EUROCONTROL Guidelines on Time-Based Separation (TBS) for Final Approach

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EUROCONTROL Guidelines on Time-Based Separation (TBS) for Final Approach

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Abstract

This document provides guidelines on the Time-Based Separation (TBS) solution on Final Approach in view of supporting the local implementation at an Airport and the necessary upgrades to the Approach and Tower Air Traffic Control Procedures and Systems.

These guidelines provide further illustration in relation to the EUROCONTROL-SPEC-167 on TBS support tool on final approach, about possible ways to implement the generic requirements to operate a TBS system.

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Indicator	Time-to-fly Modelling	TBS Mode	TBS Distance
TBS Deployment	Separation Delivery tool	DBS Mode	TBS Principles

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EXECUTIVE SUMMARY

This document provides guidelines on the Time-Based Separation (TBS) solution on Final Approach in view of supporting the local implementation at an Airport and the necessary upgrades to the Approach and Tower Air Traffic Control Procedures and Systems.

These guidelines provide further illustration in relation to the EUROCONTROL-SPEC-167 on TBS support tool on final approach, about possible ways to implement the generic requirements to operate a TBS system. Therefore, the primary target audience is Air Navigation Service Providers, who will deploy TBS operational systems, and their related ATC system providers, whenever applicable.

These guidelines are further based on the EUROCONTROL experience on the development and validation of TBS, working with several European Air Navigation Service Providers through SESAR 1 and SESAR 2020 Industrial Research Program. As part of this cooperation, multiple Real-Time Simulation campaigns were conducted using the EUROCONTROL TBS/LORD ("Landing with Optimum Runway Delivery) demonstrator prototype (Separation Delivery tool supporting TBS application), applied to several European airport environments (Paris CDG, Copenhagen, Vienna, Zurich, Milano Malpensa). In addition, it also builds on the experience gained as part of the TBS4LOWW deployment project funded by INEA/CEF under SESAR Deployment Manager (SDM) coordination.

NATS UK has operationally deployed TBS at London Heathrow and has accumulated experience of operating TBS at all times (H24) since March 2015.

These guidelines include the following elements:

- Overview of TBS Principles
- Guidance on establishing local TBS minima
- Guidance on generic requirements to operate a TBS system
- Reference material to support TBS deployment.

1. Introduction

1.1 Purpose of the document

This document provides guidelines on the Time-Based Separation (TBS) solution on Final Approach in view of supporting the local implementation at an Airport and the necessary upgrades to the Approach and Tower Air Traffic Control Procedures and Systems.

These guidelines provide further illustration in relation to the EUROCONTROL SPEC 167 on TBS support tool on final approach [RD 1], about possible ways to implement the generic requirements to operate a TBS system.

These guidelines are further based on the EUROCONTROL experience on the development and validation of TBS, working with several European Air Navigation Service Providers through SESAR 1 and SESAR 2020 Industrial Research Program. As part of this cooperation, multiple Real-Time Simulation campaigns were conducted using the EUROCONTROL TBS/LORD ("Landing with Optimum Runway Delivery) demonstrator prototype (Separation Delivery tool supporting TBS application), applied to several European airport environments (Paris CDG, Copenhagen, Vienna, Zurich, Milano Malpensa). In addition, it also builds on the experience gained as part of the TBS4LOWW deployment project funded by INEA/CEF under SESAR Deployment Manager (SDM) coordination.

NATS UK has operationally deployed TBS and support tool at London Heathrow - named *Intelligent Approach ('IA')* separation delivery tool - and has accumulated experience of operating TBS at all times (H24) since March 2015.

1.2 EUROCONTROL Guidelines

EUROCONTROL guidelines, as defined in EUROCONTROL Regulatory and Advisory Framework (ERAF), are advisory materials and contain:

"Any information or provisions for physical characteristic, configuration, material, performance, personnel or procedure, the use of which is recognised as contributing to the establishment and operation of safe and efficient systems and services related to ATM in the EUROCONTROL Member States."

Therefore, the application of EUROCONTROL guidelines document is not mandatory.

In addition, EUROCONTROL Regulatory and Advisory Framework specifies that:

"EUROCONTROL Guidelines may be used, inter alia, to support implementation and operation of ATM systems and services, and to:

- *complement EUROCONTROL Rules and Specifications;*
- *complement ICAO Recommended Practices and Procedures;*
- *complement EC legislation;*
- *indicate harmonisation targets for ATM Procedures;*
- *encourage the application of best practice;*
- *provide detailed procedural information."*

1.3 Use of the document

This document is intended to be read and used by all civil and military ATS Providers in the EUROCONTROL Member States (41) and Comprehensive Agreement States (2).

EUROCONTROL makes no warranty for the information contained in this document, nor does it assume any liability for its completeness or usefulness. Any decision taken on the basis of the information is at the sole responsibility of the user.

1.4 Maintenance of the Guidelines

This EUROCONTROL Guidelines document has been developed under the EUROCONTROL Regulatory and Advisory Framework (ERAF) and is maintained by EUROCONTROL in accordance with this framework and in line with the EUROCONTROL Standards Development Procedures. The procedures are described in detail in Annex A.

1.5 Conventions

The following conventions used in this EUROCONTROL Guidelines are applicable to the requirements, which are reproduced from the TBS Specification [RD 1]: The conventions are as follows:

a. "**Shall**" – indicates a statement of specification, the compliance with which is mandatory to achieve the implementation of the TBS Specification.
b. "**Should**" – indicates a recommendation or best practice, which may or may not be satisfied by all systems claiming conformity to the TBS Specification.
c. "**May**" – indicates an optional element.

Numbers within square brackets are used to identify reference documents listed in section 1.8, e.g. [1] identifies the first reference documents of section 1.8.

Every requirement and recommendation in the TBS Specification is followed by a structured identifier, which can be used to uniquely reference the requirement/recommendation from associated documents and traceability tools. Such identifiers have the form:

TBS-[Fn]-[nnn]

where:

[Fn]: is a sequence of characters to identify the functional area to which the requirement applies, e.g. "FLIGHT" for requirements related to TBS support tool flight data inputs;

[nnn]: is a numeric identifier for a sequence of requirements within the same functional area[1].

The functional areas are:

- FLIGHT: Flight data inputs;
- SURV: Surveillance data inputs;
- SEP: Separation data inputs;
- SPAC: Spacing data inputs;
- MET: Meteorological data inputs;
- SEQ: Approach arrival sequence inputs;

[1] Requirement numbers are initially allocated incrementally in tens. This aids the subsequent management of this guidelines document allowing new requirements to be inserted between existing requirements whilst maintaining a logical number sequence.

- SPEED: Aircraft speed profile / time-to-fly modelling;
- CALC: Separation and spacing calculation;
- COMP: Compression spacing calculation;
- HMI: Human Machine Interface for Controller Working Positions;
- SAF: Safety mitigation elements;
- CNTR: Operational control and monitoring.

1.6 Abbreviations and acronyms

Abbreviation	Term
3D	3-Dimentional
ADA	Arrival-Departure-Arrival
AMAN	Arrival Manager
ANSP	Air Navigation Service Provider
APP	Approach
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
ATM	Air Traffic Management
CALC	TBS separation / spacing calculation requirements
CNTR	Operational control and monitoring requirements
COMP	Compression spacing calculation
CR	Change Request
CSPR	Closely Spaced Parallel Runways
CWP	Controller Working Position
DASC	Digital Avionics Systems Conference
DBS	Distance Based Separation
DDA	Departure-Departure-Arrival
DF	Deceleration Fix
DP	Delivery Point
EASN	European Aeronautics Science Network

Abbreviation	Term
EC	European Commission
EU	European Union
ERAF	EUROCONTROL Advisory Framework
FLIGHT	Flight data input requirements
FTD	Final Target Distance
H24	24-Hour Operations
HMI	Human Machine Interface
ICAO	International Civil Aviation Organization
ICAO WTC	ICAO Wake Turbulence Category
ICAO WTG	ICAO Wake Turbulence Groups
ICAO WT DBS	ICAO Wake Turbulence Distance Based Separation
ITD	Intermediate Target Distance
LiDAR	Light Detection and Ranging
LORD	Landing with Optimised Runway Delivery
LVP	Low Visibility Procedures
MET	Meteorological data inputs
M/L	Machine Learning
MRS	Minimum Radar Separation
MTOM	Maximum Take-Off Mass
NM	Network Manager
ORD	Optimised Runway Delivery
OSED	Operational Service and Environment Definition
PCP	Pilot Common Project
PWS	Pair Wise Separation
RECAT EU	Re-categorisation in EU (scheme)
RECAT PWS	Re-categorisation in PWS (scheme)

Abbreviation	Term
ROT	Runway Occupancy Time
RWY	Runway
SAF	Safety mitigation element requirements
SAR	Safety Assessment Report
SEP	Separation data inputs
SEQ	Approach arrival sequence inputs
SESAR	Single European Sky ATM Research
SF	Stabilization Fix
SODAR	Sonic Detection And Ranging
SPAC	Spacing data inputs
STAR	Standard Terminal Arrival Route
SURV	Surveillance data input requirements
T2F	Time-to-fly
TAS	True Air Speed
TBS	Time Based Separation
THR	Threshold
TMA	Terminal Control Area
WT	Wake Turbulence
WTC	Wake Turbulence Category
WVE	Wake Vortex Encounter Can also be called wake turbulence encounter (WTE)

1.7 Definitions

Term	Definition
Approach Arrival Sequence	A list of aircraft presented in the expected order of arrival.
Arrival aircraft	Arrival aircraft means those to be sequenced on final approach.

Term	Definition
Compression distance	A distance that represents the amount of compression predicted to occur between two aircraft from the time the leader passes a defined point (typically the deceleration fix) and the time the leader reaches the runway threshold.
Final Target Distance (FTD) indicator	A reference on the Final Approach and Tower Runway CWP to visualise the minimum applicable separation, under DBS or TBS operations.
Intermediate Target Distance (ITD) indicator	A reference on the Final Approach and Tower Runway CWP to visualise the predicted compression distance for ensuring Optimum Runway Delivery (ORD).
DBS mode	A mode of operation when indicators are calculated using distance based wake separation rules.
Distance based wake turbulence radar separation rules	Wake turbulence radar separation rules defined in distance which can be category based or aircraft pair based.
Characterisation of aircraft flying time / expected ground aircraft speed profile / time-to-fly model	A model which defines an expected aircraft ground speed profile or time-to-fly model needed for converting time to distance in the separation / spacing calculation. The characterization of flying time profile (also denoted in the EUROCONTROL Guidance as time-to-fly profile) is a vector providing, for various distances, the time required for a flight to travel the reference applicable separation distance minima down to landing runway threshold. By interpolation in this vector, the flying time can then be obtained for any distance down to runway threshold. This flying time profile depends on the flight groundspeed profile, itself as a function of the flight airspeed profile and on the wind profile
Glide-slope wind conditions	MET information along the glideslope (At minima from threshold to a distance corresponding to the separation delivery point plus the maximum separation to apply). Can be one or more of wind effect, wind speed and / or wind direction.
Indicator	A reference on the Final Approach and Tower Runway CWP to visualise the indicator distance.
Indicator distance	The distance computed for an indicator which represents the required separation or spacing.
Individual spacing gaps	An increase of separation behind a given aircraft in the approach sequence, this one can be, for example, requested for clearing a departure in mix mode
In-trail aircraft pair	A consecutive pair of aircraft on final approach which are using the same final approach track segment.
Minimum radar separation	The minimum allowable separation allowed between two aircraft based upon the radar performance requirements.

Term	Definition
Minimum runway time separation	Is the time separation rule ensuring safe operation on the runway. Primarily, this time separation result from the runway occupancy time, but can also be related, for example, to other constrain like departure in mix mode or runway inspection
Minimum runway spacing	Is the spacing rule ensuring safe operation on the runway. Primarily, this spacing result from the runway occupancy time, but can also be related, for example, to other constrain like departure in mix mode or runway inspection
Not-in-trail aircraft pair	A consecutive pair of aircraft on final approach which are not using the same final approach track segment (i.e. parallel runways).
Separation	A legal minimum time or distance allowed between two aircraft
Separation Delivery tool	ATC automation system/tool which can be used as TBS support tool
Spacing	A time or distance between two aircraft which does not represent a separation.
TBS distance	The distance that an aircraft will fly for a given time and expected groundspeed (considering wind effect)
TBS mode	A mode of operation when indicators are calculated using time based wake separation rules.
TBS support tool	A tool that converts the required time separation / spacing into the equivalent distance separation / spacing for the prevailing headwind conditions and displays this on the CWP.
Time based wake turbulence radar separation rules	Wake turbulence radar separation rules defined in time, which can be category based or aircraft pair based.

1.8 Reference material to support TBS deployment

[RD 1] EUROCONTROL Specification for Time Based Separation (TBS) support tool for Final Approach, EUROCONTROL-SPEC-167, dated 01/02/2018

https://www.eurocontrol.int/publication/eurocontrol-specification-time-based-separation-tbs-support-tool-final-approach

The EUROCONTROL TBS Specification document provides a list of functional requirements to operate TBS with a TBS support tool.

The document provides a list of performance requirements (initially traced to the European "PCP" 716/2014 regulation, now repealed), those TBS Specifications have a voluntary status and were developed in collaboration with stakeholders from air navigation service provides, airports, aircraft operators, industry bodies and trade associations.

These specifications are thus not mandatory and provided on a voluntary basis to Member States and stakeholders to support the TBS deployment.

- **EUROCONTROL 'generic safety case'**

EUROCONTROL has developed a 'generic safety case' on TBS principles, addressing the acceptable level of safety of TBS regarding wake turbulence risk assessment based on LiDAR data-driven wake decay analysis, and the principle of local TBS minima determination. It aims at avoiding the need to re-demonstrate TBS principles such as the headwind effect on wake turbulence risk when deploying TBS.

This TBS Principle Safety Case has been developed by EUROCONTROL and submitted to EASA in view of supporting the TBS provisions into the EASA regulatory system, and is available on request to EUROCONTROL (runway-package@eurocontrol.int) by ANSPs and Authorities engaging into TBS deployment.

This document presents the safety case on Time-based Separation Minima for Final Approach (TBS Principles) as alternative to Distance-based Separation. By operating with TBS minima, established from equivalent time to fly the distance minima in calm wind conditions, the delivered time spacing between aircraft on final approach will be maintained across headwind conditions. The wake turbulence encounter risk assessment provides assurance that these TBS minima converted from a reference distance-based separation (DBS) scheme are acceptably safe due to the effect of wind on wake decay. Examples of TBS minima obtained from air speed profile measurements are provided in an Annex of the TBS principle Safety Case document.

The Safety Case report is an integral part of this Guideline document as Annex B.

1.9 Document structure

The document is structured as follows:

- Section 1 describes the purpose, scope and structure of the document and lists reference documents, explains terms and contains a list of abbreviations.
- Section 2 contains an overview of TBS Principles.
- Section 3 provides guidance on establishing local TBS minima.
- Section 4 provides guidance on generic requirements to operate a TBS system.
- Annex A describes the Guidelines update procedure.
- Annex B provides the Safety Case report: Time-Based Separation (TBS) Principles as Alternative to Static Distance-Based Separation for Final Approach.

- Annex C provides traceability to requirements from EUROCONTROL Specification for Time Based Separation (TBS) support tool for Final Approach, EUROCONTROL-SPEC-167 [RD 1].

2. Overview of TBS principles

2.1 TBS Goals

Headwind conditions on final approach cause a reduction of the aircraft ground speed which results in an increased time separation for each aircraft pair, a reduction of the landing rate, and a lack of stability of the runway throughput during arrival operations.

This has a **negative impact** not only on the achieved capacity, generating delays, but also on the predictability of operations, flight and fuel efficiency.

The Time-Based Separation (TBS) concept is addressing this problem by enabling stable arrival runway throughput in all headwind conditions on final approach. This is achieved by stabilising the delivered time spacing between aircraft on final approach across headwind conditions.

TBS consists in the separation of aircraft in sequence on the final approach to a runway using time intervals instead of distances. These time intervals are established based on the time-to-fly distance minima between aircraft in low wind conditions.

TBS principle is to **maintain equivalent time separation across headwind conditions.** This will result in a **reduction of the applicable distance separation minima as the headwind increases.**

Figure 1 provides an illustration of the TBS concepts (with indicative example of TBS time values).

Time-Based Separation thus improves the landing rate resilience to headwind conditions on final approach by recovering the lost landing rate currently experienced when applying distance-based separation (DBS).

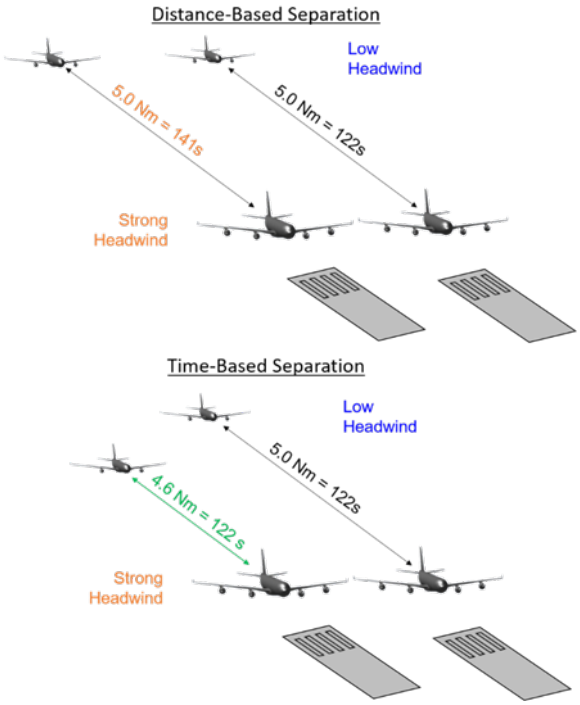


Figure 1**: **Illustration of the TBS concept

2.2 Reference TBS minima

The time-based separation minima are derived from the distance-based wake turbulence separation (DBS) minima in **low wind conditions**. These reference wind conditions are to be selected locally and are subject to the local wake risk assessment.

The wake turbulence risk assessment developed in the TBS Principles safety case relies on low wind conditions corresponding to surface wind conditions lower than 5 kts total wind (all directions). Therefore, the distance minima reduction resulting from the application of TBS minima will become effective as the wind speed increases above 5 kts. Below this threshold or in case of tailwind conditions above 5kts, standard distance-based minima remain applicable. Low wind conditions therefore typically correspond to headwind component 9 km/h (5 kt) or less.

However more conservative criteria can be defined and applied locally. As examples, the operational threshold for low wind can be raised to:

- Example #1: 7kts headwind or more, and no tailwind
- Example #2: ground total wind lower than or equal to 5 kts and with maximum ground tailwind of 2 kts

In given wind conditions, for a given aircraft type and for a given DBS minimum, due to the variability in aircraft flying airspeed, a time separation distribution is observed. When operating DBS, as headwind increases, this distribution is seen to be shifted towards larger values. This is illustrated in Figure 2.

