RDD Phase 4 Report

Reduced Divergence Departures Project Summary and Recommendations

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Introduction

Background

In the UK and worldwide, generic guidance exists that states aircraft may depart from the same runway with a time-based spacing of no less than one minute providing that the successive aircraft are on Standard Instrument Departures (SIDs) which diverge by no less than 45° immediately after departure.

The application of modern Performance Based Navigation (PBN) SIDs provides much greater certainty regarding the positioning of aircraft relative to the SID nominal centreline compared to older conventional navigation SIDs. With the increasing prevalence of PBN-capable aircraft and the implementation of PBN SIDs and routes within the UK, the aviation industry is seeking ways of using the improved navigational performance to enable enhanced airspace design and efficiency. Towards this goal, research into PBN capability has already led to the UK CAA's Enhanced Route Spacing Guidance for PBN [CAP1385[1]].

A reduction of the 45° divergence requirement for one-minute departures would have the potential to improve both airspace efficiency and runway throughput and/or enable noise mitigation measures e.g. by making room for additional routes for noise sharing/relief purposes. The Reduced Divergence Departure (RDD) Project Team therefore aims to identify and safety assure a generic RDD requirement that is applicable to PBN SIDs (RNAV1 or higher) at any UK airport, with the goal of providing evidence to support the inclusion of an RDD procedure into a relevant CAA publication such as MATS Part 1 or CAP1385.

The Project Team

The team comprises individuals who have extensive experience in Air Traffic Control, Instrument Flight Procedure (IFP) Design, Safety Assurance, and Quantitative Risk Assessment. In particular, team members have prior experience in researching PBN navigational performance and reduced divergence departures.

Scope of the Report

This document provides an overview of the outcomes of the RDD Project, including a summary of key learnings and a set of recommendations for the implementation of Reduced Divergence Departures.

[1] Performance-Based Navigation, Enhanced Route Spacing Guidance, CAP 1385 (2016)

Project Phases and Outputs

Phase 1 – Desktop Review

The Desktop Review report[2] describes the results of a desktop review of existing regulatory standards, guidance, and operation experience. The report details the relevant generic standards that are applicable within the UK and globally; and considers and discusses some known deviations from those generic standards in current operational practice.

Phase 2 – Qualitative Risk Assessment

The Qualitative Risk Assessment report[3] describes the results of Phase 2 of the RDD Project. It details the results of a series of interviews with operational experts, including pilots, tower controllers and radar controllers. The purpose of the interviews was to understand operational practice more fully, understand operational limitations on departure speed variability, perform an initial partial hazard identification process, enable the development of a risk map, and start to assess the feasibility and usefulness of possible changes to operational practice.

The report presents a list of identified RDD risks and possible mitigations. This does not comprise a complete safety case for the implementation of RDD procedures, however it does provide an outline of some key factors necessary to be considered within such a safety case. Air Navigation Service Providers, or other relevant parties, would be required to conduct their own safety assurance, including full hazard identification, if taking the RDD concept forward.

Phase 3 – Quantitative Risk Assessment

The Quantitative Risk Assessment report[4] details the quantitative risk assessment methodology, the "Time to Reach" Collision Risk Model, developed for the purpose of identifying minimum safe divergence angles between PBN SIDs for one-minute departures. It presents the results of the analysis across a range of UK airports, identifying options for new PBN SID divergence guidance which is generically applicable across the UK.

[2] Phase 1 Report – Desktop Review, RDD Project Team, 2022

[3] Phase 4 Report – Qualitative Risk Assessment, RDD Project Team, 2023

[4] Phase 4 Report – Quantitative Risk Assessment, RDD Project Team, 2023

Minimum Safe Divergence

The Collision Risk Modelling performed in Phase 3 of the project has identified a set of PBN SID (RNAV1 or higher) divergence cases which meet the criteria to be considered acceptably safe. It must be noted that this is based on the risk of collision due to departure speed variation and lateral navigational inaccuracy only. Other safety factors may apply which would determine that larger divergence angles are needed. Many of those possible safety factors are described in the Qualitative Risk Assessment report.

Table 1 shows the minimum safe divergence cases. They are described in terms of the minimum divergence angle between PBN SIDs, the minimum distance from the Departure End of the Runway (DER) that divergence can start, the minimum interval between rotations of successive departures, and the set of aircraft types that would be eligible for the RDD procedure. The baseline departure spacing interval is 60 seconds, with an additional interval of 75 seconds included to enable RDD procedures at airports where terrain or noise considerations would require a later divergence.

