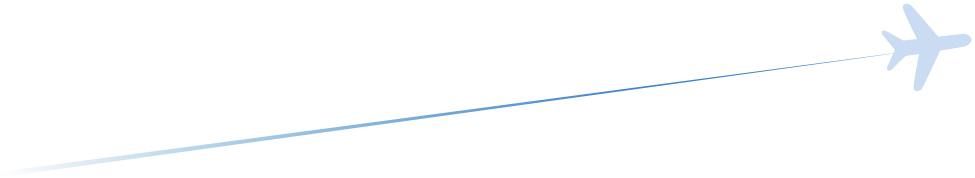

SESAR Solution 02-03: SPR-INTEROP/OSED for V3 - Part II - Safety Assessment Report

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PJ 02 EARTH

MINIMUM PAIR SEPARATION BASED ON RSP

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Abstract

This document specifies the results of the safety assessments carried out in SESAR 2020 Wave 1 by Project PJ02 Solution 03 (Minimum Pair Separations Based on Required Surveillance Performance (RSP)) by the European Organisation for the Safety of Air Navigation (EUROCONTROL).

This Safety Assessment Report (SAR) represents the Part II of the SPR-INTEROP/OSED (Safety and Performance - Interoperability Requirements/ Operational Service and Environment Definition) and contributes to the SPR-INTEROP/OSED Part I and TS/IRS (Technical Specifications/ Interface Requirement Specification) documents.

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1 Executive Summary

This document contains the Specimen Safety Assessment for a typical application of the Project 02 – Solution 03 (Minimum Pair Separations Based on Required Surveillance Performance (RSP)). The report presents the assurance that the Safety Requirements for the V1-V3 phases are complete, correct and realistic, thereby providing all material to adequately inform the PJ02-03 Solution SPR-INTEROP/OSED.

This SAR represents the Part II of the SPR-INTEROP/OSED and contributes to the SPR-INTEROP/OSED Part I and TS/IRS documents.

2 Introduction

2.1 Background

The impact of employing the in-trail 2 NM MRS on final approach on the controller delivery performance was investigated in SESAR 1 P06.08.01 in the context of employing Time Based Static Pairwise Separation with Optimised Runway Delivery on final approach [8][9].

The proposed RSP requirements and the results of the validation on the controller delivery performance to the in-trail 2NM MRS on final approach have been consolidated into the SESAR 1 Operational Focus Area (OFA) 01.03.01 deliverables [5][6][7].[1]

2.2 Operational Concept Overview

SESAR Solution PJ02-03 aims at developing and validating the concept of Minimum Pair Separation Based on RSP, in support of a reduction of the in-trail Minimum Radar Separation from 2.5 NM to 2 NM on final approach. The concept is targeting a direct positive impact on runway throughput (Capacity, Cost Efficiency and Resilience) in Very Large, Large and Medium airports (Terminal Very High, High and Medium Complexity).

In order to be able to apply the in-trail 2 NM MRS on final approach the Final Approach Controller and the Tower Runway Controller will need to be provided with and utilise the surveillance service covered by a safety case that guarantees the RSP for the 2 NM separation on final approach.

A technical study conducted in the project proves that surveillance services including the Primary & Secondary Surveillance services with at least a 4s update rate (for example the Multi-Radar Tracking Service with a 4s update rate) and the Automatic Dependent Surveillance Broadcast (ADS-B) Surveillance Service with at least a 1s update rate are able to fulfil the RSP needed for reducing the minimum separation to 2NM on final approach.

It has to be noted that another assessment of the Wide Area Multilateration (WAM) Surveillance Service in a big European airport highlighted that it did not meet the RSP requirements due to low-level coverage issues.

The types of approach procedures for which the in-trail 2 NM MRS will be applied include the precision Instrument Landing System (ILS) approach procedures, the Ground Based Augmentation System (GBAS) approach procedures and the Area Navigation (RNAV) / Global Navigation Satellite System (GNSS) non-precision approach procedures.

[1] The opinions expressed herein reflect the author's view only. Under no circumstances shall the SESAR Joint Undertaking be responsible for any use that may be made of the information contained herein.

It is envisaged that the in-trail 2 NM MRS is being applied in conjunction with the Time Based Separation (TBS), Weather Dependant Separation (WDS) or the Static-Pairwise Separation (S-PWS) concepts for arrivals, with support by the Optimised Runway Delivery (ORD) tool.

The ORD support tool assists controllers in visualizing the separation minima applicable at the runway landing threshold and the spacing that needs to be conformed to up to the lead aircraft crossing the final approach Deceleration Fix (DF) in order to conform to the required separation to the runway landing threshold delivery point. The spacing helps the controllers in coping with the effect of distance spacing compression on final approach from the lead aircraft crossing the DF to the lead aircraft crossing the runway landing threshold. The ORD support tool will require enhancing to support the in-trail 2 NM MRS. This includes supporting Spacing Minimum being reduced to less than 2.5 NM down to 2 NM and supporting ROT Spacing and TB Wake Separations that are less than 2.5 NM down to 2 NM.

The reduction to 2 NM MRS is operationally feasible only when the Separation/Spacing Minima constraints and the provision of appropriate ROT Spacing are actively managed through the supporting of specific ATC procedures allowing predefined conditions influencing ROT to be satisfied (e.g. braking action reported as good, no runway contaminants such as lush, snow or ice, etc.)

The operational concept is described in the OSED [10] via three Use Cases:

- Use Case-1: Planned Changes of Final Approach Separation (deciding on the Separation/Spacing Minima to be applied in the prevailing operating conditions in the context of the reduction of the MRS to 2NM on final approach);
- Use Case-2a: MRS 2NM with ORD Tool;
- Use Case-2b: MRS 2NM without ORD Tool.

For more details about the operational concept, please see the PJ02-03 OSED/SPR/INTEROP document [10].

2.3 Details of the change

The Baseline

The Baseline is the current Final Approach operations with the 2.5 NM MRS. The baseline was discussed during the Human Performance (HP) and Safety (SAF) scoping & change assessment session which took place in Charles de Gaulle (CDG) in November 2017. Although each Very Large, Large or Medium airport has a specific procedure, it can be concluded that, mostly, the MRS used on the Final Approach path is 2.5 NM (for more information, the document “PJ02 03 Reference scenario” [15] provides the details of the current operations in CDG, London Heathrow (LHR) and Vienna (VIE) airports) .

However, the area where 2.5NM MRS applies is specific to each airport. Two categories have been identified:

- 2.5NM MRS extended to the base leg: case of Heathrow - separation between individual pairs of aircraft following the same final approach track or adjacent parallel runway approach tracks or between an aircraft on intercept or base leg and a preceding aircraft on the straight in final

approach track, provided that the second aircraft of any given pair is within 20 NM from the runway landing threshold, the surveillance accuracy is adequate and wake turbulence separation is not required between the specific aircraft in each pair;

- 2.5NM MRS limited to the point of convergence to the final approach path: case of e.g. CDG or Vienna (separation between individual pairs of aircraft following the same final approach track or between an aircraft converging to the final approach path with an angle of less than X° and a preceding aircraft on the final approach track, provided that the second aircraft of any given pair is within 12 NM from the runway landing threshold, the surveillance accuracy is adequate, wake turbulence separation is not required between the specific aircraft in each pair).

The Change

The main changes compared to the Baseline are:

- The ATCOs will apply reduced Separation/Spacing Minima or ROT Spacing (down to the 2NM MRS) to certain categories or aircraft pairs, supported by specific procedures and/or the ORD supporting tool;
- More specifically, each Use Case involves specific changes, as follows:
    - Use Case-1. Planned Changes of Final Approach Separation, describing how the Tower and Approach Supervisors coordinate between each other to decide the Separation/Spacing Minima to be used. The coordination includes analysing the specific weather conditions and the decision with regards to the last/first aircraft the new Separation/Spacing Minima is applicable from. Once decided, the new Separation/Spacing Minima are communicated to the Approach and Tower Controllers;
    - Use Case-2a. MRS 2NM with ORD Tool: the use of a separation delivery support tool (the ORD tool) that, for a local traffic and the local meteorological conditions, computes the required separation minima possibly reduced down to the MRS 2 NM MRS where and when possible accounting for weather dependant wake constraints and applicable ROT spacing. The ORD tool support needs to be adapted for considering the in-trail MRS constraint change from 2.5NM to 2NM on the straight-in final approach.
    - Use Case-2b. MRS 2NM without ORD Tool: this can be applied with the European separation standard for aircraft wake turbulence (RECAT-EU) Distance Based Wake Turbulence Category (WTC) scheme, allowing the Distance Based Separation (DBS) minima associated to some pair categories to be reduced from 2.5 NM to 2.0 NM provided that reduced MRS is also acceptable from a ROT point of view. It is also possible to apply 2NM MRS with the ICAO WTC Distance Based scheme, but this requires a wind based conditional reduction of the Separation/Spacing Minima for the accommodation of the Medium-Medium categories. This means that when applying 2NM MRS with the ICAO WTC DBS scheme, the Separation/Spacing Minima can be reduced to 2NM only if the wind conditions are above a certain threshold. This conditional application, based on wind criteria, will require the airport to dispose of adequate means for wind measuring (on surface and glide path) in order to get both

actual wind values and wind prediction for managing the safe activation/deactivation of the Separation/Spacing mode. For the safety analysis for the ICAO M-M pairs, please see Appendix E.

2.4 General Approach to Safety Assessment

A Broader approach

The safety assessment has been conducted in accordance with the SESAR Safety Reference Material (SRM) [1] and associated Guidance [2]. The SRM is based on a twofold approach:

- a new *success approach* which is concerned with the safety of the Minimum Pair Separation Based on RSP arrival procedures concept, in the absence of failure; and
- a conventional *failure approach* which is concerned with the safety of the Minimum Pair Separation Based on RSP arrival procedures concept, in the event of failure within the end-to-end System

These two approaches are applied to the derivation of safety properties at each of two successive stages of the development of the Minimum Pair Separation Based on RSP, as follows:

Safety specification at the OSED Level

This is defined as what the new concepts have to achieve at the Air Traffic Management (ATM) operational level in order to satisfy the requirements of the airspace users - *i.e.* it takes a "black-box" view of the new method of operations and includes what is "shared" between the users and the Air Traffic Service (ATS) Providers.

From a safety perspective, the user requirements are expressed in the form of SAfety Criteria (SAC) and the Specification is expressed in the form of Safety Objectives (functionality & performance and integrity/reliability properties), which are derived during the V1 and V2 phases of the development lifecycle. The purpose is to check the completeness of the OSED and identify possible additional validation objectives to be revealed by the safety analysis in view of their inclusion in the Validation plans.

Safe Design at the SPR Level

This describes what the new concept is actually like internally and includes all those system properties that are not directly required by the users but are implicitly necessary in order to fulfil the specification and thereby satisfy the user requirements. Design is essentially an internal, or "white-box", view of the Minimum Pair Separation Based on RSP operations. This is more generally called the SPR-level Model and is expressed in terms of human and machine "actors" that deliver the functionality.

From a safety perspective, the Design is expressed in the form of Safety Requirements (sub-divided into functionality & performance and integrity/reliability properties), which are derived starting with the V2 phase of the development lifecycle. The purpose here is to feed the SPR/INTEROP/OSED with a complete and correct set of safety requirements. Furthermore, if relevant, interact with the validation exercises so as to include additional safety validation objectives and obtain validation feedback regarding certain proposed safety requirements.

2.5 Scope of the Safety Assessment

The following parts of the safety assessment lifecycle are covered by the current issue of the SAR:

- **V1** - through initial identification of safety implications of the Change and the definition of Safety Criteria
- **V2 & V3**- through establishing Safety Objectives (**at OSED level**) to deliver the Safety Criteria and the derivation of Safety Requirements for the logical design (**at SPR and TS level**) to satisfy the Safety Objectives (based on combined safety analysis of the design, data analysis for wake encounter risk and safety-related measurements, observations and debriefing of the validation exercises). The safety assessment for Safety Requirements derivation will align with the design maturity (i.e. successive inclusion of OIs). The safety assessment will be conducted to the level of granularity decided by the Project for the OSED/SPR/INTEROP and TS/IRS documents for the design of the Functional system for the Solution (encompassing people, procedures & airspace and equipment). **Only for the technical elements** of the Functional system design, the safety requirements will be derived at two levels: SPR level (high-level technical elements) and TS level (Functional Blocks out of which the high-level technical elements are built), whilst ensuring requirements traceability of the latter towards the SPR level requirement(s). The V2&V3 safety assessment outcomes are documented in this SAR.

The current version of the SAR covers the Use Cases included in the OSED/SPR/INTEROP [10], which are:

- Use Case-1: Planned Changes of Final Approach Separation (deciding on the Separation/Spacing Minima to be applied in the prevailing operating conditions in the context of the reduction of the MRS to 2NM on final approach);
- Use Case-2a: MRS 2NM with ORD Tool;
- Use Case-2b: MRS 2NM without ORD Tool.

The Safety assurance activities will be conducted in line with the SESAR Safety Reference Material (SRM) [1] and accompanying Guidance [2].

2.6 Layout of the Document

Section 1 presents the executive summary of the document

Section 2 provides a high level description of the change and background of the Minimum Pair Separation Based on RSP arrival procedures concept, the principles of the safety assessment in SESAR and the scope of this safety assessment

Section 3 addresses the safety specification at OSED level, through the definition of Safety Criteria (SAC), the determination of Safety Objectives (SO) and link to validation objectives

Section 4 addresses the safe design at SPR level, through the derivation of Safety Requirements (SR) and link to validation results

Appendix A which shows the AIM models applicable to PJ02.03

Appendix B which shows the complete set of EATMA models used to derive the functionality and performance Safety Objectives

Appendix C which shows the results of the PJ02.03 SAF and HP Workshop at Heathrow Airport

Appendix D showing the results of the scoping and change assessment workshop

Appendix E showing the analysis done for the conditional application enabling the 2.0NM MRS concept for ICAO M-M pairs

Appendix G showing the consolidated list of Safety Requirements

Appendix H showing the Collision Risk Modelling for Heathrow Approaches performed by NATS

Appendix I showing the Surveillance Performance Assessment of 2NM Separations at Heathrow performed by NATS

3 Safety specifications at the OSED Level

3.1 Scope

This section addresses the following activities:

- Description of the key properties of the Operational Environment that are relevant to the safety assessment – section 3.2

- The description of the benefits of the new concept – section 3.3

- Identification of the pre-existing hazards that affect traffic in the relevant operational environment (airspace, airport) and the risks which are expected to be reasonably mitigated to some degree and extent by the operational services provided by the Solution – section 3.5

- Setting of the SAfety Criteria (from the Solution Safety Plan [3]) – section 3.4

- Comprehensive determination of the operational services that are provided by the Solution to address the relevant pre-existing hazards and derivation of Safety Objectives (success approach) in order to mitigate the pre-existing risks under normal operational conditions – section 3.5

- Assessment of the adequacy of the operational services provided by the Solution under abnormal conditions of the Operational Environment – section 3.7

- Assessment of the adequacy of the operational services provided by the Solution in the case of internal failures and mitigation of the System-generated hazards (derivation of Safety Objectives (failure approach)) – section 3.8

- Achievability of the SAfety Criteria – section 3.9

- Validation & verification of the safety specification – section 3.10

3.2 Solution Operational Environment and Key Properties

This sub-section describes the key properties of the Operational Environment that are relevant to the PJ02-03 safety assessment (information summarized from the OSED/SPR/INTEROP, section 3.2 [10]).

3.2.1 Airspace and Airport characteristics

Very Large, Large and Medium airports, and Terminal Very High, High and Medium Complexity sub operational environments.

3.2.2 Airspace Users – Flight Rules

Instrument Flight Rules (IFR) traffic only

3.2.3 Traffic Levels and complexity

In Baseline: level of traffic in peak hours as per the current Runway (RWY) throughput at Very Large, Large and Medium airports.

With Solution: level of traffic in peak hours as per the increased RWY throughput enabled by the Solutions for Very Large, Large and Medium airports.

3.2.4 Terrain Features – Obstacles

No specific terrain features or obstacles.

3.2.5 Separation Minima

In the Baseline Scenario the ICAO radar separation standards for arrivals [17] with an MRS of 2.5 NM (intended to protect aircraft from MAC risk on final approach) and WT separation standards as per currently applicable WTC separation schemes of ICAO [17], UK or RECAT-EU (intended to protect aircraft from adverse Wake Turbulence Encounters -WTEs).

With the Solution Scenario, the 2NM MRS could be applied with any Wake Separation rules, whilst accounting for the necessary adaptations required for the wake aircraft pairs in the interval between 2 and 2.5 NM. There is also a need to take into account the Separation/Spacing Minima and/or the ROT Spacing constraints where the required spacing for the lead aircraft to be clear of the runway for the follower aircraft to be able to land may be greater than both the MRS and the required Wake Separation.

For the complete set of conditions necessary to employ the 2NM MRS concept please see the OSED [10].

3.2.6 Ground ATM capabilities & CNS aids

In Baseline Scenario:

- Instrument Landing System/Microwave Landing System (for precision ILS approach procedures) Ground Based Augmentation System (GBAS) for GBAS approach procedures and adequate RNAV/GNSS coverage and related infrastructure for RNAV/GNSS non-precision approach procedures
- Surveillance System (TMA and on Approach& Final Approach path) with sufficient update rates: for example, Primary & Secondary Surveillance services with at least a 4s update rate, or the Automatic Dependent Surveillance Broadcast (ADS-B) Surveillance Service with at least a 1s update rate;
- Flight Data Processing System
- Arrival Manager (might be required on Very Large and Large airports but not systematically on Medium airports)
- Surveillance System for Surface Movement (e.g. Advanced Surface Movement Guidance and Control System (A-SMGCS))
- Tower CWPs (Airport Tower Supervisor, Tower Runway Controller, Tower Ground Controller, Tower Clearance Delivery Controller or Apron Manager)
    - Electronic Flight Progress Strips
    - Traffic Situation View Display

- Meteorological Information Display
- ATC Voice Communications

- TMA CWPs (TMA Supervisor, TMA Planning Controller, Intermediary and Final Approach Controllers)
  - Flight Progress Strips (Either electronic or paper)
  - Radar Situation View Display
  - ATC Voice Communications

With Solution Scenario:

Besides the need for ORD tool support which is part of the Change, the following ground ATM capabilities are considered in the operational environment:

- Required Surveillance Performance for the 2NM separation as described in the OSED/SPR/INTEROP [10]. For example, Primary & Secondary Surveillance services with at least a 4s update rate (for example the Multi-Radar Tracking Service with a 4s update rate) and the Automatic Dependent Surveillance Broadcast (ADS-B) Surveillance Service with at least a 1s update rate.
- Local environment weather information and wind forecasting and monitoring capabilities (in order to support the Wind based conditional Separation/Spacing Minima reduction down to 2NM MRS (for ICAO M-M pairs – more details in Appendix E); and Use Case-2a: 2NM MRS with the ORD tool, as the ORD tool support relies on wind forecasting and monitoring for the calculation of the ITD in DB-modes and for both ITD and FTD in TB-modes)

3.2.7 Aircraft ATM capabilities

No change from Baseline, i.e.:

- Capability for intercepting and flying the Final Approach path for precision ILS approach procedures, GBAS approach procedures or RNAV/GNSS non-precision approach procedures
- Transponder (Elementary Mode-S Surveillance (ELS) or Mode A/C)
- Flight Management System (FMS) Capability
- Air-Ground Voice Communication System (VCS)

3.3 Stakeholder's expectations which impact Safety

The improvements expected from PJ02.03 which impact Safety are:

- **Runway Capacity:** The reduction of separation has a direct impact on runway throughput and therefore runway capacity.

- **Resilience:** The change introduced by this solution is based on the non-constraining wake factor, if the headwind conditions on final approach change for example the ATCO will be informed and the separation will be adapted accordingly. Thus the time separation for non-wake constrained pairs may be stabilised beyond that of the ROT Spacing distance reducing to the current in-trail 2.5 NM MRS constraint in moderate headwind conditions to that of the ROT

Spacing distance reducing to below the 2.5NM MRS to up to the new 2 NM MRS constraint in strong and very strong headwind conditions.

For information about the other KPIs impacted by this project, please see the OSED/SPR/INTEROP [10].

3.4 SAfety Criteria

Safety Criteria (SAC) define the acceptable level of safety (i.e. accident and incident risk level) to be achieved by the Solution under assessment, considering its impact on the ATM/ANS functional system and its operation.

The SAC setting is driven by the analysis of the impact of the Change on the relevant AIM models and it needs to be consistent with the SESAR safety validation targets defined by PJ 19.04 (as per [12]).

For PJ02-03 the Safety Validation Target is:

"The reduction in the total number of WAKE Final Approach accidents per year of -0.32% and in the total number of RWY Collision accidents per year of -0.22%, due to SESAR 2020 improvements with respect to a hypothetical "do nothing" scenario, in which no changes are made to ATM safety of the Baseline (2005) while traffic is allowed to increase until it reaches the capacity level targeted for SESAR in 2035."

(note that the safety benefit is the outcome of maintaining the Baseline safety levels whilst accepting the Capacity benefit i.e. traffic increase brought in by the Concept)

Two sets of safety criteria are formulated:

- A first one aimed at ensuring an appropriate Separation design i.e. definition of separation minima and associated application rules which, if correctly followed in operation, guarantee safe operations on final approach path;

- A second one aimed at ensuring correct Separation delivery i.e. that the defined separation minima and associated application rules are correctly followed for separation delivery by ATC.

Note the SACs derived in the next paragraphs are applicable when the 2NM MRS concept is applied with and possibly without the ORD Separation Delivery Tool. Details about if the ORD Separation Delivery Tool could/needs to be used to demonstrate a specific SAC are provided in the safety assurance strategy for each SAC.

SEPARATION DESIGN

With regards to the design of the surveillance separation minima below 2.5NM and down to 2NM:

- on risk of infringement of surveillance separation minima on final approach path, with potential for Imminent collision (see in AIM MAC FAP model MF4 in A.1):

M-SAC#1: The probability per approach of aircraft infringing the surveillance separation minima (with potential for Imminent collision) on final approach path when the ATM/ANS functional system is performing as specified shall be no greater in operations with reduced MRS down to 2NM than with MRS at 2.5NM.

Safety assurance strategy for the design of MRS 2NM separation minima & rules with or without the tool:

- providing evidence that the RSP enables safe employment of the 2NM MRS (potential need for collision risk modelling)
- providing evidence that ATCO can manage the separation on final approach path without infringing the surveillance separation minima more often than with MRS at 2.5NM (based on time estimation of sequences of events, potentially fed by RTS observation of the actual ATCO reaction time); two aspects need to be included:
    - the ATCO performance without triggering the STCA*;
    - the ATCO reaction in response to an STCA alert (basically similar to the one in Baseline operations, but is it still fast enough in order to prevent an imminent collision, i.e. a large radar separation infringement?)

*It should be noted that this is only applicable for the airports where STCA is kept active on the final approach path.

With regards to the design of the WT separation minima, i.e. identifying aircraft pairs (in DB and TB modes) and wind conditions (in TB mode only) for which there is no wake constraint above the 2NM minima:

- on risk of WT Encounter on Final Approach related to correct application of the WT scheme under consideration (see in AIM WT on Final Approach model in A.2 the outcome of precursor WE6S “Imminent wake encounter under fault-free conditions” not mitigated by barrier B2 “Wake encounter avoidance”):

W-SAC#1: For an aircraft type pair on Final Approach path spaced at a value below 2.5NM but above 2NM, and in the applicable wind conditions, the pair-wise wake turbulence encounter severity shall not be higher than the severity of reference aircraft type pair (selected as acceptable baseline with proven extensive operations) at ICAO minima and in reasonable worst-case conditions[2].

Safety assurance strategy for the design of WT separation minima & rules:

- For Static MRS reduction:
    - With or without the tool: make use of the DB RECAT-EU WT scheme, by retaining only those pairs with DB minima equal or below 2NM.
    - With tool only: make use of the RECAT-EU-PWS WT scheme (Table 19 in RECAT-EU-PWS Safety Case [11]), by retaining only those pairs with minima equal or below 2NM.

The following safety issue remains still to be addressed:

[2] Reasonable worst case conditions recognized for WT separation design as detailed at [8] §4.2.1

ISSUE#001: The frequency of wake turbulence encounters at lower severity levels might increase for MRS infringements bigger than 0.5NM due to the reduced separation minima. As the frequency of wake turbulence encounters at each level of severity depends on local traffic mix, local wind conditions and proportion of time of application of the concept, there is a need to find a suitable way for controlling the associated potential for WT-related risk increase.

Proposed strategy:

- Either to perform assessment for several airport samples in order to demonstrate the low effect of MRS reduction on frequency of WT encounter of higher severities.
- Or to derive a safety recommendation for the local implementation of a specific WT separation concept to conduct an analysis which, for the given local traffic mix and wind conditions, estimates the net effect on the frequency of wake turbulence encounters at each level of severity in comparison to an accepted baseline.
- It should be noted that that the infringement procedures with respect to the MRS require controllers to immediately restore the MRS or to discontinue the approach due to the impact of such infringements on MAC risk. Normally, this should happen before the infringement grows to 0.5NM under separation.

With regards to the design of separations accounting for the ROT spacing constraint, i.e. identifying aircraft pairs and/or wind conditions that maintain situations when the ROT spacing is higher than the 2NM minima to an acceptable level:

- on risk of Runway Conflict when APP ATCO correctly applies the ROT constraint (see RP2.4 in RWY Col model):

R-SAC#1: For an aircraft type pair on Final Approach path spaced at a value below 2.5NM but above 2NM, and in the applicable wind conditions, the probability per approach of runway conflict resulting from Conflicting ATC Clearances when correctly following the applicable ROT spacing minima shall be no higher than that probability for a reference aircraft type pair (selected as acceptable baseline with proven extensive operations) in reasonable worst-case conditions and with MRS at 2.5NM.

Safety assurance strategy to account for the ROT spacing constraint:

- The data analysis will identify the aircraft pairs and/or the wind conditions, in each Use Case, for which MRS can be reduced while maintaining the probability of separation provision below ROT minima to an acceptable level. This will be performed by comparing the ROT distribution to the time separation distribution corresponding to the reduced MRS. The ROT distribution is intrinsically aircraft type and airport-dependent (as it depends on the runway exit geometry). Example of application of the developed methodology will be analysed based on data from some exemplary airports. The “acceptable” rate of aircraft pairs delivered below ROT minima will also be defined on a local basis corresponding to the value observed today, and allowing the APP and TWR ATCO to safely deal with them. For airports with high average ROT, the ROT constraint

might become a show-stopper for the concept. Meanwhile, SESAR PJ02.08 is working at defining ROT more granularly (e.g. defining ROT aircraft or category wise rather than an average ROT value), which may provide the means to implement the 2NM MRS for these airports as well.

- In the Real Time Simulation (RTS), the traffic samples with the pre-calculated rate of ROT-constrained aircraft pairs will be presented to ATCOs in order to validate that they can operate safely (based on ATCOs debriefing/subjective feedback and on counting the Go arounds due to ROT, ensuring the acceptable Go around rate is not overpassed).

SEPARATION DELIVERY

MAC accident:

A set of SACs are defined in order to ensure that the reduced MRS down to 2NM is correctly applied for **separation assurance and delivery of the non-wake constrained pairs**, i.e. that the right System in terms of People, Procedures, Equipment (e.g. separation delivery tool) is designed such as to enable safe operation. The correct application of reduced MRS down to 2NM needs to account for the radar separation constraints during interception. For achieving that, the safety risk related to radar under-separation (during interception and Final Approach path) and its precursors needs to be controlled, driven by the AIM MAC Final Approach model (see A.1).

- on risk of Imminent collision during interception and final approach (see in AIM MAC FAP model MF4):

M-SAC#F1: The probability per approach of Imminent collision during interception and final approach shall be no greater in operations with reduced MRS down to 2NM than with MRS at 2.5NM.

Safety assurance strategy with or without the tool:

- recording of 2NM radar separation infringements and comparison against the number of 2.5NM radar separation infringements in Baseline (separation minima to be modulated for the interception area) (from RTS, acknowledging the limited statistical relevance in relation to the rare occurrences);
- expert-based analysis of failure causes, risk assessment and mitigation.
- Note: the risk assessment, in terms of harmful effect of the 2NM separation infringement should also account for the WT encounter effect. As explained in the next paragraph (definition SACs for Wake turbulence accident), a large infringement (with more than 0.5NM) of the 2NM separation minima has a higher potential for wake encounter than an equivalent infringement of the 2.5NM separation minima.

The following Safety issue (coupled with a performance issue) has been identified:

ISSUE#002: In current operations, under specific conditions (applicable at most of the Very Large, Large and Medium airports) MRS is reduced to 2.5NM on the Final Approach path (up to a certain distance from the threshold) but 3 NM apply on the base leg and upstream. Heathrow represent an exception, as the reduction to 2.5NM is extended to the base leg provided that

the lead aircraft is established on the straight-in extended runway centre-line and that the second aircraft of any given pair is within 20 NM from the threshold.

It is expected that the extension of 2.5NM MRS to the base leg will be beneficial for the gain in RWY throughput (the RTS will assess the expected reduction of the gain in RWY throughput in relation to the need for maintaining 3NM until the aircraft is converging for interception and then progressively catching up attempting to reach 2NM MRS later on the final approach path). Furthermore, it is expected that the extension of 2.5NM MRS to the base leg would contribute to the reduction of the separation minima infringement during the transitioning to 2NM MRS on final approach, thanks to the smoothening of this transition (progressive reduction from 3NM to 2.5NM followed by 2.5NM to 2NM).

A safety assessment is required for the extension of 2.5NM MRS to the base leg on Very Large, Large and Medium airports other than Heathrow.

The related safety case performed by NATS for Heathrow would be a desirable input for addressing within the PJ02-03 the above safety&performance issue.

- on risk of Imminent infringement (radar separation) during interception and final approach path (see in AIM MAC FAP model MF5.1 & MF5.2 in A.1):

M-SAC#F2: The probability per approach of Imminent infringement during Interception & final approach shall be no greater in operations with reduced MRS down to 2NM than with MRS at 2.5NM

Safety assurance strategy with or without the tool:

- recording the 2NM under-separations (large and small) and comparison against the number of 2.5NM under-separations (from RTS)
- expert-based analysis of failure causes, risk assessment and mitigation (similar to the one performed for PJ02.03).

- on risk of Crew/Aircraft induced spacing conflicts (spacing conflicts induced by Crew/Aircraft and not related to ATC instructions) during interception and final approach (see in AIM MAC FA model MF9 and MF7 in A.1):

M-SAC#F3: The probability per approach of Crew/Aircraft induced spacing conflicts during interception & final approach shall be no greater in operations with reduced MRS down to 2NM than with MRS at 2.5NM

Safety assurance strategy with or without the tool: The reduction of MRS down to 2NM might increase the occurrence of speed deviations due to Pilots reluctance of getting closer to the leading aircraft. The risk will be considered and a potential mitigation could be a requirement for the new reduced MRS information to be widely disseminated to Pilots.

Wake turbulence accident:

No specific SAC is defined for the issue regarding the large infringement (more than 0.5NM) of the 2NM separation minima which has a higher potential for wake encounter compared to the same infringement of the 2.5NM separation minima. This is because the safety assurance strategy proposed

to be applied in relation to the M-SAC#F1 (that has been identified for the MAC accident) is considered sufficient for covering both the risk for imminent collision and the risk for severe wake encounter which are associated to the separation minima infringement.

Regarding the **potential side effect** of the 2NM separation minima (applied to non wake constrained pairs) **on the separation delivery of the wake constrained pairs**, via impact on ATCOs workload or Situation Awareness, the following need to be considered:

- on risk of Unmanaged under-separation (wake) during interception and final approach of the wake constrained aircraft pairs (see in AIM WT model WE 7F.1 in A.2):

W-SAC#F2: The probability per approach of Unmanaged under separation (wake) of wake constrained pairs during interception & final approach shall be no greater in operations with reduced MRS down to 2NM than with MRS at 2.5NM.

Safety assurance strategy with or without the tool: via RTS - both debriefing with participating ATCOs and comparison of significant wake separation infringements (e.g. more or equal than 0.25NM) between Solution and Baseline, (acknowledging the limited statistical relevance in relation to the rare occurrences).

- on risk of Imminent infringement (wake) during interception and final approach (related to wake constrained aircraft pairs) (see in AIM WT model WE 8 in A.2):

W-SAC#F4: The probability per approach of Imminent infringement (wake) of wake constrained pairs during Interception & final approach shall be no greater in operations with reduced MRS down to 2NM than with MRS at 2.5NM

Safety assurance strategy with or without the tool: via RTS - both debriefing with participating ATCOs and comparison of minor wake separation infringements (e.g. less than 0.25NM) between Solution and Baseline.

RWY Collision accident:

- on risk of Imminent Inappropriate Landing (see in AIM RWY collision model A.3, the precursor RP2.4 which might be caused by e.g. spacing management by APP ATCO without considering ROT constraint and which outcome is mitigated by B2: ATC Collision Avoidance involving e.g. last moment detection by TWR ATCO with or without Runway Incursion Monitoring and Conflict Alert System RIMCAS):

R-SAC#F1: The probability per approach of Runway Conflict resulting from Conflicting ATC clearances shall be no greater in operations with reduced MRS down to 2NM than with MRS at 2.5NM

- R-SAC#1 is intended for ensuring that the number of occurrences where APP ATCO transfers to TWR ATCO an aircraft without enough ROT spacing (thus involving Go around) will not increase.

It should be noted that no SAC was derived for the risk of Runway conflict due to premature landing (not cleared by ATCO) or unauthorised RWY entry of ac/vehicle as no change is introduced by the 2NM MRS concept compared to today's operations.

3.5 Relevant Pre-existing Hazards

A pre-condition for performing the safety assessment for the introduction of a new Concept is to understand the impact it would have in the overall ATM risk picture. The SRM Guidance D and E [2] provides a set of Accident Incident Models (AIM - one per each type of accident) which represent an integrated risk picture with respect to ATM contribution to aviation accidents.

In order to determine which AIM models are relevant for the PJ02 Solution 3, this sub-section presents the relevant aviation hazards that have been identified within the HP&SAF scoping & change assessment session (using Guidance F.2.2 of [2]). The relevant pre-existing hazards for Final Approach, together with the corresponding ATM-related accident types and AIM models are presented in **Error! Reference source not found.**.

Pre-existing Hazards [Hp]	ATM-related accident type& AIM model
Hp#1a "Adverse wake encounter on Final Approach"	Wake Turbulence-induced Accident (WTA) on Final Approach & associated AIM model in Appendix A.2
Hp#2a "Situation in which the intended 4D trajectories of two or more airborne aircraft are in conflict during interception & final approach"	Mid-Air Collision (MAC) on the Final Approach path- & associated AIM model in Appendix A.1
Hp#3 "The preceding landing aircraft are not clear of the runway-in-use"	Runway Collision (RC) & associated AIM model in Appendix A.3

Table 1 Pre-existing hazards relevant for Final Approach

3.6 Mitigation of the Pre-existing Risks – Normal Operations

3.6.1 Operational Services to Address the Pre-existing Hazards

The concept under assessment is applicable to the final approach operations from interception until the aircraft has landed. Therefore, both Approach Control Service and Aerodrome Control Service are impacted. The Air Traffic Management / Air Navigation (ATM/ANS) services listed in Table 2 below have been considered relevant for these concepts:

ID[3]	Air Navigation Service Objective	Pre existing Hazard
Approach and Landing		

[3] SP= SeParate aircraft with other aircraft

SP1a	Maintain spacing/separation between aircraft during interception of the final approach path	**Hp#1a** (WTA risk) **Hp#2a** (MAC risk)
SP1b	Maintain spacing/separation between aircraft on the same final approach path	**Hp#1a** (WTA risk) **Hp#2a** (MAC risk) **Hp#3** (Rwy collision risk)
SP2	Maintain aircraft separation between successive arrivals on the Runway Protected Area (RPA)	**Hp#3** (Rwy collision risk)

Table 2: Relevant ATM/ANS and Pre-existing Hazards for Arrivals

3.6.2 Derivation of Safety Objectives (Functionality & Performance – success approach) for Normal Operations

The purpose of this section is to derive functionality & performance Safety Objectives (as part of the success approach) in order to mitigate the pre-existing aviation risks under normal operational conditions (i.e. those conditions that are expected to occur on a day-to-day basis) such as to meet the defined Safety Criteria.

