EUR/SAM Corridor:
2019 Collision Risk Assessment

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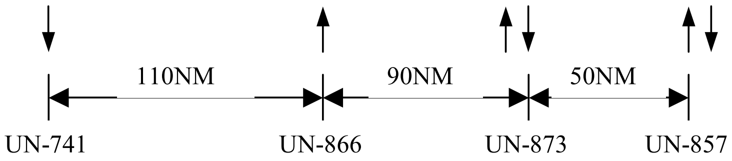
Executive Summary

This report presents the 2019 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 2019. 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 2019 to 31st August 2019. 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 2019, 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 2.9% 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 2019 are representative of the whole year, the calculated lateral collision risk is $2.3203*10^{-9}$, whilst the lateral collision risk estimated for 2029 with an annual traffic growth rate of 2.9% is $3.0881*10^{-9}$. 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 2019 (assuming traffic levels of August 2019 are representative of the whole year), is estimated to be $2.9057*10^{-12}$ and the technical vertical collision risk estimated for 2029 with an annual traffic growth rate of 2.9%, $3.8673*10^{-12}$. 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 $3.0459*10^{-7}$, which greatly exceeds the TLS.

In previous safety assessments, such as [Ref. 3], [Ref. 5], [Ref. 8], [Ref. 9], [Ref. 10] or [Ref. 101], 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 2019 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 2019 to 31st August 2019 and with the number of flights and the flight time required for some of the calculations extrapolated for the complete year 2019.

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. 34]. 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. 34], where the changes or new information regarding the airspace in the year 2019 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, have been made available from 1st August 2019 to 31st August 2019. When data, such as the number of flights or flight time for the rest of 2019 has been necessary, it has been extrapolated using information from Canaries as a basis.

Data for the complete year 2019 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 2019 to 31st December 2019. 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 2019, 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 2019 between FL290 and FL410 have been analysed.

Table 1 shows the values obtained for the Canaries UIR in 2019 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	6931	18,96825397	63.70	60.03	16.74
B738	3205	8,771209633	39.47	34.31	12.50
B77W	2981	8,158182813	73.90	60.90	18.50
B763	2980	8,155446086	47.60	54.90	15.90
B752	2719	7,441160372	47.32	38.05	13.60
A339	2220	6,075533662	63.66	64.00	16.79
A359	1935	5,295566502	66.80	64.75	17.05
B789	1759	4,813902573	62.80	60.10	16.90
A320	1408	3,85331144	37.57	34.10	11.76
B788	1399	3,828680898	56.70	60.10	16.90
A343	1232	3,37164751	63.70	60.30	16.74
B772	1180	3,229337712	63.70	60.90	18.50
A346	1179	3,226600985	74.37	63.60	17.80
A333	937	2,564313082	63.70	60.03	16.74
B748	681	1,863711002	76.30	65.45	19.50
B744	534	1,461412151	70.70	64.40	19.40
A21N	509	1,392993979	44.51	35.80	11.76
A20N	482	1,319102354	37.57	35.80	11.76
A321	402	1,100164204	37.57	34.10	11.76
B38M	233	0,637657362	39.50	35.90	12.30
B77L	188	0,514504652	67.78	61.68	18.50
A319	187	0,511767926	33.84	34.10	11.76
B733	141	0,385878489	33,40	28,90	11,10
B737	102	0,279146141	33.60	34.30	12.50
FA7X	101	0,276409414	22.82	25.80	7.74
E35L	100	0,273672687	26.33	21.17	6.76
GLEX	98	0,268199234	30.30	28.65	7.57
CL60	78	0,213464696	20.86	19.35	6.28
F2TH	51	0,139573071	20.21	19.33	7.55
E190	51	0,139573071	36.24	28.72	10.57
C17	48	0,13136289	53.00	51.80	16.80
F900	45	0,123152709	20.20	19.30	7.60
LJ35	37	0,101258894	14.71	11.97	3.71
A400	36	0,098522167	42.40	45.10	14.70
GLF5	33	0,090311987	29.42	28.50	7.87
GLF4	26	0,071154899	26.90	23.79	7.64
LJ60	26	0,071154899	17.89	13.35	4.44
FA8X	25	0,068418172	24.46	26.29	7.94
FA50	20	0,054734537	18.52	18.96	6.97

Aircraft type	Count	% AC	Length (m)	Wingspan (m)	Height (m)
CRJX	19	0,051997811	39.01	26.02	7.50
GLF6	16	0,04378763	30.41	30.36	7.72
IL96	15	0,041050903	69.10	73.30	20.78
GL5T	15	0,041050903	28.69	28.65	7.70
LJ45	13	0,035577449	17.68	14.58	4.30
A124	12	0,032840722	69.10	73.30	20.78
H25B	10	0,027367269	15.60	15.70	5.40
E135	10	0,027367269	26.33	20.04	6.76
G280	10	0,027367269	20.30	19.20	6.50
CRJ2	10	0,027367269	26.80	21.21	6.30
A310	7	0,019157088	46.40	43.89	15.80
IL76	7	0,019157088	46.59	50.50	14.76
E295	7	0,019157088	41.50	35.10	10.90
CL30	6	0,016420361	20.90	18.40	6.10
E550	6	0,016420361	20.74	20.25	6.44
E290	5	0,013683634	36.20	33.70	11.00
E195	5	0,013683634	38.65	28.72	10.55
C750	5	0,013683634	22.05	19.38	5.84
WW24	4	0,010946907	15.90	13.70	4.80
C680	4	0,010946907	11.22	14.95	4.56
LJ55	4	0,010946907	16.80	13.30	4.50
IL62	4	0,010946907	53.12	43.30	12.35
ASTR	4	0,010946907	16.94	16.05	5.54
C68A	3	0,008210181	18.97	22.05	6.38
E545	3	0,008210181	19.69	20.25	6.43
A342	3	0,008210181	59.39	60.30	16.74
MD11	2	0,005473454	61.20	51.70	17.60
B735	2	0,005473454	31.01	28.88	11.10
B734	2	0,005473454	36,40	28,90	11,10
B739	2	0,005473454	42,1	34,3	12,6
C5	2	0,005473454	75,3	67,9	19,8
C56X	2	0,005473454	15.80	17.00	5.20
B773	2	0,005473454	73,90	60,90	19,30
G150	2	0,005473454	17.30	16.94	5.82
KC39	2	0,005473454	32.70	35.10	10.30
E145	1	0,002736727	29.87	20.04	6.75
A330	1	0,002736727	63.60	60.30	16.70
C650	1	0,002736727	14.29	15.91	4.57
C560	1	0,002736727	14.90	13.80	4.20

Aircraft type	Count	% AC	Length (m)	Wingspan (m)	Height (m)
E75L	1	0,002736727	31.68	28.65	9.86
C130	1	0,002736727	29,79	28,26	8,38
A340	1	0,002736727	59.39	60.30	16.70
GALX	1	0,002736727	18.99	17.71	6.52
GL7T	1	0,002736727	33.90	31.70	8.20
P8	1	0,002736727	39.50	37.06	12.80
B722	1	0,002736727	46,69	32,92	10,36
PC12	1	0,002736727	14,40	16,20	4,30
Unknown	4	0,010946907	----	----	----

Table 1.
Aircraft population and number of flights per type during 2019 in the Canaries UIR.

The data sample in the Canaries UIR includes 36540 flights of 87 different aircraft types. The population is dominated by large and medium airframes such as A330-200, B737-800, B777-300ER, B767-300, B757-200, A330-900 or A350-900 or B787-900. These 8 types make up about 67.68% of the total number of flights. The next 16 types, which also belong to the Airbus and Boeing families, make up another 29.54% and the rest 2.78% is distributed among the other 63 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 2019 to 31st December 2019, 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 2019 to 31st August 2019.

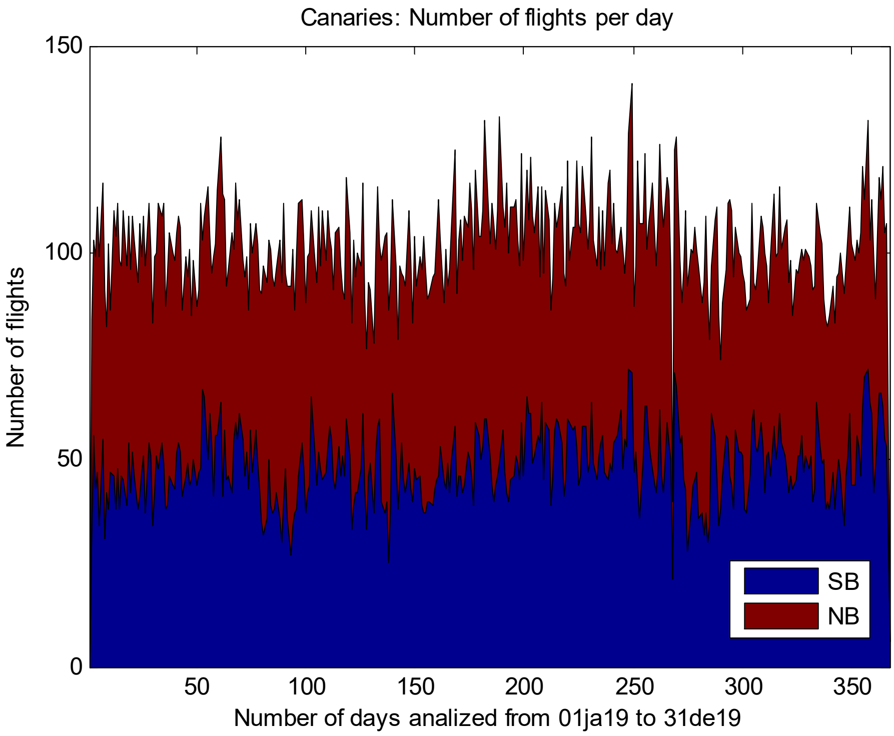


Figure 1.
Number of flights per day in the Canaries. Year 2019

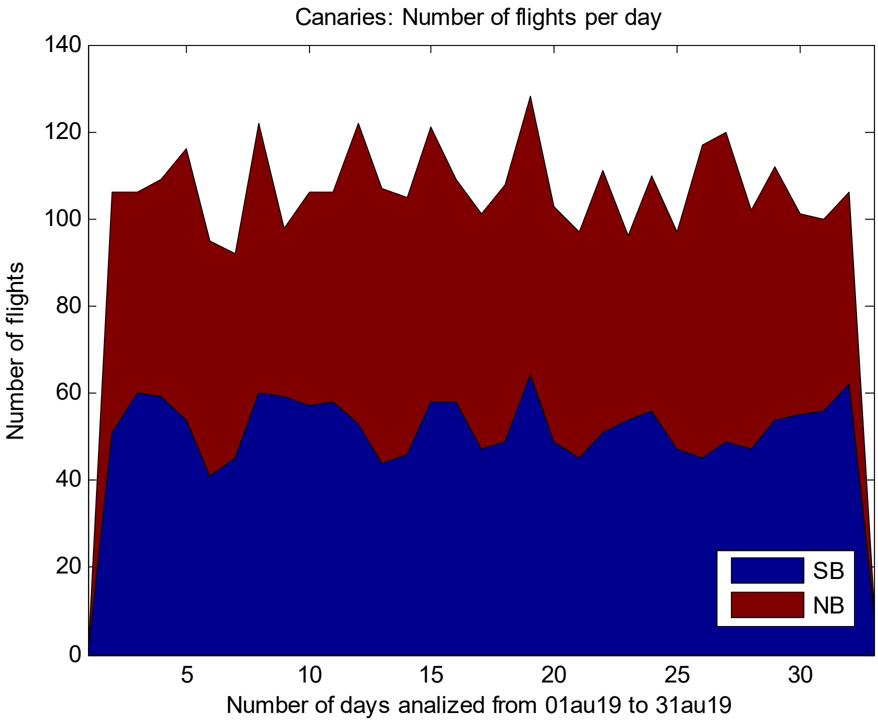


Figure 2.
Number of flights per day in the Canaries. August 2019

The overall average traffic for 2019 is 99.56 flights per day with a standard deviation of 13.39 flights per day, while in August the average is 99.24 with a standard deviation of 25.77 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.

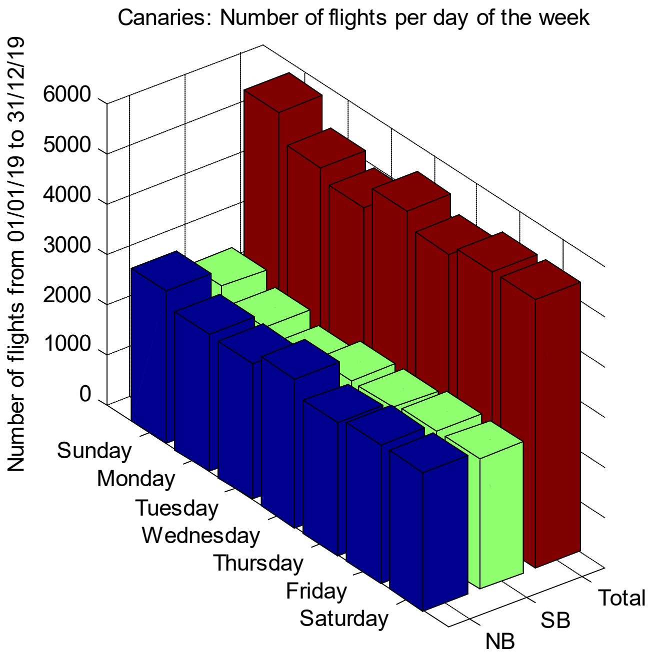


Figure 3.
Number of flights per day of the week in the Canaries. Year 2019

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 2019.

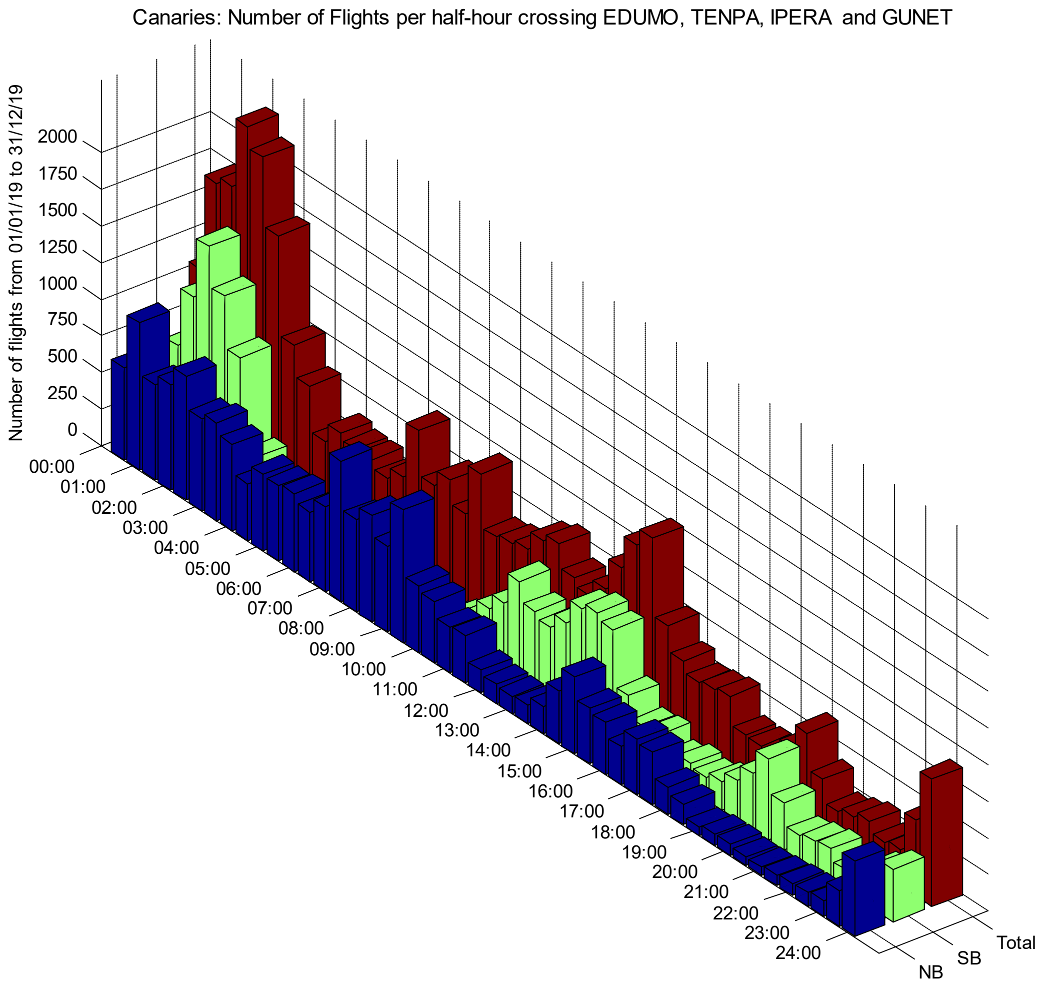


Figure 4.
Number of flights per half-hour crossing EDUMO, TENPA, IPERA and GUNET. Year 2019

It can be seen that during 2019, 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 3277 aircraft detected in Canaries during August 2019. Following, Figure 6 shows the temporal distribution of the 2856 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 7:00h and, in a lower extent, from 08:00h to 14:00h.

