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CAR/SAM Regional Planning and Implementation Group (GREPECAS)

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Twenty-Sixth Scrutiny Working Group Meeting (GTE/26) of the CAR/SAM Regional Planning and Implementation Group (GREPECAS)
Mexico City, Mexico, 12 to 16 October 2026

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

Vertical Safety Analysis for Caribbean Airspace Designated to the NAARMO RMA - 2025

(Presented by the North American Approvals Registry and Monitoring Organization (NAARMO))

EXECUTIVE SUMMARY

This paper provides the vertical safety monitoring report for the continued safe use of the Reduced Vertical Separation Minimum (RVSM) in Caribbean (CAR) Region airspace designated to the NAARMO Regional Monitoring Agency (RMA). This airspace includes the Mexico, Miami Oceanic, New York West, Houston Oceanic, 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 2025.

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 2025. There are 57 reported occurrences accounting for 29 minutes spent at an unexpected/incorrect Flight Level (FL) during calendar year 2025. This report also contains an estimate of the vertical collision risk. The vertical collision risk estimate for the airspace meets the Target Level of Safety (TLS) value of 5.0×10^{-9} fatal accidents per flight hour

Action:	The meeting is invited to review and discuss the information contained in this paper.
Strategic Objectives:	• Every Flight is Safe and Secure • Aviation Delivers Seamless, Accessible, and Reliable Mobility for All
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 for Advanced Aerospace, fulfils the role of Regional Monitoring Agency (RMA) for the continued-safe use of the RVSM in the U.S. Caribbean Airspace.

1.2 The analysis in this paper examines the Mexico, Miami Oceanic, New York West, Houston Oceanic and San Juan Flight Information Regions (FIRs) airspace within the Caribbean (CAR) Region. 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 2025. 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 180 such reports submitted to the NAARMO for calendar year 2025.

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 Houston Oceanic, Mexico, 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 ATOP DR&A aircraft position data within the New York West FIR (shown in green) and the TFMS aircraft position data for the Mexico (shown in red), ADS-B data for Houston Oceanic (shown in blue), ADS-B data for Miami Oceanic (shown in orange) and ADS-B data for San Juan (shown in teal) FIRs for 23 December 2025.

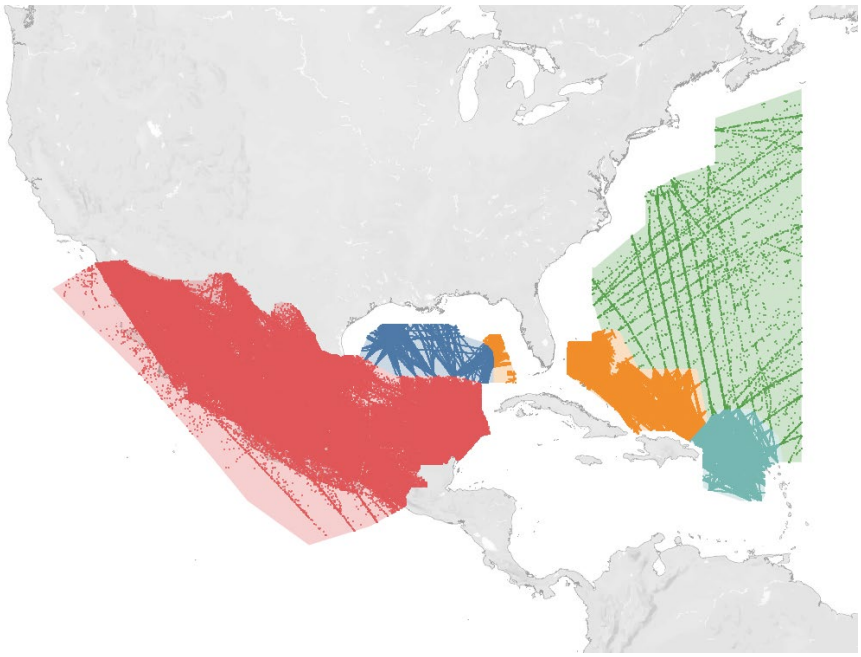


Figure 2-1. Houston Oceanic, Mexico, Miami Oceanic, New York West, San Juan FIRs Air Traffic Operations – 23 Dec 2025

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 2025. 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 traffic levels have returned to pre-pandemic levels, indicating a sustained recovery.