To derive the Safety Objectives we need to interpret, from a safety perspective, the OSED Operational Concept specification (i.e. how the PJ02-03 concept contributes to the aviation safety) by making use of the European Air Traffic Management Architecture (EATMA) representation as per the Operational layer. More specifically, this means using the OSED Use Cases and their representation through the EATMA Process Models as defined by the PJ02-03 OSED [10] and as shown in Appendix B. The purpose is to derive a complete list of Safety Objectives, allowing to specify the Change involved by the Concept at the operational service level, by considering the 2NM MRS concept as a series of continuous processes described through the Use Cases. That allows showing how the Safety Objectives participate in the achievement of the relevant operational services and contribute to safety barriers (in the relevant AIM models) i.e. how they contribute to meeting the Safety Criteria.

Table 3 presents the consolidated list of functionality & performance Safety Objectives (SO) under normal operational conditions. The link to the Safety Criteria is shown in the last column for each SO, via the relevant Use Case and operational service that are concerned with the change and allowed the SO derivation.

ID	Safety Objective *(success approach)*	Use Case	Operational Service	Related SAC# (AIM Barrier or Precursor)
	Applicable with or without the Separation Delivery Tool			
SO 012	2NM MRS shall be applied only when the Separation/Spacing Minima constraints and the provision of appropriate ROT Spacing are actively managed through the supporting of specific ATC procedures allowing predefined conditions influencing ROT to be satisfied (e.g. braking action reported as good, no runway contaminants such as lush, snow or ice, etc.)	MRS 2NM without ORD tool (Figure 16) MRS 2NM with ORD tool (Figure 15)	SP1a: Maintain spacing/separation between aircraft during interception of the final approach path SP2b: Maintain spacing/separation between aircraft on the same final approach path	**R-SAC#1**
SO 006	When applying 2NM MRS, ATC shall sequence and instruct aircraft to intercept the final approach path such as to establish and maintain the 2NM MRS minimum on the final approach segment (including estimating the correct compression to be applied) with or without the help of the Target Distance Indicators	MRS 2NM without ORD tool (Figure 16) MRS 2NM with ORD tool (Figure 15)	SP1a: Maintain spacing/separation between aircraft during interception of the final approach path SP2b: Maintain spacing/separation between aircraft on the same final approach path	**M-SAC#F1** **M-SAC#F2** **W-SAC#F2** **W-SAC#F4**

SO 010	When applying 2NM MRS, ATC shall provide correct spacing from final approach path acquisition until landing such that to ensure the correct separation minima delivery based on correctly computed separation indicators	As above	SP1b: Maintain spacing/separation between aircraft on the same final approach path	**M-SAC#F1** **M-SAC#F2** **W-SAC#F2** **W-SAC#F4** **R-SAC#1**
Applicable only with the Separation Delivery Tool				
SO 008	The Target Distance Indicators shall be calculated and displayed to correctly and accurately represent the greatest constraint out of wake separation minima, MRS, the runway spacing or other spacing constraint (e.g. departure gaps)	MRS 2NM with ORD tool (Figure 15)	As above	**M-SAC#F1** **M-SAC#F2** **W-SAC#F2** **W-SAC#F4** **R-SAC#1**
SO 009	The design of the Separation Delivery Tool and associated operating procedures and practises shall not negatively impact Flight Crew/Aircraft who shall be able to follow ATC instructions in order to correctly intercept the final approach path in the mode under consideration	As above	SP1a: Maintain spacing/separation between aircraft during interception of the final approach path	**M-SAC#F3**

SO 011	ATC and Flight Crew/Aircraft shall ensure that the final approach path is flown whilst respecting the aircraft speed profile (unless instructed otherwise by ATC or airborne conditions require to initiate go around) in order to ensure correctness of the separation indicators	As above	SP1b: Maintain spacing/separation between aircraft on the same final approach path	**M-SAC#F3**

Table 3: Safety Objectives (success approach) Normal Conditions

3.7 Safety Objectives under Abnormal Conditions

The purpose of this section is to assess the ability of operations based on the new MRS separation mode and ATC tools to work through (robustness), or at least recover from (resilience) any abnormal conditions that might be encountered relatively infrequently (these might be either operational situations/use cases that have not been covered in 3.6.2 or conditions external to the scope of the new System which are not under control).

3.7.1 Identification of Abnormal Conditions

The following abnormal conditions have been identified in PJ02.01 and are also relevant for this solution:

ID	Abnormal Scenario
1	Change of Aircraft landing runway intent (with the Separation Delivery Tool)
2	Abnormal procedural aircraft airspeed and/or abnormal stabilized approach speed
3	Lead aircraft go-around
4	Delegation of separation to Flight Crew
5	Actual Wind on final approach different from the wind used for FTD/ITD computation
6	Flight Crew Notification of Aircraft Speed non-conformance
7	Unexpected drop of surface wind below safe threshold
8	Late change of landing runway (not planned)
9	Wet runway/icy runway affecting normal breaking action
10	Normal runway exit not available

Note in the analysis below, it is specified for each abnormal situation if it applies to when the 2NM MRS concept is used with or without the Separation Delivery tool.

1/ CHANGE OF AIRCRAFT LANDING RUNWAY INTENT **(WITH THE SEPARATION DELIVERY TOOL)**

No change introduced by this solution compared to PJ02.01.

Mitigation SO 103 also applies to Sol 03.

2/ ABNORMAL PROCEDURAL AIRCRAFT AIRSPEED AND/OR ABNORMAL STABILIZED APPROACH SPEED **(WITH THE SEPARATION DELIVERY TOOL)**

This situation represents the case of an aircraft not respecting the procedural airspeed before the Deceleration Fix (e.g. respecting 160 IAS) or the stabilized approach speed specific to the aircraft type (e.g. VAPP) after the Deceleration Fix.

This could be a problem when the Separation Delivery Tool is used for the application of 2NM MRS, the risk being that the ITD (for all pairs) and FTD (only for ICAO M-M pairs in TB mode) are erroneous,

as its computation is based on the pre-defined True Air Speed (TAS) profile for that aircraft type, with potential for imminent infringement and need to instruct a missed approach due to compression after the deceleration fix – mitigation as per SO 102 –i.e. aircraft speed conformance alert.

For the affected aircraft, ATC need to manage compression manually.

3/ Lead aircraft go-around **(with or without the Separation Delivery Tool)**

This situation represents the case where the lead Aircraft is executing a missed approach at any point during the final approach (either instructed by ATC or decided by Flight Crew).

In case the separation delivery tool is used, the risk is for ATCO to not update the arrival sequence which might involve the use of incorrect TDIs (corresponding to a different aircraft) with potential for imminent infringement and ultimately large under-separation – mitigation is derived as per SO 103.

Regardless if the separation delivery tool is used or not, a generic wake risk assessment needs to be performed for the 2NM MRS non wake pairs for the case where the leader performs a go-around and the follower, separated at or close to the separation minima, continues its descent possibly crossing the leader's descending wake. Mitigation derived as per SR3.034.

4/ Delegation of separation to Flight Crew **(with or without the Separation Delivery Tool)**

No change introduced by this solution compared to PJ02.01.

6/ Flight Crew Notification of Aircraft Speed non-conformance **(with the Separation Delivery Tool)**

No change introduced by this solution compared to PJ02.01.

Mitigation SO 104 also applies to Sol 03.

8/ Late change of landing runway - not planned **(with the Separation Delivery Tool)**

No change introduced by this solution compared to PJ02.01.

Mitigation SO 105 also applies to Sol 03.

9/ Wet runway/icy runway affecting normal breaking action **(with or without the Separation Delivery Tool)**

A wet and icy runway, affecting the normal breaking action would affect the ROT, which will have an impact on the minimum Separation/Spacing. This is mitigated by the normal operations SO 002.

10/ Normal runway exit not available **(with or without the Separation Delivery Tool)**

The unavailability of a runway exit could affect the ROT, which could have an impact on the minimum Separation/Spacing. Mitigation as per normal operations SO 002.

3.7.2 Potential Mitigations of Abnormal Conditions

The following Safety Objectives considering the abnormal conditions identified above have been derived for arrivals, applicable only with the separation delivery tool:

ID	Description	Abnormal Scenario
SO 102	ATC shall be alerted when the aircraft speed varies significantly from the procedural airspeed and/or the stabilized approach speed used for the TDIs computation (speed conformance alert) in order to manage compression manually	2
SO 103	ATC shall maintain an updated arrival sequence order following a late change of aircraft runway intent or a go-around	1 and 3
SO 104	ATC shall take into account, for the merging on to final approach, the notified approach procedural airspeed non-conformance issues and any notified employment of a slow or fast landing stabilisation speed to determine the additional spacing that is required to be set up behind the ITD indication	6
SO 105	The Target Distance Indicators shall be correctly updated in case of late (not planned) change of landing runway	8

Table 4: List of Safety Objectives (success approach) for Abnormal Operations for the PJ02.03

3.8 Mitigation of System-generated Risks (failure approach)

This section concerns operations in the case of internal failures. Before any conclusion can be reached concerning the adequacy of the safety specification at the OSED level, it is necessary to assess the possible adverse effects that failures internal to the end-to-end Functional System supporting the new radar separation mode and ATC tools might have upon the provision of the relevant operations and to derive safety objectives (failure approach) to mitigate against these effects.

This section provides the list of the identified Operational Hazards, their operational effects, with the mitigation of those effects and the associated severity. The severity classification scheme is based on the Wake Turbulence Accident on Final Approach and the Mid Air Collision on Final Approach Models (see Appendix A).

3.8.1 Identification and Analysis of System-generated Hazards

This section contains the list of hazards relevant to PJ02.03, initially identified in PJ02.01, and further refined to reflect the developments of PJ02.03 during a workshop which took place at Heathrow Airport premises on March 29th 2019. The workshop was facilitated by SAF and HP experts from EURCONTROL and it included APP, TWR ATCOs and Supervisors, together with safety, human performance and concept experts. For the full list of participants please see Appendix C.

The Operational Hazards have been identified at operational service level, i.e. aligned to the Safety Objectives in normal conditions and such as to allow their anchoring into the AIM Wake Turbulence Accident model.

The following tables provide the consolidated list of the identified Operational Hazards from Sol 01 and which are applicable for Sol 03 as well, with their operational effects, the mitigations protecting against effect propagation and the allocated severity, updated and validated in the frame of PJ02.03. The severity allocation was based on the severity classification schemes of the relevant Accident Incident Models (AIM) as per the guidance to SRM [2] (Guidance E) and which are included in Appendix A.

Note since all operational hazards from Sol 01 are relevant in Sol 03, all have been kept and are shown in Table 5 even though Sol 03 does not introduce changes in all of them. However, fault trees will be developed and shown in detail only for the hazards in which a change is introduced by Sol 03. The analysis from Sol 01 will be referenced for the rest.

ID	Hazard Description	High Level Causes (derived from Success SO)	Operational Effects	Mitigations protecting against propagation of effects	Severity *(most probable effect)*
Hz#01a		Applicable with or without the Separation Delivery Tool: Inadequate ATCO instruction Inadequate ATCO-pilot communication	ATCO may be drawn into reducing below the 2.5 NM MRS and 1000ft before the current transition procedures (from 3 to 2.5NM or 1000ft) allow, especially when the Separation Delivery Tool is used, due to the ATCO being drawn in delivering to the TDI. This means an imminent infringement, i.e. spacing is eroded with risk for temporary and limited under-separation (e.g. less than 0.5 NM) during separation establishment on Final App or later during Final App can happen.	**Protective Mitigations** Resolve situation by vectoring, level instructions or go-around WAKE FAP B3 Management of Imminent Infringement MAC FAP B3 ATC Collision Avoidance	WK-FA-SC3b MAC-FA-SC3
Hz#01b	Separation not being recovered following imminent infringement of A/C pair instructed by ATC	Applicable with or without the Separation Delivery Tool:	Large under-separation (of more than e.g. 0.5 NM) occurs during separation establishment on Final App or later during Final App.	**Protective Mitigations** With respect to WTE risk: Follower within WV influence area, WV survival in the flight path (F6) – this is degraded	WK-FA-SC3a MAC-FA-SC2b

[4] Example: LOC overshoot resulting in the follower catching-up the leader that performed the overshot; one cause might be the wrong or untimely ATCO heading instruction; a second cause might be the late Pilot response.

	to merge on the Final Approach interception	(e.g. Go around, break off etc- depends on the triggering event) ATCO failure to instruct timely the separation recovery action before the imminent infringement is evolving to a large under-separation Pilot failure to timely execute the separation recovery instruction		with MRS 2NM (compared to MRS 2.5NM) **Use case with the Separation Delivery Tool**: The **use of tool is expected to mitigate** that risk increase by contributing to the reduction of separation infringements thanks to the increased separation delivery accuracy. **Use case without the Separation Delivery Tool**: **With regards to risk of wake encounter**: A DBS separation table will be used manually (e.g. RECAT-EU). The non wake pairs can be delivered in RSVA below 2NM MRS subject to local ROT spacing procedures (encompassing necessary wind conditions, RWY conditions, etc.). **With regards to risk of MRS infringement** (e.g. case of radio failure affecting both aircraft): **SAF REQ: a Collision Risk Model shall be built**	

				locally, allowing to prove that the collision risk is at acceptable levels considering the distribution of the aircraft pairs, wind conditions, etc. WAKE FAP F6 Wake Decay & Transport MAC FAP B2 ACAS Warning	
Hz#02a	Inadequate separation management of a spacing conflict due to aircraft deviation from Final Approach interception profile without ATC instruction given	Applicable with or without the Separation Delivery Tool: Unanticipated pilot/aircraft behaviour during interception (overshoot; a/c lateral, vertical or speed deviation; wrong a/c turns on the indicator)	Spacing is eroded with risk for temporary and limited under-separation (e.g. less than 0.5 NM) during separation establishment on Final App or later during Final App	**Protective Mitigations** ATC recovery from imminent infringement by adequate action (vectoring, level instructions or go-around) Continue with the currently applicable rules for allowing to decrease from 3NM to 2.5NM upon turning on to intercept (spacing buffer leaving room for separation recovery during interception) WAKE FAP B3 Management of Imminent Infringement	WK-FA-SC3b MAC-FA-SC3

				MAC FAP B3 ATC Collision Avoidance	
Hz#02b	Separation not being recovered following imminent infringement due to aircraft deviation from Final Approach interception profile without ATC instruction given				
Hz#03a	Inadequate separation management of an aircraft pair naturally catching-up as instructed by ATC on the Final Approach	Applicable only with the Separation Delivery Tool: Inadequate use of separation indicators by the APP ATCO when a/c is established on final Lack/loss of indicator for one aircraft on Final App	Imminent infringement, i.e. spacing is eroded with risk for temporary and limited under-separation (e.g. less than 0.5 NM) the Final App	**Protective Mitigations** ATCO detects the missing indicator and: Aircraft established on Final approach stabilized with 160kts IAS and behind ITD is allowed to continue the approach, otherwise initiate Go around	WK-FA-SC3b MAC-FA-SC3

				WAKE FAP B3 Management of Imminent Infringement MAC FAP B3 ATC Collision Avoidance	
Hz#03b	Separation not being recovered following imminent infringement by an aircraft pair instructed by ATC on the Final Approach				
Hz#4a	Inadequate separation management of a spacing conflict due to aircraft deviation from Final Approach profile without ATC instruction given	Applicable with or without the Separation Delivery Tool:	Spacing is eroded with risk for temporary and limited under-separation (e.g. less than 0.5 NM) on the Final App	**Protective Mitigations** Supported by catch-up warning; Re-clear a/c to fly a different speed if possible OR Go-around; WAKE FAP B3 Management of Imminent Infringement MAC FAP B3 ATC Collision Avoidance	WK-FA-SC3b MAC-FA-SC3
Hz#4b	Separation not being recovered				

	following imminent infringement due to aircraft deviation from Final Approach profile without ATC instruction given				
Hz#05	One or multiple separation minima infringements due to undetected corruption of separation indicator	Applicable only with the Separation Delivery Tool: Corruption of one or multiple separation indicators	Large under-separation (of more than e.g. 0.5 NM) occurs for one or multiple aircraft pairs on the Final App	**Protective Mitigations** Partial mitigation: Buffer for ITD and FTD take margins on the wind computation. In DB-mode: ATCO will realise that the tool is using incorrect wind reference because successive aircraft separated correctly using the indicators will have the tendency to infringe the correct FTD as the leader decelerates, triggering a go-around by the TWR controller.	WK-FA-SC3a MAC-FA-SC2b *However, because multiple aircraft might be affected before failure is detected, a Safety Objective more demanding than the corresponding hazard severity will be allocated*

				In TB-mode for ICAO M-M pairs: It is difficult for the ATCO to realise that the tool is using incorrect wind reference. The a/c will be separated according to a wrong FTD, i.e. wake separation infringement. *For the incorrect separation indicator in relation to speed non-conformance:* go-around of the follower (because TDI might be wrong) WAKE FAP F6 Wake Decay & Transport MAC FAP B2 ACAS Warning	*via an impact modification factor IM=20*
Hz#06	One or multiple imminent infringements due to lack/loss of separation indicator for multiple or all aircraft	Applicable only with the Separation Delivery Tool:	One or multiple imminent infringements, i.e. spacing is eroded with risk for temporary and limited under-separation (e.g. less than 0.5 NM) on the Final App	**Protective Mitigations** ATCO detects the missing indicators and reverts to Baseline DBS (a supporting DBS table is required, especially in TB PWS with multiple categories)	WK-FA-SC3b MAC-FA-SC3 *However, because multiple aircraft might be affected before failure is detected, a*

				Aircraft established on Final approach stabilized with 160kts IAS and behind ITD are allowed to continue the approach All other aircraft – either not established on Final or not at stabilized IAS 160kts or not behind ITD: - Initiate Go-around or break off - Establish ICAO DBS asap WAKE FAP B3 Management of Imminent Infringement MAC FAP B3 ATC Collision Avoidance	*Safety Objective more demanding than the corresponding hazard severity will be allocated via an impact modification factor IM=10*
Hz#08	Runway conflict due to landing clearance in conflict with another landing (ROT not respected)	ATCO not compliant with correct ROT Wrong sequence planning information Loss or corruption of the sequence list tool	The situation when an arrival aircraft is landing on a runway which is being used by another aircraft which just landed, the two aircraft being thus in conflict, but where the situation is solved by the corrective action of the TWR ATCO (e.g. initiate go-around).	**Preventive Mitigations:** A wrong Sequence planning information is systematically detected by ATCO (via his situation awareness & own view of the correct sequence and possible use of a gap)	RWY-C SC3

				A failure, loss or corruption of the sequence list tool will have an impact on the ATCO performance, but is safely mitigated by ATCO keeping full awareness of the sequence in the short term. ATCO will apply a more conservative strategy (e.g. instruct 2 departures in a gap instead of the 3 initially planned), will estimate the departures fitting in the arrival gaps by himself. **Protective Mitigations** Go around timely instructed & executed (RWY Col AIM Barrier B2)	

Table 5: System-Generated Hazards and Analysis

3.8.2 Derivation of Safety Objectives (integrity/reliability)

Safety Objectives (addressing integrity/reliability) are formulated to limit the frequency at which the operational hazards in section 3.8.1 could be allowed to occur using the Risk Classification Scheme defined in Appendix A.

Table 5 lists the failure Safety Objectives (integrity/reliability) to be considered during the design phase.

Even though all the hazards identified in section 3.8.1 have been allocated two severities since they impact both WAKE FAP and MAC FAP, quantitative figures have been assigned only for the WAKE FAP severities. This is because there were no figures for the severity classification scheme of the MAC FAP model at the creation of this safety assessment report. When the figures for the MAC FAP model will be available, the two severities (MAC and WAKE) will have to be compared and the most stringent should be applied for the Safety Objectives in Table 5.

SO ref (hazard severity)	Safety Objectives (integrity/reliability)
Safety Objectives relative to the Final Approach interception phase	
SO 201 SO#01a (WK-FA SC-3b MAC-FA-SC3) Applicable with or without the Separation Delivery Tool	The frequency of occurrence of the inadequate separation management of a pair of aircraft instructed by ATC to merge on the Final Approach interception (which is nevertheless recovered by ATC i.e. SMI[5]≤0.5NM), shall not be greater than 2x10-3 /approach *(2x10-3/approach means 2 occurrences every 3 days for an airport with 135,000 landings per year)* ***Explanation:*** *Computation of the Safety Objective:* $SO = \frac{MTFoO}{N*IM} = \frac{1E-02}{5*1}$ *= 2E-03 occurrences per approach* *Computation of the no of occurrences per day: 1/(2E-03*135000/365) = 0.74* *Which comes to 2 occurrences every 3 days*
SO 202 SO#01b (WK-FA-SC3a MAC-FA-SC2b)	The frequency of occurrence of separation not being recovered following imminent infringement of A/C pair instructed by ATC to merge on the Final Approach interception (SMI>0.5NM) shall not be greater than 4x10-5/ approach *(4x10-5/approach means 6 occurrence per year for an airport with 135,000 landings per year)*

[5] SMI stands for Separation Minima Infringement (WT or MRS)

Applicable with or without the Separation Delivery Tool	
SO 203 SO#02a (WK-FA SC-3b MAC-FA-SC3) Applicable with or without the Separation Delivery Tool	The frequency of occurrence of the inadequate separation management of a spacing conflict due to aircraft deviation from Final Approach interception profile without ATC instruction given (which is nevertheless recovered by ATC i.e. SMI≤0.5NM), shall not be greater than 2x10-3 /approach *(2x10-3/approach means 2 occurrences every 3 days for an airport with 135,000 landings per year)*
SO 204 SO#02b (WK-FA-SC3a MAC-FA-SC2b) Applicable with or without the Separation Delivery Tool	The frequency of occurrence of separation not being recovered following imminent infringement due to aircraft deviation from Final Approach interception profile without ATC instruction given (SMI>0.5NM) shall not be greater than 4x10-5/approach *(4x10-5/approach means 6 occurrence per year for an airport with 135,000 landings per year)*
Safety Objectives relative to the Final Approach phase	
SO 205 SO#03a (WK-FA SC-3b MAC-FA-SC3) Applicable with or without the Separation Delivery Tool	The frequency of occurrence of the inadequate separation management of an aircraft pair naturally catching-up as instructed by ATC on the Final Approach (which is nevertheless recovered by ATC i.e. SMI≤0.5NM) shall not be greater than 2x10-3 /approach *(2x10-3/approach means 2 occurrences every 3 days for an airport with 135,000 landings per year)*
SO 206 SO#03b (WK-FA-SC3a MAC-FA-SC2b) Applicable with or without the	The frequency of occurrence of separation not being recovered following imminent infringement by an aircraft pair instructed by ATC on the Final Approach (SMI>0.5NM) shall not be greater than 4x10-5/approach *(4x10-5/approach means 6 occurrences per year for an airport with 135,000 landings per year)*

Separation Delivery Tool	
SO 207 SO#04a (WK-FA SC-3b MAC-FA-SC3) Applicable with or without the Separation Delivery Tool	The frequency of occurrence of the inadequate separation management of a spacing conflict due to aircraft deviation from Final Approach profile without ATC instruction given (which is nevertheless recovered by ATC i.e. SMI≤0.5NM) shall not be greater than 2x10-3 /approach *(2x10-3/approach means 2 occurrences every 3 days for an airport with 135,000 landings per year)*
SO 208 SO#04b (WK-FA-SC3a MAC-FA-SC2b) Applicable with or without the Separation Delivery Tool	The frequency of occurrence of separation not being recovered following imminent infringement due to aircraft deviation from Final Approach profile without ATC instruction given (SMI>0.5NM) shall not be greater than 4x10-5/approach *(4x10-5/approach means 6 occurrences per year for an airport with 135,000 landings per year)*
SO 212 Hz#08 (RWY-C SC3)	The frequency of occurrence of a runway conflict due to conflicting ATC clearances shall not be greater than 10-7/movement. (10-7/movement means 2,6x10-4/day) It should be noted that **2,6x10-4/day** is **too stringent** for this type of operational hazard. This value will be updated once the Severity Classification Scheme for the Runway Collision Model is updated.
Safety Objectives relative to Interception and Final Approach (common mode failures)	
SO 209 SO#05 (WK-FA-SC3a MAC-FA-SC2b; IM=20) Applicable only with the Separation Delivery Tool	The frequency of occurrence of one or multiple separation minima infringements due to undetected corruption of separation indicator (SMI>0.5NM) shall not be greater than 2x10-6/approach *(2x10-6/approach means 1 occurrences every 4 years for an airport with 135,000 landings per year)* *Explanation:* *Computation of the no of occurrences per year: 1/(2E-6*135000/365 = 7.4E-04* *Which comes to 1 occurrence every 1350 days which represents 1 occurrence every 3.7 years (rounded down to 1 occurrence every 4 years)*

SO 210 SO#06 (WK-FA-SC3a MAC-FA-SC2b; IM=10) Applicable only with the Separation Delivery Tool	The frequency of occurrence of one or multiple imminent infringements due to lack/loss of separation indicator for multiple or all aircraft (which are nevertheless recovered by ATC i.e. SMI≤0.5NM) shall not be greater than 2x10-4 /approach *(2x10-4/approach means 1 occurrence every 15 days for an airport with 135,000 landings per year)*

Table 6: Safety Objectives (integrity/reliability) for the PJ02-03

Figure 1 depicts the structure relating the different Safety Objectives as determined by the causal links between the corresponding hazards, respectively for the interception phase (IA) and during the final approach (FA). The safety objectives corresponding to the hazards based on common modes failures (addressing both phases) are stand-alone (no link to other hazards). This structure is further detailed in section 4.5 within the causal analysis of each hazard, based on Fault Trees.

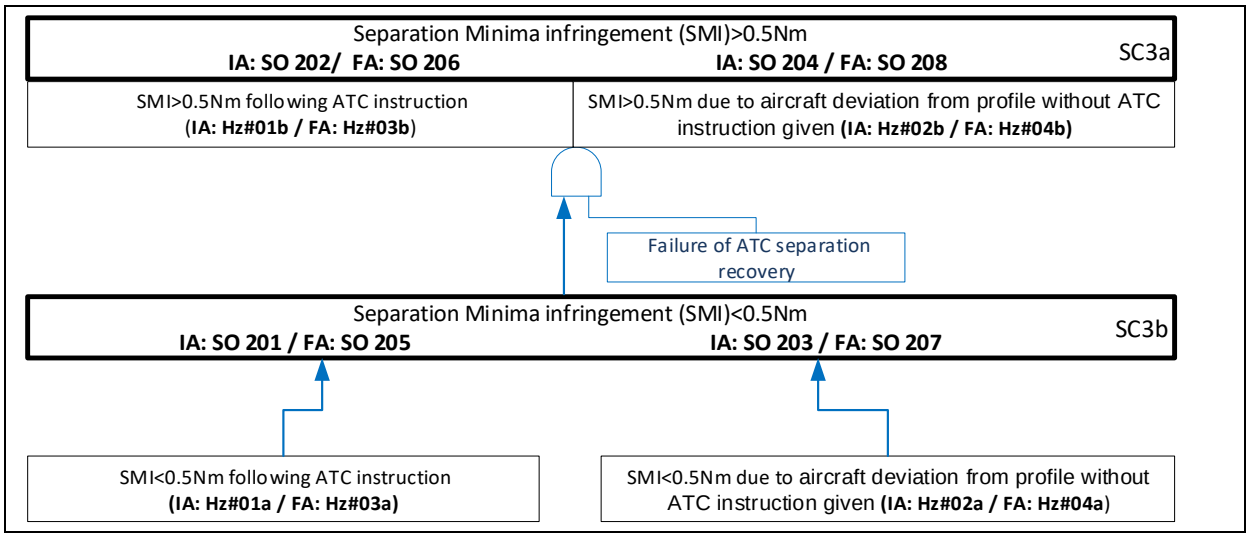

Figure 1: Safety Objectives with Hazards associated tothe Interception of the Final Approach (IA) respectively the Final Approach until delivery at the threshold (FA)

3.9 Achievability of the Safety Criteria

As specified in the Safety Plan [3], safety evidence will be collected from the validation exercises planned as per the Validation Plan [14]. Safety Validation Objectives are defined in the Validation Plan and the safety-related outcomes of the validation exercises will feed the Safety Criteria and will be traced back to the safety validation objectives. Decision for deriving (or not) Safety Requirements will be taken from these results.

The exercise safety validation objectives and the related success criteria are summarized in Table 7 below, for all the safety relevant exercises performed in the frame of PJ02.03. The last column indicates the Safety Criteria that are covered by each validation exercise or other validation method (e.g. safety assessment through analysis and brainstorming with operational experts).

Exercise ID, Name, Objective	Exercise Validation objective	Success criterion	Safety Criteria coverage
EXE-PJ02-03 VALP-RTS02: RTS conducted by EUROCONTROL to assess the operational feasibility and acceptability of reducing the in-trail Minimum Radar Separation (MRS) from 2.5 NM to 2 NM under applicable separation scheme on the final approach under IMC. The main focus of this real time simulation was to assess the in-trail 2 NM MRS combined with TB PWS for arrivals and the ORD tool (Use case [MRS-2a] MRS 2NM with ORD Tool) under segregated mode runway operations.	**OBJ-PJ2.03-V3-VALP-SA1** To assess the impact on operational safety of applying an in-trail Minimum Radar Separation of 2NM during interception and final approach compared to applying the 2.5NM Minimum Radar Separation.	**CRT-PJ2.03-V3-VALP-SA3-001** The level of operational safety is maintained and not negatively impacted under the in-trail 2 NM MRS with ORD tool during interception and final approach compared to when applying the in-trail 2.5 NM MRS without indicators, despite the potential increase in controller workload (in relation to the expected throughput increase).	**M-SAC#1** **W-SAC#F2** **W-SAC#F4**
		CRT-PJ2.03-V3-VALP-SA3-002 Evidence that using the in-trail 2 NM MRS with ORD tool will decrease the number of separation minima infringements compared to using the in-trail 2.5 NM MRS without indicators (in order to compensate for the potential severity increase of the wake separation infringements and of the radar separation infringements – the latter in relation to the reduction of the time available for ATCO and Pilot reaction time)	**M-SAC#F1** **M-SAC#F2**

		CRT-PJ2.03-V3-VALP-SA3-003 The number of Go around due to inadequate consideration of ROT constraint is not increased (for RWY conflicts)	**R-SAC#F1**
	RTS02 Prototyping session: 2NM MRS DBS ICAO <u>NO SUPPORTING TOOL.</u> Even though safety was assessed during this prototyping session, there were no official safety validation objectives for it. Please see section 4.6 for the results.		
EXE-PJ02-03 VALP-FTS03: Conducted by CRIDA to support the Safety Assessment for the in-trail 2 NM arrival separation concept on the final approach. This FTS assessed the safety impact of the in-trail 2 NM arrival separation solution on the final approach with regards to the risk of collision due to a catch up scenario using multiple aircraft types as the leader and follower pairs. This FTS focused on Use case [MRS-2b] MRS 2NM <u>without ORD Tool</u>	**OBJ-PJ02.03-V3-VALP-SA1** To provide evidence that the minimal pair arrival separation reduction to 2 NM on final approach is safe using currently available surveillance means	**CRT-PJ2.03-V3-VALP-SA3-001** At least one of the surveillances means tested shows no collisions for all included aircraft pairs.	**M-SAC#1**

EXE-PJ02-03 VALP-FTS01 Conducted by EUROCONTROL to support the CBA for the reduction of the in-trail radar separation minima to 2 NM on the final approach. This RTS covered multiple generic environments and supported the validation of the capacity benefit for a range of operational configurations. This FTS focused on Use case [MRS-2a] MRS 2NM with ORD Tool.	No Safety Validation Objective needed to be set for this FTS

Table 7 PJ02.03 exercise safety validation objectives and the related success criteria

3.10 Validation & Verification of the Safety Specification

This section describes the processes by which safety criteria and objectives were derived as well as details of the competencies of the personnel involved.

The Safety Criteria have been derived based on information collected during the HP&SAF Scoping & Change assessment workshop, which took place on the 23th of November 2017. The workshop gathered significant participation of the PJ02.03 operational and technical experts. For more details about the workshop please see the attachment in Appendix D.

The functionality and performance SOs (normal conditions) have been derived based on the up to date EATMA Process Models describing the OSED Use Cases. Furthermore, a HAZID identification & safety requirements validation workshop was organised on March 29th 2019 at Heathrow Airport premises in order to address the concept covered to date (aligned with the completed exercise RTS2 focused on the application of 2NM MRS with the ORD tool). The workshop was facilitated by SAF and HP experts from EURCONTROL and it included APP, TWR ATCOs and Supervisors, together with safety, human performance and concept experts. For the full list of participants and more details about the workshop results please see Appendix C.

The current safety assessment report also takes on board the relevant results from SESAR 1 P06.08.01, namely:

- P06.08.01 TB S-PWS Safety Assessment [9] appendix I about AO-0309 (Minimum Pair Separations based on Required Surveillance Performance - 2NM Radar Separation)

4 Safe Design at SPR Level

4.1 Scope

This section addresses the following activities:

- Description of the SPR-level model of the end-to-end Solution ATM System - Section 4.2
- Derivation, from the Safety Objectives (Functionality and Performance) in Section 3.6.2, of Safety Requirements for the SPR-level design– Section 4.2.2
- Analysis of the operation of the SPR-level design under normal operational conditions– Section 4.3
- Analysis of the operation of the SPR-level design under abnormal conditions of the Operational Environment– Section 4.4
- Assessment of the adequacy of the SPR-level design in the case of internal failures and mitigation of the System-generated hazards– Section 4.5
- Justification that the SAfety Criteria are capable of being satisfied in a typical implementation– Section 4.6
- Realism of the SPR-level design – Section 4.7
- Validation & Verification of the Specification– Section 4.8

4.2 The Solution SPR-level Model – NSV-4 EATMA Diagram

The SPR-level Model in this context is an architectural representation of the Solution System design in the form of an NSV-4 EATMA diagram. This model is entirely independent of the eventual physical implementation of the design. It describes the main human tasks, machine functions and airspace design in accordance with the three Use Cases from the OSED [10].

4.2.1 Description of SPR-level Model

Figure 2, Figure 3 and Figure 4 show the EATMA NSV4 diagrams, which is the equivalent of the SPR-level Model.

