EUR/SAM Corridor: 2017 Collision Risk Assessment

Code: NYVI-IDSA-INF-019-18-1.0
Prepared: 28/05/18
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Change record

The Change record reflects, at least, the last three modifications made in the document.

Issue	Date	Affected pages	Changes
0.1	04/05/18	All	Document creation
1.0	28/05/18	All	Final version

Distribution control sheet

Copy	Name	Post	Organization
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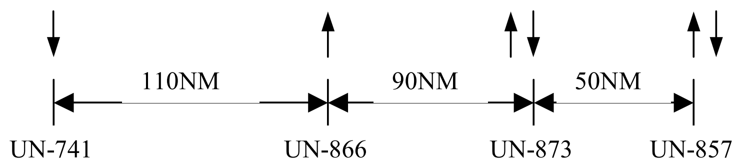
Executive Summary

This report presents the 2017 collision risk assessment made for the EUR/SAM Corridor. It assesses the current and projected lateral and vertical collision risk in the Corridor, where RNP10 and RVSM are implemented, for flight levels between FL290 and FL410.

Two quantitative risk assessments, based on suitable versions of the Reich Collision Risk Model, have been carried out. The first assessment corresponds to the lateral collision risk whilst the second one concerns the vertical collision risk. The vertical collision risk assessment has been split into two parts. The first part considers the risk due to technical causes, whilst the second one considers the complete risk due to all causes, including the operational ones.

The analysed scenario is the airspace where RNP10 and RVSM are implemented. The current route network structure is composed of four nearly parallel north-south routes, being the two easternmost bidirectional and the other two, unidirectional. Traffic on the DCT Area, placed to the west of the current UN-741, has not been considered in the analysis.



Current route network

As far as crossing traffic is concerned, apart from the traffic on the published routes that crosses the Corridor in SAL, Dakar and Recife (UR-976/UA-602, UL-435 and UL-695/UL-375, respectively), traffic that crosses the Corridor using non-published routes with carry more than 50 flights per year have been considered.

The internal software tool CRM, used in previous studies, has been updated and used to obtain the different parameters of the Reich Collision Risk Model in each one of the UIRs crossed by the Corridor.

The CRM program uses flight plan data obtained from Palestra, Enaire's database for the Canaries, and traffic data from the samples provided by SAL, Dakar and Atlantic-Recife. Real data from the Canaries has been available for the complete year 2017. However not all the data from the rest of the FIRs/UIRs was available at the end of the year. The traffic samples used to perform this analysis are the ones from 1st August 2017 to 31st August 2017. This month has been selected as it was the one with the higher number of flights from the months with all the information available. The number of flights and the flight time for the complete year 2017, required for some of the calculations, have been extrapolated.

Besides, extrapolation of traffic data has been necessary in some cases in order to obtain the traffic distribution along the Corridor and on crossing routes. Therefore, trajectories and information at required waypoints (i.e., time and FL) have been assumed, considering the most logical routes and speeds. This may have an influence on the results, as several assumptions have been made due to the incompleteness and inconsistencies, in some cases, of the provided data.

Considering a number of parameters such as probabilities of lateral and vertical overlaps, lateral, vertical and crossing occupancies, average speed, average relative velocities and aircraft dimensions, the lateral, technical vertical and total vertical collision risks have been assessed and compared with the maximum Target Level of Safety (TLS) values allowed, $TLS = 5 \cdot 10^{-9}$, $TLS = 2.5 \cdot 10^{-9}$ and $TLS = 5 \cdot 10^{-9}$, respectively.

The risk has been evaluated in 6 different locations along the Corridor and an estimation of the collision risk for the next 10 years has been calculated, assuming a traffic growth rate of 4.5% per year.

The results obtained are very similar in all the locations and the risk associated to the Corridor is the largest of all the values obtained.

Assuming that the traffic levels of August 2017 are representative of the whole year, the calculated lateral collision risk is $2.9374*10^{-9}$, whilst the lateral collision risk estimated for 2027 with an annual traffic growth rate of 4.5% is $4.5617*10^{-9}$. These values do not take into account traffic on the DCT Area routes.

As far as the technical vertical risk is concerned, the value of the collision risk for 2017 (assuming traffic levels of August 2017 are representative of the whole year), is estimated to be $7.5962*10^{-14}$ and the technical vertical collision risk estimated for 2027 with an annual traffic growth rate of 4.5%, $1.1797*10^{-13}$. Both values are below the TLS.

Regarding the vertical risk due to large height deviations, it has been calculated using the LHD notifications reported by the four involved States. Taking these LHDs into account, the total vertical risk in the Corridor is $1.1294*10^{-7}$, which greatly exceeds the TLS.

In previous safety assessments, such as [Ref. 3], [Ref. 5], [Ref. 8] or [Ref. 9], it was remarked that all the deviations received had been due to coordination errors between ATC units and not related to RVSM operations. In the same way, it was also explained that none of those reports received indicated that there had existed any traffic in conflict. This is also the case of this study.

Given that coordination errors continue to be the main cause of occurrence of LHD, the use of adequate corrective actions to reduce this type of errors should be applied as soon as possible in order to reduce the risk levels.

1. Introduction

This report presents the 2017 collision risk assessment made for the EUR/SAM Corridor. It assesses the current and projected lateral and vertical collision risk in the Corridor, where RNP10 and RVSM are implemented, with real data of traffic between FL290 and FL410 collected from 1st August 2017 to 31st August 2017 and with the number of flights and the flight time required for some of the calculations extrapolated for the complete year 2017.

For this study, the program CRM has been updated and used to obtain the different parameters of the Reich Collision Risk Model in each one of the UIRs crossed by the Corridor. Taking these values into account and the traffic forecast for the future, it has been possible to estimate the collision risk for the following years.

To perform the present study, the procedure has been the one described in [Ref. 32]. Any change with respect to that document will be explained and detailed in the present document.

2. Airspace description

The airspace description is the one presented in [Ref. 32], where the changes or new information regarding the airspace in the year 2017 are included.

2.1. Data sources and software

For this study, flight progress data from the Canaries, SAL, Dakar and Atlantic ACCs, between FL290 and FL410, havebeen made available from 1st August 2017 to 31st August 2017. When data, such as the number of flights or flight time for the rest of 2017 has been necessary, it has been extrapolated using information from Canaries as a basis.

Data for the complete year 2017 from the Canaries are based on the flight progress information stored in Palestra, Enaire's database. It consists of initial flight plan data updated by the controllers with pilot position reports.

The analysed Palestra flight plans have been those which cover the time period from 1st January 2017 to 31st December 2017. They include reports for all waypoints in the Canaries UIR.

Besides data from Palestra, traffic samples from SAL, Dakar and Atlantic-Recife have also been available for this assessment for all 2017, although not all of them was available at the moment of performing this assessment. Data provided by States include information from all aircraft overflying the airspace on the four main routes of the Corridor.

Regarding crossing routes, SAL and Dakar provide traffic information from airways UR-976/UA-602 and UL-435, respectively. On the other hand, Recife provides crossing traffic data from route UL-375/UL-695.

2.2. Aircraft population

The most common aircraft types, the number of flights per type and the proportion of these types over the total of flights detected during 2017 between FL290 and FL410 have been analysed.

Table 1 shows the values obtained for the Canaries UIR in 2017 together with the geometric dimensions of these aircraft types. Similar results have been obtained for the rest of UIRs.

Aircraft type	Count	% AC	Length (m)	Wingspan (m)	Height (m)
A332	5278	20,903%	63.70	60.03	16.74
B738	3664	14,511%	39.47	34.31	12.50
B752	1975	7,822%	47.32	38.05	13.60
A320	1974	7,818%	37.57	34.10	11.76
B77W	1639	6,491%	73.90	60.90	18.50
B772	1405	5,564%	63.70	60.90	18.50
A333	1400	5,545%	63.70	60.03	16.74
B763	1170	4,634%	47.60	54.90	15.90
A346	1100	4,356%	74.37	63.60	17.8
A343	905	3,584%	63.70	60.30	16.74
B748	803	3,18%	76.30	65.45	19.50
B788	577	2,285%	56.70	60.10	16.90
A319	498	1,972%	33.84	34.10	11.76
B789	464	1,838%	62.80	60.10	16.90
A321	371	1,469%	37.57	34.10	11.76
B744	350	1,386%	70.70	64.40	19.40
A359	252	0,998%	66.80	64.75	17.05
B77L	178	0,705%	67.78	61.68	18.50
E190	176	0,697%	36.24	28.72	10.57
B737	153	0,606%	33.60	34.30	12.50
FA7X	103	0,408%	22.82	25.80	7.74
E35L	97	0,384%	26.33	21.17	6.76
GLEX	75	0,297%	30.30	28.65	7.57
F900	49	0,194%	20.20	19.30	7.60
CL60	45	0,178%	20.86	19.35	6.28
F2TH	44	0,174%	20.21	19.33	7.55
A400	38	0,15%	42.40	45.10	14.70
B762	29	0,115%	48.50	47.60	15.80
GLF5	27	0,107%	29.42	28.50	7.87
MD11	27	0,107%	61.20	51.70	17.60

Aircraft type	Count	% AC	Length (m)	Wingspan (m)	Height (m)
GLF4	24	0,095%	26.90	23.79	7.64
C17	23	0,091%	53.00	51.80	16.80
A21N	23	0,091%	44.51	35.8	11.76
K35R	19	0,075%	41.50	39.90	12.70
GLF6	17	0,067%	30.41	30.36	7.72
A124	17	0,067%	69.10	73.30	20.78
FA50	17	0,067%	18.52	18.96	6.97
GL5T	16	0,059%	28.69	28.65	7.70
B733	15	0,059%	33.40	28.90	11.10
E135	14	0,055%	26.33	20.04	6.76
LJ35	14	0,055%	14.71	11.97	3.71
FA8X	11	0,044%	24.46	26.29	7.94
A310	10	0,040%	46.40	43.89	15.80
CRJ9	10	0,040%	36.20	23.30	7.50
E170	10	0,040%	29.90	26.00	9.67
LJ60	10	0,040%	17.89	13.35	4.44
LJ45	9	0,036%	17.68	14.58	4.30
ASTR	8	0,032%	16.94	16.05	5.54
IL76	8	0,032%	46.59	50.50	14.76
CRJX	7	0,028%	39.01	26.02	7.50
C650	6	0,024%	14.29	15.91	4.57
LJ55	6	0,024%	16.80	13.30	4.50
E550	6	0,024%	20.74	20.25	6.44
CRJ2	6	0,024%	26.80	21.21	6.30
GALX	6	0,024%	18.99	17.71	6.52
C680	6	0,024%	11.22	14.95	4.56
CL30	5	0,020%	20.90	18.40	6.10
C750	5	0,020%	22.05	19.38	5.84
H25B	4	0,016%	15.60	15.70	5.40
B734	4	0,016%	36.40	28.90	11.10
IL96	4	0,016%	69.10	73.30	20.78
B764	4	0,016%	61.40	51.90	16.80
FA10	3	0,012%	13.86	13.08	13.08
C56X	3	0,012%	15.80	17.00	5.20
J328	2	0,008%	20.90	20.90	7.20
C550	2	0,008%	13.30	14.40	4.40
E145	2	0,008%	29.87	20.04	6.75
A342	2	0,008%	59.39	60.30	16.74
H25C	2	0,008%	16.40	15.70	5.20

Aircraft type	Count	% AC	Length (m)	Wingspan (m)	Height (m)
B773	2	0,008%	73.80	60.90	18.70
B722	2	0,008%	46.70	32.90	10.40
E75L	2	0,008%	31.68	28.65	9.86
K35E	2	0,008%	41.50	39.90	12.70
CL35	1	0,004%	20.90	21.00	6.10
C25C	1	0,004%	14.30	15.10	4.20
A35K	1	0,004%	73.78	64.75	17.08
DC10	1	0,004%	55.20	50.40	17.90
A340	1	0,004%	59.39	60.30	16.70
G150	1	0,004%	17.30	16.94	5.82
G280	1	0,004%	20.30	19.20	6.50
A330	1	0,004%	63.60	60.30	16.70
B735	1	0,004%	31.01	28.88	11.10
Unknown	7	0,028%	----	----	----

Table 1.
Aircraft population and number of flights per type during 2017 in the Canaries UIR.

The data sample in the Canaries UIR includes 25252 flights of 90 different aircraft types. The population is dominated by large and medium airframes such as A330-200, B737-800, B757-200, A320, B777-300AR, B777-200LR or A330-300, B747-800 and A350-900. These 7 types make up about 68.65% of the total number of flights. The next 11 types, which also belong to the Airbus and Boeing families, make up another 26.40% and the rest 4.95% is distributed among the other 72 aircraft types.

2.3. Temporal distribution of flights

Several graphs, showing the temporal distribution of flights, will be displayed in this section. The first one, Figure 1, shows the distribution of the number of flights per day in EDUMO, TENPA, IPERA and GUNET from 1st January 2017 to 31st December 2017, differentiating between northbound (NB) and southbound (SB) traffic. Next, Figure 2 shows the distribution of the number of flights per day in the Canaries for the traffic sample selected in this study: from 1st August 2017 to 31st August 2017.

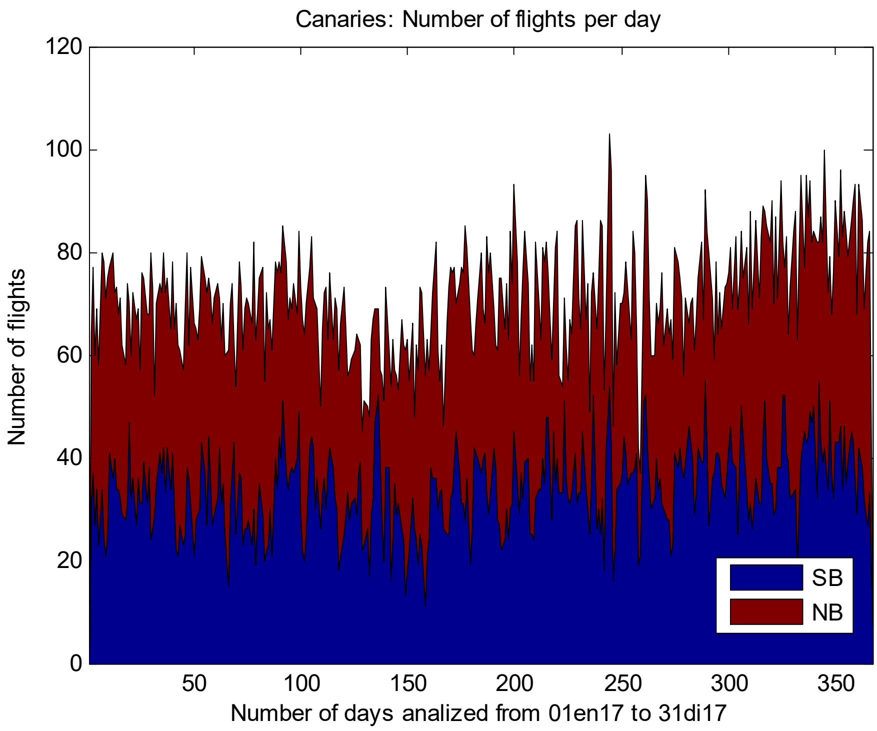


Figure 1.
Number of flights per day in the Canaries. Year 2017

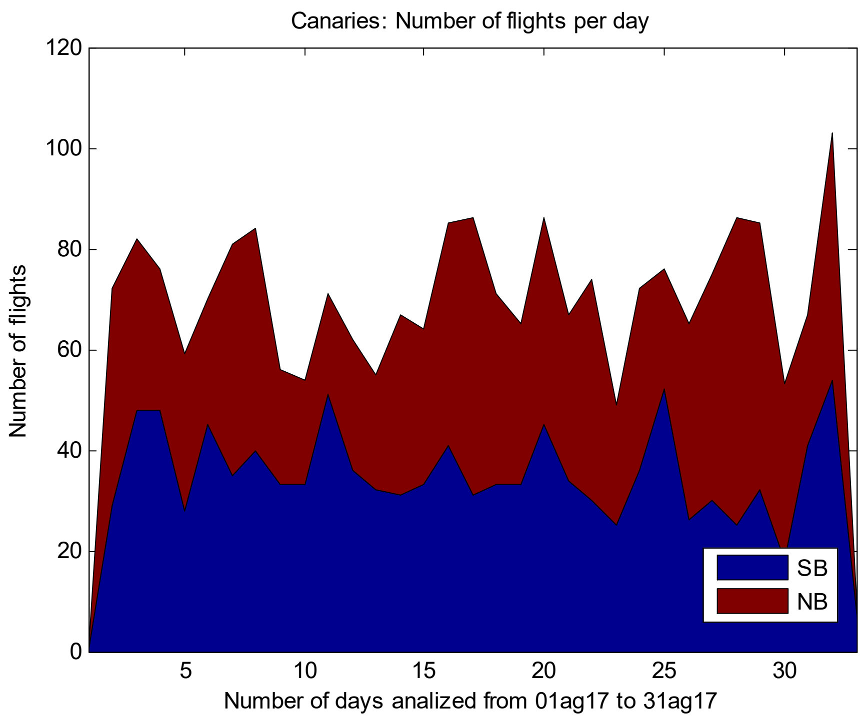


Figure 2.
Number of flights per day in the Canaries. August 2017

The overall average traffic for 2017 is 68.8 flights per day with a standard deviation of 11.86 flights per day, while in August the average is 65.52 with a standard deviation of 19.84 flights per day. So, August can be considered as a representative month of the whole year.

Figure 3 shows the distribution of the yearly traffic over the days of the week.

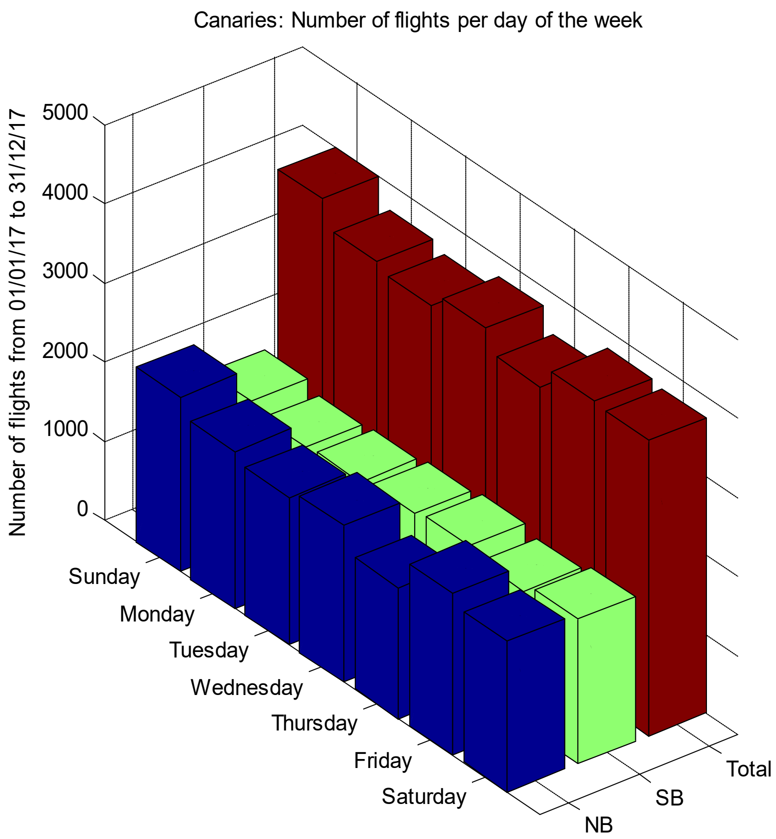


Figure 3.
Number of flights per day of the week in the Canaries. Year 2017

The distributions of flights per half-hour are shown in the following figures. The first one shows the distribution of flights obtained with the time of waypoint crossing in EDUMO, TENPA, IPERA and GUNET (Canaries) during 2017.

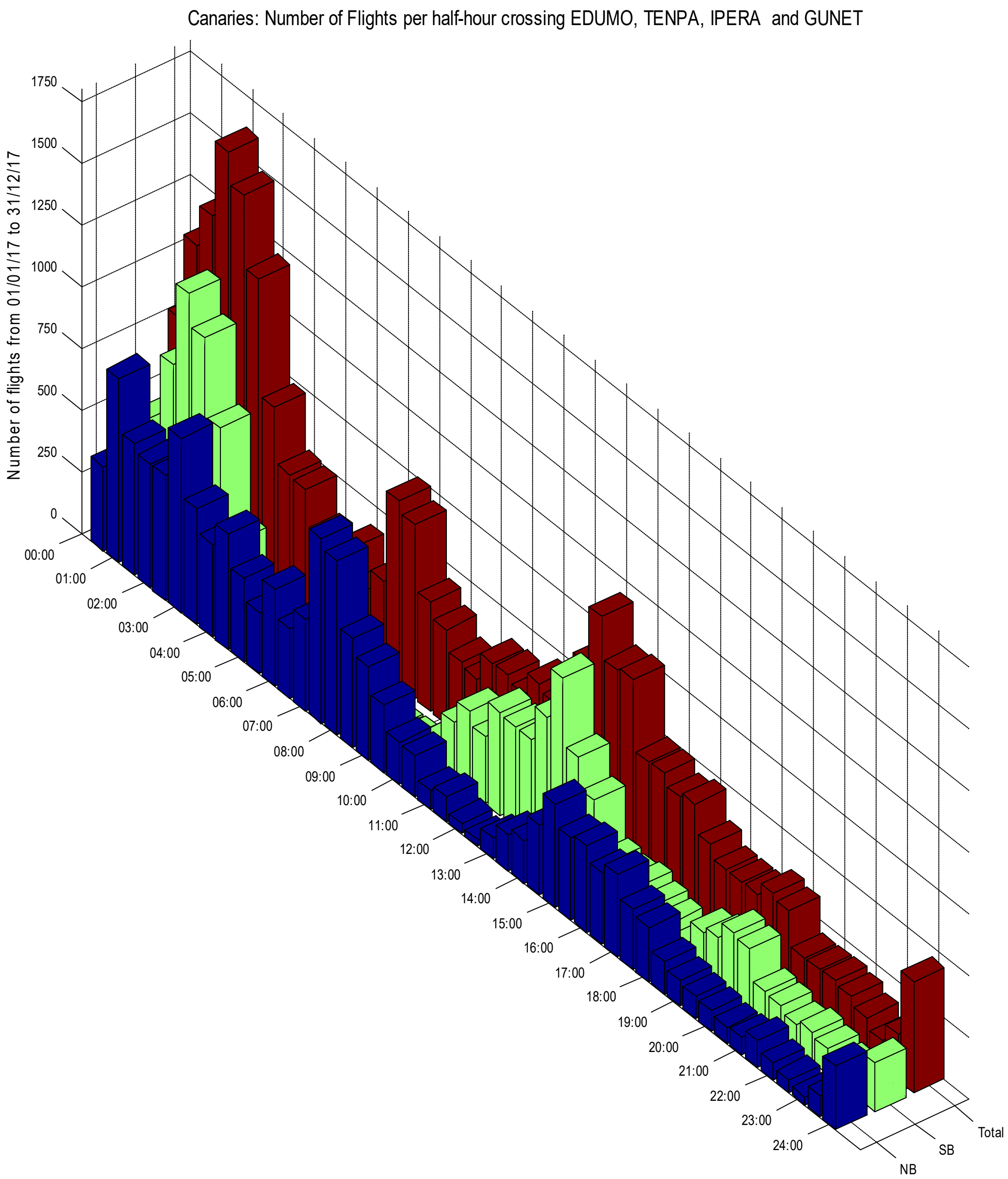


Figure 4.
Number of flights per half-hour crossing EDUMO, TENPA, IPERA and GUNET. Year 2017

It can be seen that during 2017, in the Canaries, it is from 00:00h to 3:00h and from 11:00 to 15:00h when the highest concentration of southbound flights occurs, while most of the northbound aircraft concentrate from 00:00h to 10:00h.

