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Agenda Item 2: **Review of RVSM Airspace Safety Assessment Project for the CAR and SAM Regions**

Safety Assessment of the RVSM Airspace of CAR/SAM Regions

(Presented by CARSAMMA)

EXECUTIVE SUMMARY	
The aim of this document is to show, by means of argument and supporting evidence that, how the criteria defined in ICAO Doc 9574 are being met in the CAR/SAM regions RVSM airspace and what additional corrective actions are needed.	
Strategic Objectives:	• Safety
References:	• Manual on Implementation of a 300 m (1,000 ft) Vertical Separation Minimum Between FL 290 and FL 410 Inclusive, International Civil Aviation Organization, Doc 9574, Montreal, March 1992 • 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, Doc 9937, Montreal, February 2010 • Advanced Studies Institute RVSM monitoring program (software) (IEAv - COMAER) • GTE/13 Report

1. Introduction

1.1 This report shows the results of a safety assessment relevant to the operational phase of implementation of the Reduced Vertical Separation Minimum (RVSM) in the airspace of the Caribbean and South American regions (CAR/SAM). This phase corresponds to the continuation of implementation strategy of the *Manual on Implementation of a 300 m (1000 ft) Vertical Separation Minimum between FL 290 and FL 410 inclusive, ICAO, Montreal,* Doc 9574, 1st edition 1992, 2nd edition 2000.

1.2 According to Doc 9574 and Doc 9937, the assessment should be carried out to ensure that the operations in the RVSM airspace do not induce an increase in the collision risk, such that the total vertical risk does not exceed the safety objectives established.

2. Airspace Data Collection

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

2.2 **On Traffic Movement Data Collection** – the sample used to estimate the passing frequency and the dynamic and physical parameters of the typical aircraft for the collision risk assessment was collected in the period from 1 to 30 November 2013, of the CAR/SAM Region 34 FIRs. From among the data received in terms of flight hours of the collected sample, a total of 157,438 hours were received from all mentioned FIRs, 24,702 hours (~15%) received from the CAR region and 132,736 hours (~85%) from the SAM region. As in previous occasions, much of the data received from some States could not be used to advantage by different reason: errors in entrance and exit time (e. g. exit time occurring simultaneously to or before the entrance time), lack of information for identifying and locating routes and waypoint position reporting points, or even submission of data after deadline. Nevertheless, all submitted data was used in another CARSAMMA product, such as RVSM Airspace Audit in which non RVSM certified aircrafts are commented by CARSAMMA to the rest of RMA and Civil Aviation Authorities involved.

2.3 **Aircraft Population** – in accordance with Doc 9574 and Doc 9937 of the RVSM, it is necessary that 100% of the RVSM approved aircraft population meet the RVSM requirements.

2.3.1 During the safety assessment, CARSAMMA has detected some aircrafts that were not in their RVSM database and used this space during 2013. This entailed a world research, achieved thanks to the support of other regions ICAO monitoring agencies, through their database intersection. At the end of the process, some aircrafts non RVSM certified by any State were found, as described in Figure 1.

REGION	STATE	FIR	DELIVERED	PROCESSED	# FLIGHTS	NO RVSM	%
SAM	ARGENTINA	CORDOBA	ok	ok	3781	2	0.05%
		EZEIZA	ok	ok	7340	17	0.23%
		MENDOZA	ok	ok	3275	90	2.75%
		RESISTENCIA	ok	ok	2899	9	0.31%
		COMODORO	ok	ok	1763	69	3.91%
	BOLIVIA	LA PAZ	ok	ok	2683	2	0.07%
	BRAZIL	ATLANTICO	ok	ok	31970	14	0.04%
		RECIFE	ok	ok			
		AMAZONICA	ok	ok	22414	0	
		BRASILIA	ok	ok	65535	25	0.04%
		CURITIBA	ok	ok	37495	61	0.16%
	CHILE	PUNTA ARENAS	ok	ok	448	3	0.67%
		SANTIAGO	ok	ok	9748	13	0.13%
		ANTOFAGASTA	ok	ok			
		ISLA DE PASCUA	ok	ok			
		PUERTO MONTT	ok	ok	689	1	0.15%
	COLOMBIA	BARRANQUILLA	ok	ok	6397	15	0.23%
		BOGOTA	ok	ok	7333	3	0.04%
	ECUADOR	GUAYAQUIL					
	GUYANA	GEORGETOWN					
	FRENCH GUYANA	ROCHAMBEAU					
	PANAMA	PANAMA					
	PARAGUAY	ASUNCION	ok	ok	1063	55	5.17%
	PERU	LIMA	ok	ok	13234	15	0.11%
	SURINAME	PARAMARIBO					
	URUGUAY	MONTEVIDEO	ok	ok	3544	13	0.37%
	VENEZUELA	MAIQUETIA					
SUBTOTAL			**21**	**21**	**221611**	**407**	**0.18%**
CAR	COCESNA	CENTRAL AMERICA	ok	ok	11457	37	0.32%
	CUBA	HAVANA	ok	ok	15767	41	0.26%
	HAITI	PORT AU PRINCE	ok	ok	3090	61	1.97%
	JAMAICA	KINGSTON					
	DOMINICAN REP.	SANTO DOMINGO	ok	ok	5982	136	2.27%
	TRINIDAD & TOBAGO	PIARCO	ok	ok	5235	18	0.34%
	NETHERLANDS ANTILLES	CURACAO					
	SUBTOTAL		**5**	**5**	**41531**	**293**	**0.71%**
			DELIVERED	**PROCESSED**	**# FLIGHTS**	**NO RVSM**	**%**
		TOTAL CAR/SAM	**26**	**26**	**263142**	**700**	**0.27%**

2.3.2 This data was presented during the Monitoring Agencies Meeting, held in May 2014 in the ICAO office in Paris, France, where RMA were informed about aircraft without RVSM approval using this space.