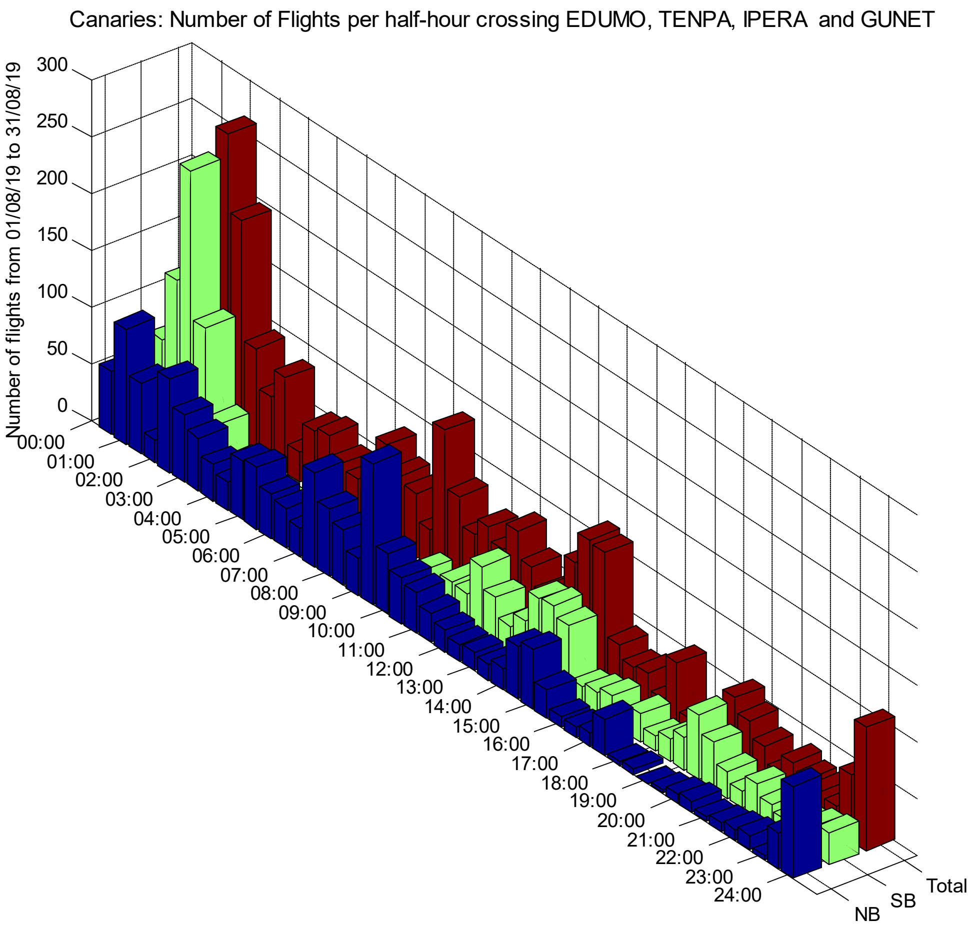


Figure 5.
Number of flights per half-hour crossing EDUMO, TENPA, IPERA and GUNET. August 2019

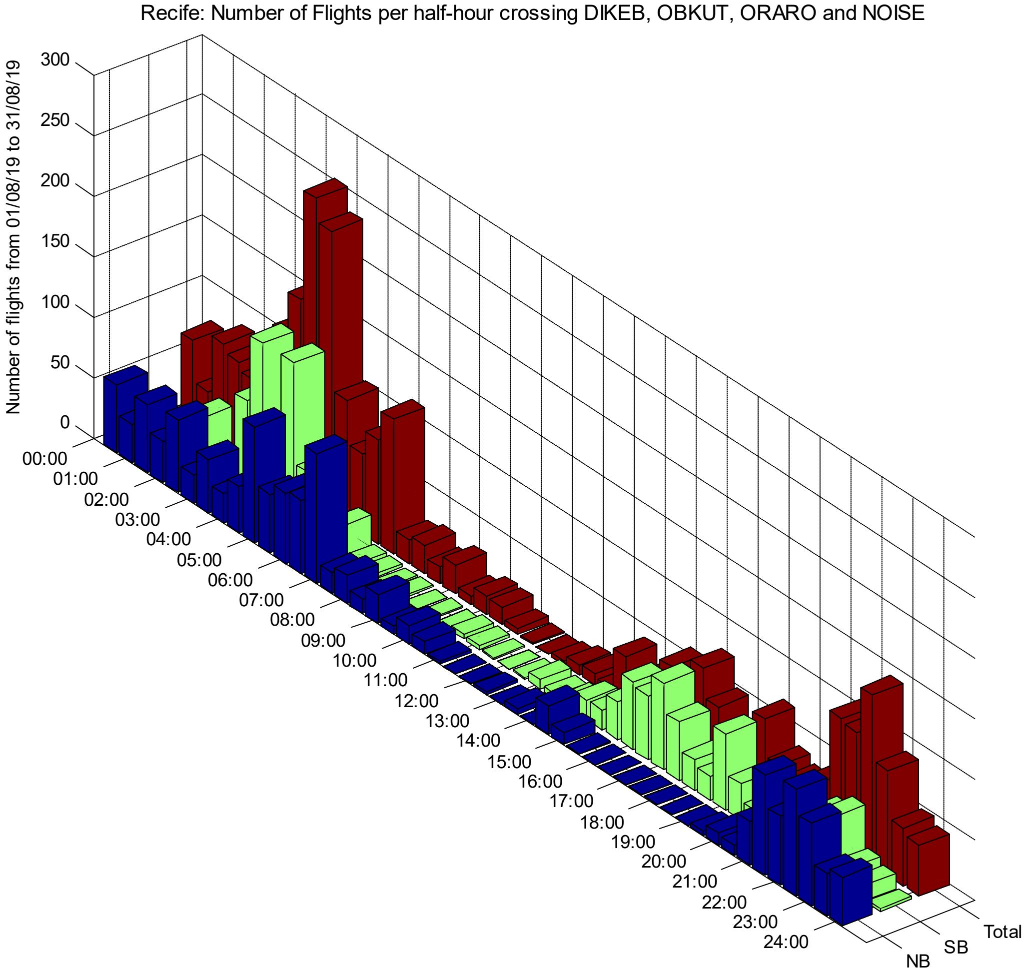


Figure 6.
Number of flights per half-hour crossing DIKEB, OBKUT, ORARO and NOISE. August 2019

2.4. Traffic distribution per flight level

Traffic distribution per flight level during 2019 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.

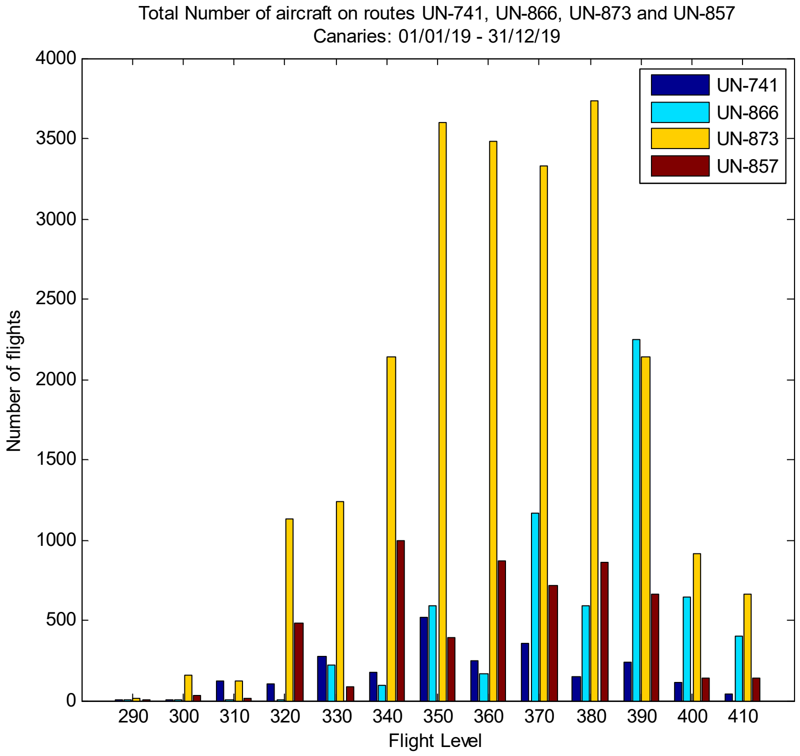


Figure 7.
Number of aircraft on routes UN-741, UN-866, UN-873 and UN-857 in the Canaries

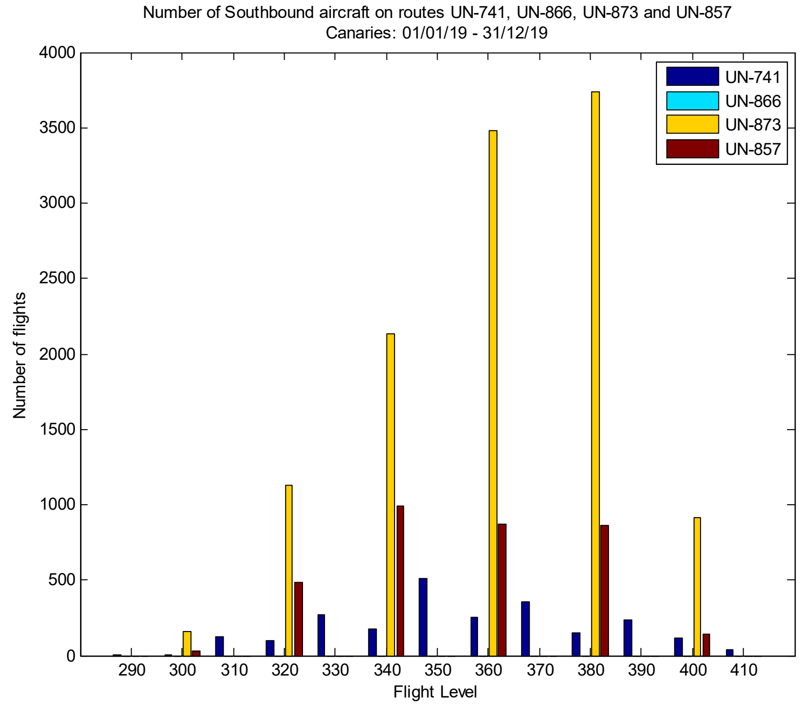


Figure 8.
Number of Southbound aircraft on routes UN-741, UN-866, UN-873 and UN-857 in the Canaries

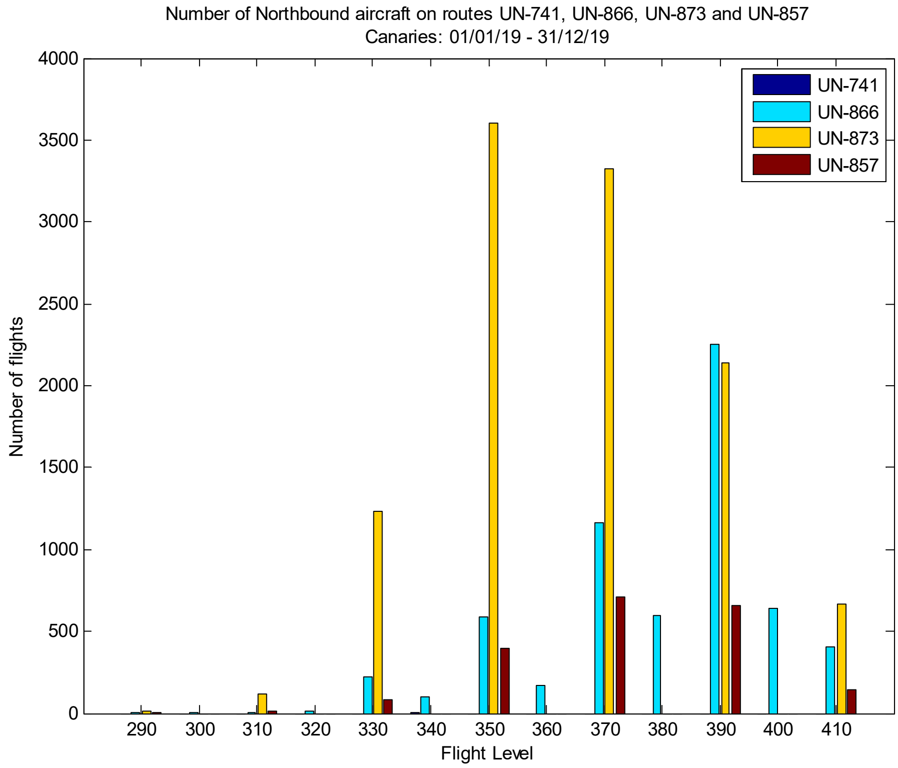


Figure 9.
Number of Northbound aircraft on routes UN-741, UN-866, UN-873 and UN-857 in the Canaries

3. Lateral collision risk assessment

As it has been said, the Reich model to calculate lateral collision risk is explained in [Ref. 34]. In the following sections all the parameters required for the calculation (those that appear in Equation 1) will be analysed.

$$N_{ay} = P_y(S_y) \cdot P_z(0) \cdot \frac{\lambda_y}{S_x} \cdot \left\{ E_{y_{same}} \cdot \left[\frac{|\Delta \bar{v}|}{2 \cdot \lambda_x} + \frac{|\overline{\dot{y}}|}{2 \cdot \lambda_y} + \frac{|\overline{\dot{z}}|}{2 \cdot \lambda_z} \right] + E_{y_{opposite}} \cdot \left[\frac{2 \cdot |\bar{v}|}{2 \cdot \lambda_x} + \frac{|\overline{\dot{y}}|}{2 \cdot \lambda_y} + \frac{|\overline{\dot{z}}|}{2 \cdot \lambda_z} \right] \right\}$$

Equation 1.

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	190.17	177.93	52.26
SAL1	209.24	198.41	56.01
SAL2	206.12	195.39	55.48
Dakar1	205.38	193.72	55.23
Dakar2	205.56	193.95	55.30
Recife	205.95	194.46	55.42

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 $P_z(0)=0.46756$.

3.3. Average ground speed: v

Using the limitation to 575 kts explained in [Ref. 34], 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:

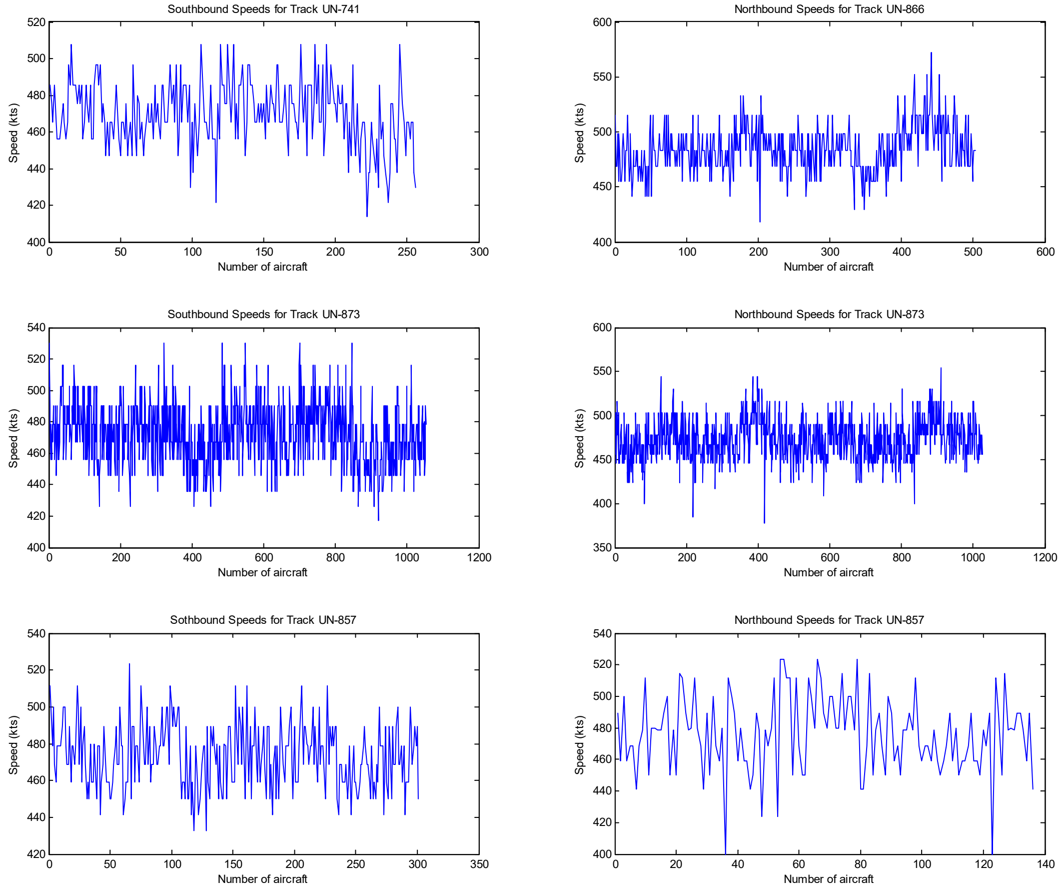


Figure 10.
Speeds limited to 575 kts in the current scenario in the Canaries

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	471.91	478.15	475.03
SAL1	474.37	459.26	466.81
SAL2	455.05	475.36	465.20
Dakar1	479.53	478.01	478.77
Dakar2	485.92	461.26	473.59
Recife	473.22	464.35	468.78

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	13.7	20.6	17.1
SAL1	28.2	33.9	31.1
SAL2	45.0	23.1	34.1
Dakar1	20.9	22.1	21.5
Dakar2	25.3	24.8	25.0
Recife	20.9	22.1	21.5

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. 34], 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. 34]. In 2019, 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	120619	IPERA	IPERA-ISOKA	9 minutes

Table 5.
Lateral deviations reported in 2019

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 2.

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 2019	3277	2886	2560	2866	2834	2856
Jan-Dic 2019	36540	*32180*	*28545*	*31957*	*31600*	*31846*

Table 6.
Number of aircraft considered for the α calculation

Using Equation 2 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	$8.1982*10^{-5}$
SAL1	$9.3088*10^{-5}$
SAL2	$1.0494*10^{-4}$
Dakar1	$9.3738*10^{-5}$
Dakar2	$9.4796*10^{-5}$
Recife	$9.4066*10^{-5}$

Table 7.
α for each FIR

Using Equation 11 of [Ref. 34], the lateral overlap probability obtained for the different lateral separations between routes existing in the Corridor are the following ones:

RNP10 **S_{ymin}=50NM**	**$P_y(50)$**	**$P_y(90)$**	**$P_y(110)$**	**$P_y(140)$**
Canaries	$5.7381*10^{-8}$	$1.5944*10^{-8}$	$1.0688*10^{-8}$	$5.8655*10^{-9}$
SAL1	$6.9347*10^{-8}$	$2.0188*10^{-8}$	$1.3533*10^{-8}$	$7.4269*10^{-9}$
SAL2	$7.3923*10^{-8}$	$2.2412*10^{-8}$	$1.5023*10^{-8}$	$8.2450*10^{-9}$
Dakar1	$6.8015*10^{-8}$	$1.9849*10^{-8}$	$1.3305*10^{-8}$	$7.3021*10^{-9}$
Dakar2	$6.8593*10^{-8}$	$2.0096*10^{-8}$	$1.3471*10^{-8}$	$7.3931*10^{-9}$
Recife	$6.8427*10^{-8}$	$1.9994*10^{-8}$	$1.3402*10^{-8}$	$7.3553*10^{-9}$

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. 34], 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 2019 to 31st August 2019, 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. 22], the annual traffic growth rate for the traffic flows in the Canary Islands airspace would be 2.9%.

