EUR/SAM Corridor: 2021 Collision Risk Assessment

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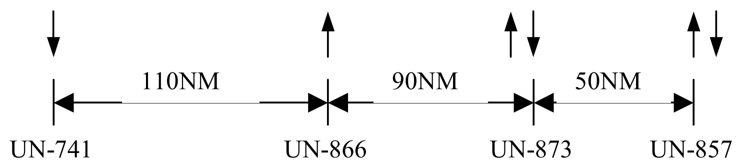
Executive Summary

This report presents the 2021 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 2021. 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 August 2021 to 31st August 2021. This month has been selected as it was the one with the highest number of flights from the months with all information available. The number of flights and the flight time for the complete year 2021, 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 [Ref. 24], the traffic outlook for the future has been strongly impacted by COVID-19, backing to pre-1990 flight levels. However, more than 80% of pre-pandemic traffic had been recovered by the end of 2021.

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:

- High Scenario: Recovery to 2019 level in mid-2023
    - Efficient vaccination campaign within Europe and globally
    - Reliable vaccine (also against variants)
    - Effective test-trace-isolate programme
    - Less travel restriction
    - Coordinated interregional approach
    - Good passenger confidence
    - Savings glut/Pent-up demand
    - Faster bounce-back of business travel
    - Airports well able to bring back capacity
- Baseline Scenario: Recovery to 2019 level by end 2023
    - Vaccine roll-out reaching herd immunity levels within Europe
    - Reliable vaccine (also against variants)
    - Effective test-trace-isolate programme
    - Limited travel restriction
    - Coordinated European approach
    - Relatively good passenger confidence
    - Savings glut/Pent-up demand
    - Business travel return to pre-COVID19 levels in 2023
    - Airports well able to bring back capacity
- Low Scenario: Recovery to 2019 level after 2027
    - Patchy uptake of vaccine
    - Need of updated vaccines
    - Frequent reintroduction of lockdowns and mask mandates
    - Strong travel restriction
    - Coordinated European approach
    - Long-haul flows restarting as of end 2022
    - Demand is bouncing back for 60-70% of travellers but reluctance to fly for rest
    - Permanent drop in propensity to fly
    - Growing environmental constraint
    - Airport difficulties to operate as pre-COVID

In this study the most optimistic scenario has been chosen (High Scenario).

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 57%, 19%, 10% and 3% in 2022, 2023, 2024 and 2025 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 August 2021 are representative of the whole year, the calculated lateral collision risk is $3.2452*10^{-9}$, whilst the lateral collision risk estimated for 2024 with an annual traffic growth rate of 57%, 19%, 10% and 3% in 2022, 2023, 2024 and 2025 respectively is $6.8693*10^{-9}$. The 2021 value is below the TLS, but the estimated 2025 value exceeds it. 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 2021 (assuming traffic levels of August 2021 are representative of the whole year), is estimated to be $1.4153*10^{-14}$ and the technical vertical collision risk estimated for 2025 with an annual traffic growth rate of 57%, 19%, 10% and 3% in 2022, 2023, 2024 and 2025 respectively, $2.9959*10^{-14}$. 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 $2.9636*10^{-8}$, which exceeds the TLS.

In previous safety assessments, such as [Ref. 3], [Ref. 5], [Ref. 8], [Ref. 9], [Ref. 10], [Ref. 101], [Ref. 102] or [Ref. 103], 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 2021 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 2021 to 31st August 2021 and with the number of flights and the flight time required for some of the calculations extrapolated for the complete year 2021.

For this study, the sw application 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. 37]. 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. 37], where the changes or new information regarding the airspace in the year 2021 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 2021 to 31st August 2021. When data, such as the number of flights or flight time for the rest of 2021 has been necessary, it has been extrapolated using information from Canaries as a basis.

Data for the complete year 2021 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 2021 to 31st December 2021. 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 2021. 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 2021 between FL290 and FL410 have been analysed.

Table 1 shows the values obtained for the Canaries UIR in 2021 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	2830	19.3055	63.66	64	16.79
B789	1168	7.9678	62.8	60.1	16.9
A20N	1069	7.2924	37.57	35.8	11.76
A359	1055	7.1969	66.8	64.75	17.05
A332	1022	6.9718	63.7	60.03	16.74
B77W	990	6.7535	73.9	60.9	18.5
A21N	913	6.2283	44.51	35.8	11.76
B763	793	5.4096	47.6	54.9	15.9
B38M	607	4.1408	39.5	35.9	12.3
A333	555	3.7861	63.7	60.03	16.74
B748	553	3.7724	76.3	65.45	19.5
B738	492	3.3563	39.47	34.31	12.5
B788	421	2.8720	56.7	60.1	16.9
B77L	359	2.4490	67.78	61.68	18.5
B744	292	1.9920	70.7	64.4	19.4
E190	208	1.4189	36.24	28.72	10.57
A320	198	1.3507	37.57	34.1	11.76
GLEX	99	0.6754	30.3	28.65	7.57
A321	97	0.6617	37.57	34.1	11.76
B737	90	0.6140	33.6	34.3	12.5
CL60	76	0.5185	20.86	19.35	6.28
B772	71	0.4843	63.7	60.9	18.5
E35L	54	0.3684	26.33	21.17	6.76
F900	50	0.3411	20.2	19.3	7.6
A319	50	0.3411	33.84	34.1	11.76
FA7X	47	0.3206	22.82	25.8	7.74
A343	38	0.2592	63.7	60.3	16.74
GLF4	37	0.2524	26.9	23.79	7.64
C17	36	0.2456	53	51.8	16.8
A400	35	0.2388	42.4	45.1	14.7
IL76	23	0.1569	46.59	50.5	14.76
F2TH	23	0.1569	20.21	19.33	7.55
FA8X	21	0.1433	24.46	26.29	7.94
A310	19	0.1296	46.4	43.89	15.8
LJ45	18	0.1228	17.7	14.6	4.3
E295	17	0.1160	41.5	35.1	10.9
B752	16	0.1091	47.32	38.05	13.6
GLF6	15	0.1023	30.41	30.36	7.72
GLF5	13	0.0887	29.42	28.5	7.87

FA50	13	0.0887	18.52	18.96	6.97
A124	13	0.0887	69.1	73.3	20.78
H25B	12	0.0819	15.6	15.7	5.4
LJ35	12	0.0819	14.71	11.97	3.71
E550	11	0.0750	20.74	20.25	6.44
A35K	11	0.0750	73.78	64.75	17.08
GL5T	8	0.0546	28.69	28.65	7.7
B78X	8	0.0546	68.3	60.1	16.9
LJ60	8	0.0546	17.89	13.35	4.44
E195	7	0.0478	38.65	28.72	10.55
HA4T	6	0.0409	21.08	18.82	5.97
WW24	6	0.0409	15.9	13.7	4.8
C680	5	0.0341	11.22	14.95	4.56
E545	5	0.0341	19.69	20.25	6.43
G280	5	0.0341	20.3	19.2	6.5
CL35	4	0.0273	20.9	21	6.1
ASTR	4	0.0273	16.94	16.05	5.54
FA20	4	0.0273	17.15	16.32	5.32
K35R	3	0.0205	41.5	39.9	12.7
E135	3	0.0205	26.33	20.04	6.76
E390	3	0.0205	33.43	33.94	11.43
GA6C	3	0.0205	29.2	29	7.8
Other	3	0.0205	N/D	N/D	N/D
E290	2	0.0136	36.2	33.7	11
FA10	2	0.0136	13.8	13.1	4.6
GALX	2	0.0136	18.99	17.71	6.52
H25C	2	0.0136	16.4	15.7	5.2
KC39	2	0.0136	32.7	35.1	10.3
P8	2	0.0136	39.5	37.6	12.8
G150	2	0.0136	17.3	16.94	5.82
LJ55	2	0.0136	16.8	13.3	4.5
LJ75	1	0.0068	17.7	15.5	4.31
B463	1	0.0068	31	26.34	8.61
HDJT	1	0.0068	12.71	12.15	4.03
B735	1	0.0068	31	28.9	11.1
CRJ2	1	0.0068	26.8	21.21	6.3
GL7T	1	0.0068	33.9	31.7	8.2
B733	1	0.0068	33.4	28.9	11.1
E55P	1	0.0068	15.6	15.9	5.1
E3CF	1	0.0068	46.6	45	12.7

GA5C	1	0.0068	28.2	26.7	7.8
E35	1	0.0068	7.7	10	2.3
F28	1	0.0068	27.4	23.6	19.3
E170	1	0.0068	29.9	26	9.67
C56X	1	0.0068	15.8	17	5.2
C25B	1	0.0068	14.3	15.1	4.1
CL30	1	0.0068	20.9	18.4	6.1

Table 1.
Aircraft population and number of flights per type during 2021 in the Canaries UIR

The data sample in the Canaries UIR includes 14659 flights of 86 different aircraft types. The population is dominated by large and medium airframes such as A330-900, B787-900, A320-NEO, A350-900, A330-200, B777-300ER, A321-NEO or B767-300. These 8 types make up about 67.13% of the total number of flights. The next 7 types, which also belong to the Airbus and Boeing families, make up another 22.37% and the rest 10.51% is distributed among the other 71 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 2021 to 31st December 2021, 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 2021 to 31st August 2021.

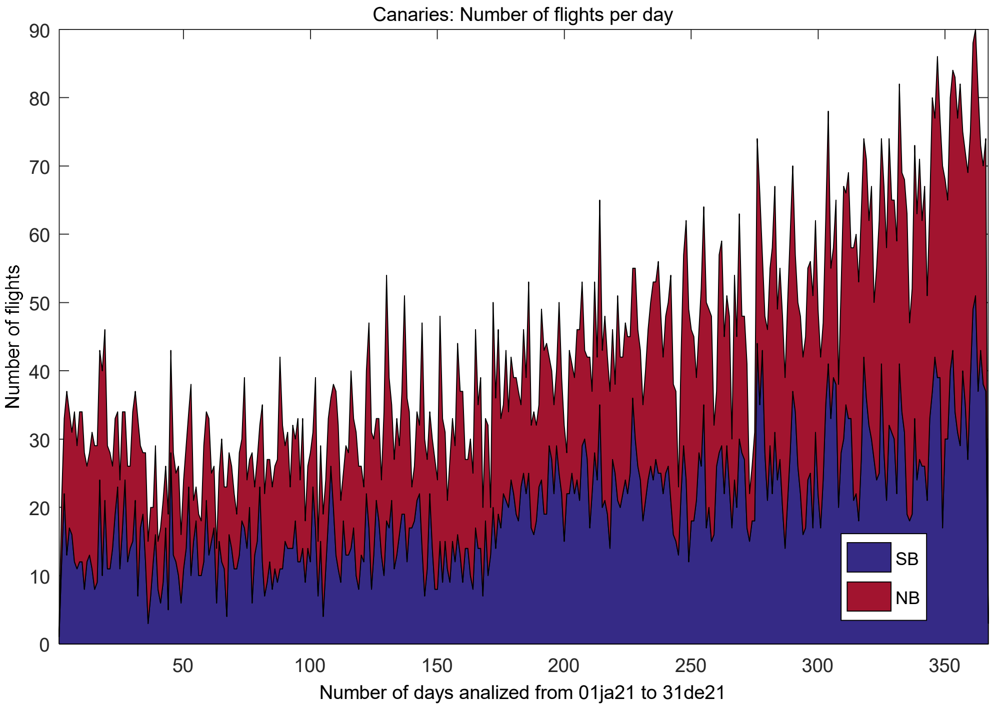


Figure 1.
Number of flights per day in the Canaries. Year 2021

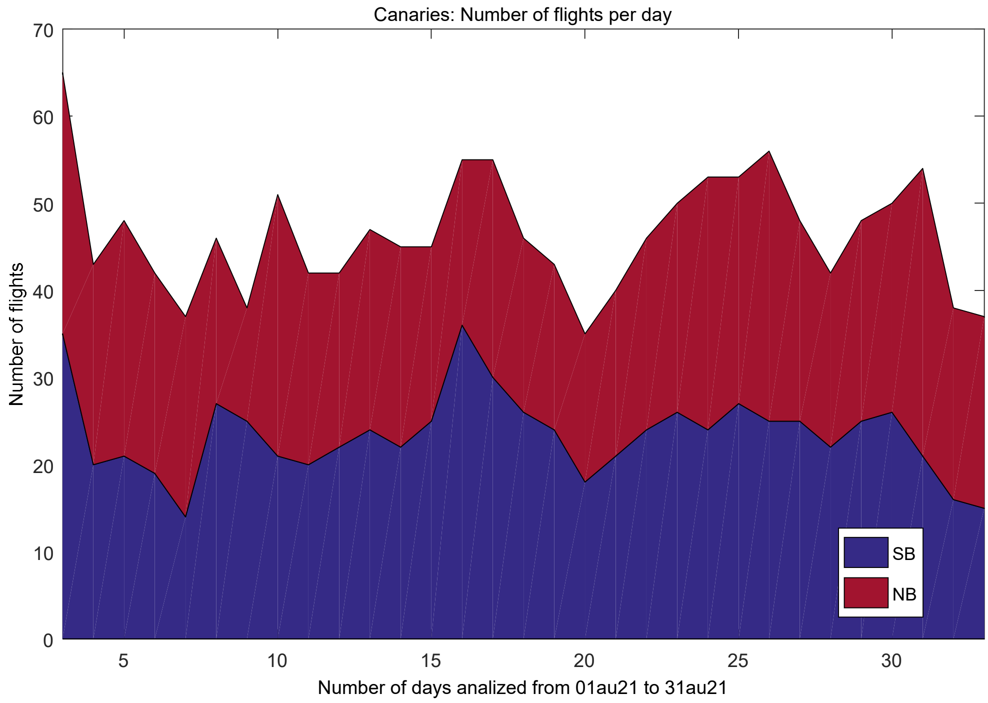


Figure 2.
Number of flights per day in the Canaries. August 2021

The overall average traffic for 2021 is 39.94 flights per day with a standard deviation of 16.66 flights per day, while in August the average is 40.56 with a standard deviation of 14.18 flights per day.

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

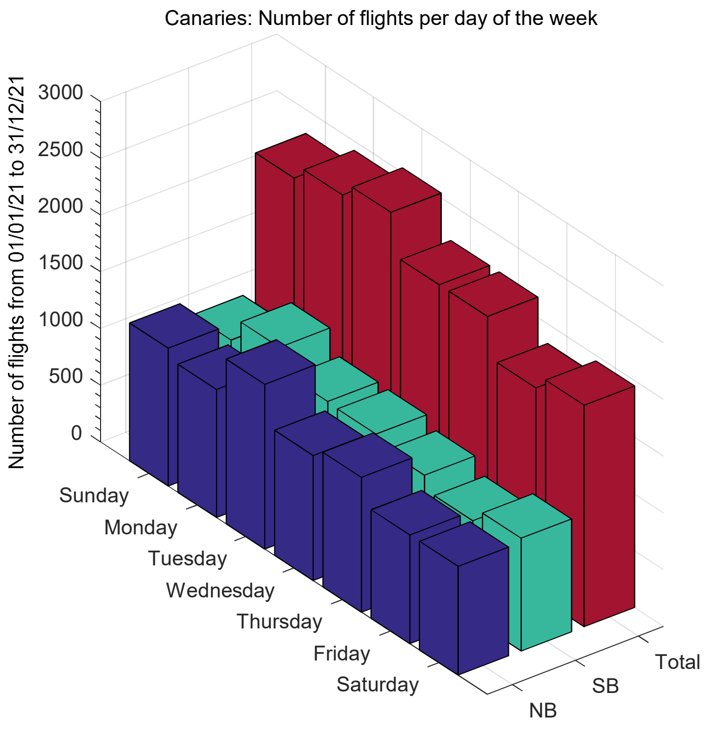


Figure 3.
Number of flights per day of the week in the Canaries. Year 2021

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 2021.