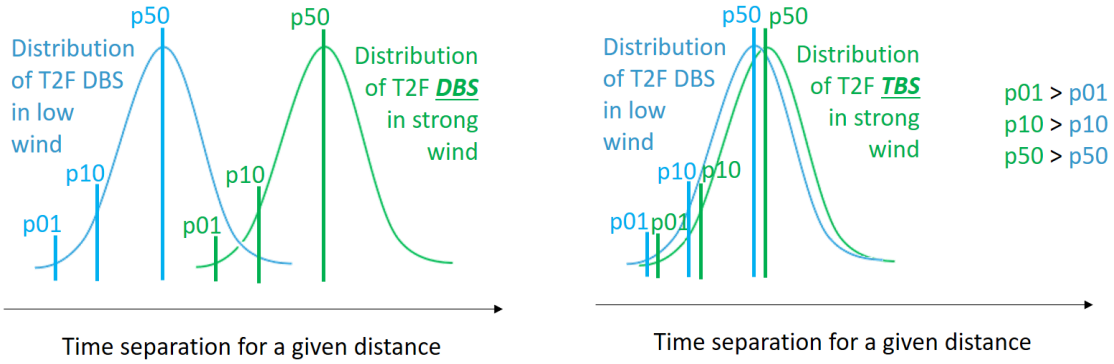


Figure 2: Example of time separation evolution corresponding to a given distance when operating DBS (left) or TBS (right) in low or strong headwind conditions.

The objective of TBS is to maintain equivalent time-separation distribution across headwind conditions. This is achieved through a dynamic reduction of the applicable distance separation minima as the headwind increases. This constraint can be verified through the comparison of quantiles, e.g., 1st, 10th and 50th (median) of the time separation distribution in calm wind conditions.

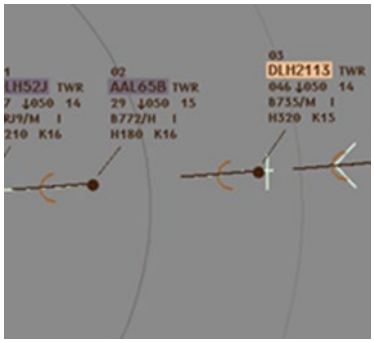
The TBS minima rules are therefore established from the distribution of equivalent time-to-fly of the distance minima in low wind conditions.

Alternatively, an approach taken by NATS during the Intelligent Approach (IA) tool implementation included airline education programme on the significance of conformance to speed instruction on final approach. As a result, speed monitoring showed an improvement in speed conformance, allowing reduced variability in aircraft speeds and associated levels of uncertainty.

The time intervals can be **established from various distance-based separation schemes** (e.g., ICAO provisions based on Wake Turbulence Categories (WTC), ICAO provisions based on WT Groups, RECAT-EU, RECAT-EU-PWS), using applicable air speed profiles measurements. The resulting time distributions will be a function of the separation minima at the separation delivery point on final approach and must be **established on a local basis**.

The TBS minima can be established per aircraft type, wake turbulence category or group.

2.3 TBS delivery tool for Controllers



There will be a need to facilitate delivery of time-based separation minima by the final approach and tower controllers, with a **TBS support tool**. It provides **a TBS distance indicator**, enabling the ATM system to visualise on the surveillance display the distance corresponding to the applicable TBS minima, and **taking in account the aircraft airspeed and the prevailing wind conditions**.

This indicator support is displayed on the extended runway centreline of the Final Approach controller and the Tower Controllers surveillance display.

The TBS support tool will need several inputs to calculate the appropriate separation / spacing indicators: the approach sequence, the reference time separation minima, the surveillance info (such as aircraft position) and flight plan info (such as aircraft type), the applicable time-to-fly characterization (aircraft groundspeed profile) and the wind profile on final.

Intrinsic variability of the aircraft airspeed profile and of the wind generate uncertainty that needs to be accounted for and factored in the indicator calculation. Buffers are therefore added to cope with the wind and aircraft airspeed uncertainties.

Depending on the actual set-up of the TBS support tool, and where necessary to mitigate the identified local hazards, the tool may also feature safety alerting functions to warn in case of wrong sequence or non-conformant approach airspeed.

Finally, it may also integrate all applicable separation minima (e.g., Wake minima, Minimum Radar Separation) and spacing (e.g., ROT, Gap) needs.

2.4 Impact on wake turbulence risk

By introducing possible dynamic variation of distance separation minima as a function of head wind, with the application of fixed TBS minima between successive arrivals, in strong headwind conditions, due to the distance separation reduction, aircraft pairs will be exposed to reduced wake age compared to their current situation under DBS wake turbulence scheme application. TBS thus impacts the wake strength that can be potentially encountered.

Indeed, the headwind component transports the vortices toward the follower aircraft. When applying DBS, since the distance separation is maintained constant whatever the headwind condition, at first order, the age of the vortex potentially encountered by the follower remains constant. Conversely, when applying TBS in prevailing headwind conditions, because the time separation between the aircraft is maintained constant, the age of the vortex potentially encountered by the follower is reduced. However, it is known from literature that, close to the ground, which constitutes the design case, the headwind enhances the wake vortex decay.

Therefore, as illustrated in Figure 3, the enhanced wake decay will be mitigating the effect of headwind transport blowing younger vortices toward the follower aircraft.

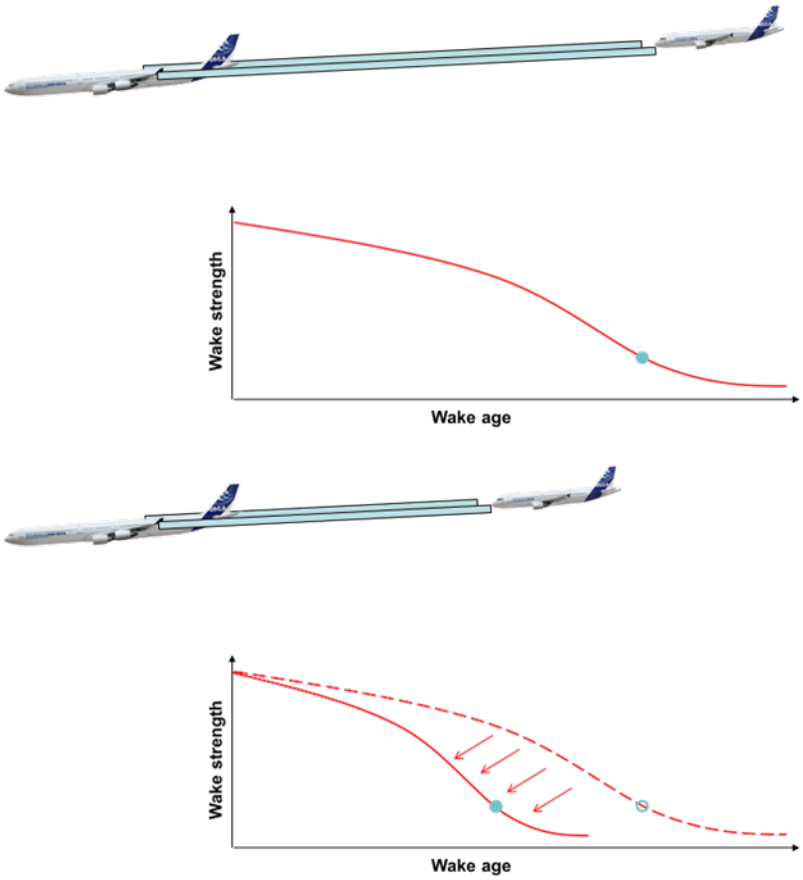


Figure 3: schematic view of why TBS wake risk remains acceptable compared to DBS. Top: Low wind condition, Bottom: Strong headwind condition

This means, in terms of wake turbulence risk, that the probability per approach of wake turbulence encounter of a given severity for a given traffic pair at TBS minima on final approach segment and for any headwind conditions must not increase compared to the same traffic pair spaced at DBS minima in reasonable worst conditions recognized for WT separation design. This has been shown through wake turbulence encounter risk assessment based on wake data analysis.

Moreover, as demonstrated in EUROCONTROL Safety Case on TBS principles (see Annex B) in case of strong wind conditions, the positive impact of the total wind on the wake decay allows for further reduction of the time separations even below the TBS minima. Those TBS margins depend on the total surface wind.

In terms of impact on overall probability of wake vortex encounter, the impact can be expected to be limited and around 5 to 10% potential increase, since:

- In low wind, there will be no difference between TBS and DBS in terms of risk exposure (since in low wind the TBS spacing are by definition equal to the DBS),
- In moderate to strong headwind, there might be an increase due to the exposure to younger wakes, however in those conditions the wind impacts both the wake decay and transport, limiting the overall risk of wake vortex encounter

Wake Vortex Encounter (WVE) reports statistics from a major European airport show that about 15% of WVEs are reported under moderate to strong headwind conditions. If the encounter probability increases by, e.g., 50% under these moderate to strong headwind conditions, this then represents an overall increase between 5 and 10%. This percentage increase is provided for guidance only and does not eliminate the need for the assessment of the local wake risk".

However, NATS UK has reported that the operational use of TBS (deployed in 2015) at London Heathrow has delivered significant arrival throughput and performance benefits, and this has all been achieved without any increase in reported wake vortex encounters or go-arounds."

2.5 Optimised Runway Delivery (ORD), complementing TBS

In order to safely deliver the separation at the separation delivery point (typically the runway threshold), the Controllers usually takes some buffers when spacing the traffic on final. These buffers are taken by experience of the expected traffic airspeed behaviour (compliance to ATC airspeed instruction and typical landing airspeed), and can lead to an average over-separation between 0.5NM and 1NM (above the applicable minima).

These buffers also result from the uncertainty related to the compression between traffic on final due to the natural distance catch-up and the difference in final approach airspeeds.

Therefore, an aircraft behaviour prediction can enable improved separation delivery performance compared to today, while maintaining or even reducing the associated ATCO workload.

Moreover, when applying TBS, due to the significant variation in applicable separation minima, the compression buffers can no longer be accurately estimated by the controllers. There is thus a need for a separation support tool to also provide this information.

In the ORD concept, the Controllers are presented with information of the applicable spacing, based on the predicted compression between successive arrivals on final, in order to accurately and efficiently deliver the separation minimum at the separation delivery point (i.e., runway threshold).

It must be noted that ORD necessitates an accurate aircraft groundspeed prediction across operating conditions, for ensuring safety but also for efficiency as a too conservative definition of buffer can lead to a reduction of efficiency.

The TBS and ORD solutions deliver significant operational benefits:

- full resilience to headwind,
- increased separation delivery efficiency enabled by the use of a Separation Delivery tool,
- increased safety by reducing risk of loss of separation on final,
- maintained or reduced Controller workload.

This tool then also enables the integration of other and more complex separation and spacing rules (e.g. static wake turbulence pair-wise separation, also called RECAT-PWS), which further increase efficiency in runway usage.

Those solutions can deliver up to 15% runway throughput gain depending on the airport operating environment and traffic mix.

2.6 EUROCONTROL LORD Demonstrator

EUROCONTROL has developed a demonstrator of separation delivery tool, called LORD (Landing with Optimised Runway Delivery) that can be used as TBS support tool. In LORD, a TBS and an ORD indicator are used and displayed on the Controller Working Position HMI:

- a **separation minimum distance indicator (Final Target Distance – FTD)**, enabling the ATM system to visualise on the surveillance display the distance corresponding to

the applicable TBS minima, and **taking into account the aircraft airspeed performance and prevailing wind conditions**.

and in addition

- an Intermediate Target Distance (ITD), as separation delivery aid for Controllers, to optimise the compression buffers and ensuring optimum runway delivery (ORD).

The FTD indicator corresponds to the minimum distance separation to be applied between leader and follower, when the leader is overflying the separation delivery point (e.g., the runway threshold). The FTD shall account for all applicable separations and spacing constraints (e.g., wake turbulence, runway occupancy time, surveillance) in the prevailing wind conditions.

The ITD indicator is giving the ATCO information about how to separate the aircraft at a pre-agreed speed in order to have separation reserve for anticipating on compression effect. When operating TBS, the compression effect is indeed more complicated to anticipate due to the larger variability in applicable separation minima. The ITD is the distance separation applicable when the leader aircraft is at a prescribed glide speed before deceleration to final approach speed such that the FTD will be obtained at the separation Delivery Point (DP).

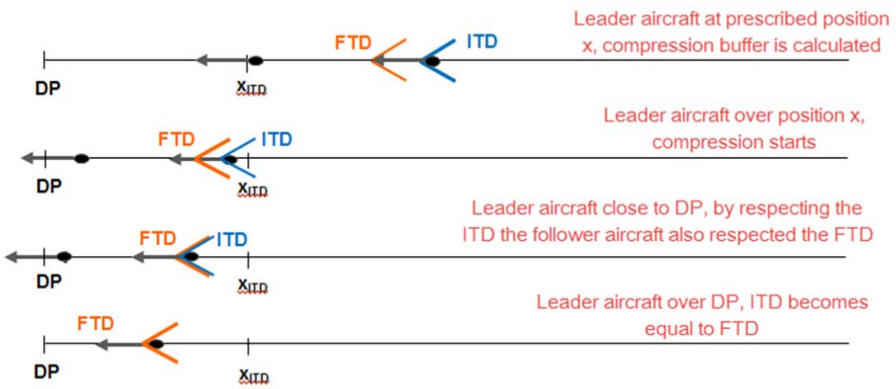


Figure 4: Schematic view of FTD and ITD definition

To prevent spacing infringement, different support alerts are also implemented in the tool. These alerts are to be used as safety nets to quickly identify potential issues in the approach/landing phase and allow the controller to take corrective actions.

The LORD demonstrator separation support tool is also able to account for and to provide indication of more complex business rules to the ATCOs such as Runway Occupancy Time, Spacing gap for departure, pairwise wake separation minima, weather dependent separation, separation increase/reduction in case of Enhanced Approach Procedure operation.

The LORD demonstrator was used by Air Traffic Controllers during Real-Time Simulation campaigns with several airport environments (incl. Vienna, Paris, Copenhagen, Zurich, Milan).

2.7 TBS deployment in Europe

Time Based Separations operations have been in operations at all times (H24) at Heathrow Airport since March 2015. Then, the separation delivery tool in use at Heathrow was further enhanced in March 2018 with the inclusion of ORD and RECAT-EU concepts.

Several projects for the deployment of TBS, ORD and related concepts are currently on-going in Europe.

The EUROPEAN ATM MASTER PLAN Level 3 - Implementation plan reports the current situation of TBS deployment in Europe:

https://www.eurocontrol.int/publication/european-atm-master-plan-implementation-plan-level-3

https://www.atmmasterplan.eu/downloads

3. Guidance on establishing local TBS Minima and Flying Time characterisation

The TBS concept application relies on the following key steps:

1) TBS wake turbulence minima are locally established (derived from any distance-based separation scheme and flight time characteristics)
2) Applicable TBS minima is determined for a given aircraft pair (based on type, group or category) of arrival traffic
3) The equivalent distance separation minimum to be delivered is determined by taking into account the wind conditions
4) The distance minimum can be capped, to conform to surveillance minima as applicable.

3.1 TBS Configuration checklist

3.1.1 Definition of applicable Wake Separation Minima

- Selection of Reference Distance-Based wake turbulence Separation scheme

The reference applicable DBS wake Turbulence scheme is required to display the applicable wake turbulence separation minima in DBS mode and to calculate the corresponding TBS minima in TBS mode.

TBS can be derived and operated from the following reference schemes:

- ICAO legacy wake separation based on wake turbulence categories
- RECAT-EU (ref. EASA 2020/469 AMC7 to ATS.OR.220)
- ICAO enhanced wake separation based on wake turbulence groups
- RECAT-EU-PWS
- Any other local/national distance-based scheme approved by local authority

- Selection whether the tool will operate in Time-Based or in Distance-Based mode

If TBS is applied, the TBS minima will be converted into distance indicators varying depending on the wind conditions. In DBS mode, static separation minima are applied.

3.1.2 Definition of applicable Surveillance minimum (MRS)

Depending on the Radar Surveillance performance, the applicable Minimum Radar Separation (MRS) rules shall be provided to the TBS support tool .

3.1.3 Definition of ROT spacing constraints

Specific ROT spacing rules (if any) are also required as input for the TBS support tool

3.1.4 Definition of all use cases that shall be accounted for by the TBS support tool

A complete list of use cases shall be provided in order to allow development of all corresponding functionalities in the TBS support tool (e.g., single runway, Parallel dependent or independent runway, mixed runway mode with Gap, low visibility, runway change, Go around)

3.2 Establish reference TBS Wake Turbulence minima

3.2.1 Option 1: TBS minima established on aircraft-wise basis

The time-based separation minima are **derived from the distance-based wake turbulence separation (DBS) minima in low wind conditions**. These reference wind conditions are to be selected locally and are subject to the local wake risk assessment.

The TBS minima are established from the distribution of equivalent time-to-fly of the distance minima in low wind conditions. It is therefore necessary to **properly convert the distance separation minima into the time for the following arrival aircraft to cover that distance**. Because of the variability in aircraft airspeed behaviour and local airport operation influence, the minima have to be **established on a local basis.**

The **first step** in defining the TBS minima is thus to **collect local surveillance and surface wind data** (typically covering at least one year of operation to capture seasonal effects).

Then, using only tracks measured **in low wind conditions** (to be defined locally but typically corresponding to surface wind conditions lower than 5 kts), the **time-to-fly profile** (i.e., vector of observed time needed to travel a distance down to runway threshold for various distance values) **distribution** (i.e., at least median, p10 and p1 statistics) has to be determined for each aircraft type.

Finally, using the **reference applicable DBS wake turbulence** scheme, the **median/p10/p1 TBS minima matrices** are built by, calculating, for each aircraft pair, the time corresponding to the applicable DBS minimum through **interpolation of the median/p10/p1 time-to-fly (T2F) vector** of the follower aircraft:

$$TBS_{p50} = T2F_{p50,low\ wind}(DBS)$$

$$TBS_{p10} = T2F_{p10,low\ wind}(DBS)$$

$$TBS_{p1} = T2F_{p1,low\ wind}(DBS)$$

TBS minima must be locally established, since the aircraft airspeed behaviour can vary between aerodromes/locations. For separation minima delivery on final approach applicable to runway threshold, this **conversion** should be done **per aircraft type**. Indeed, final approach airspeed profile varies between aircraft types and flight conditions. Different airspeed reduction on the glide and variation in stabilized final approach airspeed result in various time separations for a same distance separation.

Note that, an approach taken by NATS during the Intelligent Approach (IA) tool implementation included airline education programme on the significance of conformance to speed instruction on final approach. As a result, speed monitoring showed an improvement in speed conformance, allowing reduced variability in aircraft speeds and associated levels of uncertainty.

For aircraft types for which sufficient amount of data are available enabling its groundspeed profile characterization, TBS minima can be established and operated (with corresponding distance indication calculated with prevailing wind conditions and displayed to Approach and Arrival Runway Controllers). For the other aircraft types for which these data are not available or not in sufficient number, DBS should continue to be used.

3.2.2 Option 2: TBS minima based on aircraft categories or groups

Alternatively, TBS minima can be computed for the WT category or group, and not for the individual aircraft types.

As a result, the tool does not have to revert to DBS mode for all aircraft types where insufficient data is available to enable time-to-fly analysis for TBS calculations. The tool therefore does not have to switch between TBS and DBS modes when the aircraft types are known (are listed in ICAO Doc 8643) and glideslope wind information is available.

Similarly to Option 1, TBS minima should be locally established as aircraft airspeed behaviour can vary between aerodromes / locations.

Reference aircraft speeds can be calculated from the downlinked Mode S parameter IAS (wind conditions should still be considered, to avoid capturing gust adjustments).

Complex algorithm validation and safety assurance activities are required prior to introducing the solution to operations.

3.3 Time-To-Fly / Air speed profile behaviour modelling for TBS indicator calculation

The move from distance to time-based rules allowing efficient and safe separation management requests to properly model/predict aircraft groundspeed and behaviour in short final and the associated uncertainty.

