ENAIRE

EUR/SAM Corridor: 2020 Collision Risk Assessment

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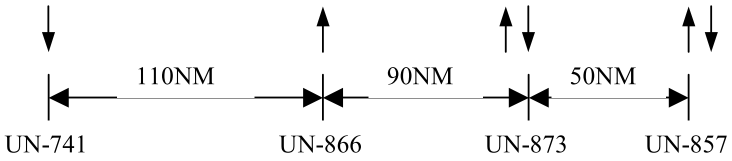
Executive Summary

This report presents the 2020 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 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 2020. However not all the data from the rest of the FIRs/UIRs was available at the end of the year. At the time of starting this study, no SAL traffic data was available, so they had to be extrapolated from the traffic data of the Canary Islands and Dakar. Neither was available traffic data from Dakar since June, so the traffic samples used to perform this analysis are the ones from 1st May 2020 to 31st May 2020. This month has been selected as it was the one with the highest number of flights from the months with all information available (except SAL) after the start of the COVID pandemic. The number of flights and the flight time for the complete year 2020, 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.

According to Eurocontrol, the traffic outlook for the future has been strongly impacted by COVID-19, backing to pre-1990 flight levels. Because of this, the traffic forecast for the next years has been made considering three possible scenarios considering all possible risks and their relative impacts.

In this study the most optimistic scenario has been chosen (Scenario 1), in which the 2019 level is recovered in 2024, assuming that vaccine is widely made available for travellers (or end of pandemic) by summer 2021.

The risk has been evaluated in 6 different locations along the Corridor and an estimation of the collision risk for the next four years has been calculated, assuming a traffic growth rate of 59%, 30%, 14% and 10% in 2021, 2022, 2023 and 2024 respectively.

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 May 2020 are representative of the whole year, the calculated lateral collision risk is $4.3250*10^{-10}$, whilst the lateral collision risk estimated for 2024 with an annual traffic growth rate of 59%, 30%, 14% and 10% in 2021, 2022, 2023 and 2024 respectively is $1.211*10^{-9}$. Both values are below the TLS. 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 2020 (assuming traffic levels of May 2020 are representative of the whole year), is estimated to be $1.5806*10^{-12}$ and the technical vertical collision risk estimated for 2024 with an annual traffic growth rate of 59%, 30%, 14% and 10% in 2021, 2022, 2023 and 2024 respectively, $4.0971*10^{-12}$. 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 $1.3003*10^{-8}$, which exceeds the TLS.

In previous safety assessments, such as [Ref. 3], [Ref. 5], [Ref. 8], [Ref. 9], [Ref. 10], [Ref. 101] or [Ref. 102], 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 2020 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 May 2020 to 31st May 2020 and with the number of flights and the flight time required for some of the calculations extrapolated for the complete year 2020.

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. 36]. 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. 36], where the changes or new information regarding the airspace in the year 2020 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 May 2020 to 31st May 2020. When data, such as the number of flights or flight time for the rest of 2020 has been necessary, it has been extrapolated using information from Canaries as a basis.

Data for the complete year 2020 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 2020 to 31st December 2020. 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 2020, although not all of them were 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 2020 between FL290 and FL410 have been analysed.

Table 1 shows the values obtained for the Canaries UIR in 2020 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)
A339	1705	13,46336071	63,66	64,00	16,79
A332	1530	12,08149084	63,70	60,03	16,74
B763	1112	8,780795957	47,60	54,90	15,90
A359	1104	8,717624763	66,80	64,75	17,05
B789	919	7,256790903	62,80	60,10	16,90
B77W	883	6,972520531	73,90	60,90	18,50
B738	874	6,901452937	39,47	34,31	12,50
B752	597	4,714150347	47,32	38,05	13,60
A20N	401	3,166456096	37,57	35,80	11,76
B748	377	2,976942514	76,30	65,45	19,50
B772	370	2,92166772	63,70	60,90	18,50
A21N	337	2,661086545	44,51	35,80	11,76
B788	291	2,297852179	56,70	60,10	16,90
B744	281	2,218888187	70,70	64,40	19,40
A320	263	2,076753001	37,57	34,10	11,76
A346	249	1,966203411	74,37	63,60	17,80
A333	222	1,753000632	63,70	60,03	16,74
E190	103	0,813329122	36,24	28,72	10,57
B737	83	0,655401137	33,60	34,30	12,50
A321	74	0,584333544	37,57	34,10	11,76
GLEX	68	0,536955148	30,30	28,65	7,57
E35L	60	0,473783955	26,33	21,17	6,76
A400	55	0,434301958	42,40	45,10	14,70
C17	52	0,410612761	0,00	0,00	0,00
CL60	52	0,410612761	20,86	19,35	6,28
FA7X	52	0,410612761	22,82	25,80	7,74
B733	51	0,402716361	33,40	28,90	11,10
A319	50	0,394819962	33,84	34,10	11,76
A343	49	0,386923563	63,70	60,30	16,74
B77L	27	0,21320278	67,78	61,68	18,50
E295	27	0,21320278	41,50	35,10	10,90
LJ35	27	0,21320278	14,71	11,97	3,71
FA50	24	0,189513582	18,52	18,96	6,97
GLF4	22	0,173720783	26,90	23,79	7,64
FA8X	21	0,165824384	24,46	26,29	7,94
GLF5	18	0,142135186	29,42	28,50	7,87
B735	17	0,134238787	31,00	28,90	11,10
F900	14	0,110549589	20,20	19,30	7,60
LJ60	14	0,110549589	17,89	13,35	4,44

Aircraft type	Count	% AC	Length (m)	Wingspan (m)	Height (m)
F2TH	12	0,094756791	20,21	19,33	7,55
H25B	11	0,086860392	15,60	15,70	5,40
GLF6	10	0,078963992	30,41	30,36	7,72
E550	9	0,071067593	20,74	20,25	6,44
MD11	9	0,071067593	61,20	51,70	17,60
IL76	8	0,063171194	46,59	50,50	14,76
LJ45	8	0,063171194	17,70	14,60	4,30
B743	7	0,055274795	70,70	59,60	19,30
B78X	7	0,055274795	68,30	60,10	16,90
C680	7	0,055274795	11,22	14,95	4,56
E195	7	0,055274795	38,65	28,72	10,55
A342	6	0,047378395	59,39	60,30	16,74
E290	6	0,047378395	36,20	33,70	11,00
HA4T	6	0,047378395	21,08	18,82	5,97
B739	5	0,039481996	42,10	34,30	12,60
B762	5	0,039481996	48,50	47,60	15,80
GALX	5	0,039481996	18,99	17,71	6,52
GL5T	5	0,039481996	28,69	28,65	7,70
A124	4	0,031585597	69,10	73,30	20,78
CL30	4	0,031585597	20,90	18,40	6,10
FA10	4	0,031585597	13,80	13,10	4,60
A318	3	0,023689198	31,40	34,10	12,60
CL35	3	0,023689198	20,90	21,00	6,10
CRJ2	3	0,023689198	26,80	21,21	6,30
CRJX	3	0,023689198	39,10	26,20	7,50
IL62	3	0,023689198	53,12	43,30	12,35
WW24	3	0,023689198	15,90	13,70	4,80
A310	2	0,015792798	46,40	43,89	15,80
C650	2	0,015792798	14,29	15,91	4,57
E135	2	0,015792798	26,33	20,04	6,76
G150	2	0,015792798	17,30	16,94	5,82
G280	2	0,015792798	20,30	19,20	6,50
H25C	2	0,015792798	16,40	15,70	5,20
J328	2	0,015792798	20,90	20,90	7,20
KC39	2	0,015792798	32,70	35,10	10,30
A330	1	0,007896399	63,60	60,30	16,70
B734	1	0,007896399	36,40	28,90	11,10
B777	1	0,007896399	67,78	61,68	18,50
C30J	1	0,007896399	29,80	40,40	11,84

Aircraft type	Count	% AC	Length (m)	Wingspan (m)	Height (m)
C56X	1	0,007896399	15,80	17,00	5,20
C68A	1	0,007896399	18,97	22,05	6,38
C750	1	0,007896399	22,05	19,38	5,84
DA7	1	0,007896399	22,82	25,80	7,74
E75L	1	0,007896399	31,68	28,65	9,86
GA6C	1	0,007896399	29,20	29,00	7,80

Table 1.
Aircraft population and number of flights per type during 2020 in the Canaries UIR.

The data sample in the Canaries UIR includes 12664 flights of 84 different aircraft types. The population is dominated by large and medium airframes such as A330-900, A330-200, B767-300, A350-900, B787-900, B777-300ER, B737-800 or B757-200. These 8 types make up about 68.89% of the total number of flights. The next 8 types, which also belong to the Airbus and Boeing families, make up another 22.04% and the rest 9.07% is distributed among the other 68 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 2020 to 31st December 2020, 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 May 2020 to 31st May 2020.

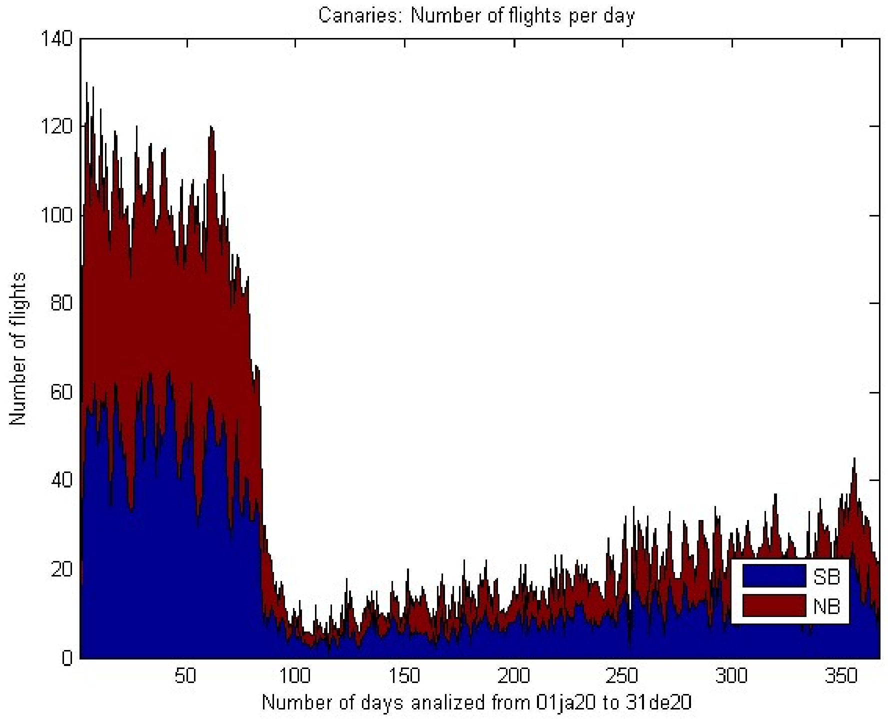


Figure 1.
Number of flights per day in the Canaries. Year 2020

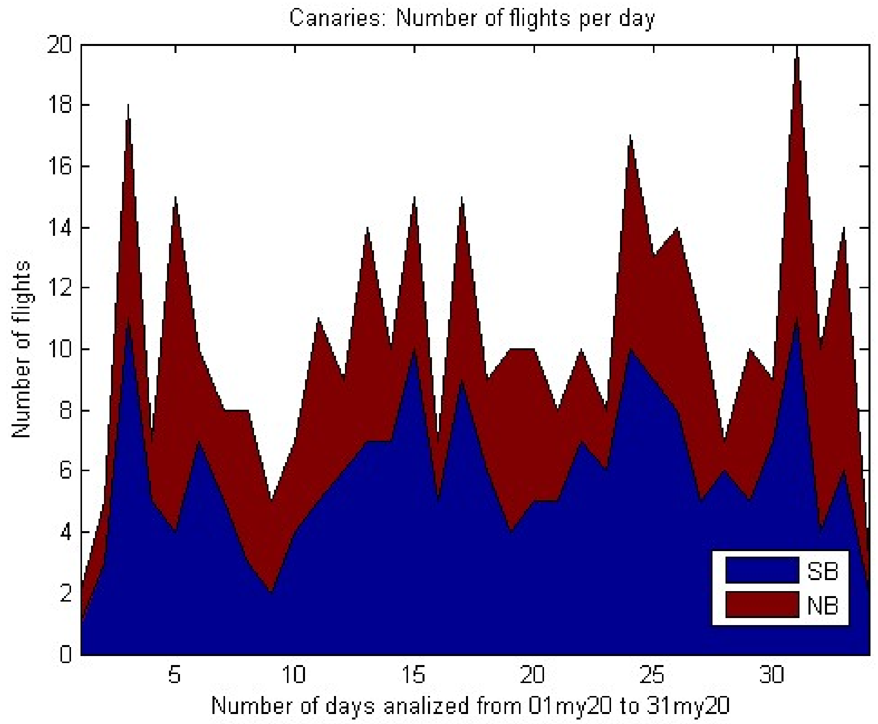


Figure 2.
Number of flights per day in the Canaries. May 2020

The overall average traffic for 2020 is 34.51 flights per day with a standard deviation of 35.25 flights per day, while in May the average is 8.26 with a standard deviation of 4.53 flights per day.

However, given the exceptional situation of 2020, a significant difference is observed in these data between the situation prior to the pandemic (January - March) and the one after (April - December):

- January – March: 87.94 flights per day with a standard deviation of 29.31 flights per day
- April – December:: 16.25 flights per day with a standard deviation of 8.74 flights per day

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

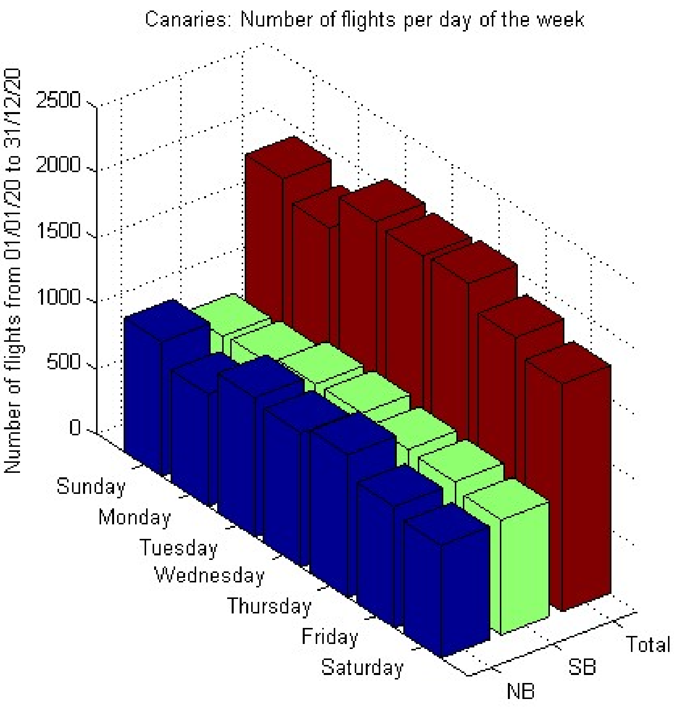


Figure 3.
Number of flights per day of the week in the Canaries. Year 2020

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 2020.