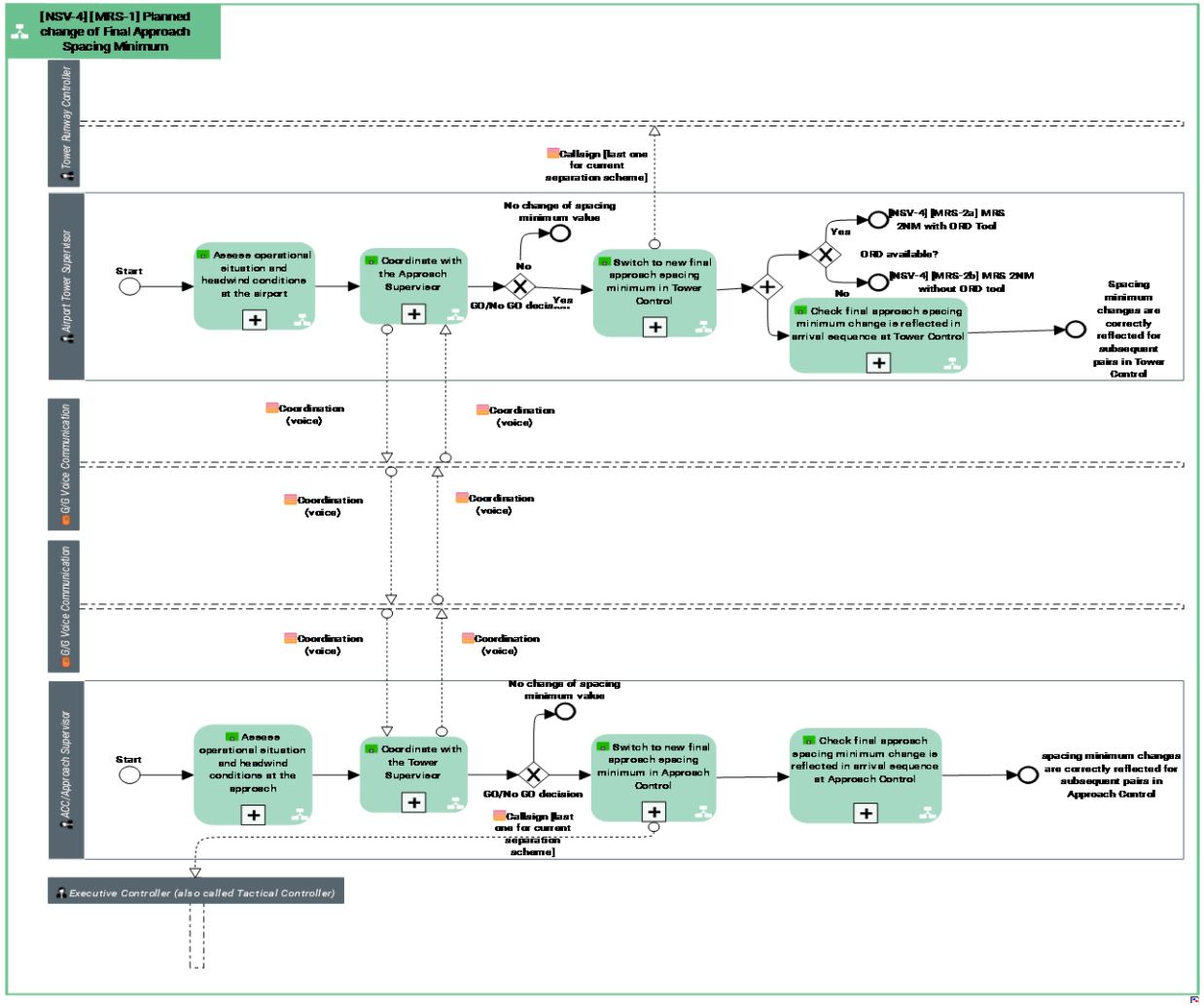

Figure 2 UC 1 Planned change of Final Approach Separation NSV4 EATMA diagram

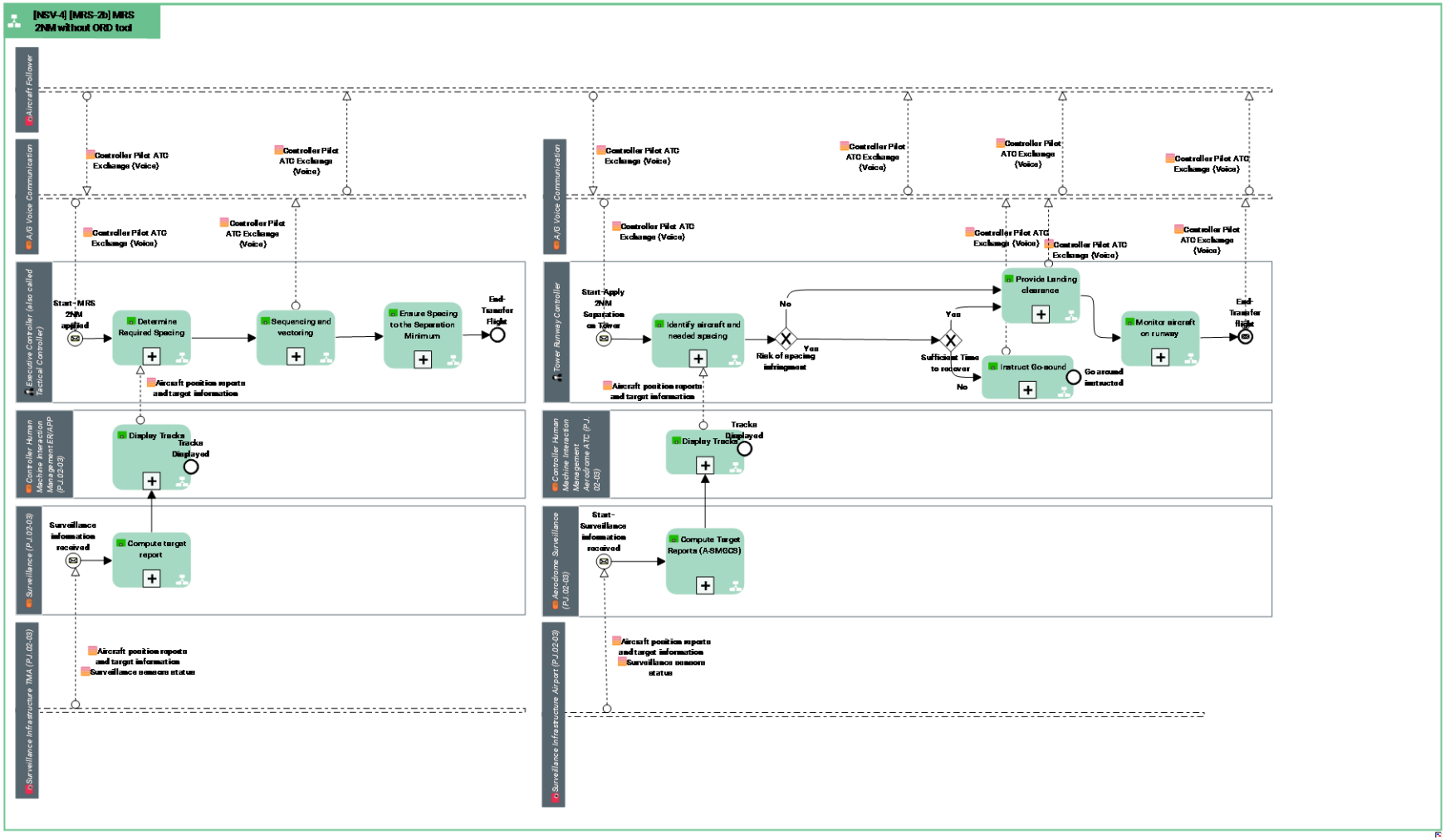

Figure 3 UC 2 MRS 2NM without ORD Tool NSV4 EATMA diagram

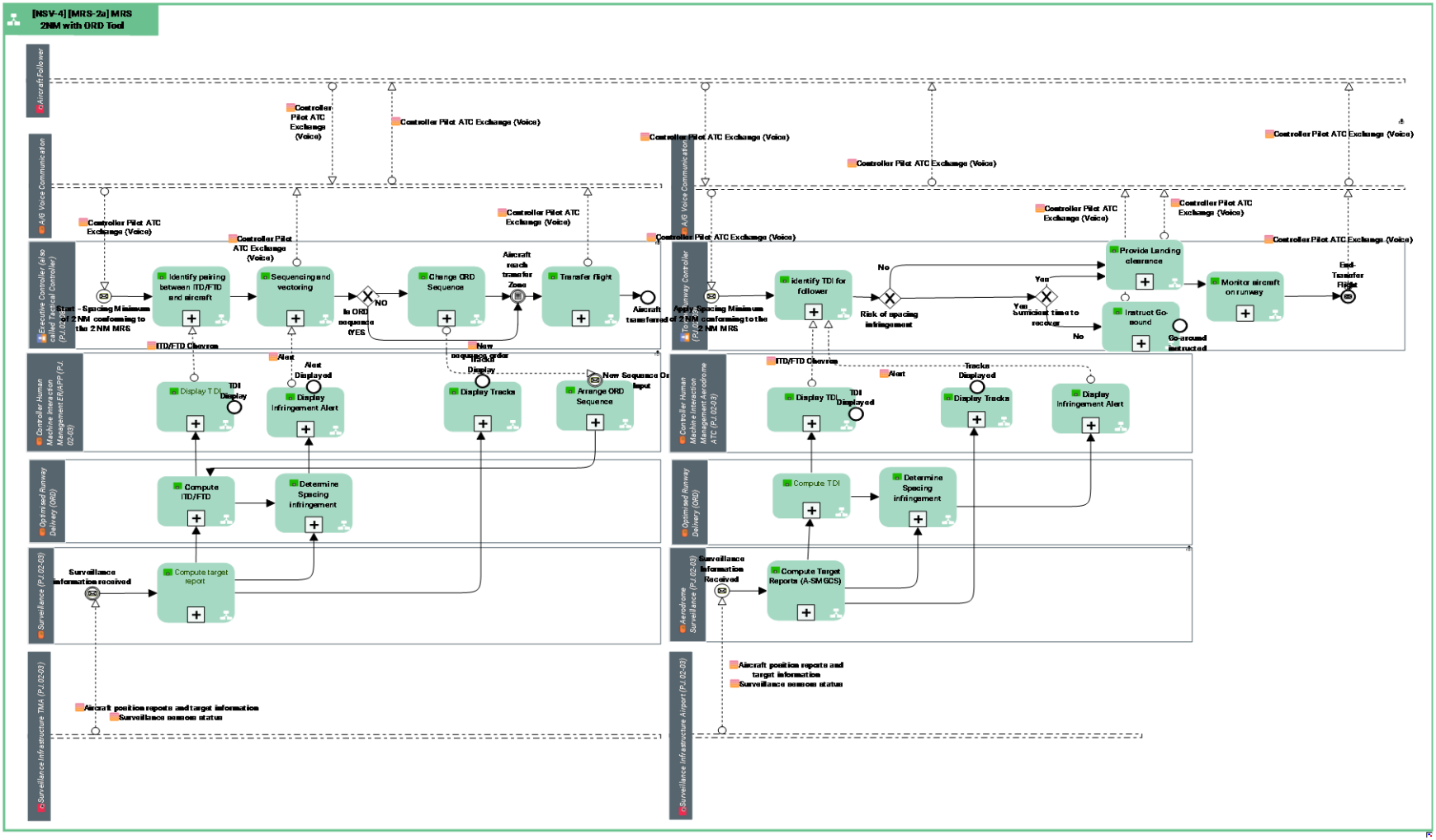

Figure 4 UC 3 MRS 2NM with ORD Tool NSV4 EATMA diagram

Function	Description
Arrange ORD Sequence	The System shall allow the ATCO to change the arrival sequence, the ORD computes the separation minima based on this sequence.
Change ORD Sequence	The system shall allow the ATCO to change the ORD list to reflect the arrival sequence.
Compute ITD/FTD	This function computes the ITD and FTD for the Approach position.
Display TDI	This function allows the display of the Target Display Indicator, depending on the implementation and local choice, it can be either ITD, FTD or both.
Identify pairing between ITD/FTD and aircraft	ATCO shall identify the TDI for each aircraft in the ORD computation zone.
Compute target report	The function calculates the position of the aircraft based on the surveillance input.
Transfer flight	The controller instructs the aircraft to contact the next ATS Unit.

Table 8 Description of the EATMA NSV4 diagram - UC [MRS2a] MRS 2NM with ORD Tool

4.2.2 Derivation of Safety Requirements (Functionality and Performance – success approach)

Table 9 below, uses the outcome of the previous sub-section and the Safety Objectives from Section 3.6.2 to derive the corresponding Safety Requirements (Functionality and Performance) by considering the SPR level Model (i.e. the NSV4 EATMA Diagram).

For the requirements where it is not specified, it shall be considered that they apply for both with and without the ORD tool. When a requirement applies only for the case "with" or "without" the ORD tool, it is specified in the requirement's text.

Safety Objectives **(Functionality and Performance from success approach)**	**Safety Requirement**	**Maps on to EATMA Diagram**
Applicable with or without the Separation Delivery Tool		
2NM MRS shall be applied only when the Separation/Spacing Minima constraints and the provision	SR3.030 The reduction to 2 NM MRS shall be applied only when the Separation/Spacing Minima constraints and the provision of	*MRS 2NM without ORD Tool:* APP "Compute target report" "Display tracks"

of appropriate ROT Spacing are actively managed through the supporting of specific ATC procedures allowing predefined conditions influencing ROT to be satisfied (e.g. braking action reported as good, no runway contaminants such as lush, snow or ice, etc.)	appropriate ROT Spacing are actively managed through the supporting of specific ATC procedures allowing predefined conditions influencing ROT to be satisfied (e.g. braking action reported as good, no runway contaminants such as slush, snow or ice, etc.)	TWR "Compute target report (A-SMGCS)" "Display tracks" *MRS 2NM with ORD Tool:* APP *"Compute target report"* *"Display tracks"* TWR "Compute target report (A-SMGCS)" "Display tracks"
When applying 2NM MRS, ATC shall sequence and instruct aircraft to intercept the final approach path such as to establish and maintain the 2NM MRS minima on the final approach segment (including estimating the correct compression to be applied) with or without the help of the Target Distance Indicators	SR3.001 The Approach controllers and, if applicable, Tower controllers shall be supported by a surveillance system compatible with a safety case that guarantees the required surveillance performance for the application of the 2NM minimum radar separation *For an example of a local surveillance performance assessment case study, please see Appendix H which contains the Surveillance Performance Assessment of 2NM Separations at Heathrow Airport.*	*MRS 2NM without ORD Tool:* APP "Compute target report" "Display tracks" TWR "Compute target report (A-SMGCS)" "Display tracks" *MRS 2NM with ORD Tool:* APP *"Compute target report"* *"Display tracks"* TWR "Compute target report (A-SMGCS)" "Display tracks"
	SR3.002 The longitudinal position update interval shall be less than or equal to 4 seconds.	As above
	SR3.003 The pressure altitude update interval shall be less than or equal to 4 seconds	As above
	SR3.004 The aircraft identity update interval shall be less than or equal to 4 seconds.	As above
	SR3.005 The probability of the longitudinal position update shall be greater than or equal to 97%.	As above
	SR3.006 The ratio of missed 3D positions involved in long gaps shall be less than or equal to 0.25%.	As above

	SR3.007 The longitudinal positional RMS error shall be less than or equal to 200 metres per flight.	As above
	SR3.008 The ratio of longitudinal position update interval involved in a series of at least 3 consecutive errors larger than 0.5 Nm shall be less than or equal to 0.003%.	As above
	SR3.009 The average data age of the forwarded pressure altitude shall be less than or equal to 2.5 seconds.	As above
	SR3.010 The ratio of incorrect forwarded pressure altitude shall be less than or equal to 0.01%.	As above
	SR3.011 The unsigned pressure altitude error shall be less than or equal to 300ft in 98.5% of the cases.	As above
	SR3.012 The delay in the change in emergency indicator/SPI report shall be less than or equal to 7.5 seconds.	As above
	SR3.013 The delay in the change in aircraft identity shall be less than or equal to 15 seconds.	As above
	SR3.014 The probability that the update of the aircraft identity with valid and correct values shall be greater than or equal to 98%.	As above
	SR3.015 The ratio of incorrect aircraft identity shall be less than or equal to 0.1%.	As above
	SR3.016 The rate of descent RMS error should be less than or equal to 500 ft/min.	As above
	SR3.017 The track velocity RMS error shall be less than or equal to 4 m/s.	As above

	SR3.018 The track velocity angle RMS error shall be less than or equal to 10 degrees.	As above
	SR3.019 The density of uncorrelated false target reports shall be less or equal to 1 false target report per 855 updates.	As above
	SR3.020 The probability of a critical failure shall be less than or equal to 2.5x10^-5 per hour of operation.	As above
	SR3.026 Local procedures/rules shall be defined in order to ensure safe transition of the aircraft from 3NM to 2NM MRS, such as to avoid loss of separation minima during on base leg	MRS 2NM without ORD Tool: APP *"Determine Required Spacing"* MRS 2NM with ORD Tool: APP *"Identify pairing between ITD/FTD and aircraft"*
	SR3.033 When operating under 2NM MRS without the Separation Delivery Tool, the APP ATCO shall receive additional training to emphasize the specific use of the IAS and GS indications for managing separation at interception	MRS 2NM without ORD Tool: Executive Controller *"Determine Required Spacing"*
	SR3.027 When the Separation Delivery Tool is used, the training curricula shall ensure the ATCOs are capable of maintaining the required separations on base leg (horizontal and vertical) despite getting in the habit of working with the TDIs on the axis	MRS 2NM without ORD Tool: APP *"Determine Required Spacing"* MRS 2NM with ORD Tool: APP *"Identify pairing between ITD/FTD and aircraft"*
	SR3.035 If the introduction of 2NM MRS with ORD requires to change the current surveillance system (e.g. for a higher update rate) in local implementation, there shall be a synchronisation of the update rate between the APP and TWR ATCOs radar screens in order to allow smooth radar visualisation upon aircraft transfer from APP to TWR	N/A

	SR3.037 When the 2NM MRS concept is applied in TB-modes, DB PWS-A and/or WDS-A, the Intermediate Approach, Final Approach and Tower Controllers shall be provided with a Separation Delivery Tool displaying Target Distance Indicators (TDI) to enable consistent and accurate application of separation rules on final approach and landing	MRS 2NM with ORD Tool: APP "*Identify pairing between ITD/FTD and aircraft*"
	The following requirements from PJ02.01 also apply: REQ-02.01-SPRINTEROP-ARR0.0470 REQ-02.01-SPRINTEROP-ARR0.0480 REQ-02.01-SPRINTEROP-ARR0.0920 REQ-02.01-SPRINTEROP-ARR0.0930 REQ-02.01-SPRINTEROP-ARR0.0940 REQ-02.01-SPRINTEROP-ARR0.0941 REQ-02.01-SPRINTEROP-ARR0.0550 REQ-02.01-SPRINTEROP-ARR0.0910 REQ-02.01-SPRINTEROP-ARR0.0540 REQ-02.01-SPRINTEROP-ARR0.0570 REQ-02.01-SPRINTEROP-ARR0.0852 REQ-02.01-SPRINTEROP-ARR0.0870 REQ-02.01-SPRINTEROP-ARR0.1310 REQ-02.01-SPRINTEROP-ARR0.1380 REQ-02.01-SPRINTEROP-ARR0.1570	
When applying 2NM MRS, ATC shall provide correct spacing from final approach path acquisition until landing such that to ensure the correct separation minima delivery based on correctly computed separation indicators	The following requirements from PJ02.01 apply: REQ-02.01-SPRINTEROP-ARR0.0110 REQ-02.01-SPRINTEROP-ARR3.0120 REQ-02.01-SPRINTEROP-ARR0.0130 REQ-02.01-SPRINTEROP-ARR0.0131 REQ-02.01-SPRINTEROP-ARR0.0132 REQ-02.01-SPRINTEROP-ARR0.0133 REQ-02.01-SPRINTEROP-ARR3.0150 REQ-02.01-SPRINTEROP-ARR3.0151 REQ-02.01-SPRINTEROP-ARR3.0152 REQ-02.01-SPRINTEROP-ARR0.0161 REQ-02.01-SPRINTEROP-ARR3.0163 REQ-02.01-SPRINTEROP-ARR0.0164 REQ-02.01-SPRINTEROP-ARR0.0165 REQ-02.01-SPRINTEROP-ARR0.0167 REQ-02.01-SPRINTEROP-ARR3.0170 REQ-02.01-SPRINTEROP-ARR0.0180 REQ-02.01-SPRINTEROP-ARR0.0190 REQ-02.01-SPRINTEROP-ARR0.0200	

	REQ-02.01-SPRINTEROP-ARR0.0220 REQ-02.01-SPRINTEROP-ARR0.0230 REQ-02.01-SPRINTEROP-ARR0.0240 REQ-02.01-SPRINTEROP-ARR0.0280 REQ-02.01-SPRINTEROP-ARR0.0290 REQ-02.01-SPRINTEROP-ARR0.0300 REQ-02.01-SPRINTEROP-ARR0.0310 REQ-02.01-SPRINTEROP-ARR1.0320 REQ-02.01-SPRINTEROP-ARR0.0321 REQ-02.01-SPRINTEROP-ARR0.0700 REQ-02.01-SPRINTEROP-ARR0.0791 REQ-02.01-SPRINTEROP-ARR0.0792 REQ-02.01-SPRINTEROP-ARR0.0793 REQ-02.01-SPRINTEROP-ARR0.0795 REQ-02.01-SPRINTEROP-ARR0.0796 REQ-02.01-SPRINTEROP-ARR0.0800 REQ-02.01-SPRINTEROP-ARR0.0860 REQ-02.01-SPRINTEROP-ARR0.0870 REQ-02.01-SPRINTEROP-ARR0.0970 REQ-02.01-SPRINTEROP-ARR0.0990 REQ-02.01-SPRINTEROP-ARR3.1000 REQ-02.01-SPRINTEROP-ARR0.1250
Applicable only with the Separation Delivery Tool	
The Target Distance Indicators shall be calculated and displayed to correctly and accurately represent the greatest constraint out of wake separation minima, MRS, the runway spacing or other spacing constraint (e.g. departure gaps)	The following requirements from PJ02.01 apply: REQ-02.01-SPRINTEROP-ARR0.0060 REQ-02.01-SPRINTEROP-ARR1.0070 REQ-02.01-SPRINTEROP-ARR0.0080 REQ-02.01-SPRINTEROP-ARR0.0100 REQ-02.01-SPRINTEROP-ARR0.0130 REQ-02.01-SPRINTEROP-ARR0.0131 REQ-02.01-SPRINTEROP-ARR0.0132 REQ-02.01-SPRINTEROP-ARR0.0139 REQ-02.01-SPRINTEROP-ARR0.0133 REQ-02.01-SPRINTEROP-ARR0.0140 REQ-02.01-SPRINTEROP-ARR3.0150 REQ-02.01-SPRINTEROP-ARR3.0151 REQ-02.01-SPRINTEROP-ARR3.0152 REQ-02.01-SPRINTEROP-ARR3.0160 REQ-02.01-SPRINTEROP-ARR0.0161 REQ-02.01-SPRINTEROP-ARR0.0162 REQ-02.01-SPRINTEROP-ARR3.0163 REQ-02.01-SPRINTEROP-ARR0.0164 REQ-02.01-SPRINTEROP-ARR0.0165 REQ-02.01-SPRINTEROP-ARR0.0167 REQ-02.01-SPRINTEROP-ARR0.0200 REQ-02.01-SPRINTEROP-ARR0.0220

	REQ-02.01-SPRINTEROP-ARR0.0230 REQ-02.01-SPRINTEROP-ARR0.0240 REQ-02.01-SPRINTEROP-ARR0.0257 REQ-02.01-SPRINTEROP-ARR0.0270 REQ-02.01-SPRINTEROP-ARR0.0280 REQ-02.01-SPRINTEROP-ARR0.0290 REQ-02.01-SPRINTEROP-ARR0.0300 REQ-02.01-SPRINTEROP-ARR0.0310 REQ-02.01-SPRINTEROP-ARR1.0320 REQ-02.01-SPRINTEROP-ARR0.0321 REQ-02.01-SPRINTEROP-ARR0.0370 REQ-02.01-SPRINTEROP-ARR0.0380 REQ-02.01-SPRINTEROP-ARR0.0390 REQ-02.01-SPRINTEROP-ARR0.0410 REQ-02.01-SPRINTEROP-ARR0.0420 REQ-02.01-SPRINTEROP-ARR0.0490 REQ-02.01-SPRINTEROP-ARR0.0580 REQ-02.01-SPRINTEROP-ARR0.0590 REQ-02.01-SPRINTEROP-ARR0.0620 REQ-02.01-SPRINTEROP-ARR0.0630 REQ-02.01-SPRINTEROP-ARR0.0650 REQ-02.01-SPRINTEROP-ARR0.0651 REQ-02.01-SPRINTEROP-ARR3.0660 REQ-02.01-SPRINTEROP-ARR0.0670 REQ-02.01-SPRINTEROP-ARR0.0680 REQ-02.01-SPRINTEROP-ARR0.0681 REQ-02.01-SPRINTEROP-ARR0.0690 REQ-02.01-SPRINTEROP-ARR0.0691 REQ-02.01-SPRINTEROP-ARR0.0710 REQ-02.01-SPRINTEROP-ARR0.0720 REQ-02.01-SPRINTEROP-ARR0.0730 REQ-02.01-SPRINTEROP-ARR0.0740 REQ-02.01-SPRINTEROP-ARR0.0750 REQ-02.01-SPRINTEROP-ARR0.0770 REQ-02.01-SPRINTEROP-ARR0.0780 REQ-02.01-SPRINTEROP-ARR0.0790 REQ-02.01-SPRINTEROP-ARR0.0851 REQ-02.01-SPRINTEROP-ARR0.0900 REQ-02.01-SPRINTEROP-ARR3.1520 REQ-02.01-SPRINTEROP-ARR3.1540
The design of the Separation Delivery Tool and associated operating procedures and practises shall not negatively impact Flight Crew/Aircraft who shall be able to follow ATC instructions in order to	The following requirement from PJ02.01 applies: REQ-02.01-SPRINTEROP-ARR0.1410

correctly intercept the final approach path in the mode under consideration	
ATC and Flight Crew/Aircraft shall ensure that the final approach path is flown whilst respecting the aircraft speed profile (unless instructed otherwise by ATC or airborne conditions require to initiate go around) in order to ensure correctness of the separation indicators	The following requirements from PJ02.01 apply: REQ-02.01-SPRINTEROP-ARR3.0500 REQ-02.01-SPRINTEROP-ARR0.1420

Table 9: Mapping of Safety Objectives to the NSV4 EATMA Model Elements

4.3 Analysis of the SPR-level Model – Normal Operational Conditions

The operational scenarios in Normal conditions are analysed for a typical specimen final approach operational environment and range of normal operating conditions which is detailed in the Use Cases of the OSED [10].

This process allowed to check the completeness of the set of safety requirements derived in the previous sub-section4.2.2 (through mapping of Safety Objectives to the NSV4 EATMA Model Elements) and to derive additional requirements as appropriate, as it is driven by the more dynamic view (time sequence of actions and events) enabled by the operational scenarios/Use Cases.

No additional safety requirements have resulted from this analysis.

4.3.1 Effects on Safety Nets – Normal Operational Conditions

The new 2NM MRS separation mode and ATC tools do not impact the safety net associated to ground collision avoidance (e.g. MSAW, TAWS) since obstacle clearances are not modified with this concept.

The application of the new MRS separation mode is reducing the distance separation between aircraft therefore it might impact STCA. To address the impact on STCA, **SR3.300** has been derived to make sure STCA is adjusted to take into account the 2NM MRS separation. No increase in false alerts is expected from ACAS when operating under 2NM MRS.

Depending on local factors (e.g. runway layout, the range of the RIMCAS system around the airport, local operational procedures, etc.), the reduced separation between aircraft could have an impact on the RIMCAS and ASMGCS level 2 systems. It is recommended that, prior to implementing 2NM MRS, a local study is done on the impact of the 2NM MRS concept on the parameters of RIMCAS and ASMGCS level 2, if these systems are used at the corresponding airport.

4.4 Analysis of the SPR-level Model – Abnormal Operational Conditions

This section ensures that the SPR-level Design is complete, correct and internally coherent with respect to the Safety Requirements (Functionality and Performance) derived for the abnormal operating conditions.

4.4.1 Scenarios for Abnormal Conditions

REF _Ref11934603 \h Table 10 below recalls the different scenarios relative to the abnormal conditions identified in Section 3.7.1 and for which new Safety Objectives have been derived at 3.7.2, analyses the causal factors or possible influences and presents the risk mitigation.

Ref	Abnormal Conditions / SO (*Functionality and Performance)*	Possible influences or causal factors	Mitigations (SR 0xx and/or A 0xx)
1	Change of Aircraft landing runway intent.	No change from Sol 01. Same mitigations as in Sol 01 apply	No change from Sol 01. Same mitigations as in Sol 01 apply
2	Abnormal procedural aircraft airspeed and/or abnormal stabilized approach speed.	Pilot basic airmanship not respected. Aircraft problem.	Detect abnormal airspeed (through alerting) and manage compression manually.
3	Lead aircraft go-around.	Loss of separation on final. Severe Wake Encounter. Runway not in sight at minima. Loss of ILS guidance in IFR. Insufficient spacing between successive landings. Landing runway occupied. Late landing clearance. Unstable approach below 500ft.	Inform separation tool about the sequence order change due to the missed approach (if not automatic) in order to have correct separation indications.
4	Delegation of separation to Flight Crew.	No change from Sol 01. Same mitigations as in Sol 01 apply	No change from Sol 01. Same mitigations as in Sol 01 apply

6	Flight Crew Notification of Aircraft Speed non-conformance.	No change from Sol 01. Same mitigations as in Sol 01 apply	No change from Sol 01. Same mitigations as in Sol 01 apply
8	Late change of landing runway (not planned).	No change from Sol 01. Same mitigations as in Sol 01 apply	No change from Sol 01. Same mitigations as in Sol 01 apply

Table 10: Safety Requirements or Assumptions to mitigate abnormal conditions

4.4.2 Derivation of Safety Requirements (Functionality and Performance) for Abnormal Conditions

Table 11 below, uses the outcome of the previous sub-section and the Safety Objectives from Section 3.7.2 to derive the corresponding Safety Requirements (Functionality and Performance) by considering the SPR level Model.

Safety Objectives for abnormal conditions	Safety Requirements (functionality and performance) for abnormal conditions	Map on to
ATC shall be alerted when the aircraft speed varies significantly from the procedural airspeed and/or the stabilized approach speed used for the TDIs computation (speed conformance alert) in order to manage compression manually	The following requirements from PJ02.01 apply: REQ-02.01-SPRINTEROP-ARR0.1500 REQ-02.01-SPRINTEROP-ARR0.1510 REQ-02.01-SPRINTEROP-ARR0.1700 REQ-02.01-SPRINTEROP-ARR0.1710	
	SR3.302: A generic wake risk assessment shall be performed for the 2NM MRS non-wake pairs in the specific case when the leader is performing a break-off/go-around and the follower, separated at or close to the separation minima, continues its descent crossing the leader's descending wake	
	The following requirements from PJ02.01 also apply: REQ-02.01-SPRINTEROP-ARR0.0440 REQ-02.01-SPRINTEROP-ARR0.0441 REQ-02.01-SPRINTEROP-ARR0.0960 REQ-02.01-SPRINTEROP-ARR0.0560	

	REQ-02.01-SPRINTEROP-ARR0.0550 REQ-02.01-SPRINTEROP-ARR0.0910 REQ-02.01-SPRINTEROP-ARR0.0561 REQ-02.01-SPRINTEROP-ARR0.0950 REQ-02.01-SPRINTEROP-ARR0.0540
	The following requirements from PJ02.01 apply: REQ-02.01-SPRINTEROP-ARR0.1360 REQ-02.01-SPRINTEROP-ARR0.1370
	The following requirements from PJ02.01 apply: REQ-02.01-SPRINTEROP-ARR0.0560 REQ-02.01-SPRINTEROP-ARR0.0550 REQ-02.01-SPRINTEROP-ARR0.0910 REQ-02.01-SPRINTEROP-ARR0.0561 REQ-02.01-SPRINTEROP-ARR0.0950 REQ-02.01-SPRINTEROP-ARR0.0540

Table 11: Operational Scenarios – Abnormal Conditions

4.5 Design Analysis – Case of Internal System Failures

The objective of this analysis consists in determining how the system architecture (encompassing people, procedures, equipment) designed for the 2NM radar separation and ATC tools can be made safe in presence of internal system failures. For that purpose, the method consists in apportioning the Safety Objectives of each hazard into Safety Requirements to elements of the system driven by the analysis of the hazard causes.

Fault tree analysis is used to identify the causes of hazards and combinations thereof, accounting for safeguards already specified in the current standards and for any indication on their effectiveness but also accounting for the safety requirements derived in Section 4.2.2 and 4.4.2 during the design analysis in normal and abnormal conditions.

Fault tree analysis is used in this safety assessment mainly to identify mitigations to reduce the likelihood that specific failures occur or would propagate up to the Hazard. These mitigations are then captured as additional Qualitative Safety Requirements (Functionality and Performance).

Quantitative Safety Requirements will not be derived in this safety assessment. This will however need to be done by the industry in the validation stages prior to implementation (i.e. V4 onwards).

4.5.1 Causal Analysis

For each system-generated hazard (see chapter 3.8.1), a top-down identification of internal system failures that could cause the hazard was conducted. The hazards are:

- Hazards applicable to Interception and Final Approach (based on common mode failures):
    - **Hz#05**: One or multiple separation minima infringements due to undetected corruption of separation indicator
    - **Hz#06**: One or multiple imminent infringements due to lack/loss of separation indicator for multiple or all aircraft
- Hazards relative to the approach interception and associated to ATC instructions:
    - **Hz#01b**: Separation not being recovered following imminent infringement of A/C pair instructed by ATC to merge on the Final Approach interception
    - **Hz#01a**: Inadequate separation management of a pair of aircraft instructed by ATC to merge on the Final Approach interception
- Hazards relative to the approach interception and originated by Crew/Aircraft:
    - **Hz#02b**: Separation not being recovered following imminent infringement due to aircraft deviation from Final Approach interception profile without ATC instruction given
    - **Hz#02a**: Inadequate separation management of a spacing conflict due to aircraft deviation from Final Approach interception profile without ATC instruction given
- Hazards during the Final Approach and associated to ATC instructions:
    - **Hz#03b**: Separation not being recovered following imminent infringement by an aircraft pair instructed by ATC on the Final Approach
    - **Hz#03a**: Inadequate separation management of an aircraft pair naturally catching-up as instructed by ATC on the Final Approach
    - **Hz#08:** Runway conflict due to landing clearance in conflict with another landing (ROT not respected)
- Hazards during the Final Approach and originated by Crew/Aircraft:
    - **Hz#04b**: Separation not being recovered following imminent infringement due to aircraft deviation from Final Approach profile without ATC instruction given
    - **Hz#04a**: Inadequate separation management of a spacing conflict due to aircraft deviation from Final Approach profile without ATC instruction given

The purpose of the causal analysis is to increase the detail of risk mitigation strategy through the identification of all possible causes. This way it will be possible to identify the corresponding Safety Requirements to meet the Safety Objective of the Operational Hazard under consideration.

Note, as mentioned previously, these hazards have been previously identified in Sol 01. Even though they are all relevant to Sol 03, the 2NM MRS concept does not introduce changes in all of them. Therefore, in order to avoid clutter, fault trees will be developed only for the hazards in which a change is introduced by the 2NM MRS concept. The fault trees (together with their mitigations) for which there is no change compared to Sol 01, will be referenced to Sol 01.

Fault trees are elaborated by detailing the hazard in a combination of failures (i.e. Basic Causes and failure of mitigations) linked by different gates, i.e. "AND" and "OR" gates. The “AND” and “OR” gates will serve in the quantification process later on during the concept lifecycle.

Existing mitigations (i.e. already captured as safety requirements in sections 4.2.2 and 4.4.2 dealing) are identified and, where necessary, additional Mitigation Means are proposed in order to reduce the likelihood of occurrence of the Operational Hazard. The additional Mitigation Means are formalized as Safety Requirements.

4.5.1.1 Hz#05: One or multiple separation minima infringements due to undetected corruption of separation indicator *(only with the separation Delivery Tool)*

No change from Sol 01. Please see Sol 01 SAR [16] for details about this hazard. The mitigations from this hazard have been consolidated in section 4.5.3.

4.5.1.2 Hz#06: One or multiple imminent infringements due to lack/loss of separation indicator for multiple or all aircraft *(only with the separation Delivery Tool)*

No change from Sol 01. Please see Sol 01 SAR [16] for details about this hazard. The mitigations from this hazard have been consolidated in section 4.5.3.