	2.0nm	2.5nm	3.0nm	3.5nm	4.0nm	4.5nm
60s, groups 3-5	15	25	-	-	-	-
60s, groups 4-5	15	15	-	-	-	-
75s, groups 3-5	10	10	10	15	20	30

Table 1: Minimum safe divergence angles by divergence point

The aircraft type sets are intended to replicate a typical MATS Part 2 Departure Table speed group, with group 5 being the fastest speed group representing the fast jets category. Table 2 shows the aircraft types used within the modelling by speed group, and it is intended that other aircraft types of equivalent performance can be included within these groups. If new aircraft types become available with performance characteristics outside of the envelope of those typical within these speed groups, consideration should be given as to whether they would be eligible for RDD operations, or whether further specific risk analysis should be performed. It has been determined that slower aircraft types than those shown would not be eligible for an RDD procedure.

Speed Group	Included Types
5	A388, A306, A310, A332, A333, A339, A359, A35K, B744, B748, B752, B753, B762, B763, B764, B772, B77L, B77W, B788, B789, B78X, 290, 295, 7M9, A20N, A21N, A318, A319, A320, A321, B38M, B39M, B733, B734, B735, B737, B738, B739, BCS1, BCS3, C680, C68A, CJT, CRJX, E170, E175, E190, E195, E20, E290, E295, E35L, E75L, FA5X, GL5T, GL7T, GLF4, GLF5, GLF6, GS5, L45, LJ35, LJ45, LJ60, LJ75
4	BE40, C56X, C650, CJL, CL30, CL35, CL60, CRJ2, CRJ9, DH8D, E135, E145, E55, E550, E55P, EM5, EP3, F2TH, F900, FA50, FA7X, FA8X, G280, GLEX, H25B, H25C, J328, SF50, 510, C25A, C25B, C25C, C25M, C501, C510, C525, C550, C55B, CJ1, E50P, EA50, PC24
3	AT45, AT46, AT6, AT72, AT75, AT76, C30J, DH8C, JS41, SF34, SW4, B350, BE20, BET, E121, PC12

Table 2: Example aircraft types within speed groups

The results are applicable only in the case of departures which enter surveillance airspace (i.e. aircraft are identified on radar within 1nm of the DER). Therefore, RDD cannot be applied in procedural airspace.

The analysis has conservatively assumed that identical climb gradients are attained between RDD SIDs. Any difference in required climb gradients or altitude constraints between RDD SIDs in practice would have a beneficial effect on the collision risk due to a higher likelihood of vertical separation between successive departures at the point at which they attain longitudinal overlap. Therefore, the implementation of RDD would impose no additional restrictions on climb gradients or altitude constraints of PBN SIDs.

The analysis has been performed using a simplified and conservative characterisation of PBN SIDs and does not assume any specific SID design elements. The implementation of RDD would therefore require no changes to SID design criteria from the existing requirements in PANS OPS or UK specific IFP design rules.

The RDD divergence cases described above have been assessed across a wide range of UK airports at which RDD might be applied now or in the future, from Heathrow to Southampton, so the results can be considered as generically applicable for surveillance airspace across the UK.

The collision risk has been assessed for pairs of aircraft for which the current one-minute 45° divergence criteria would apply, namely non-wake pairs, and pairs for which the lead aircraft is in the same or a faster speed group than the follower. Any pair of departures for which a two-minute or greater spacing is required today would not be eligible for the RDD procedure.

Since this quantitative safety analysis has been completed using novel risk modelling methodology, it would be beneficial for a full review of the analysis to be carried out by a suitably qualified party, fully independent of the RDD Project Team. This would assess the correctness and conservativeness of the complex modelling, and allow regulatory authorities confidence that the analysis does not under-estimate risk due to the implementation of RDD.

Recommendation: Perform a full review of the quantitative safety analysis by a suitably qualified third party.

Additionally, it is understood that completion of all necessary safety work, including the additional research described herein, would be required before inclusion of RDD as a generic standard in MATS Part 1 could be considered. However, since this analysis allows significant additional understanding of the risks due to RDD and provides a potential breakthrough enabling more efficient and systemised airspace design, it would be beneficial to provide an update to the general discussion on RDD in CAP 1385. The existing discussion in CAP 1385 is based on older modelling work with a much smaller sample size and limited airport and fleet mix applicability. The development of the modelling methodology used within this research builds on the learnings from the prior research, and an understanding of the limitations of that methodology. Subject to the new modelling being assessed as suitably conservative, this research can be considered to supersede the prior research.

Recommendation: Update the section on RDD in CAP 1385 with key findings from this research.

