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CAR/SAM Regional Planning and Implementation Group (GREPECAS)

WORKING PAPER

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of the CAR/SAM Regional Planning and Implementation Group (GREPECAS)
Asynchronous (virtual): 9 to 25 September 2026
In person: 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 MEXICO AIRSPACE – 2025

(Presented by 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 Mexico Airspace. 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 data from the Mexico Area airspace for calendar year 2025. This report contains a summary of LHD reports received by the NAARMO for the calendar year 2025. There are thirty-four reported LHDs in calendar year 2025. This report also contains an estimate of the vertical collision risk. The vertical collision risk estimate for Mexico area airspace is 2.48×10^{-9} fatal accidents per flight hour, which satisfies the target level of safety (TLS) of 5.0×10^{-9} fapfh.

Action:	Note and discuss the information provided.
Strategic Objectives:	• Safety • Air Navigation Capacity and Efficiency
References:	• ICAO Doc 9574 • ICAO Doc 9937

1. Introduction

1.1 Mexico implemented the Reduced Vertical Separation Minimum (RVSM) between flight level 290 and flight level 410, inclusive, in all sovereign and delegated Mexico airspace on January 20, 2005. The North American Aviation Trilateral States, Mexico, Canada, and the United States, agreed to implement the RVSM on the same date in all North American airspace.

1.2 The North American Approvals Registry and Monitoring Organization (NAARMO), a service delegated by the Federal Aviation Administration (FAA) 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 North American airspace.

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. The resulting vertical risk estimate includes portions of Gulf of Mexico (GOMEX), Mexico domestic, Mexico offshore/oceanic, and Mexico-USA corridor airspace.

2 Discussion

2.1 Traffic Data

2.2 The NAARMO has access to the Federal Aviation Administration's (FAA's) Traffic Flow Management System (TFMS), which includes aircraft observations in Mexico airspace. These data include flight observations from four area control centers (ACCs) – Mexico City (MMEX), Monterrey (MMTY), Mazatlán (MMZT), and Mérida (MMID). Each traffic movement record within the TFMS data sample contains the date, time, latitude, longitude, flight level, aircraft flight identification, aircraft type, origin airport and the destination airport. The TFMS data contain frequent position estimates for each flight – a position estimate is provided approximately once a minute. **Figure 2-1** presents the aircraft positions provided in the TFMS data for 27 December 2025.

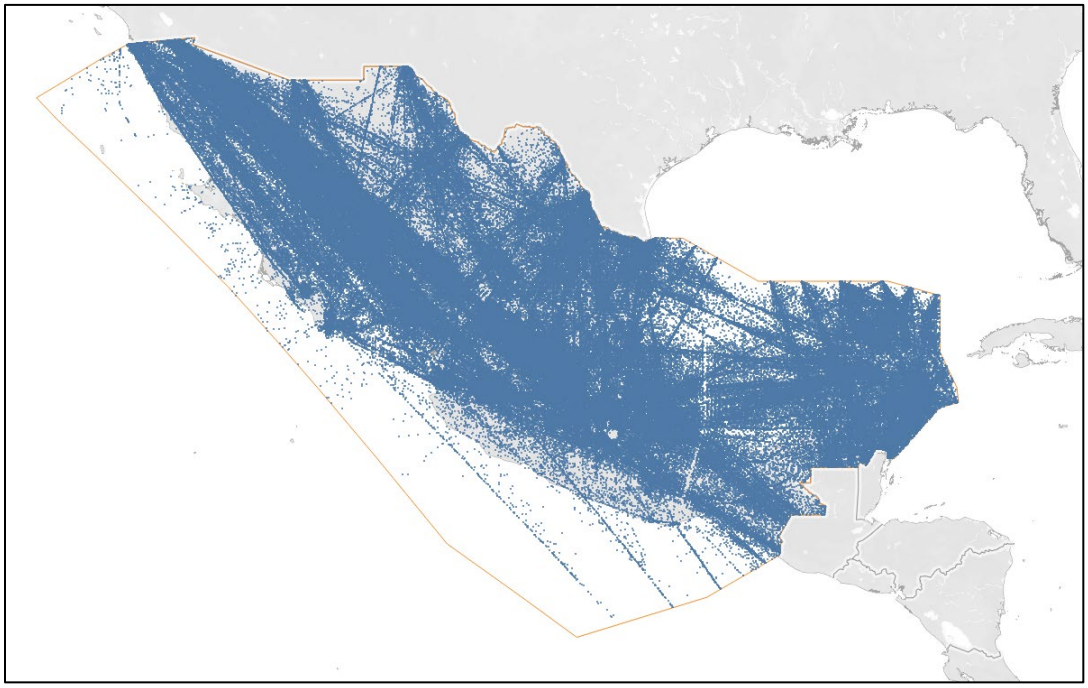


Figure 2-1. Aircraft Position Data Provided in TFMS – 27 December 2025

2.3 The traffic flows observed within Mexico are based on traffic volume and patterns. The traffic flows include a portion of the Gulf of Mexico (GOMEX), Mexico offshore, and Mexico domestic airspace. These traffic flows are depicted in **Figure 2-2** below.