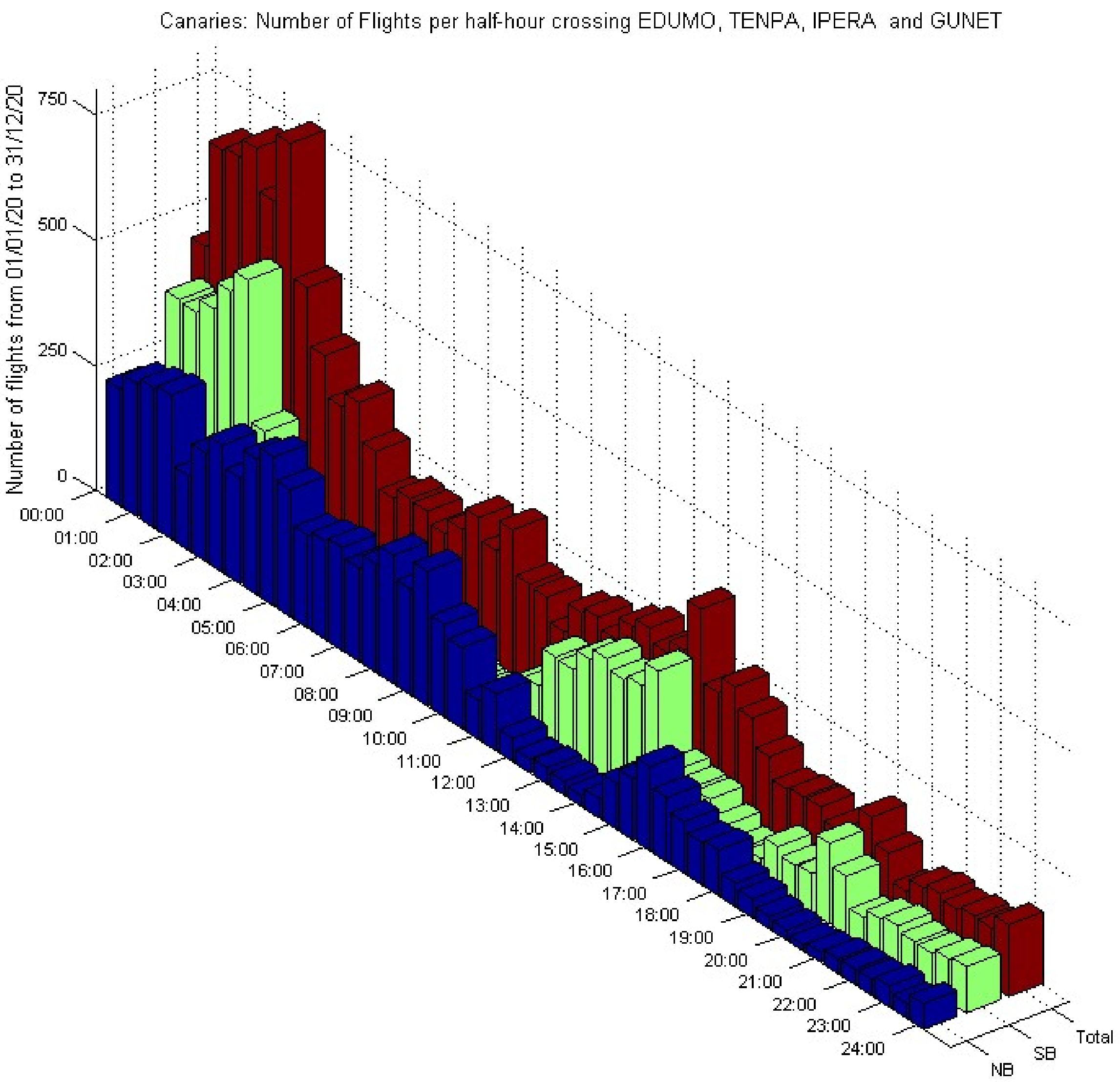


Figure 4.
Number of flights per half-hour crossing EDUMO, TENPA, IPERA and GUNET. Year 2020

It can be seen that during 2020, 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 16:00h.

Figure 5 shows the temporal distribution for the 284 aircraft detected in Canaries during May 2020. Following, Figure 6 shows the temporal distribution of the 325 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 14:00h to 24:00h.

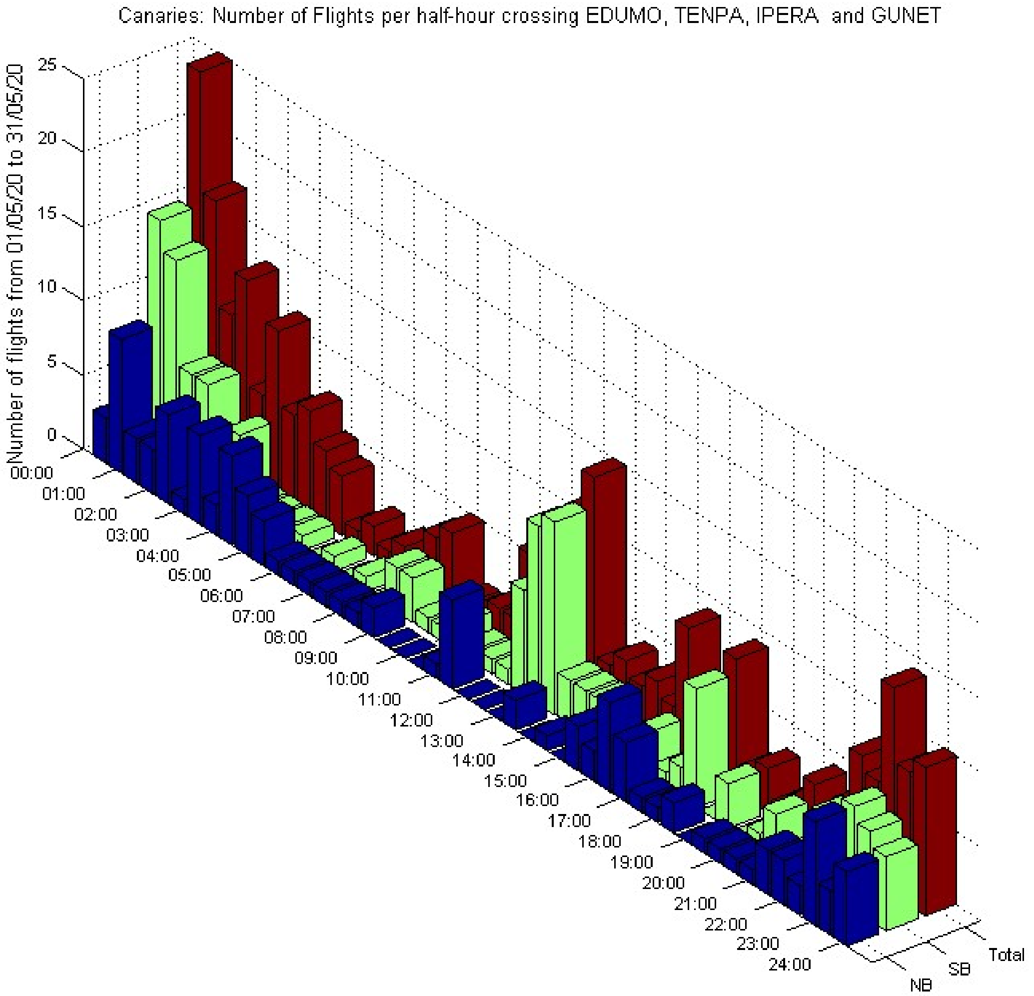


Figure 5.
Number of flights per half-hour crossing EDUMO, TENPA, IPERA and GUNET. May 2020

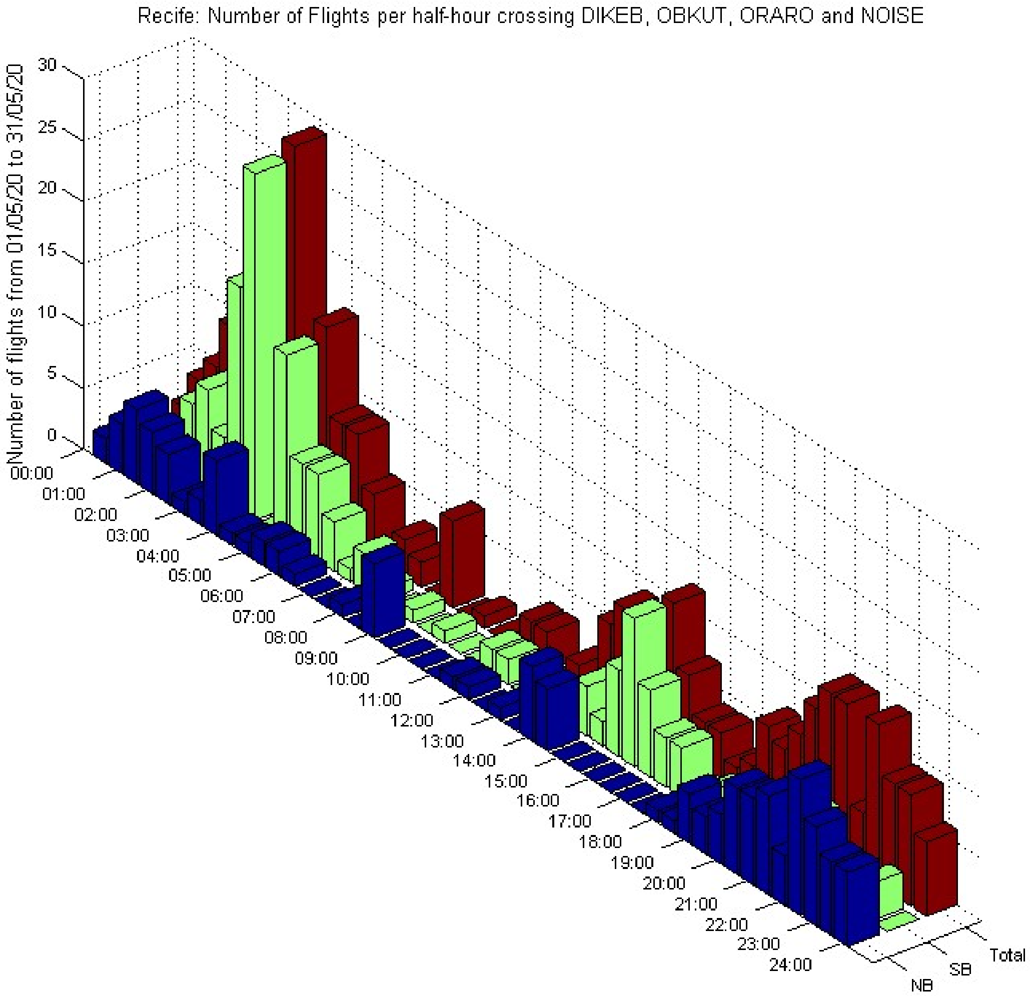


Figure 6.
Number of flights per half-hour crossing DIKEB, OBKUT, ORARO and NOISE. May 2020

2.4. Traffic distribution per flight level

Traffic distribution per flight level during 2020 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.

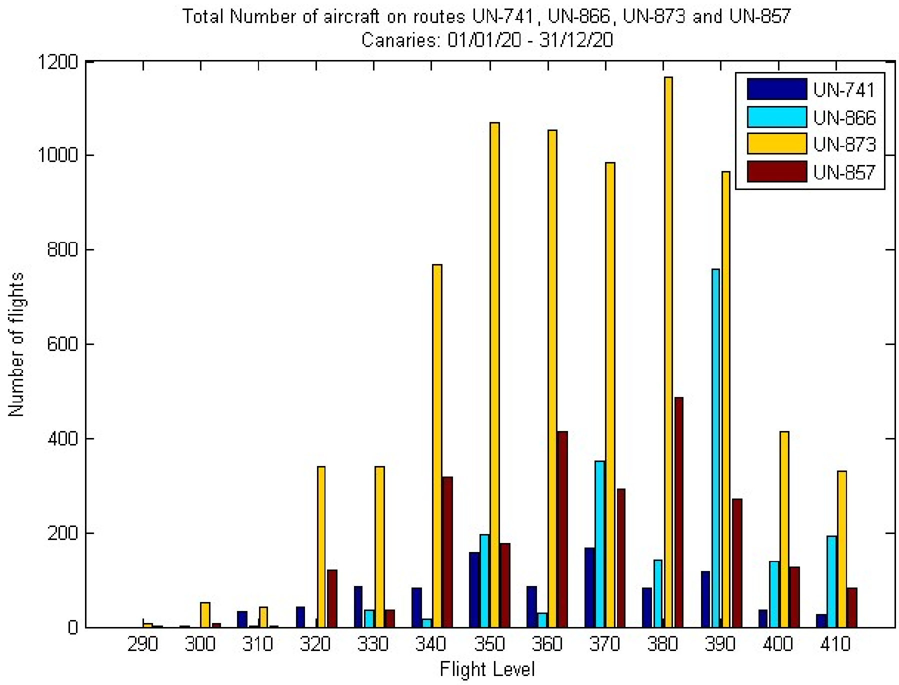


Figure 7.
Number of aircraft on routes UN-741, UN-866, UN-873 and UN-857 in the Canaries

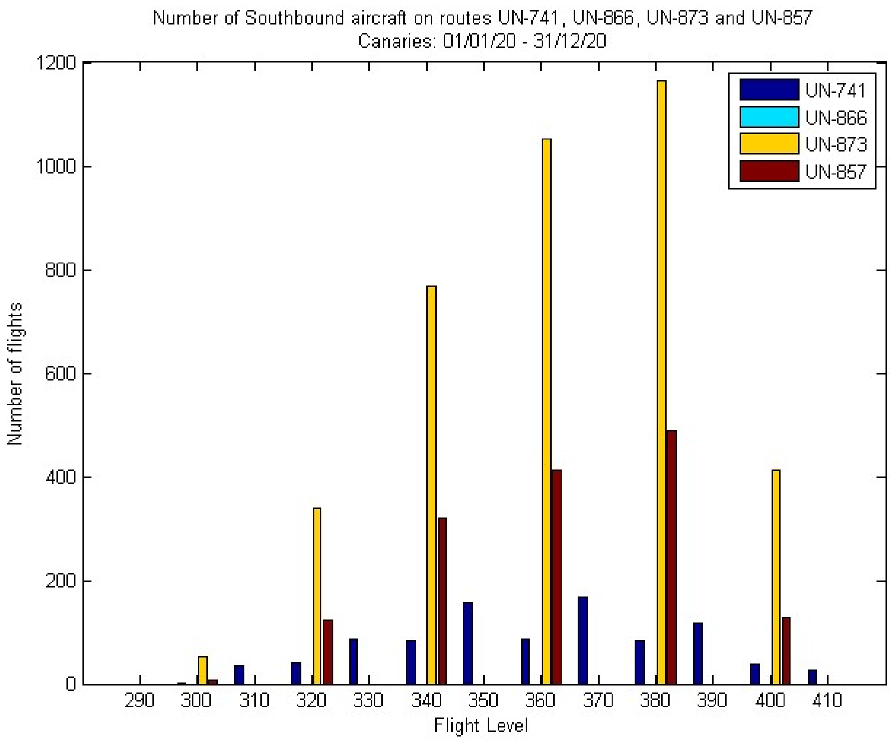


Figure 8.
Number of Southbound aircraft on routes UN-741, UN-866, UN-873 and UN-857 in the Canaries

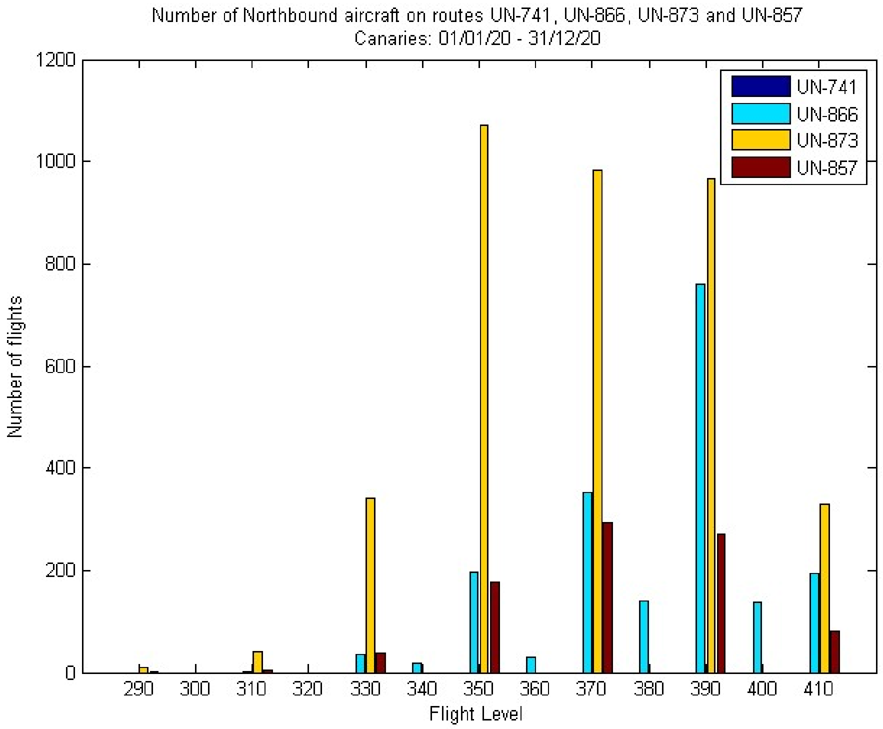


Figure 9.
Number of Northbound aircraft on routes UN-741, UN-866, UN-873 and UN-857 in the Canaries

3. Lateral collision risk assessment

As it has been said, the Reich model to calculate lateral collision risk is explained in [Ref. 36]. 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	192.03	180.95	52.74
SAL1	214.23	196.68	56.47
SAL2	214.23	196.68	56.47
Dakar1	205.87	193.91	55.81
Dakar2	206.77	194.63	55.98
Recife	203.10	190.44	54.99

Table 2.
Average aircraft dimensions

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

In this collision risk assessment, the values for $P_z(0)$ and $P_z(1000)$ (see 4.1.5) have been calculated using the Eurocontrol RVSM Tool. In the case of Pz(0), the obtained result has been $P_z(0)$=0.48712.