2.4 **Data On Vertical Deviations -** Statistically representative vertical deviations of less than 300 ft. The atypical large height vertical deviations AAD, collected from the CAR/SAM regions, were added to the typical AAD deviations for a new fitting of the AAD probability distribution function. The statistical data (mean and standard deviation) of the ASE distribution functions for each group of aircraft types were obtained from the CARSAMMA error calculation database, developed and maintained by Agency judges, thanks to an information exchange between DECEA (Brazil) and FAA (United States), which enabled the creation of CARSAMMA Laboratory.

Type	Average AAD	Std Dev AAD
A158	-0.020	0.155563
A318	0.052	0.135493
A319	-1.940	3.793161
A320	-0.275	0.459619
A330	0.055	0.063640
AN15	0.090	0.000000
ASTR	-0.020	0.043589
B200	-0.017	0.051962
B300	-0.060	0.088034
B350	0.010	0.311127
B400	0.280	0.593970
B727	-0.020	0.000000
B737	-0.077	0.103712
B747	0.070	0.000000
B767	0.019	0.080078
BA34	-0.320	0.000000
BD10	0.015	0.031091
BD70	-0.085	0.106066
BE20	-0.043	0.089629
BE30	-0.040	0.000000
BE35	-0.550	0.000000
BE40	-0.054	0.023022
C510	0.020	0.068920
C525	-0.065	0.052263
C550	-0.070	0.608346
C551	-8.028	20.756274
C560	0.007	0.297836
C56X	-0.025	0.148492
C650	2.265	4.436759
C680	-0.094	0.072319
C750	-0.030	0.042426
CITA	0.160	0.000000
CL30	0.040	0.000000
CL60	-0.030	0.010000
CRJ9	0.030	0.000000
D7X	0.060	0.000000
DC10	-0.010	0.000000
DC9	-0.020	0.000000
DC91	0.000	0.042426

Tipo	Promédio AAD	DesvEst de AAD
E135	4.722	15.108023
E145	0.467	23.728288
E190	-0.008	0.035162
E50P	-1.496	7.485550
E55P	-0.030	0.036228
F200	-0.010	0.000000
F50	-0.140	0.000000
F7X	-0.110	0.000000
F900	-0.040	0.070000
FA20	-0.097	0.103086
FA50	-0.565	1.195010
FA7X	0.170	0.000000
G150	-0.003	0.005774
G200	0.000	0.014142
G550	0.000	0.000000
G600	0.000	0.014142
GLF2	-0.620	0.000000
GLF4	-0.110	0.000000
H25	-0.005	0.134350
H25A	-0.166	0.396018
H25B	-9.244	20.675807
H400	-0.045	0.091924
I124	0.090	0.000000
I125	0.010	0.000000
K200	-0.090	0.000000
LJ31	-0.001	0.095546
LJ35	0.016	0.177195
LJ40	-0.023	0.075000
LJ45	-0.022	0.134626
LJ55	-0.030	0.084853
LJ60	0.032	0.102831
MD82	-0.010	0.000000
MD83	-0.038	0.084083
MU30	-0.230	0.000000
PA42	-0.080	0.000000
PRM1	0.030	0.084853
TB70	-0.190	0.000000
WW24	-0.010	0.000000
ACFT típica	**-0.216**	**1.332446**
	AAD típica	**DesvEst típica**

Tabla 1. AAD values (average and standard deviation)

3. Demonstration of the Technical Feasibility of RVSM Application in the CAR/SAM Regions

3.1 Conditions that Quantify the Global System Performance Specification.

3.1.1 Passing Frequency N_z***(segment)*** – the passing frequency was determined individually for each route segment, each airway, each airspace FIR of the CAR/SAM regions. The passing frequency peak occurred in the FIR SKED, SPIM and SBAZ, LET-AIRES segment of the UA301 airway.

3.1.2 Vertical occupancy ***E_z(crossing)*** – Vertical occupancy assessment on crossing routes was derived from the traffic samples received from the CAR/SAM FIRs in terms of traffic density. The vertical occupancy is estimated to be 0,055352. In the same way, assessments on passing frequencies in the same sense and in opposite sense were derived from the traffic samples received from the CAR/SAM FIRs. Passing frequencies in the same sense and in opposite sense were assessed in 0,009033 y 0,048316, respectively.

3.2 Aircraft Size

3.2.1 The aircraft length (**λx**), wingspan (**λy**) and height (**λz**) shown in Table 1 were used in the estimation of risk for the CAR/SAM RVSM safety assessment. These numerical values were estimated from the traffic sample.

Aircraft	λ_z **Height (NM)**	λ_x **Length (NM)**	λ_y **Wingspan (NM)**
Average Aircraft	0,005319	0,022495	0,019430

Table 1 - Aircraft Size Used in the CAR/SAM RVSM Safety Assessment

3.2.2 Estimation of the risk for proximate aircraft pairs at adjacent flight levels on crossing routes requires the diameter of the disk representing the shape of an aircraft in the horizontal plane **λh.** This value has been taken as **0,02350nm** for average aircraft in the CAR/SAM airspace.

3.3 Relative Aircraft Speeds

3.3.1 Table 3 presents the numerical values and sources for estimation of relative aircraft speeds used in the CAR/SAM safety assessment. The numerical values of average relative along-track speed and average absolute aircraft ground speed are those obtained from the analysis of the traffic sample. CARSAMMA used the numerical value of relative cross-track speed $\overline{|\dot{y}|}$ already used in the safety assessment of other regions, i.e. **13 knots**.

3.3.2 The numerical value for the relative horizontal-plane speed of a pair of aircraft on crossing routes in horizontal overlap was determined from the angle of route intersections in a route system analysed assuming that the speed of an individual aircraft $\overline{|V|}$ is **443,48 knots**.

3.3.3 The numerical value of 1.5 knots for relative vertical speed $\overline{|\dot{z}|}$, shown in Table 3 is that used in both the NATCMA and Pacific (PAARMO) RVSM safety assessments.