Figure 5 shows the temporal distribution for the 2162 aircraft detected in Canaries during August 2017. Following, Figure 6 shows the temporal distribution of the 1785 aircraft detected over this period in Recife, according to the time of day at which they crossed DIKEB, OBKUT, ORARO and NOISE waypoints. They also distinguish between northbound (NB) and southbound (SB) traffic.

In this figure, it can be seen that in Recife the highest traffic concentration occurs between 00:00h and 8:00h and, in a lower extent, from 15:00h to 24:00h.

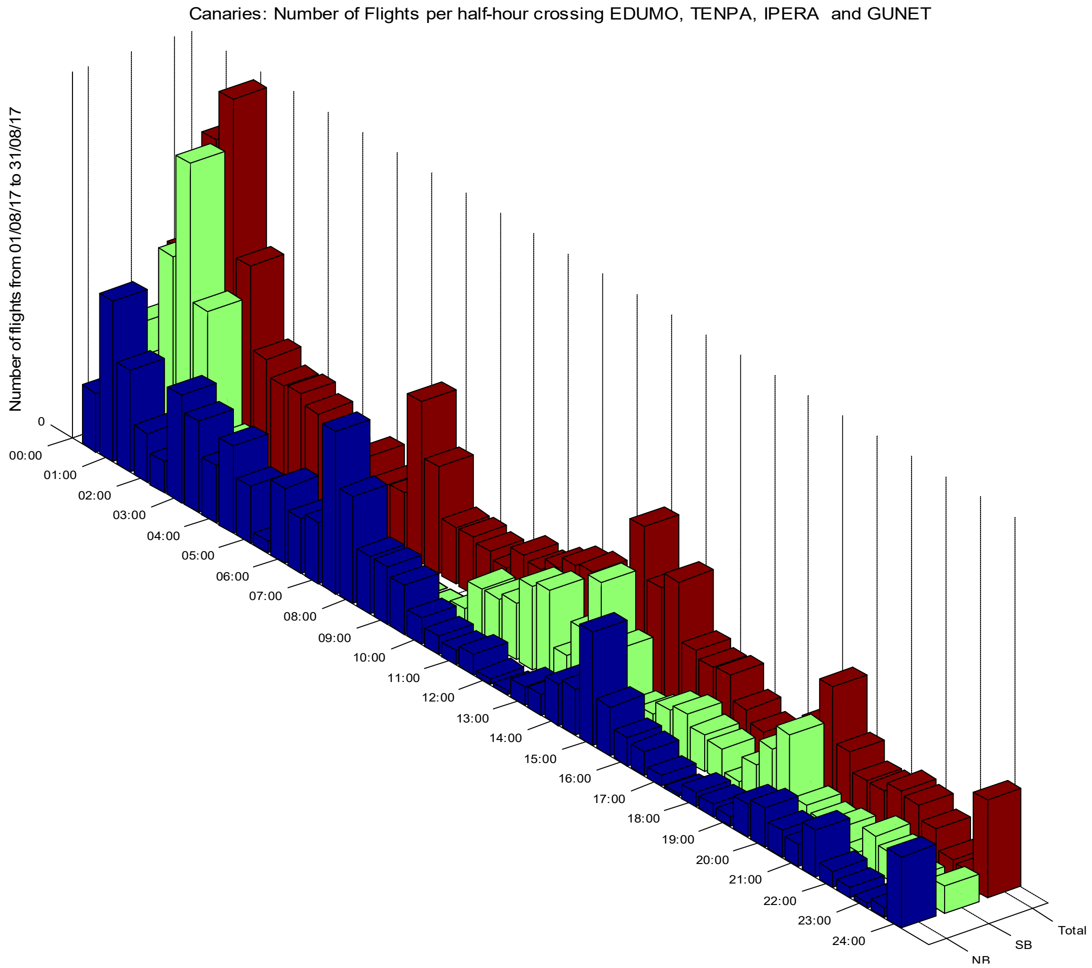


Figure 5.
Number of flights per half-hour crossing EDUMO, TENPA, IPERA and GUNET. August 2017

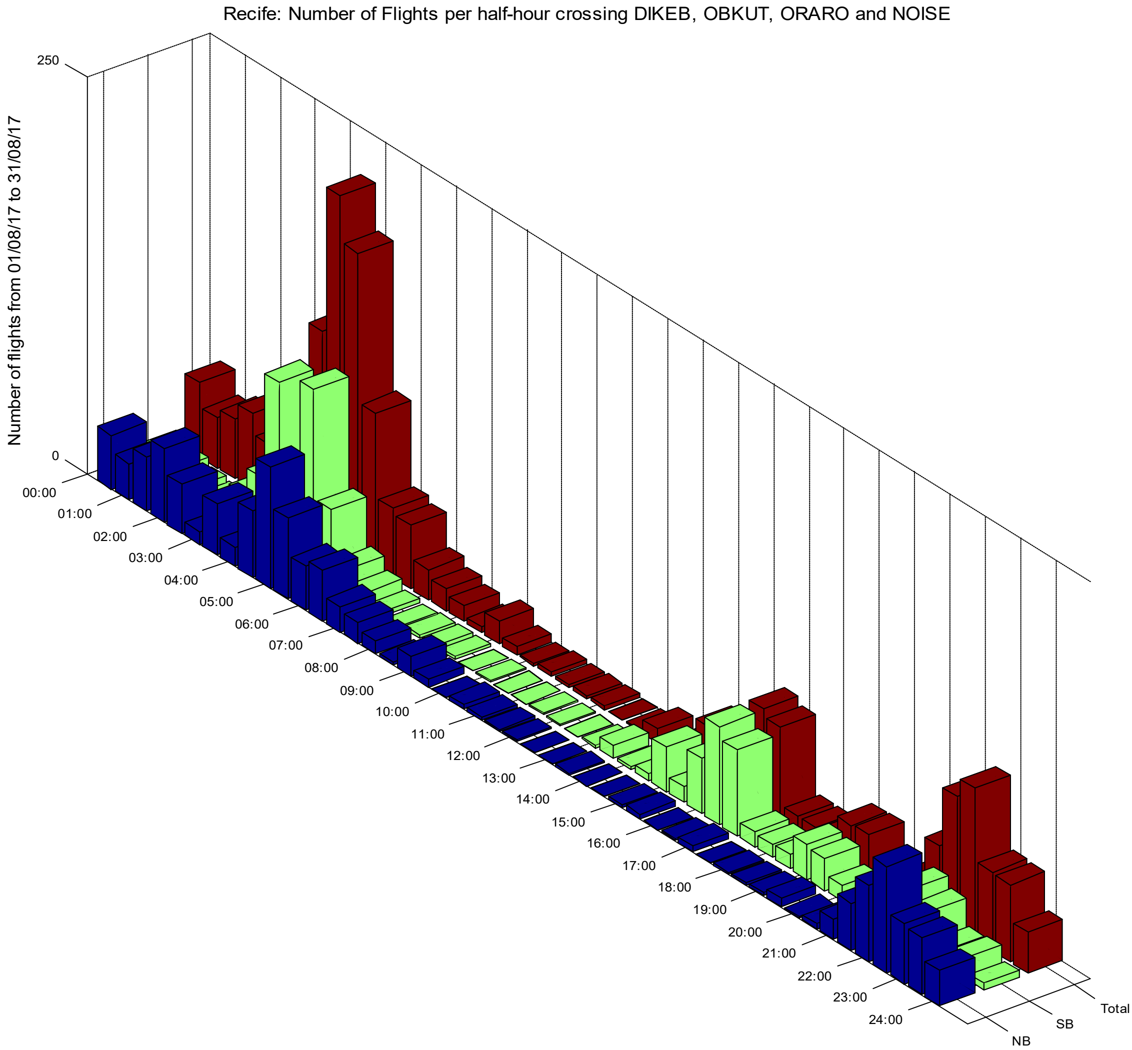


Figure 6.
Number of flights per half-hour crossing DIKEB, OBKUT, ORARO and NOISE. August 2017

2.4. Traffic distribution per flight level

Traffic distribution per flight level during 2017 will be depicted in the graphics of this section. Figure 7 shows the total amount of traffic for the main routes in the Canaries, distributed by route and flight level. Figure 8 and Figure 9 are similar, but they only include the southbound and the northbound traffic, respectively.

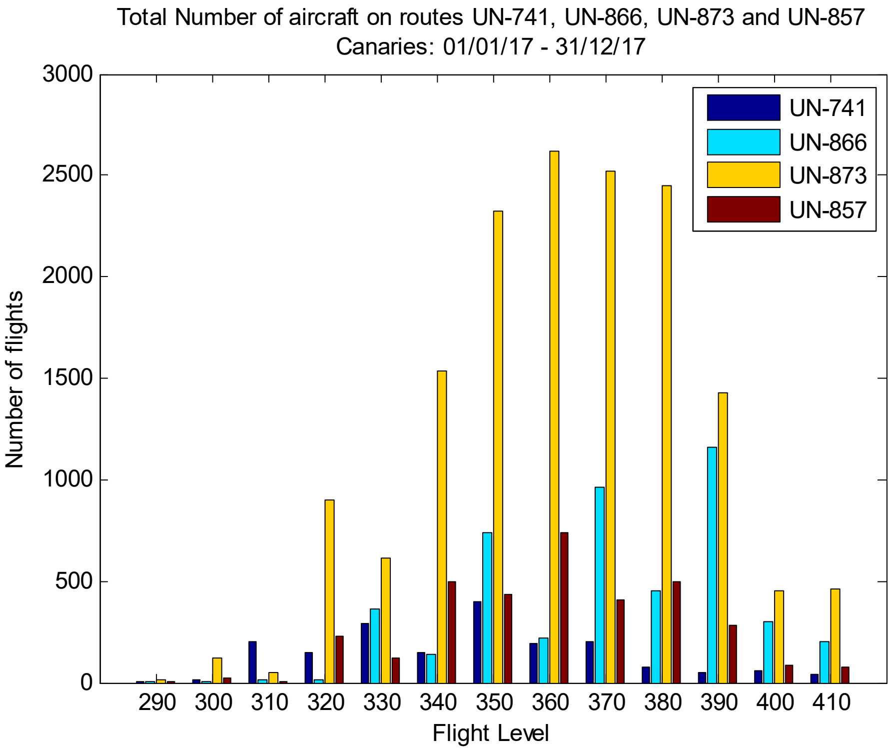


Figure 7.
Number of aircraft on routes UN-741, UN-866, UN-873 and UN-857 in the Canaries

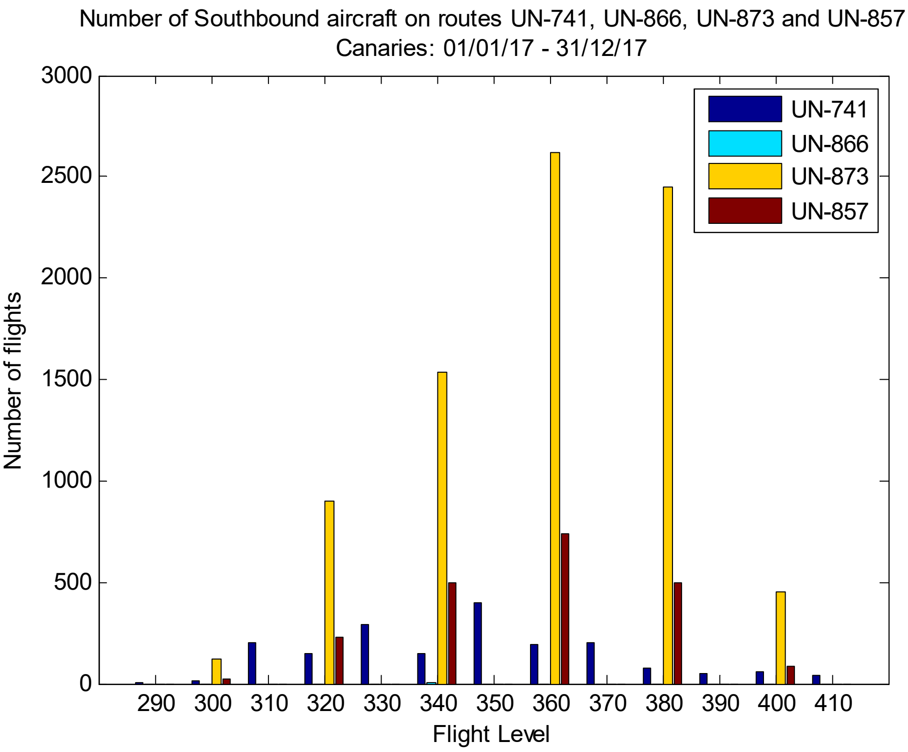


Figure 8.
Number of Southbound aircraft on routes UN-741, UN-866, UN-873 and UN-857 in the Canaries

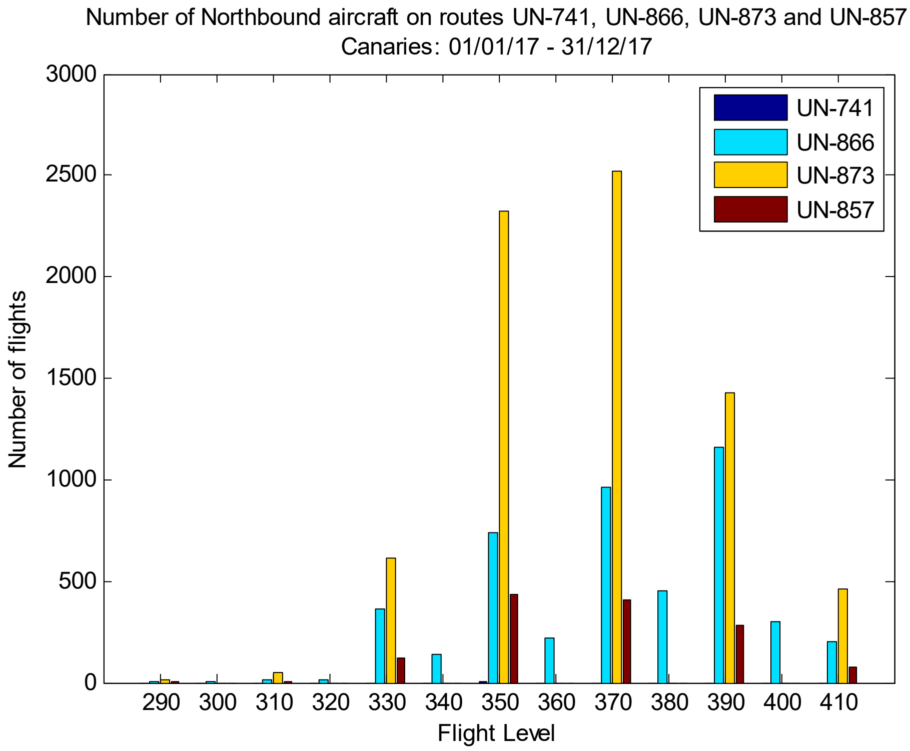


Figure 9.
Number of Northbound aircraft on routes UN-741, UN-866, UN-873 and UN-857 in the Canaries

3. Lateral collision risk assessment

As it has been said, the Reich model to calculate lateral collision risk is explained in [Ref. 32]. In the following sections all the parameters required for the calculation (those that appear in Equation 1 of the mentioned document) will be analysed.

3.1. Average aircraft dimensions: $\lambda_x, \lambda_y, \lambda_z$

In previous Table 1, the dimensions of the aircraft types found in the Canaries UIR during the studied period were presented. Using this information, the average aircraft dimensions have been calculated with the dimensions of each aircraft type and the proportions of flights by type as weighting factors. These data are shown in Table 2.

Location	Value Length (λ_x) (ft)	Wingspan (λ_y) (ft)	Height (λ_z) (ft)
Canaries	181.76	166.95	50.68
SAL1	212.37	197.13	56.57
SAL2	209.17	193.88	55.76
Dakar1	208.08	192.61	55.49
Dakar2	208.21	192.74	55.53
Recife	209.92	193.51	55.99

Table 2.
Average aircraft dimensions

3.2. Probability of vertical overlap: $P_z(0)$

In this collision risk assessment, the values for $P_z(0)$ and $P_z(1000)$ (see 4.1.5) have been calculated using the Eurocontrol RVSM Tool. In the case of Pz(0), the obtained result has been $P_z(0)=0.50102$.

3.3. Average ground speed: v

Using the limitation to 575 kts explained in [Ref. 32], the speed of each aircraft that flew during the analysed period of time on each route in the Canaries UIR is shown in the following graphs:

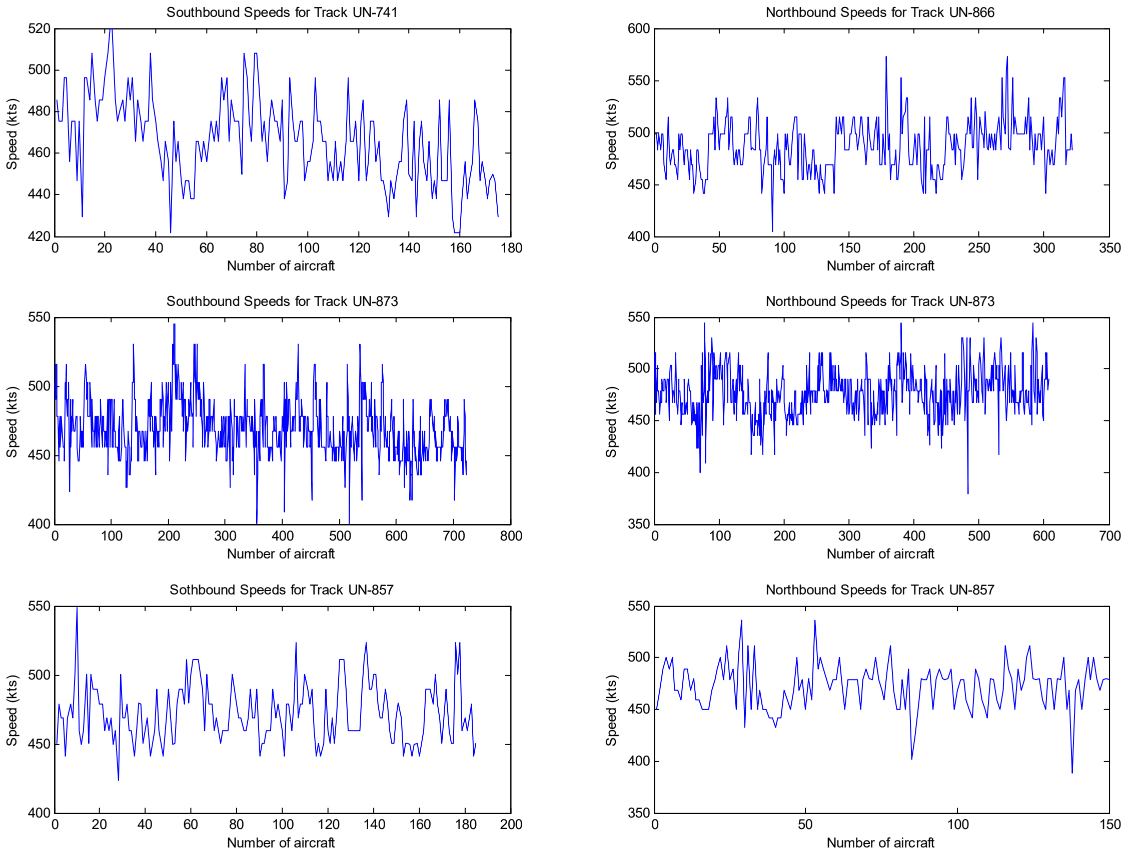


Figure 10.
Speeds limited to 575 kts in the current scenario in the Canaries

Similar graphs can be obtained for the rest of locations.

From these speeds, the average ground speed obtained in the different locations is shown in Table 3:

Location	Average speeds		
	Southbound (kts)	Northbound (kts)	Average (kts)
Canaries	469.3	479.1	474.2
SAL1	468.0	460.9	464.4
SAL2	463.9	476.9	470.4
Dakar1	471.3	466.0	468.7
Dakar2	473.8	469.5	471.6
Recife	465.9	464.5	465.2

Table 3.
Average speeds

3.4. Average relative longitudinal, lateral and vertical speeds: Δv, $\bar{\dot{y}}$ and $\bar{\dot{z}}$

The results obtained for the current scenario for relative longitudinal speeds can be seen in Table 4. The value considered in the collision risk assessment is the one shown in the last column of the table.

Location	Average relative longitudinal speeds		
	Southbound (kts)	Northbound (kts)	Average (kts)
Canaries	15.0	21.0	18.0
SAL1	19.5	31.1	25.3
SAL2	45.5	16.2	30.8
Dakar1	24.2	38.6	31.4
Dakar2	27.7	27.5	27.6
Recife	18.4	29.9	24.2

Table 4.
Average relative longitudinal speeds

As far as the average relative lateral and vertical speeds are concerned, in this study, the values considered have been $|\bar{\dot{y}}| = 42\ kts$ and $|\bar{\dot{z}}| = 1.5\ kts$, respectively, as it is described in[Ref. 32], in previous risk assessments and as it was considered in [Ref. 2].

