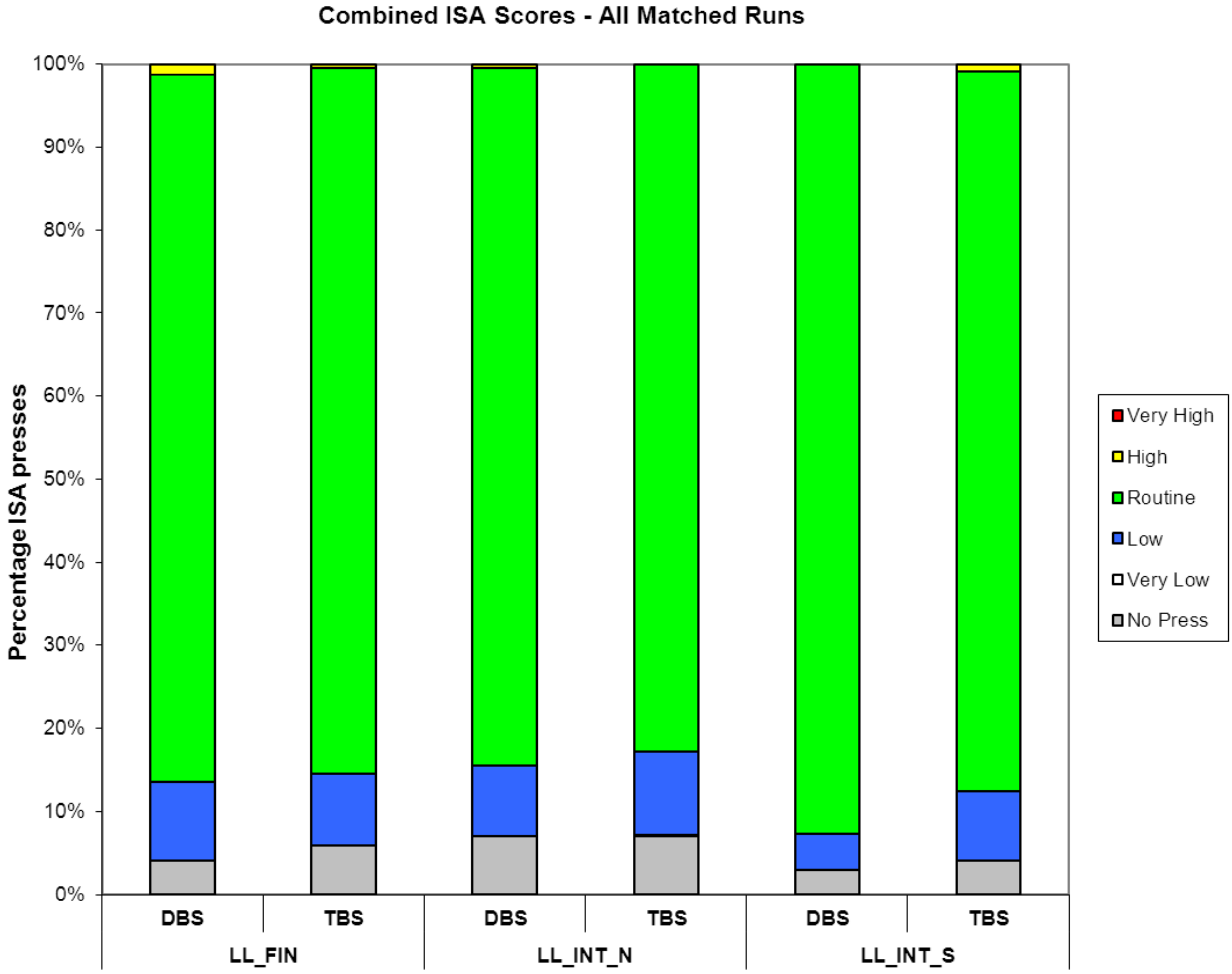


Figure 14: Instantaneous Self-Assessment (ISA) Scores – All Matched exercise runs

As with other metrics, the first 10 minutes were excluded in analysis as ‘run in time’. The ISA scores recorded for the eleven matched exercise runs analysed (Match 4 excluded) indicate that normal working levels ‘Routine’ (3) were experienced for the majority of the validation exercise runs with no significant variance between TBS and DBS. A few ‘High’ (4) workload scores were recorded for short periods in both TBS and DBS, which is normal for busy but comfortable operation. Conversely a small number of ‘Low’ (2) workload scores were recorded during the main part of the validation exercise runs, which again is normal with the fluctuations in traffic levels and complexity.

Bedford Workload Scale

The self-assessed Bedford Workload scale was included in the End of Run questionnaires completed after each exercise run for all TBS exercise runs and DBS matched exercise runs. Two charts have been produced: one for comparison of the matched exercise runs, and a second for all TBS exercise runs.

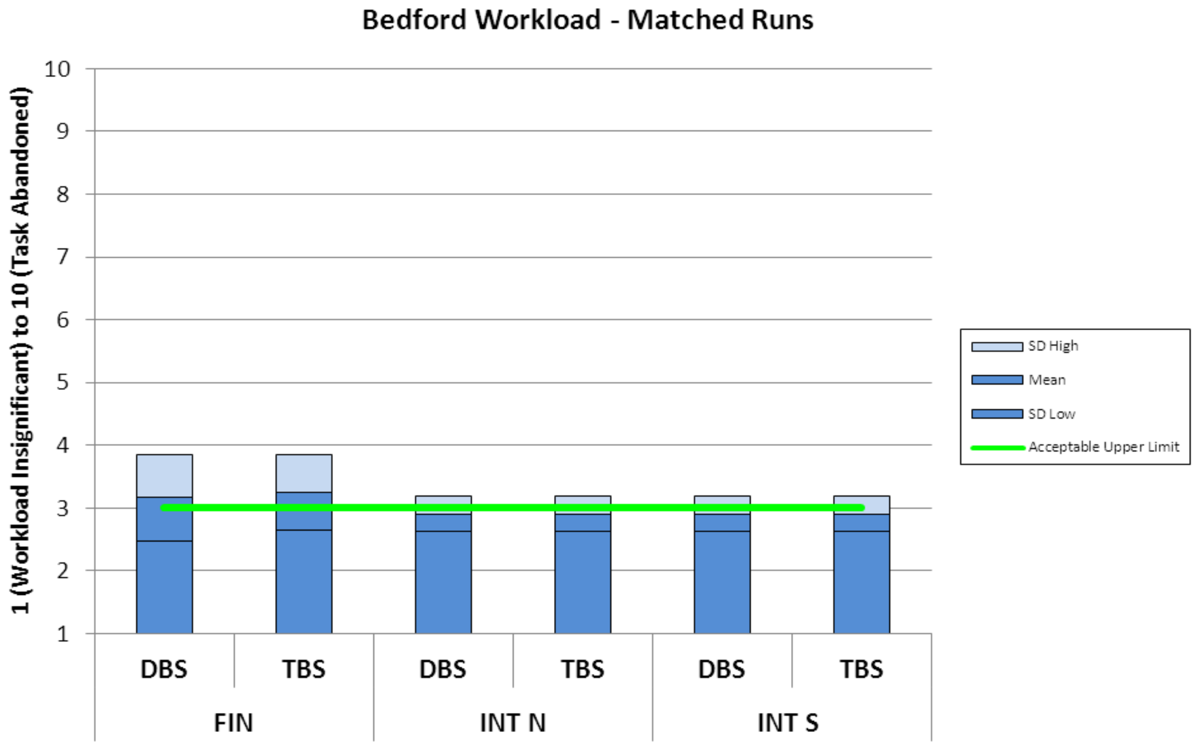


Figure 15: Bedford Workload – Matched exercise runs (excluding 'Match 4')

The Bedford Workload results for the matched exercise runs indicate that the workload between DBS and TBS was almost identical; the Intermediate Controller North and South (INT N and INT S) results were precisely identical, though there was a very slight but insignificant increase in workload for the Final Director Controller (FIN) with TBS. These results indicate there was no statistically significant difference in the mean workload scores between DBS and TBS.

Assessing the Bedford Workload results for matched exercise runs against the 'Acceptable Upper Limit' of 3 shown on the chart, it can be seen that the FIN scores for both DBS and TBS exercise runs are just above the limit. The Mean scores fall between 3 ('*Enough spare capacity for all desirable additional tasks*') but below 4 ('*Insufficient spare capacity for early attention to additional tasks*'). This indicates that the traffic samples and wind profiles used for the matched exercise runs were realistically busy exercises. Although the scores were above the target limit, the fact that both DBS and TBS scores are so similar for FIN suggests the workload was acceptable.

Comparative DBS and TBS Workload scores for the Final Director Controller (FIN) indicate a very slight increase in workload which resulted from random variations between the match runs. The Median and first quartile (25^{th} percentile) were identical between DBS and TBS – hence no 'Box and Whisker' chart shown. The only difference was the minimum workload increased to 3 with TBS (*Enough spare capacity for all desirable additional tasks*) instead of 2 with DBS (*Workload low*); the maximum workload scores were identical.

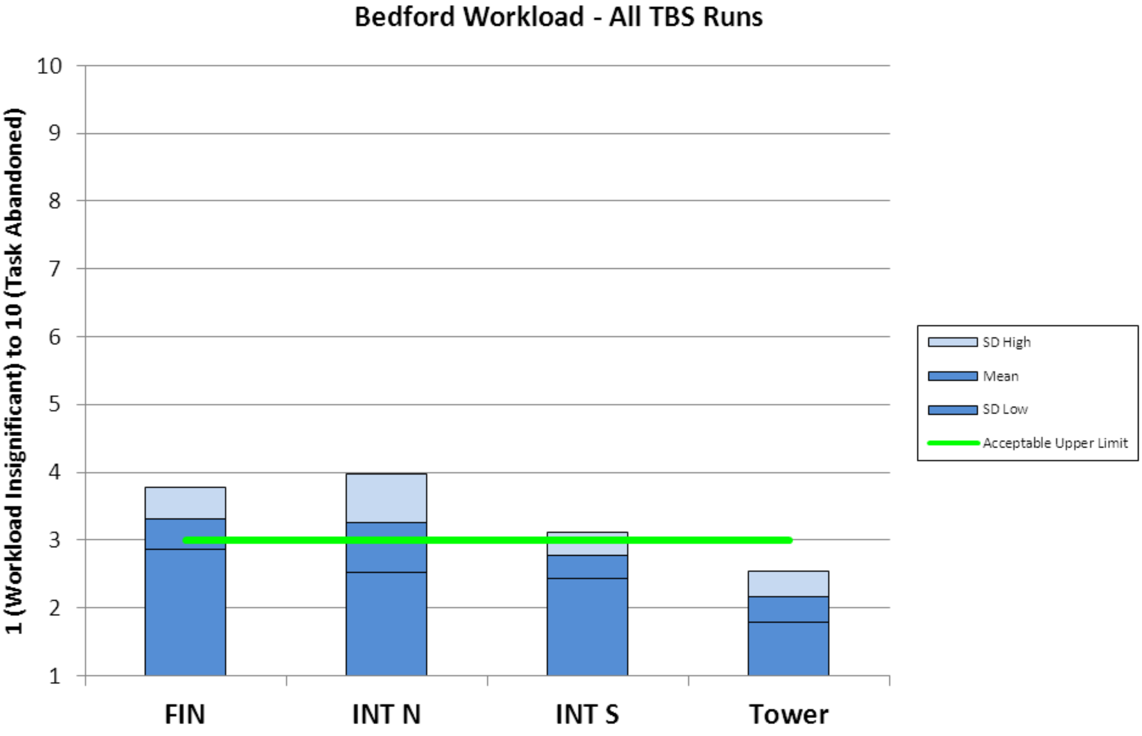


Figure 16: Bedford Workload – all measured TBS exercise runs for each role

Given that the same traffic samples and wind profiles, with some variations, were used for all other TBS exercise runs, the workload scores for both the FIN and the INT N being just above 3 would also appear reasonable and acceptable; see the chart for all TBS exercise runs above.

The INT N scores were affected by one controller as INT N on one scenario exercise run (blocked runway); therefore the workload scores for this exercise run were certainly going to be higher. This would normally be factored down by the number of times an individual returned workload scores across a number of exercise runs; an average is calculated for each individual. In this case, the individual controller only attended for one day and once as INT N, therefore only the one higher Bedford Workload was available for this controller. Taking this into account, the INT N scores are acceptable.

Debriefs

Safety debrief results are presented in section 6.1.3.2.2 above.

Situation Awareness (SA) – it was reported that there was a perceived drop in Situation Awareness compared to current DBS operations (also evident in the China Lakes SA scores in the End of Run questionnaires). Under DBS operation the position of the leader and follower aircraft is considered when judging turn-timings, under TBS operation there is a tendency to focus on the TBS indicator and the follower aircraft, with less scan time on the flight strips. This resulted in reduced awareness of: a) aircraft wake vortex categories; b) specific aircraft types; c) actual lateral distances between the leader and follower aircraft. This reduced awareness between leader and follower aircraft increases the reliance on the Time Separation Tool (TST) in terms of accuracy and reliability.

Workload – the perceived impact on controller workload was mixed. Overall, the behaviour of the indicators was considered to be intuitive. However, the TBS indicators do require interpretation as references rather than targets; the degree of interpretation varied by individual controller. In some situations controllers felt they struggled to "*see through*" the indicators to understand the situation. A few of the controllers perceived the TBS indicators as "*clutter*", thus slightly increasing workload.

Controller Acceptance Rating Scale (CARS)

The Controller Acceptance Rating Scale (CARS) results are presented in section 6.1.3.2.3 above. The CARS results indicate that TBS is acceptable for all four measured positions from the Heathrow Approach exercise.

Questionnaires

End of Run Questionnaires

NATS Picture Scale

The NATS Picture Scale was included in the End of Run questionnaire and consisted of four questions. Two questions showed differences between DBS and TBS for the FIN controller.

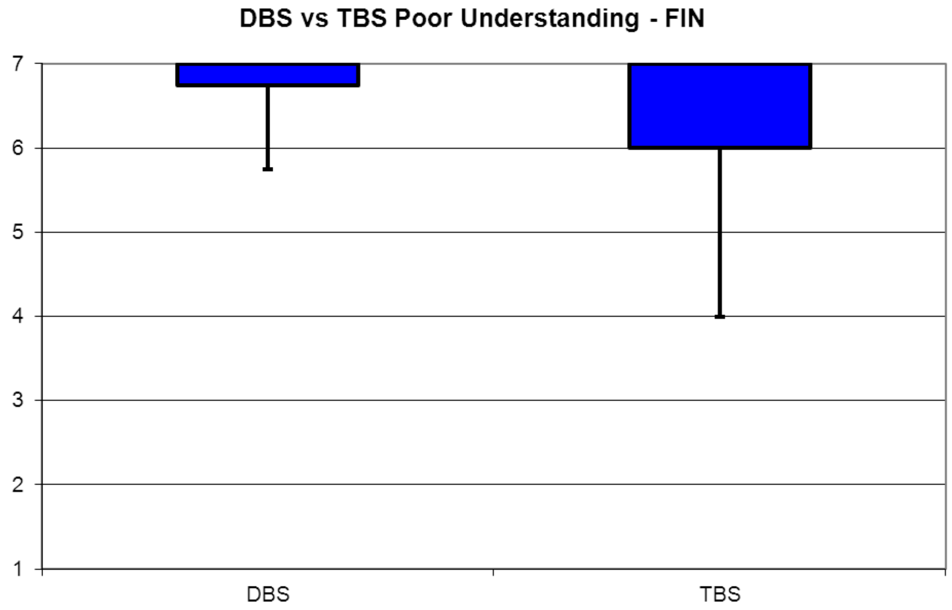


Figure 17: NATS Picture Scale Scores for Poor Understanding – FIN

The NATS Picture Scale for understanding of the traffic situation indicates there was slightly reduced understanding of the traffic situation for the FIN controller when using TBS; see the 'Box and Whisker' chart above. However, the Median for both remains identical at 7, though the lower quartile falls to 6 with a minimum score of 4. There is no statistical significance with these scores, which corresponds with the Situation Awareness results suggesting this is more a training and familiarization effect.

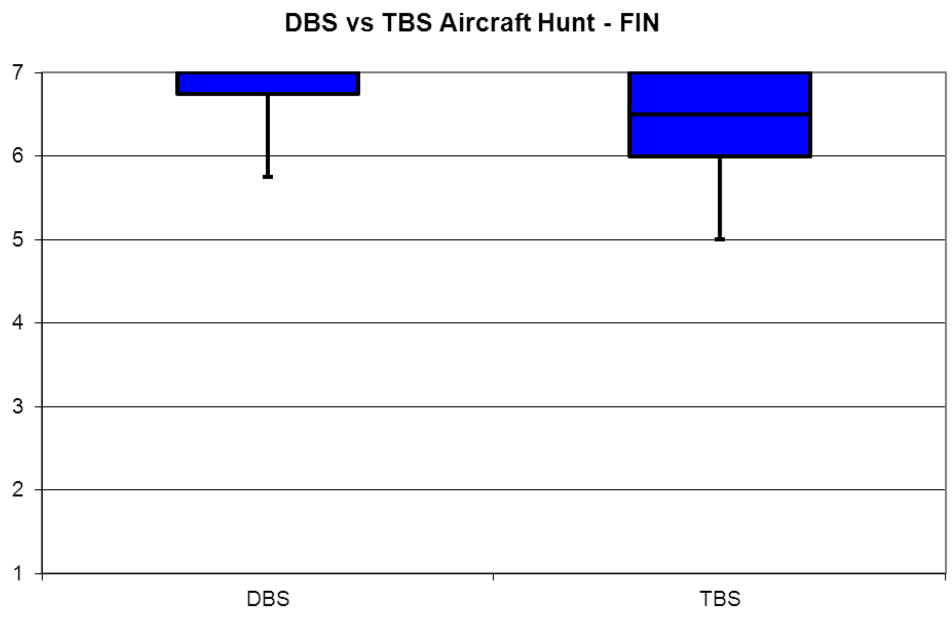


Figure 18: NATS Picture Scale Scores for Aircraft Hunt – FIN

As can been seen from the 'Box and Whisker' chart above, with TBS, the FIN controller needed to 'hunt' in the flight progress strip bay to find some aircraft when they called in on frequency because their scan focus had moved more onto the Radar display and TBS indicators and away from the flight strips. However, the difference between DBS and TBS is not statistically significant and from other measures it is known that more aircraft were being handled per hour under TBS adding to the number of flight strips.

Comparative DBS and TBS Bedford Workload and Situation Awareness scores for INT N and INT S were almost identical, indicating there is negligible difference in Workload and Situation Awareness for these roles operating with TBS compared with current operations with DBS. The NATS Picture Scale results for INT N and INT S were also almost identical, indicating there is negligible difference between TBS and DBS. The comparison is perhaps best summed up by comments from the controllers themselves in questionnaires:

- "*TBS does not influence operation of INT N.*"
- "*There doesn't appear to be much impact on the INT N position from the TBS system.*"
- "*TBS does not affect INT S."*
- "*TBS not affecting INT S role.*"
- "*INT N and INT S operations were largely unaffected by the use of TBS other than monitoring the landing rate by reference to delivery of aircraft in their proximity to the indicators.*"

6.1.3.2.5 Acceptability of the TBS Tool Concept in General

OBJ-06.08.01-VALP-0010-0045 This section presents the results for the objective: "*To assess the acceptability of the TBS tool concept in general by the Final Approach Controller, Intermediate Approach Controller, Runway Controller, Approach and Tower Supervisors, and Pilot*." Note: Approach and Tower Supervisor and Pilot Human Performance were not assessed because the pseudo pilots were not sufficiently representative. This objective was introduced after the TC Approach validation exercise was conducted with edition 00.01.03 of the VALP [4]; post exercise analysis and this report have been amended accordingly.

Summary: There were mixed opinions during debriefs with a few controllers viewing the TBS indicators as "*clutter*", thus slightly increasing their workload. Concerns were highlighted during debriefs with TBS tool accuracy, reliability and responsibilities. Controller trust was eroded by tool indicator errors which once lead to a loss of Wake separation as the tool displayed the incorrect minima**.** The Madsen & Gregor Trust scores were unacceptable for Perceived Reliability. SHAPE scores were acceptable for all roles.

Debriefs

Safety debrief results are presented in section 6.1.3.2.2 above.

Training and Familiarization and **Non-Wake Separation** debrief results are presented in section 6.1.3.2.3 above.

Trust – by necessity, the controllers had to place a great deal of trust in the TBS tool and as a result they did not necessarily check that the displayed TBS separation was correct. As a consequence there was a reliance on the accuracy and reliability of the TST. Two key issues are the integrity of the sequence order and the accuracy of the calculations for time based separation. Controllers queried the division of responsibilities between controllers and the system (TBS indicators): who is responsible if TBS indicates an incorrect separation and the controller follows the advice and there is an incident?

Questionnaires

Madsen & Gregor Trust Questionnaire

A summary table is provided below:

Question	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
R1. The system always provides the advice I require to make my decision.	0	2	3	2	0
R2. The system performs reliably.	0	2	3	2	0
R3. The system responds the same way under the same conditions at different times.	0	2	2	3	0
R4. I can rely on the system to function properly.	0	3	3	1	0
R5. The system analyzes problems consistently.	0	2	3	2	0
T1. The system uses appropriate methods to reach decisions.	0	0	2	4	1
T2. The system has sound knowledge about this type of problem built into it.	0	0	4	3	0
T3. The advice the system produces is as good as that which a highly competent person could produce.	0	0	5	1	1
T4. The system correctly uses the information I enter.	0	0	4	3	0
T5. The system makes use of all the knowledge and information available to it to produce its solution to the problem.	0	1	2	4	0
U1. I know what will happen the next time I use the system because I understand how it behaves.	0	1	1	5	0
U2. I understand how the system will assist me with decisions I have to make.	0	0	0	6	1
U3. Although I may not know exactly how the system works, I know how to use it to make decisions about the problem.	0	0	0	7	0
U4. It is easy to follow what the system does.	0	0	0	7	0
U5. I recognize what I should do to get the advice I need from the system the next time I use it.	0	0	1	6	0
F1. I believe advice from the system even when I don't know for certain that it is correct.	0	3	2	2	0
F2. When I am uncertain about a decision I believe the system rather than myself.	0	5	2	0	0
F3. If I am not sure about a decision, I have faith that the system will provide the best solution.	0	4	3	0	0
F4. When the system gives unusual advice I am confident that the advice is correct.	0	4	3	0	0
F5. Even if I have no reason to expect the system will be able to solve a difficult problem, I still feel certain that it will.	0	3	3	1	0

R = Perceived Reliability
T = Perceived Technical Competence
U = Perceived Understandability
F = Faith

Table 23: Madsen & Gregor Trust Questionnaire Summary (Seven Participants)

The most favourable and consistently scored area was '**Perceived Understandability**', which scored strongly with 'Agree' to all five questions; this indicates that the training and familiarization was sufficient and the TBS tool is reasonably intuitive to use.

The next most favourable area was '**Perceived Technical Competence**', though the scores are more varied; the results indicate that TBS uses appropriate methods to reach decisions and it makes use of all the information available, however there is a more neutral response to the quality of advice the system produces and the system's knowledge and use of information entered into it.

The '**Perceived Reliability**' category is mixed, though it tends towards being neutral, which indicates the controllers were uncertain about the reliability of the prototype TBS tool in terms of correct and consistent advice presented. This resulted from problems with the simulated TBS system, and other simulation effects such as the use of EFD and INT N Support role to populate the landing sequence.

The '**Faith**' category was apparently the least favourable result with all questions tending towards 'Disagree', indicating that the participants have reservations about the TBS tool and do not completely trust the tool; the most significant question being F2, which indicates most of the participants believe their own judgement rather than the system. In the context of controller behaviour and the way controllers are trained to operate, this is to be expected; controllers are trained to use their own judgement to assess the situation and identify any inconsistencies in the information they are being presented and to adjust their actions accordingly. The apparently lower scores for 'Faith' are normal for ATC operations in order to detect problems and avoid incorrect actions based on invalid data. In the context of TBS operations, there is the need to ensure controllers can still apply their own judgement based on quickly accessed information.

SHAPE Teamwork (STQ-s) Questionnaire

A summary table is provided below.

Question	0 Never	1	2	3	4	5	6 Always
1) … it was clear to me which tasks were my responsibility.	0	0	0	0	0	2	5
2) … it was clear to me which tasks were carried out by the other team members.	0	0	0	0	0	2	5
3) … it was clear to me which tasks I shared with the other team members.	0	0	0	0	0	2	5
4) … the system enabled the team to prioritise tasks efficiently.	0	0	1	0	2	2	2
5) … the system helped the team to synchronize their actions.	0	1	0	0	1	3	2
6) … the goals of the team were clearly defined.	0	0	1	0	1	2	3
7) … the system promoted a smooth flow of information.	0	1	0	0	2	4	0
8) … the system helped the team to follow the procedures.	0	1	0	0	2	4	0
9) … the system helped me to detect the other team members' inaccuracies or mistakes.	0	0	1	0	1	4	1
10) … the system helped me to share information about developing traffic situations with other team members.	0	1	2	0	1	3	0
11) … I liked working in the team.	0	0	0	0	0	3	4
12) … I felt supported by other team members.	0	0	0	0	0	3	4

Table 24: SHAPE Teamwork (STQ-s) Questionnaire Summary (Seven Participants)

The most favourable responses were to questions 1, 2, 3, 11 and 12; these indicate that the controllers were clear about their tasks and responsibilities and those of other team members, and felt supported by the team.

The questions that scored least favourably related to the system helping the controller with controlling tasks, team working and following procedures: questions 4 to 10 inclusive. However, these lower scores were primarily from one individual who described the TBS indicators as "clutter" throughout the simulations. All the other participants were generally more positive about the TBS system.

Overall the SHAPE Teamwork questionnaire results were favourable, though the controllers were less confident of how well the TBS system supported team working tasks.

6.1.3.2.6 Usability of the TBS Controller Tool Support HMI

OBJ-06.08.01-VALP-0010-0050 This section presents the results for the objective: "*To assess the utility and usability of the TBS controller tool support.*"

Summary: The HMI design shape, colour, size and display priority were all acceptable and there were no specific comments about the HMI design from debriefs. All CARS Mean scores are acceptable, though FIN was only just above the lower limit. There was some instability with TBS indicators, primarily with TEAM functionality with a tendency to jump centre lines. Some indicator problems were caused by incorrect sequence order in the EFD. Controller reliance on the TBS means that tool errors are likely not to be noticed leading to a potential loss of separation, unless there are specific training and procedural processes in place to mitigate this. The production TBS tool needs to be more accurate and reliable than the prototype used for the simulations.

Questionnaires

End of Participation Questionnaires

Summary tables for Heathrow Approach controllers and Tower controllers are provided below:

Question	Yes	Possibly (with improvements)	No
3.3 Was the HMI **shape** acceptable?	6	0	0
3.3 Was the HMI **colour** acceptable?	6	0	0
3.3 Was the HMI **size** acceptable?	5	0	1
3.3 Was the HMI **display priority** acceptable?	5	0	1

Question	Essential	Very Useful	Useful	Not Useful	Caused Problems
3.1 How useful were the Indicators at the different positions? FIN	3	1	2	0	0
3.1 How useful were the Indicators at the different positions? INT N	0	0	2	4	0
3.1 How useful were the Indicators at the different positions? INT S	0	0	2	4	0

Question	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
3.2 TBS helped me to identify any potential losses of separation.	0	1	1	3	1

Table 25: Heathrow Approach Controllers End of Participation – Usability of the TBS Tool HMI

Six of the ten Heathrow Approach controller participants completed the End of Participation questionnaire; four controllers only attended one day, which was considered insufficient exposure to TBS and the measured positions to contribute.

The scores indicate the TBS Human Machine Interface (HMI) was generally acceptable in shape, colour, size and display priority. The results indicate the TBS tool is very useful to the Final Director Controller (FIN) and essential for the TBS concept to be implemented. However, TBS is not so useful or essential to the Intermediate controllers (North & South).

There was a wide spread of views to the question "*TBS helped me to identify any potential losses of separation.*" Four of the six controllers responded that TBS did help them identify potential losses of separation. However, of the other two controllers, one responded neutrally and the other responded that TBS did not help.

Although the question "*The separation indicator did not distract from my tasks as FIN controller*" was not included in the questionnaires, controllers did write comments about the TBS indicators and whether they were too intrusive or distracting. This question was introduced with edition 00.01.01 of the VALP [2] during the conduct of the TC Approach exercise when it was too late to include it; questionnaires were prepared with edition 00.01.00 of the VALP [1]. From debriefs it is known that one controller felt the TBS indicators were distracting (see the End of Run comments below), however, most other controllers felt the indicators were helpful and not distracting. Overall it can be deduced that the majority of controllers felt the TBS indicators did not distract from their tasks as FIN controller. The relevant comments are provided below:

- Question 3.3 'Shape' "*Clear when target return was on, outside or inside the indicator, did not find display too cluttered nor distracting, and no colour clash / conflict*."
- Question 3.3 'Size' "*Clear, yet not too obtrusive. I did not find the indicators at all distracting*."
- End of Run questionnaire comments "*Comment referring to score of '6' for CARS: Markers distracting. General: Still finding markers distracting regards my judgement of distance*." and "*Again found TBS lines very distracting regards working out my own distances.*"

Question	Yes	Possibly (with improvements)	No
3.3 Was the HMI **shape** acceptable?	1	0	0
3.3 Was the HMI **colour** acceptable?	1	0	0
3.3 Was the HMI **size** acceptable?	1	0	0
3.3 Was the HMI **display priority** acceptable?	1	0	0

Question	Essential	Very Useful	Useful	Not Useful	Caused Problems
3.1 How useful were the Indicators at the different positions? TOWER	0	0	1	0	0

Question	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
3.2 TBS helped me to identify any potential losses of separation.	0	0	1	0	0

Table 26: Heathrow Tower Runway Controller End of Participation – Usability of the TBS Tool HMI

Only one Heathrow Tower Runway controller was available for the simulations, during which they attended two days. The Heathrow Runway controller role will be specifically assessed during forthcoming simulations with exercise 06.080.01 VP-302.

Aircraft Landing Sequence Order

The need for an INT N Support role to assist with agreeing the landing sequence and maintaining the sequence order on the Electronic Flight Data (EFD) display for the TST calculations was not representative of planned operations with EFD for the FIN controller position and caused some problems with incorrect aircraft sequence ordering. These issues should be overcome with the planned operation with EFD for the FIN controller position to provide the landing sequence. The following controller comments relate to sequence order issues:

- Further Comments section "*Change to the sequence order can generate wrong information to FIN. This must be addressed for the operational system otherwise we will not have confidence in TBS*."
- End of Run questionnaire "*Happy with system overall - still unsure of how reliable it will be regarding correct order as unable to use EFD for FIN position at the moment*."
- End of Run questionnaire "*This particular level of traffic, we would be a lot more fluid with our order and at the moment it's too confusing to swap them round.*"

Debriefs

Safety debrief results are presented in section 6.1.3.2.2 above.

Training and Familiarization and **Non-Wake Separation** debrief results are presented in section 6.1.3.2.3 above.

Situation Awareness (SA) and **Workload** debrief results are presented in section 6.1.3.2.4 above.

Trust debrief results are presented in section 6.1.3.2.5.

Controller Acceptance Rating Scale (CARS)

The Controller Acceptance Rating Scale (CARS) results are presented in section 6.1.3.2.3 above. The CARS results indicate that TBS is acceptable for all four measured positions from the Heathrow Approach exercise.

Scenario Events

Twenty one scenarios are considered to pass and be 'OK'; see Appendix C for the Scenario coverage summary. Five scenarios failed to pass and are indicated as 'NOK', these scenarios are discussed below:

SCN09 (B): Pilot speed non-conformance leads to catch-up on final. Pilot flies higher IAS on joining centreline. Catches and (potentially) infringes Non-Wake separation.

- Unrealistic pilot speed non-conformance caused a significant reduction in user confidence with TBS operation. One of the unrealistic speed non-conformances resulted in a go around because separation was going to be lost. Pilot/aircraft speed non-conformance realism was improved during the simulations and it seems probable that with the improved realism this scenario would be acceptable. However, this particular scenario was not re-run.

SCN20: TST calculating separation incorrectly (due error / incorrect wind information) causing too small a separation being displayed for the wind conditions.

- The FIN did not notice an unusually low indication of separation minima by the TST between two heavy wake vortex category aircraft until it was pointed out by the expert observer; 2.5 Nm was indicated for a normal wake constraint of 4 Nm, TBS equivalent should have been about 3.5 Nm in the wind conditions; this was a spontaneous error and was not deliberately introduced. This resulted in a loss of Wake separation that was not recorded by the system. The FIN completely trusted the accuracy of the TBS indicators for separation and positioned the following aircraft accordingly; this event caused the FIN and other watching participants to "re-evaluate" their trust in the TBS tool and double check the wake vortex categories rather than focusing and relying on the TBS indicators alone.

SCN22: Late change of landing runway - before 4DME.