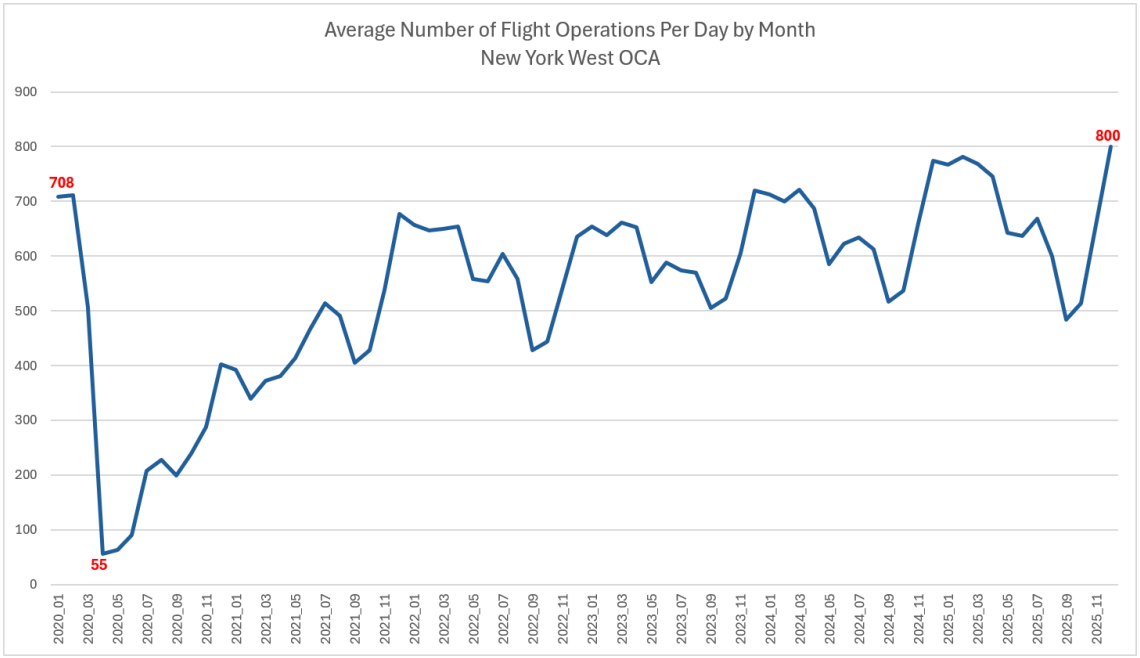


Figure 2-2. New York West FIR, average number of flight operations per day by month – calendar year 2020 through 2025

2.1.5 As shown in **Figure 2-3**, the average number of daily flight operations within the New York West FIR increased from 656 in calendar year 2024 to approximately 677 in 2025, representing an increase of about 3.2 percent.

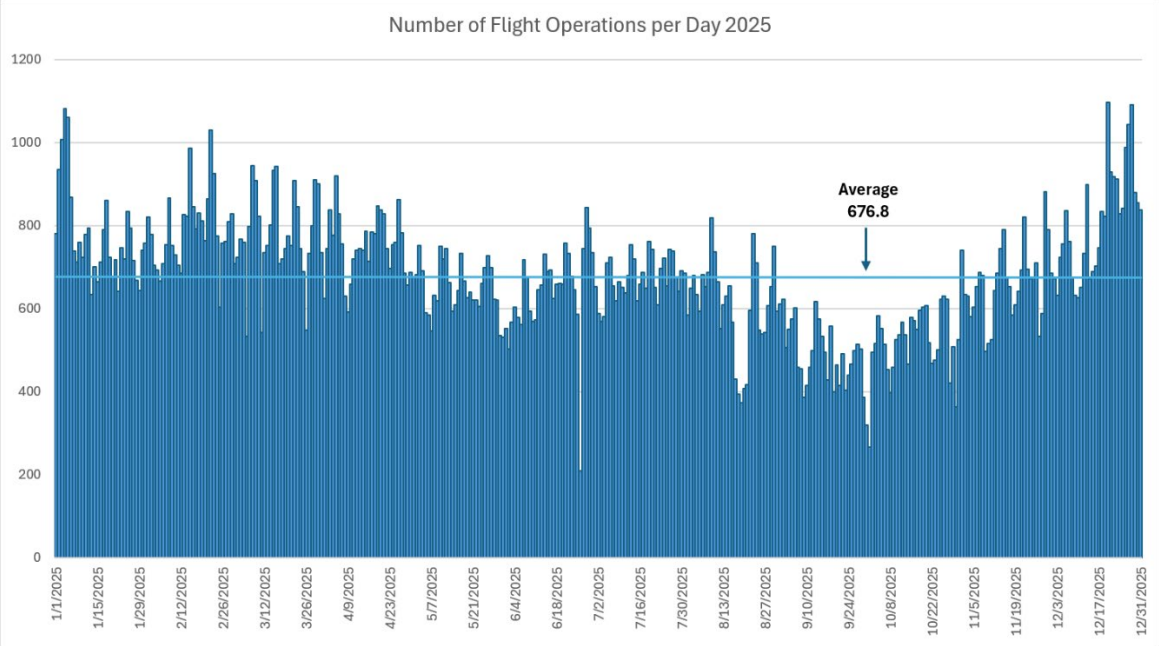


Figure 2-3. New York West FIR, Number of flight operations per day – calendar year 2025

2.2 Reported Large Height Deviations (LHDs)

2.2.1 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 180 reported occurrences reviewed by the scrutiny group for the Mexico and 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 57 validated LHD occurrences during calendar year 2025.