4.5.1.3 Hz#01b: Separation not being recovered following imminent infringement of A/C pair instructed by ATC to merge on the Final Approach interception *(applicable with or without the Separation Delivery Tool)*

This hazard occurs during the Final Approach interception and its basic causes have been captured in the Hz#01b Fault Tree (See Figure 5).

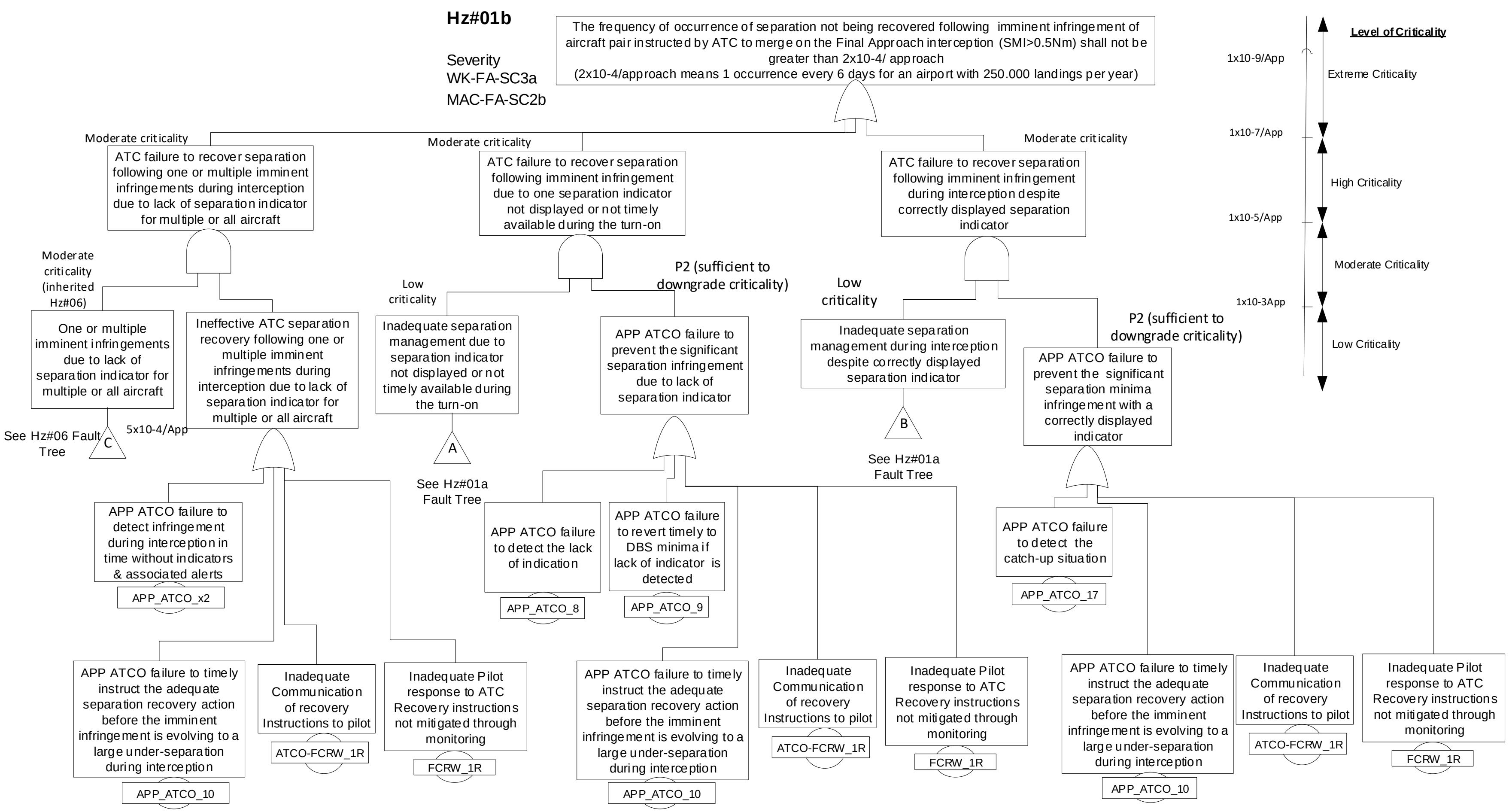

Figure 5: Hz#01b Fault Tree for the PJ02.03

The table below describes the basic causes of the Hazard Hz#01b Fault Tree and identifies the mitigations/safety requirements necessary to satisfy the associated Safety Objective

Type of failure	Cause Id	Cause description	Mitigation/Safety Requirement
ATC failure to recover separation following one or multiple imminent infringements during interception due to lack of separation indicator for multiple or all aircraft			
One or multiple imminent infringements due to lack of separation indicator for multiple or all aircraft	See Hz#06 Fault Tree (ref C) in PJ02.01	See Hz#06 table in PJ02.01 One or multiple imminent infringements due to lack of separation indicator for multiple or all aircraft, if not timely managed by ATC, evolve into large under-separation (SMI>0.5NM).	
APP ATCO failure to detect infringement during interception in time without indicators & associated alerts	APP_ATCO_x2	Not having the indicators and associated alerts, APP ATCO fails to detect in time the infringement at interception	The following mitigating requirements from PJ02.01 apply: • **REQ-02.01-SPRINTEROP-ARR0.1010** Local operational procedures shall be developed for handling traffic situations with missing Target Distance Indicators in different WT separation modes for both controllers and supervisors. • **REQ-02.01-SPRINTEROP-ARR0.1020** Controllers and Supervisors shall regularly receive training on reversal procedures (TB to DB modes) and contingency measures in case of abnormal and degraded modes of operation (e.g. loss of one TDI, loss of all TDIs etc.) • **REQ-02.01-SPRINTEROP-ARR0.1721** In case of separation tool failure with loss of all TDIs (aircraft already established

			and aircraft going to intercept), the Controllers shall revert to DBS without indicators for all aircraft (one or several aircraft might be instructed to break-off) • **REQ-02.01-SPRINTEROP-ARR0.1730** In case of separation tool failure with loss of TDI computation (TDIs preserved for aircraft already established) a specific separation tool failure alert shall be provided and the Controllers shall revert to DBS without indicators for aircraft without TDIs. Only for aircraft already established, TDIs that continue to be displayed can be used up to the separation delivery point • **REQ-02.01-SPRINTEROP-ARR0.1640** In case of Separation Tool Failure, the Supervisors and Controllers shall receive a message containing the source of the tool failure
APP ATCO failure to timely instruct the adequate separation recovery action before the imminent infringement is evolving to a large under-separation during interception	APP_ATCO_10	APP ATCO does not instruct timely a go around before the imminent infringement due to the missing indicator is evolving to a large under-separation (SMI>5NM) during interception.	All the mitigations from APP_ATCO_x2 apply plus the ones below
			In case of go-around/break-off instructed by ATCO: • **SR3.302** A generic wake risk assessment shall be performed for the 2NM MRS non-wake pairs in the specific case when the leader is performing a break-off/go-

			around and the follower, separated at close to the separation minima, continues its descent crossing the leader's descending wake
			If considered, STCA will trigger outside a pre-defined region (e.g. 4NM at Heathrow): • **SR3.300** If available for the Final Approach Controllers, the Short Term Conflict Alert shall be adjusted to accommodate the 2NM MRS concept
Inadequate Communication of recovery Instructions to pilot	ATCO-FCRW_1R	APP ATCO inadequately communicates the recovery instructions to the crew	All the mitigations from APP_ATCO_x2 apply.
Inadequate Pilot response to ATC Recovery instructions not mitigated through monitoring	FCRW_1R	The APP ATCO does not detect the inadequate pilot response (to the recovery instruction) through readback and fails to monitor the situation such that to apply a corrective mitigation	No new requirement derived for the ATCO because it is considered that the monitoring of what the crew does after is given an instruction does not change compared to today's operations.
ATC failure to recover separation following imminent infringement due to one separation indicator not displayed or not timely available during the turn-on			
Inadequate separation management due to separation indicator not displayed or not timely available during the turn-on.	See Hz#01 Fault Tree (ref A)	See Hz#01 table. The lack of separation indicator leads to separation minima infringement during the merging of the aircraft onto the final approach, which if not timely managed by ATC evolves into large under-separation (SMI>0.5NM).	
APP ATCO failure to detect the lack of indication affecting one aircraft.	APP_ATCO_8	APP ATCO does not detect the missing separation indicator and merges the aircraft onto the final approach without the required separation (missing indicator affecting one aircraft).	The following mitigations (PJ02.01 requirements) apply: • **REQ-02.01-SPRINTEROP-ARR0.0800** The HMI design shall allow Controllers to identify the aircraft associated with each displayed indicator.

			• **REQ-02.01-SPRINTEROP-ARR0.0450** If there is insufficient information to calculate a TDI then that TDI shall not be provided, together with a visual warning. • **REQ-02.01-SPRINTEROP-ARR0.0460** If the required input to calculate a time based wake separation is not available and a conservative wind input is not used, then the distance based wake separation minima may instead be used to calculate the FTD provided that the change in computation is clearly displayed to the ATCO.
APP ATCO failure to revert timely to DBS minima if lack of indicator is detected.	APP_ATCO_9	APP ATCO does not revert timely to DBS minima when missing indicator is detected.	Same mitigations as for APP_ATCO_x2 apply.
APP ATCO failure to timely instruct the adequate separation recovery action before the imminent infringement is evolving to a large under-separation during interception	APP_ATCO_10	See above.	As for APP_ATCO_10 above
Inadequate Communication of recovery Instructions to pilot	ATCO-FCRW_1R	See above.	As for ATCO-FCRW_1R above
Inadequate Pilot response to ATC Recovery instructions not mitigated through monitoring	FCRW_1R	See above.	As for FCRW_1R above
ATC failure to recover separation following imminent infringement during interception despite correctly displayed separation indicator			

Inadequate separation management during interception despite correctly displayed separation indicator.	See Hz#01a Fault Tree (ref B)	See Hz#01a table. The inadequate separation management during interception (despite a correct display of the separation indicator) leads to separation minima infringement, which if not timely managed by ATC evolves into large under-separation (SMI>0.5NM).	
Inadequate Communication of recovery Instructions to pilot	ATCO-FCRW_1R	See above.	As for ATCO-FCRW_1R above
Inadequate Pilot response to ATC Recovery instructions not mitigated through monitoring	FCRW_1R	See above.	All mitigations from FCRW_1R above apply, plus the following additional mitigation: • **REQ-02.01-SPRINTEROP-ARR0.1530** The Approach Controllers shall be alerted in case the aircraft instructed to turn onto the Target Distance Indicator on the runway extended centre-line is not the one planned in the Arrival Sequencing Tool list. • **REQ-02.01-SPRINTEROP-ARR0.1560** In case of sequence error alert the Approach Controllers shall perform corrective action to re-establish consistency between the actual sequence order and the Arrival Sequencing Tool list.
APP ATCO failure to timely instruct the adequate separation recovery action before the imminent infringement is evolving to a large under-separation during interception	APP_ATCO_10	ATCO fails to instruct speed adjustment instruction (depending on the triggering event) in order to solve the imminent infringement.	The following mitigations apply from PJ02.01: • **REQ-02.01-SPRINTEROP-ARR0.0130** In TB mode, the FTD computed by the tool to indicate the wake separation applicable at the delivery point shall take into consideration:

			• The time separation from the wake turbulence separation table (for WDS the separation tables might be more than one depending on the total/cross wind values); • The aircraft pair (from the arrival sequence list); • The glideslope headwind profile; • The follower time-to-fly profile obtained either from modelled time-to-fly profile in the considered headwind conditions • The time separation buffer considering uncertainties of final approach speed profiles of the a/c pair and of the glide slope wind prediction • **REQ-02.01-SPRINTEROP-ARR3.0150** The ITD computed by the tool for all separation and spacing constraints (wake separation in DB and TB modes, MRS, ROT and other spacing constraints) shall take in consideration: • The FTD for the considered aircraft pair • The glideslope headwind profile • The leader and follower time-to-fly profiles obtained either from modelled time-to-fly profile in the considered headwind conditions • The time separation buffer considering uncertainties of final approach speed

			profiles of the a/c pair and of the glide slope wind prediction • **REQ-02.01-SPRINTEROP-ARR0.0791** When spacing ITD is infringed by the aircraft, the ATCOs shall be aware of the next most constraining separation factor ITD and FTD (e.g. Wake or MRS) on the APPROACH and TOWER positions. • **REQ-02.01-SPRINTEROP-ARR0.0795** For the Approach HMI, in case of high/low priority ITD infringement, the Approach Controller shall be able to assess if he can proceed safely.
			If considered, STCA will trigger outside a pre-defined region (e.g. 4NM at Heathrow): • **SR3.300** as above

Table 12: Derivation of Mitigation/Safety Requirements for Hazard Hz#01b for the PJ02.03

4.5.1.4 Hz#01a: Inadequate separation management of a pair of aircraft instructed by ATC to merge on the Final Approach interception *(applicable with or without the Separation Delivery Tool)*

This hazard occurs during the Final approach interception.

Basic causes for such failures have been captured in the Hz#01a Fault Tree (See Figure 6).

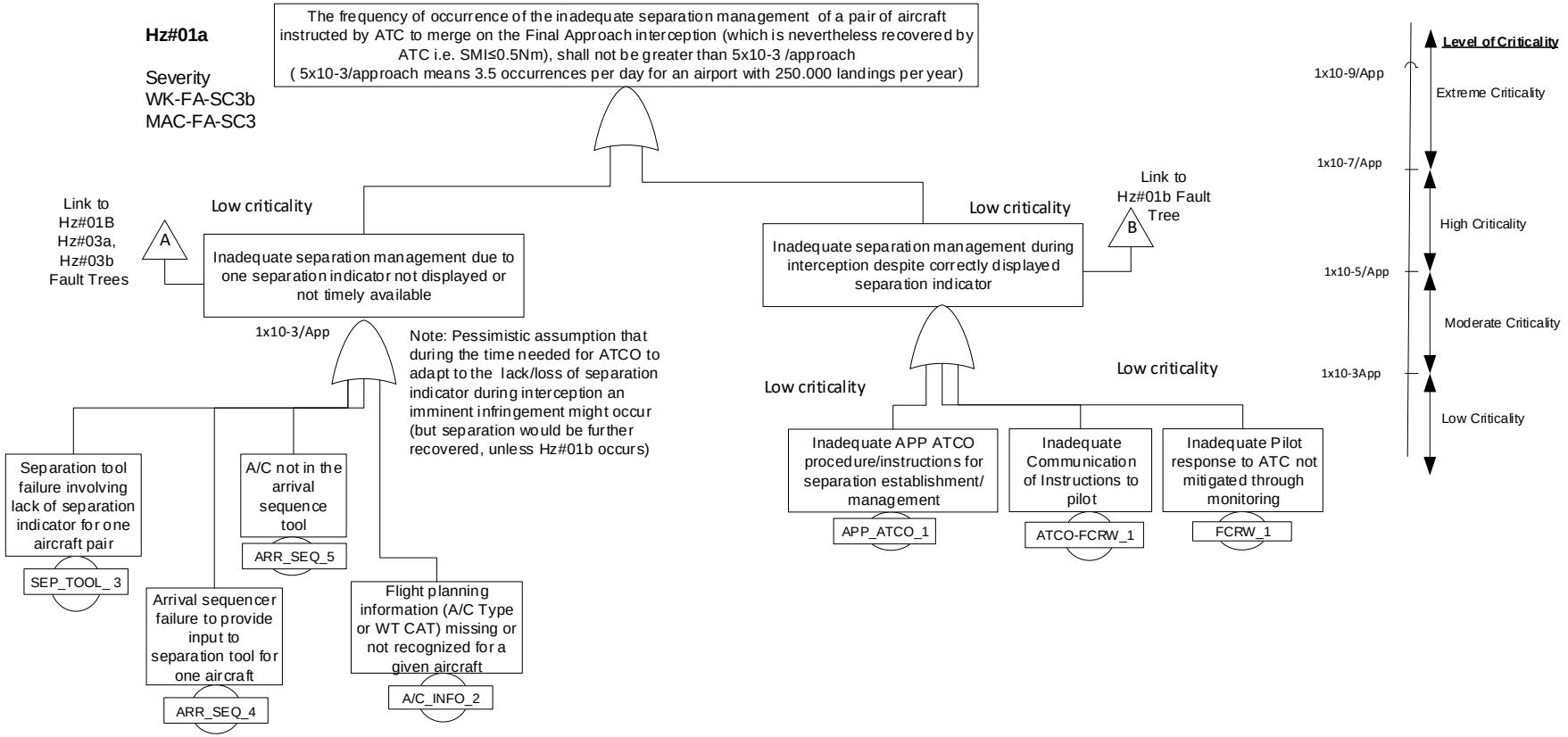

Figure 6: Hz#01a Fault Tree for the PJ02.03

The table below describes the basic causes of the Hazard Hz#01a Fault Tree and identify the mitigations/safety requirements necessary to satisfy the associated Safety Objective.

Type of failure	Cause Id	Cause description	Mitigation/Safety Requirement
Inadequate separation management due to one separation indicator not displayed or not timely available during the turn-on			
Separation tool failure involving lack of separation indicator for one aircraft pair.	SEP_TOOL_3	The separation tool fails to display the separation indicator for one aircraft or display it too late for the interception of the final approach.	The following mitigations apply from PJ02.01: • **REQ-02.01-SPRINTEROP-ARR0.0630** Criteria to determine the time for displaying indicators for each CWP shall be specified depending upon the local operation's needs. • **REQ-02.01-SPRINTEROP-ARR0.0110** The Separation Delivery tool shall provide to ATCOs a visualisation (FTD indicator) of the required minimum separation or spacing on final approach that needs to be delivered after considering all in-trail and if applicable not-in-trail constraints. **REQ-02.01-SPRINTEROP-ARR0.1010** Local operational procedures shall be developed for handling traffic situations with missing Target Distance Indicators in different WT separation modes for both controllers and supervisors.
Arrival sequencer failure to provide input to separation tool for one aircraft.	ARR_SEQ_4	The arrival sequencer does not provide information to the separation tool for one aircraft despite inputs being correct.	The following mitigations apply from PJ02.01: • **REQ-02.01-SPRINTEROP-ARR0.0300** The approach arrival sequence information shall be provided to the Separation Delivery tool.

			• **REQ-02.01-SPRINTEROP-ARR0.1720** If the Approach Arrival Sequence Service fails, the Separation Delivery tool shall continue displaying TDIs for aircraft already established and shall stop displaying TDIs for all other aircraft • **REQ-02.01-SPRINTEROP-ARR0.0400** It shall be demonstrated that the data inputs including flight data, approach arrival sequence information and glideslope wind conditions to the Separation Delivery are sufficiently robust.
A/C not in the arrival sequence.	ARR_SEQ_5	An aircraft not planned for this arrival is authorized to land (e.g. aircraft in emergency).	The following mitigations apply from PJ02.01: • **REQ-02.01-SPRINTEROP-ARR0.1570** If an aircraft that needs to be inserted in the arrival sequence cannot be input into the Arrival Sequence Service, the Approach Controller shall inhibit the Target Distance Indicator corresponding to the follower aircraft whose position in the actual sequence is taken by the newly inserted aircraft and the Approach Controller shall observe DBS WT Category separation for the impacted pairs of aircraft ISSUE 03: Whether the Approach or Tower Controllers shall be able to inhibit a Target Distance Indicator for a particular aircraft (both FTD and ITD) remains to be further validated. In case Controllers are allowed to inhibit both FTD

			and ITD for a particular aircraft, a means to recall the lack of TDI needs to be specified in order to mitigate the risk of a wrong association by ATCO of the aircraft with the FTD/ITD of another aircraft (e.g. change colour (fade) when inhibited). See mitigation of FDP_1 and A/C_INFO_1 at Hz#05.
Flight planning information (A/C Type or WT CAT) missing or not recognized for a given aircraft.	A/C_INFO_2	The separation tool does not receive or not recognize the aircraft type and/or the Wake Turbulence Category for one aircraft.	The following mitigations apply from PJ02.01: • **REQ-02.01-SPRINTEROP-ARR0.1441** At the first contact with the Approach, the flight crew shall provide the Aircraft type or alternatively this information could be provided to the Approach Controller via data link and the Approach Controller shall cross check this information with the information displayed on the CWP • **REQ-02.01-SPRINTEROP-ARR0.1440** Approach control shall check the validity of Flight Plan information displayed on the CWP (ICAO aircraft type, wake category) • **REQ-02.01-SPRINTEROP-ARR0.0430** When a flight data input error (e.g. missing or wrong ICAO aircraft type or wake category) is detected, it shall be possible to update the corresponding information into the input for the separation delivery tool • **REQ-02.01-SPRINTEROP-ARR0.0400** It shall be demonstrated that the data inputs including flight data, approach

			arrival sequence information and glideslope wind conditions to the Separation Delivery are sufficiently robust • **REQ-02.01-SPRINTEROP-ARR0.0220** Aircraft identifier, ICAO aircraft type and wake category for all arrival aircraft, including subsequent updates to this information, shall be provided to the Separation Delivery tool. • **REQ-02.01-SPRINTEROP-ARR0.1730** In case of separation tool failure with loss of TDI computation (TDIs preserved for aircraft already established) a specific separation tool failure alert shall be provided and the Controllers shall revert to DBS without indicators for aircraft without TDIs. Only for aircraft already established, TDIs that continue to be displayed can be used up to the separation delivery point
Inadequate separation management during interception despite correctly displayed separation indicator			
Inadequate APP ATCO procedure/instructions for separation establishment/management	APP_ATCO_1	ATCO may be drawn into delivering to TDI and reducing below the 2.5 NM MRS and 1000ft before the current transition procedures (from 3 to 2.5NM or 1000ft) allow. Note it is out of scope of PJ02-03 to seek safety evidence which would allow passing below 2.5NM upon turning on to intercept.	• **SR3.026**: Local procedures/rules shall be defined in order to ensure safe transition of the aircraft from 3NM to 2NM MRS, such as to avoid loss of separation minima during on base leg • **SR3.027**: When the Separation Delivery Tool is used, the training curricula shall ensure the ATCOs are capable of

			maintaining the required separations on base leg (horizontal and vertical) despite getting in the habit of working with the TDIs on the axis • **SR3.033**: When operating under 2NM MRS without the Separation Delivery Tool, the APP ATCO shall receive additional training to emphasize the specific use of the IAS and GS indications for managing separation at interception The following mitigations apply from PJ02.01: • **REQ-02.01-SPRINTEROP-ARR0.1250** Approach and Tower Controllers shall be fully trained to apply the procedures for the new separation modes and the use of the Separation Delivery Tool and supporting systems (e.g. alerts) with indicators prior to deployment. • **REQ-02.01-SPRINTEROP-ARR3.0170** If the ORD concept is implemented, the Approach controller shall vector the follower aircraft so that it stays on or behind the corresponding ITD.
Inadequate Communication of Instructions to pilot	ATCO-FCRW_1	As for ATCO-FCRW_1R in Hz#01b when the indicators are correctly displayed	
Inadequate Pilot response to ATC not mitigated through monitoring	FCRW_1		No new requirement derived for the ATCO because it is considered that the monitoring of

			what the crew does after is given an instruction does not change compared to today's operations.

Table 13: Derivation of Mitigation/Safety Requirements for Hazard Hz#01a for the PJ02.03

4.5.1.5 Hz#02b: Separation not being recovered following imminent infringement due to aircraft deviation from Final Approach interception profile without ATC instruction given ***(applicable with or without the Separation Delivery Tool)***

This hazard occurs during the Final approach interception and its causes have been captured in the Hz#02b Fault Tree (See Figure 7).

Note: The combination between the occurrences of a Crew/Aircraft induced conflict and its inadequate separation management or separation recovery due to separation indicator not displayed or not timely available during the turn-on, for one or multiple aircraft, is not further analysed. Given that it displays a low probability, it is not worth it for the derivation of Safety Requirements

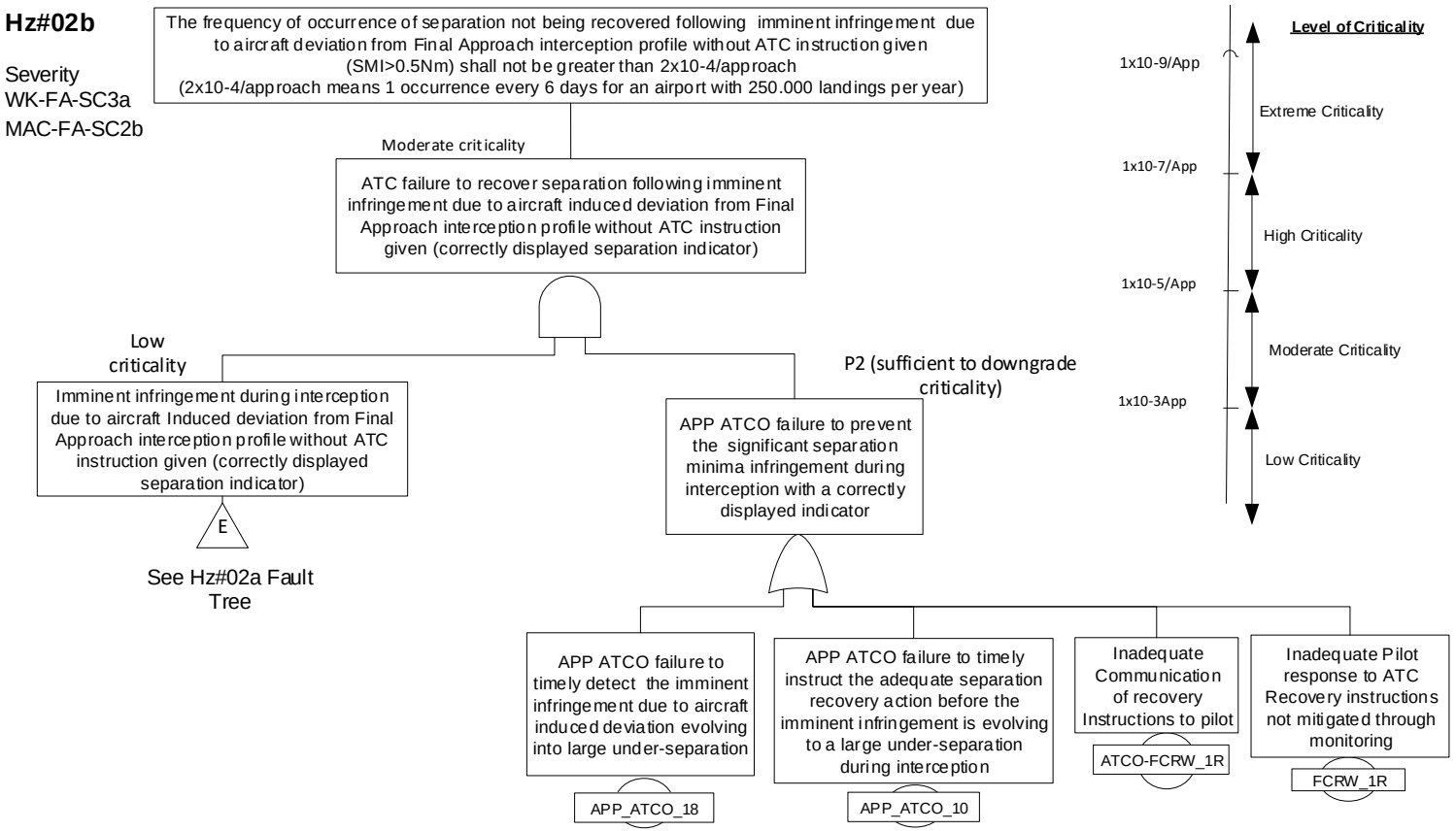

Figure 7: Hz#02b Fault Tree for the PJ02.03

The table below describes the basic causes of the Hazard Hz#02b Fault Tree and identify the mitigations/safety requirements necessary to satisfy the associated Safety Objective.

Type of failure	Cause Id	Cause description	Mitigation/Safety Requirement
Imminent infringement during interception due to aircraft Induced deviation from Final Approach interception profile without ATC instruction given (correctly displayed separation indicator)	See Hz#02a Fault Tree (ref E)	See Hz#02a table. The aircraft deviation from the cleared trajectory leads to an imminent infringement (SMI<0.5NM).	
APP ATCO failure to prevent the significant separation minima infringement during interception with a correctly displayed indicator			
APP ATCO failure to timely detect the imminent infringement due to aircraft induced deviation evolving into large under-separation	APP_ATCO_18	APP ATCO failure to timely detect the imminent infringement evolving into large under-separation (A/C deviation from cleared trajectory).	It is assumed that the approach controller verifies the adherence to the radar vectoring instruction, the actual aircraft speed and speed trend during the interception on the radar display (as per Baseline operations). The following mitigations apply from PJ02.01: • **REQ-02.01-SPRINTEROP-ARR0.1350** Procedures shall be defined regarding required actions if catching up or infringing the ITD or FTD. • **REQ-02.01-SPRINTEROP-ARR0.0791** When spacing ITD is infringed by the aircraft, the ATCOs shall be aware of the next most constraining separation factor ITD and FTD (e.g. Wake or MRS) on the APPROACH and TOWER positions.

			• **REQ-02.01-SPRINTEROP-ARR0.0795** For the Approach HMI, in case of high/low priority ITD infringement, the Approach Controller shall be able to assess if he can proceed safely. • **REQ-02.01-SPRINTEROP-ARR0.0710** The tool shall automatically display the FTD (if not already displayed) if the aircraft comes within a defined distance of the computed FTD. This distance shall be configurable within the tool.
APP ATCO failure to timely instruct the adequate separation recovery action before the imminent infringement is evolving to a large under-separation during interception	APP_ATCO_10	APP ATCO failure to instruct timely a go around before the imminent infringement is evolving to a large under-separation during interception.	The following mitigations apply from PJ02.01: • **REQ-02.01-SPRINTEROP-ARR0.0110** The Separation Delivery tool shall provide to ATCOs a visualisation (FTD indicator) of the required minimum separation or spacing on final approach that needs to be delivered after considering all in-trail and if applicable not-in-trail constraints. • **REQ-02.01-SPRINTEROP-ARR3.0120** If the ORD concept is considered, the Separation Delivery tool shall provide to ATCOs a visualisation (ITD indicator) of the required spacing on final approach to be delivered at the deceleration fix in order to deliver the required minimum separation / spacing at the delivery point. • **REQ-02.01-SPRINTEROP-ARR0.0130** In TB mode, the FTD computed by the tool to indicate the wake separation applicable at

			the delivery point shall take into consideration: • The time separation from the wake turbulence separation table (for WDS the separation tables might be more than one depending on the total/cross wind values); • The aircraft pair (from the arrival sequence list); • The glideslope headwind profile; • The follower time-to-fly profile obtained either from modelled time-to-fly profile in the considered headwind conditions • The time separation buffer considering uncertainties of final approach speed profiles of the a/c pair and of the glide slope wind prediction • **REQ-02.01-SPRINTEROP-ARR3.0150** The ITD computed by the tool for all separation and spacing constraints (wake separation in DB and TB modes, MRS, ROT and other spacing constraints) shall take in consideration: • The FTD for the considered aircraft pair • The glideslope headwind profile • The leader and follower time-to-fly profiles obtained either from modelled time-to-fly profile in the considered headwind conditions • The time separation buffer considering uncertainties of final approach speed

			profiles of the a/c pair and of the glide slope wind prediction
			In case of go-around/break-off instructed by ATCO: • **SR3.302** A generic wake risk assessment shall be performed for the 2NM MRS non-wake pairs in the specific case when the leader is performing a break-off/go-around and the follower, separated at close to the separation minima, continues its descent crossing the leader's descending wake
			If considered, STCA will trigger outside a pre-defined region (e.g. 4NM at Heathrow): • **SR3.300** If available for the Final Approach Controllers, the Short Term Conflict Alert shall be adjusted to accommodate the 2NM MRS concept
Inadequate Communication of recovery Instructions to pilot	ATCO-FCRW_1R	As for ATCO-FCRW_1R in Hz#01b when the indicators are correctly displayed	
Inadequate Pilot response to ATC Recovery instructions not mitigated through monitoring	FCRW_1R	As for FCRW_1R in Hz#01b	

Table 14: Derivation of Mitigation/Safety Requirements for Hazard Hz#02b for the PJ02.03

4.5.1.6 Hz#02a: Inadequate separation management of a spacing conflict due to aircraft deviation from final approach interception profile without ATC instruction given *(applicable with or without the Separation Delivery Tool)*

This hazard occurs during the Final approach interception and its causes have been captured in the Hz#02a Fault Tree (See Figure 8).

Note: The combination between the occurrences of a Crew/Aircraft induced conflict and its inadequate separation management due to separation indicator not displayed or not timely available during the turn-on, for one or multiple aircraft, is not further analysed. Given that it displays a low probability, it is not worth it for the derivation of Safety Requirements.

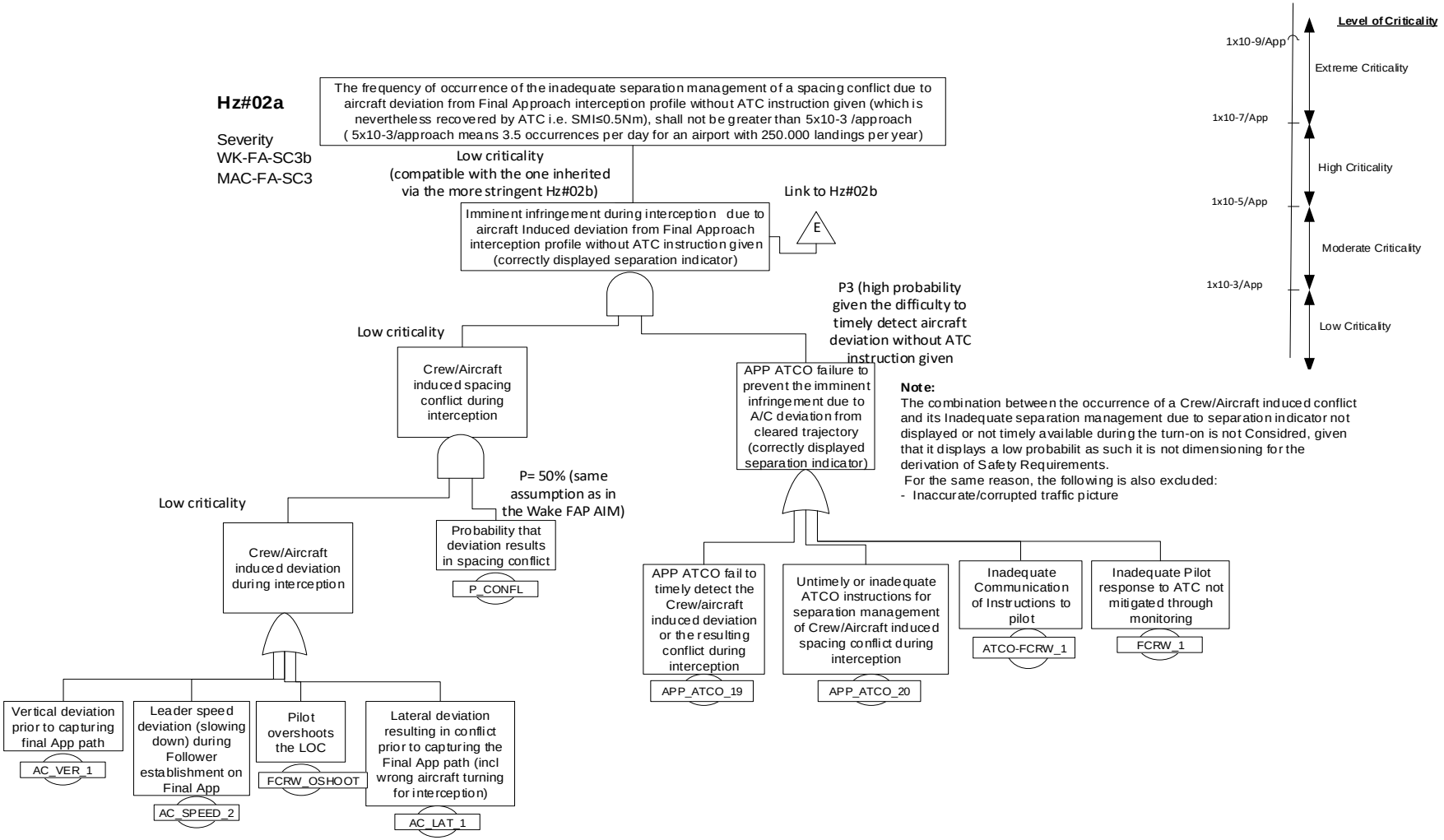

Figure 8: Hz#02a Fault tree for the PJ02.03

The table below describes the basic causes of the Hazard Hz#02a Fault Tree and identify the mitigations/safety requirements necessary to satisfy the associated Safety Objective.

