International Civil Aviation Organization

Twenty-Ninth Meeting of the Regional Airspace Safety Monitoring Advisory Group (RASMAG/29)

Bangkok, Thailand, 19 – 22 August 2024

Agenda Item 3: Reports from Asia/Pacific RMAs and EMAs

RVSM RISK ASSESSMENT IN THE BRISBANE, HONIARA, MELBOURNE, NAURU, AND PORT MORESBY FLIGHT INFORMATION REGIONS

1 JANUARY 2023 TO 31 DECEMBER 2023

(Presented by Australian Airspace Monitoring Agency)

SUMMARY

This paper presents an airspace Safety Review of RVSM airspace risk in the Brisbane, Honiara, Melbourne, Nauru, and Port Moresby Flight Information Regions (FIRs) for the period 1 January 2023 to 31 December 2023. The risk meets the Target Level of Safety (TLS) of 5.0 x 10^{-9} fatal accidents per flight hour (fapfh). A brief quantitative assessment of the safety reporting culture is also conducted.

Results show a technical risk of 0.101 x 10^{-9}, an operational risk of 1.41 x 10^{-9} and a total risk of 1.51 x 10^{-9}, all below the TLS.

1. INTRODUCTION

1.1 This report provides an airspace Safety Review of RVSM airspace risk in the Brisbane, Honiara, Melbourne, Nauru, and Port Moresby FIRs for the period 1 January 2023 to 31 December 2023. The review is undertaken using a 12-month data sample period.

1.2 All airspace safety estimates and TLS values in this report are measured in terms of fatal accidents per flight hour (fapfh).

1.3 The estimated risk is compared to the TLS of no more than 2.5 x 10^{-9} for the technical component of the risk, and 5.0 x 10^{-9} for the total weighted risk.

1.4 The results indicate risk below the TLS.

1.5 A 19th October 2023 LHD assessed as Category E (ATC coordination error as a result of human factor issues) involved one FIR coordinating an aircraft at the wrong flight level (FL310 instead of FL330, at which the aircraft crossed into the Melbourne FIR) and was reported as lasting 13 minutes in duration. The location was at DOGAR with transfer from Colombo to Melbourne FIR. This occurrence constituted almost half of the weighted operational risk.

2. DISCUSSION

Data Sources

2.1 *Traffic Sample Data (TSD):* TSD covering four weeks of the month of December 2023. of aircraft operating in the Brisbane, Honiara, Melbourne, Nauru, and Port Moresby FIRs was used as required by ICAO Regional agreement.

2.2 *Large Height Deviations (LHDs):* A cumulative 12-month data set of LHD reports was used, covering 1 January 2023 to 31 December 2023. All FIRs submitted LHD reports for all 12 months, including nil returns.

Summary of LHD Occurrences

2.3 The number of reported LHD occurrences, non-zero-duration LHDs, total LHD duration (in minutes), and total number of levels crossed for the period 1 January 2023 to 31 December 2023 are shown by month in **Table 1** with unusual values highlighted. The number of reported LHDs, duration, and levels crossed are shown in **Figure 1**.

Table 1: Summary of LHD occurrences by month for the period 1 January 2023 to 31 December 2023. High values are highlighted.

Month	Number of reported LHDs	Number of non-zero-duration LHDs	LHD duration (minutes)	Number of levels crossed
2023				
January	5	0	0.0	0.0
February	2	0	0.0	0.0
March	3	3	7.0	1.0
April	7	2	0.7	0.0
May	4	3	7.5	0.0
June	5	3	11.0	2.0
July	7	2	1.5	1.0
August	9	4	4.3	4.0
September	4	2	1.5	0.5
October	4	2	14.0	0.0
November	9	1	0.5	0.5
December	6	1	0.5	0.0
Total	**65**	**23**	**48.45**	**9.0**
Previous year (2022)	**74**	**33**	**40**	**0**

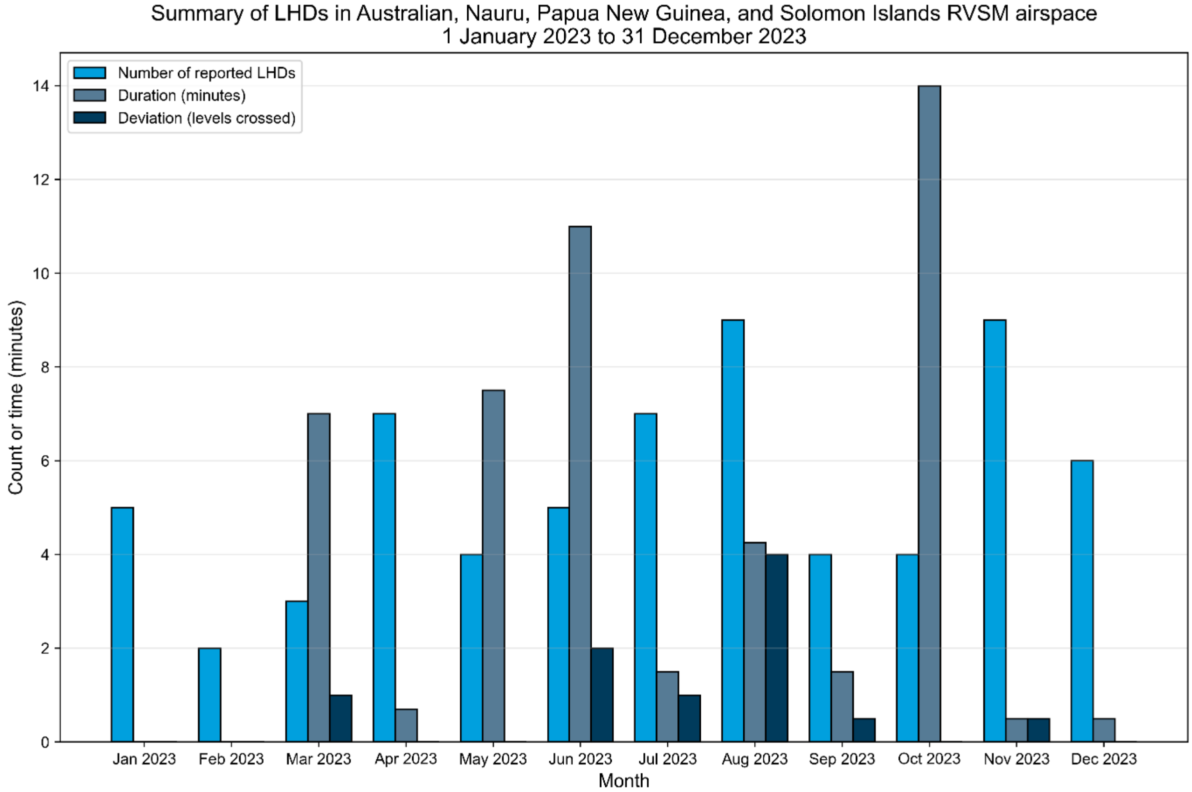

Figure 1: Number of LHDs, duration of LHDs, and number of levels crossed by month for the period 1 January 2023 to 31 December 2023.

2.4 The number of reported LHDs, total LHD duration (in minutes), and total number of levels crossed for the period 1 January 2023 to 31 December 2023 are shown by LHD category in **Table 2** and **Figure 2**.

Table 2: Summary of LHD occurrences by category for 1 January 2023 to 31 December 2023. Data for 2022 is shown for comparison. Unusual values are highlighted. The 19th of October LHD of 13 minutes is noted for Category E. The Category D occurrences are driven by a 2023-05-24 LHD of 6 minutes and a 2023-06-23 LHD of 10 minutes, both at ADMAR on the Australian mainland East coast.

		2023			**2022**		
LHD category	**LHD category description**	**Number LHDs**	**Duration of LHDs (minutes)**	**Number of levels crossed**	**Number LHDs**	**Duration of LHDs (minutes)**	**Number of levels crossed**
A	Flight crew failing to climb/descend the aircraft as cleared	12	11.00	3	8	14.5	0
B	Flight crew climbing/descending without ATC clearance	5	3.25	4	11	10	0
C	Incorrect operation or interpretation of airborne equipment	16	0	0	11	0	0
D	ATC system loop error	15	19.50	0	5	6	0
E	Coordination errors in the ATC-to-ATC transfer or control responsibility as a result of human factors issues	12	13.00	0	32	6	0

		2023			2022		
LHD category	**LHD category description**	**Number LHDs**	**Duration of LHDs (minutes)**	**Number of levels crossed**	**Number LHDs**	**Duration of LHDs (minutes)**	**Number of levels crossed**
F	Coordination errors in the ATC-to-ATC transfer or control responsibility as a result of equipment outage or technical issues	1	0	0	1	0	0
G	Deviation due to aircraft contingency event leading to sudden inability to maintain assigned flight level	1	1.00	1	0	0	0
H	Deviation due to airborne equipment failure leading to unintentional or undetected change of flight level	0	0	0	0	0	0
I	Deviation due to turbulence or other weather-related cause	1	0.20	0	4	2.5	0
J	Deviation due to TCAS resolution advisory; flight crew correctly following the resolution advisory	1	0.50	1	2	1	0
K	Deviation due to TCAS resolution advisory; flight crew incorrectly following the resolution advisory	0	0	0	0	0	0
L	An aircraft being provided with RVSM separation is not RVSM approved	0	0	0	0	0	0
M	Other	1	0	0	0	0	0
Total		**65**	**48.45**	**9**	**74**	**40**	**0**

