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CAR/SAM Planning and Implementation Regional Group (GREPECAS)
Twenty Fourth Scrutiny Working Group Meeting (GTE/24)
Mexico City, Mexico, 5 to 9 August 2024

Agenda Item 3: **Review of the Results of Large Height Deviation (LHD) and the Collision Risk Model (CRM) Analysis**

3.8 Presentation of the CRM 2023 and an analysis of the contributing causes of this risk in Flight Information Regions (FIRs) that presented a value above the Target Level of Safety (TLS) Collision Risk Assessment (CRA).

VERTICAL SAFETY MONITORING REPORT FOR U.S. CARIBBEAN AIRSPACE – 2023

(Presented by NAARMO)

EXECUTIVE SUMMARY

This paper provides the vertical safety monitoring report for the continued safe use of the Reduced Vertical Separation Minimum (RVSM) in The United States Caribbean Airspace. This airspace includes the Miami, New York West, and San Juan Flight Information Regions (FIRs). The safety assessment has been conducted according to the methodology endorsed by the International Civil Aviation Organization (ICAO). This work makes use of Large Height Deviation (LHD) reports and Traffic Sample Data (TSD) for calendar year 2023.

The purpose of this report is to compare actual performance to safety goals related to continued use of the RVSM. This report contains a summary of LHD reports received by the NAARMO for the calendar year 2023. There are 63 reported occurrences accounting for 48 minutes spent at an unexpected/incorrect Flight Level (FL) during calendar year 2023. This report also contains an estimate of the vertical collision risk. The vertical collision risk estimate for the airspace exceeds the Target Level of Safety (TLS) value of 5.0×10^{-9} fatal accidents per flight hour.

Strategic Objectives:	• Safety • Air Navigation Capacity and Efficiency
References:	• ICAO Doc 9574 • ICAO Doc 9937

1. Introduction

1.1 The North American Approvals Registry and Monitoring Organization (NAARMO), a service delegated to the William J. Hughes Technical Center, fulfills the role of Regional Monitoring Agency (RMA) for the continued-safe use of the RVSM in the U.S. Caribbean Airspace.

1.2 This airspace consists of the Miami, New York West, and San Juan Flight Information Regions (FIRs), and contains operations travelling between North America and the Caribbean. The U.S. FAA is the Air Traffic Service (ATS) provider for this airspace. The NAARMO conducts the on-going airspace safety monitoring activities to help ensure the continued safe use of the RVSM.

1.3 This report covers the calendar year 2023. Within this report, the reader will find a summary of the Large Height Deviation (LHD) reports received by the NAARMO and the corresponding vertical collision risk estimate. There were 63 such reports submitted to the NAARMO for calendar year 2023.

2 Discussion

2.1 Traffic Sample Data

2.1.1 The NAARMO has access to the Federal Aviation Administration's (FAA's) Automatic Dependent Surveillance – Broadcast (ADS-B) and Traffic Flow Management System (TFMS) data for Miami Oceanic and San Juan airspace. The ADS-B data contain frequent aircraft position data. The TFMS data provide projected aircraft position data based on filed flight plans.

2.1.2 The source of traffic data for the New York West FIR is the FAA Advanced Technologies and Oceanic Procedures (ATOP) oceanic automation system data reduction and archives (DR&A). These data contain all the reported aircraft positions, as well as the pilot-ATC High Frequency (HF) radio communications and Controller Pilot Data Link Communications (CPDLC) messages.

2.1.3 Figure 2-1 shows the aircraft position locations within the New York West FIR and the ADS-B data for the Miami Oceanic and San Juan FIRs for 1- 9 December 2023. The Miami Oceanic and San Juan traffic observed in the ADS-B data are combined with the New York West traffic observed in the ATOP DR&A.

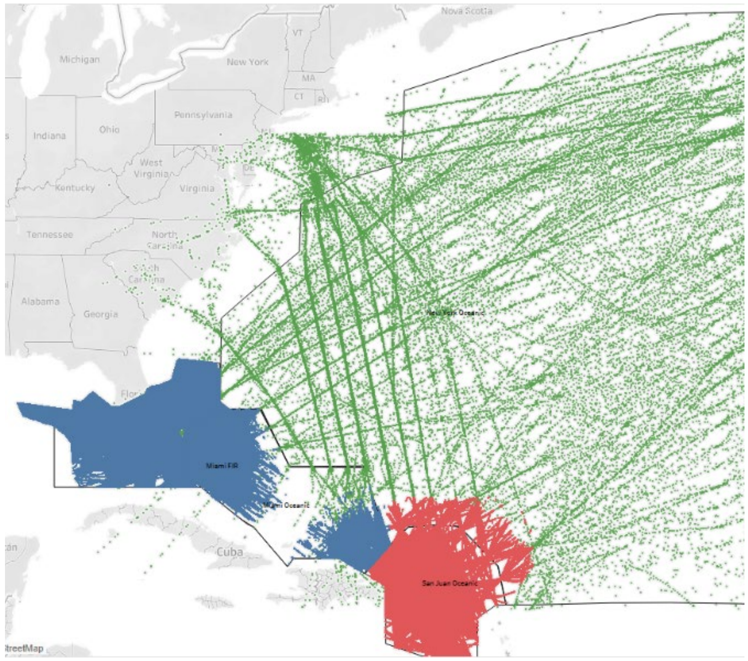


Figure 2-1. Miami Oceanic, New York West, San Juan FIRs Air Traffic Operations – 1-9 Dec 2023