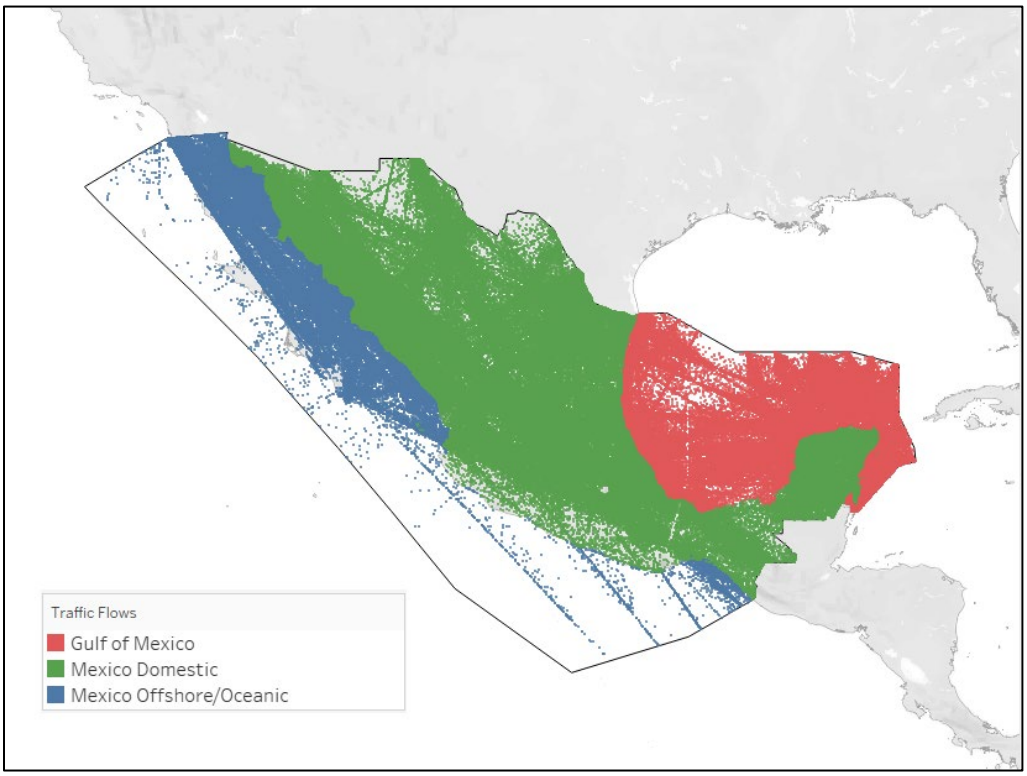


Figure 2-2. Mexico Traffic Flows

2.4 The portion of GOMEX airspace (red) considered in this analysis includes flight segments that cross into the Houston Oceanic Flight Information Region (FIR) over the Gulf of Mexico. Mexico offshore airspace (blue) refers to observed air traffic near the Pacific Ocean where radar surveillance may not be available. Mexico domestic airspace (green) includes all aircraft operations not considered GOMEX or offshore airspace. Radar surveillance is available in Mexico domestic airspace.

2.5 **Figure 2-3** shows the number of flights by day in the Mexico TFMS data for December 2025. The horizontal orange line represents the average number of flight operations per day observed in the data sample. The average number of flight operations per day observed in the TFMS data is **4,024 flights per day**, this is an increase in the average 3,844 flights per day observed in December 2024.