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 2029, with the annual traffic growth rate indicated before, 2.9%.

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 2019 till 31st August 2019 in the Canaries, SAL, Dakar and Recife UIR/FIRs.

Number of flights August 2019	Canaries	SAL1	SAL2	Dakar1	Dakar2	Recife
Number of flights on UN-741	256	223	190	341	321	402
Number of flights on UN-866	504	514	529	521	547	564
Number of flights on UN-873	2079	1297	1400	1485	1497	1502
Number of flights on UN-857	437	350	347	371	372	309
Total number of flights	3275	2384	2466	2718	2737	2777
Number of same direction proximate pairs for tracks UN-866/UN-873	48	49	54	58	65	56
Number of same direction proximate pairs for tracks UN-866/UN-857	18	15	15	16	20	10
Number of same direction proximate pairs for tracks UN-873/UN-857	117	77	92	96	97	75
Number of opposite direction proximate pairs for tracks UN-741/UN-866	6	4	3	6	1	7
Number of opposite direction proximate pairs for tracks UN-866/UN-873	12	5	10	11	10	12
Number of opposite direction proximate pairs for tracks UN-866/UN-857	4	3	4	5	2	1

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

Assuming an annual traffic growth rate of 2.9%, the occupancies for the next 10 years are summarized in Table 10. It holds that occupancy is approximately proportional to traffic flow rate:

2.9% annual traffic growth		Canaries 2019-2029	SAL1 2019-2029	SAL2 2019-2029	Dakar1 2019-2029	Dakar2 2019-2029	Recife 2019-2029
Same direction lateral occupancy	**UN-873/UN-857 (E_{ysame})**	0.0715-0.0951	0.0646-0.0860	0.0746-0.0993	0.0706-0.0940	0.0709-0.0943	0.0540-0.0719
	UN-866/UN-873 (E^{*}_{ysame})	0.0293-0.0390	0.0411-0.0547	0.0438-0.0583	0.0427-0.0568	0.0475-0.0632	0.0403-0.0537
	UN-866/UN-857 (E^{**}_{ysame})	0.0110-0.0146	0.0126-0.0167	0.0122-0.0162	0.0118-0.0157	0.0146-0.0195	0.0072-0.0099
Opposite direction lateral occupancy	**UN-866/UN-873 ($E_{yopposite}$)**	0.0073-0.0098	0.0042-0.0056	0.0081-0.0108	0.0081-0.0108	0.0073-0.0098	0.0086-0.0115
	UN-741/UN-866 ($E^{*}_{yopposite}$)	0.0037-0.0049	0.0034-0.0045	0.0024-0.0032	0.0044-0.0059	0.0007-0.0010	0.0050-0.0067
	UN-866/UN-857 ($E^{**}_{yopposite}$)	0.0024-0.0033	0.0025-0.0033	0.0032-0.0043	0.0037-0.0049	0.0015-0.0019	0.0007-0.0010

Table 10.
Lateral occupancy estimate for the Canaries until 2029 with an annual traffic growth rate of 2.9%

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 2029 in the different locations are the ones shown in the following table and figures.

Lateral collision risk	2.9% annual traffic growth					
	Canaries	SAL1	SAL2	Dakar1	Dakar2	Recife
2019	$1.4115*10^{-9}$	$1.7062*10^{-9}$	$2.3203*10^{-9}$	$1.9266*10^{-9}$	$1.7888*10^{-9}$	$1.6619*10^{-9}$
2020	$1.4525*10^{-9}$	$1.7557*10^{-9}$	$2.3875*10^{-9}$	$1.9824*10^{-9}$	$1.8407*10^{-9}$	$1.7101*10^{-9}$
2021	$1.4946*10^{-9}$	$1.8066*10^{-9}$	$2.4568*10^{-9}$	$2.0399*10^{-9}$	$1.8941*10^{-9}$	$1.7597*10^{-9}$
2022	$1.5379*10^{-9}$	$1.8590*10^{-9}$	$2.5280*10^{-9}$	$2.0991*10^{-9}$	$1.9490*10^{-9}$	$1.8107*10^{-9}$
2023	$1.5825*10^{-9}$	$1.9129*10^{-9}$	$2.6013*10^{-9}$	$2.1600*10^{-9}$	$2.0055*10^{-9}$	$1.8632*10^{-9}$
2024	$1.6284*10^{-9}$	$1.9684*10^{-9}$	$2.6768*10^{-9}$	$2.2226*10^{-9}$	$2.0637*10^{-9}$	$1.9172*10^{-9}$
2025	$1.6757*10^{-9}$	$2.0254*10^{-9}$	$2.7544*10^{-9}$	$2.2870*10^{-9}$	$2.1235*10^{-9}$	$1.9728*10^{-9}$
2026	$1.7242*10^{-9}$	$2.0842*10^{-9}$	$2.8343*10^{-9}$	$2.3534*10^{-9}$	$2.1851*10^{-9}$	$2.0300*10^{-9}$
2027	$1.7743*10^{-9}$	$2.1446*10^{-9}$	$2.9165*10^{-9}$	$2.4216*10^{-9}$	$2.2485*10^{-9}$	$2.0889*10^{-9}$
2028	$1.8257*10^{-9}$	$2.2068*10^{-9}$	$3.0011*10^{-9}$	$2.4918*10^{-9}$	$2.3137*10^{-9}$	$2.1495*10^{-9}$
2029	$1.8786*10^{-9}$	$2.2708*10^{-9}$	$3.0881*10^{-9}$	$2.5641*10^{-9}$	$2.3808*10^{-9}$	$2.2118*10^{-9}$

Table 11.
Lateral collision risk for the period 2019-2029 in the Corridor

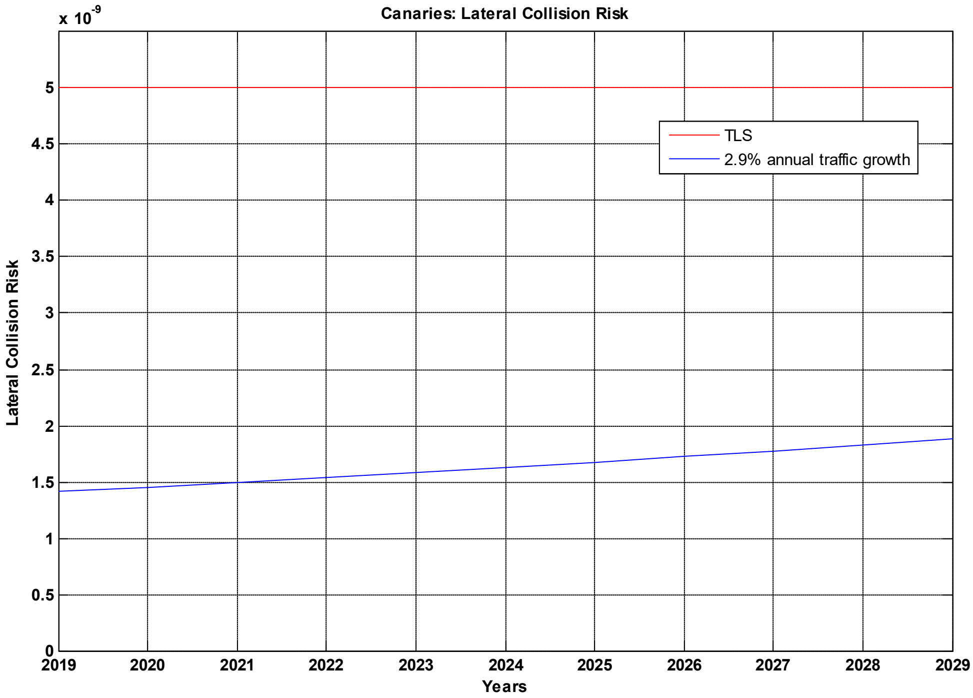


Figure 11.
Lateral collision risk for the period 2019-2029 in the Canaries

Figure 12.
Lateral collision risk for the period 2019-2029 in SAL1

Figure 13.
Lateral collision risk for the period 2019-2029 in SAL2

Figure 14.
Lateral collision risk for the period 2019-2029 in Dakar1

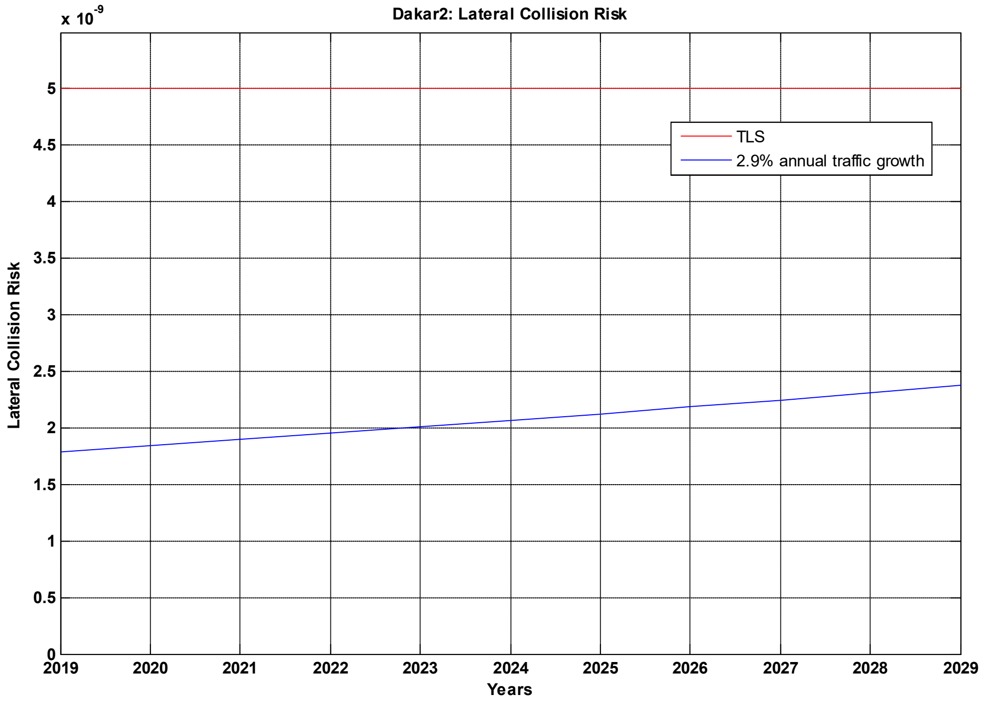


Figure 15.
Lateral collision risk for the period 2019-2029 in Dakar2

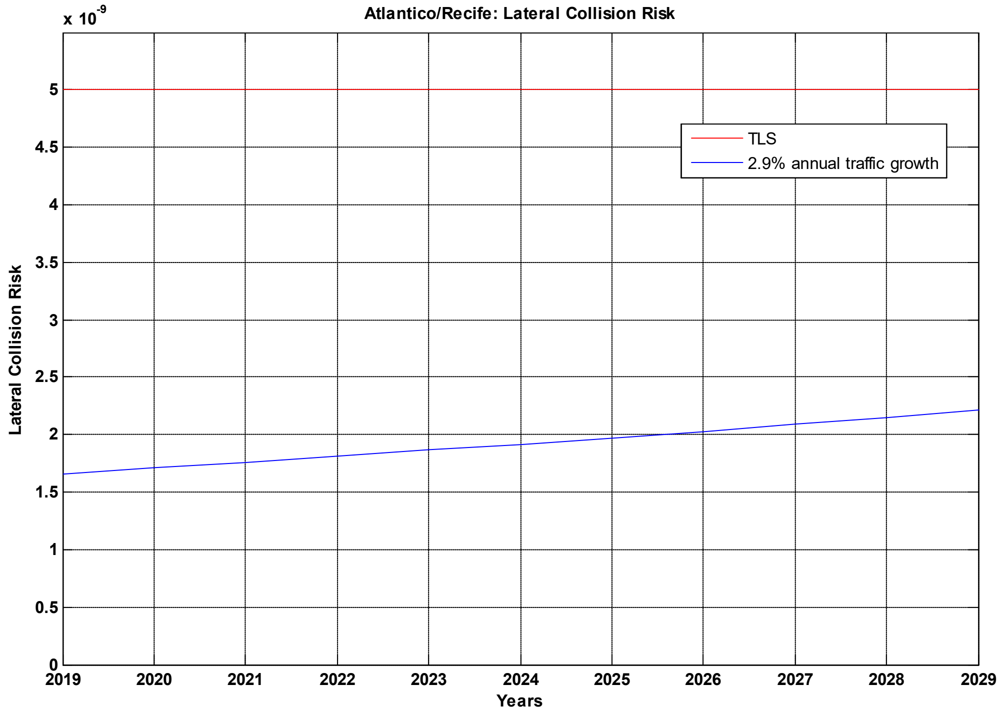


Figure 16.
Lateral collision risk for the period 2019-2029 in Recife

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 2.9% 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 aircrafts 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. 34]. In the following sections all the parameters required for the calculation (those that appear in Equation 3) will be analysed.

$$N_{az} = P_z(S_z) \cdot P_y(0) \cdot \frac{\lambda_x}{S_x} \cdot \left\{ E_{z_{same}} \cdot \left[\frac{|\Delta \bar{v}|}{2 \cdot \lambda_x} + \frac{|\overline{\dot{y}}|}{2 \cdot \lambda_y} + \frac{|\overline{\dot{z}}|}{2 \cdot \lambda_z} \right] + E_{z_{opposite}} \cdot \left[\frac{2 \cdot |\bar{v}|}{2 \cdot \lambda_x} + \frac{|\overline{\dot{y}}|}{2 \cdot \lambda_y} + \frac{|\overline{\dot{z}}|}{2 \cdot \lambda_z} \right] \right\} +$$
$$+ P_z(S_z) \cdot \sum_{1}^{n} P_h(\theta_i) \cdot E_z(\theta_i) \cdot \left\{ \frac{v_{rel}(\theta_i)}{\frac{\pi \lambda_h}{2}} + \frac{|\overline{\dot{z}}|}{2 \cdot \lambda_z} \right\}$$

Equation 3.

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 (λ_x) (ft)	Wingspan (λ_y) (ft)	Height (λ_z) (ft)
Canaries	190.17	177.93	52.26
SAL1	209.24	198.41	56.01
SAL2	206.12	195.39	55.48
Dakar1	205.38	193.72	55.23
Dakar2	205.56	193.95	55.30
Recife	205.95	194.46	55.42

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. 34], the most conservative assumption consists of assuming that the full aircraft population are using GNSS, α=1. Thus, taking the probability density as Gaussian[1], 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. 34]. 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. 16]). This probability has only been calculated whenever proximate events have been detected (no proximate events were detected in Canaries FIR this year), as it will be seen in 4.1.6.

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

[1] *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)**	**$P_h(\theta)$**
SAL1	0.0344 NM	UR-976/UA-602 (GAMBA)	95-85	$5.8737*10^{-7}$
		ULTEM-LUMPO (IRENE)	91-89	$5.8506*10^{-7}$
		BAMUX-SEPOM (BS001)	102-78	$5.9905*10^{-7}$
		BAMUX-ILGAS (BI001)	95-85	$5.8737*10^{-7}$
		OBOMO-ILGAS (BS001)	92-88	$5.8535*10^{-7}$
		ULTEM-ILGAS (RL001)	108-72	$6.1741*10^{-7}$
		EDUMO-BI002 (BI002)	127-53	$7.4318*10^{-7}$
		CVS-BS004 (CVS)	150-30	$1.2827*10^{-6}$
		CVS-BS004 (BS004)	150-30	$1.2033*10^{-6}$
		CVS-INESS (CVS)	137-43	$8.7593*10^{-7}$
		CVS-BS002 (CVS)	150-30	$1.2033*10^{-6}$
		CVS-BS002 (BS002)	150-30	$1.2033*10^{-6}$
		NEMDO-BI003 (BI003)	154-26	$1.3748*10^{-6}$
		CARME-PISPU (PISPU)	145-35	$1.0464*10^{-6}$
		IREDO-BL003 (IREDO)	134-46	$8.2888*10^{-7}$
		IREDO-BL003 (BL003)	134-46	$8.2888*10^{-7}$
		CVS-BL004 (CVS)	134-46	$8.2888*10^{-7}$
		CVS-BL004 (BL004)	134-46	$7.8850*10^{-7}$
		CVS-UGAMA (CVS)	101-79	$5.9677*10^{-7}$
		CVS-UGAMA (UGAMA)	101-79	$5.9116*10^{-7}$

Table 13.
Horizontal overlap probabilities in SAL1

Horizontal overlap probability				
Location	**Diameter (λ_h)**	**Route (Point)**	**Angles (º)**	$P_h(\theta)$
SAL2	0.0339 NM	BULBO-ORABI (BULBO)	157-23	$1.3844*10^{-6}$
		CARME-KENOX (CARME)	148-32	$1.1007*10^{-6}$
		CARME-KENOX (KENOX)	149-31	$1.1331*10^{-6}$
		CARME-PISPU (CARME)	144-36	$9.9029*10^{-7}$
		BAMUX-KENOX (KENOX)	162-18	$1.8973*10^{-6}$
		MARIA-IREDO (MARIA)	107-73	$5.8923*10^{-7}$
		MARIA-IREDO (IREDO)	105-75	$5.5960*10^{-7}$
		EXTER-IREDO (IREDO)	131-49	$7.6515*10^{-7}$
		CVS-INESS (INESS)	138-42	$8.6687*10^{-7}$
		KENOX-DENER (DENER)	133-47	$7.9062*10^{-7}$
Dakar1	0.0338 NM	UL-435 (DIGUN)	98-82	$5.6958*10^{-7}$
		ENUGO-APIGU (ENUGO)	96-84	$5.6695*10^{-7}$
		APOXA-GONSA (APOXA)	92-88	$5.6397*10^{-7}$
		SAGRO-LIRAX (SAGRO)	93-87	$5.6444*10^{-7}$
		GARKO-LIRAX (GARKO)	96-84	$5.6695*10^{-7}$
		XUVIT-DIGUN (DIGUN)	158-22	$1.5523*10^{-6}$
		TARIM-DIGUN (DIGUN)	169-11	$3.0517*10^{-6}$
		LIRAX-IRAVU (LIRAX)	154-26	$1.3246*10^{-6}$
		SAGRO-BUXON (SAGRO)	124-56	$6.8844*10^{-7}$
		TARIM-SAGRO (SAGRO)	167-13	$2.5891*10^{-6}$
		SAGRO-MOSOK (SAGRO)	137-43	$8.4395*10^{-7}$
		SAGRO-MOSOK (MOSOK)	137-43	$8.4395*10^{-7}$
		ENUGO-IP007 (ENUGO)	159-21	$1.6232*10^{-6}$
Dakar2	0.0338 NM	DIGUN-ENOTO (DIGUN)	140-40	$8.9866*10^{-7}$
		DIGUN-ENOTO (ENOTO)	139-41	$8.7995*10^{-7}$
		IP007-NANIK (NANIK)	160-20	$1.7042*10^{-6}$
		IP008-NANIK (NANIK)	169-11	$3.0571*10^{-6}$
		IRAVU-MESAB (MESAB)	153-27	$1.2808*10^{-6}$
		DIGUN-MOVGA (DIGUN)	146-34	$1.0365*10^{-6}$
Recife	0.0339 NM	UL-695 (DIKEB)	97-83	$5.7130*10^{-7}$
		ERETU-PUGSA (ERETU)	165-15	$2.2626*10^{-6}$

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

4.1.4. Relative velocities

Equation 27 in [Ref. 34] 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	10.2068	16.1825	13.1946
SAL1	21.5911	28.3015	24.9463
SAL2	46.9120	13.1514	30.0317
Dakar1	18.2186	23.8281	21.0234
Dakar2	23.9792	20.6649	22.3220
Recife	30.1423	16.1330	23.1376

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. 24]. 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:

$$v_{rel}(\theta_i) = \sqrt{v_1^2 + v_2^2 - 2v_1v_2\cos(\theta_i)}$$

Equation 4.