RDD Implementation Considerations

Aircraft Separation

The current one-minute 45° divergence allows successive departures to rapidly attain the Minimum Radar Separation (MRS) of 3nm, enabling rapid transfer of control from the Departure Controller to the receiving Controller. Under RDD divergence of 15° or less, there is the potential for aircraft to remain in closer proximity than the MRS for an extended period of time, requiring transfer of control to occur prior to MRS being attained. From a collision risk perspective, these aircraft can be treated as procedurally separated if the required departure spacing has been applied, as a form of deemed separation.

In practice, it is likely that further turns on the SIDs would increase the spacing between tracks more rapidly than the minimum assessed for Collision Risk Modelling purposes.

There are a number of implementation issues that airports/ANSPs should consider which are set out below. However, as each implementation will be different depending on the SID configuration proposed, detailed exploration of all of these may not be necessary.

Pilot Understanding and Pilot/ATC Communication

From the qualitative risk assessment exercise, it became apparent that it would be beneficial for pilots to understand the implications of RDD and know when they are flying on an RDD procedure with other aircraft potentially in closer proximity than is typical today.

Departure speed variability can be high based on differences in aircraft configuration and thrust settings. Those are determined while the aircraft is on the stand and are affected by factors such as equipment failures above the Minimum Equipment List. In discussion with pilots and controllers, it became apparent that the controllers would expect to be informed about "significantly less than normal" initial climb and/or acceleration performance, but that the pilots would not typically do so. It would therefore be useful for RDD familiarisation to be given to pilots to ensure that they would inform ATC of abnormal speed/climb performance, enabling the Departure Controller to leave additional spacing behind the aircraft.

Consideration: Provide RDD familiarisation briefings to operators prior to RDD implementation.

Consideration: Identify an appropriate means of informing pilots that they are flying an RDD procedure, such as specification on the SID chart or by ATC communication.

In addition, a concern was raised about the possibility of Airborne Collision Avoidance Systems (ACAS/TCAS) triggering alerts or displaying distracting information during high-workload phases of departure for the pilot.

Consideration: Investigate the impact of RDD on ACAS/TCAS.

Track Conformance Monitoring

Where aircraft are on narrowly diverging SIDs it may be difficult for the controller to assess track conformance, both visually for the Departure Controller, and on radar. It may therefore be useful to investigate and develop appropriate tool support such as SID markings on the radar screen, or automated track conformance monitoring.

Consideration: Consider track conformance monitoring for PBN SIDs.

In addition, existing ATC separation monitoring tools such as the Short-Term Conflict Alert (STCA) may need to be assessed and configured appropriately to prevent erroneous alerts while aircraft are on diverging SIDs but separated by less than the MRS.

Consideration: Assess existing ATC separation monitoring tools for suitability for RDD.

Achievability of Minimum Departure Spacing

Despite departure spacing rules applying to the time interval between rotations, the Departure Controller only has control of the time at which an aircraft starts its roll. The Departure Controller must exercise their experience and judgement to determine the likely roll length of the aircraft, and in some cases the aircraft will rotate more rapidly than expected, resulting in under-spacing. On an RDD procedure, the consequences of this under-spacing may be more severe than they are under current operations.

It may be useful to develop tool support for the Departure Controller to alert them when under-spacing has occurred. This would allow closer monitoring of the aircraft pair, and if necessary trigger the vectoring of one of the aircraft to ensure MRS is more rapidly attained.

Consideration: Consider departure spacing tool support.

Events Causing Failure to Follow the SID

Weather

In the event of severe weather conditions, aircraft may need to deviate from the SID prior to receiving clearance to do so. This would be more dangerous on RDD procedures where the aircraft are potentially closer to other aircraft than they would be under current operations.

Consideration: Suspend RDD operations (increase MDI) during severe weather events.

EFATO

In the event of an Engine Failure After Take Off (EFATO), the aircraft may need to initiate an emergency turn to return to the airfield or may continue to climb straight ahead. It is likely that the aircraft would maintain a low altitude below other climbing traffic, however the full implications of EFATO in an RDD environment have not been assessed.

Consideration: Investigate the impact of EFATO on RDD procedures.

Wake Turbulence

Given that RDD pairs of aircraft may remain in closer proximity for longer than they would under current operations, it would be useful to assess the possibility of in-air wake turbulence due to wake vortices being blown into the path of proximate traffic.

Consideration: Assess the risk of in-air wake turbulence due to RDD.

SID Design Considerations

Re-Convergence

Under current operations there are examples of SIDs which initially diverge by 45° or more, but then re-converge. Despite MATS Part 1 permitting one-minute departure intervals for those SIDs, the local rules in MATS Part 2 require two-minute departure intervals due to the re-convergence, and this should also hold true for RDD SIDs.

