



Aeronautical Assessment of Denham Aerodrome for HS2
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Align JV



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Contents

Executive Summary	1
Recommendations	3
Mitigations	3
1. Introduction	4
1.1 Denham Aerodrome and HS2	4
1.2 Scope of Aeronautical Study	5
1.3 Report Structure	6
2. Data Utilised	7
2.1 Previous Reports	7
2.2 Consultation	9
2.3 Data Analysis	9
2.4 Sensitivity of assumptions	15
3. Obstacle Limitation Surfaces	17
3.1 General	17
3.2 Aerodrome Safeguarding – HS2 during construction	17
3.3 Aerodrome Safeguarding – HS2 operational	21
4. Quantitative Crash Probability Analysis based on Accident Records	22
4.1 Accident Record	22
4.2 AAIB Database for Denham Aerodrome	23
4.3 Accident Locations at Denham Aerodrome	25
4.4 AAIB Database analysis for other relevant records	28
4.5 Crash Location Probability	31
4.6 Risk Summary of Crash location on Viaduct	37
5. Runway 06 Take-off Collision Risk	39
5.1 Helicopter risk	39
5.2 Assessment Method	39
5.3 Hazard and Consequence	50
5.4 Probability	51
5.5 Risk Summary	52
6. Runway 24 Landing Collision Risk	53
6.1 Helicopter Risk	53
6.2 Assessment Method	53
6.3 Hazard and Consequence	58
6.4 Probability	58
6.5 Risk Summary	59
7. Circuit 06/24 – Forced Landing Area Availability	60
7.1 Local Flying Area	60
7.2 Method	61

7.3	Landing Field Analysis Outputs.....	66
7.4	Risk Summary.....	69
8.	Crosswind Runway – Forced Landing Field Availability.....	70
8.1	Method.....	70
8.2	Landing Field Analysis Outputs.....	71
8.3	Risk Summary.....	73
9.	Environment.....	74
9.1	Landscape Planting and Risk of Bird Strike	74
9.2	Dust Control.....	76
9.3	Lighting.....	76
10.	Third Party Risk	77
11.	Mitigations.....	78
11.1	Reasonably Practical and Required Recommendations and Mitigations	78
11.2	Assessment of Reasonably Required Mitigations	78
11.3	Proposed Mitigations	82
11.4	Rejected potential mitigations measures.....	82
12.	Conclusions and Recommendations	84
12.1	Conclusions	84
12.2	Recommendations	84
	Appendix.....	85

Table of Figures

Figure E.1.1: Existing forced landing location area for engine failure on Runway 06 Take Off	1
Figure E.1.2: HS2 operational - forced landing location area for engine failure on Runway 06 Take Off	1
Figure E.1.3: HS2 construction stage - forced landing location area for engine failure on Runway 06 Take Off	2
Figure E.1.4: HS2 construction stage - forced landing location area for engine failure on Runway 24 Landing	2
Figure 2.1: Historic Annual Aircraft Movements at Denham Aerodrome	10
Figure 2.2: Denham Aerodrome Layout	12
Figure 2.3: Runway 06 / 24 declared distances layout (Google Maps, 2020)	13
Figure 2.4: Crane Elevations provided by Align JV	14
Figure 3.1: Plan View OLS map and HS2 Construction	18
Figure 3.2: Approach Surface for Non-Instrument Approach Rwy 24 and Take-off Climb Surface for Rwy 06	19
Figure 3.3: Approach Surface for Non-precision Instrument Approach Runway 24	20
Figure 4.1: Number of accidents per 10-year period at Denham Aerodrome	24
Figure 4.2: Accident locations related to Denham Aerodrome	26
Figure 4.3: Coordinate system proposed for Landing and Take-offs accident locations.	27
Figure 4.4: Landing accident distance from runway threshold at Denham Aerodrome	27
Figure 4.5: Take-off incidents distance from TODA end at Denham Aerodrome	28
Figure 4.6: Landing accidents distance from runway threshold at Denham and Other UK Airports	30
Figure 4.7: Take-off incidents distance from TODA end at Denham Aerodrome + Other UK Airports	30
Figure 4.8: CPD take-off crash locations - X distance from TODA end	33
Figure 4.9: CPD Landing Crash Locations - X distance ($x < 0$)	33
Figure 4.10: CPD Landing Crash locations - X distance ($X > 0$)	34
Figure 4.11: Location of the viaduct	35
Figure 4.12: Crash location involving viaduct probability determination	36
Figure 5.1: Critical Zone after Take Off - Plan View	40
Figure 5.2: Critical Zone After Take Off - Section shown on Northern Edge of TOCS	41
Figure 5.3: Critical Zone After Take Off - Section shown on extension of runway centreline	41
Figure 5.4: Critical Zone After Take Off - Section shown on Southern Edge of TOCS	42
Figure 5.5: Take-off climb path zones of risk of crashing onto the HS2 viaduct.	44
Figure 5.6: Critical Zone – Sketch of proportion of glide slopes analysis.	46
Figure 5.7: Angle Proportion analysis in critical zone for HS2 Operational	47
Figure 5.8: Take-off on Runway 06 – HS2 Operational	47
Figure 5.9: Take-off on Runway 06 - HS2 Construction - Piling works	49
Figure 5.10: Take-off on Runway 06 - HS2 Construction - Pier cap and pier construction	49
Figure 5.11: Take-off on Runway 06 - HS2 Construction - Launching Girder works	49
Figure 5.12: Rwy 06 Take-off - Drift distribution in metres	50
Figure 6.1 Critical Zone – Approach- Plan View	53
Figure 6.2 Critical Zone on Approach - Section shown on extension of runway centreline	54
Figure 6.3: Landing on Runway 24 – HS2 Operational	55
Figure 6.4: Landing on Runway 24 – HS2 Construction – Piling works	56
Figure 6.5: Landing on Runway 24 – HS2 Construction – Pier cap and pier construction	56
Figure 6.6: Landing on Runway 24 – HS2 Construction – Launching Girder works	56
Figure 6.7: Rwy 24 Landing - Drift distribution in metres	57
Figure 7.1: LFA extract from AIP AD 2.EGLD-4-1 (Circuit)	60
Figure 7.2: Basic Circuit pattern – Flight Circuit 06	62
Figure 7.3: Existing Potential Landing Areas identified for Denham Aerodrome	63
Figure 7.4: Flight circuit points	64
Figure 7.5: Landing site suitability selection – Existing Scenario	64
Figure 7.6: Landing site suitability selection – HS2 Construction Scenario	65
Figure 7.7: Landing site suitability selection – HS2 Operational Scenario	65
Figure 7.8: Landing Field Availability Results- Flight Circuit 06	67
Figure 7.9 Landing Field Availability Results- Flight Circuit 24	67
Figure 7.10: HS2 footprint during Construction	68
Figure 7.11: HS2 footprint during Operations	69
Figure 8.1: Crosswind Runway 12/30 typical circuit pattern	70

Figure 8.2 Landing Field Availability Results- Flight Circuit 12	72
Figure 8.3 Landing Field Availability Results- Flight Circuit 30	72
Figure 9.1: HS2 Indicative Tree Less Plan – Viaduct.....	74
Figure 9.2: HS2 Proposed Landscaping for the Colne Valley Viaduct.....	75
Figure A.1: Effective target area extracted from CRR 150/1997	87
Figure A.2: Crash location sections involving probability determination.....	89

Table of Tables

Table 1.1 Extracts from the Register of Undertakings and Assurances v1.8	4
Table 2.1: Denham Traffic Scenariosf	10
Table 2.2: Current Airport Traffic Mix.....	11
Table 2.3: Single engine piston fixed wing operations by aircraft type	11
Table 2.4: Runway usability percentages and estimated annual aircraft movements.....	12
Table 2.5: Expected elevation for construction equipment on site under the take-off and approach path.....	15
Table 3.1: Summary of results of Obstacle Limitation Surfaces analysis	21
Table 3.2: HS2 Operational elements elevations	21
Table 4.1: Type of accident statistics.....	24
Table 4.2: Immediately preceding phase of flight statistics at Denham Aerodrome.....	24
Table 4.3: Immediately preceding phase of flight statistics at comparable airports	29
Table 4.4: Denham On-Airport Helicopter Accident Records.....	31
Table 4.5: Single crash probability of location on viaduct results	36
Table 4.6: Crash rates for an aircraft collision with the viaduct	37
Table 4.7: Crash probability results for current traffic.....	37
Table 4.8: Crash probability results for forecast traffic	38
Table 5.1: Probability for Runway 06 Take Off	52
Table 6.1: Probability for Runway 24 Landing.....	58
Table 7.1: Emergency landing fields availability for Runway 06/24	66
Table 7.2: Percentage of Circuit with no suitable forced landing field available	69
Table 8.1: Emergency landing fields availability for Runway 12/30.	71
Table 8.2: Percentage of circuit with no suitable forced landing field available.....	73
Table 11.1: UK CAP 760 Chapter 3 Probability Classifications and Jacobs Result Ranges	80
Table 11.2: Combination of Results from Sections 5 and 6 for Take-off and Landing	81
Table 11.3: Proposed Mitigations Summary	82
Table A.1: Viaduct height calculation.....	87
Table A.2: Crash probability results for current traffic.....	88
Table A.3: Crash probability results for forecast traffic	88
Table A.4: Crash probability results without HS2 along the take-off climb and final approach for current traffic	89
Table A.5: Crash probability results with HS2 along the take-off climb and final approach for current traffic	90
Table A.6: Crash probability results without HS2 along the take-off climb and final approach for forecast traffic	90
Table A.7: Crash probability results with HS2 along the take-off climb and final approach for forecast traffic	90

Executive Summary

This aeronautical assessment concludes that the construction and operation of the authorised works does have an impact on the safety of operations at Denham Aerodrome.

Previous work had seemingly relied upon the rail viaduct being shielded from aircraft collision by adjacent trees, but this is not the case for single engine aircraft suffering an engine failure just before overflying the viaduct. Figure E.1.1 shows the existing situation where the blue zone indicates the likely area of a forced landing into treetops or a ditching, both of which have a high survivability, after an engine failure in the critical zone. Figure E.1.2, Figure E.1.3 and Figure E.1.4 show how the viaduct occupies a portion of that area, increasing the risk of a fatal outcome if there were an engine failure in the critical zone.

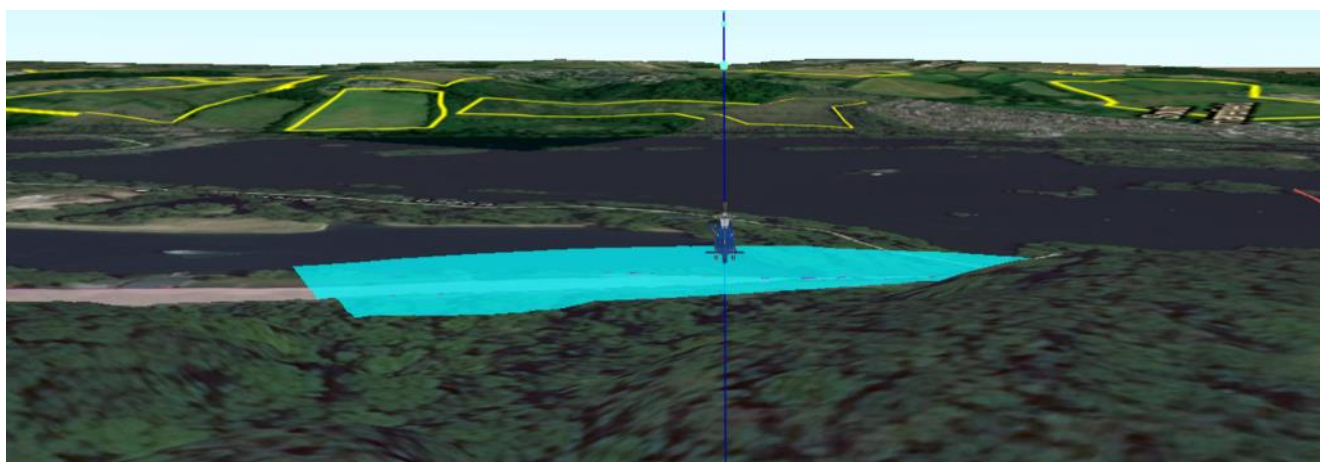


Figure E.1.1: Existing forced landing location area for engine failure on Runway 06 Take Off

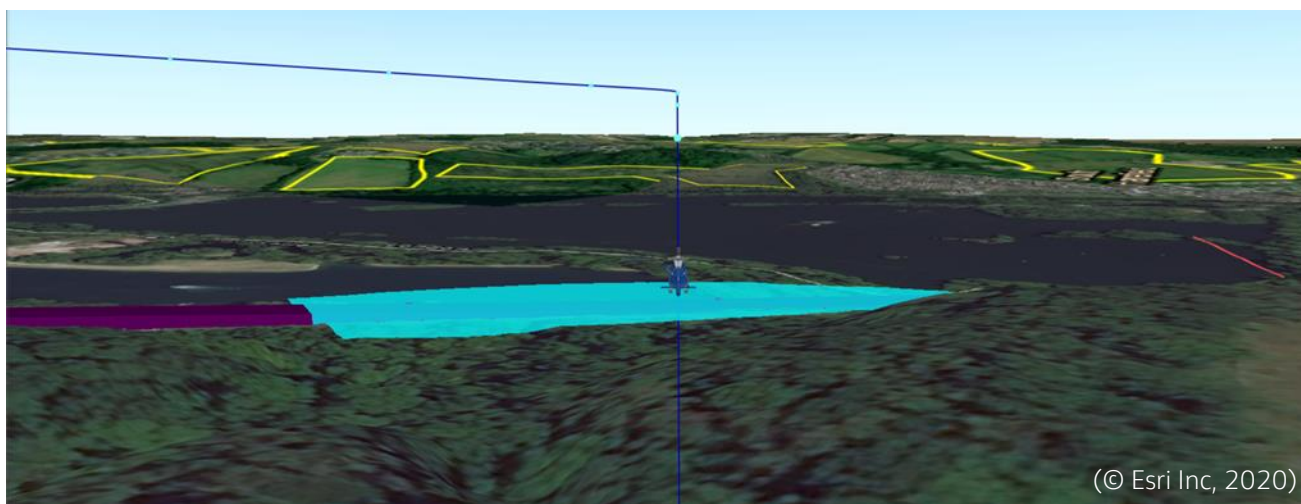


Figure E.1.2: HS2 operational - forced landing location area for engine failure on Runway 06 Take Off

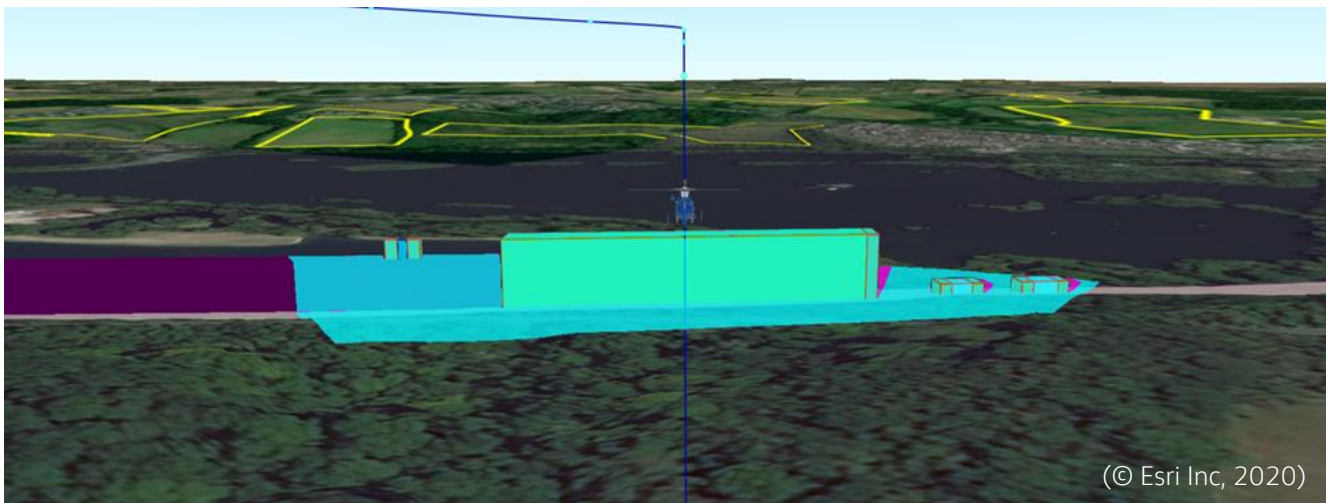


Figure E.1.3: HS2 construction stage - forced landing location area for engine failure on Runway 06 Take Off

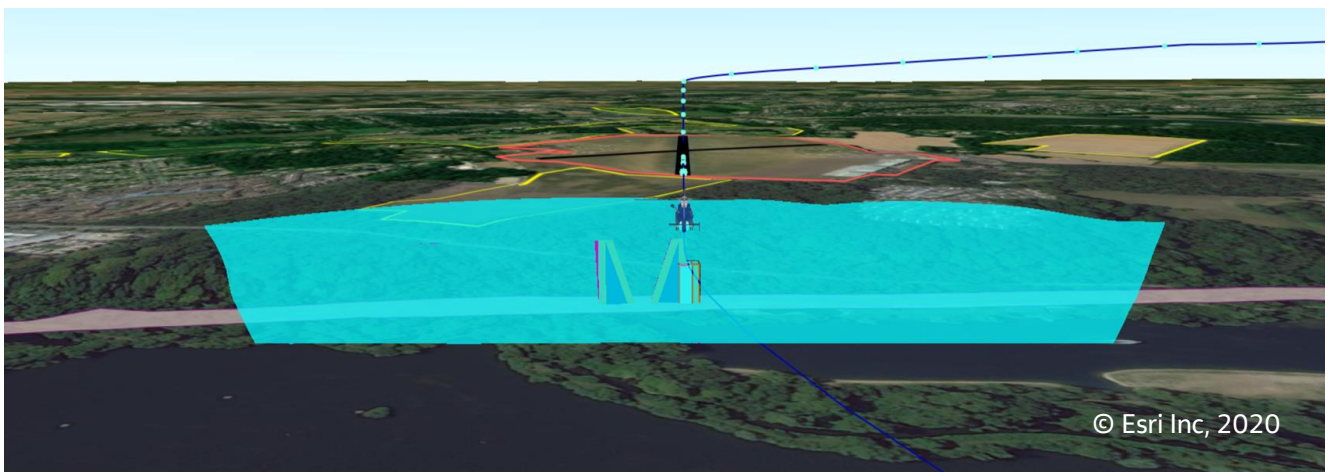


Figure E.1.4: HS2 construction stage - forced landing location area for engine failure on Runway 24 Landing

There is a possibility of a single engine aircraft colliding with the viaduct if it suffers an engine failure on take-off towards the viaduct, or on landing towards the viaduct approaching from the northeast. The probability of this happening once HS2 is operational is low. It is only slightly higher than the existing probability of a fatal outcome from the same occurrence of an engine failure. The combined recurrence period of such an incident is calculated as one in 492 years at the current level of air traffic which is classified as a "Remote" probability by UK CAA CAP 760, the same classification as in the existing situation for a fatal forced landing into the treetops or on ditching. There being no change in the probability classification of a fatal aircraft accident, the tolerability is assessed to be the same as in the existing situation.

During the HS2 construction period there is an increased risk of a fatal outcome from such an engine failure. However, the probability expressed by combining the results for take-off and for landing as a combined recurrence period is less frequent than what was being experienced for the 10 years of traffic from 1990 to 1999 and is also classified as a "Remote" probability. It is concluded that the probability of a fatal outcome during the construction phase is similarly assessed as tolerable. After an initial Jacobs analysis for higher cranes (used without constraints), AlignJV amended the construction method. As a result, cranes are now lower in height and are assessed as two cranes per three pier locations (constrained use). This is now considered by AlignJV to be as low as reasonably practicable. The construction phase is expected to last for less than one year underneath the TOCS and the AS. It is concluded that no further mitigation measures are reasonably required for this case, other than to ensure that the crane heights used in the assessment are taken forward into the construction specification.

The availability of suitable areas of land for survivable forced field landings (emergency landings) on the crosswind runway circuits is significantly reduced by the HS2 authorised works in the main construction site compound, especially during the construction phase. To mitigate this, it is suggested that the circuit pattern should be modified to route further away from the site compound and that the earliest return of the construction site compound to open landscaped areas to facilitate forced landings should be prioritised.

Recommendations

- 1) That the mitigation measures proposed in Section 11.3 are given due consideration and, where appropriate and compliant with the tests of reasonableness described in Section 11.1, are implemented.
- 2) That dust control measures are included in the construction specification.
- 3) That the design and the construction specification require that lights, other than obstacle lights, are shaded to stop vertical light spread and are shaded to stop directional light in line and towards or away from runway centrelines.
- 4) That in accordance with CAP 168 Paragraph 4.77 construction infrastructure, including craneage, be lit with obstacle lights.
- 5) That HS2 Ltd should consider the inclusion of dealing with the risk of aircraft accidents on the viaduct in their plans for the safe operation of the railway.
- 6) For the particular case of the construction period, U&A 2633 deals with rescue and evacuation procedures and requires that, *"The Promoter will in consultation with the Aerodrome Manager put in place appropriate rescue and evacuation procedures for the recovery of aircraft at the West Hyde main construction site for the duration of the construction period."* It is recommended that this work is extended to include the continuing requirement for appropriate rescue and evacuation procedures at all of the HS2 route through the Denham Aerodrome local flying area during the long-term operational phase.
- 7) That the earliest return of the construction site compound to open landscaped areas to facilitate forced landings should be prioritised.

Mitigations

The following mitigations are proposed.

Degradation of Safety to be Addressed	Proposed Mitigations
1. Probability of collision with the viaduct after an engine failure during the initial climb of a take-off from Runway 06 by rotary wing aircraft (helicopters).	1. Denham Airport operator to recommend all Runway 06 take-offs by helicopters to be initiated in the southwest portion of the aerodrome, if no cost is associated.
2. Probability of collision with the viaduct after an engine failure during the initial climb of a take-off from Runway 06 and for engine failure on final approach to a landing on Runway 24 by fixed wing aircraft. HS2 in construction phase	2. Construction method has been developed to limit crane heights and numbers of cranes in the zone underneath the TOCS and AS. Construction contract documents should specify these constraints on crane heights and numbers in the zone underneath the TOCS and AS.
3. Reduced availability of suitable areas for forced field landings after engine failure.	3. Denham Aerodrome operator to consider whether temporary improvements can be made for the cross-wind runway circuits during the HS2 construction period by adjusting the circuit pattern. HS2 Ltd to prioritise the early return of the construction site compound to open landscaped areas.

1. Introduction

1.1 Denham Aerodrome and HS2

Denham Aerodrome is a general aviation airport located to the north-east of Slough, immediately to the north-east of the M25 and M4 junction. The proposed HS2 route passes only some 550m to the east of the aerodrome boundary. The Denham Aerodrome operator made representations at various stages as the HS2 route was selected to set out their concerns at the impact of the HS2 route, its construction and its operation on the safety of aircraft operations at Denham Aerodrome.

The HS2 Act, fully titled as the High Speed Rail (London to West Midlands) Act 2017, includes a register of Undertakings and Assurances (U&A) which are commitments given by the Promoter of HS2 during the passage of the Bill. The register at its current version v1.8 is available on the gov.uk website. Five of the Undertakings and Assurances are seemingly in response to the concerns expressed by the operators of Denham Aerodrome and key descriptions of each of them, as extracts from the register, are tabulated below.

Table 1.1 Extracts from the Register of Undertakings and Assurances v1.8

U&A ref id	Subject	Text (where relevant)
2630	Consultation	The Promoter will require the assessor to consult with the Aerodrome Manager of Denham Aerodrome and to have regard to the Aerodrome Manager's expert advice on the potential impact of the construction and operation of the authorised works on the safe operation of the Aerodrome.
2631	Aeronautical study	The Promoter will, so far as reasonably practicable, give effect to the conclusions and recommendations (if any) of the said assessment in the detailed design of the HS2 project (including the Colne Valley Viaduct) in so far as it affects the safe operation of Denham Aerodrome.
2632	Mitigation works	The Promoter will undertake such mitigation works at the Aerodrome as are found to be reasonably required by the said assessment, subject to obtaining any necessary consents and subject to the Petitioner granting any necessary rights of access.
2633	Rescue and evacuation procedures	The Promoter will in consultation with the Aerodrome Manager put in place appropriate rescue and evacuation procedures for the recovery of aircraft at the West Hyde main construction site for the duration of the construction period.
2634	Aeronautical study	The Promoter will procure an appropriate aeronautical study (the assessment) to be undertaken by a suitably qualified person or firm, of the potential impact of the construction and operation of the authorised works on Denham Aerodrome.

AlignJV appointed Jacobs for a start on 01/07/20 to carry out the aeronautical study (the assessment), thus satisfying, upon completion of this report, U&A 2634. This report presented is the deliverable from that appointment and sets out the aeronautical study work that was carried out. The brief for the study included the

U&A requirement to consult with the Aerodrome Manager of Denham Aerodrome, thus satisfying U&A 2630. As reported in Section 2 of this report, several consultation discussions took place between the Jacobs staff carrying out the aeronautical study and the Aerodrome Manager. In forming the findings of this report Jacobs consider that they have given due regard to the Aerodrome Manager's expert advice.

U&A 2631 and 2632 are outside the scope of this aeronautical study, being assurances of what the Promoter will do in the light of the findings of the aeronautical study. Nevertheless, they give valuable context for the purpose of the aeronautical study and confirm the actions to be taken by the Promoter in putting into effect the conclusions, recommendations and mitigations arising from this aeronautical study, subject to tests of being reasonably practicable and reasonably required respectfully.

The requirements of U&A 2633 for rescue and evacuation procedures relating to the recovery of aircraft from the West Hyde main construction site is largely outside the scope of this aeronautical study. However, comment is made upon this matter in Section 10 of this report because the timely rescue of personnel on board an aircraft suffering a forced landing or crash into the construction site is a material safety consideration.

1.2 Scope of Aeronautical Study

International Civil Aviation Organization (ICAO) documents provide a definition of an Aeronautical Study in for example ICAO Doc 9734 Part A 2nd Edition 2006 Appendix B: Definitions, as follows.

"Aeronautical Study. *A study of an aeronautical problem to identify possible solutions and select a solution that is acceptable without degrading safety."*

It is noted that the aeronautical problem to be addressed is given in the U&A as "... the potential impact of the construction and operation of the authorised works on the safe operation of the Aerodrome." From this it is noted that the aeronautical study is not required to be a study of all aviation issues at Denham Aerodrome, nor of other safety issues relating to the operation of a high-speed railway line in close proximity to an airport. It is also noted that from the ICAO definition, solutions should be sought to be acceptable without degrading safety.

Having regard to consultation with the Aerodrome Manager at Denham Aerodrome, the key areas of concern for the potential impact of the HS2 authorised works are considered to be:

- a. The potential for collision with the viaduct after suffering engine failure on take-off on Runway 06
- b. The potential for collision with the viaduct after suffering engine failure on landing on Runway 24
- c. The reduction in available areas for survivable forced landings in the circuit and the local flying area
- d. Landscaping: the need not to increase bird strike risk
- e. Lighting: the need to have obstacle lights where appropriate but not to have distracting lights
- f. The need to control dust during construction.

The methodology adopted in this aeronautical study has been to use quantitative analysis to investigate items **a, b and c** above, allowing a comparison of the scale of any degradation of safety due to the impact of the HS2 works whilst both making use of previous reports and Jacobs own qualitative assessment for items **d, e and f**. For the quantitative assessments **a, b and c** risk assessments have been carried out using the guidelines given in UK Civil Aviation Authority Publication (CAA CAP) 760 – Guidance on the Conduct of Hazard Identification, Risk Assessment and the Production of Safety Cases. This utilises the steps of Hazard Identification, Consequence, Probability and from these parameters forms an assessment of Risk and the Tolerability of that Risk.

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1.3 Report Structure

This introductory section is followed by Section 2 – Data Utilised which summarises and reviews key relevant historic reports and data sources used in the production of the report presented. Section 3 reviews the proposed HS2 infrastructure relative to clearances under the Denham Aerodrome Obstacle Limitation Surfaces. Section 4 provides a Quantitative Crash Probability Analysis based on actual historic Accident Records. This provides an indication of the likelihood of an accident on the site of the viaduct and provides a useful check on the validity of other theoretical quantitative analyses carried out in sections 5 and 6 as it is based on actual accident data. .

Section 5 – Runway 06 Take-off, considers the specific case of an engine failure during the initial climb on take-off on Runway 06 towards the northeast and the probability of that resulting in a fatal outcome, both during the existing situation, for HS2 during construction and when HS2 is operational. This provides a quantitative measure of any degradation of safety and shows how the probability compares with an aviation industry benchmark. Section 6 – Runway 24 Landing, provides a similar analysis for an engine failure during a landing approach over the viaduct from the northeast for a landing on Runway 24.

Sections 7 and 8 provide a description of the analysis of the availability of suitable areas of land for forced field landing (emergency landing) for aircraft in the Runway 06-24 circuit and for the crosswind runway 12-30 (grass runway) respectively. Section 9 – Environment considers the issues of landscaping and bird strike hazard, dust during construction and lighting.

To supplement the main scope of this report, Section 10 provides comment on third party risk and makes recommendations for liaison on rescue and evacuation procedures with the operator of Denham Aerodrome.

Proposed mitigations for instances where there is a significant degradation of safety such that mitigation is reasonably required are described and tabulated in Section 11. Conclusions and Recommendations are brought together in Section 12.

The Appendix contains calculations using an alternate method for assessing the risk of collision with the proposed viaduct as described in Contract Research Report CRR 150/1997, together with comments on the differences found between the results of the two methods.

2. Data Utilised

2.1 Previous Reports

2.1.1 Review of Safety and Risk Assessment Report by HS2 – March 2015

A report, titled *SAFETY AND RISK ASSESSMENT CONSTRUCTION OF HS2 RAILWAY VIADUCT IN PROXIMITY TO DENHAM AIRPORT*, document control reference C222-ATK-HW-REP-020-000001 | P03 | 03 March 2015 was reviewed.

The document control sheet indicates it as the final issue. However, it should be noted that in Appendix 3 to that report the diagram "Denham Airport Runway Section-C222-ATK-CV-DSK-020-000036" is marked as "Preliminary – Draft Initial" and as "Work-in-Progress". The diagram as drawn and included in the report is incorrect. One clear error is that the line labelled as the "Obstacle Limitation (5% Gradient)" is not drawn at 5%.

Although the trees shown on the diagram seem to have been drawn as an artistic representation, nevertheless the diagram clearly shows that the proposed HS2 catenary infrastructure extends vertically above the adjacent trees drawn. This means that an aircraft suffering an engine failure could possibly collide with the HS2 infrastructure. This situation is confirmed by the more recent landscaping drawing included in Section 9 of this report as Figure 9.2

Take-off Risk Assessment

The report failed to take into account the probability of such an engine failure on take-off on Runway 06 ending in a collision with the viaduct. On the contrary there seems to have been a belief that the trees would shield the viaduct from any such collision. The narrative of the report gives in Section 7.1 the statement:

"With reference to the drawings provided in Appendix 3, the line of trees across from Tilehouse Lane towards HS2 viaduct are in closer proximity to the Obstacle Limitation Surface than the viaduct. The OLS is equally defined by the trees adjacent to the viaduct. In the event of a collision these trees are likely to be impacted prior to HS2 infrastructure."

The risk assessment table for a number of risks including engine failure on take-off is provided as 10.2 in Appendix 2 of the report as Case 2.2. It would appear that the potential for an aircraft to collide with the viaduct has not been recognised as the notes simply state:

"Trees near north-eastern boundary likely to be impacted prior to reaching viaduct."

Whereas this would be the case for a situation where the aircraft came down into the woods prior to reaching the viaduct, it would not be the case for an aircraft whose glide slope after engine failure would bring the aircraft into collision with the viaduct.

In the risk assessment table at 10.2 of the report, the only additional mitigation measure proposed is *"Promulgation of obstruction data"*. This would not mitigate the risk of collision with the HS2 viaduct and its infrastructure. A pilot would have no realistically feasible avoiding manoeuvre options available after an engine failure at such an early phase of the take-off climb, whilst at approximately 100 ft above runway level and about 10 seconds from impact with the ground. In the absence of any possibility of avoiding the viaduct, pilot knowledge of the existence of the obstruction of the viaduct would do nothing to change the probability of a likely fatal consequence from collision with the viaduct and therefore is not a valid mitigation.

The take-off situation during the construction phase is assessed in 10.2 Case 2.3 of the report. The authors of the report were apparently aware of a construction methodology, but it seems assessed the risk as acceptable by noting that the Obstacle Limitation Surface (OLS) would not be obstructed by the construction plant. The OLS only deals with normal operations, whereas the risk assessment 10.2 Case 2.3 is clearly attempting to assess

amongst other issues, an engine failure on take-off. For single engine aircraft such a case clearly involves flight below the OLS, terminating with contact with the ground. The height of the construction plant which can be expected to be higher than the final completed works due to craneage would increase the probability of a fatal collision. This has not been considered.

Landing Risk Assessment

Turning now to the risk assessment of engine failure on landing on Runway 24 the risk assessment is shown in 10.3 Case 3.2 in Appendix 2 of that report. The diagram shown in Appendix 3 referred to above shows that the ground level and tree top level continues to fall to the east of the viaduct. This reduces further any shielding that the trees might have provided and opens up the viaduct to unprotected collision from a landing aircraft that suffers an engine failure in a location where the glideslope would inevitably end in a collision with the viaduct.

In assessing the risk as acceptable, the note provided in the explanation states:

"The trees near north eastern boundary will be more of an impact; this is due to the raise in ground level towards the airport runway. The ground slopes steeply towards to the viaduct and the lakes." (Sic).

However, the trees being referred to are to the southwest of the viaduct, and the landing aircraft is approaching from the northeast. The trees do not affect the probability of collision with the viaduct.

Comments made above on the mitigation measures proposed regarding the case for an engine failure on take-off apply equally to the same mitigation measures proposed for the engine out case on landing. They would not change the probability of a likely fatal collision with the viaduct and therefore are not valid mitigations.

Other Risk Assessments in the report

There are further risk assessments in the report on the availability of forced landing field areas and on the risk to helicopters. No comment is made upon those assessments. A more detailed quantitative assessment of the availability of areas suitable for forced landings is made in this Jacobs Aeronautical Study.

Summary

The report C222-ATK-HW-REP-020-000001 |P03 | 03 March 2015 titled as: Safety and Risk Assessment Construction of HS2 railway viaduct in proximity to Denham Aerodrome is considered not to have correctly assessed the risk of single engine aircraft suffering engine failure during critical portions of the take-off climb over the viaduct, or of the final landing approach over the viaduct leading to a likely fatal collision with the viaduct.

2.1.2 HS2 Environmental Statement

Reference has been made to the HS2 issue of the London-West Midlands Environmental Statement, Volume 2, Community Forum Area Report CFA7, Colne Valley. Within that document paragraphs 2.6.24 and 2.6.25 are given below for ease of reference.

2.6.24 The viaduct was part of the scheme announced in January 2012, however, the alignment has been moved approximately 60m to the north-east in the Proposed Scheme compared with the January 2012 announced route. The operators of Denham Aerodrome raised concerns about the possibility of aircraft from the aerodrome colliding with the viaduct structure and proposed that the height of the viaduct be lowered.

2.6.25 HS2 Ltd has undertaken a safety assessment of the proposed alignment in response to the concerns raised by the Aerodrome and do not consider that there is a risk. Therefore, lowering the height of the viaduct will not be necessary to allow the safe operation of the Aerodrome and altering the vertical alignment has not been investigated further. This decision was predominately based on health and safety requirements

rather than environmental considerations. Environmental constraints were considered in the initial decision to include a viaduct over the Colne Valley as part of the work to develop the scheme consulted upon in 2011 and contained within the route announced in January 2012.

From this it is clear that HS2 Ltd did not investigate further the alteration of the vertical alignment to allow lowering of the viaduct because, informed by their safety assessment, they did not consider that there was a risk.

2.1.3 HS2 Context Report Prepared for London Borough of Hillingdon – May 2017

It must be recognised that the HS2 route is now well defined within the Limits of Deviation included as Planning Controls in the HS2 Act. A description of those controls is included in paragraphs 1.8 to 1.17 of the Context Report. Of relevance is paragraph 1.10 which confirms to what extent the route may be varied and is included below for ease of reference.

1.10 The scheduled works must be constructed in the locations and to the levels relevant to each scheduled work shown on the deposited plans and sections (the 'Limits of Deviation'). The scheduled works may deviate vertically downwards from the levels shown to any extent, and may deviate upwards up to 3 metres subject to the upper limits defined for certain works such as stations, depots or shafts.

2.2 Consultation

2.2.1 Request for Information to AlignJV

A number of requests for information were made by Jacobs to AlignJV, who have provided access to drawings of the current state of design. Jacobs wish to acknowledge the co-operation of AlignJV staff in providing the required data.

2.2.2 Request for Information and Consultation with Denham Aerodrome

Similarly, Jacobs wishes to acknowledge the co-operation of the manager of Denham Aerodrome for her assistance in the provision of Denham Aerodrome traffic data, for providing additional information about aircraft accidents and incidents at and near to Denham Aerodrome, and for her time and advice during several telephone conferences and virtual meetings to discuss the aeronautical study methodology and relevant data.

2.3 Data Analysis

2.3.1 Air Traffic Movements

Denham Airport (or Aerodrome) was consulted regarding traffic movements. Jacobs was provided historic information from 1985 to 2019. In discussions with Denham Aerodrome it was agreed that the traffic movement record should be extended to match the accident record data. Therefore, it was necessary to estimate the traffic movements for years 1973 to 1984 as described in Section 3. The missing data was assumed to be at the same level as 1985 traffic movements.