Parameter Symbol	Parameter Definition	Parameter Value	Source for Value
$\overline{\lvert \Delta V \rvert}$	Average absolute value of the relative along-track speed between aircraft on same direction routes	24.482 knots	Estimated from CAR/SAM sample
$\overline{\lvert V \rvert}$	Average absolute value of the aircraft ground speed	443.48 knots	Estimated from CAR/SAM sample
$\overline{\lvert \dot{y} \rvert}$	Average absolute value of the relative cross track speed for an aircraft pair nominally on the same track	13 knots	Value used in NAT RVSM safety assessment
$\overline{\lvert \dot{h}(\theta) \rvert}$	Average absolute value of the relative horizontal speed during overlap for aircraft pairs on routes with crossing angle varying from 5 to 175 degrees	Depends on the angle of intersection	Corresponds to an average aircraft speed of 448.50 knots
$\overline{\lvert \dot{z} \rvert}$	Average absolute value of the relative vertical speed of an aircraft pair that have lost all vertical separation	1.5 knots (all traffic flows)	Value used in NAT and Pacific RVSM safety assessments

Table 3 - Relative Aircraft Speeds Used in the CAR/SAM RVSM Safety Assessment

3.4 **Probability of Lateral Overlap** – For the typical aircraft flying in CAR/SAM Regions, with wingspan of **0,019430nm**, using an approximation dictated by a distribution described by an exponential double function, the value $\mathbf{P_y(0) = 0{,}0648}$ was obtained.

3.5 **Probability of Vertical Overlap Attributable to Technical Height-Keeping Performance -** As noted previously, technical risk is considered to arise from the effects of turbulence, loss of height-keeping as well as from aircraft altimetry and altitude-keeping system performance errors. Hence, the estimation of the probability of vertical overlap must take into account the contributions of vertical errors arising from all of these sources.

3.5.1 The GTE has consistently called on ATS providers, airspace users and others to forward monthly reports of all sorts of LHD to CARSAMMA. While not all ATS units have provided these monthly reports, those received by CARSAMMA from January through December 2013 have highlighted just a few significant instances of LHD attributable to turbulence. Because of the important effect of this parameter on vertical collision risk, CARSAMMA has taken a cautious approach to specify its numerical value. The approach considered the LHD from the NAT region added to the LHD from the 7 CAR/SAM FIR, which resulted in the values shown in Table 4.

$P_Z(1000)$	$P_Z(0)$	$P_y(0)$
2,463×10-9	0,241328	0,064837

Table 4 - Results for the Vertical and Lateral Overlap Probability

3.6 Identification of the causes of height keeping errors inconsistency – the causes of deviations correspond to atmospheric turbulence and other possible flight technical errors as autopilot or even to operational conditions of air traffic control not identified in the incident reports.

3.7 Verification of Technical TLS (Technical Risk) - The goal is to demonstrate that the TLS of $2{,}5\times10^{-9}$ fatal accidents per aircraft flying hour is satisfied according to a significant level of confidence. The technical risk that represents the CAR/SAM region was evaluated considering the movements of all CAR and SAM FIRs. In Table 5 below, the parameters of the Technical Collision Risk Model for 2013 are shown.

PARAMETERS	AIRSPACE		
	CARIBBEAN	SOUTH AMERICA	CAR/SAM REGIONS
$P_y(0)$	0,0632	0,0653	0,0648
$P_z(0)$	0,255115	0,227542	0,241328
$P_z(1000)$	$2{,}463\times10^{-9}$	$2{,}463\times10^{-9}$	$2{,}463\times10^{-9}$
λ_x(nm)	0,02186	0,02297	0,022495
λ_y(nm)	0,01884	0,02062	0,01943
λ_z(nm)	0,00512	0,00523	0,00531
λ_h(nm)	0,024186	0,02297	0,02350
$\overline{\lvert V\rvert}\ (nm/h)$	444,68	442,93	443,48
$\overline{\lvert \Delta V\rvert}\ (nm/h)$	24,975	23,921	24,482
$\overline{\lvert \dot{y}\rvert}\ (nm/h)$	20	20	20
$\overline{\lvert \dot{z}\rvert}\ (nm/h)$	1,5	1,5	1,5
$N_x(op)$	0,036522	0,064602	0,048316
$N_x(mismo)$	0,0034407	0,013421	0,009033
$E_z(cruce)$	0,064381	0,046323	0,055352
S_x(nm)	82,4091	75,8595	79,1343

Table 5. Vetical Collison Technical Risk Parameters Summary

3.7.1 The collision risk was assessed separately for the CAR and SAM regions and for the total CAR/SAM airspace.

3.8 Effect of the Growing Traffic - the evolution of collision risk in the period from 2008 to 2017 was estimated for an annual traffic growing rate of 8 % (IATA) that directly affects the passing frequency numerical value. The forecasts are shown in Fig. 2 below**.** Note that, until 2017, the technical risk will be below the limit of 2.5×10^{-9}.

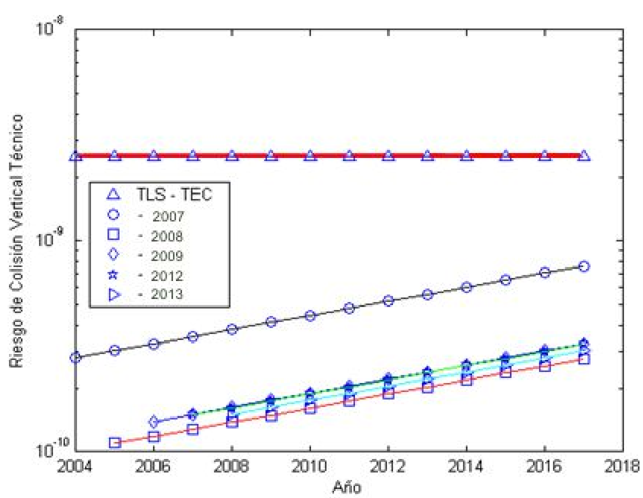


Figure 2. Collision Risk Growth Forecast of the CAR/SAM Region

4. Operational Risk

4.1 The CRM for operational risk was developed in connection with the CAR/SAM RVSM implementation. As such, it reflects certain operational characteristics of the CAR/SAM airspace that are not common to other airspaces.

