



Agenda Item 1: Review of the previous CARSAMMA and Scrutiny Group meetings Conclusions and Recommendations

a) Results on 2016 safety assessment (CRM) in Reduced Vertical Separation Minimum (RVSM) airspace

VERTICAL COLLISION RISK (CRM) FOR THE YEAR 2016 IN THE CAR/SAM REGIONS

(Presented by CARSAMMA)

SUMMARY	
This working paper presents a summary of the calculation of the vertical collision risk in CAR/SAM Regions in 2016 using the CRM methodology.	
REFERENCES:	
<ul style="list-style-type: none">• ICAO Doc 9574-AN/934, Third Edition - 2012.• ICAO Doc 9937-AN/477, First Edition - 2012.• Aircraft Movements in the RVSM airspace in 2016.• Report of Large Height Deviations (LHD) in 2016.	
<i>ICAO strategic objectives:</i>	<i>A - Safety</i>

1. Background

1.1 The purpose of this work is to show that the safety criteria defined in ICAO Doc 9574 and Doc. 9937 continues to be met in the RVSM airspace of the CAR/SAM Regions.

1.2 This document reports on the analysis of the vertical collision risk in RVSM airspace in 2016 in the Flight Information Regions (FIR) of the Caribbean and South America. For this work, the Vertical Collision Risk Model (CRM) calculation methodology was used, as recommended by ICAO in RVSM airspace.

2. Analysis

2.1 This report presents the results of the safety assessment in the year 2016 in RVSM airspace of the Caribbean and South America (CAR/SAM). This step corresponds to the continuation of the implementation strategy of RVSM.

2.2 According to Doc. 9574 and Doc. 9937, the assessment must be made to ensure that operations in RVSM airspace not induce an increase in the risk of collision such that the total vertical risk does not exceed safety targets defined.

2.3 For the quantitative assessment, the Reich Vertical Collision Risk Model is used, as recommended by ICAO. This is a model of intensive mathematical foundations that, after analysing aircraft movements (spreadsheets containing data on flights conducted in RVSM airspace), calculates the target level of safety (TLS) of the Flight Region under study. Several calculation tools and databases are used for the various calculations during the process, as well as several hours of analysis by experts.

2.4 This working paper contains a summary of the results of the assessment of continuing safety of the 300 m (1000 ft) reduced vertical separation minimum in Caribbean and South American airspace in 2016.

2.5 The RVSM safety assessment covers a period of twelve consecutive months.

2.6 Special attention should be paid to ensure that:

- All aircraft operating in reduced vertical separation minimum airspace are RVSM-certified;
- The aircraft certification is current;
- The target level of safety (TLS) of 5×10^{-9} mortal accidents per flight hour (for tracking height-keeping in a representative sample of aircraft) continues to be met;
- The use of RVSM does not increase the level of risk due to operational errors and contingency procedures;
- There is evidence of aircraft altimetry system (ASE) stability;
- The introduction of RVSM does not increase the level of risk due to operational errors and flight contingencies, in accordance with a predefined level of statistical confidence;
- Additional effective safety measures are adopted to reduce the collision risk and to meet the safety targets due to operational errors and contingency procedures;
- There is evidence of stability of the altimetry system error (ASE);
- Air traffic control procedures continue to be effective.

3. **CAR/SAM Airspace**

3.1 The airspace of the CAR/SAM Regions is composed of 34 Flight Information Regions (FIR) consisting of the following States: Antigua and Barbuda, Netherlands Antilles, Argentina, Barbados, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, El Salvador, Ecuador, Granada, Guadeloupe, Guatemala, Guyana, French Guiana, Haiti, Honduras, Jamaica, Martinique, Nevis, Nicaragua, Panama, Paraguay, Peru, Dominican Republic, St. Barthelemy, St. Kitts and Nevis, St. Lucia, St. Vincent and Grenadines, Suriname, Trinidad & Tobago, Uruguay and Venezuela.

3.2 Each part of the airspace was treated as an isolated system, with its own statistical parameters.

3.3 Collect of Data Traffic Movement - The sample used to evaluate the frequency of passage and physical and dynamic parameters of typical aircraft for assessing the risk of collision, was collected in the period between 01 and 31 December 2016, of the 32 FIRs of the CAR/SAM Regions. In these shipments data, in terms of flight hours of the collected samples there were received 1,160,614.66 flight hours of all FIR mentioned, with 329,143.16 hours of CAR Region (28.36%) and 831,471.50 hours of SAM Region (71.64%). As in previous years, much of the data received from some States could not be exploited in CRM for various reasons, including errors in the times of entry and exit RVSM space (less than or equal time input output), lack of complete information to identify and locate fixed routes and notification, or even data sent beyond the deadline. However, all data sent was exploited in another product of CARSAMMA, which is the Audit of RVSM airspace.