It can be observed that during the 1990s Denham Aerodrome experienced a higher level of movements, then during the 2000s the traffic decreased and picked up again from the 2010s to date. This is evidenced by the 10-year rolling average which shows a smoother tendency for the aircraft movements.

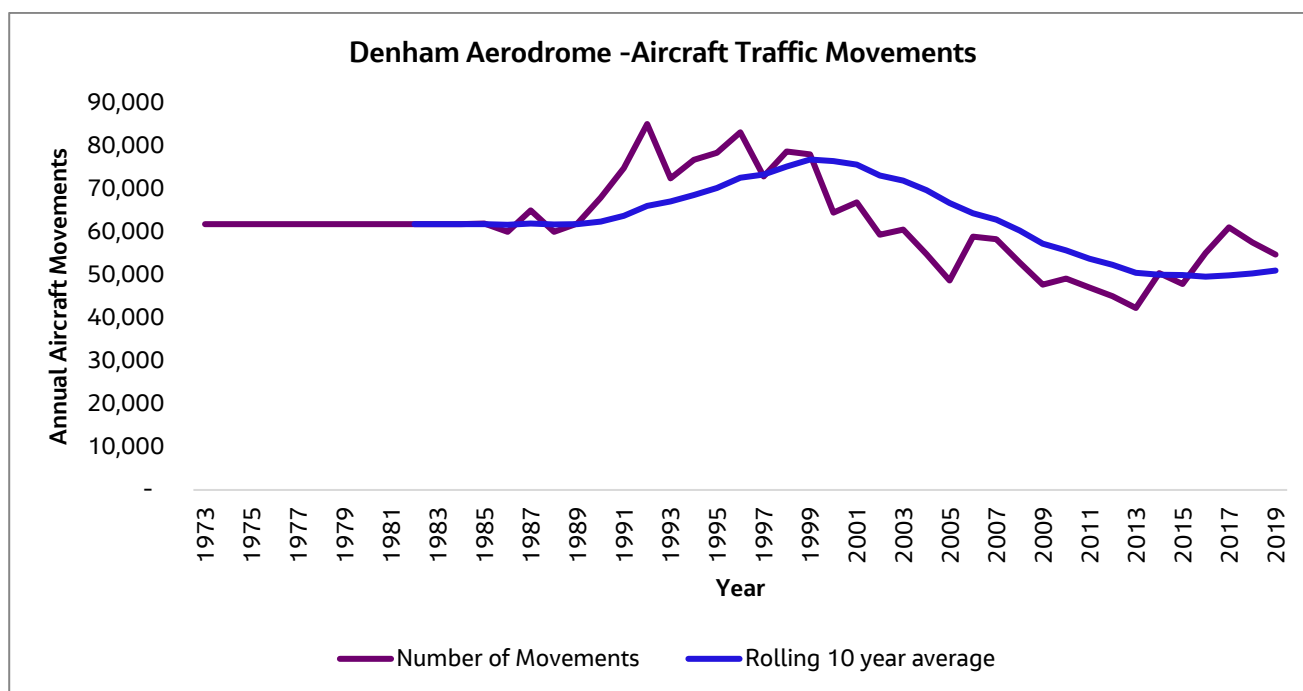


Figure 2.1: Historic Annual Aircraft Movements at Denham Aerodrome

The fact that the aerodrome experienced a higher level of activity than currently suggests that there is capacity in the airfield to grow the current activity at least to past levels. Therefore, it was agreed with Denham Aerodrome that two levels of traffic would be analysed in the present study, namely current and forecasted traffic. The current level of traffic is determined by the 10-year rolling average from 2010 to 2019. The forecasted level of traffic is determined by the maximum value from the 10-year rolling average curve. The latter was experienced between 1990 to 1999. Then, it was possible to determine the overall traffic movements experience at Denham between 1973 and 2019.

It was further assumed that 50% of the movements were take-offs and 50% were landings.

Table 2.1: Denham Traffic Scenarios

	No. Aircraft Movements
Total traffic 1973 - 2019	2,902,409
Take-off movements 1973 - 2019	1,451,205
Landing movements 1973 - 2019	1,451,204
Current Traffic	51,055 per year
Forecasted Traffic	76,853 per year

Jacobs requested Denham Aerodrome to provide details of traffic mix, aircraft types and runway utilisation percentages. Denham Aerodrome shared a study published in August 2020 for the Proposed Motorway Service Station North of Denham Airport (PL/19/2260/OA) and instructed Jacobs that information regarding Denham operations should be obtained from that document. The report outlines that the aerodrome serves a mix of single-engine and twin-engine fixed wing aircraft and helicopters. The following proportions were reported:

Table 2.2: Current Airport Traffic Mix

Aircraft Type	Percentage
Single engine fixed wing aircraft	60%
Single engine Helicopters	30%
Twin-engine helicopters	9%
Twin-engine fixed wing aircraft	1%
Total	100%

Therefore, 90% of the operations are performed by single engine aircraft with the other 10% by twin-engine aircraft. Looking only at fixed wing aircraft, 98% of the operations are performed by single engine aircraft.

The report provides a breakdown of the single engine piston fixed wing aircraft as shown in Table 2.3. It can be observed that Cessna 152, 172 and PA 28 represent 81.73% of the single engine aircraft movements. These are typical representative aircraft for training and flight schools. Denham Aerodrome reported that in 2019, approximately 20% of flights involved circuits and approximately 50% of all movements were training flights (fixed wing and helicopter). Due to the high percentage of aircraft with similar characteristics and for simplicity of analysis, it was considered reasonable to use the operational characteristics of the PA 28 aircraft to represent a typical light aircraft operating at Denham Aerodrome.

Table 2.3: Single engine piston fixed wing operations by aircraft type

Aircraft Type	Percentage
Cessna 152	38.08%
Cessna 172	10.51%
Cessna 182	4.17%
Cessna 206	0.39%
Cessna 210	0.42%
Other Cessna	0.20%
Piper PA 28	28.97%
Piper PA 32	0.57%
Piper PA 46	1.59%
Other Piper	0.24%
Cirrus SR20	0.70%
Cirrus SR22	4.33%
De Havilland DHC1	0.82%
Mooney M20	1.12%
Socata TB9	1.28%
Other types	6.61%

2.3.2 Denham Aerodrome Operations

Figure 2.2 shows two operational runways at Denham Aerodrome as declared in the Aeronautical Information Publication (AIP). The main Runway 06/24 is an asphalt runway. Runway 12/30 is a grass runway primarily used during strong crosswinds. EASA Certification Specifications and Guidance Material for Aerodromes Design (CS-ADR-DSN), 2017 outlines in its guidance material that the maximum admissible crosswind component for the type of aircraft operating at Denham Aerodrome is 10 knots (kt).

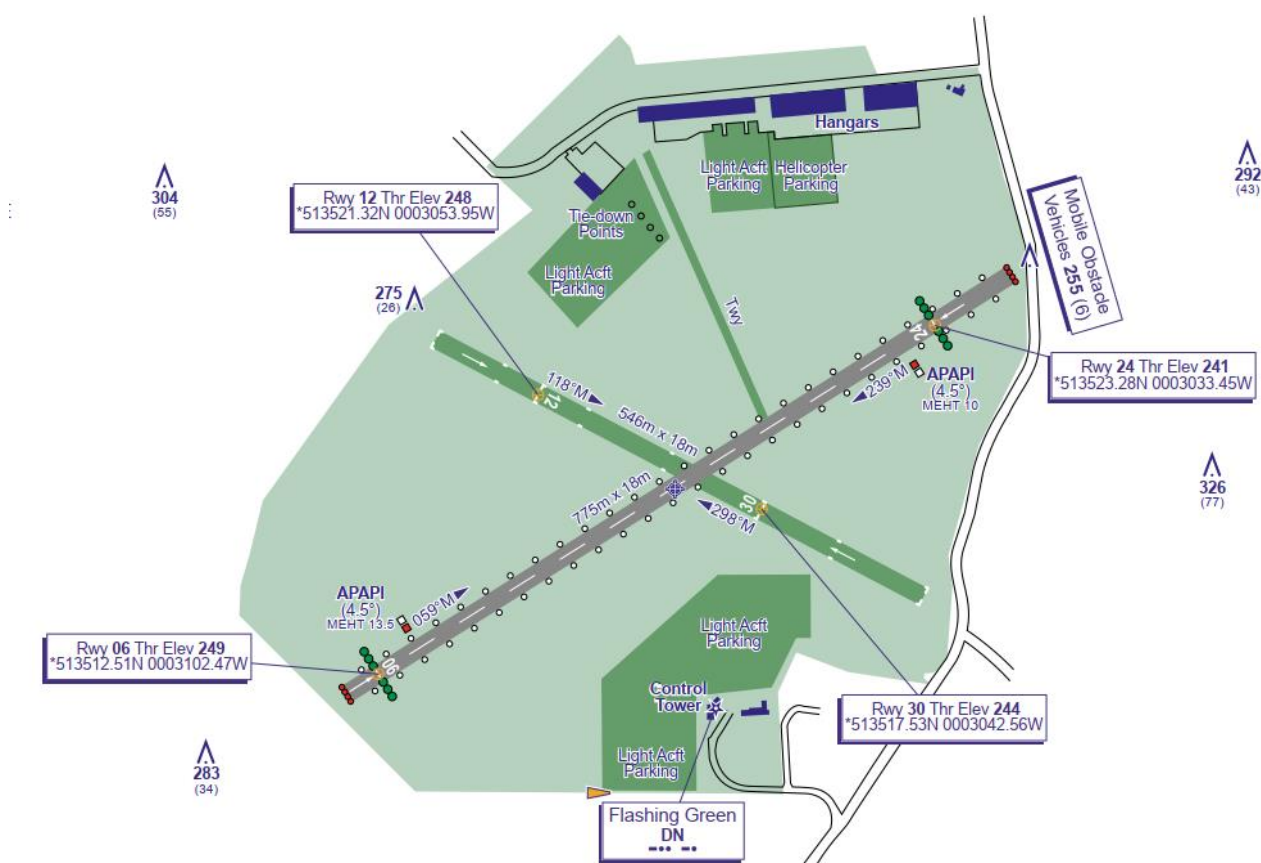


Figure 2.2: Denham Aerodrome Layout

To estimate the runway utilisation percentage, 10 years of wind data available from the Met Office for RAF Northolt in close proximity to Denham was used. The Federal Aviation Administration (FAA) wind rose generator was used to calculate the wind coverage for each runway direction. This was then used to estimate the number of movements of fixed wing aircraft for each runway direction.

Table 2.4: Runway usability percentages and estimated annual aircraft movements

Runway direction	Percentage of utilisation	Current Traffic – Fixed wing Aircraft movements per year	Forecast Traffic – Fixed wing Aircraft movements per year
Runway 24 Landings	61.2%	9,530	14,345
Runway 06 Take-offs	33.4%	5,201	7,829
Crosswind runway	5.4%	841	1266

The runway declared distances were obtained from the AIP. Figure 2.3 shows a layout where the declared distances for Runway 06/24 have been overlaid on a satellite image. It is noted that Runway 24 has a displaced threshold of 89m from the edge of the paved area. The position of the threshold is used as reference to set out the Approach Surface which will be used to assess if the HS2 infrastructure is considered an infringement to a landing on Runway 24.

Similarly, it can be observed that for a take-off on Runway 06 an aircraft has a TORA and TODA matching at 686m.

Looking at Runway 06, the figure shows that a distance of 686m is available for an aircraft to carry out a take-off (TODA). The end point of the TODA is used as reference to set out the Take-off Climb Surface which will be used to determine if HS2 infrastructure is considered an infringement to a take-off on Runway 06. Another characteristic noted from the layout is that the Runway 06 TODA end and Runway 24 threshold are at the same location.

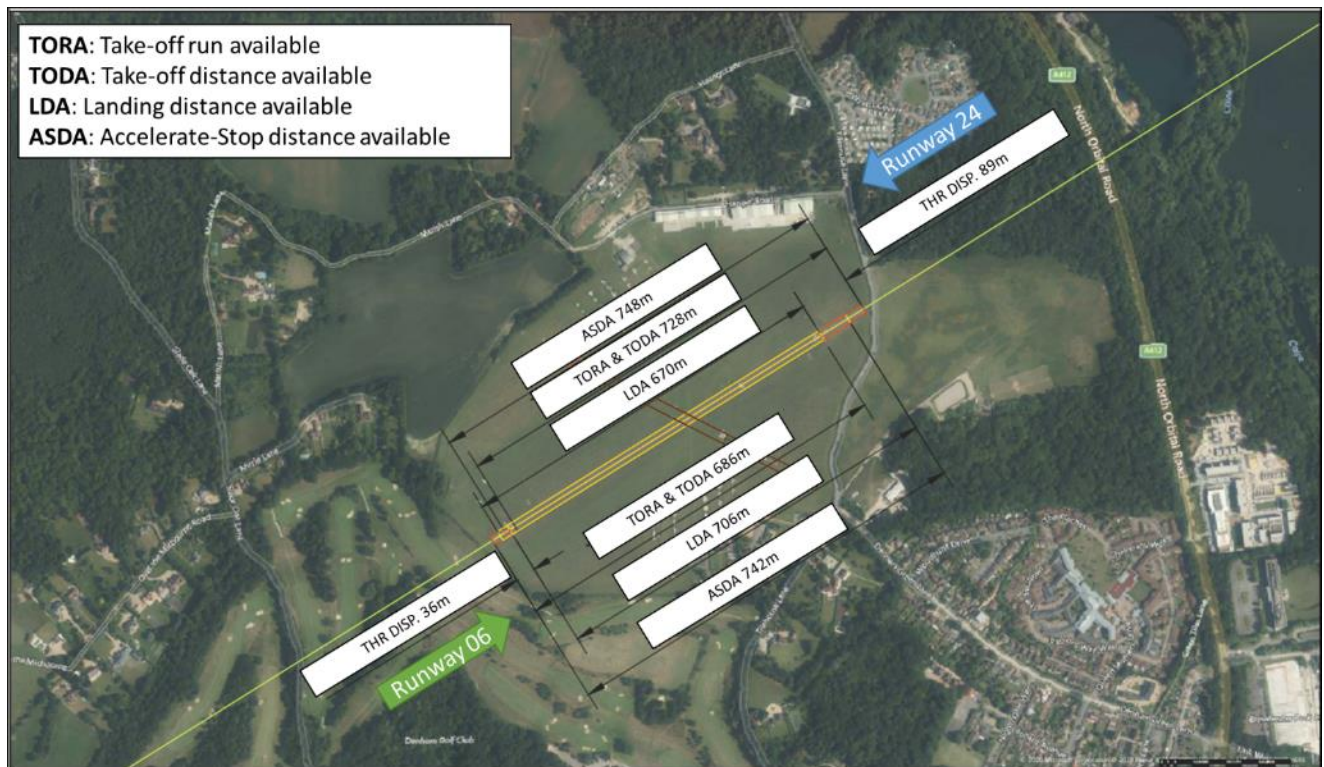


Figure 2.3: Runway 06 / 24 declared distances layout (Google Maps, 2020)

The end point of the TODA determines the distance at which an aircraft is expected to reach an altitude of 50ft above ground during a normal take-off operation. After this point, the aircraft is expected to climb at a specific gradient determined by the aircraft type and configuration selected by the pilot. To establish the climb gradient for the representative aircraft, for this assessment a conservative approach was taken and the most onerous characteristics were considered. The climb gradient was obtained from the Pilot Operating Handbook for the PA28 aircraft. The assumptions included maximum take-off weight, full throttle lean mixture at 79 KIAS¹ and the aerodrome reference temperature obtained from the AIP. These assumptions result in a 7.4% climb gradient from the end of the TODA at a height of 50ft.

Following a similar procedure for landing, the approach gradient for the representative aircraft was determined. During normal operations, a pilot would aim to touch down the wheels of the aircraft at the aiming point of the runway. The aiming point of the runway is established at 150m from the landing threshold. The glidepath selected is determined by the angle of the navigational aid (APAPI), which is provided at the airport. The APAPI angle of approach is outlined in the AIP as 4.5°, this is converted to a gradient of 7.87%. It is recognised that other approaches could be flown, and would be flown as part of pilot training, but the glideslope indicated by the APAPI is the lowest glideslope that would normally be flown and is considered appropriate for testing the impact of HS2 infrastructure on the safety of normal operations.

¹ KIAS: Knots - indicated air speed

2.3.3 HS2 Construction data

As part of the RFI responses, ALIGN JV provided the crane heights, material stockpiling, construction compound areas and work stages that would use to build the Colne Valley Viaduct.

Crane height information was provided for works along the Colne Valley Viaduct. Crane elevations provided by Align JV are shown in Figure 2.4:

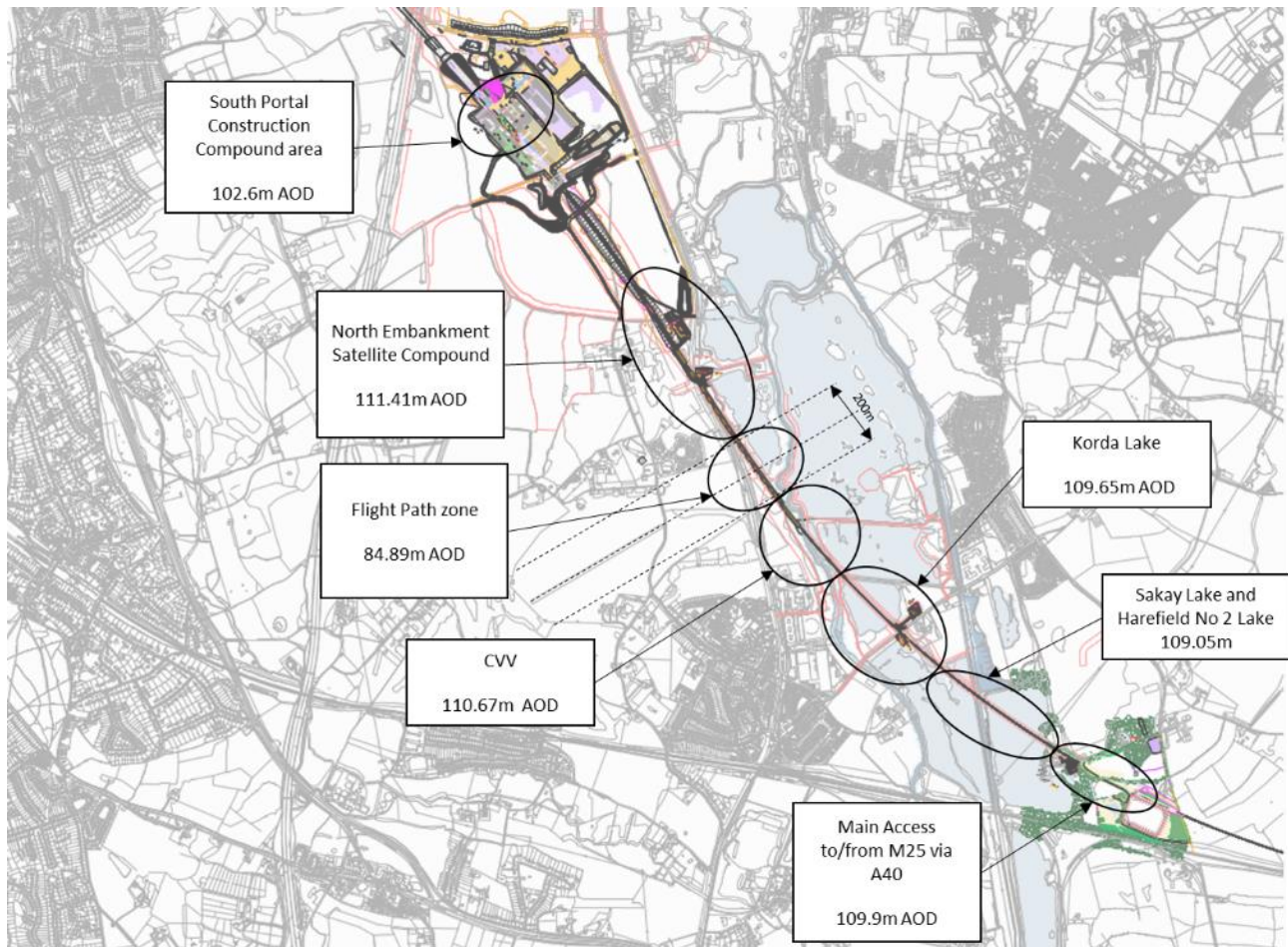


Figure 2.4: Crane Elevations provided by Align JV

More detailed information about the cranes and sequencing of works was provided for the section that would be directly under the take-off and approach paths.

The crane heights during the various construction phases were subject to change during the initial stages of this assessment study. From a potential height of 98m AOD, these were optimised to 88m AOD and later 84.89m AOD, following Jacobs' input. Jacobs and AlignJV conducted two workshops where the construction methodology was discussed and the potential impacts on aircraft operations was explained.

Following the discussions with Align JV, it became apparent that analysing the cranes alone would not accurately represent the construction methodology because cranes would not always be present in the site under the take-off and approach path. It was mentioned that cranes would be present during piling, cofferdam, pile cap and pier construction phases. However, the construction of the viaduct would be carried out using a launching girder of an elevation of 68m AOD.

The piling and cofferdam works are the first to occur; during these works one piling rig and one leader rig would be present. These would have an elevation of 68m AOD for the piling rig and 67m AOD for the leader rig. Two supporting cranes would be on site for works on every three piers.

During pile cap and pier construction, two supporting cranes would operate on site for every three piers of construction.

During the construction of the viaduct with the launching girder, there would be no cranes present on site. Subsequently, cranes of up to 68m AOD would be used to install noise barriers on the viaduct.

The construction equipment elevations and activities are summarised in Table 2.5.

Table 2.5: Expected elevation for construction equipment on site under the take-off and approach path

Construction activity	Construction equipment expected on site	Expected max elevation AOD
Piling	Crane Piling rig	84.89 m 68m
Cofferdam	Leader rig	67m
Pier cap and pier construction	Crane	84.89m
Viaduct construction	Launching girder	68m
Noise barrier installation	Crane	68m

It is expected that during the construction phase the piling rigs, cranes and then the launch girder will be in place under the take-off and approach path for about 10 months in total.

The elevation of the finished viaduct is determined as the elevation AOD of the rail line plus 7.5m for the infrastructure holding the wiring and catenary. The height of the infrastructure holding the wiring and catenary over the rail line were provided by Align JV. This is approximately 60m AOD.

2.4 Sensitivity of assumptions

Throughout this assessment report, where assumptions have had to be made, care has been taken that the assumptions are sensible, but also reasonably conservative in the direction of not understating the probability of a collision with the viaduct. The following is a list of conservative assumptions applied in this study:

1. In Section 4 the accident rate for Denham Airport is estimated from 46 years of historic records of accidents. There is evidence from the USA AOPA Air Safety Institute Joseph T. Nall reports ²that GA safety is improving with time. Any such allowance in the treatment of the statistics for Denham Airport would be subjective and applied to a very small statistical sample, which in itself does not justify a reduction in the crash rate. However, over the long term it can be expected that the industry improvement in the GA safety performance will have a beneficial effect on the accident rate at Denham Airport. No such improvement has been incorporated in the assessment.
2. All Single Engine Planes (SEP) have been assessed as piston-engined for the power system failure rate, with no reduction for the Pilatus PC 12 that has a turboprop engine which have a much lower failure rate.
3. Twin-engine fixed wing aircraft have been included in the traffic volume for calculation of recurrence periods of the probability of collision with the viaduct. That means that the twin engine aircraft traffic has been assessed at the same power system failure rate as for single-engine aircraft whereas a somewhat lower total power system failure rate would be applicable.
4. The assumption of a 100% fatality rate for collision with the viaduct does not allow for the likelihood of a non-fatal collision, as some glancing collisions may be survivable. However, such potential reduction of the fatality rate is difficult to quantify.

² Aircraft Owners and Pilots Association (AOPA). Visited on April 2021.

The 30th Joseph T. Nall Report. <https://www.aopa.org/training-and-safety/air-safety-institute/accident-analysis/joseph-t-nall-report/nall-report-figure-view?category=all&year=2018&condition=all&report=true>.

5. References to the survivability rate of forced landings are varied. An AOPA article on Emergency Landings³ quotes the fatality rate of a forced landing as roughly 10% with that from ditching at about 20%. The overall assumption of 10% used in this study is therefore conservative.
6. The viaduct has been assessed as a solid structure, from ground level up to the top of the overhead power lines. It is feasible that some crash landings may occur underneath the viaduct span in between two piers and be more likely to be survivable than a direct collision with the main structure of the viaduct itself.
7. It has been assumed that the pilot would be unable to make corrections to the glideslope down to the collision point following a power system failure in the critical zone. Jacobs agrees with the description provided by the Denham Aerodrome Manager in her oral evidence given to the Select Committee in March 2015 that there is no prospect of manoeuvring by turning away from the viaduct. There are only a few seconds available to react and if the pilot follows the correct training to maintain airspeed the glideslope will be largely pre-determined from external parameters such as the headwind component. However, the ability to steepen or flatten the glideslope to avoid a collision with the viaduct may exist in some cases.

³ Rossier, Robert N. Visited on April 2021. Emergency Landings. <https://www.aopa.org/training-and-safety/students/flighttestprep/skills/emergency-landings>

3. Obstacle Limitation Surfaces

3.1 General

To evaluate the potential impacts of HS2 infrastructure on Denham Aerodrome airspace and procedures, the relevant Obstacle Limitation Surfaces were modelled in 3D.

Two scenarios were considered for the modelling of the Obstacle Limitation Surfaces:

- HS2 construction
- HS2 operational

The requirements of the Obstacle Limitation Surfaces are determined by the type of approach (i.e. precision, non-precision, non-instrument) and the runway number code as defined by CAP 168. According to Denham's Aeronautical Information Publication (AIP), the largest take-off run available (TORA) is 728m, therefore the runway code number is 1. The type of approach is determined as non-instrument approach because instrument approach navigational aids are not provided. Additionally, Denham Aerodrome has applied for a GPS approach to be implemented, this would mean that the approach procedures would be upgraded from non-instrument to non-precision instrument approach. Therefore, the latter will also be considered in this section.

Based on CAP 168 Chapter 4, the following Obstacle Limitation Surfaces should be established for a non-instrument and non-precision instrument approach runway:

- Conical Surface;
- Inner Horizontal Surface;
- Transitional Surface;
- Approach Surface; and
- Take-off Climb Surface.

It is noted that only the surfaces that would be affected by the HS2 infrastructure have been analysed.

There are two main differences between a non-instrument and a non-precision instrument approach runway. First, the slope of the Approach Surface changes from 5% for the non-instrument to 3.33% for the non-precision instrument runway. The Inner Horizontal Surface is defined as a circle centred on the mid-point of the runway of 2,000m radius for the case of a non-instrument runway, however, it changes to a circle of 4000m radius for the non-precision instrument case.

The Obstacle Limitation Surfaces map was overlaid with the infrastructure expected during HS2 construction and when HS2 is operational. The most onerous condition is expected to be during the construction due to the use of cranes to build the viaduct.

3.2 Aerodrome Safeguarding – HS2 during construction

Align JV provided the relevant information regarding expected crane usage, material stockpiling and construction compounds. The relevant crane information is shown in Figure 2.4.

This was overlaid on the Obstacle Limitation Surfaces Map to identify areas of potential concern as shown in Figure 3.1.

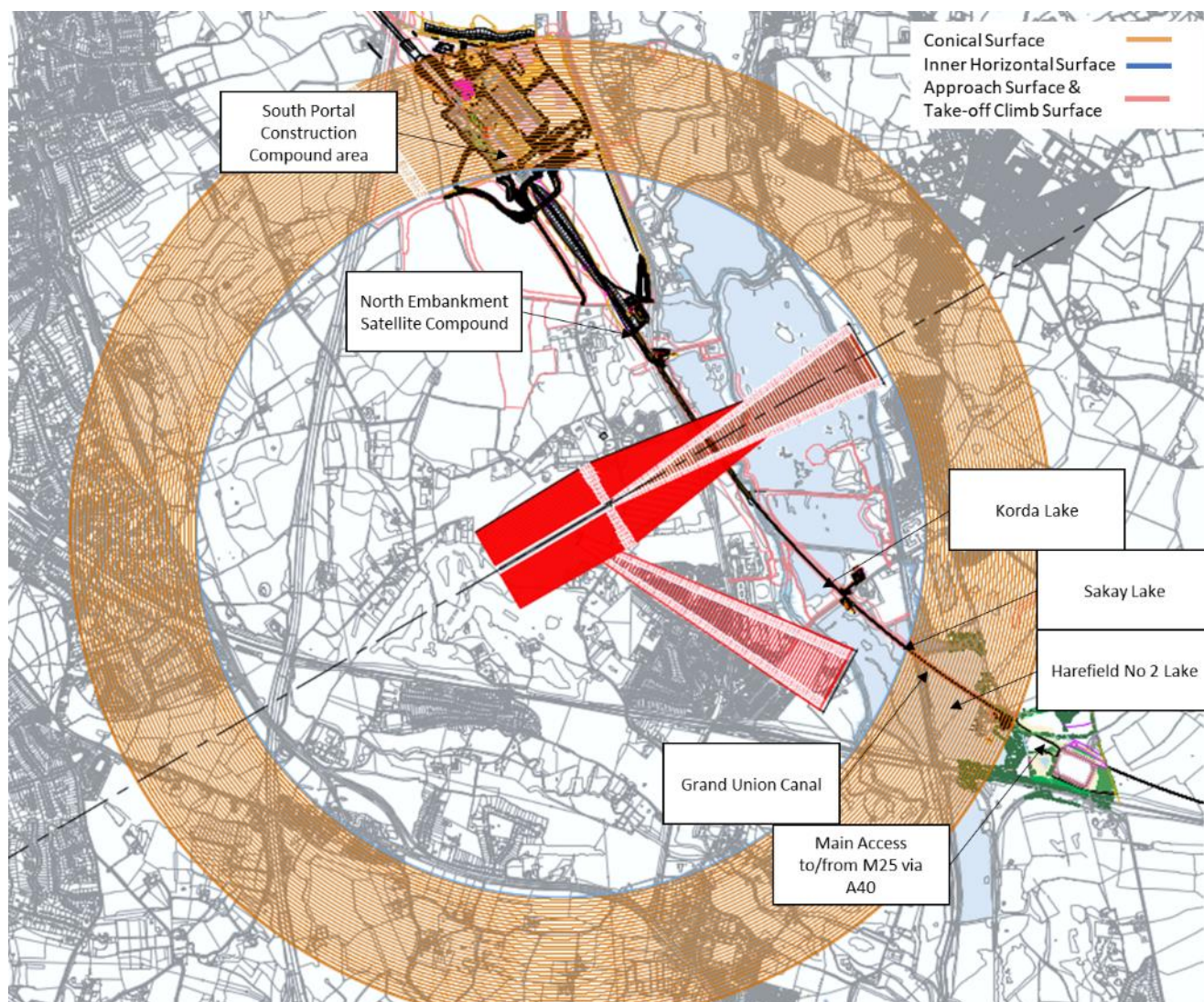


Figure 3.1: Plan View OLS map and HS2 Construction

The Approach Surface for the Non-Instrument Approach Runway 24 and Take-off Climb Surface for Runway 06 are shown in Figure 3.2. The figure illustrates that the viaduct crosses the Approach Surface/Take-off Climb Surface at an angle. The north edge is the closest point to the runway, the Approach Surface/Take-off Climb Surface would permit approximately up to 104m crane elevation AOD directly over the rail line. Therefore, the proposed crane elevation of 84.89m AOD is not considered to be an infringement. The Transitional Surface appears adjacent to the Approach Surface. It is sloping up at 20% until it reaches the Inner Horizontal Surface at 118.46m elevation AOD.

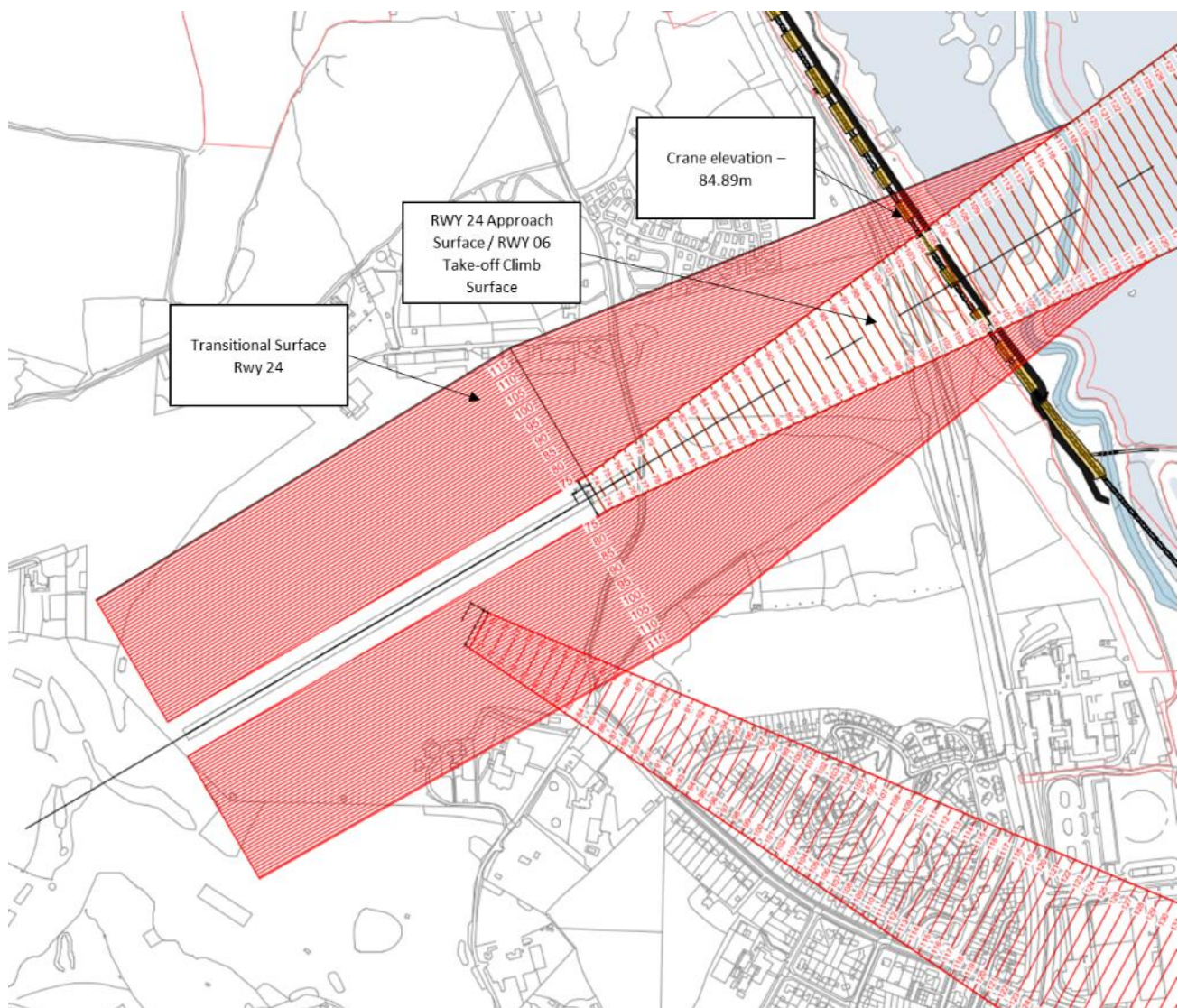


Figure 3.2: Approach Surface for Non-Instrument Approach Rwy 24 and Take-off Climb Surface for Rwy 06

For the case of a non-precision instrument approach, the Approach Surface at 3.33% is shown in Figure 3.3. The figure shows that the Approach Surface would permit an elevation of up to 94m on the north edge where the viaduct crosses the surface. Since the expected height of the crane is 84.89m AOD, it is not considered an infringement. However, obstacle lighting should still be considered.