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)	θ (º)	$V_{rel}(\theta)$ (kts)
SAL1	UR-976/UA-602 (GAMBA)	466.81	482.42	85	641.39
				95	699.93
	ULTEM-LUMPO (IRENE)	466.81	459.79	89	649.48
				91	660.92
	BAMUX-SEPOM (BS001)	466.81	468.99	78	588.93
				102	727.26
	BAMUX-ILGAS (BI001)	466.81	468.05	85	631.58
				95	689.25
	OBOMO-ILGAS (BS001)	466.81	470.37	88	651.03
				92	766.29
	ULTEM-ILGAS (RL001)	466.81	480.32	72	556.82
				108	766.29
	EDUMO-BI002 (BI002)	466.81	455.85	53	411.81
				127	825.74
	CVS-BS004 (CVS)	466.81	486.21	28	231.32
				152	924.73
	CVS-BS004 (BS004)	466.81	486.21	30	247.37
				150	920.57
	CVS-INESS (CVS)	466.81	469.14	43	343.03
				137	870.83
	CVS-BS002 (CVS)	466.81	468.71	30	242.14
				150	903.65
	CVS-BS002 (BS002)	466.81	468.41	30	242.14
				150	903.65
	NEMDO-BI003 (BI003)	466.81	446.42	26	206.39
				154	889.84
	IREDO-BL003 (IREDO)	466.81	490.94	46	374.88
				134	881.67
	IREDO-BL003 (BL003)	466.81	490.94	46	374.88
				134	881.67
	CVS-BL004 (CVS)	466.81	493.06	46	375.83
				134	883.63
	CVS-BL004 (BL004)	466.81	493.06	46	375.83
				134	883.63
	CVS-UGAMA (CVS)	466.81	477.21	79	600.52
				101	728.46
	CVS-UGAMA (UGAMA)	466.81	476.91	82	619.18
				98	712.27
	CARME-PISPU (PISPU)	466.81	486.94	35	287.44
				145	909.63

SAL2	CARME-KENOX (CARME)	465.20	499.29	32	267.86
				148	827.18
	CARME-KENOX (KENOX)	465.20	505.39	32	262.25
				148	935.36
	CARME-PISPU (CARME)	465.20	486.94	35	294.95
				145	905.57
	MARIA-IREDO (MARIA)	465.20	472.20	73	557.62
				107	753.55
	MARIA-IREDO (IREDO)	465.20	472.20	75	570.69
				105	743.71
	EXTER-IREDO (IREDO)	465.20	499.80	49	401.42
				131	878.23
	CVS-INESS (INESS)	465.20	469.14	42	334.86
				138	872.28
	KENOX-DENER (DENER)	465.20	563.00	47	419.69
				133	943.73
	BAMUX-KENOX (KENOX)	465.20	470.79	18	146.53
				162	924.47
	BULBO-ORABI (BULBO)	465.20	493.72	23	193.21
				157	939.69

Table 16.
Relative speeds in crossings (SAL)

Location	Crossing route	V_1 (kts)	V_2 (kts)	θ (º)	$V_{rel}(\theta)$ (kts)
Dakar1	UL-435 (DIGUN)	478.77	492.00	82	636.96
				98	732.70
	ENUGO-APIGU (ENUGO)	478.77	493.26	84	650.50
				96	722.42
	APOXA-GONSA (APOXA)	478.77	500.86	88	68069
				92	704.85
	SAGRO-LIRAX (SAGRO)	478.77	492.76	87	668.83
				93	704.79
	GARKO-LIRAX (GARKO)	478.77	467.66	84	633.34
				96	703.37
	XUVIT-DIGUN (DIGUN)	478.77	478.42	22	939.60
				158	182.64
	TARIM-DIGUN (DIGUN)	478.77	507.66	11	98.82
				169	981.89
	LIRAX-IRAVU (LIRAX)	478.77	499.91	26	221.12
				154	953.60
	SAGRO-BUXON (SAGRO)	478.77	477.96	56	449.16
				124	844.74
	TARIM-SAGRO (SAGRO)	478.77	482.77	13	108.92
				167	955.35
	SAGRO-MOSOK (SAGRO)	478.77	472.45	43	348.67
				137	885.03
	SAGRO-MOSOK (MOSOK)	478.77	472.45	43	348.67
				137	885.03
	ENUGO-IP007 (ENUGO)	478.77	453.57	21	171.70
				159	916.74
Dakar2	DIGUN-ENOTO (DIGUN)	473.59	489.07	40	329.57
				140	904.62
	DIGUN-ENOTO (ENOTO)	473.59	489.07	31	337.44
				139	901.71
	IP007-NANIK (NANIK)	473.59	478.27	20	165.35
				160	937.40
	IP008-NANIK (NANIK)	473.59	480.43	11	91.69
				169	949.63
	IRAVU-MESAB (MESAB)	473.59	495.83	27	227.34
				153	942.65
	DIGUN-MOVGA (DIGUN)	473.59	487.91	34	291.45
				146	919.49
Recife	UL-695 (DIKEB)	468.79	469.87	83	621.97
				97	703.01
	ERETU-PUGSA (ERETU)	468.79	490.49	15	127.05
				165	951.07

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

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

With 2019 traffic and height-keeping performances information, the probability of vertical overlap has been calculated by means of Equation 43 in [Ref. 34], using the Eurocontrol RVSM Tool, being the resulting values $P_z(1000) = 9.92762 \cdot 10^{-12}$ and $P_z(0) = 0.46756$.

4.1.6. Vertical occupancy

As it is explained in [Ref. 34], 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 program for the current time and an estimate of the occupancy until 2029, with the annual traffic growth rate previously indicated, 2.9%.

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 2019.

Vertical occupancy	August 2019
Number of flights on UN-741	256
Number of flights on UN-866	503
Number of flights on UN-873	2079
Number of flights on UN-857	437
Total number of flights on main airways	3275
Number of same direction vertical proximate pairs for tracks UN-741	28
Number of same direction vertical proximate pairs for tracks UN-866	44
Number of opposite direction vertical proximate pairs for tracks UN-873	279
Number of opposite direction vertical proximate pairs for tracks UN-857	9
Total number of same direction proximate events	72
Total number of opposite direction proximate events	288
Same direction vertical occupancy (S_x=80NM)	0.0440
Opposite direction vertical occupancy (S_x=80NM)	0.1759

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 2019
Number of flights on crossing flight NORED-ETIBA	2
Total number of flights on main routes (UN-741, UN-866, UN-873 and UN-857)	3275
Total number of flights	3277

Table 19.
Number of flights in Canaries airspace

The total number of flights is 3277.

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. 20], 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. 34]. In the following tables, 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. It is to be noted that only data for the crossing routes for which proximate pairs have been detected are presented. However, no proximate events were detected in Canaries FIR this year.

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 2019 to 2029 with an annual traffic growth rate of 2.9% are shown in Table 20.

2.9% annual traffic growth	2019	2021	2023	2025	2027	2029
Same direction vertical occupancy	0.0440	0.0466	0.0493	0.0522	0.0553	0.0585
Opposite direction vertical occupancy	0.1759	0.1862	0.1972	0.2088	0.2211	0.2341

Table 20.
Vertical occupancy estimate for the Canaries until 2029 with an annual traffic growth rate of 2.9%

4.1.6.b. SAL1

Table 21 collects some results on same and opposite vertical occupancy in SAL1, obtained with data from August 2019.

Number of flights	August 2019
Number of flights on UN-741	223
Number of flights on UN-866	514
Number of flights on UN-873	1297
Number of flights on UN-857	350
Total number of flights on main airways	2384
Number of same direction vertical proximate pairs for tracks UN-741	27
Number of same direction vertical proximate pairs for tracks UN-866	44
Number of opposite direction vertical proximate pairs for tracks UN-873	55
Number of opposite direction vertical proximate pairs for tracks UN-857	0
Total number of same direction proximate events	71
Total number of opposite direction proximate events	55
Same direction vertical occupancy (S_x=80NM)	0.0596
Opposite direction vertical occupancy (S_x=80NM)	0.0461

Table 21.
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 2019
Number of flights on UR-976/UA-602	123
Number of flights on ULTEM-LUMPO	102
Number of flights on BAMUX-SEPOM	6
Number of flights on BAMUX-ILGAS	84
Number of flights on OBOMO-ILGAS	84
Number of flights on ULTEM-ILGAS	5
Number of flights on ULTEM-SEPOM	1
Number of flights on EDUMO-BI002	11
Number of flights on CVS-BS004	5
Number of flights on IPERA-BI004	2
Number of flights on CVS-INESS	10
Number of flights on CVS-BL002	2
Number of flights on CVS-BS002	4
Number of flights on NEMDO-BI003	27
Number of flights on CARME-PISPU	23
Number of flights on IREDO-BL003	16
Number of flights on IRENE-KESIK	15
Number of flights on CVS-BL004	4
Number of flights on CVS-UGAMA	77
Number of flights on CVS-DENER	2
Number of flights on CVS-CARME	3
Number of flights on main routes (UN-741, UN-866, UN-873 and UN-857)	2384
Total number of flights	2886

Table 22.
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 (502 flights). Therefore, the total number of flights is 2886.

The time windows to obtain proximate pairs and the number of proximate events are, in this case, the ones shown in Table 23. 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	---	466.81	482.42	95º	15	9	12
				85º	14	0	35
ULTEM-LUMPO	---	466.81	459.79	91º	15	6	30
				89º	15	25	13
BAMUX-SEPOM	---	466.81	468.99	102º	17	3	1
				78º	14	0	6
BAMUX-ILGAS	---	466.81	468.05	95º	16	10	26
				85º	14	3	14
OBOMO-ILGAS	---	466.81	470.37	92º	15	10	26
				88º	15	3	14
ULTEM-ILGAS	---	466.81	480.32	108º	18	0	1
				72º	13	0	2
EDUMO-BI002	BI002	459.31	455.85	127º	24	0	5
				53º	12	0	0
CVS-BS002	BS002	459.31	468.71	150º	40	0	0
				30º	11	0	1
	CVS	469.90	468.71	150º	40	0	2
				30º	11	1	0
CVS-BS004	CVS	469.90	486.21	152º	42	0	4
				28º	11	0	0
	BS004	468.60	486.21	150º	39	0	3
				30º	11	0	0
CVS-INESS	CVS	469.90	469.14	137º	28	0	3
				43º	11	2	0

NEMDO-BI003	BI003	469.90	446.42	154º	47	2	11
				26º	11	1	16
CARME-PISPU	PISPU	469.90	486.94	145º	34	5	0
				35º	11	0	20
IREDO-BL003	IREDO	459.31	490.94	134º	26	0	8
				46º	11	0	0
	BL003	469.90	490.94	134º	26	0	6
				46º	11	0	0
CVS-BL004	CVS	469.90	493.06	134º	26	0	1
				46º	11	0	0
	BL004	468.60	493.06	131º	25	0	0
				49º	11	1	0
CVS-UGAMA	CVS	469.90	477.21	101º	16	0	11
				79º	14	5	3
	UGAMA	468.60	476.91	98º	16	0	3
				82º	14	1	2

Table 23.
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. 66 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 2019 to 2029 with an annual traffic growth rate of 2.9% are shown in Table 24. Only crossings different from zero have been shown.

2.9% annual traffic growth				2019	2021	2023	2025	2027	2029
Same direction vertical occupancy				0.0596	0.0631	0.0668	0.0707	0.0749	0.0793
Opposite direction vertical occupancy				0.0461	0.0489	0.0517	0.0548	0.0580	0.0614
Crossing occupancy	UR-976/UA-602	---	95º	0.0090	0.0095	0.0101	0.0107	0.0113	0.0120
			85º	0.0243	0.0257	0.0272	0.0290	0.0305	0.0323
	ULTEM-LUMPO	---	91º	0.0223	0.0242	0.0256	0.0271	0.02287	0.0304
			89º	0.0173	0.0183	0.0194	0.0206	0.0218	0.0231
	BAMUX-SEPOM	---	102º	0.0021	0.0022	0.0023	0.0025	0.0026	0.0028
			78º	0.0042	0.0044	0.0047	0.0049	0.0052	0.0055
	BAMUX-ILGAS	---	95º	0.0194	0.0205	0.0218	0.0230	0.0244	0.0258
			85º	0.0097	0.0103	0.0109	0.0115	0.0122	0.0129
	OBOMO-ILGAS	---	92º	0.0194	0.0205	0.0218	0.0230	0.0244	0.0258
			88º	0.0097	0.0103	0.0109	0.0115	0.0122	0.0129
	ULTEM-ILGAS	---	108º	0.0007	0.0007	0.0008	0.0008	0.0009	0.0009
			72º	0.0014	0.0015	0.0016	0.0016	0.0017	0.0018
	EDUMO-BI002	BI002	127º	0.0035	0.0037	0.0039	0.0041	0.0044	0.0046
			53º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	CVS-BS004	CVS	152º	0.0028	0.0029	0.0031	0.0033	0.0035	0.0037
			28º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
		BS004	150º	0.0021	0.0022	0.0023	0.0025	0.0026	0.0028
			30º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	CVS-INESS	CVS	137º	0.0021	0.0022	0.0023	0.0025	0.0026	0.0028
			43º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	CVS-BS002	BS002	150º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
			30º	0.0007	0.0007	0.0008	0.0008	0.0009	0.0009
		CVS	150º	0.0014	0.0015	0.0016	0.0016	0.0017	0.0018
			30º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	NEMDO-BI003	BI003	154º	0.0076	0.0081	0.0085	0.0090	0.0096	0.0101
			26º	0.0111	0.0117	0.0124	0.0132	0.0139	0.0148
	CARME-PISPU	PISPU	145º	0.0021	0.0022	0.0023	0.0025	0.0026	0.0028
			35º	0.0139	0.0147	0.0155	0.0165	0.0174	0.0184
	IREDO-BL003	IREDO	134º	0.0055	0.0059	0.0062	0.0066	0.0070	0.0074
			46º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
		BL003	134º	0.0042	0.0044	0.0047	0.0049	0.0052	0.0055
			46º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	CVS-BL004	CVS	134º	0.0007	0.0007	0.0008	0.0008	0.0009	0.0009
			46º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	CVS-UGAMA	CVS	101º	0.0076	0.0081	0.0085	0.0090	0.0096	0.0101
			79º	0.0028	0.0029	0.0031	0.0033	0.0035	0.0037
		UGAMA	98º	0.0021	0.0022	0.0023	0.0025	0.0026	0.0028
			82º	0.0014	0.0015	0.0016	0.0016	0.0017	0.0018

Table 24.
Vertical occupancy estimate for SAL1 until 2029 with an annual traffic growth rate of 2.9%

4.1.6.c. SAL2

Table 25 collects some results on same and opposite vertical occupancy in SAL2, obtained with data from the August 2019.

Number of flights	August 2019
Number of flights on UN-741	190
Number of flights on UN-866	529
Number of flights on UN-873	1400
Number of flights on UN-857	347
Total number of flights on main airways	2466
Number of same direction vertical proximate pairs for tracks UN-741	21
Number of same direction vertical proximate pairs for tracks UN-866	44
Number of opposite direction vertical proximate pairs for tracks UN-873	102
Number of opposite direction vertical proximate pairs for tracks UN-857	2
Total number of same direction proximate events	65
Total number of opposite direction proximate events	104
Same direction vertical occupancy (S_x=80NM)	0.0527
Opposite direction vertical occupancy (S_x=80NM)	0.0843

Table 25.
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 2019
Number of flights on XIBOT-MOGSA	3
Number of flights on BULVO-ORABI	14
Number of flights on SNT-BOTNO	26
Number of flights on SVT-KENOX	7
Number of flights on CARME-KENOX	10
Number of flights on CARME-PISPU	23
Number of flights on BAMUX-KENOX	15
Number of flights on MARIA-IREDO	13
Number of flights on EXTER-IREDO	9
Number of flights on EXTER-CARME	3
Number of flights on CVS-INESS	10
Number of flights on KENOX-DENER	1
Number of flights on CVS-DENER	2
Number of flights on CVS-CARME	3
Number of flights on main routes (UN-741, UN-866, UN-873 and UN-857)	2466
Total number of flights	2560

Table 26.
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 94 of them. Therefore, the total number of flights in this case is 2560.

The time windows to obtain proximate pairs and the number of proximate events are, in this case, the ones shown in Table 27. 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**
BULBO-ORABI	BULBO	465.33	493.72	157º	50	0	11
				23º	11	2	0
CARME-KENOX	CARME	469.65	499.29	148º	36	1	4
				32º	11	0	0
	KENOX	449.46	505.39	149º	38	0	0
				31º	11	0	2
CARME-PISPU	CARME	469.65	486.94	144º	33	1	1
				36º	11	0	0
BAMUX-KENOX	KENOX	449.46	470.79	162º	66	0	0
				18º	11	1	3
MARIA-IREDO	MARIA	449.46	472.20	107º	18	0	0
				73º	13	2	1
	IREDO	469.65	472.20	105º	17	0	1
				75º	13	0	0
EXTER-IREDO	IREDO	469.65	499.80	131º	24	0	5
				49º	11	0	0
CVS-INESS	INESS	463.42	469.14	138º	29	0	3
				42º	11	0	0
KENOX-DENER	DENER	469.65	563.00	133º	24	0	1
				47º	11	0	0

Table 27.
Time windows for crossing occupancies and number of proximate events in SAL2

Here again, as it happened in SAL1, there are 5 proximate events at the same flight level within 15 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 2019 to 2029 with an annual traffic growth rate of 2.9% are shown in Table 28. Only data for crossing trajectories in which proximate events have been detected are included.