3.3. Average ground speed: v

Using the limitation to 575 kts explained in [Ref. 36], 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:

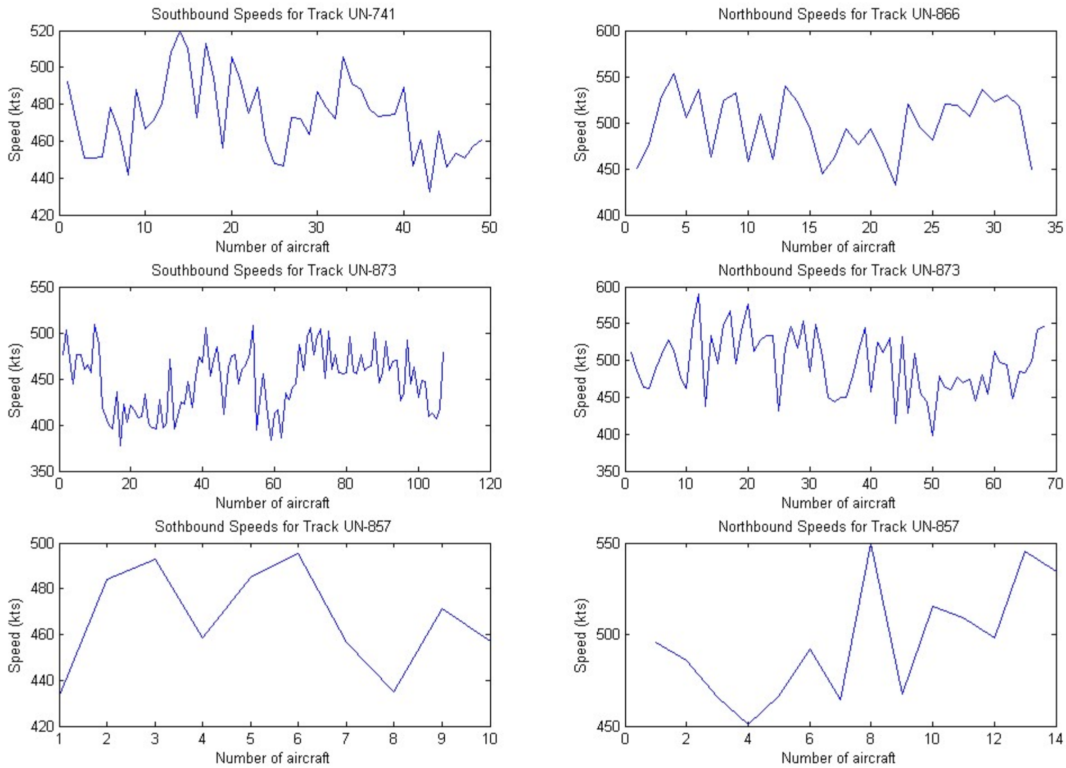


Figure 10.
Speeds limited to 575 kts in the current scenario in the Canaries

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	463.03	494.74	478.89
SAL1	460.20	494.38	477.29
SAL2	469.89	483.94	476.91
Dakar1	468.92	490.52	479.72
Dakar2	473.83	485.45	479.64
Recife	468.06	473.06	470.56

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	1.03	0	1.03
SAL1	0.79	8.42	4.60
SAL2	9.36	5.10	7.23
Dakar1	0	21.95	21.95
Dakar2	0	0	0
Recife	4.21	0	4.21

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. 36], 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. 36].

Therefore, the same assumptions made in [Ref. 2] and [Ref. 6] can be considered 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 May. Table 5 shows the number of aircraft in May 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
May 2020	284	214	206	291	297	325
Jan-Dic 2020	12664	*9364*	*9186*	*12976*	*13244*	*14492*

Table 5.
Number of aircraft considered for the α calculation

Using Equation 2 and taking the number of aircraft indicated in Table 5, different values of α have been calculated for each FIR. Table 6 summarizes the assumptions and the obtained results.

FIR	α
Canaries	$2.3653*10^{-4}$
SAL1	$3.1987*10^{-4}$
SAL2	$3.2607*10^{-4}$
Dakar1	$2.3084*10^{-4}$
Dakar2	$2.2617*10^{-4}$
Recife	$2.0669*10^{-4}$

Table 6.
α for each FIR

Using Equation 11 of [Ref. 36], 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	$1.2597*10^{-7}$	$4.6599*10^{-8}$	$3.1237*10^{-8}$	$1.7144*10^{-8}$
SAL1	$1.7662*10^{-7}$	$6.8494*10^{-8}$	$4.5914*10^{-8}$	$2.5199*10^{-8}$
SAL2	$1.7958*10^{-7}$	$6.9824*10^{-8}$	$4.6805*10^{-8}$	$2.5689*10^{-8}$
Dakar1	$1.3231*10^{-7}$	$4.8735*10^{-8}$	$3.2668*10^{-8}$	$1.7929*10^{-8}$
Dakar2	$1.3061*10^{-7}$	$4.7928*10^{-8}$	$3.2128*10^{-8}$	$1.7633*10^{-8}$
Recife	$1.1881*10^{-7}$	$4.2856*10^{-8}$	$2.2856*10^{-8}$	$1.5767*10^{-8}$

Table 7.
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. 36], 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 May 2020 to 31st May 2020, but it also presents an estimate of the collision risk over a 4 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. 23], the annual traffic growth rate for the traffic flows in the Canary Islands airspace would be 59%, 30%, 14% and 10% in 2021, 2022, 2023 and 2024 respectively.

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 2024, with the annual traffic growth rate of 59%, 30%, 14% and 10% in 2021, 2022, 2023 and 2024 respectively.

Table 8 shows the number of aircraft and the number of same and opposite direction proximate pairs detected on the four routes, from 1st May 2020 till 31st May 2020 in the Canaries, SAL, Dakar and Recife UIR/FIRs.

Number of flights May 2020	Canaries	SAL1	SAL2	Dakar1	Dakar2	Recife
Number of flights on UN-741	49	47	47	85	83	95
Number of flights on UN-866	33	33	33	38	40	45
Number of flights on UN-873	175	105	105	136	139	157
Number of flights on UN-857	24	21	21	20	20	25
Total number of flights	281	206	206	279	282	322
Number of same direction proximate pairs for tracks UN-866/UN-873	0	1	1	1	0	0
Number of same direction proximate pairs for tracks UN-866/UN-857	0	0	0	0	0	0
Number of same direction proximate pairs for tracks UN-873/UN-857	1	1	1	0	0	1
Number of opposite direction proximate pairs for tracks UN-741/UN-866	0	0	0	0	0	0
Number of opposite direction proximate pairs for tracks UN-866/UN-873	0	0	0	0	0	0
Number of opposite direction proximate pairs for tracks UN-866/UN-857	0	0	0	0	0	0

Table 8.
Lateral occupancy parameters in the Corridor FIR/UIRs

Assuming an annual traffic growth rate of 59%, 30%, 14% and 10% in 2021, 2022, 2023 and 2024 respectively, the occupancies for the next 4 years are summarized in Table 9. It holds that occupancy is approximately proportional to traffic flow rate:

59%, 30%, 14% and 10% annual traffic growth until 2024		Canaries 2020-2024	SAL1 2020-2024	SAL2 2020-2024	Dakar1 2020-2024	Dakar2 2020-2024	Recife 2020-2024
Same direction lateral occupancy	UN-873/UN-857 (E_{ysame})	0.0071-0.0184	0.0097-0.0251	0.0097-0.0251	0.0000-0.0000	0.0000-0.0000	0.0062-0.0161
	UN-866/UN-873 (E^{*}_{ysame})	0.0000-0.0000	0.0097-0.0251	0.0097-0.0251	0.0072-0.0184	0.0000-0.0000	0.0000-0.0000
	UN-866/UN-857 (E^{**}_{ysame})	0.0000-0.0000	0.0000-0.0000	0.0000-0.0000	0.0000-0.0000	0.0000-0.0000	0.0000-0.0000
Opposite direction lateral occupancy	UN-866/UN-873 ($E_{yopposite}$)	0.0000-0.0000	0.0000-0.0000	0.0000-0.0000	0.0000-0.0000	0.0000-0.0000	0.0000-0.0000
	UN-741/UN-866 ($E^{*}_{yopposite}$)	0.0000-0.0000	0.0000-0.0000	0.0000-0.0000	0.0000-0.0000	0.0000-0.0000	0.0000-0.0000
	UN-866/UN-857 ($E^{**}_{yopposite}$)	0.0000-0.0000	0.0000-0.0000	0.0000-0.0000	0.0000-0.0000	0.0000-0.0000	0.0000-0.0000

Table 9.
Lateral occupancy estimate until 2024 with an annual traffic growth rate of 59%, 30%, 14% and 10%

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 2024 in the different locations are the ones shown in the following table and figures.

Lateral collision risk	**59%, 30%, 14% and 10% annual traffic growth until 2024**					
	Canaries	**SAL1**	**SAL2**	**Dakar1**	**Dakar2**	**Recife**
2020	$1.3938*10^{-10}$	$4.0602*10^{-10}$	$4.3250*10^{-10}$	$7.6654*10^{-11}$	0	$1.2254*10^{-10}$
2021	$2.2162*10^{-10}$	$6.4557*10^{-10}$	$6.8768*10^{-10}$	$1.2188*10^{-10}$	0	$1.9484*10^{-10}$
2022	$2.8811*10^{-10}$	$8.3924*10^{-10}$	$8.9399*10^{-10}$	$1.5844*10^{-10}$	0	$2.5329*10^{-10}$
2023	$3.2844*10^{-10}$	$9.5674*10^{-10}$	$1.0191*10^{-9}$	$1.8063*10^{-10}$	0	$2.8875*10^{-10}$
2024	$3.6128*10^{-10}$	$1.0524*10^{-9}$	$1.1211*10^{-9}$	$1.9869*10^{-10}$	0	$3.1763*10^{-10}$