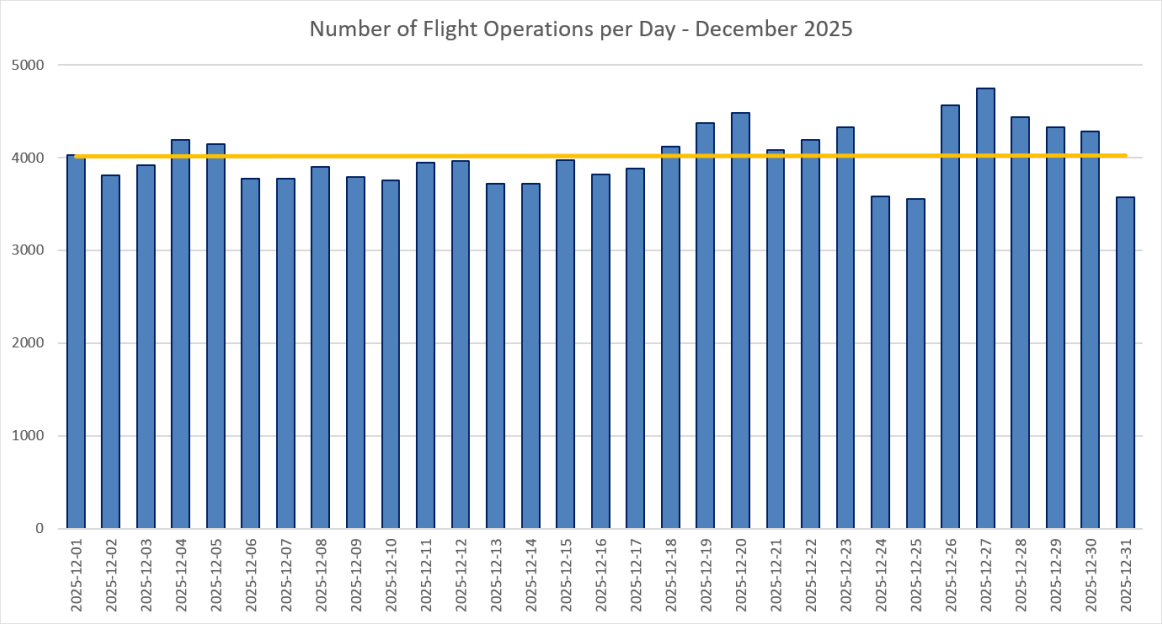


Figure 2-3. Number of Flight Operations per Day – December 2025

2.6 Reported Large Height Deviations (LHDs)

2.7 The NAARMO received 34 LHD reports in this dataset. Most were associated with the Mérida (MMID) FIR, which accounted for 30 reports (88.2%). Mexico City (MMEX) and Mazatlán (MMZT) each accounted for one report (2.9%), as did the Albuquerque (ZAB) and Los Angeles (ZLA) sectors. No reports were listed for Monterrey (MMTY).

2.8 After review, nine reported occurrences were determined to be risk-bearing events. **Table 2-1** contains a summary of all the qualifying reported LHDs by month. The last row of Table 2-1 shows there were six minutes of flying time at incorrect flight levels and eight flight levels crossed without clearance.

Table 2-1. Qualifying Reported LHDs for Mexico and GOMEX Airspace – 2025

Month	Count	Duration at Incorrect FL (min)	Number of FLs Crossed
January 2025	1		
February 2025	1	1	
March 2025	1	3	
April 2025	1		2
May 2025	1	1	
June 2025	1		
July 2025	1		5
August 2025	0		
September 2025	0		
October 2025	2	1	1

Month	Count	Duration at Incorrect FL (min)	Number of FLs Crossed
November 2025	0		
December 2025	0		
Total 2025	**9**	**6**	**8**

2.9 Four of the seven LHD reports involve the flight crew climbing/descending without ATC clearance (LHD categories B). **Table 2-2** summarizes the qualifying LHD reports by cause. The seven LHD reports are attributable to vertical operational risk.

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

LHD Category Code	LHD Category Description	Number of LHD	Duration at Incorrect FL (min)	Number of FLs Crossed
B	Flight crew climbing/descending without ATC clearance	4	3	8
E1	Coordination errors in the ATC -to-ATC transfer of control responsibility as a result of human factors issues (incorrect FL, time or route)	3	2	0
E2	Negative coordination in the ATC-to-ATC transfer of control responsibility	2	1	
	TOTALS	**9**	**6**	**8**

2.10 **Figure 2-4** shows the approximate aircraft locations of the 9 reported LHDs in 2025 attributed to operational risk. The size of the circle represents the vertical risk estimate for each reported LHD and the color represents the LHD category assigned to the event.



Figure 2-4. Risk Bearing Qualifying LHD Reports – 2025

2.11 Observed LHD Trends

2.11.1 Errors in ATC Coordination

2.11.2 The trend in LHDs involving ATC coordination is decreasing for calendar year 2025. There were 5 reported coordination errors in 2025, compared to 14 reported coordination errors in 2024.

