ATM/COMM/5 - WP/02
04/10/06

International Civil Aviation Organization
CAR/SAM Regional Planning and Implementation Group (GREPECAS)
Fifth Meeting of the Air Traffic Management / Communications, Navigation and Surveillance Subgroup (ATM/CNS/SG/5) - ATM Committee
Lima, Peru, 13-17 November 2006

Agenda Item 1: RVSM Operational use in the CAR/SAM Regions

OPERATIONAL USE OF RVSM IN THE CAR/SAM REGIONS

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Presented by the ATM Committee Chairman)

SUMMARY

This Working Paper contains information on the safety assessment related with RVSM technical and post-implementation operational risks, the corrective actions to maintain the total risk below the agreed TLS for the CAR/SAM Regions and considerations concerning full operational implementation of the RVSM.

References:

- AP/ATM/12 Report
- Doc 9754 - RVSM Implementation Manual.

1. Introduction

CAR/SAM Regions RVSM Post-implementation safety assessment

1.1 During its Tenth Meeting (May 2005) the CAR/SAM Regions RVSM Task Force analysed the safety assessment associated to RVSM implemented in January 2005 within the CAR/SAM Regions airspace.

1.2 The safety assessment presented at AP/ATM/10 meeting indicated that the risk level of implemented RVSM attributable to all causes did not exceed the amount that can be tolerated as per the agreed safety goal (the Target Level of Safety - TLS). In order to update this safety assessment and declare full operational the RVSM use, according to the Doc. 9574, the CARSAMMA requested some States/International Organizations to collect traffic samples that would reflect the operations roughly one year after the implementation.

1.3 A summary of the assessment carried out is following. The full RVSM post-implementation safety assessment report in the CAR/SAM Regions presented by CARSAMMA is shown in **Appendix A** to this working paper.

2. Analysis

Technical risk

2.1 The goal is to demonstrate that TLS of 2.5×10^{-9} fatal accidents per aircraft flying hours is satisfied according to a significant level of confidence**.** The technical risk that represents the CARSAM Region was evaluated considering the movement of three different adjacent FIR from the CAR Region and four from the SAM Region as it was done in the pre-implementation safety analysis. The selection of the FIRs was done according with those that presented the larger frequency determined, according to the transit sample collected from 1 to 15 December 2005. At that opportunity, FIR Havana, Central America and Kingston FIRs and Curitiba, Brasilia, Recife and sector Manaus from Amazónica FIR were used at that time. This selection was made keeping in mind the great influence of the collision risk transition due to the vertical separation loss.

2.2 The collision risk was evaluated separately to the CAR and SAM Regions and for the total CAR/SAM airspace, as it is shown in table below, where IOP represents the phase after implementation and FM-I represents operations a year after implementation.

Technical Collision Risk

Caribbean		*South America*		*CAR/SAM*	
FM-I	*IOP*	*FM-I*	*IOP*	*FM-I*	*IOP*
0.140×10^{-9}	0.112×10^{-9}	0.036×10^{-9}	0.081×10^{-9}	0.076×10^{-9}	0.098×10^{-9}

Effect of the traffic growing

2.3 The evolution of collision risk in the period 2004 to 2015 was estimated to traffic growing annual rate of 8 % that direct affects the passing frequency value, noting that technical risk until year 2015 will be below the limit of 2.5×10^{-9}.

Operational Risk

2.4 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 that are not common to other airspaces.

2.5 The LHD identified through the reports received by CARSAMMA may be due to operational procedures, adverse meteorological conditions or emergency procedures due to equipment failures or pressurization and can be divided in four main group types:

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

d) deviations due to ACAS.

Classification of errors to the risk evaluation

2.6 The causes of the group errors were classified and contribute to two different events:

- *Aircraft leveling in wrong flight level*;
  According information analysed, 43 aircrafts had levelled in wrong flight level, reaching 4215 seconds with the average time spent in wrong flight level of 0.02723 hours and two of them in the opposite direction of the flow.
- *Aircraft climbing/descending through one or more flight levels*.
  According to information analysed, 20 crossings of flight levels have occurred without ATC clearance and thirteen of them in the opposite direction of the flow.

2.7 All de deviation due to non severe meteorological effects (more than or equal to 300ft and less than 1000ft) were considered in the AAD distribution.

2.8 The deviation due to *ACAS (TCAS)* were classified and analysed according to a specific model. For this it was developed a composite distribution of typical and atypical performance considering the *ACAS* deviations using the same model composed of a double-double exponential as used to the AAD distribution.

Risk Assessment for the RVSM operation in the CAR/SAM Regions

2.9 An estimate of risk associated with all causes in connection with the RVSM use was presented. The technical and operational risk values were combined to estimate the total risk attributable to all causes for the system.

2.10 The vertical collision risk was calculated with the Reich Collision Risk Model associated to each group of LHD. In the following table the values of risk for the resulting models are presented:

- N_{az}^{tec} is the technical vertical risk;
- N_{az}^{ne} is the vertical risk due to aircraft leveling in wrong flight level;
- N_{az}^{nc} is the vertical risk due to an aircraft crossing a flight level without ATC clearance;
- N_{az}^{ACAS} is the vertical risk due to ACAS advisories; and
- N_{az} is the vertical collision risk due to all causes or the total risk.

Collision Risks to the CAR/SAM Region

Risk	CAR		SAM		CAR/SAM		*TLS*
	FM-I	IOP	FM-I	IOP	FM-I	IOP	
N_{az}^{Tec}	1.4×10^{-10}	1.1×10^{-10}	3.6×10^{-11}	8.1×10^{-11}	7.6×10^{-11}	9.8×10^{-11}	5.0×10^{-9}
N_{az}^{ACAS}	1.3×10^{-10}	2.4×10^{-11}	3.4×10^{-11}	1.6×10^{-11}	7.1×10^{-11}	2.0×10^{-11}	
N_{az}^{ne}	2.6×10^{-9}	0.0	8.2×10^{-9}	3.0×10^{-9}	6.1×10^{-9}	1.8×10^{-9}	
N_{az}^{nc}	3.9×10^{-10}	0.0	8.8×10^{-10}	1.2×10^{-10}	6.7×10^{-10}	7.6×10^{-11}	
N_{az}^{Total}	3.3×10^{-9}	1.4×10^{-10}	9.0×10^{-9}	3.2×10^{-9}	6.9×10^{-9}	2.0×10^{-9}	

2.11 Assessment carried out considering technical risk plus the risk due to all other causes, indicated that the total risk for the CAR/SAM Region is greater than the agreed TLS.

2.12 It is necessary to remark that this total risk was strongly influenced by the LHD. Most of them due to error in ATC-unit-to-ATC-unit coordination messages. Those errors are not caused by the RVSM operation, but due to common procedures in transferring aircraft from one ATC Unit to another.

2.13 Considering the above the Meeting considered it necessary to continue to monitor the LHD to keep them inside the acceptable limits.

Remedial actions

2.14 According to the traffic in the CAR/SAM Regions it can be tolerate roughly 1253 seconds per year of aircraft leveling in wrong flight level, considering that no one cross a flight level without ATC clearance, without exceeding the agreed TLS. Or, considering that no one aircraft level in a wrong flight level it can be tolerate until 97 flight level crossings without ATC clearance with a rate of climb/descend of 10 kt without exceeding the agreed TLS.

2.15 Consequently, to reduce the risk it is necessary effective remedial actions to reduce the time spent in wrong flight levels and the number of flight levels crossed without ATC clearance. Remedial actions must be taken to reduce the causes of misunderstandings between pilots and controllers and incorrect clearances as well as transition messages between ATC units.

2.16 Based on the data collected in the CAR/SAM Regions the best remedial action would be eliminating the errors in transition messages between ATC units.

Total risk after the remedial actions

2.17 The appropriate remedial actions shall result in a maximum time spent in wrong flight level so that the collision risk will not exceed the TLS. If we exclude the type M LHD from the analysis, the estimated result of total risk attributable to all causes related to the use of RVSM in the CAR/SAM Regions is below TLS.

2.18 Summarizing, it could be seen from the technical risk estimated for the combined RVSM implementations is 7.6 x 10 $^{-11}$. This estimate satisfies the agreed TLS value of no more than 2.5 x 10^{-9} fatal accidents per flight hour due to the loss of a correctly established vertical separation standard of 1000 ft.

2.19 The total risk estimated for the combined RVSM for the CAR/SAM airspace with the remedial action is 2 x 10 $^{-9}$. The estimated total risk associated to combined technical and operational risk satisfies the agreed TLS value of no more than 5.0 x 10^{-9} fatal accidents per flight hour due to all causes, as shown in the table below:

Collision Risks for the CAR/SAM Regions after Corrective Actions

Collision Risks	**CAR/SAM**	***TLS***
N_{az}^{Tec}	7.6×10^{-11}	5.0×10^{-9}
N_{az}^{ACAS}	7.1×10^{-11}	
N_{az}^{ne}	1.6×10^{-9}	
N_{az}^{nc}	6.7×10^{-10}	
N_{az}^{Total}	2.4×10^{-9}	

Recommendations

2.20 The recommendations described in this section have as objective help in the efforts that should be done in the next tasks associated with the collision risk evaluation after the RVSM implementation in the CAR/SAM Regions.

