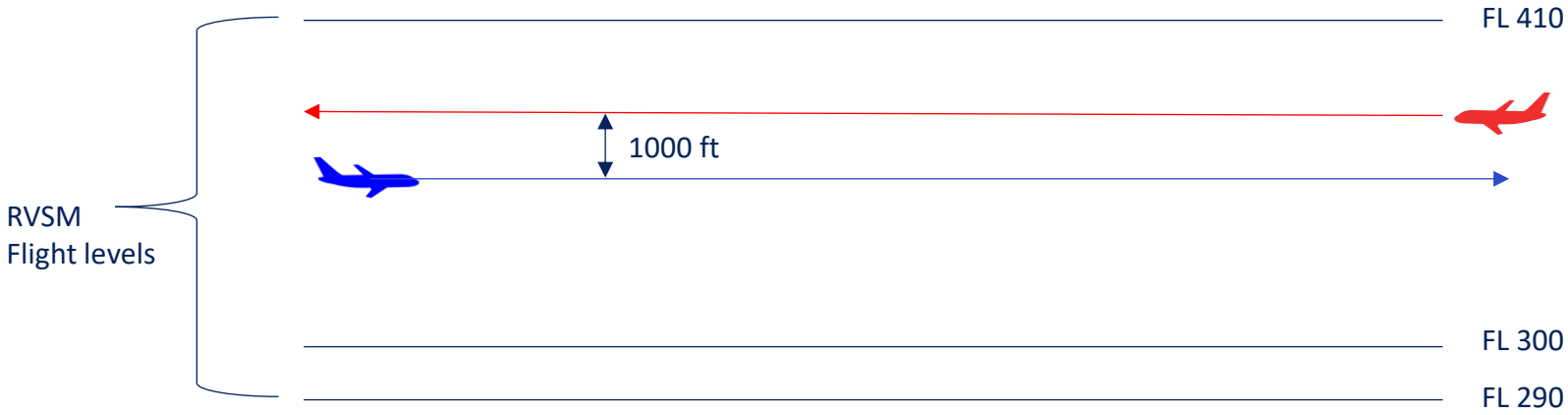
RVSM vertical safety assessment

Airspace Safety Seminar, RASMAG/31
Australian Airspace Monitoring Agency (AAMA)
29 June 2026

Outline

Content

- RVSM safety assessment (focus on vertical risk, but relevant also for lateral and longitudinal risk)
- Operational risk
- Technical risk
- Total risk



In addition to Height Keeping monitoring, ICAO requires Regional Monitoring Agencies to monitor:

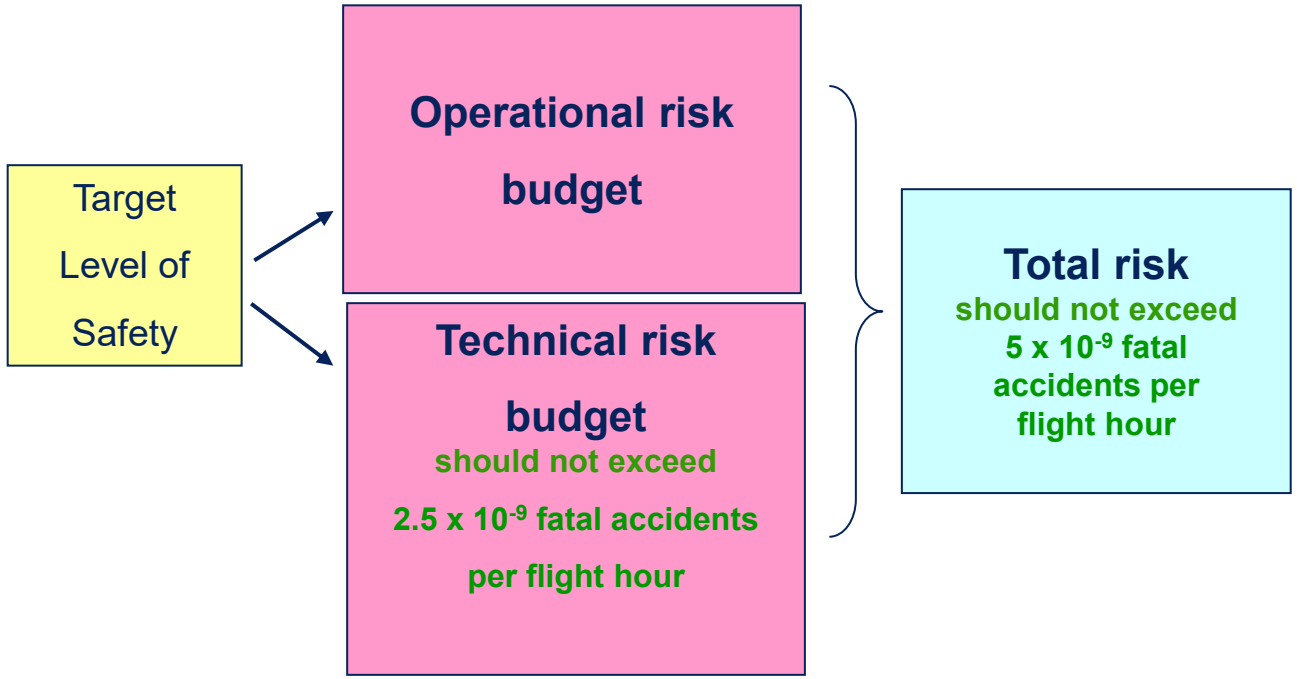
- Average risk across RVSM airspace
- Risk from operational errors

Results are reported to ICAO at regional and global meetings.