Type of failure	Cause Id	Cause description	Mitigation/Safety Requirement
Crew/Aircraft induced spacing conflict during interception			
Vertical deviation prior to capturing final App path.	AC_VER_1	The vertical deviation from instructed interception altitude might involve capturing final approach path from above or below with impact on the actual speed profile (which will be different from the TAS profile used by the separation tool). As a consequence in TB-modes the FTD computation will be erroneous and the ITD will be erroneous in all modes.	The following mitigations apply from PJ02.01: • **REQ-02.01-SPRINTEROP-ARR0.1420** For all modes (where FTD and/or ITD are based on a pre-defined aircraft speed profile of the follower), Flight Crew shall be briefed and reminded (e.g. via information campaigns) on the importance to respect on the Final Approach path the ATC speed instructions until the start of the deceleration and/or the published procedural airspeed on final approach and to notify Controller in a timely manner in case of inability to conform to one of those.
Leader speed deviation (slowing down) during Follower establishment on Final App	AC_SPEED_2	The leader aircraft slows down when the follower intercepts the final approach path	The following mitigations apply from PJ02.01 (for the leader aircraft): • **REQ-02.01-SPRINTEROP-ARR0.1420** For all modes (where FTD and/or ITD are based on a pre-defined aircraft speed profile of the follower), Flight Crew shall be briefed and reminded (e.g. via information campaigns) on the importance to respect on the Final Approach path the ATC speed instructions until the start of the deceleration and/or the published procedural airspeed on final approach and to notify Controller in a timely manner in case of inability to conform to one of those.
Pilot overshoots the LOC.	FCRW_OSHOOT		Same occurrence& effect as per current operations.

Lateral deviation resulting in conflict prior to capturing the Final App path (including wrong aircraft turning for interception)	AC_LAT_1		Same occurrence & effect as per current operations.
APP ATCO failure to prevent the imminent infringement due to A/C deviation from cleared trajectory (correctly displayed separation indicator)			
APP ATCO fail to timely detect the deviation from the cleared trajectory or the resulting conflict during interception.	APP_ATCO_19	APP ATCO does not detect timely the aircraft deviation from the cleared trajectory because she/he is vectoring or adjusting trajectories of other aircraft merging to the final approach.	A025: The Approach Controller monitors all traffic merging to the final approach to detect any deviation from instructed profile. A020: The Approach Controller asks to correct the aircraft trajectory (heading, speed or altitude) during the approach interception if she/he thinks that it will solve the spacing conflict, i.e. avoid imminent infringement. If not she/he takes corrective actions like initiating missed approach. Level of APP ATCO workload and Situation Awareness during 2NM MRS (with and without tool) during interception have been validated as acceptable; thus a reduction of APP ATCO capability to detect Crew/Aircraft induced spacing conflict during interception is not expected.
Untimely or inadequate ATCO instructions for separation management of Crew/Aircraft induced spacing conflict during interception.	APP_ATCO_20	Upon detection, APP ATCO does not instruct timely or adequately for ensuring separation management of Crew/Aircraft induced spacing conflict during interception.	Level of APP ATCO workload and Situation Awareness during 2NM MRS (with and without tool) during interception have been validated as acceptable; thus a reduction of APP ATCO capability to ensure separation management of Crew/Aircraft induced spacing conflict during interception is not expected.
Inadequate Communication of Instructions to pilot	ATCO-FCRW_1	As for ATCO-FCRW_1R in Hz#01b when the indicators are correctly displayed	

Inadequate Pilot response to ATC not mitigated through monitoring	FCRW_1	As for ATCO-FCRW_1R in Hz#01b	

Table 15: Derivation of Mitigation/Safety Requirements for Hazard Hz#02a for the PJ02.03

4.5.1.7 Hz#03b: Separation not being recovered following imminent infringement by an aircraft pair instructed by ATC on the Final Approach *(applicable with or without the Separation Delivery Tool)*

This hazard occurs during the Final approach and its basic causes and combinations thereof have been captured in the Hz#03b Fault Tree (See Figure 9).

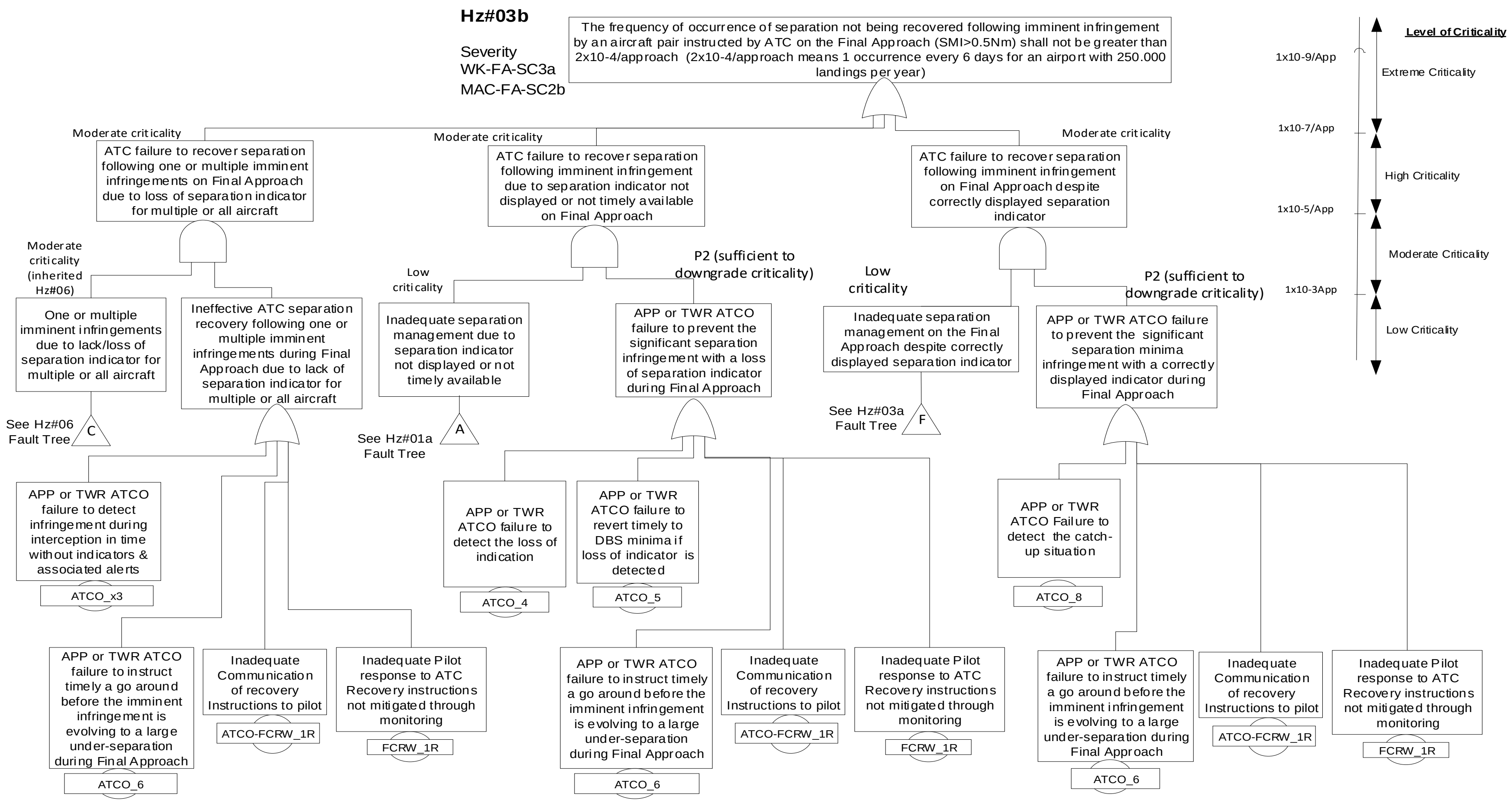

Figure 9: Hz#03b Fault Tree for the PJ02.03

Table 16 below describes the basic causes of the Hazard Hz#03b Fault Tree and identifies the mitigations/safety requirements necessary to satisfy the associated Safety Objective.

Type of failure	Cause Id	Cause description	Mitigation/Safety Requirement
ATC failure to recover separation following one or multiple imminent infringements on Final Approach due to loss of separation indicator for multiple or all aircraft			
One or multiple imminent infringements due to lack/loss of separation indicator for multiple or all aircraft.	See Hz#06 Fault Tree (ref C)	See Hz#06 table.	
APP or TWR ATCO failure to instruct timely a go around before the imminent infringement is evolving to a large under-separation during Final Approach.	ATCO_6	APP or TWR ATCO failure to instruct timely a go around before the imminent infringement is evolving to a large under-separation during Final Approach.	The following mitigating requirements from PJ02.01 apply: • **REQ-02.01-SPRINTEROP-ARR0.1010** Local operational procedures shall be developed for handling traffic situations with missing Target Distance Indicators in different WT separation modes for both controllers and supervisors. • **REQ-02.01-SPRINTEROP-ARR0.1020** Controllers and Supervisors shall regularly receive training on reversal procedures (TB to DB modes) and contingency measures in case of abnormal and degraded modes of operation (e.g. loss of one TDI, loss of all TDIs etc.) • **REQ-02.01-SPRINTEROP-ARR0.1721** In case of separation tool failure with loss of all TDIs (aircraft already established and aircraft going to intercept), the Controllers shall revert to DBS without

			indicators for all aircraft (one or several aircraft might be instructed to break-off) • **REQ-02.01-SPRINTEROP-ARR0.1730** In case of separation tool failure with loss of TDI computation (TDIs preserved for aircraft already established) a specific separation tool failure alert shall be provided and the Controllers shall revert to DBS without indicators for aircraft without TDIs. Only for aircraft already established, TDIs that continue to be displayed can be used up to the separation delivery point • **REQ-02.01-SPRINTEROP-ARR0.1640** In case of Separation Tool Failure, the Supervisors and Controllers shall receive a message containing the source of the tool failure
			In case of go-around/break-off instructed by ATCO: • **SR3.302** A generic wake risk assessment shall be performed for the 2NM MRS non-wake pairs in the specific case when the leader is performing a break-off/go-around and the follower, separated at close to the separation minima, continues its descent crossing the leader's descending wake

			If considered, STCA will trigger outside a pre-defined region (e.g. 4NM at Heathrow): • **SR3.300** If available for the Final Approach Controllers, the Short Term Conflict Alert shall be adjusted to accommodate the 2NM MRS concept
APP or TWR ATCO failure to detect infringement during interception in time without indicators & associated alerts	ATCO_x3	Not having the indicators and associated alerts, APP or TWR ATCO fails to detect in time the infringement at interception	As for ATCO_6
Inadequate Communication of recovery Instructions to pilot	ATCO-FCRW_1R	As for ATCO-FCRW_1R in Hz#01b when the indicators are not displayed	
Inadequate Pilot response to ATC Recovery instructions not mitigated through monitoring	FCRW_1R	As for FCRW_1R in Hz#01b	
ATC failure to recover separation following imminent infringement due to separation indicator not displayed or not timely available on Final Approach			
Inadequate separation management due to separation indicator not displayed or not timely available.	See Hz#01a Fault Tree (ref A)	See Hz#01a table. The detected loss of separation indicator during the final approach may lead to imminent infringement.	
APP or TWR ATCO failure to detect the loss of indication.	ATCO_4	APP or TWR ATCO does not detect the loss of separation indicator in order to prevent the separation infringement.	The following mitigations apply from PJ02.01: • **REQ-02.01-SPRINTEROP-ARR0.0520:** Approach and Tower Supervisors shall be made aware if any tool / monitoring / alerting features are lost or inoperative.

APP or TWR ATCO failure to revert timely to DBS minima if loss of indicator is detected.	ATCO_5	APP or TWR ATCO does not revert timely to DBS minima when the loss of indicator is detected.	The following mitigation applies from PJ02.01: • **REQ-02.01-SPRINTEROP-ARR0.1020** Controllers and Supervisors shall regularly receive training on reversal procedures (TB to DB modes) and contingency measures in case of abnormal and degraded modes of operation (e.g. loss of one TDI, loss of all TDIs etc.)
APP or TWR ATCO failure to instruct timely a go around before the imminent infringement is evolving to a large under-separation during Final Approach.	ATCO_6	As above.	As for ATCO_6 above
Inadequate Communication of recovery Instructions to pilot	ATCO-FCRW_1R	As for ATCO-FCRW_1R in Hz#01b when the indicators are not displayed	
Inadequate Pilot response to ATC Recovery instructions not mitigated through monitoring	FCRW_1R	As for FCRW_1R in Hz#01b	
ATC failure to recover separation following imminent infringement on Final Approach despite correctly displayed separation indicator			
Inadequate separation management on the Final Approach despite correctly displayed separation indicator.	See Hz#03a Fault Tree (ref F)	See Hz#03a table. Inadequate separation management on the Final Approach despite correctly displayed separation indicator may lead to imminent infringement.	
APP or TWR ATCO Failure to detect the catch-up situation.	ATCO_8	APP or TWR ATCO does not detect the catch up situation involving imminent infringement despite correct separation indicator is displayed.	The following mitigations apply from PJ02.01: • **REQ-02.01-SPRINTEROP-ARR3.1540:** The Separation Delivery tool may provide automatic monitoring and warning of catch up of the ITD.

			• **REQ-02.01-SPRINTEROP-ARR0.1350:** Procedures shall be defined regarding required actions if catching up or infringing the ITD or FTD.
APP or TWR ATCO failure to instruct timely a go around before the imminent infringement is evolving to a large under-separation during Final Approach.	ATCO_6	As per ATCO_6 above	As per ATCO_6 above
Inadequate Communication of recovery Instructions to pilot	ATCO-FCRW_1R	As for ATCO-FCRW_1R in Hz#01b when the indicators are correctly displayed	
Inadequate Pilot response to ATC Recovery instructions not mitigated through monitoring	FCRW_1R	As for FCRW_1R in Hz#01b	

Table 16: Derivation of Mitigation/Safety Requirements for Hazard Hz#03b for the PJ02.03

4.5.1.8 Hz#03a: Inadequate separation management of an aircraft pair naturally catching-up as instructed by ATC on the Final Approach *(applicable only with the Separation Delivery Tool)*

This hazard occurs during the Final approach and its basic causes and combinations thereof have been captured in the Hz#03a Fault Tree (See Figure 10).

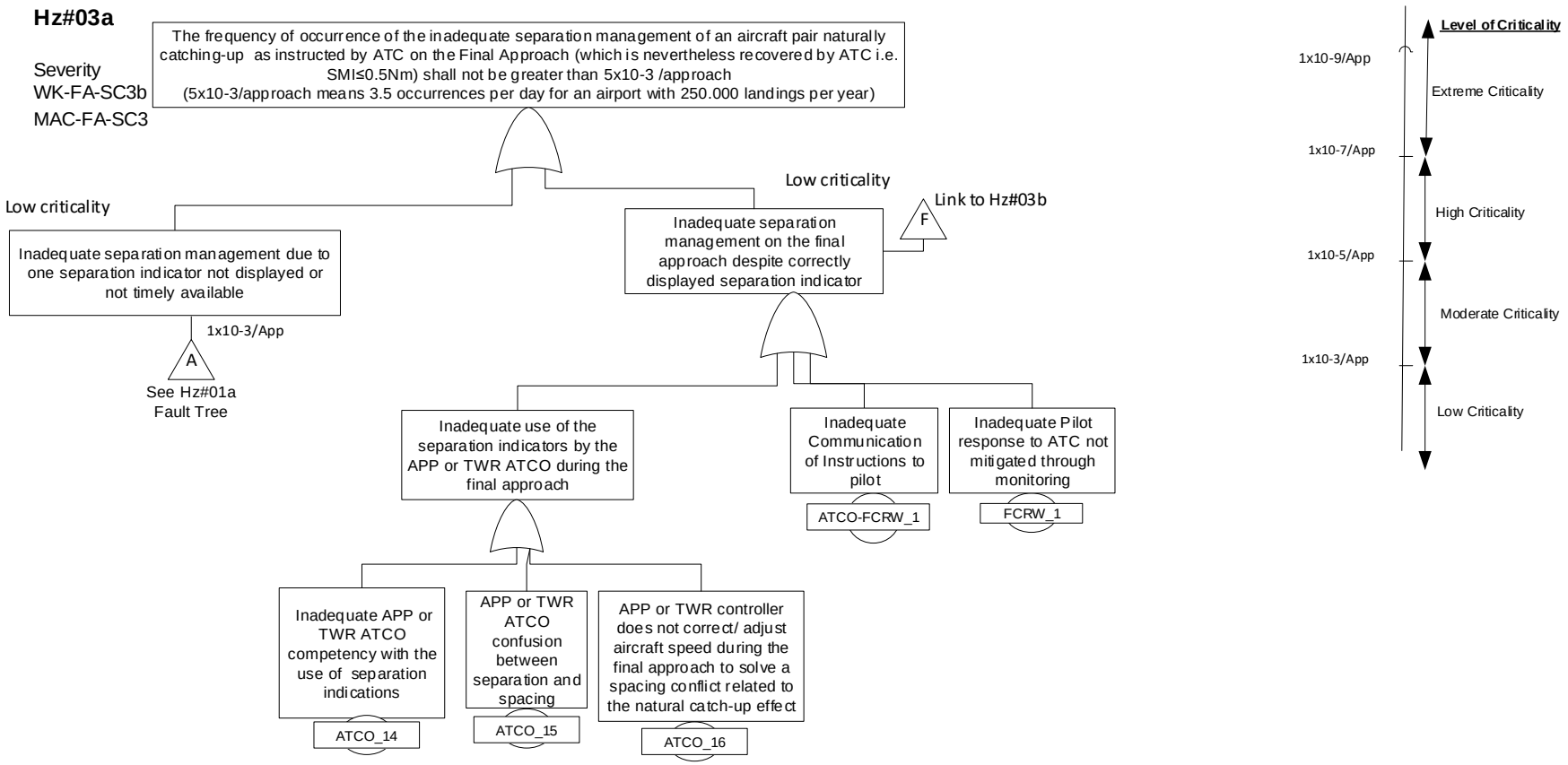

Figure 10: Hz#03a Fault Tree for the PJ02.03

Table 17 below describes the basic causes of the Hazard Hz#03a Fault Tree and identifies the mitigations/safety requirements necessary to satisfy the associated Safety Objective.

Type of failure	Cause Id	Cause description	Mitigation/Safety Requirement
Inadequate separation management due to separation indicator not displayed or not timely available.	See Hz#01a Fault Tree. (ref A)	See Hz#01a table. The inadequate separation management due to separation indicator not displayed or not timely available leads to an imminent infringement during the final approach considering the aircraft pair (SMI<0.5NM).	
Inadequate separation management on the final approach despite correctly displayed separation indicator			
Inadequate use of the separation indicators by the approach or Tower controller during the Final Approach.	ATCO_14	Inadequate APP or TWR ATCO competency with the use of separation indicators.	The following mitigation applies from PJ02.01: • **REQ-02.01-SPRINTEROP-ARR0.1250** Approach and Tower Controllers shall be fully trained to apply the procedures for the new separation modes and to use of the Separation Delivery Tool and supporting systems (e.g. alerts) with indicators prior to deployment. • **REQ-02.01-SPRINTEROP-ARR2.0971** The Tower Controller shall ensure that the actual spacing behind the leader aircraft is not infringing the FTD and in case of imminent infringement he shall apply adequate corrective action like delegating visual separation to Flight Crew or instructing go-around.
	ATCO_15	APP or TWR ATCO confusion between separation (e.g. MRS, wake) and spacing indicators (e.g. ROT).	The following mitigation applies from PJ02.01: **REQ-02.01-SPRINTEROP-ARR0.0691** The Controllers shall be able to visually distinguish (via colour or symbol) if Target Distance Indicators are relative to WT, MRS or ROT (or other spacing constraint).

	ATCO_16	APP or TWR controller does not correct/ adjust aircraft speed during the final approach to solve a spacing conflict related to the natural catch-up effect.	The following mitigations apply from PJ02.01: • **REQ-02.01-SPRINTEROP-ARR3.1540** The Separation Delivery tool may provide automatic monitoring and warning of catch up of the ITD. • **REQ-02.01-SPRINTEROP-ARR0.1350** Procedures shall be defined regarding required actions if catching up or infringing the ITD or FTD. • **REQ-02.01-SPRINTEROP-ARR0.0792** For the Tower HMI, in case of high priority ITD infringement, the Tower Controller shall be able to assess if he can proceed safely with landing. • **REQ-02.01-SPRINTEROP-ARR0.0795** For the Approach HMI, in case of high/low priority ITD infringement, the Approach Controller shall be able to assess if he can proceed safely. • **REQ-02.01-SPRINTEROP-ARR0.0710** The tool shall automatically display the FTD (if not already displayed) if the aircraft comes within a defined distance of the computed FTD. This distance shall be configurable within the tool. • **REQ-02.01-SPRINTEROP-ARR3.0500** Once the follower aircraft has been positioned w.r.t ITD and before the leader reaches its deceleration point, the Controller shall apply speed instructions in accordance to

			the reference glide slope air speed used for ITD calculation. • **REQ-02.01-SPRINTEROP-ARR0.0165** The Tower Controller shall monitor and ensure that there is no infringement of the FTD. • **REQ-02.01-SPRINTEROP-ARR0.1500** The Approach and/or Tower controller shall be alerted by the speed conformance alert function when the actual aircraft speed differs by more than a locally-defined threshold from the aircraft speed profile used for the TDIs computation. • **REQ-02.01-SPRINTEROP-ARR0.1700**: In TB-modes, in case of speed conformance alert before the stabilisation fix, the Final Approach or Tower Controllers shall check whether the actual spacing behind the leader aircraft is below the distance-based WTC separation minima and if positive shall apply adequate corrective actions: airspeed instructions, path stretching instructions (if allowed after localiser interception), delegation of visual separation to Flight Crew and, if necessary, missed approach instruction, and shall manage the impact on subsequent aircraft in the arrival sequence.

			A035: Approach and/or Tower Controller could delegate the wake or MRS separation to the flight crew in case visual separation conditions apply.
Inadequate Communication of Instructions to pilot	ATCO-FCRW_1	As for ATCO-FCRW_1R in Hz#01b when the indicators are correctly displayed	
Inadequate Pilot response to ATC not mitigated through monitoring	FCRW_1	As for FCRW_1R in Hz#01b	

Table 17: Derivation of Mitigation/Safety Requirements for Hazard Hz#03a for the PJ02.03

4.5.1.9 Hz#04b: Separation not being recovered following imminent infringement due to aircraft deviation from Final Approach profile without ATC instruction given *(applicable with or without the Separation Delivery Tool)*

This hazard occurs during the Final approach and its basic causes and combinations thereof have been captured in the Hz#04b Fault Tree (See Figure 11).

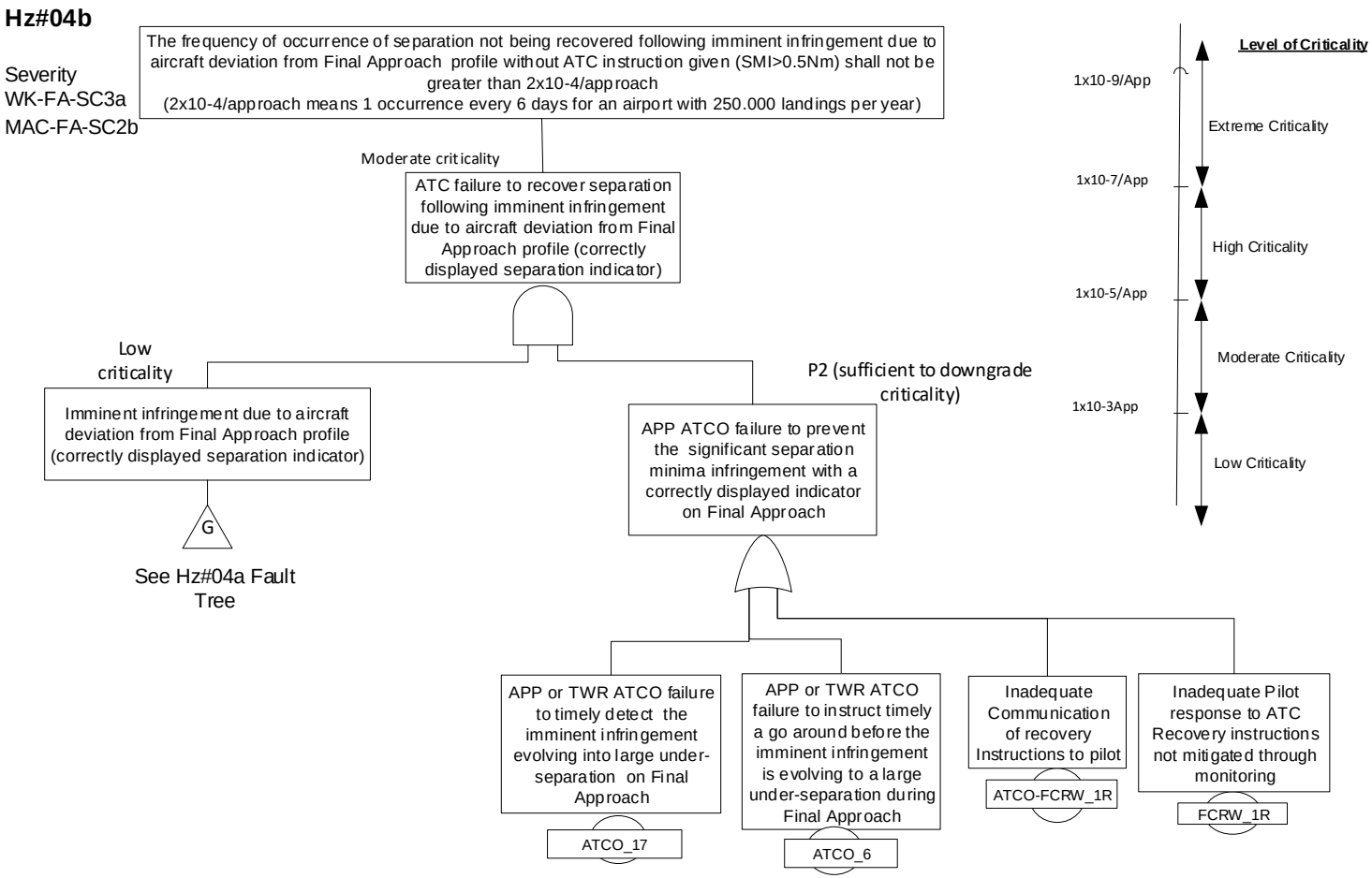

Figure 11: TB Hz#04b Fault Tree for the PJ02.03

Table 18 below describes the basic causes of the Hazard Hz#04b Fault Tree and identifies the mitigations/safety requirements necessary to satisfy the associated Safety Objective.

Type of failure	Cause Id	Cause description	Mitigation/Safety Requirement
Imminent infringement during interception due to aircraft deviation from Final Approach profile (correctly displayed separation indicator).	See Hz#04a Fault Tree (ref G)	See Hz#02a table.	
APP ATCO failure to prevent the significant separation minima infringement with a correctly displayed indicator			
APP or TWR ATCO failure to timely detect the imminent infringement evolving into large under-separation on Final Approach.	ATCO_17	Aircraft deviates from speed instructions or from the nominal stabilized approach speed and APP or TWR ATCO does not detect the catch up situation with imminent infringement evolving into large under-separation despite correct separation indicator is displayed.	It is assumed that the approach and tower controller verifies the actual speed of the aircraft and the speed trend during the final approach. The following mitigations apply from PJ02.01: • **REQ-02.01-SPRINTEROP-ARR3.1540** The Separation Delivery tool may provide automatic monitoring and warning of catch up of the ITD. • **REQ-02.01-SPRINTEROP-ARR0.1350** Procedures shall be defined regarding required actions if catching up or infringing the ITD or FTD. • **REQ-02.01-SPRINTEROP-ARR0.1500** The Approach and/or

			Tower controller shall be alerted by the speed conformance alert function when the actual aircraft speed differs by more than a locally-defined threshold from the aircraft speed profile used for the TDIs computation. • **REQ-02.01-SPRINTEROP-ARR0.1700**: In TB-modes, in case of speed conformance alert before the stabilisation fix, the Final Approach or Tower Controllers shall check whether the actual spacing behind the leader aircraft is below the distance-based WTC separation minima and if positive shall apply adequate corrective actions: airspeed instructions, path stretching instructions (if allowed after localiser interception), delegation of visual separation to Flight Crew and, if necessary, missed approach instruction, and shall manage the impact on subsequent aircraft in the arrival sequence. • **REQ-02.01-SPRINTEROP-ARR0.0792** For the Tower HMI, in case of high priority ITD infringement, the Tower Controller shall be able to assess

			if he can proceed safely with landing. • **REQ-02.01-SPRINTEROP-ARR0.0795** For the Approach HMI, in case of high/low priority ITD infringement, the Approach Controller shall be able to assess if he can proceed safely. • **REQ-02.01-SPRINTEROP-ARR0.0710** The tool shall automatically display the FTD (if not already displayed) if the aircraft comes within a defined distance of the computed FTD. This distance shall be configurable within the tool.
APP or TWR ATCO failure to instruct timely a go around before the imminent infringement is evolving to a large under-separation during Final Approach.	ATCO_6	APP or TWR ATCO failure to instruct timely a go around before the imminent infringement is evolving to a large under-separation during Final Approach.	As per ATCO_6 in Hz#03b
Inadequate Communication of recovery Instructions to pilot	ATCO-FCRW_1R	As for ATCO-FCRW_1R in Hz#01b when the indicators are correctly displayed	
Inadequate Pilot response to ATC Recovery instructions not mitigated through monitoring	FCRW_1R	As for FCRW_1R in Hz#01b	

Table 18: Derivation of Mitigation/Safety Requirements for Hazard Hz#04b for the PJ02.03

4.5.1.10 Hz#04a: Inadequate separation management of a spacing conflict due to aircraft deviation from Final Approach profile without ATC instruction given ***(applicable with or without the Separation Delivery Tool)***

This hazard occurs during the Final approach and its basic causes and combinations thereof have been captured in the Hz#04a Fault Tree (See Figure 12).

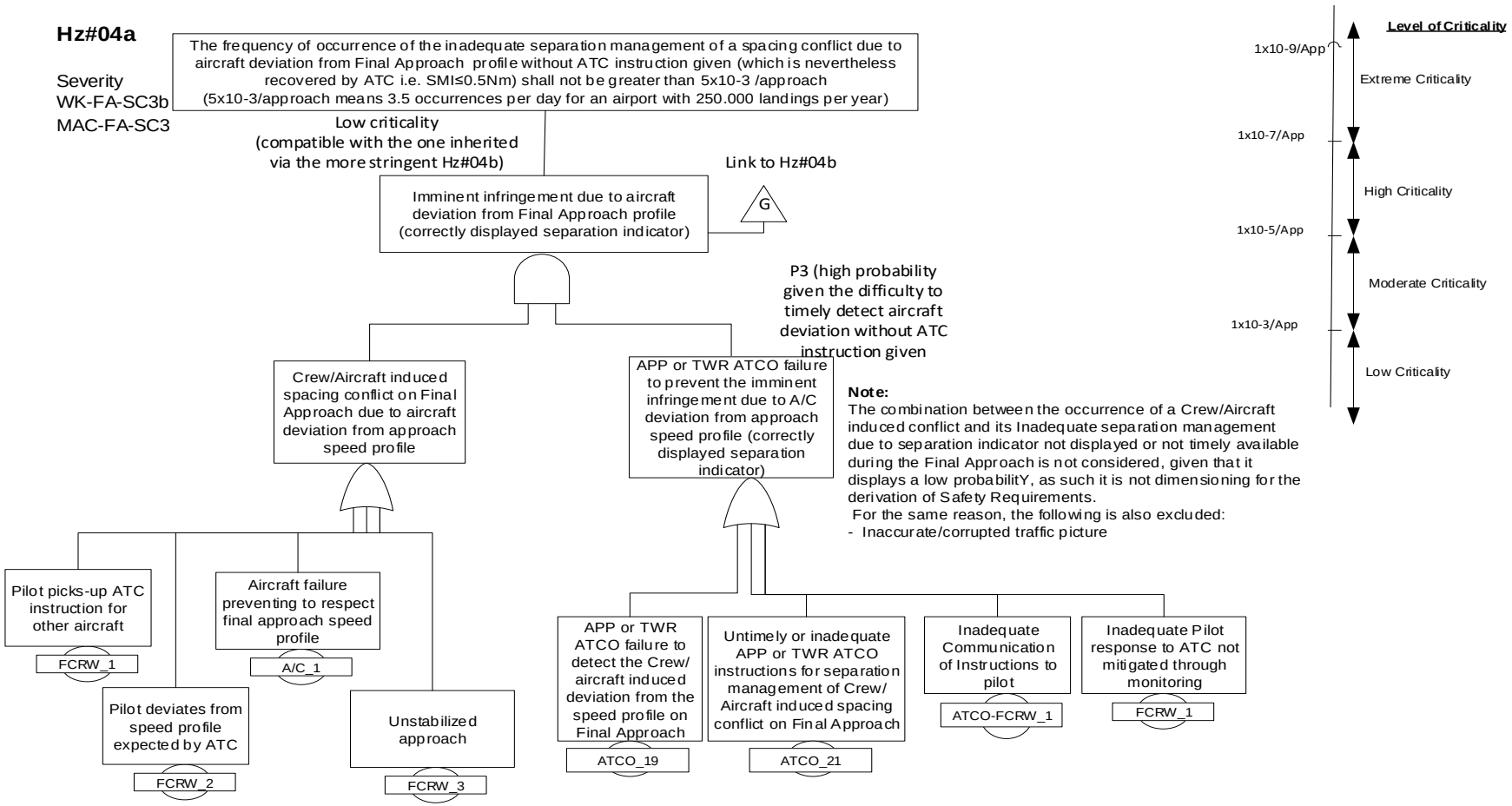

Figure 12: Hz#04a Fault Tree for the PJ02.03

Table 19 below describes the basic causes of the Hazard Hz#04a Fault Tree and identifies the mitigations/safety requirements necessary to satisfy the associated Safety Objective.

