International Civil Aviation Organization
North American, Central American and Caribbean Office

WORKING PAPER

GTE/18 — WP/06
13/09/18

CAR/SAM Planning and Implementation Regional Group (GREPECAS) Eighteenth Scrutiny Working Group Meeting (GTE/18)

Mexico City, Mexico, 22 – 26 October 2018

Agenda Item 1: **Review of the conclusions and recommendations of previous meetings of CARSAMMA and the Scrutiny Group**

a) 2017 Results of the Safety Assessment (CRM) in the Air Space of Minimized Vertical Separation (RVSM).

RISK OF VERTICAL COLLISION (CRM) OF THE YEAR 2017 IN THE CAR/SAM REGIONS

(Presented by CARSAMMA)

EXECUTIVE SUMMARY	
This working paper presents a summary of the vertical collision risk calculation in the CAR/SAM Regions in 2017 using the CRM methodology.	
Action:	Take note and review the contents of this Working Paper.
Strategic Objectives:	• Safety
References:	• ICAO Doc 9574 - *Manual on a 300 m (1 000 ft) Vertical Separation Minimum Between FL 290 and FL 410 Inclusive,* AN /934, Third Edition - 2012. • ICAO Doc 9937 - *Operating Procedures and Practices for Regional Monitoring Agencies in Relation to the Use of a 300 m (1 000 ft) Vertical Separation Minimum Between FL 290 and FL 410 Inclusive*, AN / 477, First Edition - 2012. • Movement of aircraft in the RVSM space in 2017. • Reports of Large Height Deviations (LHD) in 2017.

1. Introduction

1.1 The purpose of this paper 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 vertical collision risk in the RVSM airspace in 2017 in the Flight Information Regions (FIR) of the Caribbean and South America. For this work, the calculation methodology of the vertical Collision Risk Model (CRM) was used, as recommended by ICAO in the RVSM airspace.

2. Analysis

2.1 This report presents the results of the safety assessment in 2017 in the RVSM airspace of the Caribbean and South America (CAR/SAM). This step corresponds to the continuation of the RVSM implementation strategy.

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

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 fundamentals that, after analyzing the movements of aircraft (spreadsheets containing data on flights made in RVSM airspace), calculates the Target Level of Safety (TLS) of the Flight Information Region (FIR) under study. Several calculation tools and databases are used for 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 continuous safety assessment of the reduced vertical separation minimum of 300 m (1000 ft) in the Caribbean and South American airspace in 2017.

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

2.6 Special attention should be paid to:

- All aircraft operating in airspace of reduced vertical separation minimum are RVSM certified;
- The certification of the aircraft is current;
- The Target Safety Level (TLS) of 5 x 10-9 fatal accidents per flight hour continues to be met (for height tracking in a representative sample of aircraft);
- The use of RVSM does not increase the level of risk due to operational errors and contingency procedures;
- There is evidence of the stability of the aircraft Altimetry System Error (ASE);
- The introduction of RVSM does not increase the level of risk due to operational errors and flight contingencies, according to a predefined level of statistical confidence;
- Effective additional safety measures are adopted to reduce the risk of collision and meet safety goals due to operational errors and contingency procedures;
- 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) composed of the following States: Antigua and Barbuda, Netherlands Antilles, Barbados, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Guatemala, Guyana, French Guiana, Haiti, Honduras, Jamaica, Martinique, Nevis, Nicaragua, Panama, Paraguay, Dominican Republic, Saint Barthelemy Saint Kitts and Nevis and Saint Lucia, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, Uruguay and Venezuela.

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

3.3 Collection of Traffic Data - The sample used to evaluate the frequency of passage and physical and dynamic parameters of typical aircraft to assess the collision risk, was collected in the period between 01 and 31 December 2017 of the 34 CAR/SAM FIRs. In these data of movements of the samples collected, 397,265 flight registry lines were received from the aforementioned FIRs. All records were refined, subtracting 369,724 lines of flight records validated in the process. However, all the data sent was exploited in another CARSAMMA product, which is the RVSM airspace audit.

3.4 Regarding the occurrence LHD reported in the CAR/SAM Regions, CARSAMMA received a total of 1,127 LHD in 2017. After the analysis and validation carried out through teleconferences with representatives of the ICAO Regional Offices in Mexico and Peru, IATA and CARSAMMA, 982 of these LHD were considered valid, being 947 in the CAR/SAM Regions.