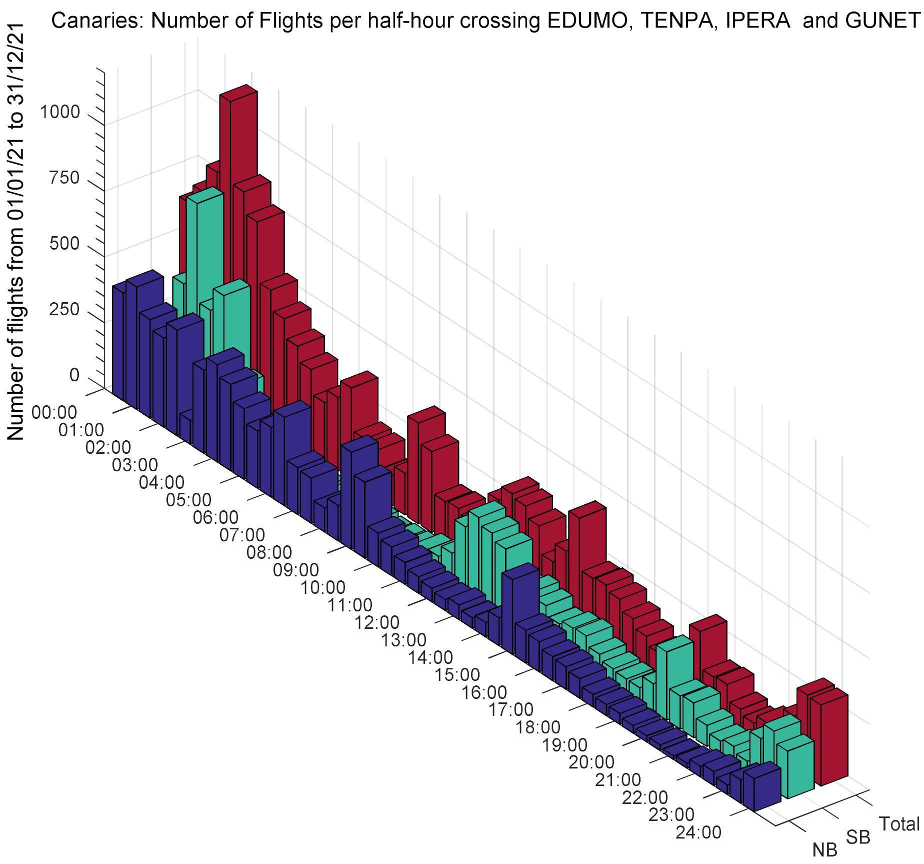


Figure 4.
Number of flights per half-hour crossing EDUMO, TENPA, IPERA and GUNET. Year 2021

It can be seen that during 2021, 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 1385 aircraft detected in Canaries during August 2021. Following, Figure 6 shows the temporal distribution of the 1106 aircraft detected over this period in Recife, according to the time of day at which they crossed DIKEB, OBKUT, ORARO and KOPDU 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 00:01h and 06:00h and, in a lower extent, from 14:00h to 24:00h.

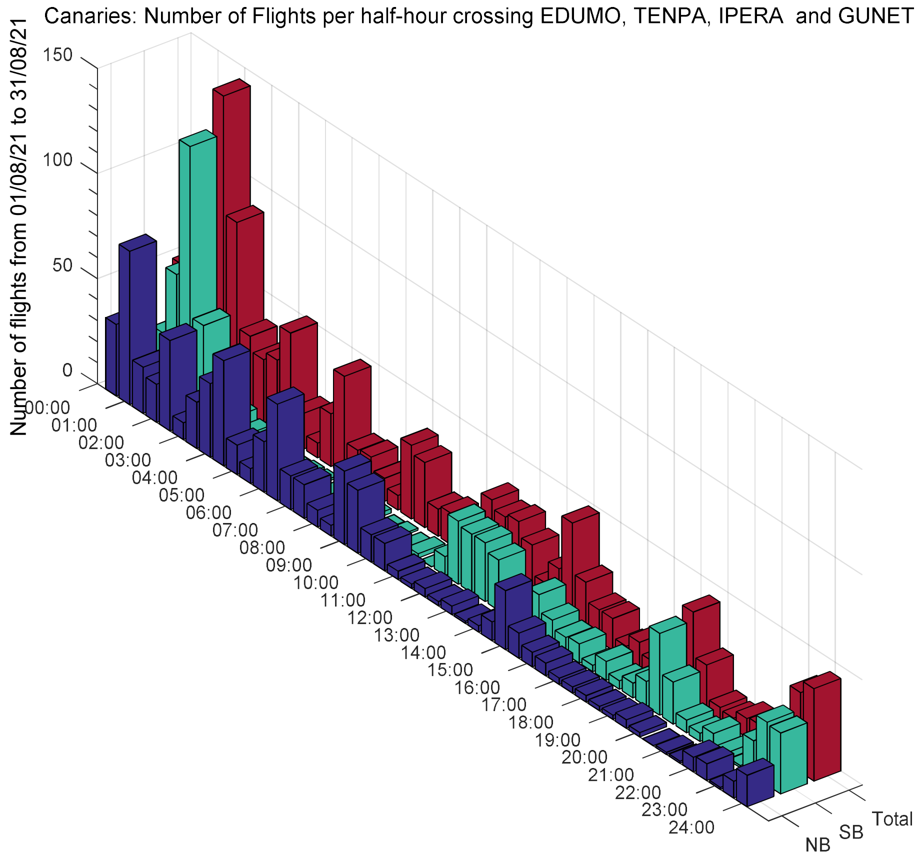


Figure 5.
Number of flights per half-hour crossing EDUMO, TENPA, IPERA and GUNET. August 2021

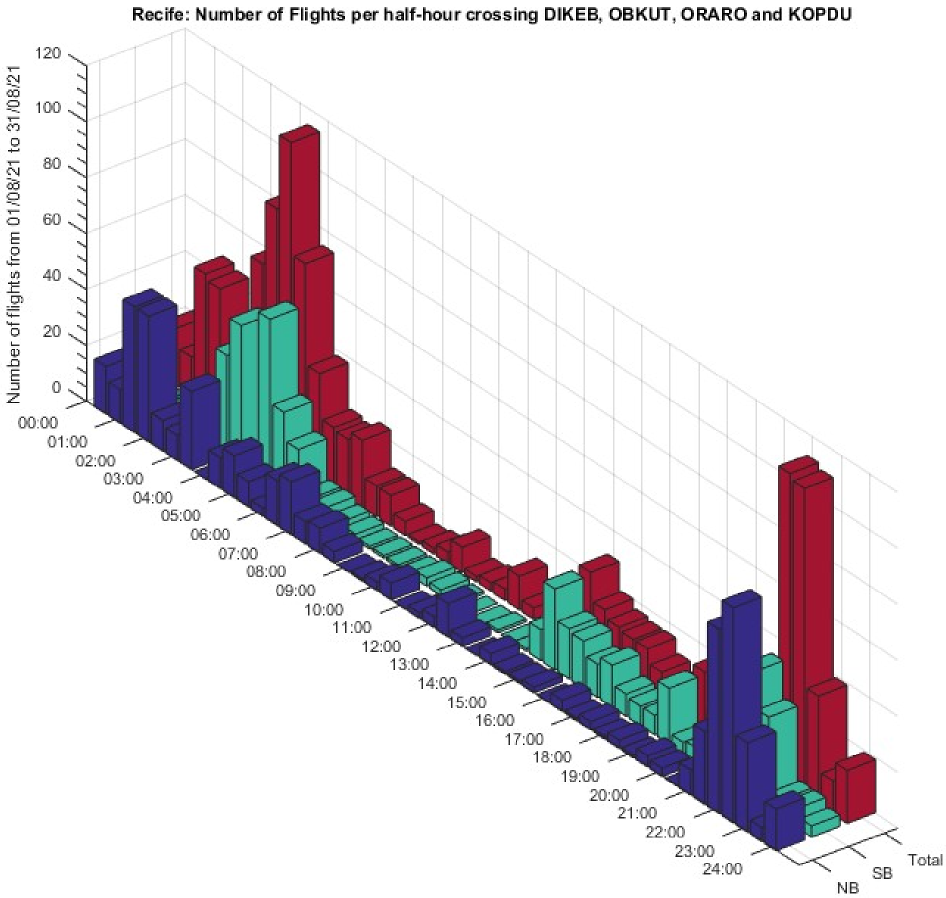


Figure 6.
Number of flights per half-hour crossing DIKEB, OBKUT, ORARO and KOPDU. August 2021

2.4. Traffic distribution per flight level

Traffic distribution per flight level during 2021 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.

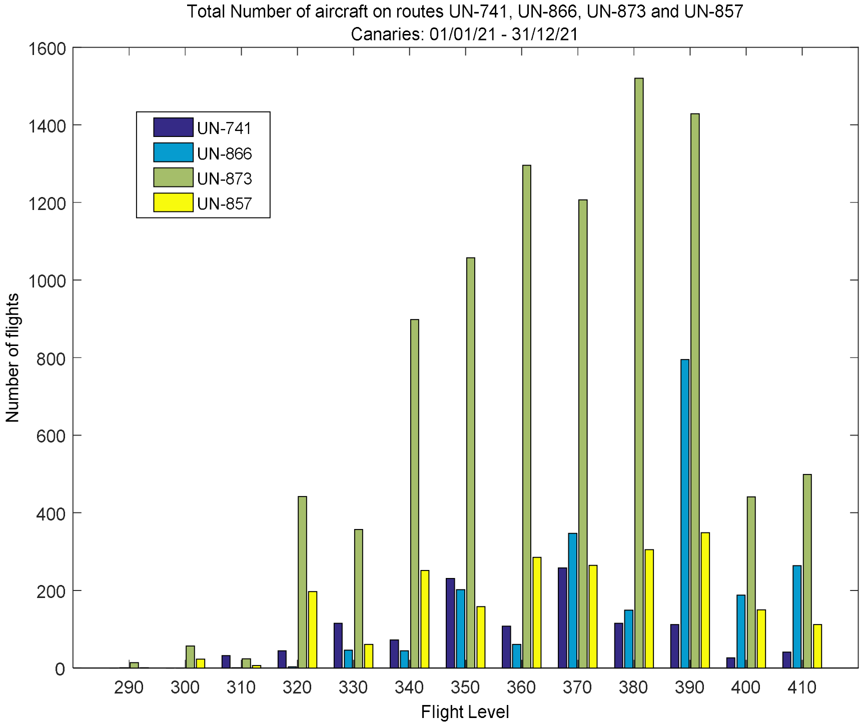


Figure 7.
Number of aircraft on routes UN-741, UN-866, UN-873 and UN-857 in the Canaries

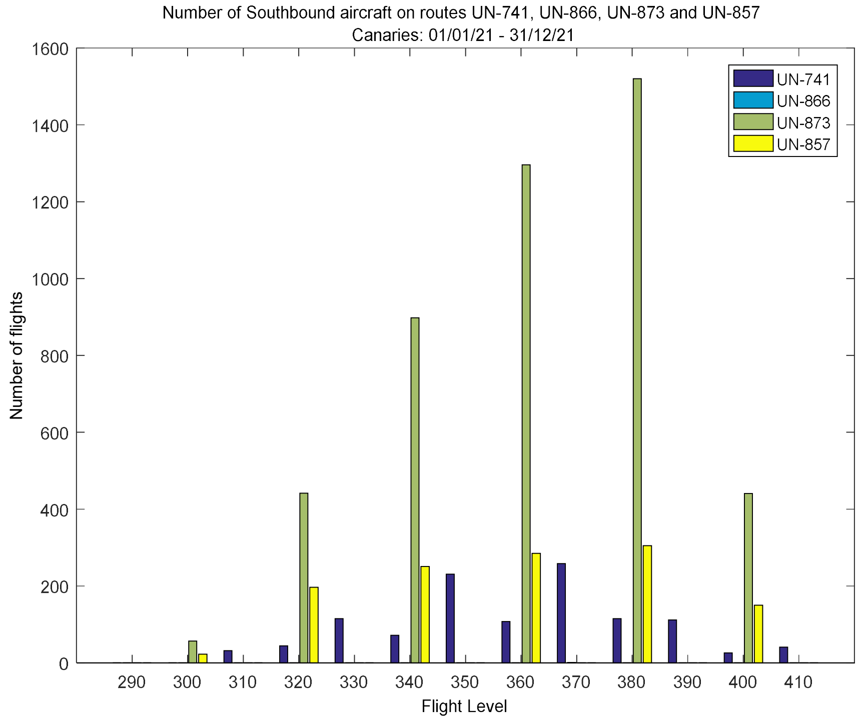


Figure 8.
Number of Southbound aircraft on routes UN-741, UN-866, UN-873 and UN-857 in the Canaries

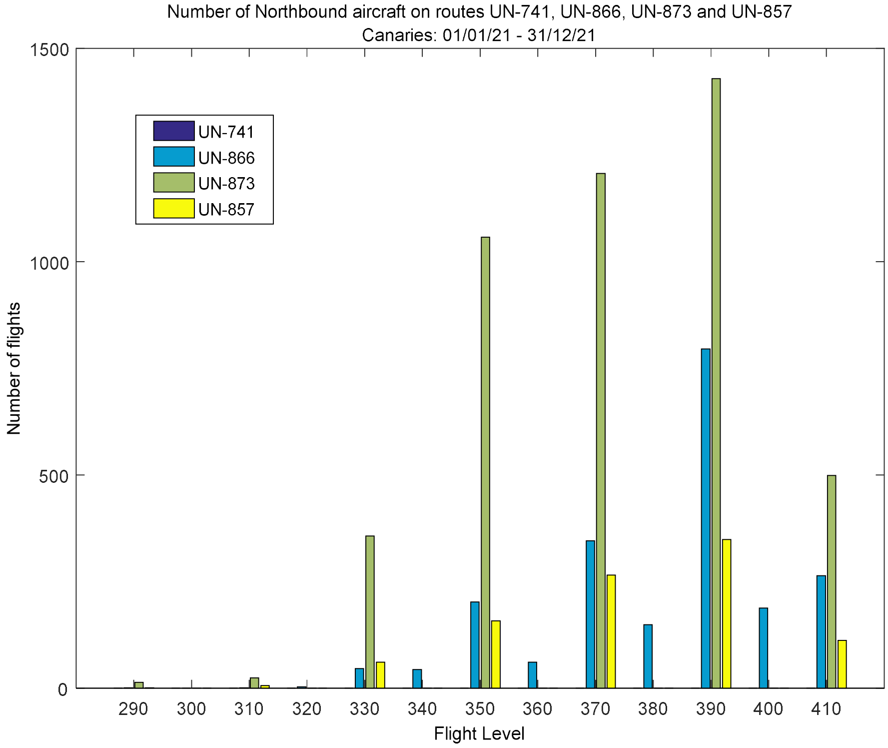


Figure 9.
Number of Northbound aircraft on routes UN-741, UN-866, UN-873 and UN-857 in the Canaries

3. Lateral collision risk assessment

As it has been said, the Reich model to calculate lateral collision risk is explained in [Ref. 37]. 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	184.48	174.84	50.36
SAL1	207.15	197.92	55.12
SAL2	201.51	193.53	54.14
Dakar1	201.55	192.57	53.89
Dakar2	201.53	192.52	53.88
Recife	203.66	194.08	54.46

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 $P_z(0)=0.52193$.

3.3. Average ground speed: v

Using the limitation to 575 kts explained in [Ref. 37], 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:

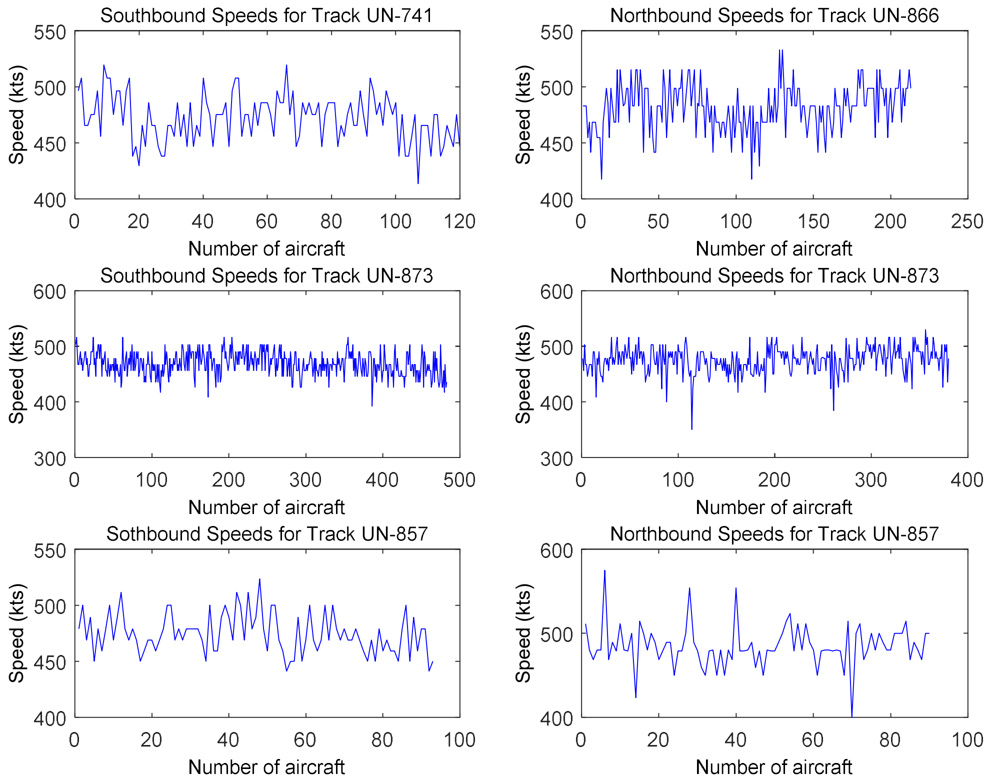


Figure 10.
Speeds limited to 575 kts in the current scenario in the Canaries

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	471.72	480.41	476.06
SAL1	477.93	458.99	468.46
SAL2	459.48	473.24	466.36
Dakar1	481.67	488.55	485.11
Dakar2	488.50	463.83	476.16
Recife	471.94	457.23	464.58

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	9.79	16.58	13.18
SAL1	18.69	26.42	22.56
SAL2	77.63	14.59	46.11
Dakar1	10.65	16.99	13.82
Dakar2	22.24	32.89	27.41
Recife	10.34	28.27	19.30

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. 37], 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. 37].