Type of failure	Cause Id	Cause description	Mitigation/Safety Requirement
Crew/Aircraft induced spacing conflict on Final Approach due to aircraft deviation from approach speed profile			
Pilot picks-up ATC instruction for other aircraft.	FCRW_1	Pilot picks-up ATC instruction for other aircraft.	No specific SR for radio communication. Current read-back/hear-back procedures to be applied.
Pilot deviates from speed profile expected by ATC.	FCRW_2	Pilot deviates from speed profile expected by ATC.	The following mitigation applies from PJ02.01: • **REQ-02.01-SPRINTEROP-ARR0.1420** For all modes (where FTD and/or ITD are based on a pre-defined aircraft speed profile of the follower), Flight Crew shall be briefed and reminded (e.g. via information campaigns) on the importance to respect on the Final Approach path the ATC speed instructions until the start of the deceleration and/or the published procedural airspeed on final approach and to notify Controller in a timely manner in case of inability to conform to one of those.
Aircraft failure preventing to respect final approach speed profile.	AC_1	Aircraft failure (slat, flap, engine,…) led to the impossibility to respect the approach speed profile.	The following mitigation applies from PJ02.01: • **REQ-02.01-SPRINTEROP-ARR0.1420** For all modes (where FTD and/or ITD are based on a pre-defined aircraft speed profile of the follower), Flight Crew shall be briefed and reminded (e.g. via

			information campaigns) on the importance to respect on the Final Approach path the ATC speed instructions until the start of the deceleration and/or the published procedural airspeed on final approach and to notify Controller in a timely manner in case of inability to conform to one of those.
Un-stabilized approach.	FCRW_3	Failure of the Flight crew to assess or to manage the aircraft's energy during the approach.	The following mitigation applies from PJ02.01: • **REQ-02.01-SPRINTEROP-ARR0.1270:** ATCO training shall ensure that the operation in new WT separation modes will not lead to more un-stabilized approaches due to late/rush aircraft stabilisation as a result of tighter spacing and more frequent speed adjustments. However, a greater number of instructions might temporarily occur during the introduction of the new concept.
APP or TWR ATCO failure to prevent the imminent infringement due to A/C deviation from approach speed profile (correctly displayed separation indicator)			
APP or TWR ATCO failure to detect the Crew/aircraft induced deviation from the speed profile on Final Approach	ATCO_19	APP or TWR ATCO does not detect timely the aircraft deviation from the speed profile.	The following mitigations apply from PJ02.01: • **REQ-02.01-SPRINTEROP-ARR0.1500** The Approach and/or Tower controller shall be alerted by the speed conformance alert function when the actual aircraft speed differs by more than a locally-

			defined threshold from the aircraft speed profile used for the TDIs computation. • **REQ-02.01-SPRINTEROP-ARR0.1700**: In TB-modes, in case of speed conformance alert before the stabilisation fix, the Final Approach or Tower Controllers shall check whether the actual spacing behind the leader aircraft is below the distance-based WTC separation minima and if positive shall apply adequate corrective actions: airspeed instructions, path stretching instructions (if allowed after localiser interception), delegation of visual separation to Flight Crew and, if necessary, missed approach instruction, and shall manage the impact on subsequent aircraft in the arrival sequence. • **REQ-02.01-SPRINTEROP-ARR0.1420** For all modes (where FTD and/or ITD are based on a pre-defined aircraft speed profile of the follower), Flight Crew shall be briefed and reminded (e.g. via information campaigns) on the importance to respect on the Final Approach path the ATC speed instructions until the start of the deceleration and/or the published procedural airspeed on final approach and to notify Controller in a timely manner in case of inability to conform to one of those.

			• **REQ-02.01-SPRINTEROP-ARR2.0971** The Tower Controller shall ensure that the actual spacing behind the leader aircraft is not infringing the FTD and in case of imminent infringement he shall apply adequate corrective action like delegating visual separation to Flight Crew or instructing go-around.
Untimely or inadequate APP or TWR ATCO instructions for separation management of Crew/Aircraft induced spacing conflict on Final Approach	ATCO_21	Upon detection, APP or TWR ATCO does not instruct timely or adequately for ensuring separation management of Crew/Aircraft induced spacing conflict during interception.	Level of APP and TWR ATCO workload and Situation Awareness during 2NM MRS (with and without tool) during Final Approach have been validated as acceptable; thus a reduction of APP ATCO capability to ensure separation management of Crew/Aircraft induced spacing conflict during interception is not expected.
Inadequate Communication of recovery Instructions to pilot	ATCO-FCRW_1R	As for ATCO-FCRW_1R in Hz#01b when the indicators are correctly displayed	
Inadequate Pilot response to ATC Recovery instructions not mitigated through monitoring	FCRW_1R	As for FCRW_1R in Hz#01b	

Table 19: Derivation of Mitigation/Safety Requirements for Hazard Hz#04a for the PJ02.03

4.5.1.11 Hz#08: Runway conflict due to landing clearance in conflict with another landing (ROT not respected)

This hazard occurs during the Final approach and its basic causes and combinations thereof have been captured in the Hz#08 Fault Tree Figure 13

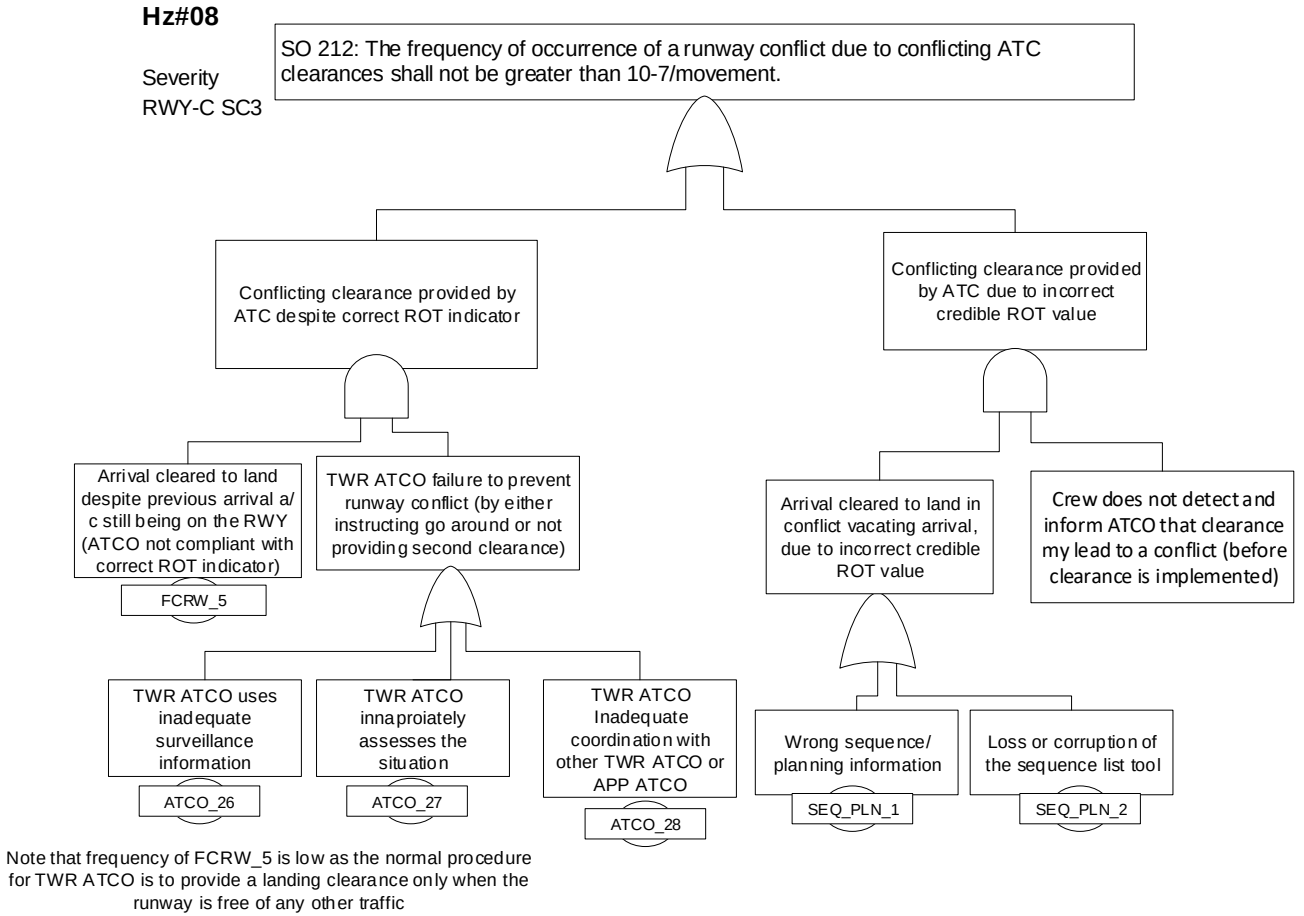

Figure 13 Hz#08 Fault Tree

Type of failure	Cause Id	Cause description	Mitigation/Safety Requirement
Conflicting clearance provided by ATC despite correct ROT indicator			
Arrival cleared to land despite previous arrival a/c still being on the RWY (ATCO not compliant with correct ROT indicator)	FCRW_5	ATCO is not compliant with the ROT indicator	The following mitigations apply from PJ02.01: • **REQ-02.01-SPRINTEROP-ARR0.0162**: The tool in any mode shall display TDIs representing the greatest constraint out of all applicable in-trail or not in-trail separation constraints. The constraints can be the high priority separation (e.g. Wake and MRS) and the low priority runway spacing (ROT) and other spacing constraints (e.g. departure GAP, runway inspections, etc.).
Conflicting clearance provided by ATC due to incorrect credible ROT value			
Wrong sequence/planning information	SEQ_PLN_1		The following mitigations apply from PJ02.01: • **REQ-02.01-SPRINTEROP-ARR0.0940**: In case of a change of the arrival sequence order position of an aircraft, the Approach controller shall check that the arrival sequence order has been updated to reflect the change • **REQ-02.01-SPRINTEROP-ARR0.0550:** If there is a change to the sequence order or runway intent, the Approach Controller should check that each indicator for each affected aircraft pair has been updated. • **REQ-02.01-SPRINTEROP-ARR0.0941**: The sequence manager shall ensure that for the change of the sequence order there

			is no overlap (or lack of awareness) between the actions taken by the Intermediate Approach Controller and the Final Approach Controller, by allowing only one change at a time. • **REQ-02.01-SPRINTEROP-ARR0.0800:** The HMI design shall allow Controllers to identify the aircraft associated with each displayed indicator. • **SR1.200 (Example of REQ-02.01-SPRINTEROP-ARR0.0852**): The Intermediate and Final Approach controllers shall be the masters of the Final Approach arrival sequence and shall be able in a simple and timely way to update the sequence, insert or remove an aircraft and amend the sequence when there is a go-around in accordance with their strategy for the interception with no adverse impact on workload. • **REQ-02.01-SPRINTEROP-ARR0.0540**: Controllers shall be trained to check the aircraft landing runway intent and that the aircraft order is correct and coherent with the arrival sequence list. They shall check if and that the aircraft order is displayed in the arrival sequence list and/or if the aircraft sequence number is displayed in the radar label in accordance with their intended sequence.
Loss or corruption of the sequence list tool	SEQ_PLN_2		Corruption of the sequence list: mitigated through the software assurance process which defines the

			acceptably safe level of confidence in the arrival sequence service prior to implementation. Additionally, the following mitigations apply from PJ02.01: • **REQ-02.01-SPRINTEROP-ARR0.0410:** The software assurance level of the Separation Delivery tool and supporting tools shall be determined by the V4 safety assessment As for the loss of the arrival sequence service: • **REQ-02.01-SPRINTEROP-ARR0.1720:** If the Approach Arrival Sequence Service fails, the Separation Delivery tool shall continue displaying TDIs for aircraft already established and shall stop displaying TDIs for all other aircraft

Table 20 Derivation of Mitigation/Safety Requirements for Hazard Hz#08 for the PJ02.03

4.5.2 Common Cause Analysis

The main common causes have been identified through an initial causal analysis of the successive WTA AIM barriers B3, B4, B5, B6 and B3a. They are related to the use of the separation indicators, as a lack of information, or incorrect information would affect all those ATM safety barriers.

To deal with the common causes, two dedicated operational hazards have been defined, and risk appropriately assessed and mitigated:

- **Hz#05**: One or multiple imminent infringements not detected and not recovered due to undetected corruption of separation indicator *(only with the separation Delivery Tool)*
- **Hz#06**: One or multiple imminent infringements due to lack of separation indicator for multiple or all aircraft *(only with the separation Delivery Tool)*

4.5.3 Formalization of Mitigations

This section derives the mitigations to reduce the likelihood that specific failures would propagate up to the Hazard (i.e. operational level) – these mitigations are then captured as additional Safety Requirements (Functional and Performance) considering the outcome of the causal analysis and more particularly the Mitigations identified in each table accompanying the hazard fault trees.

Table 21 below summarize the new safety requirements (functionality & performance) that have been derived in order to mitigate risk associated to the system generated hazards (i.e. mitigation which have not been already captured during the design analysis in Normal operations or in presence of Abnormal conditions).

Reference	Mitigation to System generated Hazard	Hazard
SR3.300	If available for the Final Approach Controllers, the Short Term Conflict Alert shall be adjusted to accommodate the 2NM MRS concept	Hz#01b Hz#02b Hz#03b Hz#04b
SR3.301	A local Collision Risk Assessment shall be performed to prove that the collision risk of pairs of aircraft concerned by MRS 2NM, is at acceptable safety levels considering the local distribution of the aircraft pairs, wind conditions, etc. *For an example of a CRM, please see Appendix G which contains a CRM performed by NATS for the Heathrow final approaches.*	Hz#01b Hz#02b Hz#03b Hz#04b
	The following mitigating requirements also apply from PJ02.01: REQ-02.01-SPRINTEROP-ARR0.0142 REQ-02.01-SPRINTEROP-ARR0.0166 REQ-02.01-SPRINTEROP-ARR0.0400	

	REQ-02.01-SPRINTEROP-ARR0.0430 REQ-02.01-SPRINTEROP-ARR0.0450 REQ-02.01-SPRINTEROP-ARR0.0460 REQ-02.01-SPRINTEROP-ARR0.0510 REQ-02.01-SPRINTEROP-ARR0.0520 REQ-02.01-SPRINTEROP-ARR2.0971 REQ-02.01-SPRINTEROP-ARR0.1010 REQ-02.01-SPRINTEROP-ARR0.1020 REQ-02.01-SPRINTEROP-ARR0.1350 REQ-02.01-SPRINTEROP-ARR0.1440 REQ-02.01-SPRINTEROP-ARR0.1441 REQ-02.01-SPRINTEROP-ARR0.1530 REQ-02.01-SPRINTEROP-ARR0.1560 REQ-02.01-SPRINTEROP-ARR0.1640 REQ-02.01-SPRINTEROP-ARR0.1720 REQ-02.01-SPRINTEROP-ARR0.1721 REQ-02.01-SPRINTEROP-ARR0.1730 REQ-02.01-SPRINTEROP-ARR0.1600 REQ-02.01-SPRINTEROP-ARR0.1650 REQ-02.01-SPRINTEROP-ARR0.1660 REQ-02.01-SPRINTEROP-ARR0.1770 REQ-02.01-SPRINTEROP-ARR0.1270	

Table 21 Additional functionality & performance safety requirements and assumptions to mitigate System generated Hazards

4.6 Achievability of the SAfety Criteria

In Section 3.9 of the present document the safety-relevant validation objectives for each Safety Criteria have been defined for the safety assurance activities to be conducted according to the safety demonstration strategy.

This section outlines the results of the safety assurance activities in response to those validation objectives. These results encompass results of the validation exercises or outcomes of the safety-dedicated workshops (making use of operational experts' judgment). Such results may confirm that the validation objectives are satisfied (thus proving that the correspondent SAC is met) or may allow to validate Safety Requirements or to derive new ones (consolidated in the dedicated sections 4.2.2, 4.4.2 and 4.5.3).

It is recalled that at SPR-design level, Safety Objectives have been mapped to Safety Requirements for normal conditions (section 4.2.2), for abnormal conditions (section 4.4.2) and for failure aspects (section 4.5.3). It was shown in these sections (using a combination of safety engineering techniques, safety assessment and results from validation exercises) that these Safety Requirements satisfy the Safety Objectives which in turn have been already shown to satisfy the Safety Criteria.

The information regarding the safety requirements that have been derived within the safety assessment is provided in Appendix E (providing the consolidated list of the functionality & performance safety requirements).

Table 22 summarizes the results for the Safety KPA dedicated to each of the SESAR solution success criteria identified in the VAL PLN [14] for the relevant validation exercises. For detailed results please see the corresponding VALR [13].

Exercise ID, Name, Objective	Exercise Validation objective	Success criterion	Safety Criteria coverage	Validation results & Level of safety evidence
EXE-PJ02-03 VALP-RTS02: RTS conducted by EUROCONTROL to assess the operational feasibility and acceptability of reducing the in-trail Minimum Radar Separation (MRS) from 2.5 NM to 2 NM under applicable separation scheme on the final approach under IMC. The main focus of this real time simulation was to assess the in-trail 2 NM MRS combined with TB PWS for arrivals and the ORD tool (Use case [MRS-2a] MRS 2NM with ORD Tool) under segregated mode runway operations.	**OBJ-PJ2.03-V3-VALP-SA1** To assess the impact on operational safety of applying an in-trail Minimum Radar Separation of 2NM during interception and final approach compared to applying the 2.5NM Minimum Radar Separation.	**CRT-PJ2.03-V3-VALP-SA3-001** The level of operational safety is maintained and not negatively impacted under the in-trail 2 NM MRS with ORD tool during interception and final approach compared to when applying the in-trail 2.5 NM MRS without indicators, despite the potential increase in controller workload (in relation to the expected throughput increase).	**M-SAC#1** **W-SAC#F2** **W-SAC#F4**	Overall, the controllers were seen to apply the safe standard practices when applying TB-PWS MRS 2NM with ORD tool in the simulation, during nominal operations. Regarding degraded mode of operations, two types of failure were simulated: ORD tool failure, wrong a/c type in the flight plan. During both failure modes, the APP and TWR Controllers successfully employed safe contingency procedures to deal with the non-nominal situations.
		CRT-PJ2.03-V3-VALP-SA3-002 Evidence that using the in-trail 2 NM MRS with ORD tool will decrease the number of separation minima infringements compared to using the in-trail 2.5 NM MRS without indicators (in order to compensate for the potential severity increase of the wake	**M-SAC#F1** **M-SAC#F2**	Given the limited number of runs and the low number of under-separation events, a meaningful statistical analysis could not be done to draw a conclusion for comparison of the number of under-separations between the reference and the solution runs. Also note that although there was one small under-separation in the solution scenario,

		separation infringements and of the radar separation infringements – the latter in relation to the reduction of the time available for ATCO and Pilot reaction time)		this does not allow us to conclude that safety is degraded compared to the reference scenario. As for the separation infringements on base leg, it was concluded that there was no increase in separation non-conformances before alignment or on the base leg due to reduction of MRS to 2.0NM.
		CRT-PJ2.03-V3-VALP-SA3-003 The number of Go around due to inadequate consideration of ROT constraint is not increased (for RWY conflicts)	**R-SAC#F1**	The number of ROT related Go-arounds was of same order of magnitude in the solution scenario compared to the reference. However, the validity of this conclusion is limited by the low relevance of the statistics involved by the low number of runs.
	RTS02 Prototyping session: 2NM MRS DBS ICAO <u>NO SUPPORTING TOOL</u>		conducted to assess the operational feasibility and acceptability of applying 2.0NM MRS between medium-medium aircraft pairs with DBS ICAO separations <u>and no controller support tool.</u> The results of the prototyping session showed that safety was not negatively impacted in the solution scenario (i.e. 2.0NM MRS applied between M-M ICAO pairs with no tool) compared to the reference scenario: • Under the wind conditions tested, the number of go-arounds was not found to increase in solution scenario (2.0NM MRS applied between ICAO M-M pairs with no tool)	

				compared to the reference scenario (Vienna current operations – i.e. 2.5NM MRS applied for all MRS aircraft); • There was no increase in the number of under spacings observed in the solution scenario exercise runs compared to the reference scenario exercise runs; The reduction of MRS to 2.0 NM for M-M MRS pairs under certain wind conditions did not lead to more separation non-conformances before alignment, as only one case occurred during a reference run.
EXE-PJ02-03 VALP-FTS03: Conducted by CRIDA to support the Safety Assessment for the in-trail 2 NM arrival separation concept on the final approach. This FTS assessed the safety impact of the in-trail 2 NM arrival separation solution on the final approach with regards to the risk of collision due to a catch up scenario using multiple aircraft types as the leader and follower pairs. This FTS focused on Use case [MRS-2b]	**OBJ-PJ02.03-V3-VALP-SA1** To provide evidence that the minimal pair arrival separation reduction to 2 NM on final approach is safe using currently available surveillance means	**CRT-PJ2.03-V3-VALP-SA3-001** At least one of the surveillance means tested shows no collisions for all included aircraft pairs.	**M-SAC#1**	ulfils the criteria for safe operations under certain conditions, whereas ADS-B fulfils the criteria under all conditions. Only a few certain pairs of aircraft might need to be limited in separation for weather dependent separations where the wake vortex separation is not taken into consideration. *For an example of a local surveillance performance assessment case study, please see Appendix H which contains the Surveillance Performance Assessment of 2NM Separations at Heathrow Airport.*

MRS 2NM without ORD Tool				
EXE-PJ02-03 VALP-FTS01 Conducted by EUROCONTROL to support the CBA for the reduction of the in-trail radar separation minima to 2 NM on the final approach. This RTS covered multiple generic environments and supported the validation of the capacity benefit for a range of operational configurations. This FTS focused on Use case [MRS-2a] MRS 2NM with ORD Tool.	No Safety Validation Objective needed to be set for this FTS			

Table 22 PJ02.03 exercise safety validation objectives and the related success criteria - Summary of the results

4.7 Realism of the SPR-level Design

The development and safety analysis of the design would be seriously undermined if it were found in the subsequent Implementation phase that the Safety Requirements were either not 'testable' or impossible to satisfy (i.e. not achievable), and / or that some of the assumptions were in fact incorrect.

4.7.1 Achievability of Safety Requirements / Assumptions

All of the Safety Requirements have been demonstrated as capable of being satisfied in a typical implementation because they have been tested during validation exercises or because their achievability has been confirmed with Controllers, pilots and ground manufacturer during meetings, SAF/HP workshop or debriefing sessions.

In case achievability could not be completely demonstrated, no requirement has been derived but an issue has been identified instead.

4.7.2 "Testability" of Safety Requirements

Most of the safety requirements are verifiable by direct means which could be by equipment and/or integrated system verification report, training certificate, published procedures, AIP information, etc.

For some safety requirements, verification should rely on appropriate assurance process to be implemented. This is particularly true for the development of the separation delivery and arrival sequencing tools (e.g. based on Software and/or hardware assurance level) but also for the data quality and assurance process of the separation tool configuration files.

4.8 Validation & Verification of the Safe Design at SPR Level

A safety team encompassing controllers, pilots, ground suppliers, engineers, Safety and Human Performance specialists have supported this safety assessment.

In addition to the activities conducted at OSED level, the first step was checking the PJ02.01 safety assessment because these two solutions are very similar, then additional safety requirements have been derived in normal, abnormal and failure conditions to satisfy the Safety Objectives identified in Sol 03. In addition to the SAF/HP workshop, several meetings were organised to consolidate the list of safety requirements in particular to obtain consistent Safety and HP requirements.

The causal analysis and the related PJ02.03 safety requirements derivation/update have been conducted by the safety assessment team and has been progressively validated in a HAZID identification & safety requirements validation workshop at Heathrow Airport premises. The participants to the workshop were:

Organisation	Name	Position
Vienna Airport	Günther Borek	APP ATCO & SUP
	Haris Usanovic	TWR & APP ATCO & TWR SUP
NATS	Andrew Belshaw	SAF expert
	Adam Spink	TWR ATCO
	Charles Morris	Concept design expert
	Michael Benson	TWR ATCO
	Andrew Garrett	APP ATCO
EUROCONTROL	Dana Botezan	HP expert
	Laura Carbo	SAF expert
	Nicolas Fota	SAF expert

	Mihai Ogica	SAF expert
	Mohamed Ellejmi	Project Manager

Table 23 PJ02.03 HAZID at Heathrow Airport - Participants

The validation has been further complemented by submitting the results (as documented in this safety assessment report) to the internal validation by a panel of PJ03 operational, design and technical experts (see the list of reviewers internal to the project on the cover page of this safety assessment report).

5 Acronyms and Terminology

Term	Definition
150k	150,000
A380	Airbus A380
ACT	Activation
ACAS	Airborne Collision Avoidance System
ATC/M/S	Air Traffic Control / Management / System
ATCO	Air Traffic Controller
ADS-B	Automatic Dependent Surveillance Broadcast
A-SMGCS	Advanced Surface Movement Guidance and Control System
AIM	Accident Incident model
A/C	Aircraft
ANS	Air Navigation Services
APP	Approach
ARR	Arrival
CDG	Charles de Gaulle Airport
CWP	Controller Working Position
DBS	Distanced Based Separation
EARTH	The project acronym for SESAR 2020 PJ02 incr**EA**sed **R**unway and Airport **TH**roughput
EATMA	European Air Traffic Management Architecture
EUROCONTROL	European Organisation for the Safety of Air Navigation
ENAIRE	Spanish Air Navigation Service Provider
FMS	Flight Management System
FA/P	Final Approach
FTD	Final Target Distance indicator
FTS	Fast Time Simulation
FCRW	Flight Crew

GBAS	Ground Based Augmentation System
GNSS	Global Navigation Satellite System
G/S	Glide Slope
GS	Ground Speed
HP	Human Performance
HP#X	Pre-existing Hazard
Hz#X	Hazard
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
ILS	Instrument Landing System
ITD	Initial Target Distance indicator
IAS	Indicated Air Speed
IM	Impact Modifier
IA	Interception of the Final Approach
INTEROP	Interoperability
IRS	Interface Requirement Specification
INFO	Information
KPI	Key Performance Indicator
KTS	Knots
LHR	London Heathrow Airport
MRS	Minimum Radar Separation
M-M	Medium-Medium
MAC	Mid Air Collision
NATS	UK Air Navigation Service Provider
NM	Nautical Miles
OSED	Operational Service and Environment Definition
ORD	Optimal Runway Delivery
OFA	Operational Focus Area

PJ02.03	Project 02.03
PWS-EU	Pair-Wise Separation wake turbulence scheme
RWY	Runway
RECAT-EU	European separation standard for aircraft wake turbulence
RSVA	Reduced Separation in the Vicinity of an Aerodrome
ROT	Runway Occupancy Time
RSP	Required Surveillance Performance
RPA	Runway Protected Area
RTS	Real Time Simulation
RIMCAS	Runway Incursion Monitoring and Conflict Alert System
RNAV	Area Navigation
RC	Runway Collision
REQ	Requirement
SAR	Safety Assessment Report
SPR	Safety and Performance Requirements
SESAR	Single European Sky ATM Research
S-PWS	Static Pair-Wise Separation
SRM	Safety Reference Material
SAC	SAfety Criteria
SO	Safety Objective
SR	Safety Requirement
SEQ	Sequence
Sol 01/03	Solution 01/03
SAP	Safety Assessment Plan
SAF	Safety
SMI	Separation Minima Infringement
SP	SeParate aircraft with other aircraft
SC	Severity Criteria

STCA	Short Term Conflict Alert
TS	Technical Specifications
TB	Time Based
TAS	True Air Speed
TBS	Time Based Separation
TMA	Terminal Manoeuvring Area
TWR	Tower
TAS	True Air Speed
TDI	Target Distance Indicator
TCAS RA	Traffic Collision Avoidance System Resolution Advisory
UK6	UK Wake Turbulence Separation Category
UC1	Use Case
V1-V3	Validation Maturity Level 1 to Level 3
VIE	Vienna Airport
VCS	Voice Communication System
WDS-A	Weather Dependant Separation for Arrivals
WT/E	Wake Turbulence / Encounter
WAM	Wide Area Multilateration
WTC	Wake Turbulence Category

Table 24: Acronyms and terminology

6 References

Safety

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[5] OFA 01.03.01 Enhanced Throughput Consolidated Final Step 1 OSED, D30, 00.01.00, 31.05.2016

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[7] OFA 01.03.01 Enhanced Runway Throughput Consolidated Final Step 1 Interop, D34, 00.01.00, 25/05/2016

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[10] SESAR Solution PJ02-03 SPR-INTEROP/OSED for V3 - Part I, Edition 00.00.05, 22 March 2019

[11] EUROCONTROL Wake Turbulence Re-Categorisation and Pair-Wise Separation Minima on Approach and Departure (RECAT-PWS-EU) Safety Case Edition 1.2 14/04/2016

[12] PJ19 Validation Targets (2018), Edition 01.00.00, 26 February 2018

[13] SESAR Solution PJ02-03 VALR for V3, Edition 00.00.03, 20 June 2019

[14] SESAR Solution PJ02-03: Validation Plan (VALP) Part I for V3, Edition 00.01.00, 28th February 2019

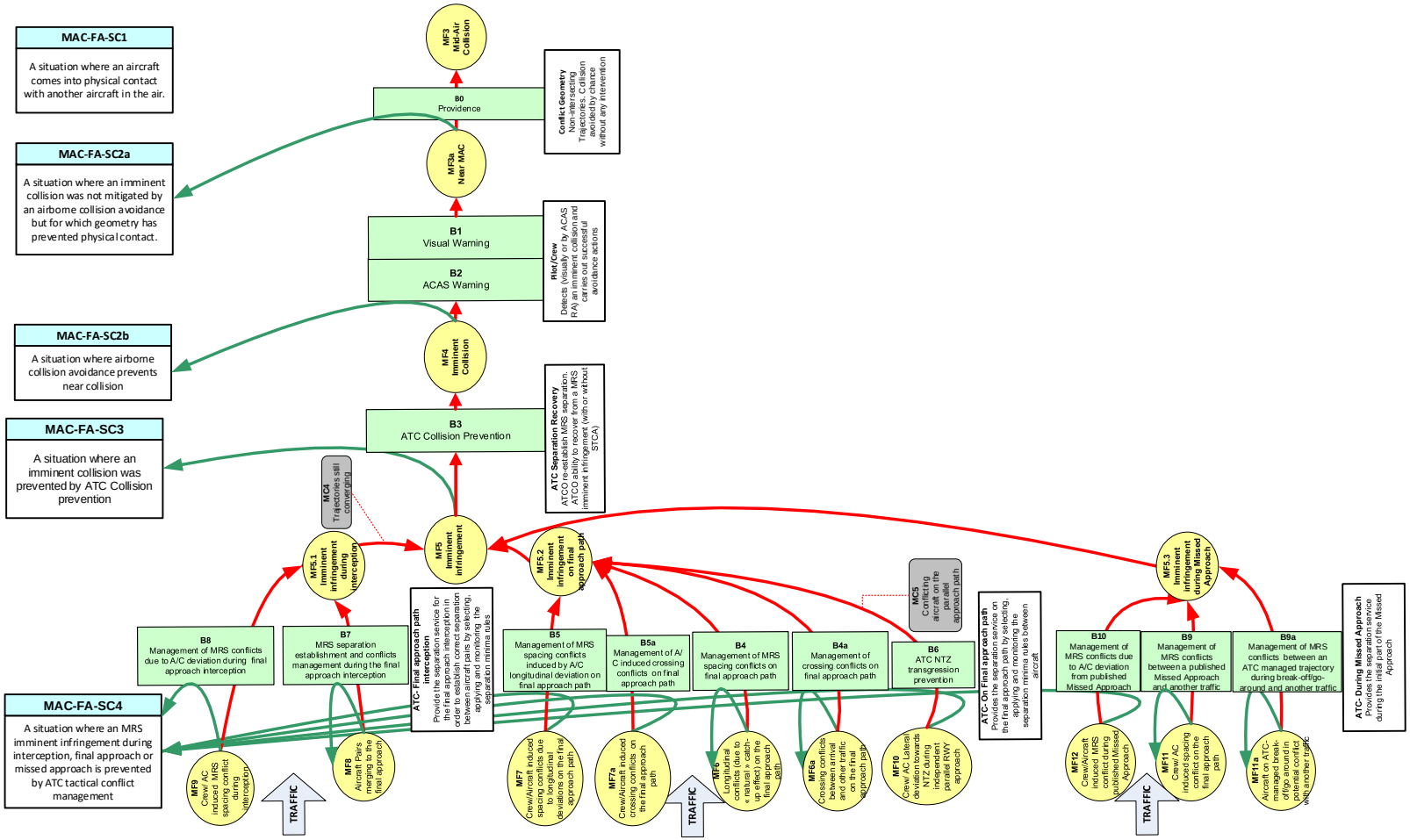
[15] PJ02-03 Reference Scenario, Edition 00.01.00, May 2018

[16] SESAR Solution PJ02.03 SPR-INTEROP/OSED for V3 – Part II Safety Assessment Report, Edition 00.01.01, September 2019

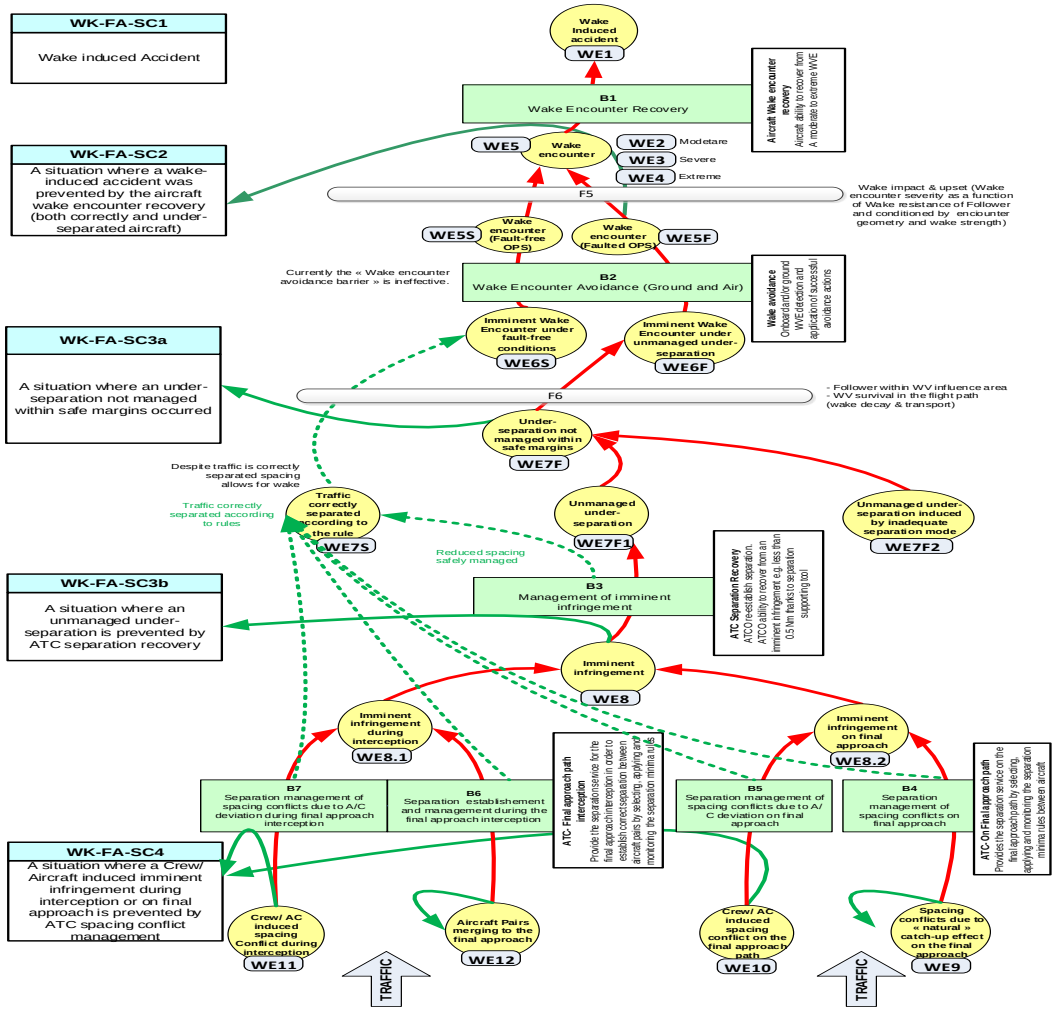
[17] ICAO Doc 4444 Air Traffic Management, Sixteenth Edition, 2016

Appendix A AIM Models applicable to PJ02.03

A.1 MAC on FAP


MAC-FA-SC1
A situation where an aircraft comes into physical contact with another aircraft in the air.
MAC-FA-SC2a
A situation where an imminent collision was not mitigated by an airborne collision avoidance but for which geometry has prevented physical contact.
MAC-FA-SC2b
A situation where airborne collision avoidance prevents near collision
MAC-FA-SC3
A situation where an imminent collision was prevented by ATC Collision prevention
MAC-FA-SC4
A situation where an MRS imminent infringement during interception, final approach or missed approach is prevented by ATC tactical conflict management
MF3 Mid-Air Collision
B0 Providence
Conflict Geometry Non-intersecting Trajectories. Collision avoided by chance without any intervention
MF3a Near MAC
B1 Visual Warning
B2 ACAS Warning
Pilot/Crew Detects (visually or by ACAS RA) an imminent collision and carries out successful avoidance actions
MF4 Imminent Collision
B3 ATC Collision Prevention
ATC Separation Recovery ATCO re-establish IMRS separation. ATCO ability to recover from a MRS imminent infringement (with or without STCA)
MC4 Trajectories still converging
MF5 Imminent infringement
MF5.1 Imminent infringement during interception
MF5.2 Imminent infringement on final approach path
MF5.3 Imminent infringement during Missed Approach
MC5 Conflicting aircraft on the parallel approach path
ATC- Final approach path interception Provide the separation service for the final approach interception in order to establish safe separation between aircraft pairs by selecting, applying and monitoring the separation minima rules
ATC- On Final approach path Provides the separation service on the final approach path by selecting, applying and monitoring the separation minima rules between aircraft
ATC- During Missed Approach Provides the separation service during the initial part of the Missed Approach
B8 Management of MRS conflicts due to A/C deviation during final approach interception
B7 MRS separation establishment and conflicts management during the final approach interception
B5 Management of MRS spacing conflicts induced by A/C longitudinal deviation on final approach path
B5a Management of A/C induced crossing conflicts on final approach path
B4 Management of MRS spacing conflicts on final approach path
B4a Management of crossing conflicts on final approach path
B6 ATC NTZ transgression prevention
B10 Management of MRS conflicts due to A/C deviation from published Missed Approach
B9 Management of MRS conflicts between a published Missed Approach and another traffic
B9a Management of MRS conflicts between an ATC managed trajectory during break-off/go-around and another traffic
MF9 Crew/ AC induced MRS spacing conflict during interception
MF8 Aircraft Pairs merging to the final approach
MF7 Crew/Aircraft induced spacing conflicts due to longitudinal deviations on the final approach path
MF7a Crew/Aircraft induced crossing conflicts on the final approach path
MF6 Long lasting conflicts (due to « natural » catch-up effect) on the final approach path
MF6a Crossing conflicts between arrival and other traffic on the final approach path
MF10 Crew/ AC Lateral deviation towards NTZ during independent / parallel RNP approach
MF12 Crew/Aircraft induced spacing conflict during published Missed Approach
MF11 Crew/ AC induced spacing conflict on the final approach path
MF11a Aircraft or ATC-managed break-off/go around in potential conflict with another traffic
TRAFFIC
TRAFFIC
TRAFFIC

A.2 WAKE on FAP



Severity Class Scheme for final approach Wake Induced Accident

AIM WAKE BARRIER MODEL (Final Approach) v2.1

A.3 Runway Collision Model

No simplified version of the Runway Collision Model was available at the creation of this Safety Assessment Report.