2.2.2 The 57 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 57 validated LHD reports. **Table 2-2** summarizes the reported LHDs categorized by general cause. Three of the 57 reported LHDs listed in Table 2-2 are technical risk events. Two of the technical risk LHD reports are category J, flight crew correctly following the TCAS RA and one 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.

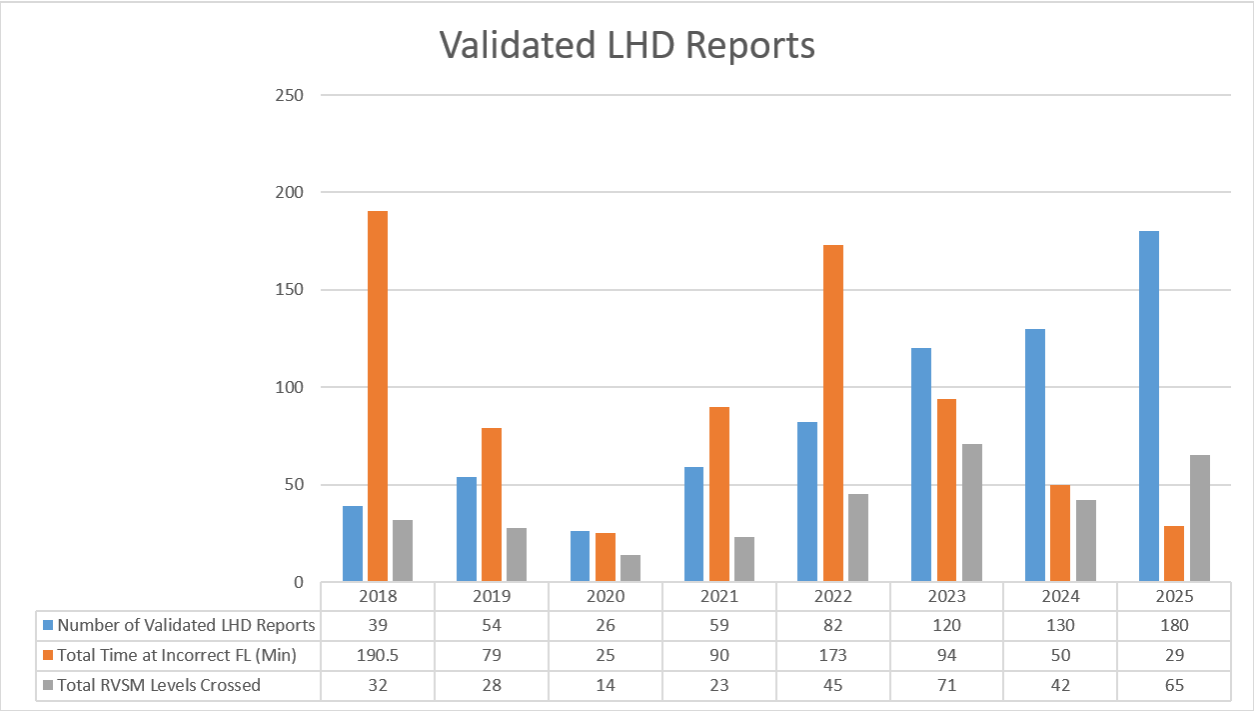
Table 2-1. Validated LHDs – 2025

Month	Count	Duration at Unexpected FL (mins)	Number of Unexpected FLs Crossed
Jan-25	7	2	11
Feb-25	5	8	0
Mar-25	10	3.5	13
Apr-25	5	1	12
May-25	3	1.5	0
Jun-25	3	1	0
Jul-25	8	0	16
Aug-25	6	2	1
Sep-25	4	6	3
Oct-25	3	2	1
Nov-25	2	2	2
Dec-25	1	0	6
TOTAL	**57**	**29**	**65**