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 August. Table 5 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 2021	1385	1536	1095	1274	1255	1106
Jan-Dic 2021	14659	*16257*	*11590*	*13484*	*13283*	*11706*

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	$2.0434*10^{-4}$
SAL1	$1.8425*10^{-4}$
SAL2	$2.5845*10^{-4}$
Dakar1	$2.2214*10^{-4}$
Dakar2	$2.2550*10^{-4}$
Recife	$2.5588*10^{-4}$

Table 6.
α for each FIR

Using Equation 11 of [Ref. 37], 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	$1.0827*10^{-7}$	$3.8985*10^{-8}$	$2.6133*10^{-8}$	$1.4342*10^{-8}$
SAL1	$1.1306*10^{-7}$	$3.9859*10^{-8}$	$2.6718*10^{-8}$	$1.4664*10^{-8}$
SAL2	$1.2838*10^{-7}$	$4.6989*10^{-8}$	$3.1498*10^{-8}$	$1.7287*10^{-8}$
Dakar1	$1.2775*10^{-7}$	$4.6757*10^{-8}$	$3.3142*10^{-8}$	$1.7202*10^{-8}$
Dakar2	$1.2929*10^{-7}$	$4.4751*10^{-8}$	$3.1808*10^{-8}$	$1.7457*10^{-8}$
Recife	$1.4467*10^{-7}$	$5.4278*10^{-8}$	$3.6384*10^{-8}$	$1.9969*10^{-8}$

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. 37], 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 2021 to 31st August 2021, 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. 24], the annual traffic growth rate for the traffic flows in the Canary Islands airspace would be 57%, 19%, 10% and 3% in 2022, 2023, 2024 and 2025 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 2025, with the annual traffic growth rate of 57%, 19%, 10% and 3% in 2022, 2023, 2024 and 2025 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 August 2021 till 31st August 2021 in the Canaries, SAL, Dakar and Recife UIR/FIRs.

Number of flights August 2021	Canaries	SAL1	SAL2	Dakar1	Dakar2	Recife
Number of flights on UN-741	120	115	69	134	123	193
Number of flights on UN-866	213	181	201	224	225	227
Number of flights on UN-873	863	527	586	635	638	635
Number of flights on UN-857	183	173	169	198	197	161
Total number of flights	1379	996	1025	1191	1183	1216
Number of same direction proximate pairs for tracks UN-866/UN-873	12	10	10	8	11	9
Number of same direction proximate pairs for tracks UN-866/UN-857	0	1	1	3	4	4
Number of same direction proximate pairs for tracks UN-873/UN-857	28	25	24	24	30	24
Number of opposite direction proximate pairs for tracks UN-741/UN-866	1	0	1	2	1	2
Number of opposite direction proximate pairs for tracks UN-866/UN-873	1	2	3	4	4	2
Number of opposite direction proximate pairs for tracks UN-866/UN-857	0	0	0	0	1	0

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

Assuming an annual traffic growth rate of 57%, 19%, 10% and 3% in 2022, 2023, 2024 and 2025 respectively, the occupancies for the next 4 years are summarized in Table 9. It holds that occupancy is approximately proportional to traffic flow rate:

57%, 19%, 10% and 3% annual traffic growth until 2025		Canaries 2021-2025	SAL1 2021-2025	SAL2 2021-2025	Dakar1 2021-2025	Dakar2 2021-2025	Recife 2021-2025
Same direction lateral occupancy	**UN-866/UN-873 (E*ysame)**	0.0174-0.0368	0.0201-0.0425	0.0195-0.0413	0.0134-0.0284	0.0186-0.0394	0.0148-0.0313
	UN-873/UN-857 (E_{ysame})	0.0406-0.0859	0.0502 0.1063	0.0468-0.0991	0.0420-0.0889	0.0507-0.1074	0.0395-0.0836
	UN-866/UN-857 (E^{**}_{ysame})	0.0000-0.0000	0.0020-0.0043	0.0020-0.0041	0.0050-0.0107	0.0068-0.0143	0.0066-0.0139
Opposite direction lateral occupancy	**UN-741/UN-866 ($E^{*}_{yopposite}$)**	0.0015-0.0031	0.0000-0.0000	0.0020-0.0041	0.0034-0.0071	0.0017-0.0036	0.0033-0.0070
	UN-866/UN-873 ($E_{yopposite}$)	0.0015-0.0031	0.0040-0.0085	0.0059-0.0124	0.0067-0.0142	0.0068-0.0143	0.0033-0.0070
	UN-866/UN-857 ($E^{**}_{yopposite}$)	0.0000-0.0000	0.0000-0.0000	0.0000-0.0000	0.0000-0.0000	0.0017-0.0036	0.0000-0.0000

Table 9.
Lateral occupancy estimate until 2025 with an annual traffic growth rate of 57%, 19%, 10% and 3%

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 2025 in the different locations are the ones shown in the following table and figures.

Lateral collision risk	57%, 19%, 10% and 3% annual traffic growth until 2025					
	Canaries	**SAL1**	**SAL2**	**Dakar1**	**Dakar2**	**Recife**
2021	$1.3514*10^{-9}$	$2.0462*10^{-9}$	$3.2452*10^{-9}$	$2.6516*10^{-9}$	$3.2194*10^{-9}$	$2.4476*10^{-9}$
2022	$2.1218*10^{-9}$	$3.2125*10^{-9}$	$5.0949*10^{-9}$	$4.1631*10^{-9}$	$5.0544*10^{-9}$	$3.8427*10^{-9}$
2023	$2.5249*10^{-9}$	$3.8228*10^{-9}$	$6.0630*10^{-9}$	$4.9541*10^{-9}$	$6.0148*10^{-9}$	$4.5728*10^{-9}$
2024	$2.7774*10^{-9}$	$4.2051*10^{-9}$	$6.6693*10^{-9}$	$5.4495*10^{-9}$	$6.6163*10^{-9}$	$5.0301*10^{-9}$
2025	$2.8607*10^{-9}$	$4.3313*10^{-9}$	$6.8693*10^{-9}$	$5.6130*10^{-9}$	$6.8148*10^{-9}$	$5.1810*10^{-9}$