The standard reference wake turbulence separation minima for approach are historically expressed in distances, like to the reference ICAO or RECAT-EU provisions.

In given wind conditions, for a given aircraft type and for a given DBS minimum, due to the **variability in aircraft flying airspeed**, a **time separation distribution is observed**.

TBS application necessitates a Controller support tool for displaying the corresponding separation distance. This TBS indicator support (i.e., FTD) is displayed on the extended runway centreline of the Final Approach controller and the Tower Controllers surveillance display. The indicator is a function of the TBS minima for the aircraft pair, and of the calculated aircraft groundspeed profile which depends also on the wind.

When operating TBS with this TBS distance indicator, the **obtained time-separation distribution must be aligned or be greater than the actual time-separation distribution observed in low wind** conditions **for the same aircraft type**. This constraint can be verified through the comparison of quantiles, e.g., 1st, 10th and 50th (median) of the time separation distribution in low wind conditions.

TBS indicator computation thus necessitates the development of a time-to-fly model allowing the conversion from time to distance separation. Intrinsic variability of aircraft behaviour and wind generate uncertainty that needs to be also accounted for and factorized in the indicator calculation. Buffers are therefore added in the models used for the indicator calculation to cope with those uncertainties.

The first step in the development and validation of such time-to-fly model is thus the **collection of local surveillance and glide slope wind data** (typically covering at least one year of operation to capture seasonal effects). This dataset can be the same as that used for TBS minima determination except that the glide slope wind data are also required.

Based on this database, a time-to-fly model (and possibly associated buffers) must be developed allowing conversion of TBS minima into TBS indicator in line with TBS design criteria. This model can be based on analytical modelling or calibrated through Machine Learning techniques.

It should be noted that an approach taken by NATS during the Intelligent Approach (IA) tool implementation included airline education programme on the significance of conformance to speed instruction on final approach. As a result, speed monitoring showed an improvement in speed conformance, allowing to reduce variability in aircraft speeds and associated levels of uncertainty, thus improving efficiency.

4. Guidance on generic requirements to operate a TBS system

Requirements from the EUROCONTROL Generic TBS Specification are referenced in red (e.g., ''Req. TBS-010 - Distance Based wake turbulence separation rules shall be provided to the TBS support tool based on ICAO aircraft type'').

Those requirements are then further expanded to provide additional information and to explain how to implement them

4.1 Traffic data inputs

4.1.1 Aircraft type designator

Req. TBS-FLIGHT-010

ICAO aircraft types for all arrival aircraft shall be provided to the TBS support tool.

The ICAO aircraft type is composed of 4 letters and/or digits corresponding to aircraft types: E.g., B773 (Boeing 777-300) or A321 (Airbus A321). These codes are defined by the International Civil Aviation Organization (ICAO), and published in the ICAO Document 8643 Aircraft Type Designators (see https://www.icao.int/publications/doc8643/Pages/default.aspx). They appear in the ITEM 9 of the flight plan information. If no such designator has been assigned, or in the case of formation flights comprising more than one type, “ZZZZ” is inserted instead.

This information allows the mapping with the RECAT-EU categories or any new Wake Turbulence Scheme (e.g., RECAT-Pairwise Separations). It is also used to predict the expected aircraft behaviour and associated uncertainty (by looking at the specific aircraft groundspeed profile in the model). Therefore, integrity has to be ensured.

4.1.2 Wake category

Req. TBS-FLIGHT-020

Wake category for all arrival aircraft should be provided to the TBS support tool.

In order to establish separation distance or time between aircraft, the currently used ICAO wake category matches ICAO aircraft types (e.g., A330, B777) with a weight category using H, M, L letters for respectively Heavy (e.g., A330, B777), Medium (e.g., A320, B737) and Light (Cessna 120, Piper). For further details, see https://www.skybrary.aero/index.php/ICAO_Wake_Turbulence_Category

Since the ICAO wake category is only provided into the flight plan, if the system uses another wake turbulence scheme (e.g., RECAT-EU) a mapping table will be needed between the ICAO aircraft type and the RECAT-EU categories.

4.1.3 Runway intent

Req. TBS-SEQ-030

Runway intent for all arrival aircraft shall be provided to the TBS support tool.

The runway in use for landing is provided by the ATC and based on the published aeronautical charts, which are published by each local country. The European Aeronautical Information Service Database (https://www.eurocontrol.int/service/european-ais-database) gathers them for the majority of the countries. It is broadcasted in the ATIS (https://www.skybrary.aero/index.php/Automatic_Terminal_Information_Service_(ATIS)) to the Flight Deck. When more than one runway is available for landing the ATCO will inform the Flight Deck on the runway selected for the flight.

The runway intent/STAR procedure is read from the flight information available from the ATC system and shall be accounted for in the sequence determination (e.g., transmitted by the Arrival Manager (AMAN)), see Section 4.3.

One independent sequence will be needed for each approach sequence on independent runways. For dependent runways (e.g., CSPR) a single sequence shall be used to take in account the related constraints.

If the ATCO decides to update the runway intent of an aircraft (e.g., when multiple parallel runways are in operation), a different runway intent for the aircraft to land shall be selected automatically by the system or manually, for instance, in the label or in the AMAN, depending on local preferences. This could trigger re-computation of the TBS indicator (i.e., the Final Target Distance Indicator -FTD).

4.1.4 Aircraft position

Req. TBS-SURV-010

Aircraft position, including altitude, for all arrival aircraft shall be provided to the TBS support tool.

The constant and automatic update of the aircraft position (in 3D) will allow the system to provide an updated aircraft arrival separation.

Req. TBS-SURV-015

Provided aircraft position should have the same performance as the applicable ATC display used for separation purposes.

The TBS support tool performance in terms of accuracy or refresh rate is particularly important.

For instance, should different refresh rates exist, misleading interpretations on the infringement of the TBS indicator (i.e., the FTD) could occur. Therefore, and for consistency reasons, the refresh rate of the aircraft position and the refresh rate to display the TBS indicator needs to be the same. The indicator display shall be updated at the same time with no discernible difference as the radar update of the associated aircraft.

4.1.5 Airborne parameters

Req. TBS-SURV-020

Downlinked airborne parameter data may be provided to the TBS support tool.

The downlink aircraft parameter airspeed is not mandatory to be able to correctly operate the TBS support tool. However, it is necessary for the monitoring and alerting features of the tool when predicting a non-conformant final airspeed behaviour, if a monitoring function is required by the tool (i.e., it may not be required if the same function already exists as a separate tool – the case of the Intelligent Approach tool at Heathrow).

Mode-S data (https://www.skybrary.aero/index.php/Mode_S) can be used to extrapolate a glideslope wind profiler. The profiler can then be used as an input for the FTD computation (see Section 4.4)

Other parameters like aircraft weight, intent flap setting or final approach airspeed, which are presently not downlink aircraft parameters, could be useful to improve groundspeed profile prediction.

4.1.6 Separation and spacing data inputs

The term 'separation' refers to the minimum time or space ATC must provide between aircraft in line with ICAO Doc 4444 (PANS-ATM) and/or wake separation scheme adopted. Separations need to be respected at all times. If infringed, ATC are required to either take corrective action or break off the approach, depending on where aircraft is on the approach and subject to local procedures.

The term 'spacing' refers to the time or space interval that is applied between two successive flights due to operational or safety reasons. If infringed, it might not pose a serious safety risk (at that moment). Therefore, an assessment of a spacing infringement should be analysed on a case by case, e.g., with ROT constraints.

Spacing/separations can be expressed in distance or time according to the different applicable constraints (e.g., TBS wake rules, distance-based surveillance minima, runway occupancy time, gap time spacing…). When more than one constraint applies, only the most constraining separation/spacing will be normally used to define the target distance indicators.

4.1.6.1 *Separation data inputs*

The separation inputs consist in:

- Wake Turbulence (WT) separation rules
- Surveillance separation (Minimum Radar Separation-MRS) constraint

The Wake Turbulence Separation can be expressed as Static Distance-Based Separation (DBS), or Time-Based Separation (TBS) computed from a reference DBS scheme.

4.1.6.1.1 Static Distance-Based WT Separation Scheme

Req. TBS-SEP-010

Distance based wake turbulence separation rules shall be provided to the TBS support tool based on ICAO aircraft type

WT category-based DBS schemes, leader and follower aircraft types are aggregated into categories based on static criteria (e.g., MTOM, span). Therefore, the associated separation tables are always based on leader and follower aircraft category.

Possible category-based DBS scheme are:

- ICAO WTC legacy
- RECAT-EU
- ICAO WTG (“RECAT”)
- any other local scheme (approved by local authority)

The DBS wake minima can also be defined on a pairwise basis such as the RECAT-PWS scheme.

4.1.6.1.2 Time-Based Separation WT minima

Req. TBS-SEP-020

Time based wake turbulence separation rules shall be provided to the TBS support tool based on ICAO aircraft type.

The TBS minima established in Section 3.2 are an essential input to the TBS support tool for TBS indicator computation.

4.1.6.1.3 Default separation for unknown aircraft types

Req. TBS-FLIGHT-030

Default separation rule shall be defined if provided ICAO aircraft type is not recognised by TBS support tool.

Req. TBS-SEP-025

Default separation rule shall be defined if provided ICAO aircraft type is not recognised by TBS support tool.

If the aircraft type is unknown, the system shall use a default rule that needs to be defined conservatively enough to ensure acceptable safety level whatever the aircraft type is concerned.

This will have a negative impact on the overall separation optimisation but should be rare enough to not impact the overall tool performance significantly.

4.1.6.1.4 Surveillance Separation rules

Req. TBS-SEP-030

All applicable Minimum Radar Separation (MRS) rules shall be provided to the TBS support tool.

Depending on the Radar Surveillance performance, the applicable Minimum Radar Separation (MRS) rules shall be provided to the TBS support tool.

4.1.6.2 *Spacing data inputs*

4.1.6.2.1 Minimum ROT

Req. TBS-SEP-040

Minimum runway time separation shall be provided to the TBS support tool.

and

Req. TBS-SPAC-010

Minimum runway spacing shall be provided to the TBS support tool

The TBS support tool needs, as input, the minimum runway spacing applicable locally for each aircraft type. They are expressed in terms of minimum runway occupancy time (ROT) per aircraft type or per aircraft category.

By default, Runway Occupancy Time (ROT) minima are usually agreed per wake category with the local regulation authority. Note that these minima depend on the runway (and runway direction) since the runway exit location influences the ROT. That minimum shall always be respected. This means that in certain cases, the wake or surveillance separations may not be the prevailing constraint.

ROT values vary depending on the runway and taxiway layout, aircraft type and airline procedures, and should be assessed locally.

Note that it might be easier to define ROT distance-based spacing constraints to avoid complex arguments about time separation targets. These minima are frequently confused with the MRS minima that are also applied for ROT reasons (i.e., according to ICAO PANS ATM Doc 4444, the application of MRS reduced to 2.5 NM is indeed related to average ROT).

4.1.6.2.2 Runway spacing (e.g. GAP)

Req. TBS-SPAC-020

All applicable spacing rules to be managed by the tool shall be provided to the TBS support tool.

In addition to ROT, other runway spacing constraints can be managed by the TBS support tool. The system allows the ATCO to input any necessary spacing time between two arrivals in order to respect any kind of runway constraints like, for instance, a runway inspection.

Req. TBS-SPAC-030

Individual spacing gaps between aircraft pairs should be provided to the TBS support tool.

In mixed mode operations the priority is given to arriving aircraft on the glide. For that case a Gap shall be created between two arrivals if a departure must be cleared. Generally, these spacing separations are defined in distance (e.g., 5 or 6NM between two arrivals). These gaps can be translated into time separation (following the same process as defined for other separation) or directly expressed in time (considering that the initial gap created in distance was intended to provide

a pre-defined time to clear one or more departures) in the TBS support tool by input by the Final Approach Controller.

In mixed mode runway operations with a number of departures similar to the number of arrivals, it might be needed to systematically create a Gap between each arrival. Even if these gaps may not always be necessary, this methodology will be more efficient since such coordination between Tower and Final Approach ATCOs may be highly time consuming.

In this case the TBS support tool will replace all separations by a spacing which value corresponds to the predefined Gap. More advanced gaping / grouping strategies (e.g., ADA (Arrival-Departure-Arrival), DDA (Departure-Departure-Arrival)) can also be considered to accommodate arrival and departure demands. They can rely on algorithms implemented in the sequence manager (e.g. AMAN) and further transmitted to the TBS support tool.

4.1.6.3 *Visual separation rules*

Req. TBS-SPAC-040

If allowed without TBS, visual separations may be also allowed by the TBS support tool.

If visual separations are locally allowed, the ATCO has the possibility to deactivate the visualisation of the TBS indicator (FTD) and all associated alerts. The rest of the indicators could still be displayed for the rest of the traffic and the sequence remains untouched.

Note that if visual separation applies to a leader aircraft, the computation of the TBS indicator of the follower will take the leader actual position as reference.

Furthermore, even if the aircraft separation is delegated to the leader aircraft's flight deck, the same functionality can also be used for the follower, therefore, visual separation could be applied to one or more consecutive flights

4.2 Met Data inputs

In order to calculate the TBS indicators, the TBS support tool requires several met inputs. In addition to the surface wind (measured by the runway anemometer), the vertical profile of the wind all along the glide slope must be provided. Finally, if using M/L models for indicator calculation, additional met inputs are required.

4.2.1 Surface wind input

In order to compute the TBS distance indicators, the TBS support tool needs to know, amongst other inputs, the surface wind conditions (speed and direction).

The anemometer surface wind measurement has the following typical parameters:

- Vertical range = 10m
- Typical Refresh rate = range between 10s and 1min
- Vertical Resolution= only one value at 10 m height

4.2.2 Glide-slope wind profile input

Req. TBS-MET-010

The best-estimate of the glide-slope wind condition nowcast shall be provided to the TBS support tool.

In order to compute the TBS indicator from the predicted aircraft ground speed, the TBS support tool needs to know the 2D Wind vector at specific altitude values (i.e., the glide-slope wind profile).

For FTD computation, the headwind has to be characterised from the ground up to the minimum between the glide interception altitude (from 2000 to 5000ft) and an altitude corresponding to the larger separation locally applicable (e.g., under ICAO WT DBS scheme, the largest separation is 8 NM which corresponds to about 2500 ft on a 3° glide).

Many options exist to characterise the wind vertical profile. A priori, all are acceptable but a low refresh rate in an environment with high wind variability, a short-range measurement requesting extrapolation to a high interception altitude or a low vertical resolution in an environment with significant variation of wind speed or direction (wind shear) will impose larger buffers when computing the TBS distance indicator to be acceptably reliable.

Alternatively, the wind input can be delegated to the MET office which would provide the wind vertical profile considering various wind source information (e.g., sensor(s), modelling). As an example, in real operations at Heathrow Airport the separation delivery tool uses a wind profiler built on Mode-S data downlinked from aircraft.

The full wind information is built from the surface wind at 10m provided by the anemometer complemented by a wind profiler for values above 10 m.

Different device options can be envisaged to compute the 2D wind vector profile. These devices or profilers depend on the source which provides the wind, see Table 1.

Type of wind profiler	LIDAR wind profiler	SODAR wind profiler	METEO RADAR wind profiler
Typical parameters	Vertical range > 1500 m Refresh rate= 1 s Vertical Resolution= 50 m	Vertical range = 200-600m Refresh rate= 10 min Vertical Resolution= 25 m	Vertical range = 1500m Typical Refresh rate= 15 min Vertical Resolution= 100 m

Table 1: Comparison of various wind vertical profiler solutions

Regarding Mode-S derived wind profile, the wind profile is derived from the Mode-S data of previous flights and the vertical range, refresh rate, and vertical resolution depends on previous traffic.

Typically, the wind profile is computed through averaging all recent (e.g., past 10 minutes) wind measurements on predefined segments (e.g., 0.25 NM) at various distances from the runway threshold.

Not all aircraft have a MODE-S equipment installed to downlink meteo data. Additionally, there is a need to have a frequent number of aircraft in 10-20 minutes to provide accurate information on the wind speed and direction at specific altitudes. Therefore, if there is not much traffic pressure at a specific time of the day then the collected Mode-S data will be sporadic. Consequently, due to its intermittent nature, Mode S data could be complemented by another wind profile measurement device (e.g., LIDAR, SODAR, RADAR, model). Alternatively, the tool may revert to DBS when insufficient meteorological data is available via Mode S; staleness criteria must be defined in the tool.

Note also that the wind profile derivation from Mode-S data requires some calibration of the algorithm to account for bias in magnetic heading measurement of each aircraft type.

4.2.3 Other MET data inputs if using M/L models

In case of M/L approach for FTD calculation, the Mode-S temperature and pressure, if available, shall be provided to the TBS support tool

In case of M/L approach for FTD calculation, the crosswind, temperature and pressure vertical profiles, if available, shall be provided.

4.3 Approach Sequence inputs

This functional block builds the sequence to be used in the computation of the TBS support tool indicators.

The arrival sequence is

- either determined automatically or
- based on an initial sequence determined automatically and then presented to the ATCO through a sequence list that can be updated.

In the latter, it also allows the ATCO to update the arrival sequence as a function of the tactical variations observed or imposed in order to optimise the arrival sequence list.

The approach sequence inputs are thus provided either by other ground systems or directly introduced by the ATCO into the TBS support tool.

4.3.1 Initial sequence

Req. TBS-SEQ-010

The approach arrival sequence information shall be provided to the TBS support tool.

In certain environments, the aircraft sequence is frozen quite early in time in order to be directly provided to the TBS support tool (through an AMAN or any other sequence manager). In this case the sequence determination is completely automated.

However, in many TMAs the sequence may evolve even just before the aircraft are capturing the glide path. In this last case, there are two different options to comply with the requirement:

- an initial sequence is provided to the TBS support tool as a best guess of the expected landing sequence (e.g., provided by the AMAN 40 minutes prior landing)
- initial approach arrival sequence is automatically determined by the TBS support tool using the TBS area. See TBS-SEQ-015 below.

In both cases, the initial sequence can be updated and maintained by the ATCO using an interface (e.g., a sequence list) that feeds the TBS support tool.

Req. TBS-SEQ-015

The TBS support tool may automatically determine the final approach sequence for arriving aircraft

If the initial sequence tool is not provided externally, then the TBS support tool creates it by gradually inserting the aircraft as they enter the TBS area.

The TBS area is designed locally and specifically for the tool in order to identify an aircraft and insert

it into the initial sequence list with a sequence order. It typically depends on the STARs and the airport's geographical area. It is recommended to design the TBS area in such a way that the resulting initial sequence list will need a minimal number of manual changes afterwards by the user, i.e., so that the tool provides a sequence list with the best estimated order possible.

4.3.2 Sequence update

Req. TBS-SEQ-020

Modification of the approach arrival sequence information shall be supported by the TBS support tool.

On one hand, the actual sequence of the aircraft is calculated in the background based on the real position of the aircraft (result of the projection angle between the aircraft and the localiser) already or soon to be established on the final approach by the radar tracks. On the other hand, the sequence of the aircraft in the tool is a result of the ATCO's actions.

In case of the LORD demonstrator developed by EUROCONTROL, the sequence of aircraft in the tool is determined by the order in which the aircraft enters the TBS area and the distance to the runway threshold depending on the local specific path to the centreline and runway. However, the Approach ATCO is able to modify the sequence of the aircraft as required.