2.1.4 Figure 2-2 shows the average number of flight operations per month for the New York West FIR for calendar years 2020 through 2023. Seasonal variations in traffic volume are expected in the airspace. Typically, the high traffic period for this airspace begins in November and ends in April/May. Figure 2-2 shows that by the end of calendar year 2023, traffic levels demonstrate a sustained recovery has been observed.

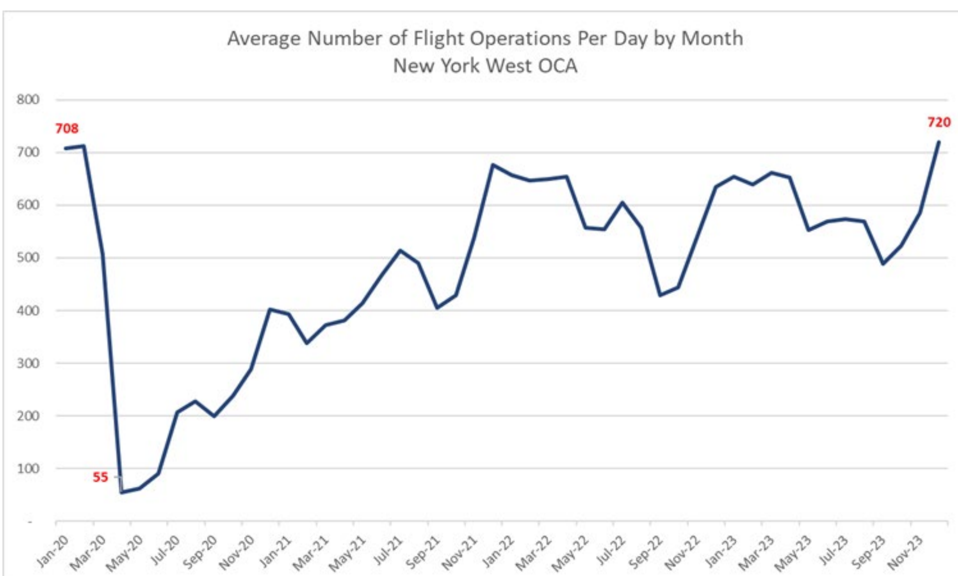


Figure 2-2. New York West FIR, average number of flight operations per day by month – calendar year 2020 through 2023

2.1.5 Figure 2-3 shows the numbers of flight operations per day for calendar year 2023. The average number of flights per day for calendar year 2023 is 607 flights, this is an increase over the average 571 flights per day estimated for calendar year 2022.

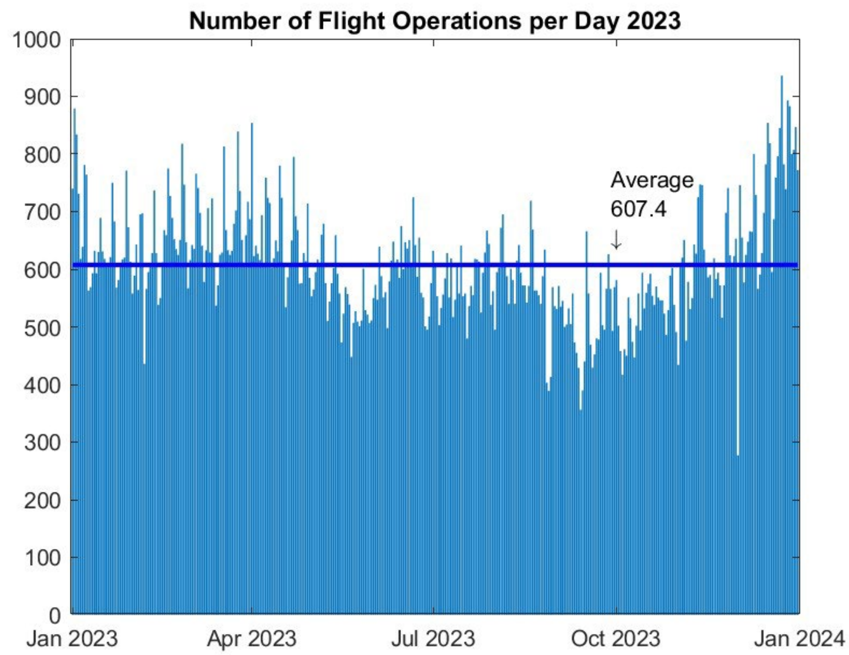


Figure 2-3. New York West FIR, Number of flight operations per day – calendar year 2023