3.4 As to the occurrence of vertical deviations (LHDs) reported in the CAR/SAM Regions, CARSAMMA received a total of 1,280 LHDs in 2016. Following the analysis and validation carried out through teleconferences with representatives of the ICAO Lima and Mexico Offices, the FIRs involved, IATA and CARSAMMA, 1,065 of these LHD were considered valid in the CAR/SAM Regions.

3.5 As during the last RMA Coordination Group meeting (RMACG12), held in May 2017 in Salvador - Brazil, it was agreed that risk factors should not be considered for LHDs whose causes involve the Human Factor, since they would be evaluated in the CARSAMMA Safety Management Systems analysis. Therefore, the 1,024 LHDs that received in the teleconferences the "E1" or "E2" code will not be considered in this study.

3.6 Therefore and applying the correct guidelines among the RMAs, the total LHD analyzed by the CRM parameters is 58 LHD, such being:

Code	A	B	C	D	F	G	H	I	J	L
LHD	6	8	2	6	16	2	3	11	1	3

3.7 The following table describes the distribution of LHD per month:

MONTH	LHD Quantity	Total Duration (sec.)	Average Duration (sec.)	Average Risk	Greater Risk	LHD Sequence
January	3	155	52	13	19	27
February	3	213	71	17	25	225
March	4	1826	457	19	37	332
April	4	240	60	22	22	343, 344, 352, 433
May	7	335	48	18	22	500, 501, 512, 548
June	7	450	64	18	30	617
July	5	212	42	21	30	670, 676
August	6	360	60	23	30	777, 790, 859
September	9	345	38	19	23	891

MONTH	LHD Quantity	Total Duration (sec.)	Average Duration (sec.)	Average Risk	Greater Risk	LHD Sequence
October	2	216	108	16	19	1015
November	5	647	129	16	22	1149
December	3	160	53	15	18	1270
Total	58	5159	89	18	37	332

Table 1

4. Aircraft movement data collection

4.1 The sample data for estimating the pass frequency and the physical parameters, as well as the dynamics of a typical aircraft for the assessment of the vertical collision risk were collected from 1 to 31 December 2016.

4.2 Aircraft movement data received from the 32 CAR/SAM FIRs was processed and used to assess RVSM airspace safety, as recommended by ICAO. The number of flight hours used is shown in **Table 2**.

Region	Flight hours	%
CAR	329,143.16	28.36 %
SAM	831,471.50	71.64 %
CAR/SAM	1,160,614.66	100.00 %

Table 2

4.3 Upon receiving the aircraft movement data, CARSAMMA proceeded to filter and process the data. **Table 3** below shows the results, and lists the aircraft that flew across the CAR/SAM FIRs, with their dimensions and percentage of flight hours, including a typical aeroplane, used as a dimension of the Vertical Risk Calculation Model.

ACFT type	Length λ_x	Wingspan λ_y	Height λ_z	Number of flights	% of flights
A320	0.020286	0.018413	0.00640	55,445	26.03%
B738	0.021328	0.018521	0.00675	47,648	22.37%
E190	0.019568	0.015507	0.00571	22,769	10.69%
A319	0.018272	0.018413	0.00640	14,039	6.59%
B737	0.018898	0.011852	0.00675	12,489	5.86%
B763	0.029644	0.025702	0.00756	10,481	4.92%
A321	0.024033	0.018413	0.00640	9,819	4.61%
A332	0.031749	0.032559	0.00940	7,886	3.70%
B772	0.034395	0.032883	0.00999	5,975	2.81%
B77W	0.034395	0.034989	0.01004	4,330	2.03%
B752	0.025551	0.020788	0.00732	3,433	1.61%
B788	0.030778	0.032397	0.00918	3,140	1.47%
B789	0.034017	0.034017	0.00918	2,037	0.96%
A343	0.034341	0.032559	0.00910	1,913	0.90%
B733	0.017279	0.016199	0.00648	1,824	0.86%