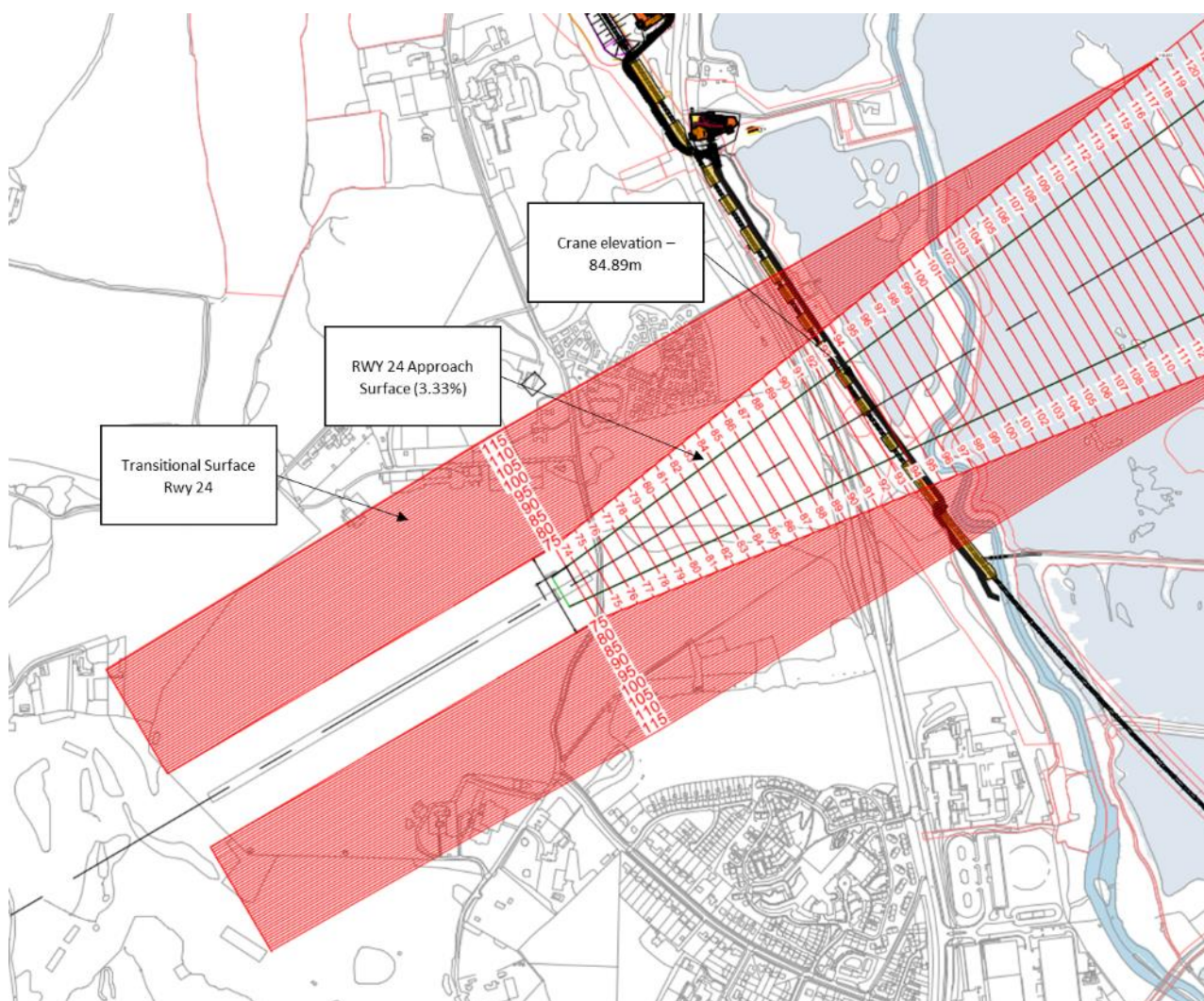


Figure 3.3: Approach Surface for Non-precision Instrument Approach Runway 24

For the Main Construction Compound and the portion of the viaduct between Harefield No. 02 Lake and the Main Access to/from M25 via A40 under the Conical Surface, the maximum expected crane elevations are 102.6m and 109.9m AOD respectively. The Conical Surface slopes upward at a 5% slope from a starting elevation of 118.46m. Consequently, it is deemed that the cranes in this section are not an infringement.

For the case of a non-precision instrument approach runway, the construction compounds and viaduct works would be under the 4000m radius Inner Horizontal Surface where the maximum permitted elevation is 118.46m. Therefore, the cranes expected for the construction activities are not deemed an infringement.

A summary of the results is shown in Table 3.1.

Table 3.1: Summary of results of Obstacle Limitation Surfaces analysis

HS2 infrastructure	Aerodrome Safeguarding Surface – Non-Instrument Runway	Aerodrome Safeguarding Surface – Non-Precision Instrument Runway	Maximum elevation of craneage	Minimum OLS permitted elevation	Mitigation measures
Main Construction Compound and Viaduct between Harefield No. Lake and Main Access to/from M25 via A40	Conical Surface	Inner Horizontal	109.9m	118.46m	Obstacle lighting
Viaduct between North Embankment and Grand Union Canal	Inner Horizontal	Inner Horizontal	111.41m	118.46m	Obstacle Lighting
Viaduct	Take-off Climb Surface Runway 06	Take-off Climb Surface Runway 06	84.89m	104m	Obstacle Lighting
Viaduct	Approach Surface Runway 24 (5%)	Approach Surface Runway 24 (3.33%)	84.89m	104m @ 5% 93m @ 3.33%	Obstacle Lighting

Additionally, it is recommended that crane operators should follow CAP 1096 to notify the UK CAA.

3.3 Aerodrome Safeguarding – HS2 operational

In the HS2 operational scenario it is assumed that HS2 has finished construction and landscaping works. The HS2 infrastructure analysed is composed of the Chiltern Tunnel South Portal, Tilehouse Lane Overbridge, Colne Valley Viaduct, trains and infrastructure holding the wiring and Catenary. The following elevations were taken from drawings 1MC05-ALJ-RT-DGA-C001-000001 to 000004 provided by Align JV. The height of the infrastructure holding the wiring and catenary over the rail line were provided by Align JV.

Table 3.2: HS2 Operational elements elevations

Element	Expected max. elevation AOD
Chiltern Tunnel South Portal	68m
Tilehouse Lane Overbridge	65m
Colne Valley Viaduct rail line	53.6m
Infrastructure holding the wiring and catenary over the rail line	+7.5m over the rail line

The same OLS analysis as outlined for HS2 Construction in Figure 2.4 was conducted for the HS2 operational scenario. It is concluded that the elements considered do not infringe the Obstacle Limitation Surfaces.

4. Quantitative Crash Probability Analysis based on Accident Records

4.1 Accident Record

The following sections of this report describe a theoretical quantitative analysis of the probability of aircraft collision with HS2 infrastructure based on accident records at Denham Aerodrome and similar aerodromes.

The Denham Aerodrome Manager has advised that an alternate method described in a Contract Research Report CRR 150/1997 carried out for the HSE should be used instead of the method described here in Sections 4.2 to 4.6. Accordingly, the calculation of the probability of collision with the proposed viaduct using CRR 150/1997 is considered in the Appendix of this report together with comments on the differences found between the results of the two methods.

As a starting point, in this Section 4, historic crash records will be analysed to obtain an initial estimate solely to demonstrate that there is a case for consideration of the risk of collision with the viaduct. However, such an empirical model based on relatively few accident records will not be appropriate on its own. For this reason, more detailed and appropriate analyses of the risk of collision with the viaduct will be carried out in Sections 5 and 6 of this report.

Flight records of accidents at Denham Aerodrome were investigated to illustrate the distribution of accidents in the vicinity of the runway ends and the airport boundary. The records were obtained from the Air Accidents Investigation Branch (AAIB) Publications.

In this report, "accident"⁴ will be used to refer to the events described in the AAIB publications, understanding that in some cases the events could be classified as an "incident"⁵.

The accident record reveals that a wide range of events can cause an accident. In most circumstances a series of events are required for accidents to develop, these can be influenced by mechanical failures, changing wind or visibility conditions, unfamiliar manoeuvres and other external factors. It is not the purpose of this section of the report to study the events that contribute to the development of an accident, but rather to quantify the probability of a potential collision with the viaduct from an accident that develops from a wide range of events based on historical evidence.

This section intends to establish the number and locations of accidents that occurred during landing and take-off operations at Denham Aerodrome. This is used to obtain a Denham Aerodrome specific crash rate. Then, additional accident records are obtained from comparable airports to create a larger dataset that would be used to quantify the probability of a collision with the viaduct when HS2 is operational and during construction. Fixed wing aircraft are considered in Section 4.2.1 and helicopter aircraft are considered in Section 4.2.2.

The accidents were split using categories for Type of Crash and the Phase of Flight immediately prior to the accident. The type of crash and phase of flight categories were defined as follows:

Type of crash definitions

- **Crash:** It was considered a crash if the aircraft impacted the ground in an uncontrolled manner
- **Controlled flight into terrain (CFIT) or Forced Landing:** A landing following typically loss of power or a mechanical failure of any part of the aircraft
- **Overrun:** A situation when an aircraft on take-off or landing roll extends beyond the end of the runway.
- **Veer-off:** A situation when an aircraft on take-off or landing roll departs the side of the runway.

⁴ **Accident.** An occurrence associated with the operation of an aircraft which, in the case of a manned aircraft, takes place between the time any person boards the aircraft with the intention of flight until such time as all such persons have disembarked, or in the case of an unmanned aircraft, takes place between the time the aircraft is ready to move with the purpose of flight until such time as it comes to rest at the end of the flight and the primary propulsion system is shut down, in which:

- a) a person is fatally or seriously injured
- b) the aircraft sustains damage or structural failure
- c) the aircraft is missing or is completely inaccessible.

⁵ **Incident.** An occurrence, other than an accident, associated with the operation of an aircraft which affects or could affect the safety of operation.

Phase of Flight definitions

- **En-route:** The en-route phase of flight is defined as that segment of flight from the termination point of a departure procedure to the origination point of an arrival procedure.
- **Landing intended to full stop:** The procedure of setting an aircraft onto the ground after flight
- **Landing: Touch part of T&G:** A landing part of a Touch and Go operation.
- **Take-off:** The procedure when an aircraft leaves the ground.
- **Take-off climb out: Missed approach or Go around.** The procedure following a missed approach or the decision to go around where the pilot applies power to gain height. The wheels never touch the ground.
- **Take-off: Go part of a T&G.** Take-off following a Touch and Go operation.
- **Take-off: Aborted Landing.** The procedure following a landing where the wheels have touched the ground however the pilot decides to abort.

4.2 AAIB Database for Denham Aerodrome

4.2.1 Fixed wing aircraft accidents

As a starting point the list of 26 accidents reported in Appendix 1 of the Landscape Planning Ltd report issued on October 2016 was used. Then, reports in the AAIB database were studied for the accidents listed and to identify other records that might not have been included. An additional 4 records were identified that were not listed in the Landscape Planning Ltd report.

Seven accidents listed in the Landscape Planning Ltd report were not available in the AAIB database. Denham Aerodrome was consulted to provide additional information about the accidents listed in the Landscape Planning and others that the aerodrome might have records. A total of 12 accident records were provided by the aerodrome.

Therefore, a total of 35 records were obtained from the AAIB database (23) and Denham Aerodrome (12).

From the 35 records, it was possible to determine the approximate location of the accidents for 26 records. From the 9 records remaining, 6 were discarded as the description suggested that the aircraft was able to return to the aerodrome and carry out a landing and 3 records' descriptions did not allow for the determination of an approximate location.

The 24 records analysed covered 46 years between 1973 to 2019. Figure 4.1 shows the number of accidents per decade, it shows that maximum number of accidents were between 1980 and 1989 with 8 accidents. The lowest number of accidents has been recorded in between 1990-1999 with 3 events. However, no definitive long-term trend is indicated and therefore the analysis will utilise all the accident records available.

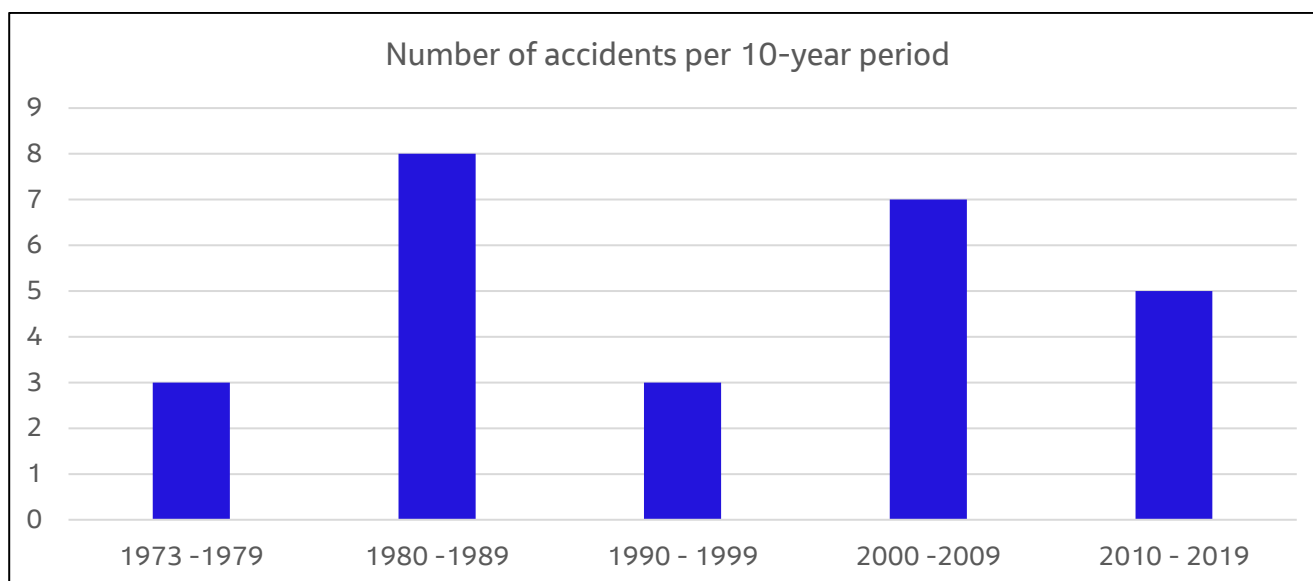


Figure 4.1: Number of accidents per 10-year period at Denham Aerodrome

The number of accidents per type of crash is shown in Table 4.1. It can be observed that 42.3% of the records were in the Crash category. The second type was CFIT or forced landing with 38.5% of the records. Runway overruns and veer-offs were less frequent at 7.7% and 11.5% respectively.

Table 4.1: Type of accident statistics

Type of Crash	No.	Percentage
CFIT or Forced Landing	10	38.5%
Crash	11	42.3%
Overrun	3	11.5%
Veer-off	2	7.7%
Total	26	100.0%

The number of records for the phase of flight immediately preceding the crash is shown in Table 4.2. It was found that 30.8% accidents occurred during a landing intended to full stop, 23.1% were take-off operations as part of a Touch and Go (T&G) and 19.2% were take-offs.

Table 4.2: Immediately preceding phase of flight statistics at Denham Aerodrome

Type of Operation	Immediately Preceding Phase of Flight	No.	Percentage
En-route	En-route	2	7.7%
Landing	Landing intended to full stop	8	30.8%
Landing	Landing: Touch part of T&G	2	7.7%
Take-off	Take-off	5	19.2%

Take-off	Take-off climb out: Missed approach or Go around	2	7.7%
Take-off	Take-off: Aborted Landing	1	3.8%
Take-off	Take-off: Go part of a T&G	6	23.1%
Total		26	100.00%

Then, if take-offs and landings are grouped into a single category it is observed that 38.5% (10) of accidents occurred during landing and 53.8% (14) occurred during take-offs.

4.2.2 Helicopter accidents

A similar approach was taken to identify accidents for helicopters. There were 2 accident records in the AAIB database. The accidents occurred in 2007 and 2015. Both accidents occurred within the airport boundary due to a dynamic rollover from hover. One was during take-off and one during landing. There were no recorded helicopter accidents at Denham Aerodrome within its local flying area, the circuits or under the landing and take-off paths. This is consistent with a statement in Section 4.5 of the Contract Research Report CRR 150/1997 carried out for the HSE (CRR 150/1997) that " Helicopter accidents on landing and take-off are confined to a small area around the helipad, extending up to 200m only from the centre of the helipad.", and that in such a situation " ... no consideration need be given to helicopter crashes ... ".

4.3 Accident Locations at Denham Aerodrome

The 26 data points were located using GIS tools around the aerodrome. The outcome is shown in Figure 4.2. The accident locations were identified as being from an immediately preceding take-off or landing. Then, the locations were measured with respect to the respective runway threshold for a landing and the respective Take-off Run Distance Available (TODA) for take-offs. Although there has not been an accident to date on the site of the proposed viaduct, the analysis of the scatter of crash locations will show that there is a probability of a crash at that location.

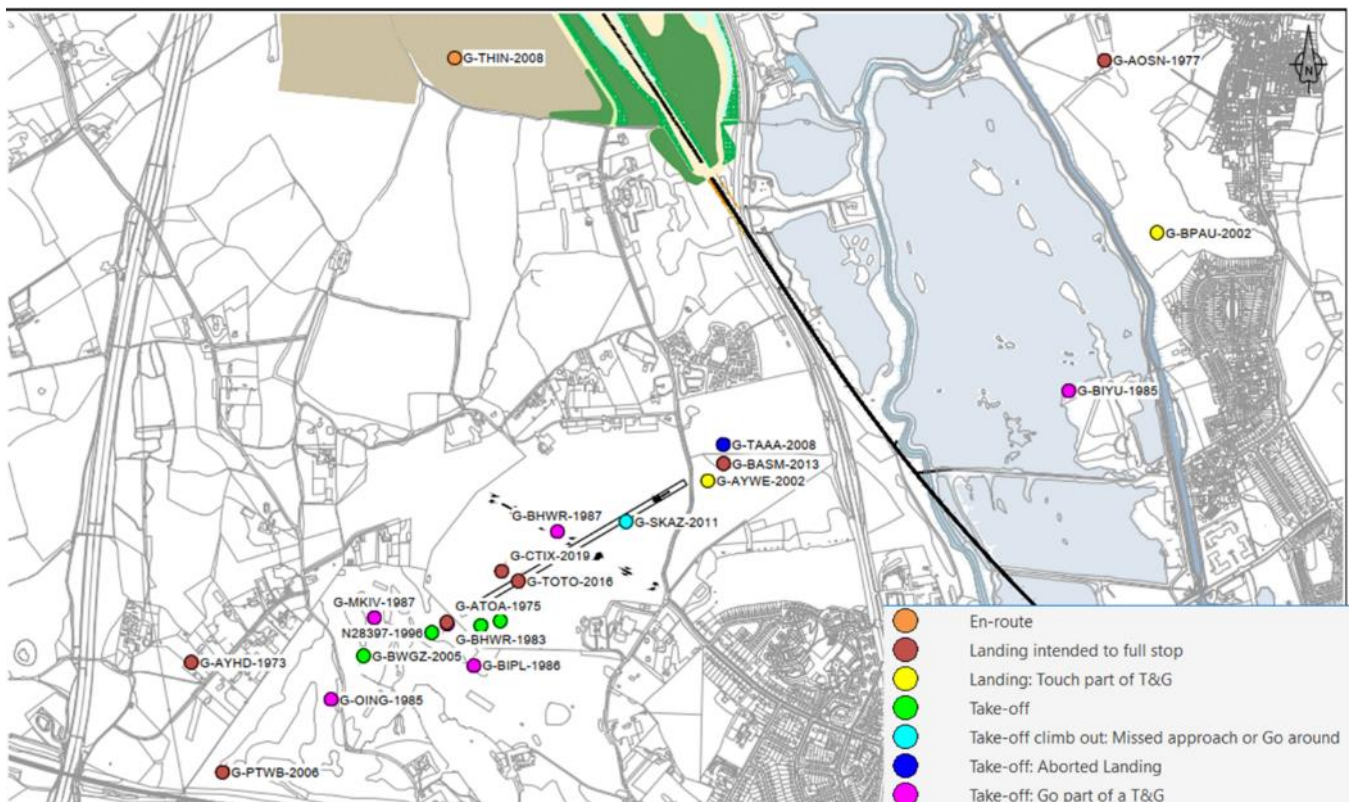
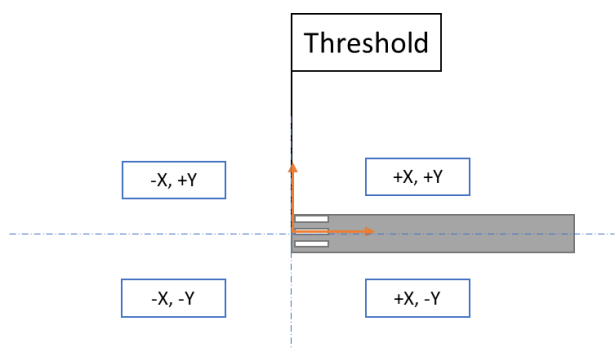


Figure 4.2: Accident locations related to Denham Aerodrome

For take-offs, the end of the TODA is taken as the reference point. This is because the TODA end represents the point that would be taken into account by all pilots' calculations for take-off and obstacle clearance to achieve 50ft clearance at the end of the TODA. For landings, the runway threshold is the recognised reference point.

The distance between the reference point and the accident location is measured in a X, Y coordinate system. The X-coordinate is measured over the extension of the centreline and the distance perpendicular to the extension of the centreline is the Y-coordinate. The convention used to define a positive measurement is defined in Figure 4.3.

Landing incident distance measure



Take-off incident distance measure

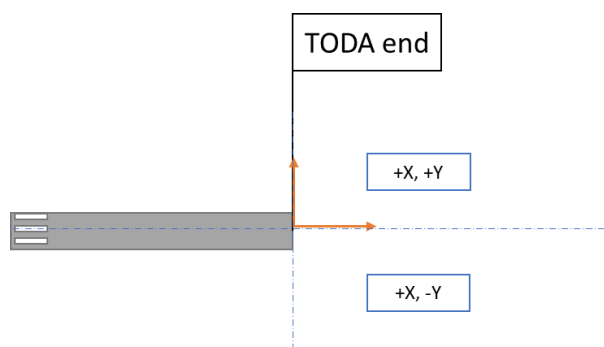


Figure 4.3: Coordinate system proposed for Landing and Take-offs accident locations.

To a reasonable degree of certainty, it can be expected that any accident that occurred to the left or to the right of the runway centreline could happen on the other side. Thus it is possible to mirror the accident locations around the X-axis. That means that an accident that happened, for example, at coordinate (300m, 200m) could also happen at (300m, -200m).

Following the sign and coordinate convention applied for this study, Figure 4.4 show the accident locations for landings measured from the runway threshold. Figure 4.5 show the accident locations for take-offs measured from the TODA end.

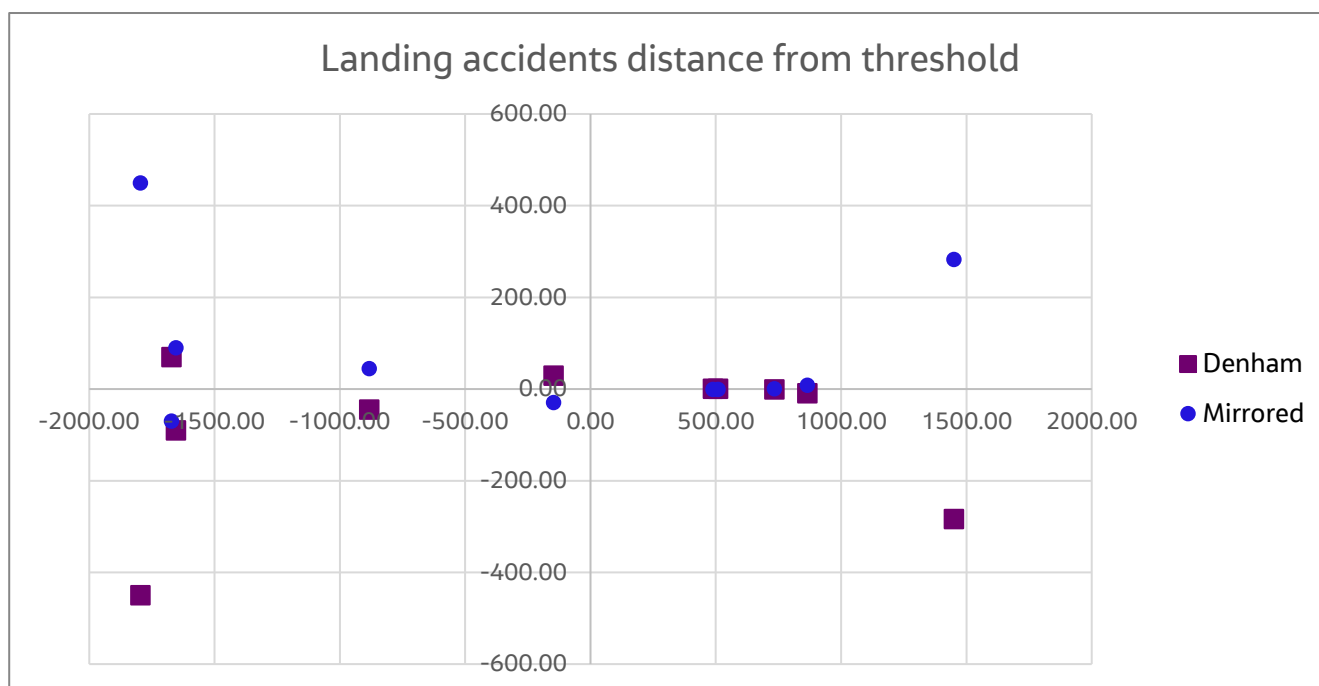


Figure 4.4: Landing accident distance from runway threshold at Denham Aerodrome

For landings, there were accidents recorded up to 1650m before the threshold and up to 1500m after the threshold. The furthest points on the Y-axis appear at approximately 450m from the runway centreline.

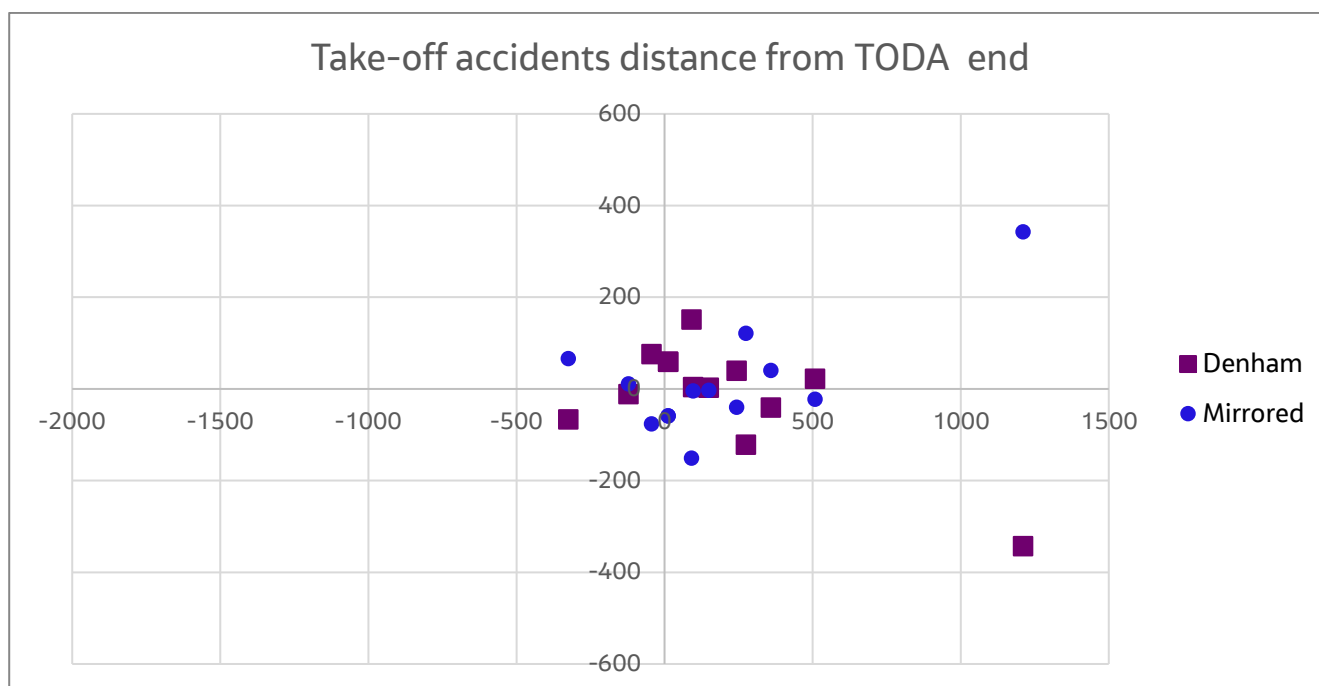


Figure 4.5. Take-off incidents distance from TODA end at Denham Aerodrome

For take-offs, the furthest points registered were 1200m from the TODA end and approximately 350m from the runway centreline. However, the distribution of incidents shows a higher density up to 500m from the TODA end.

4.4 AAIB Database analysis for other relevant records

In order to increase the amount of data to improve the validity of statistical analysis, accident records from other similar airports were obtained. This data was then measured relative to the same reference points and applying the same coordinate system convention as established for the accidents at Denham. Then, the accidents were projected as if they would have occurred at Denham Aerodrome. As a result, this allowed a larger dataset to be used to analyse the probability of aircraft accident locations being on the HS2 infrastructure.

4.4.1 Identification of comparable airports

Firstly, using the Aeronautical Information Publications (AIPs) for UK airports available from NATS website, all major UK airports which operate predominantly Regular Public Transport (RPT) flights were excluded. It was possible to obtain the runway length for all other airports. Comparable airports were selected as those which had a runway length of less than 1000m and more than 400m.

4.4.2 Extrapolation and review of accident reports

Using the shortlist of comparable airports, flight incident reports were downloaded from AAIB website. The accident reports were reviewed to identify to whether there was sufficient information to locate the accident and that the accident was comparable to those at Denham Aerodrome. That means accidents from single engine propeller aircraft in the vicinity of the aerodrome. Accidents experienced en-route, lacking sufficient geographic information or which featured operations and aircraft incomparable to Denham Aerodrome (e.g glider operations) were excluded from the study.

It was found that 54.2% accidents occurred during a landing intended to full stop and 45.8% occurred during various take-off phases.

Table 4.3: Immediately preceding phase of flight statistics at comparable airports

Type of Operation	Immediately Preceding Phase of Flight	No.	Percentage
Landing	Landing intended to full stop	13	54.2%
Take-off	Take-off	7	29.2%
Take-off	Take-off climb out: Missed approach or Go around	2	8.3%
Take-off	Take-off: Aborted Landing	1	4.2%
Take-off	Take-off: Go part of a T&G	1	4.2%
Total		24	100.00%

4.4.3 Identification of accident locations for fixed wing aircraft

The next step was to identify the approximate location of each incident in relation to the airport where the accident occurred. This was done by using the descriptions and detail included in the accident report. The location was identified on satellite mapping and measured to obtain the X, Y coordinate following the coordinate system and sign convention established in Section 4.3 on the airport where the accident occurred.

4.4.4 Assessment of fixed wing accident data

The accidents identified at Denham Aerodrome and those at other comparable airports were collated in a single database. Overall, for 50 accidents it was possible to determine the approximate location. Of these, 2 (4%) accidents were en-route, 23 (46%) were on landing and 25 (50%) were on take-off.

The locations for each of the accidents at other airports relative to landing thresholds or end of TODA at that airport were used to transfer the location of the accident to where it would have occurred if it had been at Denham Aerodrome. It is the objective of this study to determine the probability of accidents for take-offs from Runway 06 and for landings on Runway 24. Therefore, the accidents from other airports are superimposed at Denham using the Runway 06 TODA end as reference point for take-offs and threshold for Runway 24 as reference point for landing.

As such, a wider distribution of accidents was able to be graphically represented on scatter plot diagrams for take-off and landings, as can be seen in Figure 4.6 and Figure 4.7.

For landings, the accidents recorded at other UK airports were located up to 1500m before the threshold and up to 720m after the threshold. The furthest points on the Y-axis appear at approximately 70m from the runway centreline.

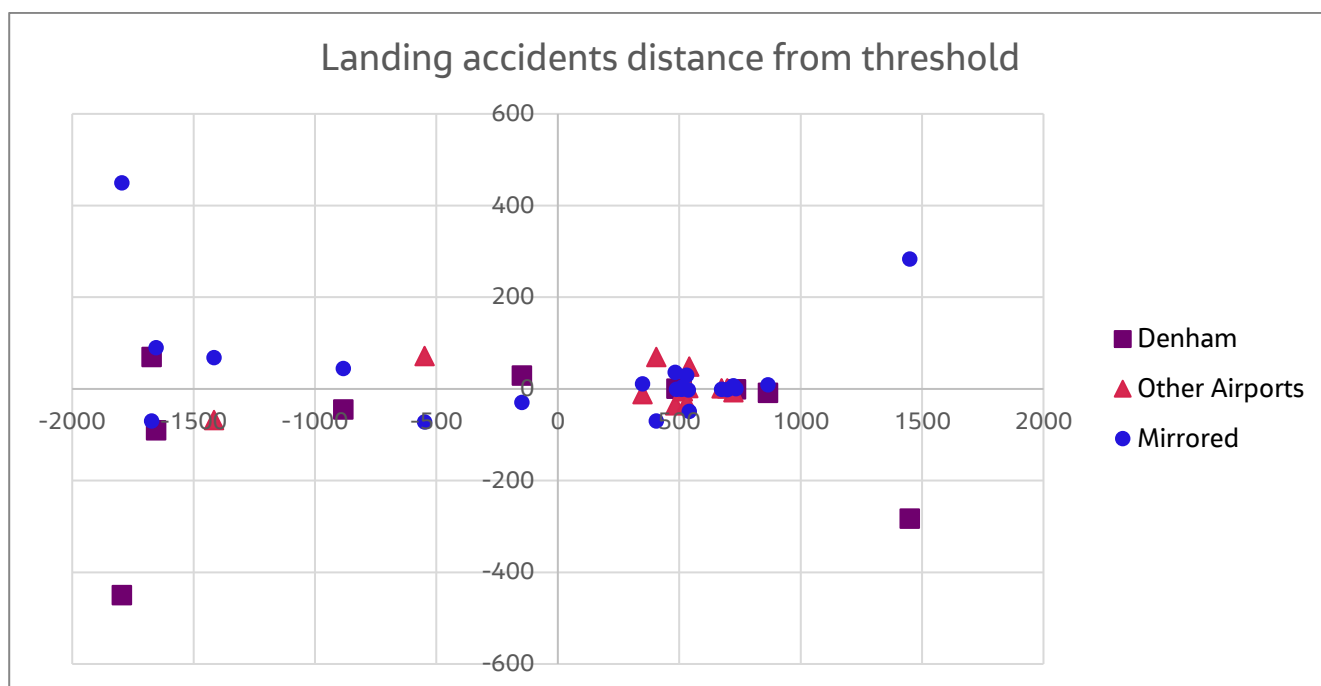


Figure 4.6: Landing accidents distance from runway threshold at Denham and Other UK Airports

For take-offs, the furthest points registered at other UK airports were approximately 900m from the TODA end and approximately 530m from the runway centreline. Similarly, as for Denham Aerodrome accidents, the distribution of accidents shows a higher density up to 500m from the TODA end.

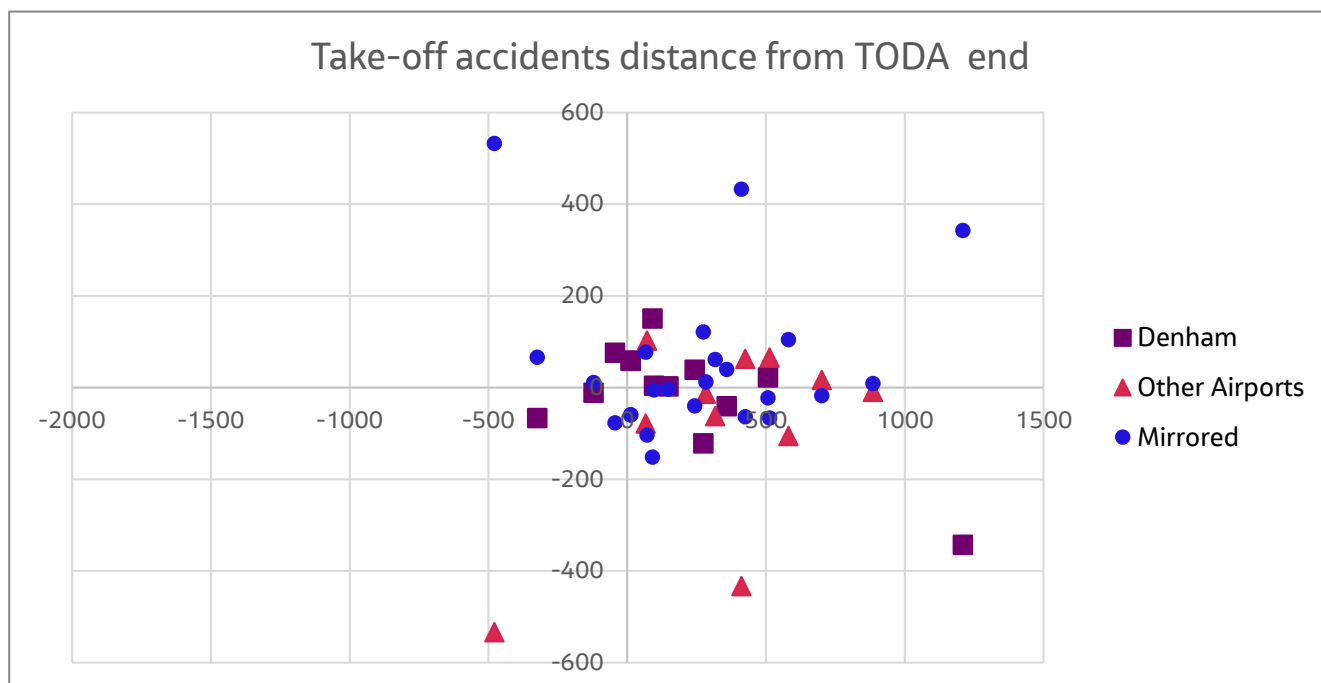


Figure 4.7: Take-off incidents distance from TODA end at Denham Aerodrome + Other UK Airports

4.4.5 Identification of accident locations and assessment of accident data for helicopters

Accident records for helicopters at other airports in the AAIB database were investigated. The accident records would be used to understand if it is common for helicopters to experience accidents off-airport but within the

approach and take-off path as the records for Denham were limited. This would determine if there's a probability of a helicopter collision with the viaduct based on past experience at similar airports.

The description of helicopter accident records available in the AAIB database provided, in general, less details to the final location of the accident when compared with the fixed wing records. It was not possible to create a crash area; however, sufficient information was revealed to determine if the accident occurred within the airport boundary or en-route.

From the comparable airports, it was possible to find 30 accident records for single engine helicopter accidents. On-airport accidents were registered in 20 occasions and the remaining 10 were En-route. En-route accidents were considered those that occurred further than 2.5Nmi from the origin or destination aerodrome. Therefore, these accidents are excluded from the analysis.