2.21 *Data on the Traffic Flow* – Approximately 40% of the received data could not be treated due to different reasons, from the non understanding of how the data should be transcribed in the spreadsheets until inconsistency of data. It is advisable that before the collection of data States pay attention to the guidelines developed for this procedure and approved by the RVSM/TF.

2.22 *Data on the Vertical Deviations due to Operational Errors* - Information on these types of events is obtained through ATC or pilot's reports. Unfortunately important data on these deviations like number of crossed flight levels, time spent in non authorized flight level are rarely informed. 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 inform them to the CARSAMMA.

2.23 The aforementioned shows the need that States/International Organizations continue their efforts to reduce LHD caused by ATC coordination errors between ATC units and continue their report to the CARSAMMA.

Development of a comprehensive profile of operators and aircraft types using CAR/SAM airspace where the RVSM is being applied

2.24 The AP/ATM/12 meeting was informed by CARSAMMA on the results of the analysis of traffic samples collected during the period 01-15 December 2005 in the CAR/SAM airspace. Traffic sample is summarized in terms of users of the observed airspace, aircraft types and most used flight levels.

2.25 This traffic sample was necessary to facilitate the safety assessment for the post implementation phase. The States concerned were noted to be those located in CAR/SAM Regions.

2.26 Traffic movement data for operations in CAR/SAM airspace were received by CARSAMMA prior to January 2006. Some data, due to the format or lack of information could not be treated. The total number of flights observed in the traffic samples is 43621. Appendix B to the report on Agenda Item 3 of the AP/ATM/12 shows information on the analysis of this survey.

Follow-up of RVSM operations

Reports of severe turbulence

3.1 The AP/ATM/12 meeting recalled that when a non-RVSM approved aircraft, carrying out an international flight or a domestic flight in excluding airspace, is experiencing severe turbulence and requests entry into RVSM airspace, the clearance should be denied according to the region’s Concept of Operations (CONOPS) manual. This could be a safety issue and guidance for this scenario should be considered.

3.2 The meeting discussed issue that incorporating guidance specific to the exception of allowing non-RVSM approved aircraft into RVSM airspace due to severe turbulence will “open the window” to allow additional exceptions for non-RVSM approved aircraft. It was analyzed the rate of occurrence of this situation and was informed that it was not a widespread action. The meeting agreed that this type of events are not regional and guidance need not be provided for the total region, consequently the amending of the CAR/SAM RVSM CONOPS document is not necessary.

3.3 The meeting was reminded that the CAR/SAM RVSM CONOPS states “suspend RVSM” when severe turbulence activity is evident in RVSM stratum and determined that this guidance was not applicable is this instance as the severe turbulence is “reported” to be at levels below the RVSM strata.

3.4 The meeting advised that when a non-RVSM approved aircraft enters RVSM airspace, 2000 ft separation must be applied; this can be an increase in workload for the controller.

3.5 As stated in RVSM CONOPS documents, non-RVSM approved international flights are not permitted to enter RVSM airspace in the regions. The meeting was of the opinion that guidance could be provided to air traffic controllers on a state by state basis, as needed. The following are suggested topics to include in recommended guidance:

a. Offer lower altitude
b. Provide a vector
c. Reroute
d. If the non approved aircraft is permitted to enter RVSM airspace
    i. Maintain current FL and provide 2000ft separation
    ii. provide a maximum duration

3.6 The Group recommended for these cases the following methods for validating reports of severe turbulence:

a) Ask nearby aircraft at the same FL
b) Request that the pilot submit a Pilot report concerning the severe turbulence.

Loss of in flight RVSM capacity in remotes and oceanic areas

3.7 With reference to the convenience of establishing a specific procedure for keeping the flight in RVSM airspace in those cases in which the RVSM-approved aircraft loses its RVSM capability in flight in oceanic or continental remote areas, the meeting divided its consideration of this issue into two separate scenarios:

a. *When direct controller pilot communications exist*:

In this situation, the pilot will report to air traffic control the loss of RVSM capability of an otherwise approved aircraft and will follow controller clearances that will be delivered based on traffic complexity, work load and the effort to maintain the highest level of safety in the airspace. 2000 feet vertical separation will be applied.

b. *When direct controller pilot communications do NOT exist*:
This situation is more difficult as the controller will NOT know that the aircraft is not mechanically capable of RVSM compliance, hence the pilot should execute the in flight contingency procedures that already exist for use in oceanic and remote airspace. Those procedures are published in exiting ICAO PANS ATM (Doc. 4444)

Identification of non-RVSM approved aircraft operating in RVSM airspace

3.8 The meeting recalled that CARSAMMA has the responsibility of developing and maintaining a database on RVSM approved aircrafts. According to information received, the Regional Agency will take appropriate actions to fulfill this task and will make it available in its web page. It is worth to mention that this database can only be developed if States/Territories elaborate their own database as established by GREPECAS through Conclusion 13/59. This information should also be submitted to CARSAMMA. In any case, the Meeting coincided that the database only should be utilized to provide information and not to be applied to force the pilot commanding the aircraft to use these data to complete Box 10 of FPL.

Renewal of RVSM clearance procedures and aircraft monitoring programmes

3.9 The meeting took note of the existence of operators who prove to be misinformed with regard to requirements and renewal of RVSM clearance procedures as well as of monitoring problems. Recognizing the above, the meeting encouraged States/Territories/International Organizations to reiterate these procedures among their operators.

4. Conclusion

Full operational use of RVSM

4.1 Taking into account that:

a) The information contained in this working paper indicated that a predetermined reliability level, from the statistical point of view, the introduction of RVSM increases the risk level, due to operational errors and in-flight contingencies.

b) Agreed TLS is being reached regarding technical performance (Technical TLS) observed of altitude maintenance of a new representative sample of aircraft population of both regions.

c) The Scrutiny Group has been established for operational deviations and measures to reduce LHD have been arranged.

d) The total estimated risk for RVSM in the CAR/SAM airspace with the adoption of corrective measures is $2,4 \times 10^{-9}$ satisfied the agreed TLS value of not more than 5×10^{-9} fatal accidents per flight hour due to all causes,

4.2 the following is submitted for consideration of the meeting:

Draft
Conclusion ATM/5/XX **Full operational use of RVSM in the CAR/SAM Regions**

Considering that the RVSM operations safety assessment in the CAR/SAM Regions indicated that objective of safety assessment is lower than TLS total regionally agreed, full operational use of RVSM implemented on 20 January 2005 in the CAR/SAM Regions is approved.

Draft
Conclusion ATM/5/XX **Corrective actions**

Considering the need to maintain the collision risk below TLS agreed, that States take the necessary actions to implement the corrective actions aimed to reduce the coordination errors between ATC units.

Draft
Conclusion ATM/5/XX **Operations safety monitoring**

Considering the need for safety assessment of RVSM operations in the CAR/SAM Regions, through the utilisation of a Collision Risk Model, States are requested to collect air traffic movement data in the period 15 to 19 January 2007, and providing the information to CARSAMMA not later than 15 February 2007. The movement data collection form used in previous collections is shown in Appendix XX to this part of the report.

5. Suggested action

5.1 The meeting is invited to:

a) Take note of the information presented in this working paper and particularly in **Appendix A**; and

b) Approve Draft Conclusion as shown in para. 4.2.

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APPENDIX A

Summary of the Reduced Vertical Separation Minimum (RVSM) Safety Assessment to Reflect the Operations Safety one year after the RVSM Implementation in CAR/SAM airspace in January 20th 2005

1. Introduction

1.1 At its Tenth Meeting (May 2005) the CAR/SAM RVSM Implementation Task Force considered the safety assessment associated with the implemented RVSM in January 2005 in CAR/SAM airspace. This safety assessment was provided jointly by the CARSAMMA, the RVSM RMA designated by the CAR/SAM Air Navigation Planning and Implementation Regional Group, and by the Task Force's Safety and Airspace Monitoring Working Group.

1.2 The safety assessment presented at APATM/10 indicated that the level of risk attributable to all causes for the implemented RVSM did not exceed the amount that can be tolerated in light of the agreed safety goal, the Target Level of Safety (TLS). In order to update this safety assessment and declare full operational the RVSM use, according to the Doc. 9574, the CARSAMMA requested some States/International Organizations to collect traffic samples that would reflect the operations roughly one year after the implementation.

1.3 The purpose of this paper is to provide a comprehensive update to the CAR/SAM safety assessment for consideration by the Task Force, addressing the RVSM use and corrective actions required.

2. Background

2.1 This section of the paper provides summary information on the internationally accepted collision risk methodology applied in assessing the safety of RVSM operation. Included in this summary are discussions of the TLS and of the collision risk model, including sources of data from the CAR/SAM Regions used to estimate its parameters.