Table 10.
Lateral collision risk for the period 2021-2025 in the Corridor

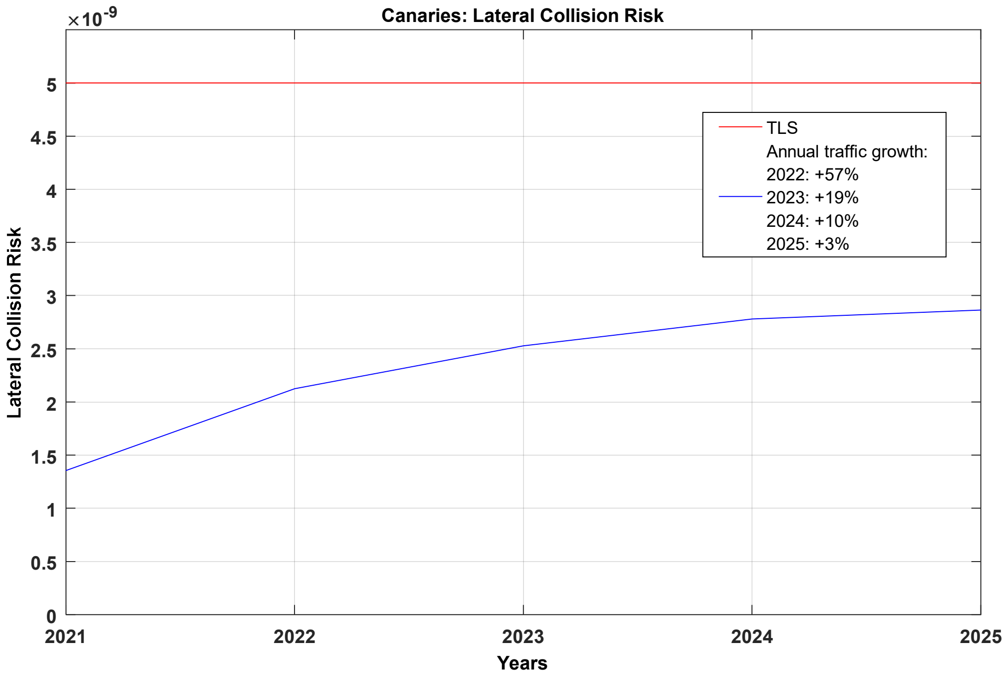


Figure 11.
Lateral collision risk for the period 2021-2025 in the Canaries

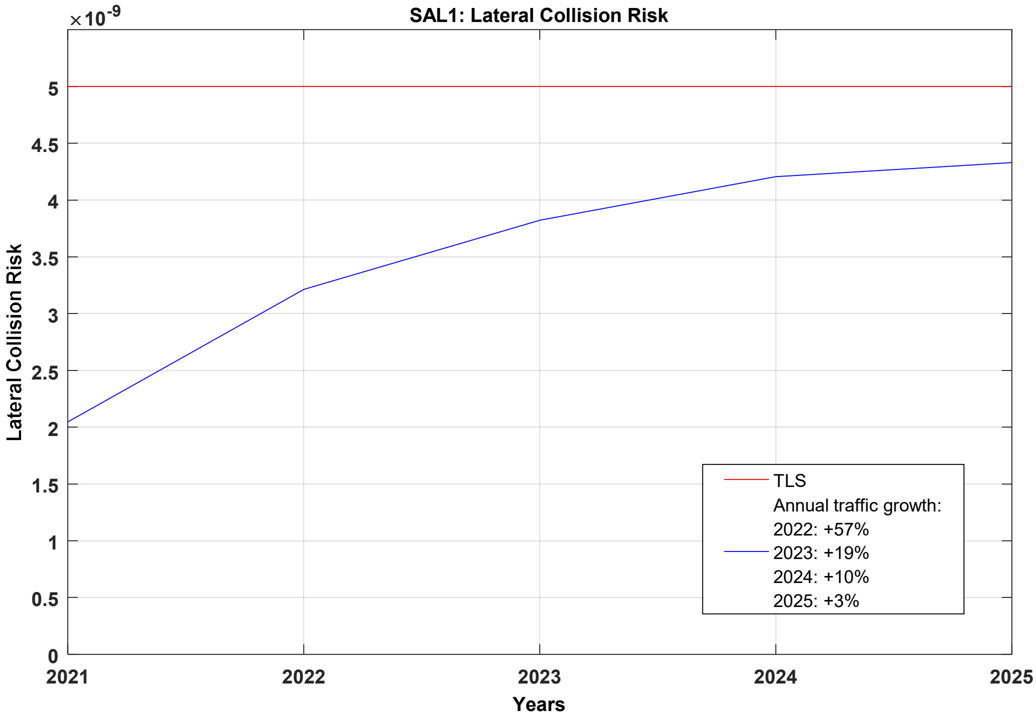


Figure 12.
Lateral collision risk for the period 2021-2025 in SAL1

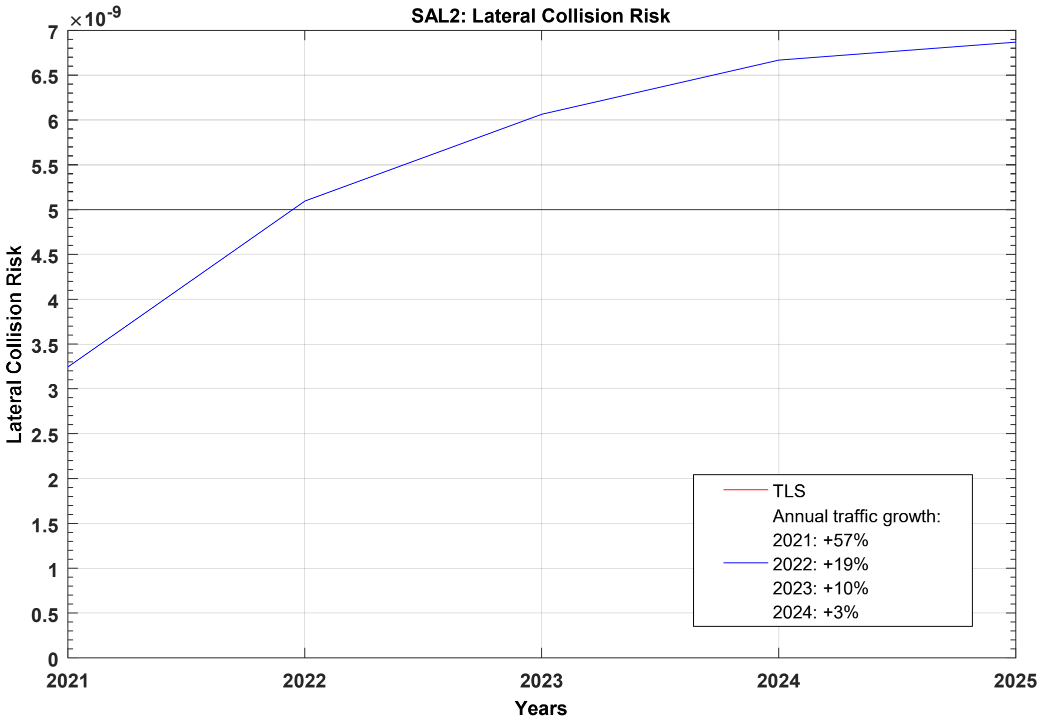


Figure 13.
Lateral collision risk for the period 2021-2025 in SAL2

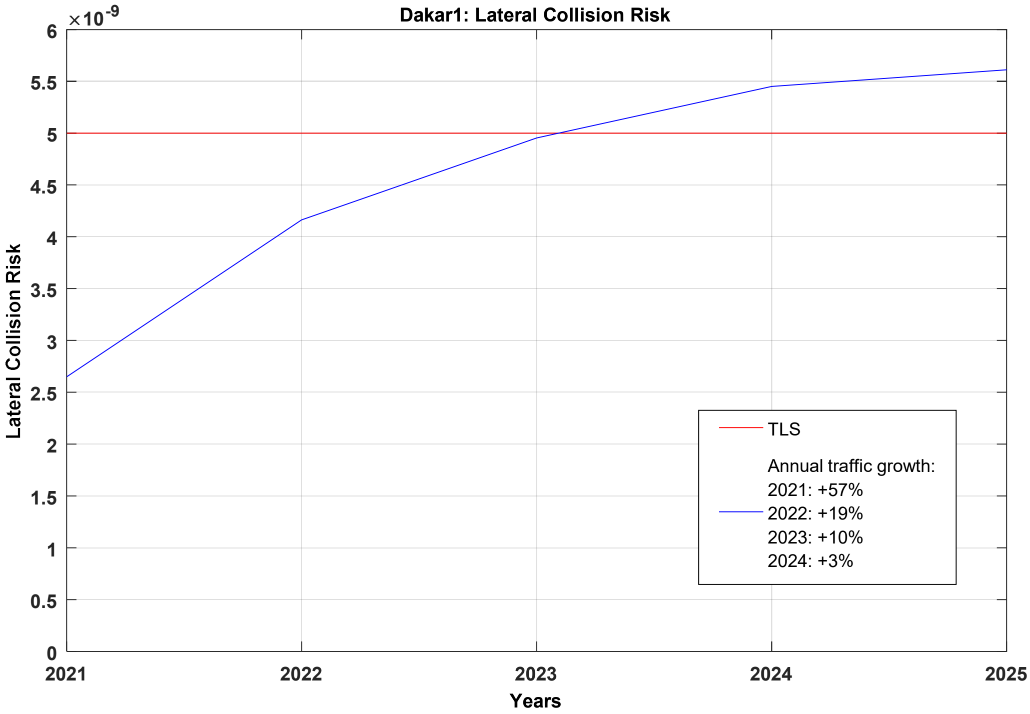


Figure 14.
Lateral collision risk for the period 2021-2025 in Dakar1

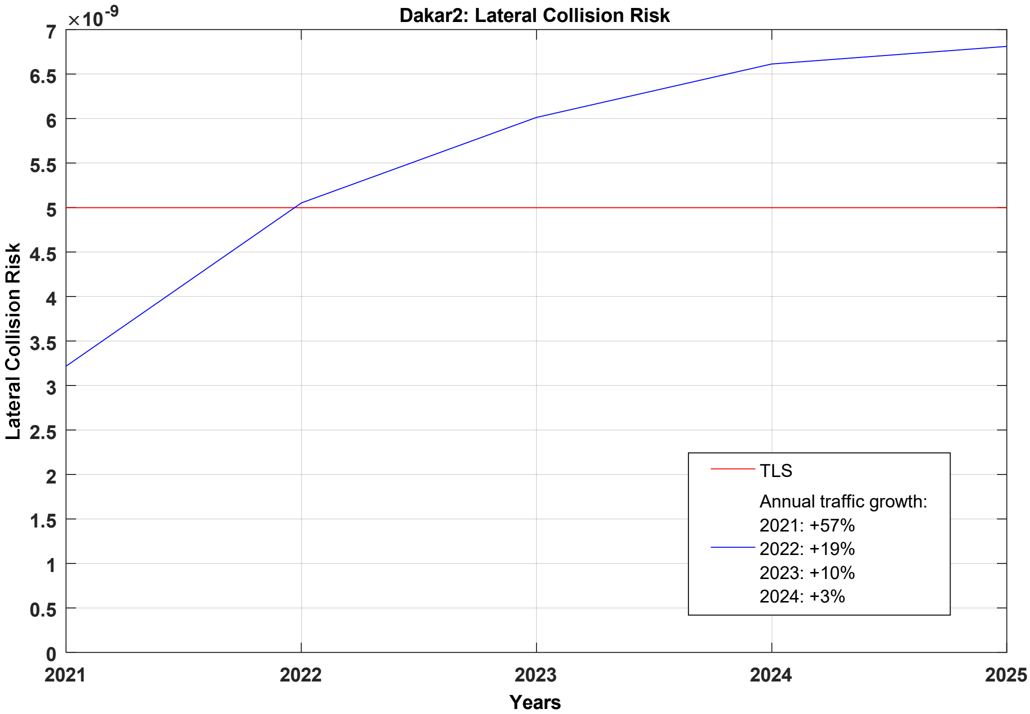


Figure 15.
Lateral collision risk for the period 2021-2025 in Dakar2

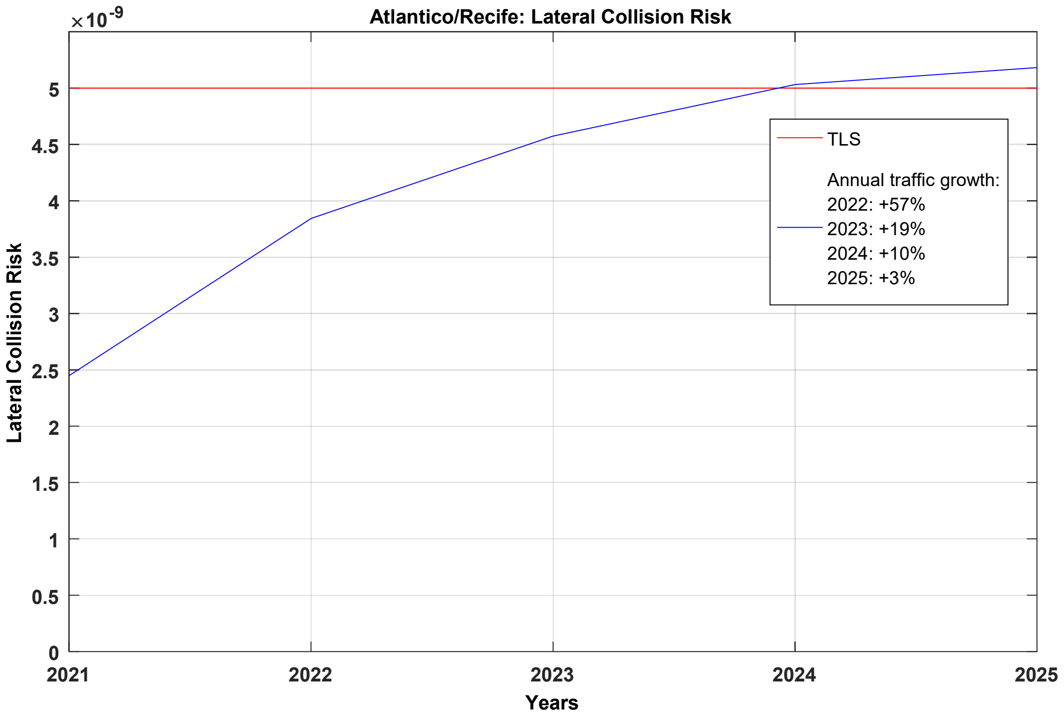


Figure 16.
Lateral collision risk for the period 2021-2025 in Recife

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 57%, 19%, 10% and 3% in 2022, 2023, 2024 and 2025 respectively, the TLS would be exceeded in the period under consideration in all analysed locations except Canaries and SAL1.

The values obtained for the lateral collision risk are similar to those ones presented in the previous collision risk assessments, [Ref. 5] to [Ref. 12]. It has also been confirmed that the results are slightly higher 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. 37]. 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	184.48	174.84	50.36	184.48
SAL1	207.15	197.92	55.12	207.15
SAL2	201.51	193.53	54.14	201.51
Dakar1	201.55	192.57	53.89	201.55
Dakar2	201.53	192.52	53.88	201.53
Recife	203.66	194.08	54.46	203.66

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. 37], 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. 37]. 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. 18]). This probability has only been calculated whenever proximate events have been detected, as it will be seen in 4.1.6.

The obtained results are shown in Table 12 and Table 13.

Horizontal overlap probability				
Location	**Diameter (λ_h)**	**Route (Point)**	**Angles (º)**	**$P_h(\theta)$**
Canaries	0.0304 NM	NORED-ETIBA (NORED)	103-77	4.6761*10^{-7}
SAL1	0.0341 NM	UR-976/UA-602 (GAMBA)	95-85	5.7570*10^{-7}
		ULTEM-LUMPO (IRENE)	91-89	5.7343*10^{-7}
		BAMUX-SEPOM (BS001)	102-78	5.8715*10^{-7}
		BAMUX-ILGAS (BI001)	95-85	5.757*10^{-7}
		OBOMO-ILGAS (BS001)	92-88	5.7372*10^{-7}
		ULTEM-ILGAS (RL001)	108-72	6.0514*10^{-7}
		RUKAV-ILGAS (OL001)	102-78	5.8715*10^{-7}
		OBOMO-MOGSA (OL001)	111-69	6.1729*10^{-7}
		CVS-BS004 (CVS)	150-30	1.2572*10^{-6}
		CARME-PISPU (PISPU)	145-35	1.0256*10^{-6}
		CVS-UGAMA (CVS)	101-79	5.8491*10^{-7}
		CVS-UGAMA (UGAMA)	101-79	5.7942*10^{-7}
SAL2	0.0332 NM	XIBOT-MOGSA (DAVID)	108-72	5.7263*10^{-7}
		TEGTO-SONVA (MARIA)	101-79	5.5156*10^{-7}
		BULBO-ORABI (BULBO)	157-23	1.3232*10^{-6}
		BULBO-ORABI (ORABI)	157-23	1.4322*10^{-6}
		CARME-PISPU (PISPU)	144-36	9.4650*10^{-7}
		MARIA-IREDO (IREDO)	105-75	5.6926*10^{-7}

Table 12.
Horizontal overlap probabilities in Canaries and SAL

Horizontal overlap probability				
Location	**Diameter (λ_h)**	**Route (Point)**	**Angles (º)**	$P_h(\theta)$
Dakar1	0.0332 NM	UL-435 (DIGUN)	98-82	$5.4851*10^{-7}$
		ENUGO-APIGU (ENUGO)	96-84	$5.4599*10^{-7}$
		XUVIT-DIGUN (DIGUN)	158-22	$1.4949*10^{-6}$
		LIRAX-IRAVU (LIRAX)	154-26	$1.2757*10^{-6}$
		SAGRO-BUXON (SAGRO)	124-56	$6.6298*10^{-7}$
		SAGRO-BUXON (BUXON)	124-56	$6.5495*10^{-7}$
		SAGRO-MOSOK (MOSOK)	137-43	$8.1274*10^{-7}$
		XUVIT-SAGRO (SAGRO)	153-27	$1.2313*10^{-6}$
Dakar2	0.0332 NM	DIGUN-ENOTO (DIGUN)	140-40	$8.6371*10^{-7}$
		IP007-NANIK (NANIK)	160-20	$1.6380*10^{-6}$
		IP008-NANIK (NANIK)	169-11	$2.9382*10^{-6}$
		IRAVU-MESAB (MESAB)	153-27	$1.2310*10^{-6}$
		DIGUN-MOVGA (DIGUN)	146-34	$9.9616*10^{-7}$
Recife	0.0335 NM	UL-695 (DIKEB)	97-83	$5.587*10^{-7}$
		ERETU-PUGSA (ERETU)	165-15	$2.2127*10^{-6}$

Table 13.
Horizontal overlap probabilities in Dakar and Recife

4.1.4. Relative velocities

Equation 27 in [Ref. 37] contains four relative speed parameters, $2|\bar{v}|$, $|\Delta\bar{v}|$, $|\bar{\dot{y}}|$ and $|\bar{\dot{z}}|$ 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	14.5648	16.5305	15.5477
SAL1	12.1627	33.9267	23.0447
SAL2	0	27.2948	27.2948
Dakar1	0	15.3526	15.3526
Dakar2	34.8383	17.9534	26.3958
Recife	10.1908	23.2961	16.7435

Table 14.
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. 27]. This value has been taken here too.

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

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

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

Equation 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 15. 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)
Canaries	NORED-ETIBA (NORED)	476.06	476.87	77	593.22
				103	745.78
SAL1	UR-976/UA-602 (GAMBA)	468.46	482.51	85	642.55
				95	701.19
	ULTEM-LUMPO (IRENE)	468.46	475.35	89	661.54
				91	673.19
	BAMUX-SEPOM (BS001)	468.46	465.98	78	588.07
				102	726.20
	BAMUX-ILGAS (BI001)	468.46	466.43	85	631.61
				95	689.28
	OBOMO-ILGAS (BS001)	468.46	476.66	88	656.57
				92	679.89
	ULTEM-ILGAS (RL001)	468.46	464.05	72	548.13
				108	754.42
	RUKAV-ILGAS (OL001)	468.46	475.83	78	594.29
				102	733.87
	OBOMO-MOGSA (OL001)	468.46	478.12	69	536.21
				111	780.12
	CVS-BS004 (CVS)	468.46	497.40	30	235.35
				150	937.20
	CARME-PISPU (PISPU)	468.46	461.37	35	279.69
				145	886.80
	CVS-UGAMA (CVS)	468.46	472.03	79	598.24
				101	725.72
	CVS-UGAMA (UGAMA)	468.46	472.03	79	598.24
				101	725.72
SAL2	XIBOT-MOGSA (DAVID)	466.36	459.63	72	544.31
				108	753.87
	TEGTO-SONVA (MARIA)	466.36	397.74	79	577.92
				101	668.19
	BULBO-ORABI (BULBO)	466.36	496.02	23	194.06
				157	943.08
	BULBO-ORABI (ORABI)	466.36	496.02	23	194.06
				157	943.08
	CARME-PISPU (PISPU)	466.36	461.37	34	286.72
				144	882.32
	MARIA-IREDO (IREDO)	466.36	455.37	75	548.34
				105	740.97

Table 15.
Relative speeds in crossings (Canaries and SAL)

Location	Crossing route	V_1 (kts)	V_2 (kts)	θ (º)	$V_{rel}(\theta)$ (kts)
Dakar1	UL-435 (DIGUN)	485.11	487.61	82	638.17
				98	734.12
	ENUGO-APIGU (ENUGO)	485.11	480.78	84	646.31
				96	717.80
	XUVIT-DIGUN (DIGUN)	485.11	493.52	22	186.92
				158	960.66
	LIRAX-IRAVU (LIRAX)	485.11	473.57	26	215.95
				154	934.12
	SAGRO-BUXON (SAGRO)	485.11	475.22	56	450.93
				124	847.93
	SAGRO-BUXON (BUXON)	485.11	475.22	56	450.93
				124	847.93
	SAGRO-MOSOK (MOSOK)	485.11	478.50	43	353.22
				137	896.56
	XUVIT-SAGRO (SAGRO)	485.11	455.08	27	221.42
				153	914.24
Dakar2	DIGUN-ENOTO (DIGUN)	476.37	486.41	40	329.43
				140	904.73
	IP007-NANIK (NANIK)	476.37	494.48	20	169.53
				160	956.11
	IP008-NANIK (NANIK)	476.37	464.67	11	94.24
				169	964.41
	IRAVU-MESAB (MESAB)	476.37	458.31	27	218.90
				153	908.87
	DIGUN-MOVGA (DIGUN)	476.37	426.05	34	268.20
				146	863.12
Recife	UL-695 (DIKEB)	464.58	479.26	83	625.51
				97	706.96
	ERETU-PUGSA (ERETU)	464.58	494.70	15	128.72
				165	951.08

Table 16.
Relative speeds in crossings (Dakar and Recife)

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

With 2021 traffic and height-keeping performances information, the probability of vertical overlap has been calculated by means of Equation 43 in [Ref. 37], using the Eurocontrol RVSM Tool, being the resulting values $P_z(1000) = 1.40906 \cdot 10^{-13}$ and $P_z(0) = 0.52193$.

4.1.6. Vertical occupancy

As it is explained in [Ref. 37], 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 2025, with the annual traffic growth rate of 57%, 19%, 10% and 3% in 2022, 2023, 2024 and 2025 respectively.

4.1.6.a. Canaries

Table 17 shows some results on same and opposite vertical occupancy in Canaries location, based on traffic levels representative of 2021.

Vertical occupancy	August 2021
Number of flights on UN-741	120
Number of flights on UN-866	213
Number of flights on UN-873	863
Number of flights on UN-857	183
Total number of flights on main airways	1379
Number of same direction vertical proximate pairs for tracks UN-741	8
Number of same direction vertical proximate pairs for tracks UN-866	8
Number of opposite direction vertical proximate pairs for tracks UN-873	42
Number of opposite direction vertical proximate pairs for tracks UN-857	0
Total number of same direction proximate events	16
Total number of opposite direction proximate events	42
Same direction vertical occupancy (S_x=80NM)	0.0232
Opposite direction vertical occupancy (S_x=80NM)	0.0609

Table 17.
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 2021
Number of flights on crossing flight NORED-ETIBA	6
Total number of flights on main routes (UN-741, UN-866, UN-873 and UN-857)	1379
Total number of flights	1385

Table 18.
Number of flights in Canaries airspace

The total number of flights is 1385.

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. 22], 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. 37]. 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 2021 to 2025 with an annual traffic growth rate of 57%, 19%, 10% and 3% in 2022, 2023, 2024 and 2025 respectively are shown in Table 19.

57%, 19%, 10% and 3% annual traffic growth until 2025	2021	2022	2023	2024	2025
Same direction vertical occupancy	0.0232	0.0364	0.0434	0.0477	0.0491
Opposite direction vertical occupancy	0.0609	0.0956	0.1138	0.1252	0.1289

Table 19.
Vertical occupancy estimate for the Canaries until 2025

4.1.6.b. SAL1

Table 20 collects some results on same and opposite vertical occupancy in SAL1, obtained with data from August 2021.

Number of flights	August 2021
Number of flights on UN-741	115
Number of flights on UN-866	181
Number of flights on UN-873	527
Number of flights on UN-857	173
Total number of flights on main airways	996
Number of same direction vertical proximate pairs for tracks UN-741	6
Number of same direction vertical proximate pairs for tracks UN-866	8
Number of opposite direction vertical proximate pairs for tracks UN-873	13
Number of opposite direction vertical proximate pairs for tracks UN-857	3
Total number of same direction proximate events	14
Total number of opposite direction proximate events	16
Same direction vertical occupancy (S_x=80NM)	0.0281
Opposite direction vertical occupancy (S_x=80NM)	0.0321

Table 20.
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 2021
Number of flights on UR-976/UA-602	106
Number of flights on ULTEM-LUMPO	40
Number of flights on BAMUX-LUMPO	1
Number of flights on BAMUX-SEPOM	13
Number of flights on BAMUX-ILGAS	118
Number of flights on OBOMO-ILGAS	34
Number of flights on ULTEM-ILGAS	16
Number of flights on RUKAV-ILGAS	135
Number of flights on OBOMO-MOGSA	40
Number of flights on CVS-BS004	5
Number of flights on CVS-BL002	2
Number of flights on CARME-PISPU	19
Number of flights on IRENE-KESIK	12
Number of flights on CVS-BL004	1
Number of flights on CVS-UGAMA	85
Number of flights on BI003-BS004	2
Number of flights on main routes (UN-741, UN-866, UN-873 and UN-857)	996
Total number of flights	1536

Table 21.
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 1536.