2.1.6 Reported Large Height Deviations (LHDs)

2.1.7 The NAARMO utilizes the FAA's Comprehensive Electronic Data Analysis and Reporting (CEDAR) database, which contains all reports of potentially safety-related events from several internal FAA sources. There were 110 reported occurrences reviewed by the scrutiny group for the U.S. Caribbean airspace. The scrutiny group consists of operational experts from each air traffic control facility, representatives from FAA Flight Standards and Airspace Safety, and safety analyses experts from the NAARMO. The scrutiny group determined there were 63 validated LHD occurrences during calendar year 2023.

2.1.8 The 63 validated LHD reports are tabulated by month and shown in Table 2-1. Table 2-1 includes the number of reports, LHD duration and the flight levels crossed without clearance by month. The scrutiny group review determined a general cause for each of the 63 validated LHD reports. Table 2-2 summarizes the reported LHDs categorized by general cause. Fourteen of the 63 reported LHDs listed in Table 2-2 are technical risk events. Most (12) of the technical risk LHD reports are category J, flight crew correctly following the TCAS RA. Two of the technical risk LHD reports are category I, turbulence or other weather-related causes. The associated duration and/or flight levels crossed for the technical risk LHDs are not included in calculation of operational vertical risk and are not shown in Table 2-2. Only the reported LHDs classified as operational risk and their associated duration at incorrect FL and number of incorrect FLs crossed without ATC clearance contribute to the operational vertical collision risk estimate.

Table 2-1. Validated LHDs – 2023

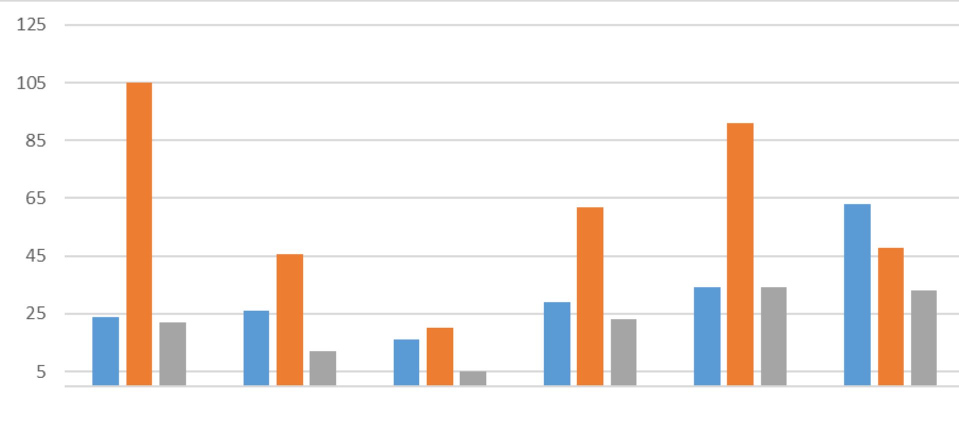
Month	Count	Duration at Unexpected FL (mins)	Number of Unexpected FLs Crossed
Jan-23	3	2	0
Feb-23	3	6	2
Mar-23	19	3	10
Apr-23	5	4	2
May-23	0	0	0
Jun-23	3	1	0
Jul-23	5	0	7
Aug-23	6	0	6
Sep-23	4	31	0
Oct-23	3	1	1
Nov-23	7	0	5
Dec-23	5	0	0
TOTAL	63	48	33

Table 2-2. Validated LHD Reports by Cause – 2023

LHD Category Code	LHD Category Description	Number of LHD	Duration at Incorrect FL (minutes)	Number of Incorrect FLs Crossed
A	Flight crew failing to climb / descend the aircraft as cleared	5	0	7
B	Flight crew climbing /descending without ATC clearance	12	0	18
C	Incorrect operation of airborne equipment	1	1	0
D	ATC system loop error; (e.g., ATC issues incorrect clearance or flight crew misunderstands clearance message)	13	39.5	7
E1	Coordination errors (wrong FL, time, route) in the ATC-unit-to-ATC-unit transfer of control responsibility as a result of human factors issues	7	2	1
E2	Negative Coordination in the ATC-unit-to-ATC-unit transfer of control responsibility as a result of human factors issues	10	5.5	0
F	Coordination errors in the ATC-to-ATC transfer of control responsibility as a result of equipment outage or technical issues	0	0	0
G	Aircraft contingency event leading to sudden inability to maintain assigned flight level	0	0	0
H	Airborne equipment failure leading to unintentional or undetected change of flight level	0	0	0