2.2 The TLS and RVSM Safety Assessment

2.2.1 The International Civil Aviation Organization's Review of the General Concept of Separation Panel (RGCSP) carried out the work leading to the guidance material of reference 1. At its Sixth Meeting (reference 2), the Panel adopted a TLS value of 2.5 fatal accidents per 10^9 flying hours as the safety goal to accompany RVSM introduction and use on a worldwide basis. This RGCSP Meeting marked the culmination of roughly five year's data collection and analysis work by several States, as well as substantial review and assessment of these results within the body. The focus of these efforts had been determination of the feasibility of implementing RVSM, with principal emphasis on assessing the ability of aircraft height-keeping systems to perform to a sufficiently high standard. At this Meeting, the Panel adopted requirements for an aircraft's height-keeping system – composed of an altimetry and an altitude-keeping system – which it judged both feasible and capable of satisfying the TLS.

2.2.2 At its Seventh Meeting (reference 3), the Panel examined new information indicating that large height deviations, arising principally from errors in granting or following ATC clearances, were occurring in portions of worldwide airspace where RVSM implementation was being contemplated. The Panel recognized that the risk associated with these events should also be taken into account when considering introduction of RVSM. Accordingly, the Panel agreed to change the overall TLS value to 5 fatal accidents per 10^9 flying hours and to recommend that this value be the upper bound on the risk of midair collision due to all causes in connection with the 1000-ft vertical separation standard above FL290. The Panel further agreed that the safety goal for aircraft height-keeping performance should remain at the previously established value of 2.5 fatal accidents per 10^9 flying hours. Finally, the Panel decided that, in assessing whether RVSM implementation would be safe, both the safety goal for aircraft height-keeping performance and the overall TLS value should be satisfied simultaneously.

2.2.3 Thus, as envisioned by the RGCSP, introduction and use of RVSM would be safe if:

(a) collision risk due to all causes does not exceed 5 fatal accidents per 10^9 flying hours, and, at the same time,

(b) collision risk due to aircraft height-keeping systems does not exceed 2.5 fatal accidents per 10^9 flying hours.

2.2.4 The Panel made clear that risk assessment in regard to aircraft height-keeping systems should take into account the effects of turbulence, loss of altitude hold and crew response to airborne collision-avoidance system alerts as well as errors arising from aircraft altimetry and altitude-keeping system performance. During safety assessment leading to successful 1997 North Atlantic (NAT) RVSM implementation, the ensemble of risk attributable to all of these causes came to be called "technical risk."

2.2.5 The Panel also made clear that risk assessment in regard to human error should take into account errors in which:

(a) aircraft fail to climb or descend as required,
(b) aircraft climb or descend without ATC clearance,
(c) ATC clearances result in losses in specified aircraft separation standards,
(d) entries into airspace at an incorrect flight level, and
(e) any other error attributable to human oversight.

2.2.6 In the safety assessment process, the summation of risk attributable to all these causes above is termed “operational risk”.

2.3 Collision Risk Modeling and RVSM Safety Assessment

2.3.1 Collision risk model for technical risk

2.3.1.1 References 2 and 3 contain detailed developments of the basic collision risk model (CRM) used in conjunction with RVSM implementation.

2.3.1.2 Reference 2 provides the model for the total technical risk, expressed as the sum of three basic types of collision risk, as:

$$N_{az} = N_{az}\,(\text{same}) + N_{az}\,(\text{opposite}) + N_{az}\,(\text{cross}) \tag{1}$$

where the terms in (1) are defined in Table 1.

Parameter	**Description**
N_{az}	Expected number of accidents per aircraft flight hour resulting from collisions due to the loss of vertical separation between aircraft pairs at adjacent flight levels
N_{az}(same)	Expected number of accidents per aircraft flight hour between aircraft pairs flying on the same route in the same direction at adjacent flight levels
N_{az}(opposite)	Expected number of accidents per aircraft flight hour between aircraft pairs flying on the same route in opposite directions at adjacent flight levels
N_{az}(cross)	Expected number of accidents per aircraft flight hour between aircraft pairs flying on crossing routes at adjacent flight levels

Table 1. Technical Risk Model Parameter Definitions

2.3.1.3 The model form appropriate for the estimation of same-route “technical” risk reflecting the contributions of pairs of aircraft at adjacent flight levels where the members of pair are flying the same or in opposite directions, N_{az}(same) and N_{az}(opposite), is:

$$N_{az}(same)+N_{az}(opp)=P_z(S_z)P_y(0)\frac{\lambda_x}{S_x}\left\{\begin{array}{l} E_z(same)\left[\dfrac{\overline{|\Delta V|}}{2\lambda_x}+\dfrac{\overline{|\dot{y}|}}{2\lambda_y}+\dfrac{\overline{|\dot{z}|}}{2\lambda_z}\right]+ \\ E_z(opp)\left[\dfrac{2\overline{|V|}}{2\lambda_x}+\dfrac{\overline{|\dot{y}|}}{2\lambda_y}+\dfrac{\overline{|\dot{z}|}}{2\lambda_z}\right] \end{array}\right\} \tag{2}$$

where the parameters of the model presented in (2) are defined in Table 2, below.

CRM Parameter	**Description**
S_Z	Vertical separation minimum.
$P_z(S_Z)$	Probability that two aircraft nominally separated by the vertical separation minimum S_Z are in vertical overlap.
$P_y(0)$	Probability that two aircraft on the same track are in lateral overlap.
λ_x	Average aircraft length.
λ_y	Average aircraft wingspan.
λ_z	Average aircraft height with undercarriage retracted.
S_x	Length of longitudinal window used to calculate occupancy.
$E_Z(same)$	Same-direction vertical occupancy for a pair of aircraft at adjacent flight levels on same route.
$E_Z(opp)$	Opposite-direction vertical occupancy for a pair of aircraft at adjacent flight levels on same route.
$\overline{\lvert \Delta V \rvert}$	Average relative along-track speed between aircraft on same direction routes.
$\overline{\lvert V \rvert}$	Average absolute aircraft ground speed.
$\overline{\lvert \dot{y} \rvert}$	Average absolute relative cross track speed for an aircraft pair nominally on the same track.
$\overline{\lvert \dot{z} \rvert}$	Average absolute relative vertical speed of an aircraft pair that have lost all vertical separation

Table 2. Same-Route Technical Risk Model Parameter Definitions

2.3.1.4 The term “occupancy” as used in table 2 refers to aircraft pairs which are “proximate” in the sense that they are within some arbitrary distance or time - for example, 80 nm or 10 minutes – of each other on the route at adjacent flight levels. This proximity is used as a measure of the relative density of aircraft pairs in airspace, with a higher relative density leading to a higher estimate of risk. The term “overlap” refers to the event that the centers of mass of two aircraft in a given – along-track, cross-track or vertical - are closer together than twice the size of an aircraft – length, wingspan or height – in that dimension.

2.3.1.5 Same and opposite direction passing frequencies, $N_x(same)$ and $N_x(opp)$, are related to the same and opposite direction vertical occupancies through the following relations:

$$N_x(same) = \frac{\lambda_x}{\hat{S}_x} E_z(same) \frac{\overline{|\Delta V|}}{2\lambda_x}$$

and

$$N_x(opp) = \frac{\lambda_x}{\hat{S}_x} E_z(opp) \frac{\overline{|V|}}{2\lambda_x}$$

where the parameters are identical to those described in the previous table.

2.3.1.6 The CARSAM airspace requires estimation of technical risk at route intersections, N_{az}(cross). The following CRM form is appropriate for this estimation:

$$N_{az}(cross) = \begin{cases} \sum_{i=1}^{n} P_h(\theta_i) P_z(S_z) \dfrac{\pi S_h}{2\left|\overline{\dot{h}(\theta_i)}\right|} \dfrac{1}{t_F} \dfrac{2K(\theta_i)}{N} \left[\dfrac{2\left|\overline{\dot{h}(\theta_i)}\right|}{\pi \lambda_h} + \dfrac{\left|\overline{\dot{z}}\right|}{2\lambda_z} \right] & for \ \dfrac{\pi S_h}{2\left|\overline{\dot{h}(\theta_i)}\right|} < t_F \\ \sum_{i=1}^{n} P_h(\theta_i) P_z(S_z) \dfrac{2K(\theta_i)}{N} \left[\dfrac{2\left|\overline{\dot{h}(\theta_i)}\right|}{\pi \lambda_h} + \dfrac{\left|\overline{\dot{z}}\right|}{2\lambda_z} \right] & for \ \dfrac{\pi S_h}{2\left|\overline{\dot{h}(\theta_i)}\right|} \geq t_F \end{cases} \qquad (3)$$

where the parameters of the model presented in (3) are defined in Table 3, below.