The accident records obtained suggest that helicopters crash occur most frequently during hover taxi or during landing at their designated area within the airfield boundary as shown by the breakdown of the type of crash and the Immediately Preceding Phase of Flight

Table 4.4: Denham On-Airport Helicopter Accident Records

Type of Crash	Immediately Preceding Phase of Flight			Subtotal
	Hover	Landing intended to full stop	Take-off climb out: Missed approach or Go around	
CFIT or Forced Landing	0	1	0	1
Crash	3	4	1	8
Rollover - Crash	8	2	0	10
Veer-off	0	1	0	1
Total	11	8	1	20

No records were found for accidents off-airport but within the approach or take-off path. The accident records show that helicopter operations would not be impacted by the viaduct.

4.5 Crash Location Probability

The distributions obtained for accidents at Denham and other UK Airports for landing and take-off are analysed to determine a cumulative probability distribution (CPD). The latter would be used to determine the likelihood of an aircraft collision on or overlapping onto the viaduct.

4.5.1 Methodology

Following industry literature⁶, it was determined that cumulative probability distribution functions to describe accident locations follow the following form:

$$F(x) = \frac{k}{e^{a \cdot x^b}}$$

Where k , a and b are fitting constants and x is the distance variable.

A cumulative probability distribution (CPD) was determined for the following cases:

1. Take-off accident locations for $x > 0$ distance from the TODA end.
2. Landing accident locations for $x < 0$ distance from the threshold.

⁶ Airport Cooperative Research Program, 2008. Report 03- Analysis of Aircraft Overruns and Undershoots for Runway Safety Areas.

3. Landing accident locations for $x > 0$ distance from the threshold.

The first CPD would be used to inform the probability of the potential for collision with the viaduct after a take-off on Runway 06.

The second CPD would inform the probability of the potential for collision with the viaduct on landing on Runway 24.

The third CPD would determine the probability of the potential for collision with the viaduct after an attempted landing on Runway 06.

The cumulative probability distribution models for the three cases above determined are presented in Figure 4.8, Figure 4.9 and Figure 4.10.

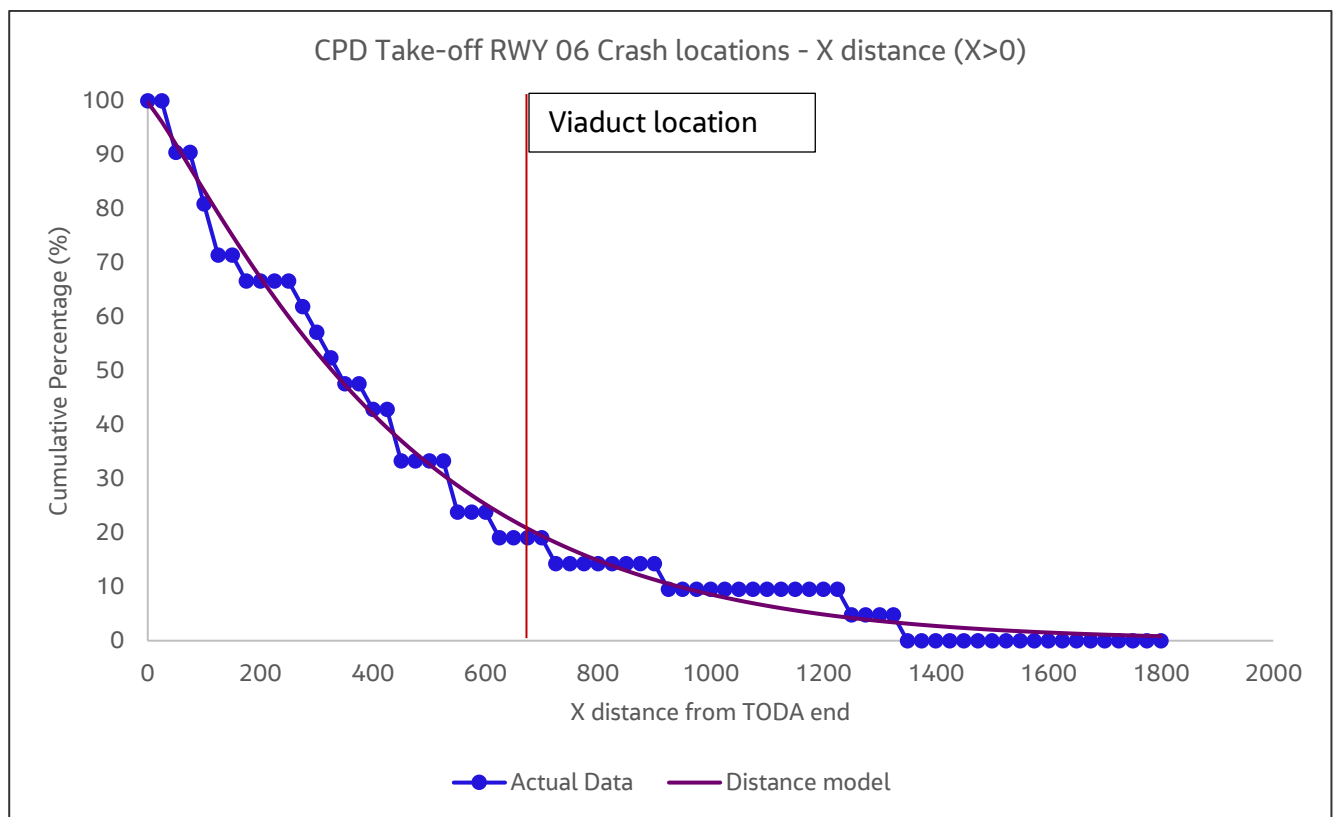


Figure 4.8: CPD take-off crash locations - X distance from TODA end

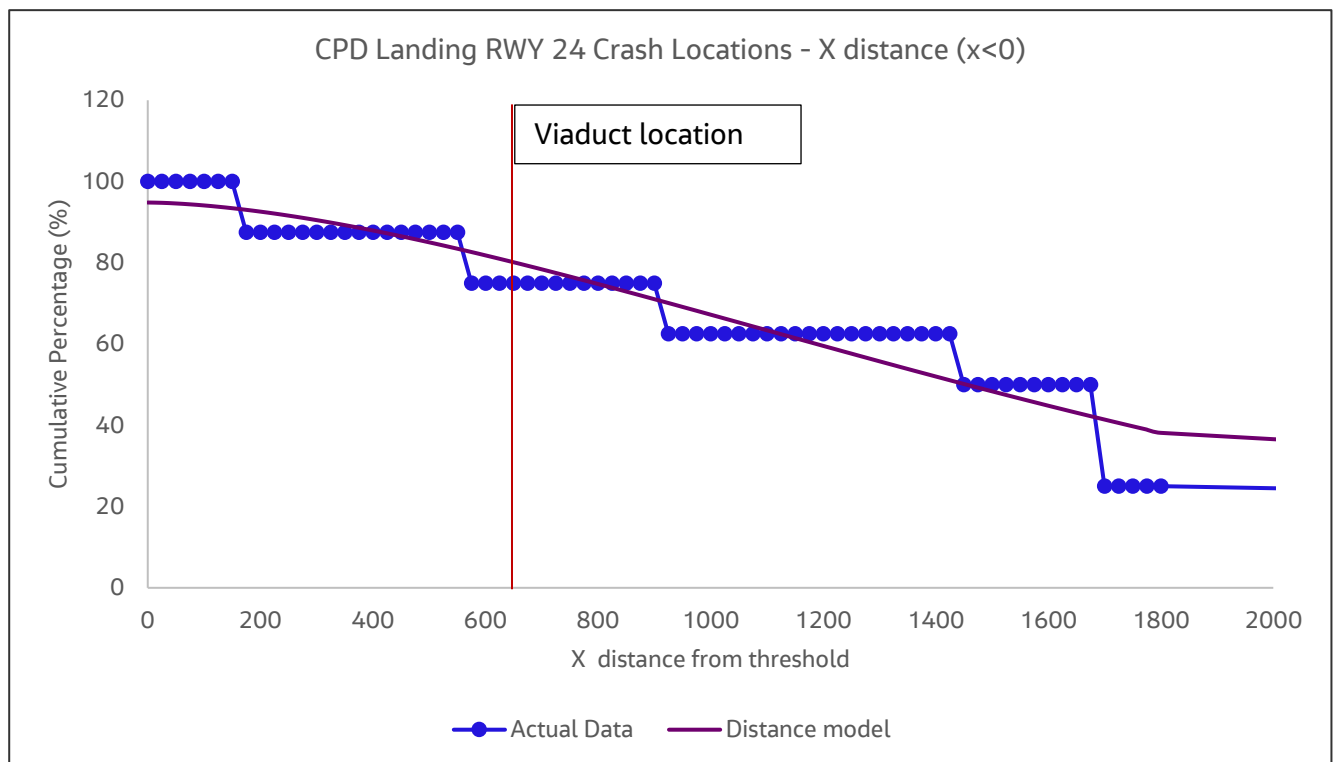


Figure 4.9: CPD Landing Crash Locations - X distance (x<0)

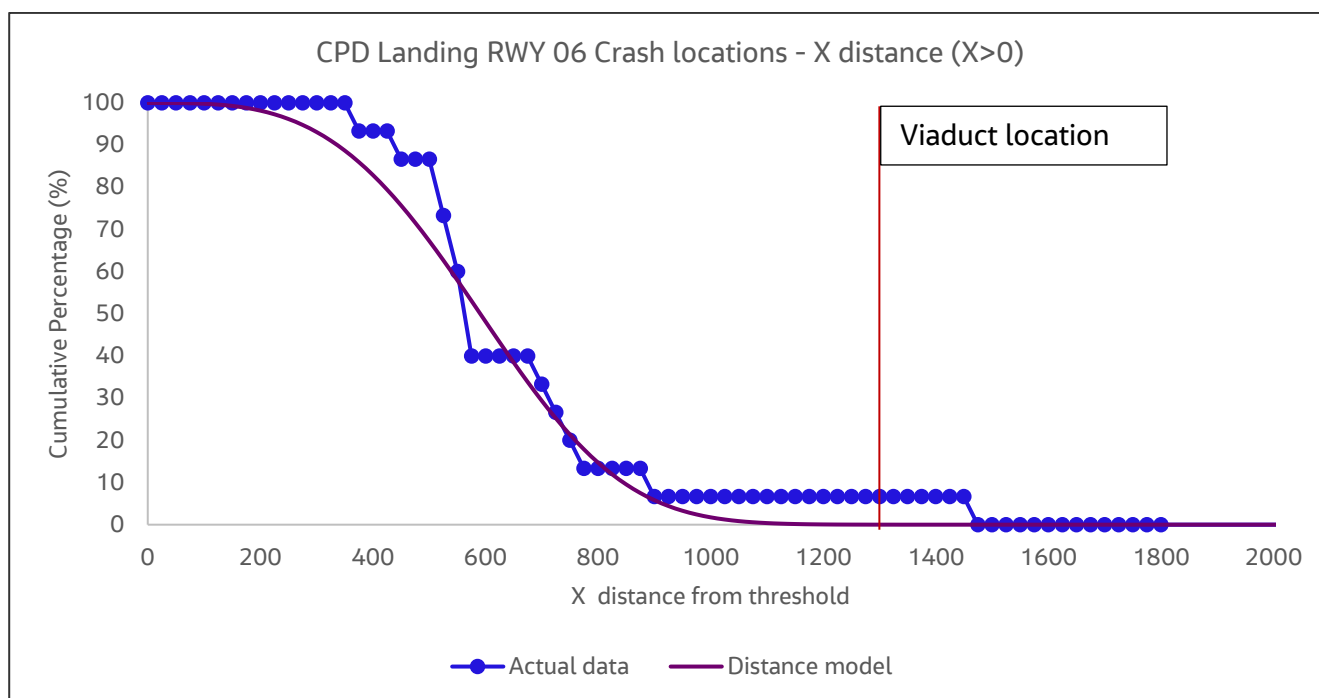


Figure 4.10: CPD Landing Crash locations - X distance ($X > 0$)

In order to estimate the probability of an accident in each CPD it is necessary to establish the location of the viaduct with respect to the TODA end for Runway 06 and threshold for Runway 24 and Runway 06. Also, the size of the crash zone for a typical light aircraft crash if it would collide with the viaduct is important. It is noted that the location of Runway 24 threshold and Runway 06 TODA end are matching. Therefore, the location of the viaduct for the assessment of take-off on Runway 06 and landing on Runway 24 is the same.

Consideration was given to the location and the alignment of the viaduct with respect to Runway 06/24. It is considered that the Take-off Climb Surface (TOCS) and Approach Surface (AS) are representative of the area expected for an aircraft to carry out take-offs and landings.

In Figure 4.11 the position and alignment of the viaduct is shown with respect to the Runway 06/24. It can be observed that the viaduct crosses the Take-off Climb Surface and Approach Surface almost at a perpendicular angle, therefore, the distance between the runway threshold and the western edge of the viaduct can be approximated to that of the extension of the runway centreline to be used in the assessment. It was found the western edge of the viaduct is located at 650m from Runway 24 threshold and the end of Runway 06 TODA and 1300m from Runway 06 threshold.

Additionally, from Figure 4.6 and Figure 4.7 it can be observed that the crash locations at an X value of 650m are contained well within 200m of the runway centreline. Therefore, it is reasonable to expect that any crash for take-off and landing will be contained within the TOCS and AS width.

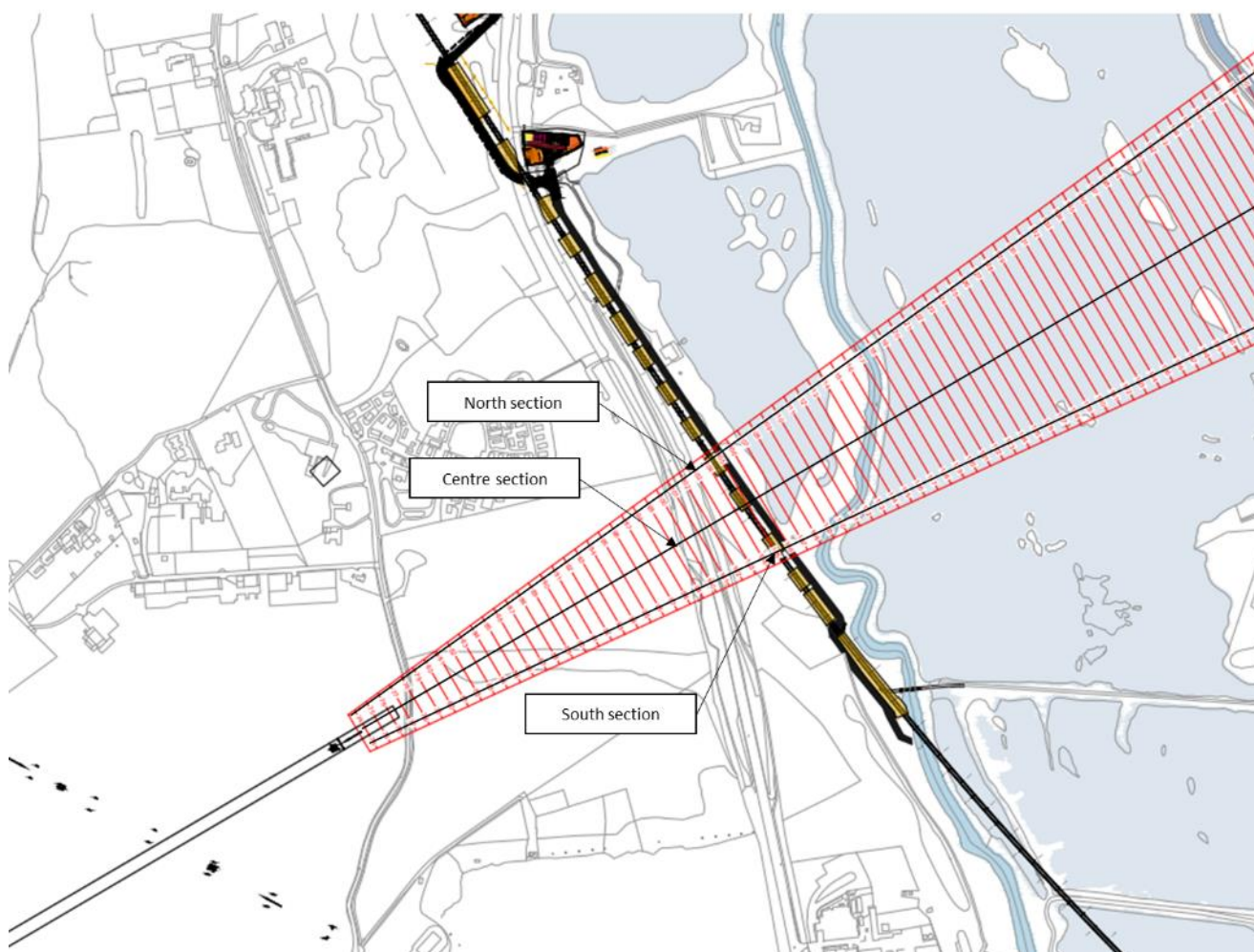


Figure 4.11. Location of the viaduct

The area of a typical light aircraft crash with significant destruction on the ground is assumed as an area of 0.05 hectare as used in work on third party risk near airports carried out by NATS, 1997. Then, it was considered that the size of the crash area with a likely fatal outcome involving interaction of the crash area with the viaduct would be the one-third of aircraft destroyed area on either side of the viaduct plus the width of the viaduct. This allows both for the area of a crash into the face of the viaduct and as a proxy for the crash area shadowed by the viaduct, but which would be a crash on the viaduct once that is constructed. As in third party risk assessment near airports, the typical shape of the destroyed area is taken to be circular. It is determined that it would have a diameter of 25.2m. The viaduct has a width of 13.4m. Therefore, the length of the crash area is two-thirds of 25.2m plus 13.4m which totals a distance of 30.2m.

The probability of a single aircraft movement crashing with the viaduct is the difference between the cumulative percentage values over the length of the total crash area calculated above as 30.2m. This is illustrated in Figure 4.12. The probability of a single aircraft movement would be the difference between CP1 and CP2. This process was repeated for the 3 cases, namely Runway 06 take-off, Runway 24 landing and Runway 06 landing.

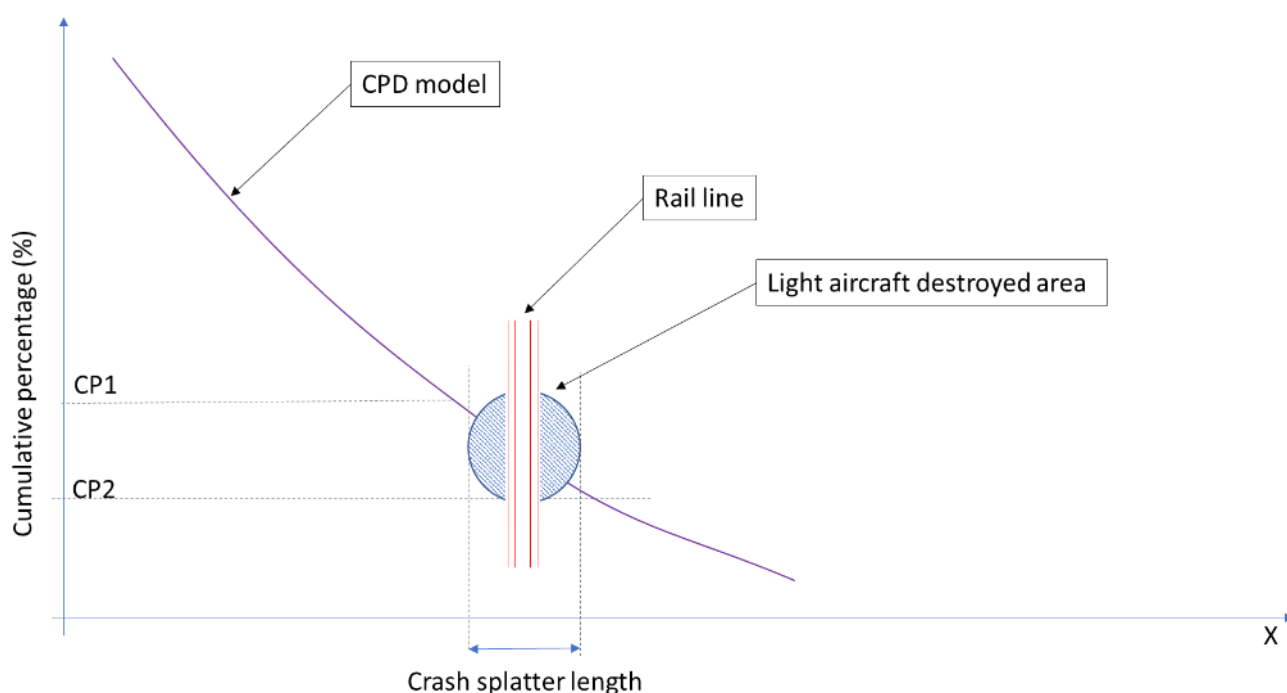


Figure 4.12: Crash location involving viaduct probability determination

Carrying out the operations set out above, the results shown in Table 4.5 are obtained. These results are the probability of a crash, once it occurs, being located such that it involves the viaduct.

Table 4.5: Single crash probability of location on viaduct results

Scenarios	Probability of a single Crash Occurrence being on viaduct
Rwy 06 take-off	1.73E-02
Rwy 24 landing	1.04E-02
Rwy 06 landing	8.17E-05

From Figure 4.10, It is noted that the position of the viaduct for the case of a long landing on Runway 06 falls on extremely low values of the cumulative percentage. At the position of the viaduct, the model is approaching asymptotically to zero. Although mathematically it is possible to calculate a probability of a crash in this area, the probability is shown to be relatively low, namely 100 times smaller than that of a Runway 06 and Runway 24. The calculated risk from a Runway 06 landing crash being on the viaduct is excluded from the combined effect of the viaduct on the runway operations as it possibly a false result from using statistical quantification at extremes of asymptotic trends and in any case is two orders of magnitude lower than for the Runway 06 take-off and the Runway 24 landing analysis.

4.5.2 Crash rates for collision with the viaduct at Denham Aerodrome

The crash rates for collision with the viaduct are now used to calculate the recurrence period and the probability of an aircraft accident with the viaduct at Denham Aerodrome for a Runway 06 take-off and a Runway 24 landing.

Table 4.6 displays the crash rates obtained for take-off and landing by applying the probability of an aircraft experiencing an accident at Denham and the probability of a single crash movement involving the viaduct. The

probability of an aircraft experiencing an accident is based on the historic movements and the number of accidents at Denham. The probability of 2.74×10^{-07} for a take-off movement is of the same order of magnitude as that for a landing movement at 1.17×10^{-07} , and in quantitative risk analysis work would be termed similar. No firm conclusions can be drawn from the difference due to the limited number of historic aircraft crashes available for the analysis.

Table 4.6: Crash rates for an aircraft collision with the viaduct

Total Aircraft movements 1973 - 2019	No of Fixed Wing takeoffs or landings at 61% x 50% each	No of Accidents		Crash Rate per Fixed Wing movement		Probability of crash being in the length of a viaduct crash zone		Combined Probability for a single movement	
		Take-off as TO	Landing as L	TO	L	TO	L	TO	L
2,902,409	885,235	14	10	1.58E-05	1.13E-05	1.73E-02	1.04E-02	2.74E-07	1.17E-07

4.6 Risk Summary of Crash location on Viaduct

The following tables illustrate the output of the probability analysis: they contain the likelihood of an aircraft crash location on or immediately adjacent to the viaduct for a take-off from Runway 06 and a landing on Runway 24 and the recurrence period of such event. An overall recurrence period is provided. The recurrence period is directly dependent on the level of traffic at the aerodrome; thus, results have been split between current and forecast traffic.

Table 4.7: Crash probability results for current traffic

Runway	Fixed Wing Takeoff Movements p.a.	Fixed Wing Landing Movements p.a.	Single Movement Probability	Recurrence Period in years	Probability in one year	
Runway 06	5201	N/A	2.74E-07	703	1.42E-03	
Runway 24	N/A	9530	1.17E-07	893	1.12E-03	
Combined Probability						2.54E-03
Combined Recurrence Period (years)						393

Table 4.8: Crash probability results for forecast traffic

Runway	Fixed Wing Takeoff Movements p.a.	Fixed Wing Landing Movements p.a.	Single Movement Probability	Recurrence Period in years	Probability in one year	
Runway 06	7829	N/A	2.74E-07	467	2.14E-03	
Runway 24	N/A	14345	1.17E-07	593	1.69E-03	
Combined Probability						3.83E-03
Combined Recurrence Period (years)						261

The recurrence period in the existing traffic case of 1 in 393 years is of the same order of magnitude as the recurrence periods for a fatal outcome from engine failure of 1 in 540 years described in Sections 5 and 6. The slightly higher probability from the analysis of accident records is expected. This would be because the accident record includes accidents from triggers other than only engine failure. It should also be noted that there are a relatively small number of accidents that have occurred and are detailed in the available database, so an exact match to a theoretical analysis would be unlikely. However, this result from actual accident data for Denham Aerodrome being within the same order of magnitude as for the theoretical analysis supports the validity of the more theoretical calculations described in Sections 5 and 6.

The Jacobs analysis above of the historic accident records is based on relatively few accident records. It is not considered appropriate for use on its own to predict the future probability of collision with the proposed viaduct. Jacobs do not authorise or endorse any such use by others. Jacobs use the historic crash records as an initial estimate only and solely to demonstrate that there is a case for consideration of the risk of collision with the proposed viaduct. Jacobs carry out a more detailed and appropriate analysis of the risk of collision with the viaduct in Sections 5 and 6 of this report.

5. Runway 06 Take-off Collision Risk

This section deals in detail with the part of the proposed Colne Valley viaduct situated under the Take-Off Climb Surface on Runway 06 which presents a hazard to aircraft suffering an engine failure. The risk to aircraft currently, when HS2 is under construction and when HS2 is in operation is considered and described in this section. In this section, 3D geometry of the viaduct, topography, trees, the construction methods, flight paths, headwind and glide slopes are all considered. The accident record supports the view that the probability and risk relate to fixed wing movements.

5.1 Helicopter risk

It is known that helicopters are manoeuvrable during autorotation after engine failure. Therefore, the additional risk to helicopter take-offs emanating from the proposed Colne Valley viaduct is negligible and not quantifiable. This is because a helicopter initiating a Runway 06 take-off near the Runway 06 threshold markings at the southwest end of the runway would be able to reach circuit height (approximately 650ft AGL to a maximum of 750 ft AGL) before overflying the viaduct, unlike fixed wing aircraft which overfly the viaduct at approximately 250ft. The extra height relative to a fixed wing aircraft on take-off will give the helicopter pilot the opportunity to manoeuvre during autorotation after engine failure and avoid the viaduct. Additionally, and as noted in Section 4.2.2 and in Section 4.5 of the CRR 150/1997 in such a situation there is no need to consider helicopter crashes. Other than recommending that helicopters should initiate a Runway 06 take-off from the southwest end of the runway, helicopters are not considered further in this part of the risk assessment which is carried out for fixed wing aircraft only.

5.2 Assessment Method

The previous Risk Assessment study that is reviewed in Section 2.1 of this report refers to the existence of trees adjacent to the viaduct, stating that *"In the event of a collision these trees are likely to be impacted prior to HS2 infrastructure"* and does not show a change in the risk profile with the HS2 infrastructure in place, the risk assessment matrix noting, *"Trees near north-eastern boundary likely to be impacted prior to reaching viaduct"*.

However, whereas this would be the case for an overrun off the end of the runway, that conclusion does not deal properly with the case for an aircraft suffering an engine failure in flight and having no option but to attempt a forced landing in the vicinity of the viaduct.

As can be seen from Figure 5.2, Figure 5.3 and Figure 5.4, there is a critical zone (shown as orange hatching in Figure 5.1) during the climb after take-off when an engine failure could leave the aircraft with no option but to glide down to an inevitable collision with the viaduct.



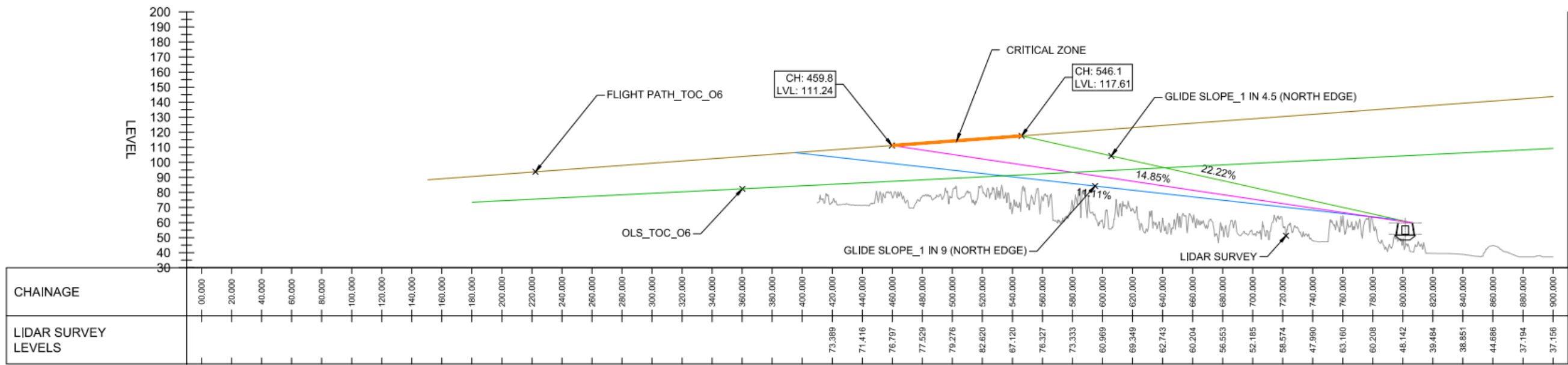


Figure 5.2: Critical Zone After Take Off - Section shown on Northern Edge of TOCS

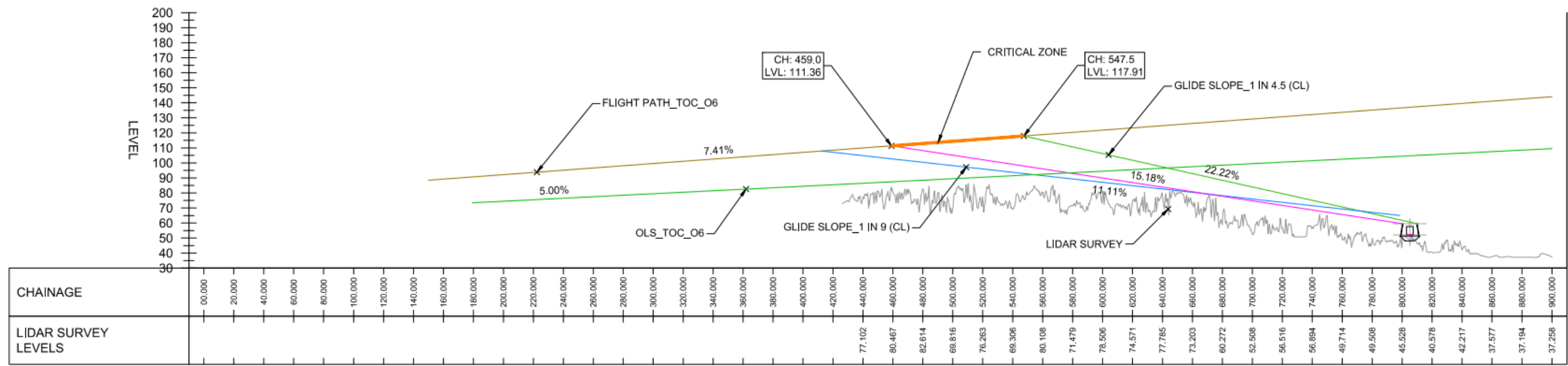


Figure 5.3: Critical Zone After Take Off - Section shown on extension of runway centreline

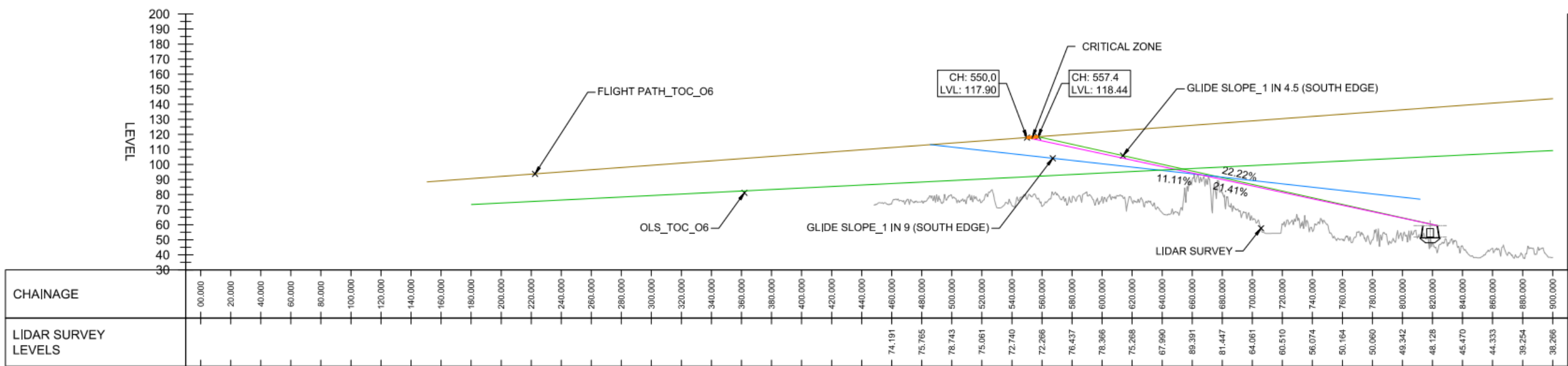


Figure 5.4: Critical Zone After Take Off - Section shown on Southern Edge of TOCS

5.2.1 Survivability rates considered

It is recognised that forced landings by single engine aircraft into treetops or ditching have a high survivability rate of about 90%. This is based on expert advice from the manager of Denham Aerodrome, supported by evidence she provided based on publication by AOPA (USA) and by Aviation Safety. Jacobs have also referenced FAA documentation⁷ that supports the view that forced landings into scrub or treetops are often survivable for small single engine aircraft. The cabin area of a typical single engine GA aircraft is designed to provide protection to the occupants for up to a 9G deceleration. Forced landings into treetops and onto flat water can be made with less than 9G. A small aircraft landing in treetops at 70 Knots ground speed, decelerating at say 4.5G would come to a stop within 15 metres. There has been an incident of such a survivable tree top landing into the woods under the Denham Runway 06 take-off path.

In contrast a forced landing that collides with the HS2 viaduct is likely to be fatal. To quantify the change in the risk of a fatal accident after an engine failure to a Single Engine Plane (SEP) aircraft on take-off, the following method has been used.

5.2.2 Existing time of exposure to landing on treetops or ditching on the lakes

Firstly, it is noted that the Runway 06 take-off path has its initial portion over woodland, a major road and lakes. As such it is an accepted risk by pilots of SEPs that an engine failure during that portion of the take-off will result in a forced landing that will result in damage to the aircraft, quite probably result in injuries to the persons on board and possibly result in one or more fatalities. A forced landing into such terrain by single engine General Aviation (GA) aircraft is generally considered to have a high survivability. It has been quoted by the Denham Aerodrome manager as about a 90% survivability. That also means a 10% likelihood of a fatal outcome.

The portion of the take-off climb when the aircraft is exposed to such a fatal hazard is taken as that portion between leaving the opportunity to carry out a forced landing within the aerodrome or the nearest available field adjacent to the aerodrome boundary, and further out in the climb when the aircraft could reach suitable land beyond the lakes for a survivable forced landing. The distance of this portion covering the length of Zones A,B,C and D in Figure 5.5 is approximately 938m. At an aircraft speed of 63KIAS and accounting for an average headwind of 5.25 kts, the aircraft is exposed for 31.6 seconds to a 10% likelihood of a fatal outcome in the existing scenario. This can also be expressed as equivalent to 3.16 seconds of exposure to 100% fatal outcome for the existing scenario. Factoring in the probability of an engine failure will give the probability in the existing condition of a fatal outcome.

⁷ FAA, 2016. Airplane Flying handbook (FAA – H – 8083-3B). U.S. Department of Transportation. Federal Aviation Administration.

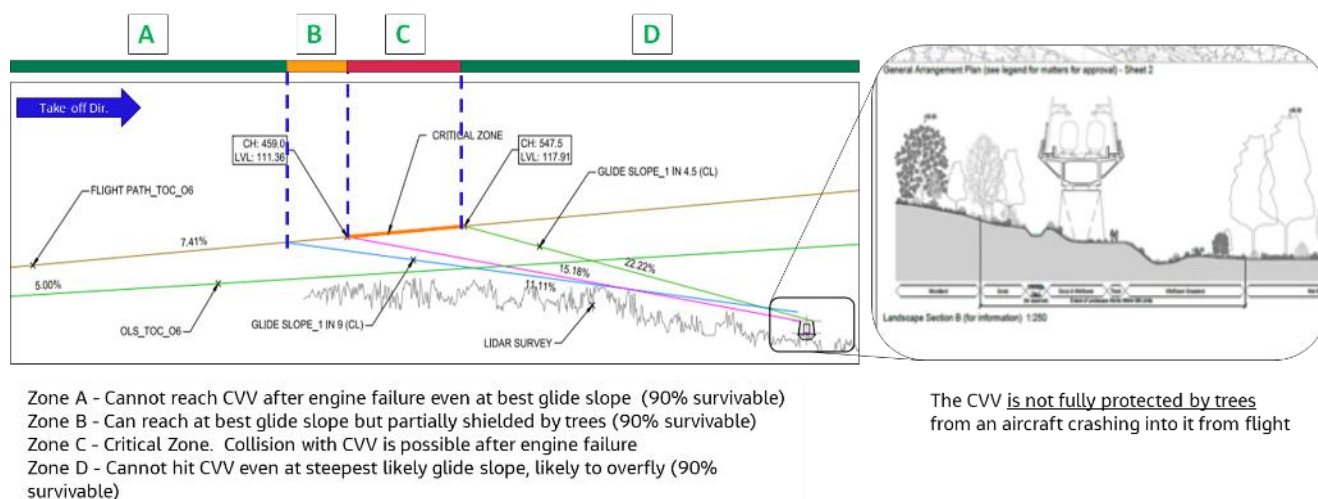


Figure 5.5: Take-off climb path zones of risk of crashing onto the HS2 viaduct.