- This was discussed during the debrief sessions, based on one exercise involving changes of landing runway, e.g. blocked runway scenario when aircraft on approach could visually switch runways. The main issue was whether the TBS indicator should be provided and switched over for a late change of runway, i.e. would it assist the FIN controller? The conclusion was a TBS indicator in the circumstances would not offer much support and benefit.

SCN26 & SCN27: Early morning TEAM and TEAM 6 Aircraft per Hour.

- The TST did not work as specified and during the simulation it quickly became apparent that the displayed spacing was too close for usability. The 2 Nm lateral spacing was too close to allow for in-trail Wake separation, i.e. 4 Nm instead of 5 Nm between aircraft on the same runway approach. Lateral spacing for TBS TEAM operation was increased to 2.5 Nm in the final exercise run of the simulations with TEAM 6 Aircraft per Hour (Run 134) and proved beneficial and "*much more appropriate*"; this modification to the TBS tool was not re-tested for early morning TEAM. Subsequently to the validation exercise it was realized that the display of in-trail Wake separation for TEAM had not worked correctly; in-trail Wake indicators were missing and were not displayed when they should have been. This suggests that if the TEAM in-trail Wake indicators had worked as intended, the 2 Nm lateral spacing would probably have been acceptable because in-trail Wake indicators would have highlighted Wake separation issues and indicated the appropriate spacing to the controller. Two TEAM related faults were identified with the TST: **1) Unstable Not-in-trail Indicators** that were observed to temporarily jump runway centrelines; **2) Wake Separation Constraint Over-ridden by Not-in-trail Separation** – in-trail Wake indicators between two aircraft on 27R were not displayed when a 27L aircraft was in between and the wake constraint was larger than the lateral spacing. These faults are discussed in detail in Section 6.1.3.2.12 **Unexpected Behaviours/Results**.

Strong Crosswind Effects

The wind for scenario exercise run TBS123 was increased to present a very strong crosswind effect during the approach. From debriefs, it was commented that the participants had not assessed TBS with very strong crosswinds, which are experienced reasonably often in live operations. A tailwind profile with a crosswind (WC4) was modified during the simulation start up by multiplying the wind speeds by 2.5 to give crosswinds up to 59 knots at 4,000 feet during the approach. This proved to be a challenging scenario as expected with TBS or DBS operation; consequently the Bedford Workload and Situation Awareness were affected, but not significantly. The expert observer commented the following on this exercise run: "*In the wind conditions it didn t seem the TBS markers were providing any benefit to the final spacing. Following aircraft would meet TBS line when lead aircraft was approx. 1 - 1.5 Nm from touchdown. Spacing did not seem to reflect the compression that would be acceptable within 4DME, but compensated for it behind the TBS marker.*"

Additional Scenario Events

FIN Controller Handovers: The opportunity was taken to assess handovers at the Final Director Controller (FIN) position, which was not originally planned; TBS handovers were performed on exercise runs TBS082, TBS131 and TBS132. Two factors enabled the inclusion of handovers: on the last day (Day 13) of the simulation during scenario exercises there were five Approach controllers available, which meant full handovers could be attempted as additional scenarios; on another day (Day 8) an Approach controller was available for just one day, so to maximize their contribution they performed handovers in TBS and DBS on a matched exercise run (handovers were performed at the same time into each matched exercise run for consistency). Handovers proved to be reasonably straightforward, though the TBS specifics will need to be incorporated into formal the handover process for training and practice.

6.1.3.2.7 Impact on Roles and Responsibilities

OBJ-06.08.01-VALP-0010-0060 This section presents the results for the objective: "*To assess the impact of the TBS concept and operational procedures on the roles and responsibilities of the Final Approach Controller, Intermediate Approach Controller, Runway Controller, Approach and Tower Supervisors, and Pilot*." Note: Approach and Tower Supervisor and Pilot Human Performance were not assessed because the pseudo pilots were not sufficiently representative.

Summary: SHAPE had acceptable scores for all roles. Questionnaires and debrief comments highlighted the need for clarification of roles and responsibilities for FIN and TWR controllers due to the absence of Tower and Approach Supervisors during the validation exercise, e.g. procedures for 3 Nm and 2.5 Nm spacing delivery with varying or borderline wind conditions for a spacing minima. It was also highlighted that FIN controllers rely on prompt pilot conformance to assure separation.

Debriefs

Safety debrief results are presented in section 6.1.3.2.2 above.

Training and Familiarization and **Non-Wake Separation** debrief results are presented in section 6.1.3.2.3 above.

Situation Awareness (SA) and **Workload** debrief results are presented in section 6.1.3.2.4 above.

Trust debrief results are presented in section 6.1.3.2.5.

Pilot/aircraft Non-conformance to Speed Instructions was a recurrent concern highlighted throughout the simulations. This is because of the controller perception during the simulation that there is more pressure to deliver to the separation minima when TBS Indicators are displayed compared with current DBS operations. Controllers felt that to use TBS Indicators to their optimum places a reliance on pilots conforming to speed instructions and the aircraft slowing down within a reasonable time period and at the rate expected by the controller. While controllers felt able to deliver aircraft tight to the indicators in the simulation, there was concern that real life variability in wind conditions and pilot non-conformance could result in infringements of 2.5 Nm spacing.

This relates to the spacing practice associated with merging a follower aircraft in a zone behind the Indicator such that spacing contingency is provided for the distance compression effects on final approach, including provision for the operationally anticipated level of pilot/aircraft non-conformance to speed instructions. The same level of anticipation is required with TBS as is currently practiced today with DBS. This issue should have no more of an impact on TBS than it does for DBS today. These controller concerns could be addressed through an operational trial.

Questionnaires

End of Participation Questionnaires

Summary tables for Heathrow Approach controllers and Heathrow Tower Runway controllers are provided below.

Question	Yes	Possibly (with improvements)	No
1.6 I feel the division of responsibility between Approach and Runway controllers is acceptable when using TBS?	4	0	2
1.7 I feel the division of responsibility between Controllers and Pilots is acceptable when using TBS?	4	0	2

Question	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
2.1 As FIN, I am clear of my responsibilities when using TBS.	0	0	0	5	1
2.1 As INT, I am clear of my responsibilities when using TBS.	0	0	0	1	5

Table 27: Heathrow Approach Controllers End of Participation – Roles and Responsibilities

Six of the ten Heathrow Approach controller participants completed the End of Participation questionnaire; four controllers only attended one day, which was considered insufficient exposure to TBS and the measured positions to contribute.

The End of Participation results for Heathrow Approach controllers indicate that the TBS concept and HMI is generally acceptable, though some improvements are required. Improvements are required to the TBS Method of Operations to clarify responsibilities between Approach controllers, Tower controllers and pilots. The following controller comments illustrate the main concerns with division of responsibilities:

- Q1.6 "*Procedures for action to be taken with under-separation need to be amplified in particular when aircraft are in communication with TWR but not yet under control (i.e. inside / outside 4DME)*."
- Q1.6 "*Tower still responsible for dictating the spacing they want, hence will specify TBS spacing required if more than the tool is suggesting*."
- Q1.6 "*The precise responsibilities will need to be clearly defined. The current procedures should however be adequate, with just a few additions for TBS*."
- Q1.7 "*If speed compliance not adhered to, who is responsible. Speed compliance is in general not good enough to work at this minima*."
- Q1.7 "*TBS minima rely on accurate and timely speed compliance, which is not the case at present*."
- Q1.7 "*TBS places a greater need on compliance of speed control from pilots and also notification of slow / fast final approach speeds*."
- Q1.7 "*The only risk when reducing WTS is the potential for more queries from pilots on the spacing from the aircraft ahead*."

Responsibilities of the Final Director Controller (FIN) controller also need to be clarified as the questionnaire responses indicate some uncertainty to their role with TBS. The INT North and South controller roles appear to be sufficiently clear, probably because TBS has less use by the INT controllers, as commented in End of Run questionnaires.

Question	Yes	Possibly (with improvements)	No
1.2 I feel the division of responsibility between Approach and Runway controllers is acceptable when using TBS?	1	0	0
1.3 I feel the division of responsibility between Controllers and Pilots is acceptable when using TBS?	1	0	0

Question	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
2.1 As Heathrow Tower controller, I am clear of my responsibilities when using TBS.	0	0	0	1	0

Table 28: Heathrow Tower Runway Controllers End of Participation – Roles and Responsibilities

Only one Heathrow Tower Runway controller was available for the simulations, during which they attended two days. The Heathrow Runway controller role will be specifically assessed during forthcoming simulations with exercise 06.080.01 VP-302.

The End of Participation results for Heathrow Tower Runway controller suggest that the TBS concept and HMI is generally useful and acceptable, though some clarification of roles and responsibilities for FIN and TWR controllers in the absence of Tower and Approach Supervisors in the validation exercise runs, e.g. clarity over operating procedures for 3 Nm and 2.5 Nm spacing.

SHAPE Teamwork (STQ-s) Questionnaire

The SHAPE Teamwork (STQ-s) Questionnaire results are presented in section 6.1.3.2.5 above. Overall the SHAPE Teamwork questionnaire results were favourable, though the controllers were less confident of how well the TBS system supported team working tasks.

6.1.3.2.8 Impact on Arrival Runway Capacity

OBJ-06.08.01-VALP-0010-0070 This section presents the results for the objective: "*To assess the impact of TBS tool support and operational procedures on the arrival runway capacity during strong wind conditions.*"

Summary: There was a statistically significant increase in aircraft landing rates with TBS up to +5 additional aircraft per hour, with a mean of 2 additional aircraft per hour, for the traffic samples and wind conditions simulated. There was a statistically significant reduction in holding times and hold entry to touchdown times; the mean reduction in holding times with TBS was 0.9 minutes with a maximum reduction of 9.4 minutes, the mean reduction in stack entry to touchdown times with TBS was 1.4 minutes with a maximum reduction of 9.3 minutes. These results are sensitive to the duration of the exercise runs.

Landing Rates – Passing 4DME

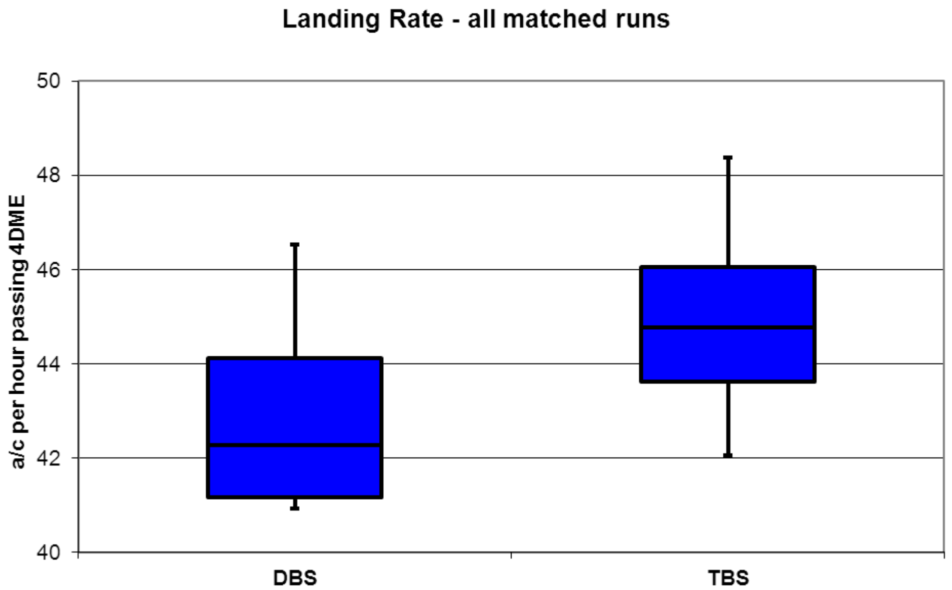


Figure 19: Aircraft Landing Rates – Passing 4DME

Aircraft landing rates (recorded at passing 4DME and adjusted to an hourly rate) were higher with TBS than DBS for each of the eleven matched exercise runs analysed (Match 4 excluded). Using the Wilcoxon Signed-Rank Test, the increased aircraft landing rates are statistically significant, indicating that using TBS does enable higher landing rates of up to 5 additional aircraft per hour, with a mean of 2 additional aircraft per hour.

Landing Times

To address the objective "*The mean difference in landing time between TBS and DBS operations shall be statistically significantly greater than zero*", the touchdown times from all of the matched exercise runs were collated and plotted such that for a given aircraft (in each matched pair of exercise runs) the touchdown time in the DBS exercise run was plotted (on the 'x' axis) against the touchdown time in the TBS exercise run (on the 'y' axis). The resulting scatter chart indicates that, as expected, the early touchdown times (i.e. those near the start of an exercise run) are clustered tightly and evenly about the 45 degree "equal" line showing that there was little or no difference between the DBS and TBS exercise runs. As the times into the validation exercise run progress, the clustering can be seen to be progressively dipping below the 45 degree "equal" line showing that as each exercise run progressed the majority of aircraft were being landed slightly earlier in the TBS exercise runs than in the DBS exercise runs.

The evident scattering of the points on the graph shows the variation between exercise runs, in particular where the approach sequence was not identical between exercise runs: in some cases pairs of aircraft were 'swapped around' such that they show an unusually early or late touchdown time in either exercise run. However, these are in the minority and the trend of the graph can be seen to move towards the DBS axis, thus indicating earlier touchdown times with TBS.

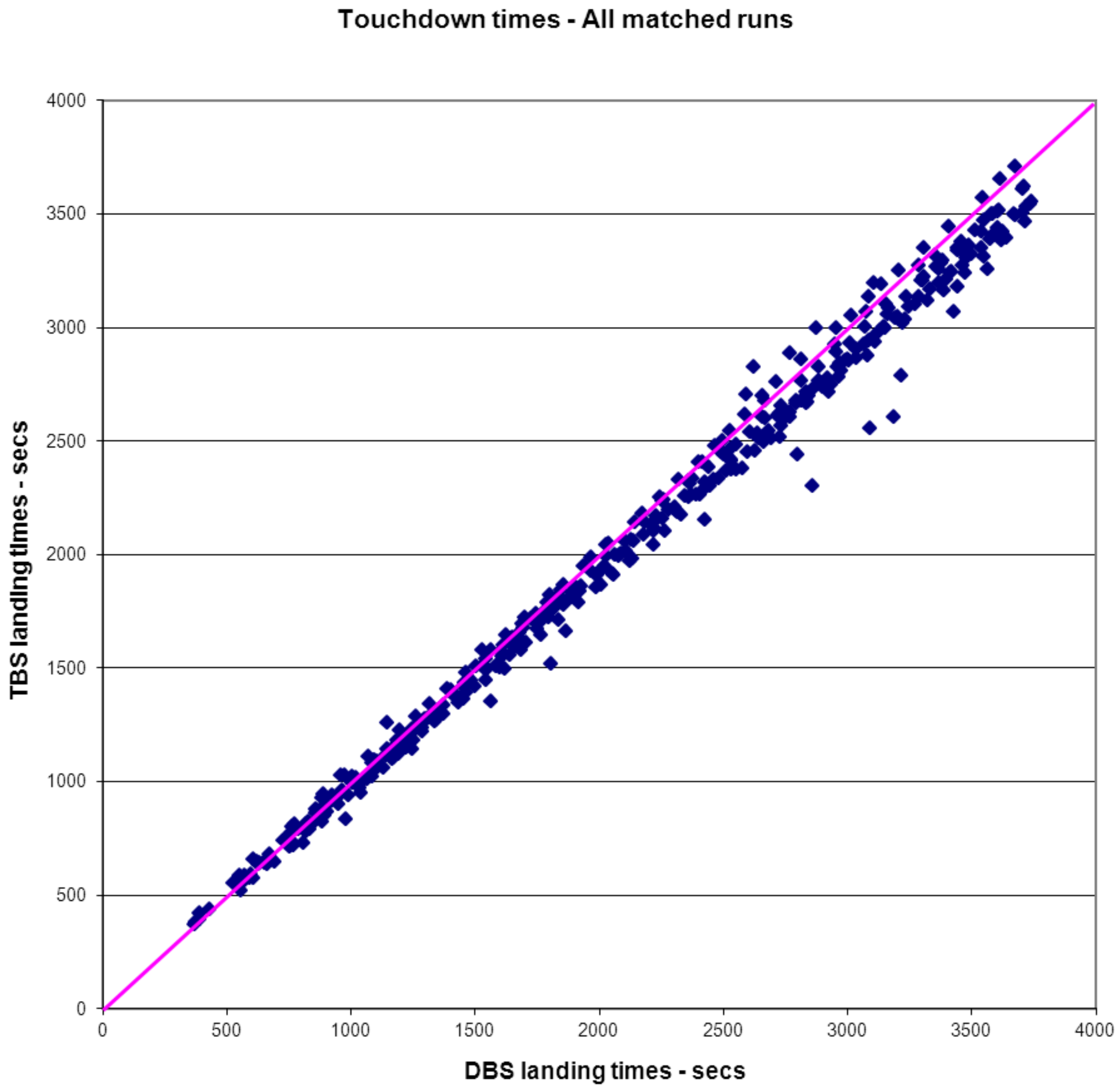


Figure 20: Aircraft Landing Times – TBS compared with DBS

6.1.3.2.9 Impact on the Efficiency of Operations

OBJ-06.08.01-VALP-0010-0080 This section presents the results for the objective: "*To assess the impact of TBS tool support and operational procedures on the efficiency of operations.*"

Summary: There was no significant difference in separation accuracy at 4DME. There was a statistically significant reduction in holding times and hold entry to touchdown times; the mean reduction in holding times with TBS was 0.9 minutes with a maximum reduction of 9.4 minutes, the mean reduction in stack entry to touchdown times with TBS was 1.4 minutes with a maximum reduction of 9.3 minutes. There were mixed interpretations to the questions on Distance To Touchdown (DTT) advisories; the intention of these questions was to confirm that controllers were still able to issue DTT advisories with TBS for CDAs, but not to actually use TBS to determine DTT information. Responses to DTT advisories highlight a training need to clarify DTT advisories and CDAs in TBS operation.

Spacing at 4DME

The aircraft spacing at 4DME results are presented in section 6.1.3.2.2 above. Aircraft separation accuracy at 4DME between DBS and TBS were almost identical. Using the Wilcoxon Signed-Rank Test, the differences in separation accuracy are not statistically significant.

Holding Times

Stack holding times were analysed for the eleven matched exercise runs (excluding 'Match 4' for the reasons described above). Aircraft callsigns were checked in each match run to confirm which hold they passed through and determine if hold entry times were available for both DBS and TBS match runs. However, not all aircraft fly through a hold because a controller can route the aircraft directly onto the base leg and approach as traffic permits. Where aircraft were not routed via a hold, the holding times were deemed to be zero, i.e. no holding. A total of 359 aircraft were included in the analysis, of which 272 were routed via a hold in both DBS and TBS exercise runs, which are good sample sizes for analysis.

A 'Box and Whisker' chart is provided below for stack holding times for all four holds combined: Bovingdon (BNN), Lambourne (LAM), Ockham (OCK) and Biggin Hill (BIG).

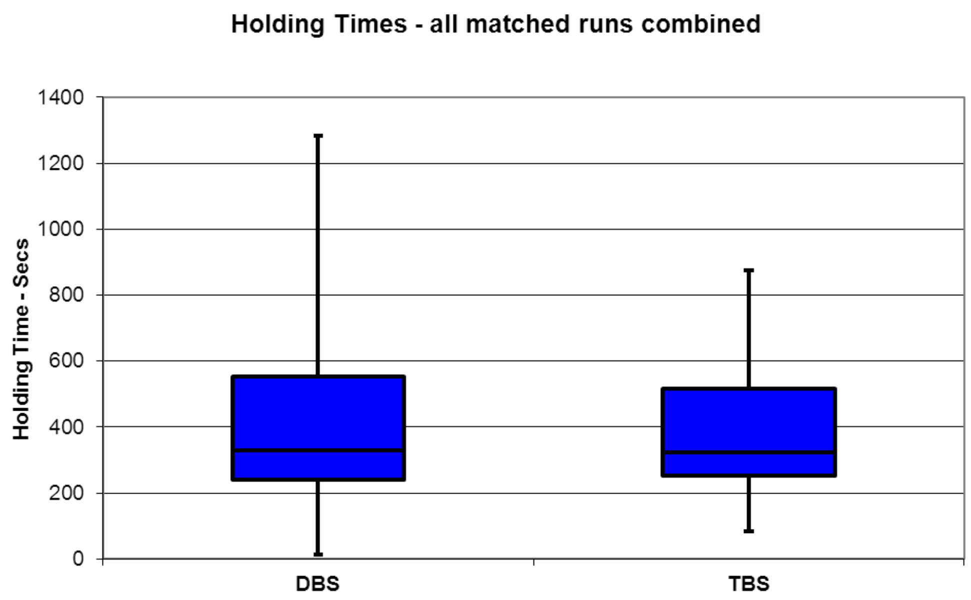


Figure 21: Stack Holding Times – All Holds and all Matched exercise runs

Stack holding times were very slightly reduced with TBS than DBS, as can be seen in the 'Box and Whisker' chart above. The Mean for DBS and TBS are identical. However, the first quartiles (25^{th} percentile) for TBS are slightly less than with DBS. The spread between maximum and minimum holding times are significantly reduced. Mean reduction in holding times with TBS was 0.9 minutes, with a maximum reduction of 9.4 minutes. The reduction in stack holding time with TBS is statistically significant terms using the Wilcoxon Signed-Rank Test.

Hold to Touchdown Times

Stack entry to touchdown times were analysed for the eleven matched exercise runs (excluding 'Match 4' for the reasons described above). Aircraft callsigns were checked in each match run to confirm which hold they passed through and determine if hold entry times were available for both DBS and TBS match runs for comparison. However, not all aircraft fly through a hold because a controller can route the aircraft directly onto the base leg and approach as traffic permits, which reduced the number of paired timings to match.

Filtering the data, it was determined that 256 aircraft data pairs with both DBS and TBS hold timings were available. Note: this figure is slightly less than the 272 aircraft which had both DBS and TBS hold times (see 'Holding Times' above), the reason for the difference being 16 aircraft entered holds but did not land before the end of the validation exercise (about one aircraft per exercise).

'Box and Whisker' charts are provided for stack holding and stack entry to touchdown times for all four holds: Bovingdon (BNN), Lambourne (LAM), Ockham (OCK) and Biggin Hill (BIG). Additional charts are provided for each of the four individual holds for more detailed comparison.

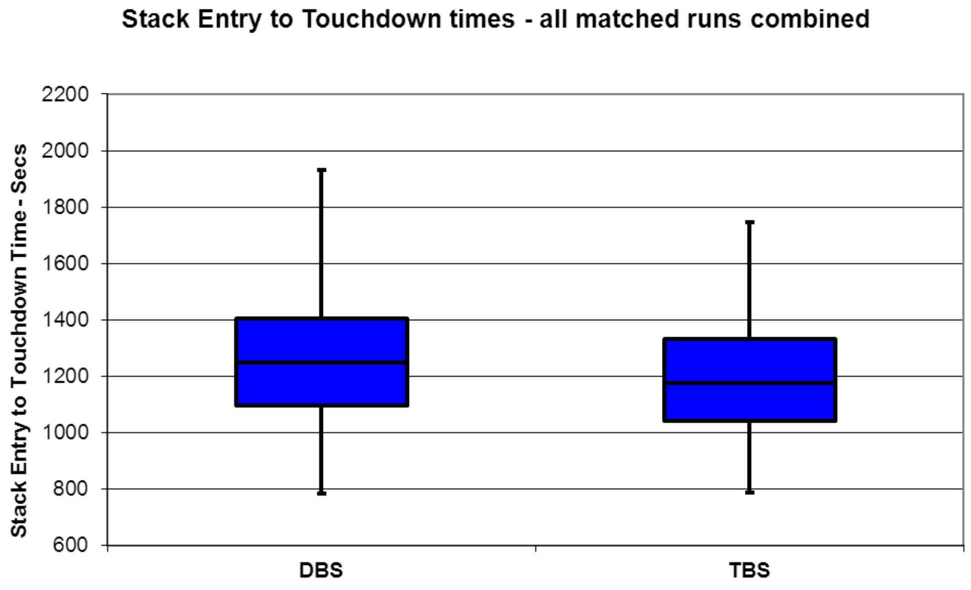


Figure 22: Stack Entry to Touchdown Times – All Matched exercise runs

Hold entry to touchdown times were slightly reduced with TBS than DBS, as can be seen in the 'Box and Whisker' chart above. The Mean and first quartiles (25^{th} percentile) for TBS are less than with DBS. The spread between maximum and minimum stack entry to touchdown times are also slightly reduced. Mean reduction in holding stack entry to touchdown times with TBS was 1.4 minutes, with a maximum reduction of 9.3 minutes. The reduction in stack entry to touchdown time with TBS is extremely significant in statistical terms using the Wilcoxon Signed-Rank Test for Statistical Significance.

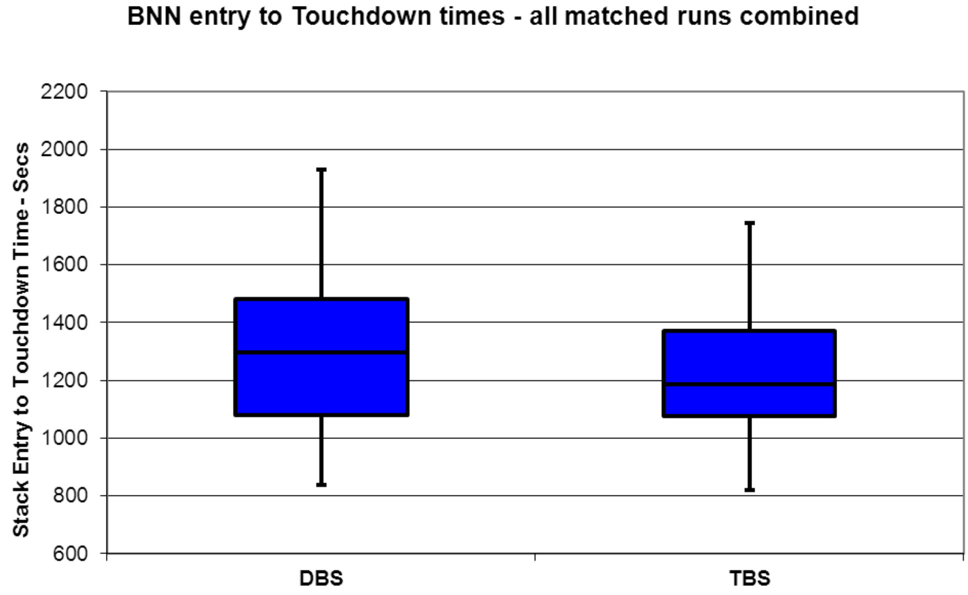


Figure 23: Stack Entry to Touchdown Times – Bovingdon (BNN) Hold

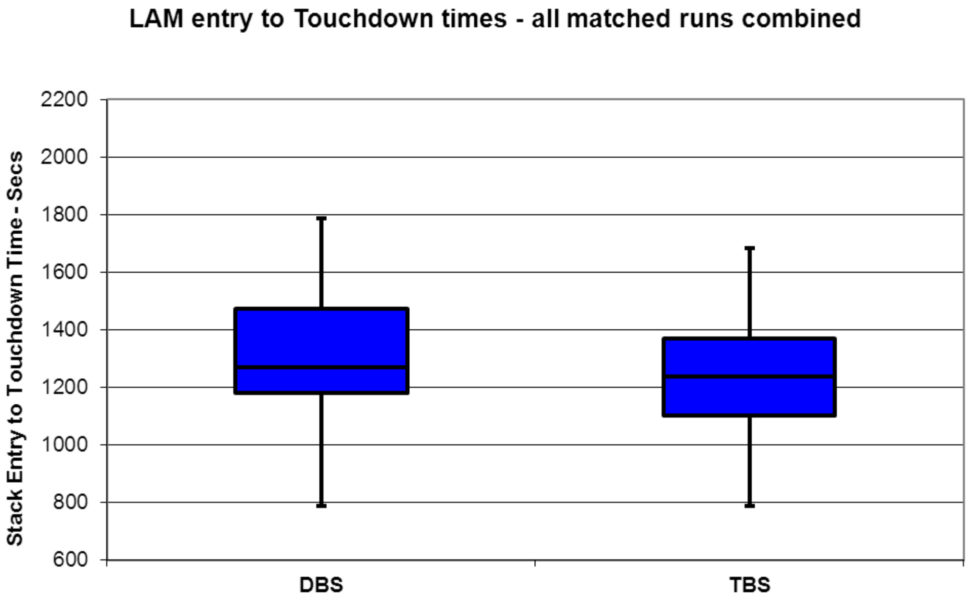


Figure 24: Stack Entry to Touchdown Times – Lambourne (LAM) Hold

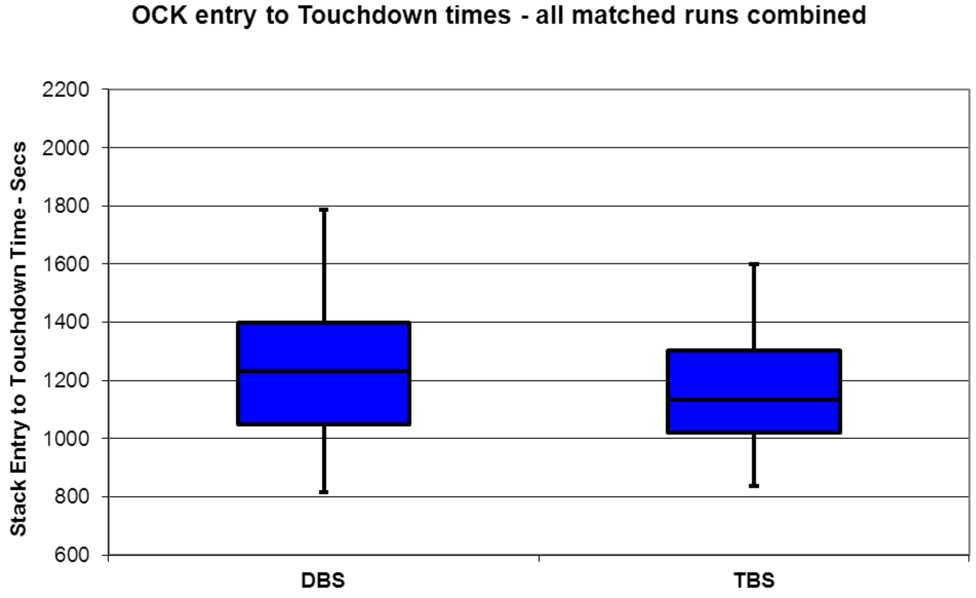


Figure 25: Stack Entry to Touchdown Times – Ockham (OCK) Hold

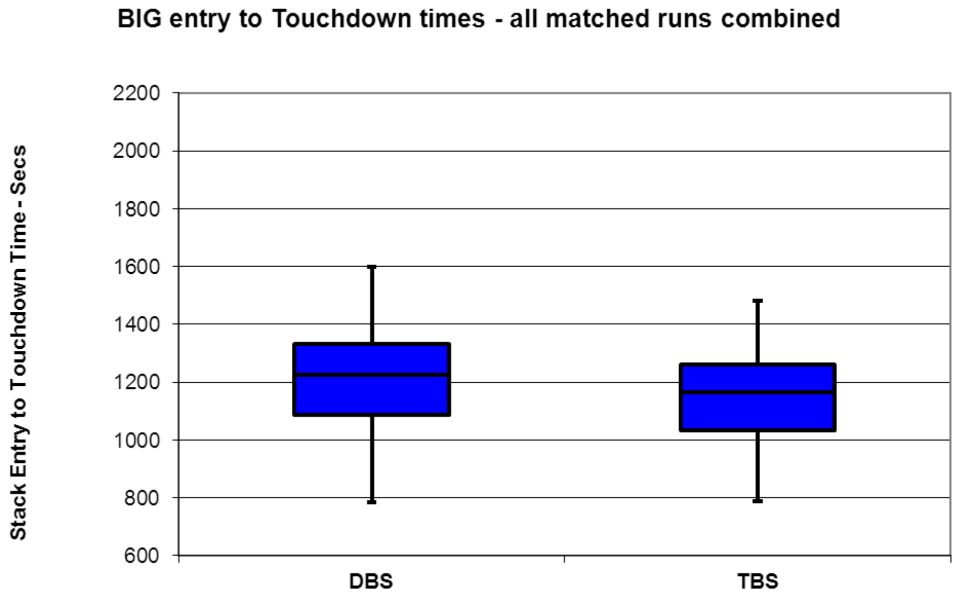


Figure 26: Stack Entry to Touchdown Times – Biggin Hill (BIG) Hold

The figure below with charts showing stack entry to touchdown times for Biggin Hill (BIG) hold with Westerly and Easterly operations indicates that times for Easterly operations were generally more consistent across the matched exercise runs with less variation in holding times and stack to touchdown times. This was consistent for all four holds, with BIG perhaps being the clearest example which is provided below.