CRM Parameter	Description
S_z	Vertical separation minimum.
$P_z(S_Z)$	Probability that two aircraft at adjacent flight levels nominally separated by the vertical separation minimum S_Z are in vertical overlap.
θ	Angle formed at the intersection of two crossing-routes
N	The number of groups made from crossing routes with similar angles of intersection
$P_h(\theta)$	Probability of horizontal overlap for two aircraft at adjacent flight levels on routes crossing at angle θ
S_h	Planned horizontal separation
λ_h	Larger of the average aircraft wingspan or fuselage length
λ_z	Average aircraft height with undercarriage retracted
S_x	Length of longitudinal window used to calculate occupancy.
$K(\theta)$	Number of proximate aircraft pairs on routes that cross at angle θ.
t_F	Average duration of flights on the crossing routes
n	Number of flights on the crossing route during the time period for which $T_h(\theta)$ hours of proximity were estimated
$T_h(\theta)$	Total time that aircraft pairs on routes that cross at angle θ are horizontally proximate.
$\left\lvert\overline{\dot{h}(\theta)}\right\rvert$	Average relative horizontal speed during overlap for aircraft pairs on routes with crossing angle θ.
$\lvert\dot{\bar{z}}\rvert$	Average absolute relative vertical speed of an aircraft pair that have lost all vertical separation

Table 3. Crossing-Route Technical Risk Model Parameter Definitions

2.3.2 Collision risk model for operational risk

2.3.2.1 The CRM appropriate for estimation of risk due to large height deviations (LHD) resulting in errors which are whole multiples of the vertical separation standard is a variation of equation (2). The proportion of the total flying time spent at incorrect levels, Pi=Q, may be interpreted as the probability that an aircraft is flying at an incorrect level. The proportion of the total flying time spent at incorrect levels, P_i, is determined by summing the individual times for each LHD and dividing by the total system flight time over the calendar interval during which LHDs were tallied. For this CAR/SAM post implementation safety assessment, the total system flight time is estimated as the total system flight time computed from the 15 days sample of traffic movements received from the CAR/SAM flight information regions (FIRs) multiplied by twenty four.

2.3.2.2 To determine the probability of vertical overlap, $P_z(1000) = P_z^{ne}(1000)$, it is necessary to multiply Q by the probability that two aircraft nominally flying at the same level are in vertical overlap, $P_z(0)$. The vertical overlap probability arising from errors resulting in deviations of integral multiples of the vertical separation standard is, therefore, given by:

$$P_z(nS_z) = P_z^{ne}(1000) = P_z(0) \times Q \tag{5}$$

Having determined the vertical overlap, $P_z(S_z)$, the collision risk for such deviations can be estimated using equation (2).

2.4 Traffic Movement Data and the RVSM Safety Assessment

2.4.1 At APATM/11, the Task Force recognized that with the change in the separation standard of 2000ft to a 1000ft separation standard and with the operational errors presented the safety of the operations should be reassessed. Accordingly, the Task Force agreed that a further sample of traffic from the CARSAM FIRs should be collected for the period 01-15 December 2005. The CARSAMMA received traffic samples from 22 FIRs.

2.5 Height-Keeping Performance Monitoring and the RVSM Safety Assessment

2.5.1 Estimation of technical risk requires the availability of information describing errors in aircraft altimetry and altitude-keeping systems. The CARSAMMA used the same source material for this information as was employed in the monitoring of safety used in the NAT Region by the Central Monitoring Agency (CMA) added with the $300\,ft \le LHD < 1000\,ft$ reported to CARSAMMA by the CAR/SAM ATS providers. This assumption is completely valid, considering that the vertical performance of the RVSM approved aircraft are roughly the same.

3. Discussion

3.1 This section of the working paper describes the process and source material for estimating values for each of the parameters in tables 1 and 2, and provides those values. Where appropriate, this section also references Task Force decisions or precedent from the CAR/SAM RVSM implementation safety assessment which influenced a choice of a value.

3.2 Aircraft size

3.2.1 The aircraft length, wingspan and height shown in table 4, was used in estimating risk for the CAR/SAM RVSM safety assessment. These values were estimated from the traffic sample.

Aircraft	**λ_z = Height (nm)**	**λ_x = Length (nm)**	**λ_y = Wingspan (nm)**
Average Aircraft	0.0064033	0.0212364	0.0189686

Table 4. Aircraft Size Used in 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, $\lambda_{h.}$ This value has been taken as 0,0212364nm for average aircraft in the CAR/SAM airspace.

3.3 Relative aircraft speeds

3.3.1 Table 7 presents the values and sources for estimation of relative aircraft speeds used in the CAR/SAM safety assessment. The values of average relative along-track speed and average absolute aircraft ground speed are those obtained from the analysis of the traffic sample. The CARSAMMA used the value of relative cross-track speed already used in the safety assessment of other Regions. The value so obtained is, 20 knots.

3.3.2 The value for the relative horizontal-plane speed of a pair of aircraft on crossing routes as they are in horizontal overlap was determined from the angle of route intersections in the route system analyzed assuming that the speed of an individual aircraft is 451.72 knots.

3.3.3 The value for relative vertical speed shown in table 5, 1.5 knots, is that used in both the NAT and Pacific RVSM safety assessments.

Parameter Symbol	**Parameter Definition**	**Parameter Value**	**Source for Value**
$\overline{\lvert\Delta V\rvert}$	Average relative along-track speed between aircraft on same direction routes	18.44 knots	Estimated from CAR/SAM sample
$\overline{\lvert V\rvert}$	Average absolute aircraft ground speed	451.72 knots	Estimated from CAR/SAM sample
$\overline{\lvert\dot{y}\rvert}$	Average absolute relative cross track speed for an aircraft pair nominally on the same track	20 knots	Value used in NAT RVSM safety assessment
$\left\lvert\overline{\dot{h}(\theta)}\right\rvert$	Average 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 average aircraft speed of 451.72 knots
$\overline{\lvert\dot{z}\rvert}$	Average absolute 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 5. Relative Aircraft Speeds Used in CAR/SAM RVSM Safety Assessment

3.4 Probability of Lateral Overlap

3.4.1 The CARSAMMA used the 0.3 NM as a s.d. of lateral keeping to estimate a value for P_y (0). The result of this estimation is a value of 0.0447.

3.5 Passing Frequency and Vertical Occupancy

3.5.1 It should be recalled that two aircraft are said to be proximate vertically, as this term relates to collision risk, if the aircraft are assigned to adjacent flight levels. Based on the operational use of the routes in CAR/SAM Regions, it is clear that aircraft pairs may be flight-planned within 1000 ft vertically on the same route or crossing route when the RVSM is applied. The CARSAMMA processed the traffic movement data in order to determine the number of proximate pairs of aircraft seen from 01-15 December 2005 in the 22 FIR analyzed. The same-direction and opposite-direction passing frequencies for aircraft operating on adjacent flight levels and the same route or the vertical occupancy for aircraft operating on crossing routes were estimated using this sample of traffic movements.

3.5.2 The estimate for the vertical occupancy on crossing routes was derived from the traffic samples received from the main 7 CAR/SAM FIR in terms of traffic density. The vertical occupancy is estimated to be 0.7003.

3.5.3 The estimates for the same-direction and opposite-direction passing frequencies were derived from the traffic samples received from the same 7 CAR/SAM FIR as well. The same-direction and opposite-direction passing frequencies are estimated to be 0.0139 and 0.2873 respectively.

3.5.4 An approximation of P_h (θ), the probability of horizontal overlap for aircraft-pairs at adjacent flight levels on routes crossing at angle θ, was determined. For the safety assessment on crossing routes it was used the value of P_h (θ) combined of all crossings with different angles from 5 to 175 degrees with a 5° interval.

3.6 Probability of Vertical Overlap Attributable to Technical Height-Keeping Performance

3.6.1 As noted previously, technical risk is considered to arise from the effects of turbulence, loss of altitude hold as well as from errors in aircraft altimetry and altitude-keeping system performance. Hence, estimation of the probability of vertical overlap must account for contributions to vertical error arising from all of these sources.

3.6.2 CARSAMMA compared the results of monitoring aircraft height-keeping performance in the NAT and in the CARSAM Region and found them to be similar. As a result, and considering the amount of data available, the CARSAMMA has used the estimates of ASE from the NAT in the operational safety assessment.

3.6.3 LHD attributable to turbulence, emergency descent through flight levels on route centerline without clearance and response to collision avoidance system advisories have the potential to adversely influence the probability of vertical overlap due to technical height-keeping performance.

3.6.4 The Task Force has consistently called on ATS providers, airspace users and others to forward monthly reports of these sorts of LHD to the CARSAMMA. While not all ATS units have provided these monthly reports, those received by the CARSAMMA for the time period January through December 2005 have highlighted just a few significant instances of LHD attributable to turbulence, emergency descents without ATC clearance or responses to collision avoidance system advisories. Because of the important effect of this parameter on vertical collision risk, the CARSAMMA has taken a cautious approach to specifying its value. This approach considered the LHD from the NAT Region added to the ones from the 7 CAR/SAM FIR as shown in the table 6 below.