The time windows to obtain proximate pairs and the number of proximate events are, in this case, the ones shown in Table 22. 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	---	468.46	482.51	85	14	0	4
				95	15	15	4
ULTEM-LUMPO	---	468.46	475.35	89	15	1	4
				91	15	0	1
BAMUX-SEPOM	---	468.46	465.98	78	14	0	1
				102	17	1	1
BAMUX-ILGAS	---	468.46	466.43	85	14	1	1
				95	16	7	21
OBOMO-ILGAS	---	468.46	476.66	88	14	0	3
				92	15	2	7
ULTEM-ILGAS	---	468.46	464.05	72	13	4	4
				108	18	1	0
RUKAV-ILGAS	---	468.46	475.83	78	13	6	9
				102	16	1	8
OBOMO-MOGSA	---	468.46	478.12	69	13	0	1
				111	18	1	2
CVS-BS004	CVS	470.79	497.40	30	11	0	0
				150	41	0	1
CARME-PISPU	PISPU	470.79	461.37	35	11	0	14
				145	35	0	0
CVS-UGAMA	CVS	470.79	472.03	79	14	5	1
				101	16	0	4
CVS-UGAMA	UGAMA	469.63	472.03	79	14	4	0
				101	16	0	0

Table 22.
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. Some 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 2021 to 2025 with an annual traffic growth rate of 57%, 19%, 10% and 3% in 2022, 2023, 2024 and 2025 respectively are shown in Table 23. Only crossings different from zero have been shown.

57%, 19%, 10% and 3% annual traffic growth until 2025				**2021**	**2022**	**2023**	**2024**	**2025**
Same direction vertical occupancy				0.0281	0.0441	0.0525	0.0578	0.0595
Opposite direction vertical occupancy				0.0321	0.0504	0.0600	0.0660	0.0680
Crossing occupancy	UR-976/UA-602	---	95º	0.0143	0.0225	0.0268	0.0294	0.0303
			85º	0.0052	0.0082	0.0097	0.0107	0.0110
	ULTEM-LUMPO	---	91º	0.0013	0.0020	0.0024	0.0027	0.0028
			89º	0.0052	0.0082	0.0097	0.0107	0.0110
	BAMUX-SEPOM	---	102º	0.0013	0.0020	0.0024	0.0027	0.0028
			78º	0.0013	0.0020	0.0024	0.0027	0.0028
	BAMUX-ILGAS	---	95º	0.0286	0.0450	0.0535	0.0589	0.0606
			85º	0.0013	0.0020	0.0024	0.0027	0.0028
	OBOMO-ILGAS	---	92º	0.0091	0.0143	0.0170	0.0187	0.0193
			88º	0.0039	0.0061	0.0073	0.0080	0.0083
	ULTEM-ILGAS	---	108º	0.0000	0.0000	0.0000	0.0000	0.0000
			72º	0.0065	0.0102	0.0122	0.0134	0.0138
	RUKAV-ILGAS	---	102º	0.0104	0.0164	0.0195	0.0214	0.0221
			78º	0.0130	0.0204	0.0243	0.0268	0.0276
	OBOMO-MOGSA	---	111º	0.0026	0.0041	0.0049	0.0054	0.0055
			69º	0.0013	0.0020	0.0024	0.0027	0.0028
	CVS-BS004	CVS	150º	0.0013	0.0020	0.0024	0.0027	0.0028
			30º	0.0000	0.0000	0.0000	0.0000	0.0000
	CARME-PISPU	PISPU	145º	0.0000	0.0000	0.0000	0.0000	0.0000
			35º	0.0182	0.0287	0.0341	0.0375	0.0386
	CVS-UGAMA	CVS	101º	0.0052	0.0082	0.0097	0.0107	0.0110
			16º	0.0026	0.0041	0.0049	0.0054	0.0055
	CVS-UGAMA	UGAMA	101º	0.0000	0.0000	0.0000	0.0000	0.0000
			79º	0.0026	0.0041	0.0049	0.0054	0.0055

Table 23.
Vertical occupancy estimate for SAL1 until 2025

4.1.6.c. SAL2

Table 24 collects some results on same and opposite vertical occupancy in SAL2, obtained with data from the August 2021.

Number of flights	August 2021
Number of flights on UN-741	69
Number of flights on UN-866	201
Number of flights on UN-873	586
Number of flights on UN-857	169
Total number of flights on main airways	1025
Number of same direction vertical proximate pairs for tracks UN-741	0
Number of same direction vertical proximate pairs for tracks UN-866	8
Number of opposite direction vertical proximate pairs for tracks UN-873	23
Number of opposite direction vertical proximate pairs for tracks UN-857	1
Total number of same direction proximate events	8
Total number of opposite direction proximate events	24
Same direction vertical occupancy (S_x=80NM)	0.0156
Opposite direction vertical occupancy (S_x=80NM)	0.0468

Table 24.
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 2021
Number of flights on XIBOT-MOGSA	11
Number of flights on TEGTO-SONVA	11
Number of flights on BULVO-ORABI	4
Number of flights on BOTNO-SNT	2
Number of flights on SVT-KENOX	1
Number of flights on BULBO-ORABI	4
Number of flights on CARME-KENOX	3
Number of flights on CARME-PISPU	19
Number of flights on BAMUX-KENOX	4
Number of flights on MARIA-IREDO	31
Number of flights on EXTER-CARME	1
Number of flights on CVS-CARME	2
Number of flights on main routes (UN-741, UN-866, UN-873 and UN-857)	1025
Total number of flights	1095

Table 25.
Number of flights in SAL2 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 in this case is 1095.

The time windows to obtain proximate pairs and the number of proximate events are, in this case, the ones shown in Table 26. 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**
XIBOT-MOGSA	---	466.36	459.63	108	18	0	2
				72	13	4	0
TEGTO-SONVA	---	466.36	397.74	101	18	4	0
				79	15	1	1
BULBO-ORABI	BULBO	465.27	496.02	157	50	0	6
				23	11	1	0
BULBO-ORABI	ORABI	466.98	496.02	157	46	0	1
				23	11	1	0
CARME-PISPU	CARME	472.82	461.37	144	34	0	1
				34	11	0	0
MARIA-IREDO	MARIA	455.21	455.37	105	18	0	0
				75	14	0	6

Table 26.
Time windows for crossing occupancies and number of proximate events in SAL2

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 2022 to 2025 with an annual traffic growth rate of 57%, 19%, 10% and 3% in 2022, 2023, 2024 and 2025 respectively are shown in Table 27. Only data for crossing trajectories in which proximate events have been detected are included.

57%, 19%, 10% and 3% annual traffic growth until 2025				2021	2022	2023	2024	2025
Same direction vertical occupancy				0.0156	0.0245	0.0292	0.0321	0.0330
Opposite direction vertical occupancy				0.0468	0.0735	0.0875	0.0962	0.0991
Crossing occupancy	XIBOT-MOGSA	---	108º	0.0037	0.0057	0.0068	0.0075	0.0077
			72º	0.0037	0.0057	0.0068	0.0075	0.0077
	TEGTO-SONVA	---	101º	0.0055	0.0086	0.0102	0.0113	0.0116
			79º	0.0018	0.0029	0.0034	0.0038	0.0039
	BULBO-ORABI	BULBO	157º	0.0110	0.0172	0.0205	0.0225	0.0232
			23º	0.0018	0.0029	0.0034	0.0038	0.0039
	BULBO-ORABI	ORABI	157º	0.0018	0.0029	0.0034	0.0038	0.0039
			23º	0.0018	0.0029	0.0034	0.0038	0.0039
	CARME-PISPU	CARME	144º	0.0018	0.0029	0.0034	0.0038	0.0039
			34º	0.0000	0.0000	0.0000	0.0000	0.0000
	MARIA-IREDO	MARIA	105º	0.0000	0.0000	0.0000	0.0000	0.0000
			75º	0.0110	0.0172	0.0205	0.0225	0.0232

Table 27.
Vertical occupancy estimated for SAL2 until 2025

4.1.6.d. Dakar1

Table 28 collects some results on same and opposite vertical occupancy in Dakar1, obtained with data from August 2021.

Number of flights	August 2021
Number of flights on UN-741	134
Number of flights on UN-866	224
Number of flights on UN-873	635
Number of flights on UN-857	198
Total number of flights on main airways	1191
Number of same direction vertical proximate pairs for tracks UN-741	0
Number of same direction vertical proximate pairs for tracks UN-866	11
Number of opposite direction vertical proximate pairs for tracks UN-873	18
Number of opposite direction vertical proximate pairs for tracks UN-857	1
Total number of same direction proximate events	11
Total number of opposite direction proximate events	19
Same direction vertical occupancy (S_x=80NM)	0.0185
Opposite direction vertical occupancy (S_x=80NM)	0.0319

Table 28.
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 2021
Number of flights on UL-435	16
Number of flights on ENUGO-APIGU	16
Number of flights on APOXA-GONSA	9
Number of flights on SAGRO-LIRAX	3
Number of flights on GARKO-LIRAX	4
Number of flights on XUVIT-DIGUN	26
Number of flights on TARIM-DIGUN	24
Number of flights on LIRAX-IRAVU	3
Number of flights on SAGRO-BUXON	14
Number of flights on TARIM-GARKO	9
Number of flights on TARIM-SAGRO	1
Number of flights on SAGRO-MOSOK	19
Number of flights on KENOX-OPADO	2
Number of flights on XUVIT-SAGRO	1
Number of flights on ENUGO-IP007	1
Number of flights on main routes (UN-741, UN-866, UN-873 and UN-857)	1191
Total number of flights	1274

Table 29.
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. Therefore, the total number of flights in this case is 1274.

The time windows to obtain proximate pairs and the number of proximate events are, in this case, the ones shown in Table 30. 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	---	485.11	487.61	98	15	2	0
				82	13	0	1
ENUGO-APIGU	---	485.11	480.78	96	15	2	3
				84	14	3	0
XUVIT-DIGUN	DIGUN	477.33	493.52	158	51	0	1
				22	10	0	0
LIRAX-IRAVU	LIRAX	474.96	473.57	154	46	0	0
				26	11	0	2
SAGRO-BUXON	SAGRO	477.33	475.22	124	21	0	0
				56	11	0	1
SAGRO-BUXON	BUXON	471.15	475.22	124	22	0	0
				56	12	0	4
SAGRO-MOSOK	MOSOK	471.15	478.50	137	28	0	0
				43	11	1	0
XUVIT-SAGRO	SAGRO	477.33	455.08	153	44	0	0
				27	11	0	1

Table 30.
Time windows for crossing occupancies and number of proximate events in Dakar1

Here again, as it happened in the locations previously analyzed, there are proximate events involving aircraft at the same flight level. Some of these events at the same level involve aircraft within 15 minutes or less 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 2021 to 2025 with an annual traffic growth rate of 57%, 19%, 10% and 3% in 2022, 2023, 2024 and 2025 respectively are shown in Table 31.

57%, 19%, 10% and 3% annual traffic growth until 2025				2021	2022	2023	2024	2025
Same direction vertical occupancy				0.0185	0.0290	0.0345	0.0380	0.0391
Opposite direction vertical occupancy				0.0319	0.0501	0.0596	0.0656	0.0675
Crossing occupancy	UL-435	---	98º	0.0016	0.0025	0.0029	0.0032	0.0033
			82º	0.0016	0.0025	0.0029	0.0032	0.0033
	ENUGO-APIGU	---	96º	0.0063	0.0099	0.0117	0.0129	0.0133
			84º	0.0016	0.0025	0.0029	0.0032	0.0033
	XUVIT-DIGUN	DIGUN	158º	0.0016	0.0025	0.0029	0.0032	0.0033
			22º	0.0000	0.0000	0.0000	0.0000	0.0000
	LIRAX-IRAVU	LIRAX	154º	0.0000	0.0000	0.0000	0.0000	0.0000
			26º	0.0031	0.0049	0.0059	0.0065	0.0066
	SAGRO-BUXON	SAGRO	124º	0.0000	0.0000	0.0000	0.0000	0.0000
			56º	0.0016	0.0025	0.0029	0.0032	0.0033
	SAGRO-BUXON	BUXON	124º	0.0000	0.0000	0.0000	0.0000	0.0000
			56º	0.0063	0.0099	0.0117	0.0129	0.0133
	SAGRO-MOSOK	MOSOK	137º	0.0000	0.0000	0.0000	0.0000	0.0000
			43º	0.0016	0.0025	0.0029	0.0032	0.0033
	XUVIT-SAGRO	SAGRO	153º	0.0000	0.0000	0.0000	0.0000	0.0000
			27º	0.0016	0.0025	0.0029	0.0032	0.0033

Table 31.
Vertical occupancy estimated for Dakar1 until 2025

4.1.6.e. Dakar2

Table 32 collects some results on same and opposite vertical occupancy in Dakar2, obtained with data from August 2021.

Number of flights	August 2021
Number of flights on UN-741	123
Number of flights on UN-866	225
Number of flights on UN-873	638
Number of flights on UN-857	197
Total number of flights on main airways	1183
Number of same direction vertical proximate pairs for tracks UN-741	0
Number of same direction vertical proximate pairs for tracks UN-866	10
Number of opposite direction vertical proximate pairs for tracks UN-873	24
Number of opposite direction vertical proximate pairs for tracks UN-857	4
Total number of same direction proximate events	10
Total number of opposite direction proximate events	28
Same direction vertical occupancy (S_x=80NM)	0.0186
Opposite direction vertical occupancy (S_x=80NM)	0.0473

Table 32.
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 2021
Number of flights on DIGUN-ENOTO	1
Number of flights on IP007-NANIK	21
Number of flights on IP008-NANIK	40
Number of flights on IP008-MOSAD	2
Number of flights on IRAVU-MESAB	3
Number of flights on DIGUN-MOVGA	11
Number of flights on main routes (UN-741, UN-866, UN-873 and UN-857)	1183
Total number of flights	1255

Table 33.
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 those that fly on DCT area. Therefore, the total number of aircraft in this case is 1255.

The time windows to obtain proximate pairs and the number of proximate pairs are, in this case, the ones shown in Table 34. 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	480.30	486.41	140	29	0	1
				40	11	0	0
IP007-NANIK	NANIK	480.30	494.48	160	57	0	0
				20	10	1	0
IP008-NANIK	NANIK	480.30	492.50	169	107	0	0
				11	10	2	0
IRAVU-MESAB	MESAB	499.99	458.31	153	45	0	0
				27	11	1	0
DIGUN-MOVGA	DIGUN	480.30	426.05	146	37	0	0
				34	12	2	0

Table 34.
Time windows for crossing occupancies and number of proximate events in Dakar2

Here again, as it happened in the locations previously analysed, there are proximate events at the same flight level 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 2021 to 2025 with an annual traffic growth rate of 57%, 19%, 10% and 3% in 2022, 2023, 2024 and 2025 respectively are shown in Table 35.

57%, 19%, 10% and 3% annual traffic growth until 2025				**2021**	**2022**	**2023**	**2024**	**2025**
Same direction vertical occupancy				0.0186	0.0292	0.0347	0.0382	0.0394
Opposite direction vertical occupancy				0.0473	0.0743	0.0884	0.0973	0.1002
Crossing occupancy	DIGUN-ENOTO	DIGUN	140º	0.0016	0.0025	0.0030	0.0033	0.0034
			40º	0.0000	0.0000	0.0000	0.0000	0.0000
	IP007-NANIK	NANIK	160º	0.0000	0.0000	0.0000	0.0000	0.0000
			20º	0.0016	0.0025	0.0030	0.0033	0.0034
	IP008-NANIK	NANIK	169º	0.0000	0.0000	0.0000	0.0000	0.0000
			11º	0.0032	0.0050	0.0060	0.0066	0.0067
	IRAVU-MESAB	MESAB	153º	0.0000	0.0000	0.0000	0.0000	0.0000
			27º	0.0016	0.0025	0.0030	0.0033	0.0034
	DIGUN-MOVGA	DIGUN	146º	0.0000	0.0000	0.0000	0.0000	0.0000
			34º	0.0032	0.0050	0.0060	0.0066	0.0067

Table 35.
Vertical occupancy estimated for Dakar2 until 2025

4.1.6.f. Recife

Table 36 collects some results on same and opposite vertical occupancy in Recife, using data from August 2021.