4.2 The definition of errors according to the causes was based on the classification approved during the GTE/13, presented and approved in a working paper related to LHD in GREPECAS in 2014. Approved LHD codes are presented in Table 6.

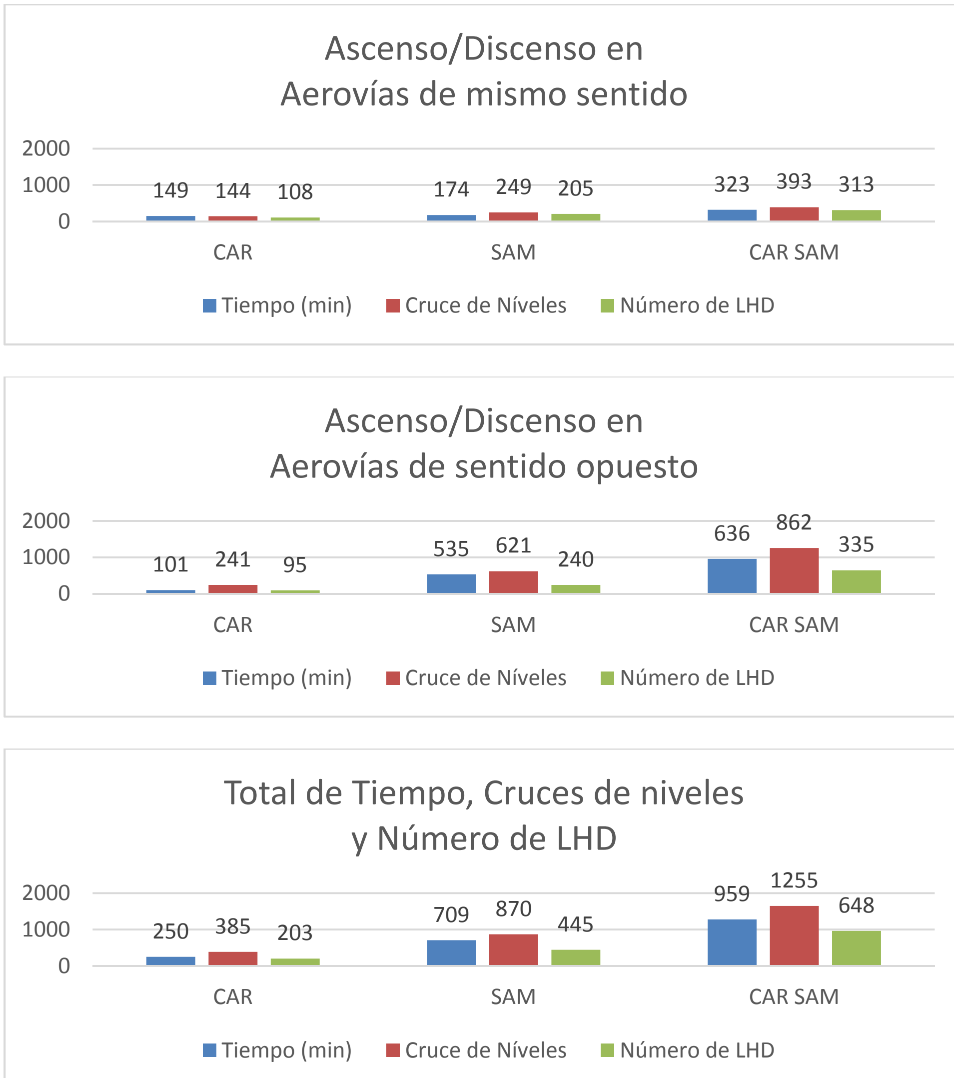
Code	Cause of large height deviation
A	Flight crew failing to climb/descend the aircraft as cleared
B	Flight crew climbing/descending without ATC clearance
C	Incorrect operation or interpretation of airborne equipment (e.g. incorrect operation of fully functional FMS, incorrect transcription of ATC clearance or re-clearance, flight plan followed rather than ATC clearance, original clearance followed instead of re-clearance, etc.)
D	ATC system loop error (e.g. ATC issues incorrect clearance or flight crew misunderstands clearance message)
E	Coordination errors in the ATC-to-ATC transfer or control responsibility as a result of Human Factors (e.g. late or non-existent coordination; incorrect time estimate/actual; flight level, ATS route, etc. not in accordance with agreed parameters)
F	Coordination errors in the ATC-to-ATC transfer or control responsibility as a result of equipment outage or technical issues
Aircraft contingency event	
G	Deviation due to aircraft contingency event leading to sudden inability to maintain assigned flight level (e.g. pressurization failure, engine failure)
H	Deviation due to airborne equipment failure leading to unintentional or undetected change of flight level
Deviation due to meteorological conditions	
I	Deviation due to turbulence or other weather-related cause
Deviation due to TCAS RA	
J	Deviation due to TCAS RA; flight crew correctly following the RA
K	Deviation due to TCAS RA; flight crew incorrectly following the RA
Other	
L	An aircraft that is not RVSM approved being provided with RVSM separation (e.g. flight plan indicating RVSM approval but aircraft not approved; ATC misinterpretation of flight plan)
M	Other — this includes flights operating (including climbing/descending) in airspace where flight crews are unable to establish normal air-ground communications with the responsible ATS unit

Tabla 6. Classification of LHD received

4.3 The LHD identified through the reports received can be divided into four main types of group:

a) ATC-pilot loop errors and incorrect clearances;
b) aircraft contingency events;
c) deviations due to meteorological effects; and
d) deviations due to ACAS (TCAS).