3.5. Lateral overlap probability: $P_y(S_y)$

To calculate the weighting factor α it has been used as a reference the Appendix A of the study made by ARINC [Ref. 2], summarized in Annex 1 of [Ref. 32]. In 2017, only one lateral deviation was reported in Canaries. SAL, Dakar and Recife did not report any lateral deviation. Information about this considered deviation is shown in Table 5.

FIR/UIR	Date	Entry point	Non-expected flown segment	Deviation
Canaries	011117	GUNET	GUNET-LIMAL	11 NM[1]

Table 5.
Lateral deviations reported in 2017

Therefore, the same assumptions made in [Ref. 2] and [Ref. 6] can be considered, i.e., conservatively, one aircraft experiencing a lateral navigation anomaly has been observed in each FIR/UIR, and the value of α can be obtained using next equation:

$$\alpha = 1 - 0.05^{1/n}$$

Equation 1

where n is the annual number of flights. As only this number is available for Canaries, extrapolations have been performed to estimate the annual flights for the other UIR/FIRs, using the number of flights of August. Table 6 shows the number of aircraft in August in each FIR and the number of aircraft estimated using the correspondence with the Canaries FIR. Data in cursive indicates if the value is estimated.

Considered period	Canaries	SAL1	SAL2	Dakar1	Dakar2	Recife
August 2017	2162	1337	1353	1607	1662	1785
Jan-Dic 2017	25252	*15616*	*15803*	*18770*	*19412*	*20849*

Table 6.
Number of aircraft considered for the α calculation

Using Equation 1 and taking the number of aircraft indicated in Table 6, different values of α have been calculated for each FIR. Table 7 summarizes the assumptions and the obtained results.

FIR	α
Canaries	$1.1864*10^{-4}$
SAL1	$1.9183*10^{-4}$
SAL2	$1.8957*10^{-4}$
Dakar1	$1.5961*10^{-4}$
Dakar2	$1.5432*10^{-4}$
Recife	$1.4369*10^{-4}$

Table 7.
α for each FIR

Using Equation 11 of [Ref. 32], the lateral overlap probability obtained for the different lateral separations between routes existing in the Corridor are the following ones:

[1] Deviation detected due to an ADS report 6 minutes after entering the FIR over GUNET, flying at 11 NM from UN857

RNP10 S_{ymin}=50NM	$P_y(50)$	$P_y(90)$	$P_y(110)$	$P_y(140)$
Canaries	$9.6241*10^{-8}$	$3.4014*10^{-8}$	$2.2801*10^{-8}$	$1.2514*10^{-8}$
SAL1	$1.1624*10^{-7}$	$4.1333*10^{-8}$	$2.7707*10^{-8}$	$1.5206*10^{-8}$
SAL2	$1.1326*10^{-7}$	$4.0172*10^{-8}$	$2.6928*10^{-8}$	$1.4779*10^{-8}$
Dakar1	$9.8480*10^{-8}$	$3.3602*10^{-8}$	$2.2524*10^{-8}$	$1.2362*10^{-8}$
Dakar2	$9.6067*10^{-8}$	$3.2510*10^{-8}$	$2.1792*10^{-8}$	$1.1960*10^{-8}$
Recife	$9.1450*10^{-8}$	$3.0392*10^{-8}$	$2.0373*10^{-8}$	$1.1181*10^{-8}$

Table 8.
Lateral overlap probability for different separations between routes with RNP10

The probability increases when the spacing between the routes decreases, as it was expected.

3.6. Lateral occupancy

As it was described in [Ref. 32], the next occupancy values must be computed:

- $E_{y_{same}}$: same direction occupancy for routes UN-873/UN-857
- $E^{*}_{y_{same}}$: same direction occupancy for routes UN-866/UN-873
- $E^{**}_{y_{same}}$, same direction occupancy for routes UN-866/UN-857
- $E_{y_{opposite}}$: opposite direction occupancy for routes UN-866/UN-873
- $E^{*}_{y_{opposite}}$: opposite direction occupancy for routes UN-741/UN-866
- $E^{**}_{y_{oppposite}}$, opposite direction occupancy for routes UN-866/UN-857

3.6.1. Traffic growth hypothesis

This study presents the collision risk calculated from data corresponding from 1st August 2017 to 31st August 2017, but it also presents an estimate of the collision risk over a 10 years horizon.

To do that, it is necessary to know the traffic forecast for that period of time in the studied airspace. Taking into account the last data given by STATFOR-EUROCONTROL for the high-growth scenario, [Ref. 20], the annual traffic growth rate for the traffic flows in the Canary Islands airspace would be 4.5%.

3.6.2. Lateral occupancy obtained values

This section presents the same direction and opposite direction lateral occupancy values provided by the CRM programme for the current time and an estimate of the occupancy until 2027, with the annual traffic growth rate indicated before, 4.5%.

Table 9 shows the number of aircraft and the number of same and opposite direction proximate pairs detected on the four routes, from 1st August 2017 till 31st August 2017 in the Canaries, SAL, Dakar and Recife UIR/FIRs.

Number of flights August 2017	Canaries	SAL1	SAL2	Dakar1	Dakar2	Recife
Number of flights on UN-741	175	151	134	212	249	442
Number of flights on UN-866	322	309	312	406	416	357
Number of flights on UN-873	1330	689	721	755	762	808
Number of flights on UN-857	335	188	186	234	235	178
Total number of flights	2162	1337	1353	1607	1662	1785
Number of same direction proximate pairs for tracks UN-866/UN-873	29	25	18	31	31	22
Number of same direction proximate pairs for tracks UN-866/UN-857	6	3	4	4	5	4
Number of same direction proximate pairs for tracks UN-873/UN-857	81	49	40	43	40	43
Number of opposite direction proximate pairs for tracks UN-741/UN-866	3	2	3	7	4	6
Number of opposite direction proximate pairs for tracks UN-866/UN-873	3	0	1	4	5	3
Number of opposite direction proximate pairs for tracks UN-866/UN-857	0	0	1	2	2	2

Table 9.
Lateral occupancy parameters in the Corridor FIR/UIRs

Assuming an annual traffic growth rate of 4.5%, the occupancies for the next 10 years are summarized in Table 10. It holds that occupancy is approximately proportional to traffic flow rate:

4.5% annual traffic growth		Canaries 2017-2027	SAL1 2017-2027	SAL2 2017-2027	Dakar1 2017-2027	Dakar2 2017-2027	Recife 2017-2027
Same direction lateral occupancy	UN-873/UN-857 (E_{ysame})	0.0749-0.1164	0.0733-0.1138	0.0591-0.0918	0.0535-0.0831	0.0481-0.0748	0.0482-0.0748
	UN-866/UN-873 (E^{*}_{ysame})	0.0268-0.0417	0.0374-0.0581	0.0266-0.0413	0.0386-0.0599	0.0373-0.0579	0.0247-0.0383
	UN-866/UN-857 (E^{**}_{ysame})	0.0056-0.0086	0.0045-0.0070	0.0059-0.0092	0.0050-0.0077	0.0060-0.0093	0.0043-0.0070
Opposite direction lateral occupancy	UN-866/UN-873 ($E_{yopposite}$)	0.0028-0.0043	0.0000-0.0000	0.0015-0.0023	0.0050-0.0077	0.0060-0.0093	0.0034-0.0052
	UN-741/UN-866 ($E^{*}_{yopposite}$)	0.0028-0.0043	0.0030-0.0046	0.0044-0.0069	0.0087-0.0135	0.0048-0.0075	0.0067-0.0104
	UN-866/UN-857 ($E^{**}_{yopposite}$)	0.0000-0.0000	0.0000-0.0000	0.0015-0.0023	0.0025-0.0039	0.0024-0.0037	0.0022-0.0035

Table 10.
Lateral occupancy estimate for the Canaries until 2027 with an annual traffic growth rate of 4.5%

3.7. Lateral collision risk

Once all the parameters are obtained, it is possible to calculate the lateral collision risk for the current scenario. This value must not exceed the maximum allowed, for which the system is considered to be safe. This threshold, denominated TLS (Target Level of Safety), has been set to $TLS = 5 \cdot 10^{-9}$. It means that $5 \cdot 10^{-9}$ accidents per flight hour are the maximum accepted.

3.7.1. Lateral collision risk obtained values

In the current system, with RNP10, two unidirectional routes and two bidirectional routes, the collision risk values obtained until 2027 in the different locations are the ones shown in the following table and figures.

Lateral collision risk	4.5% annual traffic growth					
	Canaries	SAL1	SAL2	Dakar1	Dakar2	Recife
2017	$2.2664*10^{-9}$	$2.6724*10^{-9}$	$2.6340*10^{-9}$	$2.9374*10^{-9}$	$2.4797*10^{-9}$	$2.0403*10^{-9}$
2018	$2.3684*10^{-9}$	$2.7926*10^{-9}$	$2.7525*10^{-9}$	$3.0696*10^{-9}$	$2.5913*10^{-9}$	$2.1321*10^{-9}$
2019	$2.4750*10^{-9}$	$2.9183*10^{-9}$	$2.8763*10^{-9}$	$3.2077*10^{-9}$	$2.7079*10^{-9}$	$2.2281*10^{-9}$
2020	$2.5864*10^{-9}$	$3.0496*10^{-9}$	$3.0058*10^{-9}$	$3.3521*10^{-9}$	$2.8298*10^{-9}$	$2.3284*10^{-9}$
2021	$2.7028*10^{-9}$	$3.1869*10^{-9}$	$3.1410*10^{-9}$	$3.5029*10^{-9}$	$2.9571*10^{-9}$	$2.4331*10^{-9}$
2022	$2.8244*10^{-9}$	$3.3303*10^{-9}$	$3.2824*10^{-9}$	$3.6605*10^{-9}$	$3.0902*10^{-9}$	$2.5426*10^{-9}$
2023	$2.9515*10^{-9}$	$3.4801*10^{-9}$	$3.4301*10^{-9}$	$3.8253*10^{-9}$	$3.2292*10^{-9}$	$2.6570*10^{-9}$
2024	$3.0843*10^{-9}$	$3.6367*10^{-9}$	$3.5845*10^{-9}$	$3.9974*10^{-9}$	$3.3746*10^{-9}$	$2.7766*10^{-9}$
2025	$3.2231*10^{-9}$	$3.8004*10^{-9}$	$3.7458*10^{-9}$	$4.1773*10^{-9}$	$3.5264*10^{-9}$	$2.9016*10^{-9}$
2026	$3.3681*10^{-9}$	$3.9714*10^{-9}$	$3.9143*10^{-9}$	$4.3652*10^{-9}$	$3.6851*10^{-9}$	$3.0321*10^{-9}$
2027	$3.5197*10^{-9}$	$4.1501*10^{-9}$	$4.0905*10^{-9}$	$4.5617*10^{-9}$	$3.8509*10^{-9}$	$3.1686*10^{-9}$

Table 11.
Lateral collision risk for the period 2017-2027 in the Corridor

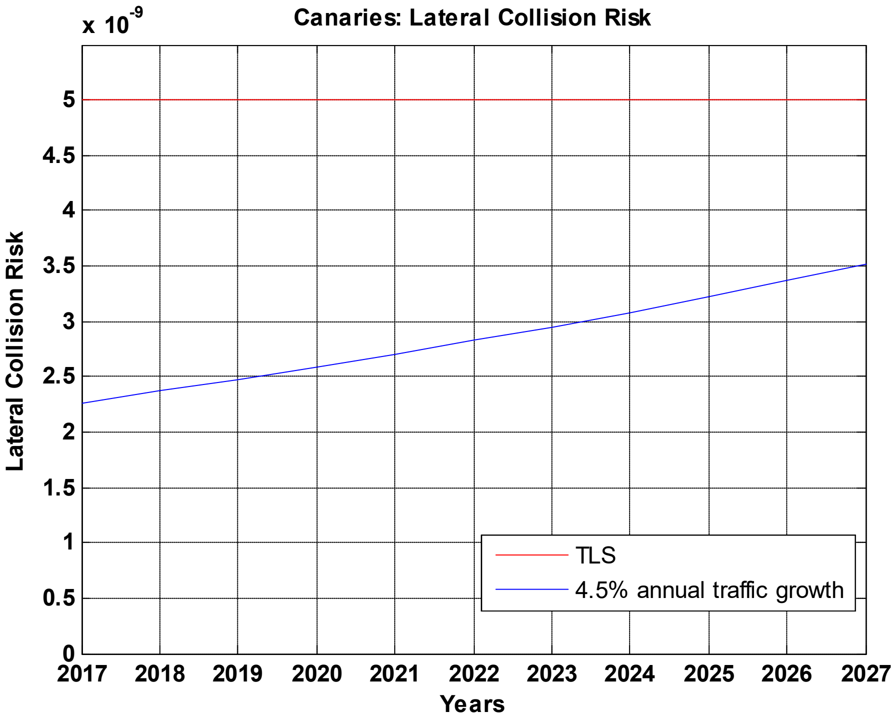


Figure 11.
Lateral collision risk for the period 2017-2027 in the Canaries.

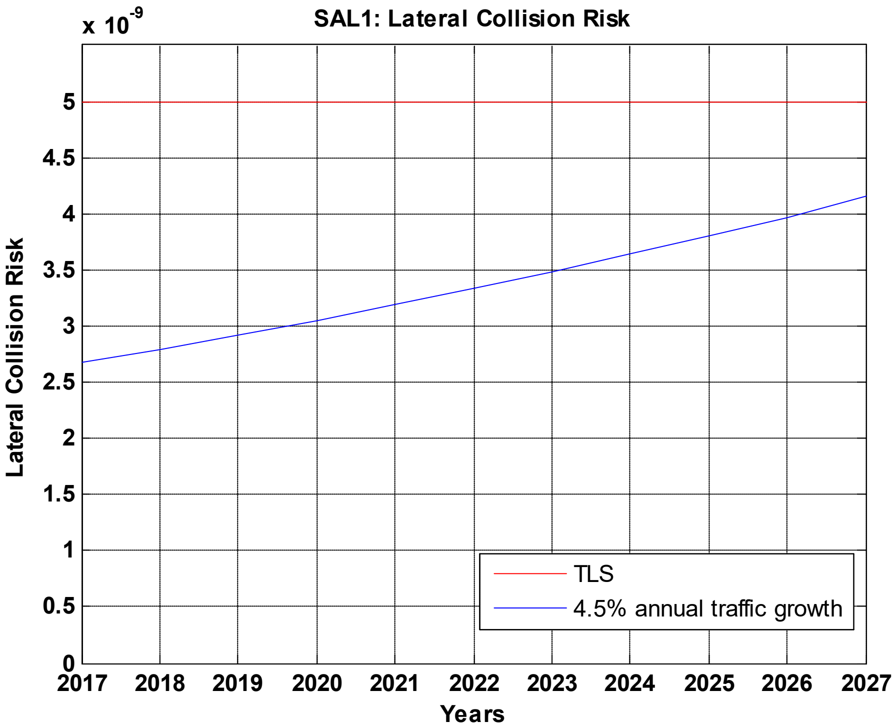


Figure 12.
Lateral collision risk for the period 2017-2027 in SAL1.

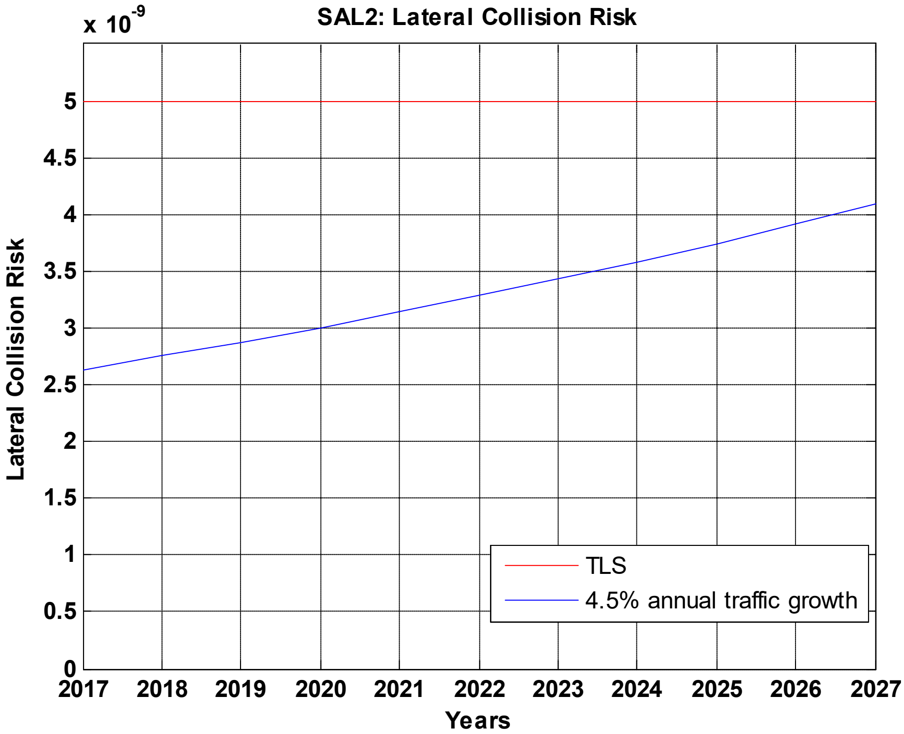


Figure 13.
Lateral collision risk for the period 2017-2027 in SAL2.

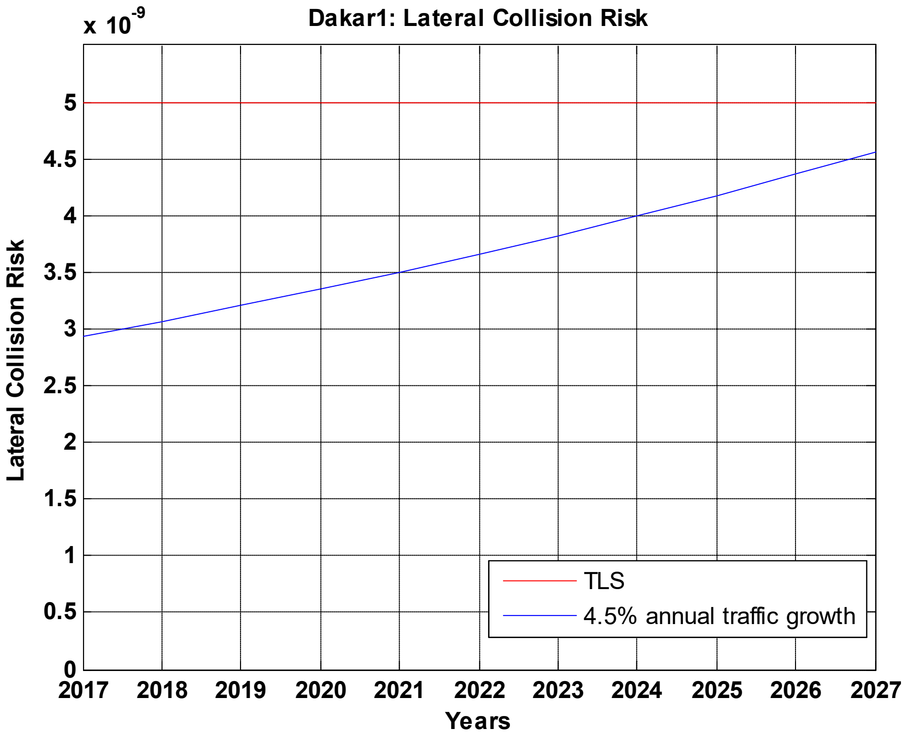


Figure 14.
Lateral collision risk for the period 2017-2027 in Dakar1.

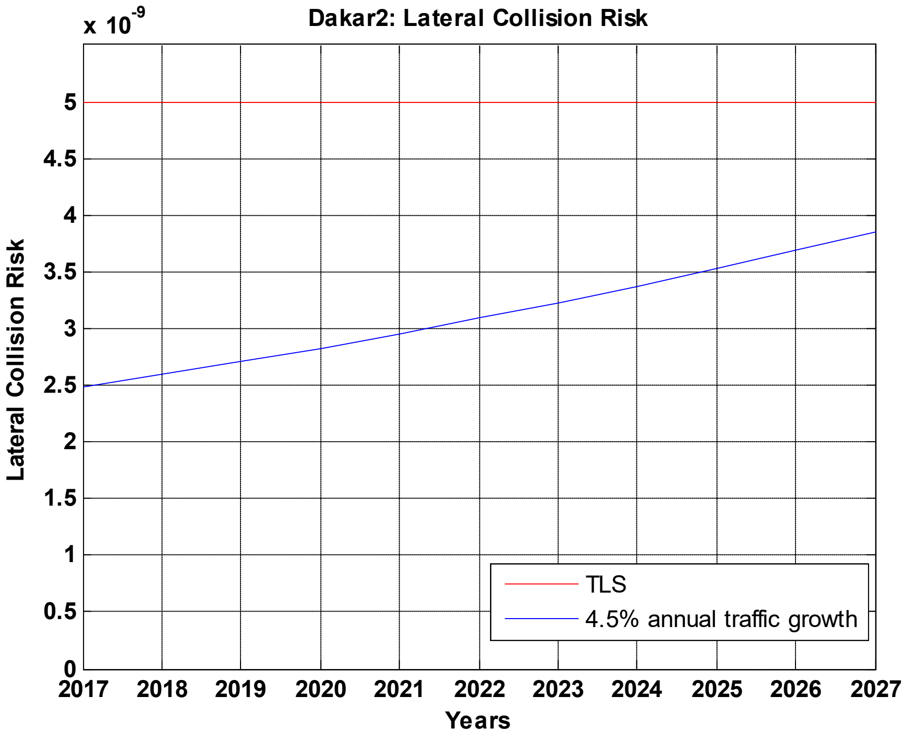


Figure 15.
Lateral collision risk for the period 2017-2027 in Dakar2.