Number of flights	August 2021
Number of flights on UN-741	193
Number of flights on UN-866	227
Number of flights on UN-873	635
Number of flights on UN-857	161
Total number of flights on main airways	1216
Number of same direction vertical proximate pairs for tracks UN-741	3
Number of same direction vertical proximate pairs for tracks UN-866	10
Number of opposite direction vertical proximate pairs for tracks UN-873	22
Number of opposite direction vertical proximate pairs for tracks UN-857	9
Total number of same direction proximate events	13
Total number of opposite direction proximate events	31
Same direction vertical occupancy (S_x=80NM)	0.0214
Opposite direction vertical occupancy (S_x=80NM)	0.0510

Table 36.
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 2021
Number of flights on UL-695/UL-375	19
Number of flights on ERETU-PUGSA	32
Number of flights on main routes (UN-741, UN-866, UN-873 and UN-857)	1216
Total number of flights	1267

Table 37.
Number of flights in Recife airspace.

All the flights on the crossing routes are not included in the number of flights on the main routes. Therefore, the total number of flights in this case is 1267.

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	---	464.58	497.26	97	16	0	0
				83	14	0	6
ERETU-PUGSA	ERETU	463.00	494.70	165	80	0	2
				15	11	0	0

Table 38.
Time windows for crossing occupancies and number of proximate events in Recife

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 2021 to 2025 with an annual traffic growth rate of 57%, 19%, 10% and 3% in 2022, 2023, 2024 and 2025 respectively are shown in Table 39.

57%, 19%, 10% and 3% annual traffic growth until 2025				**2021**	**2022**	**2023**	**2024**	**2025**
Same direction vertical occupancy				0.0214	0.0336	0.0399	0.0439	0.0453
Opposite direction vertical occupancy				0.0510	0.0800	0.0953	0.1048	0.1079
Crossing occupancy	UL-695	---	97	0.0000	0.0000	0.0000	0.0000	0.0000
			83	0.0095	0.0149	0.0177	0.0195	0.0200
	ERETU-PUGSA	ERETU	165	0.0000	0.0000	0.0000	0.0000	0.0000
			15	0.0032	0.0050	0.0059	0.0065	0.0067

Table 39.
Vertical occupancy estimated for Recife until 2025

4.1.7. Technical vertical collision risk

The technical vertical collision risk values obtained until 2025 in the different locations are the ones summarized in the following table, considering an annual traffic growth rate of 57%, 19%, 10% and 3% in 2022, 2023, 2024 and 2025 respectively. These results can also be seen in Figure 17 to Figure 28.

Technical Vertical Collision risk	**57%, 19%, 10% and 3% annual traffic growth until 2025**					
	Canaries	**SAL1**	**SAL2**	**Dakar1**	**Dakar2**	**Recife**
2021	$1.4153*10^{-14}$	$8.6874*10^{-15}$	$1.1904*10^{-14}$	$8.4062*10^{-15}$	$1.2185*10^{-14}$	$1.2871*10^{-14}$
2022	$2.2222*10^{-14}$	$1.3639*10^{-14}$	$1.8689*10^{-14}$	$1.3198*10^{-14}$	$1.9131*10^{-14}$	$2.0208*10^{-14}$
2023	$2.6442*10^{-14}$	$1.6231*10^{-14}$	$2.2239*10^{-14}$	$1.5705*10^{-14}$	$2.2765*10^{-14}$	$2.4047*10^{-14}$
2024	$2.9086*10^{-14}$	$1.7854*10^{-14}$	$2.4463*10^{-14}$	$1.7276*10^{-14}$	$2.5042*10^{-14}$	$2.6452*10^{-14}$
2025	$2.9959*10^{-14}$	$1.8389*10^{-14}$	$2.5197*10^{-14}$	$1.7794*10^{-14}$	$2.5793*10^{-14}$	$2.7246*10^{-14}$

Table 40.
Technical vertical collision risk for the period 2021-2025 in the Corridor

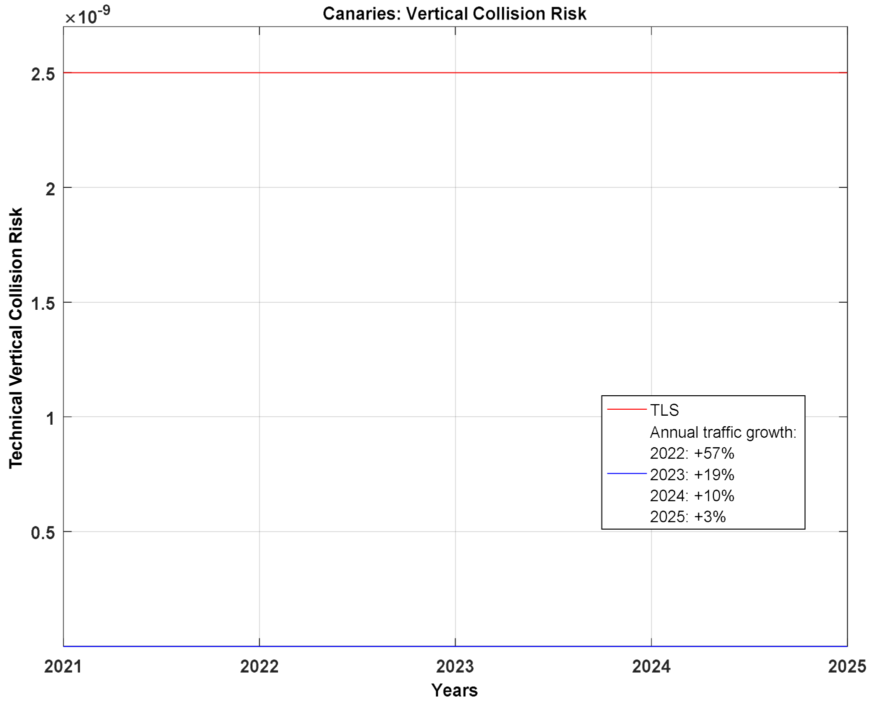


Figure 17.
Technical vertical collision risk for the period 2021-2025 in the Canaries

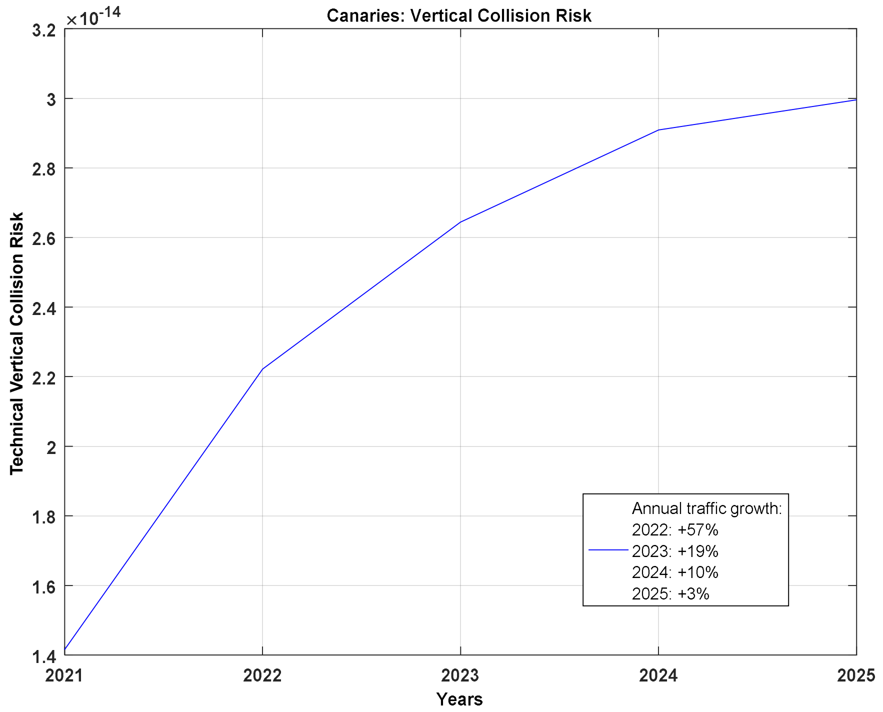


Figure 18.
Technical vertical collision risk for the period 2021-2025 in the Canaries (enlarged)

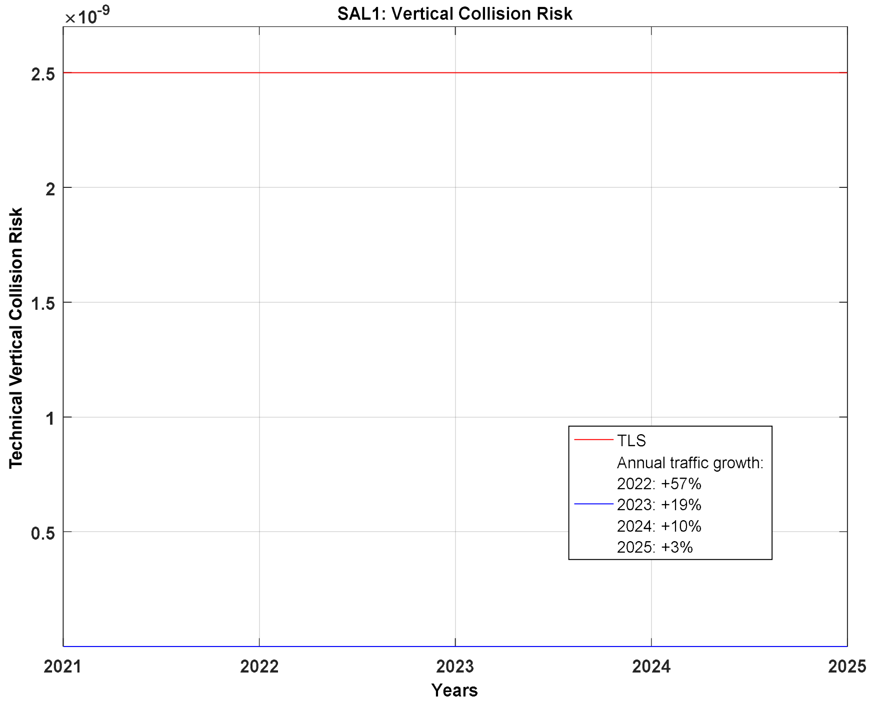


Figure 19.
Technical vertical collision risk for the period 2021-2025 in SAL1

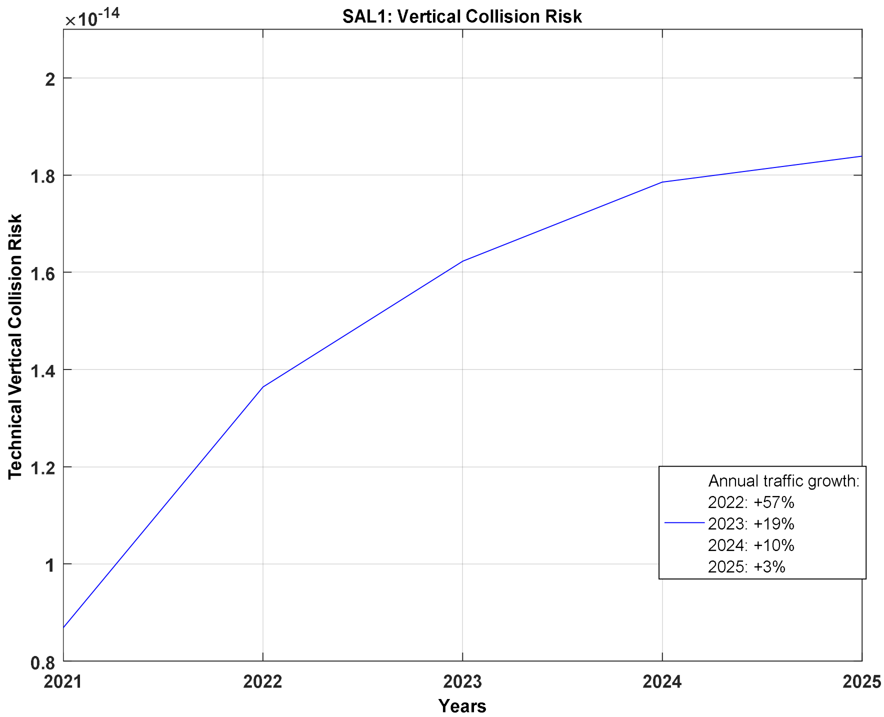


Figure 20.
Technical vertical collision risk for the period 2021-2025 in SAL1 (enlarged)

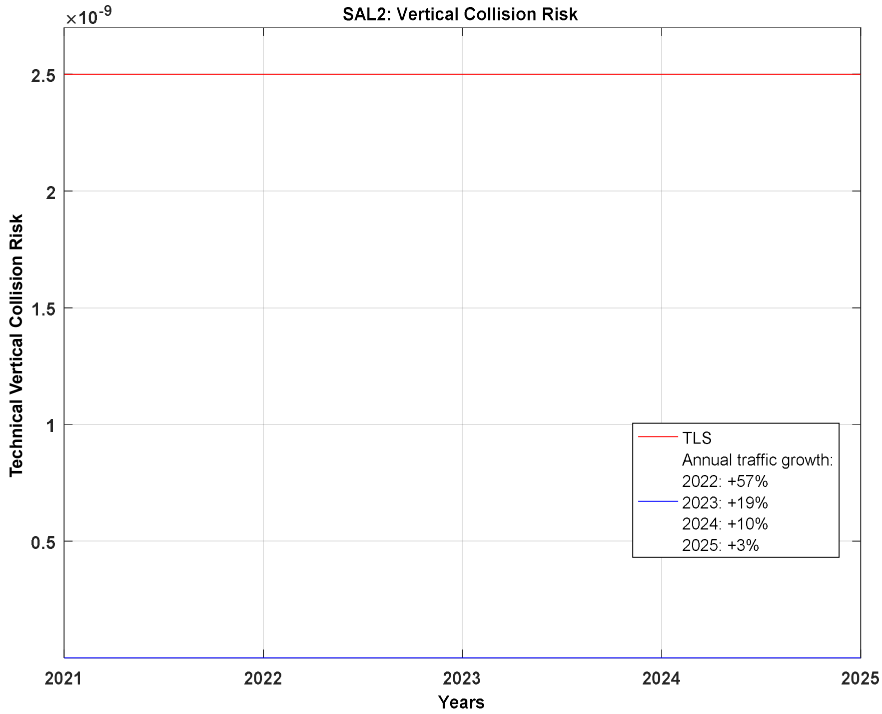


Figure 21.
Technical vertical collision risk for the period 2021-2025 in SAL2

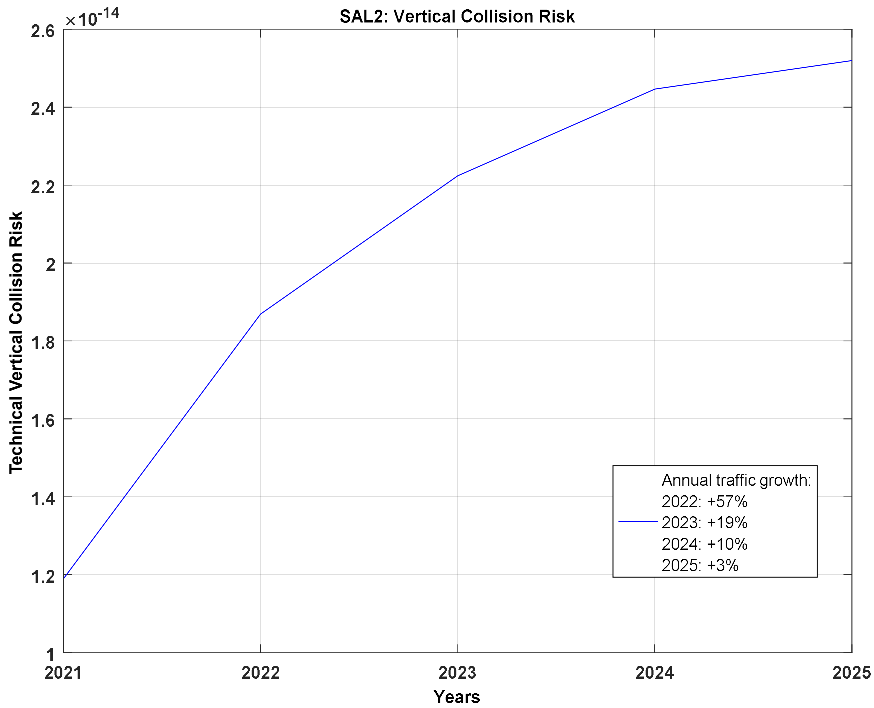


Figure 22.
Technical vertical collision risk for the period 2021-2025 in SAL2 (enlarged)

