International Civil Aviation Organization
CAR/SAM Regional Planning and Implementation Group (GREPECAS)

WORKING PAPER

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21/09/26

**Twenty-Sixth Scrutiny Working Group Meeting (GTE/26)**
**of the CAR/SAM Regional Planning and Implementation Group (GREPECAS)**
Asynchronous (virtual): 9 to 25 September 2026
In person: Mexico City, Mexico, 12 to 16 October 2026

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**Agenda Item 3:** **Review of the Results of the Analysis of Large Height Deviations (LHDs) and of the Collision Risk Model (CRM)**
**3.7 Presentation of CRM 2025 and an analysis of the causes that contributed to these risks in Flight Information Regions (FIRs) that had a value above the Collision Risk Assessment (CRA) Desired Level of Safety (TLS)**

# ESTIMATED VERTICAL COLLISION RISK IN CAR/SAM REGIONS IN 2025

(Presented by CARSAMMA)


**EXECUTIVE SUMMARY**

This Working Paper presents the quantitative assessment of the Estimated Collision Risk (CRE) for the year 2025. Similarly, contributing factors in Flight Information Regions (FIRs) whose values exceeded the Target Level of Safety (TLS) in the Estimated Vertical Collision Risk (CRE) are analysed.


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|---|---|
| **Action:** | Suggested Actions are included in Section 7. |
| *Strategic Objectives:* | • Every Flight is Safe and Secure<br>• Aviation is Environmentally Sustainable<br>• Aviation Delivers Seamless, Accessible, and Reliable Mobility for All<br>• No Country Left Behind<br>• The International Civil Aviation Convention and Other Treaties, Laws and Regulations Address All Challenges<br>• The Economic Development of Air Transport Assures the Delivery of Economic Prosperity and Societal Well-Being for All |
| *References:* | • Doc. 9574 – Manual on a Minimum Vertical Separation of 300 m (1,000 ft) between Flight Levels FL 290 and FL 410 inclusive. Third edition, 2012.<br>• Doc. 9937 – Procedures and Operational Methods for Regional Surveillance Agencies in Relation to the Use of a Minimum Vertical Separation of 300 m (1,000 ft) between FL 290 and FL 410 inclusive. Second edition, 2019. |

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|---|---|
| | • Aircraft movement data in RVSM CAR/SAM airspace (December 2025).<br>• Validated Large Altitude Deviation (LHD) reports for the year 2025. |

**1. Introduction**

1.1 The purpose of this document is to evaluate continued compliance with the safety criteria defined in ICAO Doc 9574 and Doc 9937 within the Reduced Minimum Vertical Separation (RVSM) airspace of the CAR/SAM regions.

1.2. To this end, the Caribbean and South America Regions Monitoring Agency (CARSAMMA) presents the quantitative vertical collision risk assessment for the year 2025, which covers the 34 Flight Information Regions (FIRs) under its jurisdiction.

**2. Methodological Structure and Evaluation Criteria**

2.1. Operational Safety

2.1.1 Operational safety assessment in RVSM airspace is mandatory to ensure that changes in the traffic profile and any deviations do not degrade established safety levels. The main objective is to ensure that the total risk of vertical collision remains below pre-defined regulatory limits.

2.2. Model adopted for Risk

2.2.1 Mathematical quantification uses the Reich Vertical Collision Risk Model, a standard methodology recommended by ICAO. This probabilistic model correlates dynamic and physical parameters of actual air traffic to estimate risk against the regulatory Target Level of Safety (TLS).

2.3. Data Processing

2.3.1 The processing of the data involves complex modeling and the integration of multidimensional databases correlated by CARSAMMA's team of experts. Each evaluation cycle includes the analysis of data corresponding to a period of twelve consecutive months.

2.4. RVSM Assessment Validation Tools and Criteria

2.4.1 Methodological validation is based on the following key pillars:

- **Risk Assessment Methodology**: Structured use of analytical formulation for probabilistic modeling of collisions due to loss of vertical separation.
- **Continuous Airworthiness and RVSM Certification**: In strict accordance with Document 9574, global system performance specifications require aircraft operating under RVSM standards to possess valid and up-to-date operational approval from their respective States of Registration or Operation.