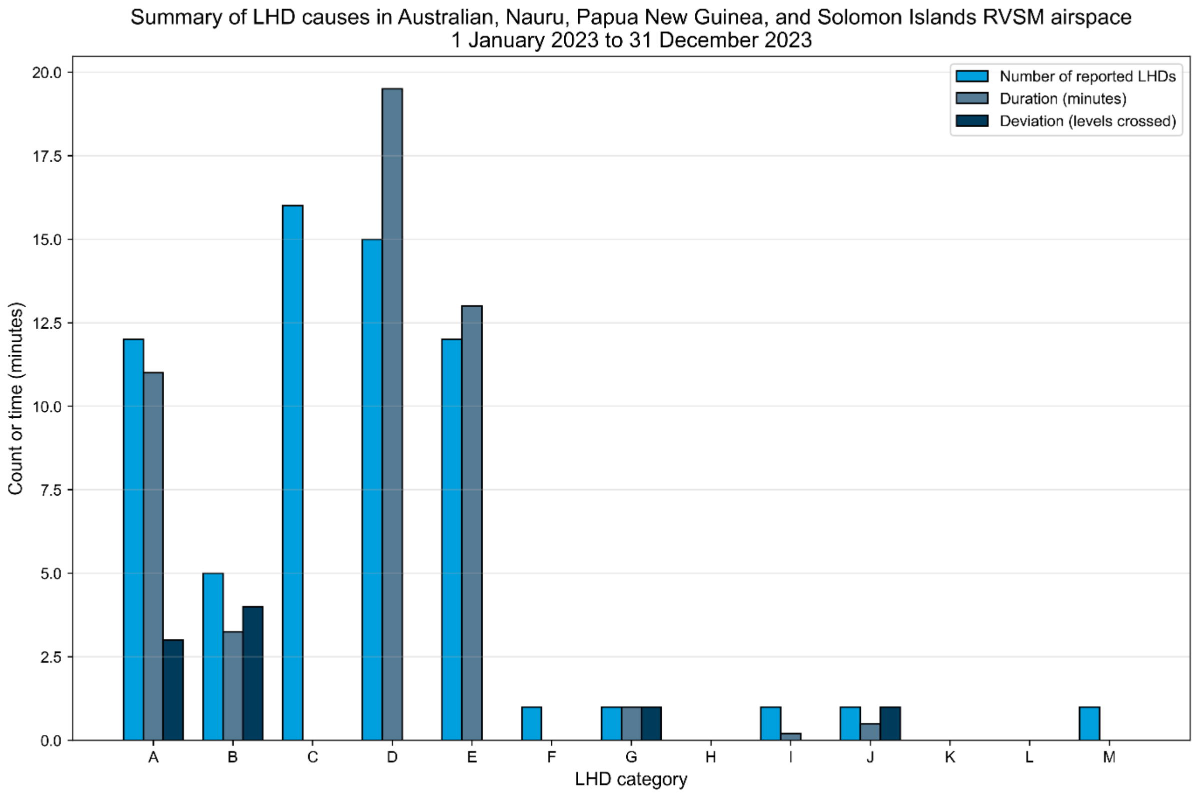

Figure 2: Number of LHDs, duration of LHDs, and number of levels crossed by LHD category for the period 1 January 2023 to 31 December 2023.

<u>Collision Risk Estimate</u>

2.5 The results for the technical, operational, and total risk for the RVSM implementation in Brisbane, Honiara, Melbourne, Nauru, and Port Moresby FIRs for 1 January 2023 to 31 December 2023 are detailed in **Table 3**. The technical risk meets the TLS value of no more than 2.5 x 10^{-9}. The operational and weighted total risk meets the specified TLS value for these components of 5.0 x 10^{-9}.

Table 3: RVSM Risk Estimates for the period 1 January 2023 to 31 December 2023. The number of estimated annual flight hours is 1,182,067 based on the December 2023 TSD. Values for 2022 are shown for comparison.

Source of risk	Risk estimate 2023	Risk estimate 2022	TLS	Comparison with TLS
Technical risk	0.101 x 10^{-9}	0.077 x 10^{-9}	2.5 x 10^{-9}	Below technical TLS
Operational risk	1.41 x 10^{-9}	1.42 x 10^{-9}	-	-
Total risk	**1.51 x 10^{-9}**	**1.50 x 10^{-9}**	**5.0 x 10^{-9}**	**Below total TLS**

2.6 The trends of the technical risk, operational risk, and total risk for the period 1 January 2023 to 31 December 2023 are shown in **Figure 3**.

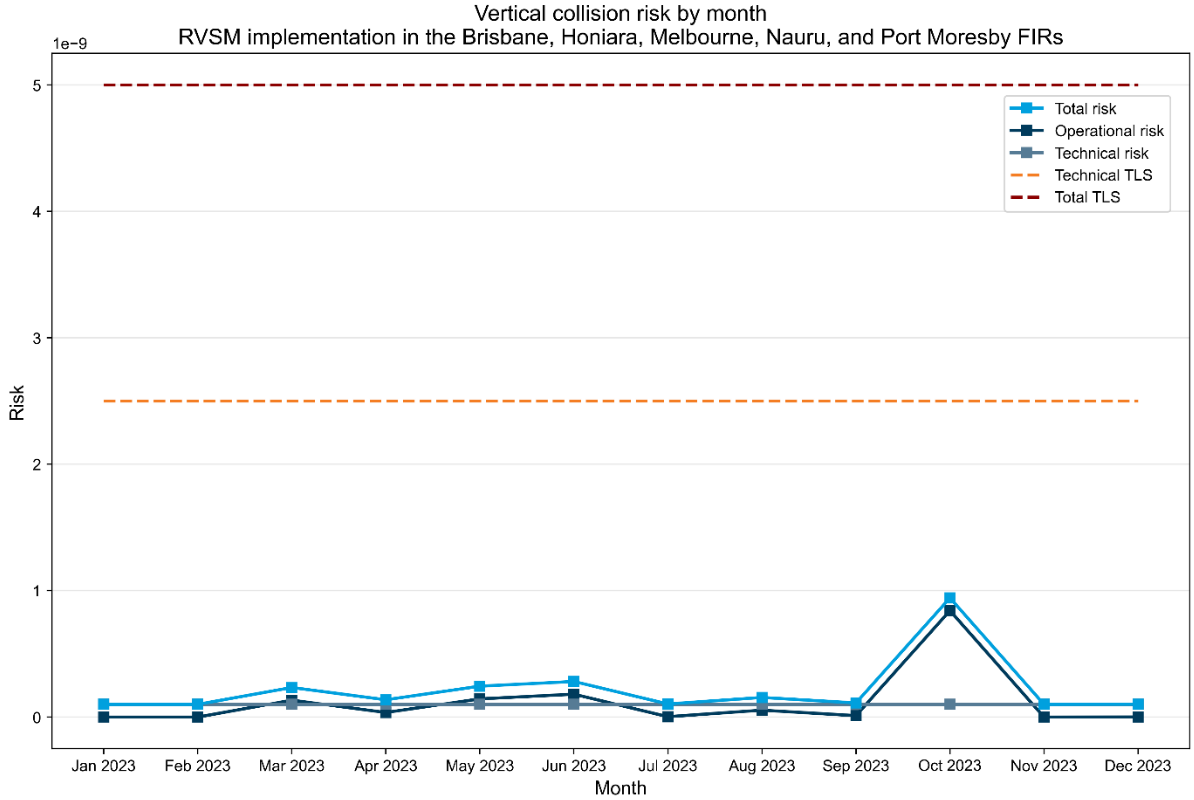

Figure 3: Trends of the technical, operational, and total risk for the period 1 January 2023 to 31 December 2023.Note the increase in October 2023 due to the 13-minute LHD noted earlier.

Assessment of Safety Reporting Culture

2.7 The 7th Meeting of the Monitoring Agencies Working Group (MAWG/7) proposed that Regional Monitoring Agencies (RMAs) assess States' reporting culture, since the RVSM risk assessment is dependent on the accuracy and quality of the LHD reports received.

2.8 MAWG/7 proposed that the reporting safety culture metric would be measured by the reporting rate of occurrence per flight hour, with occurrences grouped by attribution: Pilot/Aircrew (Categories A, B, and C), ATC (Categories D, E, and F), and others (Categories G, H, I, J, K, L, and M). The safety culture metric for Australia, Nauru, Papua New Guinea, and Solomon Islands is shown in **Table 4**.

Table 4: Safety culture metric for Australia, Nauru, Papua New Guinea, and Solomon Islands by LHD attribution for the period 1 January 2023 to 31 December 2023.