$P_Z(1000)$	$P_Z(0)$	$P_y(0)$
3.752×10^{-9}	0.3862	0.0447

Table 6. Results of the Vertical Overlap Probability

3.7 Probability of Vertical Overlap Attributable to Instances of Mistakes in Granting or Following an ATC Clearance

3.7.1 It will be recalled that estimation of $P_z(1000) = P_z^{ne}(1000)$ due to large height deviations requires determination of two quantities: (1) the proportion of total flying time spent at levels, Pi = Q, and (2) the probability that two aircraft nominally flying at the same level are in vertical overlap, Pz (0).

3.7.2 System risk is directly proportional to the amount of total flight time spent at the wrong flight levels. Estimation of this time is a key determinant of whether or not the estimated system risk will meet the TLS.

3.7.3 Operational errors are likely to result in aircraft operating at whole number multiples of the vertical separation standard from their assigned flight level. Sometimes the aircraft levels in wrong flight level in the same direction of the flow and sometimes in the opposite direction of the flow. That fact is taken into account in the collision risk analysis. The proportion of flying time spent at incorrect levels, Pi=Q, is determined as the ratio of the amount of time spent at incorrect levels to the total amount of flying time in CARSAM airspace during the period when the wrong-flight-level events occurred. As was the case in identifying large vertical errors associated with technical height-keeping performance, the CARSAMMA used the 12-month interval January through December 2005 as the period for analysis.

3.8 Technical Risk

3.8.1 The goal is to demonstrate that TLS of 2.5×10^{-9} fatal accidents per aircraft flying hours is satisfied according to a significant level of confidence. The technical risk that represents the CARSAM Region was evaluated considering the movement of three different adjacent FIR from the CAR Region and four from the SAM Region as it was done in the pre-implementation safety analysis. FIR Havana, Central America and Kingston and Curitiba, Brasília, Recife and sector Manaus from Amazônica FIR were used at that time. In the table below it is shown the parameters of the Technical Collision Risk Model for the post- implementation (IOP) and Operational (FM-I) phases for reference.

Parameters	AIRSPACE					
	CARIBBEAN		SOUTH AMERICA		CAR/SAM	
	FM-I	IOP	FM-I	IOP	FM-I	IOP
$P_y(0)$	0.0464	0.0456	0.0446	0.0440	0.0447	0.0445
$P_z(0)$	0.4095	0.4240	0.3748	0.3987	0.3862	0.4070
$P_z(1000)$	8.18×10^{-9}	8.0640×10^{-9}	1.781×10^{-9}	4.5292×10^{-9}	3.752×10^{-9}	5.6811×10^{-9}
$\lambda_x\ (MN)$	0.0224519	0.0217718	0.0206317	0.0208002	0.0212364	0.0211091
$\lambda_y\ (MN)$	0.0196701	0.0193459	0.0186196	0.0186863	0.0189686	0.0188960
$\lambda_z\ (MN)$	0.0067274	0.0066127	0.0062421	0.0063397	0.0064033	0.0064265
$\lambda_h\ (MN)$	0.0224519	0.0217718	0.0206317	0.0208002	0.0212364	0.0211091
$\overline{\lvert V\rvert}\ (MN/h)$	470.65	467.62	442.30	432.67	451.72	443.78
$\overline{\lvert\Delta V\rvert}\ (MN/h)$	20	0.	18.42	26.31	18.44	26.31
$\overline{\lvert\dot{y}\rvert}\ (MN/h)$	20	20	20	20	20	20
$\overline{\lvert\dot{z}\rvert}\ (MN/h)$	1.5	1.5	1.5	1.5	1,5	1,5
$N_x(op)$	0.3361	0.2751	0.2397	0.2228	0.2873	0.2509
$N_x(_{same})$	0.0	0.0	0.0139	0.0117	0.0139	0.1167
$E_z(cross)$	0.3743	0.2353	0.9053	0.7807	0.7003	0.5721
$S_x\ (NM)$	80	80	80	80	80	80

Table 7. Summary of the Technical Vertical Collision risk Parameters

3.8.2 The collision risk was evaluated separately to the CAR and SAM Regions and for the total CARSAM airspace, as it is shown in table 8 below.

Caribbean		**South America**		**CAR/SAM**	
FM-I	**IOP**	**FM-I**	**IOP**	**FM-I**	**IOP**
0.140x10^{-9}	0.112×10^{-9}	0.036x10^{-9}	0.081×10^{-9}	0.076x10^{-9}	0.098×10^{-9}

Table 8. Technical Collision Risk

3.8.3 Effect of the traffic growing

3.8.3.1 The evolution of collision risk in the period 2004 to 2015 was estimated to traffic growing annual rate of 8 % that direct affects the passing frequency value. The forecasts were shown in the Fig. 1, 2 e 3, below**.** Note that the technical risk, until 2015, will be below the limit of 2.5×10^{-9}.

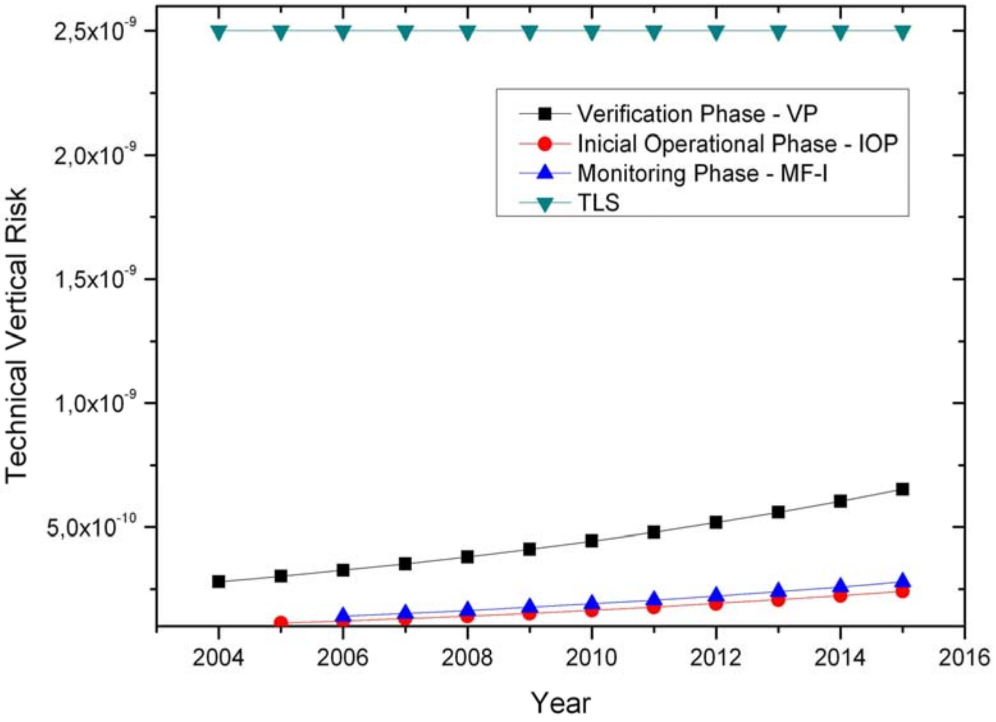

Fig 1 Technical Collision Risk Forecast

(Havana, Central American and Kingston)

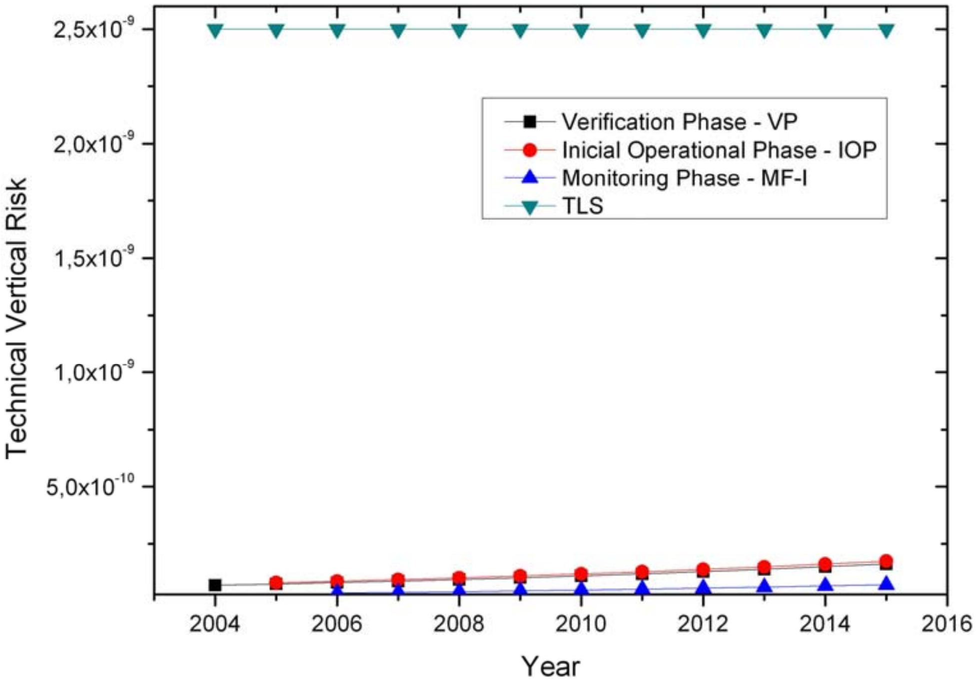

Fig 2 Technical Collision Risk Forecast

(Curitiba, Brasília, Recife and Sector Manaus (FIR Amazônica))