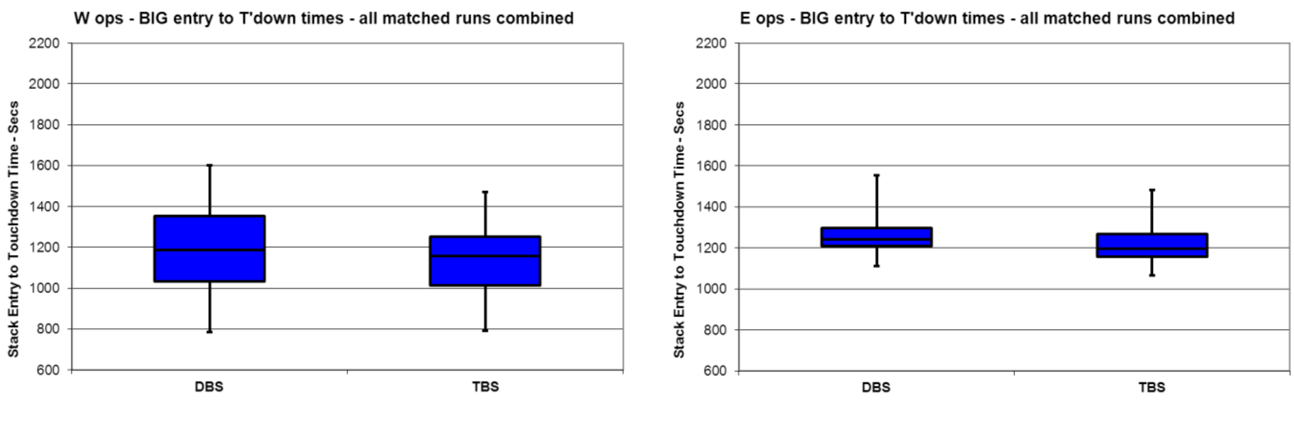


Figure 27: Stack Entry to Touchdown Times – BIG Westerly and Easterly Operations

Landing Times

The aircraft landing time results are presented in section 6.1.3.2.8 above. Plotting matched aircraft landing times demonstrates the majority of aircraft were being landed slightly earlier with the TBS than with DBS exercise runs, which is consistent with reduced holding times and increased aircraft landing rates.

Questionnaires

End of Participation Questionnaires

Summary tables for Heathrow Approach controllers and Heathrow Tower Runway controllers are provided below.

Question	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
3.2 I was still able to issue accurate distance to touchdown advice when using TBS.	0	0	1	2	3

Table 29: Heathrow Approach Controllers End of Participation – Efficiency of Operations

Six of the ten Heathrow Approach controller participants completed the End of Participation questionnaire; four controllers only attended one day, which was considered insufficient exposure to TBS and the measured positions to contribute.

The End of Participation results for Heathrow Approach controllers indicate that the TBS concept and HMI is generally acceptable, though some improvements are required. Responses to Question 3.2 for Distance To Touchdown (DTT) advisories when using TBS indicates there were mixed views over DTT. One controller commented they "*Didn't use it for Distance to Touch Down*." And another commented "*I was basing DTT on the usual DBS WV (Wake Vortex) requirements*."

The variations in scores combined with explanatory comments indicates there were mixed interpretations of the question; the intention of this question was to confirm that controllers were still able to issue Distance To Touchdown (DTT) advisories with TBS for Continuous Descent Approaches (CDAs), but not to actually use TBS to determine DTT information. The responses highlight a training need to clarify DTT advisories and CDAs in TBS operation.

Expert Observations

The expert observer questionnaires asked seven specific questions, each directly linked to validation objectives, and space was provided for comments and clarifications. Questions relating to this section are shown in the table below.

Question	Always	Mostly	Sometimes	Rarely	Never
Q.7 The quality of Distance To Touchdown (DTT) advisories is acceptable under TBS operations.	15	7	3	0	0

Table 30: Expert Observation Results Summary – Efficiency of Operations

As can be seen from the summary table above, the majority of the responses to Question 7 were 'Always'. However, there were a significant number of responses as 'Mostly' or 'Sometimes', indicating procedures for DTT advisories require clarification in training. The following observation is of relevance to Question 7:

- "*DTT can be misinterpreted, as the indicators at or beyond 20 miles are not a distance from touchdown.*"
- "*A tendency to use the DTT advisories as targets before applying speed reduction - consequently some wake vortex minima are being infringed*."
- "*DTT advisories only programmed to appear in conjunction with vortex Wake pairs*."
- "*It is possible to mistake the distance between the markers as being equivalent to the required spacing instead of the distance between an aircraft on the centreline and the following marker equating to that spacing, but faith in the quality and consistency of the DTT advisories should eliminate that doubt*."
- "*TEAM: If using the chevrons as DTT they were always short of miles as they were predicting you'd be managing 4 Nm on each runway, but realistically it was 5*." Note: a fix for this was tested using a patched software build on the final exercise run of the validation exercise (Run TBS134); this increased the TEAM spacing from 2 Nm to 2.5 Nm and proved successful.

The variations in scores combined with explanatory comments indicates there were mixed interpretations of the question; the intention of this question was to confirm that controllers were still able to issue Distance To Touchdown (DTT) advisories with TBS for Continuous Descent Approaches (CDAs), but not to actually use TBS to determine DTT information. The responses highlight a training need to clarify DTT advisories and CDAs in TBS operation.

6.1.3.2.10 Impact on the Predictability of Operations

OBJ-06.08.01-VALP-0010-0090 This section presents the results for the objective: "*To assess the impact of TBS tool support and operational procedures on the predictability of operations.*" The criteria for assessment is as follows: "*Estimated impact of TBS shall demonstrate an overall reduction, all else being equal, in the variability in arrival time due to variability in the headwind conditions on final approach*."

Summary: There was a statistically significant increase in aircraft landing rates with TBS up to +5 additional aircraft per hour, with a mean of 2 additional aircraft per hour, for the traffic samples and wind conditions simulated. There was a consistent increase in aircraft landing rates with TBS across a variety of wind conditions.

Landing Rates – Passing 4DME

The aircraft landing rates results (recorded at passing 4DME) are presented in section 6.1.3.2.8 above. The increased aircraft landing rates with TBS are statistically significant, indicating that TBS does enable higher landing rates of up to 5 additional aircraft per hour, with a mean of 2 additional aircraft per hour.

Wind Effect on Matched Exercise Runs

Five different wind scenarios were used for the matched exercise runs; two easterly (EN1 and EC3) and three westerly (WN1, WC1 and WC3) with 2.5 Nm spacing, except for WC1 which required 3 Nm spacing. These winds were combined with eight different traffic samples. As the prevailing winds in the UK are westerly, the majority of the matched exercise runs were westerly; eight westerly and three easterly. The number in parenthesis alongside the wind profile identifier in the table below indicates the number of times the wind profile was used with a matched exercise run.

The table below shows the landing rates, mean separation accuracy, median separation accuracy and the Standard Deviation (SD) separation accuracy associated with each wind profile.

Averages	Matched runs									
	EC3 (1)		EN1 (2)		WC1 (3)		WC3 (3)		WN1 (2)	
	DBS	TBS	DBS	TBS	DBS	TBS	DBS	TBS	DBS	TBS
Landing Rates	41.26	44.80	45.36	45.52	41.42	42.97	42.24	44.60	44.90	48.30
Mean sep acc	0.14	0.27	0.04	0.29	0.46	0.51	0.23	0.31	0.21	0.15
Median sep acc	0.14	0.21	0.02	0.25	0.41	0.44	0.18	0.23	0.18	0.11
StDev	0.21	0.22	0.25	0.29	0.37	0.34	0.23	0.36	0.27	0.17

Wind	Type	Description	Spacing
EC3	Easterly	Easterly Pull-Away (Leader pulling away from Follower)	2.5 Nm
EN1	Easterly	Normal - Medium Wind Profile	2.5 Nm
WC1	Westerly	Westerly Pull-Away (Leader pulling away from Follower)	3.0 Nm
WC3	Westerly	Strong Westerly Headwind - Catch-Up between Follower and Leader	2.5 Nm
WN1	Westerly	Normal - Medium Wind Profile	2.5 Nm

Table 31: Wind Effect on Matched exercise runs

Landing rates, as already discussed earlier in this section, were overall higher with TBS than with DBS. The highest landing rates achieved were during Normal wind conditions, i.e. westerly WN1 and easterly EN1. However, landing rates with easterly EN1 were almost identical between TBS and DBS; EN1 was a medium wind profile with 2.5 Nm spacing. The Challenging wind profiles (westerly WC1, WC3 and easterly EC3) had slightly lower landing rates, and in the cases of westerly WC1 and WC3 noticeably reduced separation accuracy. However, the landing rates with TBS for the Challenging (strong) wind profiles were comparatively higher than with DBS.

Westerly WC1 is of particular interest because separation accuracy was reduced for both TBS and DBS; the wind profile was a ‘Pull-Away’ wind with 3 Nm spacing. This indicates that the wind effect caused the controllers to have to allow a wider margin for separation during the approach.

Westerly WC3 also shows separation accuracy was slight reduced for TBS; the wind profile was a strong westerly ‘Catch-Up’ headwind with 2.5 Nm spacing. A wider margin for separation during the approach was therefore being applied between the TBS indicator and the Follower aircraft.

6.1.3.2.11 Impact on Environmental Performance of Aircraft

OBJ-06.08.01-VALP-0010-0100 This section presents the results for the objective: “*To assess the impact of TBS tool support and operational procedures on environmental performance of aircraft in the hold and on final approach.*”

Summary: There was a statistically significant reduction in holding times and hold entry to touchdown times; the mean reduction in holding times with TBS was 0.9 minutes with a maximum reduction of 9.4 minutes, the mean reduction in stack entry to touchdown times with TBS was 1.4 minutes with a maximum reduction of 9.3 minutes. These results are sensitive to the exercise run duration.

Holding Times

The holding times results are presented in section 6.1.3.2.9 above. Stack holding times were very slightly reduced with TBS than DBS. Mean reduction in holding time with TBS was 0.9 minutes, with a maximum reduction of 9.4 minutes. The reduction in stack holding time with TBS is statistically significant.

Landing Times

The aircraft landing time results are presented in section 6.1.3.2.8 above. Plotting matched aircraft landing times demonstrates the majority of aircraft were being landed slightly earlier with the TBS than with DBS exercise runs, which is consistent with reduced holding times and increased aircraft landing rates.

Hold to Touchdown Times

The hold entry to touchdown times results are presented in section 6.1.3.2.9 above. Hold entry to touchdown times were slightly reduced with TBS than DBS. The mean reduction in stack entry to touchdown time with TBS was 1.4 minutes, with a maximum reduction of 9.3 minutes. The reduction in holding stack entry to touchdown time with TBS is extremely significant in statistical terms.

KERMIT Fuel Burn Analysis

The NATS' Kerosene Emissions Research Model In the TMA (KERMIT) tool was used to determine relative fuel burn between Matched exercise runs for aircraft from their starting positions in the simulation to touchdown on the runway. It was not possible to calculate fuel burn and corresponding CO_2 emitted during airborne holding separately as per the validation objective criteria. However, the starting positions to touchdown on the runway provide a good data sample size (383 aircraft) and can be directly compared between DBS and TBS. The results are presented in the tables below:

Average Fuel Burn (Kg)	Overall
DBS	1882.12
TBS	1773.57
Percentage Reduction	**5.77%**

Average of CO_2 (Kg)	Overall
DBS	5985.15
TBS	5639.95
Percentage Reduction	**5.77%**

Table 32: KERMIT Fuel Burn and CO_2 Metrics for All Matched exercise runs

As illustrated in the table above, there was an overall 5.77% reduction with TBS in calculated fuel burned and CO_2 produced between the DBS and TBS Matched exercise runs. This offers a significant potential environmental benefit with TBS operation. Using the Wilcoxon Signed-Rank Test, reduction in calculated fuel burned and CO_2 emitted are statistically significant.

Average Fuel Burn (Kg)	Wind				
	EC3 (1)	**EN1 (2)**	**WC1 (3)**	**WC3 (3)**	**WN1 (2)**
DBS	2408.01	1613.65	2002.61	1923.99	1661.00
TBS	2203.05	1566.55	1911.45	1819.78	1508.01
Percentage Reduction	**8.51%**	**2.92%**	**4.55%**	**5.42%**	**9.21%**

Average of CO_2 (Kg)	Wind				
	EC3 (1)	**EN1 (2)**	**WC1 (3)**	**WC3 (3)**	**WN1 (2)**
DBS	7657.48	5131.42	6368.30	6118.29	5282.00
TBS	7005.69	4981.63	6078.41	5786.89	4795.48
Percentage Reduction	**8.51%**	**2.92%**	**4.55%**	**5.42%**	**9.21%**

Table 33: KERMIT Fuel Burn and CO_2 Metrics by Wind Profile

Colour coding has been used on the tables above to highlight lower fuel burn and CO_2 produced, and higher percentage reductions with TBS compared to DBS. The greatest fuel savings with TBS were with wind profiles Westerly Normal (WN1) and Easterly Challenging (EC3). The lowest fuel savings were with Easterly Normal (EN1). Both Westerly Challenging winds (WC1 and WC3) demonstrated a consistent fuel saving across six matched exercise runs, three exercise runs for each wind profile.

6.1.3.2.12 Unexpected Behaviours/Results

Limitations of the Simulation

Aircraft/pilot non-conformance to speed instructions was a recurrent concern highlighted throughout the simulations because it has a large impact on TBS operations. Using TBS indicators to their optimum places a reliance on pilots conforming to speed instructions and the aircraft slowing down within a reasonable time period and at the rate expected by the controller. It was not possible to fully replicate normal pilot and aircraft behaviour in the validation exercises; usually the pseudo pilot/aircraft responded too perfectly to instructions, and when non-conformances were introduced they were often too extreme or inappropriately timed to be realistic. Aircraft behaviour realism was improved during the simulations but was not perfected.

The TBS tool used for the simulation exercise was a prototype emulation of the TBS functionality, with the provision of an INT North Support role to maintain the electronic flight data (EFD) for the landing sequence applied by the TST; in operation, it is not expected that the INT North Support would be required to set up the arrival sequence order through an EFD. It is expected that the arrival sequence will be provided through a combination of AMAN and the EFD Sequence from the Final Approach Controller.

TC Approach and Heathrow Tower Supervisors were not available during the validation exercise, which meant it was not possible to realistically and dynamically co-ordinate spacing delivery between TC Approach and Heathrow Tower; spacing delivery was agreed prior to the validation activity based on the winds for each exercise run. The absence of a Heathrow Tower runway controller for most exercise runs further affected the co-ordination of spacing delivery.

The following Time Separation Tool (TST) functionality was not implemented in the prototype TST software prior to the TC Approach validation exercise, which slightly affected the usability and overall impression of the tool:

- Leader and follower aircraft catch-up warning;
- Incorrect aircraft turned onto a TBS indicator;
- Aircraft turned onto the wrong localizer/runway centreline alert.

Time Separation Tool (TST) Observed Faults

The use of a prototype TBS tool, rather than a production tool designed to an operational Software Integrity Level (SIL), provided flexibility for the simulation but was not as robust as a production tool. During the simulation, it became apparent that some functionality had not been correctly specified from earlier workshops, e.g. TEAM and aircraft go-around indicator behaviour. Feedback from this exercise has proved very useful to update the specifications to address these issues.

Unstable Not-in-trail Indicators: TST indicators for aircraft landing on the departure runway were frequently observed to experience transitory jumps between runway centrelines for the duration of the follower aircraft turning from downwind to base. For example NGE833G and IBE3174 in exercise run 111; following a change in the aircraft's landing runway the indicator would switch over to 27L, after a short time the indicator would jump back on to 27R and then back to 27L.

Wake Separation Constraint Over-ridden by Not-in-trail Separation: During TEAM operations the wake constraint between two aircraft on 27R was not taken into account when a 27L aircraft was in between; see figure below. The chevron shaped indicator for the not-in-trail spacing between BAW284 and SHT3N is displayed. This is not correct as the wake constraint between VIR40 and SHT3N is larger.

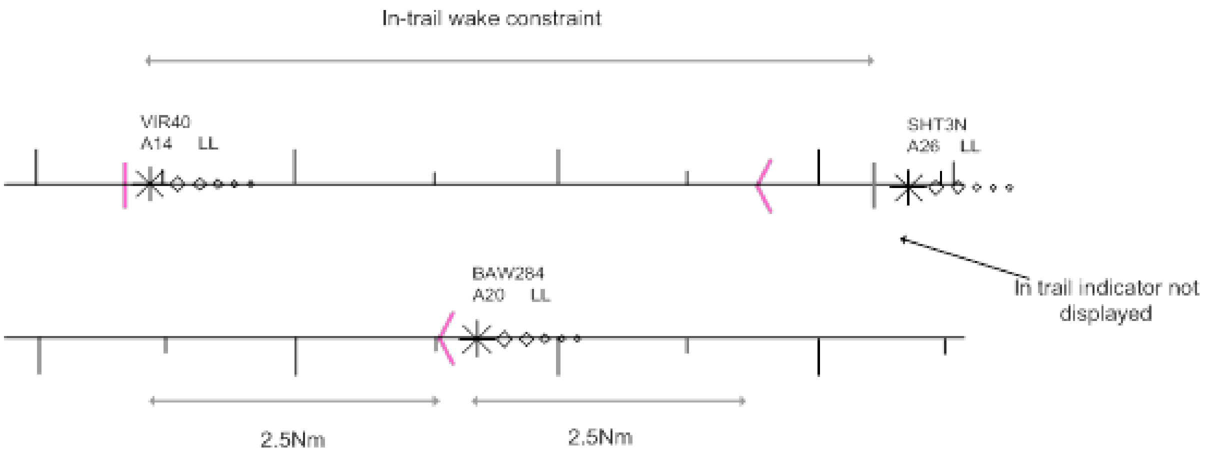


Figure 28: Wake Separation Over-Ridden by Not-in trail Separation

Indicator Behaviour during Go-around: There was an omission of tool support for this scenario; a Change Request (CR) was outstanding as it could not be implemented in time for the VP-303 validation exercise. The consequence of this omission was multiple indicators were observed on the runway centreline and it was not clear which indicator related to which aircraft. Often it was necessary to remove the aircraft from the sequence entirely and re-insert them in order to reset the

TST indicators. In the case of multiple go-arounds (exercise run TBS064) the situation became very confused. Other exercise runs affected were TBS104, TBS114 and TBS131.

Configuration Parameters not Updating the Minimum Spacing Value: Separate configuration files were set-up to enable either 2.5 Nm or 3.0 Nm spacing minimum to be applied. However, all configurations resulted in 2.5 Nm spacing minimum, and it was necessary to set-up 3.0 Nm manually. This was mainly an issue for the validation team to manually set the spacing minimum before the first aircraft turned onto base leg, though occasionally it was selected late.

Spacing Policy Reset: During some exercises when a 3.0 Nm spacing minimum was set-up manually (see above), this was found to reset to 2.5 Nm automatically without user input, e.g. exercise run 052.

Incorrect Calculation of Time Based Separation: Indicator behind ACA860 in run TBS121. The TST had an assumed speed of 60 Knots rather than 160 Knots for this aircraft. This value is controlled by a single configuration table based on aircraft wake vortex category; 160 Knots is set for every aircraft. It is unclear how a value of 60 Knots was eventually used in the calculation. This resulted in a small separation behind this aircraft (2.5 Nm when a value of around 3.5 Nm should have been used).

'Jump' of TBS Indicator: During exercise run TBS044 the indicator for BAW81V was observed to jump backwards and forwards by 0.5 Nm. Subsequent investigations revealed this was caused by a synchronization update problem, which resulted in the update of the aircraft track position being perceptible to the final approach controller separately to the update of the TST Indicator position. To resolve this, the TST Indicator position update needs to be more closely integrated into the Radar display processing system to ensure aircraft positions and corresponding TST indicator updates remain synchronized.

Indicators for too Many Aircraft in the Sequence: Indicators should only be displayed for the last aircraft established on intercept and a following (configurable) three aircraft. This was not implemented, therefore indicators were displayed for all aircraft in the sequence up to the 25 Nm limit.

Temporary Indicator De-activation: The Indicator behind MAS4 was de-activated co-incidentally with the reduction to 160 Knots in exercise run TBS132. This occurred when MAS 4 failed to capture the 09L localiser on an Intercept from the North and flew through the 09R centreline before turning on to an Intercept from the South back on to the 09L localiser. The Indicator was deactivated when MAS4 crossed the 09R centreline until turning on to the Intercept to merge on to 09L from the South. The TST needs to be designed to be more robust to deviations in flight path to allow for approaches that are not perfect and precisely on the runway centrelines.

6.1.3.3 Confidence in Results of Validation Exercise

6.1.3.3.1 Quality of Validation Exercise Results

The volume and quality of data collected for analysis was both sufficient and of good quality, which has enabled detailed analysis to be performed with a high degree of confidence in the results. All system data analysis excludes the 'run in time' of 10 minutes – this was decided before the simulation and confirmed as the appropriate 'run in period' during the simulations to allow traffic to build.

A total of ten Heathrow Approach Controllers from LTC and one Heathrow Tower Controller were involved in the validation exercise simulations. Of the ten Heathrow Approach Controllers, four were only able to attend for one day because of operational commitments; these four controllers were not requested to complete the end of participation questionnaires because one day was considered insufficient exposure to TBS and the different positions (FIN, INT N and INT S). Of the six other Heathrow Approach Controllers who attended for two or more days, two were non-operational having recently retired from operations, though both have extensive experience on Heathrow Approach, one having been closely involved with TBS through previous workshops and simulations. Overall, the simulations had a good number and good mix of controllers and operational experience to assess TBS.

Analysis was undertaken using the comparative DBS and TBS data from eleven matched exercise runs; 'Match 4' was excluded from the analysis because significant problems were experienced with the TEAM functionality, which compromised the validation exercise run. The eleven matched exercise runs yielded a good volume and quality of data for analysis.

6.1.3.3.2 Significance of Validation Exercise Results

Two methods of comparative analysis were used for operational and statistical significance:

1. **'Box and Whisker' charts**.
2. **Wilcoxon Signed-Rank Test for Statistical Significance**.

A limitation of the comparative analysis was the relatively small sample sizes from the matched exercise runs for controller metrics, e.g. End of Run questionnaires. However, sufficient data was available to test for statistical significance where differences were evident and the results of these tests reported. Much larger samples of aircraft performance data was available comparison, specifically for aircraft landing/touchdown rates, holding times and stack entry to touchdown times; sample sizes were up to 359 data points (aircraft) depending on filtering for the specific metric. With these larger sample sizes, the Wilcoxon Signed-Rank Test was able to reveal that the differences in a number of key metrics are statistically significant.

Problems were experienced with unrealistic aircraft behaviour during attempts to simulate aircraft non-conformance to speed instruction. It proved extremely difficult to fully replicate realistic pilot/aircraft non-conformance behaviour in the simulator. This resulted in two of the earlier exercise runs (Match 1) being re-run later in the simulation. Pilot/aircraft non-conformance scenarios were moved to the later simulation days when more controllers were available to assist with the type and timings of non-conformance to improve realism as far as was practicable. Pilot/aircraft behaviour realism was improved during the simulations, but it was not perfected.

Only one Heathrow Tower Runway controller was available for the simulations, during which they attended two days. Therefore the results for the Heathrow Runway controller role are limited to just one individual and should be viewed as purely indicative without any statistical significance. The Heathrow Runway controller role will be specifically assessed during forthcoming simulations with exercise 06.080.01 VP-302.

6.1.4 Conclusions and recommendations

6.1.4.1 Conclusions

The evidence from the Time Based Separation (TBS) Heathrow Approach validation exercise indicates that the TBS concept is viable and could deliver significant improvements and benefits for aircraft landing rates, holding times and stack entry to touchdown times. However, issues with the prototype TBS tool software and changes in controller scanning focus resulted in a slight but perceivable reduction in controller situation awareness. Specific conclusions are listed below:

C1. The TBS concept is viable as simulated for Heathrow Approach control and could deliver significant improvements and benefits for airport operations in terms of higher aircraft landing rates in stronger wind conditions, and reduced holding and approach times.

C2. Aircraft landing rates were consistently increased with TBS for all eleven matched exercise runs; up to 5 additional aircraft per hour were landed with TBS compared to DBS, with a mean of 2 additional aircraft per hour, for the traffic samples and wind conditions simulated. The increased aircraft landing rates are statistically significant.

C3. Holding times and Stack entry to touchdown times were reduced with TBS compared to DBS; these reductions have been demonstrated to be strongly statistically significant. The mean reduction in holding times with TBS was 0.9 minutes, with a maximum reduction of 9.4 minutes. The mean reduction in stack entry to touchdown times with TBS was 1.4 minutes, with a maximum reduction of 9.3 minutes. These results are sensitive to exercise run duration.

C4. Aircraft separation accuracy for Wake pairs at 4DME between DBS and TBS shows a clear and statistically significant improvement with TBS compared to DBS for all eleven matched exercise runs analysed; there was no improvement with TBS compared to DBS for Non-Wake pairs. However, overall TBS performed generally better than DBS. There were 11 Wake under-separation events with TBS compared to 43 with DBS, a reduction of almost 75%. A significant proportion of the Wake under-separation events occurred during each of the three Easterly operations matched exercise runs. There was no statistically significant difference for Non-Wake under-separation events.

C5. There was no statistically significant difference in controller workloads (Bedford and ISA) or R/T occupancy with TBS compared with DBS; workloads and R/T were busy but comfortable. A very slight increase was recorded for R/T, but this appears linked to the higher aircraft landing rates.

C6. Two losses of separation with TBS were recorded at 4DME during the simulation, none were recorded with DBS. One loss of separation with TBS in a Match run was detected from the TST log data at 4DME. The second loss of separation resulted from a TBS tool error which positioned the indicator too close to the Leader aircraft for the wake vortex categories of the two aircraft; the FIN controller did not detect this error, due to reduced Situation Awareness, until pointed out by the Expert Observer. To mitigate the risk of incorrect separation displayed by TBS, controllers need to be provided the means to quickly check the credibility of the indicated spacing for the aircraft types and vortex categories and the wind conditions; this needs to be incorporated into training and procedures and may require some system modifications to more clearly highlight the aircraft types/vortex categories.

C7. Analysis of highly under-separated events of Wake aircraft pairs joining the ILS indicates that TBS performed very slightly better than DBS; however this is not statistically significant because there is insufficient data for a statistical significance test. Five highly under-separated Wake events were recorded during the 11 Matched exercise runs; 3 events with DBS and 2 with TBS.

C8. Situation Awareness for the FIN controller was slightly reduced with TBS compared to DBS, this reduction was not statistically significant; the INT N and S roles were generally unaffected with TBS. The reduction in Situation Awareness for the FIN controller was evident through a move of focus onto the TST indicators away from the flight strips, with less awareness of aircraft types, wake vortex categories and the position of the lead aircraft. This indicates the TBS tool needs to be designed to a high level of integrity for accuracy and reliability, and training needs to ensure aircraft types and wake vortex categories are still checked.

C9. A number of Time Separation Tool (TST) faults were observed during the simulations that affected the usability of the prototype TBS tool and user confidence and trust. A significant fault that significantly impacted user confidence was an incorrect calculation of Time Based Separation, which led to one observed loss of Wake separation. Tactical Enhanced Arrival Mode (TEAM) functionality, particularly early morning TEAM, was unacceptable with unstable not-in-trail indicators, missing in-trail Wake indicators and lateral spacing at 2 Nm being too close; a successful single trial with 2.5 Nm spacing indicated this was an improvement.

C10. The need for an INT N Support role to assist with agreeing the landing sequence and maintaining the sequence order on the Electronic Flight Data (EFD) display for the TST calculations was unrealistic and caused some problems with workload and incorrect aircraft sequence order. This resulted in some unusual behaviour of TBS indicators, but was mitigated by mostly having the same person (not measured) on INT N Support and using the same sequence order as far as possible for each exercise run of the same traffic sample. In operational service, TBS is planned to be operated with electronic strips, which will overcome this issue.

C11. Controller trust in the TBS tool was generally low. The most significant response to the TBS tool was that most of the participants were not confident the tool would provide either the best or correct advice. One event in particular affected controller confidence in the tool; this was the loss of Wake separation between two heavy wake vortex category aircraft as a result of a TST calculation error causing the Indicators to be displayed in the wrong position. This highlighted that the TBS tool in the simulation was a prototype and that the production TBS tool needs to be very accurate and reliable. An additional factor affecting trust in the TBS tool was TEAM functionality which, though it generally performed as specified, a few faults caused the tool to be unacceptable in use for both early morning TEAM and 6 aircraft per hour TEAM.

6.1.4.2 Recommendations

The following recommendations are proposed as a result of the TBS Heathrow Approach validation exercise in February and March 2012:

R1. The scheduled Heathrow Tower simulations (6.8.1 VP-302) should proceed to assess the Runway controller interactions with the TBS tool and with aircraft landing rates and separations as delivered in the Heathrow Approach simulations. This is required to ascertain whether the aircraft delivery rates and separation from Approach control using TBS is acceptable to Runway controllers in different wind and weather conditions.

R2. The TBS tool should be progressed from a prototype software tool into a production tool designed and developed to an operational Software Integrity Level (SIL). The production tool needs to address the functionality, accuracy, reliability, stability and robustness issues highlighted in this report. Key faults to rectify are incorrect time based and wake vortex separation calculations because of controller reliance on tool accuracy. This recommendation is dependent on the outcome of the scheduled Heathrow Tower simulations (6.8.1 VP-302); see R1.

R3. Particular focus for TBS operation needs to be applied to Tactical Enhanced Arrival Mode (TEAM) functionality for both early morning and 6 aircraft per hour, which proved to be unacceptable in the simulation. A trial was performed on the final TBS exercise run of the simulation with an increase in lateral separation from 2 Nm to 2.5 Nm, from which feedback indicates a definite improvement for usability and safe separation.

R4. The TBS Method of Operations (MOps) requires some clarification over procedures for 3 Nm and 2.5 Nm spacing between Heathrow Approach controllers and Tower runway controllers; this became evident with the absence of Approach and Tower Supervisors present during the validation exercise and limited Tower runway controller support.

R5. Clarifications are required for responsibility between controllers and pilots for conformance to speed instructions due to the increased reliance with TBS on aircraft behaviour matching the controller instructions; potentially there could be more ‘go-arounds’ with TBS due to pilot non-conformance to speed instructions.

R6. Procedures for Distance To Touchdown (DTT) advisories require clarification in training in order to deliver Continuous Descent Approaches (CDAs) effectively.

R7. Training needs to address the natural tendency to view and use the TBS indicators as ‘targets’, despite being briefed to use them as moving references; the phrase “*if it looks like a target, I’ll use it like a target*” was used repeatedly. It is perhaps best to think of positioning the aircraft in a zone behind the TBS indicator, a zone that varies in distance depending on the wind conditions. For training, it would perhaps be helpful to visually illustrate the zone in the training materials and presentation slides to clarify understanding.

R8. Consideration should be given to incorporating more comprehensive wind effect calculations into the TST to enable the controllers to confidently position aircraft much closer to the TBS indicators. At present, with some strong wind conditions, controllers have to ‘aim off’ the indicators by one or even two nautical miles to allow for compression (aircraft catch-up) during the approach. This requires controllers to adjust their positioning of aircraft to the wind conditions by monitoring aircraft behaviour during the approach to judge how far behind the TBS indicator an aircraft needs to be. The TST would be more helpful to the controller if the calculations to allow for compression could be built into the tool to position the current TBS indicators further back allowing for compression, rather than having to judge the offset by eye.

R9. The TBS tool is reliant on the correct landing sequence being maintained. In operation, this could only be reliably provided using the planned AMAN and EFD tools, i.e. an electronic flight strip environment. The simulation with a hybrid of paper strips and the INT N Support role to assist with agreeing the landing sequence and maintaining the sequence order on the Electronic Flight Data (EFD) display demonstrated the importance of an electronic environment for TBS.

6.2 Validation Exercise VP-302 (Heathrow Tower) Report

The objective of this exercise was to validate that the separations delivered by TC controllers in VP-303 were acceptable to Tower controllers using the TBS tool support. The Heathrow Tower AIR Arrivals (North) controller was provided with the necessary TBS tool support to enable consistent and accurate monitoring of the delivery to the TBS rules on final approach.

6.2.1 Exercise Scope

See the Concept Overview in Section 2.1 in accordance with P6.8.1 Validation Plan for Time Based Separation (VALP) edition 00.01.03 [4].

6.2.2 Conduct of Validation Exercise

6.2.2.1 Exercise Preparation

The V&V platform used for the simulation was the Micro Nav BEST 360° real-time Heathrow Airport Tower simulator at NATS Heathrow House, London. The simulator replicates the layout and equipment of the Heathrow Tower, whilst the view from the windows is created using projections onto a 360° screen. The simulator was operated utilizing a single Tower AIR Arrivals (North) controller position for the majority of exercise runs, with Departures South for a few exercise runs, e.g. TEAM and some scenarios.

Figure 29: Micro Nav BEST 360° real-time Heathrow Airport Tower simulator

Traffic Sample Overview

As far as possible the objective was to replicate the delivered spacing, as measured at 4Nm from the runway landing threshold (referred to hereafter as 4DME), observed and recorded in the VP-303 TC Approach validation exercise held in February / March 2012.