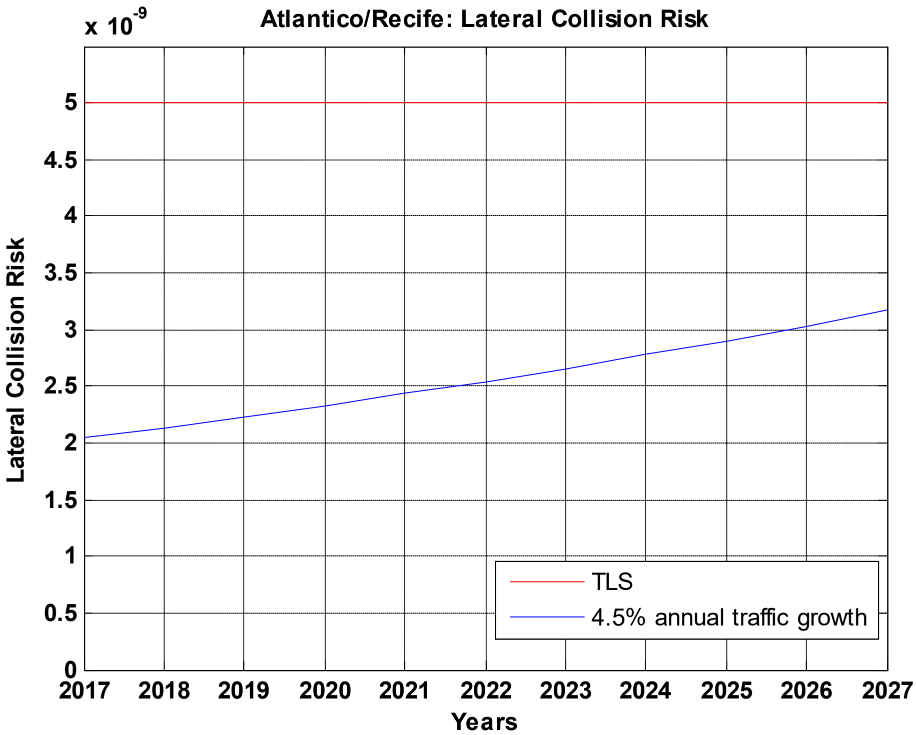


Figure 16.
Lateral collision risk for the period 2017-2027 in Recife.

3.7.2. Considerations on the results

Lateral collision risk is below the $TLS = 5 \cdot 10^{-9}$ with the current traffic flow and it is estimated that, considering 4.5% as the annual traffic growth rate, the TLS would not be exceeded in the period under consideration.

The values obtained for the lateral collision risk are similar to those ones presented in the previous collision risk assessments, [Ref. 5] to [Ref. 9]. It has also been confirmed that the results are similar in all the analysed locations.

4. Vertical collision risk assessment

4.1. Technical vertical collision risk assessment

Technical vertical risk represents the risk of a collision between aircraft on adjacent flight levels due to normal or typical height deviations of RVSM approved aircraft. It is attributable to the height-keeping errors that result from the combination of altimetry system errors (ASE) and autopilot performance in the vertical dimension.

As it has been indicated, the Reich model to calculate technical vertical collision risk is explained in [Ref. 32]. In the following sections all the parameters required for the calculation (those that appear in Equation 27 of the mentioned document) will be analysed.

4.1.1. Average aircraft dimensions: λ_x, λ_y, λ_z, λ_h

Table 2 showed the average aircraft dimensions for the lateral collision risk model. Clearly, the same dimensions apply to the vertical model. In addition, the vertical model for crossing traffic needs the average diameter of a cylinder enveloping the aircraft (λ_h), which is the largest of the average aircraft wingspan or fuselage length. Table 12 shows the pertinent average aircraft dimensions.

Location	Value Length ($\boldsymbol{\lambda_x}$) (ft)	Wingspan ($\boldsymbol{\lambda_y}$) (ft)	Height ($\boldsymbol{\lambda_z}$) (ft)
Canaries	181.76	166.95	50.68
SAL1	212.37	197.13	56.57
SAL2	209.17	193.88	55.76
Dakar1	208.08	192.61	55.49
Dakar2	208.21	192.74	55.53
Recife	209.92	193.51	55.99

Table 12.
Average aircraft dimensions for the vertical collision risk model

4.1.2. Probability of lateral overlap: $P_y(0)$

As it is indicated in [Ref. 32], the most conservative assumption consists of assuming that the full aircraft population are using GNSS, α=1. Thus, taking the probability density as Gaussian2, with 0 mean and 0.06123 NM standard deviation, the value obtained for the lateral overlap probability is: $P_y(0) = 4.6071 * 2\lambda_y$, with λ_y expressed in NM.

4.1.3. Probability of horizontal overlap: $P_h(\theta)$

As it was previously explained, in the EUR/SAM Corridor there is traffic crossing the Corridor in published routes in SAL, Dakar and Recife, but there is also some traffic crossing the Corridor in non-published routes or changing from one route to another.

Probability of horizontal overlap has been calculated for all these routes using Equation 37 in [Ref. 32]. The values of S_h and σ_{rc} considered are the same that are used in the CAR/SAM region, i.e., $S_h = 80\ NM$ and $\sigma_{rc} = 0.3\ NM$ (this last value is the one established in the Doc 9574, [Ref. 14]). This probability has only been calculated whenever proximate events have been detected, as it will be seen in 4.1.6.

The obtained results are shown in Table 13 and Table 14.

Horizontal overlap probability				
Location	Diameter ($\lambda_{\square}$)	Route (Point)	Angles (º)	$P_h(\theta)$
Canaries	0.0299 NM	NORED-ETIBA (NORED)	103-77	$4.5394*10^{-7}$
SAL1	0.0350 NM	UR-976/UA-602 (GAMBA)	95-85	$6.0508*10^{-7}$
		ULTEM-LUMPO (IRENE)	91-89	$6.0269*10^{-7}$
		BAMUX-SEPOM (BS001)	102-78	$6.1711*10^{-7}$
		BAMUX-ILGAS (BI001)	95-85	$6.0508*10^{-7}$
		ULTEM-ILGAS (RL001)	108-72	$6.3602*10^{-7}$
		BL001-BS002 (BL001)	95-85	$6.0508*10^{-7}$
		EDUMO-BI002 (BI002)	127-53	$7.6558*10^{-7}$
		CVS-BS004 (CVS)	152-28	$1.3214*10^{-6}$
		IREDO-BL003 (IREDO)	134-46	$8.5387*10^{-7}$
		IREDO-BL003 (BL003)	134-46	$8.5387*10^{-7}$
		CVS-UGAMA (CVS)	101-79	$6.1476*10^{-7}$
		CVS-UGAMA (UGAMA)	98-82	$6.0898*10^{-7}$
		NEMDO-BI003 (BI003)	154-26	$1.4163*10^{-6}$
		CARME-PISPU (PISPU)	145-35	$1.0779*10^{-6}$

Table 13.
Horizontal overlap probabilities in Canaries and SAL1

[2] *As the calculation of $P_y(0)$ is dominated by the core of the densities, the choice of the type of the probability density is less critical than for the calculation of $P_y(S_y)$.*

Horizontal overlap probability				
Location	Diameter (λ_h)	Route (Point)	Angles (º)	$P_h(\theta)$
SAL2	0.0344 NM	CARME-PISPU (CARME)	144-36	$1.0198*10^{-6}$
		BAMUX-KENOX (KENOX)	162-18	$1.9539*10^{-6}$
		MARIA-IREDO (MARIA)	107-73	$6.1336*10^{-7}$
		MARIA-IREDO (IREDO)	105-75	$6.0680*10^{-7}$
Dakar1	0.0342 NM	UL-435 (DIGUN)	98-82	$5.8467*10^{-7}$
		ENUGO-APIGU (ENUGO)	96-84	$5.8198*10^{-7}$
		GARKO-LIRAX (GARKO)	96-84	$5.8198*10^{-7}$
		XUVIT-DIGUN (DIGUN)	158-22	$1.5935*10^{-6}$
		SAGRO-BUXON (SAGRO)	124-56	$7.0668*10^{-7}$
		TARIM-SAGRO (SAGRO)	167-13	$2.6577*10^{-6}$
		SAGRO-MOSOK (MOSOK)	137-43	$8.6631*10^{-7}$
Dakar2	0.0343 NM	IP008-NANIK (NANIK)	169-11	$3.1364*10^{-6}$
		IP008-MOSAD (MOSAD)	162-18	$1.9361*10^{-6}$
		IRAVU-MESAB (MESAB)	153-27	$1.3141*10^{-6}$
Recife	0.0345 NM	UL-695 (DIKEB)	97-83	$5.9358*10^{-7}$
		ERETU-PUGSA (ERETU)	165-15	$2.3508*10^{-6}$

Table 14.
Horizontal overlap probabilities in SAL2, Dakar1, Dakar2 and Recife

4.1.4. Relative velocities

Equation 27 in [Ref. 32] contains four relative speed parameters, $2|\bar{v}|$, $|\Delta\bar{v}|$, $|\overline{\dot{y}}|$ and $|\overline{\dot{z}}|$ for the same/opposite vertical risk and relative speeds for each one of the crossing pairs of routes, $v_{rel}(\theta_i)$.

The average along track speed $2|\bar{v}|$ is taken as in the lateral collision risk model.

Regarding $|\Delta\bar{v}|$, it has been calculated, as in the lateral case, from the differences between the speeds of all the pairs of aircraft that constitute a vertical proximate pair in the same direction.

Location	Vertical average relative longitudinal speeds		
	Southbound (kts)	Northbound (kts)	Average (kts)
Canaries	12.2196	26.2266	19.2231
SAL1	23.1170	38.8055	30.9613
SAL2	93.0478	11.6314	52.3396
Dakar1	18.3701	34.3409	26.3555
Dakar2	42.9113	26.9507	34.9310
Recife	22.2550	12.0302	17.1426

Table 15.
Vertical average relative longitudinal speeds

For the vertical collision risk model, $\overline{|\dot{y}|}$ is the mean of the modulus of the relative cross-track speed between aircraft on the same track. Consequently, there is no operational reason why this relative speed should have a particularly large value. As it was presented in the previous studies, [Ref. 3] to [Ref. 9], a conservative value, 20 kts, was used based on the assessment made by ARINC in [Ref. 2] and on the AFI Region Assessment, [Ref. 22]. This value has been taken here too.

The mean relative vertical speed of the vertical collision risk model applies to aircraft that have lost their assigned vertical separation minimum of S_z. The value $\overline{|\dot{z}|} = 1.5\ kts$ will be taken here as in the lateral collision risk assessment.

As far as relative speed in crossing routes is concerned, it is obtained by:

$$v_{rel}(\theta_i) = \sqrt{v_1^2 + v_2^2 - 2v_1 v_2 \cos(\theta_i)}$$

Equation 1.

where v_1 and v_2 are the average speeds in each one of the routes and θ, the intersection angle. The relative speeds used in this study are summarized in Table 16 and Table 17. V1 refers to the average speed on the corresponding parallel route and V2, to the crossing route. As it was said before, this velocity is only calculated if proximate pairs for the crossing route are detected.

Location	Crossing route (Point)	V_1 (kts)	V_2 (kts)	$\boldsymbol{\theta}$ (º)	$V_{rel}(\boldsymbol{\theta})$ (kts)
Canaries	NORED-ETIBA (NORED)	474.19	474.36	77	590.49
				103	742.35
SAL1	UR-976/UA-602 (GAMBA)	464.44	480.83	85	638.73
				95	697.02
	ULTEM-LUMPO (IRENE)	464.44	461.32	89	648.88
				91	660.31
	BAMUX-SEPOM (BS001)	464.44	473.97	78	590.61
				102	729.31
	BAMUX-ILGAS (BI001)	464.44	447.95	85	616.53
				95	672.78
	ULTEM-ILGAS (RL001)	464.44	449.04	72	537.08
				108	739.08
	BL001-BS002 (BL001)	464.44	491.62	85	646.22
				95	705.12
	EDUMO-BI002 (BI002)	464.44	424.55	53	398.27
				127	795.80
	CVS-BS004 (CVS)	464.44	488.85	28	231.84
				152	925.00
	IREDO-BL003 (IREDO)	464.44	477.80	46	368.37
				134	867.36
	IREDO-BL003 (BL003)	464.44	477.80	46	368.37
				134	867.36
	CVS-UGAMA (CVS)	464.44	472.36	79	595.92
				101	722.88
	CVS-UGAMA (UGAMA)	464.44	472.36	82	614.63
				98	707.04
	NEMDO-BI003 (BI003)	464.44	458.11	26	207.62
				154	898.91
	CARME-PISPU (PISPU)	464.44	474.58	35	282.54
				145	895.57
SAL2	CARME-PISPU (CARME)	470.42	474.58	36	292.05
				144	898.76
	BAMUX-KENOX (KENOX)	470.42	474.39	18	147.85
				162	933.19
	MARIA-IREDO (MARIA)	470.42	461.66	73	554.47
				107	749.28
	MARIA-IREDO (IREDO)	470.42	461.65	75	567.46
				105	739.49

Table 16.
Relative speeds in crossings (Canaries and SAL)

Location	Crossing route	V_1 (kts)	V_2 (kts)	θ (º)	$V_{rel}(\theta)$ (kts)
Dakar1	UL-435 (DIGUN)	468.65	489.05	82	628.50
				98	722.91
	ENUGO-APIGU (ENUGO)	468.65	482.48	84	636.52
				96	706.90
	GARKO-LIRAX (GARKO)	468.65	473.67	84	630.55
				96	700.29
	XUVIT-DIGUN (DIGUN)	468.65	469.74	22	179.06
				158	921.15
	SAGRO-BUXON (SAGRO)	468.65	478.68	56	444.83
				124	836.45
	TARIM-SAGRO (SAGRO)	468.65	497.36	13	113.01
				167	959.80
	SAGRO-MOSOK (MOSOK)	468.65	494.12	43	353.65
				137	895.83
Dakar2	IP008-NANIK (NANIK)	471.64	483.19	11	92.24
				169	950.44
	IP008-MOSAD (MOSAD)	471.64	443.50	18	145.83
				162	903.89
	IRAVU-MESAB (MESAB)	471.64	488.48	27	224.73
				153	933.61
Recife	UL-695 (DIKEB)	465.19	479.24	83	625.89
				97	707.40
	ERETU-PUGSA (ERETU)	465.19	503.08	15	131.85
				165	960.00

Table 17.
Relative speeds in crossings (Dakar and Recife)

4.1.5. Vertical overlap probability: $P_z(S_z)$

With 2017 traffic and height-keeping performances information, the probability of vertical overlap has been calculated by means of Equation 43 in [Ref. 32], using the Eurocontrol RVSM Tool, being the resulting values $P_z(1000) = 6.04144 \cdot 10^{-13}$ and $P_z(0) = 0.50102$.

4.1.6. Vertical occupancy

As it is explained in [Ref. 32], vertical occupancy can be defined for same and opposite direction traffic in the same way as lateral occupancy.

This section presents the vertical occupancy values provided by the CRM programme for the current time and an estimate of the occupancy until 2027, with the annual traffic growth rate previously indicated, 4.5%.

4.1.6.a. Canaries

Table 18 shows some results on same and opposite vertical occupancy in Canaries location, based on traffic levels representative of 2017.

Vertical occupancy	August 2017
Number of flights on UN-741	175
Number of flights on UN-866	322
Number of flights on UN-873	1330
Number of flights on UN-857	335
Total number of flights on main airways	2162
Number of same direction vertical proximate pairs for tracks UN-741	12
Number of same direction vertical proximate pairs for tracks UN-866	17
Number of opposite direction vertical proximate pairs for tracks UN-873	75
Number of opposite direction vertical proximate pairs for tracks UN-857	5
Total number of same direction proximate events	29
Total number of opposite direction proximate events	80
Same direction vertical occupancy (S_x=80NM)	0.0268
Opposite direction vertical occupancy (S_x=80NM)	0.0740

Table 18.
Vertical occupancy due to same and opposite direction traffic in the Canaries location with current traffic levels

Apart from the traffic on the main routes, in the Canaries airspace there are some non-published crossing trajectories, as it was explained before. The number of flights on these routes can be found in the following table:

Number of flights	August 2017
Number of flights on crossing flight ISOKA-APASO	3
Number of flights on crossing flight NORED-ETIBA	8
Total number of flights on main routes (UN-741, UN-866, UN-873 and UN-857)	2162
Total number of flights	2170

Table 19.
Number of flights in Canaries airspace

Except for the traffic on the crossing route NORED-ETIBA, all the other flights on the non-published routes are already included in the number of flights on the main routes. Therefore, the total number of flights is 2170.

To calculate crossing occupancies, it is necessary to obtain the number of proximate pairs, i.e., the number of pairs for which horizontal separation is less than S_h. The value selected for S_h is set to the value used in the CAR/SAM study, [Ref. 18], i.e. $S_h = 80NM$.

Proximate events can be obtained comparing differences of passing times at the crossing point. The time window to be used in each case depends on the speeds and intersection angle of the routes, as it is explained in Annex 2 of [Ref. 32]. The values obtained for the Canaries are shown in Table 20, where v1 refers to the average speed on the corresponding parallel route, v2 refers to the average speed on the crossing route, and θ1 and θ2 are the two possible crossing angles, depending on the headings. With these time windows, the number of proximate pairs obtained can also be seen in Table 20. It is to be noted that only data for the crossing routes for which proximate pairs have been detected are presented.

Time windows for crossing routes						Number of proximate events due to crossing traffic	
Route	Point	v1 (kts)	v2 (kts)	θ (º)	t (min)	At the same FL	At adjacent FL
NORED-ETIBA	---	474.19	474.36	103º	17	0	5
				77º	13	0	1

Table 20.
Time windows for crossing occupancies and number of proximate events in the Canaries.

Once vertical occupancy is calculated based on current traffic levels, it is possible to estimate the occupancy in the following years taking into account the forecasted annual traffic growth rate. Vertical occupancy values from 2017 to 2027 with an annual traffic growth rate of 4.5% are shown in Table 21.

4.5% annual traffic growth			2017	2019	2021	2023	2025	2027
Same direction vertical occupancy			0.0268	0.0293	0.0320	0.0349	0.0382	0.0417
Opposite direction vertical occupancy			0.0740	0.0808	0.0883	0.0964	0.1052	0.1149
Crossing occupancy	NORED-ETIBA	103º	0.0046	0.0050	0.0055	0.0060	0.0066	0.0072
		77º	0.0009	0.0010	0.0011	0.0012	0.0013	0.0014

Table 21.
Vertical occupancy estimate for the Canaries until 2027 with an annual traffic growth rate of 4.5%

4.1.6.b. SAL1

Table 22 collects some results on same and opposite vertical occupancy in SAL1, obtained with data from August 2017.

Number of flights	August 2017
Number of flights on UN-741	151
Number of flights on UN-866	309
Number of flights on UN-873	689
Number of flights on UN-857	188
Total number of flights	1337
Number of same direction vertical proximate pairs for tracks UN-741	11
Number of same direction vertical proximate pairs for tracks UN-866	21
Number of opposite direction vertical proximate pairs for tracks UN-873	12
Number of opposite direction vertical proximate pairs for tracks UN-857	1
Total number of same direction proximate events	32
Total number of opposite direction proximate events	13
Same direction vertical occupancy (S_x=80NM)	0.0479
Opposite direction vertical occupancy (S_x=80NM)	0.0194

Table 22.
Vertical occupancy due to same and opposite direction traffic in SAL1 location with current traffic levels.

Apart from the traffic on the main routes, in SAL1 there is also some traffic crossing the Corridor on routes UR-976/UA-602 and on non-published routes. The number of flights on these routes can be found in the following table:

Number of flights	August 2017
Number of flights on UR-976/UA-602	122
Number of flights on ULTEM-LUMPO	79
Number of flights on BAMUX-SEPOM	11
Number of flights on BAMUX-LUMPO	1
Number of flights on BAMUX-ILGAS	50
Number of flights on ULTEM-ILGAS	12
Number of flights on BL001-BS002	4
Number of flights on IREDO-BL003	6
Number of flights on IPERA-BI004	2
Number of flights on EDUMO-BI002	10
Number of flights on NEMDO-BI003	22
Number of flights on IRENE-KESIK	1
Number of flights on CVS-UGAMA	59
Number of flights on CVS-BL002	8
Number of flights on CVS-BS004	2
Number of flights on PISPU-CARME	12
Number of flights on main routes (UN-741, UN-866, UN-873 and UN-857)	1337
Total number of flights	1669

Table 23.
Number of flights in SAL1 airspace.

All the flights on the non-published routes are already included in the number of flights on the main routes, except for the flights on the trajectories that cross the complete corridor (332 flights). Therefore, the total number of flights is 1669.

The time windows to obtain proximate pairs and the number of proximate events are, in this case, the ones shown in Table 24. It is to be noted that only data for crossing routes for which proximate events have been detected are presented.

Time windows for crossing routes						Number of proximate events due to crossing traffic	
Route	Point	v1 (kts)	v2 (kts)	θ (º)	t (min)	At the same FL	At adjacent FL
UR-976/UA-602	---	464.44	480.83	95º	15	7	6
				85º	14	1	16
ULTEM-LUMPO	---	464.44	461.32	91º	15	2	6
				89º	15	1	5
BAMUX-SEPOM	---	464.44	473.97	102º	17	0	4
				78º	14	0	4
BAMUX-ILGAS	---	464.44	447.95	95º	16	0	3
				85º	15	0	8
ULTEM-ILGAS	---	464.44	449.04	108º	18	0	1
				72º	13	0	7
IREDO-BL003	**IREDO**	453.50	477.80	134º	27	0	2
				46º	12	0	0
	BL003	470.66	477.80	134º	27	0	1
				46º	12	0	0
BL001-BS002	**BL001**	467.26	491.62	95º	15	0	1

				85º	14	0	0
EDUMO-BI002	**BI002**	453.50	424.55	127º	25	0	2
				53º	13	0	0
CVS-BS004	**CVS**	470.66	488.85	152º	41	0	3
				28º	11	0	0
NEMDO-BI003	**BI003**	470.66	458.11	154º	47	0	7
				26º	11	1	8
CVS-UGAMA	**CVS**	470.66	472.36	101º	16	0	3
				79º	14	3	0
	UGAMA	469.56	472.36	98º	16	0	1
				82º	14	3	0
PISPU-CARME	**PISPU**	470.66	474.58	145º	34	0	8
				35º	11	0	0

Table 24.
Time windows for crossing occupancies and number of proximate events in SAL1.