Table 10.
Lateral collision risk for the period 2020-2024 in the Corridor

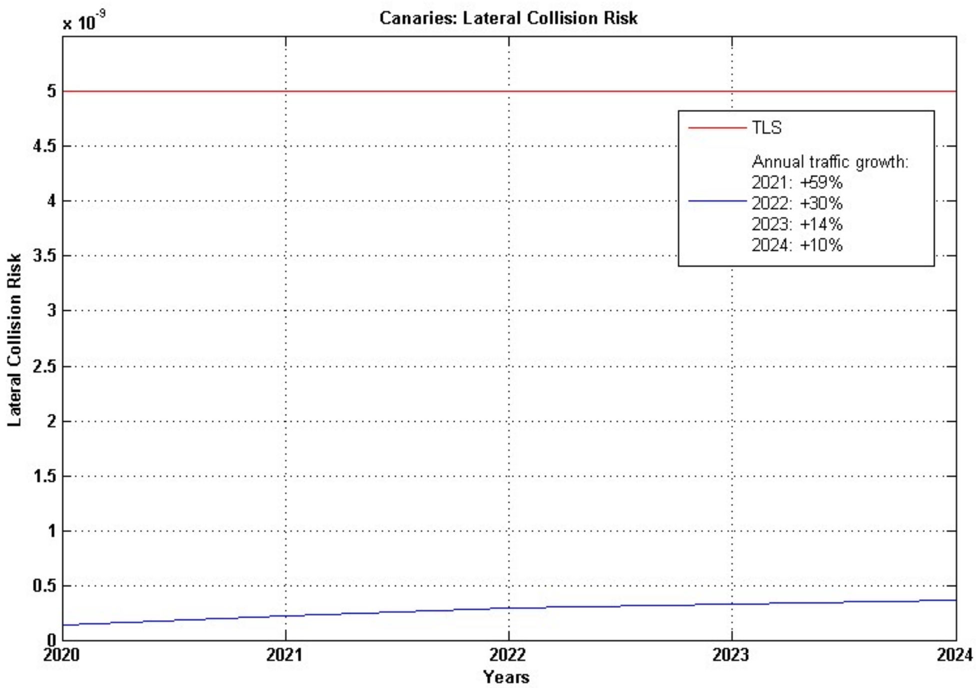


Figure 11.
Lateral collision risk for the period 2020-2024 in the Canaries

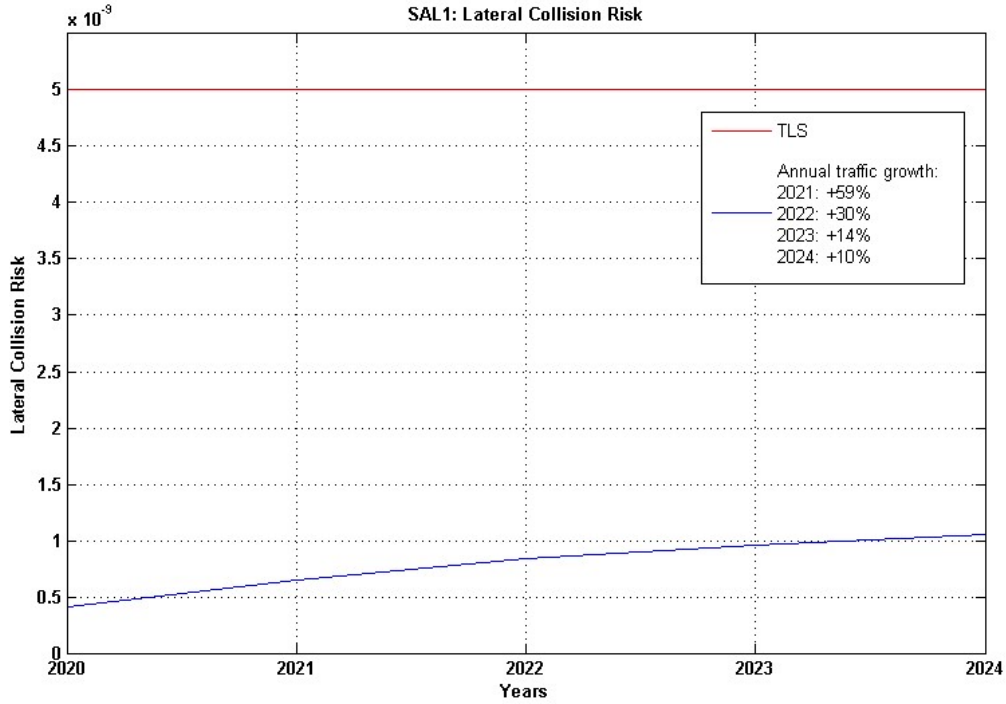


Figure 12.
Lateral collision risk for the period 2020-2024 in SAL1

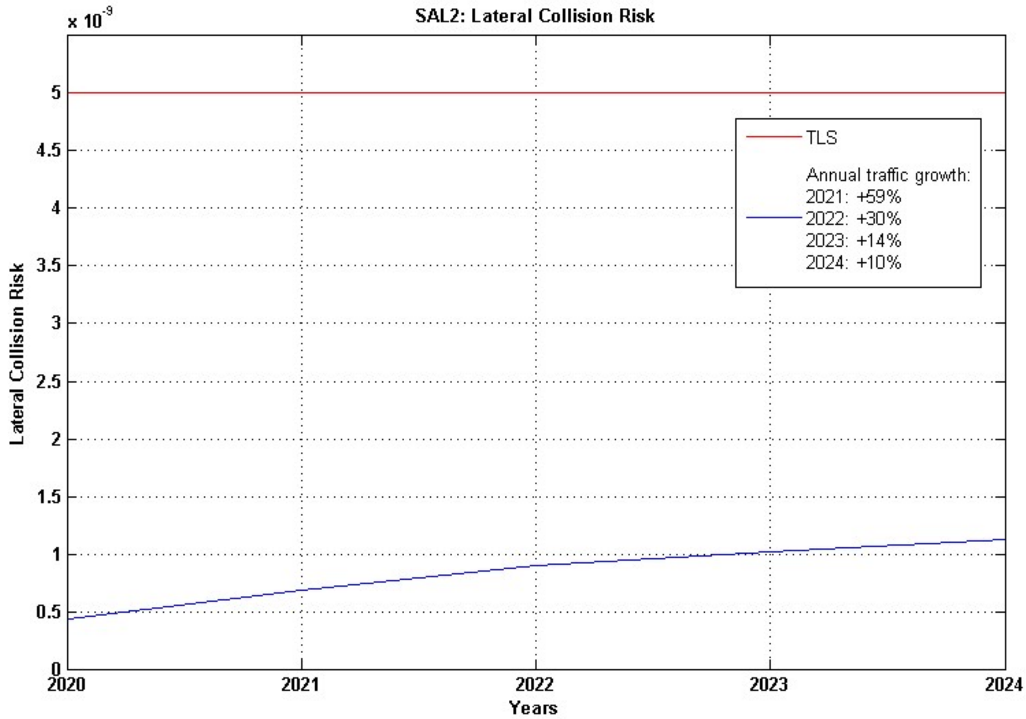


Figure 13.
Lateral collision risk for the period 2020-2024 in SAL2

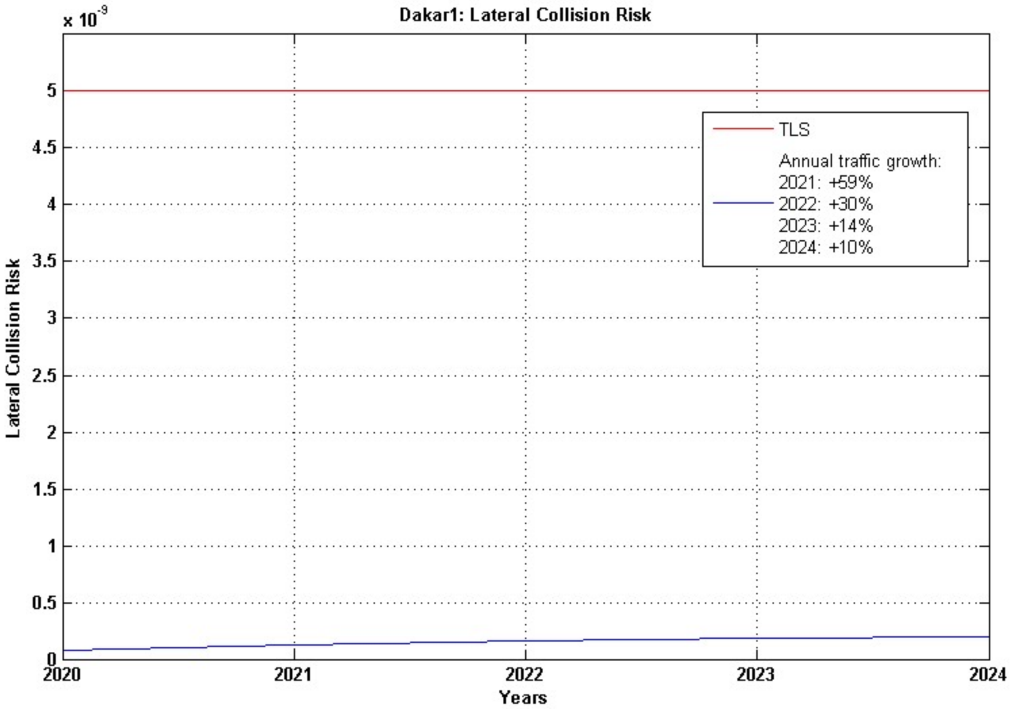


Figure 14.
Lateral collision risk for the period 2020-2024 in Dakar1

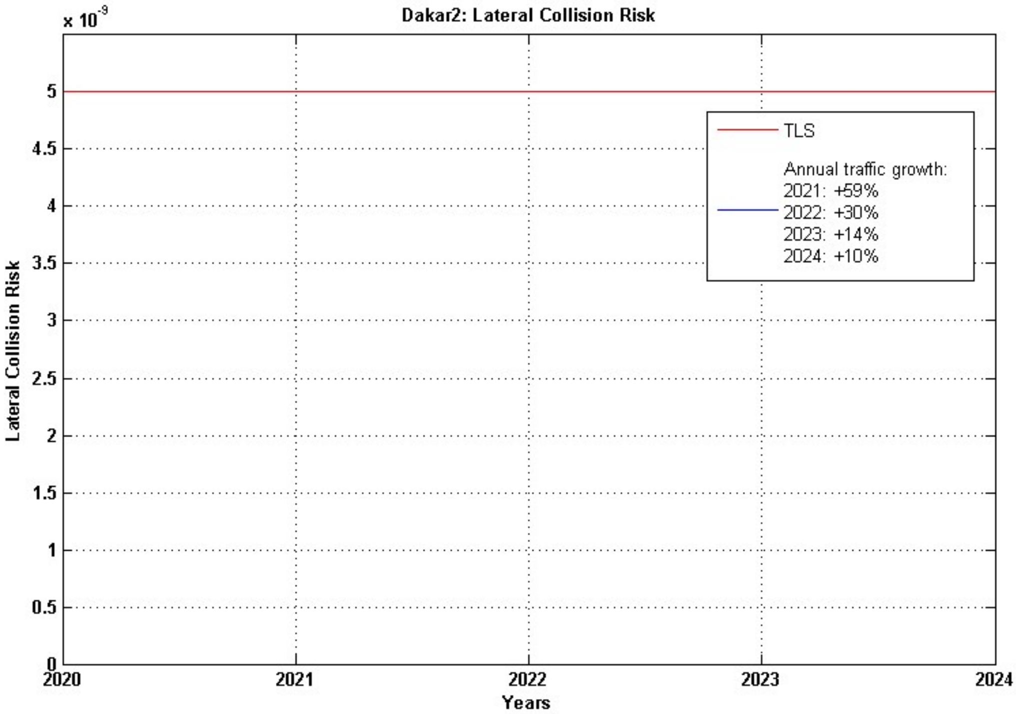


Figure 15.
Lateral collision risk for the period 2020-2024 in Dakar2

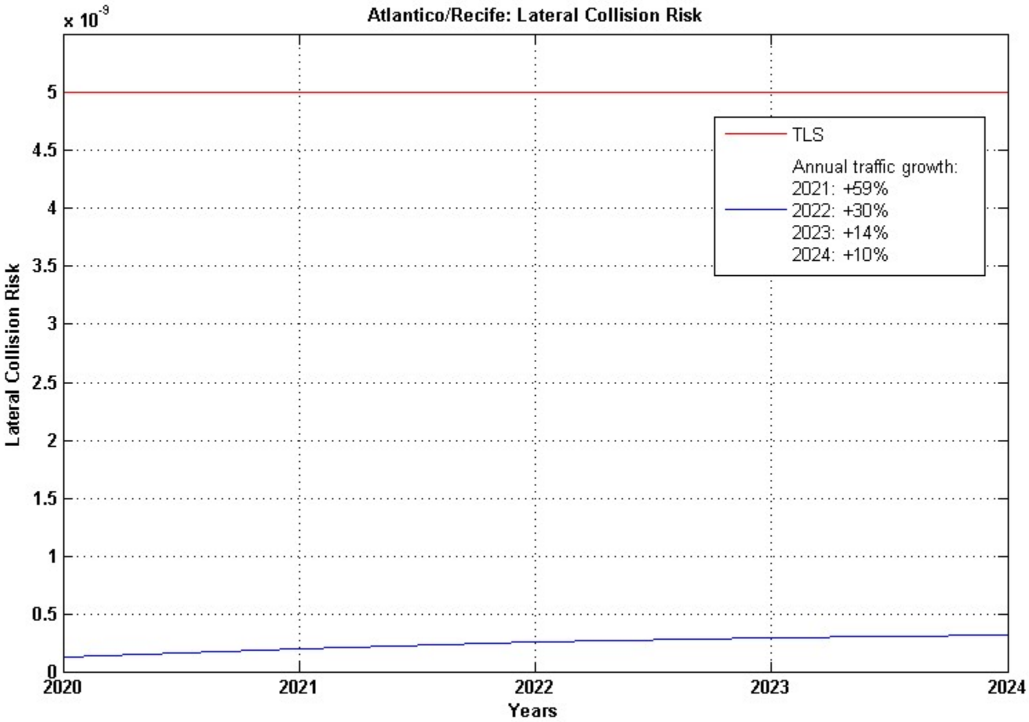


Figure 16.
Lateral collision risk for the period 2020-2024 in Recife

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 an annual traffic growth rate of 59%, 30%, 14% and 10% in 2021, 2022, 2023 and 2024 respectively, the TLS would not be exceeded in the period under consideration.

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

4. Vertical collision risk assessment

4.1. Technical vertical collision risk assessment

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

As it has been indicated, the Reich model to calculate technical vertical collision risk is explained in [Ref. 36]. In the following sections all the parameters required for the calculation (those that appear in Equation 3) will be analysed.

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

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 11 shows the pertinent average aircraft dimensions.

Location	Value Length (λ_x) (ft)	Wingspan (λ_y) (ft)	Height (λ_z) (ft)	Diameter (λ_x) (ft)
Canaries	192.03	180.95	52.74	192.03
SAL1	214.23	196.68	56.47	214.23
SAL2	214.23	196.68	56.47	214.23
Dakar1	205.87	193.91	55.81	205.87
Dakar2	206.77	194.63	55.98	206.77
Recife	203.10	190.44	54.99	203.10

Table 11.
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. 36], 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.

[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 $P_y(S_y)$.*

Probability of horizontal overlap has been calculated for all these routes using Equation 37 in [Ref. 36]. 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. 17]). This probability has only been calculated whenever proximate events have been detected (no proximate events were detected in Canaries, SAL2 and Recife FIRs this year), as it will be seen in 4.1.6.

The obtained results are shown in Table 12.

Horizontal overlap probability				
Location	**Diameter (λ_h)**	**Route (Point)**	**Angles (º)**	**$P_h(\theta)$**
SAL1	0.0353 NM	ULTEM-LUMPO (IRENE)	91-89	$6.1330*10^{-7}$
		NEMDO-BI003 (BI003)	154-26	$1.4412*10^{-6}$
		BI003-BS004 (BI003)	131-49	$8.2657*10^{-7}$
Dakar1	0.0339 NM	XUVIT-DIGUN (DIGUN)	158-22	$1.5597*10^{-6}$
Dakar2	0.0340 NM	DIGUN-ENOTO (ENOTO)	139-41	$8.9024*10^{-7}$
		DIGUN-MOVGA (DIGUN)	146-34	$1.0486*10^{-6}$

Table 12.
Horizontal overlap probabilities in SAL1, Dakar1 and Dakar2

4.1.4. Relative velocities

Equation 27 in [Ref. 36] 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	0	0	0
SAL1	23.2025	0	23.2025
SAL2	33.1359	0	33.1359
Dakar1	11.6841	0	11.6841
Dakar2	37.4703	27.7714	32.6209
Recife	4.2087	0	4.2087

Table 13.
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. 26]. 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 14. 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	V_1 (kts)	V_2 (kts)	θ (º)	$V_{rel}(\theta)$ (kts)
SAL1	ULTEM-LUMPO (IRENE)	477.29	432.71	89	638.62
				91	649.81
	NEMDO-BI003 (BI003)	477.29	502.42	26	221.74
				154	954.62
	BI003-BS004 (BI003)	477.29	401.47	49	370.89
				131	800.26
Dakar1	XUVIT-DIGUN (DIGUN)	479.72	467.60	22	181.15
				158	929.92
Dakar2	DIGUN-ENOTO (ENOTO)	479.64	497.99	41	342.80
				139	915.74
	DIGUN-MOVGA (DIGUN)	479.64	502.01	34	287.80
				146	938.78

Table 14.
Relative speeds in crossings (Dakar and Recife)

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

With 2020 traffic and height-keeping performances information, the probability of vertical overlap has been calculated by means of Equation 43 in [Ref. 36], using the Eurocontrol RVSM Tool, being the resulting values $P_z(1000) = 6.48888 \cdot 10^{-11}$ and $P_z(0) = 0.48712$.

4.1.6. Vertical occupancy

As it is explained in [Ref. 36], 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 2024, with the annual traffic growth rate of 59%, 30%, 14% and 10% in 2021, 2022, 2023 and 2024 respectively.

4.1.6.a. Canaries

Table 15 shows some results on same and opposite vertical occupancy in Canaries location, based on traffic levels representative of 2020.

Vertical occupancy	May 2020
Number of flights on UN-741	49
Number of flights on UN-866	33
Number of flights on UN-873	175
Number of flights on UN-857	24
Total number of flights on main airways	281
Number of same direction vertical proximate pairs for tracks UN-741	1
Number of same direction vertical proximate pairs for tracks UN-866	0
Number of opposite direction vertical proximate pairs for tracks UN-873	2
Number of opposite direction vertical proximate pairs for tracks UN-857	0
Total number of same direction proximate events	1
Total number of opposite direction proximate events	2
Same direction vertical occupancy (S_x=80NM)	0.0071
Opposite direction vertical occupancy (S_x=80NM)	0.0142

Table 15.
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	May 2020
Number of flights on crossing flight NORED-ETIBA	3
Total number of flights on main routes (UN-741, UN-866, UN-873 and UN-857)	281
Total number of flights	284

Table 16.
Number of flights in Canaries airspace

The total number of flights is 284.

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. 21], 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. 36]. 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.

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 2020 to 2024 with an annual traffic growth rate of 59%, 30%, 14% and 10% in 2021, 2022, 2023 and 2024 respectively are shown in Table 17.

59%, 30%, 14% and 10% annual traffic growth until 2024	2020	2021	2022	2023	2024
Same direction vertical occupancy	0.0071	0.0113	0.0147	0.0167	0.0184
Opposite direction vertical occupancy	0.0142	0.0226	0.0293	0.0335	0.0368

Table 17.
Vertical occupancy estimate for the Canaries until 2024

4.1.6.b. SAL1

Table 18 collects some results on same and opposite vertical occupancy in SAL1, obtained with data from May 2020.

Number of flights	May 2020
Number of flights on UN-741	47
Number of flights on UN-866	33
Number of flights on UN-873	105
Number of flights on UN-857	21
Total number of flights on main airways	206
Number of same direction vertical proximate pairs for tracks UN-741	1
Number of same direction vertical proximate pairs for tracks UN-866	0
Number of opposite direction vertical proximate pairs for tracks UN-873	0
Number of opposite direction vertical proximate pairs for tracks UN-857	0
Total number of same direction proximate events	1
Total number of opposite direction proximate events	0
Same direction vertical occupancy (S_x=80NM)	0.0010
Opposite direction vertical occupancy (S_x=80NM)	0

Table 18.
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	May 2020
Number of flights on UR-976/UA-602	0
Number of flights on ULTEM-LUMPO	3
Number of flights on NEMDO-BI003	1
Number of flights on BI003-BS004	4
Number of flights on main routes (UN-741, UN-866, UN-873 and UN-857)	206
Total number of flights	210

Table 19.
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. Therefore, the total number of flights is 210.