- **Target Level of Safety (TLS)**: The regulatory acceptability threshold corresponds to fatal accidents per flight hour, due to combined technical and operational causes. $5 \times 10^{-9}$
- **Altimetry System Error (ASE) Stability**: Continuous statistical evidence is required that the Altimetry System Error (ASE) of the monitored fleets remains stable and within tolerable limits.
- **Impact of operational errors and contingencies**: The introduction of the RVSM standard should not increase the risk associated with operational deviations or flight contingencies and should remain under controlled statistical control.
- **Safety mitigation measures**: Implementation of operational barriers and improvements in procedures to mitigate the impact of systemic and operational errors on the probability of vertical collision.
- **Effectiveness of ATC procedures**: Continuous verification that the procedures applied by the Air Traffic Control Units ensure the integrity of trajectories in the vertical plane.

## 3. RVSM CAR/SAM Airspace

3.1. RVSM Data Monitoring and Analysis

3.1.1 CARSAMMA systematically monitors 34 Flight Information Regions (FIRs) in the CAR/SAM regions. For statistical modelling purposes, each FIR is treated individually as an independent stochastic subsystem.

3.2. Traffic Sampling Data Collection (TDA)

3.2.1 The determination of the frequency of passage and the representative dynamic and physical parameters was based on sampling the air traffic data collected between December 1 to 31, 2025, covering 31 active FIRs.

3.2.2 The processed volume totalled 10,184,412 flight hours and 354,030 trajectory records (flight lines). The spatial distribution of the recorded sample was:

- CAR Region: 2,275,672 flight hours (22.34% of total volume).
- SAM Region: 7,908,739 flight hours (77.66% of total volume).

Note:

***Key Limitations***

- ***Missing December 2025 Data:*** *It is important to highlight that CARSAMMA did not receive traffic movement data for December 2025 from the* ***Cayenne (SOOO)****,* ***Paramaribo (SMPM)****, and* ***Lima (SPIM)*** *FIRs. Consequently, these movements were excluded from the vertical collision risk assessment.*
- ***Historical Data Gaps:*** *The lack of data extends beyond December 2025. The most recent data received for each FIR dates back significantly:*

- ***Lima (SPIM):*** *December 2024*
- ***Paramaribo (SMPM):*** *December 2022*
- ***Cayenne (SOOO):*** *December 2020*

***Operational Impact***

- ***Incomplete Exposure Modeling:*** *The vertical collision risk model relies on traffic movement data to characterize exposure and estimate simultaneous airspace/flight level occupancies.*
- ***Reduced Representativeness:*** *The absence of up-to-date data from these three FIRs compromises the completeness of the traffic sample, potentially affecting the accuracy and representativeness of the overall risk assessment for the CARSAM Region.*

***Recommendation:*** *Results of the CARSAM Region vertical collision risk assessment must be interpreted with this limitation in mind. Future analyses should prioritize securing up-to-date data submissions from the affected FIRs."*

3.3. Treatment of Large Height Deviations (LHD)

3.3.1 During the year 2025, 507 significant altitude deviation events were reported for CARSAMMA in the CAR/SAM regions. After a rigorous process of scrutiny, joint analysis and technical validation in bilateral teleconferences — with the participation of experts from CARSAMMA, the ICAO NACC and SAM Regional Offices, and IATA representatives — 309 LHD events were validated and integrated into the Collision Risk Estimate (CRE).

**4. RVSM Movement Data Processing**

4.1. The sample data collected in the reference period were used to estimate the physical and kinematic parameters of the aircraft typical of the operational scenario.

4.2. After receiving the raw data, CARSAMMA proceeded to filter, eliminate inconsistencies and process statistically. Table 2 (Appendix 1) consolidates the dimensional profile of the 20 most representative fleets operating in the CAR/SAM airspace, whose weighted dimensions define the geometric parameters of the "typical aircraft" used in the calculation of the Reich CRE.

**5. Vertical Collision Risk (CRE) Estimation**

5.1. Analysis of the risk estimation results. This section presents the quantitative results obtained for the year 2025. The structured probabilistic calculation was performed at the individualized FIR level and consolidated for the CAR/SAM regions.

5.2. Methodological parameters of the CRE model. The operational and traffic data supporting the estimation of the physical, geometric, and operational parameters of the Reich model are described in Table 3 (Appendix 2).

5.3. Technical feasibility of RVSM in CAR/SAM regions. The technical and operational sustainability of RVSM in the region is assessed based on three critical modelling parameters:

- Equivalent Frequency of Passage ($N_x$): A metric representing traffic density and geometric exposure to risk on paths in the same and opposite directions (Table 4 - Appendix 2).
- The estimated consolidated value for the CAR/SAM system was 1.6064 E-02.
- Lateral overlap probability ($P_y(0)$): Kinematic probability of nominal loss due to lateral separation of aircraft operating on the same route, and value of $P_y(0)$6.28 E-02.
- Vertical overlap probability ($P_z(1000)$: Standard probabilistic metric of 1,000 feet vertical separation loss for this cycle, with parametric value of 2.46 x E-08.