It can be seen that some proximate events involve aircraft at the same flight level. 18 of these events at the same level involve aircraft within 15 minutes or less of each other. Several reasons are possible for this apparent violation of the required separation, such as:

- A tactical flight level change to separate crossing traffic was not included in the provided data;
- There was an error in the time provided in the data;
- The air traffic controller did not register a flight level change;
- The aircraft made contact too late to allow an action by the air traffic controller;
- There was an operational error that was not registered by the air traffic controller and/or by the aircraft;
- Passing times at the crossing point are not precise, due to the need of extrapolation of the traffic data.

Further analysis would be required for these cases to identify whether they are in fact proximate events at the same level or not. No more information is available for further clarification and no deviation reports have been received. Therefore, in this assessment, for the purpose of accounting for these events in the collision risk model, the “same flight level” crossing proximity events are counted as “adjacent flight level” proximity events. This approach was also followed by ARINC in [Ref. 2]. Nevertheless, if it could be shown that these events were in fact violations of the vertical separation standard, then these events should be treated as large height keeping deviations and be accounted for in the total vertical collision risk.

With these considerations, vertical occupancy values from 2017 to 2027 with an annual traffic growth rate of 4.5% are shown in Table 25. Only crossings different from zero have been shown.

4.5% annual traffic growth				2017	2019	2021	2023	2025	2027
Same direction vertical occupancy				0.0479	0.0523	0.0571	0.0623	0.0681	0.0743
Opposite direction vertical occupancy				0.0194	0.0212	0.0232	0.0253	0.0277	0.0302
Crossing occupancy	UR-976/UA-602	---	95º	0.0156	0.0170	0.0185	0.0202	0.0220	0.0242
			85º	0.0204	0.0222	0.0243	0.0265	0.0290	0.0316
	ULTEM-LUMPO	---	91º	0.0096	0.0105	0.0114	0.0125	0.0136	0.0149
			89º	0.0072	0.0079	0.0086	0.0094	0.0102	0.0112
	BAMUX-SEPOM	---	102º	0.0048	0.0052	0.0057	0.0062	0.0068	0.0074
			78º	0.0048	0.0052	0.0057	0.0062	0.0068	0.0074
	BAMUX-ILGAS	---	95º	0.0036	0.0039	0.0043	0.0047	0.0051	0.0056
			85º	0.0096	0.0105	0.0114	0.0125	0.0136	0.0149
	ULTEM-ILGAS	---	108º	0.0012	0.0013	0.0014	0.0016	0.0017	0.0019
			72º	0.0084	0.0092	0.0100	0.0110	0.0120	0.0130
	IREDO-BL003	IREDO	134º	0.0024	0.0026	0.0029	0.0031	0.0034	0.0037
			46º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
		BL003	134º	0.0012	0.0013	0.0014	0.0016	0.0017	0.0019
			46º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	BL001-BS002	BL001	95º	0.0012	0.0013	0.0014	0.0016	0.0017	0.0019
			85º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	EDUMO-BI002	BI002	127º	0.0024	0.0026	0.0029	0.0031	0.0034	0.0037
			53º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	CVS-BS004	CVS	152º	0.0036	0.0039	0.0043	0.0047	0.0051	0.0056
			28º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	NEMDO-BI003	BI003	154º	0.0084	0.0092	0.0100	0.0110	0.0120	0.0130
			26º	0.0108	0.0118	0.0129	0.0140	0.0153	0.0167
	CVS-UGAMA	CVS	101º	0.0036	0.0039	0.0043	0.0047	0.0051	0.0056
			79º	0.0036	0.0039	0.0043	0.0047	0.0051	0.0056
		UGAMA	98º	0.0012	0.0013	0.0014	0.0016	0.0017	0.0019
			82º	0.0036	0.0039	0.0043	0.0047	0.0051	0.0056
	PISPU-CARME	PISPU	145º	0.0096	0.0104	0.0114	0.0125	0.0136	0.0149
			35º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 25.
Vertical occupancy estimate for SAL1 until 2027 with an annual traffic growth rate of 4.5%

4.1.6.c. SAL2

Table 26 collects some results on same and opposite vertical occupancy in SAL2, obtained with data from the August 2017.

Number of flights	August 2017
Number of flights on UN-741	134
Number of flights on UN-866	312
Number of flights on UN-873	721
Number of flights on UN-857	186
Total number of flights	1353
Number of same direction vertical proximate pairs for tracks UN-741	6
Number of same direction vertical proximate pairs for tracks UN-866	24
Number of opposite direction vertical proximate pairs for tracks UN-873	29
Number of opposite direction vertical proximate pairs for tracks UN-857	0
Total number of same direction proximate events	30
Total number of opposite direction proximate events	29
Same direction vertical occupancy (S_x=80NM)	0.0443
Opposite direction vertical occupancy (S_x=80NM)	0.0429

Table 26.
Vertical occupancy due to same and opposite direction traffic in SAL2 location with current traffic levels

Apart from the traffic on the main routes, in SAL2 there is also some traffic crossing the Corridor on non-published routes. The number of flights on these routes can be found in the following table:

Number of flights	August 2017
Number of flights on XIBOT-MOGSA	3
Number of flights on KENOX-DENER	2
Number of flights on SNT-BOTNO	19
Number of flights on BAMUX-KENOX	22
Number of flights on VEPOP-KENOX	1
Number of flights on CARME-KENOX	16
Number of flights on SVT-KENOX	4
Number of flights on BULVO-ORABI	3
Number of flights on MARIA-IREDO	23
Number of flights on EXTER-CARME	3
Number of flights on CVS-INESS	1
Number of flights on CARME-PISPU	12
Number of flights on main routes (UN-741, UN-866, UN-873 and UN-857)	1353
Total number of flights	1444

Table 27.
Number of flights **in SAL2 airspace**

All the flights on the crossing routes are already included in the number of flights on the main routes except for 91 of them. Therefore, the total number of flights in this case is 1444.

The time windows to obtain proximate pairs and the number of proximate events are, in this case, the ones shown in Table 28. It is to be noted that only data for crossing routes for which proximate events have been detected are presented.

Time windows for crossing routes						Number of proximate events due to crossing traffic	
Route	Point	v1 (kts)	v2 (kts)	θ (º)	t (min)	At the same FL	At adjacent FL
BAMUX-KENOX	KENOX	448.05	474.39	162º	66	0	0
				18º	11	0	2
MARIA-IREDO	MARIA	448.05	461.66	107º	18	0	0
				73º	14	1	2
	IREDO	483.20	461.66	105º	17	0	4
				75º	13	0	0
CARME-PISPU	CARME	483.20	474.58	144º	33	0	2
				36º	11	0	0

Table 28.
Time windows for crossing occupancies and number of proximate events in SAL2

Here again, as it happened in SAL1, there is a proximate event at the same flight level within 14 minutes of each other. The same reasons explained before are of application here.

No deviation reports have been received for these cases either, and therefore, the hypothesis of considering proximate events at the same flight level as proximate at adjacent flight levels will also be made for this location. Nevertheless, this hypothesis should be verified.

With these considerations, once vertical occupancy is calculated based on current traffic levels, it is possible to estimate the occupancy in the following years taking into account the forecasted annual traffic growth rate. Vertical occupancy values from 2017 to 2027 with an annual traffic growth rate of 4.5% are shown in Table 29. Only data for crossing trajectories in which proximate events have been detected are included.

4.5% annual traffic growth				2017	2019	2021	2023	2025	2027
Same direction vertical occupancy				0.0443	0.0484	0.0529	0.0578	0.0631	0.0689
Opposite direction vertical occupancy				0.0429	0.0468	0.0511	0.0558	0.0610	0.0666
Crossing occupancy	BAMUX-KENOX	KENOX	162º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
			18º	0.0028	0.0030	0.0033	0.0036	0.0039	0.0043
	MARIA-IREDO	MARIA	107º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
			73º	0.0042	0.0045	0.0050	0.0054	0.0059	0.0065
		IREDO	105º	0.0055	0.0061	0.0066	0.0072	0.0079	0.0086
			75º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	CARME-PISPU	CARME	144º	0.0028	0.0030	0.0033	0.0036	0.0039	0.0043
			36º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 29.
Vertical occupancy estimate for SAL2 until 2027 with an annual traffic growth rate of 4.5%

4.1.6.d. Dakar1

Table 30 collects some results on same and opposite vertical occupancy in Dakar1, obtained with data from August 2017.

Number of flights	August 2017
Number of flights on UN-741	212
Number of flights on UN-866	406
Number of flights on UN-873	755
Number of flights on UN-857	234
Total number of flights	1607
Number of same direction vertical proximate pairs for tracks UN-741	10
Number of same direction vertical proximate pairs for tracks UN-866	36
Number of opposite direction vertical proximate pairs for tracks UN-873	25
Number of opposite direction vertical proximate pairs for tracks UN-857	4
Total number of same direction proximate events	46
Total number of opposite direction proximate events	29
Same direction vertical occupancy (S_x=80NM)	0.0572
Opposite direction vertical occupancy (S_x=80NM)	0.0361

Table 30.
Vertical occupancy due to same and opposite direction traffic in Dakar1 location with current traffic levels

Apart from the traffic on the main routes, in Dakar1 there is also some traffic crossing the Corridor on route UL-435 and on non-published trajectories (including those that cross the complete Corridor and those that correspond to changes between routes). The number of flights on these routes can be found in the following table:

Number of flights	August 2017
Number of flights on UL-435	30
Number of flights on ENUGO-APIGU	5
Number of flights on APOXA-GONSA	2
Number of flights on GARKO-LIRAX	4
Number of flights on XUVIT-DIGUN	19
Number of flights on TARIM-SAGRO	2
Number of flights on TARIM-GARKO	2
Number of flights on TARIM-DIGUN	10
Number of flights on SAGRO-BUXON	2
Number of flights on SAGRO-MOSOK	23
Number of flights on DELAX-IRAVU	1
Number of flights on LIRAX-IRAVU	7
Number of flights on KENOX-RIXAD	1
Number of flights on ENUGO-IP007	9
Number of flights on main routes (UN-741, UN-866, UN-873 and UN-857)	1607
Total number of flights	1697

Table 31.
Number of flights in Dakar1 airspace

The flights on the crossing routes are already included in the number of flights on the main routes except for those that fly on any of the trajectories that cross the whole Corridor and those that join the main routes from the DCT area (which amount 90 flights). Therefore, the total number of flights in this case is 1697.

The time windows to obtain proximate pairs and the number of proximate events are, in this case, the ones shown in Table 32. It is to be noted that only data for crossing routes for which proximate events have been detected are presented.

Time windows for crossing routes						Number of proximate events due to crossing traffic	
Route	Point	v1 (kts)	v2 (kts)	θ (º)	t (min)	At the same FL	At adjacent FL
UL-435	---	468.65	489.05	98º	16	5	4
				82º	14	1	14
ENUGO-APIGU	---	468.65	482.49	96º	15	0	0
				84º	14	2	0
GARKO-LIRAX	---	468.65	473.67	96º	16	1	0
				84º	14	0	1
XUVIT-DIGUN	DIGUN	468.92	469.74	158º	54	0	0
				22º	11	0	2
SAGRO-BUXON	SAGRO	468.92	478.68	124º	22	1	0
				56º	12	0	0
TARIM-SAGRO	SAGRO	468.92	497.36	167º	85	0	2
				13º	10	0	0
SAGRO-MOSOK	MOSOK	448.49	494.12	137º	28	0	2
				43º	11	0	0

Table 32.
Time windows for crossing occupancies and number of proximate events in Dakar1

Here again, as it happened in the locations previously analyzed, there are proximate events at the same flight level. The same reasons explained before are of application here.

Given that no deviation reports have been received for these aircraft, it will be assumed that they are due to the extrapolation of data and the lack of data regarding flight level changes in the traffic data provided, and they will be considered as adjacent level proximate events. Nevertheless, this hypothesis should be verified when more information is available, because it may have an impact on the results in case that any of the proximate events were, in fact, at the same flight level.

With these considerations, once vertical occupancy is calculated based on current traffic levels, it is possible to estimate the occupancy in the following years taking into account the annual traffic growth rate forecasted. Vertical occupancy values from 2017 to 2027 with an annual traffic growth rate of 4.5% are shown in Table 33.

4.5% annual traffic growth				2017	2019	2021	2023	2025	2027
Same direction vertical occupancy				0.0573	0.0625	0.0683	0.0746	0.0814	0.0890
Opposite direction vertical occupancy				0.0361	0.0394	0.0430	0.0470	0.0513	0.0561
Crossing occupancy	UL-435	---	98º	0.0106	0.0116	0.0126	0.0138	0.0151	0.0165
			82º	0.0177	0.0193	0.0211	0.0230	0.0251	0.0275
	ENUGO-APIGU	---	96º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
			84º	0.0024	0.0026	0.0028	0.0031	0.0034	0.0037
	GARKO-LIRAX	---	96º	0.0012	0.0013	0.0014	0.0015	0.0017	0.0018
			84º	0.0012	0.0013	0.0014	0.0015	0.0017	0.0018
	XUVIT-DIGUN	DIGUN	158º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
			22º	0.0024	0.0026	0.0028	0.0031	0.0034	0.0037
	SAGRO-BUXON	SAGRO	124º	0.0012	0.0013	0.0014	0.0015	0.0017	0.0018
			56º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	TARIM-SAGRO	SAGRO	167º	0.0024	0.0026	0.0028	0.0031	0.0034	0.0037
			13º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	SAGRO-MOSOK	MOSOK	137º	0.0024	0.0026	0.0028	0.0031	0.0034	0.0037
			43º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 33.
Vertical occupancy estimate for Dakar1 until 2027 with an annual traffic growth rate of 4.5%

4.1.6.e. Dakar2

Table 34 collects some results on same and opposite vertical occupancy in Dakar2, obtained with data from August 2017.

Number of flights	August 2017
Number of flights on UN-741	249
Number of flights on UN-866	416
Number of flights on UN-873	762
Number of flights on UN-857	235
Total number of flights	1662
Number of same direction vertical proximate pairs for tracks UN-741	17
Number of same direction vertical proximate pairs for tracks UN-866	34
Number of opposite direction vertical proximate pairs for tracks UN-873	44
Number of opposite direction vertical proximate pairs for tracks UN-857	1
Total number of same direction proximate events	51
Total number of opposite direction proximate events	45
Same direction vertical occupancy (S_x=80NM)	0.0614
Opposite direction vertical occupancy (S_x=80NM)	0.0542

Table 34.
Vertical occupancy due to same and opposite direction traffic in Dakar2 location with current traffic levels

Apart from the traffic on the main routes, in Dakar2 there is also some traffic crossing the Corridor on non-published routes. The number of flights on these routes can be found in the following table:

Number of flights	August 2017
Number of flights on IP006-NANIK	2
Number of flights on IP007-NANIK	13
Number of flights on IP008-NANIK	196
Number of flights on IP008-MOSAD	49
Number of flights on IRAVU-MESAB	8
Number of flights on DIGUN-MOVGA	9
Number of flights on DIGUN-ENOTO	10
Number of flights on main routes (UN-741, UN-866, UN-873 and UN-857)	1662
Total number of flights	1882

Table 35.
Number of flights in Dakar2 airspace

All the flights on the non-published routes are already included in the number of flights on the main routes except for 220 of them. Therefore, the total number of aircraft in this case is 1882.

The time windows to obtain proximate pairs and the number of proximate pairs are, in this case, the ones shown in Table 36. It is to be noted that only data for crossing routes for which proximate events have been detected are presented.

Time windows for crossing routes						Number of proximate events due to crossing traffic	
Route	Point	v1 (kts)	v2 (kts)	θ (º)	t (min)	At the same FL	At adjacent FL
IP008-NANIK	NANIK	463.68	483.19	169º	110	0	0
				11º	11	4	20
IP008-MOSAD	MOSAD	463.68	443.51	162º	67	0	0
				18º	11	1	7
LIRAX-MESAB	MESAB	474.40	488.48	153º	43	0	4
				27º	11	3	0

Table 36.
Time windows for crossing occupancies and number of proximate events in Dakar2.

Here again, as it happened in the locations previously analysed, there are proximate events at the same flight level. The same reasons explained before are of application here.

No deviation reports have been received for these cases either, and therefore, the hypothesis of considering proximate events at the same flight level as proximate at adjacent flight levels will also be made for this location. Nevertheless, this hypothesis should be verified.

With these considerations, once vertical occupancy is calculated based on current traffic levels, it is possible to estimate the occupancy in the following years taking into account the annual traffic growth rate forecasted. Vertical occupancy values from 2017 to 2027 with an annual traffic growth rate of 4.5% are shown in Table 37.

<table>
<tr><td colspan="4">4.5% annual traffic growth</td><td>2017</td><td>2019</td><td>2021</td><td>2023</td><td>2025</td><td>2027</td></tr>
<tr><td colspan="4">Same direction vertical occupancy</td><td>0.0614</td><td>0.0670</td><td>0.0732</td><td>0.0799</td><td>0.0873</td><td>0.0953</td></tr>
<tr><td colspan="4">Opposite direction vertical occupancy</td><td>0.0542</td><td>0.0591</td><td>0.0646</td><td>0.0701</td><td>0.0770</td><td>0.0841</td></tr>
<tr><td rowspan="6">Crossing occupancy</td><td rowspan="2">IP008-NANIK</td><td rowspan="2">NANIK</td><td>169º</td><td>0.0000</td><td>0.0000</td><td>0.0000</td><td>0.0000</td><td>0.0000</td><td>0.0000</td></tr>
<tr><td>11º</td><td>0.0255</td><td>0.0279</td><td>0.0304</td><td>0.0332</td><td>0.0363</td><td>0.0397</td></tr>
<tr><td rowspan="2">IP008-MOSAD</td><td rowspan="2">MOSAD</td><td>162º</td><td>0.0000</td><td>0.0000</td><td>0.0000</td><td>0.0000</td><td>0.0000</td><td>0.0000</td></tr>
<tr><td>18º</td><td>0.0085</td><td>0.0093</td><td>0.0101</td><td>0.0111</td><td>0.0121</td><td>0.0132</td></tr>
<tr><td rowspan="2">LIRAX-MESAB</td><td rowspan="2">MESAB</td><td>153º</td><td>0.0043</td><td>0.0046</td><td>0.0051</td><td>0.0055</td><td>0.0060</td><td>0.0066</td></tr>
<tr><td>27º</td><td>0.0032</td><td>0.0035</td><td>0.0038</td><td>0.0042</td><td>0.0045</td><td>0.0050</td></tr>
</table>

Table 37.
Vertical occupancy estimate for Dakar2 until 2027 with an annual traffic growth rate of 4.5%

4.1.6.f. Recife

Table 38 collects some results on same and opposite vertical occupancy in Recife, obtained with data from August 2017.

Number of flights	August 2017
Number of flights on UN-741	442
Number of flights on UN-866	357
Number of flights on UN-873	808
Number of flights on UN-857	178
Total number of flights	1785
Number of same direction vertical proximate pairs for tracks UN-741	16
Number of same direction vertical proximate pairs for tracks UN-866	23
Number of opposite direction vertical proximate pairs for tracks UN-873	60
Number of opposite direction vertical proximate pairs for tracks UN-857	2
Total number of same direction proximate events	39
Total number of opposite direction proximate events	62
Same direction vertical occupancy (S_x=80NM)	0.0437
Opposite direction vertical occupancy (S_x=80NM)	0.0695

Table 38.
Vertical occupancy due to same and opposite direction traffic in Recife location with current traffic levels.

Apart from the traffic on the main routes, in Recife there is also some traffic crossing the Corridor on routes UL-695/UL-375 and on non-published routes. The number of flights on these routes can be found in the following table:

Number of flights	August 2017
Number of flights on UL-695/UL-375	38
Number of flights on ERETU-PUGSA	31
Number of flights on main routes (UN-741, UN-866, UN-873 and UN-857)	1785
Total number of flights	1854

Table 39.
Number of flights **in Recife airspace.**

The time windows to obtain proximate pairs are, in this case, the ones shown in Table 40. It is to be noted that only data for crossing routes for which proximate events have been detected are presented.

Time windows for crossing routes						**Number of proximate events due to crossing traffic**	
Route	**Point**	**v1 (kts)**	**v2 (kts)**	**θ (º)**	**t (min)**	**At the same FL**	**At adjacent FL**
UL-695	---	465.19	479.24	97º	16	4	0
				83º	14	0	7
ERETU-PUGSA	ERETU	463.85	503.08	165º	79	0	1
				15º	11	0	0

Table 40.
Time windows for crossing occupancies and number of proximate events in Recife.

As it occurred in other locations, some proximate pairs at the same flight level have been detected. In this case, 4 out of the 12 proximate pairs found are at the same flight level.

As no large height deviation reports have been received for these events, it will be considered that they are proximate events at adjacent flight levels, as it has been done in other locations, assuming that they are due to the need of extrapolation and the lack of data about flight level changes. Nevertheless, this hypothesis should be verified, because it may have an impact on the results, as it has been explained before.

With these considerations, once vertical occupancy is calculated based on current traffic levels, it is possible to estimate the occupancy in the following years taking into account the annual traffic growth rate forecasted. Vertical occupancy values from 2017 to 2027 with an annual traffic growth rate of 4.5% are shown in Table 41.

4.5% annual traffic growth				2017	2019	2021	2023	2025	2027
Same direction vertical occupancy				0.0437	0.0477	0.0521	0.0569	0.0621	0.0679
Opposite direction vertical occupancy				0.0695	0.0759	0.0828	0.0905	0.0988	0.1079
Crossing occupancy	UL-695	---	97º	0.0043	0.0047	0.0051	0.0056	0.0061	0.0067
			83º	0.0076	0.0082	0.0090	0.0098	0.0107	0.0117
	ERETU-PUGSA	ERETU	165º	0.0011	0.0012	0.0013	0.0014	0.0015	0.0017
			15º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 41.
Vertical occupancy estimate for Recife until 2027 with an annual traffic growth rate of 4.5%

4.1.7. Technical vertical collision risk

The technical vertical collision risk values obtained until 2027 in the different locations are the ones summarized in the following table, considering that the traffic growth factor is 4.5% per annum. These results can also be seen in Figure 17 to Figure 28.