2.9% annual traffic growth				**2019**	**2021**	**2023**	**2025**	**2027**	**2029**
Same direction vertical occupancy				0.0527	0.0558	0.0591	0.0626	0.0663	0.0702
Opposite direction vertical occupancy				0.0843	0.0893	0.0946	0.1001	0.1060	0.1123
Crossing occupancy	BULBO-ORABI	BULBO	157º	0.0086	0.0091	0.0096	0.0102	0.0108	0.0114
			23º	0.0008	0.0008	0.0009	0.0009	0.0010	0.0010
	CARME-KENOX	CARME	148º	0.0031	0.0033	0.0035	0.0037	0.0029	0.0042
			32º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
		KENOX	149º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
			31º	0.0016	0.0017	0.0018	0.0019	0.0020	0.0021
	CARME-PISPU	CARME	144º	0.0008	0.0008	0.0009	0.0009	0.0010	0.0010
			36º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	BAMUX-KENOX	KENOX	162º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
			18º	0.0031	0.0033	0.0035	0.0037	0.0029	0.0042
	MARIA-IREDO	MARIA	107º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
			73º	0.0008	0.0008	0.0009	0.0009	0.0010	0.0010
		IREDO	105º	0.0008	0.0008	0.0009	0.0009	0.0010	0.0010
			75º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	EXTER-IREDO	IREDO	131º	0.0039	0.0041	0.0044	0.0046	0.0049	0.0052
			49º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	CVS-INESS	INESS	138º	0.0023	00025	0.0026	0.0028	0.0029	0.0031
			42º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	KENOX-DENER	DENER	133º	0.0008	0.0008	0.0009	0.0009	0.0010	0.0010
			47º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 28.
Vertical occupancy estimate for SAL2 until 2029 with an annual traffic growth rate of 2.9%

4.1.6.d. Dakar1

Table 29 collects some results on same and opposite vertical occupancy in Dakar1, obtained with data from August 2019.

Number of flights	August 2019
Number of flights on UN-741	341
Number of flights on UN-866	521
Number of flights on UN-873	1485
Number of flights on UN-857	371
Total number of flights on main airways	2718
Number of same direction vertical proximate pairs for tracks UN-741	32
Number of same direction vertical proximate pairs for tracks UN-866	40
Number of opposite direction vertical proximate pairs for tracks UN-873	114
Number of opposite direction vertical proximate pairs for tracks UN-857	10
Total number of same direction proximate events	72
Total number of opposite direction proximate events	124
Same direction vertical occupancy (S_x=80NM)	0.0530
Opposite direction vertical occupancy (S_x=80NM)	0.0912

Table 29.
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 2019
Number of flights on UL-435	32
Number of flights on ENUGO-APIGU	11
Number of flights on APOXA-GONSA	8
Number of flights on SAGRO-LIRAX	19
Number of flights on GARKO-LIRAX	1
Number of flights on XUVIT-DIGUN	62
Number of flights on TARIM-DIGUN	69
Number of flights on LIRAX-IRAVU	14
Number of flights on SAGRO-BUXON	19
Number of flights on TARIM-GARKO	5
Number of flights on TARIM-SAGRO	20
Number of flights on SAGRO-MOSOK	34
Number of flights on KENOX-RIXAD	1
Number of flights on ENUGO-IP007	3
Number of flights on main routes (UN-741, UN-866, UN-873 and UN-857)	2718
Total number of flights	2866

Table 30.
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 148 flights). Therefore, the total number of flights in this case is 2866.

The time windows to obtain proximate pairs and the number of proximate events are, in this case, the ones shown in Table 31. 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	---	478.77	492.00	98º	15	11	2
				82º	13	0	10
ENUGO-APIGU	---	478.77	493.26	96º	15	1	6
				84º	14	6	7
APOXA-GONSA	---	478.77	500.86	92º	14	0	2
				88º	14	5	4
SAGRO-LIRAX	---	478.77	492.76	93º	15	1	2
				87º	14	1	5
GARKO-LIRAX	---	478.77	467.66	96º	16	1	0
				84º	14	0	0
XUVIT-DIGUN	DIGUN	492.61	478.42	158º	53	0	4
				22º	10	3	2
TARIM-DIGUN	DIGUN	492.61	507.66	169º	105	0	3
				11º	10	6	11
LIRAX-IRAVU	LIRAX	472.56	499.91	154º	45	0	2
				26º	11	1	0
SAGRO-BUXON	SAGRO	492.61	477.96	124º	22	0	2
				56º	12	0	0
TARIM-SAGRO	SAGRO	492.61	482.77	167º	86	1	10
				13º	10	0	0
SAGRO-MOSOK	SAGRO	492.61	472.45	137º	28	0	1
				43º	11	0	0
SAGRO-MOSOK	MOSOK	470.47	472.45	137º	28	0	0
				43º	11	0	2
ENUGO-IP007	ENUGO	492.61	453.57	159º	57	0	0
				21º	11	1	0

Table 31.
Time windows for crossing occupancies and number of proximate events in Dakar1

Here again, as it happened in the locations previously analyzed, there are 36 proximate events at the same flight level within 15 minutes of each other. 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 2019 to 2029 with an annual traffic growth rate of 2.9% are shown in Table 32.

2.9% annual traffic growth				**2019**	**2021**	**2023**	**2025**	**2027**	**2029**
Same direction vertical occupancy				0.0530	0.0561	0.0594	0.0629	0.0666	0.0705
Opposite direction vertical occupancy				0.0912	0.0966	0.1023	0.1083	0.1147	0.1214
Crossing occupancy	UL-435	---	98º	0.0091	0.0096	0.0102	0.0108	0.0114	0.0121
			82º	0.0070	0.0074	0.0078	0.0083	0.0088	0.0093
	ENUGO-APIGU	---	96º	0.0049	0.0052	0.0055	0.0058	0.0061	0.0065
			84º	0.0077	0.0081	0.0086	0.0091	0.0096	0.0102
	APOXA-GONSA	---	92º	0.0014	0.0015	0.0016	0.0017	0.0018	0.0019
			88º	0.0063	0.0067	0.0070	0.0075	0.0079	0.0084
	SAGRO-LIRAX	---	93º	0.0014	0.0015	0.0016	0.0017	0.0018	0.0019
			87º	0.0042	0.0044	0.0047	0.0050	0.0053	0.0056
	GARKO-LIRAX	---	96º	0.0007	0.0007	0.0008	0.0008	0.0009	0.0009
			84º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	XUVIT-DIGUN	DIGUN	158º	0.0028	0.0029	0.0031	0.0033	0.0035	0.0037
			22º	0.0035	0.0037	0.0039	0.0041	0.0044	0.0046
	TARIM-DIGUN	DIGUN	169º	0.0021	0.0022	0.0023	0.0025	0.0026	0.0028
			11º	0.0119	0.0126	0.0133	0.0141	0.0149	0.0158
	LIRAX-IRAVU	LIRAX	154º	0.0014	0.0015	0.0016	0.0017	0.0018	0.0019
			26º	0.0007	0.0007	0.0008	0.0008	0.0009	0.0009
	SAGRO-BUXON	SAGRO	124º	0.0014	0.0015	0.0016	0.0017	0.0018	0.0019
			56º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	TARIM-SAGRO	SAGRO	167º	0.0077	0.0081	0.0086	0.0091	0.0096	0.0102
			13º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	SAGRO-MOSOK	SAGRO	137º	0.0007	0.0007	0.0008	0.0008	0.0009	0.0009
			43º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
		MOSOK	137º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
			43º	0.0014	0.0015	0.0016	0.0017	0.0018	0.0019
	ENUGO-IP007	ENUGO	159º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
			21º	0.0007	0.0007	0.0008	0.0008	0.0009	0.0009

Table 32.
Vertical occupancy estimate for Dakar1 until 2029 with an annual traffic growth rate of 2.9%

4.1.6.e. Dakar2

Table 33 collects some results on same and opposite vertical occupancy in Dakar2, obtained with data from August 2019.

Number of flights	August 2019
Number of flights on UN-741	321
Number of flights on UN-866	547
Number of flights on UN-873	1497
Number of flights on UN-857	372
Total number of flights on main airways	2737
Number of same direction vertical proximate pairs for tracks UN-741	30
Number of same direction vertical proximate pairs for tracks UN-866	39
Number of opposite direction vertical proximate pairs for tracks UN-873	143
Number of opposite direction vertical proximate pairs for tracks UN-857	5
Total number of same direction proximate events	69
Total number of opposite direction proximate events	148
Same direction vertical occupancy (S_x=80NM)	0.0504
Opposite direction vertical occupancy (S_x=80NM)	0.1081

Table 33.
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 2019
Number of flights on IP006-NANIK	1
Number of flights on IP007-NANIK	6
Number of flights on IP008-NANIK	73
Number of flights on IP008-MOSAD	2
Number of flights on IRAVU-MESAB	14
Number of flights on DIGUN-MOVGA	17
Number of flights on DIGUN-ENOTO	28
Number of flights on main routes (UN-741, UN-866, UN-873 and UN-857)	2737
Total number of flights	2834

Table 34.
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 97 of them. Therefore, the total number of aircraft in this case is 2834.

The time windows to obtain proximate pairs and the number of proximate pairs are, in this case, the ones shown in Table 35. 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
DIGUN-ENOTO	DIGUN	480.68	489.07	140º	29	0	4
				40º	11	2	0
	ENOTO	463.12	489.07	139º	29	0	0
				31º	11	2	2
IP007-NANIK	NANIK	480.68	478.27	160º	58	0	0
				20º	11	0	1
IP008-NANIK	NANIK	480.68	480.43	169º	108	0	0
				11º	10	1	4
IRAVU-MESAB	MESAB	475.76	495.83	153º	43	0	15
				27º	11	1	0
DIGUN-MOVGA	DIGUN	480.68	487.91	146º	35	0	0
				34º	11	4	4

Table 35.
Time windows for crossing occupancies and number of proximate events in Dakar2

Here again, as it happened in the locations previously analysed, there are 10 proximate events at the same flight level within 15 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 annual traffic growth rate forecasted. Vertical occupancy values from 2019 to 2029 with an annual traffic growth rate of 2.9% are shown in Table 36.

2.9% annual traffic growth				2019	2021	2023	2025	2027	2029
Same direction vertical occupancy				0.0504	0.0534	0.0565	0.0599	0.0634	0.0671
Opposite direction vertical occupancy				0.1082	0.1145	0.1213	0.1284	0.1359	0.1439
Crossing occupancy	DIGUN-ENOTO	DIGUN	140º	0.0028	0.0029	0.0031	0.0033	0.0035	0.0037
			40º	0.0014	0.0015	0.0016	0.0017	0.0018	0.0019
		ENOTO	139º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
			31º	0.0028	0.0029	0.0031	0.0033	0.0035	0.0037
	IP007-NANIK	NANIK	160º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
			20º	0.0007	0.0007	0.0008	0.0008	0.0009	0.0009
	IP008-NANIK	NANIK	169º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
			11º	0.0035	0.0037	0.0039	0.0041	0.0044	0.0046
	IRAVU-MESAB	MESAB	153º	0.0106	0.0112	0.0119	0.0126	0.0133	0.0141
			27º	0.0007	0.0007	0.0008	0.0008	0.0009	0.0009
	DIGUN-MOVGA	DIGUN	146º	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
			34º	0.0049	0.0052	0.0055	0.0058	0.0061	0.0065

Table 36.
Vertical occupancy estimate for Dakar2 until 2029 with an annual traffic growth rate of 2.9%

4.1.6.f. Recife

Table 37 collects some results on same and opposite vertical occupancy in Recife, using data from August 2019.

Number of flights	August 2019
Number of flights on UN-741	402
Number of flights on UN-866	564
Number of flights on UN-873	1502
Number of flights on UN-857	309
Total number of flights on main airways	2777
Number of same direction vertical proximate pairs for tracks UN-741	42
Number of same direction vertical proximate pairs for tracks UN-866	40
Number of opposite direction vertical proximate pairs for tracks UN-873	139
Number of opposite direction vertical proximate pairs for tracks UN-857	8
Total number of same direction proximate events	82
Total number of opposite direction proximate events	147
Same direction vertical occupancy (S_x=80NM)	0.0591
Opposite direction vertical occupancy (S_x=80NM)	0.1059

Table 37.
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 traffic on these routes can be found in the following table:

Number of flights	August 2019
Number of flights on UL-695/UL-375	15
Number of flights on ERETU-PUGSA	63
Number of flights on MAGNO-SALPU	1
Number of flights on main routes (UN-741, UN-866, UN-873 and UN-857)	2777
Total number of flights	2856

Table 38.
Number of flights in Recife airspace.

The time windows to obtain proximate pairs are, in this case, the ones shown in Table 39. All the flights on the non-published routes are already included in the number of flights on the main routes except for 79 of them. Therefore, the total number of aircraft in this case is 2856.

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	---	468.79	469.87	97º	16	2	1
				83º	14	0	9
ERETU-PUGSA	ERETU	465.14	490.49	165º	80	0	14
				15º	11	2	0

Table 39.
Time windows for crossing occupancies and number of proximate events in Recife

As it occurred in other locations, there are two proximate events at the same flight level within 15 minutes of each other.

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 2019 to 2029 with an annual traffic growth rate of 2.9% are shown in Table 40.

2.9% annual traffic growth				**2019**	**2021**	**2023**	**2025**	**2027**	**2029**
Same direction vertical occupancy				0.0591	0.0625	0.0662	0.0701	0.0742	0.0786
Opposite direction vertical occupancy				0.1059	0.1121	0.1187	0.1257	0.1331	0.1409
Crossing occupancy	UL-695	---	97º	0.0014	0.0015	0.0016	0.0017	0.0018	0.0019
			83º	0.0063	0.0067	0.0071	0.0075	0.0079	0.0084
	ERETU-PUGSA	ERETU	165º	0.0098	0.0104	0.0110	0.0116	0.0123	0.0130
			15º	0.0014	0.0015	0.0016	0.0017	0.0018	0.0019

Table 40.
Vertical occupancy estimate for Recife until 2029 with an annual traffic growth rate of 2.9%

4.1.7. Technical vertical collision risk

The technical vertical collision risk values obtained until 2029 in the different locations are the ones summarized in the following table, considering that the traffic growth factor is 2.9% per annum. These results can also be seen in Figure 17 to Figure 28.

Technical Vertical Collision risk	2.9% annual traffic growth					
	Canaries	SAL1	SAL2	Dakar1	Dakar2	Recife
2019	$2.9057*10^{-12}$	$9.0266*10^{-13}$	$1.5434*10^{-12}$	$1.6937*10^{-12}$	$1.9709*10^{-12}$	$1.9265*10^{-12}$
2020	$2.9900*10^{-12}$	$9.2884*10^{-13}$	$1.5882*10^{-12}$	$1.7428*10^{-12}$	$2.0280*10^{-12}$	$1.9824*10^{-12}$
2021	$3.0767*10^{-12}$	$9.5578*10^{-13}$	$1.6342*10^{-12}$	$1.7933*10^{-12}$	$2.0868*10^{-12}$	$2.0399*10^{-12}$
2022	$3.1659*10^{-12}$	$9.8349*10^{-13}$	$1.6816*10^{-12}$	$1.8453*10^{-12}$	$2.1474*10^{-12}$	$2.0991*10^{-12}$
2023	$3.2577*10^{-12}$	$1.0120*10^{-12}$	$1.7304*10^{-12}$	$1.8988*10^{-12}$	$2.2096*10^{-12}$	$2.1599*10^{-12}$
2024	$3.3522*10^{-12}$	$1.0414*10^{-12}$	$1.7806*10^{-12}$	$1.9539*10^{-12}$	$2.2737*10^{-12}$	$2.2226*10^{-12}$
2025	$3.4494*10^{-12}$	$1.0716*10^{-12}$	$1.8322*10^{-12}$	$2.0106*10^{-12}$	$2.3396*10^{-12}$	$2.2870*10^{-12}$
2026	$3.5494*10^{-12}$	$1.1026*10^{-12}$	$1.8854*10^{-12}$	$2.0689*10^{-12}$	$2.4075*10^{-12}$	$2.3534*10^{-12}$
2027	$3.6524*10^{-12}$	$1.1346*10^{-12}$	$1.9400*10^{-12}$	$2.1289*10^{-12}$	$2.4773*10^{-12}$	$2.4216*10^{-12}$
2028	$3.7583*10^{-12}$	$1.1675*10^{-12}$	$1.9963*10^{-12}$	$2.1906*10^{-12}$	$2.5492*10^{-12}$	$2.4918*10^{-12}$
2029	$3.8673*10^{-12}$	$1.2014*10^{-12}$	$2.0542*10^{-12}$	$2.2541*10^{-12}$	$2.6231*10^{-12}$	$2.5641*10^{-12}$

Table 41.
Technical vertical collision risk for the period 2019-2029 in the Corridor