Looking now at the case with the HS2 infrastructure in place, a range of glide slopes which the aircraft will be committed to after an engine failure shows that there is a portion of the take-off climb during which there would be a high probability of a fatal collision with the HS2 infrastructure (Zone C in Figure 5.5).

Before describing the time of exposure in the Critical Zone it is necessary to consider the aircraft glide slopes to be analysed in the case of engine failure.

5.2.3 GA aircraft forced landing glide slopes for engine failure

To examine the likelihood of an engine failure on take-off leading to a forced landing in the vicinity of the viaduct, the take-off climb rate of a PA28 aircraft was taken as representative of many of the single engine GA aircraft operating out of Denham Aerodrome. The climb rate for the best angle of climb was taken at a climb rate in still air of 7.4%. The climb out profile is taken as commencing from a point 50 feet above the end of the Take-off Declared Distance (TODA). That climb rate profile is shown in Figure 5.2, Figure 5.3, and Figure 5.4 for a take-off along the northern, central and southern edges of the Take-Off Climb Surface. Also shown on the figures are the Lidar profiles of tree top levels and the possible range of likely glide slopes after engine failure which could result in a collision with the viaduct.

The best glide slope after engine failure of such an aircraft is of the order of 1 in 9. However, the actual glide slope achieved could be steeper for various reasons. The best glide slope of 1 in 9 is achieved at just one aircraft configuration, flaps etc. and at one specific airspeed. The aircraft will not be in that optimum state immediately upon engine failure. The pilot may be reasonably preoccupied with checking fuel pump settings etc. to attempt to remedy the power loss whilst simultaneously maintaining airspeed, flying the aircraft and choosing the best forced landing location. Typically, from an engine failure at the critical period of take-off when a forced landing in the vicinity of the viaduct is likely, there would be only about 10 seconds of flight time to prepare the aircraft for the forced landing. It is unlikely that the optimum airspeed and configuration would be achieved. In any case in the last few seconds before the forced landing it is recommended that the airspeed is reduced to lower the amount of kinetic energy to be absorbed during the forced landing. Additionally, any headwind will directly steepen the glide slope over the ground.

From these considerations the achieved glide slope would be from a best slope of 1 in 9 to something substantially steeper. To allow analysis, a reasonable assumption is that the achieved glideslope could be as steep as 1 in 4.5. That is twice as steep as the best achievable in still air at optimum airspeed. It should be noted that there would be very little opportunity for the pilot to modify the achieved glide slope during the few seconds of flight before the forced landing. However, it is suggested that a range of from 1 in 9 to 1 in 4.5 represents a reasonable range of what might be achieved in a variety of specific circumstances. The steeper glideslope is a reasonable estimate of the steepest glideslope that could be flown in the situation including side-

slipping the aircraft. The critical zone of the take-off profile is then that portion of the take-off during which a range of glideslopes from 1 in 9 to 1 in 4.5 would potentially result in a collision with the viaduct.

It is known that aircraft can crash from a take-off at steeper "glide" slopes. These would not correctly be termed glideslopes as these would likely be instances where there has been a significant loss of lift from the wings due to a stall, or an incipient or full spin. The critical part of the take-off profile where collision with the viaduct might be possible after engine failure is very soon after take-off and the aircraft would be at approximately 250 feet above aerodrome level. This is well below normal manoeuvring height of 500 feet and would avoid any pilot being tempted to turn back to the aerodrome, a manoeuvre which often leads to the aircraft being low and slow, with consequent risk of stalling and or spinning. Both the low level above ground level of the critical zone of the take-off profile and the training regime which teaches pilots to avoid making such an error should make such an incident extremely rare and unlikely to occur within the critical zone.

The Denham Aerodrome Manager has suggested other ranges of glideslopes from two sources. Neither is applicable. The range suggested from the CRR 150/1997 would give a lower probability of collision but is not applicable as it is for aircraft crashing from 2000 feet AGL and above. The other was from a study of aircraft crashes for Schiphol Airport which has a significantly larger scale of operation and aircraft size than at Denham Aerodrome, and suggests an unrealistic distribution of just two glideslopes.

5.2.4 Time of exposure in the Critical Zone (Zone C)

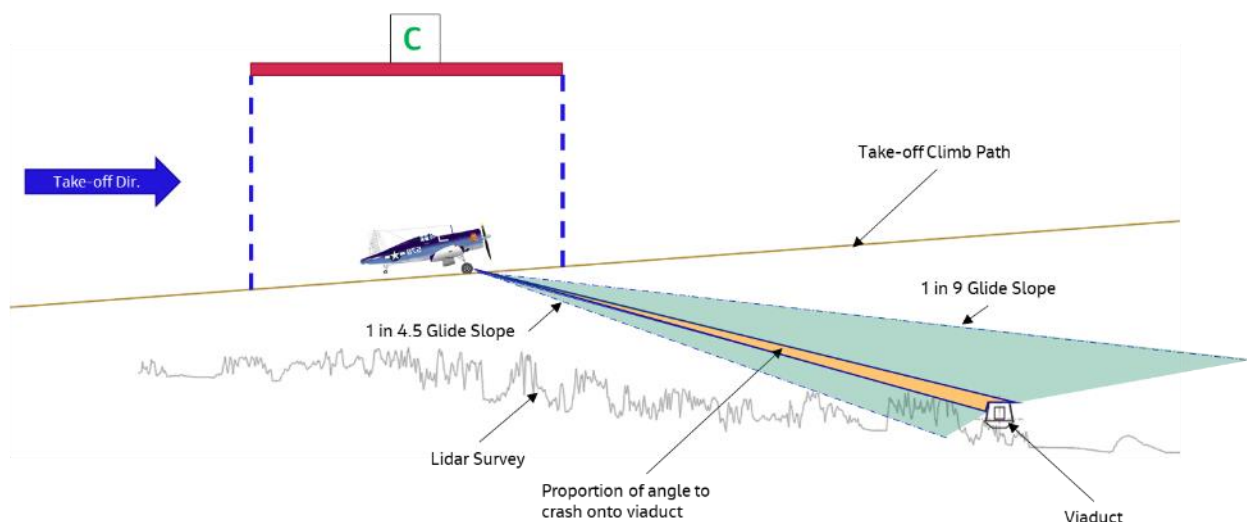
As the critical zone, shown in Figure 5.2, Figure 5.3, and Figure 5.4, is only some 300m from the end of the runway, it is likely that the aircraft will be quite close to the extended centreline of the runway. The critical zone for that case is Figure 5.3 at a length of 88.66 m which would take about 3 seconds to pass through. A 5.25 Knot headwind has been taken as wind data for the nearby airfield at RAF Northolt shows that is the average headwind component that would be experienced by a take-off on Runway 06. Figure 5.2 and Figure 5.4 show the critical zones for a take-off climb on the North and South edges of the TOCS. Neither is a worse case than for the situation on the centreline and as that is the most probable. The result of 2.98 seconds of exposure to the potential risk of collision with the viaduct after an engine failure is taken forward for further analysis.

The manager of Denham Aerodrome has advised that in her opinion the viaduct presents more than just a physical obstacle to a forced landing. A pilot suffering an engine failure in the critical zone might be panicked by the visual strength of the viaduct as an unavoidable structure, feel unable to follow normal emergency procedures and hence pilot errors could be induced. These could include not monitoring airspeed to maintain flight, attempting to stretch the glide more than is possible to get over the viaduct, or steepening the glide slope to land before the viaduct and arrive at a greater speed than should be the case for an emergency landing to normal procedures.

In considering how to include this effect in the quantitative analysis, pilot behaviour and response to the situation has been considered to be an additional element, along with the variation in headwind, aircraft type and performance, all contributing to the validity of there being a reasonably equal probability of the achieved glide slope being anything from the 1:4.5 to the 1:9 and varying the aircraft impact position uniformly between the results of those two extremes. The proportion of the impact positions occupied by the viaduct is then factored into the calculation of the probability of a fatal outcome.

At any point within that critical zone, the HS2 viaduct infrastructure will occupy as a "landing" or rather crash location only a proportion of the range of ground that the glideslopes from 1:4.5 to 1:9 would cover. That proportion has been integrated for the passage of the aircraft through the critical zone to allow the calculation of the overall risk of a fatal outcome. Figure 5.6 illustrates that at every position within the critical zone, only a proportion of the range from the flattest to the steepest glide slopes will result in a crash onto the viaduct.

Analysis of glide slopes within the Critical Zone



Zone C - Critical Zone. Collision with CVV is possible after engine failure

- 90% survivable forced landing after engine failure within the critical zone
- 0% survivable forced landing after engine failure within the critical zone

Figure 5.6. Critical Zone – Sketch of proportion of glide slopes analysis.

From Figure 5.3 it can be seen that the critical zone is defined between the glide slopes of 1 in 9 and 1 in 4.5 (15.18% and 22.22%), the difference between those two angles is 6.19 degrees. At each point within the critical zone the proportion of the angle between the 1 in 9 and 1 in 4.5 glide slopes which would result in a collision with the viaduct is analysed. These are integrated over the length of the critical zone. The results are shown in Figure 5.7 and the result of the integration corresponds to a proportion of 21.7%. This means that for the time of exposure to the critical zone of approximately 2.98 seconds, 21.7% of the 2.98 seconds are applied a 100% fatal crash rate and the remaining 78.3% of the 2.98 seconds are applied a 10% fatal crash rate. This is added to the existing time of exposure without HS2, less the 2.98 seconds, to calculate the overall equivalent time of exposure in the critical zone to a fatal accident.

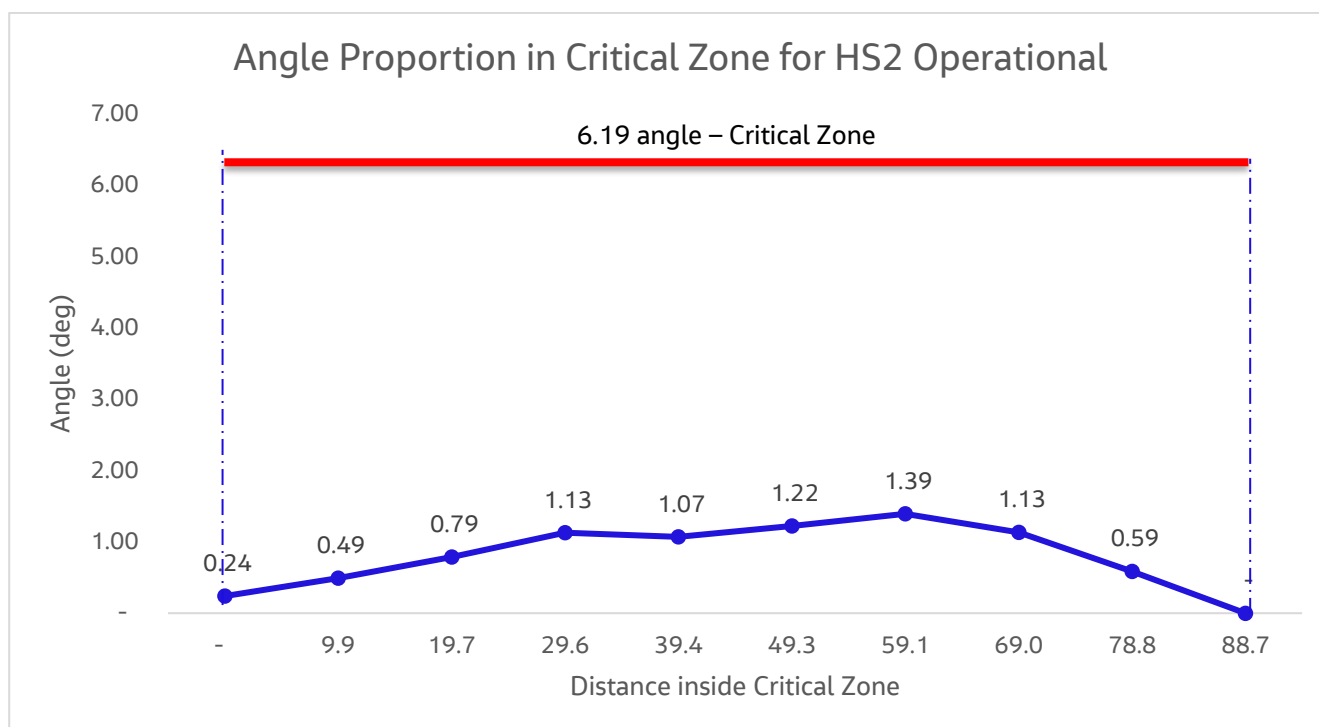


Figure 5.7: Angle Proportion analysis in critical zone for HS2 Operational

Figure 5.8 shows the above in the context of a satellite image. The image taken in the ArcGIS Earth model from just behind an aircraft on take-off on Runway 06. The aircraft is in the critical zone for potential collision with the viaduct. An engine failure in this zone would result in a range of glideslopes which lead to contact with the ground over an area shown by a blue overlay. The width of the blue zone extends from a 30 degree turn to the left to a 30 degree turn to the right. The depth of the blue zone covers the range of glideslopes from 1:4.5 to 1:9. The pilot is likely to be able to control the amount of turn, but not the actual glideslope achieved. The viaduct is seen crossing the projected crash-landing area and the proportion of the glideslope angle that would end with collision into the viaduct is used to assess the proportion of the critical zone which would be assessed as leading to a fatal outcome.

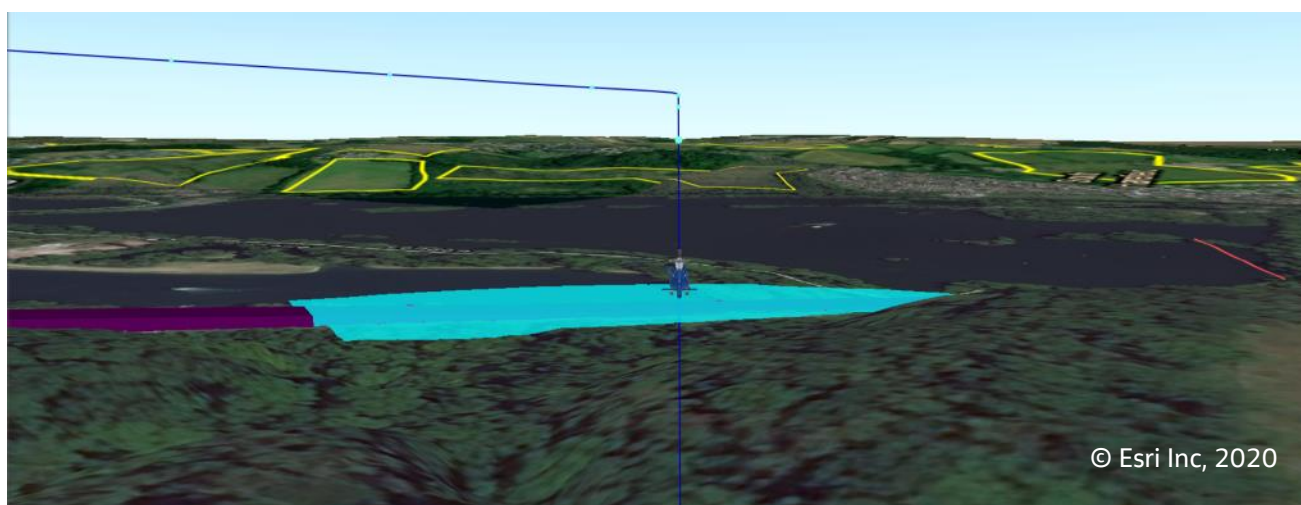


Figure 5.8: Take-off on Runway 06 – HS2 Operational

A calculation of the combined probability of a fatal outcome throughout the early take-off climb can then be made incorporating this time of exposure to the heightened probability of a fatal outcome and compared with the existing situation.

5.2.5 HS2 Construction Methodology considerations

During the HS2 construction phase the greater height of the construction works and infrastructure clearly increases the proportion of the critical zone for which there would be a fatal outcome.

In the construction case the critical zone is longer due to the increased height of the construction plant infrastructure and is calculated as 168m. Considering aircraft speed and headwind this equates to a time of exposure of 5.65 seconds. The same glide slope angle proportion analysis as described above was carried out for the construction case. It was calculated that 33.64% of the 5.65 seconds are exposed to a 100% fatal crash rate and the remaining 66.36% of the 5.65 seconds are exposed to a 10% fatal crash rate.

The HS2 construction phase has three distinct stages. In the first stage, piles for pier foundations will be bored by a piling rig and then reinforcement and concrete will be placed using cranes to form load-bearing piles. During this stage AlignJV have advised that two crawler cranes per three pier locations are expected. The second stage is the construction of the pile caps and then the piers on top of the pile groups. As in the first stage, two crawler cranes per three pier locations are expected. The third stage is the construction of the viaduct spans using a 150m long launch girder. Supported by the part of the viaduct already constructed, the girder places additional pre-cast segments to construct the next span of the viaduct. Thus, during the construction period, the construction infrastructure changes in location and height and hence does not constitute a consistent uniform obstacle. These relevant construction phases illustrated as sets of obstacles to aircraft are shown in Figure 5.9, Figure 5.10 and Figure 5.11. It is envisaged that construction adjacent to Denham Aerodrome will proceed from the north to the south.

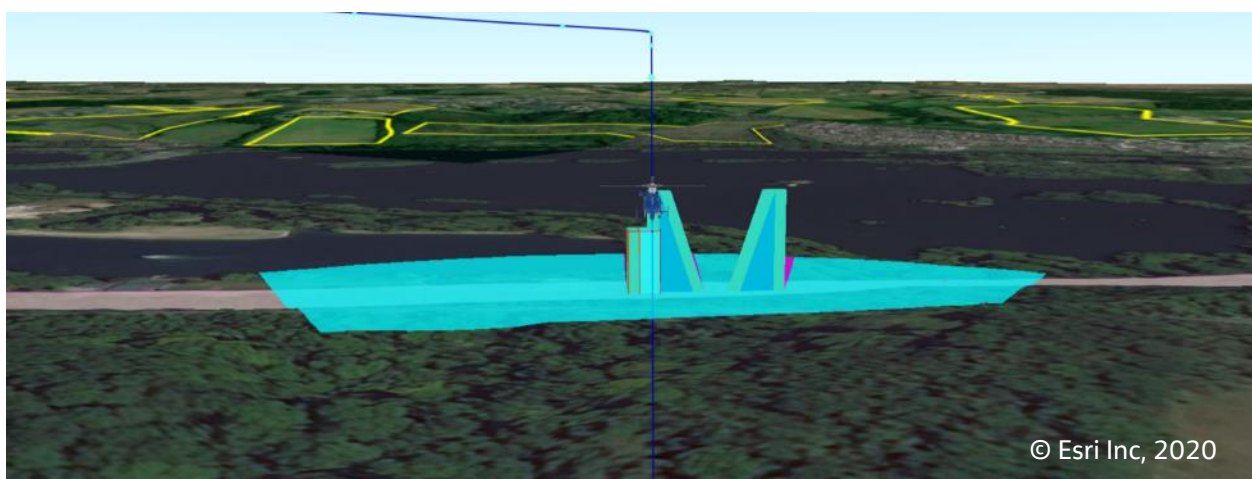


Figure 5.9: Take-off on Runway 06 - HS2 Construction - Piling works

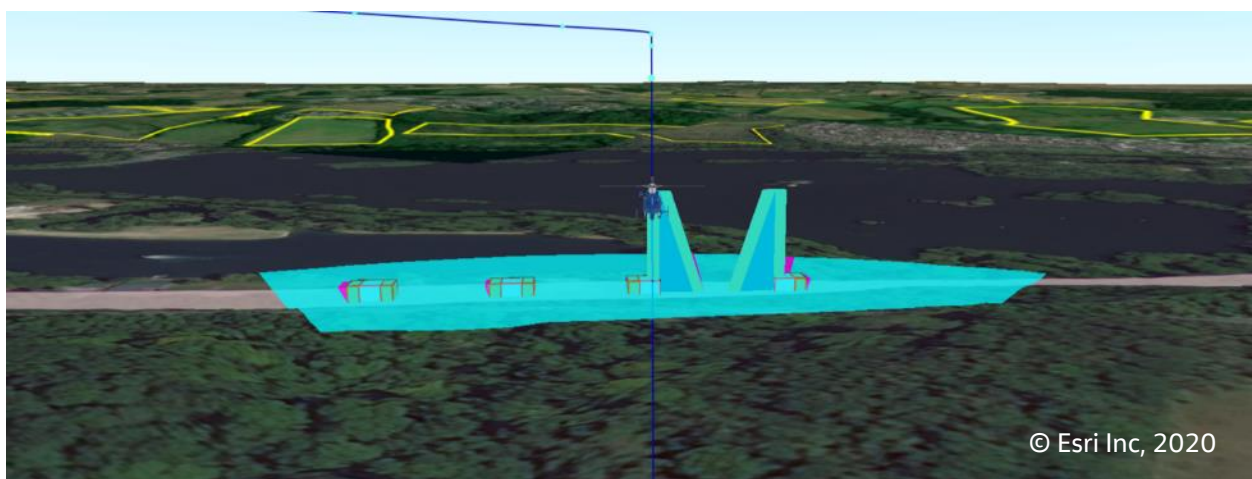


Figure 5.10: Take-off on Runway 06 - HS2 Construction - Pier cap and pier construction

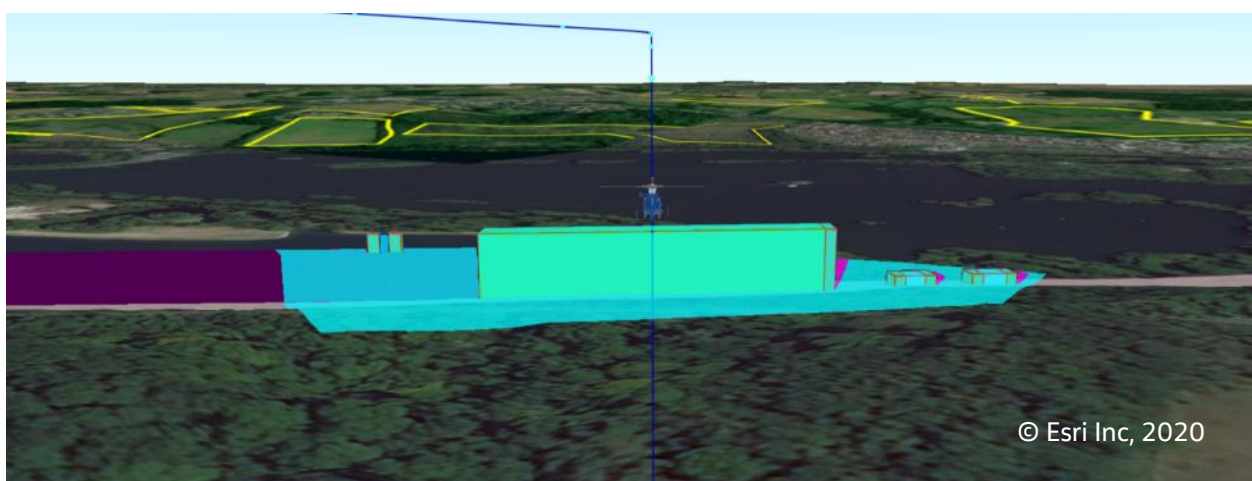


Figure 5.11: Take-off on Runway 06 - HS2 Construction - Launching Girder works

To assess the construction scenario risk, it has been necessary to consider the combined effect of this changing obstacle environment and the distribution of aircraft on and adjacent to the extended centreline of the runway.

To obtain a distribution of aircraft locations at the point of crossing the viaduct, the effect of both the crosswind and the headwind components was analysed. The wind records for ten years at nearby RAF Northolt were used

for the analysis. For take-off, the crosswind drift was applied to the flight duration from passing the end of the TODA at 50ft AGL until the crossing of the viaduct.

The aircraft speed over the ground was changed from initial climb speed to glide speed at the critical zone for engine failure. The effect of the headwind component on the aircraft ground speed was also considered.

The results of this analysis are shown in Figure 5.12. In summary 74% of the potential aircraft locations are within $\pm 75\text{m}$ either side of the extended runway centreline and 85% are within $\pm 100\text{m}$ at the point of crossing the viaduct.

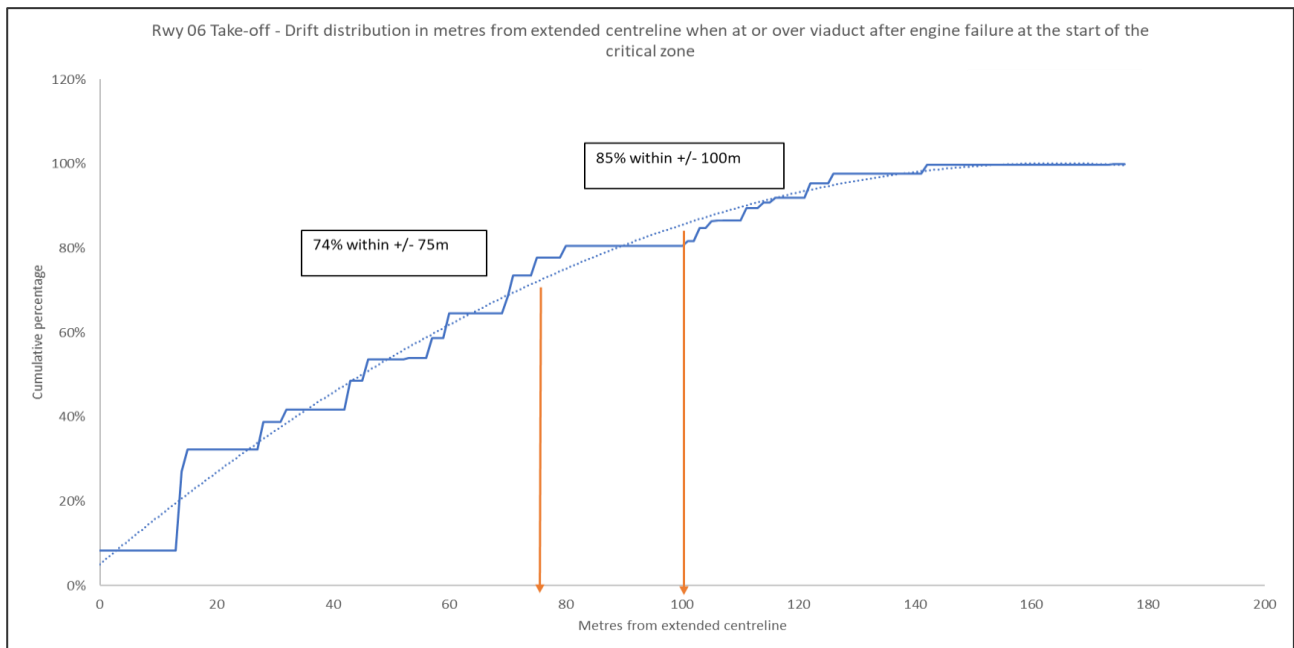


Figure 5.12: Rwy 06 Take-off - Drift distribution in metres

The detailed analysis of the likelihood of an aircraft clearing the highest construction infrastructure obstacles is the starting point for the assessment. Two detailed analyses were carried out, one for unconstrained usage of cranes (max elevation 84.89m AOD) and one for unconstrained usage of the launching girder (max elevation 68m AOD). This is then reduced by comparing:

- Cross sectional airspace area used by construction infrastructure,
- Cross sectional airspace area used by unconstrained usage of cranes and of the launching girder, forming the two base cases
- Probability of the position of the aircraft over the viaduct after being affected by crosswind.

These combined probabilities result in a reduction factor of 0.18 for piling works and 0.15 for pile cap and pier works when compared with an unconstrained usage of cranes. The reduction factor is 0.81 for the viaduct works when compared with an unconstrained usage of the launching girder. The latter reduction factor is applied to a base detailed analysis of the critical zone for clearing the launch girder which is at a lower height than for the cranes.

5.3 Hazard and Consequence

The "Hazard" is engine failure during the early portion of the take-off climb on a take-off from Runway 06. There is already the existing hazard of having to carry out a forced landing into trees or a ditching into the lakes. The consequence of such an occurrence is taken as a 10% probability of a fatal outcome.

With the HS2 infrastructure in place, the consequence is an increased probability of a fatal outcome if the engine failure occurs during a portion of the take-off climb which would result in an unavoidable collision with the viaduct.

The level of Hazard is "Hazardous" as defined by CAP 765 as it involves serious injury or death to a number of people.

5.4 Probability

The probability of an engine failure, whether total engine failure or a malfunction that results in a loss of engine power or rough running, of a SEP such as the PA28 is reported to be 12.4 in 100,000 flight hours in research carried out by the ATSB⁸. This corresponds to data available for Lycoming and Continental engines which are expected in the aircraft fleet at Denham Aerodrome.

The ATSB data used includes a range of engine power failures and malfunctions, including for example fuel problems such as carburettor icing. However, it excludes loss of power due to fuel exhaustion, fuel starvation and propeller system failures and therefore is increased as follows. From a report into propeller safety by AOPA⁹ 2005, there were 9 propeller system failures in GA aircraft in 2003. From FAA aircraft traffic statistics there were 16.68 million hours flown that year by GA single engine planes. That gives an additional failure rate of 0.054 per 100,000 hours of flight. In addition, to consider fuel exhaustion or starvation, from the historic aircraft crash reports reviewed in Section 4, an additional 6.4% is added. This gives a combined power system failure rate of 13.25 per 100,000 hours.

It has been considered whether the engine failure rate for take-off and landing should be different based on the general belief that engines fail more frequently on take-off when they are at a high-power setting. Jacobs has not found any statistically significant evidence to support this belief. Jacobs refers to the accident record studied as part of this aeronautical assessment where it was found that 23 accidents were on landing and 25 were on take-off at Denham plus other comparable airports in the UK. This implies there is no significant difference on the frequency of engine failures between landing and take-off. Additionally, in the bibliographic reference called Contract Research Report 150/1997 given in a report commissioned by the Aerodrome Manager, the accident probabilities for take-off and landing are the same, thus implying that there is no difference. Based on this, the same probability of an engine failure of a SEP is applied for take-off and landing

In calculating the recurrence periods, the total fixed wing aircraft traffic at Denham per year has been used. This includes the small number of twin engine aircraft which are thus conservatively included in the analysis as if they have the same engine failure rate as a single engine plane.

The probability of a fatal outcome after an engine failure during the initial take-off climb for a take-off on Runway 06 is assessed by applying this probability to the equivalent times of exposure to a fatal outcome obtained by the above methodology. The results are given in the table below.

⁸ Australian Transport Safety Bureau (ATSB) 2016. Engine Failures and malfunctions in light aeroplanes 2009 to 2014.

⁹ Aircraft Owners and Pilots Association (AOPA) 2005. Safety Advisor Technology No. 3. Propeller Safety.

Table 5.1: Probability for Runway 06 Take Off

	Existing force landing into treetops or ditching	HS2 Operational	HS2 Construction – Piling	HS2 Construction – Pier cap and Pier construction	HS2 Construction – Launching Girder
Equivalent time of exposure to a fatality in seconds	3.16	3.74	3.89	3.79	4.55
Ratio of increase of time of exposure	1.0 (base)	1.18	1.23	1.20	1.44
Fatality risk to a single movement due to an engine failure during initial take-off climb	1.16E-07	1.38E-07	1.43E-07	1.39E-07	1.67E-07
Equivalent Return in Number of years – Current Traffic	1,654	1,397	1,343	1,379	1,149
Equivalent Return in Number of years – Forecast Traffic	1,099	928	892	916	763

5.5 Risk Summary

The probability of a fatal outcome during take-off in the existing situation to a single aircraft movement is 1.16×10^{-07} . This is very close to the ICAO CRM benchmark of risk for a single movement of 1.0×10^{-07} and supports the view that the existing situation, although not without risk, is at industry accepted benchmark levels of tolerable risk.

When HS2 is operational, the probability of a fatal outcome during take-off increases for a single movement to 1.38×10^{-07} , an increase by a factor of 1.18 relative to the existing situation. This is only just over the ICAO CRM benchmark. The recurrence period, which considers the traffic volume per year, is over one in a thousand years. The 1.18 times increase over the existing case it is a degradation of safety, but it is likely to be within the level of accuracy of assumptions, methodology and analysis and does not make a sound case for a “Required Mitigation” if such mitigation were of a high cost. In addition, as described in Section 6.4, the probability of a fatal outcome on a Runway 24 landing for the existing situation has been calculated using the same methodology as 1.31×10^{-07} . This supports the view that a risk, being the probability of a fatal outcome, of that magnitude is considered tolerable and acceptable. Of course, any low-cost mitigations that can be identified would still be recommended as there is a small degradation of safety.

Turning now to the case of the HS2 construction scenario, the greatest probability of a fatal outcome occurs during the launching girder works, however, the results for all three phases of construction analysed are relatively close to each other. The increased height of the crane amplifies the probability of a fatal outcome to a single movement by a factor of 1.44 relative to the existing situation, the risk to a single movement being 1.67×10^{-07} .

6. Runway 24 Landing Collision Risk

Collision with the Colne Valley viaduct presents a potential hazard to aircraft approaching from the north east onto Runway 24. The collision risk currently and when HS2 is under construction and in operation is considered and described in this section.

6.1 Helicopter Risk

The accident record supports the view that the probability and risk relate to fixed wing movements only. It is known that rotary-wing aircraft (helicopters) are manoeuvrable during autorotation after engine failure. Additionally, a helicopter landing on Runway 24 will be on a steeper approach slope than for fixed wing aircraft and would be at a greater height over the viaduct. The extra height relative to a fixed wing aircraft on final approach will give the helicopter pilot the opportunity to manoeuvre during autorotation after engine failure and avoid the viaduct. Therefore, helicopters are not considered further in this part of the risk assessment which is carried out for fixed wing aircraft only.

6.2 Assessment Method

The method used is identical to that described in Section 5.2 above, with the difference being that the time of increased exposure to a fatal outcome is calculated by applying the glideslopes from points along a typical approach path. Additionally, the existing situation considers availability of suitable areas of land for a forced landing during the crosswind and final approach sections of the landing circuit.



Figure 6.1 Critical Zone – Approach- Plan View

Figure 6.1 shows the final approach of an aircraft towards the viaduct and the critical zone during which collision with the viaduct would be possible after an engine failure.

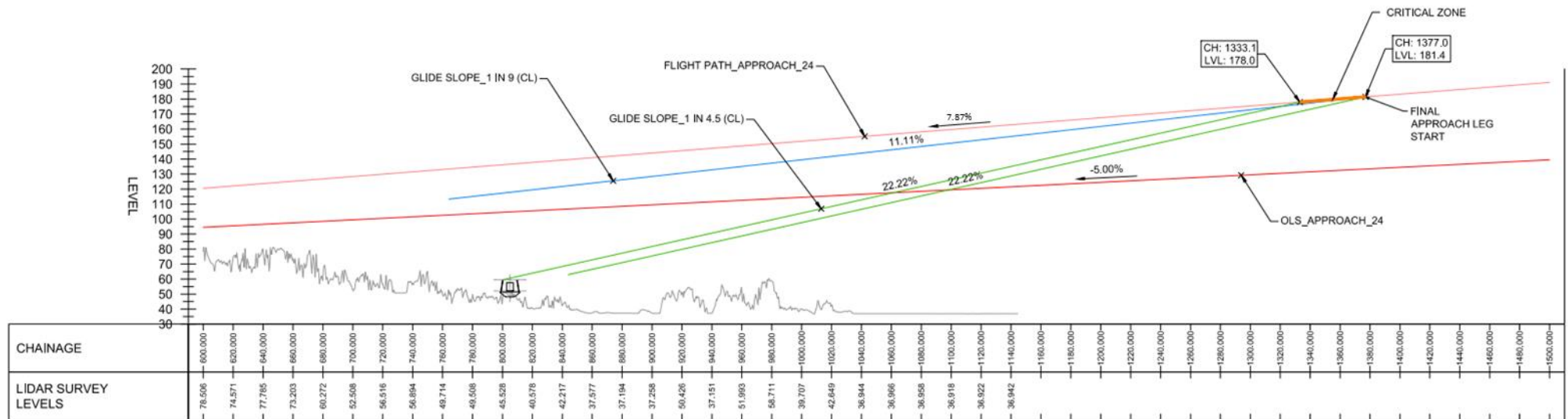


Figure 6.2 Critical Zone on Approach - Section shown on extension of runway centreline

The distance between the aircraft leaving the last suitable landing field on the other side of the lakes and the nearest field to the runway is 1041m. Considering the aircraft speed and headwind of 6.04 knots, calculated for nearby Northolt Aerodrome, the time to fly through this zone equates to 35.54 seconds. In this zone the pilots are exposed to a 10% fatal crash rate. The length of the critical zone is calculated as 43.98m for the HS2 Operational Case and 105m for the HS2 Construction Case. The time it would take the aircraft to fly through the critical zone is estimated at 1.50 and 3.60 seconds for HS2 Operational and HS2 Construction Cases respectively.

The integration of the proportion of the range of glideslope angles within the critical zone that would result in a crash onto the viaduct was calculated as 14.45%. This means that for 14.45% of the 1.50 seconds a 100% fatal crash rate is applied and for the remaining 85.55% a 10% crash rate is applied.

Figure 6.3 shows an image taken in the ArcGIS model from just behind an aircraft on finals for a landing on Runway 24. The aircraft is in the critical zone for potential collision with the viaduct. An engine failure in this zone would result in a range of glideslopes which lead to contact with the ground over an area shown by a blue overlay. The width of the blue zone extends from a 30 degree turn to the left to a 30 degree turn to the right and its depth covers the range of glideslopes from 1:4.5 to 1:9. The pilot is likely to be able to control the amount of turn, but not the actual glideslope achieved. The viaduct is seen crossing the projected crash-landing area. The proportion of the glideslope angle that would end with collision into the viaduct is used to assess the proportion of the critical zone which would be assessed as leading to a fatal outcome.