Technical Vertical Collision risk	4.5% annual traffic growth					
	Canaries	SAL1	SAL2	Dakar1	Dakar2	Recife
2017	$7.0235*10^{-14}$	$2.4904*10^{-14}$	$5.0082*10^{-14}$	$4.2027*10^{-14}$	$6.2399*10^{-14}$	$7.5962*10^{-14}$
2018	$7.3396*10^{-14}$	$2.6024*10^{-14}$	$5.2336*10^{-14}$	$4.3919*10^{-14}$	$6.5207*10^{-14}$	$7.9380*10^{-14}$
2019	$7.6699*10^{-14}$	$2.7195*10^{-14}$	$5.4691*10^{-14}$	$4.5895*10^{-14}$	$6.8141*10^{-14}$	$8.2952*10^{-14}$
2020	$8.0150*10^{-14}$	$2.8419*10^{-14}$	$5.7152*10^{-14}$	$4.7960*10^{-14}$	$7.1207*10^{-14}$	$8.6685*10^{-14}$
2021	$8.3757*10^{-14}$	$2.9698*10^{-14}$	$5.9724*10^{-14}$	$5.0118*10^{-14}$	$7.4412*10^{-14}$	$9.0586*10^{-14}$
2022	$8.7526*10^{-14}$	$3.1034*10^{-14}$	$6.2411*10^{-14}$	$5.2374*10^{-14}$	$7.7760*10^{-14}$	$9.4662*10^{-14}$
2023	$9.1465*10^{-14}$	$3.2431*10^{-14}$	$6.5220*10^{-14}$	$5.4731*10^{-14}$	$8.1259*10^{-14}$	$9.8922*10^{-14}$
2024	$9.5581*10^{-14}$	$3.3890*10^{-14}$	$6.8155*10^{-14}$	$5.7194*10^{-14}$	$8.4916*10^{-14}$	$1.0337*10^{-13}$
2025	$9.9882*10^{-14}$	$3.5415*10^{-14}$	$7.1221*10^{-14}$	$5.9767*10^{-14}$	$8.8737*10^{-14}$	$1.0803*10^{-13}$
2026	$1.0438*10^{-13}$	$3.7009*10^{-14}$	$7.4426*10^{-14}$	$6.2457*10^{-14}$	$9.2730*10^{-14}$	$1.1289*10^{-13}$
2027	$1.0907*10^{-13}$	$3.8674*10^{-14}$	$7.7776*10^{-14}$	$6.5267*10^{-14}$	$9.6903*10^{-14}$	$1.1797*10^{-13}$

Table 42.
Technical vertical collision risk for the period 2017-2027 in the Corridor

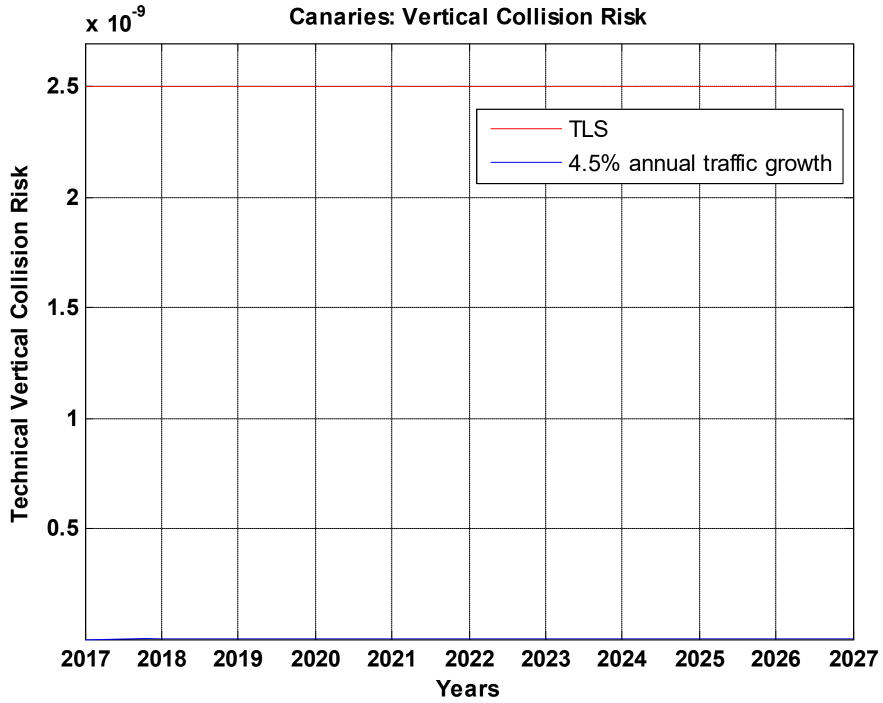


Figure 17.
Technical vertical collision risk for the period 2017-2027 in the Canaries

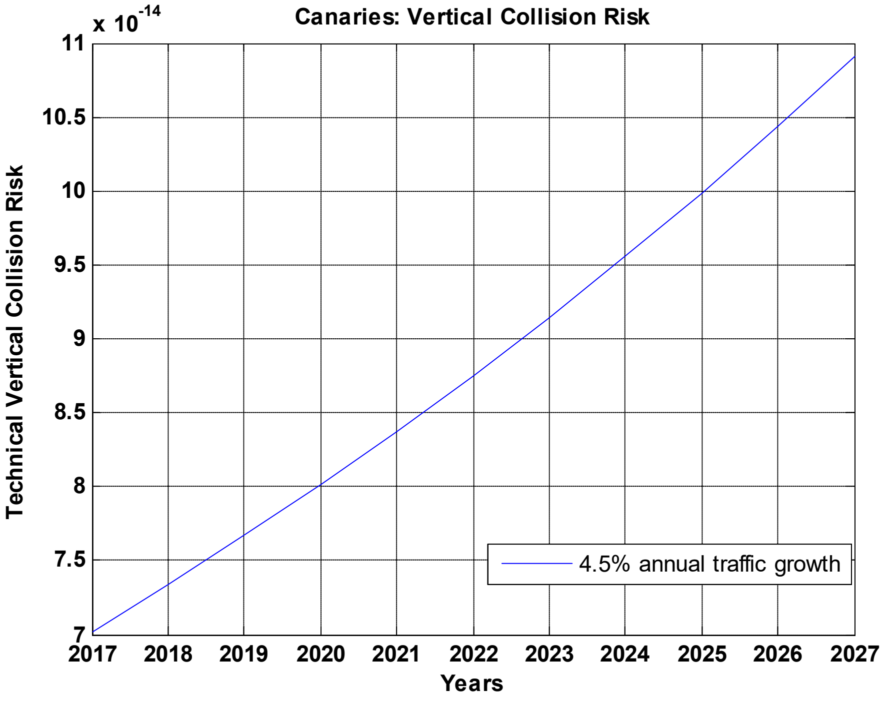


Figure 18.
Technical vertical collision risk for the period 2017-2027 in the Canaries (enlarged)

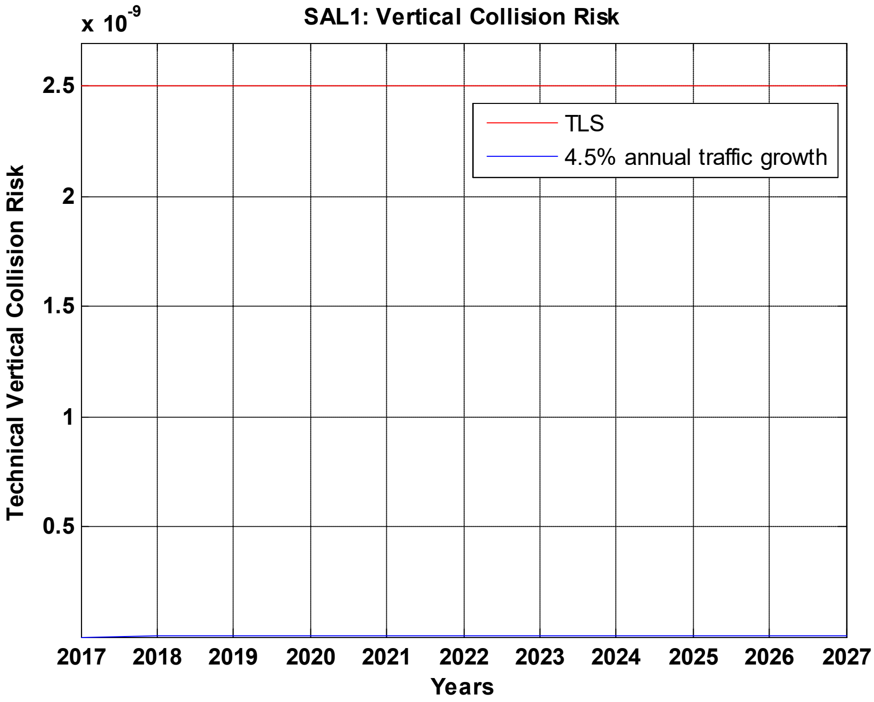


Figure 19.
Technical vertical collision risk for the period 2017-2027 in SAL1

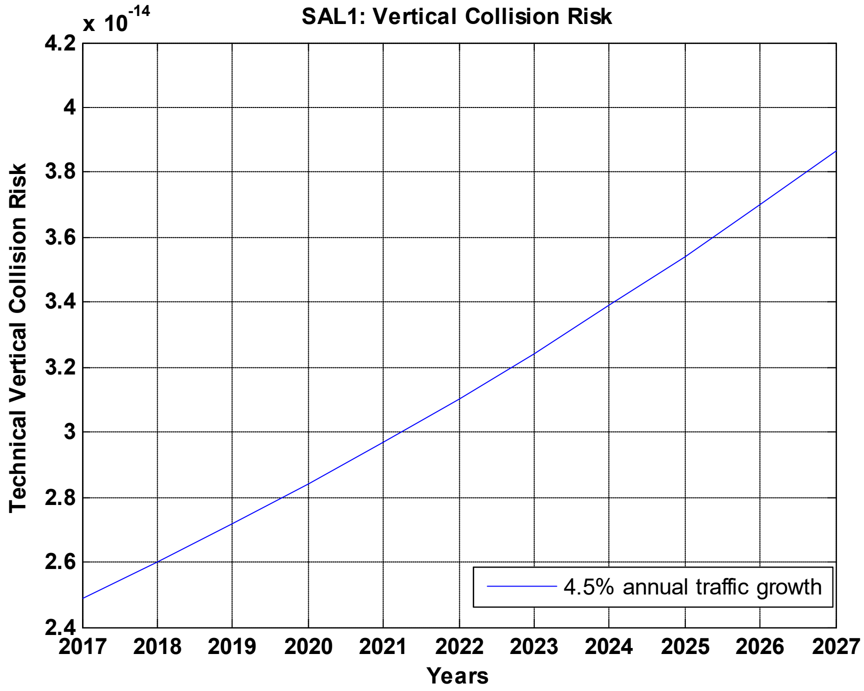


Figure 20.
Technical vertical collision risk for the period 2017-2027 in SAL1 (enlarged)

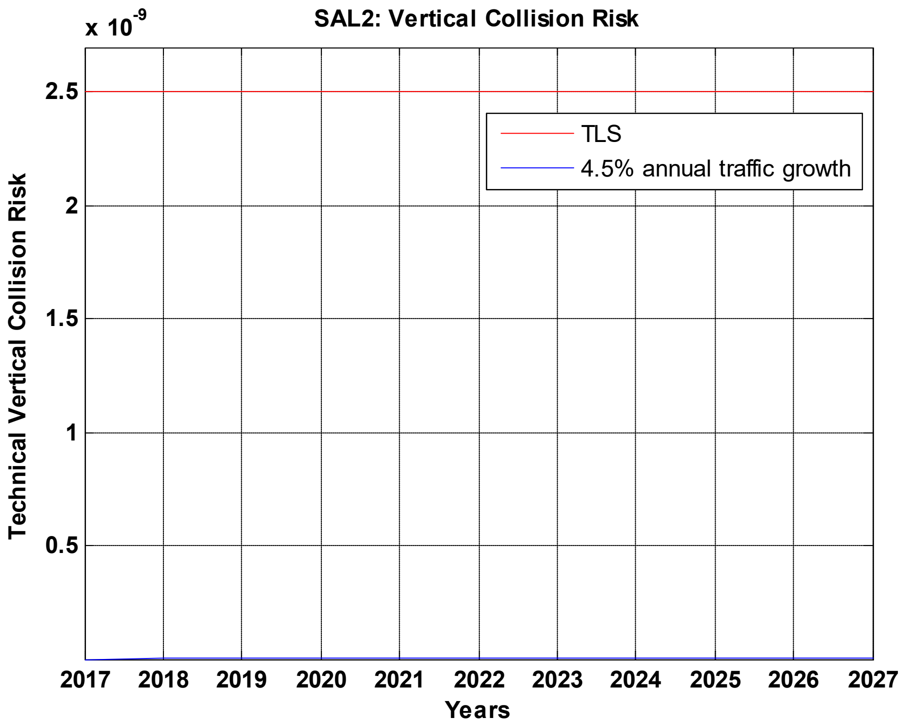


Figure 21.
Technical vertical collision risk for the period 2017-2027 in SAL2

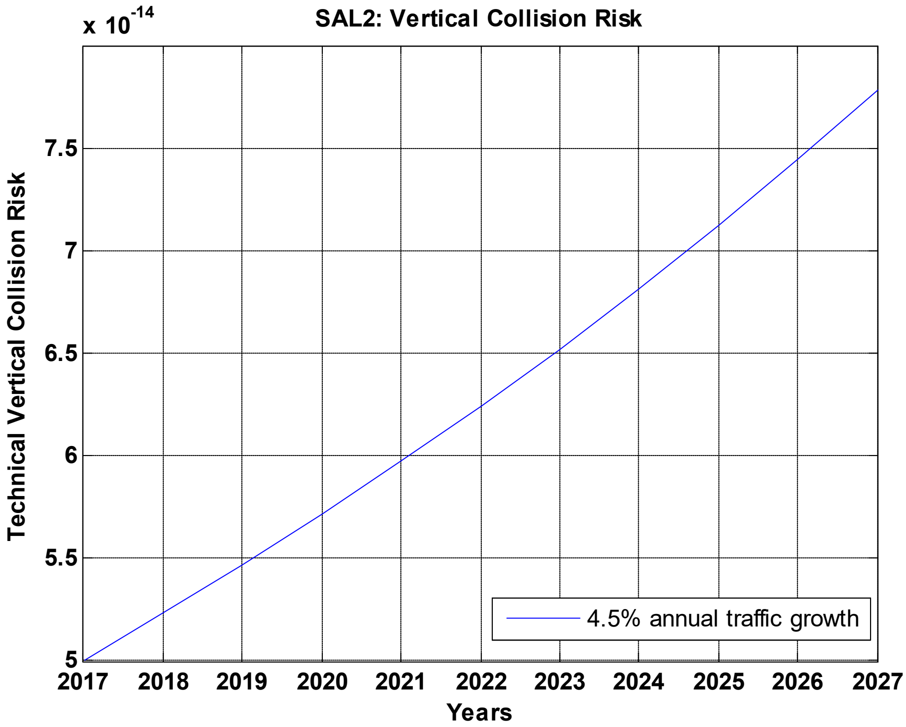


Figure 22.
Technical vertical collision risk for the period 2017-2027 in SAL2 (enlarged)

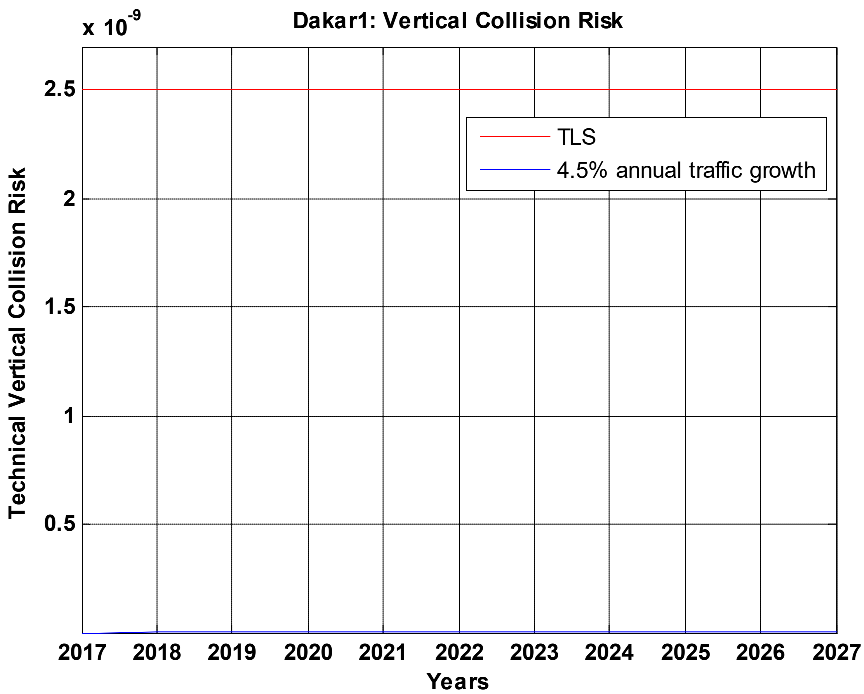


Figure 23.
Technical vertical collision risk for the period 2017-2027 in Dakar1

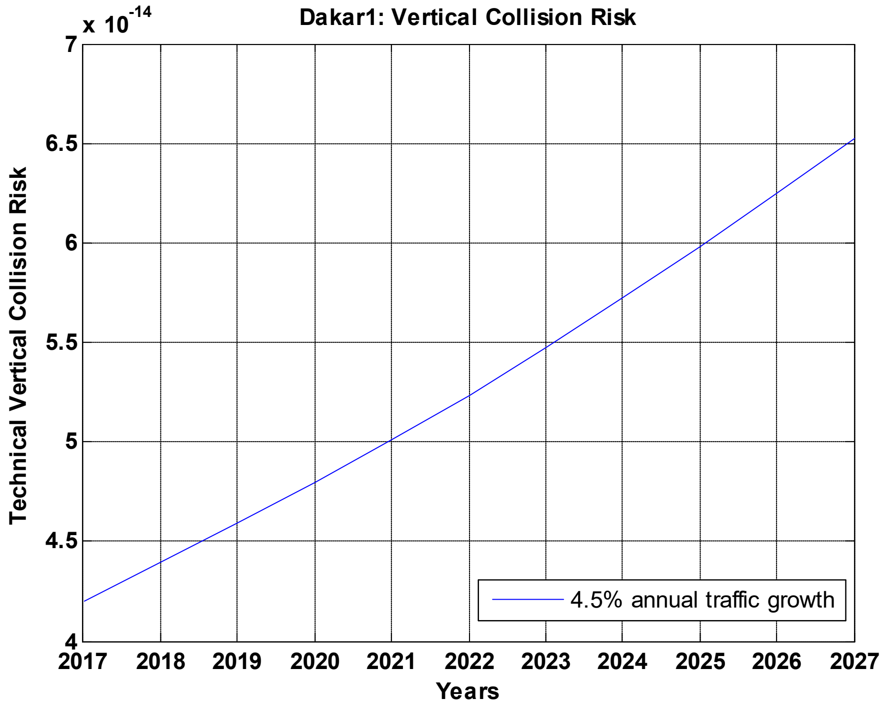


Figure 24.
Technical vertical collision risk for the period 2017-2027 in Dakar1 (enlarged)

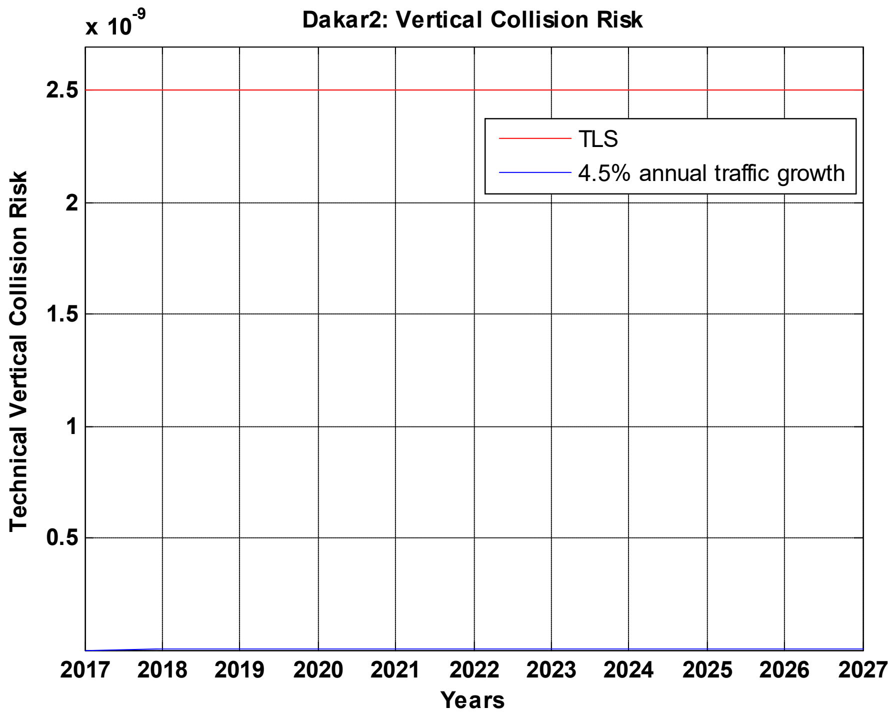


Figure 25.
Technical vertical collision risk for the period 2017-2027 in Dakar2

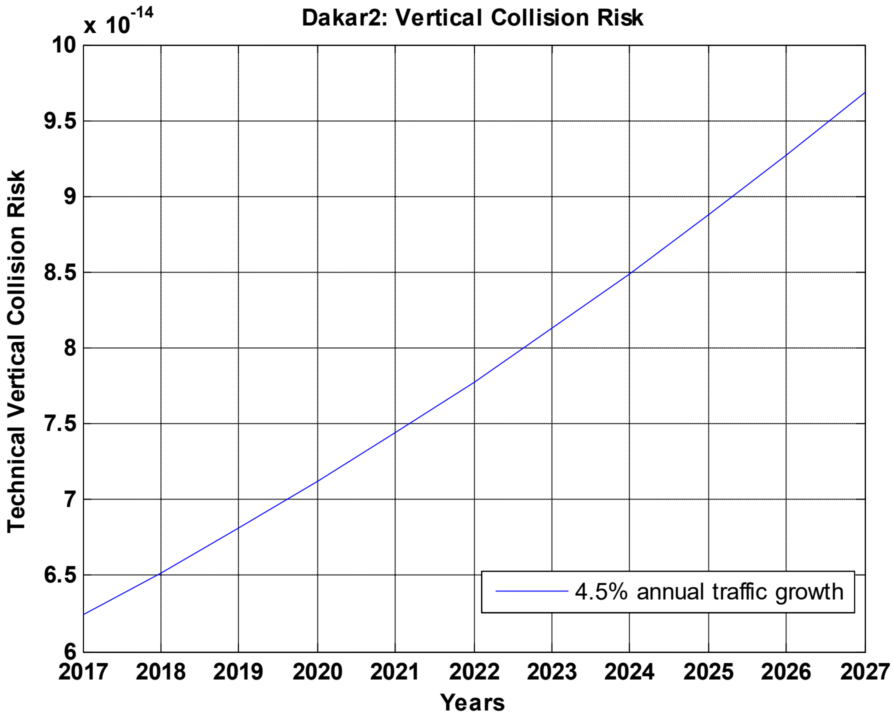


Figure 26.
Technical vertical collision risk for the period 2017-2027 in Dakar2 (enlarged)