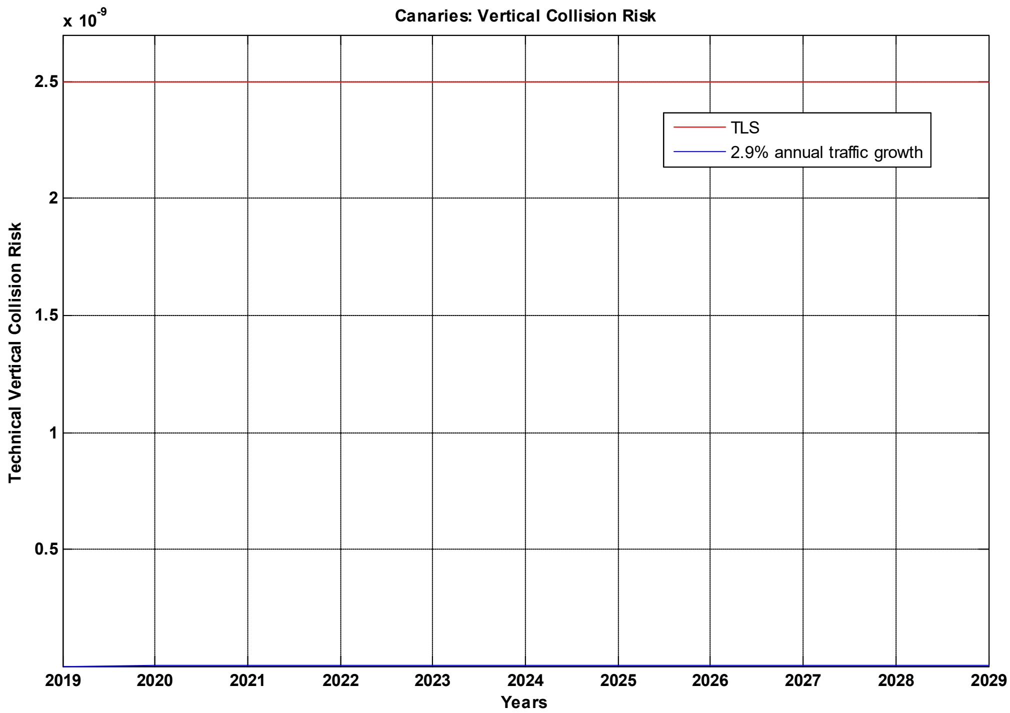


Figure 17.
Technical vertical collision risk for the period 2019-2029 in the Canaries

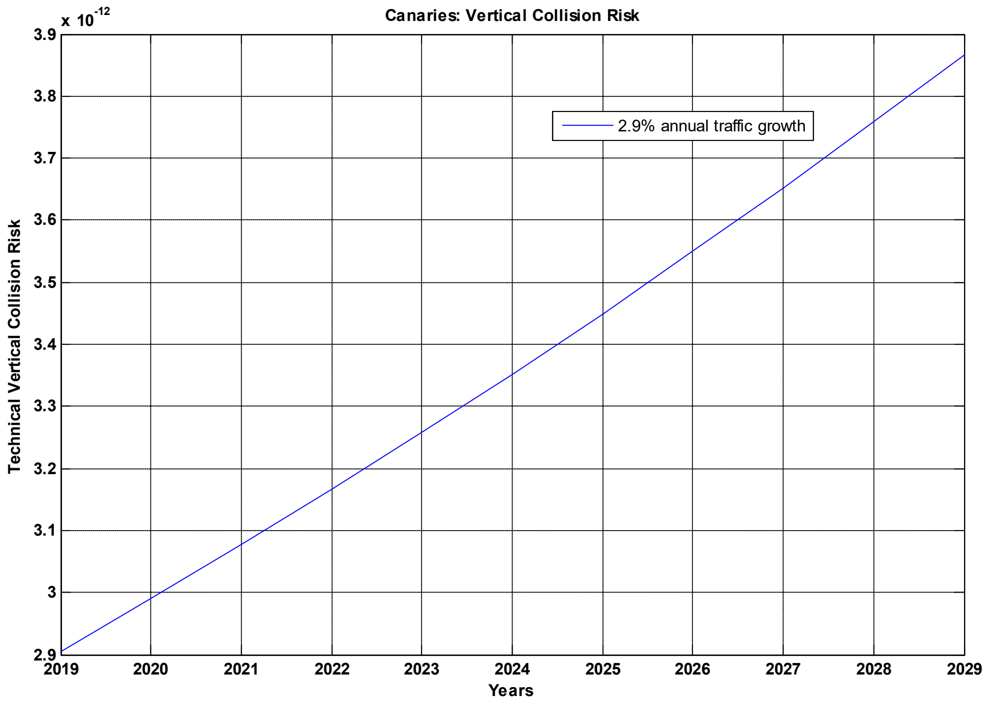


Figure 18.
Technical vertical collision risk for the period 2019-2029 in the Canaries (enlarged)

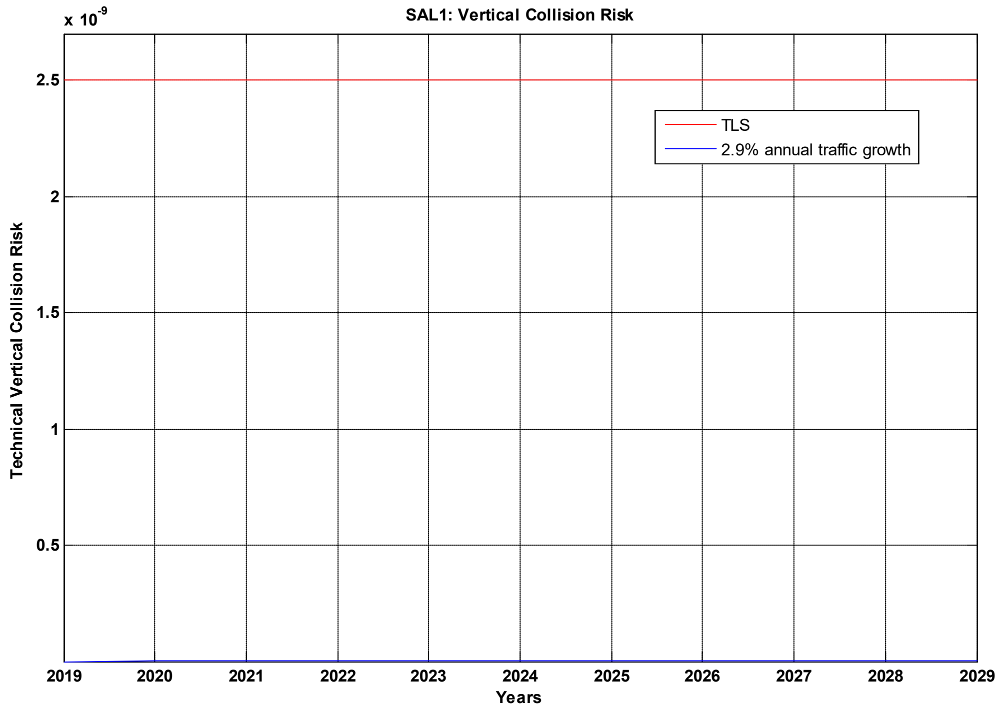


Figure 19.
Technical vertical collision risk for the period 2019-2029 in SAL1

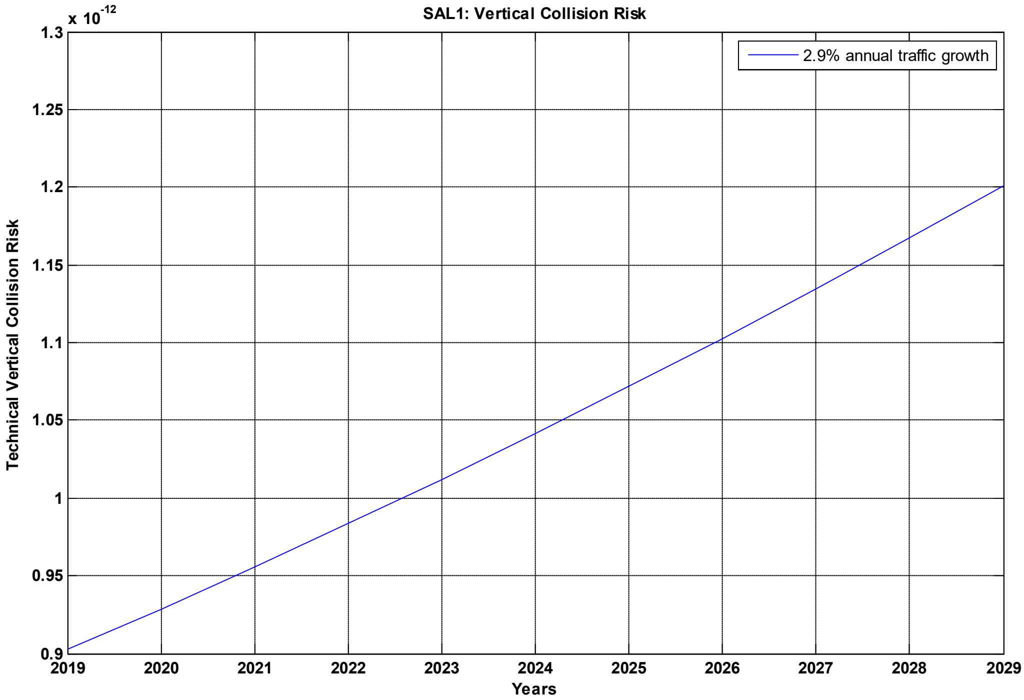


Figure 20.
Technical vertical collision risk for the period 2019-2029 in SAL1 (enlarged)

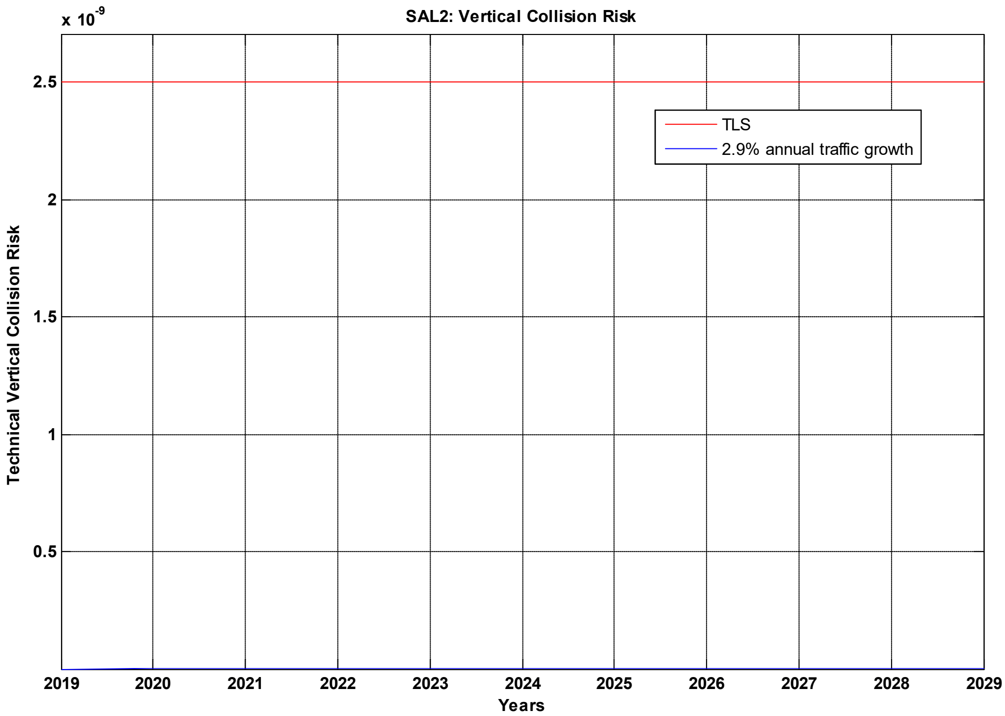


Figure 21.
Technical vertical collision risk for the period 2019-2029 in SAL2

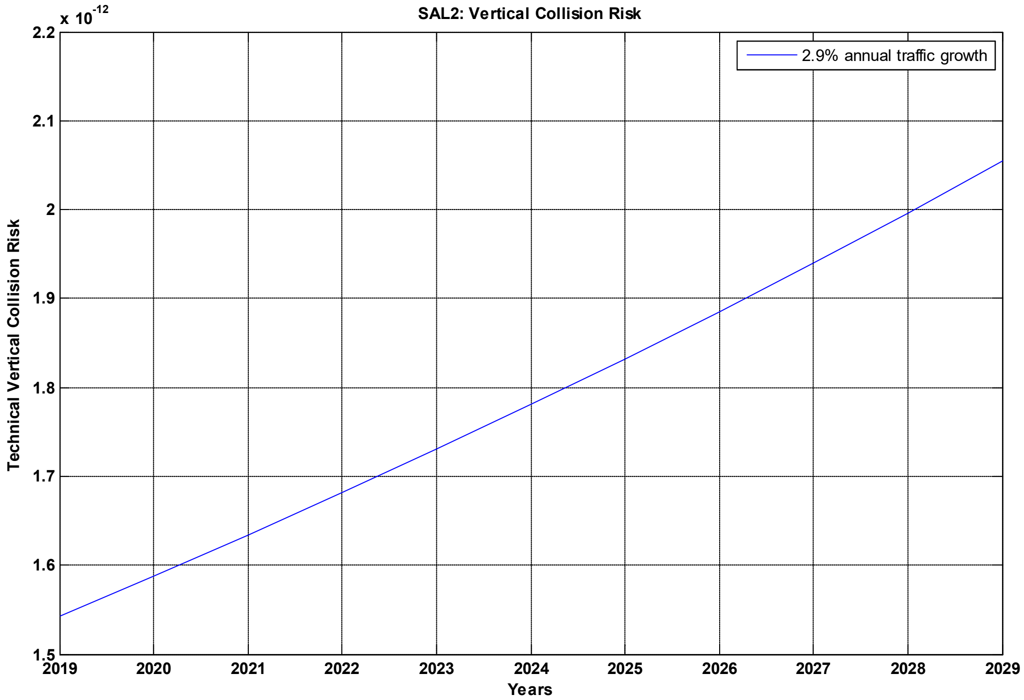


Figure 22.
Technical vertical collision risk for the period 2019-2029 in SAL2 (enlarged)

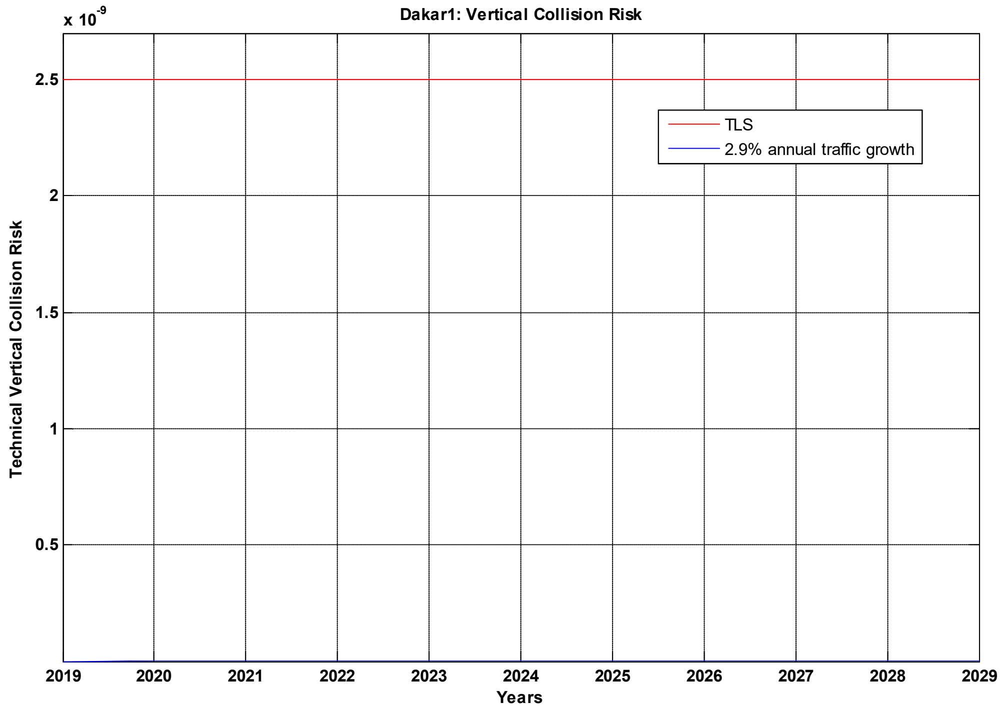


Figure 23.
Technical vertical collision risk for the period 2019-2029 in Dakar1

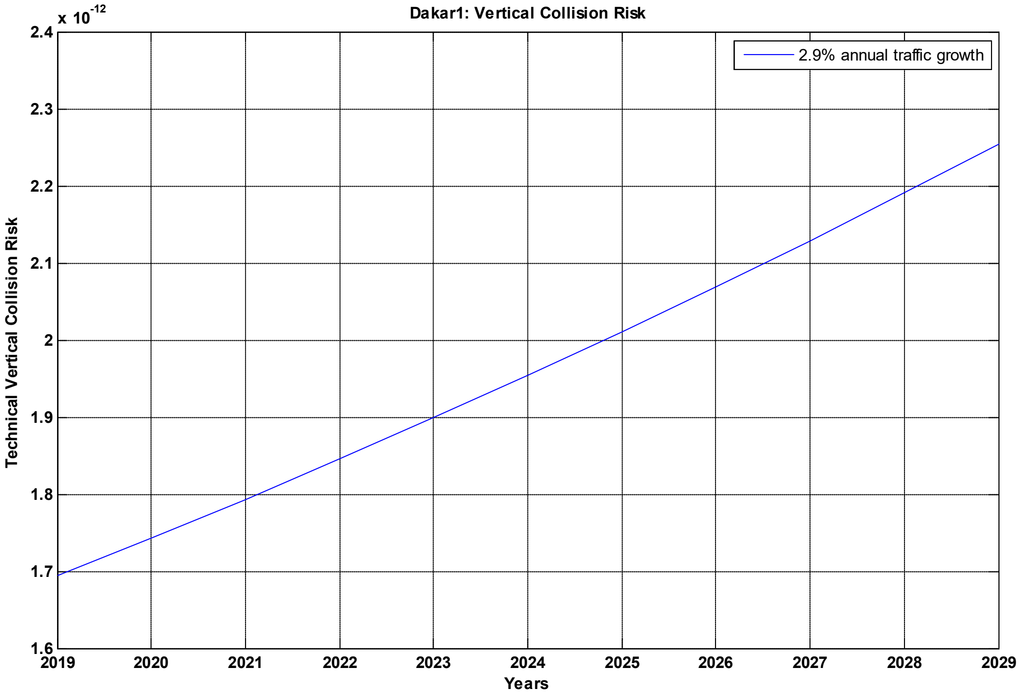


Figure 24.
Technical vertical collision risk for the period 2019-2029 in Dakar1 (enlarged)