RVSM safety assessment

Overview

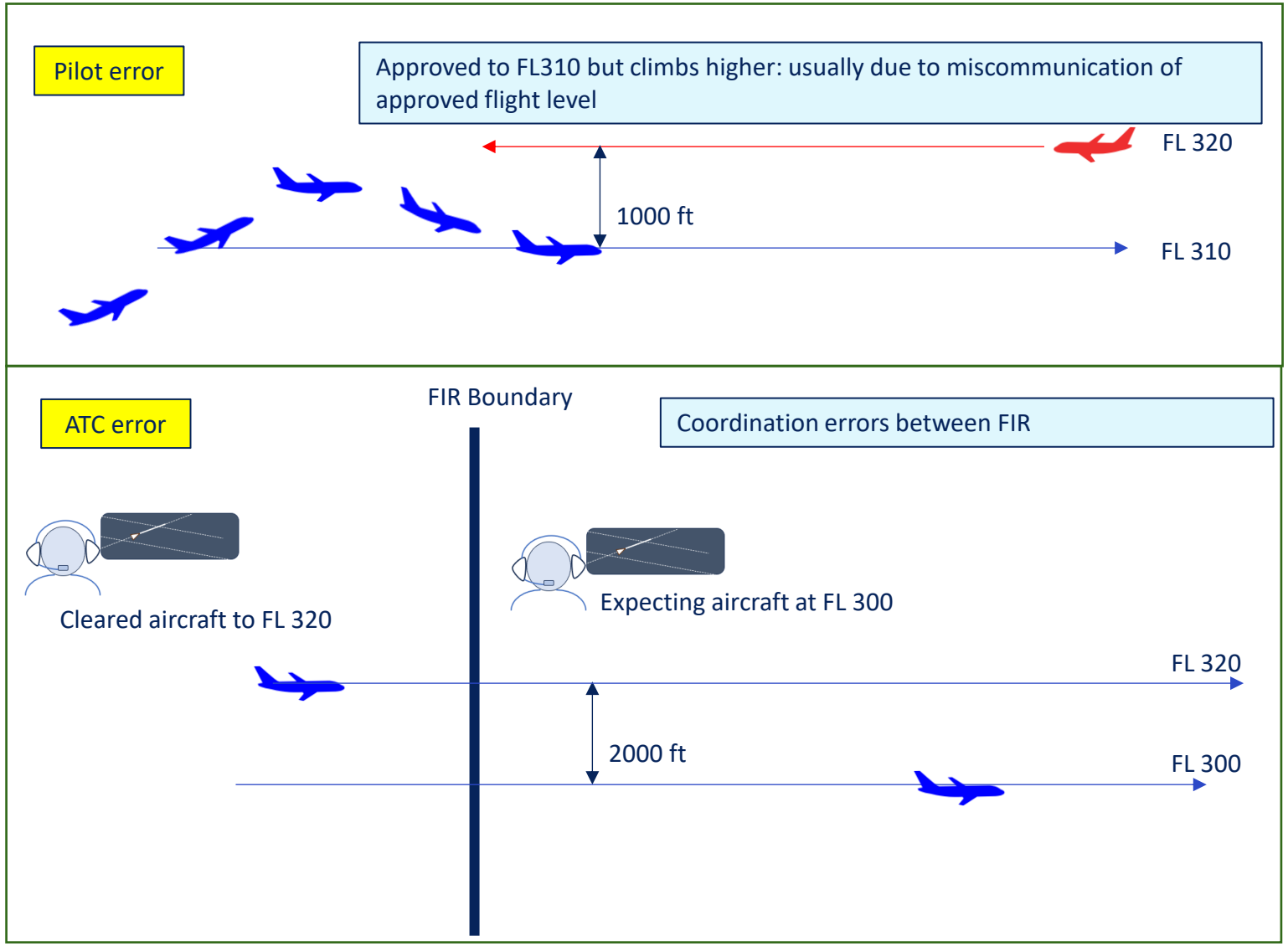
- The goal of a safety assessment is to quantify the collision risk in RVSM airspace and compare it to globally accepted Target Levels of Safety.
- An RVSM collision risk model (CRM) was developed by ICAO. Risk is the sum of two components:
  - Technical risk
  - Operational risk
- Operational risk calculation relies on analysis of operational error (OE) reports submitted by ANSPs.
- To do this analysis, RMAs require:
  - Results from aircraft height-keeping monitoring systems
  - Reports of Large Height Deviations from ANSPs
  - Traffic Sample Data (representing RVSM-level flights each December)