Appendix B EAMTA Models used to derive the functionality & performance Safety Objectives (success approach)

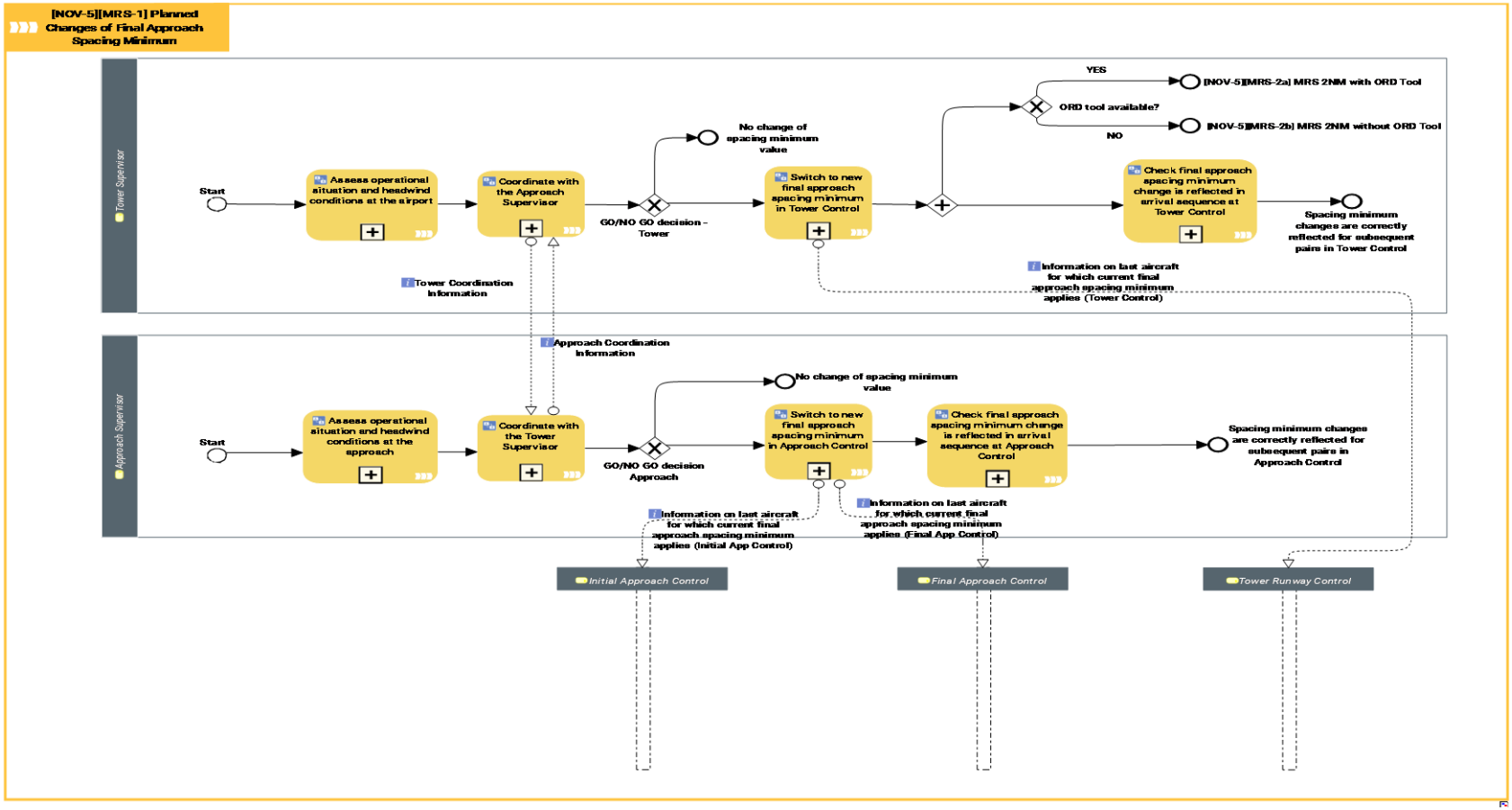


Figure 14 Planned Change of Final Approach Separation - NOV5 EATMA Diagram

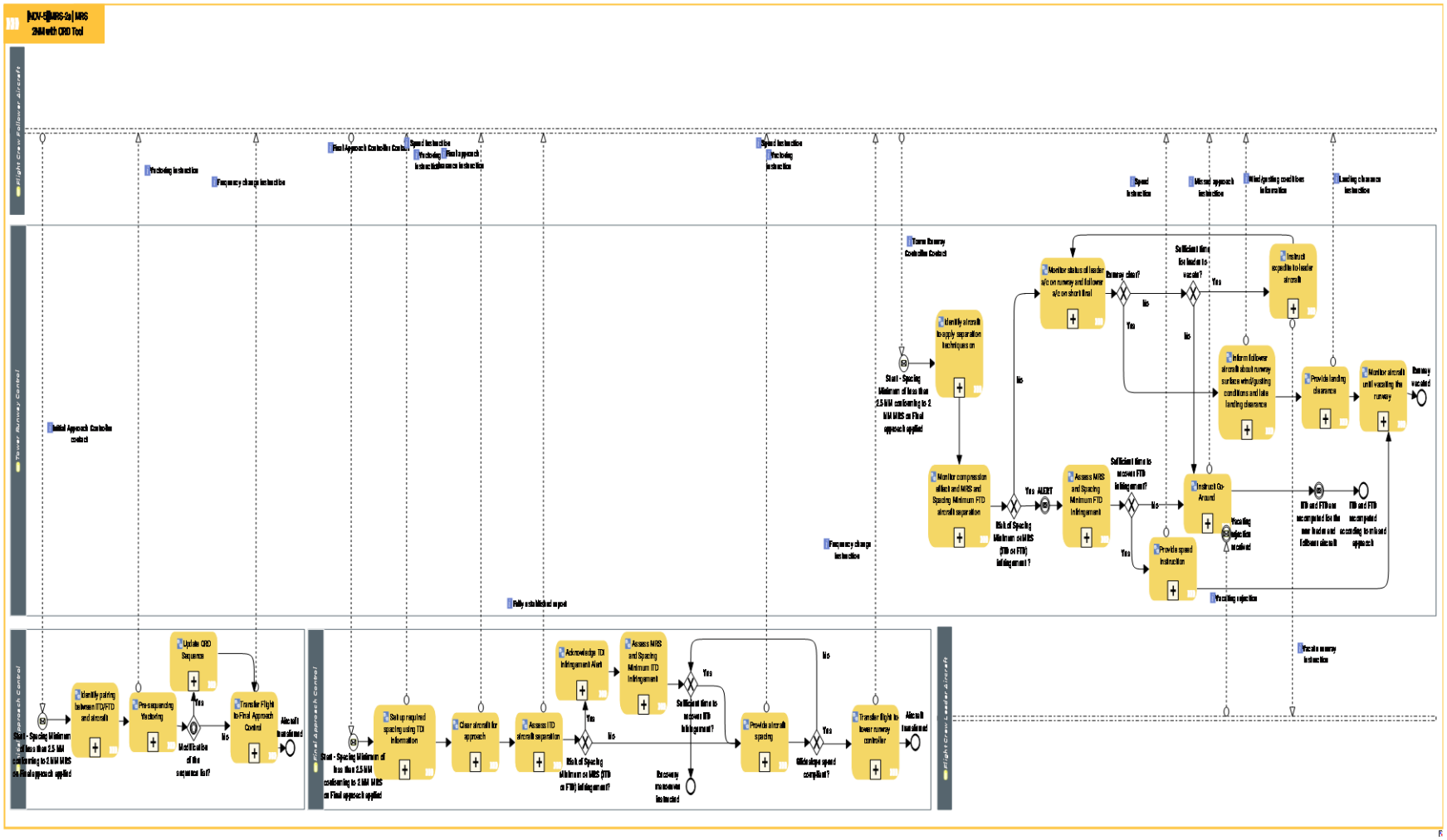


Figure 15 MRS 2NM with the ORD Tool - NOV5 EATMA Diagram

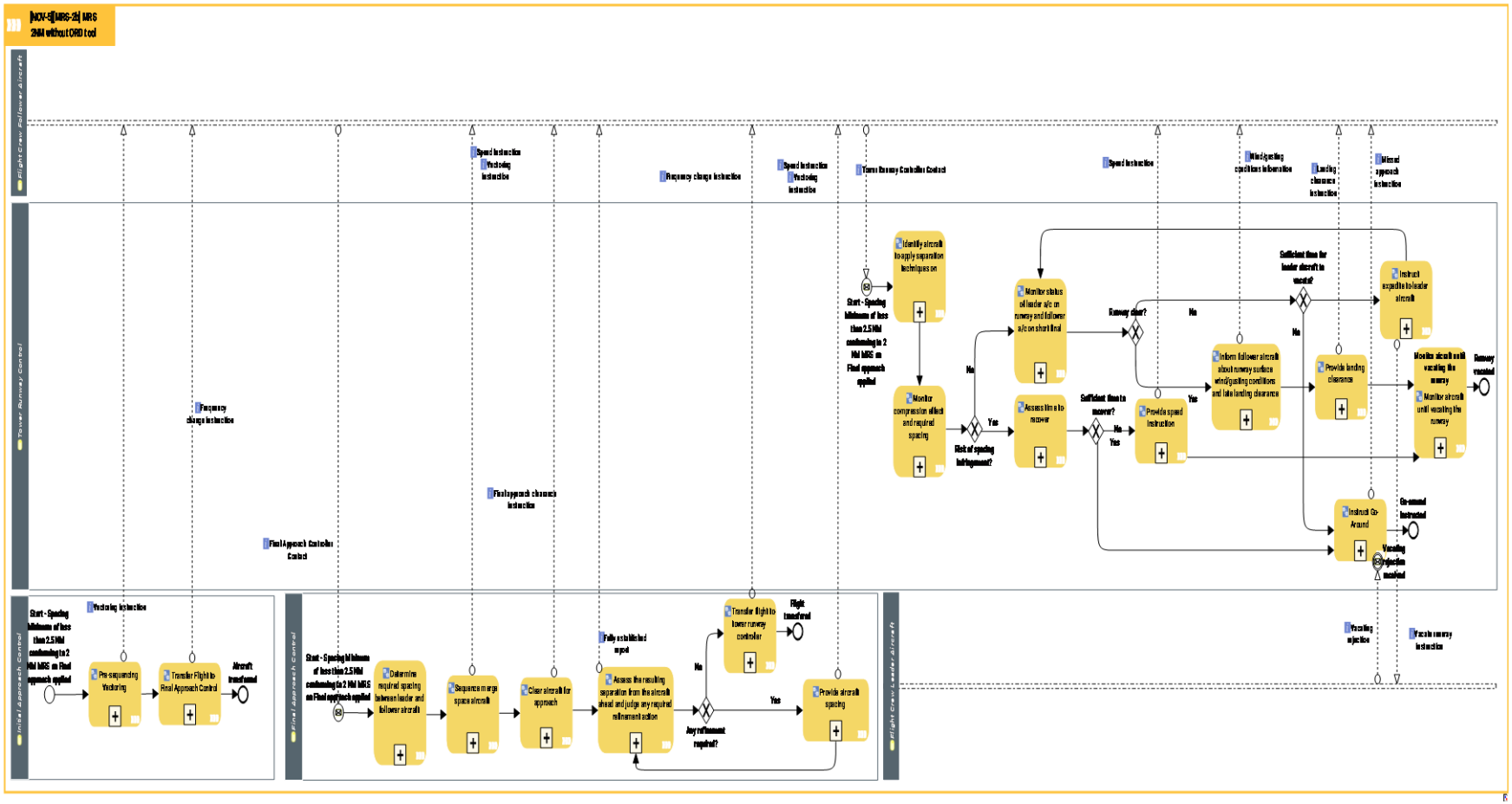


Figure 16 MRS 2NM without the ORD Tool - NOV5 EATMA Diagram

Appendix C PJ02.03 SAF & HP Workshop – Heathrow Airport 29th March 2019

A HAZID identification & safety requirements validation workshop was organised on March 29th 2019 at Heathrow Airport premises in order to address the concept covered to date (aligned with the completed exercise RTS2 focused on the application of 2NM MRS with the ORD tool). The workshop was facilitated by SAF and HP experts from EURCONTROL and it included APP, TWR ATCOs and Supervisors, together with safety, human performance and concept experts.

Participants:

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C.1 Applicable to the Interception Phase:

Possible Hz	Causes	Mitigations	Comments
1. Wrong ATC instruction during interception despite correct separation indicator • (cause for Hz#01a or Hz#02a)	(a) Inadequate procedures/instructions for separation establishment/management (b) ATCO – pilot misunderstanding	**Preventive Mitigations:** (a) Target distance indicators displayed far enough in advance on RWY extended centreline (a) INI_APP contribution (prepare traffic for ITM_APP) **Protective Mitigations** Resolve situation by vectoring, level instructions or go-around	(a) ATCO may be drawn into delivering to TDI and reducing below the 2.5 NM MRS and 1000ft before the current transition procedures (from 3 to 2.5NM or 1000ft) allow. **Outcome from the successive safety workshops& discussion: out of scope of PJ02.03 to seek safety evidence which would allow passing below 2.5NM upon turning on to intercept. (A001: current local procedures for transitioning from 3 to 2.5NM or 1000ft). HP REQ: Local procedures to define the accepted working method on transition from 3 to 2.5NM and 2NM MRS, in order to ensure the ATCOs will not overlook the separation minima on the base leg.** **HP REC: Additional support tools should be considered in order to enhance the awareness of ATCOs with regard to the separations on the base leg where no TDIs are currently displayed.** **HP REQ: The training curricula shall ensure the ATCOs are capable of maintaining the required separations on base leg (horizontal and vertical) despite getting in the habit of working with the TDIs on the axis.** The transition from 3NM (applied on intermediate approach) to 2.5NM and 2NM (applied on the final approach) could be challenging and it could come with consequences (e.g. separation infringements on the base leg). To address this,

Possible Hz	Causes	Mitigations	Comments
			the final approach controllers suggested to being able to reduce below 3NM once the lead aircraft is established on a stable intercept track for merging onto final approach. This can potentially be achieved by extending the application of the 2.5 NM MRS. Example of potential mitigation from Vienna without extending the application of 2.5NM MRS: an additional 1000ft separation is now required on the base leg. With respect to the separation delivery tool support and in particular the displaying of the Target Distance Indicator (TDI): When RSVA apply (Follower within 6NM), ORD tool should not penalize the radar separation reduction; local procedures shall be developed (See REQ Sol1 about supressing TDIs for specific pairs: REQ-02.01-SPRINTEROP-ARR0.0851 and REQ-02.01-SPRINTEROP-ARR0.0850 – See rationale for both)
HUMAN PERFORMANCE	1. Shorter shift times/ more breaks? 2. Under 2nm MRS R/T could overload the ATCO/ the frequency→ risk to miss out on relevant info in a timely manner?		

Possible Hz	Causes	Mitigations	Comments
	Interception Phase		
2. Unanticipated pilot/aircraft behaviour during interception (cause for Hz#01a orHz#02a)	(a) Pilot slow in following instruction or inadequate response to ATC (not recovered through monitoring) Expected R/T occupancy & workload increase due to 2NM. **Potential increase of risk for missing wrong readback.** (b) Overshoot (c) Lateral, vertical or speed deviation initiated by crew/aircraft (eg deviation from published speed) (d) Wrong a/c turns on the indicator (pick-up instruction for other aircraft) Note: a) is a cause for Hz#01a: Inadequate separation management during interception	**Preventive Mitigations:** (a) Detect inadequate response to ATC through monitoring of the instruction execution & correct**. SAF/HP Arg. 4: REQ REQ-06.08.01-OSED-OFA1.110: Adequate training required. Provided that adequate training is performed, according to LHR ATCO: 2NM without indicators would be safe (**most demanding scenario being the bunches of M aircraft spaced close to 2.5NM or even below; with need to manage the stabilization speed differences) . The **use of indicators** would further improve the safety & reduce workload. **Protective Mitigations** (a, b, c, d) Continue with the currently applicable rules for allowance to descend from 3NM to 2.5NM upon turning on to intercept (spacing buffer leaving room for separation recovery during interception)	Heathrow: Pilot compliance with speed instruction has been a problem at the beginning of the TBS implementation. Airlines have been briefed about the safety importance of the speed compliance with the new concept. **HP REQ: Information campaigns for flight crew.** E.g. aircraft instructed 160 kt then transferred to TWR, afterwards leader a/c reduces to 150 kt before DF with risk of separation infringement by the follower. That requires APP ATCO to quickly coordinate with TWR requiring to increase speed back to 160 kt (a) Note that Heathrow observed a significant R/T occupancy increase when they transitioned from 3NM to current 2.5NM. (Note: Outcome from ORTOP3 MRS 2NM with ORD: ATCO accept the workload increase

Possible Hz	Causes	Mitigations	Comments
	b), c) and d) are causes for Hz#02a: Inadequate separation management of a spacing conflict due to aircraft deviation from Final Approach interception profile without ATC instruction given	(a, b, c, d) ATC Recovery from imminent infringement by adequate action (vectoring, level instructions or go-around) - see line 11	and they consider it will continue to be safe. However, as a mitigation there might be a need for reducing the shift time. This has been further challenged in Heathrow 2NM safety workshop). Nonetheless, in Heathrow the application of 2.5NM MRS was not implemented with a change in shift lengths or frequency of breaks.
HUMAN PERFORMANCE	1. TDIs reduce ATCOs overall SA→ risk to focus too much on getting the a/c to the target so their focus of attention may become narrower • Not detecting the deviation on time • Not detecting downwind or base leg infringements • Need of having alerts/ alarms at this stage for identifying a, b, c or any other possible causes for this hazard?		

Possible Hz	Causes	Mitigations	Comments
3. Separation indicator not displayed or not timely available for one aircraft pair during turn-on	(a) ORD tool failure (one pair affected only)	**Preventive Mitigations**	

Possible Hz	Causes	Mitigations	Comments
(cause of Hz#01a)	(b) No input from Sequencing tool (one pair) (c) Aircraft not in arrival sequence tool (d) Flight Planning info missing/not recognized (a/c type or WT CAT)	**Protective Mitigations** ATCO detects the missing indicator and: (c) corrects the arrival sequence (a), (b), (d) ATCO applies Baseline DBS separation minima (ATCO needs to keep awareness of the aircraft type/WTC)	
HUMAN PERFORMANCE	1. Would it be easy/ enough to identify the a/c pair based on the sequence alert? 2. How would you keep the awareness for this a/c pair with regard to the DBS application (e.g. highlight?)?		

Possible Hz	Causes	Mitigations	Comments
4. Lack/loss of indicators for multiple or all aircraft Cause for Hz#06	(a) Loss of ORD Tool (b) Loss of sequencer tool (c) Loss of flight planning information	**Preventive Mitigations:** **Protective Mitigations** ATCO detects the missing indicators and reverts to Baseline DBS (a supporting DBS table is required, especially in TB PWS with multiple categories)	Applicable to both Interception and Final App phases ORTOP 3 allowed to demonstrate that in MRS 2NM with ORD ATCOs are able to safely revert to reference DBS minima- ICAO or RECAT EU

Possible Hz	Causes	Mitigations	Comments
	(d) RWY Separation mode not updated (the information about the mode of operation -segregated or mixed mode- is not sent to the arrival sequencer)	Aircraft established on Final approach stabilized with 160kts IAS and behind ITD are allowed to continue the approach All other aircraft – either not established on Final or not at stabilized IAS 160kts or not behind ITD - Initiate Go-around or break off - Establish ICAO DBS asap	
HUMAN PERFORMANCE	1. What is the role of the supervisor in case this hazard applies? For spontaneous transitions, the ATCO independently reverts to DBS, as the collaboration with the SUP might not be timely enough. 2. Would you trust the TDIs if they suddenly reappear? a. E.g. in Vienna there is a Central Control Service that gives permission to proceed after degraded modes. 3. Are alerts necessary for all these possible causes so that you quickly understand the situation and act accordingly? Where possible, there shall be an indication of the error that has occurred. **HP REQ: To be clearly specified at local level what alerts and alarms are available and what procedures apply in case of such errors.** 4. In this case is the separation table a “must have” ? What other support info you would need handy? HP REQ: ATCOs shall have the conventional separation table available (on display if required) in case they need to revert from TBS to DBS. 5. In case the possibility to “toggle on and off” the indicators exists and is applicable, what indications would you need to make sure they were intentionally removed or you are actually dealing with a degraded mode. The ATCOs would like to know whether the TDIs disappeared as a result of an error or if they are intentionally removed for DBS reversal.		

C.2 Applicable to the Interception and Final Approach Phases:

Possible Hz	Causes	Mitigations	Comments
5. Corruption of one or multiple separation indicators Cause for Hz#05	(a) Incorrect a/c type or WT CAT (b) Flight plan info corruption (c) Corruption of separation tool (d) Sep tool config failure (i.e. incorrect airspeed profile, incorrect sep table) (e) Corruption of arr seq or arr seq not (correctly) updated (f) Corrupted RWY operation mode (g) Inadequate/missing surveillance data	**Preventive Mitigations** Adequate SW assurance **Protective Mitigations** (a, b) Incorrect a/c type might be detected via Pilot reporting **(to derive SAF REQ for systematic a/c type reporting - REQ-02.01-SPRINTEROP-ARR0.1441) LHR: current procedure in place to ask a/c type at first contact with LHR approach. In the future the downlink via Mode S is considered** (c to g): Only in case of gross error ATCO might detect the corruption of the indicator/s. Upon detection: ATCO shall revert to DBS mode. If undetected, no protective mitigation available **For (h) only:** ATCO reverts to Baseline DBS with no indicators without coordination with SUP due to not enough time to coordinate (a supporting DBS	Applicable to both Interception and Final App phases LHR: in case of loss of wind input, ORD tool reverts to DBS plus

Possible Hz	Causes	Mitigations	Comments
	(h) Missing update or detected loss of the G/S headwind profile	table is required, especially in TB PWS with multiple categories). *SR668 "In TB-modes, in the degraded situation where glideslope headwind profile input is missing:* *- The Controllers shall be displayed with the loss of glideslope headwind alert and shall revert to the correspondent DB- mode (DBS or S-PWS) with use of FTD but without ITD (manual management of compression) or keep using the TB-mode with ITD and FTD computed using a conservative wind profile until the glideslope headwind profile is available again;* ***OR*** *- The Separation Delivery Tool shall automatically revert to the correspondent DB-mode or an acceptably safe TB-mode (FTD and ITD computed using a conservative wind profile). A notification of the automatic switch shall be provided to the ATCOs and Supervisors"*	conservative conditions for computing compression In case of tool loss, ATCOs apply DBS plus 1NM conservative for compression
HUMAN PERFORMANCE			

Possible Hz	Causes	Mitigations	Comments
6. Incorrect G/S wind profile used for computation Cause for Hz#05	(a) Meteo error/incorrect reference wind prediction (b) Incorrect reference wind monitoring	**Preventive Mitigations:** (b) Reference wind monitoring alert Upon detection via this alert, APP/TWR SUP or ATCOs revert from TB-mode to corresponding DB-mode (similar to lack of glideslope wind profile input; see SR688) **Protective Mitigations** Partially for both DB and TB modes: Buffer for ITD and FTD take margins on the wind computation. In DB-mode: ATCO will realise that the tool is using incorrect wind reference because successive aircraft separated correctly using the chevrons will have the tendency to infringe the correct FTD as the leader decelerates, triggering a go-around by the TWR controller. In TB-mode: It is difficult for the ATCO to realise that the tool is using incorrect wind reference.	Applicable to both Interception and Final App phases

Possible Hz	Causes	Mitigations	Comments
		The a/c will be separated according to a wrong FTD, i.e. wake separation infringement. TO DERIVE INTEGRITY/REALIABILITY SO OR SR	
HUMAN PERFORMANCE	1. What additional wind information and alert- other than the alert of loss of wind input and abrupt wind variation would you require as compared to today`s operations? What about the supervisor?		

Possible Hz	Causes	Mitigations	Comments
7. Incorrect separation indicator in relation to speed non-conformance of the leader aircraft Cause for Hz#05	(a) ATCO failure to detect a/c abnormal speed (b) Speed conformance alert failure	**Preventive Mitigations:** (a) Speed conformance monitoring alert (10NM to DF) (b) The tool computes some buffer for coping with speed non-conformance **Protective Mitigations** Go-around to Follower (because TDI might be wrong)	

Possible Hz	Causes	Mitigations	Comments
HUMAN PERFORMANCE	1. A failure of LORD related alerts would make you uncomfortable working with the LORD, prompting that other indications might be incorrect? •		

C.3 Applicable to the Final Approach Phase:

Possible Hz	Causes	Mitigations	Comments
8. Inadequate use of separation indicators by the APP ATCO when a/c is established on final • Cause for Hz#03a	(a) ATCO confusion between separation and spacing (b) ATCO does not adjust a/c speed to solve a conflict due to catch-up effect (c) Inadequate ATCO competency/currency with the use of indicators	**Preventive Mitigations:** (a to c) Catch-up alert (a to c) Adequate ATCO training for the use of indicators **Protective Mitigations** Go-around (note that ITD and FTD are computed with buffers, which gives some room to ATCO to prevent the loss of separation if the problem is detected)	

Possible Hz	Causes	Mitigations	Comments
HUMAN PERFORMANCE			

Possible Hz	Causes	Mitigations	Comments
9. Aircraft deviates from the final approach speed profile expected by ATC • Cause of Hz#04a	(a) Pilot picks up instruction for other a/c (b) Pilot deviates from expected/instructed speed profile (c) Aircraft failure (d) Un-stabilized approach	**Preventive Mitigations:** (a, b) Publish procedural air speed on Final Approach (a, b) Add briefing to airlines, provide monthly reports on speed compliance (e.g. as in EGLL), follow-up with webex/calls. **Protective Mitigations** Supported by catch-up warning; Re-clear a/c to fly a different speed if possible OR Go-around;	

Possible Hz	Causes	Mitigations	Comments
HUMAN PERFORMANCE	1. For 2nm MRS, less availability of frequency occupancy. Could a) be occurring more often and hence also detected less often?		

Possible Hz	Causes	Mitigations	Comments
10. Lack/loss of indicator for one aircraft on Final App Cause of Hz#01a and Hz#03a	(a) ORD tool failure (b) Sequencer tool failure (c) Aircraft not in the arrival sequence tool (d) Flight planning information (A/C Type or WT CAT) missing or not recognized for a given aircraft	**Preventive Mitigations:** **Protective Mitigations** ATCO detects the missing indicator and: Aircraft established on Final approach stabilized with 160kts IAS and behind ITD is allowed to continue the approach, otherwise initiate Go around Proposed saf req: Consider this non-nominal situation in Training and in the procedures (operating manual)	

Possible Hz	Causes	Mitigations	Comments
		To validate *SRx41 (REQ-02.01-SPRINTEROP-OPS3.0004): "The tool shall provide ATCOs the ability to selectively supress TDIs for specific aircraft (Rationale: For example in case of delegating responsibility for wake separation to flight deck)"*	
HUMAN PERFORMANCE	1. Would you feel comfortable working with the TDIs for the following a/c pairs? 2. Would you just increase separations for this a/c pair (DBS) and then continue with decreased separations (PWS/WDS etc)? How would you monitor it? 3. Would you consult the Supervisor → new procedure?		

Possible Hz	Causes	Mitigations	Comments
	Protective mitigation for above hazards		
11. Fail to recover from imminent infringement by adequate action Cause for: Hz#01b, Hz#02b, Hz#03b, Hz#04b	(a) ATCO failure to detect need for recovery action (e.g. Go around, break off etc- depends on the triggering event) (b) ATCO failure to instruct timely the separation recovery action before the imminent infringement is evolving to a large under-separation (c) Pilot failure to timely execute the separation recovery instruction	**Preventive Mitigations** **Use case with ORD only**: FTD (in TB concepts) and ITD (in both DB and TB concepts) are computed with buffers to **attempt to prevent** separation infringement, regardless of the value of the FTD. Outside a pre-defined region (4NM at Heathrow): STCA will trigger. **SAF REQ: STCA**	**Q5**: Upon detection, the time available to instruct&execute Go around (or break off) is reduced with MRS 2NM. Is there any impact on probability of failure to prevent separation infringement? Answer: The probability for MRS infringement remains the same (only the separation minima moved from 2.5 to 2NM, upon detection at a same time t0,

Possible Hz	Causes	Mitigations	Comments
	Heathrow: - in case of MRS infringement (no RSVA): instruct break off or Go around -in case of wake separation: if under-separation less than 0.5 NM and Leader outside 4 DME, action is taken (if feasible) e.g. speed reduction (either directly instructed by APP ATCO or coordinated with TWR), otherwise instruct break-off. If Leader within 4 DME, provide caution wake warning to Pilot (who will consider go around or not). Vienna: in case of risk of wake under-separation, delegate visual separation to Pilot, if not able then instruct Go around	**shall be tuned (on the Fin App) in order to accommodate the 2NM MRS** Indication of IAS and GS to APP ATCO (current mitigation). **SAF REQ: With 2NM MRS additional training needed to emphasize the specific use of these indications** **Protective Mitigations** With respect to WTE risk: Follower within WV influence area, WV survival in the flight path (F6) – this is degraded with MRS 2NM (compared to MRS 2.5NM). **Use case with ORD**: The **use of ORD is expected to mitigate** that risk increase by contributing to the reduction of separation infringements thanks to the increased separation delivery accuracy. ***Use case without ORD**: **With regards to risk of wake encounter**: A DBS separation table will be used manually (e.g. RECAT-EU). The non wake pairs can be delivered in RSVA below 2NM MRS	supposing that it takes x seconds until TOGA is activated, then at the time t0+x the separation will be infringed by the same distance below each minima). **Meanwhile the risk for wake encounter given a large MRS infringement (>0.5NM) is higher with MRS 2NM.** **Q6:** Does the risk of separation minima infringement increase with MRS 2NM during go-around and break-off? Answer: After the Go around or break off has been initiated, **the risk exposure is higher as it will potentially take more time to transition back to the TMA MRS of 3NM or 1,000ft** ***Both with or without ORD:** **SAF REQ: Need to conduct a generic wake risk assessment for the non-wake pairs with 2NM MRS (Follower continues**

Possible Hz	Causes	Mitigations	Comments
		subject to local ROT spacing procedures (encompassing necessary wind conditions, RWY conditions, etc.). ***With regards with risk of unacceptably high rate of Go around**: **SAF REQ: In case of no ORD tool, there shall be a conditional application of 2NM MRS that accounts for any conditions influencing ROT (e.g. wind conditions, RWY conditions, others RWY spacing constraints) in order to ensure safe operations in terms of acceptable rate of Go around due to ROT.** ***With regards to risk of MRS infringement** (e.g. case of radio failure affecting both aircraft): **SAF REQ: a Collision Risk Model shall be built locally**, allowing to prove that the collision risk is at acceptable levels considering the distribution of the aircraft pairs, wind conditions, etc. Wake impact & upset (F5) Wake encounter recovery (B1)	**descent crossing the descending wake)** **SAF REQ: Need to conduct a local collision risk modelling for that scenario** <u>Note regarding MRS 2NM without tool:</u> ORTOP3 ATCO feed-back is that no need for imminent separation infringement alert, but it could be a "nice to have feature". NATS will recommend the application of 2 NM MRS with the support of the ORD tool, due to the complex support it offers to the ATCOs based on alerts and indication of the TDIs. Currently in Heathrow there is no alert with respect the 2.5NM MRS infringement but a separation monitoring function that is displayed on the screen of the "management" for safety analyses.

Possible Hz	Causes	Mitigations	Comments
• HUMAN PERFORMANCE			

Possible Hz	Causes	Mitigations	Comments
	Abnormal conditions		
12. Unplanned blocked Runway Abnormal condition	Debris on RWY	**Protective Mitigations** Instruct Go around & break off to all aircraft established or in the process of interception - Instruct go around (alternative left, straight, right – if those alternatives are possible at the airport, for horizontal separation) - Instruct level off at different intermediary altitudes (for vertical separation) - Transfer to Departures.	ORTOP3 ATCOs do not think that the reduction to 2NM will play significantly with regard to the separation infringement during these actions. (In current operations one might not be able to prove that MRS/Wake separations are maintained).
• HUMAN PERFORMANCE			

Possible Hz	Causes	Mitigations	Comments
	Applicable to Mode Management (Selection, Transition)		
13. Incorrect selection or transition management of separation mode (e.g. 2NM with ICAO WT) • Hz#07	(a) Corrupted surface wind indication (b) Fail to detect that wind conditions are not or no more met (c) ATCO activate TB mode without SUP decision (d) Confusion between ATCO-SUP about first aircraft to be separated according to the new activated mode	**Preventive Mitigations:** SW assurance Reliable wind measurements (double source) **Protective Mitigations**	
HUMAN PERFORMANCE	1. Examples from today`s operations (e.g. when they switch to LVP)? 2. What does the SUP coordination imply? 3. How do the supervisors communicate (more need of silent communication?)? 4. What is the role of the ATCO in the transition? 5. When do the supervisors need to consult ATCOs? 6. How would the tool display this information? (both ATCO and SUP) 7. What type of alerts would they need? (both ATCO and SUP) – wind related/ mode related etc. 8. Any other potential risks remained unidentified?		