2.11.3 **Figure 2-5** shows the numbers of reported LHDs attributed to coordination. In the figure, E1 indicates the transfer of control was successful, however the receiving ATC-unit observed the aircraft on either a different flight level, time or routing than expected. Category E2 indicates negative transfer of control, the receiving ATC-unit observed the aircraft without a transfer from the sending ATC-unit. Category F indicates there were technical reasons for the transfer error.

2.11.4 **Figure 2-6** shows the vertical collision risk estimate by LHD category for calendar year 2025. From the data provided in the figure, the reported LHDs attributed to aircraft maneuvering without clearances have the highest contribution towards the risk estimate.

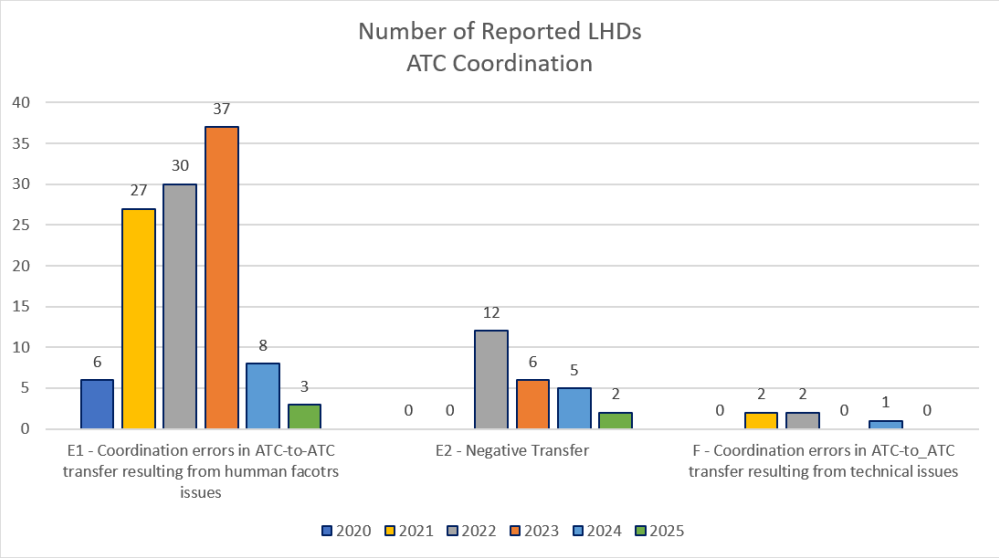


Figure 2-5. Reported ATC Coordination Events – 2025

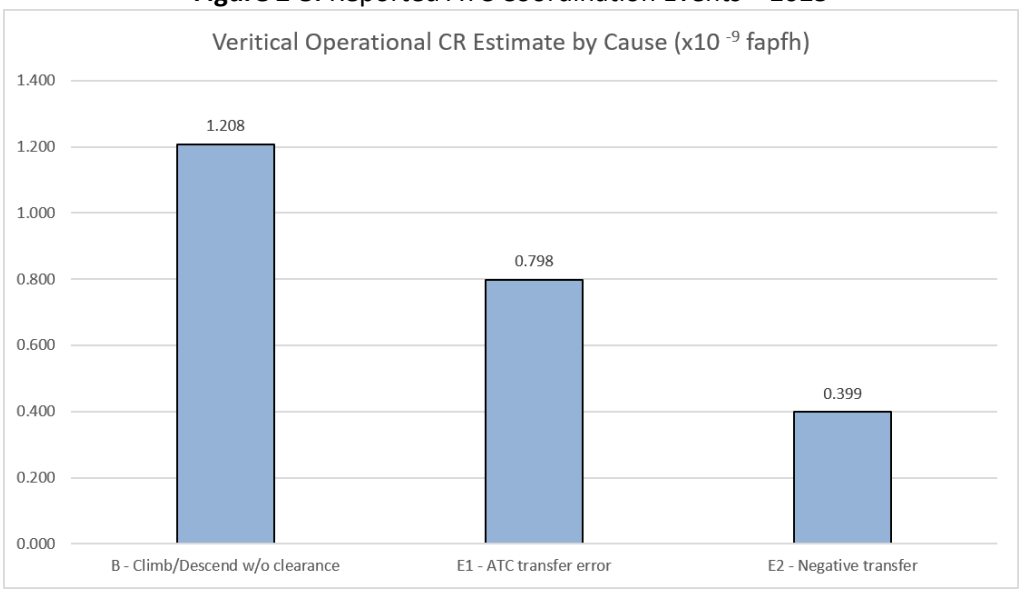


Figure 2-6. Vertical Collision Risk Estimate by LHD Category – 2025

2.12 Communication Failure Reports

2.13 During calendar year 2025, there were 23 reported occurrences specifying communication failures between ATC and the aircraft. There were no indications of pilot deviation from either cleared route or altitude during the period of communication failure. Because there were no indications of deviation from cleared route or altitude, there is no contribution towards the estimate of vertical collision risk from these occurrences.