3.5 Therefore, the total LHD analysed by category were:

CODE	A	B	C	D	E	F	G	H	I	J	K	L	M	Total
LHD	8	7	0	5	900	12	0	2	7	3	0	2	1	**947**

Table 1

3.6 The following table describes the distribution of LHD duration per month:

MONTH	LHD	Total Duration (min)	Average Duration (min)
January	**93**	**105.5**	**1.13**
February	**92**	**101.3**	**1.10**
March	**91**	**154.9**	**1.70**
April	**100**	**119.5**	**1.19**
May	**56**	**53.1**	**0.94**
June	**64**	**67.3**	**1.05**
July	**81**	**119.3**	**1.47**
August	**76**	**89.5**	**1.17**
September	**75**	**90.5**	**1.20**
October	**69**	**77.9**	**1.12**
November	**74**	**76.2**	**1.02**
December	**76**	**65.8**	**0.86**
Total	**947**	**1120.8**	**1.18**

Table 2

4. Collection of aircraft movement data

4.1 The sample data to estimate the frequency of passage and the physical parameters, as well as the dynamics of a typical aircraft for the assessment of vertical collision risk were collected from 1 to 31 December 2017.

4.2 Aircraft movement data received from the 32 CAR/SAM FIRs were processed and used to assess the safety of RVSM airspace, as recommended by ICAO. The number of flight hours used is shown in Table 3.

Region	Flight Hours	%
CAR	46801.58	21.98%
SAM	166126.5	78.02%
CAR/SAM	212,928.04	100.00%

Table 3

4.3 Upon receiving the movement data of the aircraft, CARSAMMA proceeded to filter and process the data. Table 4 shows the results and lists the aircraft that flew through the CAR/SAM FIRs, with their dimensions and percentage of flight hours, including a typical aircraft, used as a dimension of the Vertical Risk Calculation Model.

Type ACFT	Length	Wingspan	Height	Flight Hours	% Type	#Flights
B738	0.0213121	0.0185259	0.0067495	52,867.38	24.83%	87,078
A320	0.02028618	0.0184125	0.0063499	41,361.83	19.43%	68,269
E190	0.01956803	0.0155076	0.0057073	20,337.14	9.55%	33,207
A319	0.01827214	0.0184125	0.0063499	14,650.60	6.88%	24,313
A321	0.02028618	0.0184125	0.0063499	11,695.70	5.49%	20,716
B737	0.01814255	0.0185205	0.0067495	11,581.38	5.44%	17,252
B763	0.02570194	0.0296436	0.0085853	8,073.99	3.79%	18,080
A332	0.03439525	0.0324136	0.0090389	7,514.07	3.53%	14,968
B772	0.03439525	0.0328834	0.0099892	4,047.93	1.90%	9,755
B77W	0.03990281	0.0328834	0.0099892	3,706.18	1.74%	8,345
B788	0.03061555	0.0324514	0.0091253	2,696.91	1.27%	5,481
B752	0.02555076	0.0205454	0.0073434	2,568.93	1.21%	5,249
B789	0.03390929	0.0324514	0.0091253	1,836.61	0.86%	4,370
B733	0.01803456	0.0156048	0.0059935	1,818.32	0.85%	3,215
B739	0.02273218	0.0185205	0.0068035	1,448.00	0.68%	1,862
A346	0.04015659	0.0343413	0.0096112	1,364.26	0.64%	2,462
A343	0.03439525	0.0325594	0.0090389	1,278.04	0.60%	2,681
B744	0.03817495	0.0347732	0.0104752	1,258.54	0.59%	2,468
A333	0.03439525	0.0324136	0.0090389	1,195.29	0.56%	2,852
A318	0.016982	0.018413	0.006782	985.81	0.46%	1,640
B734	0.01965443	0.0156048	0.0059935	945.19	0.44%	2,039
B77L	0.03659827	0.0333045	0.0099892	922.56	0.43%	1,739
B748	0.0411987	0.0353402	0.0105292	921.92	0.43%	1,600
CRJ2	0.01447084	0.0114525	0.0034017	726.87	0.34%	1,196
H25B	0.00842333	0.0084773	0.0029158	663.1	0.31%	974
E50P	0.00108	0.001296	0.003996	650.01	0.31%	1,012
MD83	0.024352	0.01771	0.004886	631.88	0.30%	953
C56X	0.00853132	0.0091793	0.0028078	594.02	0.28%	898
CL60	0.0112635	0.0104482	0.0033909	584.2	0.27%	868
E175	0.017105	0.014038	0.005253	553.65	0.26%	695
LJ60	0.00965983	0.0072084	0.0023974	529.51	0.25%	827
B764	0.033153	0.028024	0.007559	505.26	0.24%	1,745
LJ35	0.00794276	0.0064633	0.0020032	498.8	0.23%	837
B762	0.026188	0.025702	0.007559	485.56	0.23%	935