Table 2-2. Validated LHD Reports by Cause – 2025

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	7	0	10
B	Flight crew climbing /descending without ATC clearance	16	3	30
D	ATC system loop error; (e.g., ATC issues incorrect clearance or flight crew misunderstands clearance message)	1	0	0
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	15	13.5	9
E2	Negative Coordination in the ATC-unit-to-ATC-unit transfer of control responsibility as a result of human factors issues	10	12.5	0
G	Aircraft contingency event leading to sudden inability to maintain assigned flight level	5	0	16
I	Turbulence or other weather related causes	1	0	0
J	TCAS resolution advisory; flight crew correctly following the resolution advisory	2	0	0
	TOTAL	**57**	**29**	**65**

2.2.3 In 2025, a total of 180 Large Height Deviations (LHDs) were reported, reflecting an increase compared to previous years. This rise corresponds with the associated growth in flight activity. **Figure 2-4** presents a comparison of reported LHDs, their durations, and the flight levels crossed without ATC clearance from 2018 through 2025.



	2018	2019	2020	2021	2022	2023	2024	2025
Number of Validated LHD Reports	39	54	26	59	82	120	130	180
Total Time at Incorrect FL (Min)	190.5	79	25	90	173	94	50	29
Total RVSM Levels Crossed	32	28	14	23	45	71	42	65

Figure 2-4. Validated LHD Reports, calendar years 2018 through 2025

2.3 Significant LHD reports

2.3.1 In 2025, there were 35 reported LHDs associated with errors in ATC transfers, including categories E1 and E2. The largest contributor to vertical risk was an event in NY West airspace involving opposite-direction traffic. After the aircraft's flight plan was deleted from the ATOP system, a replacement flight plan entered through the domestic ATC system was rejected, preventing the flight from being properly coordinated. The aircraft's position report was routed to an error queue, and the aircraft was operating within NY West airspace for approximately four minutes without a correct profile in the ATOP system. The occurrence was assigned LHD category E2, with a secondary category of F, reflecting a coordination error during the ATC transfer associated with a technical issue.

2.3.2 Coordination errors are the primary contributors to vertical operational risk, with category B representing the second largest contributor. There were 16 category B LHDs in 2025, 11 in New York West, 4 in Mexico and 1 in Miami/San Juan FIRs.

2.3.3 There were seven category A events reported in NY West and the Miami/San Juan area, each involving flight levels crossed without clearance. In one event, the pilot confirmed that the aircraft could reach the cleared flight level by the crossing fix and correctly read back the clearance to cross at that altitude. However, the aircraft did not meet the crossing restriction and crossed the fix at a lower altitude than was cleared. ZMA had terminated radar service while the aircraft was still climbing,

without verifying compliance with the crossing restriction. The altitude discrepancy resulted in losses of nonradar separation with three aircraft being worked by ZNY. This event was classified as category A, with a secondary category of E1.

2.4 In order to calculate the vertical collision risk for the CAR airspace designated to NAARMO, the operational risk-bearing LHD events are separated into four areas;

- Houston Oceanic FIR,
- Mexico FIR,
- Miami Oceanic and San Juan FIRs, and
- New York West FIR.

2.4.1 **Table 2-3** 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 2025. The size of the circles in Figure 2-5 represents the vertical collision risk estimate for the reported LHD.

Table 2-3. Validated operational LHDs by area – 2025

Airspace	Number of LHD	Duration at unexpected FL (min)	Number of unexpected FLs crossed
Miami Oceanic/San Juan FIRs	22	14.5	15
New York West FIR	23	5.5	42
Houston Oceanic	1	1	0
Mexico	11	8	8
Total	**57**	**29**	**65**