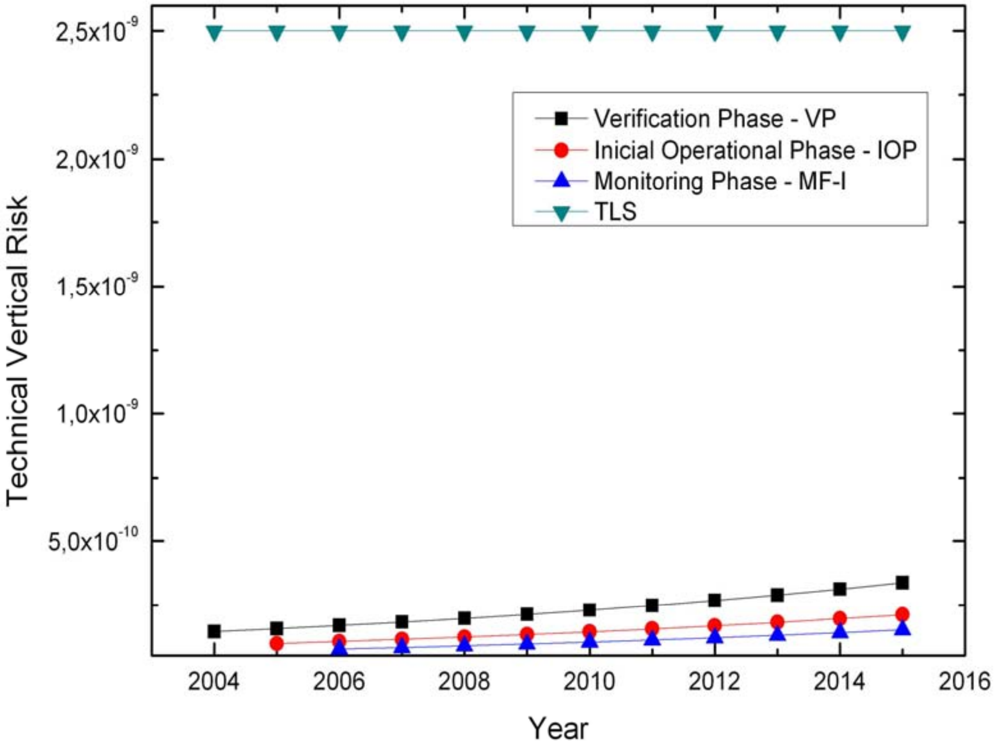

Fig 3 Technical Collision Risk Forecast

(CAR/SAM)

3.9 Operational Risk

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

3.9.2 The LHD identified through the reports received by CARSAMMA may be due to operational procedures, adverse meteorological conditions or emergency procedures due to equipment failures or pressurization and can be divided in four main group types:

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

3.9.3 The errors definition according to the causes was based on the classification approved by the SWG at AP/ATM/11 and presented on the paper related to LHD at this meeting. The tables 9 and 10 below show the large deviations (equal to or larger than 1000ft) for the region analyzed, considered operational and received by CARSAMMA, which types and causes are described in the table 11. In the tables 9 and 10, the last four columns are referred to the numbers of crossed flight levels, n^{nc}, in the same (s) and opposite (op) direction of flow.

Date	**Acft type**	**Fix**	**Clr FL**	**LHD**	**Time (sec))**		**Error**	n_s^{nc}	n_{op}^{nc}
					S	**Op**			
25/5/2005	B738	BEROX	330	-2000	90	0	M	0	0
17/5/2005	A310	ETBOD	340	2000	90	0	M	0	0
1/8/2005	B757	RETAK	350	2000	15	0	M	0	0
1/8/2005	B738	VESKA	330	2000	15	0	M	0	0
1/8/2005	B752	PIGBI	340	2000	15	0	M	0	0
5/8/2005	A300	VESKA	320	4000	15	0	M	0	0
5/8/2005		VESKA	320	4000	15	0	M	0	0
8/8/2005		BEROX	340	2000	15	0	M	0	0
21/8/2005	MD88	LENUK	310	2000	90	0	M	0	0
31/8/2005	B763	IRGUT	340	2000	15	0	M	0	0
8/10/2005	B738	POKAK	360	-2000	90	0	M	0	0
9/10/2005	B752	PIGBI	360	2000	90	0	M	0	0
10/10/2005	B738	PIGBI	370	2000	90	0	M	0	0
10/10/2005	LJ35	ETBOD	400	-5000	0	90	M	0	0
15/10/2005	B752	POKAK	360	-2000	90	0	M	0	0
10/10/2005	LJ35	VESKA	430	-5000	90	0	M	0	0
25/10/2005	A300	VESKA	320	2000	90	0	M	0	0
26/10/2005	IL62	IRGUT	380	-2000	90	0	M	0	0
27/10/2005	LJ35	BEROX	410	-6000	90	0	M	0	0
28/10/2005	B738	VESKA	380	-4000	90	0	M	0	0
1/11/2005	A346	BETIR	360	2000	90	0	M	0	0
4/11/2005	B737	ANSON	390	2000	90	0	M	0	0
24/11/2005	B737	LENOM	330	4000	30	0	I	1	2
24/11/2005	A319	RETAK	380	-3000	0	120	I	1	1
4/12/2005	B752	RETAK	360	2000	30	0	I	0	1
	B757	RETAK	310	4000	60	0	M	0	0
TOTAL					**1485**	**210**		**2**	**4**

Table 9. Operational LHD (equal to or more than 1000ft) Received by CARSAMMA from the Region CAR3.

Date	Acft type	Fix	Clr FL	LHD	Time (sec)		Error	n_s^{nc}	n_{op}^{nc}
					S	Op			
1/4/2005	B732	NELSON	300	1500	420	0	P	0	1
10/4/2005	B707	BLESS	300	2500	60	0	A	0	1
14/4/2005	A343	MLO	390	-2000	90	0	M	0	0
6/5/2005	C650	LIBRA	410	-5000	300	0	A	2	2
22/6/2005			350	2000	90	0	M	0	0
29/6/2005			350	2000	90	0	M	0	0
14/7/2005	LJ35	OIA	360	2000	30	0	M	0	0
27/7/2005		MLO	370	-2000	90	0	M	0	0
28/7/2005		JUICE	270	6000	90	0	M	0	0
10/8/2005	B738	ETANO	400	2000	90	0	M	0	0
13/8/2005	B733	ETANO	340	-2000	90	0	M	0	0
13/8/2005	B737	ETANO	400	-6000	90	0	M	0	0
3/12/2005	C17	PAKON	340	-2000	900	0	M	0	0
15/12/2005	MD82	PIGBY	380	-8000	30	0	I	3	4
16/12/2005	B763	UGURA	370	2000	30	0	M	0	0
17/12/2005	B737	MLO	370	2000	20	0	M	0	0
	A320	ALBER	330	-2000	10	0	I	0	1
TOTAL					**2520**	**0**		**5**	**9**

Table 10: Operational LHD (equal to or more than 1000ft) Received by CARSAMMA from the Region SAM4.

Type of Error	Cause of the LHD
A	Failure to climb/descend as cleared
I	ATC system loop error; (e.g. pilot misunderstands clearance message or ATC issues incorrect clearance)
M	Error in ATC-unit-to-ATC-unit transition message
P	Unknown

Table 11. Classification of the Received LHD

3.9.4 Classification of errors to the risk evaluation

The causes of the group errors were classified and contribute to two different events:

- *Aircraft leveling in wrong flight level*;

  According to the tables 9 and 10, 43 aircrafts had levelled in wrong flight level, reaching 4215 seconds with the average time spent in wrong flight level of 0.02723 hours and two of them in the opposite direction of the flow.

- *Aircraft climbing/descending through one or more flight levels.*

  According to the tables 9 and 10, it has occurred 20 crossings of flight levels without ATC clearance and thirteen of them in the opposite direction of the flow.

All de deviation due to non severe meteorological effects (more than or equal to 300ft and less than 1000ft) were considered in the AAD distribution.

The deviation due to *ACAS (TCAS)* were classified and analysed according to a specific model. For this it was developed a composite distribution of typical and atypical performance considering the *ACAS* deviations using the same model composed of a double double exponential as used to the AAD distribution. In this case the atypical performance data from the NAT Region were replaced by the ACAS deviation collected in the CARSAM Region and it was done a new adjust to the distribution function, $f_{ACAS}^{AAD}(a)$. The density function $f_{ACAS}^{AAD}(a)$ was convoluted with the density function $f^{ASE}(a)$. To originate a $f_{ACAS}^{TVE}(z)$ density function to, finally, produce an estimate to the vertical overlap probability due to ACAS, $P_z(S_z)_{ACAS}$.