The time windows to obtain proximate pairs and the number of proximate events are, in this case, the ones shown in Table 20. 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**
ULTEM-LUMPO	---	477.29	432.71	91º	15	1	2
				89º	15	0	0
NEMDO-BI003	BI003	474.07	502.42	154º	44	0	1
				26º	11	0	0
BI003-BS004	BI003	474.07	401.47	131º	27	0	0
				49º	13	0	1

Table 20.
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. One 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 2020 to 2024 with an annual traffic growth rate of 59%, 30%, 14% and 10% in 2021, 2022, 2023 and 2024 respectively are shown in Table 21. Only crossings different from zero have been shown.

59%, 30%, 14% and 10% annual traffic growth until 2024				2020	2021	2022	2023	2024
Same direction vertical occupancy				0.0097	0.0154	0.0201	0.0229	0.0252
Opposite direction vertical occupancy				0.0000	0.0000	0.0000	0.0000	0.0000
Crossing occupancy	ULTEM-LUMPO	---	91º	0.0190	0.0303	0.0394	0.0449	0.0494
			89º	0.0000	0.0000	0.0000	0.0000	0.0000
	NEMDO-BI003	BI003	154º	0.0095	0.0151	0.0197	0.0224	0.0247
			26º	0.0000	0.0000	0.0000	0.0000	0.0000
	BI003-BS004	BI003	131º	0.0000	0.0000	0.0000	0.0000	0.0000
			49º	0.0095	0.0151	0.0197	0.0224	0.0247

Table 21.
Vertical occupancy estimate for SAL1 until 2024

4.1.6.c. SAL2

Table 22 collects some results on same and opposite vertical occupancy in SAL2, obtained with data from the May 2020.

Number of flights	May 2020
Number of flights on UN-741	47
Number of flights on UN-866	33
Number of flights on UN-873	105
Number of flights on UN-857	21
Total number of flights on main airways	206
Number of same direction vertical proximate pairs for tracks UN-741	2
Number of same direction vertical proximate pairs for tracks UN-866	0
Number of opposite direction vertical proximate pairs for tracks UN-873	0
Number of opposite direction vertical proximate pairs for tracks UN-857	0
Total number of same direction proximate events	2
Total number of opposite direction proximate events	0
Same direction vertical occupancy (S_x=80NM)	0.0194
Opposite direction vertical occupancy (S_x=80NM)	0

Table 22.
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	May 2020
Number of flights on main routes (UN-741, UN-866, UN-873 and UN-857)	206
Total number of flights	206

Table 23.
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. Therefore, the total number of flights in this case is 206.

In the case of SAL2, no proximate events have been detected.

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 2020 to 2024 with an annual traffic growth rate of 59%, 30%, 14% and 10% in 2021, 2022, 2023 and 2024 respectively are shown in Table 24. Only data for crossing trajectories in which proximate events have been detected are included.

59%, 30%, 14% and 10% annual traffic growth until 2024	2020	2021	2022	2023	2024
Same direction vertical occupancy	0.0194	0.0309	0.0401	0.0458	0.0503
Opposite direction vertical occupancy	0.0000	0.0000	0.0000	0.0000	0.0000

Table 24.
Vertical occupancy estimate for SAL2 until 2024

4.1.6.d. Dakar1

Table 25 collects some results on same and opposite vertical occupancy in Dakar1, obtained with data from May 2020.

Number of flights	May 2020
Number of flights on UN-741	85
Number of flights on UN-866	38
Number of flights on UN-873	136
Number of flights on UN-857	20
Total number of flights on main airways	279
Number of same direction vertical proximate pairs for tracks UN-741	1
Number of same direction vertical proximate pairs for tracks UN-866	0
Number of opposite direction vertical proximate pairs for tracks UN-873	0
Number of opposite direction vertical proximate pairs for tracks UN-857	0
Total number of same direction proximate events	1
Total number of opposite direction proximate events	0
Same direction vertical occupancy (S_x=80NM)	0.0072
Opposite direction vertical occupancy (S_x=80NM)	0

Table 25.
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	May 2020
Number of flights on UL-435	4
Number of flights on ENUGO-APIGU	1
Number of flights on XUVIT-DIGUN	29
Number of flights on TARIM-DIGUN	6
Number of flights on LIRAX-IRAVU	3
Number of flights on SAGRO-BUXON	3
Number of flights on TARIM-SAGRO	3
Number of flights on SAGRO-MOSOK	1
Number of flights on XUVIT-SAGRO	1
Number of flights on main routes (UN-741, UN-866, UN-873 and UN-857)	279
Total number of flights	291

Table 26.
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 39 flights). Therefore, the total number of flights in this case is 291.

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**
XUVIT-DIGUN	DIGUN	467.32	467.60	158º	55	0	0
				22º	22	1	2

Table 27.
Time windows for crossing occupancies and number of proximate events in Dakar1

Here again, as it happened in the locations previously analyzed, there are no proximate event at the same flight level within 15 minutes of each other.

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 2020 to 2024 with an annual traffic growth rate of 59%, 30%, 14% and 10% in 2021, 2022, 2023 and 2024 respectively are shown in Table 28.

59%, 30%, 14% and 10% annual traffic growth until 2024				**2020**	**2021**	**2022**	**2023**	**2024**
Same direction vertical occupancy				0.0072	0.0114	0.0148	0.0169	0.0186
Opposite direction vertical occupancy				0.0000	0.0000	0.0000	0.0000	0.0000
Crossing occupancy	XUVIT-DIGUN	DIGUN	158º	0.0000	0.0000	0.0000	0.0000	0.0000
			22º	0.0206	0.0328	0.0426	0.0486	0.0534

Table 28.
Vertical occupancy estimate for Dakar1 until 2024

4.1.6.e. Dakar2

Table 29 collects some results on same and opposite vertical occupancy in Dakar2, obtained with data from May 2020.

Number of flights	May 2020
Number of flights on UN-741	83
Number of flights on UN-866	40
Number of flights on UN-873	139
Number of flights on UN-857	20
Total number of flights on main airways	282
Number of same direction vertical proximate pairs for tracks UN-741	1
Number of same direction vertical proximate pairs for tracks UN-866	1
Number of opposite direction vertical proximate pairs for tracks UN-873	0
Number of opposite direction vertical proximate pairs for tracks UN-857	0
Total number of same direction proximate events	2
Total number of opposite direction proximate events	0
Same direction vertical occupancy (S_x=80NM)	0.0142
Opposite direction vertical occupancy (S_x=80NM)	0

Table 29.
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	May 2020
Number of flights on IP008-NANIK	12
Number of flights on IRAVU-MESAB	3
Number of flights on DIGUN-MOVGA	3
Number of flights on DIGUN-ENOTO	2
Number of flights on main routes (UN-741, UN-866, UN-873 and UN-857)	282
Total number of flights	297

Table 30.
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 5 of them. Therefore, the total number of aircraft in this case is 297.

The time windows to obtain proximate pairs and the number of proximate pairs 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**
DIGUN-MOVGA	DIGUN	471.10	502.01	146º	35	0	1
				34º	11	0	0
DIGUN-ENOTO	ENOTO	485.06	497.99	139º	28	0	0
				41º	11	0	1

Table 31.
Time windows for crossing occupancies and number of proximate events in Dakar2

Here again, as it happened in the locations previously analysed, there are no proximate events at the same flight level within 15 minutes of each other.

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 2020 to 2024 with an annual traffic growth rate of 59%, 30%, 14% and 10% in 2021, 2022, 2023 and 2024 respectively are shown in Table 32.

59%, 30%, 14% and 10% annual traffic growth until 2024				**2020**	**2021**	**2022**	**2023**	**2024**
Same direction vertical occupancy				0.0142	0.0226	0.0293	0.0334	0.0368
Opposite direction vertical occupancy				0.0000	0.0000	0.0000	0.0000	0.0000
Crossing occupancy	DIGUN-MOVGA	DIGUN	146º	0.0067	0.0107	0.0139	0.0159	0.0175
			34º	0.0000	0.0000	0.0000	0.0000	0.0000
	DIGUN-ENOTO	ENOTO	139º	0.0000	0.0000	0.0000	0.0000	0.0000
			41º	0.0067	0.0107	0.0139	0.0159	0.0175

Table 32.
Vertical occupancy estimate for Dakar2 until 2024

4.1.6.f. Recife

Table 33 collects some results on same and opposite vertical occupancy in Recife, using data from May 2020.

Number of flights	**May 2020**
Number of flights on UN-741	95
Number of flights on UN-866	45
Number of flights on UN-873	157
Number of flights on UN-857	25
Total number of flights on main airways	322
Number of same direction vertical proximate pairs for tracks UN-741	2
Number of same direction vertical proximate pairs for tracks UN-866	0
Number of opposite direction vertical proximate pairs for tracks UN-873	1
Number of opposite direction vertical proximate pairs for tracks UN-857	0
Total number of same direction proximate events	2
Total number of opposite direction proximate events	1
Same direction vertical occupancy (S_x=80NM)	0.0124
Opposite direction vertical occupancy (S_x=80NM)	0.0062

Table 33.
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	**May 2020**
Number of flights on UL-695/UL-375	2
Number of flights on ERETU-PUGSA	1
Number of flights on main routes (UN-741, UN-866, UN-873 and UN-857)	322
Total number of flights	325

Table 34.
Number of flights in Recife airspace.

All the flights on the crossing routes are already included in the number of flights on the main routes. Therefore, the total number of flights in this case is 325.

In the case of Recife FIR, no proximate events have been detected.

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 2020 to 2024 with an annual traffic growth rate of 59%, 30%, 14% and 10% in 2021, 2022, 2023 and 2024 respectively are shown in Table 35.

59%, 30%, 14% and 10% annual traffic growth until 2024	**2020**	**2021**	**2022**	**2023**	**2024**
Same direction vertical occupancy	0.0124	0.0198	0.0257	0.0293	0.0322
Opposite direction vertical occupancy	0.0062	0.0099	0.0128	0.0146	0.0161

Table 35.
Vertical occupancy estimate for Recife until 2024

4.1.7. Technical vertical collision risk

The technical vertical collision risk values obtained until 2024 in the different locations are the ones summarized in the following table, considering an annual traffic growth rate of 59%, 30%, 14% and 10% in 2021, 2022, 2023 and 2024 respectively. These results can also be seen in Figure 17 to Figure 28.

Technical Vertical Collision risk	59%, 30%, 14% and 10% annual traffic growth until 2024					
	Canaries	SAL1	SAL2	Dakar1	Dakar2	Recife
2020	$1.5806*10^{-12}$	$8.7363*10^{-14}$	$1.4238*10^{-13}$	$4.0149*10^{-14}$	$1.1150*10^{-13}$	$8.1821*10^{-13}$
2021	$2.5132*10^{-12}$	$1.3891*10^{-13}$	$2.2638*10^{-13}$	$6.3836*10^{-14}$	$1.7728*10^{-13}$	$1.3010*10^{-12}$
2022	$3.2672*10^{-12}$	$1.8058*10^{-13}$	$2.9430*10^{-13}$	$8.2987*10^{-14}$	$2.3046*10^{-13}$	$1.6912*10^{-12}$
2023	$3.7246*10^{-12}$	$2.0586*10^{-13}$	$3.3550*10^{-13}$	$9.4606*10^{-14}$	$2.6273*10^{-13}$	$1.9280*10^{-12}$
2024	$4.0971*10^{-12}$	$2.2645*10^{-13}$	$3.6905*10^{-13}$	$1.0407*10^{-13}$	$2.8900*10^{-13}$	$2.1208*10^{-12}$

Table 36.
Technical vertical collision risk for the period 2020-2024 in the Corridor

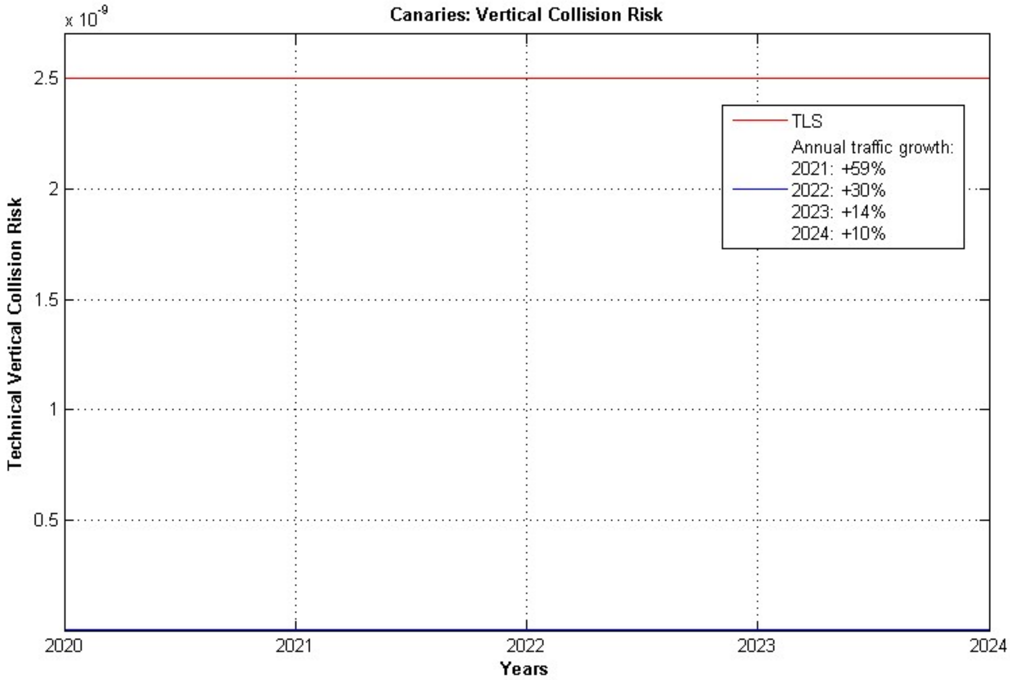


Figure 17.
Technical vertical collision risk for the period 2020-2024 in the Canaries

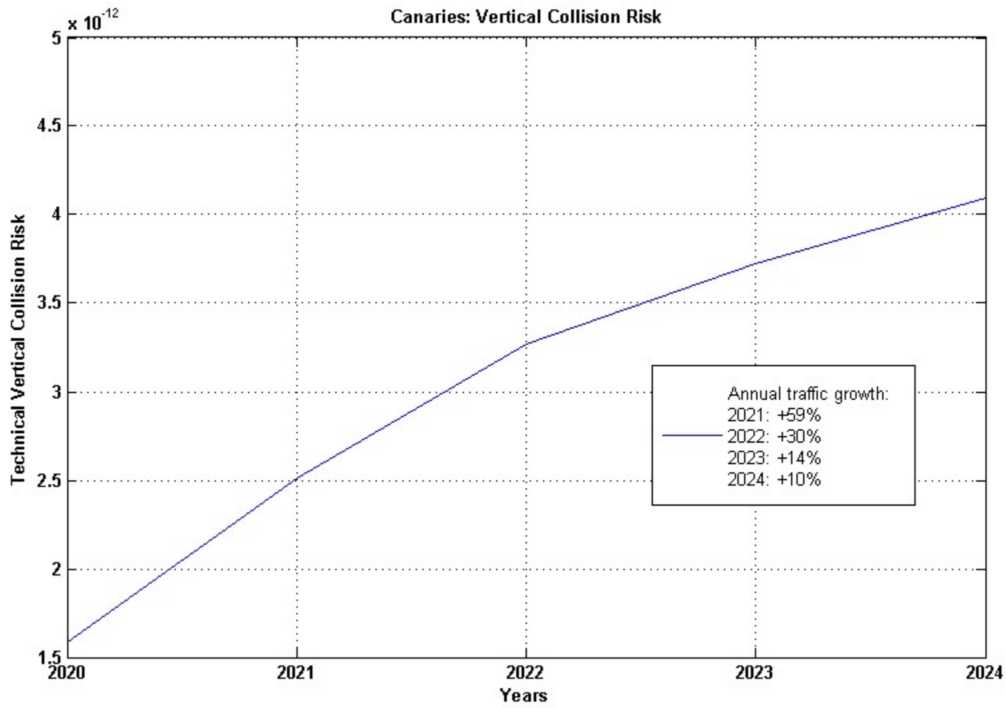


Figure 18.
Technical vertical collision risk for the period 2020-2024 in the Canaries (enlarged)