ACFT type	Length λ_x	Wingspan λ_y	Height λ_z	Number of flights	% of flights
B739	0.021328	0.018521	0.00675	1,778	0.83%
A346	0.040659	0.03426	0.00934	1,677	0.79%
B744	0.038175	0.034773	0.01048	1,327	0.62%
MD83	0.024352	0.01771	0.04887	1,277	0.60%
B767	0.033153	0.028024	0.00907	1,267	0.59%
B77L	0.034395	0.034989	0.010043	1,216	0.57%
B734	0.019708	0.015605	0.00599	823	0.39%
B764	0.033153	0.028024	0.00756	392	0.18%
Typical Acft	0.022923	0.020251	0.007219	212,985	100.00%

**Table 3 – Aircraft that flew RVSM in the CAR/SAM FIR
(Dimension measurements are expressed in nautical miles)**

5. **Collision risk safety assessment (CRM)**

5.1 This section analyses the results of the safety assessment of RVSM airspace in the CAR/SAM FIR.

5.2 The internationally accepted collision risk methodology (CRM) has been used for the safety assessment of RVSM airspace in the Caribbean and South American.

5.3 Estimates of CRM parameter:

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

Figure 1 – General Formula of the REICH Collision Risk Model

5.3.1 The material and quantity of the source used for estimating the values of each parameter of the internationally accepted Collision Risk Model (CRM) used for assessing the safety of the RVSM airspace are summarised in **Table 4**.

Parameter	Description	Value
λ_x	Mean length of the aircraft sample	0.022923nm
λ_y	Mean extent of the aircraft sample	0.020251nm
λ_z	Mean height of the aircraft sample	0.007219nm
V	Mean speed of the aircraft sample (module)	435.9665 kt/h

Parameter	Description	Value
$ \Delta V $	Relative same-direction speed of the aircraft sample (module)	32.03411 kt/h
$ \dot{y} $	Mean speed relative to the transverse approach of the aircraft sample (module)	13 kts
$ \dot{z} $	Mean relative vertical speed during loss of vertical separation of the aircraft sample (module)	1.5 kts
$P_z(0)$	Probability that two aircraft with the same nominal level overlap laterally in the aircraft sample	0.408635

Table 4 – CRM parameter estimates

5.4 Demonstration of the technical feasibility of RVSM in the CAR/SAM Regions.

5.4.1 This involves assessing the results of the values of the parameters of the REICH Collision Risk Model:

- Pass frequency N_x ;
- Probability of vertical overlap $P_z(1000)$; and
- Probability of lateral overlap $P_y(0)$.

To demonstrate this, the following objectives were established:

Generate confidence in the compliance with the technical TLS; and
 Certify ASE stability.

5.5 System performance specifications

5.5.1 Pass frequency, N_x -This is the parameter of the airspace where the aircraft is exposed to the vertical collision risk. The equivalent pass frequency was estimated taking into account aircraft flying in the same direction and in opposite directions, as shown in **Table 5**.

Pass frequency	Same direction	Opposite direction	Equivalent	Flight time (h)
CAR/SAM	0.00496611	0.02762529	0.03591072	1,160,614.66

Table 5 – Pass frequency

5.5.2 Values are related to the CAR/SAM airspace system. It should be noted that the pass frequency shown in Table 4 (0.03591072) was calculated on the basis of total filtered flight hours in the 32 CAR/SAM FIR.

- The estimated value of $P_z(1000)$ used in our calculations was 2.46×10^{-8} .

5.6 Estimating the collision risk

5.6.1 **Table 6** contains the sets of physical and dynamic parameters estimated in the REICH Collision Risk Model, as well as the follow-up to the main parameters for the CAR/SAM FIRs. All parameters were determined based on the airspace of each region being considered as an isolated system.

	Ez (same)	ΔV (same)	Ez (0p)	ΔV (op)	Ez (cross)	V
CAR/SAM	0.03898688	32.03411	0.00690632	418.36722	0.047480129	435.9665