There was no in-the-loop FIN controller, therefore the 4DME times needed to be prepared individually. As these would change in different wind conditions, the traffic sample and wind conditions were considered as coupled (a traffic sample is defined by a traffic / wind combination). The VP-302 validation exercise comprised a series of "Matched" and "Scenario" runs. The matched exercise runs were defined by the same traffic (aircraft, sequence order and wind conditions) run in TBS and DBS modes of operation. As there was a need to define the 4DME times, and these changed between TBS and DBS, each mode of operation required a separate sample. Therefore each traffic – wind – mode of operation combination required a separate sample.

The wind profiles were also taken from the VP-303 simulation. Again, these had a naming convention: Westerly (W) and Easterly (E) winds, which were either Normal (N), Challenging (C) or Variable (V). Variable in this sense means that the wind direction and strength changed over the course of the simulation exercise. A following number then identifies the configuration of the conditions (there are multiple versions of each direction / type).

A total of 14 samples were produced as follows:

Sample	Sample Name	Base Tower Sample	Wind Conditions	TBS / DBS	Existing VP-303	Minimum Spacing
1	1WWC4TBS	1W	WC4	TBS	Yes	3.0Nm
2	3WWC3TBS	3W	WC3	TBS	Yes	2.5Nm
3	1WWC1TBS	1W	WC1	TBS	Yes	3.0Nm
4	2EEV2TBS	2E	EV2	TBS	Yes	2.5Nm
5	2EEN1TBS	2E	EN1	TBS	Yes	2.5Nm
6	6EEC2TBS	6E	EC2	TBS	Yes	2.5Nm
7	1WWC4DBS	1W	WC4	DBS	No	3.0Nm
8	3WWC3DBS	3W	WC3	DBS	Yes	2.5Nm
9	1WWC1DBS	1W	WC1	DBS	Yes	3.0Nm
10	2EEV2DBS	2E	EV2	DBS	No	2.5Nm
11	2EEN1DBS	2E	EN1	DBS	Yes	2.5Nm
12	6EEC2DBS	6E	EC2	DBS	No	2.5Nm
13	4WWN1TBS	4W	WN1	TBS	Yes	2.5Nm
14	4WWN3TBS	4W	WN3	TBS	Yes	2.5Nm

Table 34: Traffic Sample specifications

The name of each sample was unique and consisted of the base sample name – wind conditions – mode of operation. For example, 6EEC2TBS is the base sample 6E with challenging easterly wind option 2 for TBS operations.

Samples 1-6 were TBS and were 'matched' with samples 7-12 (i.e. 1WWC4TBS was matched with 1WWC4DBS). Samples 13 and 14 were to be used to evaluate specific scenarios. These are discussed in more detail below.

Traffic Sample Specification

Wherever possible the ATA times (Actual Time of Arrival, at 4DME) were taken from the VP-303 TC Approach Simulation. The 14 samples had ATA times very close to those observed in the VP-303 validation exercise.

This is with the exception of the three samples for which there is "No" in the 'Existing VP-303' column above, as these three samples were not run in DBS mode during the VP-303 validation exercise. These samples are copies of the corresponding TBS samples (1WWC4TBS, 2EEV2TBS and 6EEC2TBS). The separation accuracy to TBS minima observed in the VP-303 simulation has been applied to the relevant DBS minima. For example, for a TBS minimum of 3.5 Nm for H-H and an accuracy of 0.4 Nm (giving actual separation of 3.9 Nm) the DBS spacing would be 4.0 Nm (e.g. H-H pair) + 0.4 Nm = 4.4 Nm.

Four additional aircraft were added to the end of each sample. Only aircraft with observed 4DME times from the VP-303 were able to be reproduced. These four additional aircraft are therefore at the end of the validation exercise for realism purposes; otherwise after the last VP-303 observed aircraft the sample would just end. These aircraft all had a standard separation accuracy of 0.3 Nm.

Start-Up and Behaviour on Final Approach

All aircraft started on the ILS at around 20 Nm from touchdown at 180 IAS (with one or two exceptions, see discussion of speed behaviour).

The airspeed profiles were replicated from the VP-303 simulation. The VP-303 simulation results database was queried and processed to extract the location (altitude, x/y and distance from the runway landing threshold) of each speed instruction issued by the FIN controller.

Aircraft that were slowed to 180 IAS off the ILS all start at 180 IAS at 20DME. If aircraft were slowed to 180 IAS on the ILS then they start at 20DME at the speed from which they were slowed. All subsequent speed instructions (160 IAS predominantly, but also 170 IAS and 150 IAS where observed) on the ILS are replicated at the observed DTT (Distance to Touchdown). If no 160 IAS instruction was observed (for example, for the four additional aircraft in each sample) then a standard DTT of 10DME was used for the 160 IAS instruction. The only way to trigger the speed instruction in the Micro Nav (MNL) simulator is to apply it at a given altitude. Therefore the distance to touchdown of each speed instruction has been converted to a glideslope altitude. This resulted in unrealistic altitudes: typically aircraft will not join higher than 4,000 feet, which equates to around 12DME. However, expert advice suggested this was acceptable. All aircraft therefore started at 6,000 feet at 20DME. It was concluded that this compromise did not affect the realism of the samples.

Landing Speeds were added to the traffic samples. These were based on the same landing speed profile as was simulated in the VP-303 Approach Simulation. Landing Speed behaviour splits broadly into two categories: 'Indicated' and 'Groundspeed' modes. Most aircraft types fly 'Indicated' (meaning a target VREF based on an indicated airspeed) but modern Airbus aircraft fly 'Groundspeed' (effectively maintaining a groundspeed on approach to protect against gusts). The MNL simulator cannot accurately simulate the 'Groundspeed' mode so it was approximated based upon the known wind conditions in each exercise. The aircraft were scripted to start slowing to their landing speed on crossing 4DME.

Departure Aircraft

Most samples do not have departure aircraft. This is with the exception of 4WWN1TBS and 4WWN3TBS, for which departures were considered essential and samples 6EEC2TBS and 6EEC2DBS for which they are added but were not essential to the running of the validation exercise.

Scenarios

Specific scenarios were scripted into the traffic samples. In the case of 1WWC1TBS and 2EEN1TBS the scenarios were scripted into one of the four additional aircraft at the end of the sample.

SUPERVISOR scripts were set-up so that the TBST (Time Based Separation Tool) already 'knew' about the user-defined gaps scenario SCN08. Refer to Appendix F for the full list of scenarios.

4WWN3TBS was a 'TEAM' exercise. Six aircraft were scripted to land on R27L during the validation exercise. This was based on the TEAM exercise as run during the VP-303 simulation. Two further TEAM aircraft were added to test different TEAM scenarios. Two in-trail aircraft were placed on the departure runway such that a 5 Nm gap between these aircraft was specific to allow for a departure. A gap for a runway inspection was inserted after BAW457C and an arrival was placed on the departure runway during this gap. Controllers were therefore briefed that this exercise tested a range of TEAM scenarios that may not ordinarily be seen at the same time.

Radar Minimum and Not-In-Trail Spacing

SUPERVISOR scripts were created to ensure the TST worked to the correct Radar minimum spacing for each sample. The Radar minimum spacing was set-up as per the value in the traffic sample table above. The TST has the option to set separate spacing values for HEAVY and JUMBO aircraft types. These were set to the same value as the Radar minimum for all exercises.

Not-In-Trail spacing was set to 2.5 Nm for all exercises. The TEAM scenario sample was based on the TEAM exercise run from the VP-303 validation exercise, which also used a 2.5 Nm not-in-trail minimum.

These minimum spacing values were evaluated during the data test.

Wind Conditions and Weather

The required wind profiles were all entered and loaded up at the same time as the traffic sample.

It was not possible to change to other pre-defined wind conditions during an exercise. Samples 2EEV2TBS and 2EEV2DBS had variable wind which changed throughout the course of the validation exercise: those changes needed to be input manually and at specific times to ensure that the ATA times remained correct.

The time of day / weather conditions for each sample needed to be defined. Experience from the Dry-Run activity in 2011 suggested that a grey sky, 3,500 feet cloud cover and visibility of 10k produced the best visual representation of aircraft on approach. For the VP-302 validation exercise, a grey sky with 3,000 feet cloud base was applied for the majority of exercise runs, which meant aircraft were visual at approximately 10DME.

Night time exercises were also run on 2 occasions.

Runway Occupancy Adjustment

Data recordings and observations were taken during the data test during which it became apparent that the Micro Nav BEST simulator logged runway exit times, but at a different location to the operationally defined point of runway exit. On each occasion the time was offset by a regular amount depending on which exit was in use. This led to a set of observed adjustment figures which needed to be added to the recorded runway exit times during the subsequent analysis:

DIR_OPS	EXIT	ADJUSTMENT (Seconds)
W	A10E	-7
W	A7	-10
W	A8	-12
W	A9E	-10
E	A8	-1
E	A9E	-2.5
E	A9W	-1

Table 35: Runway Exit Time Adjustment (Seconds)

These figures were calibrated during data testing based on operational input and observed aircraft behaviour.

Reduced Separation in the Vicinity of the Airport

All Matched exercises were run with Reduced Separation in the Vicinity of the Airport. This meant that controllers were able to apply visual separation between aircraft pairs not subject to wake turbulence separation constraints.

All scenario exercises were also conducted under Reduced Separation in the Vicinity of the Airport. This is with the exception of one exercise where the cloud base was lowered during the validation exercise, necessitating 3.0Nm spacing at 4DME by the TC FIN controller.

Airport Information and Runway Exits

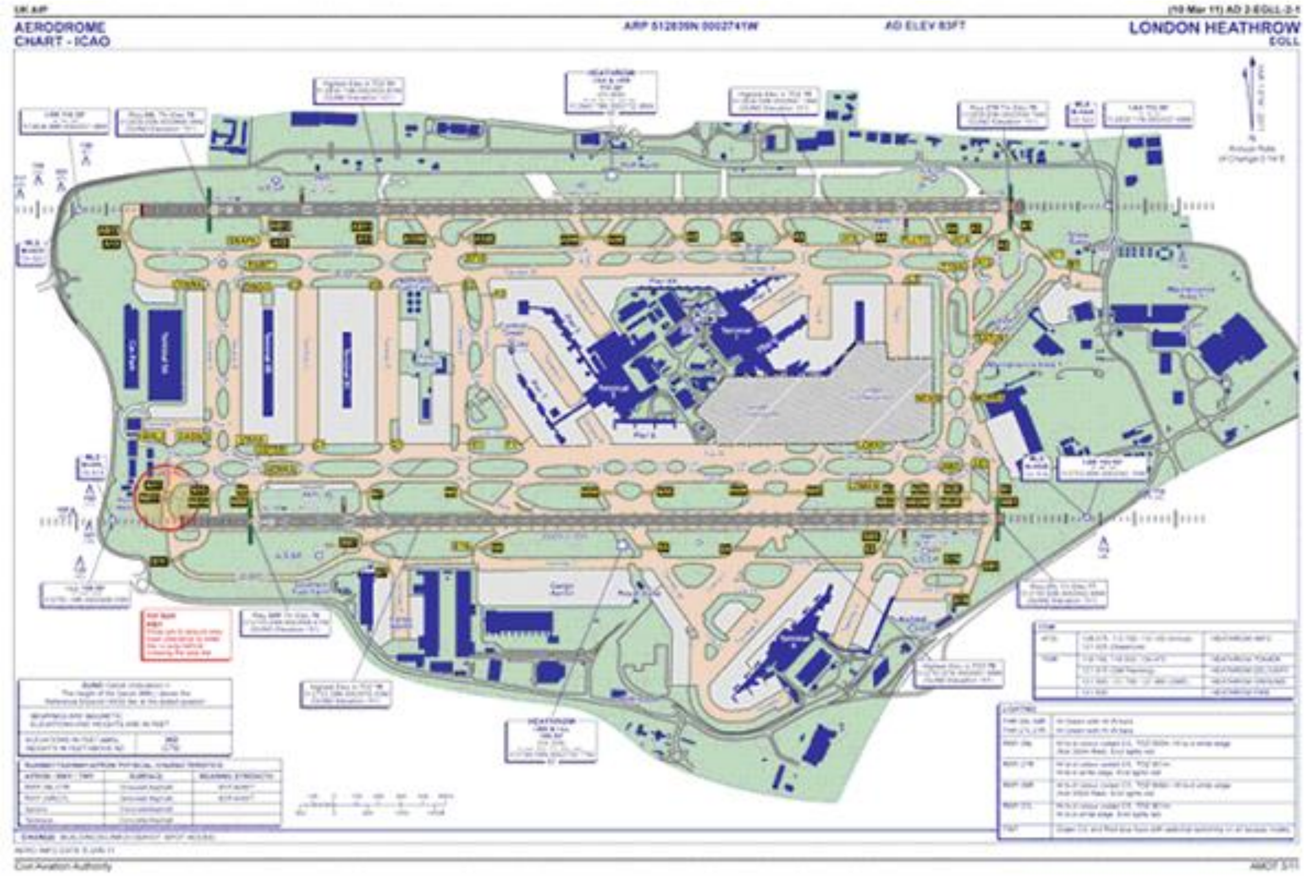


Figure 30: Heathrow Airport (EGLL) Ground Movement Map

The active runway for measurement during the validation activity was the Northern runway (27R and 09L) – Tower AIR Arrivals (North) controller. Runway exits are numbered A1 to A13 – eastern to western ends of the runway in the direction of landing on 27R. Exits 9 and 10 have east and west exits, thus giving exits A9E and A9W, and A10E and A10W.

Because the simulator automatically vacates a landing aircraft at the earliest available exit, it was found necessary to close some of the exits to prevent premature runway exits and ensure the runway occupancy data collected was realistic. This was a compromise as a few aircraft would probably have taken an earlier exit, but overall this provided the best runway occupancy data.

Sample	Sample Name	Exits Closed
1	TBS1WWC4TBS	A6, A7 & A9W
2	TBS3WWC3TBS	A6 & A9W
3	TBS1WWC1TBS	A6, A7 & A9W
4	TBS2EEV2TBS	A10E & A10W
5	TBS2EEN1TBS	A10E & A10W
6	TBS6EEC2TBS	A10E & A10W
7	TBS1WWC4DBS	A6, A7 & A9W
8	TBS3WWC3DBS	A6 & A9W
9	TBS1WWC1DBS	A6, A7 & A9W
10	TBS2EEV2DBS	A10E & A10W
11	TBS2EEN1DBS	A10E & A10W
12	TBS6EEC2DBS	A10E & A10W
13	TBS4WWN1TBS	A6, A7 & A9W
14	TBS4WWN3TBS	A6, A7 & A9W

Table 36: Runway exits closed for each traffic sample – A7 closed for surface headwinds <15 Knots

6.2.2.2 Exercise execution

The seven day TBS Heathrow Tower validation exercise was conducted between 11th July 2012 and 24th July 2012. A total of 31 exercise runs were completed with a total simulation time of 24½ hours. Eight exercise runs were DBS as baselines for the matched TBS runs; the remaining 15 exercise runs, including scenarios, were using TBS. Match runs were pairs of runs derived from the same traffic samples with the same wind conditions and same controllers from the previous TC Approach simulation, run with DBS for reference and TBS for direct comparison; the first run of the pair was alternated between DBS and TBS to mitigate any influence of running one method before the other. Daily timetables are provided in Appendix E.

Eight matched runs were planned along with a series of scenario runs. During the seven days of the simulation a total of 12 controllers took part. Of these only 2 attended on more than one day. Where possible each day was apportioned into 4 matched runs (2 pairs) plus one shorter scenario run at the end of the day. Due to the rotation of controllers a total of 5 runs were set aside for training and familiarity. On each day a pair of controllers took part, alternating between controlling on the single measured position and acting as expert observer for each run.

Nine specific scenario runs were completed. In summary, scenarios included the following: TBS indicator failure, runway closure, Tactical Enhanced Arrival Mode (TEAM – early morning and 6 aircraft per hour), Wake-only indicators, runway inspection and reduced visibility. As well as these, scenarios were also run at the end of matched runs utilising the ‘extra’ aircraft added to the end of the sample after the matched traffic had finished. Scenario coverage is listed in Appendix F.

6.2.2.3 Deviation from the planned activities

Deviations from Planned Simulation Execution

Due to the success of the data testing, the planned Customer Functionality Test was given over and used as an extra Run for Record day. Thus there were 7 planned days of simulation instead of 6. This was to allow for the higher than anticipated number of participants with the resultant extra training requirement.

Because of this, the intended training regime was adapted such that each morning began with an in-depth briefing session followed by a TBS familiarisation run for the first controller (with the second controller acting as expert observer). One controller commented that they acquired familiarity in 10 minutes.

The intended matched run on Friday, 13th July (exercise run 32) was abandoned as many aircraft were presented to the Tower AIR Arrivals (North) controller with unrealistic behaviour. It was discovered that the traffic sample had been loaded with incorrect system settings. There was sufficient flexibility in the timetable to allow the full range of matched runs to be subsequently run.

The decision was taken not to run the separation infringement scenarios (SCN 10(A) and 10(B)) as the accurate separation delivered by TC Approach necessarily led to reduced separation due to spacing compression caused by a lead aircraft with a slow landing stabilisation speed between 4DME and Runway Threshold.

The decision was taken not to run SCN20 and SCN21 (both scenarios causing misleading TBS indicator behaviour) due to the high turnover of participants and the potentially disproportionate effect that these scenarios may have had on user confidence and trust.

Deviations from the Planned Analysis

In response to discussion with controllers, one exercise was run displaying only Wake-separation indicators.

One exercise was run with reduced visibility, thus Reduced Separation in the Vicinity of the Airport did not apply. This necessitated 3.0 Nm spacing across 4DME. In this situation, indicators for radar separated pairs were used in a similar way to indicators for Wake constrained pairs such that encroachment of up to 0.5 Nm on the indicator when the lead aircraft was inside 4DME would be permissible. Encroachment of more than 0.5 Nm would result in the aircraft being broken off / diverted onto a missed approach.

6.2.3 Exercise Results

6.2.3.1 Summary of Exercise Results

See *Table 9: Exercises execution/analysis dates* in Section 3.2 and *Table 10: Summary of Validation Exercises Results* in Section 4.1 for validation objectives, success criterion and hypotheses results.

6.2.3.1.1 Results on concept clarification

The main objective of TBS validation was to finalise the V3 maturity level – Pre-industrial development and integration; see Section 2.1 Concept Overview for full details.

6.2.3.1.2 Results per KPA

KPA	Success Criterion ID	Indicators	Validation Status
Safety	CRT-06.08.01-VALP-0010-0010	NOT COVERED - not planned to be assessed.	OK
	CRT-06.08.01-VALP-0010-0015	NOT COVERED - not planned to be assessed.	
	CRT-06.08.01-VALP-0010-0020	Expert Observer: OK. Spacing at Threshold: OK. Number of go-arounds (due to spacing): OK. Late runway switches (due to spacing): OK. Wake Vortex Advisories issued to aircraft: OK. Expedited Runway Requests (due spacing): OK. Speed interventions before 4DME: OK. Clearance to land: OK. Questionnaires: OK.	
	CRT-06.08.01-VALP-0010-0030	Expert observation: OK. CARS: OK. Questionnaires: OK. Debriefs: OK. The impact of different spacing minimum values (2.5 Nm or 3.0 Nm at 4DME) and policies (low visibility, TEAM) and the way in which these will be input into the tool and by whom are areas for development along with procedures for emergency scenarios, e.g. runway closures. R/T usage Acceptable.	

Human Performance	CRT-06.08.01-VALP-0010-0020	Expert Observer: OK. Spacing at Threshold: OK. Number of go-arounds (due to spacing): OK. Late runway switches (due to spacing): OK. Wake Vortex Advisories issued to aircraft: OK. Expedited Runway Requests (due spacing): OK. Speed interventions before 4DME: OK. Clearance to land: OK. Questionnaires: OK.	OK
	CRT-06.08.01-VALP-0010-0030	Expert observation: OK. CARS: OK. Questionnaires: OK. Debriefs: OK. The impact of different spacing minimum values (2.5 Nm or 3.0 Nm at 4DME) and policies (low visibility, TEAM) and the way in which these will be input into the tool and by whom are areas for development along with procedures for emergency scenarios, e.g. runway closures. R/T usage Acceptable.	
	CRT-06.08.01-VALP-0010-0040	ISA Workload: OK. Bedford Workload: OK. Debriefs: OK. Controllers commented that the traffic samples did not include departures, runway crossers and helicopters, thus the actual equivalent operational workload would be slightly higher, though still comfortably acceptable. Madsen & Gregor Trust: OK. NATS Confidence Diamond: OK. China Lakes Situation Awareness: OK. NATS Picture Scale: OK.	
	CRT-06.08.01-VALP-0010-0045	Debriefs: OK. Controllers quickly placed a lot of trust in the tool to display the correct separation minimum between aircraft. It was not considered certain that they would detect errors should an incorrect separation be displayed. SHAPE Teamwork (STQ-s): OK. Controller Skill Levels and Training Needs not explicitly covered by validation exercise; deferred to HP assessment.	
	CRT-06.08.01-VALP-0010-0050	Debriefs: OK. Questionnaires: OK. All 12 controllers considered the HMI design acceptable with a minor change in size range. CARS: OK. The required usability of the TBS controller tool support and the harmonised integration with the other approach and runway controller tools was not planned to be explicitly covered by the validation exercise.	
	CRT-06.08.01-VALP-0010-0060	Questionnaires: OK. Debriefs: OK. Pilot responsibility for maintaining safe operation remaining unchanged was not planned to be explicitly covered by the validation exercise.	
Efficiency	CRT-06.08.01-VALP-0010-0020	Expert Observer: OK. Spacing at Threshold: OK. Number of go-arounds (due to spacing): OK. Late runway switches (due to spacing): OK. Wake Vortex Advisories issued to aircraft: OK. Expedited Runway Requests (due spacing): OK. Speed interventions before 4DME: OK. Clearance to land: OK. Questionnaires: OK.	OK
	CRT-06.08.01-	NOT COVERED - not planned to be assessed.	

	VALP-0010-0080		
Capacity	CRT-06.08.01-VALP-0010-0070	Go-arounds (due spacing): OK. Late runway switches (due spacing): OK. Landing Rate: OK. The traffic samples reflected the increased aircraft landing rates with TBS that had been evident during the Approach exercise (VP-303). Contribute to a delay saving per flight estimated as a function of the headwind on final approach and traffic mix was not explicitly covered by the validation exercise; deferred to the Business Case.	**OK**
Predictability	CRT-06.08.01-VALP-0010-0090	NOT COVERED - not planned to be assessed.	N/A
Environment	CRT-06.08.01-VALP-0010-0100	NOT COVERED - not planned to be assessed.	N/A
Cost Effectiveness	CRT-06.08.01-VALP-0010-0110	NOT COVERED - not planned to be assessed.	N/A
Acceptability	CRT-06.08.01-VALP-0010-0120	NOT COVERED - not planned to be assessed.	N/A

Table 37: Results by KPA (VP-302)

6.2.3.1.3 Results impacting regulation and standardisation initiatives

N/A

6.2.3.2 Analysis of Exercise Results

Validation Exercise results summary is provided in Section 4.1 Table 10: Summary of Validation Exercises Results.

6.2.3.2.1 Measured Positions, Measures and Analysis

The measured controller positions for all Run for Record exercises was as follows:

- Heathrow (EGLL) Tower AIR Arrivals (North) controller.

Note: measures were not collected for pseudo pilots because they were not trained aircrew, did not have representative cockpit equipment and acted as multiple pilots for the different aircraft to make any measures viable in terms of assessing pilot performance.

After each run for record exercise, every participant on each measured position completed an End of Run questionnaire for all measured TBS and DBS runs. End of Run questionnaires provide evidence for validation objectives OBJ-06.08.01-VALP-0010-0030, 06.08.01-VALP-0010-0040, 06.08.01-VALP-0010-0045, 06.08.01-VALP-0010-0050. The End of Run questionnaires collected evidence for Workload (**Bedford Workload** scale), **Situation Awareness (China Lakes scale**) and the **NATS Picture Scale** during the run. The questionnaires also included a box for comments or clarification of scores.

Controller Acceptance Rating Scale (CARS) and the **NATS Confidence Diamond** questionnaires were completed by controllers at the measured position for all TBS runs. The CARS and the NATS Confidence Diamond questionnaires provide evidence for validation objectives OBJ-06.08.01-VALP-0010-0030, 06.08.01-VALP-0010-0040, 06.08.01-VALP-0010-0045 and 06.08.01-VALP-0010-0050.

Expert Observations of the Tower AIR Arrivals (North) controller role were obtained for 27 individual runs with 12 different Tower AIR Arrivals (North) controllers. The expert observer questionnaires asked six specific questions, each directly linked to validation objectives, and space was provided for comments and clarifications. The results from expert observations provide evidence for validation objectives OBJ-06.08.01-VALP-0010-0020, and OBJ-06.08.01-VALP-0010-0030.

Structured Debriefs were conducted after every individual run, with a more detailed debrief at the end of the day; a debrief checklist was used to ensure coverage of the key items. Debrief information provides evidence for validation objectives OBJ-06.08.01-VALP-0010-0020, OBJ-06.08.01-VALP-

0010-0030, 06.08.01-VALP-0010-0040, 06.08.01-VALP-0010-0045, 06.08.01-VALP-0010-0050, and 06.08.01-VALP-0010-0060.

The End of Participation questionnaires were specifically tailored to address the validation objectives with direct and indirect questions relating to the validation objectives.

The **Madsen & Gregor (M&G) Trust questionnaire** was included in the End of Participation questionnaires. The results from this questionnaire provide evidence for validation objectives OBJ-06.08.01-VALP-0010-0040, 06.08.01-VALP-0010-0045 and OBJ-06.08.01-VALP-0010-0060. The Madsen & Gregor Trust questionnaire was completed by twelve Heathrow Tower controllers.

The **SHAPE Teamwork (STQ-s) questionnaire** was included in the End of Participation questionnaires. The results from this questionnaire provide evidence for validation objectives OBJ-06.08.01-VALP-0010-0040, 06.08.01-VALP-0010-0045 and OBJ-06.08.01-VALP-0010-0060. The SHAPE Teamwork (STQ-s) questionnaire was completed by twelve Tower AIR Arrivals (North) controllers.

For the Approach phase (VP-303) a 'run in time' of 10 minutes was required for the landing sequence to stabilize on the final approach, i.e. to achieve a steady and established approach sequence as experienced in operations. As the traffic samples created for the Tower simulation (VP-302) were based upon the stabilized landing sequence achieved during the Approach simulation, no such run-in time was required.

All separations were measured at the point the lead aircraft crossed the Landing Threshold and measuring the distance between the lead aircraft and the follower aircraft. **Separation accuracy** was calculated by subtracting the required separation minima (DBS or TBS rules) applied by the Final Approach Controller to 4DME from the achieved spacing at the runway landing threshold.

Analysis was undertaken using the comparative DBS and TBS data from eight matched runs. Three methods of comparative analysis were used:

1. **'Box and Whisker' charts** showing the Median, Upper and Lower first quartile (25th percentile), and the Maximum and Minimum scores recorded for each measure. The Upper and Lower first quartiles with the Median are shown as blue boxes on the charts in this document.

2. **Wilcoxon Signed-Rank Test for Statistical Significance**. The Wilcoxon Signed-Rank Test is a non-parametric statistical test for testing hypothesis to determine if two medians differ for match runs. The tests were conducted at the 95% significance level. No charts or tables for this analysis are provided within this report, statistical significance is reported in the supportive text to the 'Box and Whisker' charts to indicate the importance of the results.

3. **Chi-Square Test for Statistical Significance**. The Chi-Square or Chi-Squared test is a parametric statistical hypothesis test for the proportions of observed data. This test was used to test for the statistical significance of compressed and highly compressed aircraft pairs during the Matched DBS and TBS runs.

Not all 'Box and Whisker' charts have been included in this report; the reason for this is in most cases the comparative results between DBS and TBS are identical and there would be little value in including these charts. This report focuses on the measures that demonstrate differences between DBS and TBS and endeavours to explain these differences and their significance.

6.2.3.2.2 Safe Delivery of Aircraft to TBS Minima

OBJ-06.08.01-VALP-0010-0020 This section presents the results for the objective: "*To assess whether the Final and Intermediate Approach Controller can safely deliver aircraft to TBS minima in all wind conditions using the TBS tool support.*"

Summary: There was no statistically significant difference in separation accuracy at Runway Threshold between DBS and TBS matched runs. It was expected that aircraft spacing would compress between 4DME and Runway Threshold and separation be reduced. There were slightly fewer compressed Wake pairs with TBS compared to DBS; and there were more highly compressed pairs with TBS; however neither of these differences are not statistically significant. There are no statistically significant differences between the Clearance to Land margins of less than or equal to 15 seconds, Go-around instructions, numbers of Wake Vortex Advisories or Expedited Runway Vacation

Requests issued between DBS and TBS matched runs.

Spacing at Threshold

Separation accuracy at Threshold between DBS and TBS for Wake-separated pairs only shows a small improvement for TBS. The median for TBS indicates only marginal compression although the overall range of separations is similar to those of DBS. Using the Wilcoxon Signed-Rank Test, the differences in separation accuracy are not statistically significant.

Compression

The obligation is for the FIN Approach controllers to separate the aircraft on final approach such that they conform to the spacing minima for Wake and Non-Wake pairs at 4DME. Beyond 4DME the aircraft have to slow down to landing speeds with the consequence that the separation will necessarily compress. Whilst working to Reduced Separation in the Vicinity of the Airport (as applied to all of the Matched runs), controllers are able to apply visual separation between aircraft pairs not subject to wake turbulence separation constraints. The compression effect was, therefore, of no concern in the case of radar minimum separated pairs (e.g. Medium followed by Medium) as visual separation was maintained. The air arrivals controller is responsible for monitoring compression against arrivals with a wake turbulence separation requirement.

If compression is observed between Wake-separated pairs leading to separations of 0.5 Nm under the normal spacing minimum the air arrivals controller is required to take action. For example if the lead aircraft is inside 4DME the controller may issue a wake turbulence advisory to the pilot. Such advisories are intended to advise a following pilot of the possibility of wake turbulence and therefore to be able to opt for a go-around if they so choose. Comments were recorded during both runs and debriefs that the presence of the TBS indicators on the radar display made the estimation of the 0.5Nm limit to be much easier to assess. This was considered to be a significant benefit to the controllers although with the possible side effect of their issuing more frequent wake turbulence cautionary advisories, leading them to believe that without the indicators (as currently in operations) they might be missing occasions when an advisory ought to be issued.

Percentage of Compression at Threshold

Two classes of compression were analysed using the system and TST log data: **Highly Compressed** defined as >0.5 Nm under Wake separation applied to 4DME, and **Compressed** defined as up to 0.5 Nm under Wake separation applied to 4DME.

There were slightly fewer compressed Wake pairs with TBS compared to DBS (up to 0.5Nm compression); however there were slightly more highly compressed pairs with TBS (more than 0.5Nm compression).

Using the Chi-Square Test, the differences between DBS and TBS for both compressed and highly compressed for Wake-separated pairs are not statistically significant.

Percentages of Clearance to Land Margins of 15 seconds or less

The Clearance to Land margin (CTL) is the difference between the follower aircraft's threshold time and the lead aircraft's runway vacation time, taking into account the runway occupancy adjustment as described in section 6.2.2.1. Results from the matched runs are shown in the table below as a percentage of the CTL margins of 15 seconds or less for all aircraft pairs, Wake-separated pairs and radar-separated pairs.

CTL <=15s - Match Runs		
	TBS	**DBS**
All aircraft pairs	15.3%	17.4%
Wake-separated pairs	5.1%	6.3%
Non-Wake-separated pairs	21.3%	23.8%

Table 38: CTL less than or equal to 15 seconds Percentages for TBS and DBS – All Matched Runs

As illustrated in the table above, the TBS results are all slightly lower than those for DBS. However, using the Wilcoxon Signed-Rank Test on the counts, the differences between TBS and DBS aircraft pairs with CTL margins of 15 seconds or less are not statistically significant in any of the three categories.

Go-Arounds

If the separation between aircraft is too tight then there is the possibility that the controller will have to order the following aircraft to go around.

Go-Arounds - Match Runs		
	TBS	DBS
Total	1	0

Table 39: Number of Go-Arounds for TBS and DBS – All Matched Runs

There was only one go-around during a match run. This was during a TBS run. Using the Wilcoxon Signed-Rank Test, the difference between TBS and DBS for the number of Go-Arounds is not statistically significant.

Wake Vortex Advisories

If the separation between aircraft reduces to 0.5 Nm inside the Wake separation minima for that pair of aircraft then the following aircraft has to, at minimum, be cautioned of the wake vortex risk.

WV Advisories - Match Runs		
	TBS	DBS
Total	12	9

Table 40: Number of Wake Vortex Advisories for TBS and DBS – All Matched Runs

As illustrated in the table above, more WV advisories were issued to aircraft during TBS runs. However, using the Wilcoxon Signed-Rank Test, the difference between TBS and DBS for the number of WV advisories is not statistically significant.

The Wake Vortex advisory is issued so that the following aircraft could take the option of going around if they so chose. In practice, that option is rarely, if ever, exercised and the following aircraft will choose to land. This was also the practice during the simulation.