Attribution	Number of reports	Flight hours	Number of reports per flight hour (x 10^{-5})
Pilot/Aircrew (A, B, C)	33	1 182 067	2.79
ATC (D, E, F)	28	1 182 067	2.37
Other	4	1 182 067	0.338
Total	**65**	1 182 067	**5.50**

2.9 Reports were consistently made by both pilots and ATC.

2.10 LHDs with Pilot/Aircrew and ATC attribution were equally reported. A high rate of reporting of occurrences with ATC attribution is an indication of a positive reporting culture, especially if ATC are comfortable reporting on their own errors as part of a 'Just Culture' framework.

2.11 Of the 28 ATC-attributed reports received, 7 reports corresponded to errors made by neighbouring ATCs, 5 corresponded to errors made by Australian or Port Moresby ATC, and the remaining 16 corresponded to internal coordination or system loop errors. Thus, ATC were roughly equally likely to report an occurrence regardless of whether or not the unit making the error was external.

Geolocation of LHDs

2.12 A map identifying the geographic location of LHD occurrences for the period 1 January 2023 to 31 December 2023 is shown in **Figure 4**. The occurrences at each location are represented by a coloured circle, with the radius proportional to the total risk at that location. The map is intended to provide a means to identify and visualise risk hot spots related to RVSM operations.

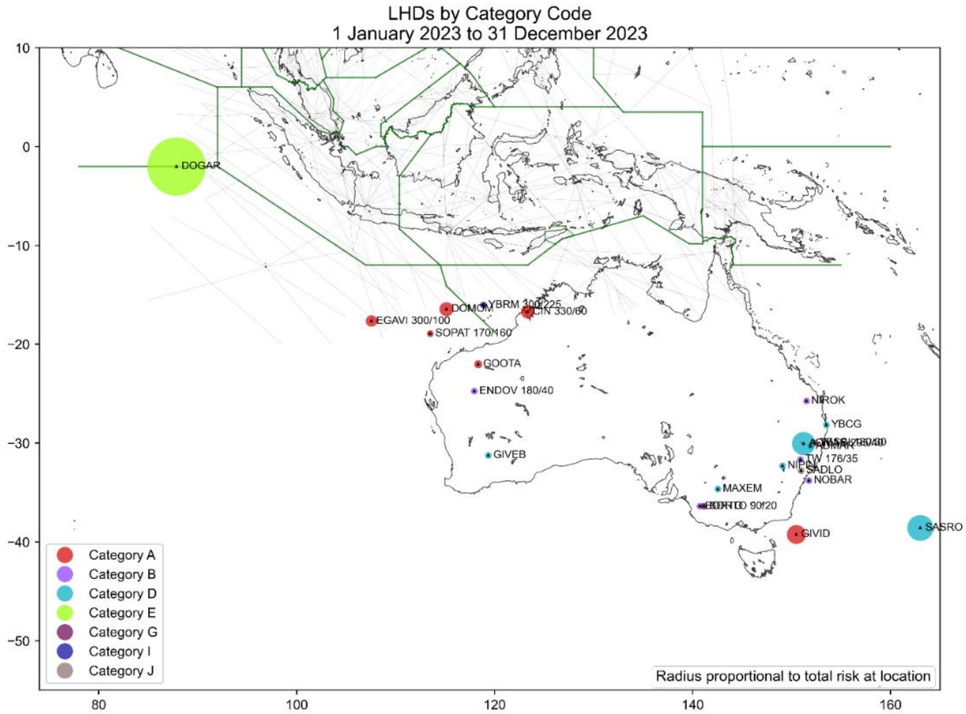

Figure 4: Geolocation of LHDs for Brisbane, Honiara, Melbourne, Nauru, and Port Moresby FIRs for the period 1 January 2023 to 31 December 2023. For comparison, the 2022 results are shown in the next figure.

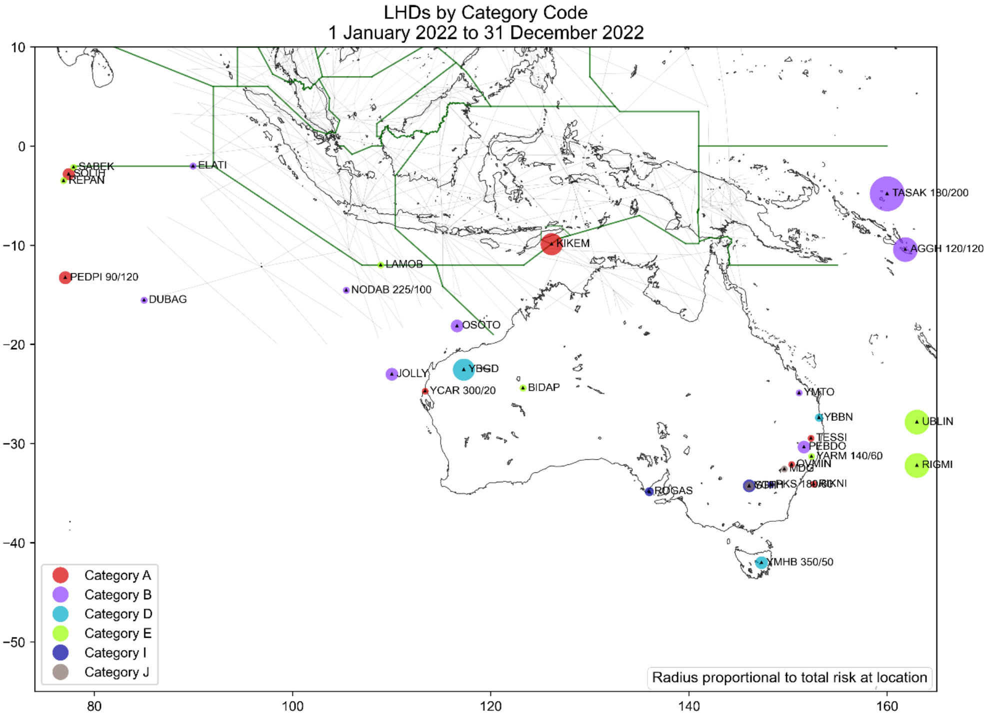

Figure 5: Geolocation of LHDs for Brisbane, Honiara, Melbourne, Nauru, and Port Moresby FIRs for the period 1 January 2022 to 31 December 2022 (previous year's results)

<u>Summary and Discussion</u>

2.13 The total risk (1.51 x 10^9) is comparable to the risks reported for the last two annual reporting periods (1.50 x 10^9 reported at RASMAG/27 and 1.73 x 10^9 reported at RASMAG/28).

2.14 The two riskiest LHDs are of interest, having occurred on two-way routes and having lasted more than 10 minutes in duration.

2.15 An October 2023 LHD assessed as Category E (ATC coordination error as a result of human factor issues) involved one FIR coordinating an aircraft at the wrong flight level (FL310 instead of the actual FL330) and was reported as 14 minutes in duration. This occurrence constitutes almost half of the weighted occupational risk for the 12-month period.

2.16 A June 2023 LHD assessed as Category D (ATS system loop error) lasted 10 minutes in duration and involved an ATC failing to issue a climb instruction through the relevant automated system to an aircraft.

2.17 In the period 1 January 2023—31 December 2023, the number of LHDs with Aircrew/Pilot attribution, 33, was comparable to the number of LHDs with ATC attribution, at 28. Category C was the most common category, wherein most involved flight crews who reported maintaining expired or non-existent block clearances.

3. ACTION BY THE MEETING

3.1 The meeting is invited to:

a) note the information contained in this paper; and

b) discuss any relevant matters as appropriate.

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Risk methodology and summary

Sources of error and risk

There are several main sources of error and hence risk:

1) **Technical risk**: this is associated with the total vertical error, dominated by the ability of an aircraft to be at the correct flight level. This itself has two components:
   a. **Assigned Altitude Deviation (AAD):** the pilot/aircraft choose to be at a non-standard altitude, for example 39,100 ft (FL 391) not FL 390.
   b. **Altimetry System Error (ASE):** the aircraft's systems believe it is at a flight level, but the equipment is incorrect. For example, the aircraft reports to ATC that it is at FL 390 (39,000 ft pressure altitude) but is in reality at (39200 ft pressure altitude).
2) **Technical risk (non RVSM approved aircraft):** This is associated with non-RVSM approved aircraft operating in the airspace, where the assumed ASE distribution is much higher than for RVSM-approved aircraft.
3) **Operational risk:** this is associated with aircraft flying at a wrong flight level or climbing/descending through flight levels without authorisation. This is characterised by two types:
   a. Time at an incorrect flight level
   b. Number of incorrect flight levels crossed.

For each of these categories, the risk is calculated for three scenarios, since the risk exposure is different in each case:

- Same-direction traffic
- Opposite-direction traffic
- Crossing traffic

An Occupancy term, E, is used to assess the relative density of traffic in each of the same, opposite and crossing cases. Occupancy is defined and explained in a later section.