Operational risk

Large height deviations

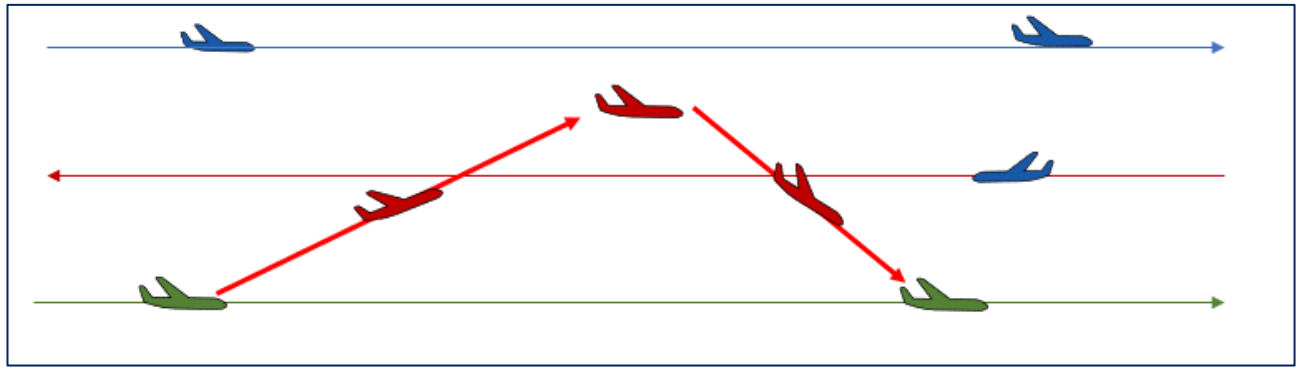
- Large Height Deviations are a subset of operational errors in RVSM airspace and are any vertical deviation of an aircraft from its expected flight level as a result of action by ATC, flight crew, or contingency.
- LHDs are grouped as:
  - Pilots climbing/descending without clearance – or failing to climb/descend as expected
  - ATS loop errors (and coordination errors between ATCs managing adjacent sectors)
  - Aircraft contingency events
  - Deviations due to meteorological events
  - Deviations due to ACAS



Operational risk

Scrutiny Group analysis

- The main purpose of a Scrutiny Group is to review each occurrence in detail and assign a qualitative risk level, in terms of:
  - Minutes spent at the incorrect level, or
  - Number of levels crossed.
- Ideally, the Scrutiny Group should consist of members with a range of expertise (including ATC knowledge and mathematics background) to ensure the group has adequate knowledge of both the risk calculations and operational procedures.
- Initial screening questions:
  - Did the event occur in RVSM airspace?
  - Was there a level deviation?
  - Was an aircraft provided with reduced separation standards while not RVSM approved?
- For example, in the figure below, a Scrutiny Group would confirm from the occurrence description that a trajectory had crossed more than 1 level – and that it was on a bidirectional route at the time.

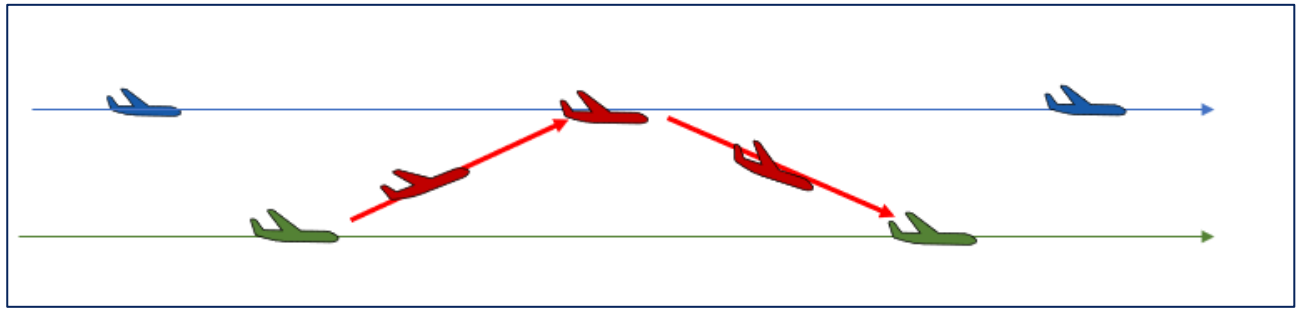


Operational error: an aircraft crossing one or more levels.

Operational risk

Scrutiny Group analysis

- After an error has been classified as an LHD, risk is assigned based on the amount of time and the number of flight levels that were unprotected during an occurrence. Considerations include:
  - Number of minutes spent at the incorrect level
  - Number of levels crossed
  - Whether or not the occurrence was managed
  - Whether the occurrence presented risk to a given airspace (as compared to, for example, an adjacent FIR)
- For example, in the figure below, a Scrutiny Group must assess how long an aircraft spent at the incorrect level.



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

Operational risk

LHD categories

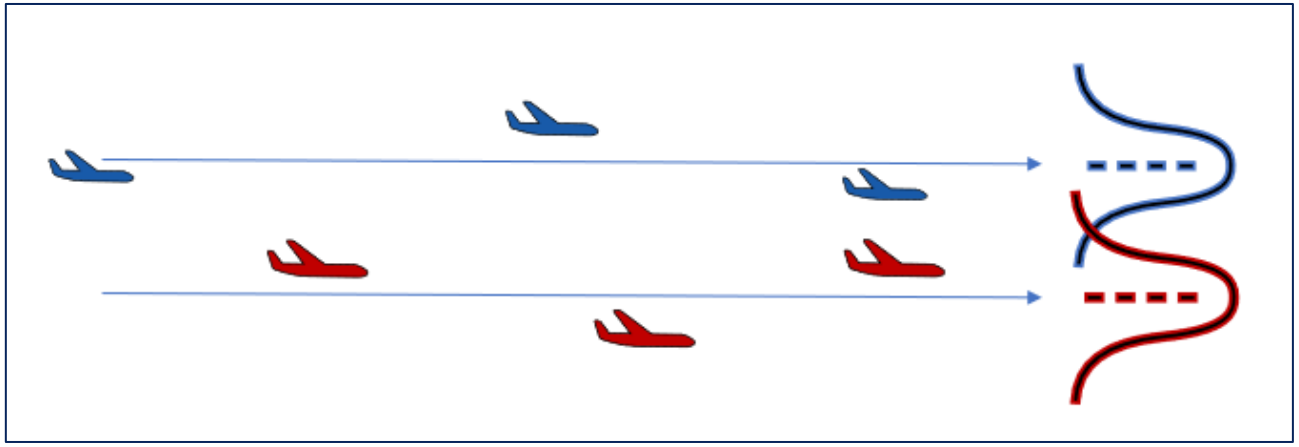
- All LHDs must be assigned a category code, as given in the table below.
- In order to reasonably and fairly compare the incidences of LHDs across different regions and Air Traffic Service Providers (ATSPs), each LHD must be categorised as consistently as possible.