2.14 After remaining consistent in 2023 and 2024, reported communication failures declined in 2025, decreasing by 23% from the previous year. **Figure 2-7** shows the observed trend.

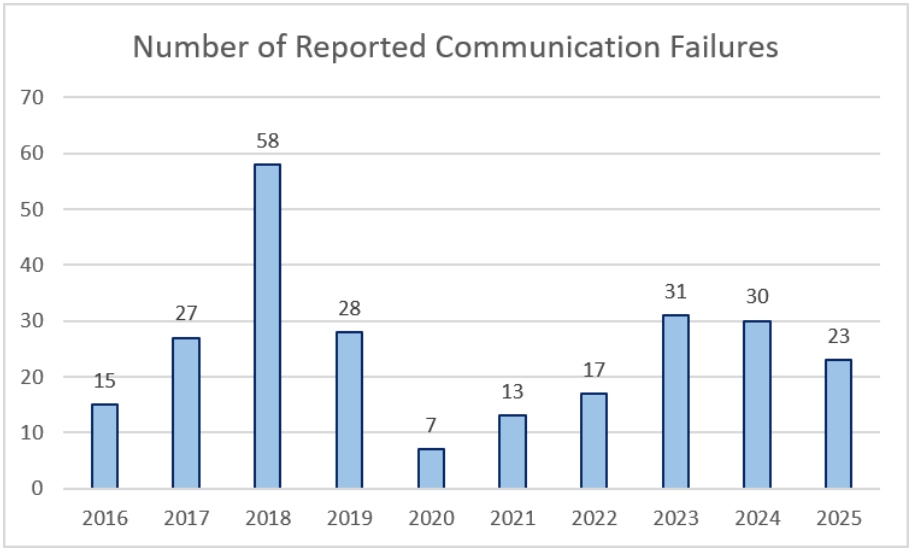


Figure 2-7. Numbers of reported communication failures by year

2.15 **Figure 2-8** shows the locations associated with the reported communication failures in calendar year 2025. The 23 reported events were distributed among multiple airspace fixes. The size of each marker represents the total duration of communication failures associated with that fix, while the marker color represents the number of reported events. Overall, the results indicate that communication failures were geographically dispersed, with no single fix accounting for a substantial concentration of events. The total duration during which ATC could not communicate with an aircraft was 553 minutes, representing a 32% decrease from the 809 minutes reported in calendar year 2024. The number of reported communication failures also decreased, declining from 30 events in 2024 to 23 events in 2025, a reduction of approximately 23%.