Possible Hz	Causes	Mitigations	Comments
	9. Any additional information needed for ATCOs? (e.g. the first aircraft in the arrival sequence to be separated according to the new mode (e.g. at least 2 min before interception) 10. Unaware whether you operate in DBS or WDS/TBS –PWS: would a simple indication of the mode of operation be enough? 11. Supervisor WKLD? → significant changes? 12. Equitable distribution of work during transition for APP – TWR (ATCO and SUP)/ communication load?		

Appendix D 2NM MRS based on SRP Scoping and Change Assessment Workshop – CDG 23rd November 2017

The slides and the results of the workshop are shown in the attached presentation.

PJ02-03 MRS_presentation_\

Appendix E Conditional Application enabling 2.0NM MRS for ICAO M-M pairs

The following analysis covers the specific case of the application of the 2.0NM MRS concept with the ICAO DBS WT scheme. Applying the concept with this scheme introduces the need to reduce the wake turbulence separation applicable to the ICAO M-M pairs below 2NM such that 2NM MRS can be applied between the aircraft in this category. This analysis should be treated as an addition to the analysis performed in the main body of the document.

E.1 Additional SAfety Criteria

Regarding the activation/deactivation of the 2NM MRS (for the wind conditional application of the concept):

- on risk of Unmanaged WT under-separation induced by inadequate selection & management of separation mode i.e. selection of and transition between MRS 2NM and the 2.5NM Separation/Spacing (see WE 7F.2 in AIM WT accident on Final Approach model in A.2):

W-SAC#F3: The probability per approach of unmanaged WT under-separation during interception & final approach shall not increase due to inadequate selection of or transition between reduced MRS down to 2NM and the 2.5NM Separation/Spacing

Safety assurance strategy with or without the tool: expert-based analysis of failure causes, risk assessment and mitigation.

No further additional SAfety Criteria needed for the application of the 2NM MRS concept with the ICAO WT scheme, however some additions need to be brought to the safety assurance strategy of **W-SAC#1**:

- For wind based conditional Separation/Spacing minima reduction (i.e. when applying the 2NM MRS concept with the ICAO WT scheme) with or without the tool: make use of the demonstration based on data mining/analysis allowing to define WT separation minima within PJ02.03 and within SESAR 1 P06.08.01. The risk of under-separation induced by the uncertainty in glideslope wind prediction and in the actual final approach speed profile needs to be mitigated by pre-determining the wind-based criterion which allows reducing the Separation/Spacing minima down to 2NM MRS and/or a buffer in the design of the WT separation minima;
- Note for wind based conditional Separation/Spacing minima reduction with the tool, there is an additional possibility for mitigating the risk of under-separation induced by the uncertainty in glideslope wind prediction and in the actual final approach speed profile by adding a separation buffer in the computation of the separation indicators displayed to the Controllers.

E.2 Additional Pre-existing Hazards

No additional pre-existing hazards, other than Hp#1a, already identified in section 3.5.

E.3 Mitigation of Pre-existing Hazards

E.3.1 Additional Operational Services to Address the Pre-existing Hazards

ID[6]	Air Navigation Service Objective	Pre existing Hazard
Planned Change of Final Approach Separation		
ACT	Determination and activation of the separation mode (in case of conditional application of the Separation/Spacing minima down to 2NM MRS)	**Hp#1a** (WTA risk)

Table 25 Additional Operational Services for the application of the 2NM MRS concept with the ICAO WT scheme

E.3.2 Additional Safety Objectives (Functionality & Performance – success approach) for Normal Operations

ID	Safety Objective *(success approach)*	Use Case	Operational Service	Related SAC# (AIM Barrier or Precursor)
Applicable <u>with or without the Separation Delivery Tool</u>				
	ATC shall be able to apply 2NM MRS rules on final approach (encompassing interception) and to safely switch between MRS 2NM and the 2.5NM Separation/Spacing	Planned Change of Final Approach Separation (Figure 14)	ACT: Determination and activation of the separation mode (in case of conditional application of the Separation/Spacing minima down to 2NM MRS)	**W-SAC#F3**
	The activation criteria of the 2NM MRS for the ICAO M-M pairs, shall mitigate against wake encounters between these pairs, in addition to taking into account the conditions that might influence the Runway Occupancy Time (e.g. wind conditions, RWY conditions,	As above	As above	As above

[6] SP= SeParate aircraft with other aircraft

	other RWY spacing constraints, availability of runway exists)			
	In case of conditional application of the 2NM MRS, ATC shall apply the correspondent minimum radar separation minimum only when the predefined activation criteria are met	As above	As above	As above
	In case of conditional application of the 2NM MRS, the wind threshold(s) for the activation criteria shall be determined to mitigate the wake encounter risk due to the uncertainties on the wind profile prediction data and on the aircraft adherence to the generic airspeed profile	As above	As above	As above
	In case of conditional application of the 2NM MRS, ATC shall apply the corresponding Separation/Spacing (e.g. 2.5NM or 3NM MRS) when the activation criteria for 2NM MRS are not met anymore	As above	As above	As above

Table 26 Additional Safety Objectives (Functionality and Performance - success approach) for Normal Operations for the application of the 2NM MRS concept with the ICAO WT scheme

E.4 Additional Safety Objectives under Abnormal Conditions

E.4.1 Identification of additional Abnormal Conditions

ID	Abnormal Scenario
5	Actual Wind on final approach different from the wind used for FTD/ITD computation
7	Unexpected drop of surface wind below safe threshold

Table 27 Additional Abnormal Conditions for the application of the 2NM MRS concept with the ICAO WT scheme

5/ ACTUAL WIND ON FINAL APPROACH DIFFERENT FROM THE WIND USED FOR FTD/ITD COMPUTATION **(WITH THE SEPARATION DELIVERY TOOL)**

No change introduced by this solution compared to PJ02.01.

Note the impact on the computed/displayed FTD only applies for the ICAO M-M pairs in Sol 03. The impact on the computed/displayed ITD applies for all pairs.

Mitigation: SO 101.

7/ UNEXPECTED DROP OF REFERENCE WIND BELOW SAFE THRESHOLD **(WITH THE SEPARATION DELIVERY TOOL)**

No change introduced by this solution compared to PJ02.01.

Mitigation SO 005, derived in section 3.6.2.

E.4.2 Potential Mitigations of Abnormal Conditions

ID	Description	Abnormal Scenario
SO 101	ATC shall be alerted when the actual wind conditions differ significantly from the wind conditions used for the TDIs computation (wind conditions monitoring alert).	5

Table 28 Additional Safety Objectives for Abnormal Situations for the application of the 2NM MRS concept with the ICAO WT scheme

E.5 Mitigation of System-generated Risks (failure approach)

E.5.1 Identification and Analysis of Additional System-generated Hazards

ID	Hazard Description	High Level Causes (derived from Success SO)	Operational Effects	Mitigations protecting against propagation of effects	Severity *(most probable effect)*
	One or multiple separation minima infringements induced by ATC through inadequate selection & management of the separation mode	Applicable with or without the Separation Delivery Tool:	Large under-separation (of more than e.g. 0.5 NM) occurs for one or multiple aircraft pairs during separation establishment on Final App or later during the Final App	WAKE FAP F6 Wake Decay & Transport MAC FAP B2 ACAS Warning	WK-FA-SC3a MAC-FA-SC2b *However, because multiple aircraft might be affected before failure is detected, a Safety Objective more demanding than the*

					corresponding hazard severity will be allocated via an impact modification factor IM=20

Table 29 Additional System-generated Hazards for the application of the 2NM MRS concept with the ICAO WT scheme

E.5.2 Derivation of Additional Safety Objectives (integrity/reliability)

SO ref (hazard severity)	Safety Objectives (integrity/reliability)
Safety Objectives relative to the management of the separation mode	
SO 211 SO#07 (WK-FA-SC3a MAC-FA-SC2b; IM=20) Applicable with or without the Separation Delivery Tool	The frequency of occurrence of one or multiple separation minima infringements induced by ATC through inadequate selection or management of a separation mode shall not be greater than 2x10-6/approach *(2x10-6/approach means 1 occurrences every 4 years for an airport with 135,000 landings per year)*

Table 30 Additional Safety Objectives (Integrity/reliability) for the application of the 2NM MRS concept with the ICAO WT scheme

E.6 Derivation of Additional Safety Requirements (Functionality and Performance – success approach)

Safety Objectives (Functionality and Performance from success approach)	Safety Requirement	Maps on to EATMA Diagram
Applicable with or without the Separation Delivery Tool		
ATC shall be able to apply 2NM MRS rules on final approach (encompassing interception) and to safely switch between MRS 2NM	The following requirements from PJ02.01 apply: REQ-02.01-SPRINTEROP-ARR0.0100 REQ-02.01-SPRINTEROP-ARR0.0530 REQ-02.01-SPRINTEROP-ARR0.0980 REQ-02.01-SPRINTEROP-ARR0.1021 REQ-02.01-SPRINTEROP-ARR0.1030	

and the 2.5NM Separation/Spacing	REQ-02.01-SPRINTEROP-ARR0.1031 REQ-02.01-SPRINTEROP-ARR0.1080 REQ-02.01-SPRINTEROP-ARR0.1120 REQ-02.01-SPRINTEROP-ARR0.1223 REQ-02.01-SPRINTEROP-ARR0.1290 REQ-02.01-SPRINTEROP-ARR0.1390	
The activation criteria of the 2NM MRS for the ICAO M-M pairs, shall mitigate against wake encounters between these pairs, in addition to taking into account the conditions that might influence the Runway Occupancy Time (e.g. wind conditions, RWY conditions, other RWY spacing constraints, availability of runway exists)	SR3.036 For the case without the Separation Delivery Tool, when using the ICAO WTC scheme, in addition to the satisfaction of ROT (see requirement REQ-02.03-SPRINTEROP-ARR4.0300), a 2NM Spacing Minimum shall be applied only when the runway surface and glideslope wind threshold is satisfied.	Planned change of Final Approach Separation: ACC/Approach Supervisor "Assess operational situation and headwind conditions at the approach" Airport Tower Supervisor: "Assess operational situation and headwind conditions at the airport"
	SR3.038 For the case without the Separation Delivery Tool, the runway surface and glide-slope wind threshold shall be defined locally and shall be such that the wake turbulence separation between ICAO M-M pairs drops below 2 NM	As above
	The following requirement from PJ02.01 also applies: REQ-02.01-SPRINTEROP-ARR2.1060	
In case of conditional application of the 2NM MRS mode, ATC shall apply the correspondent minimum radar separation minima only when the predefined activation criteria are met	SR3.036 and SR3.038 as above	
	The following requirements from PJ02.01 also apply: REQ-02.01-SPRINTEROP-ARR0.0980 REQ-02.01-SPRINTEROP-ARR2.1060 REQ-02.01-SPRINTEROP-ARR0.1100	

	REQ-02.01-SPRINTEROP-ARR0.1110 REQ-02.01-SPRINTEROP-ARR0.1330
In case of conditional application of the 2NM MRS mode, the wind threshold(s) for the activation criteria shall be determined to mitigate the wake encounter risk due to the uncertainties on the wind profile prediction data and on the aircraft adherence to the generic airspeed profile	The following requirement from PJ02.01 applies: REQ-02.01-SPRINTEROP-ARR2.1060
In case of conditional application of the 2NM MRS mode, ATC shall apply the corresponding Minimum Radar Separation mode (e.g. 2.5NM or 3NM MRS) when the activation criteria for the 2NM MRS mode are not met anymore	The following requirements from PJ02.01 apply: REQ-02.01-SPRINTEROP-ARR2.1060 REQ-02.01-SPRINTEROP-ARR0.1070 REQ-02.01-SPRINTEROP-ARR2.1222 REQ-02.01-SPRINTEROP-ARR0.1090 REQ-02.01-SPRINTEROP-ARR0.1100 REQ-02.01-SPRINTEROP-ARR0.1110 REQ-02.01-SPRINTEROP-ARR0.1330 REQ-02.01-SPRINTEROP-ARR0.1760

Table 31 Additional Safety Requirements (functionality and performance) for normal conditions for the application of the 2NM MRS concept with the ICAO WT scheme

E.7 Analysis of the SPR-level Model – Abnormal Operational Conditions

E.7.1 Analysis of the Additional Scenarios for Abnormal Conditions

Ref	Abnormal Conditions / SO (*Functionality and Performance)*	Possible influences or causal factors	Mitigations (SR 0xx and/or A 0xx)
5	Actual Wind on final approach different from the wind used for FTD/ITD computation.	No change from Sol 01. Same mitigations as in Sol 01 apply	No change from Sol 01. Same mitigations as in Sol 01 apply
7	Unexpected drop of reference wind	No change from Sol 01.	No change from Sol 01. Same mitigations as in Sol 01 apply

	below safe threshold.	Same mitigations as in Sol 01 apply	

Table 32 Analysis of the Additional Scenarios for the Abnormal Conditions for the application of the 2NM MRS concept with the ICAO WT scheme

E.7.2 Derivation of Safety Requirements (Functionality and Performance) for Abnormal Conditions

Safety Objectives for abnormal conditions	Safety Requirements (functionality and performance) for abnormal conditions	Map on to
SO 101 ATC shall be alerted when the actual wind conditions differ significantly from the wind conditions used for the TDIs computation (wind conditions monitoring alert).	SR3.238: For all DB modes with ORD (i.e. displaying ITDs) and TB modes, the Approach and Tower Controllers and Supervisors shall be alerted by the glideslope wind monitoring function about a significant difference between actual glideslope headwind profile and the glideslope headwind profile used for the TDI computation, i.e. when the predicted time-to-fly (based on the headwind profile prediction used for Target Distance Indicator computation) compared to the actual time-to-fly (based on the actual headwind measurement) exceeds a threshold to be determined locally.	
	SR3.239: In case of wind monitoring alert, the Approach and Tower Controllers shall revert to the corresponding Spacing Minimum mode (e.g. 2.5NM or 3NM Spacing Minimum), with or without the FTD and ITD indicators and when needed take corrective actions during the transition phase like instructing go-arounds.	

Table 33 Additional Safety Requirements for abnormal conditions for the application of the 2NM MRS concept with the ICAO WT scheme

E.8 Design Analysis – Case of Internal System Failures

E.8.1 Causal Analysis

Hz#07: One or multiple separation minima infringements induced by ATC through inadequate selection & management of a time based separation mode *(applicable with or without the Separation Delivery Tool)*

This hazard occurs during the execution phase due to an erroneous selection or management of the separation mode, in relation to the conditional activation of the time based WT separation modes and/or ATC tools (TBS, TB-S-PWS, TB-WDS or TB-WD-PWS).

Basic causes for such failures have been captured in the Hz#07 Fault Tree.

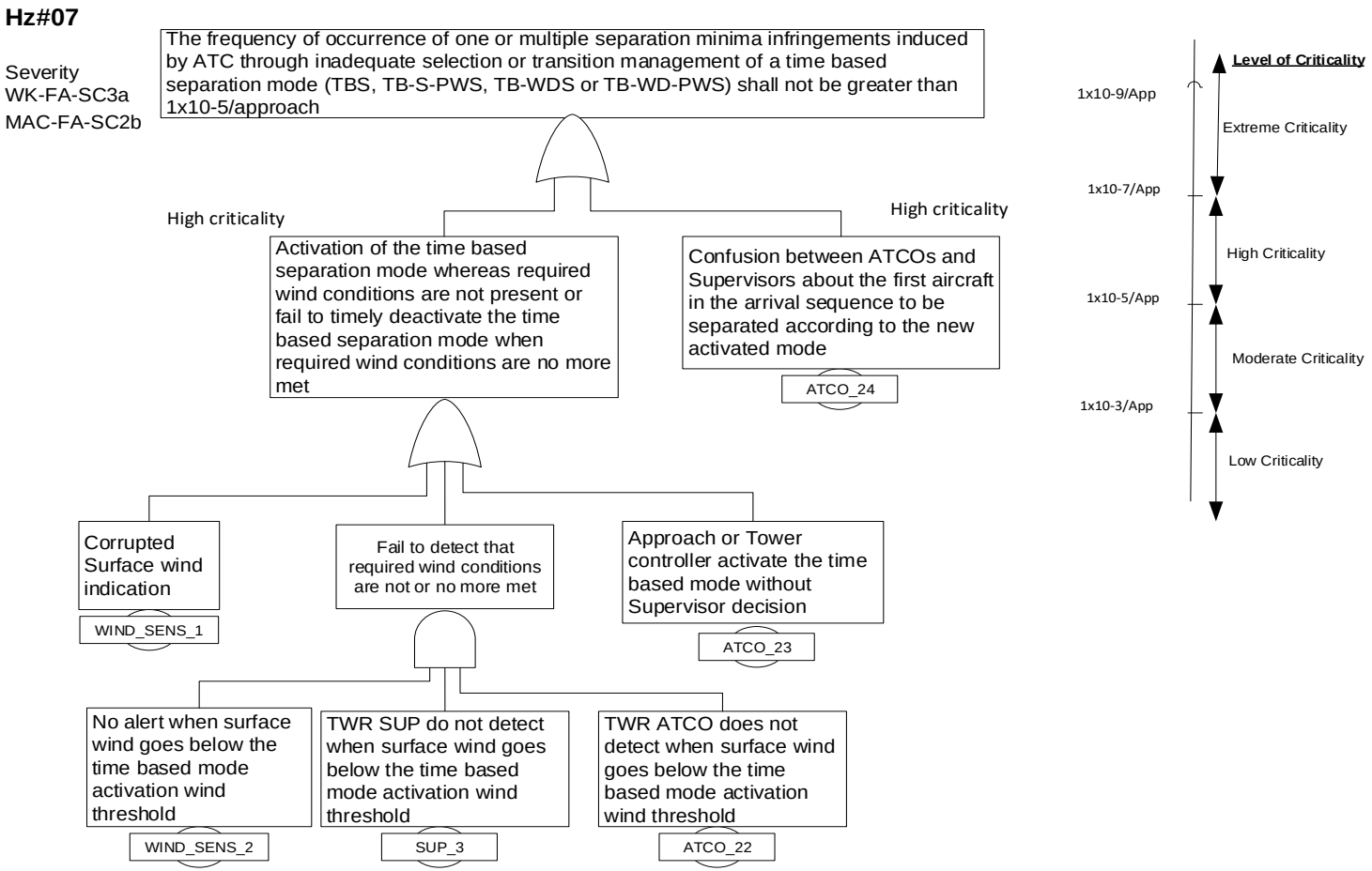

Figure 17 Hz#07 Fault Tree

The table below describes the basic causes of the Hazard Hz#07 Fault Tree and identifies the mitigations/safety requirements necessary to satisfy the associated Safety Objective.

Type of failure	Cause Id	Cause description	Mitigation/Safety Requirement
Corrupted surface wind indication.	WIND_SENS_1	Surface wind sensor provides to ATC wrong surface wind information.	**SR3.306** as above and From PJ02.01: **REQ-02.01-SPRINTEROP-ARR0.0400** It shall be demonstrated that the data inputs including flight data, approach arrival sequence information and glideslope wind conditions to the Separation Delivery are sufficiently robust.
No alert when surface wind goes below the time based mode activation threshold wind.	WIND_SENS_2	ATC is not automatically informed when surface wind goes below the Time Based PWS activation wind threshold.	**SR3.238** For all DB modes with ORD (i.e. displaying ITDs) and TB modes, the Approach and Tower Controllers and Supervisors shall be alerted by the glideslope wind monitoring function about a significant difference between actual glideslope headwind profile and the glideslope headwind profile used for the TDI computation, i.e. when the predicted time-to-fly (based on the headwind profile prediction used for Target Distance Indicator computation) compared to the actual time-to-fly (based on the actual headwind measurement) exceeds a threshold to be determined locally. **SR3.239** In case of wind monitoring alert, the Approach and Tower Controllers shall revert to the corresponding Spacing Minimum mode (e.g. 2.5NM or 3NM Spacing Minimum), with or without the FTD and ITD indicators and when needed take corrective actions during the transition

			phase like instructing go-arounds. From PJ02.01 **REQ-02.01-SPRINTEROP-ARR0.1770** Approach and Tower Supervisors shall be alerted when the wind monitoring function for the conditional application of the TB modes (glideslope headwind, total wind, cross wind) are lost or inoperative (encompassing loss of wind input) **REQ-02.01-SPRINTEROP-ARR0.1760** In case of conditional application in TB-modes, the Supervisors (Tower and Approach) and Controllers (Tower and Approach) shall be alerted automatically in advance when the predefined activation criteria will not be met anymore hence the imminent need to transition from one separation mode to another, in order to temporarily limit or regulate the flow of inbound traffic (e.g. through metering) prior to the switch of separation mode in order to manage the change and controllers workload
Tower Supervisor does not detect that surface wind goes below the time based mode activation wind threshold.	SUP_3	TWR supervisor did not notice that required surface wind conditions are not or no more satisfied.	as above
Tower Controller does not detect that surface wind goes below time based mode activation wind threshold.	ATCO_22	TWR controllers did not notice that required surface wind conditions are no more satisfied.	as above

Approach or Tower controller activate the time based mode without Supervisor decision	ATCO_23	APP or TWR ATCO activates the time based mode in their CWP whereas required wind conditions are not satisfied.	**REQ-02.01-SPRINTEROP-ARR2.1060** For TB- modes the Approach and Tower Supervisors shall collaboratively decide when the conditional (TB) mode should be activated or de activated based on meteorological data information and predefined activation criteria and on prior coordination with Controllers. **REQ-02.01-SPRINTEROP-ARR0.0980** The Tower Supervisor in coordination with the Approach Supervisor (and occasionally the Tower and Approach Controllers - in line with defined local procedures) shall determine the final approach separation mode and runway spacing constraints that are to be applied at any time by the separation delivery tool.

Figure 18 Derivation of Mitigation/Safety Requirements for Hazard Hz#07

Appendix F Consolidated list of Safety Requirements

F.1 Safety Requirements (Functionality and Performance)

The safety assessment allowed the identification of two types of functionality & performance safety requirements:

- Success approach (ensuring that the design enables safe operations in absence of failure within the Solution scope),
- Failure approach (mitigating safety risk related to failure within the Solution scope).

The following table includes the "success approach" requirements, i.e. those requirements defined during the SPR-INTEROP/OSED development that have been identified in the SAFETY category as per the method explained at §4.2.2. Column 3 indicates the operational hazard(s) that might potentially occur in case the requirement were not satisfied, whilst Column 4 provides traceability to the related success Safety Objective(s). The information regarding the validation of these "success approach" requirements is not provided in the current SAR but that is taken care of in the PJ02-03 VALR [13].

Safety Requirement ID	Safety Requirement (functionality & performance) description	Related operational hazard(s)	Related success SO(s)
SR3.001 REQ-02.03-SPRINTEROP-ARR4.0010	The Approach controllers and, if applicable, Tower controllers shall be supported by a surveillance system compatible with a safety case that guarantees the required surveillance performance for the application of the 2NM minimum radar separation	All Operational Hazards	SO 006
SR3.002 REQ-02.03-SPRINTEROP-ARR4.0020	The longitudinal position update interval shall be less than or equal to 4 seconds.	All Operational Hazards	SO 006
SR3.003 REQ-02.03-SPRINTEROP-ARR4.0030	The pressure altitude update interval shall be less than or equal to 4 seconds	All Operational Hazards	SO 006
SR3.004 REQ-02.03-SPRINTEROP-ARR4.0040	The aircraft identity update interval shall be less than or equal to 4 seconds.	All Operational Hazards	SO 006
SR3.005 REQ-02.03-SPRINTEROP-ARR4.0050	The probability of the longitudinal position update shall be greater than or equal to 97%.	All Operational Hazards	SO 006

Safety Requirement ID	Safety Requirement (functionality & performance) description	Related operational hazard(s)	Related success SO(s)
SR3.006 REQ-02.03-SPRINTEROP-ARR4.0060	The ratio of missed 3D positions involved in long gaps shall be less than or equal to 0.25%.	All Operational Hazards	SO 006
SR3.007 REQ-02.03-SPRINTEROP-ARR4.0070	The longitudinal positional RMS error shall be less than or equal to 200 metres per flight.	All Operational Hazards	SO 006
SR3.008 REQ-02.03-SPRINTEROP-ARR4.0080	The ratio of longitudinal position update interval involved in a series of at least 3 consecutive errors larger than 0.5 Nm shall be less than or equal to 0.003%.	All Operational Hazards	SO 006
SR3.009 REQ-02.03-SPRINTEROP-ARR4.0090	The average data age of the forwarded pressure altitude shall be less than or equal to 2.5 seconds.	All Operational Hazards	SO 006
SR3.010 REQ-02.03-SPRINTEROP-ARR4.0100	The ratio of incorrect forwarded pressure altitude shall be less than or equal to 0.01%.	All Operational Hazards	SO 006
SR3.011 REQ-02.03-SPRINTEROP-ARR4.0110	The unsigned pressure altitude error shall be less than or equal to 300ft in 98.5% of the cases.	All Operational Hazards	SO 006
SR3.012 REQ-02.03-SPRINTEROP-ARR4.0120	The delay in the change in emergency indicator/SPI report shall be less than or equal to 7.5 seconds.	All Operational Hazards	SO 006
SR3.013 REQ-02.03-SPRINTEROP-ARR4.0130	The delay in the change in aircraft identity shall be less than or equal to 15 seconds.	All Operational Hazards	SO 006
SR3.014 REQ-02.03-SPRINTEROP-ARR4.0140	The probability that the update of the aircraft identity with valid and correct values shall be greater than or equal to 98%.	All Operational Hazards	SO 006
SR3.015 REQ-02.03-SPRINTEROP-ARR4.0150	The ratio of incorrect aircraft identity shall be less than or equal to 0.1%.	All Operational Hazards	SO 006
SR3.016 REQ-02.03-SPRINTEROP-ARR4.0160	The rate of descent RMS error should be less than or equal to 500 ft/min.	All Operational Hazards	SO 006

Safety Requirement ID	Safety Requirement (functionality & performance) description	Related operational hazard(s)	Related success SO(s)
SR3.017 REQ-02.03-SPRINTEROP-ARR4.0170	The track velocity RMS error shall be less than or equal to 4 m/s.	All Operational Hazards	SO 006
SR3.018 REQ-02.03-SPRINTEROP-ARR4.0180	The track velocity angle RMS error shall be less than or equal to 10 degrees.	All Operational Hazards	SO 006
SR3.019 REQ-02.03-SPRINTEROP-ARR4.0190	The density of uncorrelated false target reports shall be less or equal to 1 false target report per 855 updates.	All Operational Hazards	SO 006
SR3.020 REQ-02.03-SPRINTEROP-ARR4.0200	The probability of a critical failure shall be less than or equal to 2.5x10^-5 per hour of operation.	All Operational Hazards	SO 006
SR3.026 REQ-02.03-SPRINTEROP-ARR4.0260	Local procedures/rules shall be defined in order to ensure safe transition of the aircraft from 3NM to 2NM MRS, such as to avoid loss of separation minima during on base leg	Hz#01a	SO 006
SR3.033 REQ-02.03-SPRINTEROP-ARR4.0330	When operating under 2NM MRS without the Separation Delivery Tool, the APP ATCO shall receive additional training to emphasize the specific use of the IAS and GS indications for managing separation at interception	Hz#01a	SO 006
SR3.027 REQ-02.03-SPRINTEROP-ARR4.0270	When the Separation Delivery Tool is used, the training curricula shall ensure the ATCOs are capable of maintaining the required separations on base leg (horizontal and vertical) despite getting in the habit of working with the TDIs on the axis	Hz#01a	SO 006
SR3.030 REQ-02.03-SPRINTEROP-ARR4.0300	The reduction to 2 NM MRS shall be applied only when the Separation/Spacing Minima constraints and the provision of appropriate ROT Spacing are actively managed through the supporting of specific ATC procedures allowing predefined conditions influencing ROT to be satisfied (e.g. braking action reported as good, no runway contaminants such as slush, snow or ice, etc.)	Hz#07	SO 012

Safety Requirement ID	Safety Requirement (functionality & performance) description	Related operational hazard(s)	Related success SO(s)
SR3.036 REQ-02.03-SPRINTEROP-ARR4.0360	For the case without the Separation Delivery Tool, when using the ICAO WTC scheme, in addition to the satisfaction of ROT (see requirement REQ-02.03-SPRINTEROP-ARR4.0300), a 2NM Spacing Minimum shall be applied only when the runway surface and glideslope wind threshold is satisfied.	Hz#07 Hz#02b	SO 002 SO 003
SR3.038 REQ-02.03-SPRINTEROP-ARR4.0361	For the case without the Separation Delivery Tool, the runway surface and glide-slope wind threshold shall be defined locally and shall be such that the wake turbulence separation between ICAO M-M pairs drops below 2 NM	As above	As above
SR3.302 REQ-02.03-SPRINTEROP-ARR4.0340	A generic wake risk assessment shall be performed for the 2NM MRS non-wake pairs in the specific case when the leader is performing a break-off/go-around and the follower, separated at or close to the separation minima, continues its descent crossing the leader's descending wake	SO#01b SO#02b SO#03b SO#04b	SO 103
SR3.035 REQ-02.03-SPRINTEROP-ARR4.0350	If the introduction of 2NM MRS with ORD requires to change the current surveillance system (e.g. for a higher update rate) in local implementation, there shall be a synchronisation of the update rate between the APP and TWR ATCOs radar screens in order to allow smooth radar visualisation upon aircraft transfer from APP to TWR	All Operational Hazards	SO 006
SR3.037 REQ-02.03-SPRINTEROP-ARR4.0351	When the 2NM MRS concept is applied in TB-modes, DB PWS-A and/or WDS-A, the Intermediate Approach, Final Approach and Tower Controllers shall be provided with a Separation Delivery Tool displaying Target Distance Indicators (TDI) to enable consistent and accurate application of separation rules on final approach and landing	All Operational Hazards (mitigation only when the concept is applied in TB-modes, DB PWS-A and/or WDS-A modes)	SO 006

Safety Requirement ID	Safety Requirement (functionality & performance) description	Related operational hazard(s)	Related success SO(s)
SR3.238 REQ-02.03-SPRINTEROP-ARR4.0352	For all DB modes with ORD (i.e. displaying ITDs) and TB modes, the Approach and Tower Controllers and Supervisors shall be alerted by the glideslope wind monitoring function about a significant difference between actual glideslope headwind profile and the glideslope headwind profile used for the TDI computation, i.e. when the predicted time-to-fly (based on the headwind profile prediction used for Target Distance Indicator computation) compared to the actual time-to-fly (based on the actual headwind measurement) exceeds a threshold to be determined locally.	Hz#07	SO 101
SR3.239 REQ-02.03-SPRINTEROP-ARR4.0353	In case of wind monitoring alert, the Approach and Tower Controllers shall revert to the corresponding Spacing Minimum mode (e.g. 2.5NM or 3NM Spacing Minimum), with or without the FTD and ITD indicators and when needed take corrective actions during the transition phase like instructing go-arounds.	Hz#07	SO 101 SO 005

Table 34 Safety Requirements (functionality and performance) from the "success approach"

Table 35 includes the "failure approach" requirements, i.e. those safety requirements aiming at mitigating the occurrence of the operational hazards (either preventing the occurrence of the cause or preventing the occurred cause to generate the hazard). Column 3 indicates the relevant validation activity(ies) for the requirements, whilst Column 4 shows the operational hazard it mitigates. The information regarding the validation of the safety requirements already existing in the SPR-INTEROP/OSED is not provided in the current SAR but that is taken care of in the PJ02-03 VALR [13].

Safety Requirement ID	Safety Requirement description	Validation Activity	Derived from OH
SR3.300	If available for the Final Approach Controllers, the Short Term Conflict Alert shall be adjusted to accommodate the 2NM MRS concept	Derived in SAF workshop. Since the validation exercise platform did not include an STCA tool on final	Hz#01b Hz#02b Hz#03b Hz#04b

		approach, this requirement was not tested/validated in the validation exercises.	
SR3.301	A local Collision Risk Assessment shall be performed to prove that the collision risk of pairs of aircraft concerned by MRS 2NM, is at acceptable safety levels considering the local distribution of the aircraft pairs, wind conditions, etc. *For an example of a CRM, please see Appendix G which contains a CRM performed by NATS for the Heathrow final approaches.*	Derived in SAF workshop. Since this requirement is about a local CRM, its nature prevents it from being tested/validated in SESAR validation exercises.	Hz#01b Hz#02b Hz#03b Hz#04b

Table 35. Safety requirements (functionality and performance) from the "failure approach"

F.2 Safety Requirements (integrity)

Quantitative Safety Requirements were not derived in this safety assessment. This will however need to be done by the industry in the validation stages prior to implementation (i.e. V4 onwards).

Appendix G SESAR PJ02-03 Collision Risk Modelling for Heathrow Approaches – NATS

SESAR PJ02-03
Collision Risk Mode

Appendix H SESAR PJ02-03 Surveillance Performance Assessment of 2NM Separations at Heathrow

S2020_2NM Separation at Heath

Appendix I Assumptions, Safety Issues & Limitations

I.1 Assumptions log

The following Assumptions were necessarily raised in deriving the above Functional and Performance Safety Requirements:

Ref	Assumption	Validation
	Current local procedures for transitioning from 3NM to 2.5NM or 1000ft apply	Not changed compared to the current operating methods

Table 36: Assumptions log

I.2 Safety Issues log

The following Safety Issues were necessarily raised during the safety assessment:

Ref	Safety issue	Resolution
ISSUE#001	The frequency of wake turbulence encounters at lower severity levels might increase for MRS infringements bigger than 0.5NM due to the reduced separation minima. As the frequency of wake turbulence encounters at each level of severity depends on local traffic mix, local wind conditions and proportion of time of application of the concept, there is a need to find a suitable way for controlling the associated potential for WT-related risk increase.	Either to perform assessment for several airport samples in order to demonstrate the low effect of MRS reduction on frequency of WT encounter of higher severities. Or to derive a safety recommendation for the local implementation of a specific WT separation concept to conduct an analysis which, for the given local traffic mix and wind conditions, estimates the net effect on the frequency of wake turbulence encounters at each level of severity in comparison to an accepted baseline.
ISSUE#002	In current operations, under specific conditions (applicable at most of the Very Large, Large and Medium airports) MRS is reduced to 2.5NM on the Final Approach path (up to a certain distance from the threshold) but 3NM apply on the base leg and upstream. Heathrow represent an exception, as the reduction to 2.5NM is extended to the base leg provided that the lead aircraft is established on the straight-in extended runway centre-line and the second	A safety assessment is required for the extension of 2.5NM MRS to the base leg on Very Large, Large and Medium airports other than Heathrow.

	aircraft of any given pair is within 20 NM from the threshold. It is expected that the extension of 2.5NM MRS to the base leg will be beneficial for the gain in RWY throughput (the RTS will assess the expected reduction of the gain in RWY throughput in relation to the need for maintaining 3NM until aircraft is converging for interception and then progressively catching up attempting to reach 2NM MRS later on the final approach path). Furthermore, it is expected that the extension of 2.5NM MRS to the base leg would contribute to the reduction of the separation minima infringement during the transitioning to 2NM MRS on final approach, thanks to the smoothening of this transition (progressive reduction from 3NM to 2.5NM followed by 2.5NM to 2NM). The related safety case performed by NATS for Heathrow would be a desirable input for addressing within the PJ02-03 the above safety&performance issue.	

Table 37: Safety Issues log

-END OF DOCUMENT-