There were frequent comments noted from the controllers whereby they felt that the presence of the TBS indicators assisted them in assessing when the Wake minima were being encroached by 0.5 Nm. They said that it could be difficult to assess the gap between the aircraft on the radar display to the level of accuracy required during DBS operations. The procedure that several controllers described was that they would have to wait until one of the aircraft passed a mile-marker on the extended centre-line before being able to assess the separation sufficiently accurately. With the TBS indicators they felt that they could make that assessment easily and at any time i.e. without having to wait until an aircraft passed a mile-marker. Thus, there was speculation that they may have been issuing more WV advisories during TBS runs due to the fact that they were more readily judging the 0.5 Nm infringements. The controllers further speculated that they may be missing infringements under DBS operations due to the difficulty in making the assessments.

However, when compared with the results for highly compressed Wake pairs for TBS and DBS, it can be seen that the counts of Wake Vortex advisories are of a similar proportion. Therefore, the controllers did not actually issue more WV advisories as a direct result of their being easier to detect with the TBS indicators. This being the case, it is still of note that the controllers found the assessment of Wake infringements easier with the TBS tool.

Expedited Runway Vacation Requests

After an aircraft has landed the controller monitors its progress along the runway against the expected arrival of the next aircraft. The aircraft has to be clear of the runway before a clearance to land instruction will be issued to the following aircraft. If the controller feels that the lead aircraft may not vacate the runway before the arrival of a following aircraft then they will issue a request to the landed aircraft to expedite vacation of the runway in accordance with procedures.

Expedite Runway Requests - Match Runs		
	TBS	DBS
Total	17	11

Table 41: Number of Expedite Runway Requests for TBS and DBS – All Matched Runs

There were more expedited runway requests for TBS than for DBS runs. As the traffic samples were based upon the output of the Approach simulation there were necessarily more aircraft in the TBS samples during the same period of time. Therefore the spacing between aircraft must have been tighter during the TBS runs. However, using the Wilcoxon Signed-Rank Test, the difference between TBS and DBS for the number of Expedite Runway Requests is not statistically significant.

Speed Interventions

The need for the controller to issue speed interventions to aircraft on the glide slope would be an indication of too-tight spacing.

No speed interventions were issued during any of the Matched exercise runs.

Late Runway Switches

There were no late runway switches due to spacing during the course of the simulation.

Expert Observations

The expert observer questionnaires asked six specific questions, each directly linked to validation objectives, and space was provided for comments and clarifications. Questions relating to this section are shown in the table below.

Question	Always	Mostly	Sometimes	Rarely	Never
Q.1 Tower Arrivals Controller employs safe techniques and standard controller practices.	18	0	0	0	0

Table 42: Expert Observation Results Summary – Safe Delivery of Aircraft to TBS Minima

As can be seen from the table above, Question 1 “Tower Arrivals Controller employs safe techniques and standard controller practices” was unanimously responded to as ‘Always’. This is a clear and unambiguous result.

Questionnaires

End of Participation Questionnaires

Summary tables for Heathrow Approach controllers are provided below:

Question	Yes	Possibly (with improvements)	No
1.4 I was able to monitor for separation encroachment when using TBS?	11	1	0

Question	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
3.2 The required spacing between aircraft was clear to me when using TBS.	0	0	2	6	4

Table 43: End of Participation Results Summary – Safe Delivery of Aircraft to TBS Minima

All twelve of the Tower AIR Arrivals (North) controller participants completed the End of Participation questionnaire although only two of them participated on more than one day. In contrast to the previous Approach simulation it was considered that the use of TBS separation was less complex to assimilate for the Tower controller role. Thus the End of Participation questionnaire was completed by all of the Tower participants.

The End of Participation results for Tower AIR Arrivals (North) controllers indicate that the TBS concept and HMI is acceptable. Although broadly very positive, there was some range of opinion:

Question 1.4 "*I was able to monitor for separation encroachment when using TBS?*"

- *"Differentiation between Wake and Non-Wake pairs. Non-display of Non-Wake pairs (only display after encroachment of DBS in today's ops?) Colours? Shapes?"*

There were several comments from controllers regarding differentiation between Wake and radar separated pairs, though there was not universal agreement regarding this. Some controllers wanted to see indicators displayed only for Wake pairs, although others did not agree with this view. With the exception of the comment above, all other participants were "*able to monitor for separation encroachment when using TBS".*

Question 3.2 "*The required spacing between aircraft was clear to me when using TBS*"

Ten participants either agreed or strongly agreed with this statement. Two controllers were less sure:

- *"A loss of separation by TC may not necessarily be a loss of separation by tower e.g. visual separation being applied."*
- *"Re: Losses of separation by TC: A lot easier when only for WT (Wake Turbulence)."*

As described above (see 'Losses of Separation') different constraints apply to the Tower controller compared to the Approach controller in terms of management of radar separation and Wake separation in visual conditions.

The End of Participation results suggest that Tower AIR Arrivals (North) controllers were able to monitor for separation encroachment when using TBS, and that the required spacing between aircraft was clear when using TBS.

Debriefs

Safety – during the simulation controllers quickly understood how the TBS indicators behaved and their representation of aircraft separation.

It was noted that indicators are currently removed before the lead aircraft leaves the ATM. With multi-lateration radar coverage aircraft remain on the ATM until very late. The current version of the TBS tool removes the indicator when the aircraft leaves the final approach region (FAR). This is currently set to be at the Runway Threshold. One controller suggested that this could be extended until the point at which the lead aircraft touched down (or left coverage on the ATM, whichever is sooner).

6.2.3.2.3 Task Performance of Heathrow Tower Controllers

OBJ-06.08.01-VALP-0010-0030 This section presents the results for the objective: *"To assess the acceptability of the changes to the operational procedures and practices on the Final Approach Controller, Intermediate Approach Controller, Runway Controller, Approach and Tower Supervisors, and Pilot."* Note: this activity tested the objective from the perspective of the Runway Controller.

Summary: Expert Observer and CARS results were acceptable for the TBS concept. The TBS concept and HMI is acceptable. The TBS Method of Operations was felt to be practical, manageable, realistic and achievable. R/T usage was acceptable.

Expert Observations

The expert observer questionnaires asked six specific questions, each directly linked to validation objectives, and space was provided for comments and clarifications. Questions relating to this section are shown in the table below.

Question	Always	Mostly	Sometimes	Rarely	Never
Q.1 Tower Arrivals Controller employs safe techniques and standard controller practices.	18	0	0	0	0
Q.2 Task performance for the Tower Arrivals Controller is acceptable when using TBS.	15	3	0	0	0
Q.3 New procedures and practices for the Tower Arrivals Controller are practical and manageable.	15	3	0	0	0
Q.4 TBS Method of Operations are practical and manageable.	15	3	0	0	0
Q.5 TBS Method of Operations are realistic and achievable.	16	2	0	0	0
Q.6 R/T usage is acceptable under TBS operations.	16	2	0	0	0

Table 44: Expert Observation Results Summary – Task Performance

As can be seen from the summary table above, all of the questions were responded to as ‘Always’, in the large majority of cases which indicates that these aspects are all acceptable. However, whereas question 1 was answered unanimously, each of the others recorded a few responses as ‘Mostly’.

As can be seen, the ‘Mostly’ responses were accompanied by comments expressing minor reservations such as:

- *“Easier to use TBS indicator for wake turbulence rather than make the calculation based on two reference points of DME. An obvious increase in workload. 'Expedite vacate' or land after. Shouldn t be such an increase if the TBS is accurate. Landing aircraft are operating normally but pilot workload is increased at ATC request.”*
- *“First ten minutes: much of Andy's focus was on dealing with new TBS tool and associated procedures. After first ten minutes: settled into the exercise and incorporated TBS tool into normal working practices.”*
- *“The markers cause you to fixate on the ATM and stop you looking out of the window. I can only assume that this will lessen as time progresses and the novelty wears off.”*

It should be taken into account that many of the participating controllers were only taking part for one day. They had therefore received minimal training, but had all found the new system to be straightforward to adopt. For instance, later in the day, as experience progressed, a typical comment became:

- *“No problems whatsoever.”*
- *“Standard session, no issues.”*

Overall the Expert Observation results are generally favourable for TBS operations.

Questionnaires

End of Run Questionnaires

Controller Acceptance Rating Scale (CARS)

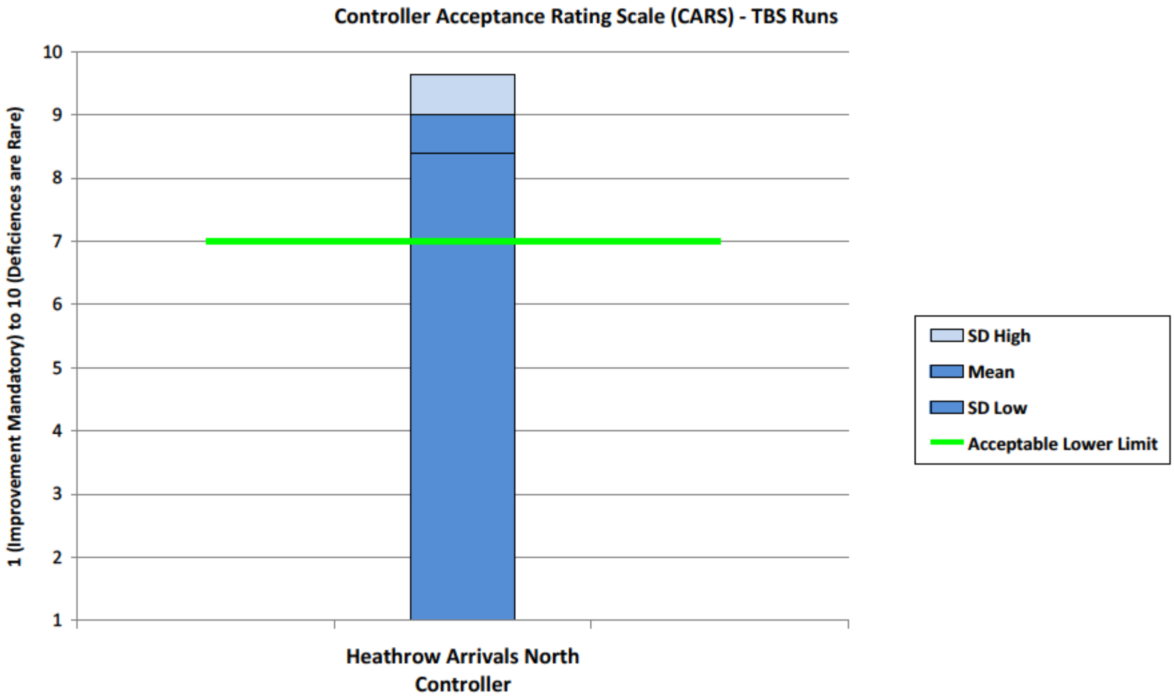


Figure 31: Controller Acceptance Rating Scale (CARS) – All TBS runs

The CARS results indicate that TBS is acceptable for the Tower AIR Arrivals (North) controller. The large majority of the results were ‘9’ and ‘10’ corresponding to:

10. Deficiencies are rare. System is acceptable and controller doesn’t have to compensate to achieve desired performance.

9. Negligible Deficiencies. System is acceptable and compensation is not a factor to achieve desired performance.

There were three responses of ‘8’ and one of ‘7’ corresponding to:

8. Mildly unpleasant deficiencies. System is acceptable and minimal compensation is needed to meet desired performance.
7. Minor but Annoying Deficiencies. Desired performance requires moderate controller compensation.

Two of these responses were accompanied by comments:

- *“More time spent than normal getting used to looking at indicators and developing your indicators as to what will work and not.”*
- *“Focussing on the 'pink line' tends to stop you checking aircraft type/FDEs (Flight Data Entries) as much. Scanning process amended.”*

Both of these responses are suggestive of training and familiarity issues, likely to be addressed by greater experience of the TBS tool.

Wake Constrained Pairs – Wake only Indicators

One run was conducted with Wake Constrained Pairs, i.e. only Wake indicators were displayed by the TST; this was run 44.

There was one expert observer comment:

"Indicators only for WT (Wake Turbulence) Separation makes it easier to spot WT degradation compared to when all indicators are shown. It still gives the Arrival Controller a clue as to whether it's increasing or decreasing the separation based on the difference from the required WT distance. WT warning phraseology not clear & concise. Indicators just to indicate a runway occupancy gap (i.e. not WT) not needed as you shall always be looking to apply a 3Nm gap (unless 2.5Nm approved). That said, sometimes you might need a bit extra for a tailwind etc., but that can be judged as normal."

"Final sim run with indicators for Wake separation in good visual conditions was the most useful of the day. This required the least increase in controller workload."

There was also much discussion on subsequent days with other participants. Some were interested to try a run with Wake-only indicators whereas others were less keen. Due to restrictions of time, there was no further opportunity for another Wake-only run.

It is of note that the BEST simulator displayed the mile markers on both sides of the centre-line. The operational displays show the markers on one side only. This may have contributed to a perception of 'clutter'.

End of Participation Questionnaires

Summary tables for the End of Participation Questionnaires are provided below:

Question	Yes	Possibly (with improvements)	No
1.1 Is Time Based Separation, as simulated, viable at Heathrow?	9	3	0

Question	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
2.1 The TBS Method of Operations are practical and manageable.	0	0	0	9	3
2.1 The TBS Method of Operations are realistic and achievable.	0	0	1	8	3

Table 45: End of Participation Questionnaire responses

The End of Participation results for Tower AIR Arrivals (North) controllers indicate that the TBS concept and HMI is acceptable, with only minor reservations. The TBS Method of Operations was felt to be practical, manageable, realistic and achievable.

The reservations regarding the viability of Time Based Separation at Heathrow (the three "Possibly (with improvements)" scores) were mainly centred around the possible clarification of the presentation of wake vortex separations:

- *"I feel wake vortex separations should be highlighted on the ATM."*
- *"Only have indication line for wake turbulence in visual conditions."*
- *"Different phraseology. Consolidation on whether to display all indicators."*

These comments refer to either specific highlights of Wake separation indicators or of only displaying Wake separation indicators. Only three such comments were recorded indicating that is not a widely held view. As described above, not all participants would be in favour of such a change.

The general view was a positive response to the TBS system.

Debriefs

Training and Familiarization – All participants were briefed in the TBS concept and provided one run for familiarization immediately following a briefing on the concept and toolset. The MOps were clearly described: in particular the use of the TBS indicators as a reference for separation. The Expert Observer role was used as familiarization for the second controller on their first view of the tool before they used it on the next run; feedback in debriefs indicated this approach worked very well. This was felt by the participants to be sufficient as the TBS concept and tool was not felt to impact greatly upon the current Tower Ops. After a short time the participants were able to adapt their technique to using the TBS indicators as a reference; feedback indicated the controllers were settled and comfortable with the tool within around 10 minutes of using TBS.

Note: a more flexible approach had to be taken with training and familiarization than is usual due to the high turnover with controllers during the validation exercise. There were no dedicated training/familiarization runs, all exercise runs were recorded, and the Expert Observer role was used as part of the familiarization process. The TBS concept briefings were specifically tailored to cover the key aspects of the concept to allow the controllers to have hands on experience as quickly as possible.

Procedures and Practices – Overall the TBS tool was felt to be useful, understandable and of benefit to operations. It was not felt to significantly change the way Tower AIR Arrivals (North) controller operates or the way they interact with other actors in the system (most notably TC FIN and aircrew) and is consistent with existing practices and procedures (2.5 Nm spacing, Wake Turbulence Separation on final).

During debriefs Tower AIR Arrivals (North) controllers did discuss the impact of different spacing minimum values (2.5 Nm or 3.0 Nm at 4DME) and policies (low visibility, TEAM) and who would be responsible for inputting this into the tool. It was explained that the principle would be for the existing roles, responsibilities and procedures to remain the same. However, an area for development is the way in which these will be input into the tool and by whom.

A wider discussion was whether indicators are required at all during runway closure scenarios; TBS becomes a low priority in these situations (as was also found during the VP-303 TC Approach simulation). It may therefore be preferable to switch indicators off altogether during such circumstances. The procedures for such emergency scenarios will need to be defined.

R/T Occupancy

The BEST simulator facility did not allow for the recording of R/T. Therefore the Expert Observers were requested to monitor the level of R/T during TBS runs and respond in the questionnaire:

Question	Always	Mostly	Sometimes	Rarely	Never
Q.6 R/T usage is acceptable under TBS operations.	16	2	0	0	0

Table 46: Expert Observer Questionnaire responses – R/T usage

It can be seen that R/T usage under TBS operations was acceptable.

6.2.3.2.4 Impact of TBS Operations on Human Performance

OBJ-06.08.01-VALP-0010-0040 This section presents the results for the objective: "*To assess the impact of the TBS tool support and operational procedures on the Human Performance of the Final Approach Controller, Intermediate Approach Controller, Runway Controller, Approach and Tower Supervisors, and Pilot.*" Note: this activity tested the objective from the perspective of the Runway Controller.

Summary: The ISA scores were acceptable between TBS and DBS. The Bedford Workload scores for all TBS runs were comfortably below the acceptable upper limit. The Picture Scale scores were also all comfortably below the acceptable lower limit with 2 questions scoring unanimous maximums and only very small difference between DBS and TBS for the other two questions. Situational Awareness remained very high at all times. The Madsen & Gregor Trust scores were acceptable for all categories.

Instantaneous Self-Assessment (ISA) Workload

The Instantaneous Self-Assessment (ISA) Workload scale rates from Very Low (1) to Very High (5). ISA scores were collected via a stand-alone touch screen panel (iPad), which prompted the controllers for their workload score every two minutes: the iPad emitted a 'beep'. If the controller did not submit a score after the prompt, the ISA screen would eventually time out and a 'no press' blank score would be recorded.

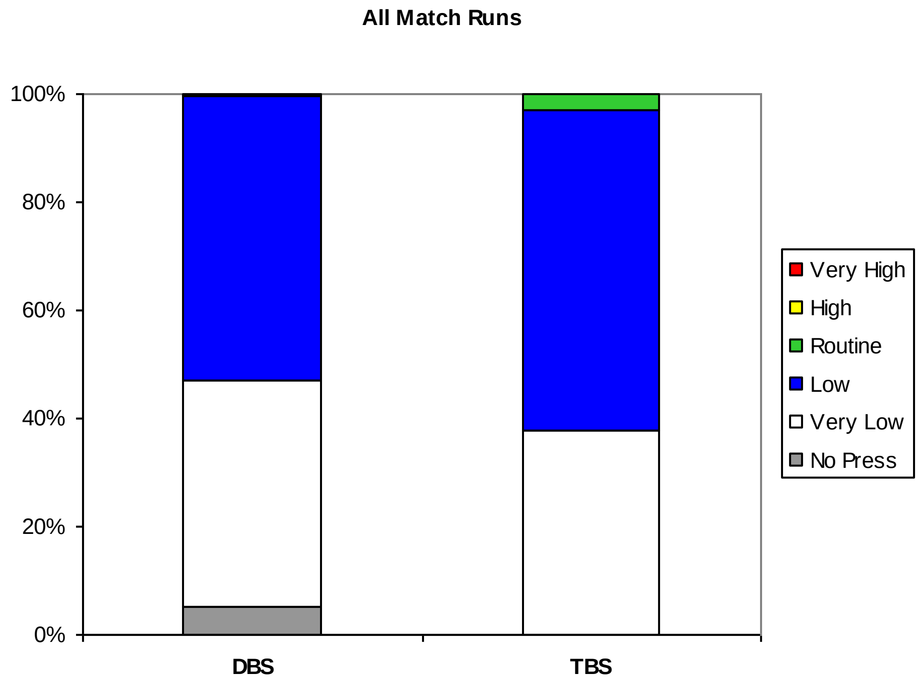


Figure 32: Instantaneous Self-Assessment (ISA) Scores – All Match Runs

The ISA scores recorded for the eight matched runs indicate that normal working levels of 'Very Low' (1) and 'Low' (2) were experienced for the majority of the runs with very little difference between TBS and DBS. A few 'Routine' (3) workload scores were recorded for short periods in both TBS and DBS (there was one occurrence of '3' during a DBS run which is not visible within the scale of the chart), which is normal for comfortable operation.

The scores are very slightly higher for TBS reflecting the fact that the traffic samples contained more aircraft and so were busier.

Several comments were recorded from the participants suggesting that while the simulation traffic levels were realistic, actual operations also include departures, runway crossers and helicopters adding to the workload and complexity. The participants were of agreement in suggesting that such activity would add a notional '0.5' to the ISA scores. Even so, the scores would still show comfortable operation.

Note: to include departures and runway crossers, the Arrivals runway would need to be 27L or 09R, for which no traffic samples were available; all traffic samples were developed for runways 27R and 09L.

Bedford Workload Scale

The self-assessed Bedford Workload scale was included in the End of Exercises questionnaires completed after each run for all TBS runs and DBS matched runs.

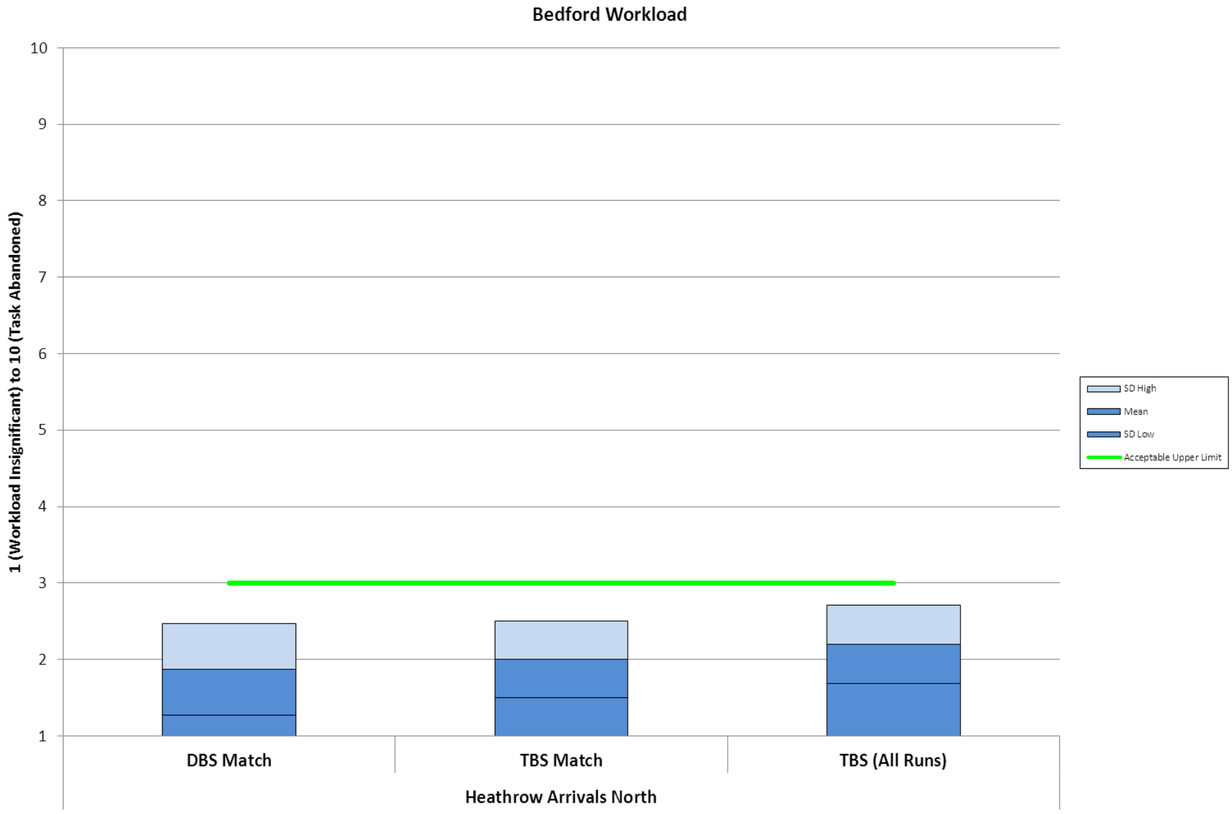


Figure 33: Bedford Workload Scores – Matched runs and all TBS runs

As shown in the chart above, all scores for the Bedford Workload measures for the DBS Match, TBS Match and all TBS runs were all comfortably below the acceptable upper limit. Using the Wilcoxon Signed-Rank Test, the differences between DBS and TBS for Bedford Workload is not statistically significant.

There were few instances of a score of '3' being recorded, corresponding to "*Enough spare capacity for all desirable additional tasks*", the large majority of scores being '2', corresponding to "*Workload low*". Thus the mean and standard deviations are clearly below the acceptable upper limit.

However, as has been described above under "The Instantaneous Self-Assessment (ISA) Workload" the simulation traffic samples did not include departures, runway crossers and helicopters, and thus the actual equivalent operational workload would be slightly higher (approximately 0.5 from feedback). The Bedford Workload scores would still be comfortably below the acceptable upper limit adding this on to the scores.

Debriefs

Safety debrief results are presented in section 6.2.3.2.2 above.

Situation Awareness (SA) – it was reported that with TBS:

- "*Improvement in SA from being able to visualize compression throughout final approach, quicker than is currently available.*"

There was some minor concern by a few (though not all) participants that the TBS indicators presented extra clutter to the Radar display. It was suggested that the mile markers on the centreline could be removed if indicators are displayed. Opinions on this varied between participants with some suggesting that 'essential' markers (e.g. at 4DME and 10DME) may be retained.

This was not seen as a definite requirement, but appeared to be linked to some feeling of clutter on the ATM with both indicators and mile markers.

Also, several participants commented that they found the indicators helpful in assessing under-separation, such as identifying when to issue wake vortex advisories, such that it was speculated that TBS-style indicators would actually be useful during normal DBS operations.

Tower AIR Arrivals (North) controllers felt they could accommodate the TBS indicators into their scan. The presence of indicators reduced the need to obtain and process information on aircraft types and wake turbulence categories from the EFPS system. The relative position of aircraft with respect to the indicators provided a more immediate assessment of the final approach spacing than current day interpretation using the range markers on the extended centreline. Controllers were able to identify which aircraft pairs required further attention with a quick scan of the ATM.

This was felt to have benefits and, potentially, some drawbacks. Some controllers felt the quicker visual scan freed up time for other tasks and allowed them to anticipate issues more quickly. Tower AIR Arrivals (North) controllers did not need to wait until the lead aircraft crossed a mile marker to determine the spacing accuracy, as they do today. Some controllers did note that they initially felt more 'passive' when using the indicators; waiting for breaches to occur rather than acting proactively. However, the general consensus was that breaches of wake turbulence separation were identified earlier with TBS than with DBS.

Workload – the perceived impact on controller workload of using the TBS tool was considered to be minimal. This is supported by such typical comments as:

- "*Initially very aware of new element and feeling the need to do something (and do it right). After a while it became evident this was a normal and routine arrivals session, with a little extra detail added"*
- *"For a First run the TBS tool was intuitive to use in a simple traffic / low workload scenario and didn't significantly add to my normal perceived workload*"

Questionnaires

End of Run Questionnaires

The following sections report results for metrics from the End of Run questionnaires.

NATS Confidence Diamond

The NATS Confidence Diamond has five scales with separate questions, the fifth scale asking for an overall confidence rating for the TBS system. The five questions were as follows:

1. I am comfortable with the procedures and policy of use associated with this system;
2. I feel well trained in the use of this system;
3. I am sure I can work well with my team when using this system;
4. I believe that the software supporting this system is suitable for my job and tasks;
5. Please rate your overall confidence in this system as a whole.

The results from these scales are presented in the chart below. The acceptable lower limit for each scale is 7.

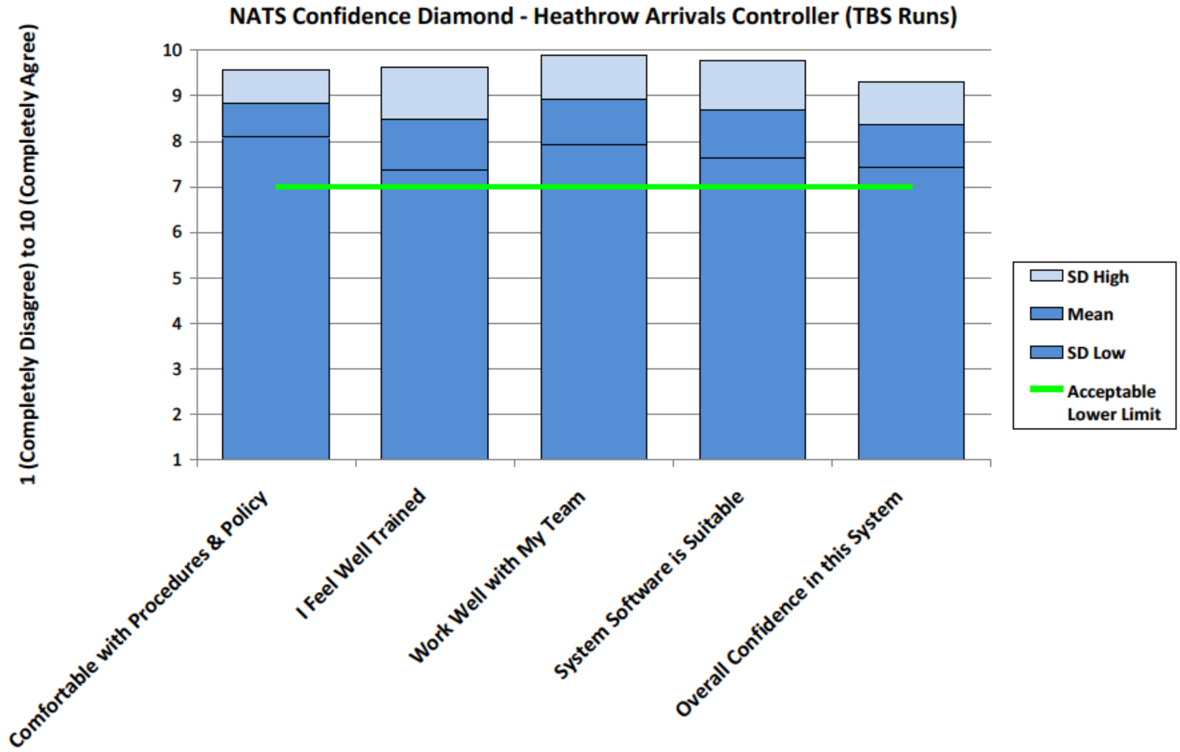


Figure 34: NATS Confidence Diamond Questions – All TBS runs

All results of the NATS Confidence Diamond were clearly above the acceptable lower limit; an entirely positive result for all 5 questions.

China Lakes Situation Awareness

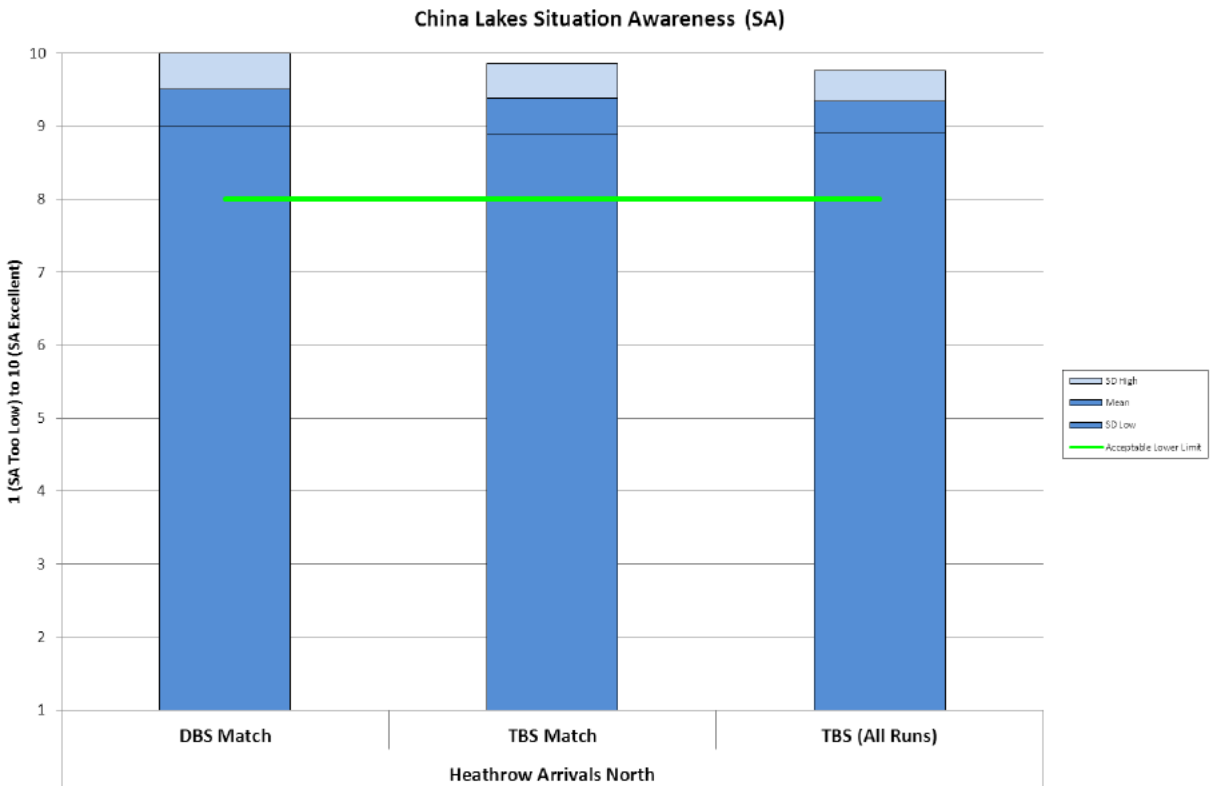


Figure 35: China Lakes Situation Awareness (SA) – Matched runs and all TBS runs

The results from the matched runs for China Lakes Situation Awareness for DBS and TBS matched runs, and all TBS runs, are comfortably above the acceptable limit. Using the Wilcoxon Signed-Rank Test, the differences between DBS and TBS for China Lakes Situation Awareness is not statistically significant. All of the individual scores are in the range of 9 or 10 indicating:

10 My SA with respect to the task was excellent. I was able to perform the task extremely well all of the time.

9 My SA with respect to the task was very good. I was able to perform the task well all of the time.

Again, an entirely positive result.