LHD Category Code	LHD Category Description	Number of LHD	Duration at Incorrect FL (minutes)	Number of Incorrect FLs Crossed
I	Turbulence or other weather related causes	3	0	0
J	TCAS resolution advisory; flight crew correctly following the resolution advisory	12	0	0
K	TCAS resolution advisory; flight crew incorrectly following the resolution advisory	0	0	0
L	An aircraft being provided with RVSM separation is not RVSM approved (e.g. flight plan indicating RVSM approval but aircraft not approved, ATC misinterpretation of flight plan)	0	0	0
M	Other	0	0	0
	TOTAL	**63**	**48**	**33**

2.1.9 An increase in the number of reported LHDs was observed in 2023 compared to the previous years. This result was expected due to the ongoing recovery from the COVID-19 pandemic and associated increase in flight activity. Figure 2-4 shows the comparison in the numbers of validated LHDs, duration and flight levels crossed without ATC Clearance for calendar years 2018 through 2023. The LHD durations in 2023 are comparable to the reported LHD durations during pre-COVID years.



	2018	2019	2020	2021	2022	2023
Number of Validated LHD Reports	24	26	16	29	34	63
Total Time at Incorrect FL (minutes)	105	45.5	20	62	91	48
Total RVSM Levels Crossed	22	12	5	23	34	33

Figure 2-4. Validated LHD Reports, calendar years 2018 through 2023

2.1.10 Communication failure reports

2.1.10.1 The reported occurrences in calendar year 2023 included many instances of communication failure. There were twenty-four communication failure reports received by NAARMO, all these reports occurred in the U.S. Caribbean airspace involving communication failures, the numbers by airspace are listed in Table 2-3.

Table 2-3. Communication Failure Reports – 2023

Airspace	Number of Communication Failure Reports - 2023
Miami Oceanic/San Juan FIRs	24
New York West FIR	0
Total	**24**

2.1.11 Significant LHD reports

2.1.11.1 The largest contribution towards vertical risk was a long duration event, greater than 20 minutes, within the New York West OCA. A data entry error during coordination for a flight caused the aircraft to fly an improper route. This event caused the aircraft to operate within the airspace for 31 minutes with incorrect information in the ATC automation system, it occurred during a low traffic density time and there was no evidence of a loss of separation. The assigned LHD category for this occurrence is category D.

2.1.11.2 The second largest contribution towards vertical risk came from an occurrence with 5 flight levels crossed without ATC clearance. In this event, the pilot descended to avoid weather without clearance and not in accordance with weather deviation procedures. This occurrence took place within the Miami Oceanic/San Juan FIRs and was assigned to category B with a secondary category I.

2.1.12 The operational risk-bearing LHD events are separated into two areas; those occurring within New York West airspace and those occurring within the Miami Oceanic/San Juan FIRs. Table 2-4 contains the breakdown of operational LHD events and associated durations for each area. Figure 2-5 shows the approximate locations of the operational LHDs in 2023. The size of the circles in Figure 2-5 represents the vertical collision risk estimate for the reported LHD.

Table 2-4. Validated operational LHDs by area – 2023

Airspace	Number of LHD	Duration at unexpected FL (min)	Number of unexpected FLs crossed
Miami Oceanic/San Juan FIRs	38	13	23
New York West FIR	11	35	10
Total	**49**	**48**	**33**