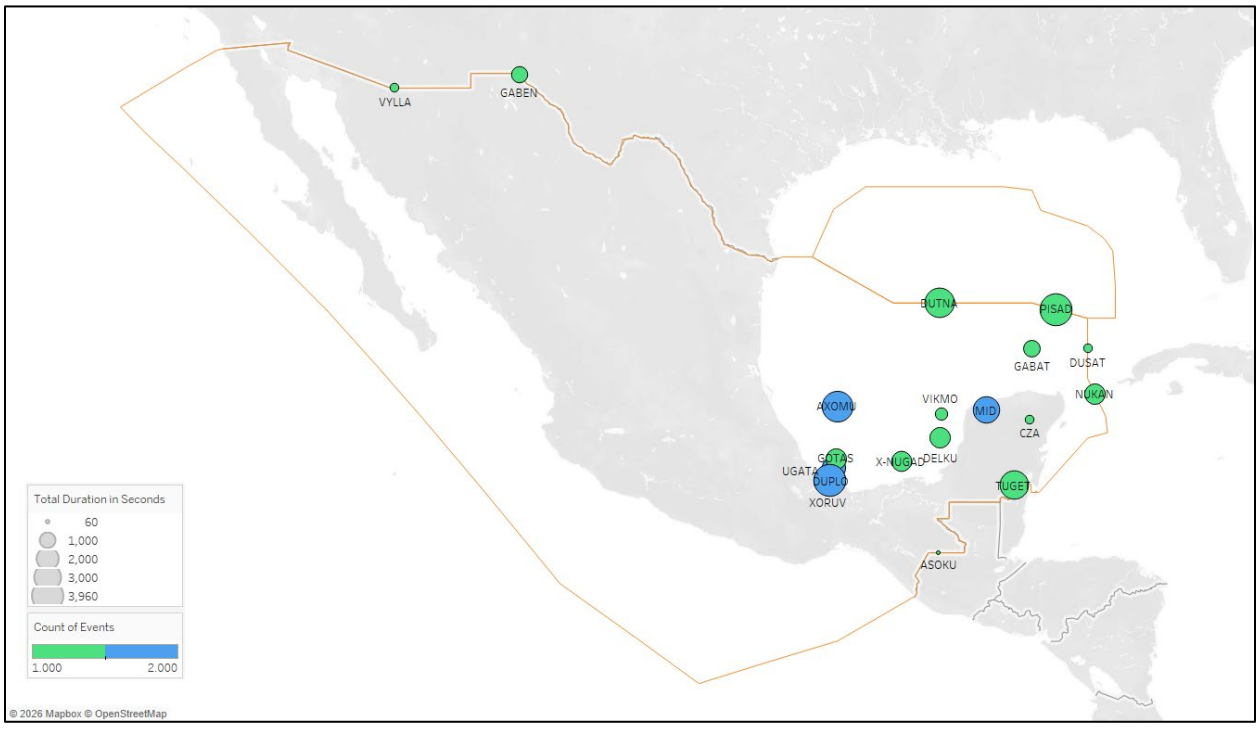


Figure 2-8. Reported Communication Failures – 2025

2.16 **Table 2-3** provides the observed operators involved with the reported communication failure reports from 2025.

Table 2-3. List of operators involved with reported communication failures – 2025

Operator	Count
AMERICAN AIRLINES	2
UNITED	2
VIVA AEROBUS	2
TYSON	1
SPIRIT	1
COPA	1
DELTA	1
SOUTH WEST	1
GEMINI	1
TAMPA	1
ALASKA AIRLINES	1
AVIANCA	1
VOLARIS	1
JETSAL	1
VOLARIS COSTA RICA	1
LATAM CARGO	1
AEROMEXICO	1
International General Aviation	3

2.17 Vertical Collision Risk Estimation

2.18 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.

2.19 The internationally agreed TLS for the 1,000-ft vertical separation standard is specified for technical and operational risk separately. The vertical technical risk is 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 is 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

2.20 Based on the December 2025 TFMS data, the NAARMO estimates approximately 1,733,292 annual flying hours for 2025 in Mexico airspace where the RVSM is applied. This is an increase from 1,525,127 annual flying hours for 2024.

2.21 Aircraft Types

2.22 **Figure 2-9** provides the top 20 aircraft types observed in December 2025 TFMS traffic data by flying hours. The aircraft types listed in Figure 2-8 account for approximately 80% of total flying hours observed in the traffic sample.