LHD category	LHD category description
A	Flight crew failing to climb/descend the aircraft as cleared
B	Flight crew climbing/descending without ATC clearance
C	Incorrect operation or interpretation of airborne equipment
D	ATC system loop error
E	Coordination errors in the ATC-to-ATC transfer of control responsibility as a result of human factors issues
F	Coordination errors in the ATC-to-ATC transfer of control responsibility as a result of equipment outage or technical issues
G	Deviation due to aircraft contingency event leading to sudden inability to maintain assigned flight level
H	Deviation due to airborne equipment failure leading to unintentional or undetected change of flight level
I	Deviation due to turbulence or other weather-related cause
J	Deviation due to TCAS resolution advisory; flight crew correctly following the resolution advisory
K	Deviation due to TCAS resolution advisory; flight crew incorrectly following the resolution advisory
L	An aircraft being provided with RVSM separation is not RVSM approved
M	Other
R	GNSS RFI

Technical risk

Overview

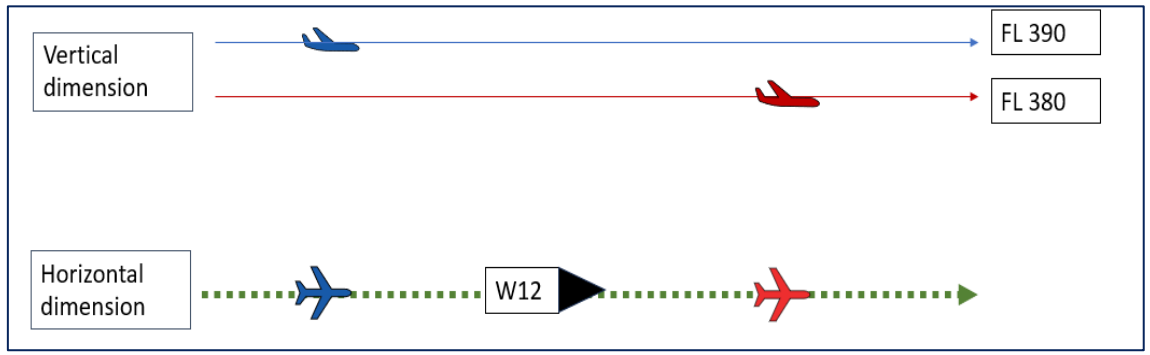
- Technical risk captures in part the risk of collision associated with an aircraft's ability to 'know' its altitude (i.e. height-keeping performance)
- Contributors to technical risk include aircraft altimetry errors and aircraft equipment failures resulting in deviations from cleared flight levels.
- It itself has two components:
  - Assigned Altitude Deviation (AAD)
  - Altimetry System Error (ASE)
- Technical risk also captures the risk of a non-RVSM approved aircraft operating in an airspace wherein the assumed ASE distribution is much higher compared to an RVSM-approved aircraft.



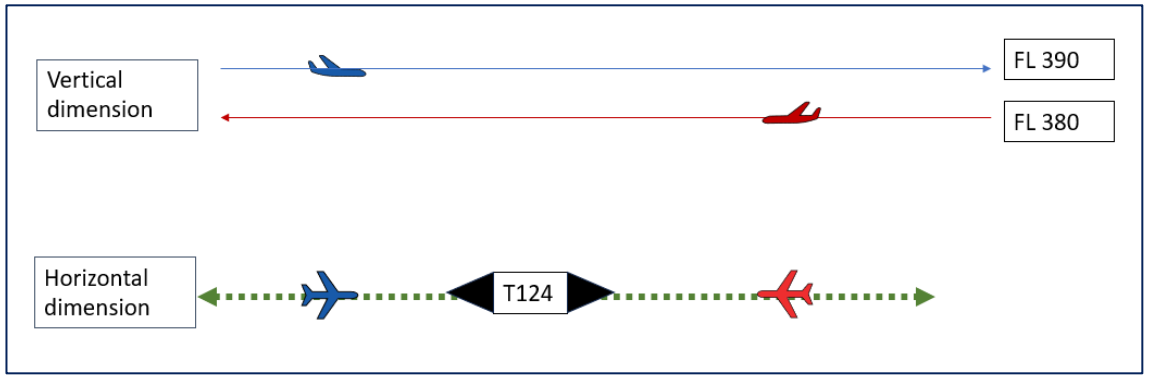
Technical error: the risk is associated with aircraft which are not able to be at the correct flight level and hence overlapping with another aircraft