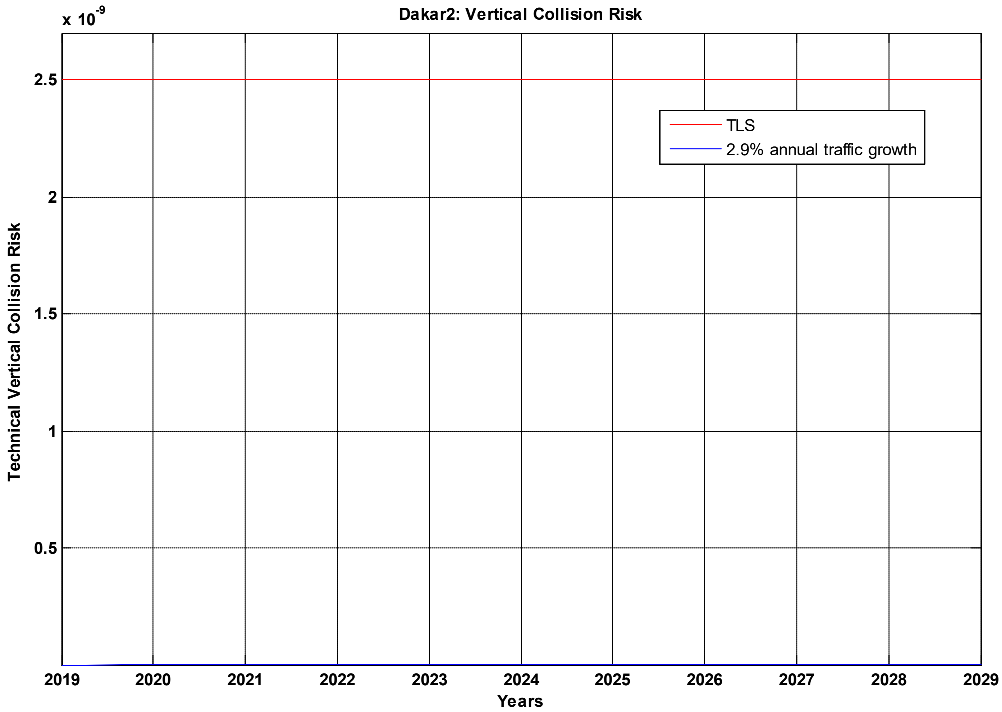


Figure 25.
Technical vertical collision risk for the period 2019-2029 in Dakar2

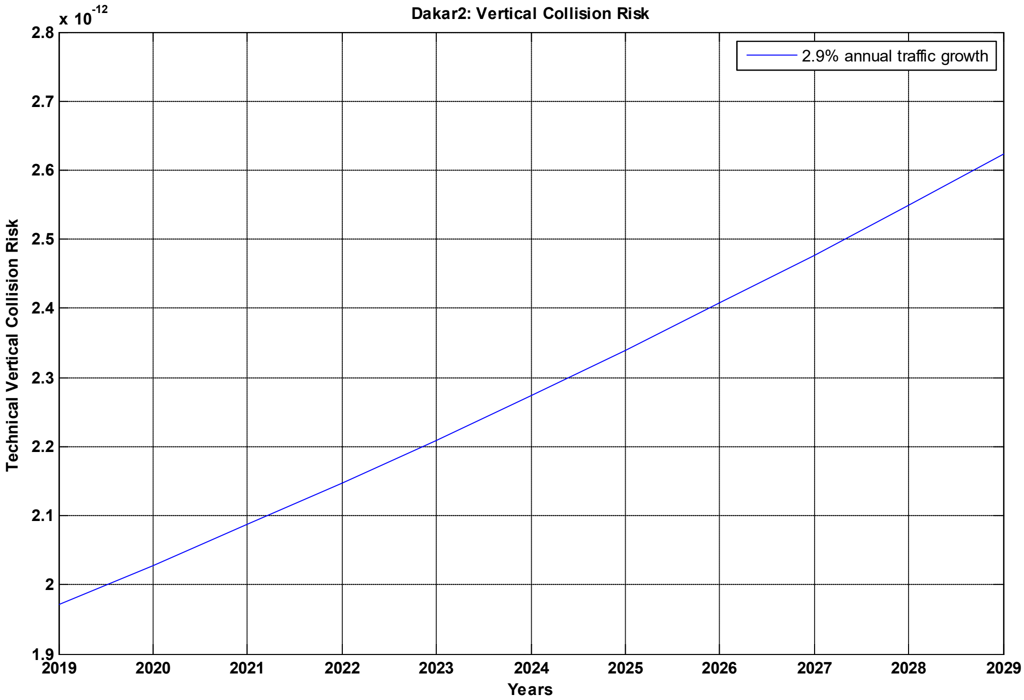


Figure 26.
Technical vertical collision risk for the period 2019-2029 in Dakar2 (enlarged)

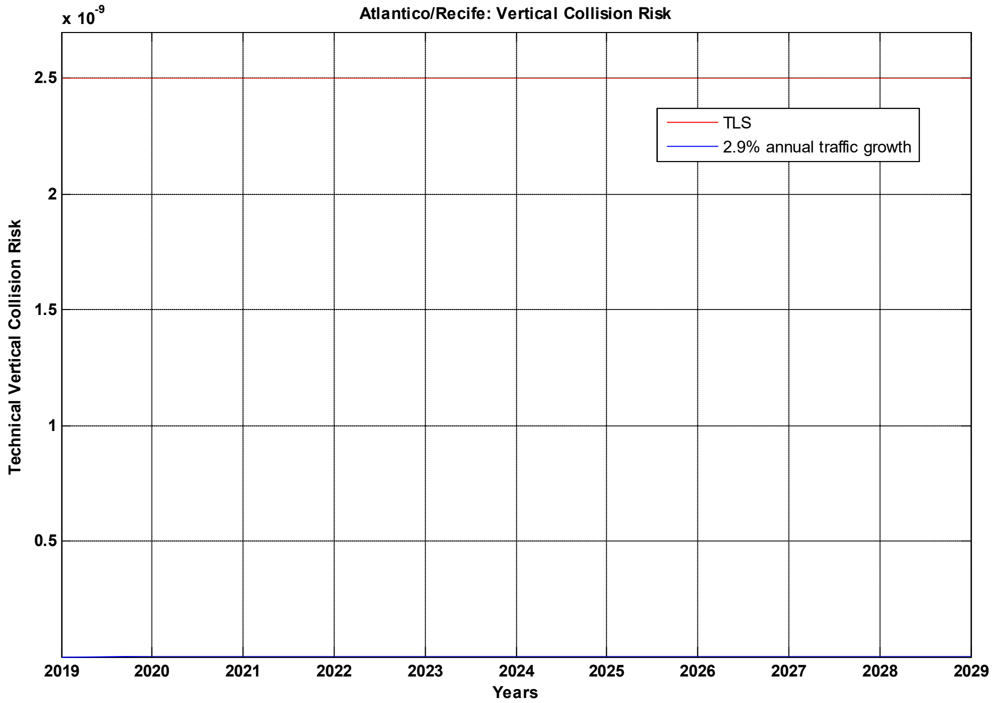


Figure 27.
Technical vertical collision risk for the period 2019-2029 in Recife

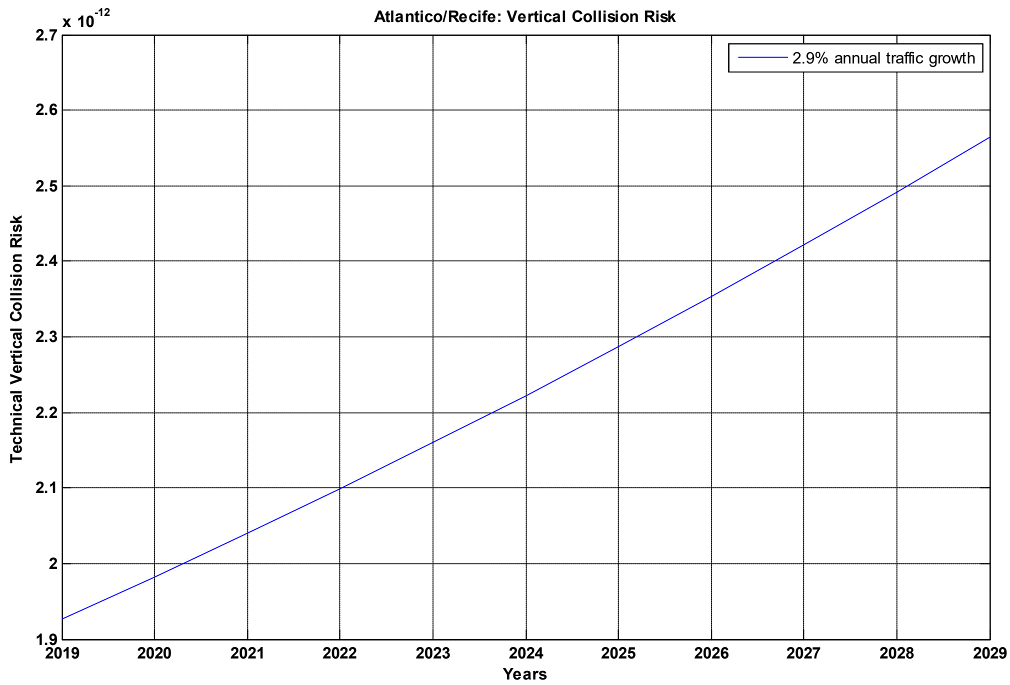


Figure 28.
Technical vertical collision risk for the period 2019-2029 in Recife (enlarged)

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 2029 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[2] must be assessed and added to the technical vertical risk.

In accordance with the ICAO recommendations ([Ref. 33]), large height deviations can be classified as reflected in Table 42. This classification has been used in the EUR/SAM Corredor.

[2] *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 42.
LHD classification according to ICAO

4.2.1. Data on EUR/SAM large height deviations

As it has been explained in [Ref. 34], 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 43 indicates the months for which LHD reports have been received before March 15th, 2020[3]. From these LHDs, only those affecting the four main routes have been considered[4]. Table 44, Table 45 and Table 46, show the details of the deviations reported in the Canaries, SAL, Dakar and Atlantic-Recife, respectively. It can happen that a State reports an LHD that affects another. In this case, the LHD will be included only in the table of the affected FIR.

[3] *The deadline agreed for all States to send their information is January 31th of the year after the one studied.*

[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-19				
Feb-19				
Mar-19				
Apr-19				
May-19				
Jun-19				
Jul-19				
Aug-19				
Sep-19				
Oct-19				
Nov-19				
Dec-19				

KEY: Available | Not available | **"No deviation" report received**

Table 43.
Received data from January 2019 to December 2019

Although in Table 43 it is indicated that there are reports associated with Recife, these are deviations not related to the Corridor, so they have not been considered in the study and are not shown in the following tables

Date	Route	Duration	Coordinated FL	Observed FL	Deviation	Cause	Category
160219	UN873	0.08333 h	FL390	FL390	0	Coordination Error	E
040419	UN857	0.08333 h	FL390	FL370	2000 ft	Coordination Error	E
090419	UN873	0.06667 h	FL350	FL350	0	Coordination Error	E
140419	UN873	0.08333 h	FL350	FL370	2000 ft	Coordination Error	E
300419	UN866	0.51667 h	FL330	FL390	6000 ft	Coordination Error	E
080619	UN873	0.08333 h	FL370	FL370	0	Coordination Error	E
120619	UN873	0.08333 h	FL390	FL370	2000 ft	Coordination Error	E
070719	UN866	0.08333 h	FL400	FL390	1000 ft	Coordination Error	E
150719	UN873	0.08333 h	FL370	FL370	0	Coordination Error	E
210819	UN857	0.08333 h	FL370	FL390	2000 ft	Coordination Error	E
091019	UN873	0.08333 h	FL410	FL410	0	Coordination Error	F
021119	UN873	0.08333 h	FL370	FL390	2000 ft	Coordination Error	E

Table 44.
Large height deviations reported in the Canaries

Date	Route	Duration	Coordinated FL	Observed FL	Deviation	Cause	Category
130119	UN741	0.08333 h	FL330	FL350	2000 ft	Coordination Error	E
220119	UN873	0.08333 h	FL340	FL340	0	Coordination Error	E
180219	UN866	0.08333 h	FL390	FL370	2000 ft	Coordination Error	E
030219	UN873	0.08333 h	FL330	FL330	0	Coordination Error	E
250319	UN873	0.08333 h	FL390	FL350	4000 ft	Coordination Error	E
240319	UN873	0.08333 h	FL390	FL310	8000 ft	Coordination Error	E
010319	UN741	0.08333 h	FL310	FL350	4000 ft	Coordination Error	E
090519	UN873	0.08333 h	FL380	FL380	0	Coordination Error	E
190619	UN866	0.08333 h	FL370	FL380	1000 ft	Coordination Error	E
300819	UN866	0.33333 h	FL370	FL390	2000 ft	Coordination Error	E
051019	UN741	0.33333 h	FL370	FL390	2000 ft	Coordination Error	E
091119	UN873	0.08333 h	FL320	FL320	0	Coordination Error	E
221219	UN873	0.08333 h	FL380	FL360	2000 ft	Coordination Error	E
261219	UN873	0.08333 h	FL340	FL340	0	Coordination Error	E

Table 45.
Large height deviations reported in SAL

Date	Route	Duration	Coordinated FL	Observed FL	Deviation	Cause	Category
100319_1	UN873	0.08333 h	FL360	FL360	0	Coordination Error	E
100319_2	UN873	0.08333 h	FL380	FL380	0	Coordination Error	E
250319	UN741	0.08333 h	FL370	FL350	2000 ft	Coordination Error	E
190419	UN857	0.08333 h	FL400	FL400	0	Coordination Error	E
220419	UN873	0.08333 h	FL360	FL320	4000 ft	Coordination Error	E
010519	UN866	0.08333 h	FL390	FL390	0	Coordination Error	E
010619	UN873	0.08333 h	FL310	FL330	4000 ft	Coordination Error	E
280819	UN866	0.33333 h	FL370	FL390	2000 ft	Coordination Error	E
190319	UN873	0.08333 h	FL380	FL380	0	Coordination Error	M
190419	UN857	0.08333 h	FL400	FL400	0	Coordination Error	E
030819	UN873	0.22222 h	FL360	FL340	2000 ft	Coordination Error	E

Table 46.
Large height deviations reported in Dakar

Date	Route	Duration	Coordinated FL	Observed FL	Deviation	Cause	Category
160719	UN873	0.08333 h	FL360	FL360	0	Coordination Error	F
141019	UN873	0.06667 h	FL340	FL360	2000 ft	Coordination Error	E

Table 47.
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 5.

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 44, Table 45, Table 46 and Table 47, there are no reports due to large height deviations not involving whole numbers of flight levels and $\mathrm{N}_{\mathrm{az}}^{*} = 0$.

All deviations reported are 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. Deviations that involve entering a new UIR before than the coordinated time have also been considered.

Consequently, the terms to be calculated are the risk due to an aircraft levelling off at a wrong level and not 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 2018, 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.

Number of flights	Jan-Dec 2019			
	Canaries	**SAL**	**Dakar**	**Recife**
Same direction time at incorrect level (h)	1.416	1.5833	1.3055	0.1500
Opposite direction time at incorrect level (h)	0	0.0833	0	0
Same direction number of crossed levels (N)	0	0	0	0
Opposite direction number of crossed levels (N)	0	0	0	0
Total FIR/UIR flight time (h)	24407.60	33694.60	45896.72	30845.79
Total Corridor flight time (h)	134844.71	134844.71	134844.71	134844.71
Wrong level, same direction vertical overlap probability	$2.7137*10^{-5}$	$2.1971*10^{-5}$	$1.3299*10^{-5}$	$2.2737*10^{-6}$
Wrong level, opposite direction vertical overlap probability	0	$1.1563*10^{-6}$	0	0
Climb/descend, same direction vertical overlap probability	0	SAL 1 0 SAL 2 0	Dakar 1 0 Dakar 2 0	0
Climb/descend, opposite direction vertical overlap probability	0	SAL 1 0 SAL 2 0	Dakar 1 0 Dakar 2 0	0
Climb/descend relative vertical speed (kts)	15	15	15	15

Table 48.
Operational vertical collision risk parameters in the Corridor

Table 49 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 2.9% per annum. These results can also be seen in Figure 29 to Figure 34.