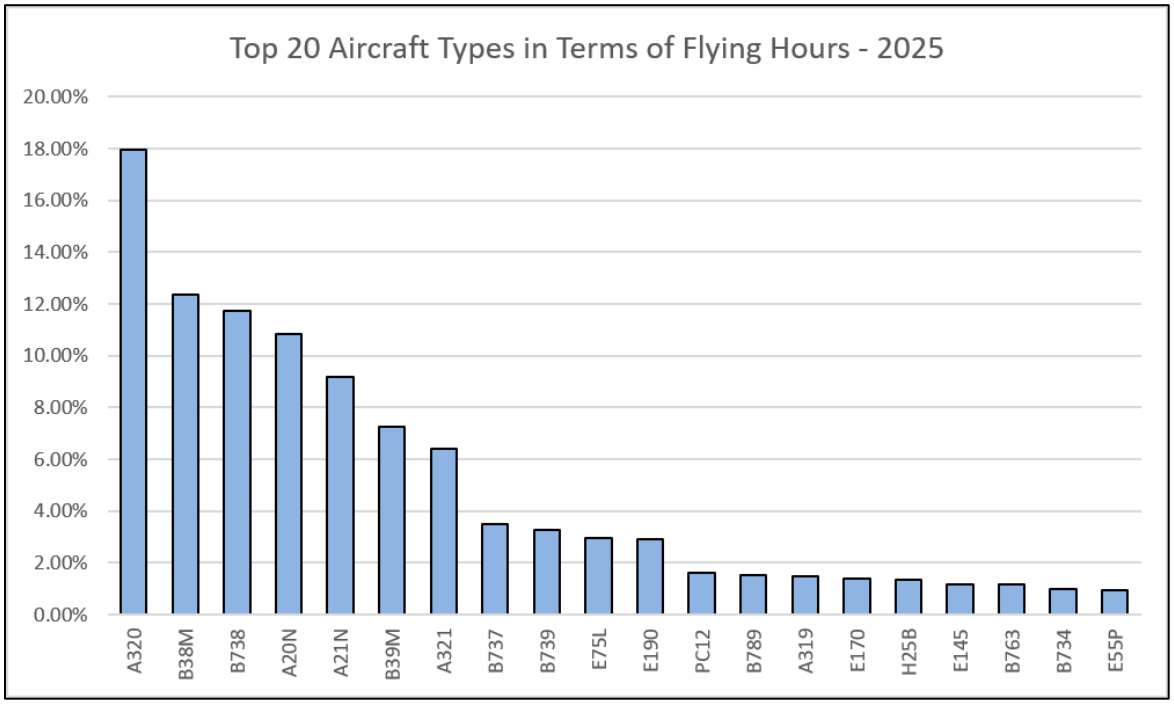


Figure 2-9. Observed Aircraft Types in Terms of Flying Hours - 2025

2.23 Aircraft Size

2.24 The collision risk model parameters related to the aircraft size are: length, wingspan, and height. These parameters are estimated directly from December 2025 TFMS 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 2025

Length λ_x (NM)	Wingspan λ_y (NM)	Height λ_z (NM)
0.0209 *[127.03 ft]*	0.0188 *[114.5 ft]*	0.0064 *[38.9 ft]*

2.25 Same-Direction, Opposite-Direction, and Crossing-Route Vertical Occupancies

2.26 The TFMS data is used to estimate the number of vertical aircraft passings per hour for each traffic flow. The traffic is separated into separate flows to account for areas of low and high traffic densities. **Table 2-5** provides the same and opposite direction vertical occupancies by traffic flow.

Table 2-5. Vertical Occupancies by Traffic Flow - 2025

Traffic Flow	Same Direction Vertical Occupancy	Opposite Direction Vertical Occupancy
GOMEX	0.088	0.218
Offshore/Oceanic	0.000	0.001
Domestic	0.032	0.071

2.27 Crossing route vertical occupancy is estimated by the number of vertically proximate aircraft pairs on routes that cross at a specific angle, ϑ. Both mathematical considerations and experience in previous safety assessments have established that the vertical occupancy estimated for pairs of aircraft at intersections of routes is generally less by an order of magnitude than that for pairs of aircraft on the same route at adjacent flight levels. Thus, it is expected that the collision risk estimate for crossing routes will be below the risk for same route adjacent flight levels. The number of crossing-route aircraft pairs for the calendar year 2025 is 395,229 aircraft pairs. This value is similar to that observed in the 2024 traffic data sample.

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

2.29 Contributory factors to RVSM technical risk include; 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. Therefore, the estimation of the vertical overlap probability must account for contributions to vertical error arising from all of these sources.

2.30 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 are obtained from either the Automatic Dependent Surveillance – Broadcast (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.

2.31 The NAARMO estimate for the probability of vertical overlap for aircraft pairs operating on adjacent flight levels, $P_z(1{,}000)$, 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.

2.32 Time spent at Unexpected FL

2.33 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 Mexico airspace during the period when the wrong-flight-level events occurred. The qualifying LHDs for calendar year 2025 contain 5 minutes of flying time spend at unexpected flight level. This time is split into the identified traffic flows based on the location provided in the reported LHD. **Table 2-6** provides the breakdown of reported LHD duration and flight levels crossed by identified traffic flow.

Table 2-6. Reported LHD Duration and Flight Levels Crossed by Traffic Flow

Traffic Flow	Reported LHD duration (min)	Number of FLs crossed without clearance
GOMEX	5	3
Offshore/Oceanic	1	0
Mexico Domestic	0	5
TOTAL	**6**	**8**

2.34 Collision Risk Model Parameters

2.35 The individual parameters of the models, their definitions, estimates, and sources are given in **Table 2-7**. These parameters are common to the vertical risk estimate for all identified traffic flows.