Technical risk

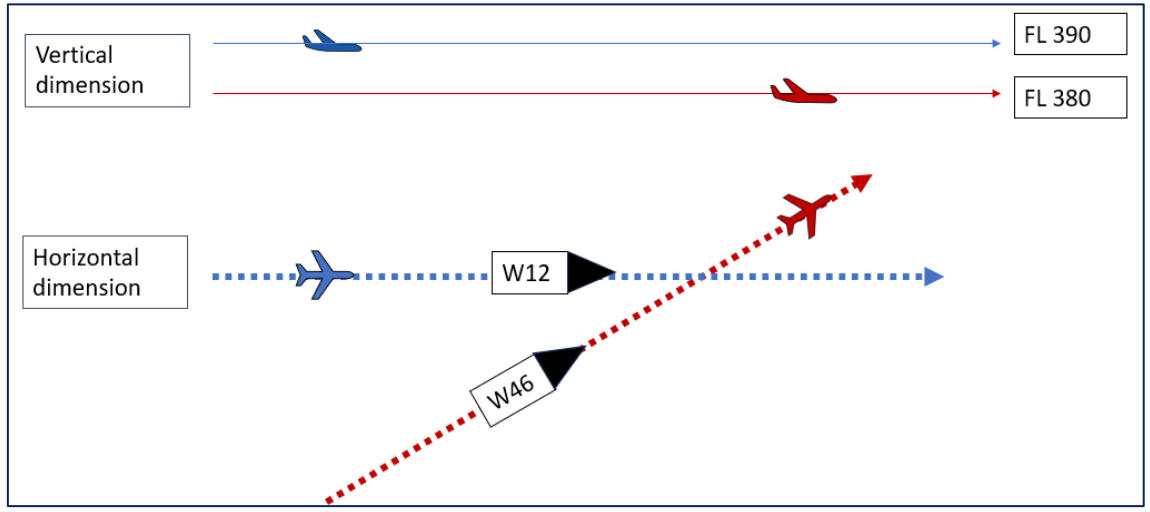
Risk is calculated for different scenarios: same-direction, opposite-direction, and crossing traffic



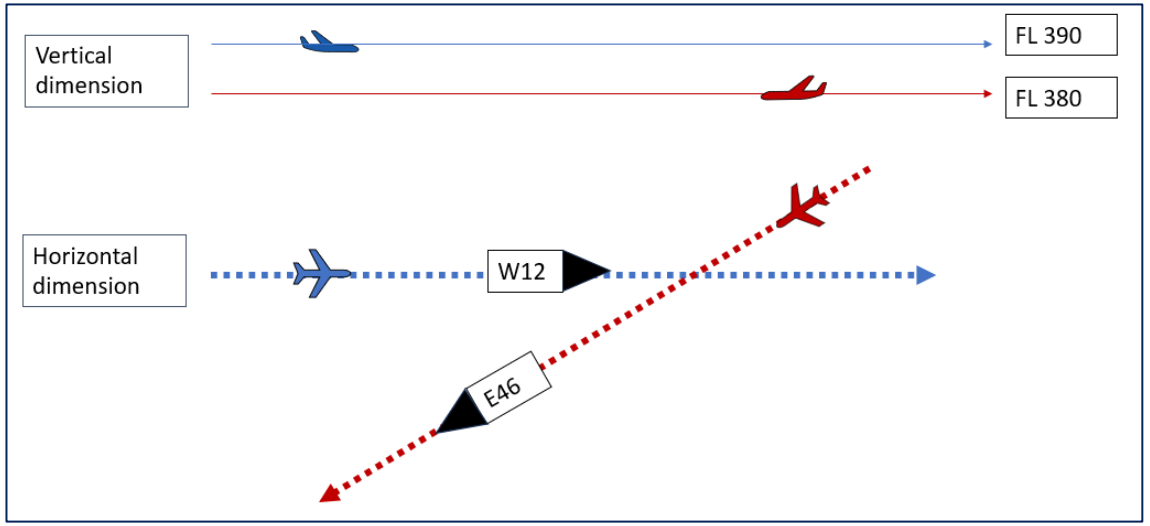
Same-direction traffic on the same two-way route.



Opposite-direction traffic on the same two-way route



Same-direction traffic on crossing routes

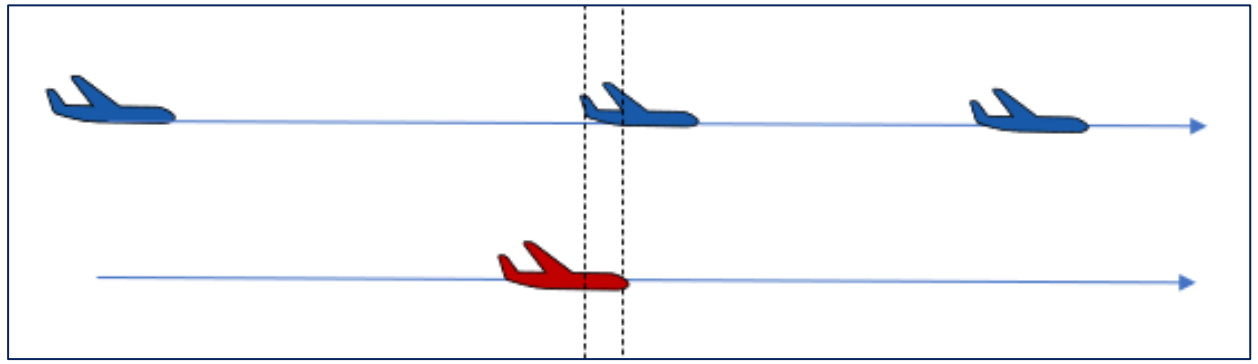


Opposite-direction traffic on crossing routes.

Technical risk

Risk scenario: same-direction traffic for parallel lateral tracks

- For simplicity, we will examine only one risk scenario – same-direction traffic for parallel lateral tracks – and calculate the risk using an application of a CRM model (Reich model).
- In simple terms, assume one aircraft is slowly passing another on a parallel track, heading in the same direction.
- The below figure 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.
- 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, and that there are multiple blue aircraft. The number of collisions in one hour can then be calculated.
- Logically, the frequency of passing and time spent are related: if the red aircraft spends 1 minute passing any blue aircraft (in longitudinal overlap), and it passes a blue aircraft 6 times an hour, the probability of being in overlap is 0.1.