4.4 Graphs 1a, 1b and 1c present error (equal to or greater than 1000 feet), considered operational, whose deviations categories and causes are described in Table 6. Crossed level numbers n_m^{nc}, in the same sense and, n_{op}^{nc}, in opposite sense are shown in graphs 1a, 1b and 1c.



Graphs 1a,1b,1c. Operational LHD (equal to or greater than 1000 feet) Received by CARSAMMA

4.5 Classification of errors for risk evaluation

4.5.1 The causes of the group errors of a) and b) points (section 4.3) were classified and they contribute to two different events:

- *Aircraft levelling at the wrong flight level*;
  According to Graphs 1a, 1b and 1c, 648 aircrafts crossing levels without authorization in opposite direction and in the same direction in CAR/SAM regions, for a total of 959 minutes, with an average time of 1.47993 minutes spent in the wrong flight level by aircraft and 335 of them in the opposite direction of the flow.

- *Aircraft climbing/descending through one or more flight levels.*
  According to Graphs 1a, 1b and 1c, 1225 crossings of flight levels occurred without clearance, 862 of them in the opposite direction of the flow.

4.5.2 All the deviations due to non-severe meteorological effects (larger than or equal to 300ft and lesser than 1000ft) were considered in the AAD distribution.

4.5.3 With respect to the deviations due to ACAS (TCAS), a distribution function formed by the typical and atypical behavior of the ACAS deviations was constructed, using a model of double-exponential form, calculated in IEAv *software*.

4.5.4 The density function $f_{ACAS}^{AAD}(a)$ so obtained was then convoluted with the density function $f^{ASE}(a)$, to generate a $f_{ACAS}^{TVE}(z)$ density function and, finally, to produce an estimate for the vertical overlap probability due to ACAS (TCAS), $P_z(S_z)_{ACAS}$.

4.6 Determination of the appropriate parameter values for each group of classified errors

4.6.1 The calculations were done separately for each region (CAR and SAM) and for the whole CAR/SAM airspace. For both airspaces, the same data (Graphs 1a, 1b and 1c) of aircraft levelling at wrong flight level n^{wl}, number of flight levels crossed without clearance n^{cl} and average time spent in wrong flight level $\bar{t}_{wl}$ were used. The climb/descent rate $|\dot{z}_c|$ was assumed to be 10 kt.

4.6.2 In Table 7 below, the group error parameters are shown, classified according to their application to the CAR/SAM regions. In this table, $P_z^{wl}(1000)$ is the vertical overlap probability due to an aircraft levelling at a wrong flight level and $P_z^{cl}(1000)$ is the vertical overlap probability due to an aircraft that crosses one or more flight levels without ATC clearance. The parameters α^{wl} and α^{cl} refer to the error rates for aircraft levelling at a wrong flight level and aircraft crossing a flight level without ATC clearance, respectively. The product $\alpha^{wl} \times \bar{t}^{wl}$ is the proportion of flying time spent in a wrong flight level.

PARAMETER	CARIBE	SOUTH AMERICA	CAR/SAM REGIONS
T (horas estimada por año)	296.424	1592.832	1889.256
α^{ne}	$2{,}133\times10^{-4}$	$3{,}370\times10^{-4}$	$2{,}977\times10^{-4}$
α^{ne}_{mismo}	$1{,}996\times10^{-4}$	$3{,}209\times10^{-4}$	$2{,}823\times10^{-4}$
α^{ne}_{op}	$1{,}376\times10^{-5}$	$1{,}605\times10^{-5}$	$1{,}532\times10^{-5}$
α^{nc}	$4{,}129\times10^{-4}$	$5{,}488\times10^{-4}$	$5{,}056\times10^{-4}$
α^{nc}_{mismo}	$1{,}996\times10^{-4}$	$2{,}664\times10^{-4}$	$2{,}451\times10^{-4}$
α^{nc}_{op}	$2{,}133\times10^{-4}$	$2{,}824\times10^{-4}$	$2{,}605\times10^{-4}$
Q_{mismo}	$8{,}034\times10^{-8}$	$5{,}861\times10^{-8}$	$3{,}673\times10^{-8}$
Q_{op}	$7{,}886\times10^{-8}$	$3{,}142\times10^{-8}$	$2{,}247\times10^{-8}$
$Q = \alpha^{ne} \times \bar{t}^{ne}$	$4{,}975\times10^{-6}$	$1{,}204\times10^{-5}$	$9{,}791\times10^{-6}$
$P_z(0)$	0,255115	0,227542	0,241328
$P_z^{ne}(1000)$	$2{,}243\times10^{-6}$	$5{,}221\times10^{-6}$	$4{,}750\times10^{-6}$
$P_z^{ne}(1000)_{mismo}$	$2{,}100\times10^{-6}$	$5{,}085\times10^{-6}$	$4{,}598\times10^{-6}$
$P_z^{ne}(1000)_{op}$	$1{,}421\times10^{-7}$	$1{,}363\times10^{-7}$	$1{,}527\times10^{-7}$
$P_z^{nc}(1000)$	$5{,}966\times10^{-7}$	$7{,}718\times10^{-7}$	$7{,}926\times10^{-7}$
$P_z^{nc}(1000)_{mismo}$	$2{,}884\times10^{-7}$	$3{,}746\times10^{-7}$	$3{,}843\times10^{-7}$
$P_z^{nc}(1000)_{op}$	$3{,}082\times10^{-7}$	$3{,}972\times10^{-7}$	$4{,}083\times10^{-7}$
$P_z^{ACAS}(1000)$	6,026×10-9	$1{,}841\times10^{-9}$	$3{,}804\times10^{-9}$

Tabla 7. Operational Error Data

4.7 **Vertical Risk Assessment due to Operational Errors**

4.7.1 This section will provide an estimate of the risk associated with all causes connected to RVSM use.

4.7.2 The vertical collision risk was calculated using the Reich Collision Risk Model associated to each group of LHD. Table 8 shows the numerical values of the following components of the risk:

- N_{az}^{tec}, the technical vertical risk;
- N_{az}^{wl}, the vertical risk due to aircraft levelling at a wrong flight level;
- N_{az}^{cl}, the vertical risk due to an aircraft crossing a flight level without ATC clearance;
- N_{az}^{ACAS}, the vertical risk due to ACAS (TCAS) advisories; and
- N_{az}, the vertical collision risk due to all causes or the total risk.