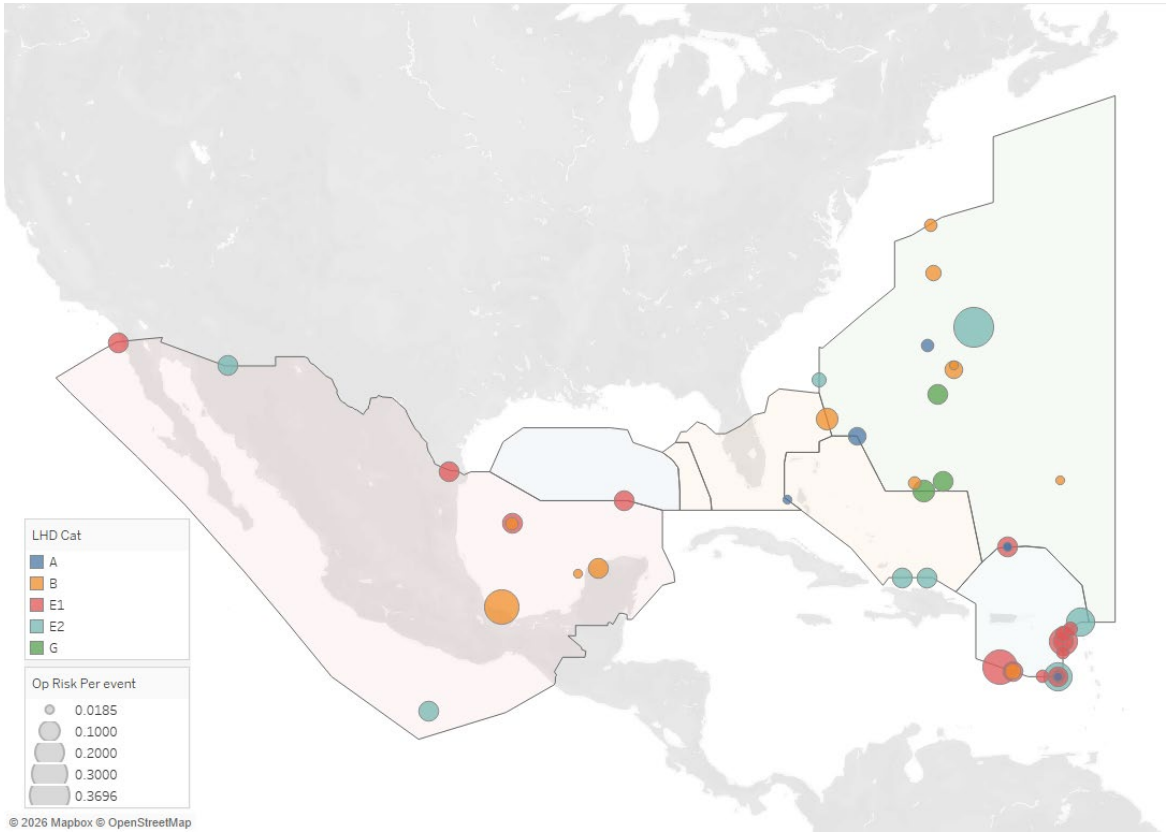


Figure 2-5. Approximate Location of the Risk-bearing LHDs – 2025

2.5 Vertical Collision Risk Estimate

2.5.1 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 TLS. The section also provides information on the sources of data used to estimate risk model parameters.

2.5.2 The internationally agreed TLS for the 1,000-ft vertical separation standard is specified for technical and operational risk separately. The vertical technical risk encompasses the hazards related to turbulence, loss of altitude control, and crew reactions to airborne collision-avoidance system alerts, as well as errors stemming from aircraft altimetry and altitude hold 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

2.5.3 Based on the December 2025 traffic data, the NAARMO estimates approximately 2,876,771 annual flying hours for 2025 in the airspace where RVSM is applied.

2.5.4 The methodology applied in the collision risk calculation for the airspace splits the airspace into four areas specified in paragraph 2.4.

2.5.5 Although the aircraft operations are similar within the four areas, the available ATC surveillance and communications differ. In addition, there are differences in the available traffic data source for the four 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.

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

2.6.1 **Figure 2-6** provides the top aircraft types observed in the December 2025 traffic data by flying hours. The two traffic data sources are maintained in the figure; Mexico, Houston, 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 80 percent of total flying hours observed in the airspace. The Airbus A320 was the leading aircraft type in both Mexico and New York West, while the Boeing 737 MAX 8 (B38M) accounted for the largest percentage of flying hours in Houston Oceanic and the combined San Juan/Miami Oceanic airspace.