Type ACFT	Length	Wingspan	Height	Flight Hours	% Type	#Flights
B722	0.021922	0.017765	0.005562	434.81	0.20%	838
E135	0.01421706	0.0108207	0.0036501	423.47	0.20%	734
C550	0.00718143	0.0077754	0.0023758	416.4	0.20%	600
C525	0.070086	0.077213	0.002262	400.37	0.19%	605
GLF4	0.01452484	0.0128456	0.0041253	369.82	0.17%	566
MD11	0.03304536	0.0279158	0.0095032	368.02	0.17%	703
MD88	0.024301	0.017718	0.004854	339.07	0.16%	450
BE40	0.079643	0.071544	0.002289	325.62	0.15%	500
LJ45	0.00955724	0.0078834	0.0023218	319.71	0.15%	475
E55P	0.00108	0.001296	0.003996	283.43	0.13%	440
A158	0.015728	0.01561	0.004422	275.73	0.13%	459
C680	0.00605832	0.0080724	0.0024622	268.72	0.13%	402
F2TH	0.01091253	0.0104374	0.0040767	254.3	0.12%	378
E195	0.019568	0.015507	0.005707	223.76	0.11%	381
B732	0.016199	0.015659	0.006479	216.76	0.10%	374
GLEX	0.01636069	0.0154698	0.0040875	196.42	0.09%	375
DC10	0.02980562	0.0272138	0.0096652	185.84	0.09%	385
A359	0.03606911	0.0349622	0.0092063	104.03	0.05%	455
Others				6,022.34	2.83%	10,023
Typical	**0.04176926**	**0.0380748**	**0.0127084**			
Total				**212,928.04**	**100%**	**369,724.00**

Table 4 - Aircraft that flew RVSM in the CAR/SAM FIRs

5. Collision risk safety assessment

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

5.2 The internationally accepted Collision Risk Model (CRM) has been used for the safety assessment of RVSM airspace in the Caribbean and South America.

5.3 Estimates of the CRM parameter:

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

Figure 1 - General Formula of the Collision Risk Model REICH

5.3.1 The material and quantity of the source used to estimate the values of each parameter of the internationally accepted CRM used to assess the safety of RVSM airspace are summarized in Table 5.

Parameter	Description	Values
λx	Average length of the aircraft sample	**0.0399185 Nm**
λy	Average wingspan of the aircraft sample	**0.036042 Nm**
λz	Average height of the aircraft sample	**0.007486 Nm**
$\lvert V \rvert$	Average speed of the aircraft sample (module)	**431.697 kts**
$\lvert \Delta V \rvert$	Relative speed of the same direction of the sample of the aircraft (module)	**35.9 kts**
$\lvert \dot{y} \rvert$	Average speed relative to the transverse approximation of the sample of the aircraft (module)	**13 kts**
$\lvert \dot{z} \rvert$	Average relative vertical velocity during loss of vertical separation of the aircraft sample (module)	**1.5 kts**
$Pz(0)$	Probability that two aircraft with the same nominal level overlap laterally in the sample of the aircraft	**0.392664**

Table 5 - Estimates of CRM parameters

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

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

- Pass Frequency Nx;
- Probability of Vertical Superposition Pz (1000); and
- Probability of Lateral Overlay Py (0).

To demonstrate this, the following objectives were established:

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

5.5 System performance specifications

5.5.1 Pass Frequency, Nx - This is the parameter of the airspace in which the aircraft is exposed to the risk of vertical collision. The equivalent Pass frequency was estimated taking into account airplanes flying in the same direction and in opposite directions, as shown in Table 6.