3.9.5 Determination of the appropriate parameter values to each group of errors classified

The calculations were done separately by Region (CAR and SAM) and to the whole CAR/SAM airspace. To both airspaces it were used the same data (Table 12) of aircrafts levelling in wrong flight level n^{ne}, number of flight levels crossed without clearance n^{nc} and average time spent in wrong flight level $\bar{t}_{ne}$. The climb/descend rate $\left|\overline{\dot{z}_c}\right|$, were assumed to be the 10 kt.

Parameter	**CAR**		**SAM**		**CAR/SAM**	
	FM-I	**IOP**	**FM-I**	**IOP**	**FM-I**	**IOP**
n^{ne}	*26*	*0.0*	*17*	*7*	*43*	*7*
n^{ne}_{same}	*24*	*0.0*	*17*	*4*	*41*	*4*
n^{ne}_{op}	*2*	*0.0*	*0*	*3*	*2*	*3*
n^{nc}_{same}	*2*	*0.0*	*5*	*1*	*7*	*1*
n^{nc}_{op}	*4*	*0.0*	*9*	*2*	*13*	*2*
n^{nc}	*6*	*0.0*	*14*	*3*	*20*	*3*
$\bar{t}^{ne}_{t}$	0.01811 h	0.0	0.04118 h	0.04246 h	0.02723 h	0.04246 h
$\bar{t}^{ne}_{same}$	*0.01719 h*	*0.0*	*0.04118 h*	*0.04583 h*	*0.02713 h*	*0.04583 h*
$\bar{t}^{ne}_{op}$	*0.02917 h*	*0.0*	*0.0*	*0.037963 h*	*0.02917 h*	*0.03796 h*
t^{ne}_{same}	*24.75 min*	0.0	*42.0 min*	*11 min*	66.75 min	*11 min*
t^{ne}_{op}	*3.50 min*	0.0	*0.0*	*6.83 min*	3.50 min	*6.83 min*
t^{ne}_{t}	*28.25 min*	0.0	*42.0 min*	*17.83 min*	70.25 min	*17.83 min*
$\overline{\lvert \dot{z}_c \rvert}$	*10 kt*	*10 kt*	*10 kt*	*10 kt*	*10 kt*	*10 kt*

Table 12. Operational Errors Data

In the table 13 below it is shown the group errors parameters classified according to the application for the CAR/SAM Regions where: $P_z^{ne}(1000)$ is the vertical overlap probability due to an aircraft levelling in wrong flight level and $P_z^{nc}(1000)$ is vertical overlap probability due to an aircraft that cross one or more flight levels without ATC clearance. The parameters, α^{ne} and α^{nc}, are referred to the errors rate for aircraft levelling in wrong flight level and aircraft crossing a flight level without ATC clearance, respectively. The product $\alpha^{ne} \times \bar{t}^{ne}$ is the proportion of flying time spent in wrong flight level.

PARAMETER	CAR		SAM		CAR/SAM	
	FM-I	IOP	FM-I	IOP	FM-I	IOP
T (hours)	249264.0	200520.0	309264.0	442054.3	558528.0	642574.3
α^{ne}	1.043×10^{-4}	0.0	5.497×10^{-5}	1.584×10^{-5}	7.699×10^{-5}	1.0894×10^{-5}
α^{ne}_{same}	9.628×10^{-5}	0.0	5.497×10^{-5}	9.049×10^{-6}	7.341×10^{-5}	6.2250×10^{-6}
α^{ne}_{op}	8.024×10^{-6}	0.0	0.0	6.787×10^{-6}	3.581×10^{-6}	4.6687×10^{-6}
α^{nc}	2.407×10^{-5}	0.0	4.527×10^{-5}	6.787×10^{-6}	3.581×10^{-5}	4.6687×10^{-6}
α^{nc}_{same}	8.024×10^{-6}	0.0	1.617×10^{-5}	2.262×10^{-6}	1.253×10^{-5}	1.5562×10^{-6}
α^{nc}_{op}	1.605×10^{-5}	0.0	2.910×10^{-5}	4.524×10^{-6}	2.328×10^{-5}	3.1125×10^{-6}
$Qsame$	7.171×10^{-8}	0.0	1.331×10^{-7}	1.037×10^{-7}	4.858×10^{-8}	7.1322×10^{-8}
Q_{op}	1.170×10^{-7}	0.0	0.0	8.587×10^{-8}	5.222×10^{-8}	5.9075×10^{-8}
$Q = \alpha^{ne} \times \bar{t}^{ne}$	1.889×10^{-6}	0.0	2.263×10^{-6}	6.724×10^{-7}	2.096×10^{-6}	4.6255×10^{-6}
$P_z(0)$	0.4095	0.4232	0.3748	0.3987	0.3862	0.4070
$P_z^{ne}(1000)$	7.736×10^{-7}	0.0	8.484×10^{-7}	2.680×10^{-7}	8.097×10^{-7}	1.8825×10^{-7}
$P_z^{ne}(1000)_{same}$	7.141×10^{-7}	0.0	8.484×10^{-7}	1.532×10^{-7}	7.720×10^{-7}	1.0757×10^{-7}
$P_z^{ne}(1000)_{op}$	5.951×10^{-8}	0.0	0.0	1.149×10^{-7}	3.766×10^{-8}	8.0676×10^{-8}
$P_z^{nc}(1000)$	3.239×10^{-8}	0.0	5.651×10^{-8}	8.605×10^{-9}	4.586×10^{-8}	6.0007×10^{-9}
$P_z^{nc}(1000)_{same}$	1.080×10^{-8}	0.0	2.018×10^{-8}	2.868×10^{-9}	1.605×10^{-8}	2.000×10^{-9}
$P_z^{nc}(1000)op$	2.159×10^{-8}	0.0	3.633×10^{-8}	5.737×10^{-9}	2.981×10^{-8}	4.000×10^{-9}
$P_z^{ACAS}(1000)$	7.511×10^{-9}	1.739×10^{-9}	1.668×10^{-9}	9.135×10^{-10}	3.515×10^{-9}	1.1533×10^{-9}

Table 13: Parameters of the Operational Errors Group Classified

3.10 Risk Assessment for the RVSM operation in the CAR/SAM Regions

3.10.1 This section will provide an estimate of risk associated with all causes in connection with the RVSM use. The technical and operational risk values are combined to estimate the total risk attributable to all causes for the system.

3.10.2 The vertical collision risk was calculated with the Reich Collision Risk Model associated to each group of LHD. In the table 14 it is presented the values of risk for the resulting models:

- N_{az}^{tec} is the technical vertical risk;
- N_{az}^{ne} is the vertical risk due to aircraft leveling in wrong flight level;
- N_{az}^{nc} is the vertical risk due to an aircraft crossing a flight level without ATC clearance;
- N_{az}^{ACAS} is the vertical risk due to ACAS advisories; and
- N_{az} is the vertical collision risk due to all causes or the total risk.

Risk	**CAR**		**SAM**		**CAR/SAM**		***TLS***
	FM-I	**IOP**	**FM-I**	**IOP**	**FM-I**	**IOP**	
N_{az}^{Tec}	1.4×10^{-10}	1.1×10^{-10}	3.6×10^{-11}	8.1×10^{-11}	7.6×10^{-11}	9.8×10^{-11}	5.0×10^{-9}
N_{az}^{ACAS}	1.3×10^{-10}	2.4×10^{-11}	3.4×10^{-11}	1.6×10^{-11}	7.1×10^{-11}	2.0×10^{-11}	
N_{az}^{ne}	2.6×10^{-9}	0.0	8.2×10^{-9}	3.0×10^{-9}	6.1×10^{-9}	1.8×10^{-9}	
N_{az}^{nc}	3.9×10^{-10}	0.0	8.8×10^{-10}	1.2×10^{-10}	6.7×10^{-10}	7.6×10^{-11}	
N_{az}^{Total}	3.3×10^{-9}	1.4×10^{-10}	9.0×10^{-9}	3.2×10^{-9}	6.9×10^{-9}	2.0×10^{-9}	

Table 14 Collision Risks to the CAR/SAM Region

3.10.3 As can be seen the total risk for the CAR/SAM Region is greater than the agreed TLS.

3.10.4 It is necessary to remark that this total risk was strongly influenced by the LHD. Most of them due to error in ATC-unit-to-ATC-unit transition message and those errors are not caused by the RVSM operation, but due to common procedures in transferring aircrafts from one ATC Unit to another.

3.10.5 Considering the above it is necessary to continue to monitor the LHD to keep them inside the acceptable limits.

3.11 Determination of the limit of time that the aircraft can spend in a wrong flight level when flying in the same direction of another aircraft in the same flight level.

3.11.1 The proportion of time that the aircraft spends in a wrong flight level is defined by the product of the error rate for the aircraft leveling in wrong flight level, α^{ne}, and the average time spent at the wrong flight level, $\bar{t}_{ne}$, it means, $\alpha^{ne}\times\bar{t}^{ne}$.