NATS Picture Scale

The NATS Picture Scale asked four questions relating to performance experienced during TBS runs, the four questions were as follows:

1. ‘Feeling of being behind’ to ‘Comfortably ahead of the game’;
2. ‘Poor understanding of the traffic situation’ to ‘Full understanding of the traffic situation’;
3. ‘Lost control of the RT’ to ‘In full control of the RT’;
4. ‘Aircraft call you and you have to hunt to recall them’ to ‘Aware of aircraft coming into your sector before they call you’.

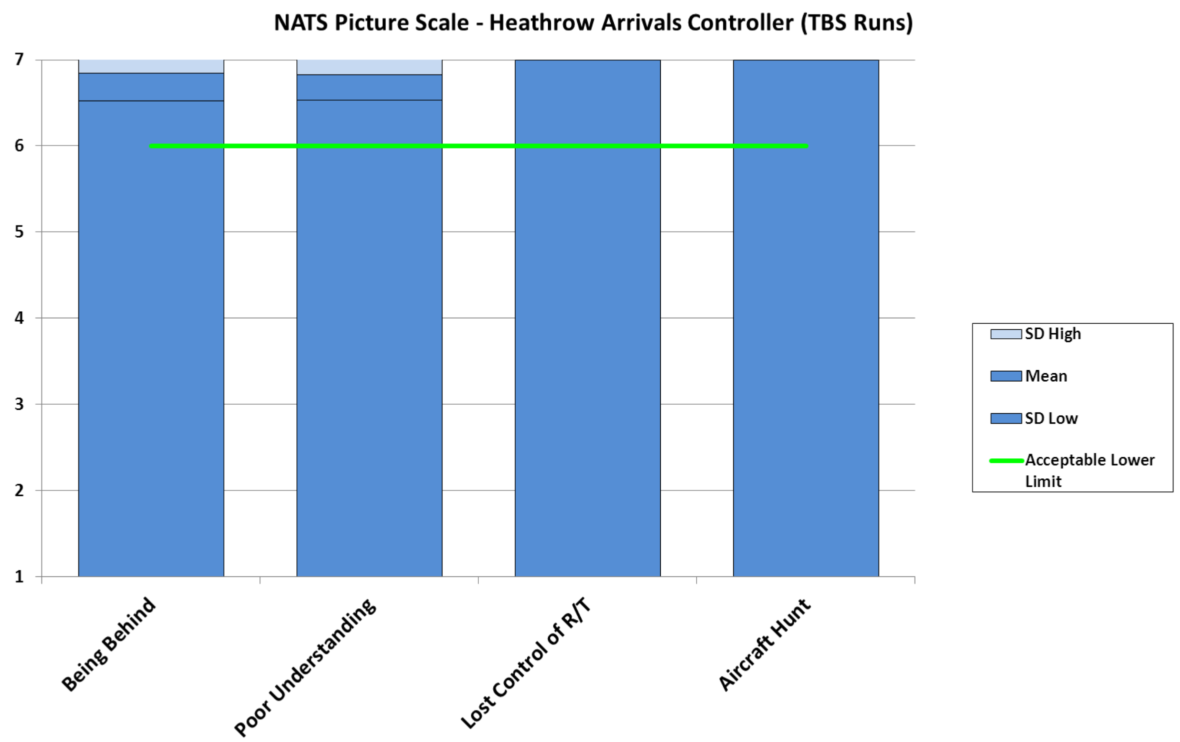


Figure 36: NATS Picture Scale – TBS runs

Results for the NATS Picture Scale are presented in the figure above. All results are clearly above the acceptable limit.

Two questions unanimously scored the maximum ‘7’ from all participants:

3. ‘Lost control of the RT’ to ‘In full control of the RT’;
4. ‘Aircraft call you and you have to hunt to recall them’ to ‘Aware of aircraft coming into your sector before they call you’.

Two questions showed minor differences between DBS and TBS for the Tower controller.

1. ‘Feeling of being behind’ to ‘Comfortably ahead of the game’;
2. ‘Poor understanding of the traffic situation’ to ‘Full understanding of the traffic situation’;

In these cases the TBS results show a slightly poorer understanding and slightly less comfortably ahead of the game. These results are not statistically significant and are within acceptable limits. It should also be borne in mind that the TBS samples were necessarily busier than the DBS samples as the traffic had been delivered during the earlier Approach simulation. The DBS samples all recorded the maximum ‘7’ for all four questions.

Madsen & Gregor Trust Questionnaire

A summary table is provided below:

Question	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
R1. The system always provides the advice I require to make my decision.	0	0	1	10	1
R2. The system performs reliably.	0	0	1	10	1
R3. The system responds the same way under the same conditions at different times.	0	0	2	9	1
R4. I can rely on the system to function properly.	0	0	2	9	1
R5. The system analyzes problems consistently.	0	0	4	8	0
T1. The system uses appropriate methods to reach decisions.	0	0	4	7	1
T2. The system has sound knowledge about this type of problem built into it.	0	0	7	5	0
T3. The advice the system produces is as good as that which a highly competent person could produce.	0	2	2	7	1
T4. The system correctly uses the information I enter.	0	0	7	5	0
T5. The system makes use of all the knowledge and information available to it to produce its solution to the problem.	0	0	3	8	1
U1. I know what will happen the next time I use the system because I understand how it behaves.	0	1	1	9	1
U2. I understand how the system will assist me with decisions I have to make.	0	0	0	11	1
U3. Although I may not know exactly how the system works, I know how to use it to make decisions about the problem.	0	0	1	10	1
U4. It is easy to follow what the system does.	0	0	2	7	3
U5. I recognize what I should do to get the advice I need from the system the next time I use it.	0	0	1	9	2
F1. I believe advice from the system even when I don't know for certain that it is correct.	0	4	1	5	2
F2. When I am uncertain about a decision I believe the system rather than myself.	3	5	2	1	1
F3. If I am not sure about a decision, I have faith that the system will provide the best solution.	1	4	5	1	1
F4. When the system gives unusual advice I am confident that the advice is correct.	1	5	4	1	1
F5. Even if I have no reason to expect the system will be able to solve a difficult problem, I still feel certain that it will.	2	3	4	2	1

R = Perceived Reliability
T = Perceived Technical Competence
U = Perceived Understandability
F = Faith

Table 47: Madsen & Gregor Trust Questionnaire Summary (Twelve Participants)

Trust – Tower AIR Arrivals (North) controllers quickly placed a lot of trust in the tool to display the correct separation minimum between aircraft on the ATM. As with TC, it was not considered certain that they would detect errors in the tool should an incorrect separation be displayed (and delivered by TC).

The most favourable and consistently scored area was ‘**Perceived Understandability**’, which scored strongly with ’Agree’ or ‘Strongly Agree’ to all five questions; this indicates that the training and familiarization was sufficient and the TBS tool is reasonably intuitive to use.

The next most favourable area was '**Perceived Reliability**'. Overall the scores are biased heavily toward 'Agree' and 'Strongly Agree' although question R5 recorded four results for 'Neither Agree or Disagree'. Overall the participants were confident about the reliability of the prototype TBS tool in terms of correct and consistent advice presented.

The '**Perceived Technical Competence**' category is more mixed. Although there was strong agreement apparent there was also some doubt expressed regarding the quality of advice the system produces and the system's knowledge and use of information entered into it.

The '**Faith**' category was apparently the least favourable result with all questions tending towards 'Disagree', indicating that the participants have reservations about the TBS tool and do not completely trust the tool; the most significant question being F2, which indicates most of the participants believe their own judgement rather than the system. In the context of controller behaviour and the way controllers are trained to operate, this is to be expected; controllers are trained to use their own judgement to assess the situation and identify any inconsistencies in the information they are being presented and to adjust their actions accordingly. The apparently lower scores for 'Faith' are normal for ATC operations in order to detect problems and avoid incorrect actions based on invalid data. In the context of TBS operations, there is the need to ensure controllers can still apply their own judgement based on quickly accessed information. This is supported by the only two comments recorded with this questionnaire:

- *"Controllers would not blindly trust any system as we are trained not to. I have faith that the system will work but only because I have a full understanding of its methodology."*
- *"Controllers always check and check again. If I don't believe the system is working, I would check."*

6.2.3.2.5 Acceptability of the TBS Tool Concept in General

OBJ-06.08.01-VALP-0010-0045 This section presents the results for the objective: "*To assess the acceptability of the TBS tool concept in general by the Final Approach Controller, Intermediate Approach Controller, Runway Controller, Approach and Tower Supervisors, and Pilot.*" Note: this activity tested the objective from the perspective of the Tower AIR Arrivals (North) controller. This objective was introduced after the TC Approach validation exercise was conducted with edition 00.01.03 of the VALP [4]; post exercise analysis and this report have been amended accordingly.

Summary: Tower AIR Arrivals (North) controllers felt they could accommodate the TBS indicators into their scan. The presence of indicators reduced the need to obtain and process information on aircraft types and wake turbulence categories from the EFPS system. The relative position of aircraft with respect to the indicators provided a more immediate assessment of the final approach spacing than current day interpretation using the range markers on the extended centreline. Controllers were able to identify which aircraft pairs required further attention with a quick scan of the ATM. SHAPE scores were acceptable for all roles.

Debriefs

Trust and Reliance – Tower AIR Arrivals (North) controllers quickly placed a lot of trust in the tool to display the correct separation minimum between aircraft on the ATM. As with TC, it was not considered certain that they would detect errors in the tool should an incorrect separation be displayed (and delivered by TC).

Questionnaires

SHAPE Teamwork (STQ-s) Questionnaire

A summary table is provided below.

Question	0 Never	1	2	3	4	5	6 Always
1) … it was clear to me which tasks were my responsibility.	0	0	0	0	1	1	10
2) … it was clear to me which tasks were carried out by the other team members.	0	0	0	0	0	2	10
3) … it was clear to me which tasks I shared with the other team members.	0	0	0	0	0	2	10
4) … the system enabled the team to prioritise tasks efficiently.	0	0	0	0	1	3	8
5) … the system helped the team to synchronize their actions.	0	0	0	0	3	3	6
6) … the goals of the team were clearly defined.	0	0	0	0	0	5	7
7) … the system promoted a smooth flow of information.	0	0	0	0	0	5	7
8) … the system helped the team to follow the procedures.	0	0	0	0	0	5	7
9) … the system helped me to detect the other team members' inaccuracies or mistakes.	0	0	0	0	0	4	8
10) … the system helped me to share information about developing traffic situations with other team members.	0	0	0	0	0	4	8
11) … I liked working in the team.	0	0	0	0	0	3	9
12) … I felt supported by other team members.	0	0	0	0	0	3	9

Table 48: SHAPE Teamwork (STQ-s) Questionnaire Summary (Twelve Participants)

The responses to all of the questions were very favourable with only slight doubt relating to questions 1, 4 and 5. It is of note that the function of the TBS system in the role of the Tower AIR Arrivals (North) controller plays little part in the team-working aspects of that role. Hence the slight ambivalence on the part of a few of the participants regarding those particular questions as the relevance of the questions was not perceived as being entirely clear.

6.2.3.2.6 Usability of the TBS Controller Tool Support HMI

OBJ-06.08.01-VALP-0010-0050 This section presents the results for the objective: "*To assess the utility and usability of the TBS controller tool support.*"

Summary: The HMI design shape, colour, size and display priority were all acceptable but with the suggestion that the current 'Large' size indicator becomes the new 'Medium' and a new larger size be made available. All CARS Mean scores are acceptable. The indicators were considered useful, intuitive and easy to use and to interpret. All scenarios run passed and were 'OK'; scenarios SCN10 (A) & (B), SCN20 and SCN21 were not conducted because of the high turnover in participants and thus the potentially disproportionate adverse impact that these scenarios could have had on the overall user confidence and trust. SCN27 (TEAM 6 Aircraft per Hour) functioned correctly without any problems following a reduction in the not-in-trail indicator spacing from 2.5 Nm to 2.0 Nm. Controllers were able to monitor for Wake separation encroachment using TBS although they tended not to use the indicators to monitor for clearance to land: refer 6.2.3.2.2.

Questionnaires

End of Participation Questionnaires

Summary tables for Heathrow Tower controllers are provided below:

Question	Yes	Possibly (with improvements)	No
1.5 I was able to monitor for wake separation encroachment when using TBS?	11	1	0
1.6 I was able to monitor for clearance-to-land using TBS?	5	1	6
3.3 Was the HMI **shape** acceptable?	12	0	0
3.3 Was the HMI **colour** acceptable?	12	0	0
3.3 Was the HMI **size** acceptable?	12	0	0
3.3 Was the HMI **display priority** acceptable?	11	0	1

Question	Essential	Very Useful	Useful	Not Useful	Caused Problems
3.1 How useful were the Indicators?	5	3	4	0	0

Question	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
3.4 Is the TBS tool intuitive and easy to use / interpret?	0	0	0	10	2

Table 49: Heathrow Tower Controllers End of Participation – Usability of the TBS Tool HMI

There was wide agreement regarding the ability to monitor for Wake separation encroachment when using TBS.

There was a wide disparity in the responses to question 1.6 "I was able to monitor for clearance-to-land using TBS?" The specific method of operation at Heathrow Airport was such that a clearance to land would only be issued when the leading aircraft had been seen to have vacated the runway. As that aircraft had already passed the radar blanking zone then the following indicator had already been extinguished. Thus the TBS tool was not used to monitor clearances-to-land at Heathrow Airport. This is supported by comments such as:

- *"Clearance to land independent of separation/spacing - other factors"*
- *"It is not a tool for issuing landing clearances"*
- *"I use visual clues out of the window to judge landing clearances"*
- *"I have never used the ATM for landing clearance - this is done visually out of the window to confirm runway is clear"*

The responses to this question fell between two camps: one group didn't use TBS to issue clearances-to-land, whereas the other group felt that TBS did not impede the issuing of clearances-to-land. As such, the apparent disparity can be disregarded.

The scores for question 3.3 indicate the TBS Human Machine Interface (HMI) was acceptable in shape, colour, size and display priority. Given the range of sizes available for the indicators during the simulation, the participants universally chose 'Large' and it was proposed the range of size should be modified. It was suggested that 'Small' becomes the current 'Medium', 'Medium' becomes the current 'Large', and 'Large' is a new size 50% larger than the existing 'Large'. The only exception for acceptability of the HMI design was for display priority of the TST indicator, as follows:

- *"Was masked by a SSR return directly over it."*

The responses to question 3.4 for the usefulness of the indicators ranged between "Useful" and "Essential". Comments accompanying these scores included:

- *"Useful with respect to wake vortex separation. Possibly a hindrance at other times"*
- *"The markers make it easy to identify potential separation issues."*
- *"Very easy to see and interpret visual data."*

- *"Provided information at a quick glance negating the requirement to calculate the distance between aircraft. Obvious benefit here is that controllers have extra time/capacity for other things."*

Participants commented that the indicators were essential for gauging time based separation but also that they provided both Tower and TC with an improved view of the catch-up that occurs after handover to Tower. Further, the indicators were also considered to be useful for assessing potential encroachment resulting in a Wake Turbulence advisory.

All of the participants either agreed or strongly agreed that the TBS tool was intuitive and easy to use and interpret.

Debriefs

HMI Design – with regards the TBS tool HMI, the consensus was that the current 'Large' indicator size should be set as Medium with a 50% increase / decrease value used for 'Large' and 'Small'. One controller did note that his view would be to just provide a single size option to minimise the amount of set-up time required when taking a hand-over. However, a lot of reference was made to other controllers who would want the larger / smaller sizes.

A potential issue was identified with regards the colour of the indicators. In day time mode the ATM has a blue background with a white centreline. In night time it has a black background with red centreline. The indicator colour of pink may not contrast well with the night time mode. This will need to be investigated.

It was suggested during the debriefs that an alert could trigger when an aircraft encroached the Wake separation by more than 0.5Nm. This could be in the form of a change of indicator colour or some flashing alert. The participant suggested that this alert should not be pre-emptive (i.e. of an impending encroachment of more than 0.5Nm) but should simply alert at the point the encroachment occurred.

Tower AIR Arrivals (North) controllers were observed to use indicators differently depending on whether the aircraft pair was Wake or radar constrained. A 3Nm marker may indicate radar minimum separation, but may also indicate Wake constraint (e.g. LM-S). If a LM-S pair was not spotted then a Wake encroachment could be missed. In practise, participants felt that they had correctly identified LM-S pairs in the traffic samples. Initially some Tower AIR Arrivals (North) controllers suggested that indicators could be removed for radar constrained pairs. An alternative suggestion was that indicators for Wake and Non-Wake pairs could be differentiated in some way perhaps with colour and/or shape. This feedback was predominantly based upon good visibility conditions.

With the exception of one scenario exercise, all exercises were run in good visibility conditions (cloud base 3,000ft, visibility to 10DME) where the Tower AIR Arrivals (North) controller was able to apply Reduced Separation in the Vicinity of the Airport, which requires visibility out to at least 6.5DME. As a result, when the lead aircraft was inside 4DME the only issue for radar separation pairs was whether the follower would obtain a landing clearance.

One exercise was run with no Reduced Separation in the Vicinity of the Airport and a 3.0Nm spacing minimum. Consequently the 2.5Nm radar separation minimum needed to be maintained to touchdown. In this case TC would need to provide 3.0Nm spacing across 4DME, with indicators set to a 3.0Nm minimum accordingly. In this situation, indicators for radar separated pairs had to be used in a similar way to indicators for Wake constrained pairs.

This was simulated once with reducing visibility conditions and a 3.0Nm spacing minimum. Encroachment of up to 0.5Nm on the indicator when the lead aircraft was inside 4DME would be permissible in line with current procedures. Encroachment of more than 0.5Nm would result in the aircraft being broken off / diverted onto a missed approach.

A number of controllers asked whether it would be possible to set-up user defined gaps (e.g. for departures / runway inspection) based on time rather than on distance. This issue has previously been raised in TBS User Groups. This will be dependent on the eventual input method / HMI for TBS.

Procedures and Practices debrief results are presented in section 6.2.3.2.3.

Controller Acceptance Rating Scale (CARS)

The Controller Acceptance Rating Scale (CARS) results are presented in section 6.2.3.2.3 above. The CARS results indicate that TBS is acceptable for the Heathrow Tower exercise.

Scenario Events

A series of scenario events were performed during the course of the Tower simulation exercise. Seven different scenarios were performed during nine specific scenario runs as shown in the table below:

Date	Run#	Sample	Sample Name	Type	Scenario
11 July 2012	15	4	TBS2EEV2TBS	Scenario	Indicator Failure
12 July 2012	25	6	TBS6EEC2TBS	Scenario	Runway Closure
13 July 2012	33	14	TBS4WWN3TBS	Scenario	TEAM 6 a/c hr Deps
13 July 2012	35	14	TBS4WWN3TBS	Scenario	TEAM 6 a/c hr Deps
15 July 2012	44	1	TBS1WWC4TBS	Scenario	Wake Only Indicators
22 July 2012	53	5	TBS2EEN1TBS	Scenario	Runway Inspection
23 July 2012	63	5	TBS2EEN1TBS	Scenario	Rwy Insp/Wake Only
24 July 2012	72	3	TBS1WWC1TBS	Scenario	Reduced Vis/S. Gap
24 July 2012	74	14	TBS4WWN3TBS	Scenario	TEAM 6 a/c hr Deps

Table 50: Specific scenario runs

Further scenarios were performed as conditions and events during Match runs. See Appendix F for the complete scenario coverage summary. All of the scenarios performed were considered to pass and be ‘OK’, except for scenarios **SCN10 (A) & (B)**, **SCN20** and **SCN21**. These four scenarios were not conducted because of the high turnover in participants and thus the potentially disproportionate adverse impact that these scenarios could have had on the overall user confidence and trust.

SCN27: TEAM 6 Aircraft per Hour.

This scenario was conducted three times during the validation exercise; exercise runs 33, 35 and 74. The first exercise run (Run 33) used 2.5 Nm not-in-trail indicators as used in the final exercise run of the TC Approach validation exercise (VP-303). Feedback from this scenario run indicated that the 2.5 Nm spacing indicators were unacceptable for Tower operations, as described in the following post run comment: “There is a potential safety issue with the not in trail chevrons at 2.5Nm. This creates a situation where some markers represent a separation minima such as in trail wake turbulence but others where the target can be inside the marker with no separation consideration.” It was decided for the next scenario runs to reduce the indicator spacing back to 2.0 Nm as originally designed and tested in the TC Approach validation exercise (VP-303). The fault with the missing in-trail Wake indicators from VP-303 was known to be fixed for this validation exercise so these should be shown when appropriate. Scenario run 35 demonstrated that 2.0 Nm indicator spacing was a significant improvement and functioned correctly without any problems, as indicated with the following comment:

- “*Not in trail markers at 2Nm made the process of monitoring the TBS tool much simpler.*”

This was reinforced by Scenario run 74 where TEAM again functioned correctly without any problems, including correctly displayed in-trail Wake indicators which did not function reliably during VP-303. Workload, Situation Awareness, NATS Picture Scale, CARS and NATS Confidence Diamond scores were all very good and acceptable for all three TEAM scenario runs.

The Wake-only indicators run (Run 44 on 15th July) was not one of the planned scenarios but was run ‘ad-hoc’ at the request of the controllers in response to discussion regarding possible differentiation between indicators for Wake or Non-Wake pairs. This was frequently discussed during the remainder of the validation exercise with no clear decision being reached as not all of the participants agreed that Wake-only indicators would be the best configuration. An alternative suggestion was that Wake and Non-Wake pairs could be differentiated in some way, perhaps with colour and/or shape.

6.2.3.2.7 Impact on Roles and Responsibilities

OBJ-06.08.01-VALP-0010-0060 This section presents the results for the objective: "*To assess the impact of the TBS concept and operational procedures on the roles and responsibilities of the Final Approach Controller, Intermediate Approach Controller, Runway Controller, Approach and Tower Supervisors, and Pilot*." Note: this activity tested the objective from the perspective of the Runway Controller.

Summary: The participants agreed that they understood their roles and responsibilities when using TBS and that the indicators helped them to detect losses of separation by TC.

Debriefs

Safety debrief results are presented in section 6.2.3.2.2 above.

Procedures and Practices results are presented in section 6.2.3.2.3 above.

Trust and Reliance debrief results are presented in section 6.2.3.2.5.

Questionnaires

End of Participation Questionnaires

Summary tables for Heathrow Tower AIR Arrivals (North) controllers are provided below.

Question	Yes	Possibly (with improvements)	No
1.2 I feel the division of responsibility between Approach and Runway controllers will be acceptable when using TBS?	12	0	0
1.3 I feel the division of responsibility between Controllers and Pilots will be acceptable when using TBS?	12	0	0

Question	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
2.1 I understood my roles and responsibilities when using TBS.	0	0	0	8	4
3.2 The separation indicators helped me detect losses of separation by TC.	0	0	1	6	5

Table 51: Heathrow Tower AIR Arrivals (North) controllers End of Participation – Roles and Responsibilities

All 12 of the participants unanimously agreed that the division of responsibility between Approach and Runway controllers will be acceptable when using TBS, and that the division of responsibility between Controllers and Pilots will be acceptable when using TBS.

All 12 of the participants either agreed or strongly agreed that they understood their roles and responsibilities when using TBS.

Eleven of the participants either agreed or strongly agreed that the separation indicators helped detect losses of separation by TC, however there was one response of 'Neither Agree or Disagree' which was accompanied by the comment:

- *"Re. Losses of separation by TC: I can do this without the indicators too."*

In this case the controller was responding to what may be seen as possible vagueness in the wording of the question such that the question may be interpreted as suggesting that a controller would otherwise need help in detecting losses of separation during current operations. This was not the intent of the question and this was the only comment referring to it in this way.

SHAPE Teamwork (STQ-s) Questionnaire

The SHAPE Teamwork (STQ-s) Questionnaire results are presented in section 6.2.3.2.5 above. Overall the SHAPE Teamwork questionnaire results were favourable, though a few participants were less confident of how well the TBS system supported team working tasks.

6.2.3.2.8 Impact on Arrival Runway Capacity

OBJ-06.08.01-VALP-0010-0070 This section presents the results for the objective: "*To assess the impact of TBS tool support and operational procedures on the arrival runway capacity during strong wind conditions.*"

Summary: There were no Spacing-related Late Runway Switches during the course of the simulation, and just one instance of a go-around during a TBS Match run; neither result was statistically significant. The adverse impact on arrival runway capacity was negligible. This validates the 3 aircraft per hour average increase in landing rate observed during the VP-303 exercise from the perspective of Heathrow Tower operations.

Landing Rates – Passing Runway Threshold

Due to the nature of the Tower exercise the landing rates passing the Runway Threshold had been previously determined by the output of the previous VP-303 Approach exercise. As described in detail in section 6.2.2.1 the traffic samples reflected the increased aircraft landing rates with TBS that had been evident during the Approach activity. Therefore, as the landing rates as presented to the Tower controller were, effectively, fixed then it remained to be seen if the Tower AIR Arrivals (North) controller could handle the extra traffic as delivered by TBS under strong wind conditions.

Go-Arounds

Throughout all of the matched runs there was only one instance of a go-around. This occurred during Run 13, Match 1 TBS. No comments were specifically recorded pertaining to the go-around and the workload scores for that run were low, along with the Situation Awareness scores being high. This is not statistically significant. Refer 6.2.3.2.2.

Spacing-related Late Runway Switches

Anticipated as an indicator of seriously unacceptable compression, there were no Spacing-related Late Runway Switches during the course of the Heathrow Tower exercise.

6.2.3.2.9 Unexpected Behaviours/Results

Limitations of the Simulation

- Runway exits artificially closed to more faithfully emulate actual operations. (Refer 6.2.2.1 Airport Information and Runway Exits).
- Necessity of re-creating traffic samples to match the output of the earlier Approach simulation due to the incompatibility between the different simulation platforms. (Refer 6.2.2.1 Exercise Preparation).
- Lack of TC Approach controllers.
- Lack of crossers and helicopter traffic which would otherwise have added to the AIR controller workload.

The lack of TC Approach controllers was also due to the incompatibility between the Micro Nav BEST Heathrow Tower simulator and the NATS ACE Approach simulator such that the Approach and Tower activities had to be run separately.

The lack of crosser and helicopter traffic was due to the fact that the traffic samples were created to reproduce those samples used during the Approach exercise (VP-303) and the resulting output thereof.

6.2.3.3 Confidence in Results of Validation Exercise

6.2.3.3.1 Quality of Validation Exercise Results

The volume and quality of data collected for analysis was both sufficient and of good quality, which has enabled detailed analysis to be performed with a high degree of confidence in the results. A total of twelve Heathrow Tower AIR Arrivals (North) controllers took part in the simulation, of whom only two participated for more than one day. It was significant that although the remaining ten participants only attended for one day each they were all able to learn the concept and function of the TBS tool very quickly and to adapt to the new method of operating with ease. All of the participants were valid Heathrow Tower AIR Arrivals (North) controllers.

Analysis was undertaken using the comparative DBS and TBS data from eight matched runs, along with questionnaires, debriefs and validation observers.

6.2.3.3.2 Significance of Validation Exercise Results

Three methods of comparative analysis were used for operational and statistical significance:

1. **'Box and Whisker' charts**.
2. **Wilcoxon Signed-Rank Test for Statistical Significance**.
3. **Chi-Square Test for Statistical Significance**.

A limitation of the comparative analysis was the relatively small sample sizes from the matched runs for controller metrics, e.g. the number of exercise runs. However, sufficient data was available to test for statistical significance where differences were evident and the results of these tests reported.

6.2.4 Conclusions and Recommendations

6.2.4.1 Conclusions

The evidence from the Time Based Separation (TBS) Heathrow Tower validation exercise VP-302 indicates that the TBS concept is viable and could deliver improvements and benefits for aircraft landing rates during strong wind conditions. Specific conclusions are listed below:

C1. The TBS concept is viable as simulated for Heathrow Tower and could deliver significant improvements and benefits for airport operations in terms of higher aircraft landing rates in stronger wind conditions.

C2. The higher aircraft landing rates as delivered by TC Approach with TBS from the VP-303 validation exercise were handled easily by the Tower AIR Arrivals (North) controller. There was no statistically significant difference in separation accuracy for wake turbulence separated pairs at Runway Threshold between DBS and TBS.

C3. It was expected that aircraft spacing would compress between 4DME and Runway Threshold and separation reduced: correspondingly there were slightly fewer compressed Wake pairs with TBS compared to DBS (up to 0.5Nm compression); although there were more highly compressed pairs with TBS (more than 0.5Nm compression) – these differences are not statistically significant.

C4. There are no statistically significant differences between the Clearance to Land margins (less than or equal to 15 seconds), Go-around instructions, numbers of Wake Vortex Advisories or Expedited Runway Vacation Requests issued between DBS and TBS.

C5. There are no statistically significant differences in controller workload (Bedford and ISA) with TBS compared with DBS.

C6. R/T usage under TBS operations was acceptable.

C7. The TBS Method of Operations was felt to be practical, manageable, realistic and achievable.

C8. The TBS Indicators were considered to be very useful for aiding in the assessment of separation infringements in particular for the assessment of severe infringements of greater than 0.5 Nm.

C9. Situation Awareness remained high and comfortably above the acceptable limit at all times, there are no statistically significant differences between DBS and TBS.

C10. Tower AIR Arrivals (North) controllers felt they could accommodate the TBS indicators into their scan; the presence of TST indicators reduced the need to obtain and process information on aircraft types and wake turbulence categories from the EFPS system. The relative position of aircraft with respect to the indicators provided a more immediate assessment of the final approach spacing than current day interpretation using the range markers on the extended centreline. This change of scan indicates that the TBS system needs a high degree of accuracy and reliability because of the high levels of trust placed on correct calculation and display of the TST indicators.

C11. All scenarios run passed and were 'OK'; scenarios SCN10 (A) & (B), SCN20 and SCN21 were not conducted because of the high turnover in participants and thus the potentially disproportionate adverse impact that these scenarios could have had on the overall user confidence and trust.

C12. SCN27 (TEAM 6 Aircraft per Hour) functioned correctly without any problems when using 2.0 Nm for the not-in-trail indicators. The in-trail Wake indicators functioned correctly; these were missing from the TC Approach validation exercise VP-303.

C13. The participants agreed that they understood their roles and responsibilities when using TBS and that the indicators helped them to detect losses of separation by TC.

C14. There were no Spacing-related Late Runway Switches during the course of the simulation, and just one instance of a go-around during a TBS Match run; neither result was statistically significant. Therefore the impact on arrival runway capacity was negligible.

C15. The volume and quality of data collected for analysis was both sufficient and of good quality, which has enabled detailed analysis to be performed with a high degree of confidence in the results.

6.2.4.2 Recommendations

The following recommendations are proposed as a result of the TBS Tower validation exercise (VP-302) conducted in July 2012:

R1. It would be of benefit, prior to implementation, to run a further simulation encompassing both Approach and Tower controllers. Such simulation functionality is not currently available, although work is progressing in this direction at NATS CTC.

During the debriefs a number of suggestions emerged regarding possible TBS tool modifications. These would require further investigation during V4 and V5 activities:

R2. Differentiation between indicators for Wake and Non-Wake constrained pairs, and between operations with or without Reduced Separation in the Vicinity of the Airport. (Refer 6.2.3.2.6 Debriefs)

R3. Review the display of mile markers and consider their selective removal. (Refer 6.2.3.2.6 Debriefs)

R4. The provision of a visual alert on the TBS indicator for 0.5Nm Wake separation encroachment. (Refer 6.2.3.2.6 Debriefs)

R5. Display the TBS indicator until the lead aircraft touches down. (Refer 6.2.3.2.2 Debriefs)

R6. Review TBS indicator display colour for ATM night mode operation. (Refer 6.2.3.2.6 Debriefs)

R7. Review TBS indicator display size options. (Refer 6.2.3.2.6 Debriefs)

R8. Adopt 2.0 Nm minimum separation for not-in-trail aircraft pairs. (Refer 6.2.3.2.6 Scenario events)

R9. The provision of Time Based Gaps for Departures / Runway Inspection. (Refer 6.2.3.2.6 Debriefs).