Consideration: RDD should not be applicable to SID pairs which diverge and then re-converge while the tracks are spaced by less than the MRS.

Sharp Turns

Research in early phases of the RDD Project suggested that RDD procedures may not be able to apply to sharp turns and wrap-around turns due to slower or more variable speed profiles on those SIDs. However, this was investigated during the quantitative risk modelling and was not found to be a significant safety factor. The Collision Risk Modelling was completed including data from sharp turns and wrap-around turns, and the minimum safe divergence cases in Table 1 also apply to those turns.

Turns in the Same Direction

The only limitation found within this work that applies to sharper turns is that relating to turns in the same direction. Figure 1 shows the nominal centrelines for a set of fictional diverging SIDs from the same runway. Aircraft will fly a circular arc to achieve the desired turn, and in cases where both aircraft are flying turns in the same direction, they will follow the same or a similar circular arc. The actual divergence point between the SIDs therefore occurs much later when both are turning in the same direction with sharper turns.

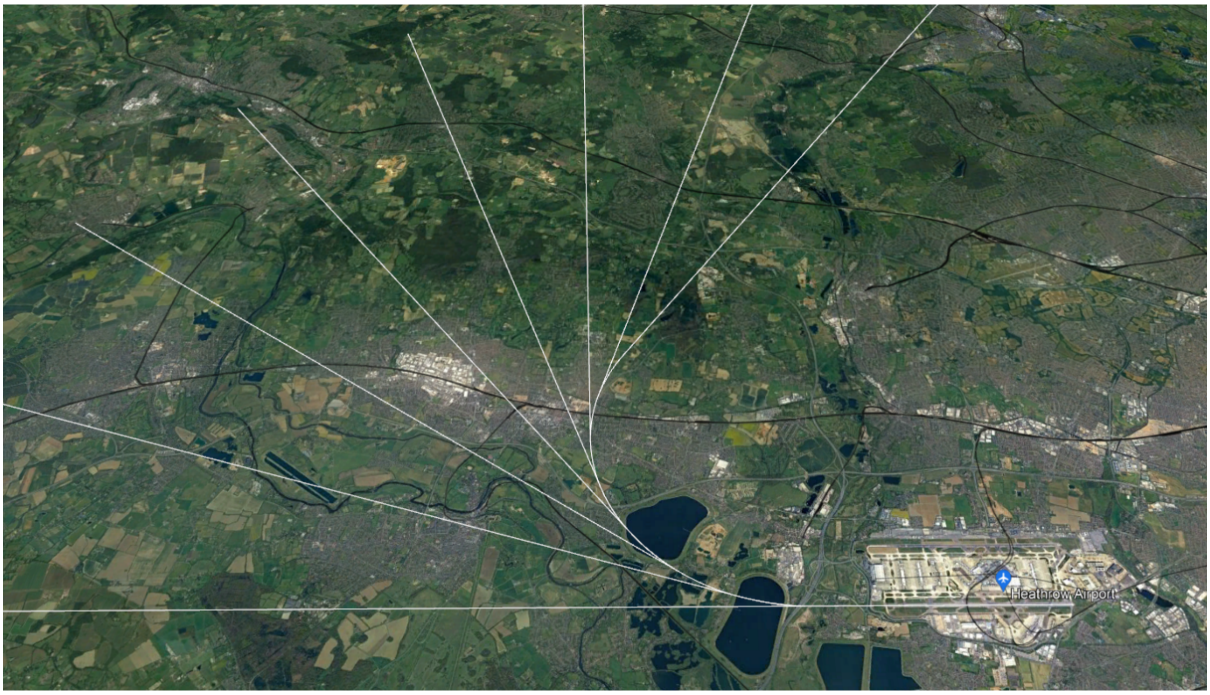

Figure 1: Nominal centrelines of diverging PBN SIDs (Google Earth)

As an example, Figure 2 shows approximately where the divergence point would fall between the SIDs marked C and D, with the yellow dashed line showing the approximate distance from the DER to the divergence point. It is clear that in order to meet a requirement that the divergence occurs no later than 2.5nm from the DER, the start of turn for both SIDs would need to be much closer to the DER than 2.5nm.