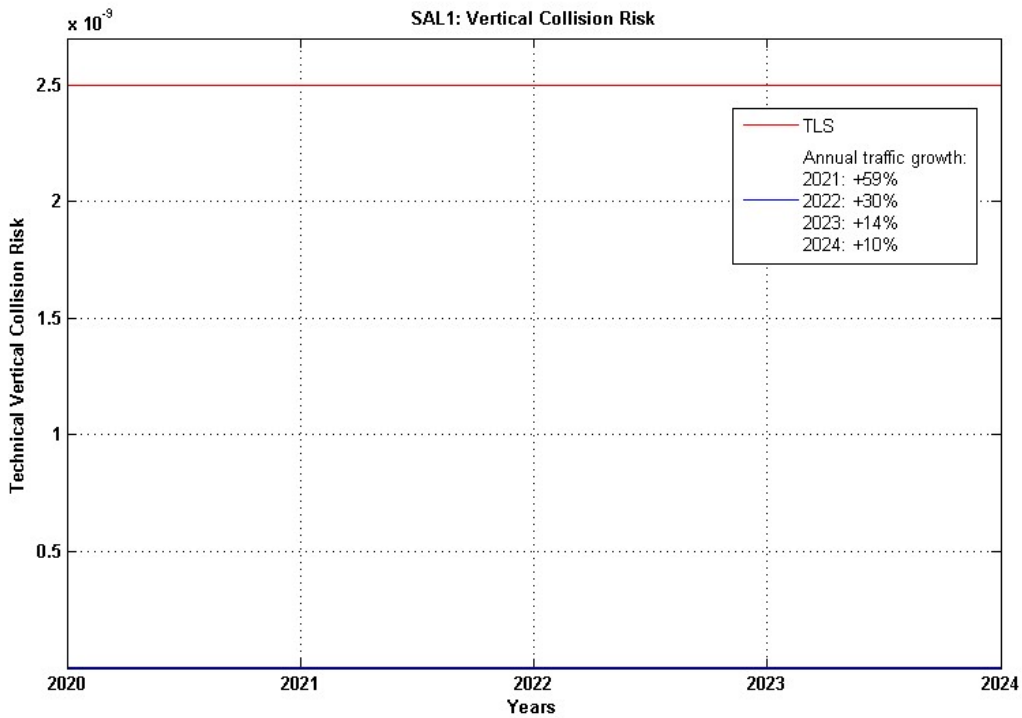


Figure 19.
Technical vertical collision risk for the period 2020-2024 in SAL1

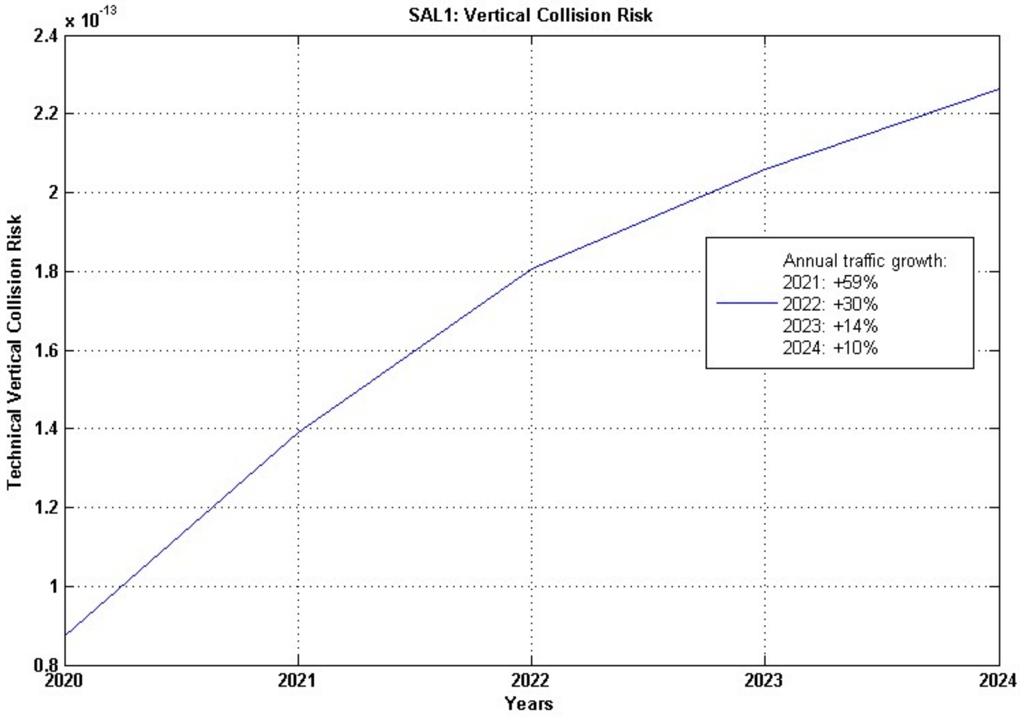


Figure 20.
Technical vertical collision risk for the period 2020-2024 in SAL1 (enlarged)

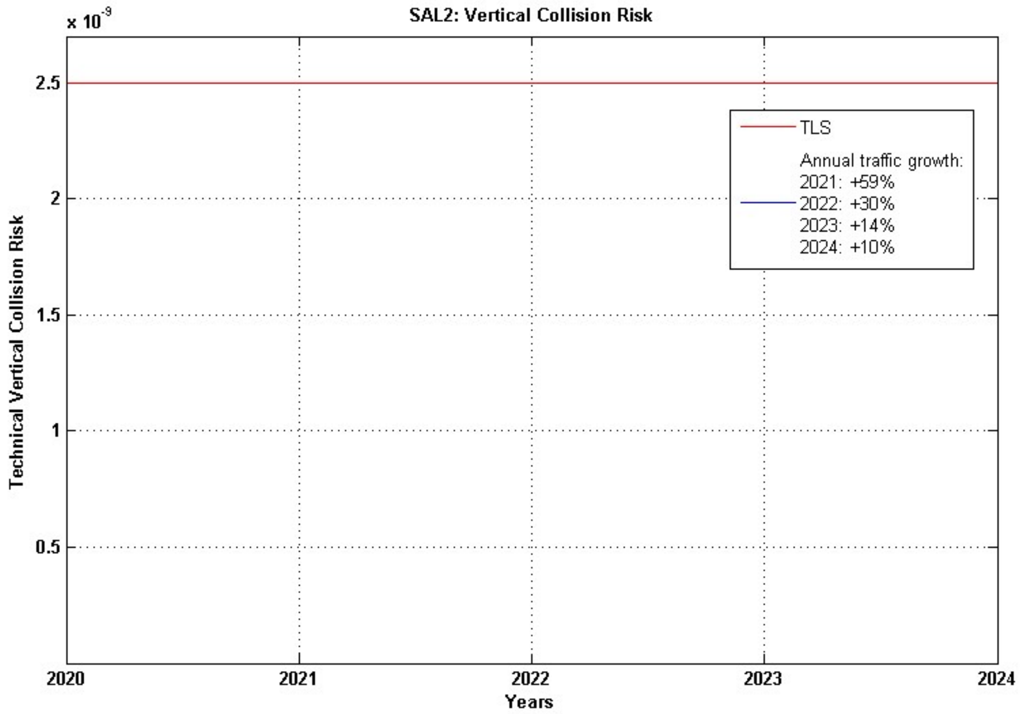


Figure 21.
Technical vertical collision risk for the period 2020-2024 in SAL2

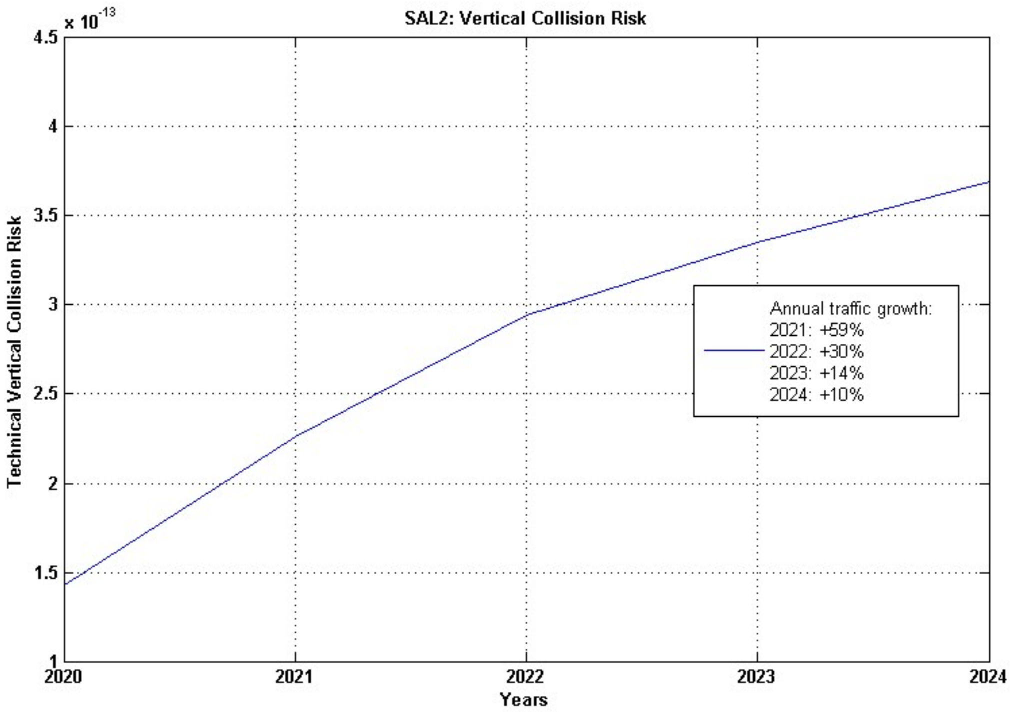


Figure 22.
Technical vertical collision risk for the period 2020-2024 in SAL2 (enlarged)

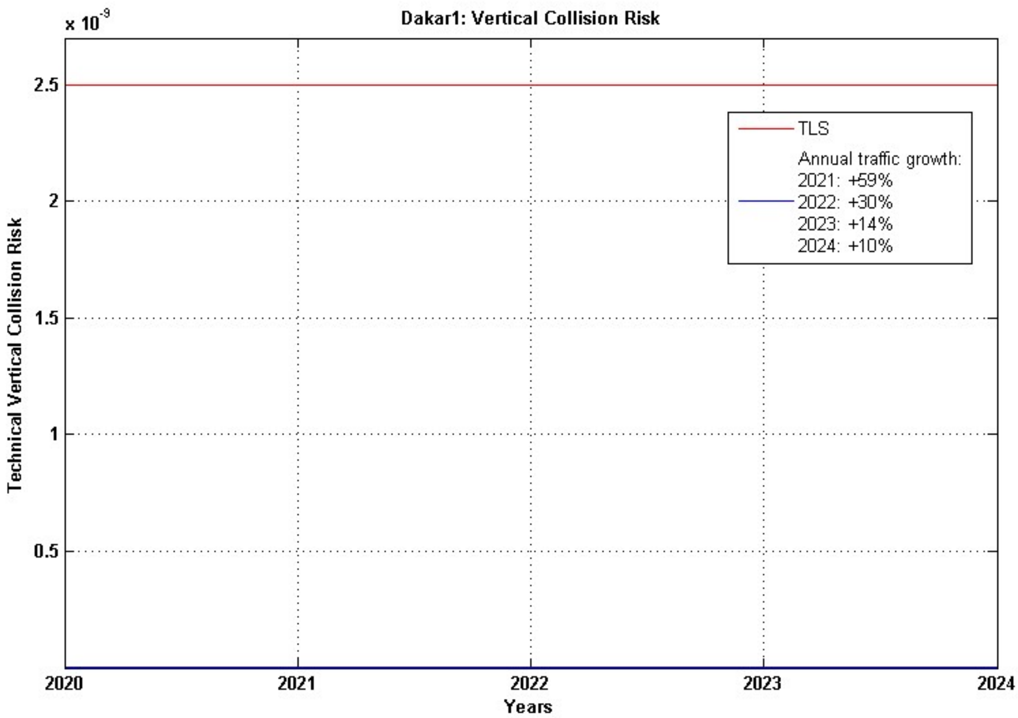


Figure 23.
Technical vertical collision risk for the period 2020-2024 in Dakar1

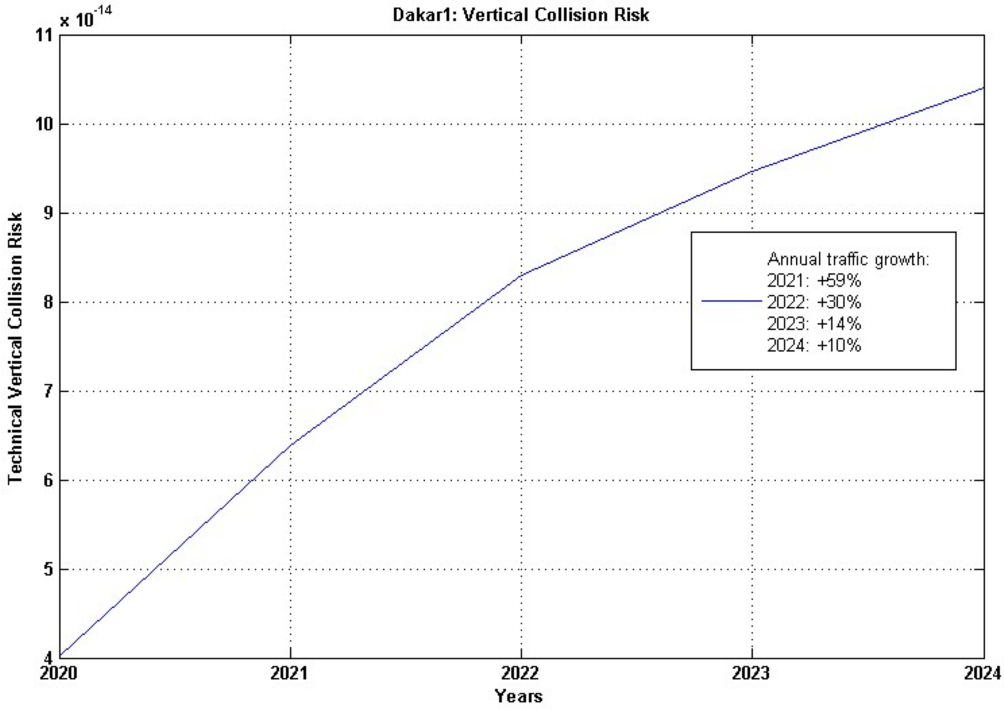


Figure 24.
Technical vertical collision risk for the period 2020-2024 in Dakar1 (enlarged)