R10. Review Indicator requirements for Tower ATCOs during runway closure scenarios and during late runway switch scenarios.

R11. Develop the procedures and associated system support for setting up the runway separation and spacing constraints and for setting up spacing gaps.

7 References

7.1 Applicable Documents

[1] P6.8.1 Validation Plan - Time Based Separation (VALP) 00.01.00 [31 August 2011]

[2] P6.8.1 Validation Plan - Time Based Separation (VALP) 00.01.01 [29 February 2012]

[3] P6.8.1 Validation Plan - Time Based Separation (VALP) 00.01.02 [28 June 2012]

[4] P6.8.1 Validation Plan - Time Based Separation (VALP) 00.01.03 [16 July 2012]

[5] 06.08.01 Operational Concept Description (OCD) and Operational Service and Environment Definition (OSED) for Time Based Separation for Arrivals (TBS) 00.00.05 [25 March 2011]

[6] 06.08.01 Time Based Separation (TBS) Data Collection Campaign and LIDAR Data Analysis Report 00.00.03 [15 February 2013]

[7] Template Toolbox 03.00.00
https://extranet.sesarju.eu/Programme%20Library/SESAR%20Template%20Toolbox.dot

[8] Requirements and V&V Guidelines 03.00.00
https://extranet.sesarju.eu/Programme%20Library/Requirements%20and%20VV%20Guidelines.doc

[9] Templates and Toolbox User Manual 03.00.00
https://extranet.sesarju.eu/Programme%20Library/Templates%20and%20Toolbox%20User%20Manual.doc

[10] European Operational Concept Validation Methodology (E-OCVM) - 3.0 [February 2010]

[11] EUROCONTROL ATM Lexicon
https://extranet.eurocontrol.int/http://atmlexicon.eurocontrol.int/en/index.php/SESAR

7.2 Reference Documents

The following documents provide input/guidance/further information/other:

[12] WP C.03, C.03-D03-Regulatory Roadmap Development and Maintenance Process
https://extranet.sesarju.eu/Programme%20Library/Forms/General.aspx

[13] WP C.03, C.03-D02-Standardisation Roadmap Development and Maintenance Process
https://extranet.sesarju.eu/Programme%20Library/Forms/General.aspx

[14] SESAR Business Case Reference Material
https://extranet.sesarju.eu/Programme%20Library/Forms/Procedures%20and%20Guidelines.aspx

[15] SESAR Safety Reference Material
https://extranet.sesarju.eu/Programme%20Library/Forms/Procedures%20and%20Guidelines.aspx

[16] SESAR Security Reference Material
https://extranet.sesarju.eu/Programme%20Library/Forms/Procedures%20and%20Guidelines.aspx

[17] SESAR Environment Reference Material
https://extranet.sesarju.eu/Programme%20Library/Forms/Procedures%20and%20Guidelines.aspx

[18] SESAR Human Performance Reference Material
https://extranet.sesarju.eu/Programme%20Library/Forms/Procedures%20and%20Guidelines.aspx

[19]D07 Guidance on list of KPIs for Step 1 Performance Assessment Ed1
https://extranet.sesarju.eu/Programme%20Library/Forms/Procedures%20and%20Guidelines.aspx

[20]ATM Master Plan
https://www.atmmasterplan.eu

[21]WP06.02 DOD for Airports

[22] WP05.02 DOD for TMA and Approach

[23] WP6 Validation Strategy for Concept Step 1 – Time Based Operations

[24] WP5 Validation Strategy for Concept Step1 – Time Based Operations

Appendix A KPA Templates

N/A

Appendix B 06.08.01 VP-303 Simulation Timetables

	DAY 1	DAY 2		DAY 3	DAY 4	DAY 5		DAY 6	DAY 7
	AM	AM		AM	AM	AM		PM	PM
								LL Tower	
AM	Saturday 11/02/2012	Sunday 12/02/2012	AM	Monday 20/02/2012	Tuesday 21/02/2012	Wednesday 22/02/2012	PM	Thursday 23/02/2012	Saturday 25/02/2012
07:00-07:15	Briefing	Briefing	07:00-07:15	Briefing	Briefing B2-06	Briefing B2-06	14:30-14:45	Briefing	Briefing
07:15-07:30	B2-06 / B2-04	B2-06 / B2-04	07:15-07:30	B1-06	**41**	**51**	14:45-15:00	E1-05	B2-06
07:30-07:45		**21**	07:30-07:45	**31**	TBS3W, WC1	TBS1W, WC1	15:00-15:15	**61**	**71**
07:45-08:00		TBS2E, EN1	07:45-08:00	TBS4W, WN1	Match3, cct 446	Match5, cct 486	15:15-15:30	TBS9W, WC3	TBS9W, WC3
08:00-08:15		**TBS**	08:00-08:15	Match2, cct 486	**DBS**	**TBS**	15:30-15:45	Scenario, cct 486	Match7, cct 446
08:15-08:30		Debrief	08:15-08:30	**TBS**	Debrief	Debrief	15:45-16:00	**TBS**	**DBS**
08:30-08:45	Aborted run	Break	08:30-08:45	Debrief	Break	Break	16:00-16:15	Debrief	Debrief
08:45-09:00	Break		08:45-09:00	Break			16:15-16:30	Break	Break
09:00-09:15		**22**	09:00-09:15		**42**	**52**	16:30-16:45	**62**	**72**
09:15-09:30	**11** TBS3W, WN1	TBS1W, WN1	09:15-09:30	**32**	TBS11W, WN1	TBS9W, WC1	16:45-17:00	TBS6E, EC2	TBS1W, WC3
09:30-09:45	Pause, Swap seats	Match1	09:30-09:45	TBS3W, WN1	Match4, cct 446	Match6, cct 486	17:00-17:15	Scenario, cct 484	Match8, cct 446
09:45-10:00	**TBS**	**TBS**	09:45-10:00	Training, cct 486	**DBS**	**TBS**	17:15-17:30	**TBS**	**DBS**
10:00-10:15	Break	Debrief	10:00-10:15	**TBS**	Debrief	Debrief	17:30-17:45	Debrief	Debrief
10:15-10:30	**12**	Break	10:15-10:30	Debrief	Break	Break	17:45-18:00	Break	Break
10:30-10:45	TBS3W, WN1		10:30-10:45	Break			18:00-18:15	**63**	
10:45-11:00	**TBS**	**23**	10:45-11:00	**33**	**43**	**53**	18:15-18:30	TBS5W, WC2	**73**
11:00-11:15	Debrief	TBS3W, WN3	11:00-11:15	TBS4W, WN1	TBS3W, WC1	TBS1W, WC1	18:30-18:45	Scenario, cct 486	TBS9W, WC3
11:15-11:30	Break		11:15-11:30	Match2, cct 446	Match3, cct 486	Match5, cct 446	18:45-19:00	**TBS**	Match7, cct 486
11:30-11:45		**TBS**	11:30-11:45	**DBS**	**TBS**	**DBS**	19:00-19:15	Debrief	**TBS**
11:45-12:00	**13** TBS4W, WN3	Debrief	11:45-12:00	Debrief	Debrief	Debrief	19:15-19:30	Break	Debrief
12:00-12:15	Pause, Swap seats	Break	12:00-12:15	Break	Break	Break	19:30-19:45	**64**	Break
12:15-12:30	**TBS**		12:15-12:30				19:45-20:00	TBS8E, EV2	
12:30-12:45	Break	**24**	12:30-12:45	**34**	**44**	**54**	20:00-20:15	Scenario, cct 484	**74**
12:45-13:00		TBS1W, WN1	12:45-13:00	TBS1W, WC1	TBS11W, WN1	TBS9W, WC1	20:15-20:30	**TBS**	TBS1W, WC3
13:00-13:15	**14**	Match1	13:00-13:15	Scenario, cct 486	Match4, cct 486	Match6, cct 446	20:30-20:45	Debrief	Match8, cct 486
13:15-13:30	TBS4W, WN3	**DBS**	13:15-13:30	**TBS**	**TBS**	**DBS**	20:45-21:00	D2	**TBS**
13:30-13:45	**TBS**	Debrief	13:30-13:45	Debrief	Debrief	Debrief	21:00-21:15		Debrief
13:45-14:00	Debrief	D2	13:45-14:00	D2	D2	D2	21:15-21:30		D2
14:00-14:15	D2								

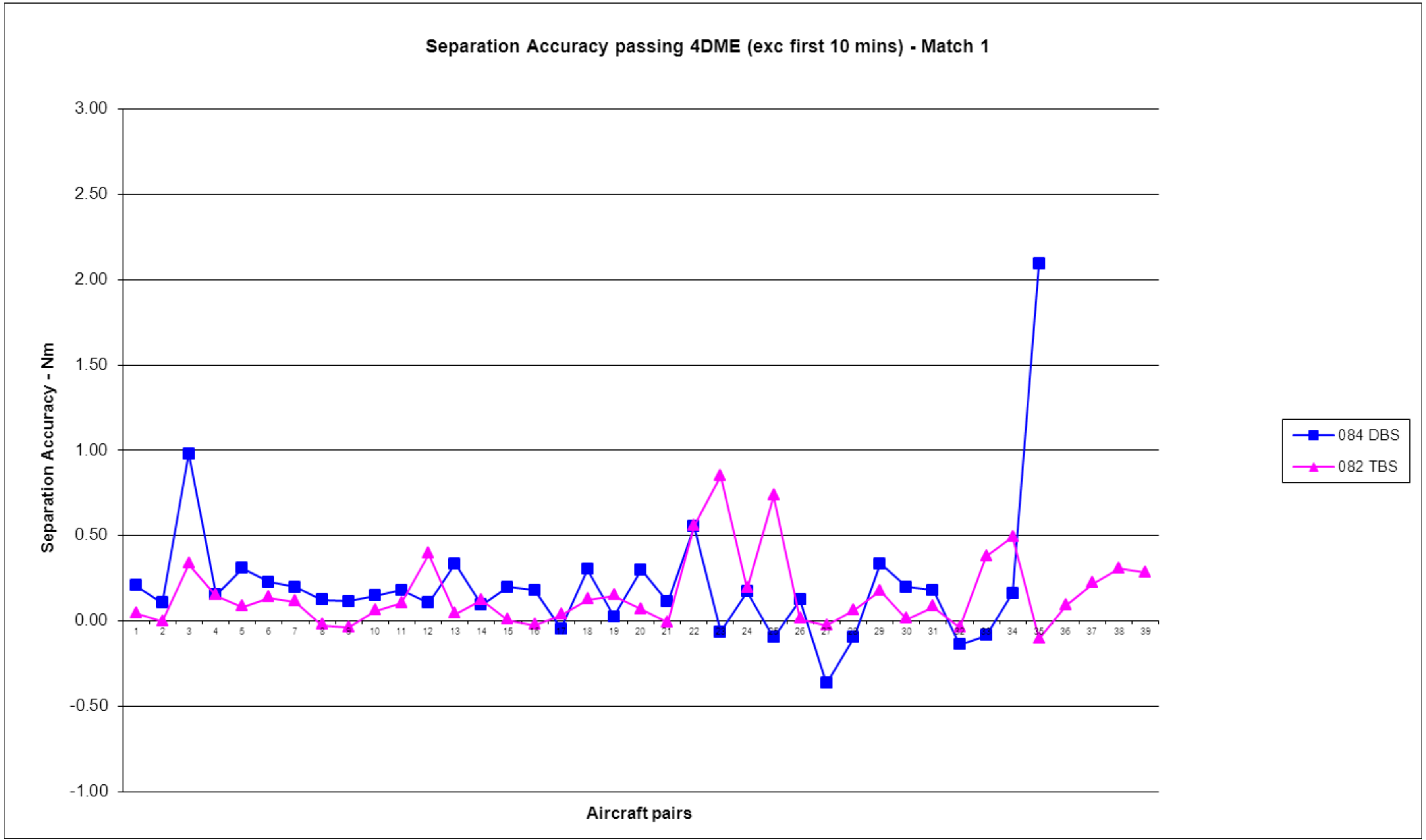
AM	DAY 8 AM Wednesday 29/02/2012	DAY 9 AM Thursday 01/03/2012	DAY 10 AM Friday 02/03/2012	PM	DAY 11 PM Saturday 03/03/2012	DAY 12 PM Sunday 04/03/2012	DAY 13 PM LL Tower Monday 05/03/2012
07:00-07:15	Briefing	Briefing	Briefing	14:30-14:45	Briefing	Briefing B2-06	Briefing B2-06
07:15-07:30	B2-06	B2-06	B2-06	14:45-15:00	B2-06	**121**	**131**
07:30-07:45	**81**	**91**	**101**	15:00-15:15	**111**	TBS1W, WC2	TBS5W, WN3
07:45-08:00	TBS3W, WC3	TBS2E, EN1	TBS6E, EC3	15:15-15:30	TBS4W, WN3	Scenario, cct 486	Scenario, cct 486
08:00-08:15	Match9, cct 486	Match10, cct 485	Match12, cct 485	15:30-15:45	Scenario, cct 486	**TBS**	**TBS**
08:15-08:30	**TBS**	**DBS**	**DBS**	15:45-16:00	**TBS**	Debrief	Debrief
08:30-08:45	Debrief	Debrief	Debrief	16:00-16:15	Debrief	Break	Break
08:45-09:00	Break	Break	Break	16:15-16:30	Break	**122**	**132**
09:00-09:15				16:30-16:45	**112**	TBS3W, WV2	TBS2E, EN3
09:15-09:30	**82**	**92**	**102**	16:45-17:00	TBS2E, EV2	Scenario, cct 486	Scenario, cct 484
09:30-09:45	TBS1W, WN1	TBS8E, EN1	TBS1W, WC4	17:00-17:15	Scenario, cct 484	**TBS**	**TBS**
09:45-10:00	Match1, cct 486	Match11, cct 485	Scenario, cct 486	17:15-17:30	**TBS**	Debrief	Debrief
10:00-10:15	**TBS**	**DBS**	**TBS**	17:30-17:45	Debrief	Break	Break
10:15-10:30	Debrief	Debrief	Debrief	17:45-18:00	Break		
10:30-10:45	Break	Break	Break	18:00-18:15		**123**	**133**
10:45-11:00	**83**	**93**	**103**	18:15-18:30	**113**	TBS5W, WC4	TBS3W, WV2
11:00-11:15	TBS3W, WC3	TBS2E, EN1	TBS6E, EC3	18:30-18:45	TBS6E, EC2	Scenario, cct 486	Scenario, cct 486
11:15-11:30	Match9, cct 446	Match10, cct 484	Match12, cct 484	18:45-19:00	Scenario, cct 484	**TBS** Wind x2.5	**TBS**
11:30-11:45	**DBS**	**TBS**	**TBS**	19:00-19:15	**TBS**	Debrief	Debrief
11:45-12:00	Debrief	Debrief	Debrief	19:15-19:30	Debrief	Break	Break
12:00-12:15	Break	Break	Break	19:30-19:45	Break		
12:15-12:30				19:45-20:00		Questionnaires	**134**
12:30-12:45	**84**	**94**	**104**	20:00-20:15	**114**		TBS1W, WC2
12:45-13:00	TBS1W, WN1	TBS8E, EN1	TBS8E, EC4	20:15-20:30	TBS4W, WN2		Scenario, cct 448
13:00-13:15	Match1, cct 446	Match11, cct 484	Scenario, cct 484	20:30-20:45	Scenario, cct 486	Debrief	**TBS**
13:15-13:30	**DBS**	**TBS**	**TBS**	20:45-21:00	**TBS**	D2	Debrief
13:30-13:45	Debrief	Debrief	Debrief	21:00-21:15	Debrief		D2
13:45-14:00	D2	D2	D2	21:15-21:30	D2		

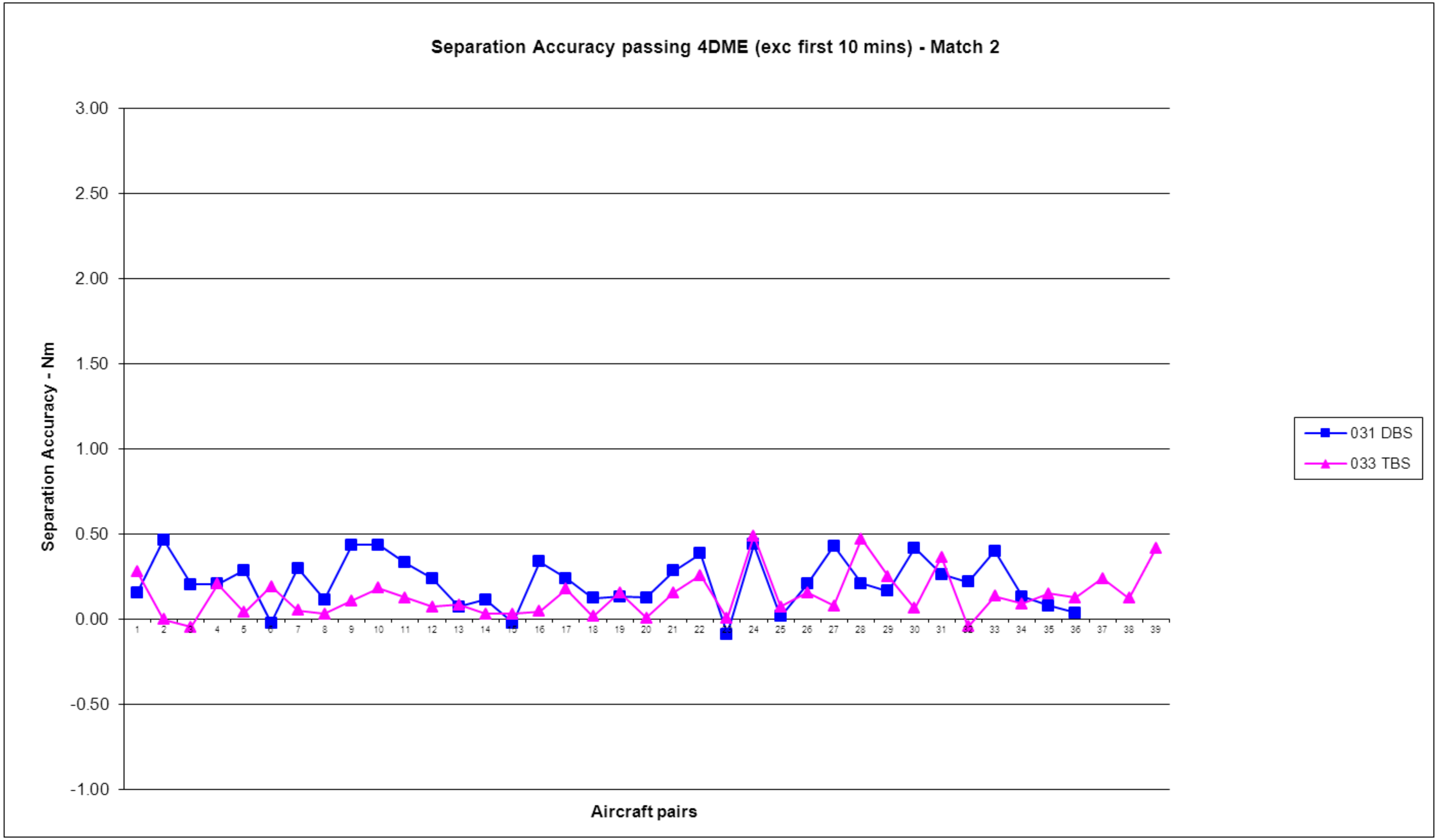
Appendix C 06.08.01 VP-303 Scenario Events Coverage

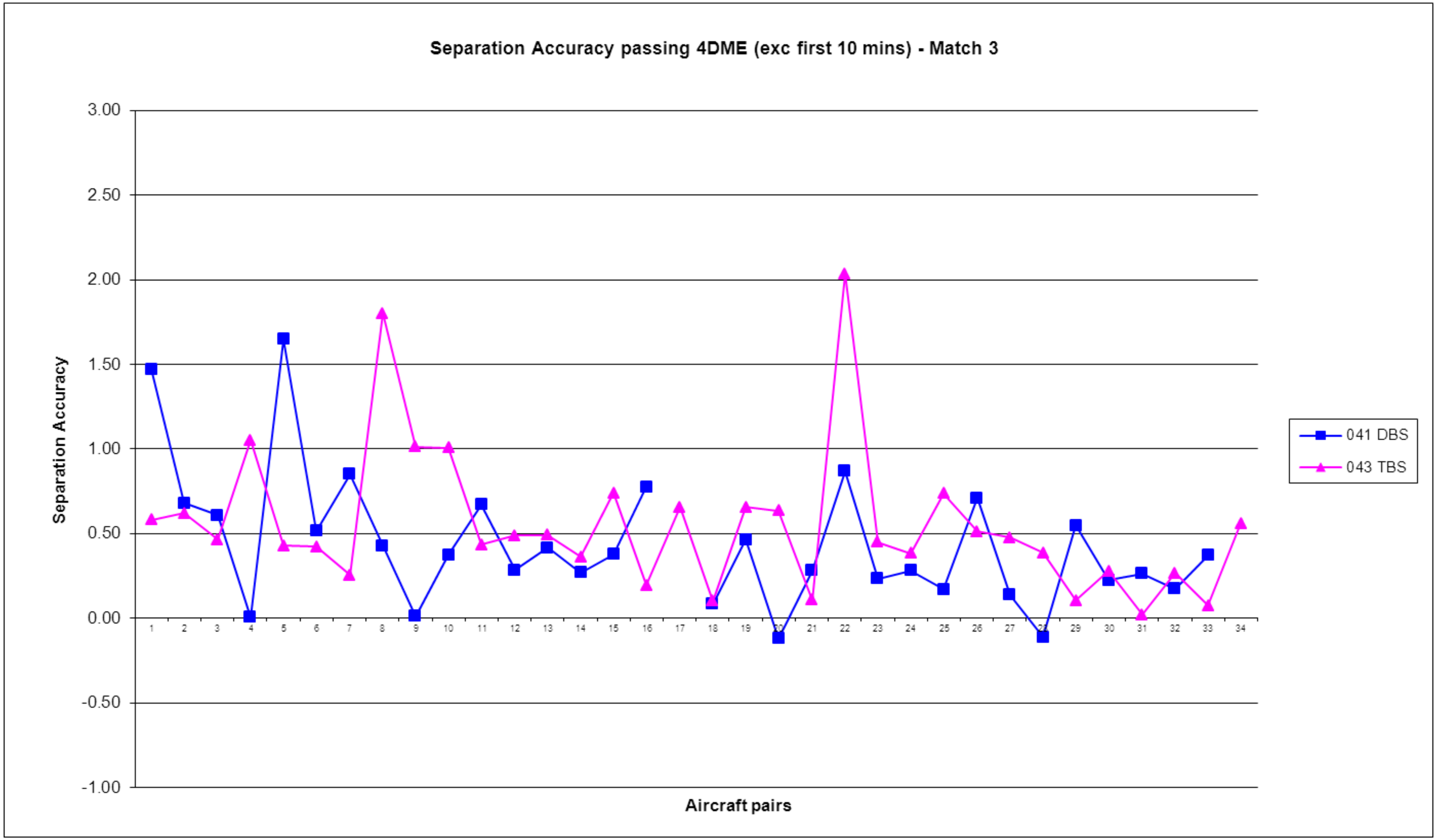
Scenario ID	Scenario Event ID	Full Description	Scenario Count	Status	VP-303
SCN01	EVNT-06.08.01-0001	Blocked Runway (a/c able to establish on alternate).	1	OK	YES
SCN02	EVNT-06.08.01-0002	Blocked Runway (a/c NOT able to establish on alternate).	1	OK	YES
SCN03	EVNT-06.08.01-0003A	Emergency Aircraft (Pan Pan).	2	OK	YES
SCN04	EVNT-06.08.01-0003B	Emergency Aircraft (Mayday).	1	OK	YES
SCN05	EVNT-06.08.01-0005	Indicator failure (multiple).	1	OK	YES
SCN06	EVNT-06.08.01-0028	CAT A Flight.	N/A	-	NO
SCN07	EVNT-06.08.01-0029	CAT B Flight.	N/A	-	NO
SCN08	EVNT-06.08.01-0030	Runway Inspection.	3	OK	YES
SCN09 (A)	EVNT-06.08.01-0006	Pilot speed non-conformance leads to catch-up on final. Pilot flies higher IAS on joining centreline. Catches and (potentially) infringes WAKE separation.	6	OK	YES
SCN09 (B)	EVNT-06.08.01-0007	Pilot speed non-conformance leads to catch-up on final. Pilot flies higher IAS on joining centreline. Catches and (potentially) infringes NON-WAKE separation.	1	NOK	YES
SCN10 (A)	EVNT-06.08.01-0008	Pilot speed non-conformance leads to catch-up on final. Pilot delays the 180kt IAS to 160kt IAS speed instruction, catches and (potentially) infringes WAKE separation.	3	OK	YES
SCN10 (B)	EVNT-06.08.01-0009	Pilot speed non-conformance leads to catch-up on final. Pilot delays the 180kt IAS to 160kt IAS speed instruction, catches and (potentially) infringes NON-WAKE separation.	3	OK	YES
SCN11 (A)	EVNT-06.08.01-0010	Pilot speed non-conformance. Slows very early from 160kt to landing speed. Aircraft behind with WAKE separation catches up signficantly (if left).	7	OK	YES
SCN11 (B)	EVNT-06.08.01-0011	Pilot speed non-conformance. Slows very early from 160kt to landing speed. Aircraft behind with NON-WAKE separation catches up signficantly (if left).	2	OK	YES
SCN12	EVNT-06.08.01-0013	Blocked R/T leads to delayed 180kt to 160kt IAS instruction.	1	OK	YES
SCN13	EVNT-06.08.01-0015	TC deliver under-separation for WAKE pair to Tower.	VP-302	-	NO
SCN14	EVNT-06.08.01-0016	TC deliver under-separation for NON-WAKE pair to Tower.	VP-302	-	NO
SCN15	EVNT-06.08.01-0017	Light wind conditions. Separation greater than current-day wake (and non-wake) separation.	2	OK	YES
SCN16	EVNT-06.08.01-0018	Extreme catch-up wind conditions. Aircraft need to be spaced at greater than the indicator further out on the ILS to prevent excessive catch-up.	7	OK	YES
SCN17	EVNT-06.08.01-0019	Pull-away conditions. FIN constrained by indicator on turn on to ILS but aircraft subsequently pull-away.	8	OK	YES
SCN18	EVNT-06.08.01-0020A	Missed approach – single aircraft, short final	2	OK	YES
SCN19	EVNT-06.08.01-0020B	Missed approach - single aircraft	3	OK	YES
SCN20	EVNT-06.08.01-0022	TST calculating separation incorrectly (due error / incorrect wind information) causing too small a separation being displayed for the wind conditions.	1	NOK	YES
SCN21	EVNT-06.08.01-0023	Incorrect TBS sequence causes too small a separation to be displayed by the TST.	6	OK	YES
SCN22	EVNT-06.08.01-0024	Late change of landing runway - before 4DME.	1	NOK	YES
SCN23	EVNT-06.08.01-0025	INTs hand over aircraft in the wrong order to FIN.	1	OK	YES
SCN24	EVNT-06.08.01-0026	Follower aircraft joins the ILS before the lead aircraft.	3	OK	YES
SCN25	EVNT-06.08.01-0027	Arrival aircraft on short final.	VP-302	-	NO
SCN26	EVNT-06.08.01-0031	Early morning TEAM.	1	NOK	YES
SCN27	EVNT-06.08.01-0032	TEAM 6 aircraft / hour.	7	NOK	YES
SCN28	EVNT-06.08.01-0033	3.0Nm minimum spacing.	11	OK	YES

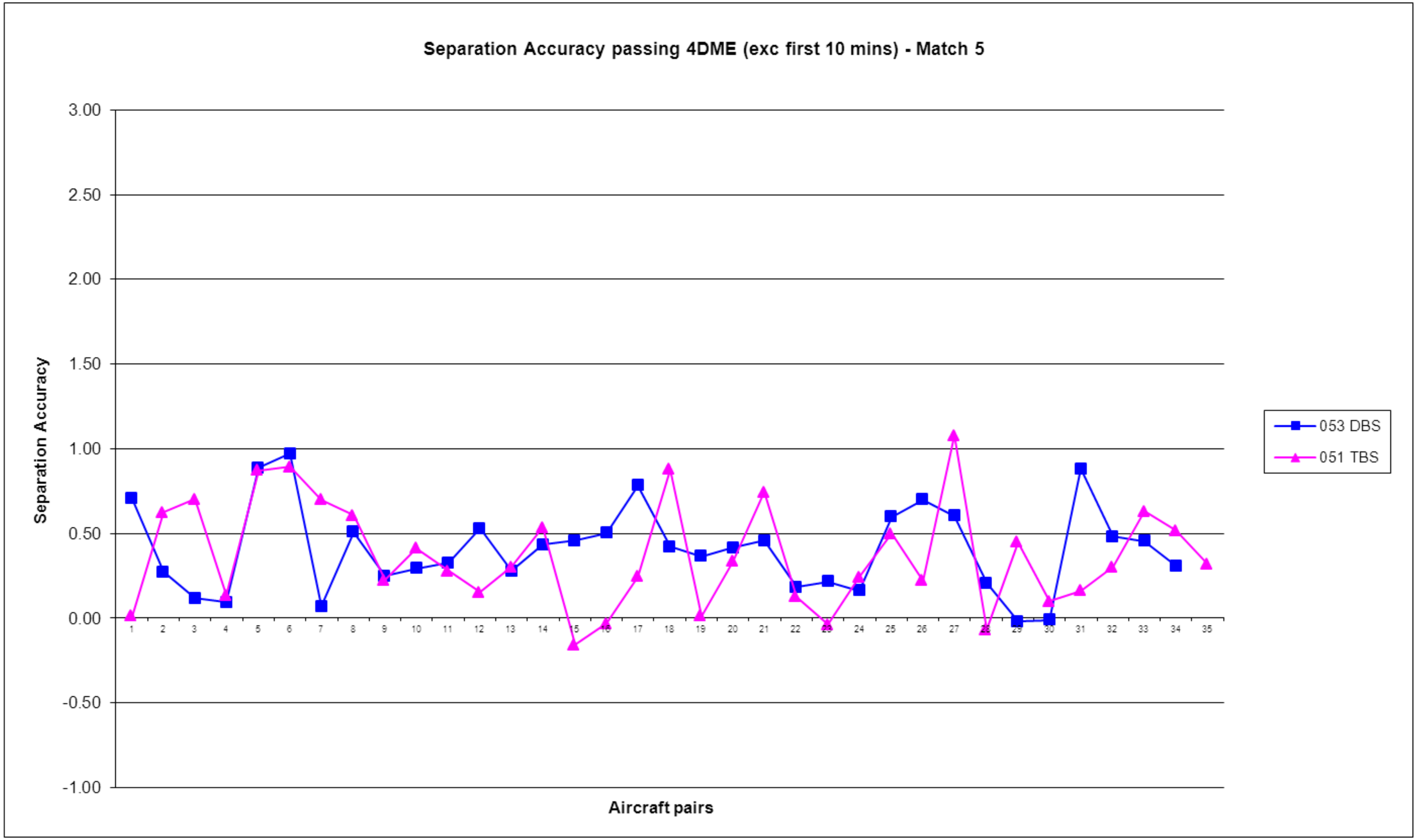
Note: Scenario Counts include all exercise runs including training exercises. Explanation and rationale for the 'NOK' Scenarios is provided in Sections 4.1 and 6.1.3.2.6.