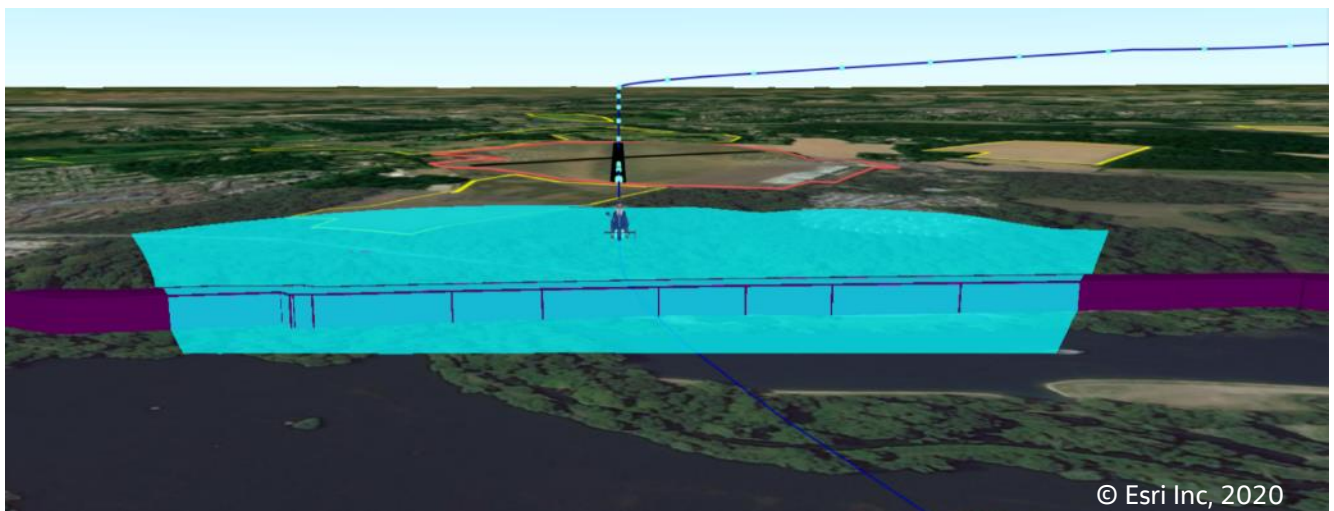


Figure 6.3: Landing on Runway 24 – HS2 Operational

During the HS2 construction phase the greater height of the construction works obviously increases the proportion for which there would be a fatal outcome.

The HS2 construction phase has three distinct stages. In the first stage, piles for pier foundations will be bored by a piling rig and then reinforcement and concrete will be placed using cranes to form load-bearing piles. During this stage AlignJV have advised that two crawler cranes per three pier locations are expected. The second stage is the construction of the pile caps and then the piers on top of the pile groups. As in the first stage, be two crawler cranes per three pier locations are expected. The third stage is the construction of the viaduct spans using a 150m long launch girder. Supported by the part of the viaduct already constructed, the girder places additional pre-cast segments to construct the next span of the viaduct. Thus, during the construction period, the construction infrastructure changes in location and height and hence does not constitute a consistent uniform obstacle. These relevant construction phases illustrated as sets of obstacles to aircraft are shown in Figure 6.4 Figure 6.5 and Figure 6.6. It is currently expected that construction adjacent to Denham Aerodrome will proceed from the north to the south.

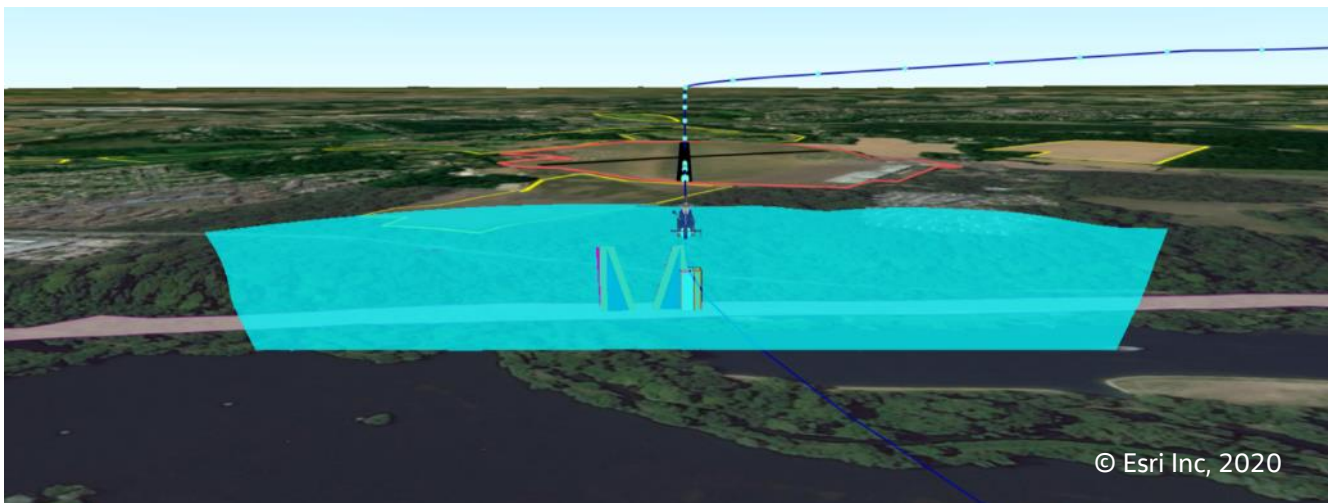


Figure 6.4: Landing on Runway 24 – HS2 Construction – Piling works

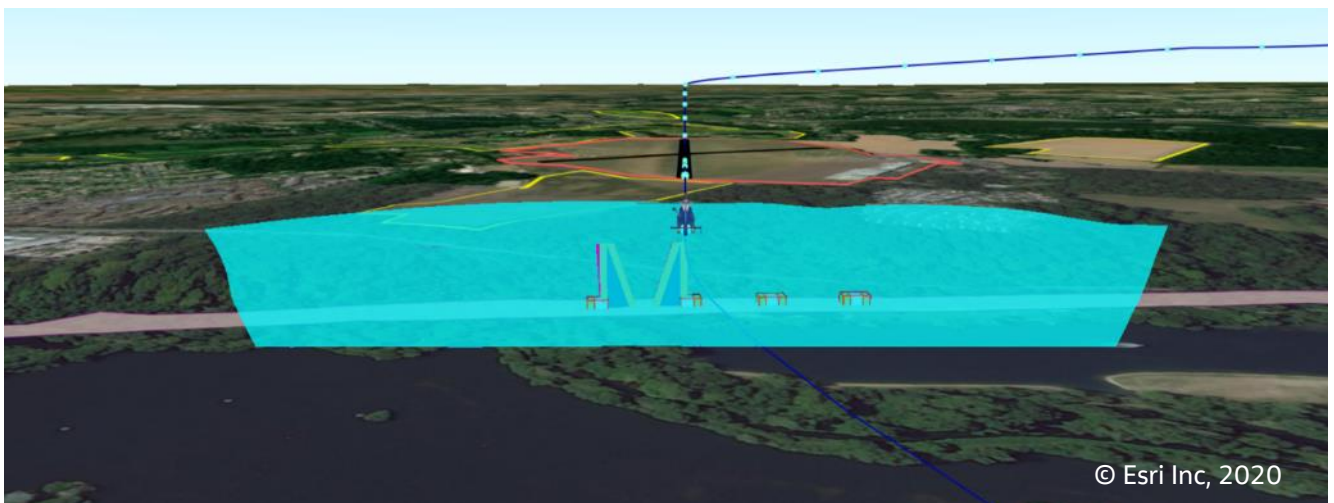


Figure 6.5: Landing on Runway 24 – HS2 Construction – Pier cap and pier construction

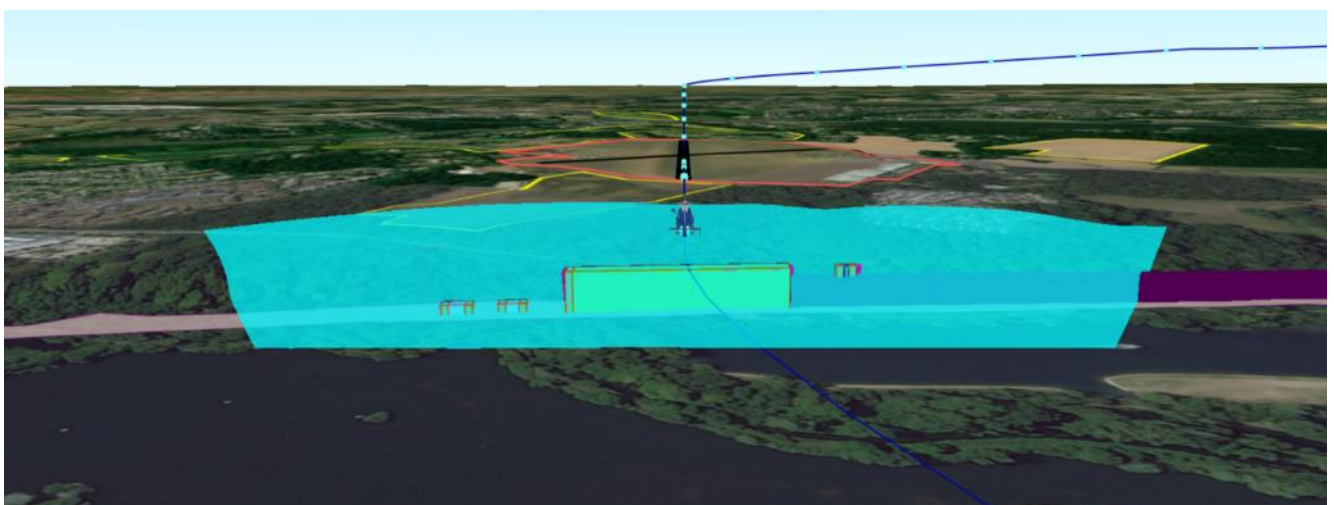


Figure 6.6: Landing on Runway 24 – HS2 Construction – Launching Girder works

To assess the construction scenario risk, it has been necessary to consider the combined effect of this changing obstacle environment and the distribution of aircraft on and adjacent to the extended centreline of the runway.

To obtain a distribution of aircraft locations at the point of crossing the viaduct, the effect of both the crosswind and the headwind components was analysed. The wind records for ten years at nearby RAF Northolt were used for the analysis. For landing the crosswind drift was applied from the point of engine failure in the critical zone. The aircraft speed over ground was changed from approach speed to glide speed at the critical zone for engine failure. The effect of the headwind component on the aircraft ground speed was also considered.

The results of this analysis are shown in Figure 6.7. In summary 85% of the aircraft locations are within $\pm 55\text{m}$ either side of the extended runway centreline and 98% are within $\pm 75\text{m}$ at the point of crossing the viaduct.

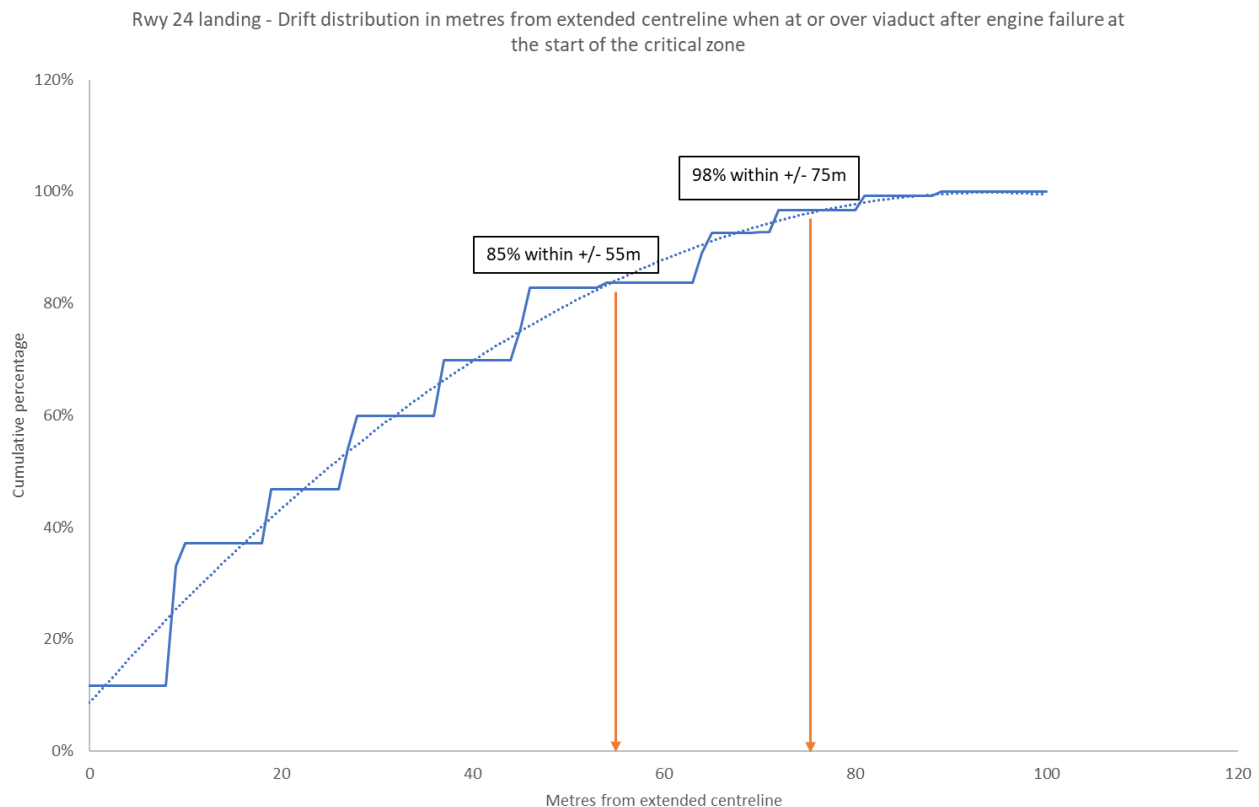


Figure 6.7: Rwy 24 Landing - Drift distribution in metres

The detailed analysis of the likelihood of an aircraft clearing the highest construction infrastructure obstacles is the starting point for the assessment. Two detailed analyses were carried out, one for unconstrained usage of cranes (max elevation 84.89m AOD) and one for unconstrained usage of launching girder (max elevation 68m AOD). This is then reduced by combining:

- Cross-sectional airspace area used by construction infrastructure,
- Cross-sectional airspace area used by unconstrained usage of cranes and launching girder as base cases,
- Probability of the position of the aircraft over the viaduct after being affected by crosswind.

These combined probabilities result in a reduction factor of 0.30 for piling works and 0.27 for pile cap and pier works when compared with an unconstrained usage of cranes. The reduction factor is 0.99 for the viaduct works when compared with an unconstrained usage of the launching girder. The latter is applied to a base detailed analysis of the critical zone for clearing the launch girder which is at a lower height than for the cranes.

6.3 Hazard and Consequence

The consideration of the Hazard and Consequence is similar to that described for a Runway 06 take-off in Section 5.2. Thus, the "Hazard" is engine failure during the final portion of the approach to a landing on Runway 24. There is already the existing hazard of having to carry out a forced landing into trees or a ditching into the lakes. The consequence of such an occurrence is taken as a 10% probability of a fatal outcome.

With the HS2 infrastructure in place, the consequence is an increased probability of a fatal outcome if the engine failure occurs during a portion of the final approach which would result in an unavoidable collision with the viaduct.

The level of Hazard is "Hazardous" as defined by CAP 765 as it involves serious injury or death to a number of people.

6.4 Probability

Using the same methodology as described in Section 5, the results are shown in the table below.

Table 6.1: Probability for Runway 24 Landing

	Existing (No HS2)	HS2 Operational	HS2 Construction – Piling	HS2 Construction – Pier cap and Pier construction	HS2 Construction – Launching Girder
Equivalent time of exposure to a fatal outcome in seconds	3.55	3.75	4.99	4.90	4.54
Ratio of increase of time of exposure	1.0 (base)	1.05	1.40	1.38	1.28
Probability for a single movement of a fatal outcome due to engine failure during approach	1.31E-07	1.38E-07	1.84E-07	1.80E-07	1.67E-07
Equivalent Return in Number of years - Current Traffic	802	760	572	582	628
Equivalent Return in Number of years - Forecast Traffic	533	505	380	387	417

6.5 Risk Summary

The probability of a fatal outcome in the existing situation is assessed as 1.31×10^{-07} for a single movement. The fact that landings on Runway 24 are a normal part of the operations at Denham Aerodrome supports the view that a probability of a fatal outcome of this order is considered to be tolerable and acceptable. This also supports the conclusion of Section 5.4 that the similar probability of a fatal outcome of 1.38×10^{-07} for a Runway 06 take-off with the HS2 viaduct operational should be considered to be a tolerable and acceptable risk.

Turning now to the case during the construction phase, the greatest probability of a fatal outcome occurs during the piling works, however, the results for all three phases analysed is relatively close to each other. The increased height of the works amplifies the probability of a fatal outcome to a single movement by a factor of 1.40 relative to the existing situation, the risk to a single movement being 1.84×10^{-07} .

7. Circuit 06/24 – Forced Landing Area Availability

7.1 Local Flying Area

The local flying area (LFA) for Denham Aerodrome is outlined in the Aeronautical Information Publication (AIP) AD 2.EGLD-6 (21 May 2020)¹⁰. Denham LFA lies within the London Control Zone due to its proximity to London Heathrow Airport. The AIP section 2.22.2 states that Visual Flight Rules (VFR) may take place within the LFA subject to the following conditions:

1. Aircraft to remain clear of cloud with the surface in sight.
2. Maximum altitude: 1000 FT QNH.
3. Minimum flight visibility 3 km.

Additionally, in section 2.22.1 it is advised that pilots joining the aerodrome circuit should do so at a height of 750 ft above ground level (1000 ft above mean sea level).

The LFA is shown in Figure 7.1 as extracted from the AIP section AD 2.EGLD-4-1. The circuit extends 2.04km between the legs parallel to the runway centreline and 3.6 km between the legs perpendicular to the extension of the runway centreline.

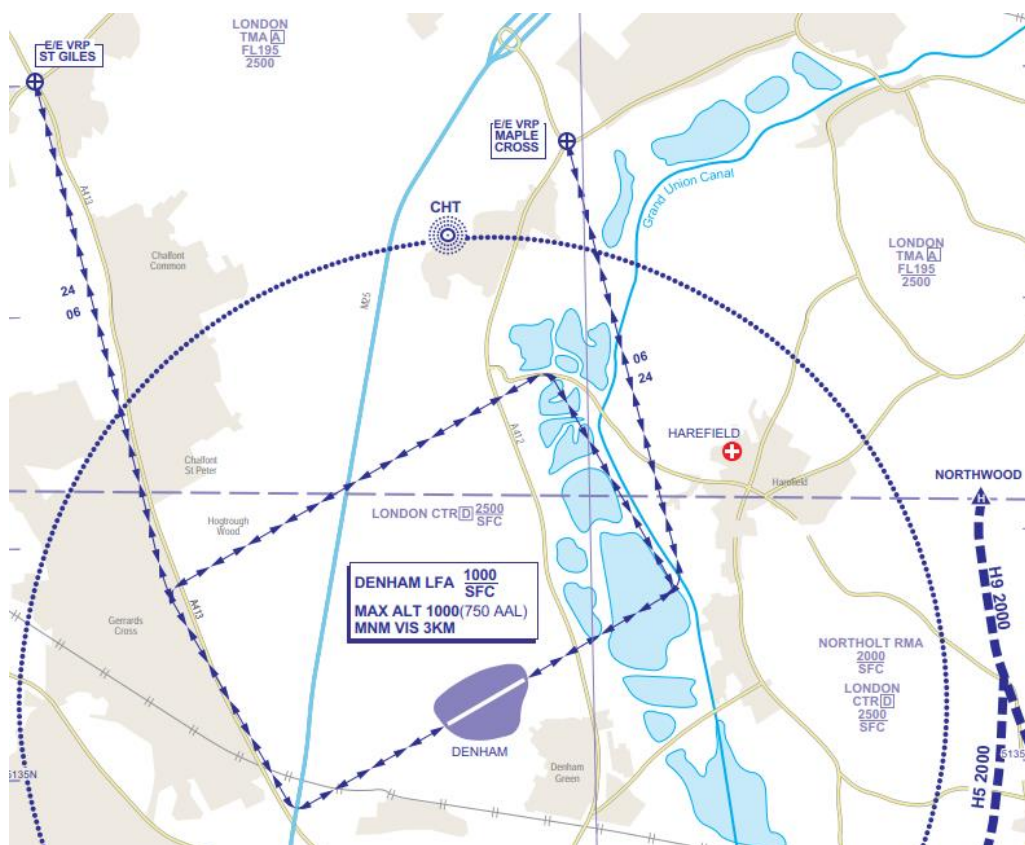


Figure 7.1: LFA extract from AIP AD 2.EGLD-4-1 (Circuit)

¹⁰ <https://www.aurora.nats.co.uk/htmlAIP/Publications/2020-09-10-AIRAC/html/index-en-GB.html>

7.2 Method

It is expected that pilots operating in and out of Denham Aerodrome follow the circuit to the best of their abilities. The emergency landing fields analysis was carried out for three scenarios:

- Existing situation,
- HS2 during construction, and
- HS2 Operational

The emergency landing fields analysis was carried out using the following assumptions:

- Aircraft would follow the circuit as outlined in the AIP, although sensitivity tests have been carried out for diversions 100m either side of the outlined circuit;
- Aircraft are not to exceed 1000 ft AMSL (or 750 ft AGL). As pilots are likely to allow for some buffer to avoid an airspace violation, the analysis was carried out for aircraft at a height of 650 ft AGL;
- After engine failure, the aircraft will continue on a glideslope of between 1 in 9 and 1 in 4.5;
- The maximum turn used by pilots when searching for an emergency landing field is +/- 30 degrees from the original heading;
- Fields with a minimum length of 300m and with slopes less than +/- 5% are considered suitable for an emergency landing. This is considered suitable land for a survivable forced landing.

The accident records support the view that the probability and risk relate to fixed wing movements only. It is known that helicopters are manoeuvrable during autorotation after engine failure. A helicopter would typically autorotate at a descent angle of about 1:4.5 and would have full manoeuvrability to a survivable landing with low descent speed and low ground speed. Helicopters are not considered further in this part of the risk assessment which is carried out for fixed wing aircraft only.

In comments provided by the Denham Aerodrome Manager it has been suggested that a method outlined by the New Zealand Civil Aviation Authority on forced landing without power pattern should be followed. However, it was found that the procedures discussed are not applicable to this study as quoted from the reference provided:

"This lesson discusses the ideal procedure to follow in the unlikely event of a total or partial engine failure in the cruise at altitude (above 1000 feet AGL as a guide) where more time is available to plan and consider options than the EFATO."

Attention is brought to the altitude reference given of 1000ft AGL. As mentioned above, pilots are restricted to 750ft AGL at Denham Aerodrome due to airspace restrictions. As airspace violations are taken very seriously, it would be expected that aircraft carry out flight at a margin below 750ft AGL. This means that pilots would be restricted on their amount of manoeuvring. After power failure it would be normal practice to land straight ahead with only up to 30 degrees turn either side of the aircraft heading at the point of power failure. Therefore, the viewshed analysis by Jacobs provides a reasonable representation of the area that the aircraft would crash land into.

7.2.1 Circuit description

A circuit comprises an initial take-off climb, crosswind leg, downwind leg, base leg and final approach leg as shown in Figure 7.2 for flight circuit 06.



Figure 7.2: Basic Circuit pattern – Flight Circuit 06

An aircraft following the circuit would carry out a take-off roll and under normal performance is expected to achieve a 15m (50ft) height at the end of the declared Take-off Distance Available (TODA). Then, it would be configured to carry out the climb along the remaining section of the take-off leg and crosswind leg. It would join the downwind leg at the assumed height of 650 ft AGL. Then, it would perform a descent along the base leg and configure the aircraft for landing following the final leg to touchdown at the aiming zone of the runway.

The climb gradient was obtained from the aircraft manual of a PA-28, which is deemed to be representative of the aircraft flying at Denham Aerodrome. It was estimated that the climb gradient would be 585 feet per minute (fpm) at the aerodrome reference conditions and the aircraft at Maximum Take-Off Weight (MTOW). The climb gradient used is 7.41% which was calculated using the climb speed.

The final leg gradient was calculated for an aircraft performing a 4.5° (7.87%) approach as outlined in the AIP Section 2.14.

As described in Section 5.1, a range of glideslopes after engine failure of from 1:9 to 1:4.5 has been used for the analysis.

7.2.2 Landing area characteristics

The ground characteristics around the flight circuit were studied to determine suitable areas for landing. The minimum length of 300m was selected. A high-level benchmarking analysis was carried out using data of 66 aircraft with an average maximum take-off weight of 1500kg. The average landing distance was found to be 330m for paved runways under ISA conditions. Although it is obvious that a greater field length is desirable, it is reasonable that a survivable emergency landing by aircraft such as the PA28 could be achieved in 300m of grassland.

The +/- 5% slope was selected following the recommendation of maximum allowed terrain slope for Runway End Safety Areas (RESA) in airports. The RESA is a prepared terrain with the objective to minimise risks to aircraft and their occupants when an airplane uses this infrastructure.

Both the land area dimensions, and the topographic slopes were assessed using Google Earth Pro and a yellow boundary was drawn around suitable areas. It should be noted that these areas are not necessarily suitable for a damage free landing, but they have been selected as the portion of the land area that should offer the possibility of a survivable forced landing. Similarly, it is possible that a survivable landing could be affected in some land areas that have not been selected. Nevertheless, the method adopted allows a quantitative comparison of the availability of land areas for survivable forced landings between the existing situation and the HS2 operational situation.

Figure 7.3 shows that some fairly narrow fields were included in the database of suitable areas. These were thoughtfully included for completeness as the crash database reviewed in Section 4 showed that there are several occurrences of aircraft successfully carrying out a forced landing on golf course fairways, including at Denham Aerodrome. Therefore it would seem incorrect to exclude areas from the assessment that had successfully contributed to a successful forced landing.



Figure 7.3: Existing Potential Landing Areas identified for Denham Aerodrome

7.2.3 Emergency landing areas availability

Once the suitable emergency landing areas were identified, flight circuits for Runway 06 (anti-clockwise) and Runway 24 (clockwise) were constructed. Because the climb gradient and the final approach gradient were not significantly different it was possible to simplify the analysis and combine both flight circuits into a single 3D path. Then, the 3D path was divided into 35 equidistant sections of 300m as shown in Figure 7.4.

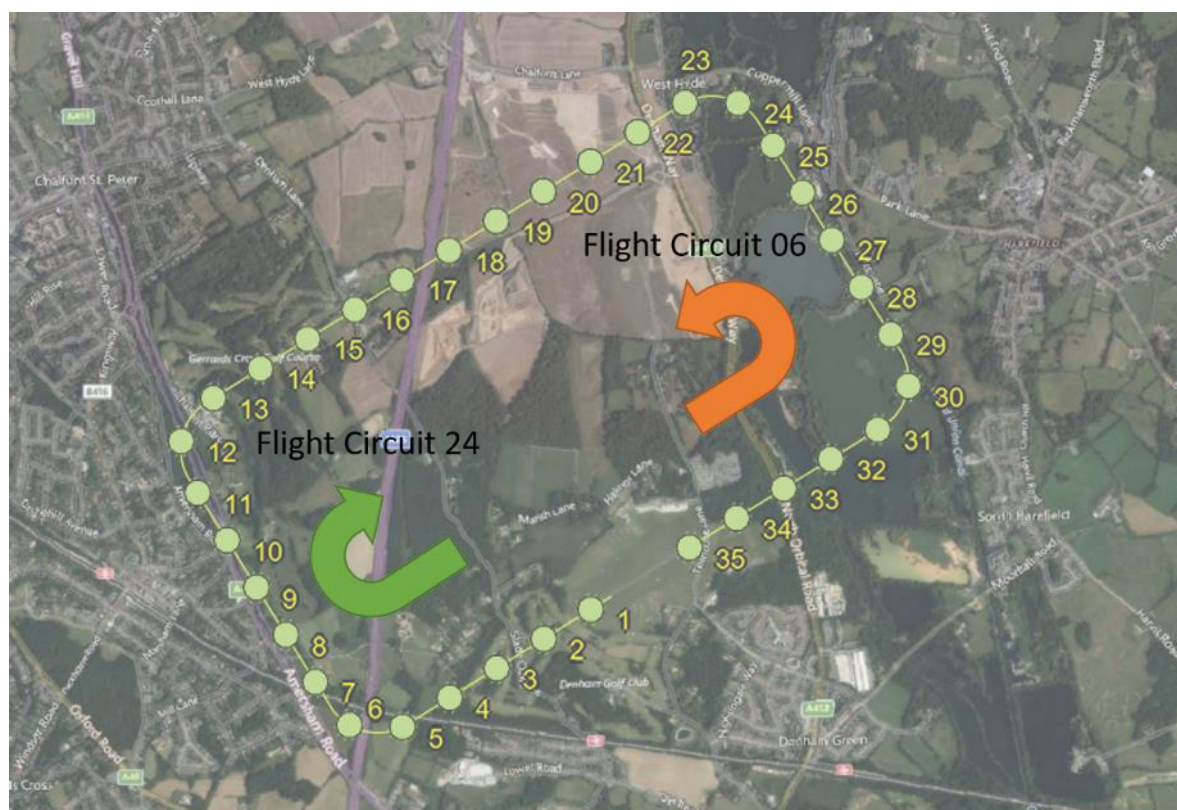


Figure 7.4: Flight circuit points

At each point in the circuit, a viewshed analysis using ArcGIS Earth was carried out considering the position of the aircraft following the flight circuit, the ground elevation, the glideslope range and turn angle either side of the aircraft heading. The blue overlay is thus the area which the aircraft could reach after engine failure, i.e. the area available between the steepest 1:4.5 glideslope and the best possible 1:9 glideslope, and for a 30 degree turn either side of the aircraft heading. Locations with only a narrow strip of land alone were not considered acceptable.

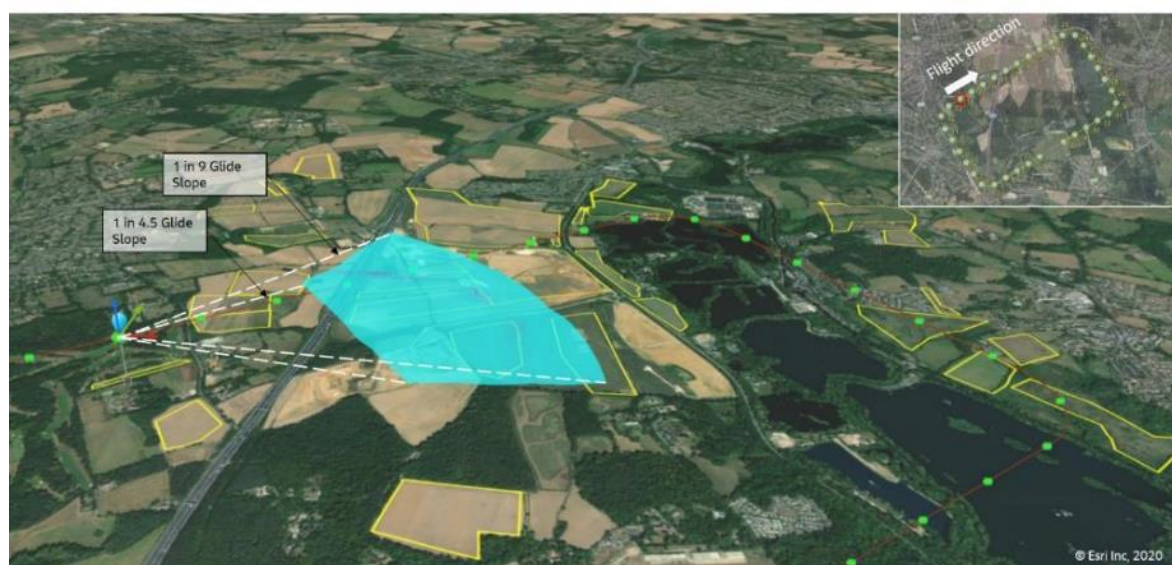


Figure 7.5: Landing site suitability selection – Existing Scenario

An example of the process to determine if a suitable landing site was in range for each point along the circuit is shown in Figure 7.6. If an identified landing site is comfortably within the reachable area (outlined by the light

blue overlay area), and reachable by a large part of the range of glideslopes, it means that for that section the aircraft would have a suitable option in case of an emergency. This process was carried out for existing conditions, HS2 during construction case and HS2 Operational case.

For HS2 during construction, the area that would be used for Construction Compound and Stockpiling material was identified, including dimensions which represent the height of crane compounds required. This allowed identification of fields which were not available for emergency landing as shown in the diagram below.

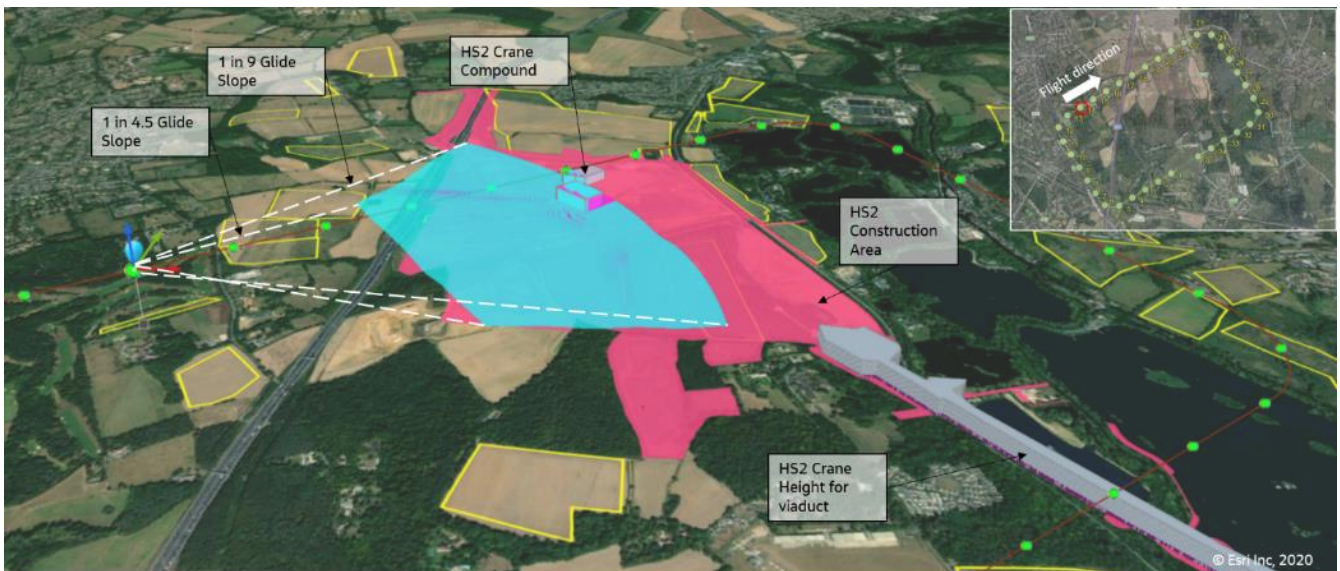


Figure 7.6: Landing site suitability selection – HS2 Construction Scenario

For HS2 operational, the outline for the infrastructure was determined. The outline included major earthworks which would change the landscape of the area and would make a field unsuitable for emergency landings.

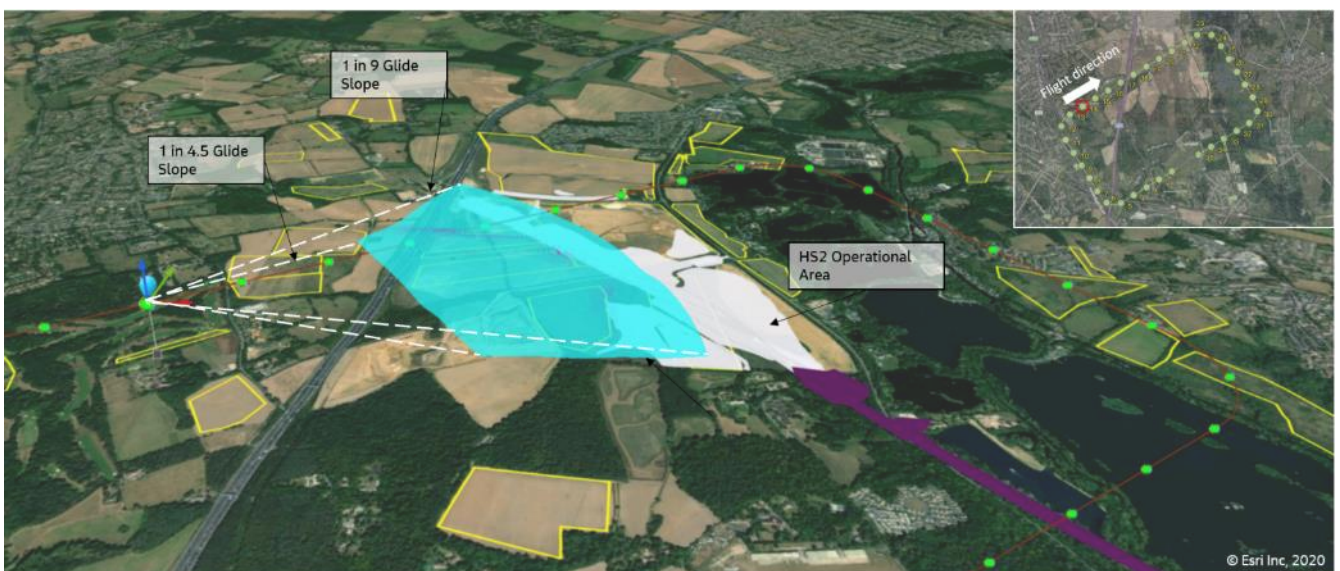


Figure 7.7: Landing site suitability selection – HS2 Operational Scenario

Images such as the above were examined for each of the 35 points around the circuit, for each circuit direction and considered the field availability for the existing situation, the HS2 construction phase and the HS2 operational cases. 37 points were examined for the crosswind runway. The outputs for Runway 06/24 and 12/30 can be seen in Section 7.3 and Section 8.2, respectively.