5.4 Testing system feasibility requires cumulative compliance with:

- Consolidated global safety margin in accordance with TLS.
- Statistical stability of the deviation of the Altimetry System Error (ASE).

5.4.1 Table 5 (Appendix 2) details the other estimated dynamic parameters. It should be noted that these values were calculated considering the conservative premise of systemic isolation by flight information region.

## 6. Conclusions on the estimation of the risk of vertical collision (CRE)

6.1 Risk profile assessment by FIR

6.1.1 Although the CAR/SAM Regions had an estimated risk of **0.7834 E-09** below the global threshold value of **5.0 E-09**, the FIRs of **Port-au-Prince, Asunción, La Paz, Curaçao and Guayaquil** recorded individual risk indices above the TLS. The main factors identified are:

- **Aircraft without RVSM approval**: The presence of uncertified flights in segregated airspace increases the risk geometrically. ANSPs and CAAs are urged to apply strict controls in the validation of flight plans, including for state-owned aircraft.
- **Tactical proximity between aircraft:** The confluence of traffic at adjacent levels in a window of less than 30 minutes increases the likelihood of collision.
- ***CARSAMMA will issue Tactical Mapping Reports for FIRs affected by risk above TLS.***
- **Severity and duration of LHD:** The duration of the event (in minutes) and the number of level crossovers heavily penalize mathematical calculation, especially in oceanic FIRs or with distant reporting points due to the delay in detection.
- Technical Error Compliance: The risk associated with technical airworthiness errors alone is **2.88 E-11**, significantly lower than the ceiling of **2.5 E-09 fatal accidents** per flight hour, demonstrating the robustness of the altimetry certification requirements maintained by fleets.

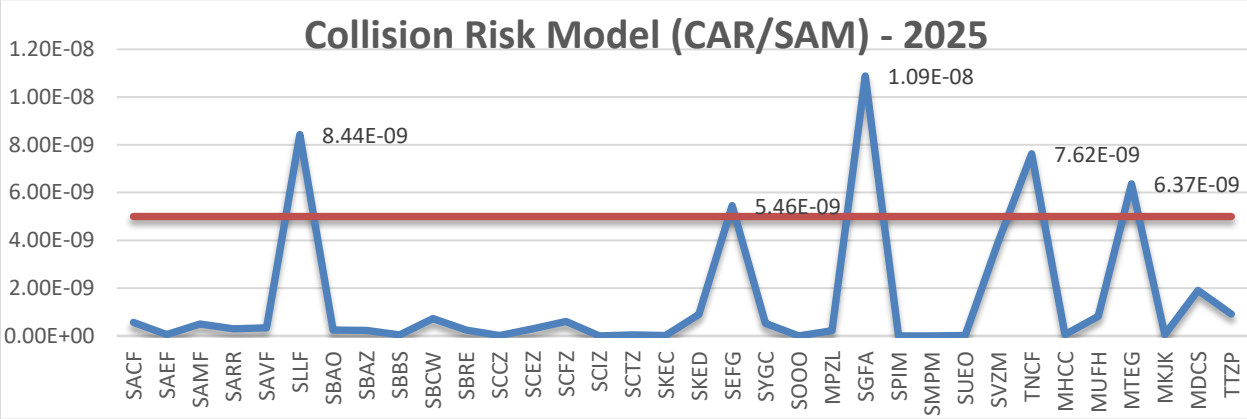



**Figure 1 - Estimated Collision Risk (CRE)**

| CAR/SAM RVSM Airspace – Estimated Flight Hours = 10,184,412 hours | | | |
|---|---|---|---|
| **Source of Risk** | **Estimated Cliff** | **TLS** | **Note** |
| **Technical Error** | **0.0288 x 10-9** | **2.5 x 10-9** | **Below** |
| **Operational error** | **0.784 x 10-9** | **-** | **-** |
| **Risk** | **0.7834 x 10-9** | **5.0 x 10-9** | **Below** |

**Table 1 – Risk of CAR/SAM**

## 7. Suggested Actions

7.1 The meeting is invited to:

a) Observe the technical information and data sent;

b) Formulate recommendations to support ongoing monitoring of LHD events and mitigation measures led by CARSAMMA.