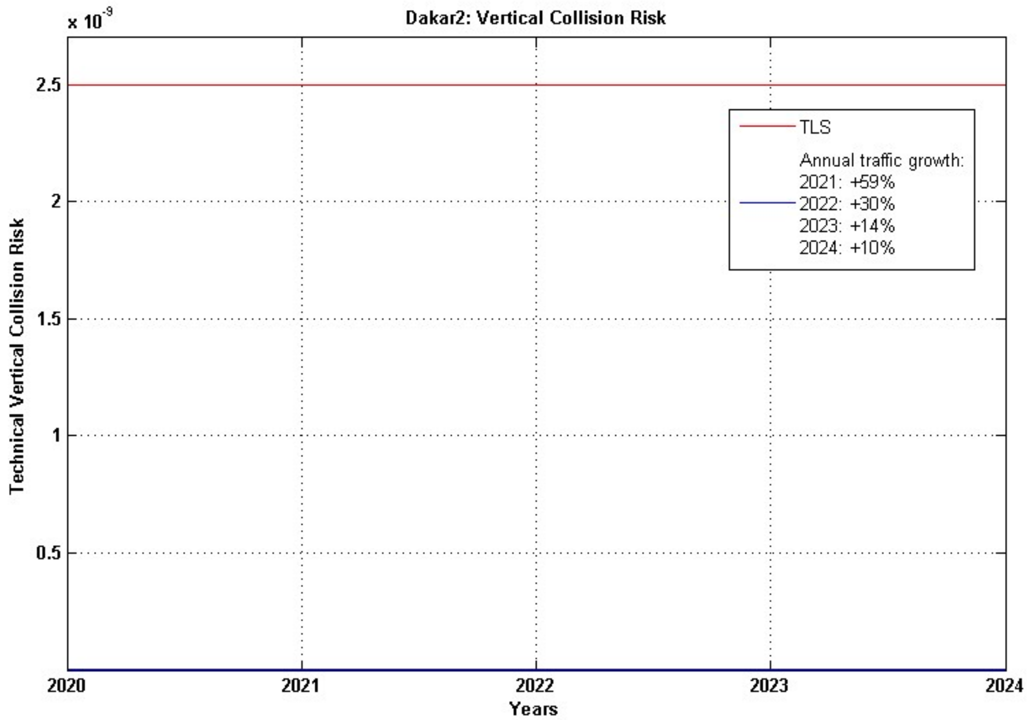


Figure 25.
Technical vertical collision risk for the period 2020-2024 in Dakar2

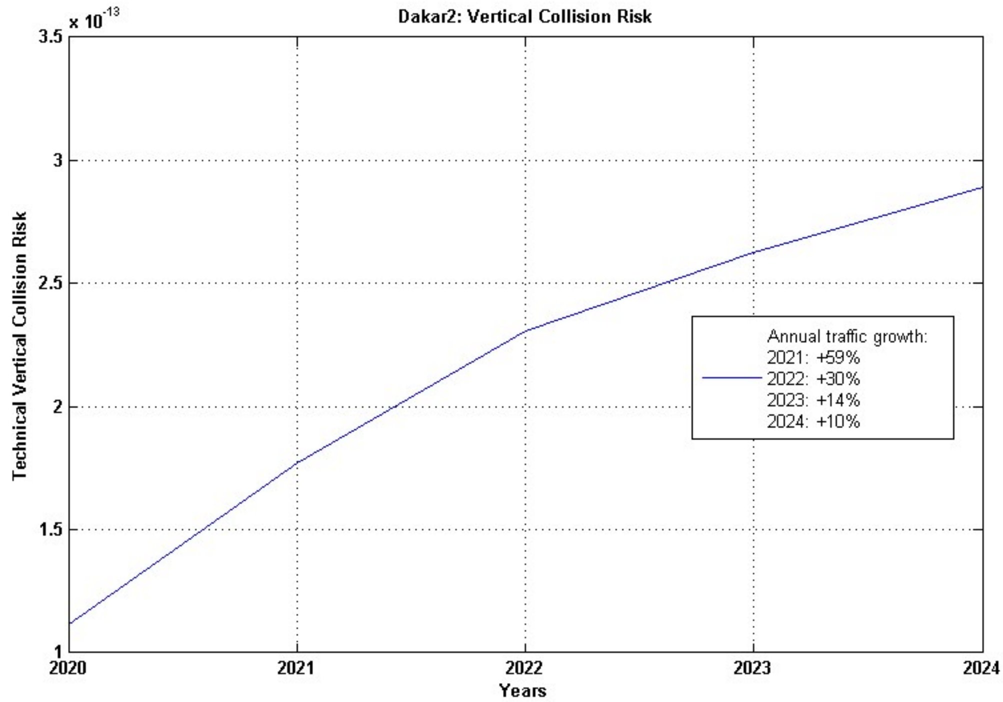


Figure 26.
Technical vertical collision risk for the period 2020-2024 in Dakar2 (enlarged)

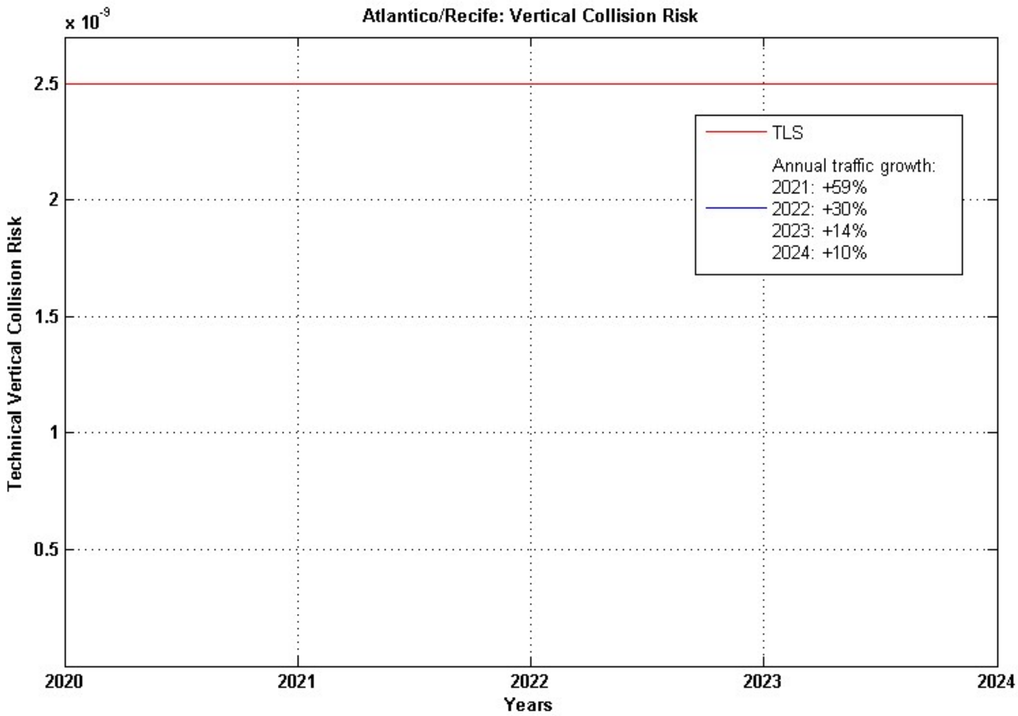


Figure 27.
Technical vertical collision risk for the period 2020-2024 in Recife

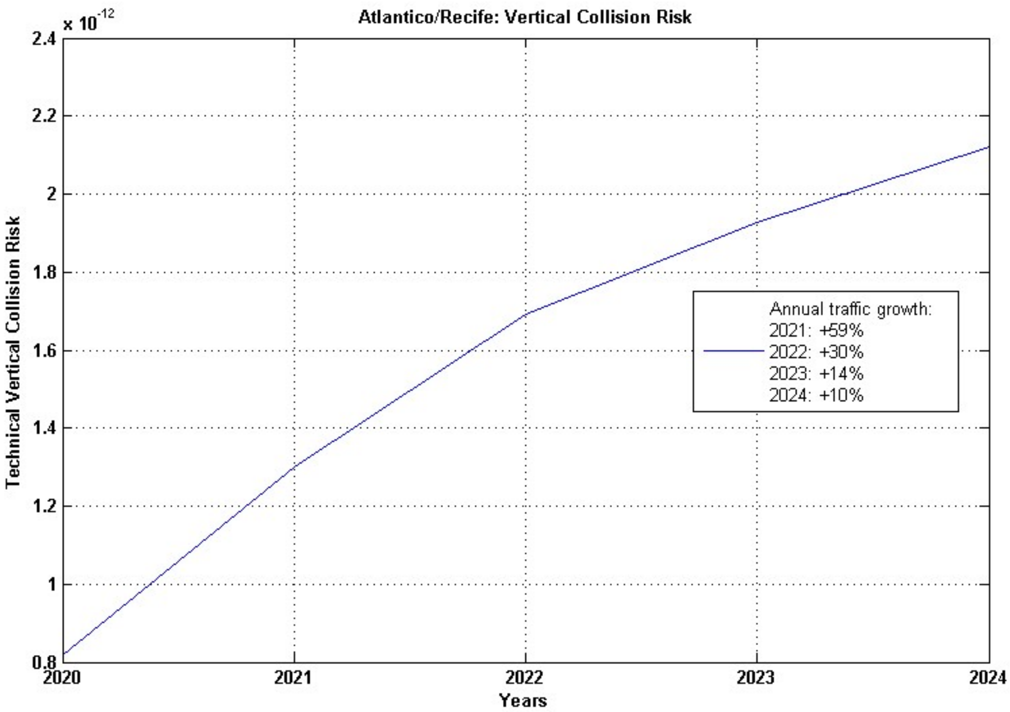


Figure 28.
Technical vertical collision risk for the period 2020-2024 in Recife (enlarged)

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 2024 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. 35]), large height deviations can be classified as reflected in Table 37. 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 37.
LHD classification according to ICAO

4.2.1. Data on EUR/SAM large height deviations

As it has been explained in [Ref. 36], 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 38 indicates the months for which LHD reports have been received before March 15th, 2021[3]. From these LHDs, only those affecting the four main routes have been considered[4]. Table 39, Table 40 and Table 41, 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-20	Available	Available	"No deviation" report received	"No deviation" report received
Feb-20	Available	Available	"No deviation" report received	"No deviation" report received
Mar-20	Available	"No deviation" report received	"No deviation" report received	"No deviation" report received
Apr-20	"No deviation" report received	"No deviation" report received	Not available	"No deviation" report received
May-20	"No deviation" report received	"No deviation" report received	Not available	"No deviation" report received
Jun-20	"No deviation" report received	Not available	Available	"No deviation" report received
Jul-20	"No deviation" report received	"No deviation" report received	"No deviation" report received	Not available
Aug-20	"No deviation" report received	Not available	"No deviation" report received	Not available
Sep-20	Available	Not available	"No deviation" report received	"No deviation" report received
Oct-20	"No deviation" report received	"No deviation" report received	Available	"No deviation" report received
Nov-20	Available	Not available	"No deviation" report received	"No deviation" report received
Dec-20	"No deviation" report received	Not available	"No deviation" report received	"No deviation" report received

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

Table 38.
Received data from January 2020 to December 2020

Date	Route	Duration	Coordinated FL	Observed FL	Deviation	Cause	Category
140120	UN866	0.05000 h	FL390	FL390	0	Coordination Error	E
170120	UN873	0.08333 h	FL390	FL370	2000 ft	Coordination Error	E
160220	UN873	0.10000 h	FL350	FL350	0	Coordination Error	E
290220	UN873	0.05000 h	FL370	FL370	0	Coordination Error	E
060320	UN873	0.08333 h	FL370	FL390	2000 ft	Coordination Error	E
140320_1	UN873	0.08333 h	FL390	FL410	2000 ft	Coordination Error	E
140320_2	UN873	0.08333 h	FL410	FL390	2000 ft	Coordination Error	E
100920	UN866	0.08333 h	FL330	FL350	2000 ft	Coordination Error	E
131120	UN866	0.08333 h	FL390	FL410	2000 ft	Coordination Error	E

Table 39.
Large height deviations reported in the Canaries

Date	Route	Duration	Coordinated FL	Observed FL	Deviation	Cause	Category
030220	UN857	0.05000 h	FL350	FL390	4000 ft	Coordination Error	E

Table 40.
Large height deviations reported in SAL

Date	Route	Duration	Coordinated FL	Observed FL	Deviation	Cause	Category
291020	UN873	0.08333 h	FL370	FL390	2000 ft	Coordination Error	E

Table 41.
Large height deviations reported in Dakar

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 39, Table 40 and Table 41, there are no reports due to large height deviations not involving whole numbers of flight levels and $N_{az}^{*} = 0$.

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 2020, 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 May in each FIR with the one calculated in the Canaries and applying the same proportion to the complete year.

Number of flights	Jan-Dec 2020			
	Canaries	SAL	Dakar	Recife
Same direction time at incorrect level (h)	0.6999	0.0500	0.0833	0
Opposite direction time at incorrect level (h)	0	0	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)	8542.71	10256.91	18343.36	14476.21
Total Corridor flight time (h)	51619.20	51619.20	51619.20	51619.20
Wrong level, same direction vertical overlap probability	$3.9914*10^{-5}$	$2.3746*10^{-6}$	$2.2129*10^{-6}$	0
Wrong level, opposite direction vertical overlap probability	0	0	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 42.
Operational vertical collision risk parameters in the Corridor

Table 43 shows the estimate of the total vertical collision risk, sum of the technical vertical risk and the operational vertical risk, with an annual traffic growth rate of 59%, 30%, 14% and 10% in 2021, 2022, 2023 and 2024 respectively. These results can also be seen in Figure 29 to Figure 34.

Total Vertical Collision risk	59%, 30%, 14% and 10% annual traffic growth until 2024					
	Canaries	SAL1	SAL2	Dakar1	Dakar2	Recife
2020	$1.3003*10^{-8}$	$3.3609*10^{-9}$	$5.2103*10^{-9}$	$1.3692*10^{-9}$	$3.8024*10^{-9}$	$8.1821*10^{-13}$
2021	$2.0675*10^{-8}$	$5.3439*10^{-9}$	$8.2844*10^{-9}$	$2.1771*10^{-9}$	$6.0458*10^{-9}$	$1.3010*10^{-12}$
2022	$2.6878*10^{-8}$	$6.9470*10^{-9}$	$1.0770*10^{-8}$	$2.8302*10^{-9}$	$7.8595*10^{-9}$	$1.6912*10^{-12}$
2023	$3.0641*10^{-8}$	$7.9196*10^{-9}$	$1.2277*10^{-8}$	$3.2264*10^{-9}$	$8.9599*10^{-9}$	$1.9280*10^{-12}$
2024	$3.3705*10^{-8}$	$8.7116*10^{-9}$	$1.3505*10^{-8}$	$3.5490*10^{-9}$	$9.8559*10^{-9}$	$2.1208*10^{-12}$

Table 43.
Total vertical collision risk for the period 2020-2024

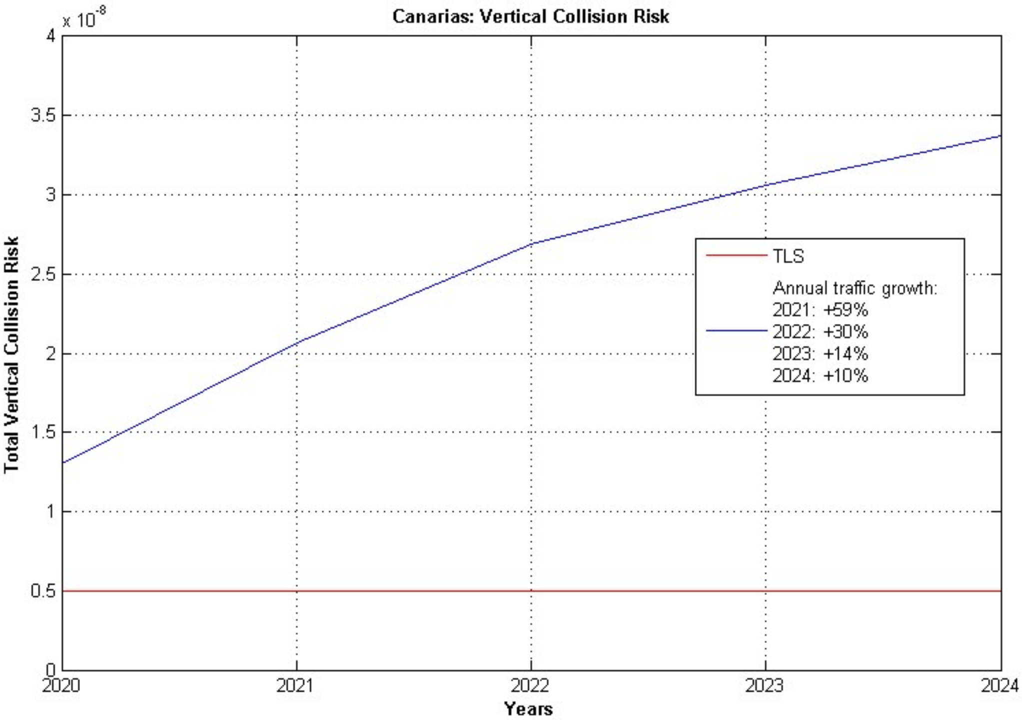


Figure 29.
Total vertical collision risk for the period 2020-2024 in the Canaries