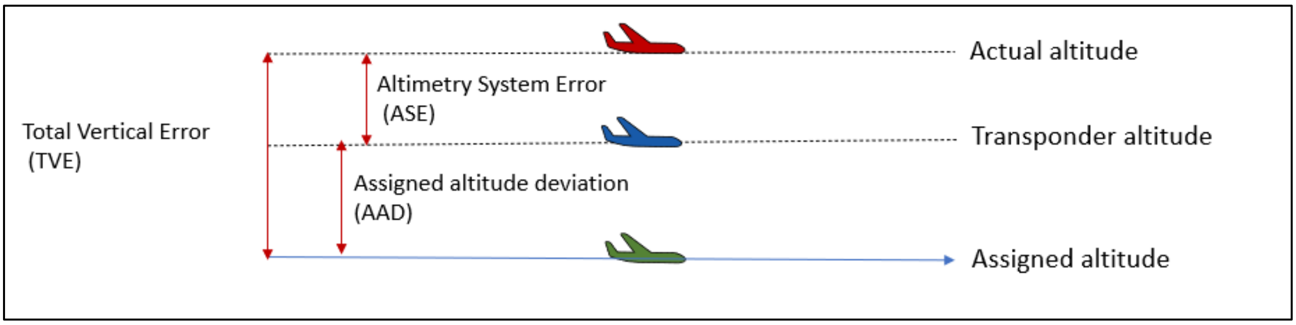

Figure 6: Different components of vertical error. The AAD is known by the pilot and reported to an ATCO. The ASE is invisible to both pilot and controller.

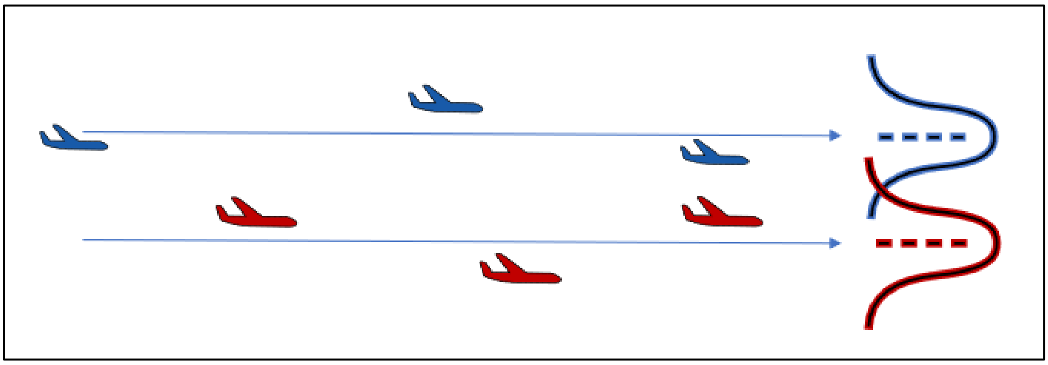

Figure 7: Technical error: The risk is associated with aircraft which are not able to be at the correct flight level and hence overlapping with another aircraft.

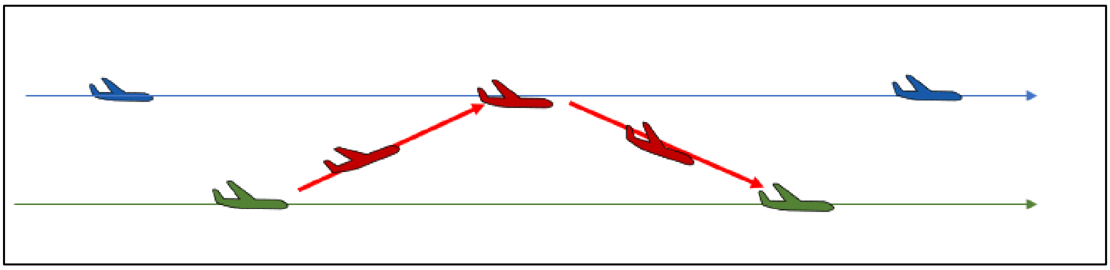

Figure 8: Operational error: an aircraft spending time on the wrong flight level.

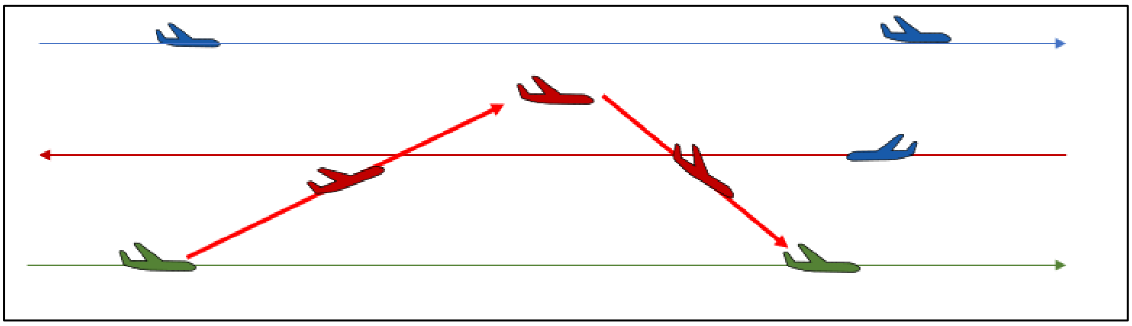

Figure 9: Operational error: an aircraft crossing one or more levels.

Same- and opposite-direction traffic

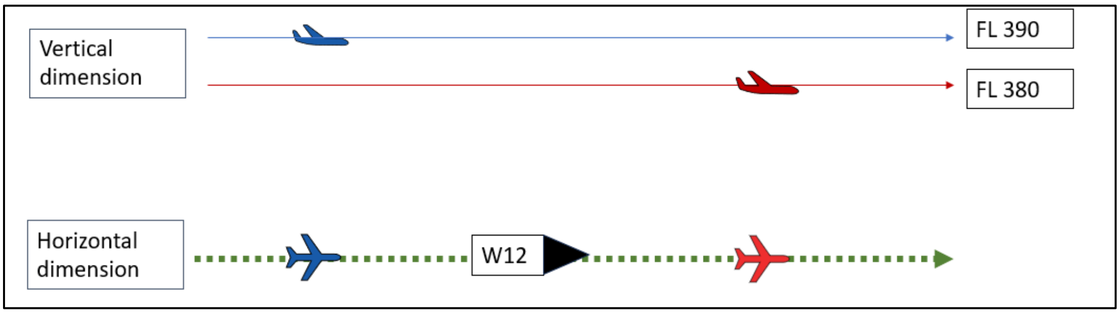

Figure 10: Example of same-direction traffic on the same two-way route.

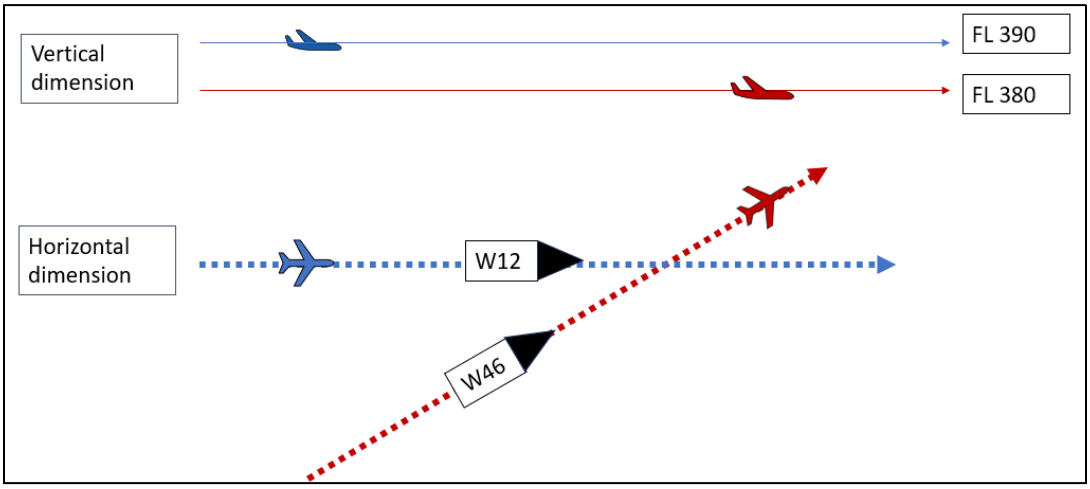

Figure 11: Example of same-direction traffic on crossing routes.

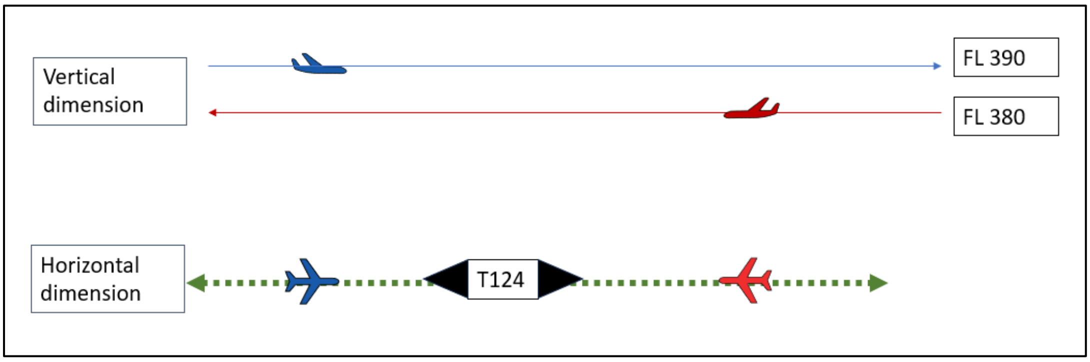

Figure 12: Example of opposite-direction traffic on the same two-way route.