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## APPENDIX 1

## REICH VERTICAL COLLISION RISK MODEL

$$N_{ax} = 2P_y(0)P_z(0)\left(\frac{\overline{|\dot{x}(m)|}}{2\lambda_x} + \frac{\overline{|\dot{y}_0|}}{2\lambda_y} + \frac{\overline{|\dot{z}_0|}}{2\lambda_z}\right)\frac{2\lambda_x}{\overline{|\dot{x}(m)|}}\frac{1}{T}\sum_s E(s)Q(s)$$

**Figure 2 – General formula of the REICH Vertical Collision Risk Model**

| ACFT Type (Top 20) | Length λx | Wingspan λy | Height λz | Percentage of flights | Length λx X % | Wingspan λy X % | Height λz X % |
|---|---|---|---|---|---|---|---|
| **A320** | 0.020286 | 0.018413 | 0.00635 | 18.81% | 0.003816 | 0.003463 | 0.001194 |
| **B738** | 0.021328 | 0.01933 | 0.006749 | 15.10% | 0.003221 | 0.002919 | 0.001019 |
| **A20N** | 0.020286 | 0.018413 | 0.00635 | 12.12% | 0.002459 | 0.002232 | 0.000770 |
| **B38M** | 0.021312 | 0.019395 | 0.006641 | 11.54% | 0.002459 | 0.002238 | 0.000766 |
| **A321** | 0.024033 | 0.018413 | 0.00635 | 6.05% | 0.001454 | 0.001114 | 0.000384 |
| **B763** | 0.029665 | 0.025686 | 0.008558 | 4.36% | 0.001293 | 0.001120 | 0.000373 |
| **B39M** | 0.022765 | 0.019395 | 0.006641 | 3.72% | 0.000847 | 0.000721 | 0.000247 |
| **A21N** | 0.024033 | 0.018413 | 0.00635 | 3.37% | 0.000810 | 0.000621 | 0.000214 |
| **B789** | 0.033909 | 0.032451 | 0.009179 | 2.57% | 0.000871 | 0.000834 | 0.000236 |
| **A332** | 0.031749 | 0.032559 | 0.009395 | 2.46% | 0.000781 | 0.000801 | 0.000231 |
| **B788** | 0.030616 | 0.032451 | 0.009125 | 2.36% | 0.000723 | 0.000766 | 0.000215 |
| **A319** | 0.018272 | 0.018413 | 0.000635 | 2.36% | 0.000431 | 0.000435 | 0.000015 |
| **B737** | 0.018898 | 0.018521 | 0.006749 | 2.07% | 0.000391 | 0.000383 | 0.000140 |
| **A359** | 0.036123 | 0.034557 | 0.009125 | 1.94% | 0.000701 | 0.000670 | 0.000177 |
| **E295** | 0.022408 | 0.01896 | 0.00589 | 1.84% | 0.000412 | 0.000349 | 0.000108 |
| **E190** | 0.019568 | 0.015507 | 0.005707 | 1.75% | 0.000342 | 0.000271 | 0.000100 |
| **B772** | 0.034411 | 0.0329 | 0.01 | 1.34% | 0.000461 | 0.000441 | 0.000134 |
| **B77W** | 0.039903 | 0.034989 | 0.009989 | 1.06% | 0.000423 | 0.000371 | 0.000106 |
| **A339** | 0.034341 | 0.032559 | 0.009098 | 0.94% | 0.000323 | 0.000306 | 0.000086 |
| **A333** | 0.034341 | 0.032559 | 0.009098 | 0.93% | 0.000319 | 0.000303 | 0.000085 |
| **Typical ACFT** | | | | **96.70%** | **0.022538** | **0.020358** | **0.006600** |

**Table 2 – Top 20 types of aircraft that flew RVSM in CAR/SAM**
**(Dimensional measurements are expressed in nautical miles)**

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# APPENDIX 2

## CRE PARAMETERS

| CRE Parameter | Description |
|---|---|
| $N_{az}$ | Number of fatal accidents per flight hour due to loss of vertical separation, |
| $S_z$ | Minimal vertical separation, |
| $P_z(S_z)$ | Probability that two aircraft nominally separated by the vertical separation minimum *Sz* are in vertical overlap, |
| $P_y(0)$ | Probability that two aircraft on the same trajectory are in lateral overlap, |
| $\lambda_x$ | Average length of aircraft, |
| $\lambda_y$ | Medium wingspan of aircraft, |
| $\lambda_z$ | Average height of aircraft with landing gear retracted, |
| $S_x$ | Length of the longitudinal window used to calculate occupancy, |
| $E_z(\text{same})$ | Vertical occupation in the same direction, |
| $E_z(\text{opp})$ | Vertical occupation in the opposite direction, |
| $V_m$ | Average ground speed of the aircraft, |
| $\dot{Y}_m$ | Relative average cross-trajectory velocity for a pair of aircraft nominally on the same trajectory, |
| $\dot{Z}_m$ | Average relative vertical velocity of a pair of aircraft that lost all vertical Separation |