Once the initial sequence is defined, tactical optimisation and vectoring of the approaching sequence may require to update the initial sequence by moving up or down some flight in the sequence or directly removing one aircraft from the list, e.g., due to a missed approach.

The logic of the tool's algorithm supporting this functionality is intrinsically related to the HMI and ATCO actions described in Section 4.5.

In the case of the Intelligent Approach (IA) tool, developed by NATS, any sequence updates (e.g., in case of go-arounds or runway changes) are performed through AMAN updates.

4.4 Compute indicator for Separation & Spacing rules (FTD)

The Final Target Distance (FTD) is the maximum distance value obtained when considering all applicable separation (wake, surveillance) and spacing (e.g., runway occupancy time) time or distance-based rules.

Therefore, it shall be computed such that no under-separation/spacing shall be observed if the follower is at a distance equal to the FTD indicator when the leader is at the separation delivery point.

The FTD computation varies depending on whether the constraint is defined in time or distance.

4.4.1 FTD computation for a Distance-based Separation or spacing constraint

For a separation/spacing constraint expressed in distance, the Final Target Distance (FTD) is equal to the applicable constraint. For the FTD in DBS there is thus no need for a buffer.

The FTD is computed as the maximum of all applicable distance-based separation and spacings.

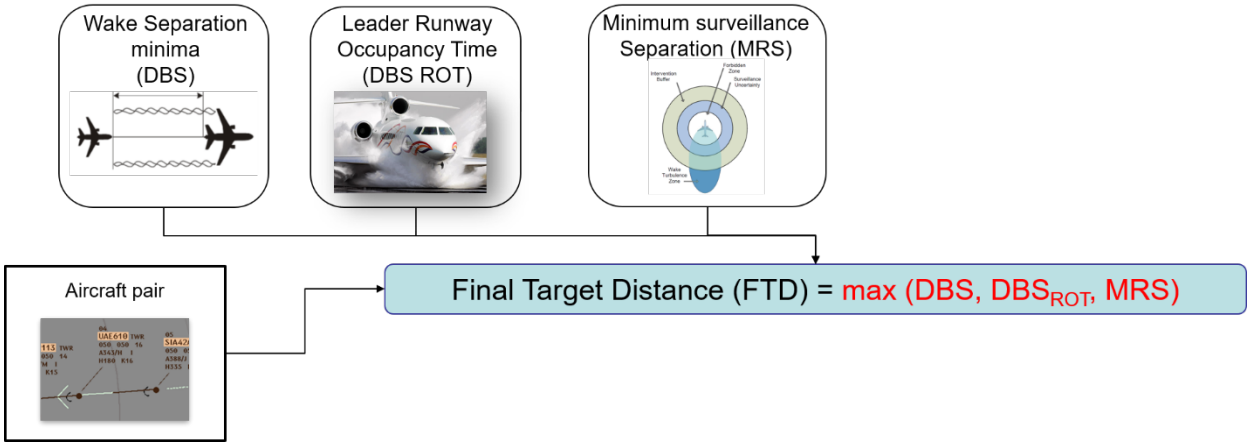


Figure 5: FTD calculation logic for distance-based separation/spacing constraints

Req. TBS-CALC-020

If using DBS mode the TBS support tool shall use the distance based wake separation rules.

In DBS mode operation, the Final Target Distance (FTD) to be calculated by the TBS support tool related to wake separation constraint corresponds to the distance-based separation to be applied at the separation delivery point

Req. TBS-CALC-040

As a minimum the TBS support tool shall support wake turbulence radar separation rules.

In case the FTD calculated by the TBS support tool is found to be lower than the minimum radar separation, the FTD shall be taken as the minimum radar separation.

Req. TBS-CALC-050

The TBS support tool may support other separation or spacing constraints.

In some cases, additional separation or spacing constraints apply on top of the wake and surveillance minima (e.g., low visibility procedure, gap spacing, runway contamination). The logic behind the separation indicator computation remains the same when considering those other distance-based spacing constraints, that is, the selected separation or spacing for the indicator computation corresponds to the largest constraint.

Req. TBS-CALC-060

All applicable separations and spacings between each in-trail aircraft pair in the approach arrival sequence shall be identified by the TBS support tool.

In case of increase of the separation and/or spacing, for instance because of a contaminated runway or LVP, the FTD will be computed considering the most constrained (i.e., the largest) separation and/or spacing constraint for in-trail aircraft pairs.

Req. TBS-CALC-070

All applicable separations and spacings between each not-in-trail aircraft pair in the approach arrival sequence shall be identified by the TBS support tool.

The TBS support tool will also compute the separation indicator by accounting for all other spacing

and separation constraints related to not in-trail aircraft pairs. Examples of such constraints concern separation for aircraft in parallel approach, separation between an aircraft in the interception phase and an aircraft on the glide.

Req. TBS-CALC-090

The maximum of all applicable separation or spacing distances managed by the TBS support tool shall be selected as the indicator distance.

The TBS support tool shall select as FTD the largest of all applicable separation or spacing distances considering:

- DBS wake separation minima,
- Minimum Radar Separation (MRS), and
- Distance-based Runway Occupancy Time (ROT) spacing of the leader aircraft.
- Other separation or spacing constraints for in-trail aircraft pairs
- Other separation or spacing constraints for not in-trail aircraft pairs

4.4.2 FTD computation for a Time-Based separation or spacing constraint

Req. TBS-CALC-030

If using TBS mode the TBS support tool shall use time based wake separation rules.

and

Req. TBS-CALC-130

If the indicator represents a time-based separation then its display option shall be configured as always on.

For a separation/spacing constraint expressed in time, the separation/spacing needs to be translated into a distance in order to be visible through the FTD on the Controller Working Position.

This translation of time into distance depends on the aircraft ground speed profile which itself depends on the true air speed profile (TAS) and on the headwind profile. Approximate TAS can be obtained through measuring groundspeed (GS) and the headwind effect on the glideslope, alternatively, it can be substituted by Indicated air speed (IAS).

Uncertainty, evolution and variation when characterising these inputs (TAS and headwind) have to be considered in order to define the distance minima corresponding to the required time separation/spacing with an acceptable level of reliability.

The FTD is then computed as the maximum of all applicable time- and distance-based separation and spacings.

In particular, the FTD can be capped to conform to surveillance minima as applicable.

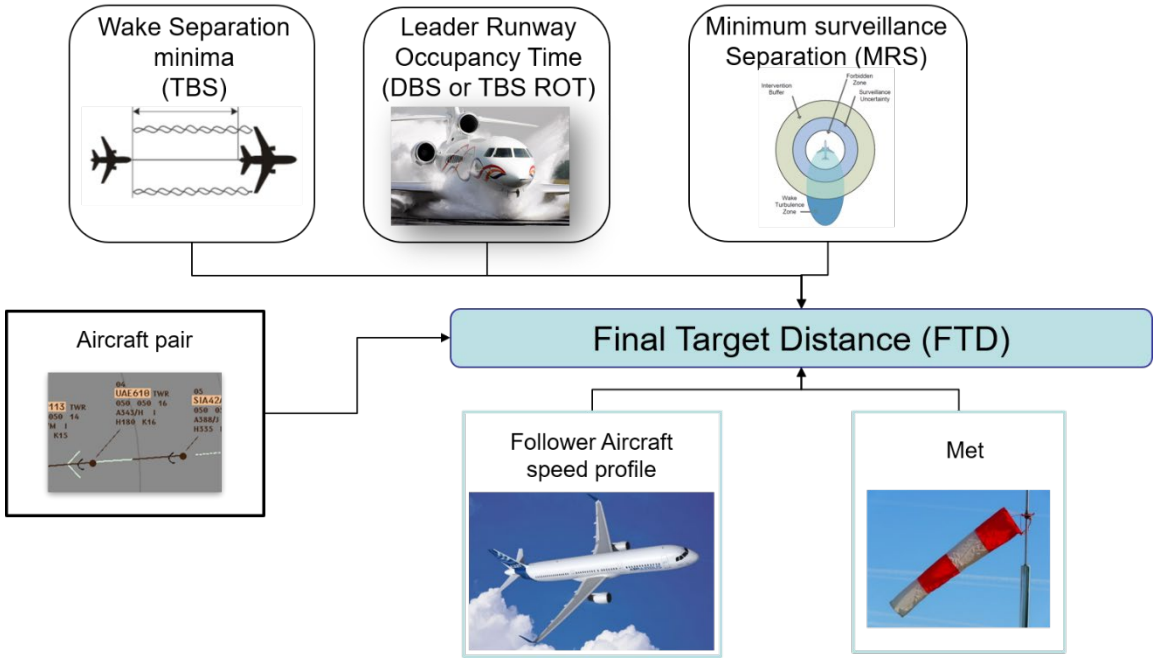


Figure 6: FTD calculation logic for time- and distance-based separation/spacing constraints

Req. TBS-CALC-080

The TBS distance for all time-based separations and spacings shall be computed by the TBS support tool considering the glide-slope wind conditions and an expected speed profile / time-to-fly model.

In Time-Based mode, the Final Target Distance (FTD) is computed such that it corresponds to the distance to be flown by the considered aircraft down to the separation delivery point in the applicable wind conditions in a time equal to the appropriate TBS for the leader / follower type, category or group pair. The distance hence decreases for increasing headwind conditions and for decreasing air speed. It is computed using the follower time-to-fly profile model.

Note that the FTD in TBS needs to account for uncertainty by defining a buffer.

4.4.2.1 *Time-to-fly modelling*

Req. TBS-SPEED-010

An expected aircraft groundspeed profile or time-to-fly (T2F) model on the final approach glide-slope shall be provided to the TBS support tool.

The TBS support tool shall use a time-to-fly model on the final approach glide-slope. Two approaches are here proposed:

1. an analytical model where the time-to-fly (T2F) is derived from an estimated true air speed (TAS) defined per aircraft type/category/group and a vertical profile of headwind, or from IAS substituting TAS
2. or, as alternative (under development), a calibrated T2F model through Machine Learning (M/L) depending on several input features (e.g., aircraft type, operator, wind, temperature, pressure, date, time of the day).

Using either approach, the models are derived from aircraft behaviour observations in the real local operational environment. Manufacturer specifications alone are indeed far from sufficient to predict the aircraft airspeed evolution with an acceptable reliability along the approach. Final approach airspeed, deceleration point, stabilisation points are, for instance, largely impacted by the pilot behaviour, airline policy or by local procedures.

4.4.2.1.1 Input data to characterise the TAS/T2F profile

The definition of the true aircraft airspeed profile (TAS) for the analytical approach or the time-to-fly (T2F) M/L model are both based on analysis of extensive local experimental data covering at least one year of operation and containing aircraft tracks (a/c type, latitude, longitude, heading, altitude, ground speed and IAS if available) and meteorological data (at least wind speed and direction).

The following paper[2] includes an example performed for the Vienna airport.

When using a Machine Learning T2F model, other meteorological data features are also used by the model: temperature, pressure, rain, visibility, etc.

4.4.2.1.2 TAS computed using analytical approach

The following paper[3] shows a study of the current practices of final approach separation delivery at major European airports. The results of this study were used as a baseline to predict aircraft airspeed performance during the development of the TBS support tool.

Amongst other calculations, this study provides an analytic definition of the TAS profile, which is based on all local radar/Mode-S dataset for an airport and calibrates the average behaviour of the following parameters per aircraft type in low headwind conditions (i.e., 0-5 knots)

The glide airspeed (Vglide) which is defined based on local procedures

- The Deceleration Fix (DF)
- The Stabilization Fix (SF)
- Final approach airspeed (Vapp)

These 4 parameters determine any TAS profile of an aircraft.

The TAS profile calculated in low wind conditions is the baseline used for further computation of the aircraft airspeed profile with stronger wind conditions. The model can indeed be adapted to account for the adaptation of the final approach airspeed to the wind conditions. The model correction shall also be calibrated based on local data.

4.4.2.1.3 T2F model based on M/L approach (under development)

The definition and calibration of a time-to-fly profile model based on M/L approach considers several features including:

- Aircraft type
- Airline
- Wind
- Temperature, pressure
- Date and time of the day
- ...

The time-to-fly profile of a given aircraft in given operational conditions is then computed using a tool

[2] De Visscher, I.; Stempfel, G.; Rooseleer, F. & Treve, V.; Data mining and Machine Learning techniques supporting Time-Based Separation concept deployment, in *37th Digital Avionics Systems Conference (DASC)*, pp 594-603, London, UK, September 23-27, **2018**

[3] G. Van Baren, C. Chalon Morgan, V. Treve, The current practice of separation delivery at major European airports, 11th USA/Europe Air Traffic Management Research and Development Seminar, Lisbon, Portugal, ATM2015

which runs the developed model.

The M/L approach allows:

- a standardised definition of aircraft time-to-fly profile conforming with TBS safety requirements
- the identification of local relevant and available features for building the model
- an easy delivery and maintenance of the model to be deployed in the Separation Delivery system
- a reduction of calibration phase thanks to the possibility of re-using another previously analysed environment

Further information on the M/L T2F model is available in this publication[4].

4.4.2.1.4 TAS/T2F model in case of absence of data

When the T2F model is based at the aircraft type level, and there is no data for a certain aircraft type, a conservative definition of the groundspeed profile may be adopted by default. It concerns the aircraft types with insufficient or no available data. Since this groundspeed profile is used to convert a time-based separation/spacing into a distance indicator, a conservative definition of the profile consists in an overestimation of the groundspeed as it leads to a larger distance for a given time interval.

Therefore, for the FTD computation, when the follower aircraft flight is lacking data or there is also any other missing information relevant for its computation (like wind condition, runway etc.), a conservative T2F profile is used corresponding to that of a similar aircraft type with a faster T2F profile so that the necessary safe buffers are automatically added in the FTD computation.

Note that in the absence of the groundspeed profile for a given aircraft type, conservative distance minima can also be used instead of the time-based separation/spacing. For instance, the DBS wake minima can be directly used instead of the FTD computed based on the TBS wake minima.

Another other option is to not compute FTD for such aircraft.

When T2F is modelled at a wake category or group level, then the speed of the category or group can be used.

4.4.2.2 *Buffer computation for FTD for a Time-Based separation or spacing constraint*

Operationally, uncertainties are found on the time-to-fly profile of the follower due to uncertainty on the aircraft airspeed profile and on the wind conditions. It is related to

- natural variations of aircraft behaviour
- wind evolution between the time at which the indicator shall be provided to the controller and the time of aircraft actual landing (typically 10 minutes).

Buffers are thus needed in the FTD computation in order to cope with those uncertainties.

[4] De Visscher, I.; Stempfel, G.; Rooseleer, F. & Treve, V.; Data mining and Machine Learning techniques supporting Time-Based Separation concept deployment, in *37th Digital Avionics Systems Conference (DASC)*, pp 594-603, London, UK, September 23-27, **2018**

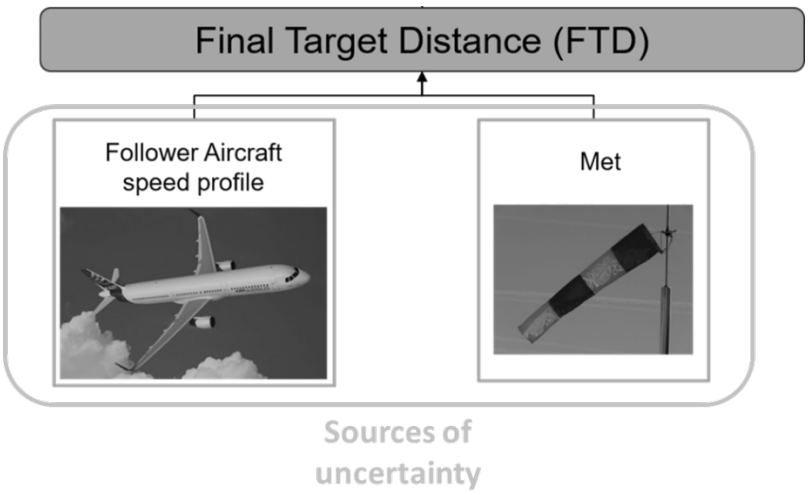


Figure 7: Sources of uncertainty for FTD calculation of time-based separation/spacing constraints

4.4.2.2.1 Rationale

Req. TBS-SAF-010

The computed TBS distance representing the time-based wake turbulence separation shall be acceptably safe from a wake risk point of view after considering the effect of uncertainty in the airspeed profile of the aircraft.

and

Req. TBS-SAF-020

The computed TBS distance representing the time-based wake turbulence separation shall be acceptably safe from a wake risk point of view after considering the effect of uncertainty in the glide-slope wind conditions.

and

Req. TBS-MET-020

Uncertainty on the actual glide-slope wind provided to the TBS support tool shall be quantified.

As previously explained, for a time-based separation/spacing constraint, the FTD is computed based on a follower T2F model using available data inputs (for meteo and aircraft). For correct delivery to the FTD, the FTD shall be provided to the ATCO at a time sufficiently before the aircraft intercepts the localiser (e.g., typically 5 to 10 minutes before landing). The FTD shall thus be computed using inputs as available 5 to 10 minutes prior to the follower landing.

Therefore, for a time-based constraint, there is an uncertainty in the FTD computation which needs to be accounted for. This uncertainty is related to

- aircraft airspeed deviation compared to the one used in the T2F model,
- wind measurement uncertainty used as input for the time-to-fly model computation,
- wind evolution between FTD computation time and actual separation delivery time.

Buffers are therefore added in the FTD calculation so that, if an aircraft is delivered exactly on the computed FTD, the obtained time separation will be equal or above the time-based separation/spacing constraint with a pre-agreed acceptable error rate.

To ensure buffers and TBS parameters continue to meet safety and performance criteria, on-going

monitoring is needed so updates can be made to the system when necessary, for example when new aircraft types are introduced.

4.4.2.2.2 Acceptable error rate as design criterion for buffer computation

The acceptable error rate for spacing constraints is to be agreed with the local authority, for example based on comparison with current practices.

When deciding on the acceptable error rate, all algorithms within the controller tool have to be considered. The assessment methodology is subject to the local safety case.

As an example, for Time-Based wake separation, a possible definition of the error rate can be based on observed time separation distribution in reference low wind conditions. The FTD shall then be computed such as to maintain a time separation distribution equivalent to what is observed for that aircraft type in calm wind conditions. Note however that, in case of strong wind conditions, time separation reductions below the TBS minima by a certain TBS margin have been shown to be acceptably safe. This allows FTD buffer reductions in such strong wind conditions (see[5]).

4.4.2.2.3 Buffer definition for FTD for a Time-Based separation or spacing constraint using analytical approach

This section and related sub-sections provide options to defining and calculating the buffer for the FTD of TBS.

The definition of the buffers can be based on a global approach covering the uncertainty related to aircraft behaviour (such as airspeed evolution, aircraft performance with specific flap configuration, etc.) but also, simultaneously, related to the spatial and temporal evolution of the wind. The combination of buffers as a result of separated treatment of aircraft behaviour uncertainty and the wind evolution uncertainty can be found to be too conservative and therefore incompatible with runway throughput enhancement.

To ensure local safety criteria are met, uncertainties in aircraft behaviour and wind conditions can be accommodated through the parameters in the various components of the system (e.g., selection of reference aircraft speed, error rate associated with forecast glideslope wind conditions), or an overall buffer applied to the resultant separation (e.g., matching of the TBS minima distribution for a wake separation, at max x% of pairs below minima for a ROT spacing).