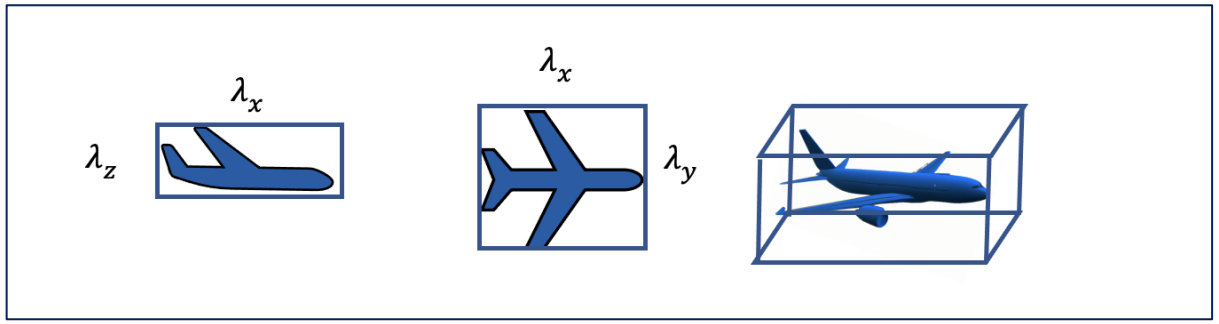


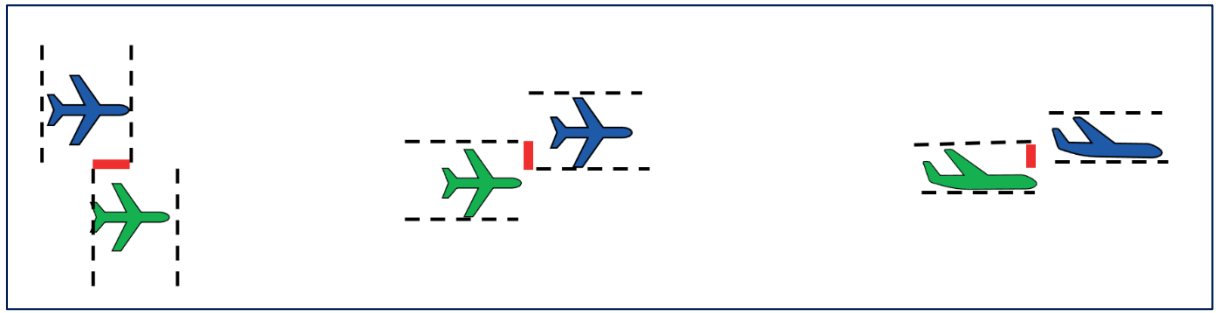
Consider a situation of the red aircraft on the lower track, being faster than the blue aircraft on the top track and slowly overtaking.

Technical risk

Risk scenario: same-direction traffic for parallel lateral tracks

- Aircraft are assumed to be rectangular boxes of size $\lambda_x, \lambda_y, \lambda_z$ in the three dimensions (see left figure below).
- For a collision to occur, the aircraft must overlap in each dimension (see right figure below).





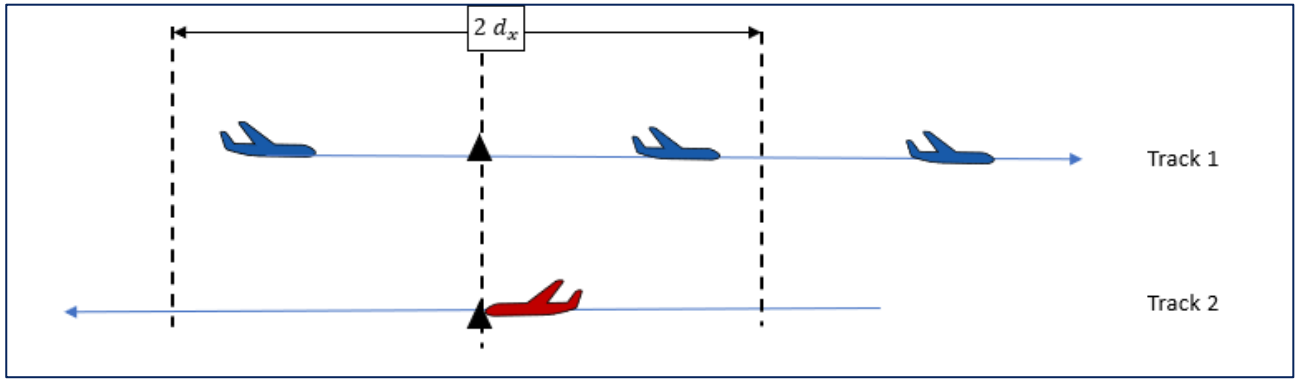
The model assumes a rectangular shape for an aircraft in each plane

The Reich model considers 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.

Technical risk

Occupancy

- For a collision, we know an aircraft must overlap in three dimensions as well as time.
- Occupancy helps capture the time dimension – it is a statistical measure of correlated airspace density related to how many aircraft may be close (proximate) to an aircraft.
- ICAO Doc 10063 states, “Occupancy is a measure of exposure of aircraft to one another”.
- The goal is to estimate the probability that another aircraft will be ‘adjacent’ and at risk if an aircraft deviates.
- Occupancy also helps us with the fact that aircraft may be separated by large distances – we can count the number of aircraft within a large distance (e.g.120 Nautical Miles) passing the same waypoint, and from that we can pro rata the chance that two aircraft will pass the waypoint at the same time.