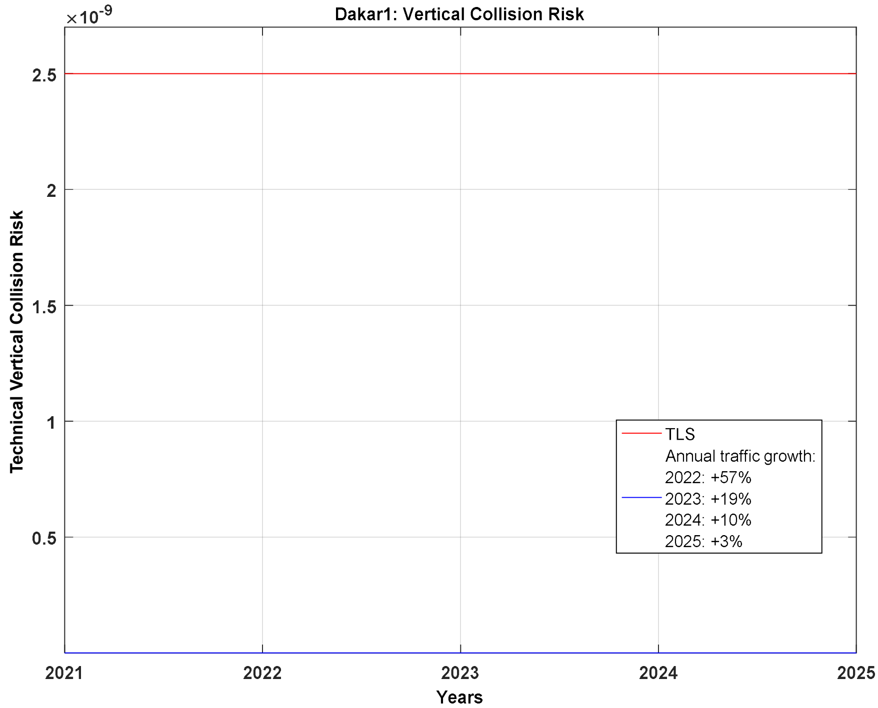


Figure 23.
Technical vertical collision risk for the period 2021-2025 in Dakar1

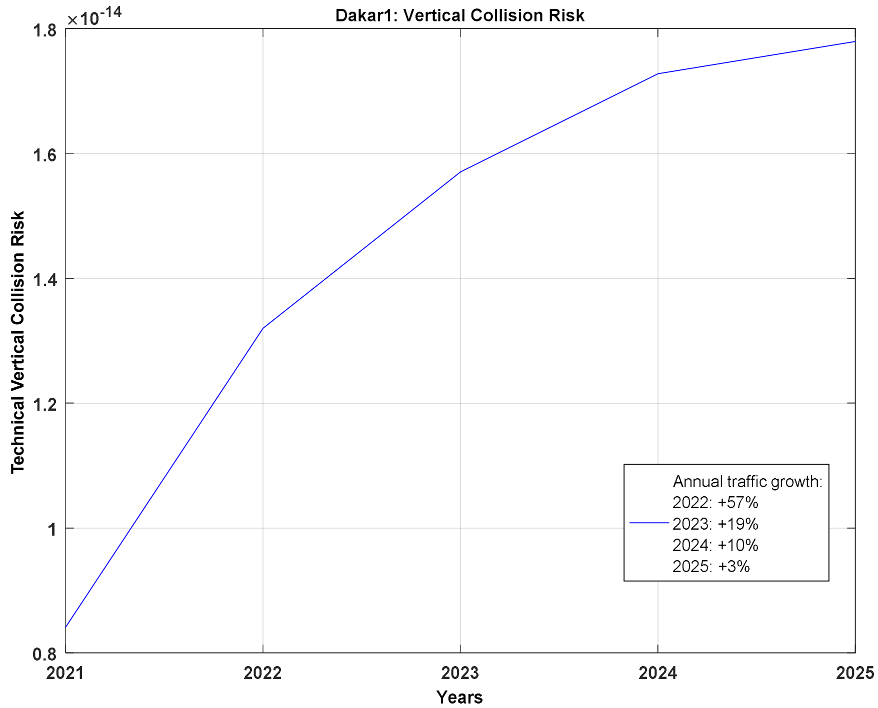


Figure 24.
Technical vertical collision risk for the period 2021-2025 in Dakar1 (enlarged)

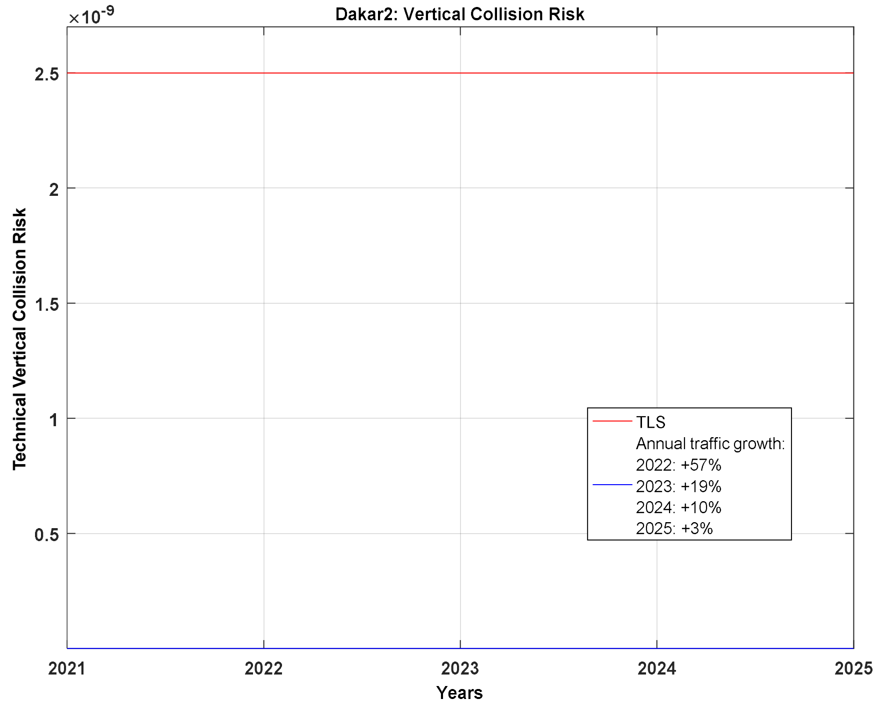


Figure 25.
Technical vertical collision risk for the period 2021-2025 in Dakar2

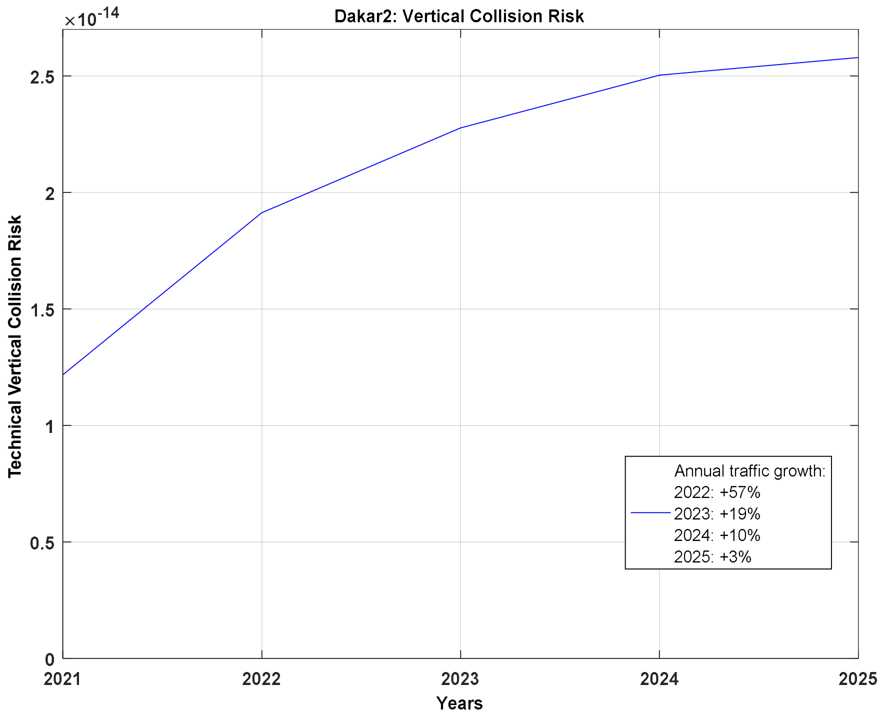


Figure 26.
Technical vertical collision risk for the period 2021-2025 in Dakar2 (enlarged)

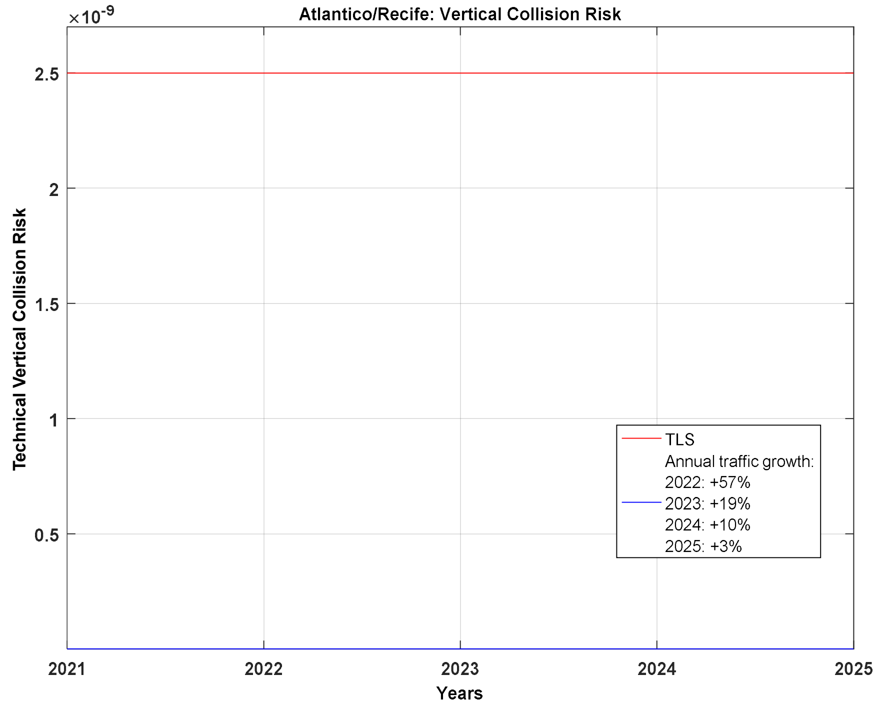


Figure 27.
Technical vertical collision risk for the period 2021-2025 in Recife

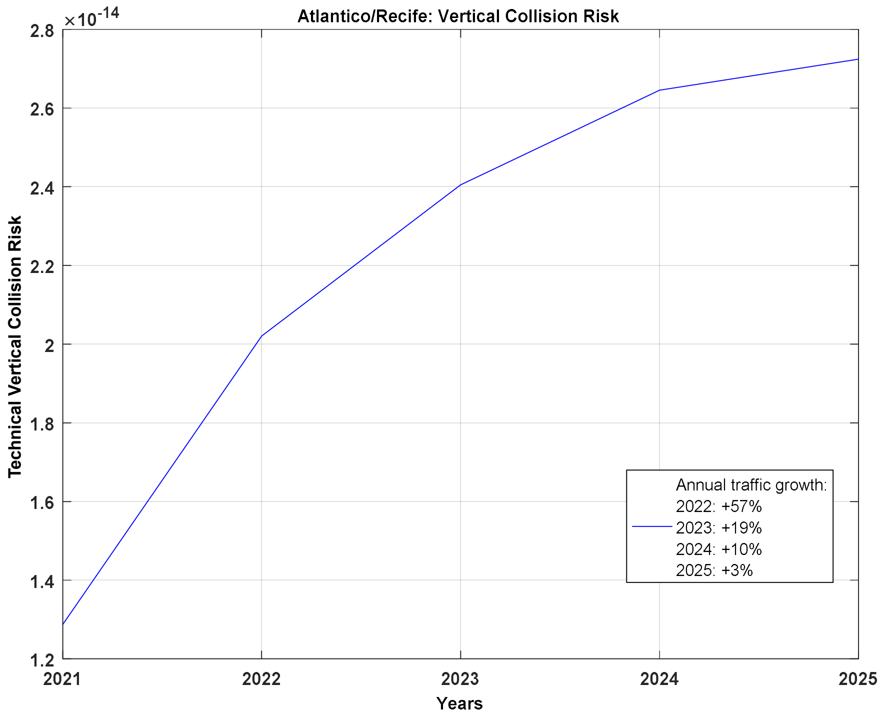


Figure 28.
Technical vertical collision risk for the period 2021-2025 in Recife (enlarged)

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 2025 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. 36]), large height deviations can be classified as reflected in Table 41. This classification has been used in the EUR/SAM Corredor.

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 41.
LHD classification according to ICAO

4.2.1. Data on EUR/SAM large height deviations

As it has been explained in [Ref. 37], 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:

[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.*

- 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 42 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 43 and Table 44, show the details of the deviations reported in the Canaries and Dakar, 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. It may also happen that a State reports LHD outside RVSM flight levels. In this case, the LHD not will be included in the tables.

Months	Canarias UIR	SAL Oceanic UIR	Dakar Oceanic UIR	Atlántico-Recife FIR/UIR
Jan-21	Available	No deviation	No deviation	No deviation
Feb-21	Available	No deviation	No deviation	No deviation
Mar-21	No deviation	No deviation	No deviation	No deviation
Apr-21	No deviation	No deviation	No deviation	No deviation
May-21	No deviation	No deviation	No deviation	No deviation
Jun-21	No deviation	No deviation	No deviation	No deviation
Jul-21	Available	No deviation	Available	No deviation
Aug-21	No deviation	No deviation	No deviation	No deviation
Sep-21	No deviation	No deviation	Available	No deviation
Oct-21	No deviation	No deviation	No deviation	No deviation
Nov-21	Available	No deviation	Available	No deviation
Dec-21	No deviation	No deviation	No deviation	No deviation

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

Table 42.
Relevant deviations considered from January 2021 to December 2021

Date	Route	Duration	Coordinated FL	Observed FL	Deviation	Cause	Category
190121	UN866	0.08333 h	FL355	FL360	500 ft	Coordination Error	E
210221	UN873	0.08333 h	FL350	FL350	0	Coordination Error	E
030721	UN873	0.08333 h	FL390	FL390	0	Coordination Error	E
121121	UN873	0.08333 h	FL390	FL370	2000 ft	Coordination Error	E

Table 43.
Large height deviations reported in the Canaries

[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.*

Date	Route	Duration	Coordinated FL	Observed FL	Deviation	Cause	Category
050721	UN873	0.08333 h	FL370	FL390	2000 ft	Coordination Error	E
010921	UN866	0.08333 h	FL350	FL370	2000 ft	Coordination Error	E
111121	UN873	0.08333 h	FL370	FL390	2000 ft	Coordination Error	E

Table 44.
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 43 and Table 44, 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 2021, 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 2021			
	Canaries	**SAL**	**Dakar**	**Recife**
Same direction time at incorrect level (h)	0.3333	0	0.2450	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)	9748.15	15751.81	19298.13	13034.96
Total Corridor flight time (h)	57833.05	57833.05	57833.05	57833.05
Wrong level, same direction vertical overlap probability	$1.7845*10^{-5}$	0	$6.7607*10^{-6}$	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 45.
Operational vertical collision risk parameters in the Corridor

Table 46 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 57%, 19%, 10% and 3% in 2022, 2023, 2024 and 2025 respectively. These results can also be seen in Figure 29 to Figure 34.