It is extremely important to note that computed buffers are valid only if they are defined based on the same wind inputs that will also be used when computing the target indicators for a certain scheme.

In order to obtain homogeneity in the error distribution yet with sufficient samples for meaningful statistical results, the buffers are designed per bucket (each defined as a wake category pair in particular surface headwind condition).

The buffer table is defined based on data analysis covering at least one year of airport operations with corresponding aircraft tracks on approach, and wind data.

4.4.2.2.3.1 Buffer computation for FTD for a Time-Based separation or spacing constraint using analytical approach

Below there is the stepped approach for a buffer computation based on an experimental database. It is an iterative process which starts with buffer=0.

1. For each aircraft pair, computation of the FTD using

[5] De Visscher, I.; Rooseleer, F.; Treve, V. & Borek, G.; Procedural Wind-Based Reduction of Separation on Final Approach: Design, Safety Assessment and Application to Vienna Airport, in Proc. *7th EASN International Conference on Innovation in European Aeronautics Research,* Warsaw, Poland, Sept 26-29, **2017***, ISSN 2523-5052*

- average aircraft airspeed model
- wind profile as available at the FTD computation time (e.g., 10 minutes before observed aircraft landing)

2. Comparison of the obtained time separation with the time separation/spacing minima
3. Computation of the error distribution per category pair and per wind condition
4. If the error rate is below designed criteria, stop. Else, increase buffer by 1s and go to step 1

4.4.2.2.3.2 Buffer maintenance for FTD for a Time-Based separation or spacing constraint using analytical approach

Evolution of the aircraft fleet with new aircraft types introduced after the initial buffer computation, evolution of procedures impacting airspeed profile or any other evolution will need regular monitoring and analysis to maintain buffers and ensure the required reliability level in the separation delivery.

For instance, when there is a new aircraft type landing at a certain airport, the most conservative strategy would be applied initially and after some months (when a significant and sufficient dataset might have been collected already on this new aircraft type) a new and correct T2F and buffer could be modelled and applied then.

4.4.2.2.4 Buffer definition using M/L approach (under development)

Estimating the necessary buffers as a solution for predicted errors is more accurate when using Machine Learning Techniques, as they typically use a wider set of inputs. Therefore, this approach is much more recommended than using data analysis for the buffer calculations of the TBS support tool. A M/L approach indeed allows better homogeneity of the error distribution across the various influence factors (aircraft types, wind, airlines, etc.).

4.4.2.2.5 Buffer and time-to-fly model monitoring

The FTD computed by the TBS support tool in TBS mode is based on a time-to-fly model which is calibrated using local surveillance and wind data.

In order to account for the uncertainty of this time-to-fly model, buffers are added in the indicator computations. Those buffers are calibrated based on past traffic.

The time-to-fly models and the associated buffers used for FTD computation are built, incorporated into the TBS support tool in its calculation algorithm and validated (which is required especially to obtain regulatory approval).

On a regular basis, the calculated TBS times and distances shall be also compared offline against operational data in order to validate that the obtained error rate is still in line with the design criteria, so the time-to-fly models and the FTD buffers are still safe to use. Else, they shall be updated accordingly.

This check then allows:

- The detection of possible changes in aircraft behaviour not observed in the past data used for model calibration (e.g., due to a modification of an airline landing flap policy -which leads to a significant change in the landing airspeed profile-) and the consequent requirement to adapt the model and the buffers accordingly.
- The refinement of the model and/or the reduction of the buffers for some cases thanks to the increased coverage of impact features (e.g., refinement of the model for an aircraft type for which too few observations were available in past data).

The tools performing the above-mentioned checks can be maintained outside the TBS support tool.

4.4.2.3 *FTD algorithm for a Time-Based separation or spacing constraint*

Req. TBS-CALC-080

The TBS distance for all time-based separations and spacings shall be computed by the TBS support tool considering the glide-slope wind conditions and an expected speed profile / time-to-fly model.

The equivalent distance for all time-based separations and spacings shall be computed by the TBS support tool considering the expected T2F profile (that depends on the TAS profile and the glide-slope wind conditions).

The maximum of all applicable separation and/or spacing distances shall be selected by the TBS support tool as the displayed indicator distance.

For Distance-Based separation/spacing constraint

$$FTD = DBS$$

where,

- FTD is the separation indicator
- DBS is the distance-base separation constraint (e.g., MRS, wake minimum)

For Time-Based separation/spacing constraint (TBS):

a) Using analytical model

$$TBS + buffer = T2F(FTD + DP) - T2F(DP)$$

where

- FTD is the separation indicator
- TBS is here the time-based separation/spacing constraint (e.g., wake TBS, ROT, Gap)
- buffer is a buffer due to aircraft and wind uncertainty
- T2F(X) is the time required by the follower aircraft to travel the distance X to the runway threshold computed from TAS model and wind profile
- DP is the distance of the separation delivery point to runway threshold (e.g., standard values are 0, 0.5, 1 NM)

b) Using M/L model (under development)

$$TBS = T2F(dist + DP) - T2F(DP)$$
$$FTD = dist + buffer$$

where

- FTD is the separation indicator
- TBS is the time-based separation/spacing constraint (e.g., wake TBS, ROT)
- dist is an estimation of the FTD indicator without accounting for T2F uncertainty
- T2F(X) is the time required by the follower aircraft to travel the distance X to the runway threshold computed by the M/L developed model using all required inputs (aircraft type, airline, wind, date, time, etc.)
- buffer is a buffer accounting for model uncertainty computed by the M/L developed model using all required inputs (aircraft type, airline, wind, date, time, etc.)
- DP is the distance of the separation delivery point to runway threshold (e.g., standard values are 0, 0.5, 1 NM)

4.4.3 Refresh of the calculation

Req. TBS-CALC-100

The latest time the indicator distance is computed shall correspond to the time a stable indicator is required by the controller

and

Req. TBS-CALC-110

If there is a change to the sequence, as maintained by the TBS support tool, the indicator distance for all affected aircraft pairs shall be re-calculated.

A refresh of the FTD could be triggered for the three following cases:

1) For a time-based separation/spacing, when the leader aircraft reaches a point where the remaining flying time equals the time horizon of the wind uncertainty buffers, the corresponding FTD shall be refreshed. For instance, if the wind considered in the buffer design study was the wind as available ten minutes before landing, an update of the FTD shall be computed at a time corresponding to 10 minutes before the expected landing of the considered follower.
2) If the sequence is updated, the new FTD shall be recomputed considering the new leader and follower aircraft types.
3) If a mode transition (e.g., from TBS to DBS) is applied, the FTD corresponding to the new mode shall be computed.

4.4.4 Transition mode

Req. TBS-CALC-010

The TBS support tool shall be able to switch between time- and distance-based wake turbulence radar separation rules.

The switch between time- and distance-based separation rules is allowed in the TBS support tool provided the swap is planned by the Supervisor at a certain time horizon in order to allow the ATCO to apply the new separations resulting from the mode switch.

Generally, this corresponds to a time when the first aircraft operating in the new separation mode can still be vectored to comply with the new separations. This usually matches a time horizon of 10 minutes and under no circumstances can affect aircraft already aligned on the runway extended centreline.

The switch from TBS to DBS will also occur in case of failure, e.g., loss of wind service.

4.5 Human Machine Interface (HMI)

When operating with Time-Based Separation (TBS), the Approach and Tower controllers must be supported by appropriate graphical representation on the traffic situation display. Below there is an example of the Approach and Tower view of the LORD demonstrator HMI.

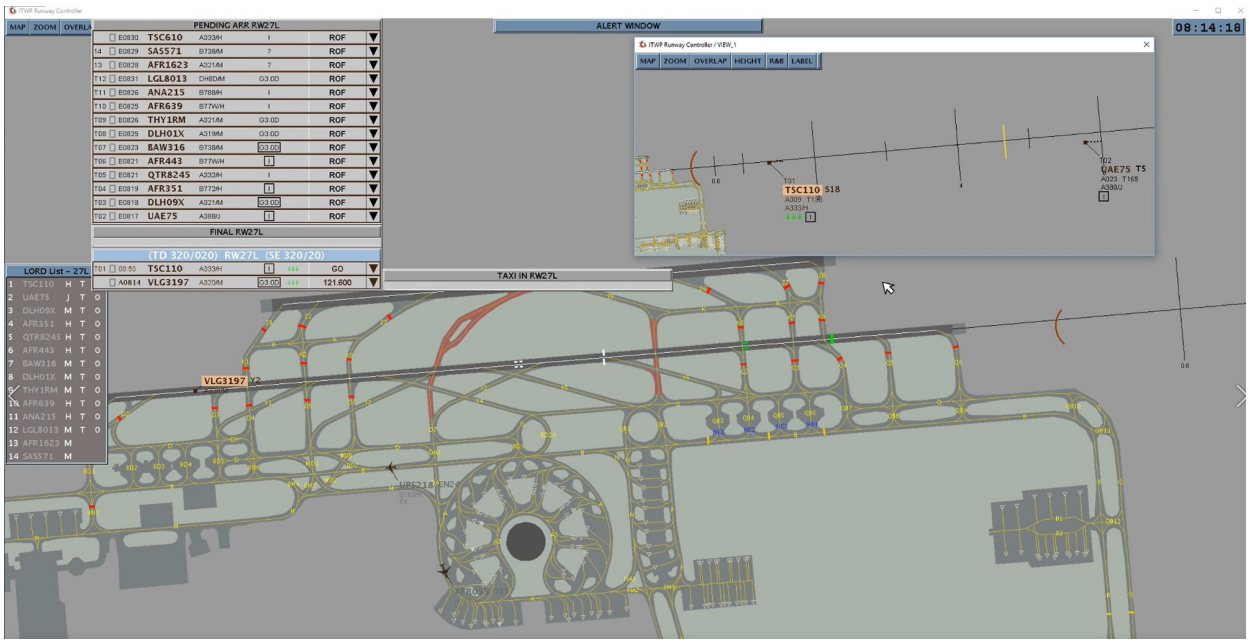


Figure 8: example of Tower view in EUROCONTROL LORD demonstrator

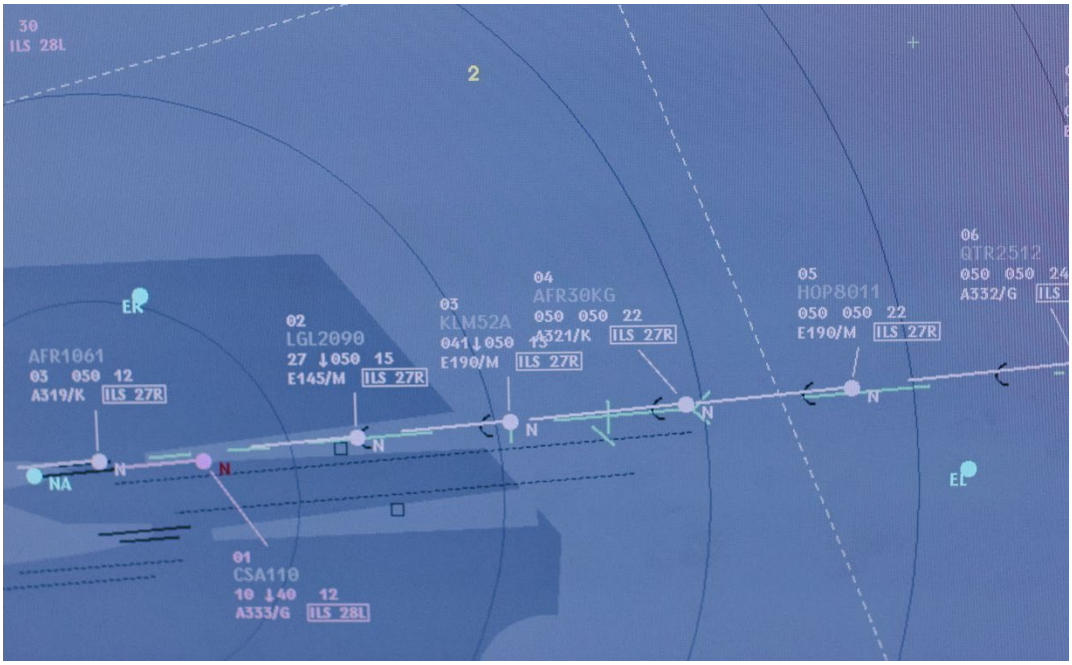


Figure 9: example of Approach view in EUROCONTROL LORD demonstrator

4.5.1 TBS Indicator

Req. TBS-HMI-010

The TBS support tool shall support the display of indicators on the CWP of the ATCO in charge of maintaining radar separation until RWY threshold.

The Final Target Distance (FTD) indicator provides an indication of the required separation / spacing between each aircraft pair, see Section 4.4. The FTD shall be made available by the TBS support tool for Approach and Tower ATCOs.

4.5.1.1 *Indicator depiction*

Req. TBS-HMI-060

The HMI design for the indicator may be configurable depending on the type of separation or spacing.

The HMI design for FTD may be configured differently depending on the type of separation or spacing constraint:

- Wake Turbulence (WT)/Minimum Radar Separation (MRS)
- Runway Occupancy Time (ROT)
- Gap (inserted by the Approach ATCO)

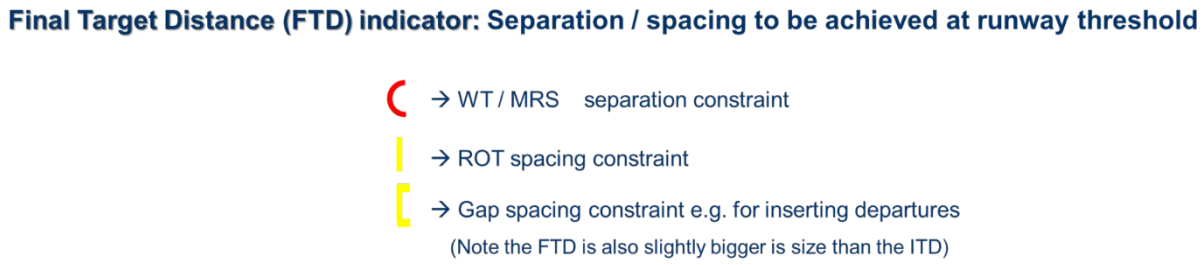
Depending on local preferences and the number of indicators displayed, all or some of the FTD indicators can have a different shape and / or colour based on the type of constraint.

It should be noted that the design, colour and size of the FTD must integrate fully into the existing CWP and must conform with the existing CWP HMI design rules / philosophy.

4.5.1.1.1 Shape

In the EUROCONTROL LORD demonstrator, the FTD is depicted on the CWP HMI in an arc shape (chevron) to ensure they were easily distinguishable from the distance markers on the centre line.

The indicators are shaped as arcs for the MRS and WT and as a straight line for ROT to allow ATCOs to position the aircraft as close to the indicator as possible.



Originally the indicators were arrow shaped but it was observed in prototyping sessions that the controllers were not positioning the aircraft close to the indicator. This was due to the fact that given the arrow shape of the indicator, when the aircraft was on the arrow the ATCOs could not tell where the minima limit was. With the arc and straight-line shaped indicator ATCOs can easily identify the limit of the separation/spacing minima even when the aircraft is positioned on or just behind the indicator.

4.5.1.1.2 Colour

In the LORD demonstrator, the colour coding of the indicators was as follows:

The colour coding used for the FTD is the same in the Approach and Tower positions:

- The FTD for separation constraints such as WT and MRS is coloured red – due to the fact that this is a safety constraint. This means that infringement of the FTD may have safety implications – hence infringement of the FTD representing a separation minimum is not allowed.
- The FTD for spacing constraints, such as ROT or a gap spacing to allow for departures in mixed mode, is coloured yellow. This is because as a spacing constraint, an infringement may not have the same safety implications as a separation constraint. Infringement of the spacing constraint may occur based on ATCO judgement if such as infringement will not have any safety implications.

4.5.1.2 *TBS indicator configuration requirements*

The TBS indicators have a series of configuration requirements which need to be considered to correctly build a TBS support tool HMI.

4.5.1.2.1 TBS indicator placement: on the extended runway centerline

Req. TBS-HMI-030

The indicators shall be displayed on the extended runway centreline of the applicable runway

TBS distance indicators are displayed all along the runway centreline of the Final Approach Controller radar display and the Tower controller and they are computed for all the aircraft inside the TBS area of computation.

4.5.1.2.2 Synchronisation of HMIs

Req. TBS-HMI-040

The indicator display should update at the same time with no discernible difference as the radar update of the associated aircraft.

The update rate of the radar screen and indicators must be synchronised so that the position of the aircraft in relation to its associated indicators can be accurately determined at the same reference point in time.

If the update rate of the radar screen HMI and indicators is not synchronised it is difficult for the ATCOs to determine the exact position of the aircraft in relation to its indicator at a given point in time.

4.5.1.2.3 Consistency between CWPs

Req. TBS-HMI-020

The displayed indicator distance shall be consistent between all applicable CWPs.

The indicators displayed on must be consistent on all applicable CWPs, i.e., all Approach and Tower ATCOs shall have the same information regarding the indicators and their respective aircraft.

If they are not consistent it could imply there is an error with the indicators and in addition, could cause confusion if further communication or co-ordination regarding the position of aircraft in relation to the indicators is required.

4.5.1.2.4 Customisation of TBS indicator display selection

Req. TBS-HMI-025:

The displayed indicators may however be customised to meet specific Tower Runway and Final Approach controller needs of the ATCO in charge of maintaining radar separation until RWY threshold.

As an option, a functionality could be provided enabling APP and TWR controller to manually select (e.g., in a control and monitoring panel of the TBS support tool) the distance from the runway threshold at which the TBS indicators are displayed on the centre line within a predefined range.

4.5.1.2.5 Clarity of indicator meaning

Req.TBS-HMI-070

If more than one type of indicator is displayed on the CWP HMI of the ATCO in charge of maintaining radar separation until RWY threshold, then the HMI design of the indicator should be clearly distinguishable to avoid ambiguity.

4.5.1.2.6 Criteria for displaying TBS indicators

TBS indicators should be displayed as soon as the vectoring instructions require the separation/spacing information (provided the flight is in the defined TBS area and in the sequence list). This moment is defined according to a combination of factors relating to the aircraft position and vectoring within a defined volume of space. The specific criteria will depend on local implementation but examples of the criteria include:

- Distance to the extended centre line[6] – (specified range to be locally defined);
- Altitude within a specific range;
- Heading within a range relative to the arrival runway centreline heading;
- A leader arrival aircraft must exist in the sequence

If TBS indicators are typically displayed on the centreline very early and if required by the tool algorithms, a refresh of the computation may be needed 10 minutes before landing to ensure the computation of the buffers are based on variability at a consistent time horizon.

4.5.1.2.7 Aircraft association to indicator

Req. TBS-HMI-050

The TBS support tool shall support the controller decision to turn onto final approach.

The Final Approach ATCO shall be provided with the TBS indicator on his/her CWP prior to interception in order to support the controller decision to turn a flight onto the final approach centreline behind its associated TBS indicator.

The TBS indicator shall thus be displayed on the runway extended centreline further than the interception point and for a defined maximum number of arrival traffic in the sequence area.

[6] Note that as the working method is found to vary between controllers, in terms of the distance at which the aircraft intercept the localiser, controllers could be enabled to manually select the distance from the runway threshold at which the TBS indicators are displayed within a predefined range when setting up the CWP HMI configuration.

Req. TBS-HMI-080

The HMI design shall allow controllers to identify the aircraft associated with each displayed indicator.

Controllers shall be able to identify the TBS indicator associated with each aircraft.