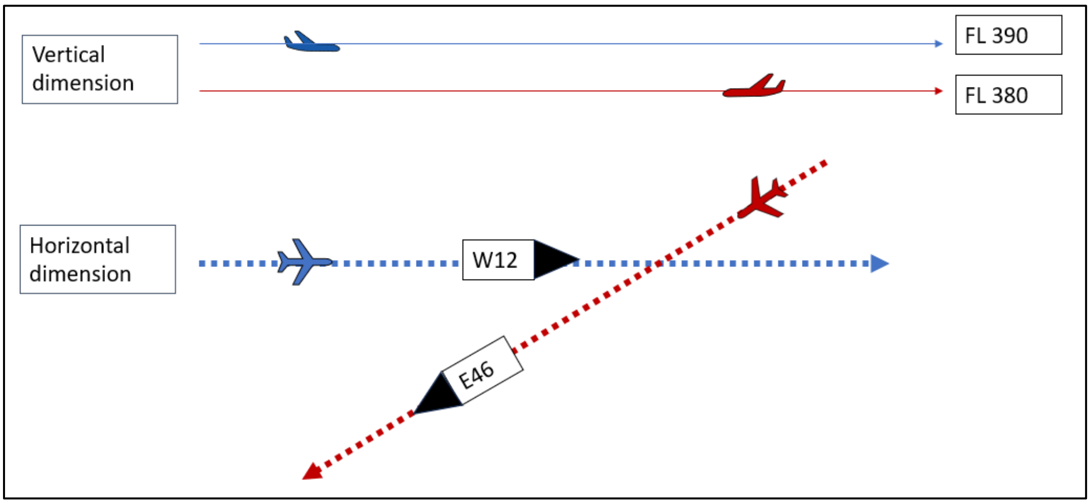

Figure 13: Example of opposite-direction traffic on crossing routes.

Reich model

For simplicity, this section mainly deals only with the same-direction traffic for parallel lateral tracks. There are numerous, more-complete, derivations of the Reich model in the reference list.

In this version of the model, the aircraft are assumed to be rectangular boxes of size $\lambda_x, \lambda_y, \lambda_z$ in the three dimensions, as shown in Figure 10. For a collision to occur, the aircraft must overlap in each dimension, as shown in Figure 11. A part of the Reich model is the time it takes the aircraft to overlap in these dimensions.

The application of the Reich model to parallel tracks, as shown in Figure 12, one aircraft is slowly overtaking the path of the other aircraft, causing a time where the aircraft are in longitudinal overlap.

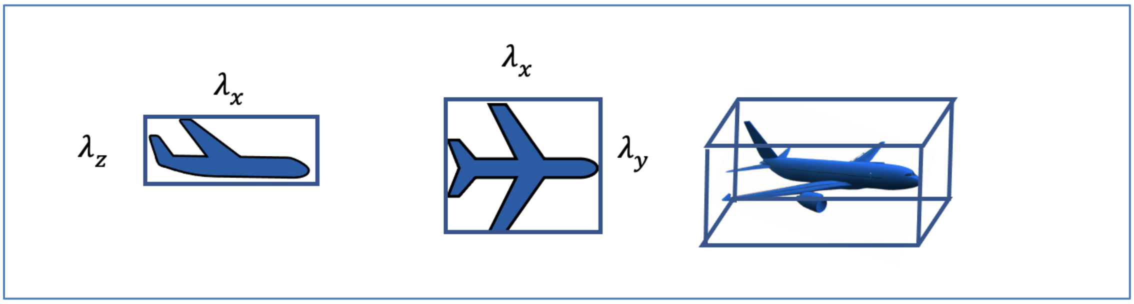

Figure 14: For this derivation we assume the rectangular shape for an aircraft.

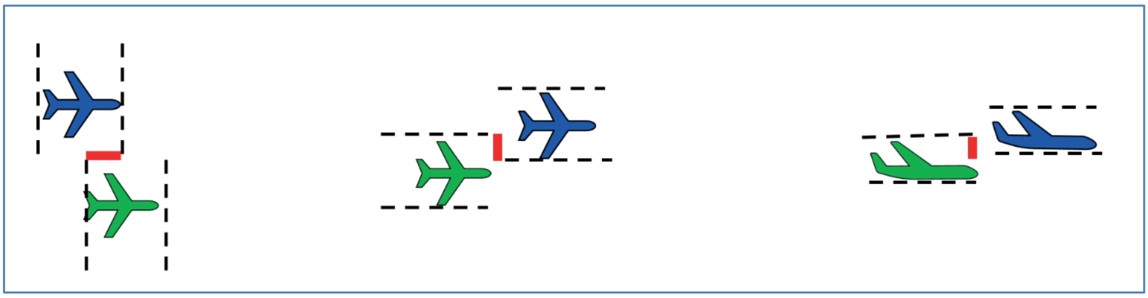

Figure 15: The Reich models consider the overlap of aircraft. The left-most plot shows two aircraft overlapping longitudinally, the middle plot shows lateral overlap, and the right-most plot shows vertical overlap. For a collision, the aircraft must overlap in all three dimensions at the same time.

Consider the simple scenario of aircraft on parallel tracks, in the same direction, with one aircraft slowly passing the other. Figure 7.3.3 shows a red aircraft on the bottom track, slowly overtaking a blue aircraft on an adjacent track. For a period of time the aircraft overlap longitudinally. The following derivations will look at the time this overlap takes and then relate this to the number of overlaps in a time period.

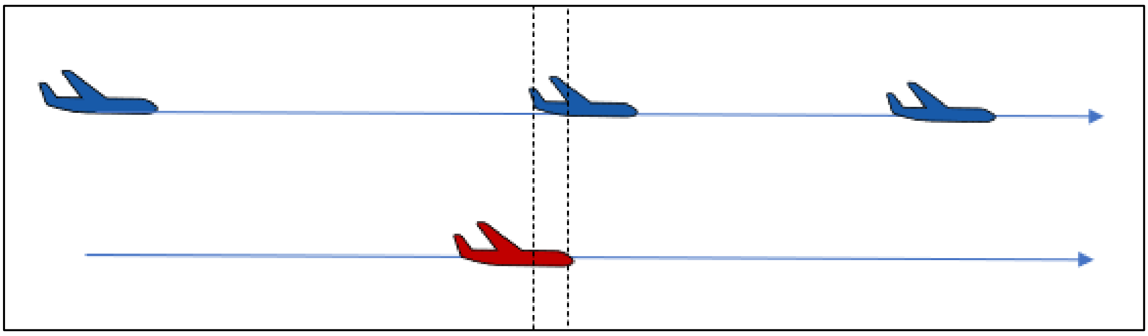

Figure 16: Consider a situation of the red aircraft on the lower track, being faster than the blue aircraft on the top track and slowly overtaking.

The following notation is used:

- f_x = number of times the aircraft pass in the *x* direction in one hour
- p_x = probability the aircraft are in longitudinal overlap at any given time point
- p_y = probability the aircraft are in lateral overlap at any given time point

- p_z = probability the aircraft are in vertical overlap at any given time point.

As the red aircraft pass the blue aircraft, there will be a time when they are in longitudinal overlap. For this example, assume that the probability of vertical overlap and lateral overlap are constants. The number of collisions in one hour is then $N_1 = f_x p_y p_z$.

The number of collisions in an hour as the aircraft potentially pass each other in any direction is then

$$N_c = f_x p_y p_z + f_y p_x p_z + f_z p_x p_y \qquad \text{Eq 1}$$

If the relative speed of the aircraft is denoted $\overline{|\dot{x}|}$, then t_x = average time (hours) spent in longitudinal overlap during a single passing is

$$t_x = \frac{2\,\lambda_x}{\overline{|\dot{x}|}} \qquad \text{Eq 2}$$

Logically, the frequency of passing and time spent are related:

$$p_x = f_x t_x \qquad \text{Eq 3}$$

For example, if the aircraft spend t_x =1 minute passing each other (in longitudinal overlap), and they pass each other 6 times an hour, the probability of being in overlap will be $p_x = \frac{6}{60} \times 1 = 0.1$. Hence,

$$f_x = \frac{p_x}{t_x} = p_x \frac{\overline{|\dot{x}|}}{2\,\lambda_x} \qquad \text{Eq 4}$$

Extending this one-dimensional case to the other dimensions gives the result:

$$N_c = p_x \frac{\overline{|\dot{x}|}}{2\,\lambda_x} p_y p_z + p_y \frac{\overline{|\dot{y}|}}{2\,\lambda_x} p_x p_z + p_z \frac{\overline{|\dot{z}|}}{2\,\lambda_x} p_x p_y \qquad \text{Eq 5}$$

$$= p_x p_y p_z \left(\frac{\overline{|\dot{x}|}}{2\,\lambda_x} + \frac{\overline{|\dot{y}|}}{2\,\lambda_y} + \frac{\overline{|\dot{z}|}}{2\,\lambda_z} \right) \qquad \text{Eq 6}$$

This is the general form for the Reich model. The term in the right-hand side is called a kinematic term, K:

$$K = \left(\frac{\overline{|\dot{x}|}}{2\,\lambda_x} + \frac{\overline{|\dot{y}|}}{2\,\lambda_y} + \frac{\overline{|\dot{z}|}}{2\,\lambda_z} \right) \qquad \text{Eq 6}$$

The longitudinal overlap can be related to Occupancy as discussed in the next section, with a sampling distance d_x :

$$N_c = E\,\frac{\lambda_x}{d_x} p_y p_z \left(\frac{\overline{|\dot{x}|}}{2\,\lambda_x} + \frac{\overline{|\dot{y}|}}{2\,\lambda_y} + \frac{\overline{|\dot{z}|}}{2\,\lambda_z} \right) \qquad \text{Eq 7}$$

Occupancy

Occupancy denoted E, appears many times in risk modelling. It is a statistical measure of correlated airspace density; related to how many aircraft may be close (proximate) to an aircraft; or as ICAO Doc 10063 notes “*Occupancy is a measure of exposure of aircraft to one another”*.