3.11.2 Establishing the TLS as the limit for the total risk and keeping the values of technical risk and the risk due to ACAS advisories, based on the data collected the maximum proportion of time that the aircraft can spend in a wrong flight level, the errors rate and the maximum tolerances are estimated and shown in the table 15 below for a climb/descend rate of 10 kt.

Parameters	**CAR**	**SAM**	**CAR/SAM**
Total flying time per year (hr)	249264.0	309264.0	558528.0
$(\alpha^{ne} \times \bar{t}^{ne})_{\max}$	6.626×10^{-7}	6.419×10^{-7}	6.235×10^{-7}
$\alpha^{ne}_{\max}$	3.659×10^{-5}	1.559×10^{-5}	2.290×10^{-5}
$\alpha^{nc}_{\max}$	1.943×10^{-4}	1.794×10^{-4}	1.745×10^{-5}
$t^{ne}_{\max}\,(s/year)$	594.62	714.64	1253.70
$n^{nc}_{\max}\,(per/year)$	48	55	97

Table 15. Proportion of Time, Errors Rate and Maximum Tolerances of Flight Level Crossings Without ATC Clearances and Time Spent in Wrong Flight Level per Year.

3.12 Remedial actions

3.12.1 As can be seen in table 15 and according to the traffic in the CAR/SAM Regions it can be tolerate roughly 1253 seconds per year of aircraft leveling in wrong flight level, considering that no one cross a flight level without ATC clearance, without exceeding the agreed TLS. Or, considering that no one aircraft level in a wrong flight level it can be tolerate until 97 flight level crossings without ATC clearance with a rate of climb/descend of 10 kt without exceeding the agreed TLS.

3.12.2 So, to reduce the risk it is necessary effective remedial actions to reduce the time spent in wrong flight levels and the number of flight levels crossed without ATC clearance. Remedial actions must be taken to reduce the causes of misunderstandings between pilots and controllers and incorrect clearances as well as transition messages between ATC units.

3.12.3 Based on the data collected in the CAR/SAM Regions the best remedial action would be eliminating the errors in transition messages between ATC units.

3.13 Total risk after the remedial actions

3.13.1 The appropriate remedial actions shall result in a maximum time spent in wrong flight level so that the collision risk will not exceed the TLS. If we exclude the type M LHD from the analysis this will result as shown below.

PARAMETER	**CAR**	**SAM**	**CAR/SAM**
n^{ne}	*3*	*5*	*8*
n^{ne}_{same}	*2*	*5*	*7*
n^{ne}_{op}	*1*	*0*	*1*
n^{nc}_{same}	*2*	*5*	*7*
n^{nc}_{op}	*4*	*9*	*13*
n^{nc}	*6*	*14*	*20*
$\bar{t}^{ne}_{t}$ (hr)	0.01667	0.04555	0.03472
$\bar{t}^{ne}_{same}$ (hr)	*0.00833*	*0.04555*	*0.03492*
$\bar{t}^{ne}_{op}$ (hr)	*0.03333*	*0.0*	*0.03333*
t^{ne}_{same} (min)	*1.0*	*13.6667*	14.6667
t^{ne}_{op} (min)	*2.0*	*0.0*	2.0
t^{ne}_{t} (min)	*3.0*	*13.6667*	16.6667
$\left\|\bar{\dot{z}}_{c}\right\|$ (kt)	*10*	*10*	*10*

Table 16. Operational Errors Data Without Type M Error

PARAMETER	**CAR**	**SAM**	**CAR/SAM**
T (hours)	249264.0	309264.0	558528.0
α^{ne}	1.204×10^{-5}	1.617×10^{-5}	1.432×10^{-5}
α^{ne}_{same}	8.024×10^{-6}	1.617×10^{-5}	1.253×10^{-5}
α^{ne}_{op}	4.012×10^{-6}	0.0	1.790×10^{-6}
α^{nc}	2.407×10^{-5}	4.527×10^{-5}	3.581×10^{-5}
α^{nc}_{same}	8.024×10^{-6}	1.617×10^{-5}	1.253×10^{-5}
α^{nc}_{op}	1.605×10^{-5}	2.910×10^{-5}	2.328×10^{-5}
Q_{same}	3.343×10^{-8}	1.473×10^{-7}	6.252×10^{-8}
Q_{op}	1.337×10^{-7}	0.0	5.968×10^{-8}
$Q = \alpha^{ne} \times \bar{t}^{ne}$	2.059×10^{-7}	7.365×10^{-7}	4.973×10^{-7}
$P_z(0)$	0.4095	0.3748	0.3862
$P_z^{ne}(1000)$	8.215×10^{-8}	2.761×10^{-7}	1.921×10^{-7}
$P_z^{ne}(1000)_{same}$	5.477×10^{-8}	2.761×10^{-7}	1.681×10^{-7}
$P_z^{ne}(1000)_{op}$	2.738×10^{-8}	0.0	2.401×10^{-8}
$P_z^{nc}(1000)$	3.239×10^{-8}	5.651×10^{-8}	4.586×10^{-8}
$P_z^{nc}(1000)_{same}$	1.080×10^{-8}	2.018×10^{-8}	1.605×10^{-8}
$P_z^{nc}(1000)_{op}$	2.159×10^{-8}	3.633×10^{-8}	2.981×10^{-8}
$P_z^{ACAS}(1000)$	7.511×10^{-9}	1.668×10^{-9}	3.515×10^{-9}

Table 17. Parameters of Classified Operational Group Errors Without Type M Error

Collision Risks	**CAR/SAM**	***TLS***
N_{az}^{Tec}	7.6×10^{-11}	5.0×10^{-9}
N_{az}^{ACAS}	7.1×10^{-11}	
N_{az}^{ne}	1.6×10^{-9}	
N_{az}^{nc}	6.7×10^{-10}	
N_{az}^{Total}	2.4×10^{-9}	

Table 18. Collision Risks for the CAR/SAM Regions After Corrective Actions

3.13.2 As can be seen in the tables above, the total risk estimate attributable to all causes in connection with the use of the RVSM in the CAR/SAM Regions is below the TLS if the remedial actions are taken.

4. Results and Conclusions

4.1 This paper provides estimates of technical, operational, and total risk for the RVSM operation in the airspace of the CAR/SAM.

4.2 As can be seen from the values presented above, the technical risk estimated for the combined RVSM implementations is 7.6×10^{-11}. This estimate satisfy the agreed TLS value of no more than 2.5 x 10^{-9} fatal accidents per flight hour due to the loss of a correctly established vertical separation standard of 1000 ft.

4.3 The total risk estimated for the combined RVSM for the CAR/SAM airspace with the remedial action is 2.4×10^{-9}. The total risk estimate associated with the combined RVSM implementation satisfies the agreed TLS value of no more than 5.0 x 10^{-9} fatal accidents per flight hour due to all causes.

4.4 The total number of flown hours considered for the analysis of risk evaluation for the CAR/SAM Regions corresponds to the total of hours of flight of Havana, Central America and Kingston FIR of the Caribbean Region, together with Curitiba, Brasília, Recife FIR and sector Manaus of Amazônica FIR of the South American Region.

4.5 Although data of vertical deviations have not been integrally obtained of the CAR/SAM Regions to determine the probability distribution function for TVE, the cumulative considerations taking the obtained typical deviations of the NAT Region, more the typical deviations collected in the CAR/SAM Regions, constitute a conservative approach for the calculation of the vertical overlap probability. The obtained value is below the established limit, however, as necessary and pertinent measure, the verification of the probability should be made through programmed collections of the typical and atypical deviations happened in the CAR/SAM Regions.

4.6 The evaluation of the growth of the technical risk for the CAR/SAM Regions, due to the growth of the air traffic, was accomplished for annual growth rates of 8% a year, up to 2015. The forecast shows that the technical risk, up to 2015, will be below the TLS of 2.5×10^{-9}.

4.7 The main operational errors (LHD) collected in the CAR/SAM Regions in the period from January through December 2005 are related to transition messages between ATC Units.

5. Recommendations

5.1 The recommendations described in this section have as objective help in the efforts that should be done in the next tasks associated with the collision risk evaluation after the RVSM implementation in the CAR/SAM Regions.

5.2 Data On the Traffic Flow – Approximately 40% of the received data could not be treated due to different reasons, from the non understanding of how the data should be transcribed in the spreadsheets until inconsistency of data. It is advisable that before the collection of data States pay attention to the guidelines developed for this procedure and approved by the RVSM TF.

5.3 Data on the Vertical Deviations due to Operational Errors - Information on these types of events is obtained through ATC or pilot's reports. Unfortunately important data on these deviations like number of crossed flight levels, time spent in non authorized flight level are rarely informed. 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 inform them to the CARSAMMA.

5.4 That States/International Organizations and airlines continue to do efforts in obtaining and informing the LHD to the CARSAMMA.