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Mexico City, Mexico, 5 to 9 August 2024

Agenda Item 3: **Review of the Results of Large Height Deviation (LHD) Analysis 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)

MEXICO AREA AIRSPACE VERTICAL SAFETY MONITORING REPORT – 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 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 2023. This report contains a summary of LHD reports received by the NAARMO for the calendar year 2023. There are fifty-six reported LHDs in calendar year 2023. This report also contains an estimate of the vertical collision risk. The vertical collision risk estimate for Mexico area airspace exceeds the target level of safety (TLS) value of 5.0 × 10-9 fatal accidents per flight hour.

Action:	Suggested action is included in Section 3.
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 WJH FAA Technical Center, fulfills 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 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. 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 (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 10 December 2023.

2.3 The different colors displayed in Figure 2-1 represent traffic flow areas of operations observed in the TFMS data. The observed aircraft positions are placed into one of the traffic flows. Portions of an individual flight operation might appear in multiple traffic flows.

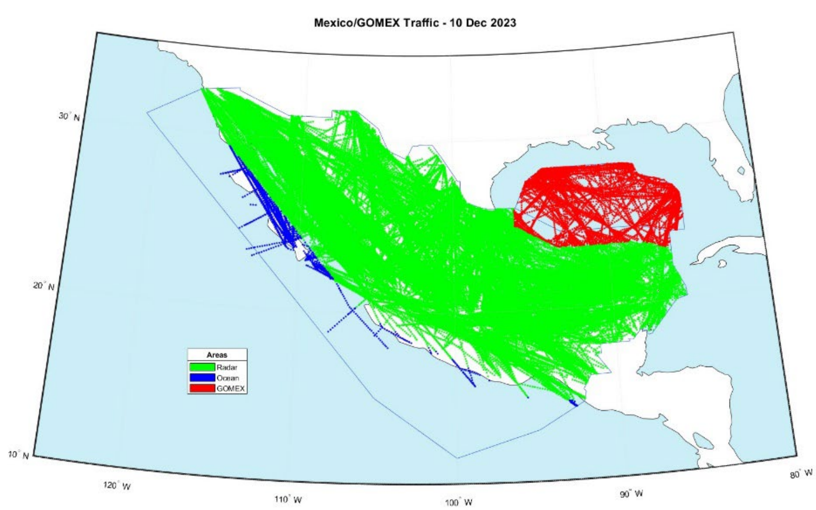

Figure 2-1. Aircraft Position Data Provided in TFMS – 10 December 2023

2.4 The traffic flows are based on traffic volume and patterns. The traffic flows include a portion of the Gulf of Mexico, Mexico offshore/oceanic, and Mexico domestic airspace. These traffic flows are described below.

2.5 The portion of GOMEX airspace considered in this analysis includes flight segments that cross the Houston Oceanic Control Area/flight information region - Mexico Control area/flight information region boundary over the Gulf of Mexico. In Figure 2-1, these are the operations shown in the red.

2.6 Mexico offshore/oceanic airspace refers to observed air traffic over the Pacific Ocean where radar surveillance may not be available. In Figure 2-1, these operations are shown in **blue**.

2.7 Mexico domestic airspace includes all aircraft operations not considered GOMEX or oceanic airspace. Radar surveillance is available in domestic airspace, in Figure 2-1 these aircraft positions are shown in green.

2.8 Figure 2-2 shows the number of flights by day in the Mexico TFMS data for December 2023. 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 3,468 flights per day, this is a slight increase in the average 3,409 flights per day observed in December 2022.

Figure 2-2. Number of Flight Operations per Day – December 2023

2.9 Reported Large Height Deviations (LHDs)

2.10 The NAARMO receives LHD reports from Mexico and USA ARTCCs. There were 107 reported occurrences during calendar year 2023. After review, fifty-six reported occurrences were determined to be risk-bearing events. The set of fifty-six reports includes five reports from Houston ARTCC. Table 2-1 contains a summary of all the qualifying reported LHDs by month. The last row of Table 2-1 shows there were thirty-five minutes of flying time at incorrect flight levels and zero flight levels crossed without clearance.

Table 2-1. Qualifying Reported LHDs for Mexico and GOMEX Airspace – 2023

Month	Count	Duration at Incorrect FL (min)	Number of FLs Crossed
January 2023	3	1	7
February 2023	4	2	2
March 2023	4	3.2	0
April 2023	12	8.5	0
May 2023	12	8	9
June 2023	4	2.5	0
July 2023	12	5.3	16
August 2023	1	1	0
September 2023	1	0	1
October 2023	0	0	0
November 2023	3	3	2
December 2023	0	0	0
Total 2023	**56**	**34.5**	**37**

2.11 Forty-three of the 56 LHD reports involve coordination errors in the ATC transfer (LHD categories E1, E2 and F). Table 2-2 summarizes the qualifying LHD reports by cause.