7.3 Landing Field Analysis Outputs

The outputs of the landing field analysis for Runway 06/24 are shown in Table 7.1. A green cell means that at least one suitable landing site was identified for the aircraft at that point on the circuit. A red cell means that there were no landing sites identified with the criteria established.

Table 7.1: Emergency landing fields availability for Runway 06/24

ID	Flight Circuit 06 - Existing	Flight Circuit 06 - HS2 Construction	Flight Circuit 06 - Operational		Flight Circuit 24 - Existing	Flight Circuit 24 - HS2 Construction	Flight Circuit 24 - Operational
35	1	1	1		1	1	1
34	-	-	-		1	1	1
33	-	-	-		1	1	1
32	-	-	-		1	1	1
31	1	1	1		-	-	-
30	1	1	1		-	-	-
29	-	-	-		-	-	-
28	-	-	-		1	1	1
27	-	-	-		1	1	1
26	1	1	1		1	1	1
25	1	1	1		1	1	1
24	1	1	1		1	1	1
23	1	-	1		1	1	1
22	1	1	1		-	-	-
21	1	1	1		1	1	1
20	1	1	1		1	1	1
19	1	1	1		1	1	1
18	1	1	1		1	1	1
17	1	1	1		1	-	-
16	1	1	1		1	-	1
15	-	-	-		1	-	1
14	-	-	-		1	-	1
13	-	-	-		1	1	1
12	-	-	-		-	-	-
11	1	1	1		-	-	-
10	-	-	-		1	1	1
9	1	1	1		1	1	1
8	1	1	1		1	1	1
7	-	-	-		1	1	1
6	-	-	-		-	-	-
5	1	1	1		1	1	1
4	1	1	1		1	1	1
3	1	1	1		-	-	-
2	1	1	1		1	1	1
1	1	1	1		1	1	1

These results are also shown in plan form in Figure 7.8 and Figure 7.9.

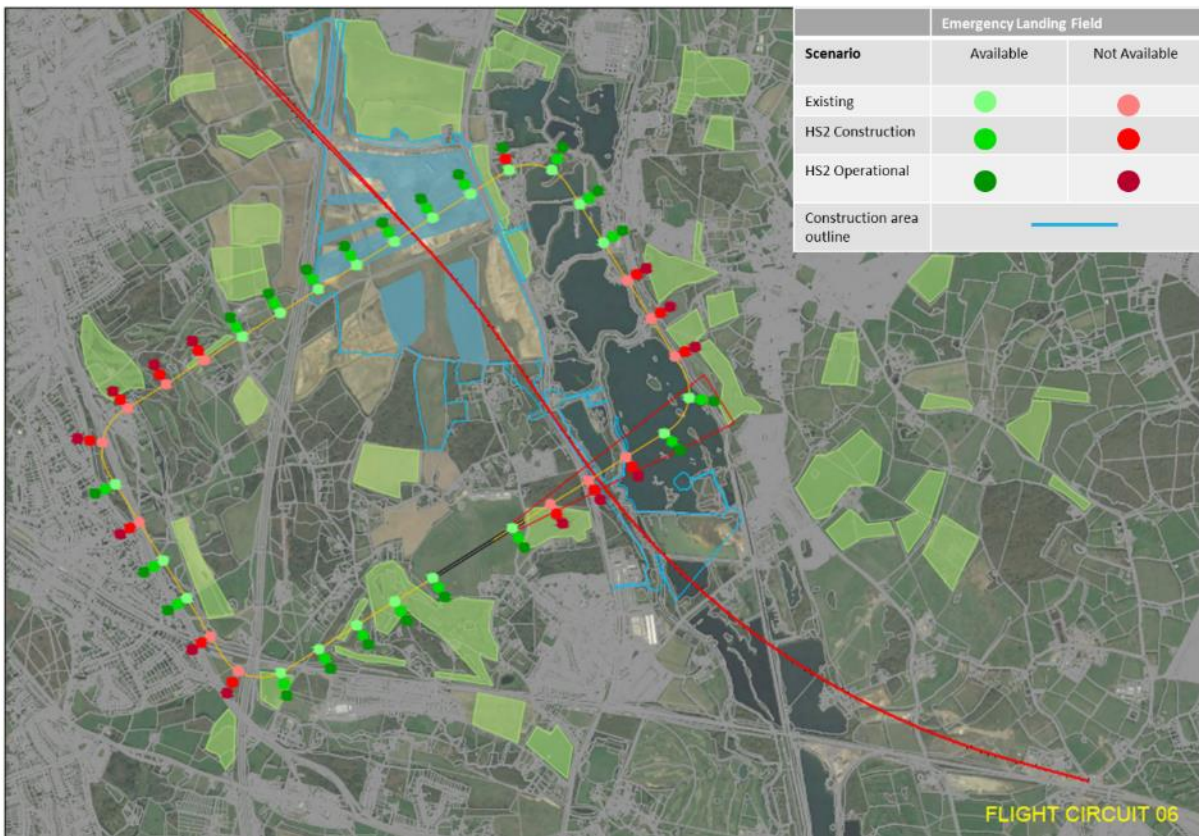


Figure 7.8. Landing Field Availability Results- Flight Circuit 06

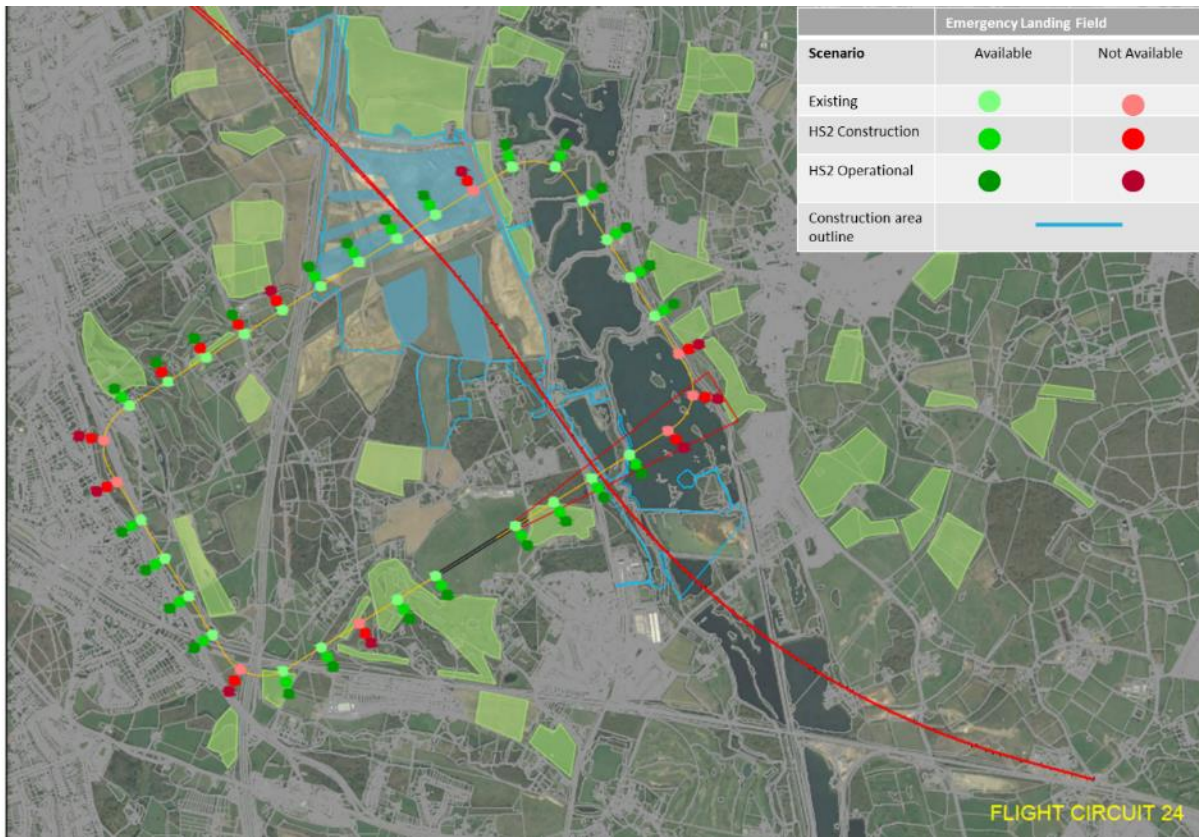


Figure 7.9 Landing Field Availability Results- Flight Circuit 24

It can be observed that for Flight Circuit 06 the construction and operation of HS2 would not affect the availability of landing sites in comparison to what is available within the existing flight circuit. There is only one point on the circuit where a landing field would no longer be available as a result of HS2 during the construction phase. This is mainly because as soon as the aircraft goes from the crosswind leg to the downwind leg of the Flight Circuit the aircraft would be able to glide past the footprint of HS2 during construction and HS2 Operational to find a suitable emergency landing field.

For Flight Circuit 24, there are a number of points on the circuit as a result of the construction of HS2 where the aircraft would not have a suitable site for an emergency landing available. This is because an aircraft would not be able to glide past the footprint of HS2 during construction. However, during the operational stage some of the area used for the Colne Valley Viaduct Main Compound is returned to grassland. This can be observed by comparing Figure 7.10 and Figure 7.11 between construction and operation.

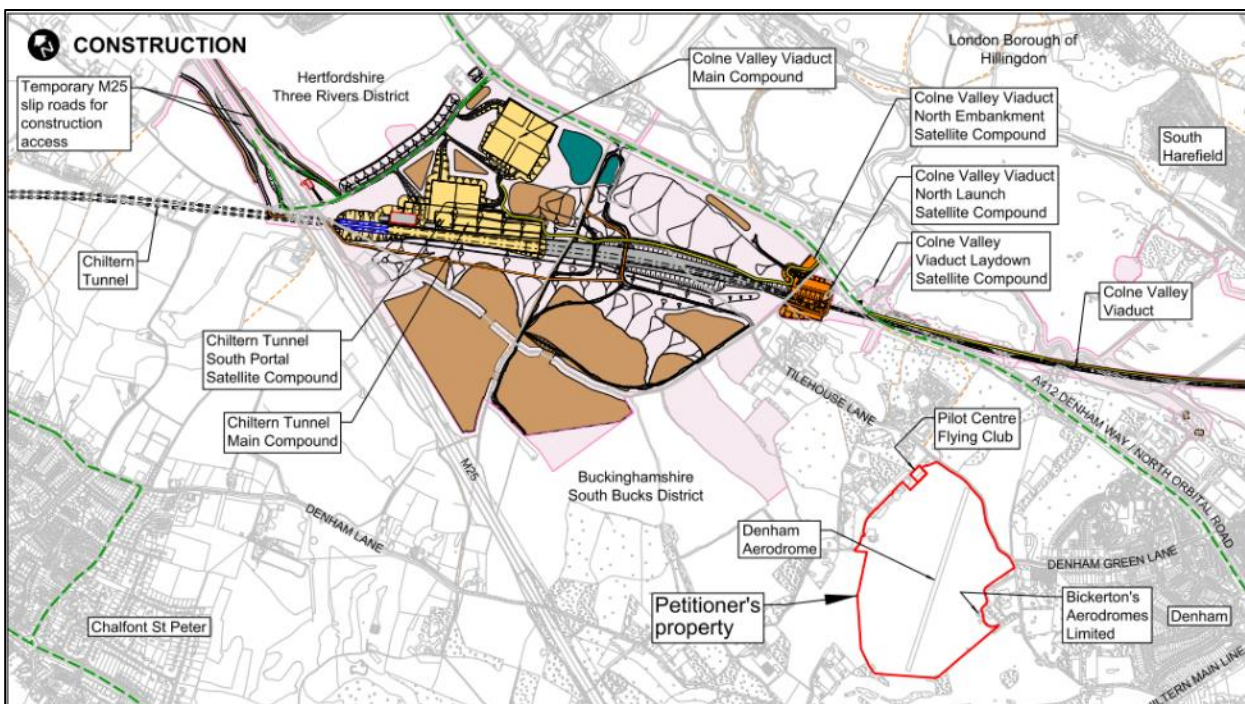


Figure 7.10: HS2 footprint during Construction

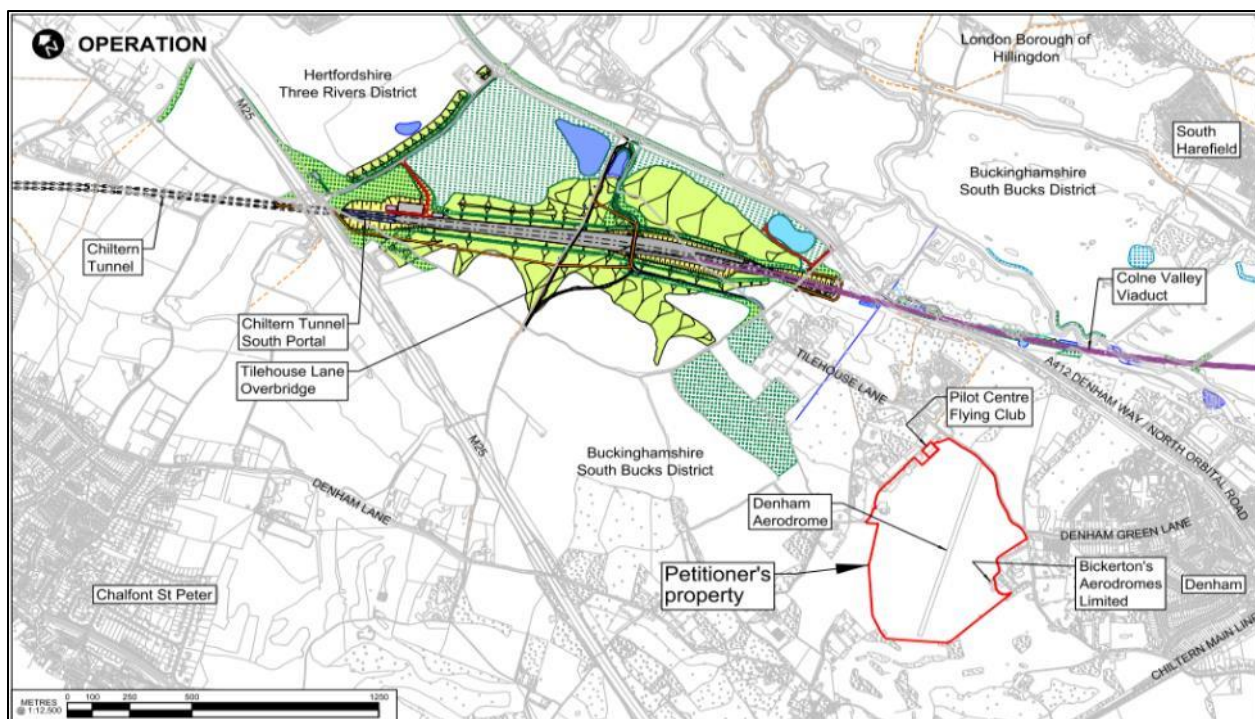


Figure 7.11: HS2 footprint during Operations

7.4 Risk Summary

The analysis presented in Table 7.2 is further summarised in the following table to show the proportion of the circuit in each case where there is no suitable landing area available.

Table 7.2: Percentage of Circuit with no suitable forced landing field available

	Existing Situation	HS2 Construction Phase	HS2 Operational
Runway 06 Anticlockwise Circuit	37%	40%	37%
Runway 24 Clockwise Circuit	23%	34%	26%

It is noted that in the existing situation up to 37% of the circuit has no suitable forced landing field available according to the methodology adopted. Since Denham Aerodrome continues to operate flying on these circuit patterns, the availability as calculated by this method is deemed to be tolerable and acceptable.

Although it is obvious that the HS2 route from the viaduct to the tunnel portal does cut across an existing large field, according to the methodology adopted to quantify the provision, there are sufficient suitable areas available to give the same result of $100\% - 37\% = 63\%$ availability for the Runway 06 circuit.

In the construction phase there is a worsening of the situation, with up to 40% of the circuit having no suitable forced landing area. However, this is only 3% worse than the existing situation. As a temporary situation it is considered not to be of sufficient significance to require mitigation.

For the Runway 24 circuit, the increase from currently 23% to 34% during the HS2 construction phase is noticeable. However, the 34% is still lower than what is being experienced on the Runway 06 circuit currently. Therefore, this is not considered to be of sufficient significance to require specific mitigation.

8. Crosswind Runway – Forced Landing Field Availability

Denham Aerodrome's secondary runway is the crosswind Runway 12/30. A typical circuit for the crosswind runway has been obtained from "The Operational Impact Assessment for proposed motorway services north of the airport"¹¹. A landing fields analysis has been undertaken in the same manner as for Runway 06/24, described in Section 7.2.

The accident records support the view that the probability and risk relate to fixed wing movements only. It is known that helicopters are manoeuvrable during autorotation after engine failure. A helicopter would typically autorotate at a descent angle of about 1 in 4.5 and would have full manoeuvrability to a survivable landing with low descent speed and low ground speed. Helicopters are not considered further in this part of the risk assessment which is carried out for fixed wing aircraft only.

The circuit for the crosswind runway is depicted in Figure 8.1.

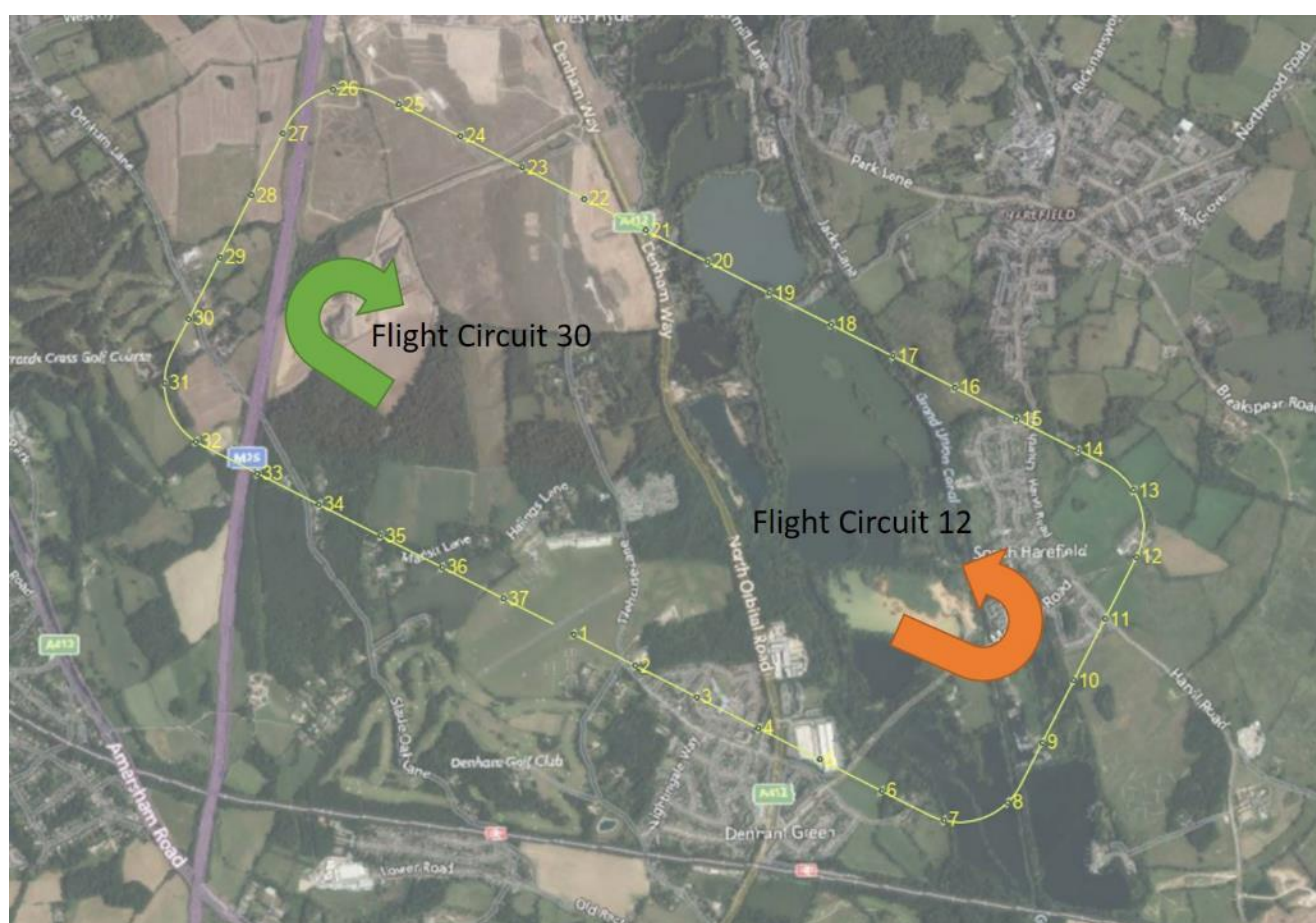


Figure 8.1: Crosswind Runway 12/30 typical circuit pattern

8.1 Method

The method used for the crosswind runway follows the same manner described in Section 7.1 for the primary runway.

¹¹ Operational Impact Assessment for Proposed Motorway Service Station North of Denham Airport, August 2020, Produced by Eddowes Aviation Safety Ltd.

8.2 Landing Field Analysis Outputs

The results for Runway 12/30 are shown in Table 8.1, below. A green cell means that at least one suitable landing site was identified and a red cell means that there were no landing sites identified with the criteria established.

Table 8.1: Emergency landing fields availability for Runway 12/30.

Point ID	Flight Circuit 12 - Existing	Flight Circuit 12 - Construction	Flight Circuit 12 - Operation		Flight Circuit 30 - Existing	Flight Circuit 30 - Construction	Flight Circuit 30 - Operation
1	1	1	1		1	1	1
2	-	-	-		1	1	1
3	-	-	-		-	-	-
4	-	-	-		-	-	-
5	-	-	-		-	-	-
6	-	-	-		-	-	-
7	-	-	-		-	-	-
8	1	1	1		-	-	-
9	1	1	1		-	-	-
10	1	1	1		-	-	-
11	1	1	1		-	-	-
12	1	1	1		-	-	-
13	1	1	1		-	-	-
14	1	1	1		1	1	1
15	1	1	1		1	1	1
16	-	-	-		1	1	1
17	1	-	-		1	1	1
18	1	-	1		1	1	1
19	1	-	1		1	1	1
20	1	-	1		1	1	1
21	1	-	1		1	1	1
22	1	-	1		1	1	1
23	1	1	1		1	1	1
24	1	1	1		-	-	-
25	1	1	1		1	-	-
26	-	-	-		1	1	1
27	1	1	1		1	-	1
28	1	1	1		1	-	-
29	1	1	1		1	-	1
30	1	1	1		1	-	1
31	1	1	1		1	1	1
32	1	1	1		1	1	1
33	1	1	1		-	-	-
34	1	1	1		1	1	1
35	-	-	-		-	-	-
36	1	1	1		1	1	1
37	1	1	1		-	-	-

These results are also shown in plan form in Figure 8.2 and Figure 8.3

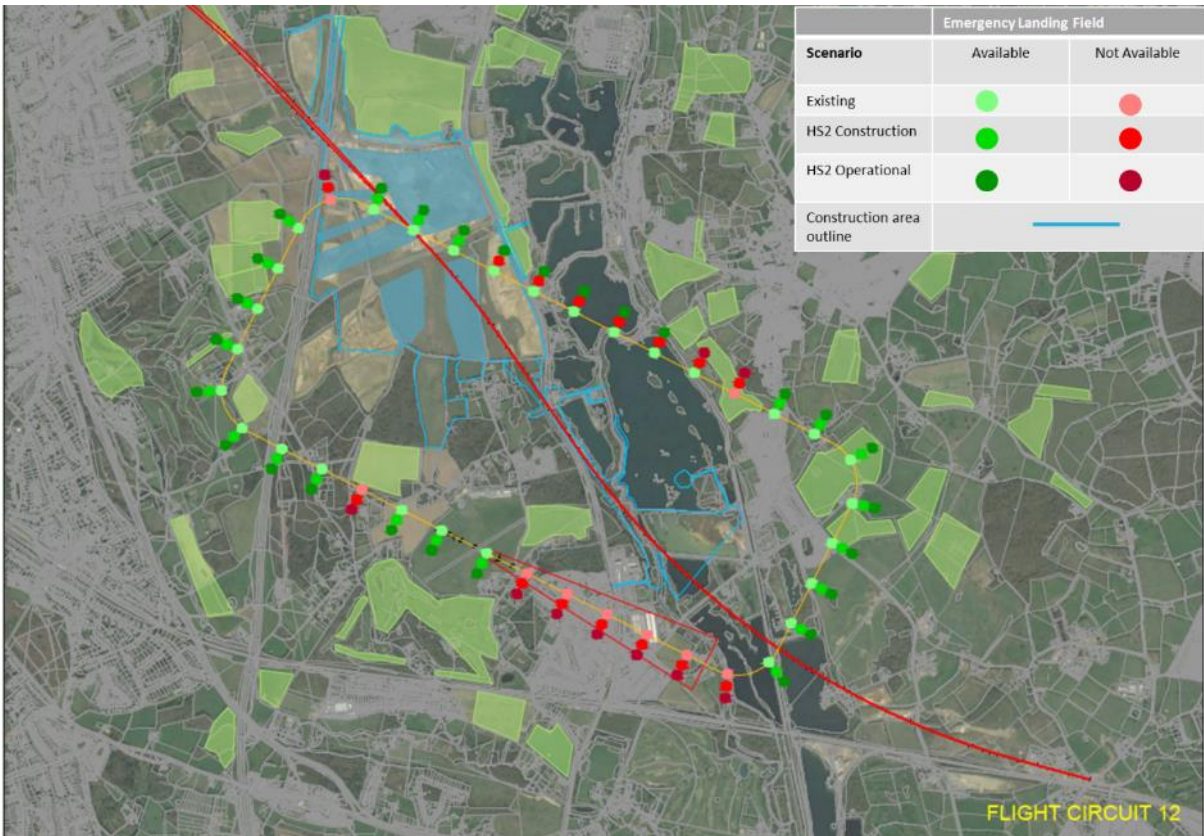


Figure 8.2 Landing Field Availability Results- Flight Circuit 12

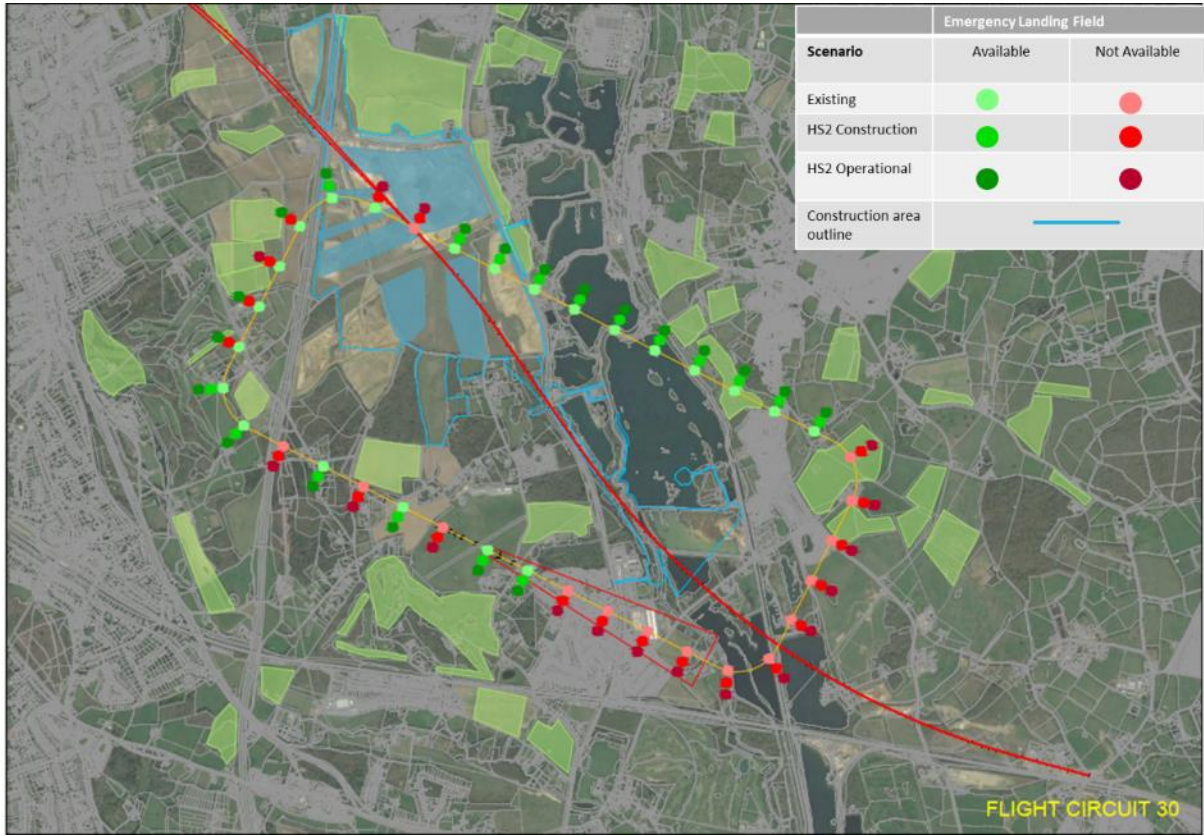


Figure 8.3 Landing Field Availability Results- Flight Circuit 30

As can be seen from the table above, the construction phase of HS2 has a greater impact on the availability of landing fields in comparison to current availability and the HS2 operational case. There are some current emergency landing fields that will no longer be available both in construction and operation phases of HS2.

8.3 Risk Summary

The analysis presented in Table 8.2 is further summarised in the following table to show the proportion of the circuit in each case where there is no suitable landing area available.

Table 8.2: Percentage of circuit with no suitable forced landing field available

	Existing Situation	HS2 Construction Phase	HS2 Operational
Runway 12 Anticlockwise Circuit	24%	40%	27%
Runway 30 Clockwise Circuit	41%	54%	46%

It is noted that for this crosswind runway, operations take place in the existing situation with up to 41% of the circuit having no suitable forced landing area available as assessed by the described methodology. As operations continue with that situation, that is deemed to be a tolerable and acceptable provision. For circuits from Runway 30 for both HS2 operational and the HS2 construction phase, the availability is significantly worse than in the existing situation. This is primarily due to overflying of the main HS2 construction compound.

Mitigation should be sought for this situation, which, given the state of definition of the HS2 authorised works in the HS2 Act, may require consideration of an amended circuit path for Runway 30.

9. Environment

9.1 Landscape Planting and Risk of Bird Strike

Migratory birds, during their migration fly at altitudes up to several thousand feet, but for most of the year birds fly under 500 ft above ground level. The most critical areas for risk of bird strike on aircraft are when the aircraft is low, either on a final approach to land or in the early part of the take-off climb. Additional tree planting in these areas would be of concern, however from the available drawings of the proposed landscaping around the proposed viaduct there will be a net reduction in trees under the Runway 06 TOCS and the Runway 24 Approach Surface. Copies of drawings available from the planning submission PL/19/3332/HS2 to Buckinghamshire Council included below show the significant amount of tree removal and limited replanting of trees in the area adjacent to the viaduct.

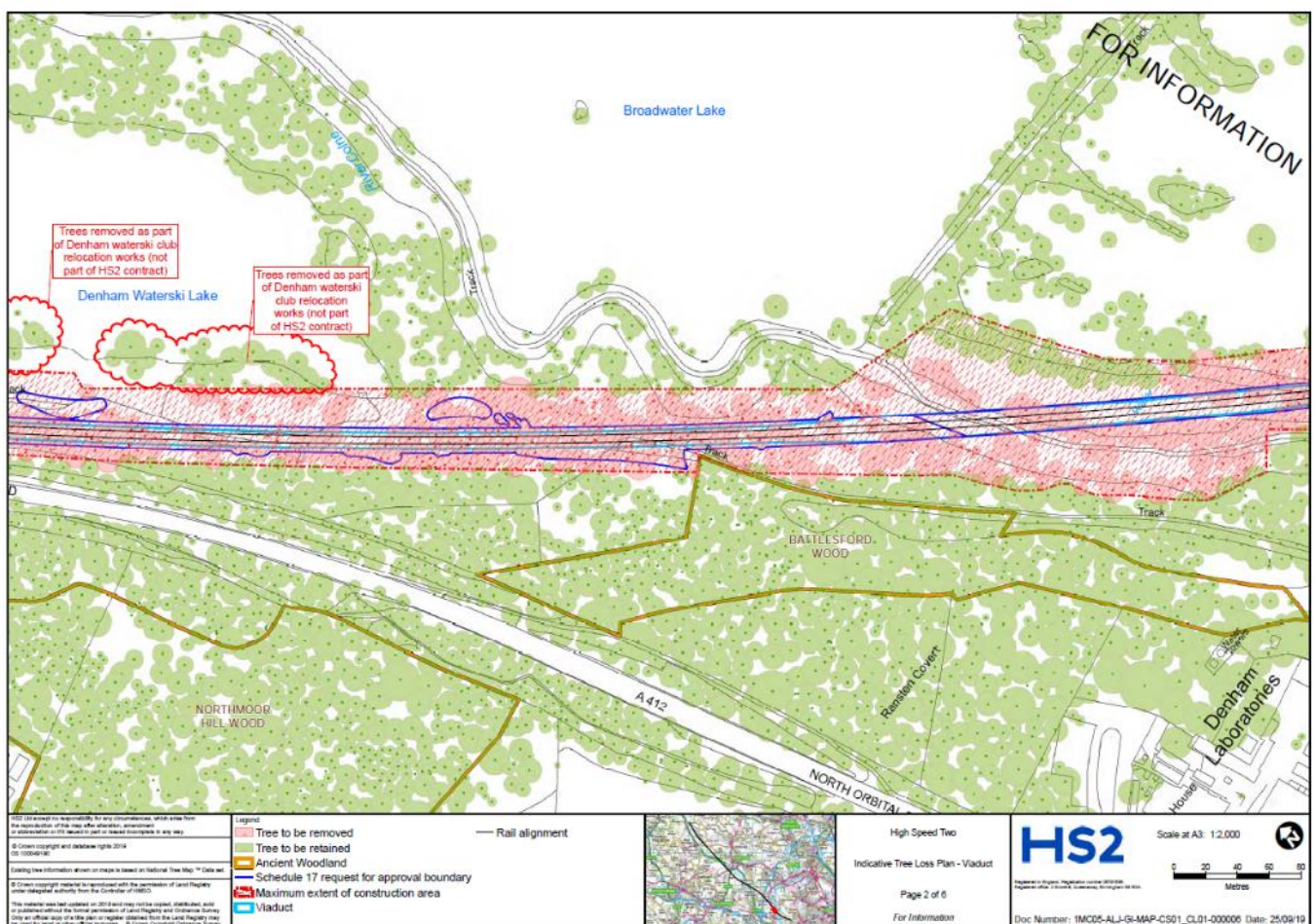


Figure 9.1: HS2 Indicative Tree Loss Plan – Viaduct

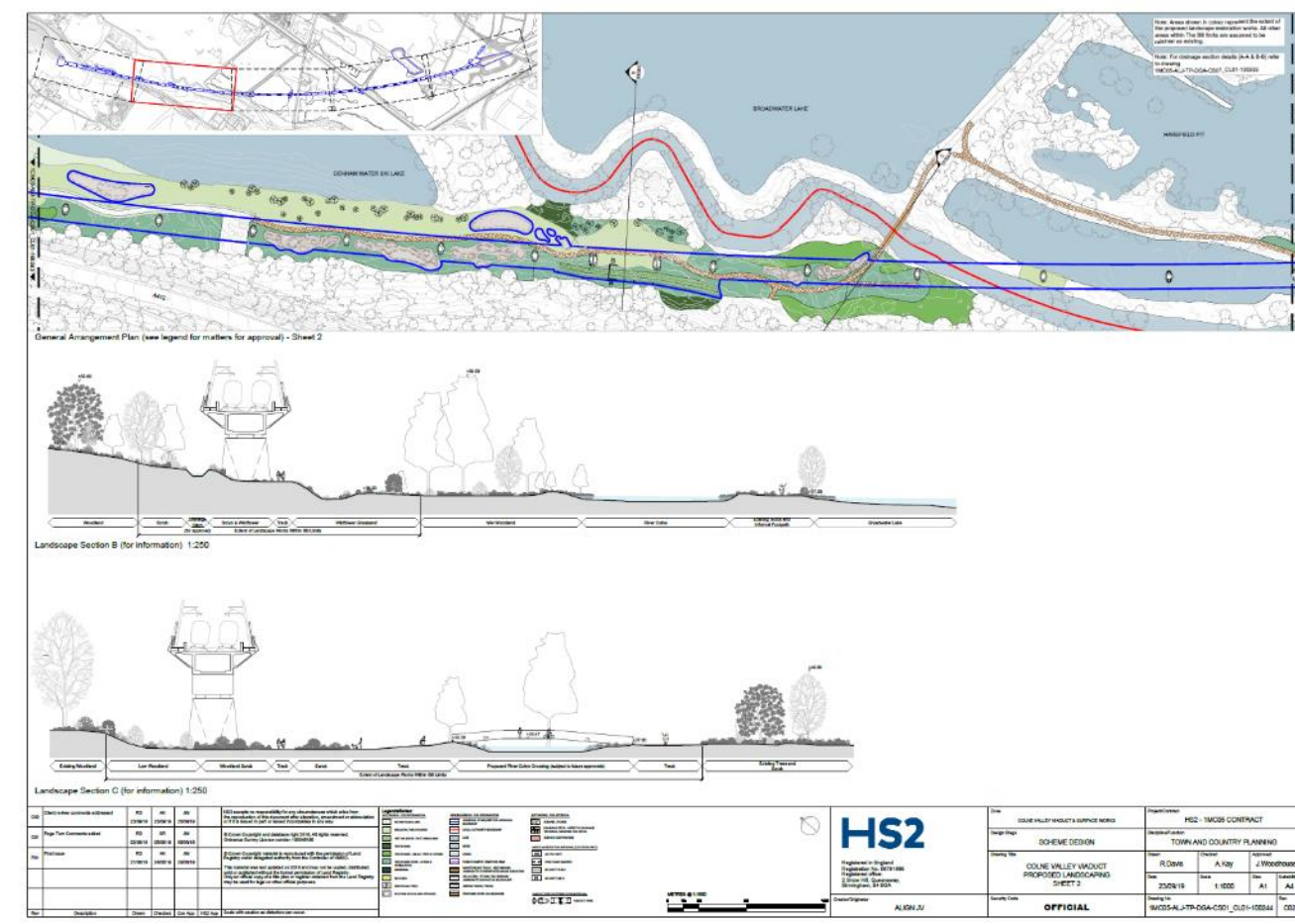


Figure 9.2: HS2 Proposed Landscaping for the Colne Valley Viaduct

The proposed planting of wetlands, grasslands or woodlands elsewhere is replacing lost habitat from the authorised works at locations where there should be no net increase in bird attractive habitat under the take-off and landing centrelines. Therefore, it is anticipated that there will be no net increase in the risk of bird strike to aircraft.