The Approach ATCO needs the indicators to be displayed on the extended runway centreline of the applicable runway in order to ensure they identify the related indicator for each aircraft within sufficient time prior to interception of the centreline so the ATCOs can verify the sequence of the indicators is in accordance with the ATCOs centreline interception strategy.

As an example, in the EUROCONTROL LORD demonstrator, this is achieved by hovering the mouse over an aircraft label which will highlight the corresponding TBS indicator associated with the highlighted aircraft. Likewise, by hovering the mouse over a TBS indicator, the associated aircraft label will be highlighted along with the selected TBS indicator. More specifically, the FTD highlighted in red and the aircraft label highlighted in green.

This enables the controllers to quickly associate which aircraft is associated with each TBS indicator (and vice versa) and also enables the controllers to check that the aircraft sequence in the sequencing tool matches the actual inbound aircraft sequence.

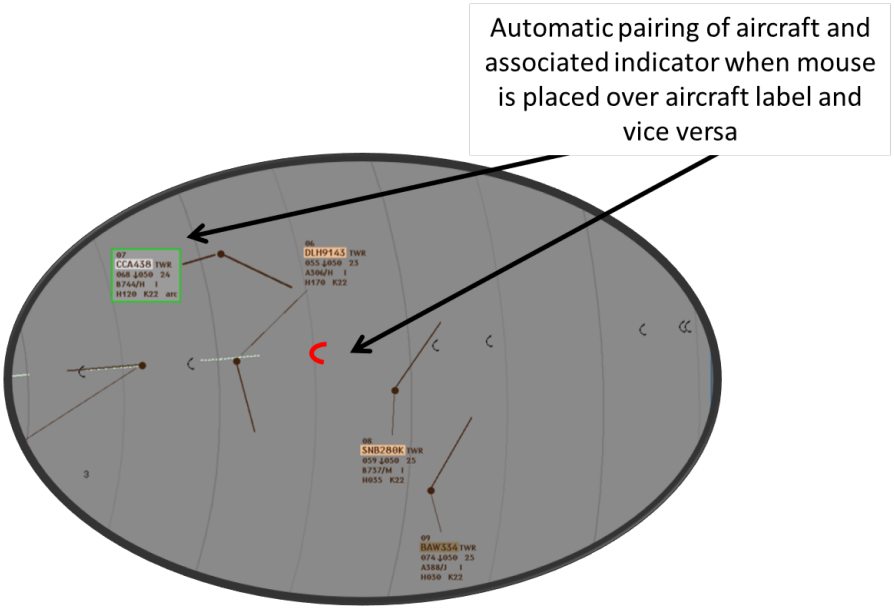


Figure 10: Example of aircraft association to indicator in EUROCONTROL LORD demonstrator

Req. TBS-SAF-075

The TBS support tool may be capable of automatic updates for the wrong aircraft being turned onto a separation indicator.

Alternatively, where the TBS indicator is displayed through automatic capture once the aircraft are in a stable sequence, such as on base leg, the indicator displayed will be that of the next in sequence aircraft, i.e., the indicators follow the sequence onto final approach.

In the case of parallel runways where there are two Final Approach ATCOs, one for each final approach, then the indicators (and related alerts) need only to be displayed for the aircraft on the

final approach under the ATCOs responsibility in order to avoid clutter and confusion. However, this is a local decision that will be made on implementation. For Closely Spaced Parallel Runways (CSPR) where one final approach ATCO is responsible for the arrivals on both runways, then the indicators and related alerts for aircraft on both final approach centre-lines must be displayed.

4.5.1.2.8 Hide feature for visual separations

Req. TBS-HMI-065

The HMI design may allow to hide indicator for a specific pair if visual separation is allowed by the ATCO for that pair.

The TBS support tool enables the ATCO to allow one or more aircraft to approach the runway under visual conditions. In order to do so, the ATCO is able to hide the corresponding TBS indicators for those aircraft while the sequence and the indicators for the rest of the traffic remain unchanged. An implementation example could be to manually switch to visual mode in the aircraft label on the HMI. The aircraft is automatically tagged with a 'V' (visual) displayed in the label which defines the type of approach.

The visual separation mode may be manually selected by the ATCO on an aircraft-to-aircraft basis or for all aircraft.

Note, in some Separation Delivery tools, this feature can be also used to hide the chevrons when the tool is in degraded mode (which provides wrong and misleading information).

4.5.2 Aircraft sequence list

Req. TBS-HMI-090

The approach arrival sequence shall be available on the Tower Runway and Final Approach CWP HMI.

Where the TBS support tool does not have auto-sequence capability, an arrival sequence shall be available on the Tower Runway and Final Approach CWP HMI to enable the controllers to easily identify the sequence of the aircraft in the arrival sequence tool. Where a numbered sequence is used, the sequence number should be clearly displayed in the aircraft label.

The arrival sequence could also be displayed independently on the CWP HMI in a separate window.

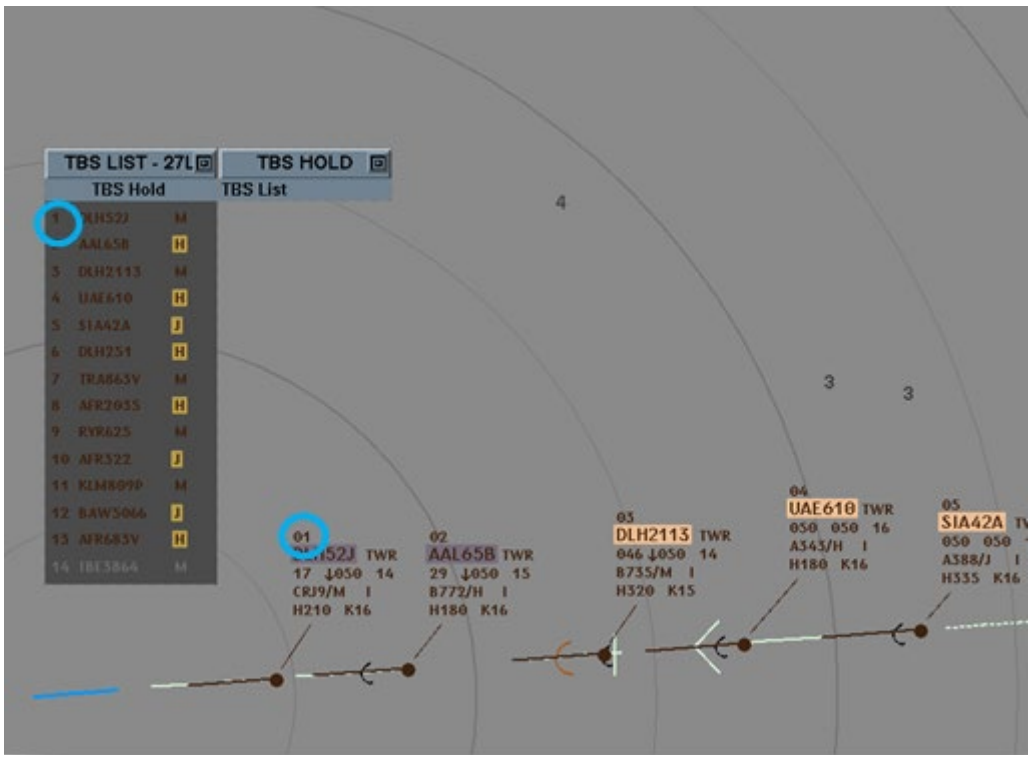


Figure 11: Example of sequence display in EUROCONTROL LORD demonstrator

The main source of information to conform to the initial sequence order should be the order in which aircraft enter a volume of airspace (typically the TBS area). The tool should be able to either automatically update the sequence to that being delivered, or controllers shall be able to tactically edit this sequence on their HMI.

Therefore, they should be able to manually change the sequence of the aircraft in a simple and timely way so they remain in control of the sequence. This can be implemented through an HMI input:

a) Via the sequence list

By drag-and-drop the selected aircraft to the desired position in the aircraft sequence list.

b) Via the aircraft label

During prototyping and real-time simulation sessions conducted by EUROCONTROL, the ATCOs prefer to change the aircraft sequence via the aircraft label as opposed to the sequence list as they claimed the aircraft label is more within the ATCOs' central vision.

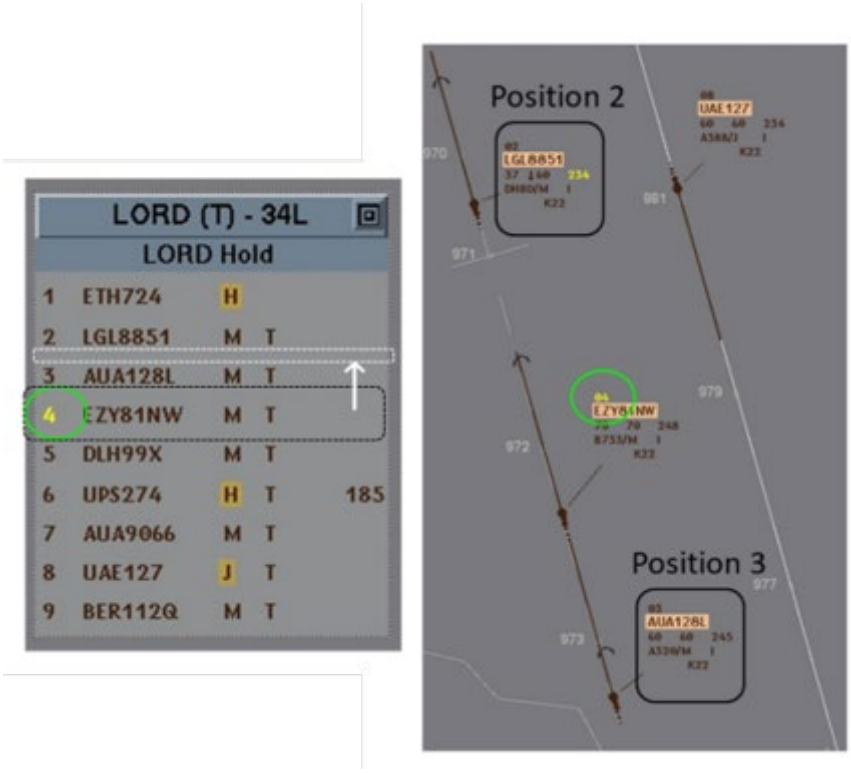


Figure 12: Example of sequence list update in the EUROCONTROL LORD demonstrator

To be noted that another implementation option is to have an automatic system identification and update of the correct sequence order for the final approach.

The most appropriate option has to be defined depending on the specific local environment characteristics. In any case the mechanism for changing aircraft sequence via the label must be intuitive and easy to execute.

For every change in the arrival sequence, the tool shall immediately re-compute the TBS indicators and reflect the change accordingly on the HMI.

Additionally, a sequencing solution needs the ability to add or remove aircraft from the sequence, for instance, during a missed approach.

There is further information about sequence alerts in Section 4.7.1.

4.5.3 Mixed mode operations (GAP insertion for arrivals)

Gaps can be introduced into the arrival sequence with the TBS support tool if necessary, for example, in case of runway inspections and mixed mode runway operations. The insertion of gaps could be automatic (typically inserted in an operational control and monitoring panel) or manual.

The manual insertion of gaps into the arrival flow by the APP ATCO was shown to be technically feasible in real time simulations conducted by EUROCONTROL.

In the LORD demonstrator, the manual insertion of gaps was performed either by selecting a pre-selectable time or by typing in a specific value into a keypad, as illustrated in Figure 13.

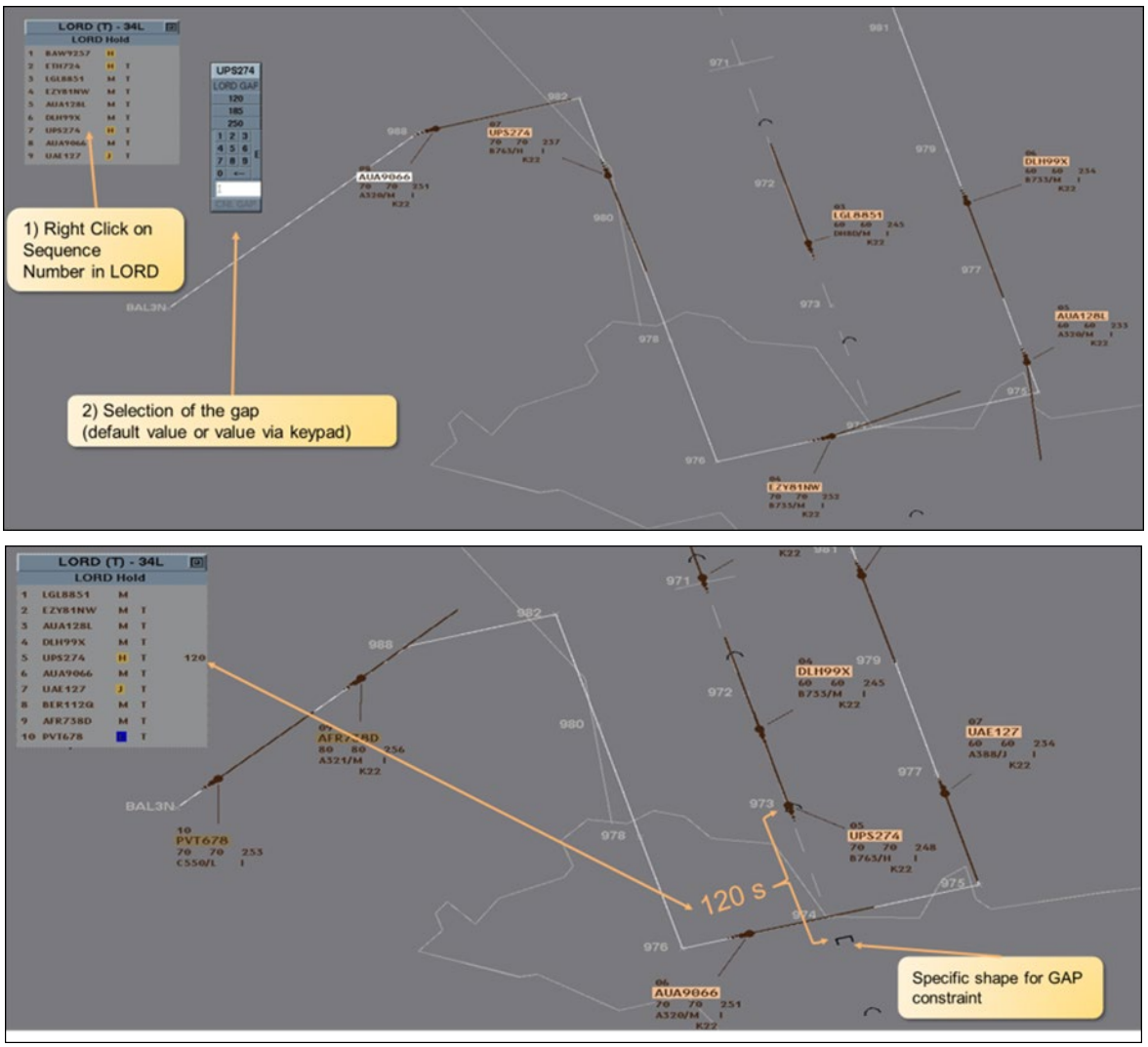


Figure 13: Example of Gap management in EUROCONTROL LORD demonstrator

4.5.4 Mode transition display on the HMI

Req. TBS-HMI-100

During a mode transition those indicators not already displayed shall use the new mode of operation.

and

Req. TBS-HMI-110

During a mode transition those indicators already displayed shall use the previous mode of operation.

Ideally the aircraft from which the change in mode of operation will apply will be clearly indicated on the ATCOs HMI e.g., by highlighting that aircraft.

4.5.5 Alert HMI

Some examples of alerts are showcased below. For further information regarding alert HMI and other alerts, see Section 4.7.

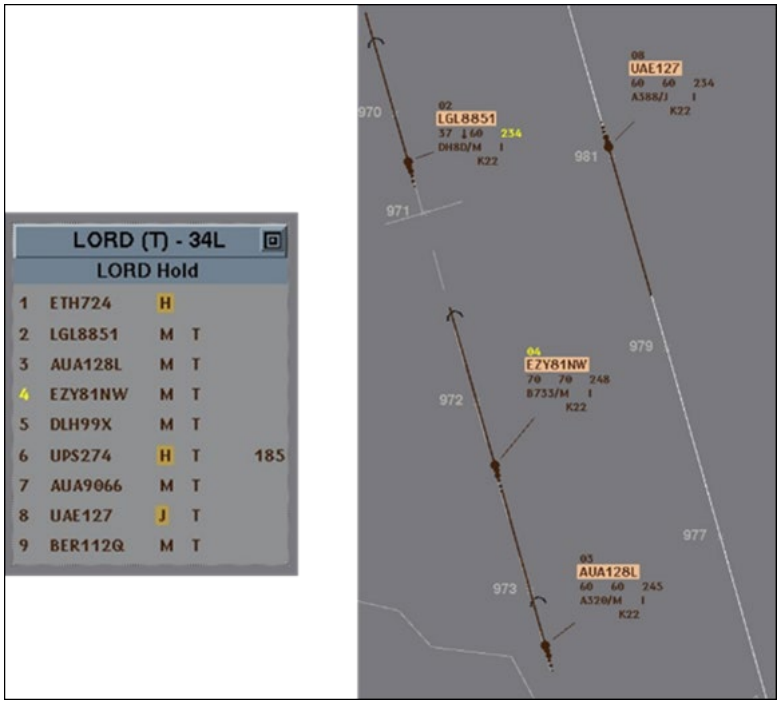


Figure 14: Example of sequence alert display in EUROCONTROL LORD demonstration tool

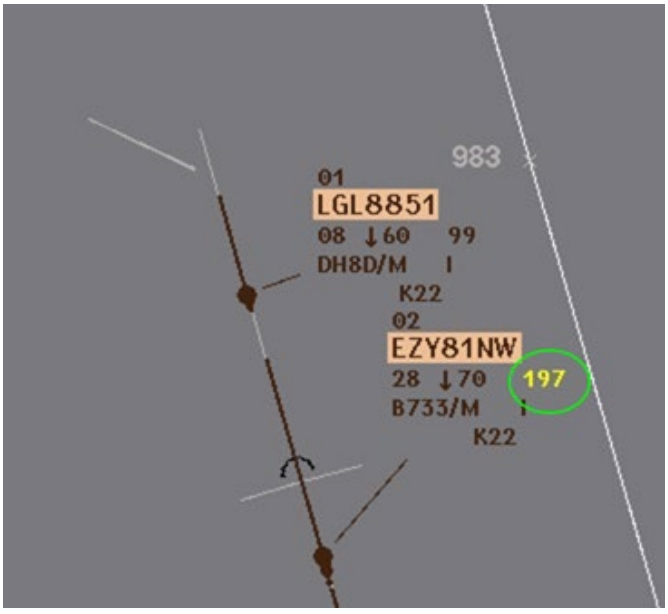


Figure 15: Example of speed conformance alert display in EUROCONTROL LORD demonstration tool

4.5.6 Operational control and monitoring panel

It is strongly recommended that the TBS support tool also includes an operational control and monitoring panel to:

- inform about the separation mode (e.g., DBS, WDS or TBS) in which the tool is operating (e.g., in EUROCONTROL LORD demonstrator this is also displayed in the sequence list)
- monitor the status of the tool and wind information (system status degradation, wind profiler...) and
- control/change the configuration parameters according to the operational scenario (such as gap values for mix mode periodic separations, change runway configuration, increase MRS in case of low visibility procedures...)
- manage the switch from one mode of operations to another (e.g., from DBS to TBS, from degraded to nominal mode, ...).