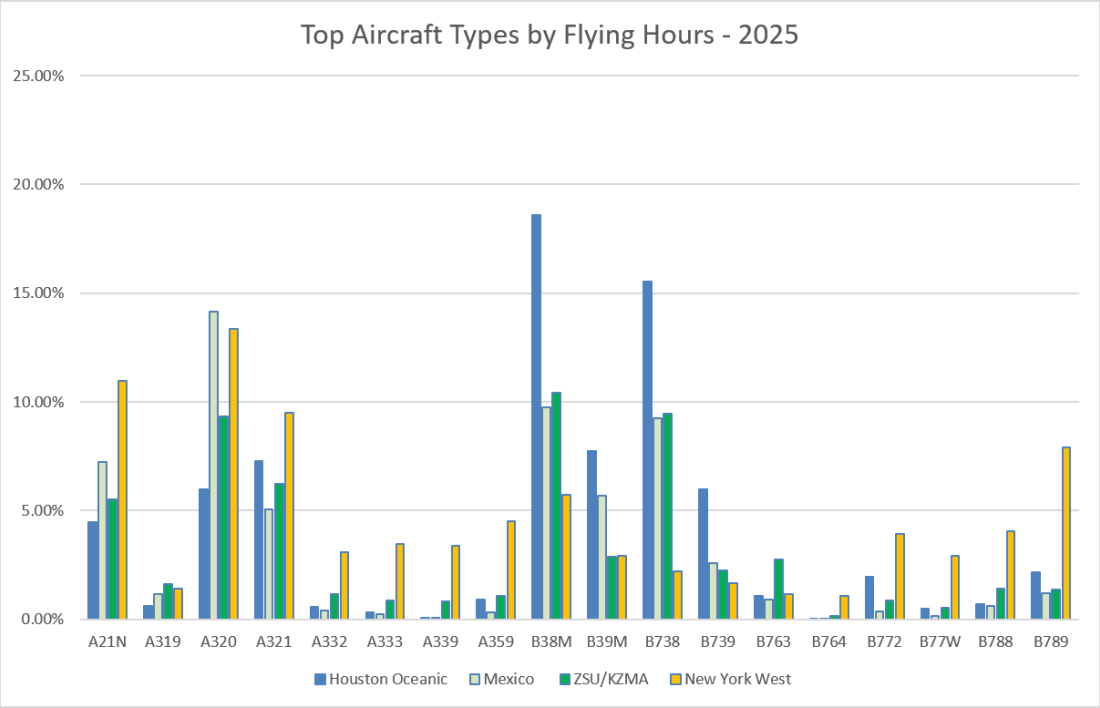


Figure 2-6. Observed Aircraft Types in Terms of Flying Hours in Miami Oceanic/San Juan and New York West Airspace - 2025

2.7 Aircraft Size

2.7.1 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 2025 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 2-4**.

Table 2-4. 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	0.0272 *(165 ft)*	0.0250 *(152 ft)*	0.0077 *(47 ft)*
Mexico	0.0209 *(127 ft)*	0.0188 *(114 ft)*	0.0064 *(39 ft)*
Houston Oceanic	0.0222 *(135 ft)*	0.0198 *(120 ft)*	0.0068 *(41 ft)*

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

2.8.1 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.

2.8.2 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 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.

2.8.3 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.

2.9 Time spent at Unexpected/Incorrect FL

2.9.1 The proportion of flying time spent at incorrect levels, P_i, 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 2025 contain 29 minutes of flying time spent at unexpected flight level.

2.9.2 Table 2-3, provided earlier in this paper, gives the duration at unexpected/incorrect flight level for all 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. **Table 2-5** provides the flying hours and ratios of time spent at unexpected flight levels by area.

Table 2-5. Flying hours and ratios of time spent at unexpected flight levels by area

Area	2025 Annual Flying Hours	Ratio of time spent at unexpected Flight Levels
Mexico FIR	1,766,533	0.5×10^{-5}
Miami/San Juan FIRs	549,888	2.6×10^{-5}
Houston Oceanic FIR	170,831	0.6×10^{-5}
New York West FIR	389,519	1.4×10^{-5}

2.10 Collision Risk Model Parameters

2.10.1 The individual parameters of the models, their definitions, estimates, and sources are given in **Table 2-6**.

Table 2-6. Vertical Collision Risk Model Parameter Estimates - 2025

Term	Definition	Estimate	Source
$P_z(S_z)$	Probability that two aircraft nominally separated by the vertical separation minimum S_z 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
$\overline{\lvert\Delta V\rvert}$	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

2.11 Results and Conclusions

2.11.1 The risk-bearing LHDs are separated based on the location of the event. The risk-bearing LHDs within each area are applied to the estimated flying hours and vertical occupancy values for the corresponding area. **Table 2-7** provides the weighted 2025 estimates of technical and operational vertical risk for each area. The last row in Table 2-7 contains the weighted sum of the risk for the Caribbean FIRs designated to the NAARMO RMA.

Table 2-7. 2025 Vertical Risk Estimates for Caribbean FIRs Designated to the NAARMO RMA ($\times 10^{-9}$ fatal accidents per flight hour (fapfh))

Airspace	Technical	Operational	Overall
New York West	0.014	0.209	0.222
Houston Oceanic	0.005	0.100	0.105
Mexico	0.046	1.477	1.523
Miami Oceanic and San Juan	0.012	2.095	2.107
Total	**0.076**	**3.881**	**3.957**

2.11.2 The estimated technical risk in the RVSM airspace is 0.076×10^{-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.

2.11.3 The operational vertical risk estimate for RVSM airspace is 3.881×10^{-9} fapfh. The sum of this value and the technical risk estimate for airspace is 3.957×10^{-9} fapfh, which **meets the overall safety goal** of 5.0×10^{-9} fapfh.