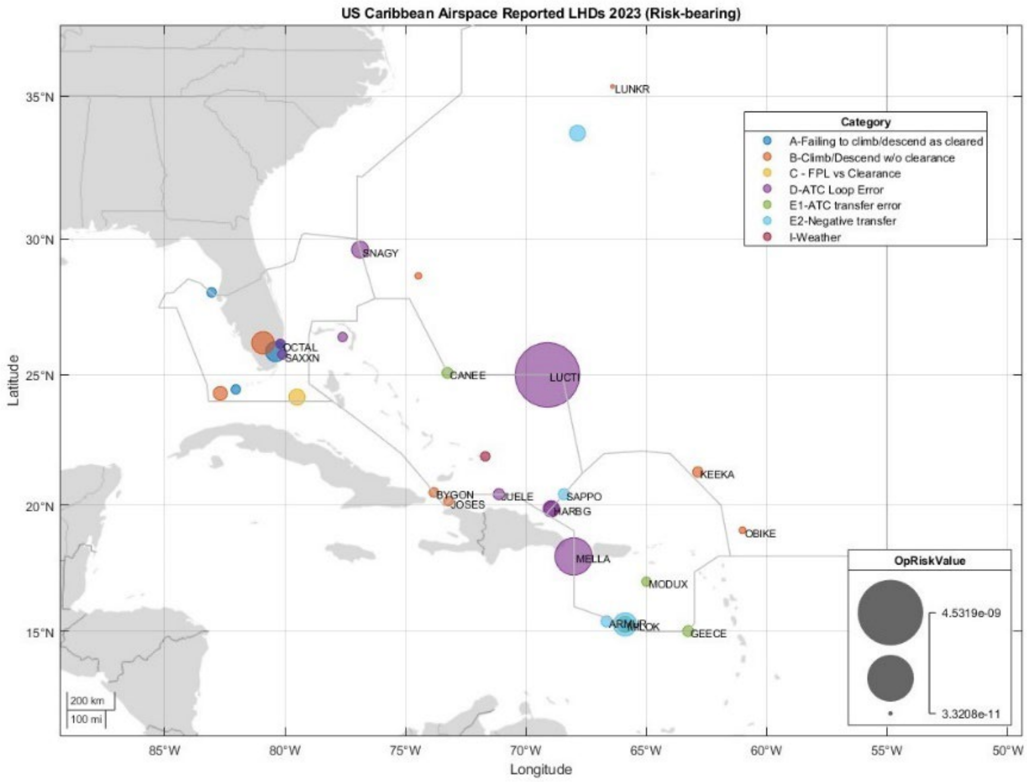


Figure 2-5. Approximate Location of the Risk-bearing LHDs – 2023

2.1.13 Vertical Collision Risk Estimate

2.1.14 This section of the paper provides the parameter estimates used in the ICAO vertical risk model. The collision risk methodology consists of a mathematical model to estimate risk for comparison to the safety criterion, the target level of safety (TLS). The section also provides information on the sources of data used to estimate risk model parameters.

2.1.15 The internationally agreed TLS for the 1,000-ft vertical separation standard is specified for technical and operational risk separately. The vertical technical risk provides the risk associated with the effects of turbulence, loss of altitude hold and crew response to airborne collision-avoidance system alerts in addition to errors arising from aircraft altimetry and altitude height-keeping system performance. The vertical operational risk estimate provides the risk associated with operational errors. The risk due to all causes is the sum of the vertical operational and technical risk estimates. The TLS for the 1,000-ft vertical separation standard is specified as:

- collision risk due to all causes does not exceed 5 fatal accidents in 10^9 flying hours, and, simultaneously,
- collision risk due to aircraft height-keeping systems does not exceed 2.5 fatal accidents in 10^9 flying hours

2.1.16 Based on the December 2023 traffic data, the NAARMO estimates approximately 744,216 annual flying hours for 2023 in the airspace where the RVSM is applied. This represents an average 7 percent increase in flying hours compared to 2022.

2.1.17 The methodology applied in the collision risk calculation for the airspace splits the airspace into two areas. The New York West airspace is considered separately from Miami Oceanic and San Juan airspace. Although the aircraft operations are similar within both areas, the available ATC surveillance and communications differ. In addition, there are differences in the available traffic data source for the two areas. The individual risk estimates for each area are combined to provide an estimate of the airspace using the observed annual flying hours within each area.

2.1.18 The airspace consists of a combination of parallel and crossing routes; therefore the total risk is expressed as the sum of three basic types of collision risk as follows:

$$N_{az}=N_{az}(same)+N_{az}(opp)+N_{az}(cross)$$

2.1.19 The terms on the right-hand side of the equation represent the expected number of accidents per aircraft flight hour resulting from collisions of aircraft-pairs assigned to adjacent flight levels due to the loss of planned vertical separation. The three terms on the right-hand side are estimated from aircraft operating on adjacent flight levels that are flying in the same direction on the same route, N_{az} (same), opposite direction on the same route, N_{az} (opp), and on crossing routes regardless of relative headings, N_{az} (cross).

2.1.20 The models for the three different types of collision risk - opposite-direction, same-direction, and crossing-routes - have basically the same structure. The estimate of vertical operational risk for same and opposite direction traffic is composed of two parts: that due to time spent at incorrect levels and that due to levels transitioned without clearance.

2.1.21 Aircraft Types Observed in Miami Oceanic, New York West, and San Juan FIRs

2.1.22 Figure 2-6 provides the top aircraft types observed in the December 2023 traffic data by flying hours. The two traffic data sources are maintained in the figure; Miami Oceanic and San Juan traffic data are sourced from the TFMS and the New York West data are sourced from the ATOP DR&A. The aircraft types in Figure 2-6 account for more than 75 percent of total flying hours observed in the airspace. The Airbus A320 is the most frequently observed aircraft in the New York West airspace. The Boeing B738 is the most frequently observed aircraft in the Miami Oceanic and San Juan airspace.