Table 2-7. Vertical Collision Risk Model Parameter Estimates

Term	Definition	Estimate	Source
$P_z(Sz)$	Probability that two aircraft operating on the same route 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 route and flight level are in vertical overlap.	0.42	Value used in the US CONUS vertical risk estimate
$Py(0)$	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.	0.0209 NM	Estimated using December 2025 Mexico TFMS sample
λy	Average aircraft wingspan.	0.0188 NM	Estimated using December 2025 Mexico TFMS sample
λz	Average aircraft height with undercarriage retracted.	0.0064 NM	Estimated using December 2025 Mexico TFMS sample
$\overline{\lvert \Delta V \rvert}$	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

2.36 Results and Conclusions

2.37 **Table 2-8** provides 2025 estimates of technical and operational vertical risk by traffic flow for the airspace.

Table 2-8. 2025 Vertical Risk Estimates for RVSM Airspace (× 10^{-9} fapfh)

Traffic Flow	Technical Risk Estimate	Operational Risk Estimate	Total Risk Estimate
GOMEX	0.03	2.28	2.31
Offshore/Oceanic	0.00	0.00	0.00
Mexico Domestic	0.04	0.13	0.17
TOTAL	**0.07**	**2.41**	**2.48**

2.38 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 target for technical height-keeping performance.

2.39 The total risk estimate for the RVSM airspace, 2.48 × 10^{-9} fapfh, which satisfies the overall safety goal of 5.0 × 10^{-9} fapfh.

2.40 **Table 2-9** and **Figure 2-10** provide the overall vertical risk estimates for calendar years 2015 – 2025 for the Mexico Area RVSM airspace. The increase in the vertical risk estimate for calendar year 2018 occurred because of three long duration reported LHDs. In 2019, the calculation method was modified to account for the different traffic flows. The traffic flows were identified and used to estimate associated parameters in the risk model. For example, the risk calculated for a reported LHD that occurred in a low traffic density, non-radar section of airspace will have a smaller risk value compared to an LHD within a high traffic density area.

Table 2-9. Overall Vertical Risk Estimates for Mexico Area RVSM Airspace

Calendar Year	Vertical Collision Risk Estimate (×10^{-9} fapfh)
2015	4.8
2016	4.8
2017	3.2
2018	16.7
2019	4.92
2020	1.51
2021	5.91
2022	4.97
2023	5.14
2024	3.05
2025	2.48

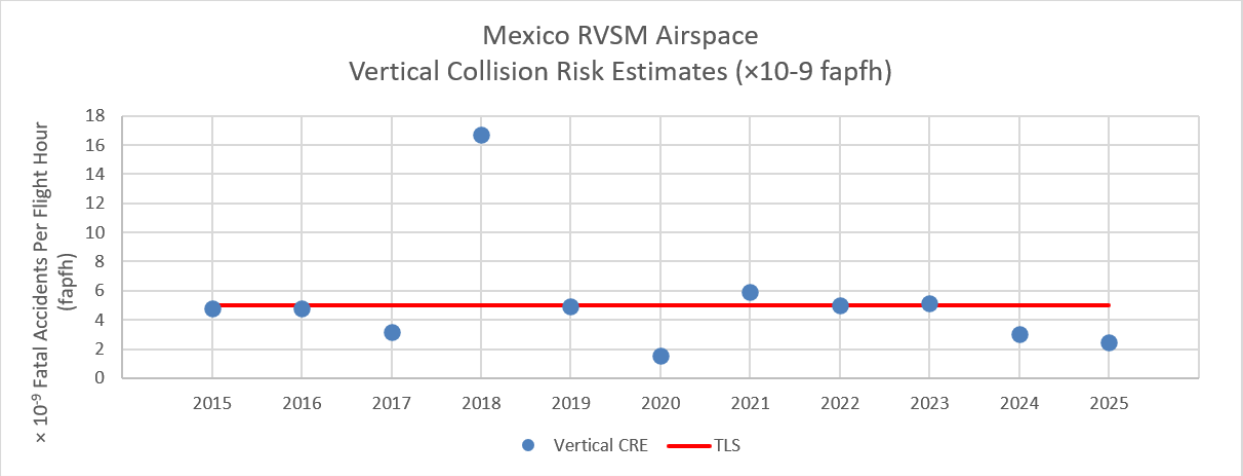


Figure 2-10. Vertical Collision Risk Estimates, Mexico Area RVSM Airspace 2015 - 2025

2.41 The vertical risk estimate for **Mexico RVSM airspace**, calculated from the sum of the first three rows in Table 2-8, is **2.48×10^{-9} fapfh**. This value **meets** the overall safety target of 5.0×10^{-9} fapfh for Mexico RVSM airspace.

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 —