**Table 3 - CRE Parameter Estimates**

| | Same Direction | Opposite Direction | Equivalent | Flight Hours |
|---|---|---|---|---|
| Frequency of Passage | 0.008942 | 0.073876 | 0.016064 | 10.184.412 |

**Table 4 – Frequency of Passage**

| CAR/SAM | Ez (same) | Ez (opp) | V | ΔV (same) | ΔV (opp) |
|---|---|---|---|---|---|
| | 0.0788701 | 0.018462 | 426.27 knots | 23.388 knots | 857.5724 knots |

**Table 5 – Physical and dynamic parameters**

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# APPENDIX 3

## LHD ANALYSIS

| Month | # LHD | Duration (min) | Cross Levels |
|---|---|---|---|
| January | 29 | 198.53 | 32 |
| February | 27 | 322.57 | 28 |
| March | 24 | 349.80 | 19 |
| April | 34 | 553.50 | 15 |
| May | 17 | 181.00 | 20 |
| June | 6 | 7.00 | 8 |
| July | 18 | 22.00 | 16 |
| August | 26 | 173.50 | 30 |
| September | 26 | 272.00 | 17 |
| October | 29 | 271.98 | 23 |
| November | 43 | 1058.80 | 26 |
| December | 30 | 112.50 | 36 |
| Total | 309 | 3523.18 | 270 |

Table 6 – LHD by Month

| Code | A | B | C | D | E1 | E2 | F1 | F2 | G | H | I | J | K | L | M | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| #LHD | 4 | 2 | 0 | 3 | 126 | 75 | 18 | 1 | 0 | 3 | 5 | 1 | 0 | 69 | 2 | 309 |

Table 7 – Number of validated LHDs

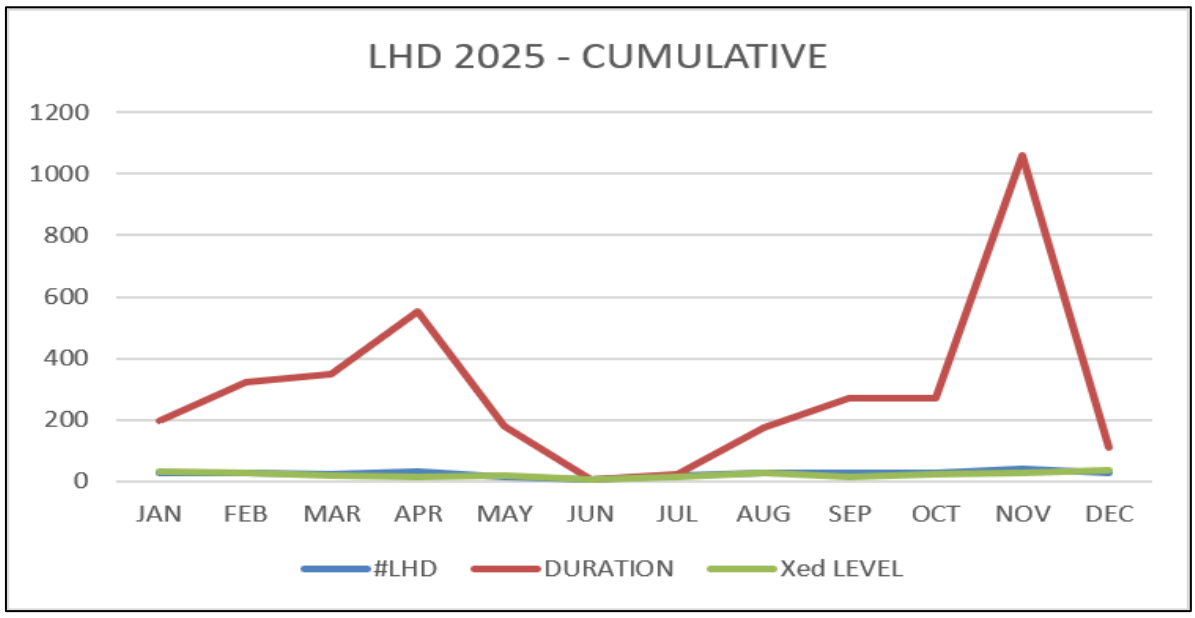



Figure 3 – Cumulative LHD (CRE)

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