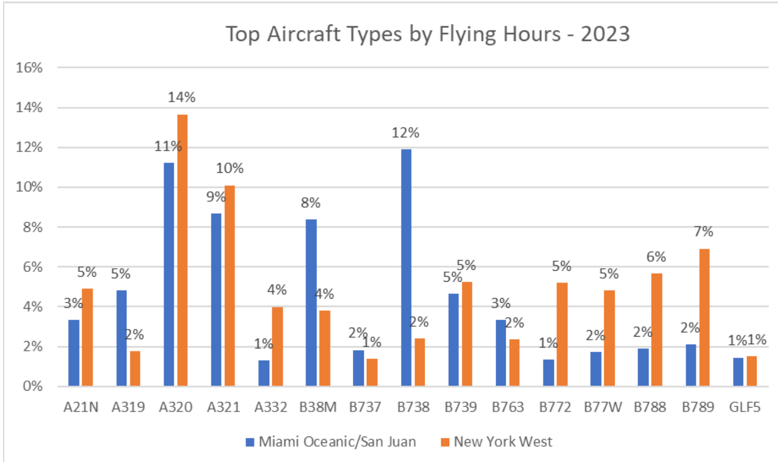


Figure 2-6. Observed Aircraft Types in Terms of Flying Hours in Miami Oceanic/San Juan and New York West Airspace - 2023

2.1.23 Aircraft Size

2.1.24 The collision risk model (CRM) parameters related to the aircraft size are: length, wingspan, and height. These parameters are estimated directly from the TFMS and ATOP DR&A December 2023 data and related aircraft specifications. The weighted dimensions are calculated using the actual dimensions of the aircraft type multiplied by the proportion of total flying time observed for the type in the traffic sample. The resulting CRM parameters for the aircraft length, wingspan, and height are presented in Table 2-5.

Table 2-5. CRM Parameter Estimates for Aircraft Size

Airspace	Length λ_x (NM)	Wingspan λ_y (NM)	Height λ_z (NM)
Miami Oceanic/San Juan	0.0223 *(135 ft)*	0.0199 *(121 ft)*	0.0066 *(40 ft)*
New York West	0.0270 *(164 ft)*	0.0249 *(151 ft)*	0.0076 *(46 ft)*

2.1.25 Same-Direction, Opposite-Direction, and Crossing-Route Vertical Passing Frequencies

2.1.26 The traffic data are used to estimate the vertical occupancy values for the airspace. Table 2-6 shows the same and opposite direction vertical occupancy estimates for the Miami Oceanic/San Juan and New York West airspace in calendar year 2023. The data show similar vertical occupancy values in 2023 compared to 2022.

Table 2-6. Same and opposite direction vertical occupancy estimates

Airspace	Same Direction Vertical Occupancy Value	Opposite Direction Vertical Occupancy Value
Miami Oceanic and San Juan	0.0235	0.0756
New York West	0.0292	0.1133

2.1.27 Probability of Vertical Overlap Attributable to Technical Height-Keeping Performance and Reported LHDs

2.1.28 RVSM technical risk is considered to arise from the effects of turbulence, loss of altitude hold and crew response to airborne collision avoidance system alerts as well as from errors in aircraft altimetry and altitude-keeping system performance. Hence, estimation of the probability of vertical overlap must account for contributions to vertical error arising from all these sources.

2.1.29 Estimates of aircraft Altimetry System Error (ASE) and Assigned Altitude Deviation (AAD) are obtained from aircraft height monitoring processes developed by NAARMO. These processes require several data sets, including meteorological and aircraft geometric height data. Aircraft geometric data is obtained from either the ADS-B data, or the GPS Monitoring Unit (GMU) system. Control of aircraft ASE is one of the principal objectives of the State RVSM approval process, which must be held by operators in airspace where the RVSM is applied.

2.1.30 The NAARMO estimate for the probability of vertical overlap for aircraft pairs operating on adjacent flight levels, P_z (1000), used in the estimate of vertical technical risk is 1.93×10^{-9}. The NAARMO estimate for the probability of vertical overlap for aircraft pairs operating on the same flight level, $P_z(0)$,used in the estimation of vertical operational risk is 0.42.

2.1.31 Time spent at Unexpected/Incorrect FL

2.1.32 The proportion of flying time spent at incorrect levels, P_ii, is determined as the ratio of the amount of time spent at incorrect levels to the total amount of flying time in the airspace during the period when the wrong-flight-level events occurred. The risk-bearing LHDs for calendar year 2023 contain 48 minutes of flying time spent at unexpected flight level.

2.1.33 Table 2-4, provided earlier in this paper, gives the duration at unexpected/incorrect flight level for both areas. The proportion of flying time spent at unexpected flight level is estimated for each area using the values in the table and dividing by the estimated flying hours for each area. The estimated annual flying hours for New York West airspace obtained from the ATOP DR&A data are 349,713 hours. The estimated annual flying hours for Miami Oceanic and San Juan airspace obtained from the combined TFMS data are 394,501 flying hours. The ratios of time spent at unexpected flight level are 1.0×10^{-4} and 0.3×10^{-4} for New York West and Miami Oceanic/San Juan airspace, respectively.