FIR	Pass Frequency		
	Same Direction	Opposite Direction	Equivalent
Curazao – TNCF	0.015254	0.22884	0.134642
Central America - MHTG	0.005787	0.067173	0.044717
Havana – MUFH	0.005432	0.06123	0.047028
Port-au-Prince – MTEG*	0.005744	0.025692	0.020451
Kingston – MKJK*	0.022827	0.477108	0.287068
Santo Domingo – MDCS	0.020552	0.032223	0.048416
Piarco – TTZP	0.01008	0.122119	0.07551
Cordoba – SACF	0.025227	0.05345	0.061368
Ezeiza – SAEF	0.005068	0.061046	0.038583
Mendoza – SAMF	0.012173	0.572642	0.304685
Resistência – SARR	0.011958	0.050564	0.044368
Comodoro Rivadavia – SAVF	0.002438	0.041924	0.024612
La Paz - SLLF	0.00655	0.092983	0.055786
Atlântico – SBAO	0.009329	0.030012	0.029051
Amazônica - SBAZ	0.008159	0.04045	0.03614
Brasília – SBBS	0.013981	0.284972	0.162941
Curitiba - SBCW	0.027545	0.245177	0.159862
Recife - SBRE	0.0074	0.207116	0.115582
Punta Arenas - SCCZ	0.010294	0.241542	0.136484
Santiago - SCEZ	0.02624	0.047962	0.058578
Antofagasta – SCFZ	0.014418	0.370611	0.207618
Isla de Pascua – SCIZ	0.000624	0.053717	0.028525
Puerto Montt - SCTZ	0.00959	0.033418	0.0309
Barranquilla - SKEC	0.006438	0.15458	0.089045
Bogotá - SKED	0.006277	0.154374	0.08872
Guayaquil – SEFG	0.008382	0.0861	0.056026
Georgetown – SYGC	0.006049	0.067904	0.044469
Cayenne – SOOO	0.01973	0.071286	0.067886
Panamá Oceanic – MPZL	0.009866	0.020956	0.025147
Asunción – SGFA	0.002546	0.056498	0.032029
Lima - SPIM	0.002735	0.026203	0.018862
Paramaribo – SMPM	0.006377	0.014843	0.016768
Montevideo - SUEO	0.009309	0.348351	0.187387
Maiquetia – SVZM	0.007465	0.149757	0.085469
CAR/SAM			0.084257

Table 6 – Pass Frequency

5.5.2 The values are related to the CAR/SAM airspace system. It should be noted that it has been calculated that the equivalent Pass frequency shown in Table 6 (0.084257) was calculated based on the flight hours of the 34 CAR/SAM FIRs.

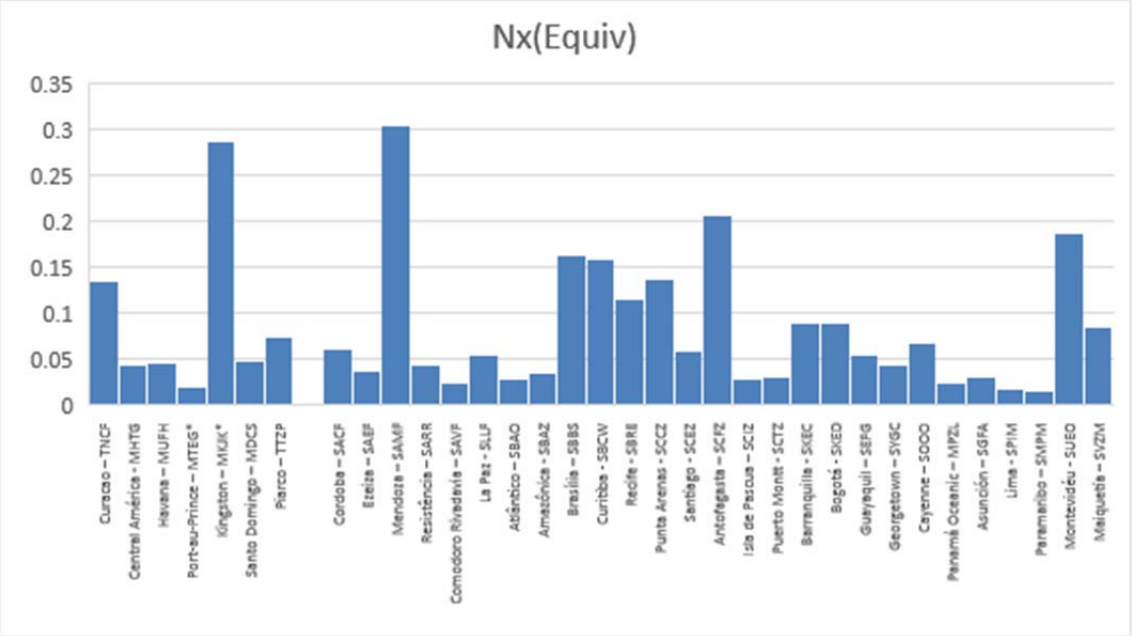

Figure 1 - Equivalent Pass Frequency

The estimated value of **Pz (1000)** used in our calculations was **2.46 x 10-8**.