Total Vertical Collision risk	2.9% annual traffic growth					
	Canaries	**SAL1**	**SAL2**	**Dakar1**	**Dakar2**	**Recife**
2019	$8.0541*10^{-8}$	$2.6529*10^{-7}$	$3.0459*10^{-7}$	$7.5576*10^{-8}$	$6.5354*10^{-8}$	$1.3393*10^{-8}$
2020	$8.2877*10^{-8}$	$2.7298*10^{-7}$	$3.1342*10^{-7}$	$7.7768*10^{-8}$	$6.7250*10^{-8}$	$1.3782*10^{-8}$
2021	$8.5280*10^{-8}$	$2.8090*10^{-7}$	$3.2251*10^{-7}$	$8.0023*10^{-8}$	$6.9200*10^{-8}$	$1.4181*10^{-8}$
2022	$8.7754*10^{-8}$	$2.8904*10^{-7}$	$3.3186*10^{-7}$	$8.2344*10^{-8}$	$7.1207*10^{-8}$	$1.4593*10^{-8}$
2023	$9.0298*10^{-8}$	$2.9742*10^{-7}$	$3.4149*10^{-7}$	$8.4732*10^{-8}$	$7.3272*10^{-8}$	$1.5016*10^{-8}$
2024	$9.2917*10^{-8}$	$3.0605*10^{-7}$	$3.5139*10^{-7}$	$8.7189*10^{-8}$	$7.5397*10^{-8}$	$1.5451*10^{-8}$
2025	$9.5612*10^{-8}$	$3.1493*10^{-7}$	$3.6158*10^{-7}$	$8.9718*10^{-8}$	$7.7583*10^{-8}$	$1.5899*10^{-8}$
2026	$9.8384*10^{-8}$	$3.2406*10^{-7}$	$3.7207*10^{-7}$	$9.2319*10^{-8}$	$7.9833*10^{-8}$	$1.6360*10^{-8}$
2027	$1.0124*10^{-7}$	$3.3346*10^{-7}$	$3.8286*10^{-7}$	$9.4997*10^{-8}$	$8.2148*10^{-8}$	$1.6835*10^{-8}$
2028	$1.0417*10^{-7}$	$3.4313*10^{-7}$	$3.9296*10^{-7}$	$9.7752*10^{-8}$	$8.4530*10^{-8}$	$1.7323*10^{-8}$
2029	$1.0719*10^{-7}$	$3.5308*10^{-7}$	$4.0539*10^{-7}$	$1.0059*10^{-7}$	$8.6982*10^{-8}$	$1.7826*10^{-8}$

Table 49.
Total vertical collision risk for the period 2019-2029

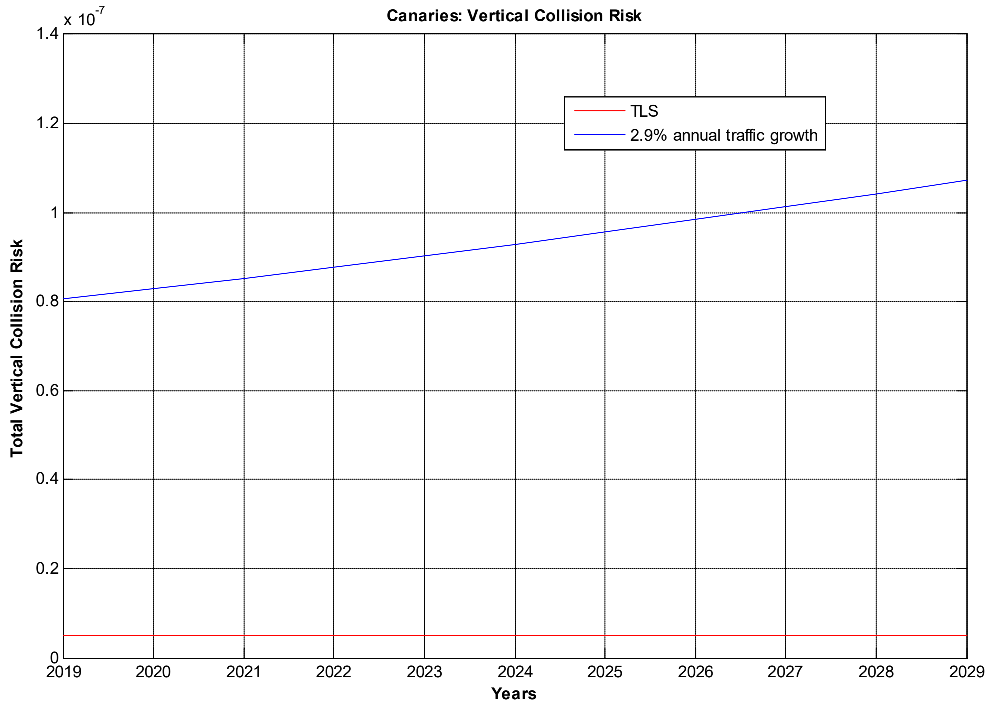


Figure 29.
Total vertical collision risk for the period 2019-2029 in the Canaries

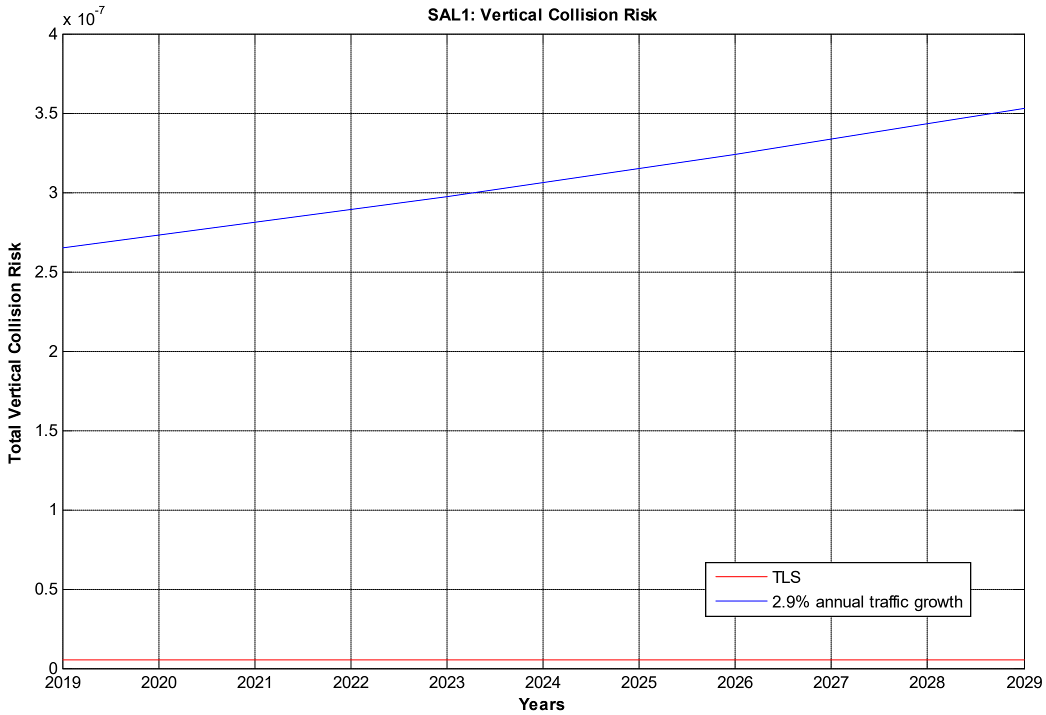


Figure 30.
Total vertical collision risk for the period 2019-2029 in SAL1

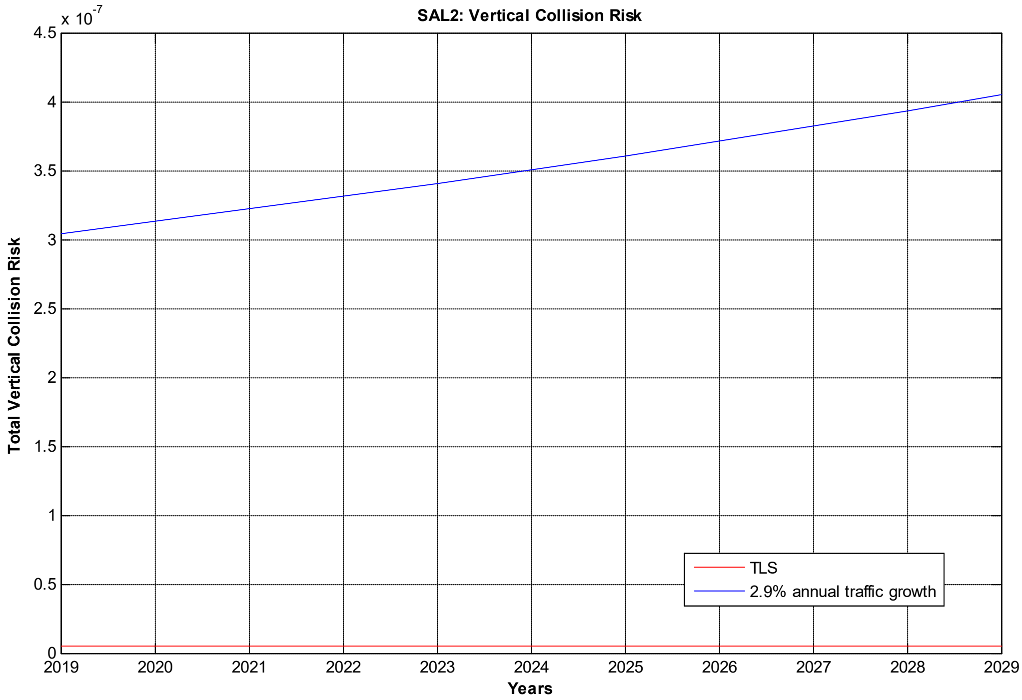


Figure 31.
Total vertical collision risk for the period 2019-2029 in SAL2

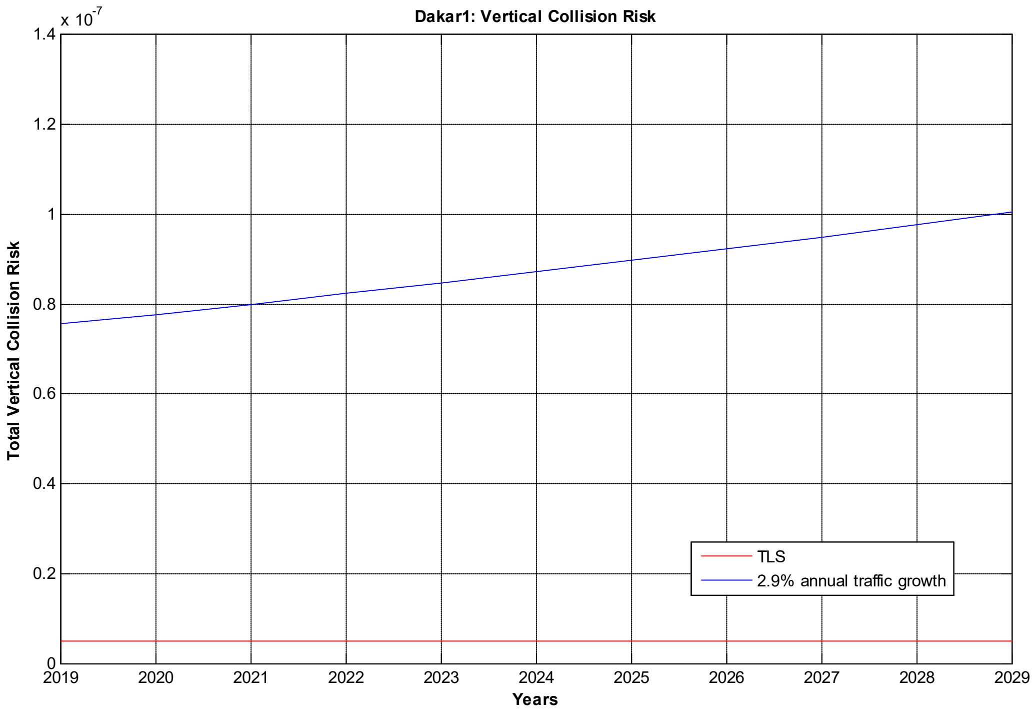


Figure 32.
Total vertical collision risk for the period 2019-2029 in Dakar1

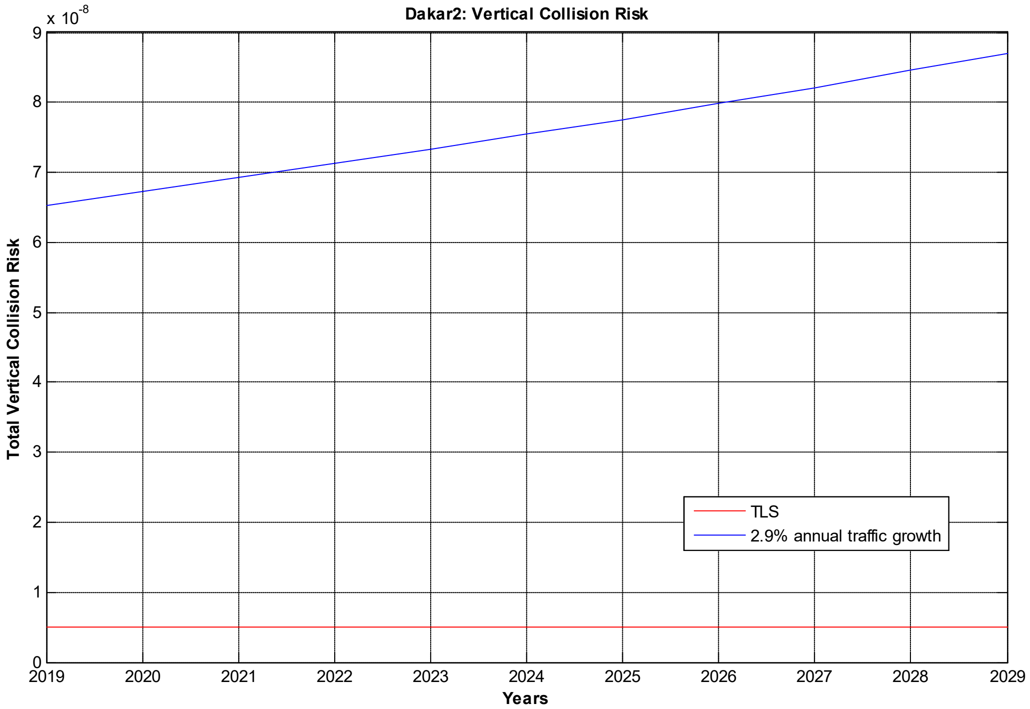


Figure 33.
Total vertical collision risk for the period 2019-2029 in Dakar2

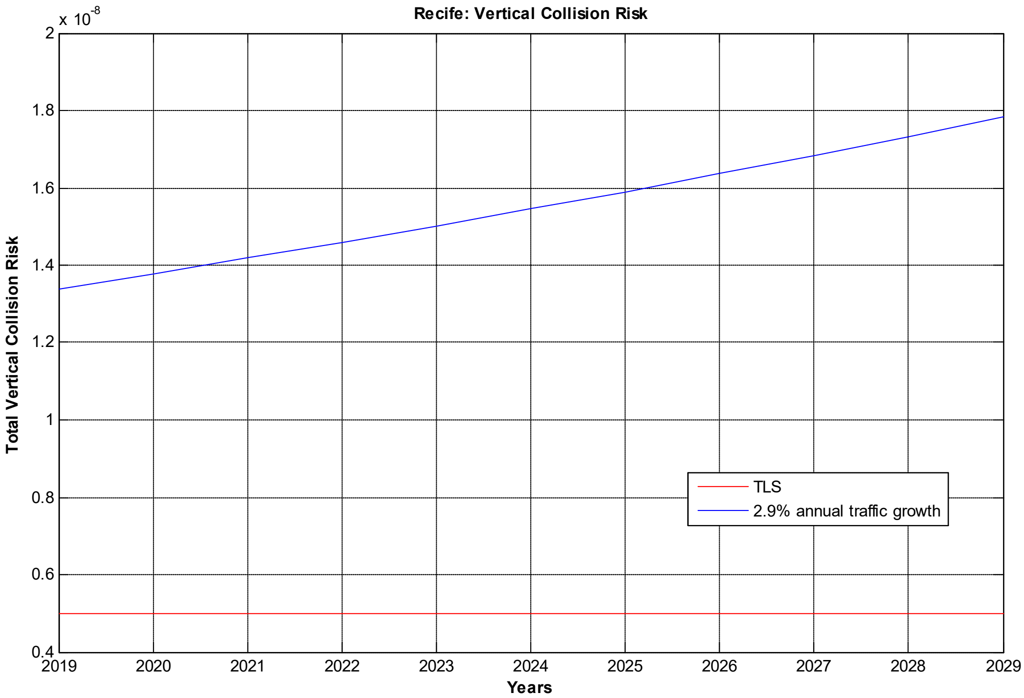


Figure 34.
Total vertical collision risk for the period 2019-2029 in Recife

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 except in the Recife FIR because in this case, no deviations were reported in the corridor (some deviations were reported not related to the corridor and not taken into account in this analysis).

In previous safety assessments, such as [Ref. 3], [Ref. 5], [Ref. 8], [Ref. 9] or [Ref. 10], 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. 30], [Ref. 31] and [Ref. 32]).

Using this value of $P_y(0)=0.059$, the obtained results are shown in Table 50.

FIR/UIR	**Vertical risk**	
	Technical risk	**Total vertical risk**
Canaries	$6.3542*10^{-13}$	$1.7613*10^{-8}$
SAL1	$1.9143*10^{-13}$	$8.5651*10^{-8}$
SAL2	$3.1080*10^{-13}$	$6.8742*10^{-8}$
Dakar1	$3.4830*10^{-13}$	$2.6145*10^{-8}$
Dakar2	$3.9827*10^{-13}$	$1.6980*10^{-8}$
Recife	$3.8908*10^{-13}$	$3.5157*10^{-9}$

Table 50.
Technical and total vertical risk using Py(0)=0.059

As it can be seen in Table 50, 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 except in the Recife FIR.

5. Conclusions

Only real traffic data for one representative 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 $P_y(50) = 5.7381 \cdot 10^{-8}$ and $P_y(50) = 7.3923 \cdot 10^{-8}$, depending on the location, whilst the lateral overlap probability obtained for $S_y = 90\,NM$ is between $P_y(90) = 1.5944 \cdot 10^{-8}$ and $P_y(90) = 2.2412 \cdot 10^{-8}$.
  - For current traffic levels, the lateral collision risk obtained is $2.3203*10^{-9}$, whilst the lateral collision risk estimated for 2029 with an annual traffic growth rate of 2.9% is $3.0881*10^{-9}$. 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 2019 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, 2019 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 2019, for S_z=1000 ft is $P_z(1000) = 9.92762 \cdot 10^{-12}$.
  - 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 0.2698 and 0.3009 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 $2.9057*10^{-12}$. The technical vertical collision risk estimated for 2029 with an annual traffic growth rate of 2.9% is $3.8673*10^{-12}$. 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 although slightly higher than in 2018.
   - 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.
- It is important to note that the content of the incident reports should be accurate and reliable, ensuring consistency of data as far as possible.
- 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).

6. Reference documentation

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[Ref. 3] EUR/SAM Corridor: "Double unidirectionality" post-implementation collision risk assessment. NIVY-IDSA-INF-001-1.0-09. January 2009.

[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] EUR/SAM Corridor: 2017 Collision risk assessment. NYVI-IDSA-INF-019-1.0/18. June 2018.

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[Ref. 15] Air Traffic Services Planning manual. Doc 9426 OACI

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[Ref. 17] 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

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[Ref. 19] The EUR RVSM Mathematical Supplement.-MDG/21 DP/01 August 2001.

[Ref. 20] CAR/SAM-Course on Introduction to Safety Assessment. Lima, 19-23/06/06 (www.lima.icao.int)

[Ref. 21] 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. 22] STATFOR. Eurocontrol Seven-Year Forecast. February 2018

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

[Ref. 24] Revised Pre-Implementation Collision Risk Assessment for RVSM in the Africa Indian Ocean Region. NLR-CR-2007-637. February 2007

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[Ref. 27] AIS-ESPAÑA. AIC 10 May 07. New route orientation on airways UN-741 and UN-866 (Corridor EUR/SAM)

[Ref. 28] AIS-ESPAÑA. AIC 30 July 09. ADS/CPDLC Operational implementation of the SACCAN FANS 1/A System in the Canarias FIR/UIR

[Ref. 29] Updated RMA Manual. SASP/13-WP/44. May 2008

[Ref. 30] "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. 31] "Airspace Safety Review for the RVSM operation In the airspace of Chinese Flight Information Regions. January 2012 - December 2012".

[Ref. 32] "Airspace Safety Review for the RVSM Implementation in Fukuoka Flight Information Region". Jan 2014 To Dec 2014"

[Ref. 33] ICAO Doc 9937 Manual of Operating Procedures and Practices for Regional Monitoring Agencies

[Ref. 34] Description of the methodology for the Collision Risk Assessment in the EUR/SAM Corridor. ENAIRE. NYVI-IDSA-INF-018-18-1.0. June 2018

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