Although defined in several ICAO documents, it can be difficult to decipher the meaning.

The goal is to estimate the probability that another aircraft will be ‘adjacent’ and at risk if an aircraft deviates. It is very difficult to find two aircraft that have such a small 'adjacent' overlap of order 0.08 NM, so instead the number of aircraft within a much larger distance (for example 120 NM) are counted and the value required found by simple proportions.

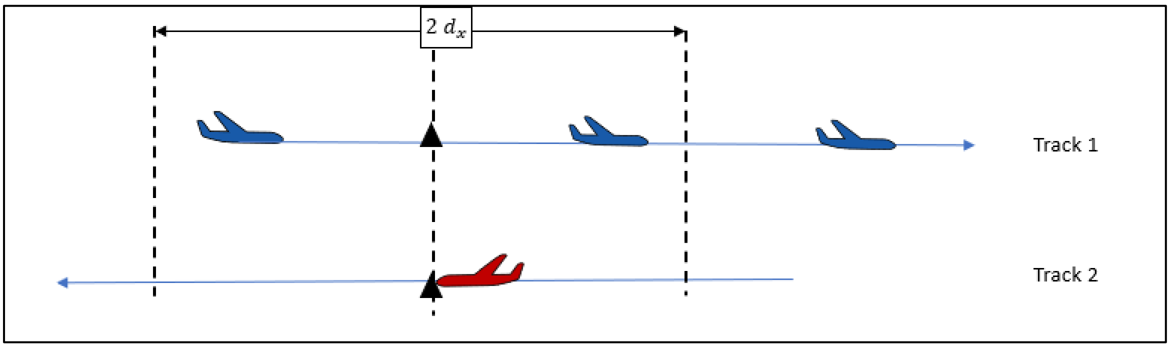

Figure 17: Occupancy is a measure how many aircraft are 'proximate', based on a statistical sample of aircraft as they pass a common waypoint.

Consider how Occupancy is practically calculated.

1) Define a distance d_x usually 120 NM (or a 15-minute equivalent value).
2) Every time an aircraft on Track 2 reaches a waypoint, count how many aircraft on Track 1 are within $\pm d_x$ of the corresponding waypoint. Call this number N_{21}^{i} with $i = 1, \ldots, M_2$ being each aircraft on Track 2.
3) Repeat this for Track 1 finding N_{12}^{j} with $j = 1, \ldots, M_1$ being each aircraft on Track 1.
4) Hence, we have observed $M_1 + M_2$ aircraft and counted $(N_{21}^{1} + N_{21}^{2} + \cdots) + (N_{12}^{1} + N_{12}^{2} + \cdots)$ proximate pairs.
5) Occupancy is the total proximate pairs divided by $M_1 + M_2$ (not twice as here we measure $\pm d_x$ not just d_x).

This will make more sense with some example values.

Let all the aircraft be separated evenly by 120 NM as in the diagram below and all aircraft have speeds of 480 knots. Assume we sample for 10 hours:

- The aircraft are 15 minutes apart.
- In 10 hours, 40 aircraft pass the waypoints on each track.
- Each aircraft will report 2 proximate pairs.
- In total 80 aircraft pass waypoints and count 160 proximate pairs
- So $E = 160/80$ which is 2.

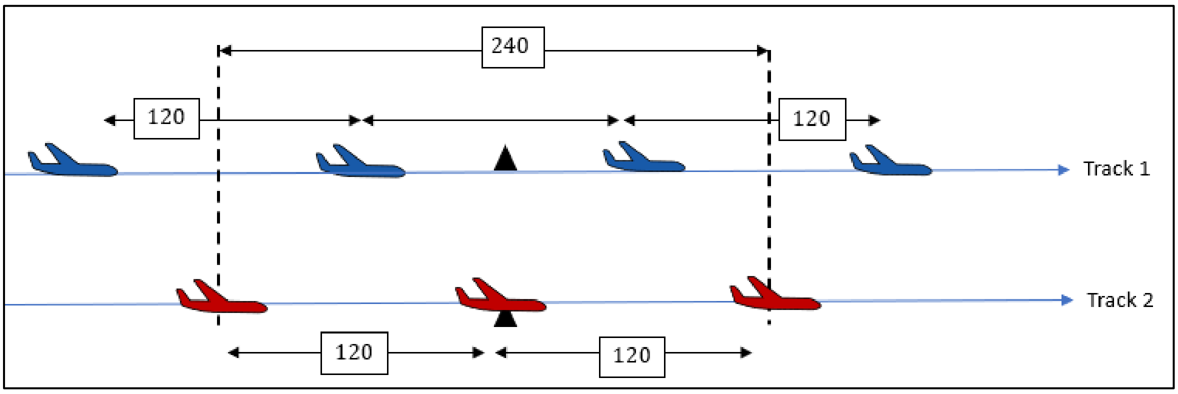

Figure 18: Example of counting proximate pairs with a sampling distance of 120 NM.

Occupancy is an estimate of the number of aircraft we see within a distance d_x. So if we expect to see E aircraft in distance 2 d_x then the expected number of aircraft within a distance d_r is (Doc 9689, v1, Appendix 13):

$$p_x \approx E \frac{d_r}{2d_x} \qquad \textit{Eq } \boldsymbol{8}$$

Combining opposite, same and crossing direction tracks

The technical risk is that due to usual operations and ASE error. The combination of opposite and same direction risk is then expressed as follows with the superscript N^T denoting the technical risk component:

$$N^T = N_{\text{same}}^T + N_{\text{opp}}^T + N_{\text{cross}}^T \qquad \text{Eq 9}$$

Using the opposite direction having passing speed $\overline{|\dot{x}|} \approx 2\,\bar{V}$.

$$N^T = P_y P_z \frac{\lambda_x}{d_x} \left[E(\text{same})\left(\frac{\overline{|\dot{x}|}}{2\lambda_x} + \frac{\overline{|\dot{y}|}}{2\lambda_y} + \frac{\overline{|\dot{z}|}}{2\lambda_z}\right) + E(\text{opp})\left(\frac{2\bar{V}}{2\lambda_x} + \frac{\overline{|\dot{y}|}}{2\lambda_y} + \frac{\overline{|\dot{z}|}}{2\lambda_z}\right)\right] + P_z P_h \left(\frac{2\,V}{\pi\lambda_{xy}} + \frac{\overline{|\dot{z}|}}{2\lambda_z}\right) \qquad \text{Eq 10}$$

The operational risk for operations at the wrong flight level, with time spent at same direction, τ_s, and opposite direction, τ_o giving:

$$N_1^O = P_y P_z \frac{\lambda_x}{d_x} \left[E(\text{same})\left(\frac{\overline{|\dot{x}|}}{2\lambda_x} + \frac{\overline{|\dot{y}|}}{2\lambda_y} + \frac{\overline{|\dot{z}|}}{2\lambda_z}\right)\frac{\tau_s}{60\,T} + E(\text{opp})\left(\frac{2\bar{V}}{2\lambda_x} + \frac{\overline{|\dot{y}|}}{2\lambda_y} + \frac{\overline{|\dot{z}|}}{2\lambda_z}\right)\frac{\tau_o}{60\,T}\right] \qquad \text{Eq 11}$$

The operational risk from aircraft crossing l_s RVSM flight levels in the same direction, and l_o RVSM flight levels in the same direction, without clearance, is given by:

$$N_2^O = P_y P_z \frac{\lambda_x}{d_x} \left[E(\text{same})\left(\frac{\overline{|\dot{x}|}}{2\lambda_x} + \frac{\overline{|\dot{y}|}}{2\lambda_y} + \frac{\overline{|\dot{z}_c|}}{2\lambda_z}\right)\frac{2\lambda_z\,l_s}{|\,\dot{z}_c\,|\;T} + E(\text{opp})\left(\frac{2\bar{V}}{2\lambda_x} + \frac{\overline{|\dot{y}|}}{2\lambda_y} + \frac{\overline{|\dot{z}|}}{2\lambda_z}\right)\frac{2\lambda_z\,l_o}{|\,\dot{z}_c\,|\;T}\right] \qquad \text{Eq 12}$$

Here $\overline{|\dot{z}_c|}$ is the vertical crossing speed (1000 ft/min = 9.87 knots), λ_z is the aircraft height, and so $\frac{2\lambda_z}{|\dot{z}_c|}$ is the expected time spent crossing the path of another aircraft. In contrast $\overline{|\dot{z}|}$ is a small vertical random motion, 1.5 knots.