Total Vertical Collision risk	57%, 19%, 10% and 3% annual traffic growth until 2025					
	Canaries	**SAL1**	**SAL2**	**Dakar1**	**Dakar2**	**Recife**
2021	$2.9636*10^{-8}$	$8.7105*10^{-15}$	$1.1904*10^{-14}$	$1.0929*10^{-8}$	$1.2658*10^{-8}$	$1.2871*10^{-14}$
2022	$4.6528*10^{-8}$	$1.3675*10^{-14}$	$1.8689*10^{-14}$	$1.7158*10^{-8}$	$1.9873*10^{-8}$	$2.0208*10^{-14}$
2023	$5.5368*10^{-8}$	$1.6274*10^{-14}$	$2.2239*10^{-14}$	$2.0419*10^{-8}$	$2.3649*10^{-8}$	$2.4047*10^{-14}$
2024	$6.0905*10^{-8}$	$1.7901*10^{-14}$	$2.4463*10^{-14}$	$2.2460*10^{-8}$	$2.6014*10^{-8}$	$2.6452*10^{-14}$
2025	$6.2732*10^{-8}$	$1.8438*10^{-14}$	$2.5197*10^{-14}$	$2.3134*10^{-8}$	$2.6794*10^{-8}$	$2.7246*10^{-14}$

Table 46.
Total vertical collision risk for the period 2021-2025

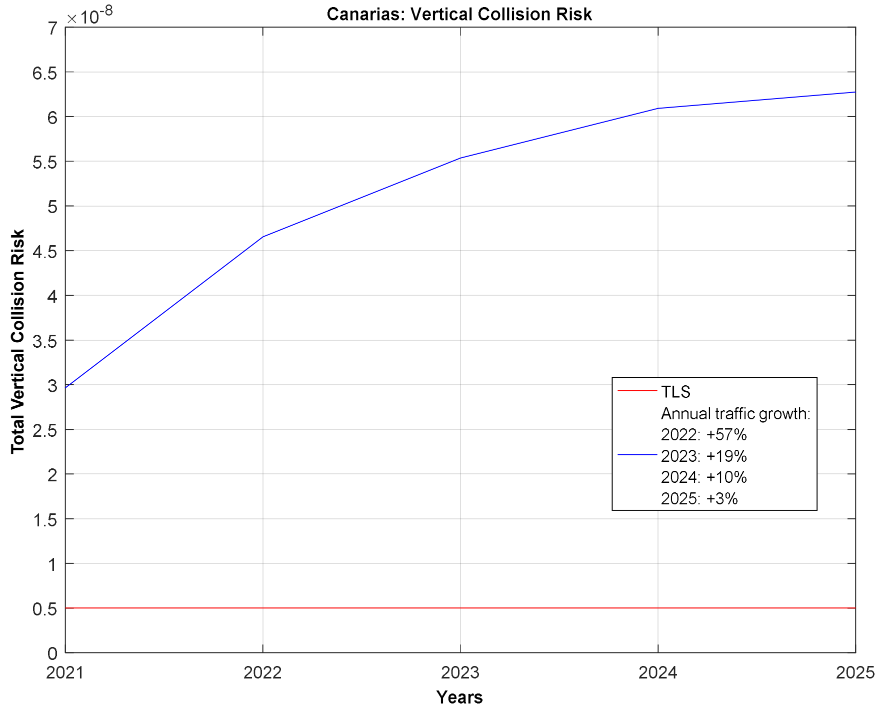


Figure 29.
Total vertical collision risk for the period 2021-2025 in the Canaries

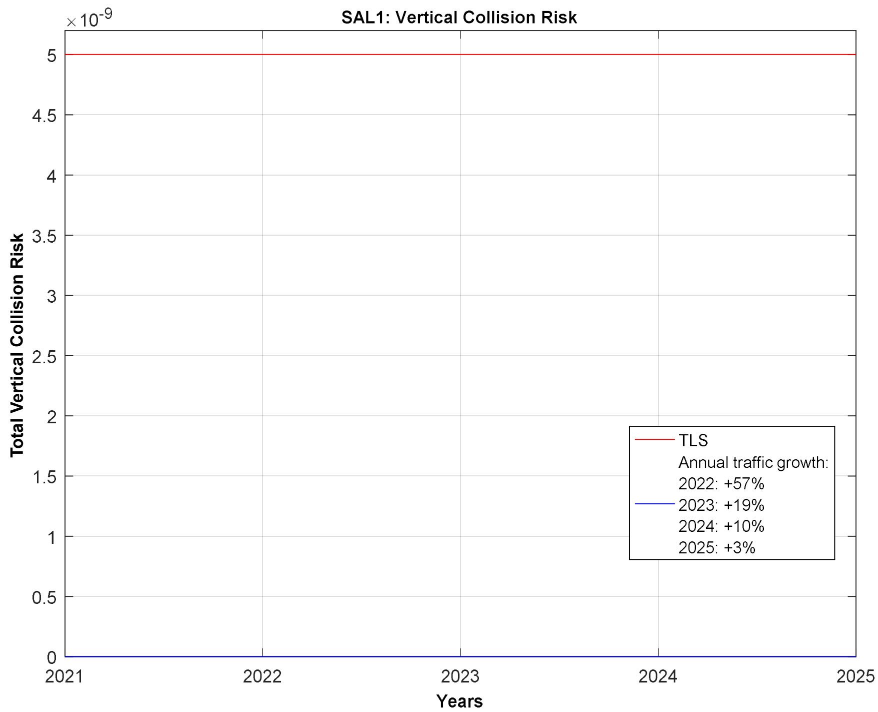


Figure 30.
Total vertical collision risk for the period 2021-2025 in SAL1

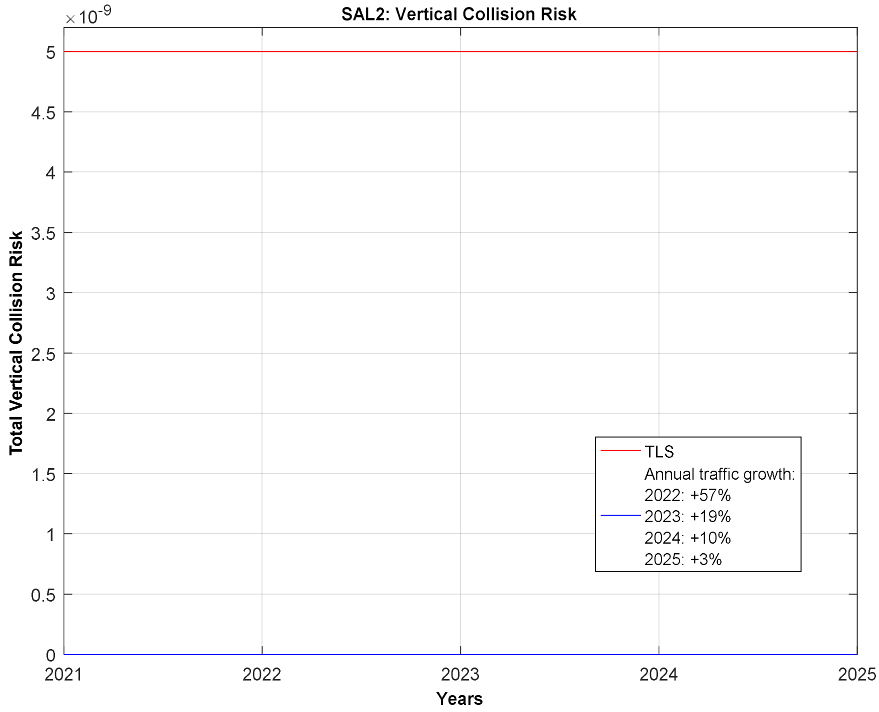


Figure 31.
Total vertical collision risk for the period 2021-2025 in SAL2

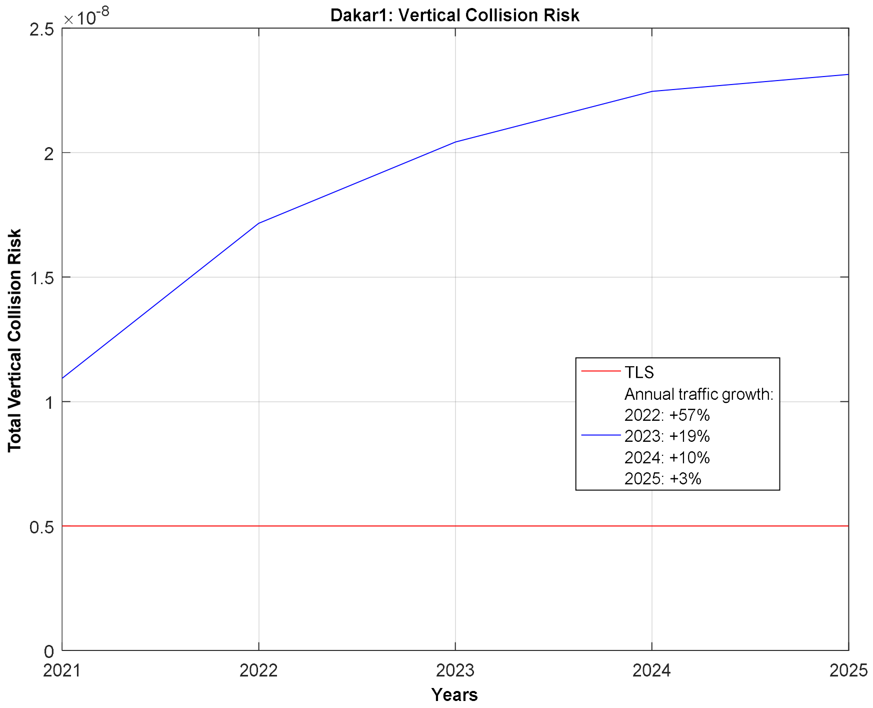


Figure 32.
Total vertical collision risk for the period 2021-2025 in Dakar1

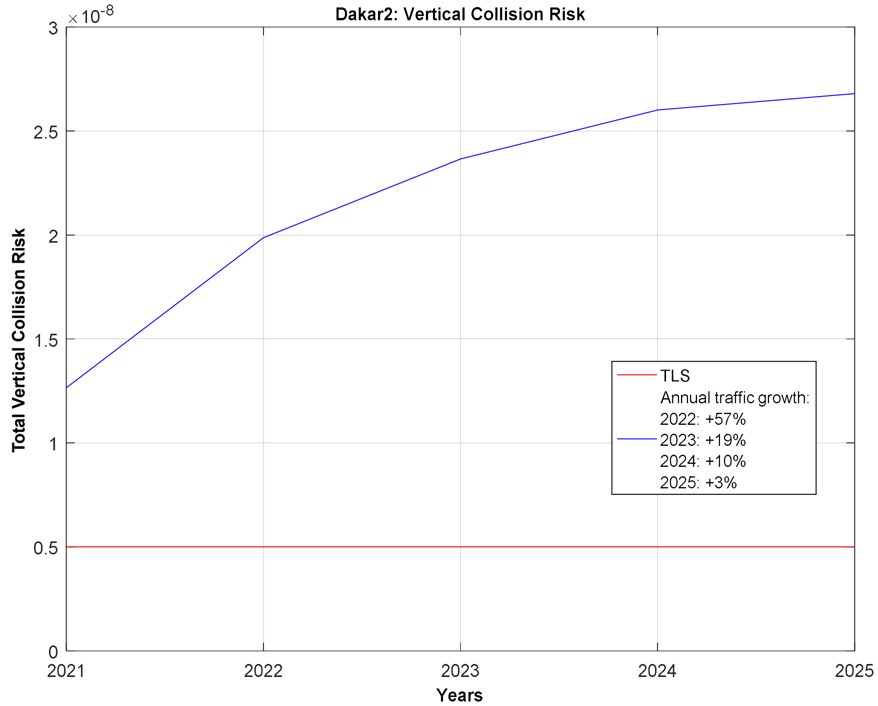


Figure 33.
Total vertical collision risk for the period 2021-2025 in Dakar2

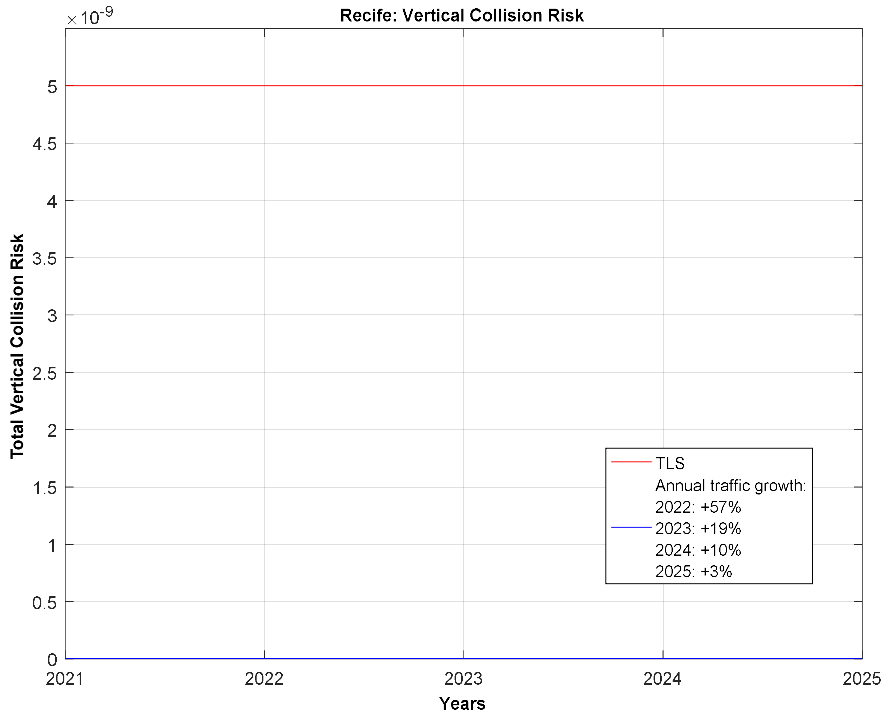


Figure 34.
Total vertical collision risk for the period 2021-2025 in Recife

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 Dakar.

In previous safety assessments, such as [Ref. 3], [Ref. 5], [Ref. 8], [Ref. 9] or [Ref. 10], [Ref.11] and [Ref.12], 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. 33], [Ref. 34] and [Ref. 35]).

Using this value of $P_y(0)=0.059$, the obtained results are shown in Table 47.

FIR/UIR	**Vertical risk**	
	Technical risk	**Total vertical risk**
Canaries	$3.1543*10^{-15}$	$7.1550*10^{-9}$
SAL1	$1.8659*10^{-15}$	$1.8659*10^{-15}$
SAL2	$2.4609*10^{-15}$	$2.4609*10^{-15}$
Dakar1	$1.7280*10^{-15}$	$3.6175*10^{-9}$
Dakar2	$2.4705*10^{-15}$	$2.9648*10^{-9}$
Recife	$2.6070*10^{-15}$	$2.6070*10^{-15}$

Table 47.
Technical and total vertical risk using Py(0)=0.059

As it can be seen in Table 47, 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 over 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, although more than 80% of pre-pandemic traffic had been recovered by the end of 2021.

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 $P_y(50) = 1.0827 \cdot 10^{-7}$ and $P_y(50) = 1.4467 \cdot 10^{-7}$, depending on the location, whilst the lateral overlap probability obtained for $S_y = 90\,NM$ is between $P_y(90) = 3.8985 \cdot 10^{-8}$ and $P_y(90) = 5.4278 \cdot 10^{-8}$.
    - For current traffic levels, the lateral collision risk obtained is $3.2452*10^{-10}$, whilst the lateral collision risk estimated for 2025 with an annual traffic growth rate of 57%, 19%, 10% and 3% in 2022, 2023, 2024 and 2025 respectively is $6.8693*10^{-9}$. 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, 2021 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 $P_z(1000) = 1.40906 \cdot 10^{-13}$.
    - The lateral overlap probability for aircraft nominally flying at adjacent flight levels of the same path, $P_y(0)$ has been obtained conservatively assuming that all aircraft are using GNSS and that their lateral path-keeping errors standard deviation is 0.0612 NM. The value obtained for $P_y(0)$ is between 0.2651 and 0.3001 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 $1.4153*10^{-14}$. The technical vertical collision risk estimated for 2024 with an annual traffic growth rate

of 57%, 19%, 10% and 3% in 2022, 2023, 2024 and 2025 is $2.9959*10^{-14}$. 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 SAL and Recife. In Canaries and Dakar locations the total vertical risk calculated is higher than 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 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:

- 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).
- It is very important that all this information is provided as soon as possible and requests for verification or clarification are dealt with within a reasonable time.

6. Reference documentation

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[Ref. 20] Summary of the Airspace Safety Review for the RVSM Implementation in Asia Region.- RASMAG/4-WP11 25/10/2005. OACI

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[Ref. 24] EUROCONTROL Forecast Update 2021-2027. European Flight Movements and Service Units. Three Scenarios for Recovery from COVID-19. October 2021

[Ref. 25] EUROCONTROL Five-Year Forecast 2021-2025. European Flight Movements and Service Units. Three Scenarios for Recovery from COVID-19. November 2020

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[Ref. 27] Revised Pre-Implementation Collision Risk Assessment for RVSM in the Africa Indian Ocean Region. NLR-CR-2007-637. February 2007

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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
LHD	LARGE HEIGHT DEVIATION
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