A corresponding interface panel can be developed to support the different purposes.

4.6 Working methods with the TBS support tool

4.6.1 Sequencing operations

If not automatically managed by the TBS support tool, a change in the aircraft sequence could occur for various reasons:

- Controllers updating the sequence according to their strategy for interception;
- Aircraft removed from sequence e.g., in case of a go-around;
- Aircraft inserted into the sequence, e.g., in case of late change of aircraft landing intent.

Change in the aircraft sequence before interception will be usually implemented by the Final Approach Planning Controller although there may be times in which the Final Approach Controller needs to also interact with the sequencing tool.

4.6.2 Final approach

The overall objective of the Final Approach Controller is to align aircraft on the final approach with the required spacing to ensure separation minima for each aircraft pair are respected all along the final approach and achieved at the separation delivery point (e.g., runway threshold).

4.6.2.1 *Working with FTD*

If working with the FTD alone, the Final Approach ATCO has to determine and apply a buffer on top of the separation minima displayed by the FTD to account for the compression in order to ensure the FTD will not be infringed once the aircraft had passed the deceleration fix on the final approach.[7]

[7] Note that another indicator could also be displayed to the Final Approach ATCO providing information on the expected compression. In the Real Time Simulations conducted by EUROCONTROL, the controller workload experienced by the final approach controller was higher when working with the FTD alone compared to when working also with the Intermediate Target Distance indicator (for ORD). This was due to the fact that with the FTD only the Final Approach ATCO had to calculate the compression to be applied on top of separation minima.

4.6.2.2 *Creating situational awareness prior to interception*

Where the TBS support tool does not auto-sequence, in order to ensure good situation awareness, it is recommended working practice that, prior to final approach segment interception of an aircraft, the ATCO places the mouse on the aircraft label to verify the TBS indicator associated with that aircraft.

In the EUROCONTROL LORD demonstrator, the FTD associated with the aircraft will be displayed and highlighted when the mouse is on the aircraft label.

4.6.2.3 *Interception of the final approach*

The Final Approach ATCO must ensure each aircraft intercepts the final approach centreline behind its associated TBS indicator. As the FTD and the aircraft are both moving in the same direction, the Final Approach ATCO must ensure the aircraft is targeting the intercept slightly ahead of the aimed position with respect to FTD. Once the aircraft has intercepted the final approach centreline behind the FTD, the Final Approach ATCO uses speed control to catch-up the FTD and position the aircraft behind the FTD with sufficient margin for compression. As the FTD moves at the same groundspeed as the lead aircraft, the ATCOs can use this knowledge to accurately adjust the airspeed of the follower aircraft so that it catches up with the FTD efficiently without infringing it.

The easiest way for the final approach controller ATCO to work with the TBS support tool is to intercept the FTD in the sequence order presented. However, traffic flows may not mean this is always possible. In this case, the aircraft of study is intercepting the final approach centreline between its lead and its follower aircraft already established on the centreline in the final approach.

4.6.2.4 *Speed control*

The TBS support tool is designed on a final approach airspeed that has to be achieved by the aircraft prior to the deceleration fix and the latest position on the final approach at which this final airspeed has to be achieved. These parameters are both variables defined within the separation algorithm in the tool that can be adjusted and adapted locally.

Furthermore, as the FTD is calculated based on the position of the lead aircraft and flies at the same groundspeed as the lead aircraft it is recommended that the airspeed profile on the final approach is standardised to ensure the smooth flow of traffic and predictable behaviour of the TBS support tool.

4.6.3 Tower operations

The overall objective of the Tower Controller is to monitor separations between aircraft pairs and intervene as if the separation minimum looks as if it will be infringed. Therefore, the Tower Controller has to monitor the position of an aircraft in relation to the FTD and ensure the aircraft does not cross the FTD.

It is important to note that Tower Controllers should use their knowledge about the aircraft type of and performance to predict whether or not the FTD will be infringed, watching out for possible outliers when monitoring the aircraft separation.

Intervention by the tower controller should not be frequent, as the aircraft should be delivered ‘’clean” to the Tower ATCO, i.e., positioned behind the FTD with sufficient compression margin so that no FTD infringement will occur prior to the separation delivery point.

4.6.3.1 *Working with FTD*

Tower Controllers primarily monitor aircraft separations and ensure the separation minima are not infringed. For that purpose, they use the FTD only and monitors the position of an aircraft in relation to the FTD for preventing FTD (i.e., separation) infringement.

It is important to note that Tower Controllers should use their knowledge about the aircraft type and performance watching out for possible outliers when monitoring aircraft separation.

If the Tower Controller predicts an infringement of the FTD is likely to occur, they should either:

- instruct a go around, or;
- if the aircraft is still under procedural control, a speed reduction could be instructed, (however, whether this is allowed or not will depend on the local procedures/particularities) provided this course of action ensures separation minimum will not be infringed prior to or at separation the delivery point.

Alternatively, where local procedures allow, visual separation or a pilot decision to continue the approach may be offered in these underseparation situations.

4.6.3.2 *FTD infringement*

An infringement of the FTD must be prevented at all times as it constitutes a separation infringement.

The Tower ATCO must use their own knowledge and experience of aircraft performance to determine whether they think an infringement of the FTD is likely to occur or not.

The instruction for a go-around shall be given prior to the FTD being infringed to ensure safe operations are maintained.

If the FTD is recurrently being infringed when under the Tower's responsibility, the Tower ATCO must inform the Final Approach to fix it, as the Final Approach is responsible for setting up the required spacing so that separation minima is not infringed on the final approach prior to the separation delivery point.

4.6.4 Mixed mode runway operations (gap insertion for arrivals)

For mixed mode runway operations, in case of gaps to be inserted into the arrival traffic flow (see Section 4.1.6.2.2), the request from Tower shall be coordinate with Approach control, as is done in current operations.

The insertion of gaps could be manual or automatic.

- It is recommended that for mixed mode runway operations where there is a regular and frequent insertion of gaps in the flow required (e.g., if the arrival-departure sequence was one arrival followed by one departure etc, or two arrivals followed by one departure or vice versa) the gap function is automated. In this case the supervisor should be able to define the mixed mode procedures (arrival-departure sequence) to be implemented for a defined period of time (e.g., GAP spacing of 120 seconds between every arrival for the next two hours) or per rate flow (e.g., GAP spacing of 120 seconds between every arrival for the next 10 arriving aircraft).
- For gaps that are not so regular or frequent the insertion of gaps could be manually inserted into the arrival flow by the supervisor. Although this functionality could also be made available on the approach controllers CWP HMI, so that under certain circumstances the APP ATCO can insert gaps into the arrival flow.

The system shall then automatically calculate and display the required gaps per aircraft pair on the approach controller CWP based on this information, depending on the aircraft type / wake vortex category and wind.

4.6.5 Mode transition

For a planned mode change the Approach and Tower Supervisors should coordinate and collaboratively decide when a mode should be activated or deactivated based, e.g., on meteorological data and predefined activation criteria.

Once agreed the Approach and Tower Supervisors shall inform the respective controllers about:

- the moment when the transition mode will occur
- the first aircraft in the arrival sequence to be separated according to that mode

The Final Approach / Approach controllers should be able to suggest and agree with the supervisor / coordinator an alternative timing /aircraft from which the mode transition should take place if they think the aircraft selected by the supervisor is not feasible for whatever reason.

Ideally to minimize the disruption and impact on the ATCOs work, the supervisor or coordinator would try to instigate a mode transition between two medium aircraft where MRS is applied or where the change in separation for that aircraft pair with the new separation scheme is zero or very limited.

The ATCOs in the approach sectors directly impacted by the mode change need to know the last aircraft in sequence that will be under the previous separation mode prior to interception when the aircraft is on the baseleg and at the latest 2 -3 minutes before the aircraft will intercept the localizer.

4.7 Alerts

Safety nets help prevent imminent or actual hazardous situations from developing into major incidents or even accidents.

They are the last system safety defence against accidents and they are intended to provide timely alerts to air traffic controllers or pilots of an increased risk to flight safety.

For this purpose, a number of different alerts which are identified through a Hazard analysis process performed on the local environment and tool set-up, should be developed with the TBS support tool to indicate actual or potential hazardous situations that require particular ATCO attention or action.

These alerts ensure safe operations are maintained when the TBS support tool is used in operations. In particular, they have three main aims:

- To facilitate the ATCO in their work and help to ensure the required separation/spacing minima are applied as accurately as possible whilst preventing the occurrence of separation infringements which would compromise safety;
- To ensure the system inputs to the TBS support tool, and hence separation / spacings displayed by the indicators, are correct;
- To ensure the aircraft are flying in line with the specifications of the tool parameters and hence ensure the correct separations / spacings are displayed by the tool on the final approach all the way down to the runway threshold.

The alerts described below have been validated in a number of prototyping sessions and real time simulations conducted by EUROCONTROL using different TMA and airport environments.

4.7.1 Sequence alert

Req. TBS-SAF-070

If the TBS support tool does not have an auto-sequence capability, it shall provide to the ATCO in charge of maintaining radar separation until RWY threshold automatic monitoring and alerting for the wrong aircraft being turned on to a separation indicator.

In order to calculate the required separation/spacing between each aircraft pair the TBS support tool requires the aircraft arrival sequence.

If the tool does not have the correct sequence, the separation / spacing indicators themselves will not be correct, and this could have serious safety consequences.

Therefore, the arrival sequence must be monitored by the system to ensure the expected sequence order of aircraft used by the tool matches the actual sequence of the aircraft established on, or soon to be established on the centreline.

As such, if there is a difference in the actual order of aircraft and the order of aircraft in the tool, then this discrepancy is indicated to the controllers via the sequence alert.

Alternatively, if the tool automatically updates the sequence, then it may be considered through local hazard analysis that such an alert is not required.

4.7.1.1 *Display on the LORD demonstrator*

The sequence alert on the EUROCONTROL LORD demonstrator consists of:

- sequence number in the aircraft label of the affected aircraft being highlighted in yellow;
- affected aircraft in the sequence list window on the CWP HMI being highlighted in yellow.

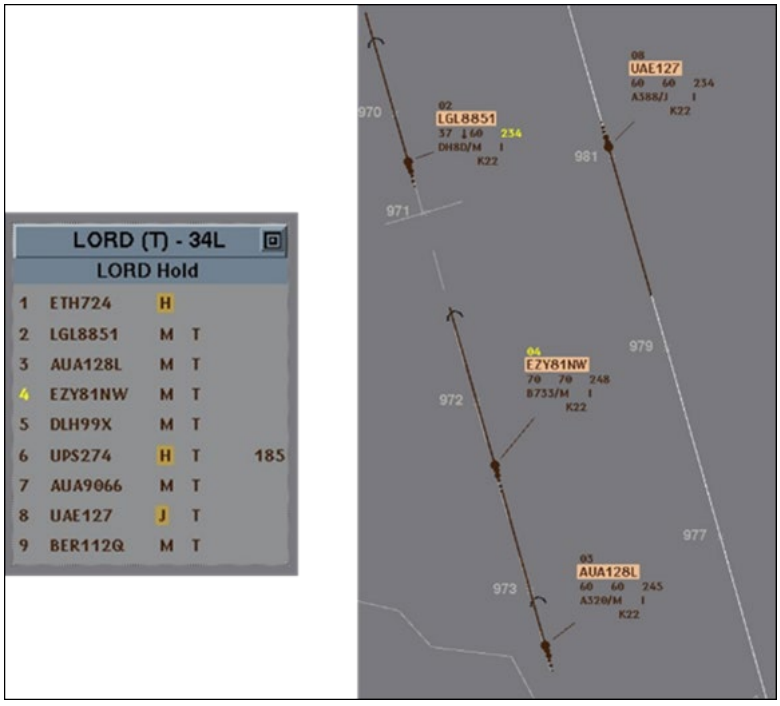


Figure 16: Example of sequence alert display in EUROCONTROL LORD demonstration tool

4.7.1.2 *Required ATCO action*

If the sequence alert is triggered, the ATCOs need to update the sequence list as soon as possible to reflect the actual one.

Depending on the environment, sequence changes will be usually implemented by Final Approach Planning Controller or any other Approach controller. Although there may be times in which the Final Approach Controller needs to also interact with the sequencing tool, for example in the instance of a sequence alert when the aircraft is on or very near the final approach centre line.

For further information about how the sequence list can be changed in the LORD demonstrator, see Section 4.5.2.

4.7.2 Speed conformance alert

Req. TBS-SAF-050

The TBS support tool shall provide to the ATCO, who is in charge of maintaining radar separation until RWY threshold, with automatic monitoring and alerting on non-conformant final approach airspeed behaviour as expected by the speed profile / time-to-fly model.

During the last stages of the final approach the TBS indicator is calculated based upon a reference airspeed. For example, in the EUROCONTROL LORD demonstrator, a reference airspeed profile in the last 8 NM to threshold consisting in a 160 kts reference airspeed down to a deceleration fix (possibly varying depending on the type) has to be achieved. If aircraft are deviating from the reference airspeed by a defined amount, then the indicators of the TBS support tool will not correctly represent the required time separation / spacing.

As such, if the difference in the actual TAS (True Airspeed) of an aircraft and predicted TAS (as modelled in the prototype/tool) is above a defined absolute value in the TBS support tool, a speed conformance alert should be triggered. The speed conformance alert is only triggered when the aircraft reaches a specific distance from runway threshold at which the final instructed reference airspeed has to be achieved.

Alternatively, the TBS support tool may be complemented by a separate non-conformant airspeed monitor and operational procedures to inform of planned non-conformant speeds.

4.7.2.1 *Display on the LORD demonstrator*

In the EUROCONTROL LORD demonstrator, the speed alert is triggered and displayed when there is 20 kts difference between the actual aircraft airspeed and the aircraft reference airspeed defined in the tool within the last 8NM from the runway threshold.

However, the value of these parameters can be defined locally depending on the safety buffer used in the tool (for more information on safety buffers see Section 4.4.2.2).

In case of the LORD demonstrator, the true airspeed of aircraft in the label is highlighted in yellow.

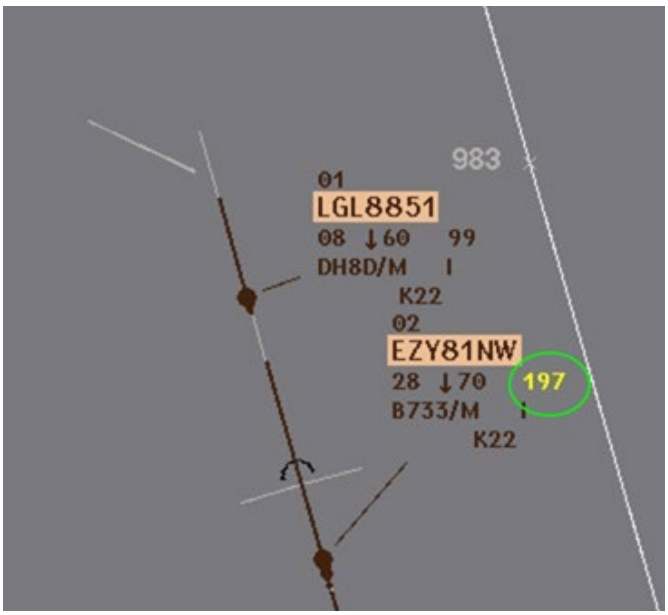


Figure 17: Example of speed conformance alert display in EUROCONTROL LORD demonstration tool

4.7.2.2 *Required ATCO action*

If a speed conformance alert is triggered, the ATCO in charge shall instruct to reduce the aircraft airspeed to the value of the airspeed parameter used in the tool.

Note that the Tower might react to a speed alert by giving a speed reduction if it is prior to the deceleration fix. This is applicable only for those Tower Control Centres where TWR controllers are allowed to provide speed control instructions.

4.7.3 Catch-up alert

Req. TBS-SAF-080

The TBS support tool shall provide automatic monitoring and alerting of catch up of the indicator.

The catch-up alert informs the Final Approach Controller if the follower aircraft is predicted to cross the indicator within a certain period of time if the speed of the aircraft remains unchanged. It is a safety net for reducing the risk of indicator infringement and therefore possible subsequent loss of separation risk.

A possible solution consists in displaying on the CWP the distance to the indicator (positive or negative) when the aircraft get close to it (with a threshold distance to be defined).

Another option consists in a catch-up visual alert (caution) displayed on the CWP HMI when the follower aircraft is flying above a defined speed in relation to the lead aircraft (the leader aircraft's speed is also the speed at which the indicator is travelling) and when the predicted time to infringement of the indicator is below a specified value. This value is defined locally. In the EUROCONTROL LORD demonstrator, a catch-up alert was developed for the ITD indicator and not directly for FTD. It is detailed below.

4.7.3.1 *Display on the LORD demonstrator*

In the EUROCONTROL LORD demonstrator, the ITD catch-up alert is displayed

- if the speed of the follower aircraft is more than 12 knots above the speed of the lead aircraft (and hence the ITD compression indicator) and
- if the predicted time to infringe the ITD is 60 seconds or less.

The values implemented in the LORD demonstrator for the catch-up alert can be adapted and tuned for the local deployment environment. In the LORD demonstrator, this alert is available from 8NM on final approach and above. It is displayed in the first line of the a/c label with word “CATCHUP’’ displayed in yellow text on the approach phase.

Figure 18: Example of ITD catch-up alert display in EUROCONTROL LORD demonstration tool

4.7.3.2 *Required ATCO action*

Whenever there is an ITD catch up the ATCO should reduce, at the earliest opportunity, the speed of the aircraft to the same speed of the lead aircraft.

4.7.4 TBS infringement risk alerting functions for TWR

Req. TBS-SAF-060

The TBS support tool shall provide to the ATCO in charge of maintaining radar separation until RWY threshold automatic monitoring and alerting of separation infringement.

The aim of the TBS support tool is to ensure that the correct separation/spacing represented by the FTD is achieved between leader and follower aircraft as the leader crosses the separation delivery point (e.g., at runway threshold). When a TBS separation is used in the FTD computation, the graphical representation of FTD can be complemented by two additional alerts. These alerts are activated after the leader aircraft has reached the delivery point. These alerts mitigate the risk of infringement of the TBS by the follower aircraft when the leader has reached the separation delivery point. This might occur in situations where the follower aircraft is flying at significantly higher airspeed than the airspeed used by the TBS support tool for the FTD computation.

Both alerts are based on the times separation monitoring after the leader has reached the separation delivery point.

Therefore, after the leader has reached the separation delivery point, the TBS support tool can compute the time separation between the leader and follower aircraft, based on the actual groundspeed of the follower aircraft, to determine the actual time required for the follower aircraft to

reach the separation delivery point.

The tool can then compare the actual time separation to the reference time separation minimum defined in the TBS support tool.

4.7.4.1 *TBS infringement risk advisory*

A TBS infringement risk advisory can be raised (e.g., “TBS” letters appearing in yellow) if the follower aircraft is within 5 seconds (configurable parameter) to the reference FTD time separation minimum. This advisory shall not be raised if the FTD computation is based on ROT or GAP.

4.7.4.2 *TBS infringement warning*

A TBS infringement warning can be raised (e.g., red “TBS” letters appearing in red) if the follower infringes the reference time separation minimum. This warning shall not be raised if the FTD is based on ROT or GAP.