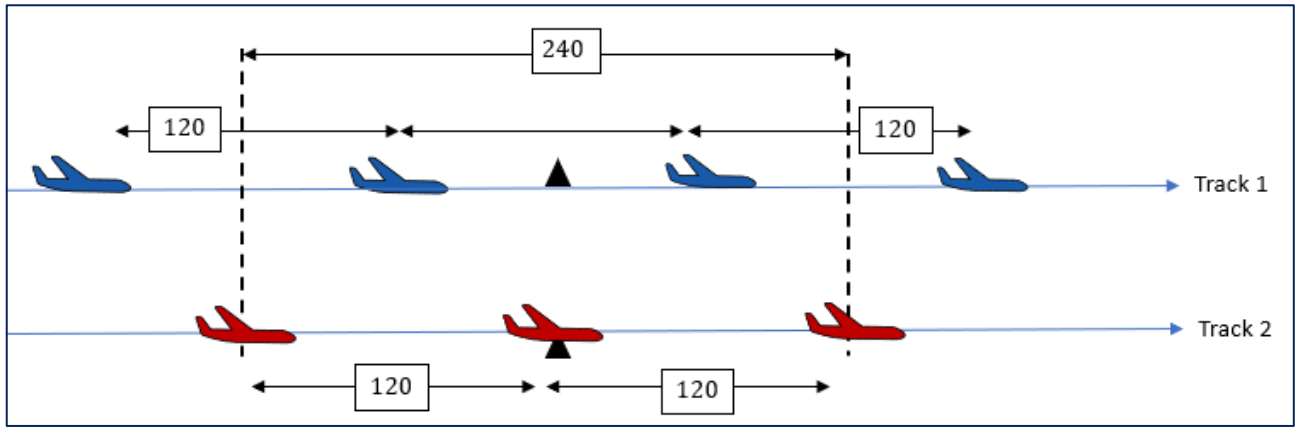


Occupancy is a measure how many aircraft are ‘proximate’, based on a statistical sample of aircraft as they pass a common waypoint.

Technical risk

Occupancy

- For example, consider again our scenario (same-direction traffic along parallel lateral tracks). Assume aircraft are evenly separated 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 we count 160 proximate pairs.
  - So $E = 160/80$ which is 2.



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

Technical risk

Combining risk scenarios to calculate technical risk

- Assuming vertical and lateral overlap is constant, we can relate longitudinal overlap to occupancy in the equation below (one form of the Reich model – relating aircraft dimensions and relative speeds and combining with overlap probabilities).

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

- We combine the results of the Reich model for opposite-, same- and crossing-direction traffic to determine the technical risk for an airspace.
- We compare technical risk to the relevant Target Level of Safety (2.5 x 10^{-9} fatal accidents per flight hour)