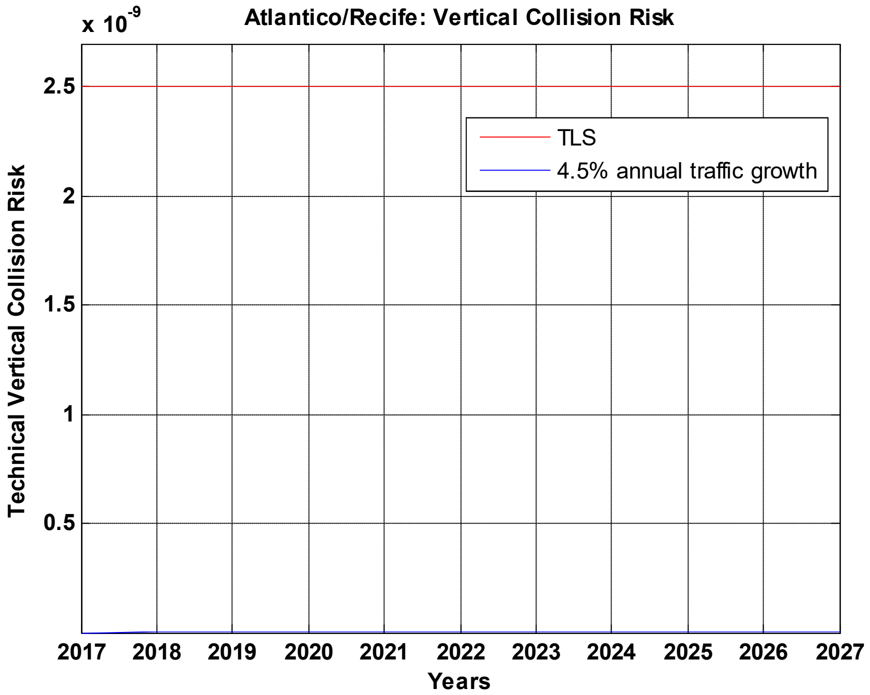


Figure 27.
Technical vertical collision risk for the period 2017-2027 in Recife

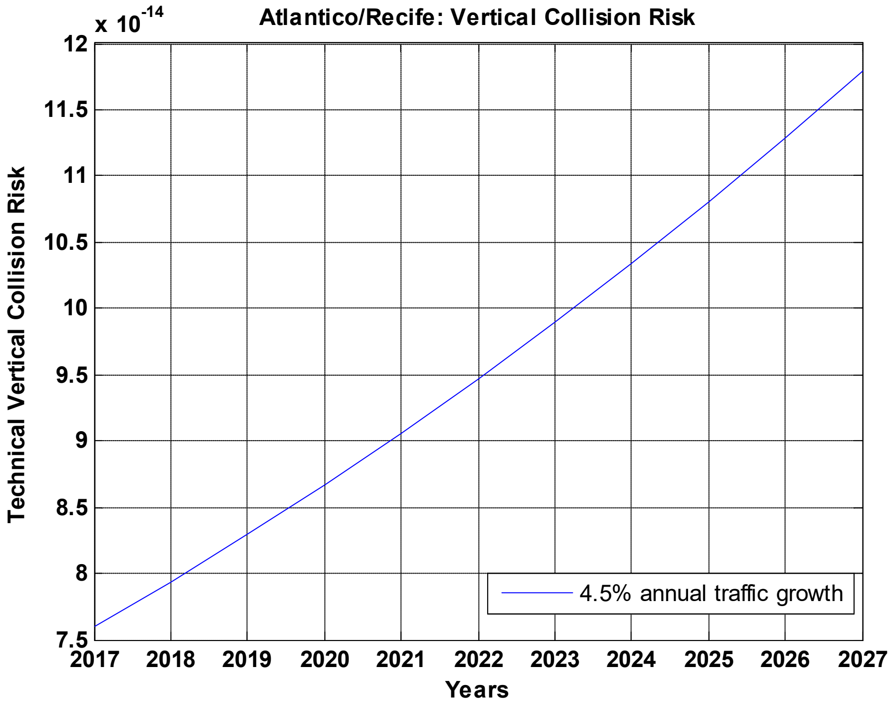


Figure 28.
Technical vertical collision risk for the period 2017-2027 in Recife (enlarged)

4.1.8. Considerations on the results

It can be seen that the estimates of the technical vertical risk are below the technical TLS even in 2027 in all the locations, and similar to the values obtained in the last year assessment ([Ref. 9]).

4.2. Total vertical collision risk assessment

In order to assess the total vertical risk, the risk due to large, atypical height deviations[3] must be assessed and added to the technical vertical risk.

In accordance with the ICAO recommendations ([Ref. 31]), large height deviations can be classified as reflected in Table 43. This classification has been used in the EUR/SAM Corredor.

[3] *A RVSM large height deviation (LHD) is defined as any vertical deviation of 90 metres/300 feet or more from the flight level expected to be occupied by the flight.*

LHD types	
Code	LHD Description
A	Flight crew fails to climb or descend the aircraft as cleared
B	Flight crew climbing or descending without ATC clearance
C	Incorrect operation or interpretation of airborne equipment
D	ATC system loop error
E	ATC transfer of control coordination errors due to human factors
F	ATC transfer of control coordination errors due to technical issues
G	Aircraft contingency leading to sudden inability to maintain level
H	Airborne equipment failure and unintentional or undetected level change
I	Turbulence or other weather related cause
J	TCAS resolution advisory and flight crew correctly responds
K	TCAS resolution advisory and flight crew incorrectly responds
L	Non-approved aircraft is provided with RVSM separation
M	Other

Table 43.
LHD classification according to ICAO

4.2.1. Data on EUR/SAM large height deviations

As it has been explained in [Ref. 32], data needed for the different models should be obtained from the large height deviation reports received from the different UIRs.

The information that has been made available for this assessment can be seen in the following tables, where the time spent at an incorrect flight level, necessary to calculate the risk due to an aircraft levelling off at a wrong level, had to be estimated in the major part of the LHDs, since it was not included in the reports. Therefore, it has been necessary to use default values according to the following set of criteria:

- Coordination error (no notification of the transfer or transfer at unexpected flight level) and detection of the aircraft when entering the UIR: 5 minutes.
- Coordination error (no notification of the transfer) and undetected aircraft in the UIR. The duration of the flight in that UIR, taking into account its speed.

Table 44 indicates the months for which LHD reports have been received. From these LHDs, only those affecting the four main routes have been considered[4]. Table 45, Table 46, Table 47 and Table 48 show the details of the deviations reported in the Canaries, SAL, Dakar and Atlantic-Recife, respectively.

[4] *The considered LHDs have been those that have taken place in the main routes and in incorporations to the main routes coming from the DCT area. It is to be noted that a larger number of deviations has been reported by States. However, not all of them concerned lateral or vertical deviations and not all of them affected the main routes or the RVSM flight levels. These deviations have not been included in the assessment and are not presented in this report.*

Months	Canarias UIR	SAL Oceanic UIR	Dakar Oceanic UIR	Atlántico-Recife FIR/UIR
Jan-17	"No deviation" report received	"No deviation" report received	"No deviation" report received	"No deviation" report received
Feb-17	Available	Available	Available	"No deviation" report received
Mar-17	"No deviation" report received	"No deviation" report received	Available	"No deviation" report received
Apr-17	"No deviation" report received	"No deviation" report received	Available	"No deviation" report received
May-17	Available	Available	Available	"No deviation" report received
Jun-17	"No deviation" report received	"No deviation" report received	Available	"No deviation" report received
Jul-17	Available	Available	Available	"No deviation" report received
Aug-17	Available	Available	"No deviation" report received	"No deviation" report received
Sep-17	"No deviation" report received	Available	Available	Available
Oct-17	Available	Available	Available	"No deviation" report received
Nov-17	"No deviation" report received	Available	Available	"No deviation" report received
Dec-17	Available	Available	Available	"No deviation" report received

KEY: Available (green) — Not available (red) — "No deviation" report received (yellow)

Table 44.
Received data from January 2017 to December 2017

Date	Route	Duration	Coordinated FL	Observed FL	Deviation	Cause	Category
260217	UN866	0.08333 h	FL390	FL390	0	Coordination Error	F
150517	UN873	0.08333 h	FL370	FL350	2000 ft	Coordination Error	E
050817	UN866	0.65000 h	FL370	FL390	2000 ft	Coordination Error	F
241017	UN866	0.08333 h	FL330	FL340	1000 ft	Coordination Error	E
011217	UN866	0.06666 h	FL330	FL350	2000 ft	Coordination Error	F
071217	UN873	0.08333 h	FL370	FL350	2000 ft	Coordination Error	F
171217	UN873	0.08333 h	FL370	FL390	2000 ft	Coordination Error	F

Table 45.
Large height deviations reported in the Canaries

Date	Route	Duration	Coordinated FL	Observed FL	Deviation	Cause	Category
050217	UN873	0.08333 h	FL340	FL340	0	Coordination Error	E
140817	UN873	0.08333 h	FL380	FL360	2000 ft	Coordination Error	E
280917	UN866	0.08333 h	FL350	FL370	2000 ft	Coordination Error	E

Table 46.
Large height deviations reported in SAL

Date	Route	Duration	Coordinated FL	Observed FL	Deviation	Cause	Category
040117	UN857	0.16666 h	FL350	FL370	2000 ft	Coordination Error	E
190417	UN873	0.08333 h	FL400	FL400	0	Coordination Error	E
230517	UN741	0.08333 h	FL350	FL360	1000 ft	Coordination Error	E
230617	RANDOM	0.16666 h	FL310	FL330	2000 ft	Coordination Error	E
310717	UN857	0 h	FL360	FL320	4000 ft	Coordination Error	B/E
120917	UN873	0.16666 h	FL360	FL400	4000 ft	Coordination Error	E
211217	UN873	0.16666 h	FL350	FL330	2000 ft	Coordination Error	E

Table 47.
Large height deviations reported in Dakar

Date	Route	Duration	Coordinated FL	Observed FL	Deviation	Cause	Category
190917	UN873	0.08333 h	FL360	FL380	2000 FT	Coordination Error	E
190917	UN741	0.08333 h	FL380	FL370	1000 FT	Coordination Error	E

Table 48.
Large height deviations reported in Recife

After an analysis of the deviation reports, it can be concluded that all of the registered deviations are due to errors in coordination between adjacent ATC units, resulting in either no notification of the transfer or in transfer at an unexpected flight level.

4.2.2. Total vertical collision risk

The total vertical risk is the sum of the technical risk and the risks due to large height deviations involving whole numbers of flight levels (both climbing/descending aircraft and level flight aircraft) and the risk due to large height deviations not involving whole numbers of flight levels. So,

$$N_{az}^{total} = N_{az}^{tech} + N_{az}^{wl} + N_{az}^{cl/d} + N_{az}^{*}$$

Equation 2.

Technical risk has already been calculated in 4.1.7.

Regarding the risk due to large height deviations, as it can be seen in Table 45, Table 46, Table 47 and Table 48, there are no reports due to large height deviations not involving whole numbers of flight levels and $\mathrm{N}_{\mathrm{az}}^{*} = 0$.

In all the deviations reported due to coordination errors between ATC units for which there is not enough information it is assumed that the level change, if any, took place in the transferring UIR following appropriate clearances and, when the aircraft entered the new UIR, the aircraft was already established at the incorrect flight level. Therefore, in these cases, the number of crossed levels is zero.

Nevertheless, the analysis of the deviations reported indicates that three levels were crossed in the period analyzed in Dakar UIR due to an aircraft climbing when entering the FIR without prior climbing information from the adjacent FIR. Therefore, there will be a contribution to the corresponding risk, $\mathrm{N}_{\mathrm{az}}^{\mathrm{cl/d}}$, in this UIR.

Consequently, the terms to be calculated are the risk due to an aircraft levelling off at a wrong level and the risk due to an aircraft climbing or descending through a flight level without a proper clearance.

Most of the parameters used to calculate these two risks have already been presented within the vertical technical collision risk section (4.1). The new values required are the ones necessary to calculate the probabilities of vertical overlap and the relative vertical speed for an aircraft climbing or descending.

In the following table, relevant data for these calculations, based on traffic levels representative for the year 2017, have been gathered, namely: the time spent at a wrong level, the number of crossed levels and the total flight time within those months in which a LHD or a "no LHD" reports have been received for each location. As the annual flight time information is only available for the Canaries FIR, the annual flight time in each FIR has been estimated relating the flight time in August in each FIR with the one calculated in the Canaries and applying the same proportion to the complete year.

<table>
<tr><th rowspan="2">Number of flights</th><th colspan="4">Jan-Dec 2017</th></tr>
<tr><th>Canaries</th><th>SAL</th><th>Dakar</th><th>Recife</th></tr>
<tr><td>Same direction time at incorrect level (h)</td><td>1.1333</td><td>0.2500</td><td>0.8333</td><td>0.1667</td></tr>
<tr><td>Opposite direction time at incorrect level (h)</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>Same direction number of crossed levels (N)</td><td>0</td><td>0</td><td>1</td><td>0</td></tr>
<tr><td>Opposite direction number of crossed levels (N)</td><td>0</td><td>0</td><td>2</td><td>0</td></tr>
<tr><td>Total FIR/UIR flight time (h)</td><td>17085.40</td><td>21780.79</td><td>31906.45</td><td>21962.20</td></tr>
<tr><td>Total Corridor flight time (h)</td><td>92734.83</td><td>92734.83</td><td>92734.83</td><td>92734.83</td></tr>
<tr><td>Wrong level, same direction vertical overlap probability</td><td>$3.3233*10^{-5}$</td><td>$5.7505*10^{-6}$</td><td>$1.3085*10^{-5}$</td><td>$3.8020*10^{-6}$</td></tr>
<tr><td>Wrong level, opposite direction vertical overlap probability</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td rowspan="2">Climb/descend, same direction vertical overlap probability</td><td rowspan="2">0</td><td>SAL 1
0</td><td>Dakar 1
$3.8162*10^{-8}$</td><td rowspan="2">0</td></tr>
<tr><td>SAL 2
0</td><td>Dakar 2
$3.8194*10^{-8}$</td></tr>
<tr><td rowspan="2">Climb/descend, opposite direction vertical overlap probability</td><td rowspan="2">0</td><td>SAL 1
0</td><td>Dakar 1
$7.6325*10^{-8}$</td><td rowspan="2">0</td></tr>
<tr><td>SAL 2
0</td><td>Dakar 2
$7.6387*10^{-8}$</td></tr>
<tr><td>Climb/descend relative vertical speed (kts)</td><td>15</td><td>15</td><td>15</td><td>15</td></tr>
</table>

Table 49.
Operational vertical collision risk parameters in the Corridor

Table 50 shows the estimate of the total vertical collision risk, sum of the technical vertical risk and the operational vertical risk, considering that the traffic growth factor is 4.5% per annum. These results can also be seen in Figure 29 to Figure 34.

Total Vertical Collision risk	4.5% annual traffic growth					
	Canaries	SAL1	SAL2	Dakar1	Dakar2	Recife
2017	$6.6713*10^{-8}$	$3.7315*10^{-8}$	$3.8062*10^{-8}$	$8.4238*10^{-8}$	$1.0343*10^{-7}$	$1.4048*10^{-8}$
2018	$6.9715*10^{-8}$	$3.8994*10^{-8}$	$3.9774*10^{-8}$	$8.8029*10^{-8}$	$1.0808*10^{-7}$	$1.4680*10^{-8}$
2019	$7.2852*10^{-8}$	$4.0749*10^{-8}$	$4.1564*10^{-8}$	$9.1990*10^{-8}$	$1.1294*10^{-7}$	$1.5340*10^{-8}$
2020	$7.6130*10^{-8}$	$4.2583*10^{-8}$	$4.3435*10^{-8}$	$9.6130*10^{-8}$	$1.1803*10^{-7}$	$1.6031*10^{-8}$
2021	$7.9556*10^{-8}$	$4.4499*10^{-8}$	$4.5389*10^{-8}$	$1.0046*10^{-7}$	$1.2334*10^{-7}$	$1.6752*10^{-8}$
2022	$8.3136*10^{-8}$	$4.6501*10^{-8}$	$4.7432*10^{-8}$	$1.0498*10^{-7}$	$1.2889*10^{-7}$	$1.7506*10^{-8}$
2023	$8.6877*10^{-8}$	$4.8594*10^{-8}$	$4.9566*10^{-8}$	$1.0970*10^{-7}$	$1.3469*10^{-7}$	$1.8294*10^{-8}$
2024	$9.0787*10^{-8}$	$5.0781*10^{-8}$	$5.1797*10^{-8}$	$1.1464*10^{-7}$	$1.4075*10^{-7}$	$1.9117*10^{-8}$
2025	$9.4872*10^{-8}$	$5.3066*10^{-8}$	$5.4128*10^{-8}$	$1.1979*10^{-7}$	$1.4708*10^{-7}$	$1.9977*10^{-8}$
2026	$9.9151*10^{-8}$	$5.5454*10^{-8}$	$5.6563*10^{-8}$	$1.2519*10^{-7}$	$1.5370*10^{-7}$	$2.0876*10^{-8}$
2027	$1.0360*10^{-7}$	$5.7949*10^{-8}$	$5.9109*10^{-8}$	$1.3082*10^{-7}$	$1.6062*10^{-7}$	$2.1815*10^{-8}$

Table 50.
Total vertical collision risk for the period 2017-2027

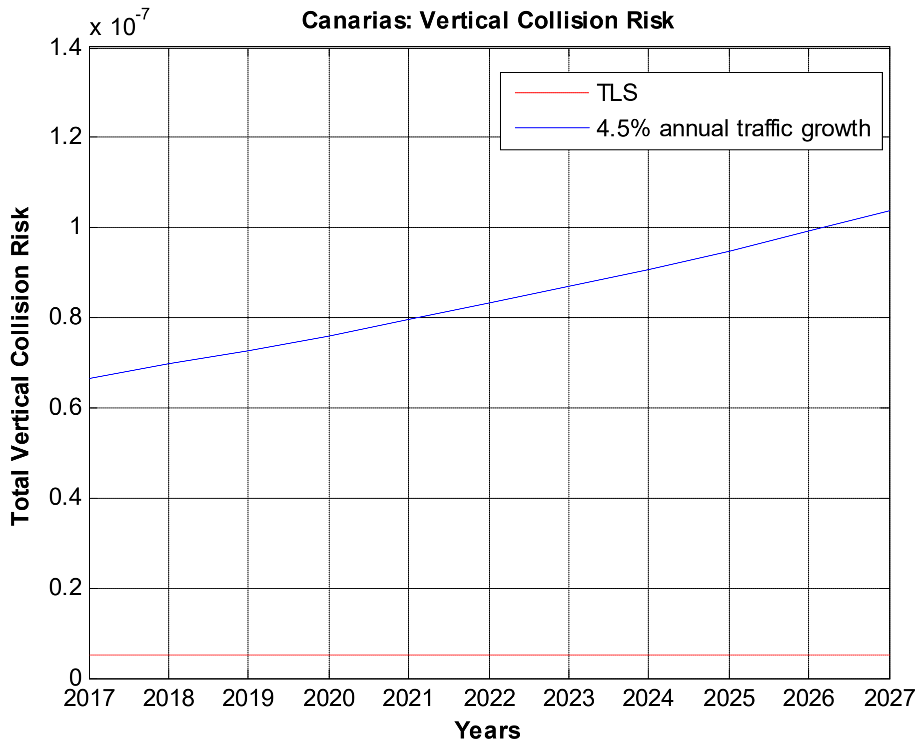


Figure 29.
Total vertical collision risk for the period 2017-2027 in the Canaries