Simplification and impact factors for LHDs

To simplify calculations the previous equations are divided into impact factors:

- I_s risk fom 1-minute at an incorrect flight level with same-direction traffic
- I_o risk fom 1-minute at an incorrect flight level with opposite-direction traffic
- I_{ls} risk fom 1 level crossed at with same-direction traffic
- I_{lo} risk fom 1 level crossed at with opposite-direction traffic.

The time and levels crossed for LHDs is accumulated for each of the n LHDs (same or opposite respectively) with $i = 1,..,n$ representing the number of LHDs in each category:

$$\tau_s = \sum_{i=1}^{n} \tau_s^i \qquad \text{Eq 13}$$

$$\tau_o = \sum_{i=1}^{n} \tau_o^i \qquad \text{Eq 14}$$

$$l_s = \sum_{i=1}^{n} l_s^i \qquad \text{Eq 15}$$

$$l_o = \sum_{i=1}^{n} l_o^i \qquad \text{Eq 16}$$

The impact factors are then

$$I_s = P_y P_z \frac{\lambda_x}{d_x} \left[E(\text{same}) \left(\frac{\overline{|\dot{x}|}}{2\lambda_x} + \frac{\overline{|\dot{y}|}}{2\lambda_y} + \frac{\overline{|\dot{z}|}}{2\lambda_z} \right) \frac{1}{60\,T} \right] \qquad \text{Eq 17}$$

$$I_o = P_y P_z \frac{\lambda_x}{d_x} \left[E(\text{same}) \left(\frac{\overline{|\dot{x}|}}{2\lambda_x} + \frac{\overline{|\dot{y}|}}{2\lambda_y} + \frac{\overline{|\dot{z}|}}{2\lambda_z} \right) \frac{1}{60\,T} \right] \qquad \text{Eq 18}$$

$$I_{ls} = P_y P_z \frac{\lambda_x}{d_x} \left[E(\text{same}) \left(\frac{\overline{|\dot{x}|}}{2\lambda_x} + \frac{\overline{|\dot{y}|}}{2\lambda_y} + \frac{\overline{|\dot{z}_c|}}{2\lambda_z} \right) \frac{2\lambda_z}{\overline{|\dot{z}_c|\; T}} \right] \qquad \text{Eq 19}$$

$$I_{lo} = P_y P_z \frac{\lambda_x}{d_x} \left[E(\text{same}) \left(\frac{\overline{|\dot{x}|}}{2\lambda_x} + \frac{\overline{|\dot{y}|}}{2\lambda_y} + \frac{\overline{|\dot{z}_c|}}{2\lambda_z} \right) \frac{2\lambda_z}{\overline{|\dot{z}_c|\; T}} \right] \qquad \text{Eq 20}$$

$$N\ (\text{operational}) = I_s \tau_s + I_o \tau_o + I_{ls} l_s + I_{ls} l_s \qquad \text{Eq 21}$$

Combining risk over regions
The risk over different regions, R_1, R_2 etc is a simple weighted aggregation based on the number of flight hours

$$N = \sum_j T_j N_j \div \sum_j T_j \qquad \text{Eq 22}$$

Basic statistics for Dec 2023

Traffic maps

This section contains illustrations of traffic and waypoints for the assigned period of Dec 2023.

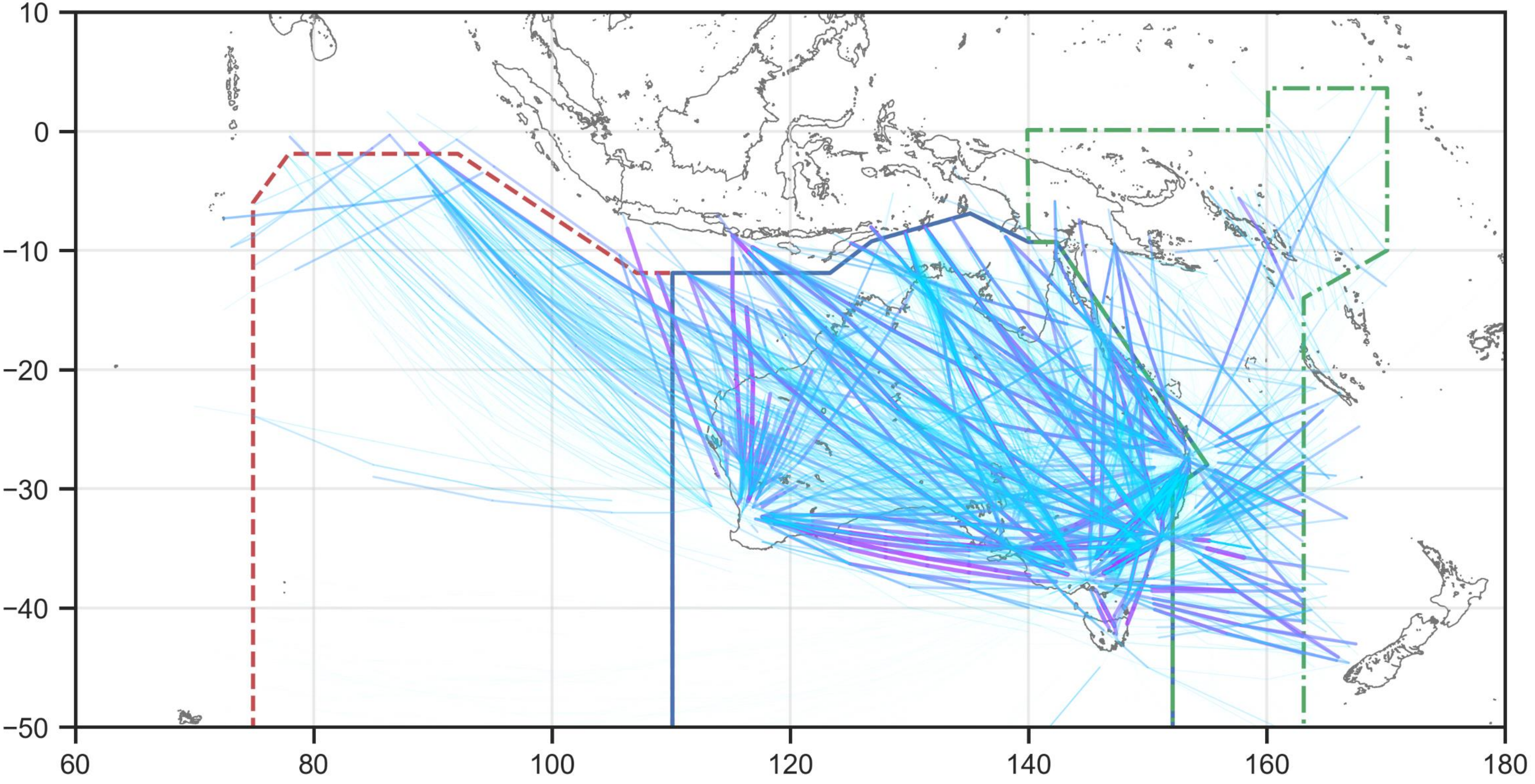

Figure 19: Waypoint pairs, colour-coded with number of flights for Dec 2023.