5.6 Estimation of collision risk

5.6.1 Table 7 contains the sets of the physical and dynamic parameters that are estimated in the risk profile, as well as the monitoring of the main parameters for the CAR/SAM FIRs. All parameters were determined based on the airspace of each region that is considered an isolated system.

	Ez(same)	Ez(opp)	Ez(cross)	ΔV(same)	ΔV(opp)	V
CAR	**0.09347**	**0.03623**	**0.03763**	**34.7953**	**725.915**	**415.881**
SAM	**0.06161**	**0.03313**	**0.02726**	**36.2907**	**693.178**	**447.513**
CAR/SAM	**0.07754**	**0.03468**	**0.03245**	**35.5430**	**709.547**	**431.697**

Table 7 - 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 8 that result from the processing of all the LHDs received and validated in 2017, plus the files that contain movements of aircraft in the RVSM airspace, processed in the CRM software specific.

6.2 In the Figure 2 we present the Collision Risk consolidated in the CAR/SAM FIRs in the year 2017 to show the estimated vertical collision risks annually and by FIR. It should be understood that the FIRs that filled the LHD report have their risk increased, but almost always due to failures caused by the FIRs adjacent to their airspace.

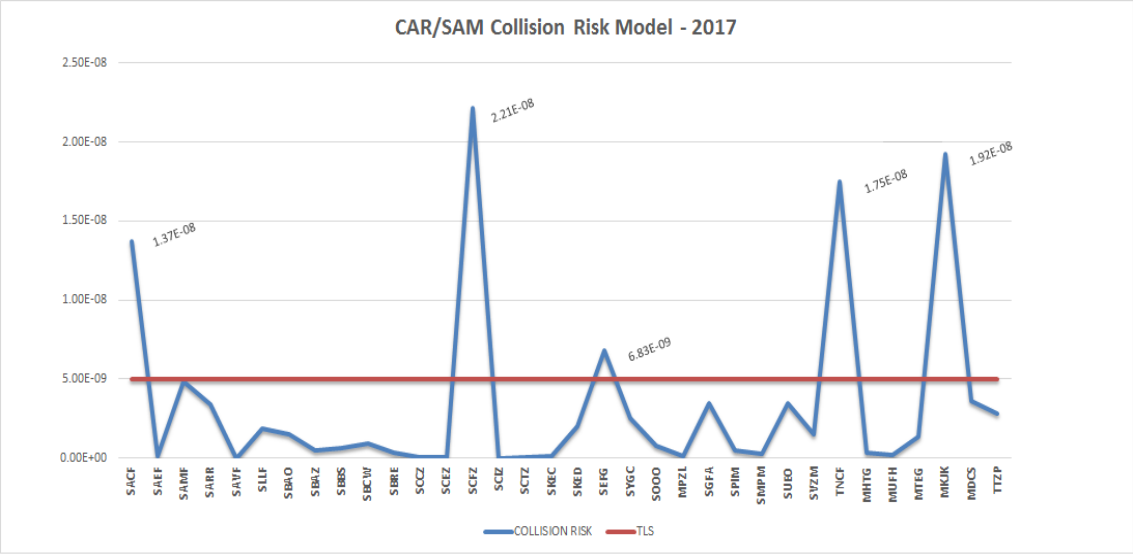

Figure 2 - Vertical Collision Risk

6.3 The technical error of the CAR/SAM FIRs satisfies the objective that establishes that it must not exceed 2.5 x 10-9 fatal accidents per flight hour due to the loss of the standard vertical separation of 1000 feet and all other causes.

- Operational risk does not have a predetermined limit according to ICAO Doc 9574.

- In the case of the CAR/SAM Regions, the estimated average risk is **2,187 x 10-9** below the TLS, which is 5.0 x 10-9.

RVSM airspace CAR/SAM Flight Hours estimated = 212,928.04			
Source of Risk	**Estimated Risk**	**TLS**	**Observation**
Technical Error	**0.0299 x 10-9**	**2.5 x 10-9**	**Below**
Operational Error	**2.157 x 10-9**	**-**	-
Risk	**2.187 x 10-9**	**5.0 x 10-9**	**Below**

Table 8

7 Suggested Action

7.1 The Meeting is invited to:

a) take note and review the contents of this working document; and

b) share experiences and express opinions on the actions of CARSAMMA in this matter.

— END —