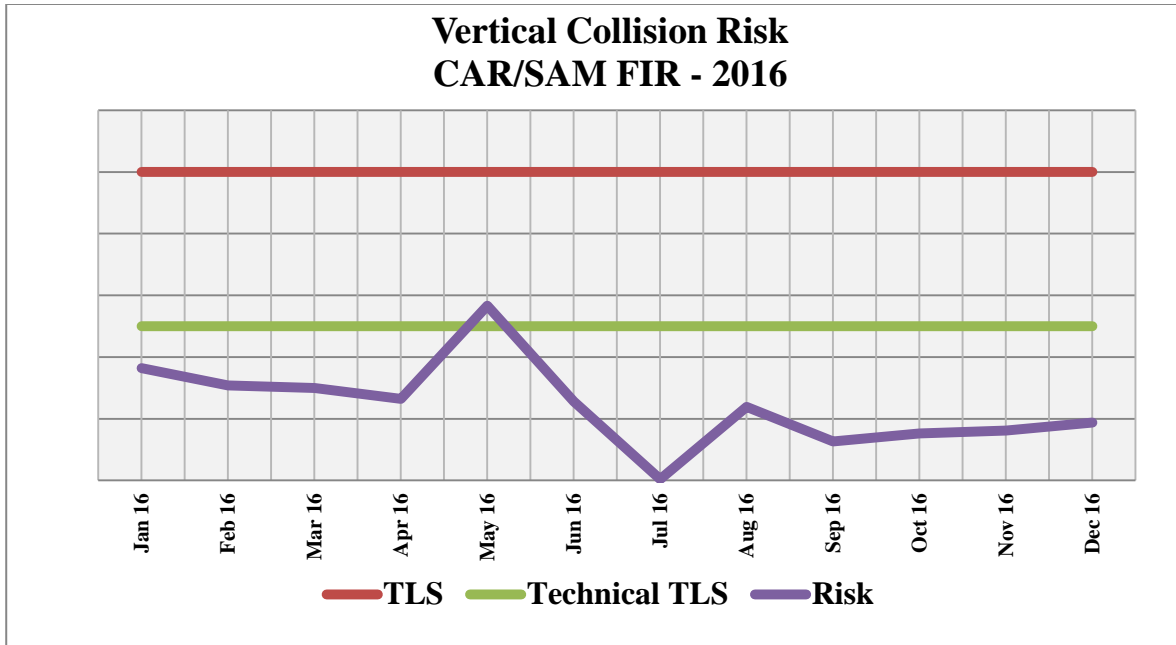
Table 6 – Physical and dynamic parameters

6. **Conclusions of the safety assessment (CRM)**

6.1 Collision Risk - The estimated values of the Operational Error are presented in Table 7, which result from processing all LHD received and validated in 2016, plus the files containing aircraft movements in RVSM airspace, as processed in the specific CRM software.

Month	Technical Error	Operational Error	Risk
January	0.0257×10^{-9}	1.799×10^{-9}	1.825×10^{-9}
February	0.0261×10^{-9}	1.514×10^{-9}	1.540×10^{-9}
March	0.0261×10^{-9}	1.478×10^{-9}	1.504×10^{-9}
April	0.0261×10^{-9}	1.298×10^{-9}	1.324×10^{-9}
May	0.0261×10^{-9}	2.799×10^{-9}	2.825×10^{-9}
June	0.0297×10^{-9}	1.255×10^{-9}	1.285×10^{-9}
July	0.0258×10^{-9}	0.013×10^{-9}	0.039×10^{-9}
August	0.0260×10^{-9}	1.161×10^{-9}	1.187×10^{-9}
September	0.0260×10^{-9}	0.060×10^{-9}	0.086×10^{-9}
October	0.0260×10^{-9}	0.738×10^{-9}	0.764×10^{-9}
November	0.0260×10^{-9}	0.785×10^{-9}	0.811×10^{-9}
December	0.0260×10^{-9}	0.922×10^{-9}	0.948×10^{-9}

Table 7 - Safety Assessment



Graph 2 - Vertical Collision Risk

6.2 The technical error of the CAR/SAM FIR satisfies the goal that states that it should not exceed 2.5×10^{-9} fatal accidents per flight hour due to loss of standard vertical separation of 1000 ft and all other causes.

- The operational risk does not have a predetermined limit according to ICAO Doc 9574.
- In the case of the CAR/SAM Regions, the estimated medium risk is 1.22×10^{-9} below the TLS, which is 5.0×10^{-9} .

CAR/SAM RVSM airspace			
Estimated flight hours = 1,160,614.66 hours			
Source of Risk	Estimated Risk	TLS	Remarks
Technical Error	0.0261×10^{-9}	2.5×10^{-9}	Below
Operational Error	1.1956×10^{-9}	-	-
Risk	1.2203×10^{-9}	5.0×10^{-9}	Below

Table 8

7. Suggested action:

7.1 The Meeting is invited to:

- a) note and review the contents of this working paper; and
- b) share experiences and express opinions concerning CARSAMMA’s actions in this matter.