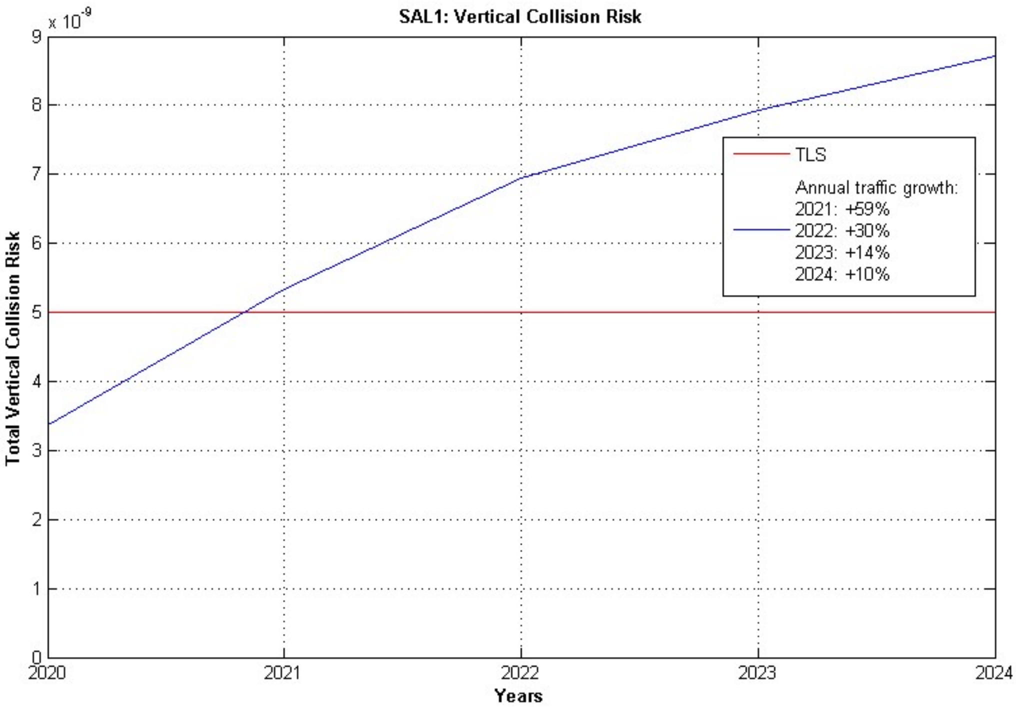


Figure 30.
Total vertical collision risk for the period 2020-2024 in SAL1

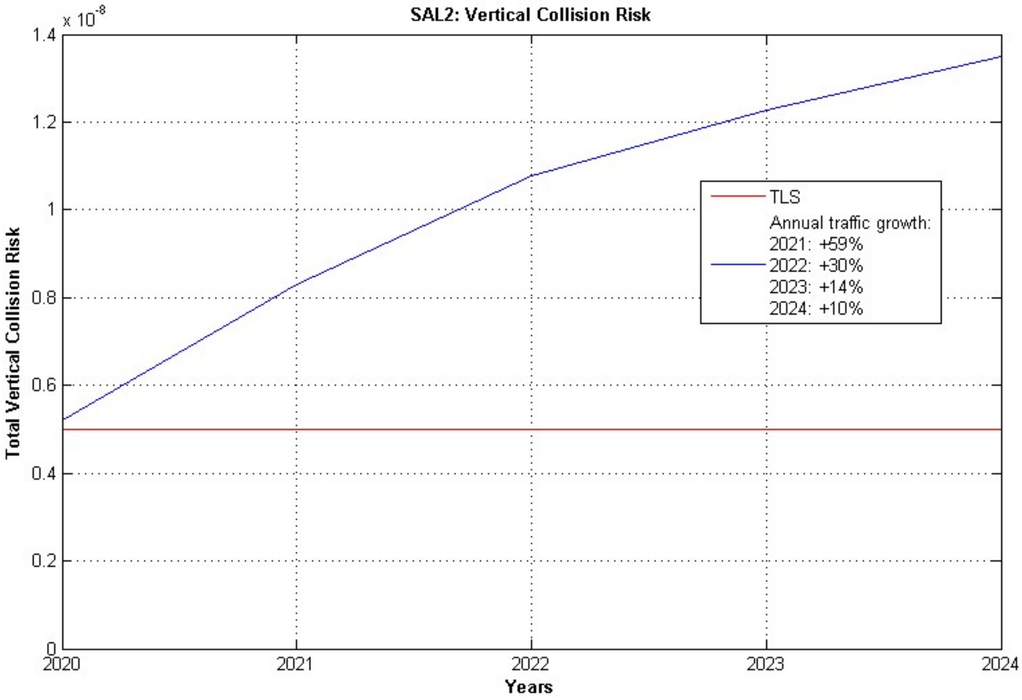


Figure 31.
Total vertical collision risk for the period 2020-2024 in SAL2

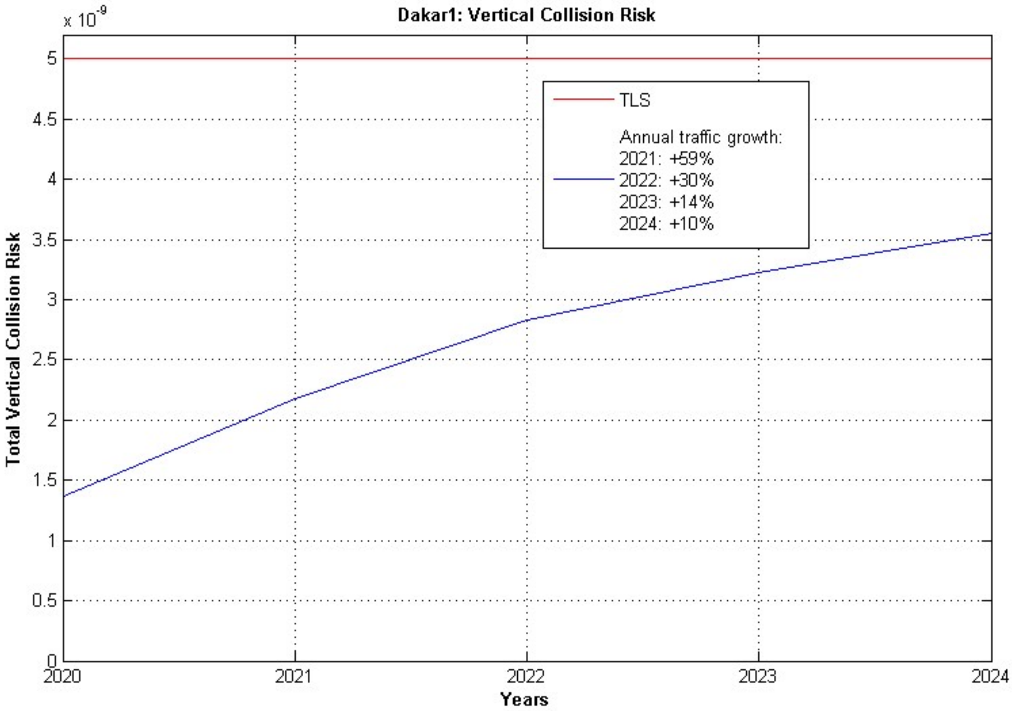


Figure 32.
Total vertical collision risk for the period 2020-2024 in Dakar1

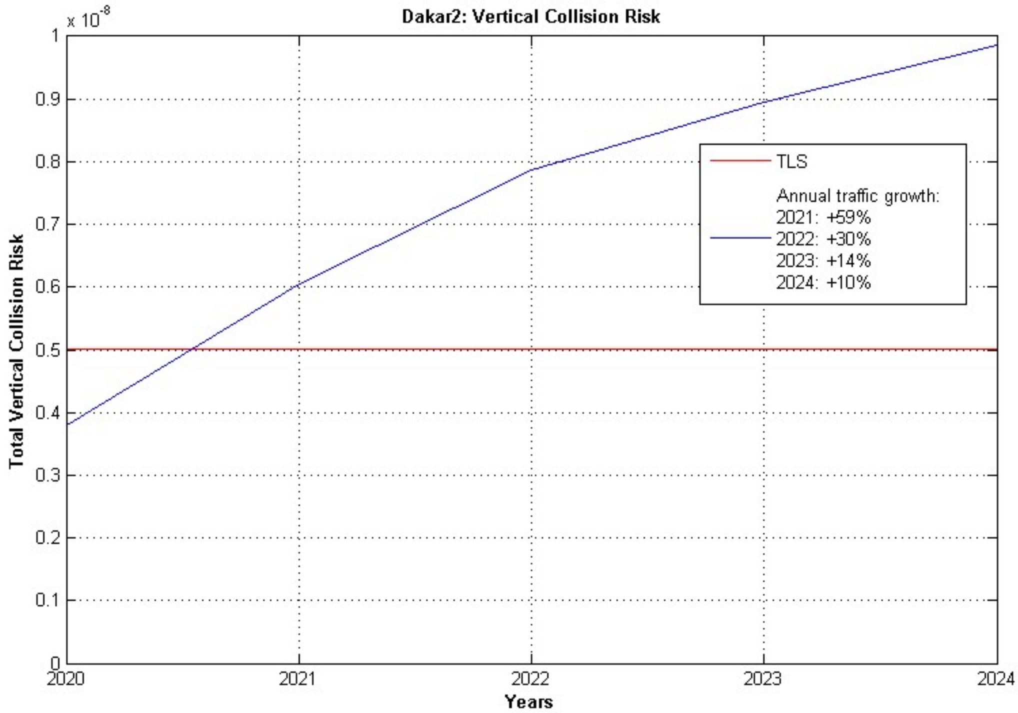


Figure 33.
Total vertical collision risk for the period 2020-2024 in Dakar2

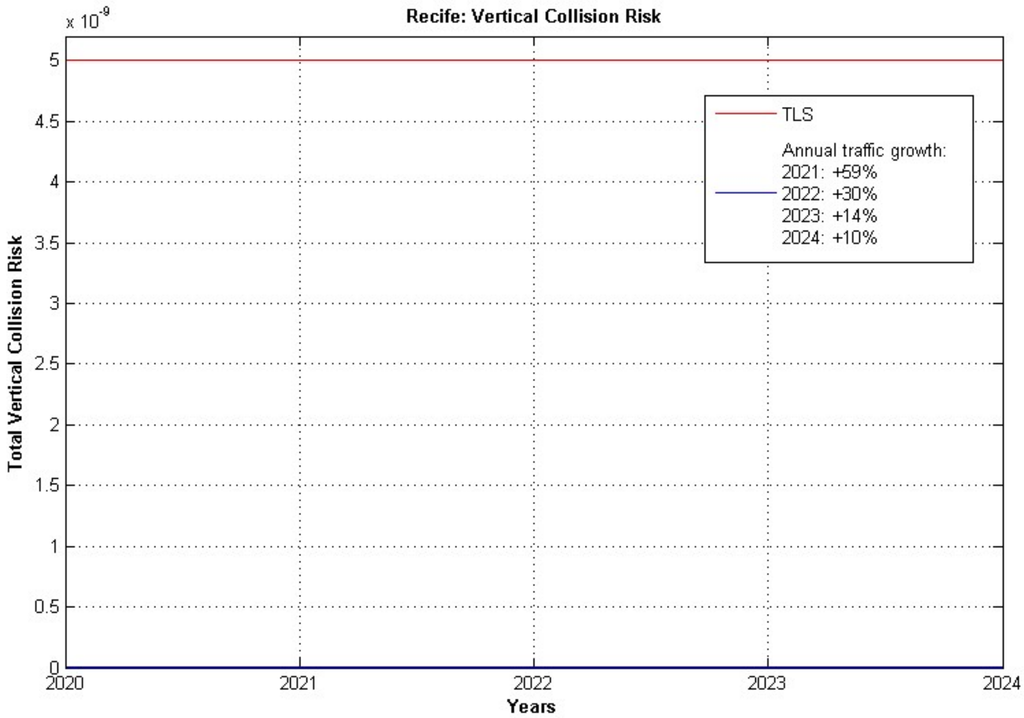


Figure 34.
Total vertical collision risk for the period 2020-2024 in Recife

4.2.3. Considerations on the results

The total vertical risk calculated using the deviations reported by the States is lower than the TLS in all locations except in Canaries and SAL2.

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. 32], [Ref. 33] and [Ref. 34]).

Using this value of $P_y(0)=0.059$, the obtained results are shown in Table 44.

FIR/UIR	Vertical risk	
	Technical risk	**Total vertical risk**
Canaries	$3.4345*10^{-13}$	$5.0049*10^{-9}$
SAL1	$4.4092*10^{-14}$	$1.6136*10^{-9}$
SAL2	$2.8161*10^{-14}$	$1.0306*10^{-9}$
Dakar1	$1.3868*10^{-14}$	$4.7313*10^{-10}$
Dakar2	$3.0774*10^{-14}$	$1.0499*10^{-9}$
Recife	$1.6715*10^{-13}$	$1.6715*10^{-13}$

Table 44.
Technical and total vertical risk using Py(0)=0.059

As it can be seen in Table 44, if a value of $P_y(0)=0.059$ were used, the results for the total vertical risk would be below the TLS in all locations except in Canaries, which would be almost identical to TLS.

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.

The traffic outlook for the future has been strongly impacted by COVID-19, backing to pre-1990 flight levels, which can be seen both in the results obtained and in the future forecast.

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 $P_y(50) = 1.1881 \cdot 10^{-7}$ and $P_y(50) = 1.7958 \cdot 10^{-7}$, depending on the location, whilst the lateral overlap probability obtained for $S_y = 90\,NM$ is between $P_y(90) = 4.2856 \cdot 10^{-8}$ and $P_y(90) = 6.9824 \cdot 10^{-8}$.
    - For current traffic levels, the lateral collision risk obtained is $4.3250 * 10^{-10}$, whilst the lateral collision risk estimated for 2024 with an annual traffic growth rate of 59%, 30%, 14% and 10% in 2021, 2022, 2023 and 2024 respectively is $1.1211 * 10^{-9}$. These values do not take into account traffic on the DCT Area route.
- 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, 2020 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 2020, for S_z=1000 ft is $P_z(1000) = 6.48888 \cdot 10^{-1}$.
    - 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 0.2744 and 0.2983 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 $1.5806 * 10^{-12}$. The technical vertical collision risk estimated for 2024 with an annual traffic growth rate

of 59%, 30%, 14% and 10% in 2021, 2022, 2023 and 2024 is $4.0971 * 10^{-12}$. Both values are below the TLS.

  - 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 lower than the TLS in SAL1, Dakar and Recife. In Canaries and SAL2 locations the total vertical risk calculated is higher than TLS but much less than in previous years.
  - Both types of technical vertical risk obtained in this study are significantly lower than those obtained in the previous safety assessment due to the reduction in traffic caused by the COVID pandemic.
  - 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 exceeds the TLS in some locations 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:

- Traffic data for some regions was not available, even for the selected month, so some data had to be extrapolated.
- 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. 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.

[Ref. 11] EUR/SAM Corridor: 2018 Collision risk assessment. NYVI-IDSA-INF-028-1.0/19. May 2019.

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[Ref. 20] The EUR RVSM Mathematical Supplement.-MDG/21 DP/01 May 2001.

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[Ref. 22] 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. 23] EUROCONTROL 5-Year Forecast 2020-2024. Detailed Forecasts. November 2020

[Ref. 24] EUROCONTROL Five-Year Forecast 2020-2024. European Flight Movements and Service Units. Three Scenarios for Recovery from COVID-19. November 2020

[Ref. 25] EUR/SAM Risk Assessments. DNV-ADS-INF-23-0.2/06. December 2006

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[Ref. 28] AIC NR 13/A/08GO 30 October 2008. Bureau NOTAM International de L'Ouest Africain. Pre-Operational Implementation of AFDP, FPASD, ADS and CPDLC within Dakar and Niamey FIRs.

[Ref. 29] AIS-ESPAÑA. AIC 10 May 07. New route orientation on airways UN-741 and UN-866 (Corridor EUR/SAM)

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[Ref. 33] "Airspace Safety Review for the RVSM operation In the airspace of Chinese Flight Information Regions. January 2012 - December 2012".

[Ref. 34] "Airspace Safety Review for the RVSM Implementation in Fukuoka Flight Information Region". Jan 2014 To Dec 2014"

[Ref. 35] ICAO Doc 9937 Manual of Operating Procedures and Practices for Regional Monitoring Agencies

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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