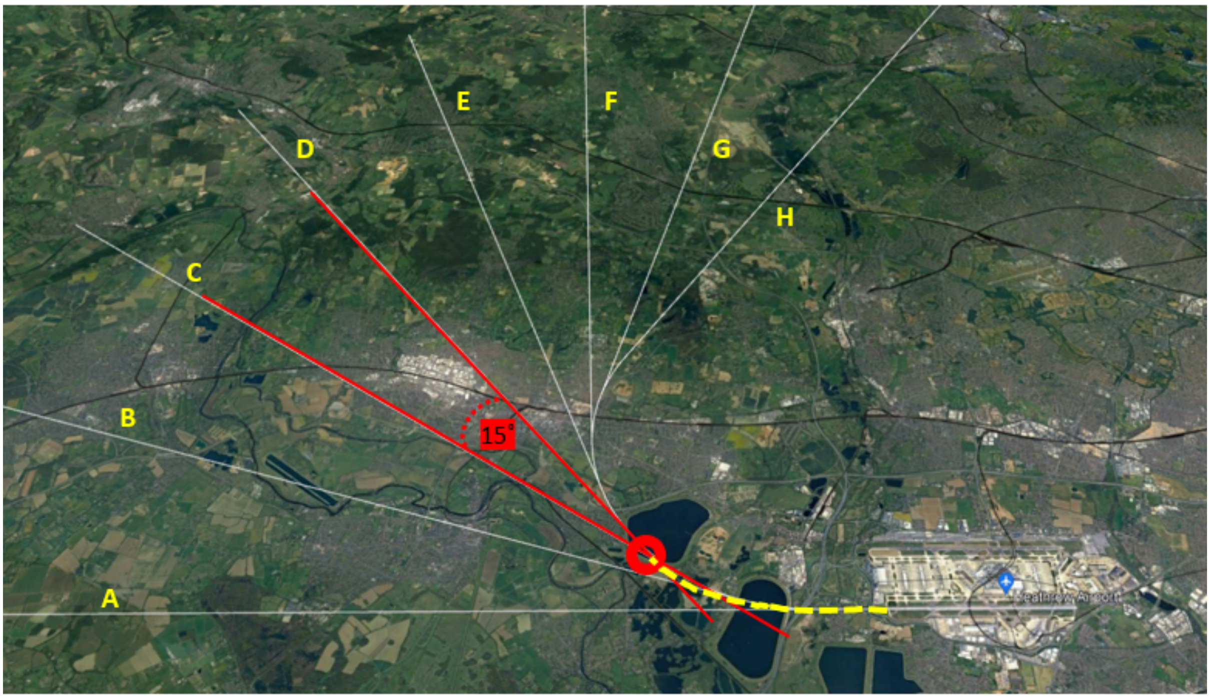

Figure 2: Divergence point of SIDs C and D, marked as red donut

It can be calculated that where both SIDs turn by approximately 60° or more in the same direction (e.g. one turns right by 60°, the other turns right by 150°), the common distance travelled over the circular arc before proper divergence occurs would be greater than 2.5nm. Therefore, the turns would need to start prior to the DER in order to meet any RDD criteria with 60s departure spacing. In practice, this disallows the possibility of RDD being applied to SID pairs with sharp turns in the same direction, regardless of the divergence angle between them, unless additional departure spacing is employed.

It should be noted that this is an approximate calculation, and the true distance to the divergence point for a SID pair would need to be assessed by the IFP designer on a case-by-case basis depending on the actual SID construction.

Recommendations

Table 3 contains the requested next steps for CAA to action that can enable sponsors of airspace change to build upon this RDD research.

Rec No.	Recommendation	Suggested owner
R1	Perform a full review of the quantitative safety analysis by a suitably qualified third party	CAA to appoint suitable reviewer
R2	Subject to 1, update the section on RDD in CAP 1385 with key findings from this research	CAA

Table 3: Recommendations

Implementation Considerations

Table 4 gives a summary of the considerations, that sponsors of airspace change wishing to apply the RDD concept should address, depending on the specifics of the RDD designs being proposed.

	Implementation Consideration for Airport/ANPS
C1	Provide RDD familiarisation briefings to operators prior to RDD implementation
C2	Identify an appropriate means of informing pilots that they are flying an RDD procedure, such as specification on the SID chart or by ATC communication
C3	Consider the impact of RDD on ACAS/TCAS
C4	Consider track conformance monitoring for PBN SIDs
C5	Assess existing ATC separation monitoring tools for suitability for RDD
C6	Consider departure spacing tool support
C7	Suspend RDD operations during severe weather events
C8	Consider the impact of EFATO on RDD SIDs
C9	Assess the risk of in-air wake turbulence due to RDD
C10	RDD should not be applicable to SID pairs which diverge and then re-converge while the tracks are spaced by less than the MRS

Table 4: Implementation Considerations