2.12 Reported LHDs and Corresponding Vertical Risk

2.12.1 **Figure 2-7** shows that coordination errors in categories E1 and E2 account for approximately 66% of the total estimated vertical risk. E1, coordination errors primarily due to human factors, is the largest contributor at 36.43%. E2 events, where no coordination occurred, contribute 29.76%. Category B events, in which flight crews climbed or descended without ATC clearance, account for 21.43%.

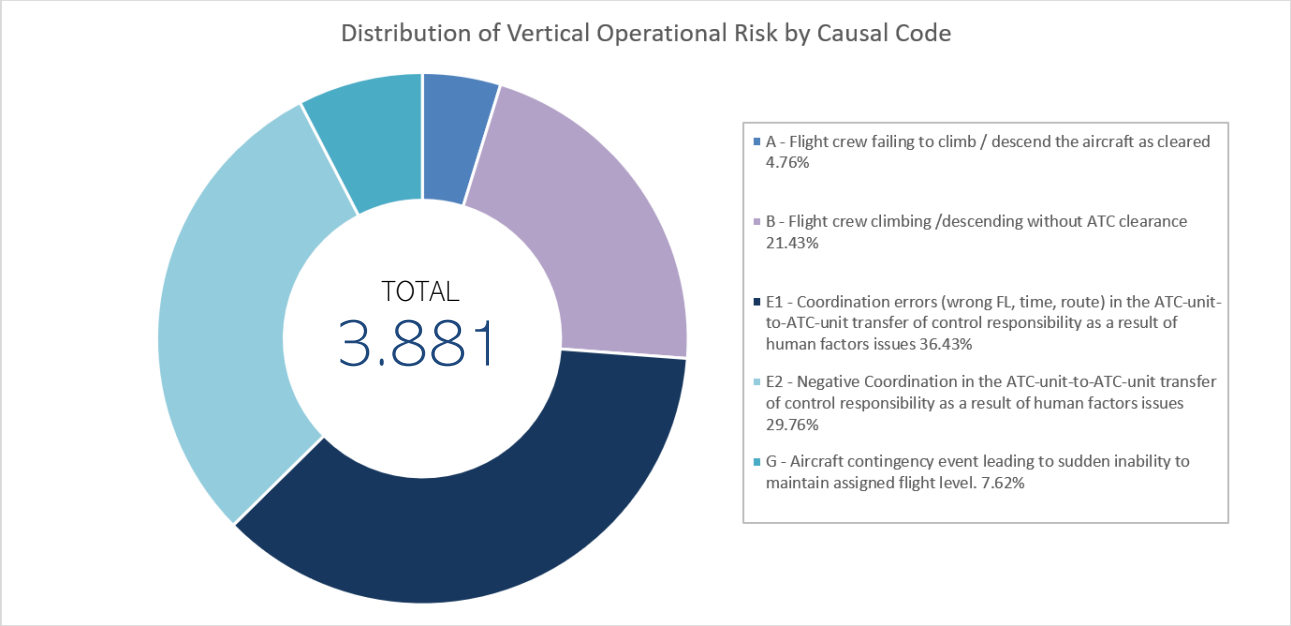


Figure 2-7. Vertical Risk Estimates by LHD Category

2.12.2 **Figure 2-8** presents the estimated vertical risk by LHD category. The vertical risk associated with Category E1 LHD reports is 1.41 × 10^{-9} fapfh, representing the majority of the total vertical risk. The next highest contributor is Category E2.