AIR SPACE			
PARAMETER	CARIBE	SOUTH AMERICA	CAR/SAM REGIONS
n_{az}^{ne}	97	372	469
n_{mismo}^{nc}	144	249	393
n_{op}^{nc}	241	621	862
n_{az}^{nc}	385	870	1255
$\bar{t}_{t}^{ne}$	0,02332 h	0,035718 h	0,03289 h
$\bar{t}_{mismo}^{ne}$	0,02335 h	0,036525 h	0,03356 h
t_{op}^{ne}	0,02292 h	0,019583 h	0,02054 h
t_{mesmo}^{ne}	8,25 min	438,3 min	519,55
t_{op}^{ne}	5,50 min	11,75 min	17,25
t_{t}^{ne}	86,75 min	450,05 min	536,80
$\overline{\lvert \dot{z}_c \rvert}$	10 kt	10 kt	10 kt

Tabla 8. Parámetros de los Errores Operacionales

4.7.3 As seen in the following Table 9 and its Graph, the total risk for CAR/SAM regions is greater than TLS.

Region	Technical Risk	Operational Risk	Total Risk
CAR	$0,00539E^{-9}$	$13,60000E^{-9}$	**$13,6E^{-9}$**
SAM	$0,01010E^{-9}$	$11,20010E^{-9}$	**$11,2E^{-9}$**
CAR/SAM	$0,00910E^{-9}$	$11,78400E^{-9}$	**$11,9E^{-9}$**
Número de LHD evaluados: 1306			
TLS	**$2,5E^{-9}$**	**-**	**$5,0E^{-9}$**

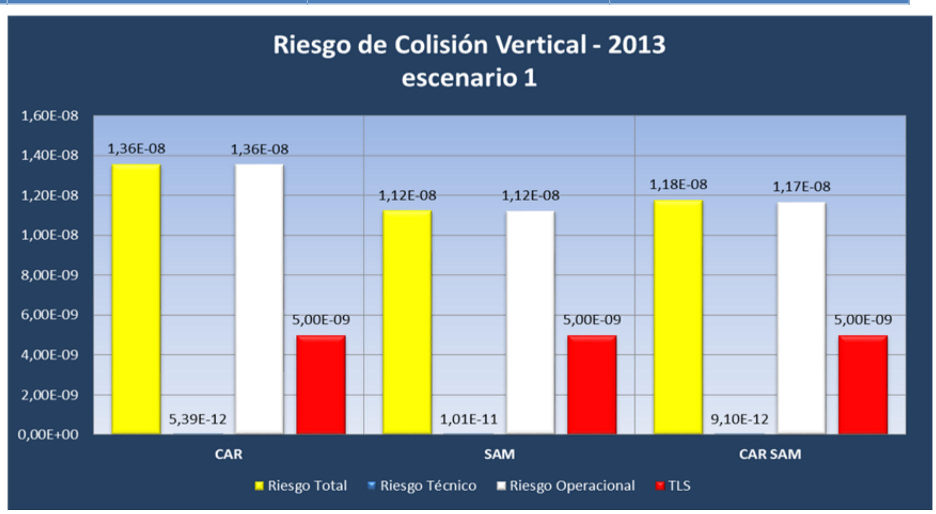


Tabla 9 y Gráfico. Riesgos de Colisión para las Regiones CAR/SAM.

4.7.4 It is important to note that the total risk was strongly influenced by the LHD, most of them due to errors between ATC-units transition messages (coordination error).

4.7.5 These types of errors are not caused by the RVSM operation, but due to wrong aircraft transfer procedures from an ATC unit to another ATC unit, and to absence of coordination errors from the ATC transfer unit (type E errors).

4.7.6 Considering the above remarks, it can be concluded that is necessary to continue to monitor the LHD to keep them inside acceptable limits.

4.8 Remedial Actions

4.8.1 To reduce the risk, the time spent at wrong flight levels and the number of flight levels crossed without ATC clearance must be reduced. Remedial actions must be taken in order to reduce the causes of transition messages between ATC units and negative transfer received from transitioning ATC-unit (E error type).

4.9 Other risk scenes for RVSM operations in CAR/SAM Regions (scene 2 and 3)

4.9.1.1 In Scene 2, CARSAMMA has decided to consider that errors of type E has influence in the application of the RVSM, that is, that these kinds of errors, when they occur, will lead to LHDs regardless the value of the RVSM applied. Therefore, in Table 10 and Graph only the errors that are directly related to the application of RVSM are presented.

4.9.1.2 The calculations have demonstrated that, for this assessment, the consideration above is equivalent to taking corrective actions resulting from the introduction of an efficient program of corrective measures to eliminate the errors in ATC-unit-to-ATC-unit transition message and in negative transfer received from transitioning ATC-unit (type E).

4.9.1.3 Scene 2 Results – In Table 10 and Graph below, risk values due to errors that affect the RVSM application (without type E errors) are presented.