Total risk

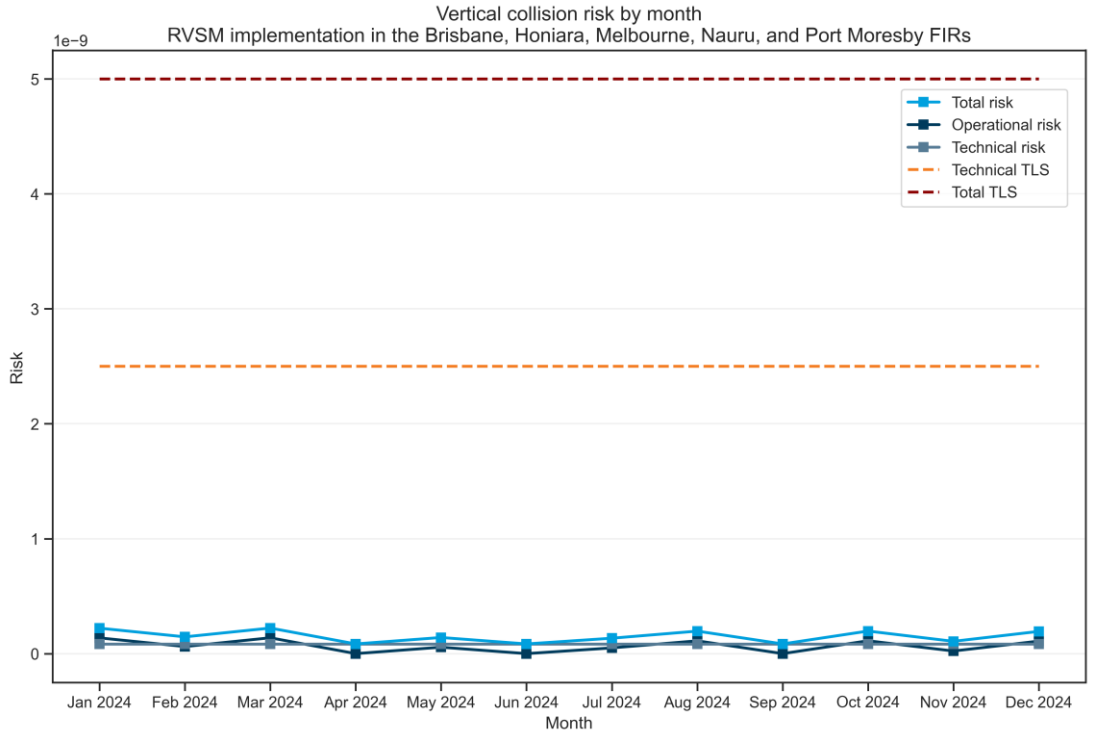
Overview

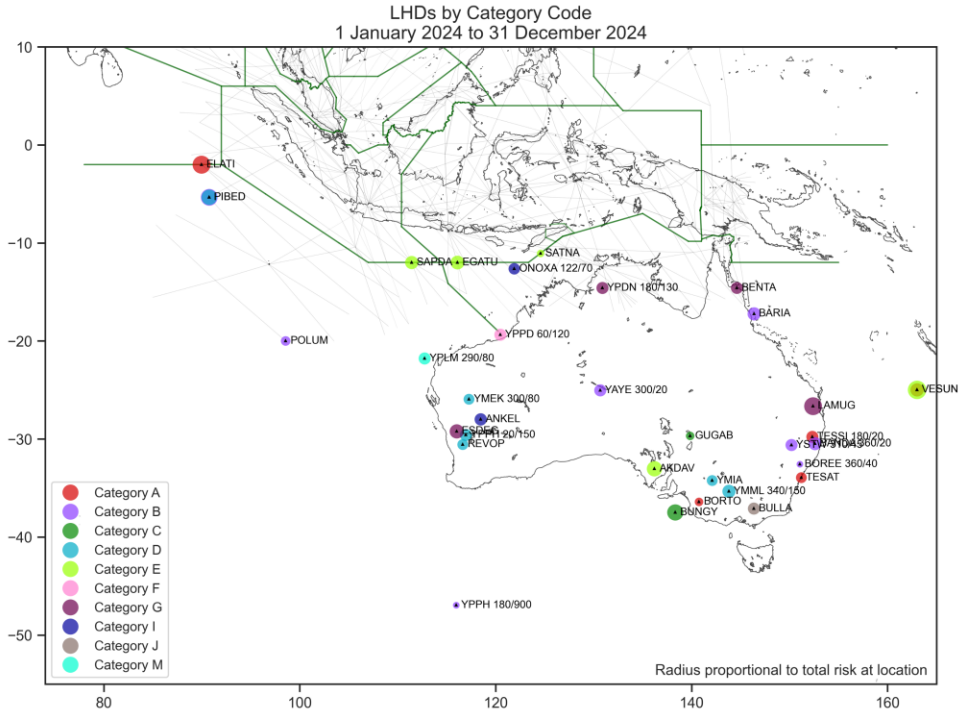
- To complete the operational risk calculations, we then break down the results into impact factors to simplify calculations:
  - I_s risk from 1-minute at an incorrect flight level with same-direction traffic
  - I_o risk from 1-minute at an incorrect flight level with opposite-direction traffic
  - I_{ls} risk from 1 level crossed at with same-direction traffic
  - I_{lo} risk from 1 level crossed at with opposite-direction traffic
- For each LHD, we sum the time and levels crossed for LHDs in each LHD category. Then we combine the results with the respective impact factors to calculate operational risk.
- We add technical risk and operational risk (aggregated by the number of flights hours in the airspace) to find total risk.
- We compare total risk to the relevant Target Level of Safety (5 x 10^{-9} fatal accidents per flight hour).

Total risk

Example: interpreting total risk results

- For calendar year 2024, total risk in Brisbane, Honiara, Melbourne, Nauru and Port Moresby FIR RVSM airspace (0.92×10^{-9}) was safer than the Target Level of Safety (5×10^{-9}).
- Half of LHDs in 2024 were risk-bearing, compared to 35% in 2023. 'Risk-bearing' means an aircraft is flying at an unprotected level for some period of time.
- Just under a third of the operational risk was contributed by 6 LHDs involving coordination errors in the ATC-to-ATC transfer or control responsibility as a result of human factors issues (Category E LHD).





Discussion

Key take-aways

- The goal of a safety assessment is to quantify the collision risk in RVSM airspace and compare it to globally accepted Target Levels of Safety.
- An RVSM collision risk model (CRM) was developed by ICAO. Risk is the sum of two components:
  - Technical risk
  - Operational risk
- Operational risk quantifies the risk associated with Large Height Deviations, which are any vertical deviation (of 300 ft or more) of an aircraft from its expected flight level.
- Technical risk in part quantifies the risk of collision associated with an aircraft's ability to 'know' its altitude (i.e. height-keeping performance).
- Total risk combines both operational risk and technical risk and is compared to a Target Level of Safety for the purpose of confirming safe RVSM operations.

Questions?

Please email aama@airservicesaustralia.com

Comprehension question

Consider the below LHD description reported by an enroute ATC belonging to FIR AAAA. Determine its LHD category. If relevant, determine the number of minutes the aircraft spent at an unprotected level as well as the number of levels crossed. Please note FIR BBBB is managed by a different state's ANSP.

At 0259, FIR BBBB coordinated XXX424 at FL310 to FIR AAAA. The aircraft arrived at the FIR AAAA boundary at 0340 and was visible on ADS-C, and a CLAM alert activated showing the aircraft was maintaining FL330. There was no amended level coordinated by FIR BBBB. FIR AAAA called FIR BBBB at 0341 who confirmed the aircraft had been issued FL330 without pre-coordination. No separation issues.

- LHD Category?
- Number of minutes?
- Number of levels crossed?

Comprehension question

- What does occupancy measure?
  A. Number of aircraft at a given waypoint, regardless of flight level
  B. Number of aircraft pairs at a given waypoint at the same or adjacent flight levels (e.g. FL300 and FL310)
  C. Number of aircraft close to a single aircraft within a given distance
  D. Number of aircraft within 120NM of each other