Concerns had been raised about bird strike risk in a report titled, "Denham Aerodrome (October 2016 –V3. Landscape Planning Ltd) ", submitted to HS2 Ltd on 21st November 2016. In their response dated 25th November 2016, HS2 Ltd provided a broader review of the proposed landscaping mitigation measures. This aeronautical study agrees with the overriding view of that review that it is not anticipated that there will be an increase in the risk of bird strike.

9.2 Dust Control

It is important that HS2 construction activities do not raise air-borne dust which has the potential to reduce visibility for pilots both landing and taking off from Denham Aerodrome and when generally making use of the Denham Aerodrome local flying area.

It is recommended that the construction specification includes clauses to require active dust control which should include a requirement to control dust by water spraying on any unsurfaced areas used by construction traffic.

9.3 Lighting

It is important that lighting of the authorised works, both during construction and in operation, is shaded to avoid direct light above the horizontal and is shaded to stop any directional beam from emerging in the direction of the runway centrelines.

It is recommended that the design is checked for satisfactory lighting provision in this regard, and that the construction specification should contain clauses to require shaded lights as described above.

During the construction stage, construction infrastructure above the final operational level of the viaduct has been found by this aeronautical study to constitute a hazard to aircraft. In accordance with CAP 168 Paragraph 4.77 such construction infrastructure, including craneage, should be lit with obstacle lights.

10. Third Party Risk

As detailed in Section 2.1.2, HS2 Ltd have previously considered that there is no risk arising from the proximity of the HS2 authorised works to Denham Aerodrome. Since this aeronautical assessment has determined that there is a risk, that should change the view taken by HS2 Ltd on the requirement for safety procedures to be developed in liaison with the operator of Denham Aerodrome.

This aeronautical assessment has dealt only with the impact of the HS2 authorised works on the safety of operations at Denham Aerodrome. It has not considered the potential impact to HS2 of an aircraft crash onto the viaduct. Guidance for the determination of public safety zones to control third party risk near to aerodromes states that a major transport route such as a main railway line should be considered to be populated to an extent similar to an area of residential development. Whereas there is some risk of an aircraft crashing onto any part of the nation including onto a railway line, the risk is clearly heightened where the viaduct passes close to the end of the main runway at Denham Aerodrome. It is recommended that HS2 Ltd should consider the inclusion of dealing with this risk in their plans for the safe operation of the railway.

For the particular case of the construction period, U&A 2633 deals with rescue and evacuation procedures and requires that, *"The Promoter will in consultation with the Aerodrome Manager put in place appropriate rescue and evacuation procedures for the recovery of aircraft at the West Hyde main construction site for the duration of the construction period."*

It is recommended that this work is extended to include the continuing requirement for appropriate rescue and evacuation procedures at all of the HS2 route through the Denham Aerodrome local flying area during the long-term operational phase.

11. Mitigations

11.1 Reasonably Practical and Required Recommendations and Mitigations

The ICAO definition of an aeronautical study includes that in response to an aviation problem there should be the identification of possible measures which do not cause a degradation of safety. The previous sections of this report have illustrated that in several ways the safety of operations at Denham Aerodrome is degraded by the construction and operation of the HS2 route on its designed alignment. Consequently, it is a requirement for this report to identify possible measures to mitigate the situation and thus to obtain no net degradation of the safety of operations at Denham Aerodrome. However, there are two tests of the reasonableness of the recommendations and mitigations emerging from this report that are required by the U&A Register to the HS2 Act.

Firstly, consider the wording of the commitment given in U&A 2631, repeated below for ease of reference.

"The Promoter will, so far as reasonably practicable, give effect to the conclusions and recommendations (if any) of the said assessment in the detailed design of the HS2 project (including the Colne Valley Viaduct) in so far as it affects the safe operation of Denham Aerodrome."

Whilst this aeronautical study is to make recommendations if required to avoid degrading safety, it is not the task of this report to determine whether they are reasonably practicable. That is for The Promoter and others monitoring the delivery of the U&A commitments to determine.

Secondly, the implementation of mitigation measures is considered in U&A 2632, which is worded as below.

"The Promoter will undertake such mitigation works at the Aerodrome as are found to be reasonably required by the said assessment, subject to obtaining any necessary consents and subject to the Petitioner granting any necessary rights of access."

Therefore, there is a need for this assessment, or aeronautical study, to consider whether a proposed mitigation measure is reasonably required. In this context the accuracy of quantitative risk analysis work should be considered. It would not be reasonable to require mitigation measures if the degradation of safety as quantified by the risk analysis was small and comparable in quantum to the level of inaccuracy in the analysis. Sections 5.4, 6.4, 7.3 and 8.3 summarise the quantitative risk analysis for Runway 06 take-off, Runway 24 landing and forced field landing availability respectively. Not all constitute a significant increase, and the implications of that consideration are discussed below where reasonably required and possible mitigations are described.

11.2 Assessment of Reasonably Required Mitigations

This section brings together the results of Sections 5 and 6 of this report. It assesses the combined probability of a fatal outcome after an engine failure during the initial take-off on Runway 06 or on the final approach to Runway 24, as shown in Table 11.2 below. The analyses described in Sections 5 and 6 gave results that are quoted in two ways. Firstly, as the probability of a fatal outcome to a single movement, and secondly by that result being expressed as the recurrence period in years on a basis of current or future annual traffic.

There is no aviation industry agreed level of tolerable risk for General Aviation individual movements. For commercial aviation, reference can be made to the ICAO Collision Risk Modelling benchmark of 1×10^{-7} per movement and this value has been used as a benchmark for other work. For example, a report by EASA¹² in 2014 into the safety assessment of runway end safety areas (RESA) notes that a study conducted for the Norwegian CAA, (Eddowes et al) propose a target level of safety of 1×10^{-7} in assessing RESA dimensions.

¹² European Aviation Safety Agency (EASA) 2014. Study on models and methodology for safety assessment of Runway End Safety Areas (RESA). 2014

In the absence of an agreed level of tolerable risk for individual movements, the probability of each case analysed in this assessment is first considered in terms of its predicted recurrence period in years.

When comparing the assessment results of the current situation with the HS2 construction and operational cases, the accuracy of quantitative risk assessment should be considered.

Risk assessments in aviation generally follow the UK CAA CAP 760 "Guidance on the Conduct of Hazard Identification, Risk Assessment and the Production of Safety Cases". Probability classifications for quantitative annual recurrence periods are given in Table 2 of CAP 760 Chapter 3, which is included here for ease of reference as Table 11.1. The table from CAP 760 has been extended to show the logarithmic scale used by CAA and the results of the probability assessments from this report are shown on that scale. It is noticeable that regardless of whether the assessment uses historic aircraft crash data, whether or not the target area approach of CRR 150/1997 is used, or whether assessed using the mechanistic method described in Sections 5 and 6 of this report, all results have the same probability classification of "Remote".









The range of probability classification is over 5 levels from "Frequent" to "Extremely Improbable". Each is shown to cover a range of a factor of 100, and the mid-point of each is a factor of 100 from the adjacent defined level of probability. In such a context a small change in a calculated probability would not be likely to change the classification of that probability and therefore is unlikely to change the resulting tolerability derived from a Risk Classification/Tolerability Matrix table since these use the probability classifications..



An appropriate benchmark of tolerability is the probability for the risk of a fatal outcome that is currently, or historically has been, accepted as a normal risk of operations at Denham Aerodrome. These have been given a **green** highlight in Table 11.2. Since the initial take-off climb on Runway 06 and the final approach to landing on Runway 24 take place over lakes and woodland, there is an existing risk of a fatal outcome. This has been assessed as a recurrence period of 1 in 359 years (relative to the air traffic using Denham in the 1990s). From Table 11.1 this is a probability classification of "Remote".

The recurrence period for a fatal accident during the initial take-off climb or final approach whilst HS2 is under construction as shown in Table 11.2 is 1 in 382 years, which would also be a probability classification as "Remote". Similarly, the recurrence periods once HS2 is operational are also classified as "Remote".

The Hazard and the Consequence of power failure followed by a fatal aircraft crash are the same in all three cases: existing, HS2 under construction and HS2 operational. All three have the same Probability Classification as "Remote" and therefore in a Risk Assessment Tolerability Matrix all three give the same result. If the initial take-off climb on Runway 06 and the final approach to Runway 24 are considered to be tolerable in the existing case, and surely they must be so or the airport should not be operating as it does, then it is equally tolerable with the authorised HS2 works in place to the resolution of quantitative assessment used in aeronautical safety assessments.

Table 11.1: As in UK CAP 760 Chapter 3 Probability Classifications and Jacobs Result Ranges

		Probability of Occurrence Definitions					
		Extremely improbable	Extremely remote	Remote	Reasonably probable	Frequent	
	Qualitative definition	Should virtually never occur	Very unlikely to occur	Unlikely to occur during the total operational life of the system	May occur once during total operational life of the system	May occur several times during operational life	
	Quantitative numerical definition	<10 ⁻⁹ per hour	10 ⁻⁷ to 10 ⁻⁹ hour	10 ⁻⁵ to 10 ⁻⁷ hour	10 ⁻³ to 10 ⁻⁵ hour	1 to 10 ⁻³ per hour	
	Quantitative annual/daily equivalent (approximate)	Never	Once in 1000 years to once in 100,000 years	Once in 10 years to once in 1000 years	Once per 40 days to once in 10 years	Once per hour to once in 40 days	
Recurrence Period N Yrs		Never	100,000	1000	10	0.11	1.14 x10 ⁻⁴
Logarithmic Scale Log N		∞	5	3	1	-1	-3
Probability to a fatal accident on the initial take-off climb or final approach assessed using mechanistic method of Sections 5 and 6. See Table 11.2							
Existing							
HS2 Under Construction							
HS2 Operational							
Probability to a fatal accident on the initial take-off climb or final approach assessed using historic accident records see Appendix (Section A.3)							
Existing							
HS2 Operational							
Probability of a collision with the viaduct HS2 Operational							
As per CRR 150/1997 (Section A.1)							
As per Jacobs Section 4							
As above with CRR150/1997 (Section A.2)							

Legend  Width covers the range of existing to forecast (as in 1990s) traffic
 Single point result

During the construction period, it should be noted also that the height of the cranes, their locations and their numbers have been reduced from the initial data provided by AlignJV in response to concerns raised. Crane heights and numbers within critical areas are now considered by AlignJV to be as low as reasonably practicable (ALARP), supported also by the duration of the construction phase under the TOCS and AS of less than one year.

Proposed mitigations for the HS2 construction phase will focus on constraining the height of construction operations to those that have been analysed as part of this assessment.

Table 11.2: Combination of Results from Sections 5 and 6 for Take-off and Landing

		Existing Forced Landing into Treetops or ditching	Worst case result during Construction Phase	HS2 Operational
Engine failure during Initial climb on take-off from Runway 06	Probability of a fatal outcome to a single movement	1.16E-07	1.67E-07	1.38E-07
	Recurrence Period in No. of Years for Current Traffic	1,654	1,149	1,397
	Recurrence Period in No. of Years for Forecast Traffic. (Based on previous sustained 10 year high)	1,099	Not Applicable as traffic not expected to increase to the "Forecast" level during the construction period	928
Engine failure during final approach to landing on Runway 24	Probability of a fatal outcome to a single movement	1.31E-07	1.84E-07	1.38E-07
	Recurrence Period in No. of Years for Current Traffic	802	572	760
	Recurrence Period in No. of Years for Forecast Traffic. (Based on previous sustained 10 year high)	533	Not Applicable as traffic not expected to increase to the "Forecast" level during the construction period	505
Combined for take-off and landing	Recurrence Period in No. of Years for Current Traffic	540	382	492
	Recurrence Period in No. of Years for Forecast Traffic. (Based on previous sustained 10 year high)	359	Not Applicable as traffic not expected to increase to the "Forecast" level during the construction period	327

However, this report has made it clear that the viaduct is not fully shielded from aircraft collision from flight by the trees or the topography. The viaduct is a new object in the obstacle environment at the end of the runway and the results when expressed as probabilities for an individual movement show that there is a minor degradation of safety. Although as described above, in the context and accuracy of quantitative risk assessment those results do not present a robust case for reasonably required mitigation; the response to a degradation of safety must be to seek mitigation where that is reasonably practicable. To this end AlignJV were asked to consider whether lowering the viaduct was reasonably practicable. AlignJV have responded to confirm that the viaduct adjacent to Denham Aerodrome is as low as is reasonably practicable, being constrained by clearances over nearby major and local roads.

11.3 Proposed Mitigations

The following mitigations are proposed.

Table 11.3: Proposed Mitigations Summary

Degradation of Safety to be Addressed	Proposed Mitigations
1. Probability of collision with the viaduct after an engine failure during the initial climb during a take-off from Runway 06 by rotary wing aircraft (helicopters).	1. Denham Aerodrome operator to recommend all Runway 06 take-offs by helicopters to be initiated in the southwest portion of the aerodrome, if no cost is associated.
2. Probability of collision with the viaduct after an engine failure during the initial climb during a take-off from Runway 06 and for engine failure on final approach to a landing on Runway 24 by fixed wing aircraft. HS2 in construction phase	2. Construction method has been developed to limit crane heights and numbers of cranes in the zone underneath the TOCS and AS. Construction contract documents should specify these constraints on crane heights and numbers in the zone underneath the TOCS and AS.
3. Reduced availability of suitable areas for forced field landings after engine failure.	3. Denham Aerodrome operator to consider whether temporary improvements can be made for the cross-wind runway circuits during the HS2 construction period by adjusting the circuit pattern. <u>HS2 Ltd to prioritise the early return of the site compound to open landscaped areas.</u>

11.4 Rejected potential mitigations measures

11.4.1 South-westerly Runway Extension

In addition to the proposed mitigations listed above, consideration was given to the potential benefits to be gained from physical changes to the aerodrome and its main runway. One option considered was to extend the runway to the southwest, into the adjacent golf course, thus allowing the take-off on Runway 06 to take place further from the viaduct, allowing aircraft to overfly the viaduct at a greater height. However, this has not been pursued further and is not a recommended mitigation measure for several reasons.

The risk being mitigated is that described in 3 in the table of proposed mitigations and is a minor degradation of safety which would not justify such an expensive mitigation. Secondly, as the GA aircraft being considered climb at just over 7%, only 7m more clearance over the viaduct is obtained for each 100m of runway extension. This would not be enough to significantly reduce the risk of collision with the viaduct. Thirdly, land acquisition issues, the likelihood that planning permission may not be granted and the elapsed timescale to implement such a project means that it would be unlikely to deliver the intended mitigation.

11.4.2 New Main Runway with Different Orientation

Another option considered was to develop a new runway on an alignment rotated clockwise from the existing main runway. This would result in a take-off path to the east with greater separation between runway end and viaduct, thus achieving an increased height by aircraft overflying the viaduct. At that point, the HS2 infrastructure would also be shielded by a steep wooded hillside.

However, in addition to the same issues of land acquisition and planning permission, this option would direct the take-off traffic on Runway 06 over residential housing areas in Harefield and would probably be assessed as environmentally unsatisfactory.

12. Conclusions and Recommendations

12.1 Conclusions

This aeronautical assessment concludes that the construction and operation of the authorised works do have an impact on the safety of operations Denham Aerodrome.

There is a possibility of a single engine aircraft colliding with the viaduct if it suffers an engine failure on take-off towards the viaduct, or on landing towards the viaduct approaching from the northeast. The probability of this happening once HS2 is operational is low. It is only slightly higher than the existing probability of a fatal outcome from the same occurrence of an engine failure. The combined recurrence period of such an incident is calculated as one in 492 years at the current level of air traffic which is classified as a "Remote" probability, the same as in the existing situation for a fatal forced landing into the treetops or on ditching. There being no change in the probability classification of a fatal aircraft accident the tolerability is assessed to be the same as in the existing situation.

During the HS2 construction period there is an increased risk of a fatal outcome from such an engine failure. However, the probability expressed by combining the results for take-off and for landing as a combined recurrence period is less frequent than what was being experienced for the 10 years of traffic from 1990 to 1999 and is also classified as a "Remote" probability. It is concluded that the probability of a fatal outcome during the construction phase is similarly assessed as tolerable. After an initial Jacobs analysis of higher cranes (used without constraints), AlignJV adapted the construction method. As a result, cranes are now lower in height and are assessed as two cranes per three pier locations (constrained use). This is now considered by AlignJV to be as low as reasonably practicable. The construction phase is expected to last for less than one year underneath the TOCS and the AS. It is concluded that no further mitigation measures are reasonably required for this case, other than to ensure that the crane heights used in the assessment are taken forward into the construction specification.

The availability of suitable areas of land for survivable forced field landings on the crosswind runway circuits is significantly reduced by the HS2 authorised works in the main construction site compound area, especially during the construction phase. To mitigate this, it is suggested that the circuit pattern should be modified to route it further away from the site compound and that the earliest return of the site compound to open landscaped areas to facilitate forced landings should be prioritised.

12.2 Recommendations

- 1) That the mitigation measures proposed in Section 11.2 are given due consideration and, where appropriate and compliant with the tests of reasonableness described in Section 11.1, are implemented.
- 2) That dust control measures are included in the construction specification.
- 3) That the design and the construction specification require that lights, other than obstacle lights, are shaded to stop vertical light spread and are shaded to stop directional light in line and towards or away from runway centrelines.
- 4) That in accordance with CAP 168 Paragraph 4.77 construction infrastructure, including craneage, be lit with obstacle lights.
- 5) That HS2 Ltd should consider the inclusion of dealing with the risk of aircraft accidents on the viaduct in their plans for the safe operation of the railway.
- 6) For the particular case of the construction period, U&A 2633 deals with rescue and evacuation procedures and requires that, *"The Promoter will in consultation with the Aerodrome Manager put in place appropriate rescue and evacuation procedures for the recovery of aircraft at the West Hyde main construction site for the duration of the construction period."* It is recommended that this work is extended to include the continuing requirement for appropriate rescue and evacuation procedures at all of the HS2 route through the Denham Aerodrome local flying area during the long-term operational phase.
- 7) That the earliest return of the site compound to open landscaped areas to facilitate forced landings should be prioritised.

Appendix A.

A.1 Collision Probability Analysis using CRR 150/1997

The Denham Aerodrome Manager has advised that an alternate method described in a Contract Research Report CRR 150/1997 carried out for the HSE should be used instead of the method described in Sections 4.2 to 4.6 of this report.

Contract Research Report CRR 150/1997 was carried out by AEA Technologies for the HSE. That CRR includes the caveat that "*The contents and conclusions of this report are those of the authors and are not necessarily HSE policy.*" Much of the source material for CRR 150/1997 was prepared as part of the General Nuclear Safety Research Programme. A well-argued method for assessing the background risk of aircraft crashing into industrial or nuclear plant sites nationwide is presented. The method is extended to make allowances for heightened risk such as under airways and when the site is reasonably close to an aerodrome. However, there are shortcomings described in the CRR that particularly affect the treatment of aircraft crashes on take-off or landing close to runway ends and in particular for light aircraft crashes.

Equations provided for calculation of the crash distribution in the vicinity of an aerodrome in CRR 150/1997 were updated in that report in an attempt to remedy the shortcomings but they cannot be applied close to a runway end and were not updated for light aircraft. If the methods and parameters from CRR 150/1997 were applied, then the calculation proceeds as follows.

The probability of a collision onto the proposed viaduct for a single movement is given by the following equation.

$P = \text{Target Area of Structure} \times \text{Probability of a crash} \times \text{Probability of the crash occurring within the target area}$

For the Target Area of the Structure, the length is taken from the work carried out on behalf of Denham Aerodrome as 42.04m and the length is taken as the width of the Take Off Climb Surface at the proposed viaduct which is 190m. The Target Area is thus $8 \times 10^{-3} \text{ Km}^2$.

The probability of a crash occurring, either on take-off or on landing, is given in CRR 150/1997 as 1.2×10^{-6} . It is noted here that the same probability is quoted for a take-off accident as for a landing accident. Also the authors of CRR 150/1997 seem to have a good understanding that the level of accuracy in quantitative risk analysis work is at an Order of Magnitude level by commenting that the value of 1.2×10^{-6} is considered to be in good agreement with that put forward by another source of 3×10^{-6} .

The probability of the crash occurring in a unit of area is given by the following equation. The same distribution is used for landings and for take-off crash locations.

$$F(r, \text{Theta}) = 0.08 e^{-r/2.5} e^{-\text{Theta}/60}$$

Where r and Theta represent the vector of the location being considered, r being in Km from the runway end and Theta being the angle in degrees off the runway centreline. For simple calculation r will be taken as 650m, being 0.65 Km and Theta as zero. There would be a slight reduction in the result if the lower values for the area either side of the runway centreline and beyond 650m were calculated and used. Using the worst case parameters, the result is:

$$F(r, \text{Theta}) = 0.08 e^{-0.65/2.5} = 0.0617 \text{ Km}^{-2}$$

The three parameters are now multiplied together to give the probability of a collision with the proposed viaduct.

$P = 8 \times 10^{-3} \times 1.2 \times 10^{-6} \times 0.0617 = 5.9 \times 10^{-10}$ per movement for either a take-off or a landing.

This result differs markedly from estimates of the collision risk from the Jacobs analysis and give a much lower probability of collision with the viaduct. The CRR method gives a result that is 464 times less likely than the result given in Table 4.6 of this report for take-off crashes and 198 times less likely for a landing crash. The

absolute value of 5.9×10^{-10} gives a combined recurrence period for either a take-off or a landing crash colliding with the viaduct of over one in a hundred thousand years at 1 in 115,075 years for the current traffic level.

The marked difference between the results from the methods and parameters put forward in CRR 150/1997 and the results of the analysis of albeit very limited numbers of historic accidents described in Section 4.2 to 4.6 of this report suggests either that the equations and parameters from CRR 150/1997 may be inappropriate for use at Denham Aerodrome, or that the conclusions from the Jacobs empirical model in Section 4 may be inappropriate due to the limited number of accident records available for analysis.

From the above, the calculation method proposed in CRR 150/1997 is not considered to be appropriate guidance for aircraft crash probabilities at the site of the Colne Valley Viaduct under the take-off and approach flight paths to Denham Aerodrome. Nor may the Jacobs empirical model based on relatively few accident records be appropriate on its own. For this reason Jacobs use the historic crash records as an initial estimate only, solely to demonstrate that there is a case for consideration of the risk of collision with the viaduct, but carry out a more detailed and appropriate analysis of the risk of collision with the viaduct in Sections 5 and 6 of this report. Report sections 4.2 to 4.6 are based solely on the data of actual historic crash locations, as treated statistically to provide a crash location distribution in the vicinity of the runway ends. It has served to demonstrate in as incontrovertible a manner as possible, with assumptions that cannot be challenged as being taken such as to overstate the risk, that historical data shows there is a risk of an aircraft crashing onto, or with the crash area overlapping onto, the viaduct. This has usefully countered any comments which stated that there have been no recorded incidents of an aircraft crash on the location of the proposed viaduct.

A separate point has been made in advice from the Denham Aerodrome Manager about the lack of consideration of the height of the viaduct in the Jacobs report when considering the quantitative crash probability based on accident records. There are valid reasons why Jacobs chose not to include a detailed assessment of the effect of the height of the viaduct in Sections 4.2 to 4.6 of the Jacobs report. For the methods and parameters described in CRR 150/1997 to be valid it is important that they are mutually consistent. The range of accident data used to establish the crash distribution function should be matched and be consistent with the range of data used to define the accident probability and the range of glide or dive slopes in the final stages of a crash and their probabilities of occurrence. That may or may not be the case for the parameters proposed in CRR 150/1997 but it cannot be the case for the data considered by Sections 4.2 to 4.6. Here, by limiting the data to accidents at Denham or at similar aerodromes only a restricted data set is available, and the accident reports for these accidents do not include details of the final glide or dive slope immediately prior to the accident. A detailed assessment which does include the height of the structure and the effect of partial shielding by topography and trees is given in Sections 5 and 6 of the Jacobs report.

Notwithstanding the shortcomings of the equations proposed for use in CRR 150/1997, and the possibly inappropriate parameters, the essential nature of the method used in CRR 150/1997 is that the probability of an aircraft coming down on a glideslope out of the sky on its way to an accident location is combined with the probability of an appropriate range of glideslopes. For a given structure height, the probability of those glideslopes necessarily involving a collision with the structure can then be calculated. This is exactly the method followed in Sections 5 and 6 of the Jacobs report; so the essence of what the Denham Aerodrome Manager terms the conventional method has been followed by Jacobs.

A.2 Collision Probability Analysis using CRR 150/1997 Target Area and Jacobs probability density functions for collisions on target area

This sub-section explores how the results obtained in Section 4 would change if the crash area length is calculated as suggested in CRR 150/1997.

The target area length can be calculated using the effective target area equation A1.2 in CRR 150 / 1997 which deals with unidirectional crashes from the East and West. Where, l is the width of the viaduct, w is the length of the viaduct under the TOCS/AS, h is the height of the viaduct, f_i is the proportion of crashing aircraft having descent angle θ as per Table 9. The dimensions are also shown in the extracted Figure A1.2

$$A_{EW} = lw + wh \sum_{i=1}^{i=n} f_i \cot \theta_i \quad (A1.2)$$

Figure A1.2
Effective target area of an unshielded structure

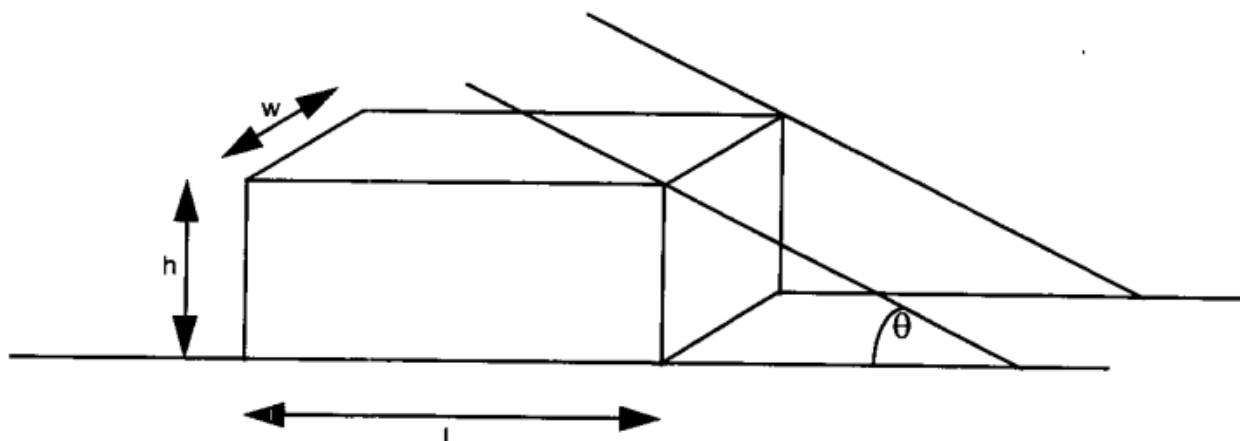


Figure A.1: Effective target area extracted from CRR 150/1997

The height of the viaduct is calculated based on information provided by Align JV for the proposed rail alignment. This was calculated on the North edge, Centre, and South edge of the TOCS/AS as shown in the table below. It was found that the greatest height of the viaduct is on the Northern edge of the TOCS/AS at 20.43m. Therefore, this is considered for the target area calculations.

Table A.1: Viaduct height calculation.

	North Section TOCS	Centre Section TOCS	South Section TOCS
Ground elevation (m AOD)	39.345	40.52	40.517
Proposed rail line (m AOD)	52.278	52.082	51.885
Height of wiring above rail line (m)	7.5	7.5	7.5
Height of the viaduct (m)	20.43	19.06	18.87

Then, considering the descent angle distribution set out in Table 9 of CRR 150/1997 a weighted average for $f_i \cot \theta$ of 1.24 is obtained. This is used to calculate the target area length which can be simply obtained by:

$$\text{Target Area length} = l + 1.24 * h$$

Width of the viaduct: $l=13.4\text{m}$

Height of the viaduct: $h=20.43\text{m}$

The target area length is therefore calculated at 38.73m. This is then applied to the crash location probability density functions obtained in Section 4 of the present report. The results are shown in the tables below.

Table A.2: Crash probability results for current traffic

Runway	Fixed wing Take-off movements p.a.	Fixed wing Landing movements p.a.	Single Movement Probability	Recurrence Period in years	Probability in one year	
Runway 06	5,201	N/A	3.39E-07	567	1.77E-03	
Runway 24	N/A	9,530	1.50E-07	699	1.43E-03	
Combined probability						3.20E-03
Combined recurrence period in years						313

Table A.3: Crash probability results for forecast traffic

Runway	Fixed wing Take-off movements p.a.	Fixed wing Landing movements p.a.	Single Movement Probability	Recurrence Period in years	Probability in one year	
Runway 06	7,829	N/A	3.39E-07	376	2.66E-03	
Runway 24	N/A	14,345	1.50E-07	464	2.15E-03	
Combined probability						4.81E-03
Combined recurrence period in years						208

With the current traffic levels at Denham Aerodrome it can be seen that the combined recurrence period for an aircraft crash location on or immediately adjacent to the viaduct changes from 1 in 393 years (as per Section 4) to 1 in 313 years. For the forecast traffic the recurrence period changes from 1 in 261 years (as per Section 4) to 1 in 208 years.

A.3 Collision Probability Analysis using CRR 150/1997 Target Area and Jacobs probability density functions for accidents on the take-off climb and final approach

This section analyses the probability of an aircraft having an accident between the airfield boundary and the first field available on the other side of the lakes where a survivable forced landing can be performed. This section uses the CRR 150/1997 Target Area and Jacobs' probability density functions outlined in Section 4.

The aim of this section is to determine the baseline for the existing scenario without HS2 where an accident on the treetops or the lakes is deemed 90% survivable throughout the take-off climb or final approach to the aerodrome. Then, this is compared this to the probability of a 100% fatal accident if the crash occurs on the target area length and 90% survivable on the treetops or lakes outside of the target area. This will provide a measure of the change of probability with and without HS2. The sections analysed are presented in the sketch below (Figure A.2

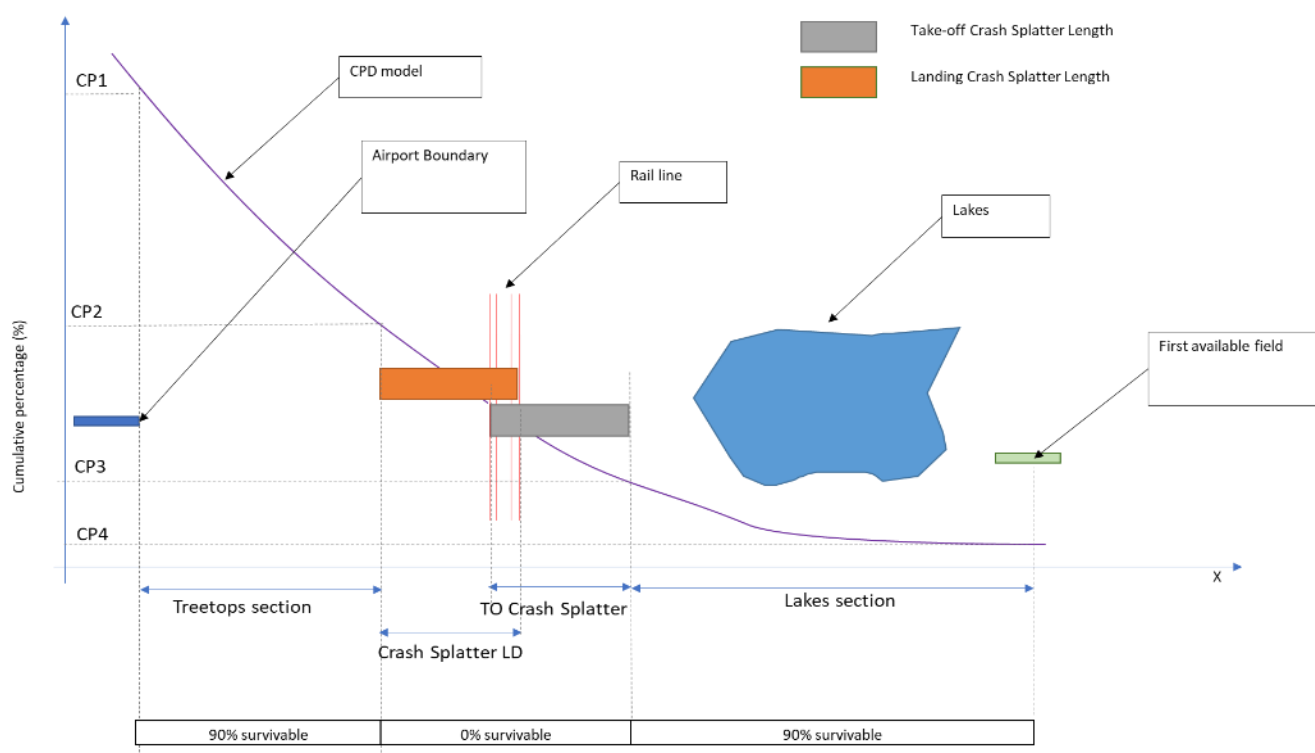


Figure A.2: Crash location sections involving probability determination

Using the same methodology as explained in Section 4, the probability to a single movement in the section between the airfield boundary and the start of the crash area is calculated. Similarly, for the probability to a single movement for the section between the end of the crash area and the first field available on the other side of the lakes is calculated. Both probabilities are applied to a factor of 90% survivability (10% fatal).

For the section of the target area, the probability calculated in the section above represents the likelihood of an aircraft colliding with the viaduct. This section applies a 10% fatal outcome for the existing scenario without HS2. For the case with HS2 operational a 100% fatal outcome in the length of the target area is applied.

The results obtained represent the likelihood of an aircraft crash location having a fatal outcome on the take-off climb portion for a take-off from Runway 06 and on the final approach for a landing on Runway 24, based on CRR 150/1997. The recurrence period of such event is also shown. An overall recurrence period is provided, this is directly dependent on the level of traffic at the aerodrome, thus, results have been shown for current and forecast traffic.

Table A.4: Crash probability results **without HS2** along the take-off climb and final approach for current traffic

Runway	Fixed wing Take-off movements p.a.	Fixed wing Landing movements p.a.	Single Movement Probability	Recurrence Period in years	Probability in one year	
RWY 06 Takeoff	5,201.0	N/A	1.24E-06	155	6.46E-03	
RWY 24 Landing	N/A	9,530.0	3.90E-07	269	3.72E-03	
Combined probability						1.02E-02
Combined recurrence period in years						98

Table A.5: Crash probability results **with HS2** along the take-off climb and final approach for current traffic

Runway	Fixed wing Take-off movements p.a.	Fixed wing Landing movements p.a.	Single Movement Probability	Recurrence Period in years	Probability in one year	
RWY 06 Takeoff	5,201.0	N/A	1.55E-06	124	8.05E-03	
RWY 24 Landing	N/A	9,530.0	5.25E-07	200	5.01E-03	
Combined probability						1.31E-02
Combined recurrence period in years						77

Table A.6: Crash probability results **without HS2** along the take-off climb and final approach for forecast traffic

Runway	Fixed wing Take-off movements p.a.	Fixed wing Landing movements p.a.	Single Movement Probability	Recurrence Period in years	Probability in one year	
RWY 06 Takeoff	7,829	N/A	1.24E-06	103	9.73E-03	
RWY 24 Landing	N/A	14,345	3.90E-07	179	5.60E-03	
Combined probability						1.53E-02
Combined recurrence period in years						65

Table A.7: Crash probability results **with HS2** along the take-off climb and final approach for forecast traffic

Runway	Fixed wing Take-off movements p.a.	Fixed wing Landing movements p.a.	Single Movement Probability	Recurrence Period in years	Probability in one year	
RWY 06 Takeoff	7,829	N/A	1.55E-06	83	1.21E-02	
RWY 24 Landing	N/A	14,345	5.25E-07	133	7.54E-03	
Combined probability						1.97E-02
Combined recurrence period in years						51