Region	Technical Risk	Operational Risk	Total Risk
CAR	0,00539E^{-9}	0,0595E^{-9}	**0,0649E^{-9}**
SAM	0,01010E^{-9}	0,0655E^{-9}	**0,0755E^{-9}**
CAR/SAM	0,00910E^{-9}	0,0643E^{-9}	**0,0734E^{-9}**
Number of LHD assessed: 31			
TLS	**2,5E^{-9}**	**-**	**5,0E^{-9}**

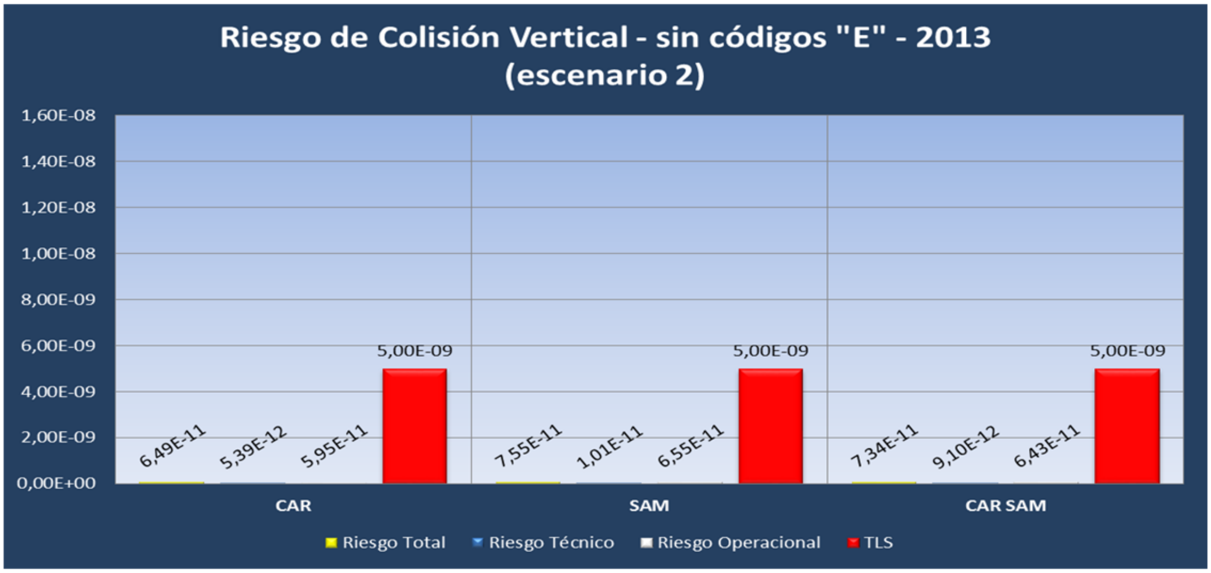


Tabla 10 y Gráfico. Riesgos de Colisión para las Regiones CAR/SAM (sin los LHD con códigos "E").

4.9.2.1 In scene 3, CARSAMMA, at the request of experts attending teleconferences through the year, has carried out an study in which errors occurred in the South Atlantic are not considered. Therefore, errors without LHD in AORRA area are presented in Table 11 and Graph.

4.9.2.2 Corrective measures to be adopted should result from the implementation of a better detection, communication and coordination training structure, in addition to the creation of a "South Atlantic Working Group (GTAS)", so study is presented to GREPECAS where:

a) AORRA area is considered category A so it is maintained at an acceptable safety level; or
b) AORRA area is not considered RVSM space, maintaining itself as G space;
c) ATC units: FHAW an EGYP participation in teleconferences is requested for the involved LHD analysis.

4.9.2.3 Scene 3 Results – In the Table 11 and Graph below risk values due to all error are presented, without considering AORRA area errors.

Region	Technical Risk	Operational Risk	Total Risk
CAR	0,00539E^{-9}	10,3000E^{-9}	**10,3000E^{-9}**
SAM	0,01010E^{-9}	8,5100E^{-9}	**8,5200E^{-9}**
CAR/SAM	0,00910E^{-9}	8,8800E^{-9}	**8,89004E^{-9}**
Número de LHD evaluados: 1205			
TLS	**2,5E^{-9}**	**-**	**5,0E^{-9}**

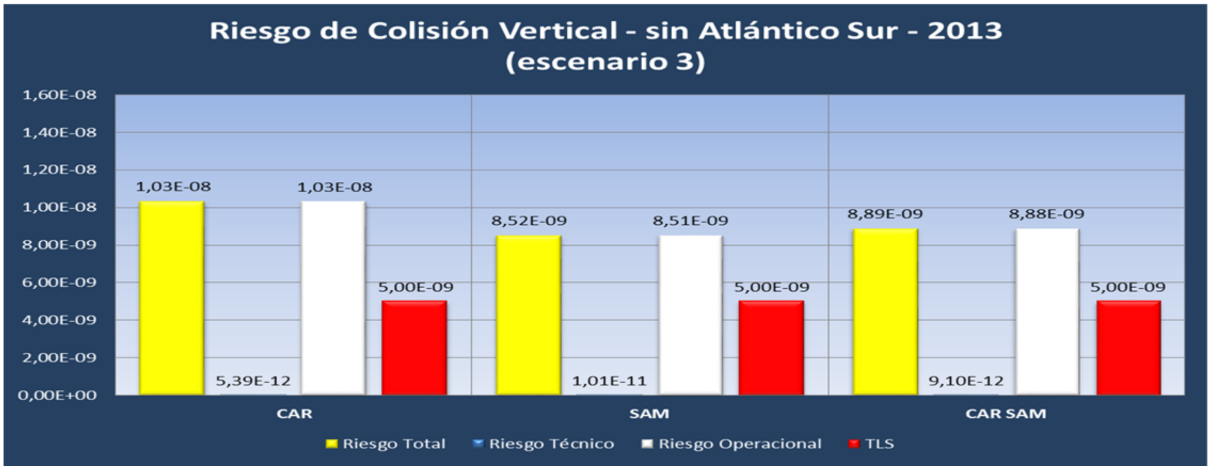


Tabla 11 y Gráfico. Riesgos de Colisión para las Regiones CAR/SAM (sin los LHD del Atlántico Sur).

5. Results and Conclusions

5.1 This paper provides estimates of the technical, operational, and total risks for the RVSM operation in the CAR/SAM airspace, and also for all kinds of errors present in the incident reports sent to CARSAMMA.