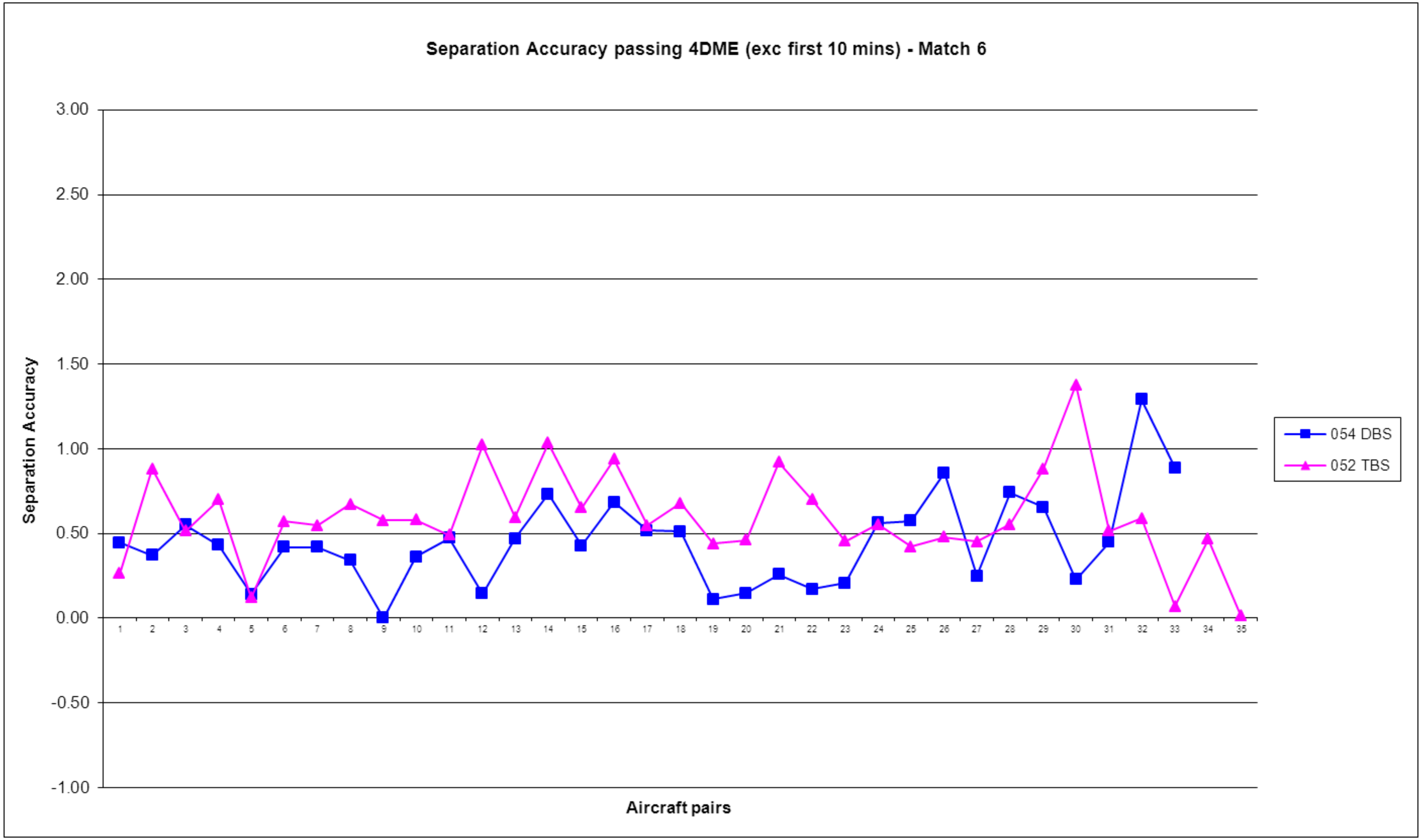
Appendix D 06.08.01 VP-303 Separation Accuracy Passing 4DME

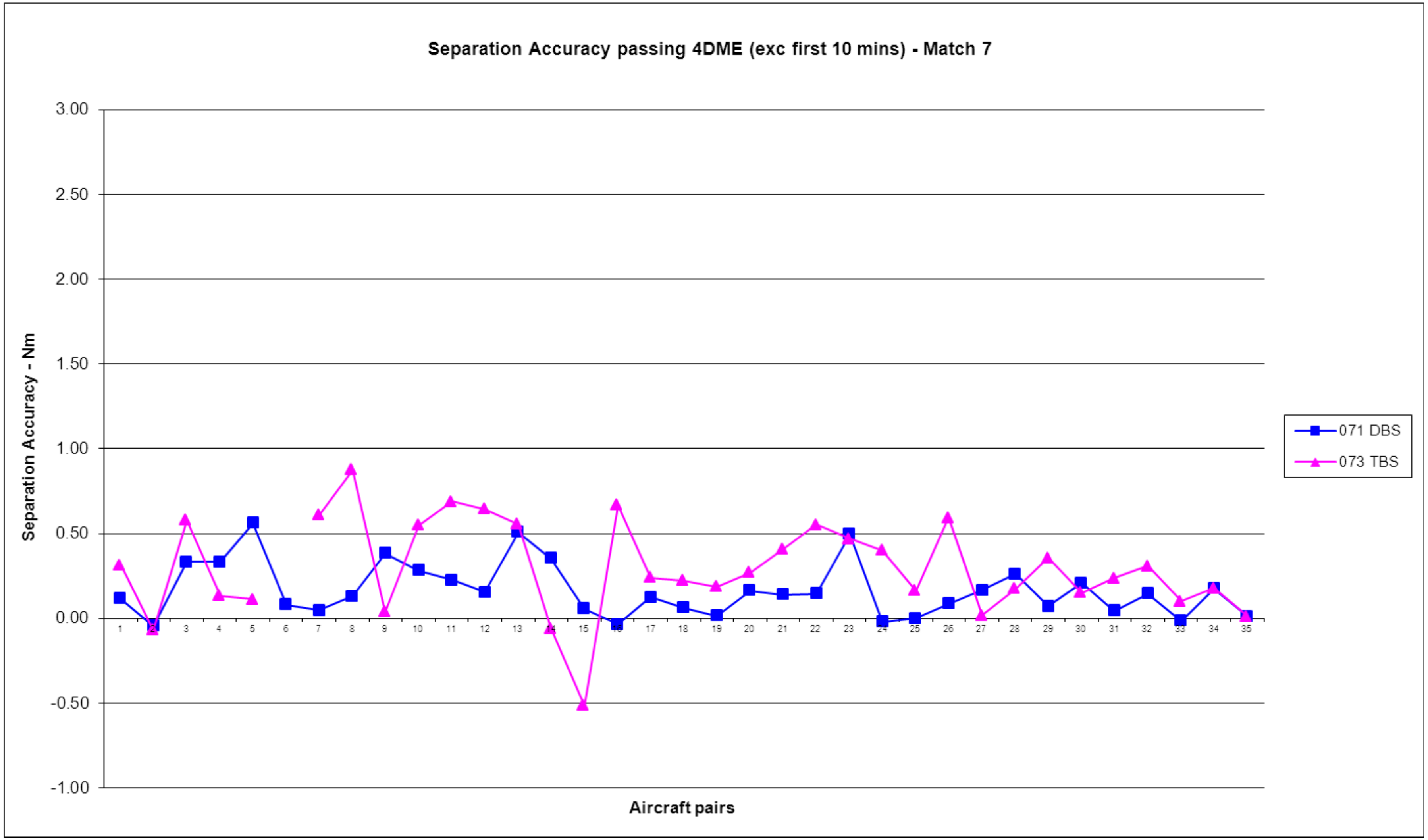


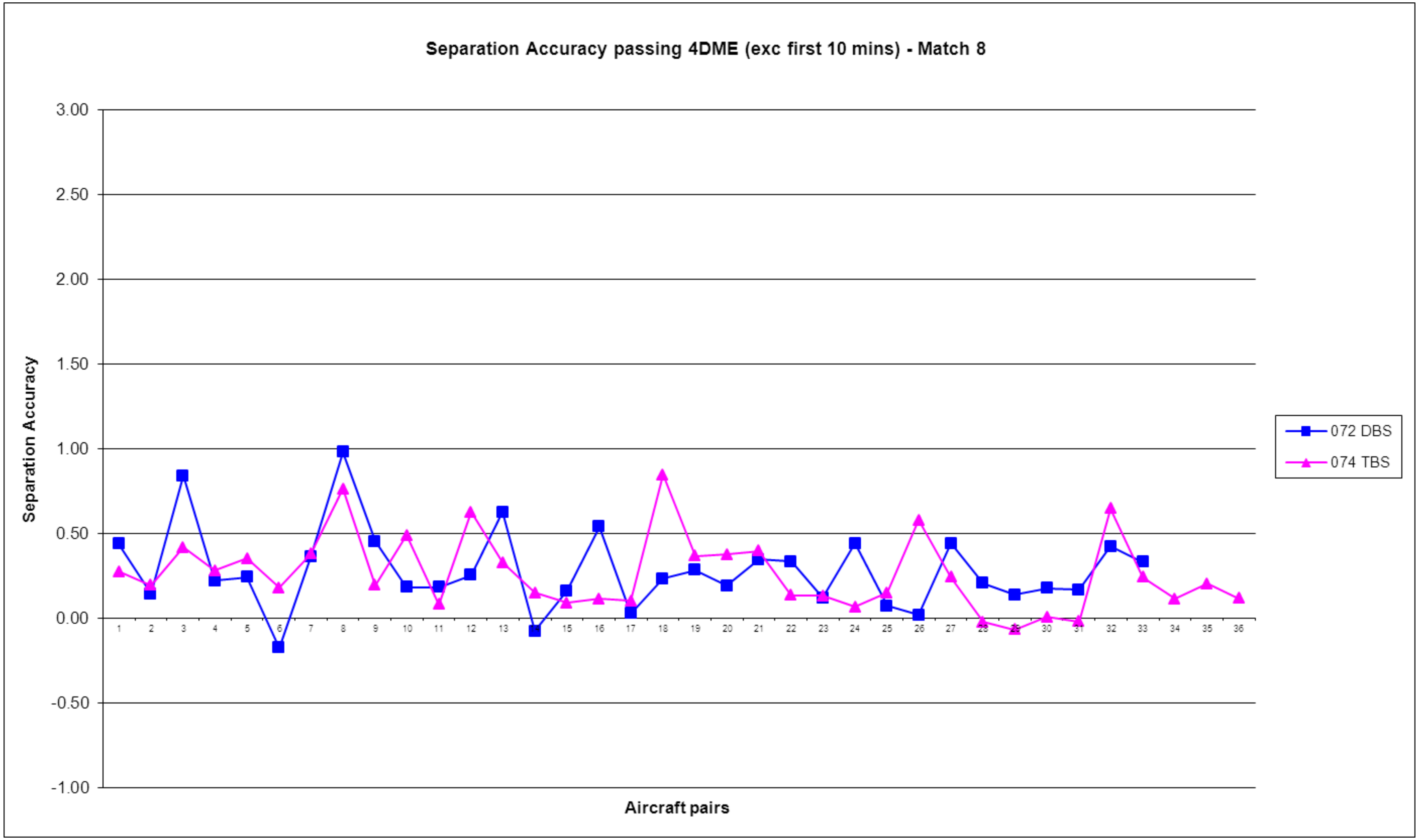

Separation Accuracy passing 4DME (exc first 10 mins) - Match 2
Separation Accuracy - Nm
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
Aircraft pairs
031 DBS
033 TBS

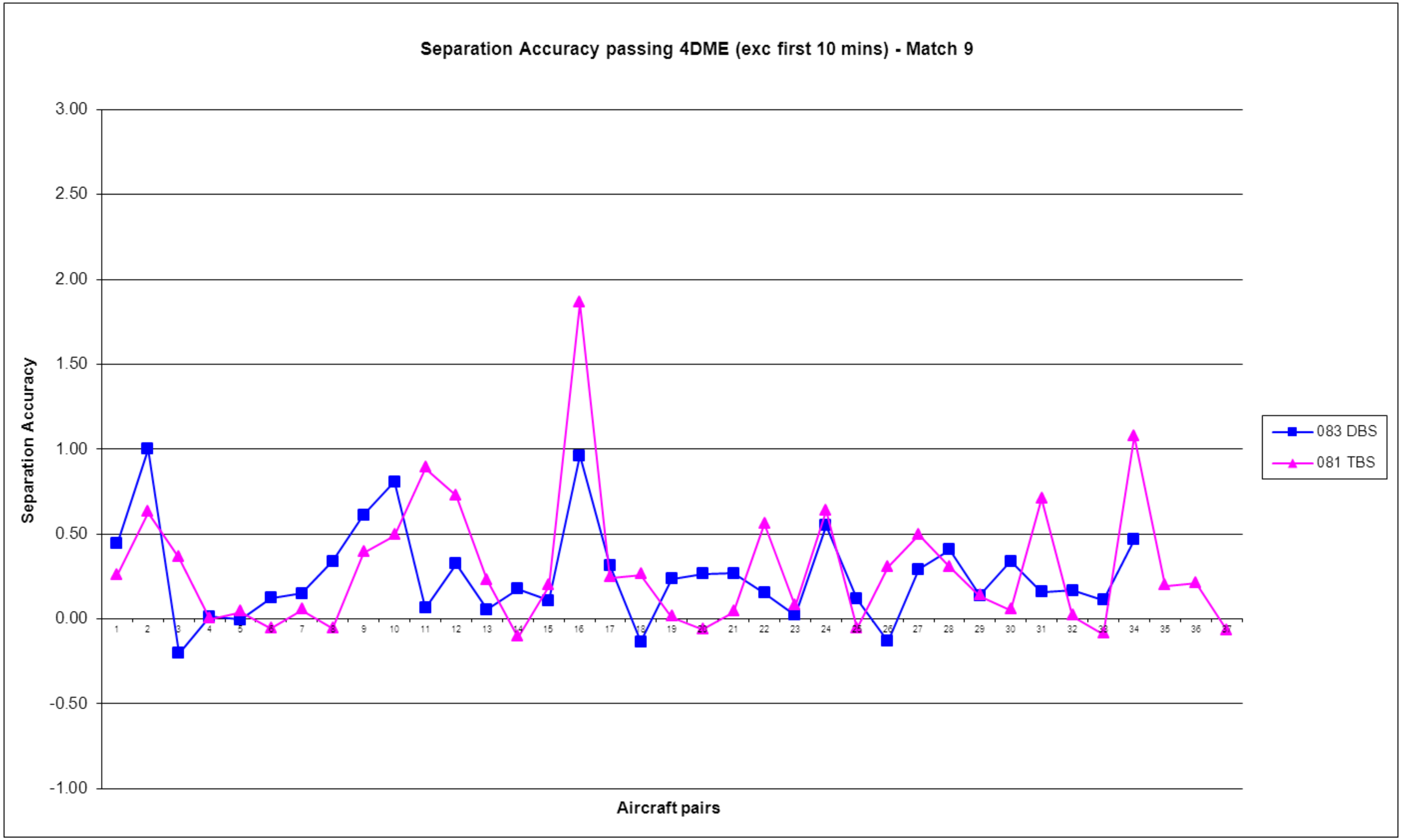

Separation Accuracy passing 4DME (exc first 10 mins) - Match 3
Separation Accuracy
Aircraft pairs
041 DBS
043 TBS
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00

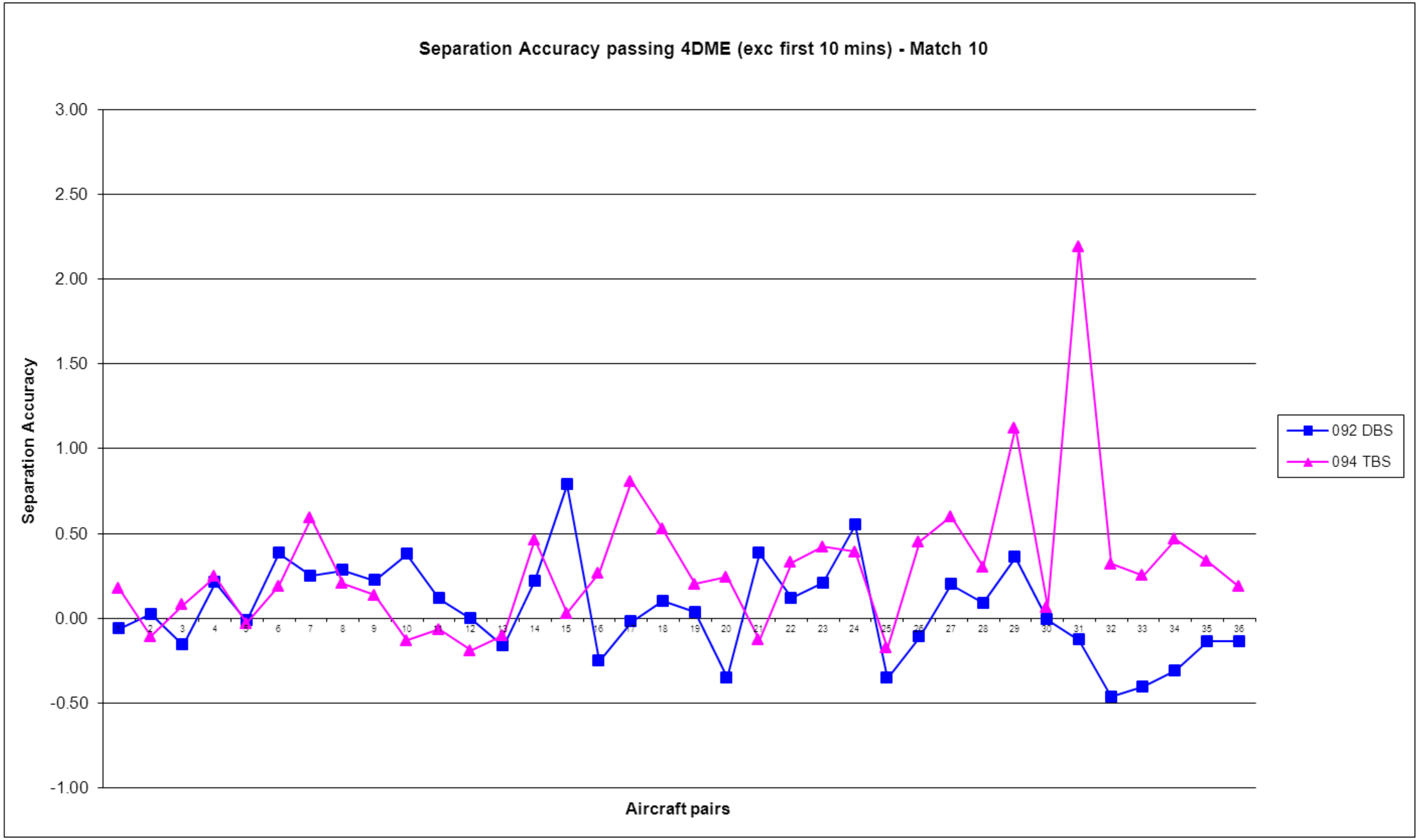

Separation Accuracy passing 4DME (exc first 10 mins) - Match 5
Separation Accuracy
Aircraft pairs
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
053 DBS
051 TBS

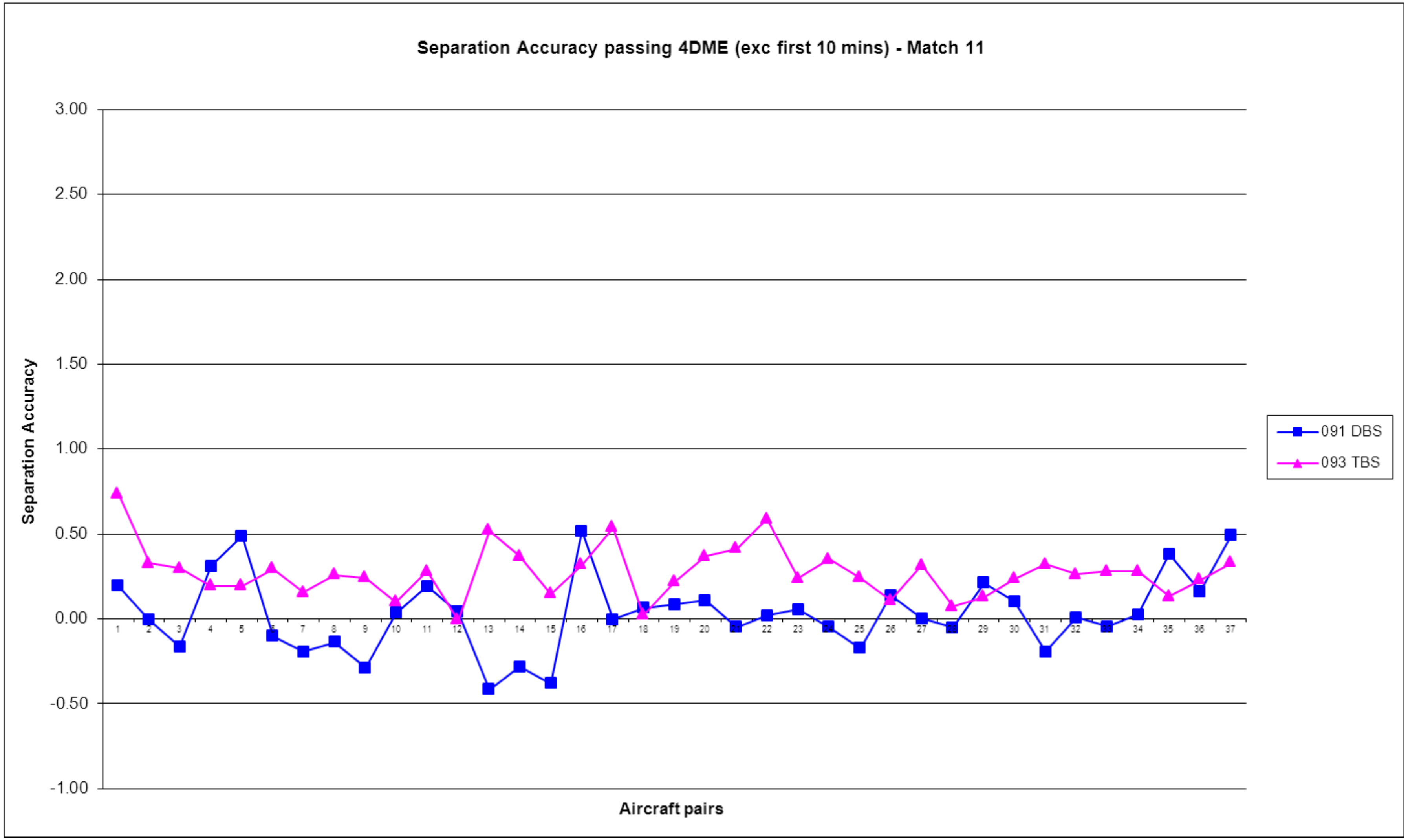

Separation Accuracy passing 4DME (exc first 10 mins) - Match 6
Separation Accuracy
Aircraft pairs
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
054 DBS
052 TBS

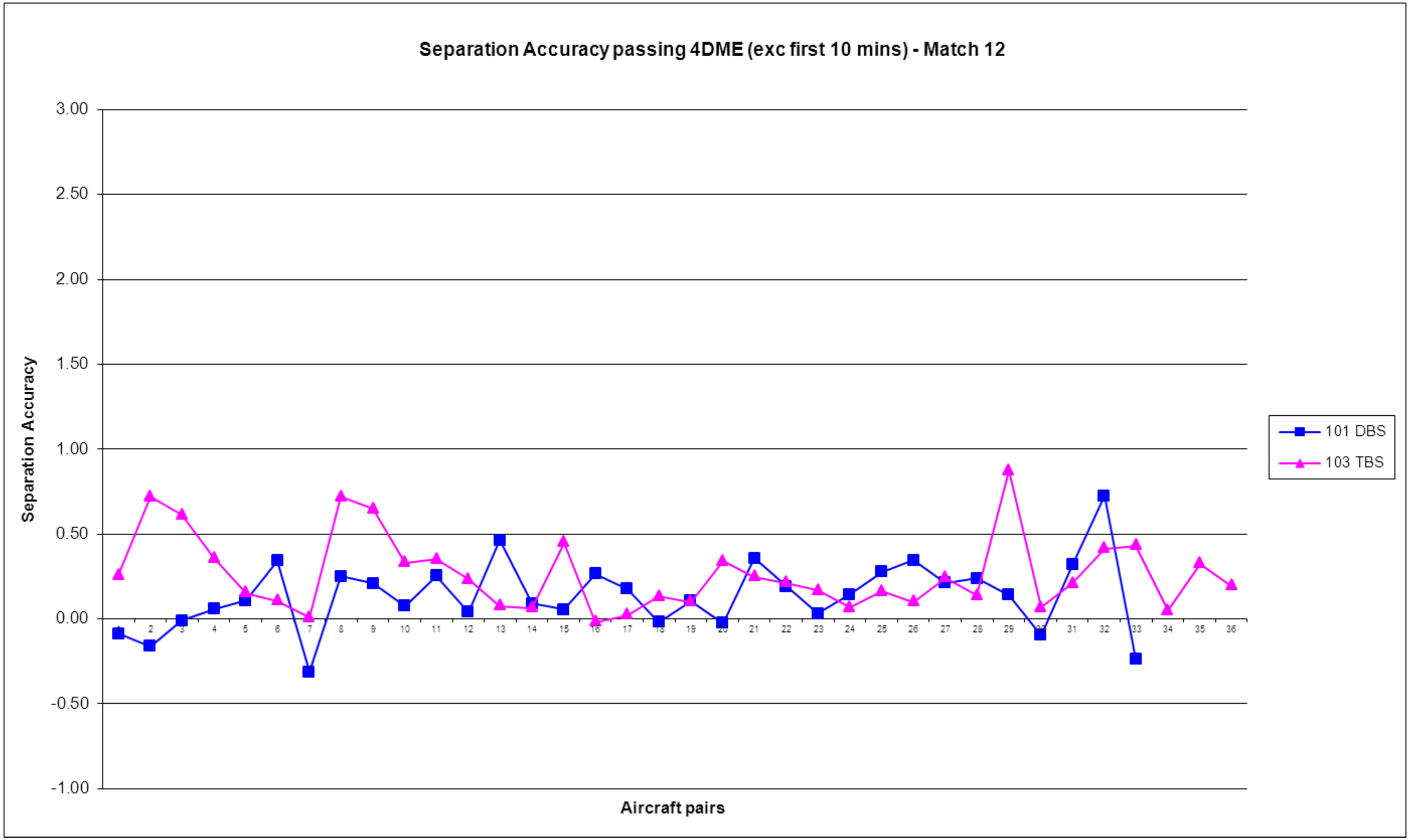

Separation Accuracy passing 4DME (exc first 10 mins) - Match 7
Separation Accuracy - Nm
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
Aircraft pairs
071 DBS
073 TBS


Separation Accuracy passing 4DME (exc first 10 mins) - Match 8
Separation Accuracy
Aircraft pairs
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
072 DBS
074 TBS


Separation Accuracy passing 4DME (exc first 10 mins) - Match 9
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
Separation Accuracy
Aircraft pairs
083 DBS
081 TBS


Separation Accuracy passing 4DME (exc first 10 mins) - Match 10
Separation Accuracy
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
Aircraft pairs
092 DBS
094 TBS


Separation Accuracy passing 4DME (exc first 10 mins) - Match 11
Separation Accuracy
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
Aircraft pairs
091 DBS
093 TBS


Separation Accuracy passing 4DME (exc first 10 mins) - Match 12
Separation Accuracy
Aircraft pairs
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
101 DBS
103 TBS

Appendix E 06.08.01 VP-302 Simulation Timetables

	DAY 1 Day	DAY 2 Day	DAY 3 Day	DAY 4 Day
Day	Wednesday 11/07/2012	Thursday 12/07/2012	Friday 13/07/2012	Sunday 15/07/2012
10:00-10:15	Briefing	Briefing	Briefing	Briefing
10:15-10:30				
10:30-10:45				
10:45-11:00	**11**	**21**	**31**	**41**
11:00-11:15	TBS3WWC 3DBS	TBS2EE V2TBS	TBS1WWC1TBS	TBS2EEN1TBS
11:15-11:30	**Match1**	**Match3**	**TBS Ops**	**Match5**
11:30-11:45				
11:45-12:00	Debrief	Debrief	Debrief	Debrief
12:00-12:15	Break	Break	Break	Break
12:15-12:30	**12**	**22**	**32**	**42**
12:30-12:45	TBS1WWC 4DBS	TBS1WWC1TBS	TBS6EEC2TBS	TBS1WWC1TBS
12:45-13:00	**Match2**	**Match4**	**Match'**	**TBS Ops**
13:00-13:15				
13:15-13:30	Debrief	Debrief	Debrief	Debrief
13:30-13:45	Break	Break	Break	Break
13:45-14:00	**13**	**23**	**33**	
14:00-14:15	TBS3WWC 3TBS	TBS2EE V2DBS	TBS4WWN3TBS	**43**
14:15-14:30	**Match1**	**Match3**	Scenario	TBS2EEN1DBS
14:45-15:00				**Match5**
15:00-15:15	Debrief	Debrief	Debrief	
15:15-15:30	Break	Break	Break	Debrief
15:30-15:45	**14**	**24**	**34**	Break
15:45-16:00	TBS1WWC 4TBS	TBS1WWC1DBS	TBS2EEN1TBS	**44**
16:00-16:15	**Match2**	**Match4**	**TBS Ops**	TBS1WWC4TBS
16:15-16:30				Scenario
16:30-16:45	Debrief	Debrief	Debrief	
16:45-17:00	Break	Break	Break	Debrief
17:00-17:15	**15**	**25**	**35**	
17:15-17:30				
17:30-17:45	Debrief	Debrief	Debrief	
17:45-18:00				

	DAY 5 Day	DAY 6 Day
Day	Sunday 22/07/2012	Monday 23/07/2012
07:30-07:45	Briefing	Briefing
07:45-08:00		
08:00-08:15		
08:15-08:30		
08:30-08:45	**51**	**61**
08:45-09:00	TBS1WWC4TBS	TBS1WWC1TBS
09:00-09:15	**TBS Ops**	**TBS Ops**
09:15-09:30		
09:30-09:45	Debrief	Debrief
09:45-10:00	Break	Break
10:00-10:15	**52**	**62**
10:15-10:30	TBS1WWC1TBS	TBS3WWC3DBS
10:30-10:45	**Match6**	**Match7**
10:45-11:00		
11:00-11:15	Debrief	Debrief
11:15-11:30	Break	Break
11:30-11:45		
11:45-12:00	**53**	**63**
12:00-12:15	TBS2EEN1TBS	TBS2EEN1TBS
12:15-12:30	Scenario	Scenario
12:30-12:45		
12:45-13:00	Debrief	Debrief
13:00-13:15	Break	Break
13:15-13:30	**54**	**64**
13:30-13:45	TBS1WWC1DBS	TBS3WWC3TBS
13:45-14:00	**Match6**	**Match7**
14:00-14:15		
14:15-14:30	Debrief	Debrief
14:45-15:00		

	DAY 7 Day
Day	Tuesday 24/07/2012
10:00-10:15	Briefing
10:15-10:30	
10:30-10:45	
10:45-11:00	**71**
11:00-11:15	TBS6EEC2TBS
11:15-11:30	**Match8**
11:30-11:45	
11:45-12:00	Debrief
12:00-12:15	Break
12:15-12:30	**72**
12:30-12:45	TBS1WWC1TBS
12:45-13:00	Scenario
13:00-13:15	
13:15-13:30	Debrief
13:30-13:45	Break
13:45-14:00	**73**
14:00-14:15	TBS6EEC2DBS
14:15-14:30	**Match8**
14:45-15:00	
15:00-15:15	Debrief
15:15-15:30	Break
15:30-15:45	**74**
15:45-16:00	TBS4WWN3TBS
16:00-16:15	Scenario
16:15-16:30	
16:30-16:45	Debrief
16:45-17:00	
17:00-17:15	
17:15-17:30	
17:30-17:45	
17:45-18:00	

Appendix F 06.08.01 VP-302 Scenario Events Coverage

Scenario ID	EVNT ID	Full Description	Scenario Count	Status
SCN01	EVNT-06.08.01-0001	Blocked Runway (a/c able to establish on alternate).	1	OK
SCN05	EVNT-06.08.01-0005	Indicator failure (multiple).	1	OK
SCN08	EVNT-06.08.01-0030	Runway Inspection.	4	OK
SCN10 (A)	EVNT-06.08.01-0008	Pilot speed non-conformance leads to catch-up on final. Pilot delays the 180kt IAS to 160kt IAS speed instruction, catches and (potentially) infringes WAKE separation.	0	-
SCN10 (B)	EVNT-06.08.01-0009	Pilot speed non-conformance leads to catch-up on final. Pilot delays the 180kt IAS to 160kt IAS speed instruction, catches and (potentially) infringes NON-WAKE separation.	0	-
SCN11 (A)	EVNT-06.08.01-0010	Pilot speed non-conformance. Slows very early from 160kt to landing speed. Aircraft behind with WAKE separation catches up signficantly (if left).	1	OK
SCN11 (B)	EVNT-06.08.01-0011	Pilot speed non-conformance. Slows very early from 160kt to landing speed. Aircraft behind with NON-WAKE separation catches up signficantly (if left).	1	OK
SCN13	EVNT-06.08.01-0015	TC deliver under-separation for WAKE pair to Tower.	9	OK
SCN14	EVNT-06.08.01-0016	TC deliver under-separation for NON-WAKE pair to Tower.	1	OK
SCN15	EVNT-06.08.01-0017	Light wind conditions. Separation greater than current-day wake (and non-wake) separation.	9	OK
SCN16	EVNT-06.08.01-0018	Extreme catch-up wind conditions. Aircraft need to be spaced at greater than the indicator further out on the ILS to prevent excessive catch-up.	8	OK
SCN18	EVNT-06.08.01-0020A	Missed approach – single aircraft, short final	6	OK
SCN19	EVNT-06.08.01-0020B	Missed approach - single aircraft	2	OK
SCN20	EVNT-06.08.01-0022	TST calculating separation incorrectly (due error / incorrect wind information) causing too small a separation being displayed for the wind conditions.	0	-
SCN21	EVNT-06.08.01-0023	Incorrect TBS sequence causes too small a separation to be displayed by the TST.	0	-
SCN22	EVNT-06.08.01-0024	Late change of landing runway - before 4DME.	1	OK
SCN27	EVNT-06.08.01-0032	TEAM 6 aircraft / hour. (2.5Nm spacing reduced to 2.0Nm for later runs).	3	OK
SCN28	EVNT-06.08.01-0033	3.0Nm minimum spacing.	9	OK

-END OF DOCUMENT-