4.7.5 Wrong aircraft type or category alert

The TBS support tool may raise a WTC mismatch alert to the controller in case there is a detected mismatch in the applicable wake turbulence categories.

The TBS support tool may raise an aircraft mismatch alert to the controller in case there is a detected mismatch in the aircraft type.

In today's environment, the provided aircraft type into the flight plan may not always be corresponding to the aircraft which is actually operating the flight. For instance, this may occur due to a human error when fulfilling the flight plan or due to a late change of aircraft as a result of a technical problem.

Considering the extensive use of the aircraft type information made by the TBS support tool, this may have more safety consequences than in the current environment.

Even if this remains relatively rare, a local procedure shall be considered to handle this potential hazard:

- It can be manual, e.g., at the first contact with the Approach, the flight crew shall provide the Aircraft type or
- Automated e.g., cross check with the Mode-S or verification of the agreement between wake turbulence category and aircraft type using a database

In case the verification is automated, the aircraft/WTC mismatch alert shall be raised to the controller in case discrepancy is detected by the system.

4.7.5.1 *Required ATCO action (under development):*

In case an error in aircraft type is detected by the system or the ATCO, the ATCO shall contact the pilot to verify/confirm the aircraft type. When a missing or wrong ICAO aircraft type or wake turbulence category is detected, it shall be completed or corrected in the Flight Plan data resulting in an update of the TBS indicator calculation.

4.8 Abnormal and Degraded Mode

The main scenarios leading to a degraded mode include

- Loss or degradation of inputs

  - Glideslope Wind profile
  - Approach Arrival Sequence Service
  - Flight data
  - Any other data used for the TBS indicator computation
- Loss of whole or part of the system support functions (indicators or alerting)

In case of failure or abnormal situation, a transition to the degraded mode is put in place and an alert shall be provided by the TBS support tool to the Controllers and Supervisors.

In those cases, the TBS indicator calculation, HMI and related working methods shall be adapted.

4.8.1 Advisory and warning alerts

Req. TBS-CNTR-010

The TBS support tool shall provide alert to controllers and supervisors in case of degradation of the data Inputs.

In case of loss or degradation of the TBS support tool data input quality, a warning accompanied by an indication of the failure source shall be provided to the Supervisors, Approach and Tower Controllers.

Req. TBS-CNTR-020

The TBS support tool shall alert controllers and supervisors in case of failure of the TBS support tool.

Approach and Tower Supervisors shall be alerted if any TBS support tool functionalities including supervision and alerting/warning functions are lost, inoperative or degraded.

For example, the Intelligent Approach (IA) tool, developed by NATS, reports service degradation via the TBS table (which provides, in the IA tool, reference TBS distance and DBS minima, shown on the ATC surveillance display). The TBS values are removed if TBS is not available. Complete system failure results in DBS & TBS values being removed.

4.8.2 TBS indicator calculation

In case of temporary loss of the glideslope headwind profile input, the TBS support tool may continue to use, for FTD computation, the latest available headwind profile input during a period of time for which the headwind input has been shown to still be usable by the TBS support tool through a wind stability analysis (to be performed using local historical data). After that period, the glideslope headwind profile input is considered to be permanently lost.

In case of temporary degradation of the glideslope headwind profile input (i.e., presence of outlier), the TBS support tool may continue to use, for FTD computation, the latest available reliable headwind profile input during a period of time for which the headwind input has been shown to still be usable by the TBS support tool through a wind stability analysis (to be performed using local historical data). After that period, if reliable glideslope headwind profile input is still not available, the glideslope headwind profile input is considered to be permanently lost.

The wind used for TBS indicator computation has a certain period of validity (typically 5 to 10 minutes). In cases of temporary loss or degradation of the wind inputs lower than this validity period, the calculated TBS indicators are still reliable since the buffers used in their computation account for this time horizon.

In case of permanent loss of the glideslope headwind profile input, the TBS support tool may either compute the FTD according to the distance-based wake separation or compute a conservative FTD possibly using wind inputs from the supervisor

When operating in a TBS-modes, in the degraded situation where glide-slope headwind profile input is missing, the computation of TBS FTD values is severely impacted. Therefore, the TBS support tool may revert to the corresponding DBS-mode or keep using the TBS-mode with FTD computed using a conservative wind profile.

A notification of the automatic switch shall be provided to the ATCOs and Supervisors.

Note that in case some of the inputs used for TBS indicator calculation are lost or degraded, the TBS indicators will still be calculated but they are not reliable and shall thus not be display on the ATCO CWP.

4.8.3 HMI

4.8.3.1 *Advisory and warning alerts*

Req. TBS-CNTR-010

The TBS support tool shall provide alert to controllers and supervisors in case of degradation of the data Inputs.

In case of loss or degradation of the TBS support tool data input quality, a warning accompanied by an indication of the failure source shall be provided to the Supervisors, Approach and Tower Controllers.

Req. TBS-CNTR-020

The TBS support tool shall alert controllers and supervisors in case of failure of the TBS support tool.

Approach and Tower Supervisors shall be alerted if any TBS support tool functionalities including supervision and alerting/warning functions are lost, inoperative or degraded. When the degraded mode is active, the warning shall be provided in the Approach and Tower CWP as well as on the Supervisor operational control and monitoring panel.

4.8.3.2 *TBS indicator display*

Req. TBS-CNTR-010

The TBS support tool shall provide alert to controllers and supervisors in case of degradation of the data Inputs.

In case of loss or degradation of the sequence input, the definition of TBS support tool shall be able to specify which circumstances (outage, degradation) will affect TBS support tool presentations (TBS indicators and list). It may hide all TBS indicators for which the calculation is impaired by the degradation (if the TBS support tool is still functional for the remaining pairs) and the Controllers shall revert to standard separation for aircraft without TBS indicators.

In case of loss or degradation of the aircraft data input, the TBS support tool may hide all TBS indicators for which the calculation is impaired by the affected input and the Controllers shall then revert to DBS without indicators for aircraft without TBS indicators.

The TBS support tool may not display all TBS indicators for which the calculation is impaired by missing or degraded inputs.

Req. TBS-CNTR-020

The TBS support tool shall alert controllers and supervisors in case of failure of the TBS support tool.

In case of TBS support tool failure preventing TBS Indicator computation, the TBS support tool may not display all TBS indicators for which the calculation is impaired by a tool failure.

4.8.4 Working methods

Req. TBS-CNTR-020

The TBS support tool shall alert controllers and supervisors in case of failure of the TBS support tool.

Approach and Tower Supervisors shall be alerted if any TBS support Tool functionalities including supervision and alerting/warning functions are lost, inoperative or degraded.

In case of loss of TBS indicator displays for one or more aircraft, the Approach and Tower Controllers shall revert to contingency DBS minima for all pairs and Supervisor shall switch off TBS support Tool for evaluation. In degraded modes, the default procedures should indeed be to switch back to applicable wake turbulence DBS scheme procedures – with or without the indicators of the TBS support tool, depending on the cause for the degradation.

In cases where there are no more TBS indicators displayed for one or more aircraft, local operational procedures shall be developed for handling traffic situations with missing indicators in different WT separation modes for both controllers and supervisor.

ANNEX A - Guidelines Update Procedures

It is necessary to periodically check this EUROCONTROL Guidelines for consistency with referenced material. The Guidelines is also expected to evolve following real project and field experience, as well as advances in technology.

The main objectives of a regular review are:

a) to improve the quality of the requirements (e.g. clarity, testability, etc.);
b) to verify that the level of detail published is adequate;
c) to ensure that design-oriented requirements, imposing unnecessary constraints to technical solutions, have been avoided;
d) to ensure that advances in technology are properly reflected;
e) to make all stakeholders, including industry, aware of the latest developments.

The update process for this EUROCONTROL Guidelines may be summarised as follows:

Stakeholders may provide change proposals either through existing working arrangements (e.g., established working groups) or by sending a formal Change Request (CR) to the generic email address: standardisation@eurocontrol.int

The CR needs to provide following minimum elements:

- Originator information (name, Organisation, contact details)
- Guidelines title, number and edition date
- Page, chapter, section (subsection) where the issue appears
- Description of the issue and reason for change
- Specific change proposal text (incl. potential alternatives, if any).

Main steps towards a revised version:

- Agency (Standardisation unit) will assess each CR in coordination with content owners, classify the urgency and establish the CR impact category (major, minor or editorial).
- Agency will then prepare resolution proposal(s) and, if needed, discuss those with the originator and/or relevant working arrangements. Note: CR will be grouped into “change packages” to consider reasonable update cycles.
- Agreed changes will be integrated into a revised version “Proposed Issue” including a summarised list of changes.
- Consultation will be performed in accordance with the CR impact category identified:
    - Major changes need consultation at working layers (e.g., working group or Team)
    - Editorial changes may be implemented directly at any stage though grouped with change packages.

Note: Identified errors which may cause potential problems when implementing, may be corrected directly via separate “Corrigendum”.

The Agency will apply this process in an objective and impartial way and will consult stakeholders as needed and in line with the formal Standards Development Process.

ANNEX B - Time-Based Separation (TBS) Principles as Alternative to Static Distance-Based Separation for Final Approach: Safety Case Report

The content of this annex is provided in a separate file.

ANNEX C - Traceability to requirements from EUROCONTROL Specification for Time Based Separation (TBS) support tool for Final Approach

This annex contains a traceability table between the requirements from EUROCONTROL Specification for Time Based Separation (TBS) support tool for Final Approach, EUROCONTROL-SPEC-167 [RD 1]. The annex covers all requirements specified in EUROCONTROL-SPEC-167 except for the cases detailed and justified in the table.

The first and second columns list the requirements from EUROCONTROL-SPEC-167.

The third column specifies whether or not the requirement is covered in the Guideline document.

The fourth column identifies the section in the Guideline document which covers the requirements or provides a justification in case a given requirement is not covered.

# Req. SPEC 167	Requirement	Status in Guidelines 187	Justification/comment
TBS-FLIGHT-010	ICAO aircraft type for all arrival aircraft shall be provided to the TBS support tool.	Covered	Section 4.1.1
TBS-FLIGHT-020	Wake category for all arrival aircraft should be provided to the TBS support tool.	Covered	Section 4.1.2
TBS-FLIGHT-030	Default separation rule shall be defined if provided ICAO aircraft type is not recognised by TBS support tool.	Covered	Section 4.1.6.1.3
TBS-SURV-010	Aircraft position, including altitude, for all arrival aircraft shall be provided to the TBS support tool.	Covered	Section 4.1.4
TBS-SURV-015	Provided aircraft position should have the same performance as the applicable ATC display used for separation purposes.	Covered	Section 4.1.4
TBS-SURV-020	Downlinked airborne parameter data may be provided to the TBS support tool.	Covered	Section 4.1.5
TBS-SEP-010	Distance based wake turbulence separation rules shall be provided to the TBS support tool based on ICAO aircraft type.	Covered	Section 4.1.6.1.1
TBS-SEP-020	Time based wake turbulence separation rules shall be provided to the TBS support tool based on ICAO aircraft type.	Covered	Section 4.1.6.1.2
TBS-SEP-025	Default separation rule shall be defined if provided ICAO aircraft type is not recognised by TBS support tool.	Covered	Section 4.1.6.1.3

TBS-SEP-030	All applicable Minimum Radar Separation (MRS) rules shall be provided to the TBS support tool.	Covered	Section 4.1.6.1.4
TBS-SEP-040	Minimum runway time separation shall be provided to the TBS support tool.	Covered	Section 4.1.6.2.1. Moved to spacing input as related to ROT
TBS-SPAC-010	Minimum runway spacing shall be provided to the TBS support tool.	Covered	Section 4.1.6.2.1.
TBS-SPAC-020	All applicable spacing rules to be managed by the tool shall be provided to the TBS support tool.	Covered	Section 4.1.6.2.2
TBS-SPAC-030	Individual spacing gaps between aircraft pairs should be provided to the TBS support tool.	Covered	Section 4.1.6.2.2
TBS-SPAC-040	If allowed without TBS, visual separations may be also allowed by the TBS support tool.	Covered	Section 4.1.6.3
TBS-MET-010	The actual glide-slope wind conditions shall be provided to the TBS support tool.	Covered	Section 4.2.2
TBS-MET-020	Uncertainty on the actual glide-slope wind provided to the TBS support tool shall be quantified.	Covered	Section 4.4.2.2.1
TBS-SEQ-010	The approach arrival sequence information shall be provided to the TBS support tool.	Covered	Section 4.3.1
TBS-SEQ-015	The TBS tool may automatically determine the final approach sequence for arriving aircraft	Covered	Section 4.3.1
TBS-SEQ-020	Modification of the approach arrival sequence information shall be supported by the TBS support tool.	Covered	Section 4.3.2
TBS-SEQ-030	Runway intent for all arrival aircraft shall be provided to the TBS support tool.	Covered	Section 4.1.3

TBS-SPEED-010	An expected aircraft speed profile or time-to-fly model on the final approach glide-slope shall be provided to the TBS support tool.	Covered	Section 4.4.2.1
TBS-CALC-010	The TBS support tool shall be able to switch between time and distance based wake turbulence radar separation rules.	Covered	Section 4.4.4
TBS-CALC-020	If using DBS mode the TBS support tool shall use the distance based wake separation rules.	Covered	Section 4.4.1
TBS-CALC-030	If using TBS mode the TBS support tool shall use time based wake separation rules.	Covered	Section 4.4.2
TBS-CALC-040	As a minimum the TBS support tool shall support wake turbulence radar separation rules.	Covered	Section 4.4.1
TBS-CALC-050	The TBS support tool may support other separation or spacing constraints.	Covered	Section 4.4.1
TBS-CALC-060	All applicable separations and spacings between each in-trail aircraft pair in the approach arrival sequence shall be identified by the TBS support tool.	Covered	Section 4.4.1
TBS-CALC-070	All applicable separations and spacings between each not-in-trail aircraft pair in the approach arrival sequence shall be identified by the TBS support tool.	Covered	Section 4.4.1
TBS-CALC-080	The TBS distance for all time based separations and spacings shall be computed by the TBS support tool considering the glide-slope wind conditions and an expected speed profile / time-to-fly model.	Covered	Sections 4.4.2 and 4.4.2.3
TBS-CALC-090	The maximum of all applicable separation or spacing distances managed by the TBS support tool shall be selected as the indicator distance.	Covered	Section 4.4.1
TBS-CALC-100	The latest time the indicator distance is computed shall correspond to the time a stable indicator is required by the controller.	Covered	Section 4.4.3

TBS-CALC-110	If there is a change to the sequence, as maintained by the TBS support tool, the indicator distance for all affected aircraft pairs shall be re-calculated.	Covered	Section 4.4.3
TBS-CALC-130	If the indicator represents a time based separation then its display option shall be configured as always on.	Covered	Section 4.4.2
TBS-COMP-010	A compression distance should be calculated by the TBS support tool considering the glide-slope wind conditions and an expected speed / time-to-fly profile.	Not covered	Concerns compression distance indicator calculation not directly related to TBS
TBS-HMI-010	The TBS support tool shall support the display of indicators on the CWP of the ATCO in charge of maintaining radar separation until RWY threshold.	Covered	Section 4.5.1
TBS-HMI-020	The displayed indicator distance shall be consistent between all applicable CWPs.	Covered	Section 4.5.1.2.3
TBS-HMI-025	The displayed indicators may however be customised to meet specific Tower Runway and Final Approach controller needs of the ATCO in charge of maintaining radar separation until RWY threshold.	Covered	Section 4.5.1.2.4
TBS-HMI-030	The indicators shall be displayed on the extended runway centreline of the applicable runway.	Covered	Section 4.5.1.2.1
TBS-HMI-040	The indicator display should update at the same time with no discernible difference as the radar update of the associated aircraft.	Covered	Section 4.5.1.2.2
TBS-HMI-050	The TBS support tool shall support the controller decision to turn onto final approach.	Covered	Section 4.5.1.2.7
TBS-HMI-060	The HMI design for the indicator may be configurable depending on the type of separation / spacing.	Covered	Section 4.5.1.1
TBS-HMI-065	The HMI design may allow to hide indicator for a specific pair if visual separation is allowed by the ATCO for that pair.	Covered	Section 4.5.1.2.8

TBS-HMI-070	If more than one type of indicator is displayed on the CWP HMI of the ATCO in charge of maintaining radar separation until RWY threshold, then indicator HMI design should be clearly distinguishable to avoid ambiguity.	Covered	Section 1.1.1.1.1
TBS-HMI-080	The HMI design shall allow controllers to identify the aircraft associated with each displayed indicator.	Covered	Section 4.5.1.2.7
TBS-HMI-090	The approach arrival sequence, as maintained by the TBS support tool, may be available on the CWP HMI of the ATCO in charge of maintaining radar separation until RWY threshold.	Covered	Section 4.5.2
TBS-HMI-100	During a mode transition (e.g., DBS to TBS) those indicators not already displayed shall use the new mode of operation.	Covered	Section 4.5.4
TBS-HMI-110	During a mode transition (e.g., DBS to TBS) those indicators already displayed shall use the previous mode of operation.	Covered	Section 4.5.4
TBS-HMI-120	The compression indicator distance should be displayed on the CWP HMI of the ATCO in charge of maintaining radar separation until RWY threshold.	Not covered	Concerns compression distance indicator calculation not directly related to TBS
TBS-SAF-010	The computed TBS distance representing the time based wake turbulence separation shall be acceptably safe from a wake risk point of view after considering the effect of uncertainty in the speed profile of the aircraft.	Covered	Section 4.4.2.2.1
TBS-SAF-020	The computed TBS distance representing the time based wake turbulence separation shall be acceptably safe from a wake risk point of view after considering the effect of uncertainty in the glide-slope wind conditions.	Covered	Section 4.4.2.2.1
TBS-SAF-030	If compression indicators are implemented, the computed compression distance shall be acceptably safe after considering the effect of uncertainty in the speed profile of the aircraft.	Not covered	Concerns compression distance indicator calculation not directly related to TBS
TBS-SAF-040	If compression indicators are implemented, the computed compression distance shall be acceptably safe after considering the effect of uncertainty in the glide-slope wind conditions.	Not covered	Concerns compression distance indicator calculation not directly related to TBS

TBS-SAF-050	The TBS support tool shall provide to the ATCO in charge of maintaining radar separation until RWY threshold automatic monitoring and alerting on non-conformant final approach airspeed behaviour as expected by the expected speed profile / time-to-fly model.	Covered	Section 4.7.2
TBS-SAF-060	The TBS support tool shall provide to the ATCO in charge of maintaining radar separation until RWY threshold automatic monitoring and alerting of separation infringement.	Covered	Section 4.7.4
TBS-SAF-070	The TBS support tool shall provide to the ATCO in charge of maintaining radar separation until RWY threshold automatic monitoring and alerting for the wrong aircraft being turned on to a separation indicator.	Covered	Section 4.7.1
TBS-SAF-075	The TBS support tool may be capable of automatic updates for the wrong aircraft being turned onto a separation indicator.	Covered	Section 4.5.1.2.7
TBS-SAF-080	The TBS support tool shall provide automatic monitoring and alerting of catch up of the indicator.	Covered	Section 4.7.3
TBS-CNTR-010	The TBS support tool shall provide alert to controllers and supervisors in case of degradation of the data Inputs.	Covered	Sections 4.8.1, 4.8.3.1, 4.8.3.2
TBS-CNTR-020	The TBS support tool shall alert controllers and supervisors in case of failure of the TBS support tool.	Covered	Sections 4.8.1, 4.8.3.1, 4.8.3.2 and 4.8.4

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