5.2 The total number of flown hours that is considered for the risk analysis of the CAR/SAM regions corresponds to the total of flight hours for the CAR and SAM FIRs. In short, the SAM region contributes with 84,30% of the total flight hours and the CAR region with 15,69%.

5.3 The technical vertical collision risk for the Caribbean region, South American region and for all airspace of the CAR/SAM regions was evaluated separately. All regions show numerical values of the technical risk below the TLS.

5.4 As can be seen from the values presented above (Tables 9, 10, y 11), the estimated technical risk is 0.093×10^{-9}. This estimate satisfies the agreed TLS value of no more than 2.5×10^{-9} fatal accidents per flight hour due to the loss of a correctly established vertical separation standard of 1000 ft.

5.5 The evaluation of the technical risk for the CAR/SAM regions due to the air traffic growth was carried out for annual growth rates of 8% (IATA) until 2017. The forecast shows that the technical risk will be below the TLS of 2.5×10^{-9} until 2017.

5.6 However, the total vertical collision risk due to a combination of technical height-keeping errors and operational errors, estimated in number of fatal accidents per flight hour, is above the tolerable maximum limit. For the CAR region it is equal to $13{,}6\times10^{-9}$, for the SAM region $11{,}2\times10^{-9}$ and for the CAR/SAM regions about $11{,}9\times10^{-9}$. The suggested action is to reduce type E errors.

5.7 The main operational errors (LHD) collected from the CAR/SAM regions in the period from January to December 2013 are related to transition messages failures between Air Traffic Control (ATC) units and errors concerning lack of coordination by the transfer ATC unit (1015 LHD of E type). The evolution of these errors since 2014 and of other errors can be seen in Table 12 below.

5.8 The States of the CAR/SAM regions should be aware that each Large Height Deviation (LHD) error corresponds to a danger warning. As a consequence, remedial actions should be applied independently of the results of the risk evaluation. Therefore, additional remedial actions must be taken to eliminate errors of the following types:

- A - Failure to climb/descend as cleared;
- B - Climb/descent without ATC unit clearance;;
- D - ATC system loop error; (e.g. pilot misunderstands clearance message or ATC issues incorrect clearance);
- H - Deviation due to equipment failure;
- I - Deviation due to turbulence or other weather related cause;
- J - Deviation due to a TCAS resolution advisory; flight crew correctly following a TCAS resolution advisory; and
- L - Non RVSM-approved Aircraft.

5.9 The evolution of large errors presented in Table 12 corroborates the conclusions on the collision risk possibilities in the CAR/SAM Regions. Therefore, strong efforts are needed to motivate States to apply additional safety measures.

LHD Code

Código LHD	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	TOTAL	%
A	2	1	2	0	1	7	2	2	5	9	1	32	0,61%
B	3	1	0	1	8	8	9	5	7	18	6	66	1,26%
C	0	0	0	0	0	2	0	2	3	7	11	25	0,48%
D	0	0	6	31	3	9	5	0	3	2	0	59	1,13%
E	16	25	56	78	262	396	600	616	644	1015	1275	4983	95,04%
G	0	0	0	0	0	0	2	0	0	0	0	2	0,04%
H	1	1	0	0	2	7	1	1	4	5	3	25	0,48%
I	0	0	0	0	6	5	2	7	3	4	5	32	0,61%
M	0	0	3	3	1	5	1	2	4	0	0	19	0,36%
TOTAL	22	28	67	113	283	439	622	635	673	1060	1301	5243	100,00%

Table 12. LHDs Evolution
* Numbers in red are estimations

6. Special Recommendation:

6.1 The recommendations described in this section have the objective of helping in the efforts that will be required by the next tasks associated with the collision risk evaluation.

6.2 **Data on Traffic Flow** –data received from several State could not be treated due to different reasons: from lack of understanding on how the data should be transcribed to the spreadsheets to data inconsistency. It is advisable that, before the collection of data, a training procedures on how to fill the template be adopted.

6.3 **Data on Technical Vertical Deviations**– a planning effort should be made to define the best methodology of data collection on technical vertical deviation. Additionally, a work program should be elaborated to show that the Altimetry System Error (ASE) for RVSM approved aircrafts remains steady. This task could be carried out along with the implementation of a continued monitoring program of the aircraft altimetry system performance. Such program will have to foresee the monitoring of the mentioned system of altimetry at least once every two years or intervals of 1000 hours of flight for aircraft (whichever occurs last).

6.4 **Monitoring Altimetry System –**the CAR/SAM regions will have to establish a program for implantation of monitoring units for the verification of aircraft altimetry system. This program will have to be composed of a system of independent monitoring units installed in strategically located positions, in the higher traffic flow density areas. The objective is to monitor the largest number of aircraft for verification of the altimetry system error (ASE) stability and to check if the technical risk remains compatible with the agreed TLS of $2{,}5 \times 10^{-9}$

6.5 **Data on Vertical Deviations due to Operational Errors** – Information on these types of events is obtained through ATC or pilots reports. Important data on these deviations, like number of crossed flight levels and time spent at non-authorized flight level, are rarely informed by the pilots. As these deviations are consequences of errors or contingency actions, States should develop a work plan to obtain these data with a high level of confidence and share them with CARSAMMA

6.6 **Data on Deviations due to ACAS (TCAS)** – monitoring of the TCAS encounters should be effective in the sense of confirm the operational performance due to such events.

6.7 **States/International Organizations and Airlines** should continue to apply their best efforts toward obtaining and informing CARSAMMA of LHD events

7. Suggested action:

7.1 The meeting is invited to:

a) recognize the present working paper terms, and the States who are willing to, may use the information provided here as a reference for LHDs mitigation;

b) approve the scenario that best shows for the development of the analysis of RVSM space operational safety, according to CRM methodology, as well as grant that it may serve as a guide to the member States in the execution of coordination to the ATCO training activities, work load distribution, risk mitigation; and

c) present such decision to GREPECAS members, for their information and approval.

— END —