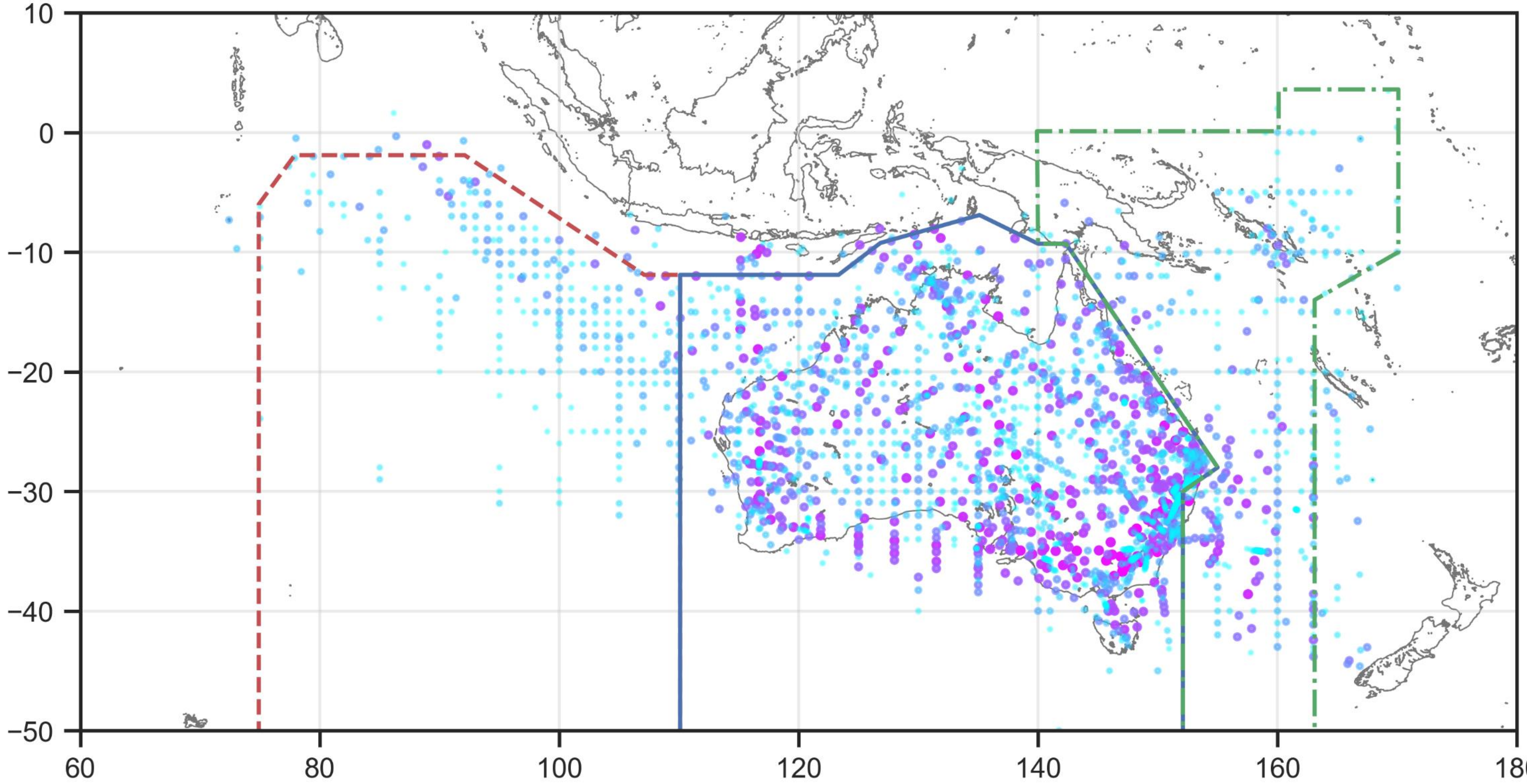

Figure 20: Waypoints, colour-coded with number of flights for Dec 2023.

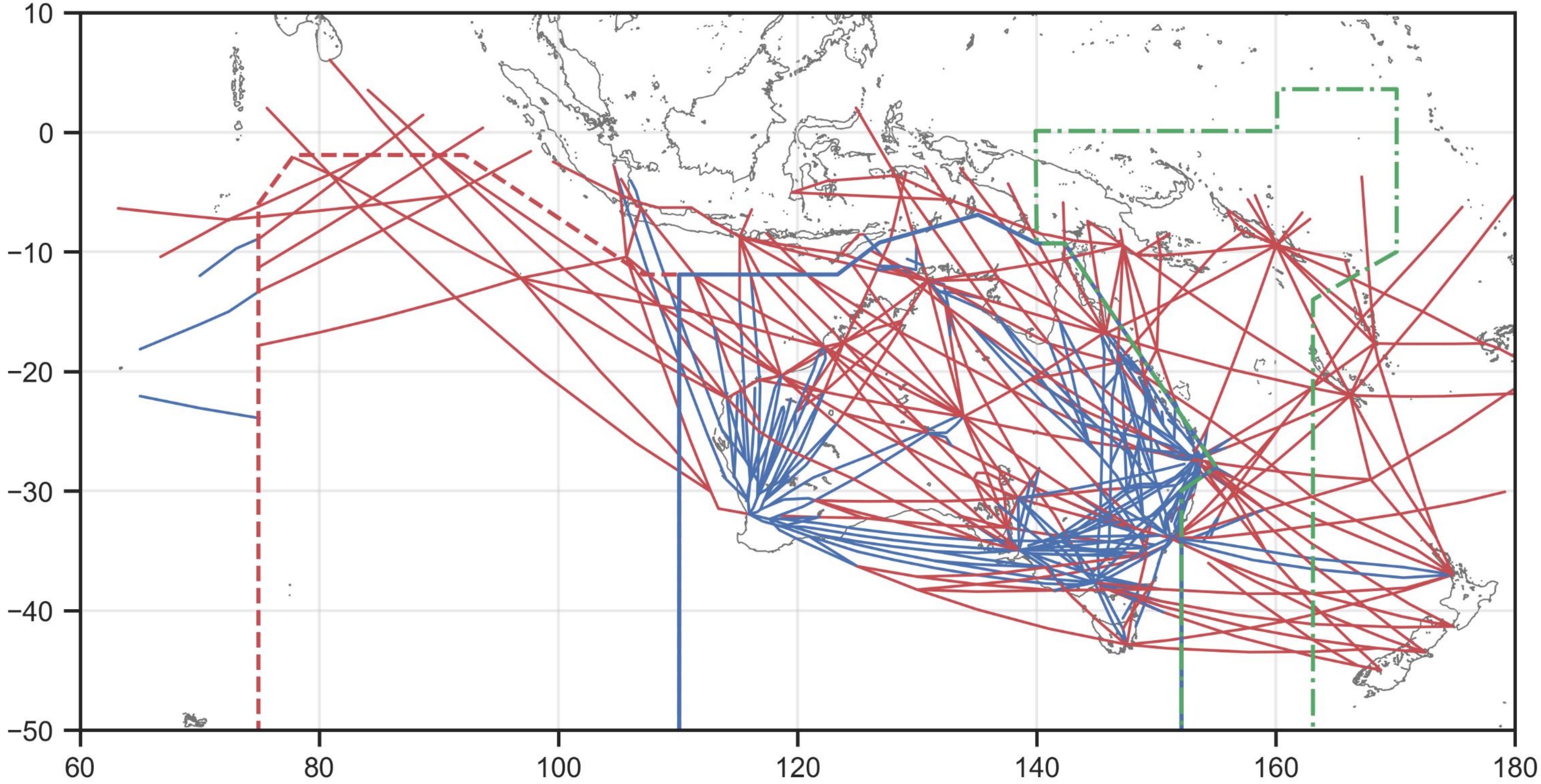

Figure 21: One-way (blue) and two-way (red) routes.

Data by region

Detail of data in AAMA results for the sample period and technical risk components. The domestic 2-way routes contribute highest to the overall weighted risk. The Indian Ocean 2-way route has the highest risk per flight hour of the regions examined.

group	λ_x	λ_y	λ_z	V kn	E_s	E_c	E_o	dV_s	dV_c	dV_o	T (hours/yr	Technical risk	Sx	Py0	Pz0	Ph	Tech risk group	Contribution to overall risk
DOM_1	0.021	0.023	0.007	450	0.063	0.015	0.025	40	347	856	384906	2.3E-09	112	0.020	0.356	7.2E-10	5.8E-11	1.9E-11
DOM_2	0.025	0.027	0.008	463	0.199	0.046	0.043	32	402	913	677413	2.7E-08	116	0.023	0.396	2.7E-09	1.2E-10	6.9E-11
IND_1	0.034	0.036	0.010	492	0.007	0.000	0.017	1	0	889	3953	4.5E-11	123	0.030	0.515	0.0E+00	4.7E-11	1.6E-13
IND_2	0.036	0.038	0.011	496	0.221	0.017	0.068	13	284	920	41145	3.0E-09	124	0.032	0.554	1.7E-09	2.2E-10	7.8E-12
OTH_1	0.030	0.031	0.009	489	0.044	0.042	0.000	38	256	0	3417	7.0E-11	122	0.026	0.450	3.1E-09	6.7E-12	1.9E-14
OTH_2	0.030	0.032	0.009	501	0.154	0.000	0.000	12	0	0	167	1.2E-11	125	0.026	0.451	0.0E+00	1.2E-11	1.6E-15
TAS_1	0.025	0.028	0.008	463	0.063	0.028	0.000	37	267	0	12550	8.4E-11	116	0.023	0.406	1.7E-09	8.7E-12	9.2E-14
TAS_2	0.024	0.026	0.008	462	0.152	0.079	0.032	31	487	913	58515	4.1E-09	115	0.023	0.396	4.6E-09	9.1E-11	4.5E-12
SUM											**1182066**						**1.01E-10**	**1.01E-10**
MEAN	0.024	0.026	0.008	460				34	380	882			114	0.022	0.389	2.1E-9	**1.01E-10**	**1.01E-10**

Table 1: Nomenclature

DOM_1: Domestic 1-way routes DOM_2: Domestic 2-way routes IND_1: Indian Ocean 1-way routes IND_2: Indian Ocean 2-way routes TAS_1: Tasman 1-way routes TAS_2: Tasman 2-way routes OTH: other regions	$\boldsymbol{\lambda_x}$ Aircraft length in NM $\boldsymbol{\lambda_y}$ Aircraft width in NM $\boldsymbol{\lambda_z}$ Aircraft height in NM Speed: Average speed in region knots E_same: Occupancy – same direction E_opp: Occupancy – opposite direction E_cross: Occupancy – crossing	Speed diff: speed difference Hours per year: flight hours S_x mean separation distance in NM $P_y(0)$ lateral overlap probability on same track $P_z(0)$ vertical overlap probability at same altitude $P_z(h)$ vertical overlap probability at 1000 ft Technical risk overall