2.1.34 Collision Risk Model Parameters

2.1.35 The individual parameters of the models, their definitions, estimates, and sources are given in Table 2-7.

Table 2-7. Vertical Collision Risk Model Parameter Estimates - 2023

Term	Definition	Estimate	Source
$P_z(S_z)$	Probability that two aircraft nominally separated by the vertical separation minimum *Sz* are in vertical overlap.	1.93×10^{-9}	Value used in the US CONUS vertical risk estimate
$P_z(0)$	Probability that two aircraft operating on the same flight level are in vertical overlap	0.42	Value used in the vertical risk estimates for Pacific airspace
$P_y(0)$	Probability that two aircraft on the same track are in lateral overlap.	0.1	Value used in the vertical risk estimates for Pacific airspace
λx	Average aircraft length.	0.0223 NM and 0.0270 NM	Estimated from Miami Oceanic/San Juan and New York West traffic data
λy	Average aircraft wingspan.	0.0199 NM and 0.0249 NM	Estimated from Miami Oceanic/San Juan and New York West traffic data
λz	Average aircraft height with undercarriage retracted.	0.0066 NM and 0.0076 NM	Estimated from Miami Oceanic/San Juan and New York West traffic data
Ez(same)	Same-direction vertical occupancy for a pair of aircraft at adjacent flight levels on same route.	0.0235 and 0.0292	Estimated from Miami Oceanic/San Juan and New York West traffic data
Ez(opp)	Opposite-direction vertical occupancy for a pair of aircraft at adjacent flight levels on same route.	0.0756 and 0.1133	Estimated from Miami Oceanic/San Juan and New York West traffic data
$\overline{\lvert\Delta V\rvert}$	Average absolute relative along-track speed between aircraft on same-direction routes.	13 knots	Value used in the North Atlantic, Pacific, and US Domestic airspace vertical risk estimates
$\overline{\lvert V\rvert}$	Average absolute aircraft ground speed.	480 knots	Value used in the North Atlantic, Pacific, and US Domestic airspace vertical risk estimates
$\overline{\lvert\dot{y}\rvert}$	Average absolute relative cross-track speed for an aircraft pair nominally on the same route.	5 knots	Value used in the North Atlantic, Pacific, and US Domestic airspace vertical risk estimates
$\overline{\lvert\dot{z}\rvert}$	Average absolute relative vertical speed of an aircraft pair that have lost all vertical separation	1.5 knots	Value used in the North Atlantic, Pacific, and US Domestic airspace vertical risk estimates

F(NY)	Estimated flying hours within New York West FIR	349,102	Estimated from FAA ATOP DR&A for New York West airspace
F(MS)	Estimated flying hours within Miami Oceanic and San Juan FIRs	394,500	Estimated from TFMS data for Miami Oceanic and San Juan airspace

2.1.36 Results and Conclusions

2.1.37 The risk-bearing LHDs are separated based on the location of the event. The risk-bearing LHDs within New York West airspace are applied to the estimated flying hours and vertical occupancy values for New York West airspace. The same method is applied to the data for Miami Oceanic and San Juan airspace. Table 2-8 provides the weighted 2023 estimates of technical and operational vertical risk for Miami Oceanic, New York West and San Juan airspace. The last row in Table 2-8 contains the weighted sum of the risk from the two areas.

Table 2-8. 2023 Vertical Risk Estimates for Miami Oceanic, New York West and San Juan Airspace (× 10^{-9} fatal accidents per flight hour (fapfh))

Airspace	Technical	Operational	Overall
New York West	0.04	5.45	5.49
Miami Oceanic and San Juan	0.03	6.60	6.63
Total	**0.07**	**12.05**	**12.12**

2.1.38 The estimated technical risk in the RVSM airspace is 0.07 × 10^{-9} fatal accidents per flight hour (fapfh). This estimate is significantly below 2.5 × 10^{-9} fapfh, which is the portion of the TLS set as the safety goal for technical height-keeping performance.

2.1.39 The operational vertical risk estimate for RVSM airspace 12.05 × 10^{-9} fapfh. The sum of this value and the technical risk estimate for airspace is 12.12 × 10^{-9} fapfh, which is larger than the overall safety goal of 5.0 × 10^{-9} fapfh.

2.1.40 Reported LHDs and Corresponding Vertical Risk

2.1.40.1 The largest contribution towards the estimate of vertical risk comes from a reported category D LHD with a duration of 31 minutes. The risk estimate associated with this occurrence is 4.5 × 10^{-9} fapfh, a value that is more than a third of the overall vertical risk estimate.

2.1.40.2 Figure 2-7 shows the estimates of vertical risk by LHD category. The vertical risk estimate associated with Category D LHD reports is 7.53 × 10^{-9} fapfh, most of this vertical risk value is attributed to the 31-minute occurrence. The next largest category in terms of contribution towards vertical risk is category E1.