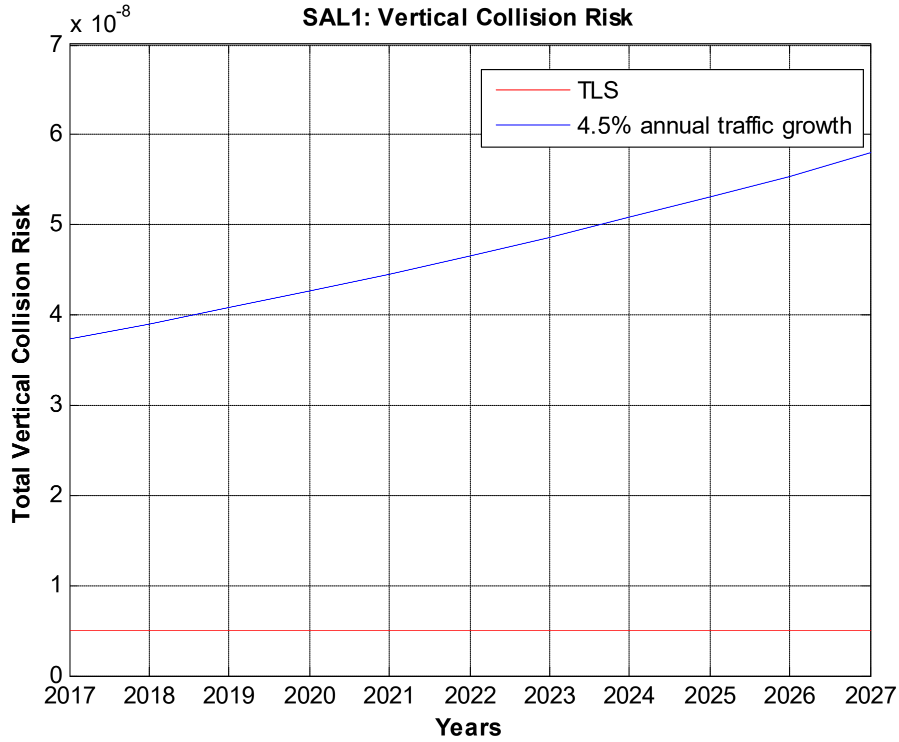


Figure 30.
Total vertical collision risk for the period 2017-2027 in SAL1

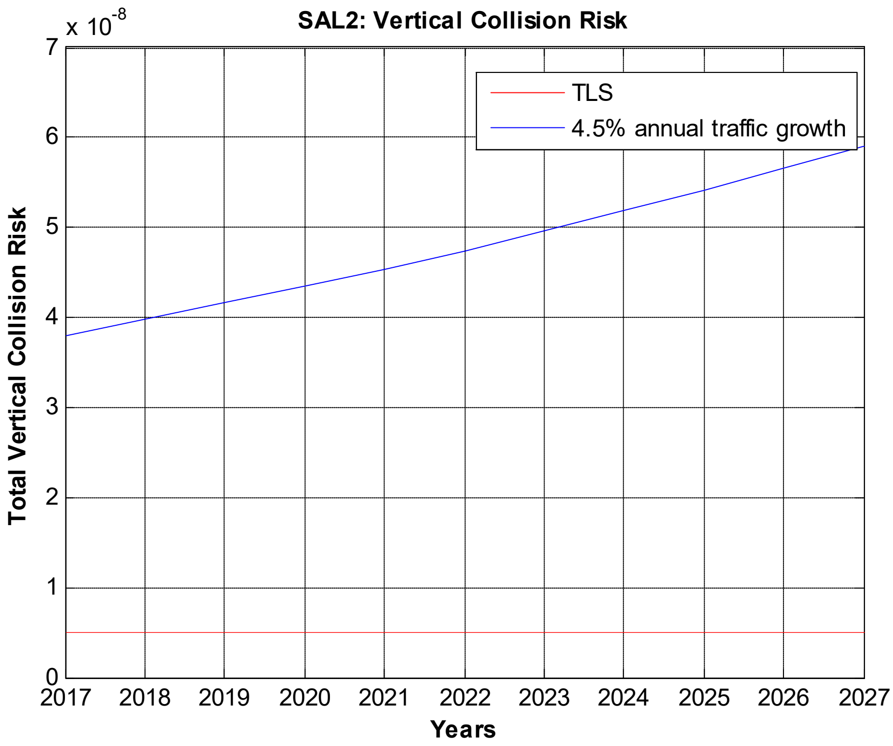


Figure 31.
Total vertical collision risk for the period 2017-2027 in SAL2

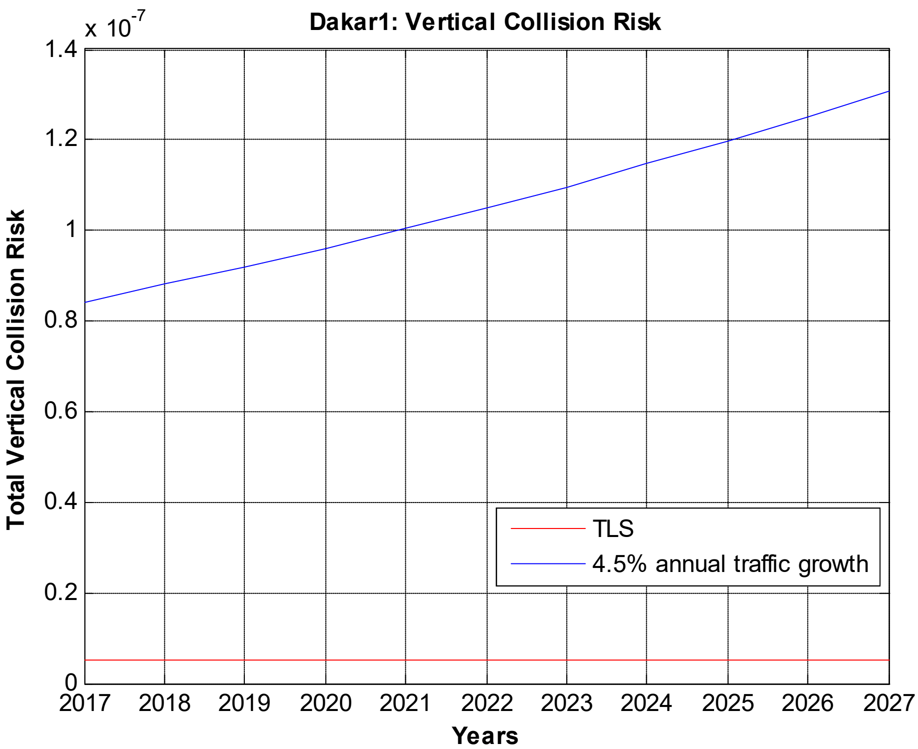


Figure 32.
Total vertical collision risk for the period 2017-2027 in Dakar1

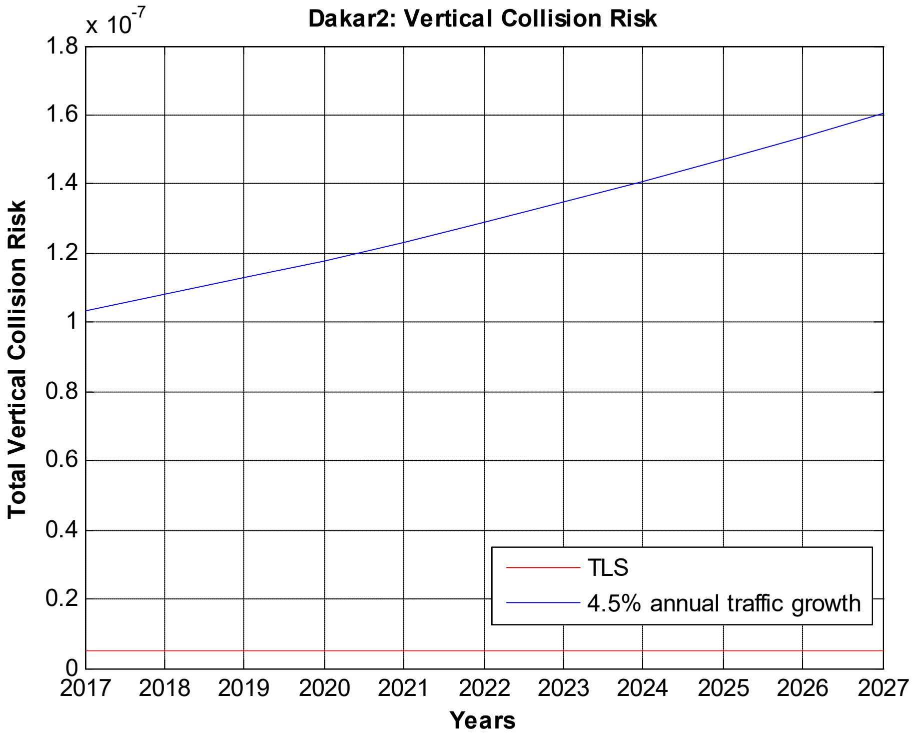


Figure 33.
Total vertical collision risk for the period 2017-2027 in Dakar2

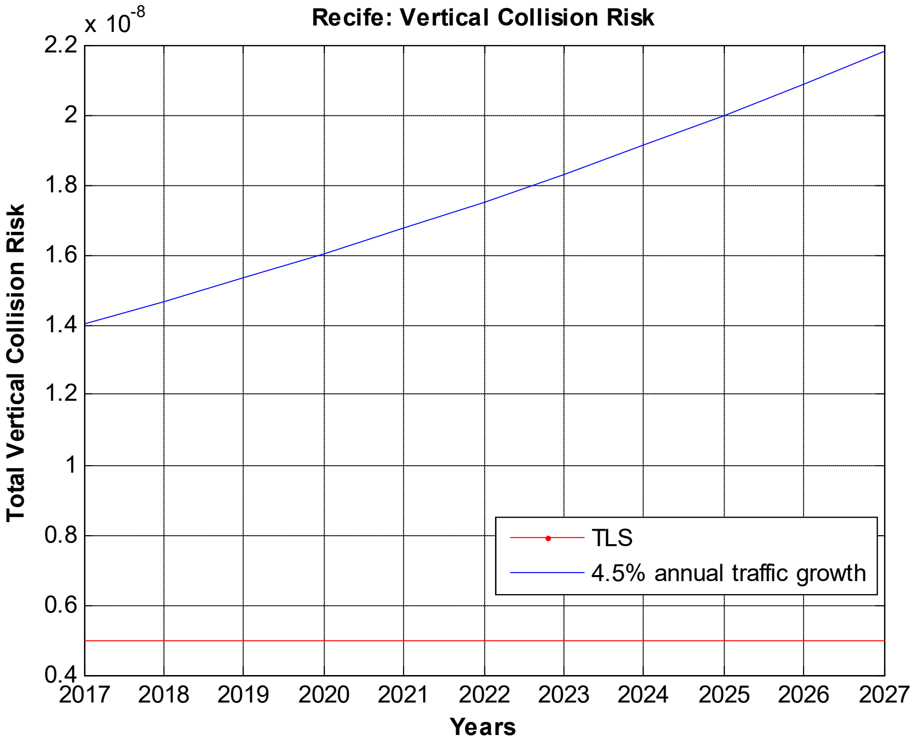


Figure 34.
Total vertical collision risk for the period 2017-2027 in Recife

4.2.3. Considerations on the results

The total vertical risk calculated using the deviations reported by the States is higher than the TLS in all locations.

In previous safety assessments, such as [Ref. 3], [Ref. 5], [Ref. 8] or [Ref. 9], it was remarked that all the received deviations had been due to coordination errors between ATC units and not related to RVSM operations. In the same way, it was also explained that the deviation reports indicated that there was not any traffic in conflict. That is also the case of this study.

The same problem, the collision risk being higher than the TLS if coordination errors are taken into account, was already identified in the previous safety assessments and the corresponding conclusions were presented. Nevertheless, it is also advisable to insist on the need of implementing adequate corrective actions to reduce operational errors in the Corridor.

4.2.3.a. Influence of the $P_y(0)$ value

As it was indicated in 4.1.2, the selected value of $P_y(0)$ could be overly conservative, having this parameter a direct influence on the vertical collision risk results. Alternative calculations have also been made using a value of $P_y(0)$=0.059, which is more similar to the ones used in European studies and in the Collision Risk Assessments performed by other Regional Monitoring Agencies ([Ref. 28], [Ref. 29] and [Ref. 30]).

Using this value of $P_y(0)$=0.059, the obtained results are shown in Table 51.

FIR/UIR	Vertical risk	
	Technical risk	Total vertical risk
Canaries	$1.6384*10^{-14}$	$16.5273*10^{-9}$
SAL1	$0.5536*10^{-14}$	$13.9746*10^{-9}$
SAL2	$1.0112*10^{-14}$	$8.2563*10^{-9}$
Dakar1	$0.8687*10^{-14}$	$21.3481*10^{-9}$
Dakar2	$1.2753*10^{-14}$	$24.0944*10^{-9}$
Recife	$1.5338*10^{-14}$	$3.2209*10^{-9}$

Table 51.
Technical and total vertical risk using Py(0)=0.059

As it can be seen in Table 51, even if a value of $P_y(0)$=0.059 were used, the results for the total vertical risk would still be above the TLS.

5. Conclusions

Given that not all the traffic data from the different UIRs for the required period of time were available at the end of the year, only real traffic data for one month from all Corridor UIRs have been used for this study. Besides, some information was still missing and some inconsistencies have been detected. However, more information is available for large height deviation reports, as information for all FIR/UIR and months has been received. Nevertheless, some conservative assumptions had to be made regarding the modelling of probability densities and the extrapolation of traffic data.

Taking this into account, the following conclusions can be extracted from the analysis in the six different locations considered (the risk associated to the Corridor is considered to be the largest of the values calculated for each location):

- Lateral collision risk assessment:
    - The probability of lateral overlap increases as the separation between routes decreases, as it was expected. The value obtained for $S_y = 50\,NM$ is between $P_y(50) = 9.1450 \cdot 10^{-8}$ and $P_y(50) = 1.1624 \cdot 10^{-7}$, depending on the location, whilst the lateral overlap probability obtained for $S_y = 90\,NM$ is between $P_y(90) = 3.0392 \cdot 10^{-8}$ and $P_y(90) = 4.1333 \cdot 10^{-8}$.
    - For current traffic levels, the lateral collision risk obtained is $2.9374*10^{-9}$, whilst the lateral collision risk estimated for 2027 with an annual traffic growth rate of 4.5% is $4.5617*10^{-9}$. These values do not take into account traffic on the DCT Area route.
    - It should be remarked that the values of lateral technical collision risk for 2017 and the projection to the next 10 years, are similar to those obtained in previous collision risk assessments.

- Vertical risk assessment:
    - Vertical risk is split into two parts, one for the technical vertical risk and the second one for the vertical risk due to all causes. The same collision risk model is used for both. The differences are the value of the vertical overlap probability and the relative vertical speed to use in each one.
    - The probability of vertical overlap due to technical causes was based on the probability distribution of Total Vertical Error (TVE). This was obtained by convoluting probability distributions of Altimetry System Errors (ASE) and typical Assigned Altitude Deviation (AAD). In the absence of any direct monitoring data from the EUR/SAM Corridor, 2017 height-keeping data and models from the EUR airspace provided by Eurocontrol have been used.
    - The value of the vertical overlap probability calculated by means of EUROCONTROL RVSM tool with traffic data from the Canaries for 2017, for S_z=1000 ft is $P_z(1000) = 6.0414 \cdot 10^{-13}$.
    - The lateral overlap probability for aircraft nominally flying at adjacent flight levels of the same path, $P_y(0)$ has been obtained conservatively assuming that all aircraft are using GNSS and that their lateral path-keeping errors standard deviation is 0.0612 NM. The value obtained for $P_y(0)$ is between 0.2532 and 0.2989 depending on the location, which is much higher than the value assumed by the RGCSP, 0.059.
    - The value of the vertical technical collision risk for the current traffic levels is estimated to be $7.5962*10^{-14}$. The technical vertical collision risk estimated for 2027 with an annual traffic growth rate of 4.5% is $9.4662*10^{-14}$. Both values are below the TLS.

  - The technical vertical risk obtained in this study is similar to the one obtained in the previous safety assessment.
  - The vertical risk due to large height deviations has been calculated using the deviations reported by the States. The total vertical risk calculated using these deviations is much higher than the TLS.
  - All the deviations received were due to a coordination error or resulted in a coordination error, and they are not related to RVSM operations.
  - The same problem, the collision risk being higher than the TLS if coordination errors are taken into account, was already identified in the previous safety assessments.

It can be concluded that lateral and technical vertical collision risks are below the TLS. Nevertheless, the validity of these results depends on the validity of the assumptions made.

Regarding the total vertical risk, the risk greatly exceeds the TLS even with current traffic levels. In any case, as the main problem, coordination errors, is clearly identified, the use of adequate corrective actions to reduce coordination errors in the Corridor would reduce the risk. These measures should be applied as soon as feasible.

As the accuracy of the assessment greatly depends on the availability and accuracy of the data provided, it is recommended that for next assessments:

- Accurate flight progress data from all FIR/UIRs be made available, including as much information as possible in the traffic samples, to facilitate the verification of traffic flows, distribution and passing frequencies used in the analysis.
- Data on lateral and vertical deviations obtained from radar data and incident reports should be provided in order to improve the estimation of overlap probabilities (a continuous monitoring process is required to obtain a representative data sample on deviations for future assessments).
- All LHDs should be reported and better information about LHDs must be made available, as not always complete information about them has been provided.

6. Reference documentation

[Ref. 1] Atlas South Atlantic Crossing 57C, 22 Dec 05. Air navigation Chart

[Ref. 2] Risk Assessment of RNP10 and RVSM in the South Atlantic Flight Identification Regions Including an Assessment for Limited Implementation of RVSM on RN741. (ARINC)

[Ref. 3] EUR/SAM Corridor: "Double unidirectionality" post-implementation collision risk assessment. NIVY-IDSA-INF-001-1.0-09. January 09.

[Ref. 4] First approach to 2009 Collision Risk Assessment within the EUR/SAM Corridor. NYVI-IDSA-INF-008-1.0/10. May 2010.

[Ref. 5] EUR/SAM Corridor: 2009 Collision risk assessment. NYVI-IDSA-INF-036-1.0/10. December 2010.

[Ref. 6] EUR/SAM Corridor: 2010 Collision risk assessment. NYVI-IDSA-INF-003-1.0/12. February 2012.

[Ref. 7] EUR/SAM Corridor: 2014 Collision risk assessment. NYVI-IDSA-INF-007-1.0/16. February 2016.

[Ref. 8] EUR/SAM Corridor: 2015 Collision risk assessment. NYVI-IDSA-INF-074-1.0/16. February 2017.

[Ref. 9] EUR/SAM Corridor: 2016 Collision risk assessment. NYVI-IDSA-INF-017-1.0/17. June 2017.

[Ref. 10] AIP Spain. AIS. AIC 17/Jan/01

[Ref. 11] Separation and Airspace Safety Panel. A New Parameter for Gross Lateral Errors (SASP-WG/A/2-WP/4, 21/10/01)

[Ref. 12] Manual on airspace planning methodology for the determination of separation minima (ICAO Doc 9689-AN/953)

[Ref. 13] Air Traffic Services Planning manual. Doc 9426 OACI

[Ref. 14] ICAO Document 9574 (2nd edition). Manual on Implementation of a 300m (1000ft) Vertical Separation Minimum between FL290 and FL410 inclusive.

[Ref. 15] RVSM Safety Assessment of the Australian Airspace for the period 1 Jan 2004 through 31 Dec 2004.-RASMAG/3-WP/16 06/06/2005. OACI

[Ref. 16] Summary of the Airspace Safety Review for the RVSM Implementation in Asia Region.- RASMAG/4-WP11 25/10/2005. OACI

[Ref. 17] The EUR RVSM Mathematical Supplement.-MDG/21 DP/01 August 2001.

[Ref. 18] CAR/SAM-Course on Introduction to Safety Assessment. Lima, 19-23/06/06 (www.lima.icao.int)

[Ref. 19] SAT/12-TF/1 Report. Appendix A to the Report on Agenda Item 2: An Update to the Summary of Reduced Vertical Separation Minimum (RVSM) Safety Assessment to Reflect the Operations Safety after the RVSM Implementation in CAR/SAM airspace in January 20th.- 5-9/09/06

[Ref. 20] STATFOR. Eurocontrol Seven-Year Forecast. February 2018

[Ref. 21] EUR/SAM Risk Assessments. DNV-ADS-INF-23-0.2/06. December 2006

[Ref. 22] Revised Pre-Implementation Collision Risk Assessment for RVSM in the Africa Indian Ocean Region. NLR-CR-2007-637. February 2007

[Ref. 23] Application of offset tracks. NLR. September 2007

[Ref. 24] AIC NR 13/A/08GO 30 October 2008. Bureau NOTAM International de L'Ouest Africain. Pre-Operational Implementation of AFDP, FPASD, ADS and CPDLC within Dakar and Niamey FIRs.

[Ref. 25] AIS-ESPAÑA. AIC 10 May 07. New route orientation on airways UN-741 and UN-866 (Corridor EUR/SAM)

[Ref. 26] AIS-ESPAÑA. AIC 30 July 09. ADS/CPDLC Operational implementation of the SACCAN FANS 1/A System in the Canarias FIR/UIR

[Ref. 27] Updated RMA Manual. SASP/13-WP/44. May 2008

[Ref. 28] "Airspace Safety Review of RVSM in Australian, Nauru, Papua New Guinea and Solomon Islands Airspace. January 2014 to December 2014", "Airspace Safety Review of the RVSM Implementation in Indonesian Airspace. January 2014 To December 2014".

[Ref. 29] "Airspace Safety Review for the RVSM operation In the airspace of Chinese Flight Information Regions. January 2012 - December 2012".

[Ref. 30] "Airspace Safety Review for the RVSM Implementation in Fukuoka Flight Information Region". Jan 2014 To Dec 2014"

[Ref. 31] ICAO Doc 9937 Manual of Operating Procedures and Practices for Regional Monitoring Agencies

[Ref. 32] Description of the methodology for the Collision Risk Assessment in the EUR/SAM Corridor

7. Acronyms

AAD	ASSIGNED ALTITUDE DEVIATION
ADS	AUTOMATIC DEPENDENT SURVEILLANCE
ASE	ALTIMETRY SYSTEM ERROR
ATC	AIR TRAFFIC CONTROL
ATS	AIR TRAFFIC SERVICES
DE	DOUBLE EXPONENTIAL DISTRIBUTION
EUR/SAM	EUROPE/SOUTH AMERICA
FIR	FLIGHT INFORMATION REGION
FL	FLIGHT LEVEL
FMC	FLIGHT MANAGEMENT COMPUTER
FTE	FLIGHT TECHNICAL ERROR
G	GAUSSIAN DISTRIBUTION
GL	GENERALISED LAPLACE DISTRIBUTION
HFDL	HIGH FREQUENCY DATA LINK
HMU	HEIGHT MONITORING UNIT
kts	KNOTS
MASPS	MINIMUM AVIATION SYSTEM PERFORMANCE STANDARDS
MDG	MATHEMATICS DRAFTING GROUP (EUROCONTROL)
NAT	NORTH ATLANTIC
NM	NAUTICAL MILE
RGCSP	REVIEW OF THE GENERAL CONCEPT OF SEPARATION PANEL
RNP	REQUIRED NAVIGATION PERFORMANCE
RVSM	REDUCED VERTICAL SEPARATION MINIMUM
SAT	SOUTH ATLANTIC
SATCOM	SATELLITE COMMUNICATIONS

SATMA	SOUTH ATLANTIC MONITORING AGENCY
STATFOR	AIR TRAFFIC STATISTICS AND FORECASTS (EUROCONTROL)
TVE	TOTAL VERTICAL ERROR
UIR	UPPER FLIGHT INFORMATION REGION