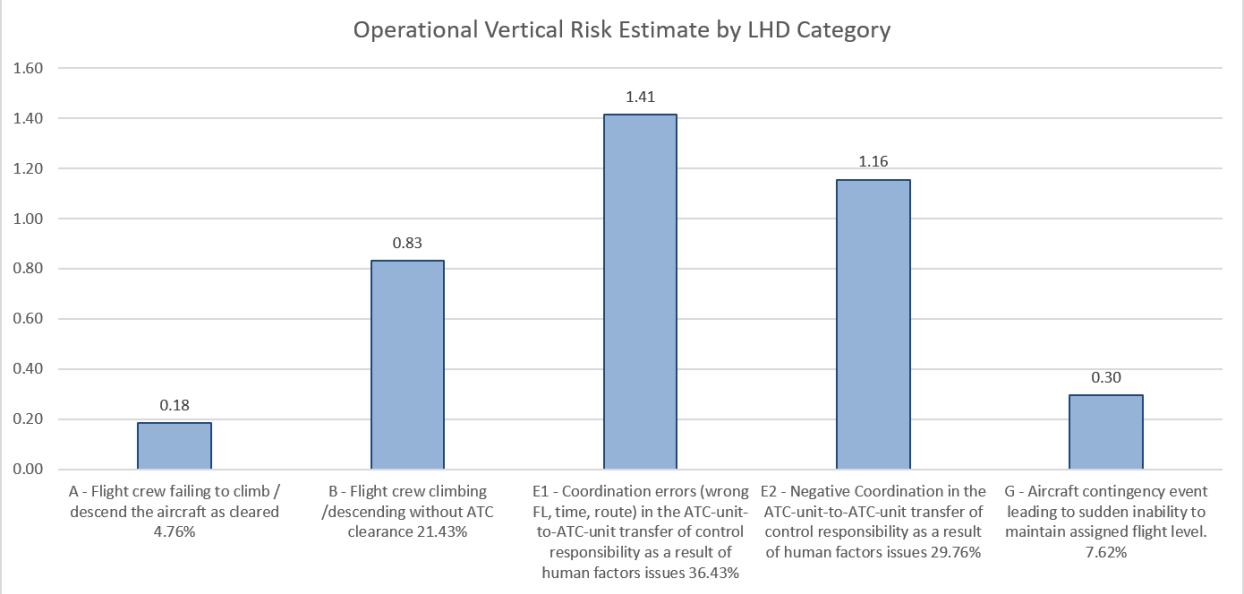


Figure 2-8. Vertical Risk Estimates by LHD Category (× 10^{-9} fatal accidents per flight hour (fapfh))

2.12.3 The estimated vertical risk estimate for 2025, shown in Table 2-7, is a decrease from that estimated for calendar year 2024. The decrease in the vertical risk estimate is directly related to the time spent at unexpected flight levels as shown in Figure 2-4. For comparison, **Table 2-8** and **Figure 2-9** provide the vertical risk estimates for calendar years 2022 through 2025.

Table 2-8. Vertical Risk Estimates for the Caribbean FIRs Designated to the NAARMO RMA (× 10^{-9} fatal accidents per flight hour (fapfh))

Calendar Year	Technical Risk	Operational Risk	Overall Vertical Risk Estimate	TLS
2022	0.08	13.0	13.1	5
2023	0.07	8.7	8.75	5
2024	0.08	4.92	5.00	5
2025	0.08	3.88	3.96	5

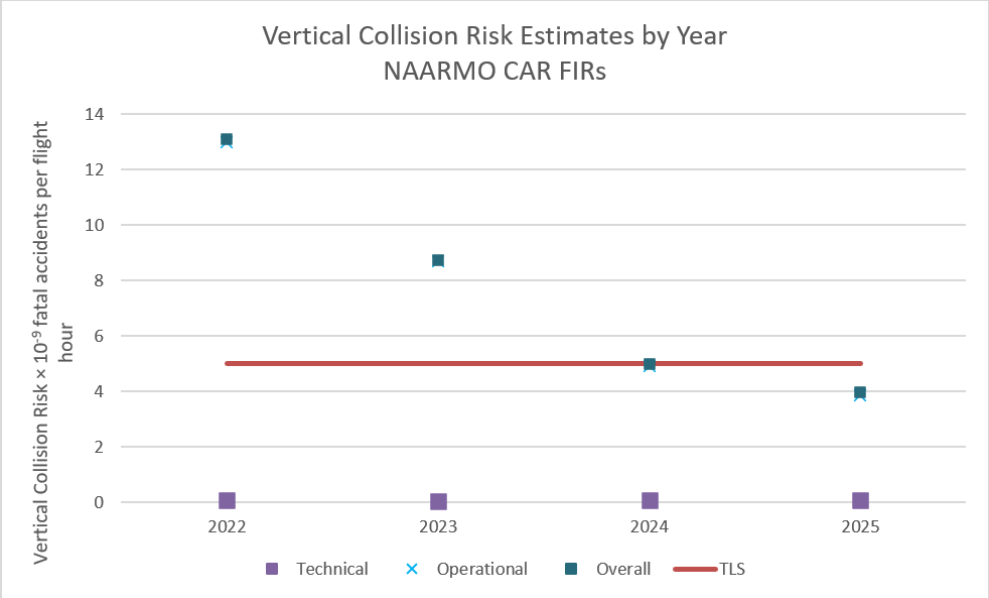


Figure 2-9. Vertical Risk Estimates for Caribbean FIRs Designated to the NAARMO RMA (× 10^{-9} fatal accidents per flight hour (fapfh))

3. Action by the meeting

3.1 The GTE is invited to:

a) note and discuss the information provided, and

b) request both ATC-units involved in category E LHD occurrences continue to share information to improve validation results.

— END —