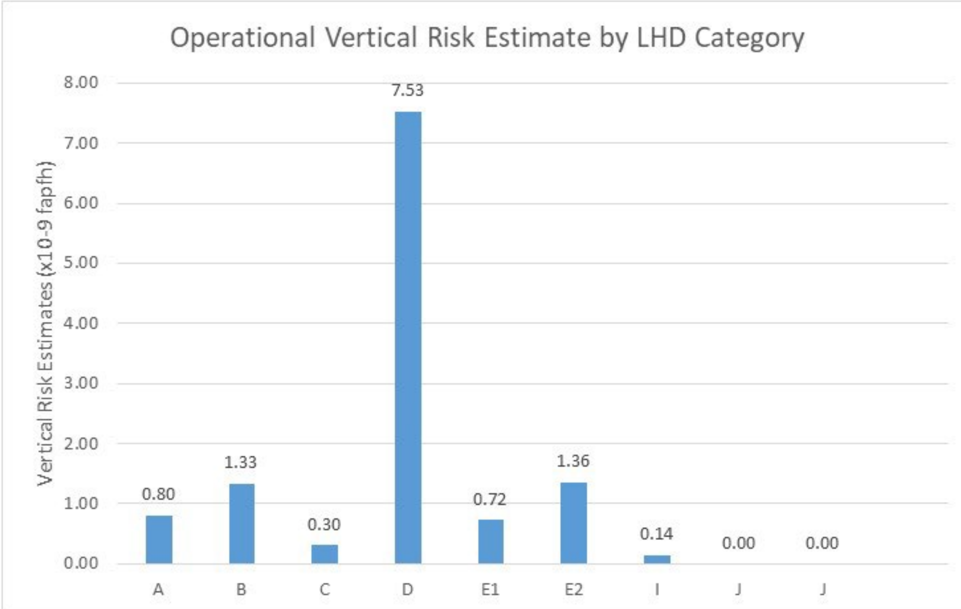


Figure 2-7. Vertical Risk Estimates by LHD Category (× 10^{-9} fatal accidents per flight hour (fapfh)

2.1.40.3 The estimated vertical risk estimate for 2023, shown in Table 2-8, is a decrease from that estimated for calendar year 2022. The decrease in the vertical risk estimate is directly related to the increase in the time spent at unexpected flight levels as shown in Figure 2-4. For comparison, Table 2-9 and Figure 2-8 provide the vertical risk estimates for calendar years 2018 through 2023.

Table 2-9. Vertical Risk Estimates for Miami Oceanic, New York West and San Juan Airspace (× 10^{-9} fatal accidents per flight hour (fapfh))

Calendar Year	Technical Risk	Operational Risk	Overall Vertical Risk	TLS
2018	0.07	48.04	48.11	5
2019	0.07	20.67	20.75	5
2020	0.07	5.61	5.68	5
2021	0.08	14.28	14.36	5
2022	0.07	17.92	17.99	5
2023	0.07	12.05	12.12	5

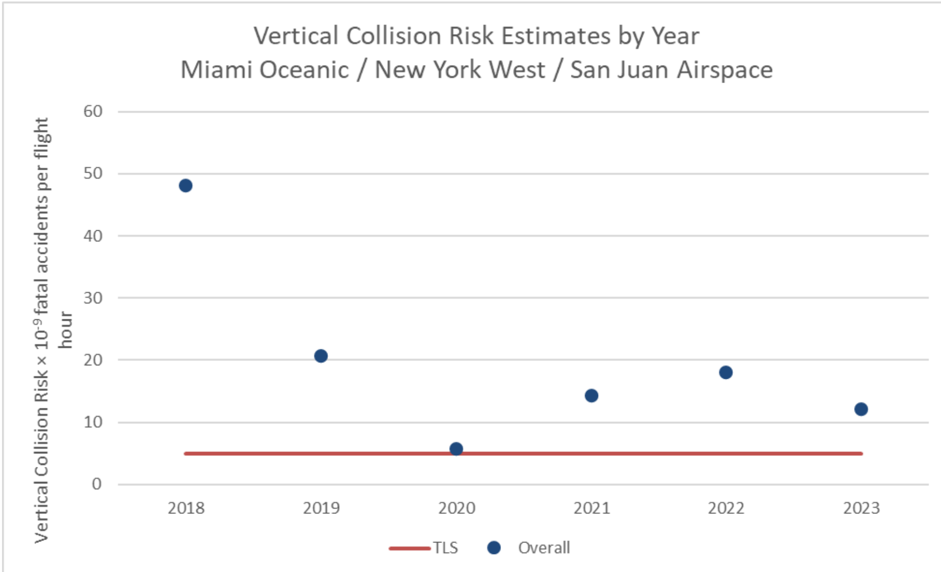


Figure 2-8. Vertical Risk Estimates for Miami Oceanic, New York West and San Juan Airspace (× 10^{-9} fatal accidents per flight hour (fapfh))

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