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

LHD Category Code	LHD Category Description	Number of LHD	Duration at Incorrect FL (min)	Number of FLs Crossed
A	Flight crew failing to climb/descend the aircraft as cleared	3	2	2
B	Flight crew climbing/descending without ATC clearance	3	0.5	3
C	Flight plan followed rather than ATC clearance	2	0	8
D	ATC system loop error; (e.g. ATC issues incorrect clearance or flight crew misunderstands clearance message)	1	0	1
E1	Coordination errors in the ATC -to-ATC transfer of control responsibility as a result of human factors issues (incorrect FL, time or route)	37	27	2

LHD Category Code	LHD Category Description	Number of LHD	Duration at Incorrect FL (min)	Number of FLs Crossed
E2	Negative coordination in the ATC-to-ATC transfer of control responsibility	6	5	0
F	Coordination errors in the ATC -to-ATC transfer of control responsibility as a result of an outage or technical issues	0	0	0
G	Aircraft contingency event leading to sudden inability to maintain assigned flight level (e.g. pressurization failure, engine failure)	4	0	21
	TOTALS	**56**	**34.5**	**37**

2.12 Figure 2-3 shows the approximate aircraft locations the 56 reported LHDs in 2023. The size of the circle represents the vertical risk estimate for each reported LHD.

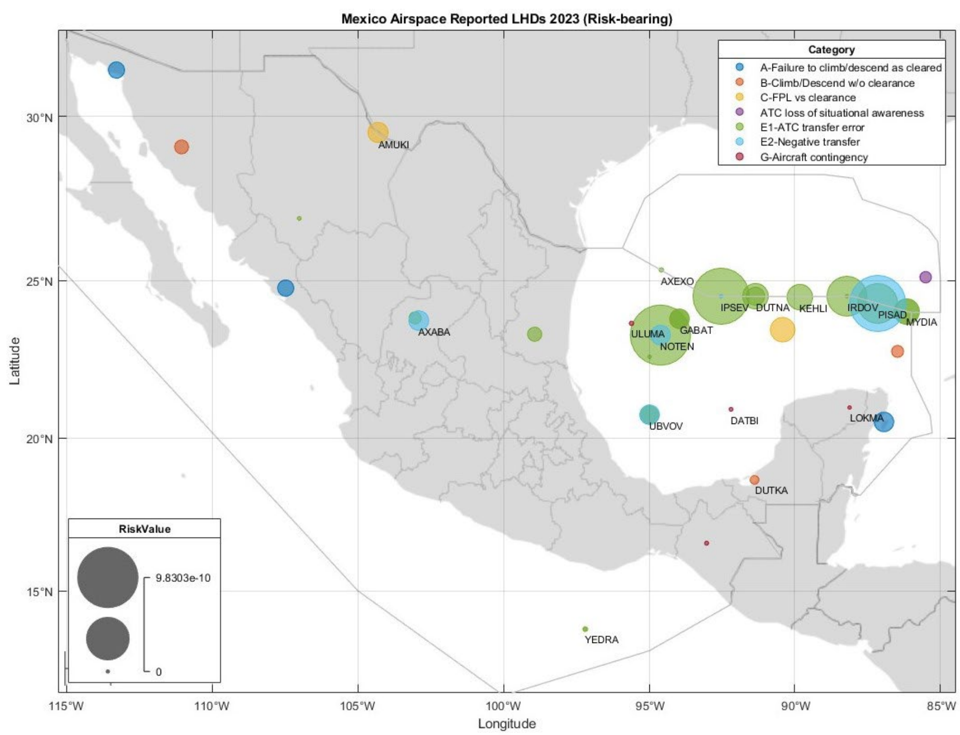

Figure 2-3. Qualifying LHD Reports – 2023

2.13 The reported LHDs are summarized by the traffic flows described in paragraph 2.4. The traffic flows identified include GOMEX, offshore/oceanic, Mexico domestic, and Mexico-USA corridor airspace.

2.14 The Mexico-USA corridor airspace is the airspace consisting of the Control Area (CTA)/Flight Information Region (FIR) between:

2.14.1 Los Angeles and Mazatlán Centers;

2.14.2 Albuquerque and Mazatlán Centers;

2.14.3 Albuquerque and Monterrey Centers; and

2.14.4 Houston and Monterrey Centers

2.15 GOMEX Airspace

2.15.1 There were 9 reported LHDs for the GOMEX traffic flow in 2023. The details of these reported occurrences were communicated via emails and via teleconference. Eight of these reported LHDs involved category E LHDs, there were 6 category E1 LHDs reported and 1 category E2 LHDs reported. Category 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.

2.16 Offshore/Oceanic Airspace

2.17 There were 4 reported LHDs within the oceanic traffic flow in 2023. All of these reported LHDs were errors in the ATC transfer of aircraft. There were 4 category E1 occurrences.

2.18 Mexico Domestic Airspace

2.18.1 There were 36 reported LHDs for Mexico airspace in 2023. Twenty-five of these reported LHDs involved errors in the ATC transfer of control responsibility between adjacent FIRs; 22 reports were classified as E1 and 3 classified as E2. The total duration associated with the category E LHDs was 17.2 minutes. Many of the category E reports occurred at the NOTEM airspace fix, a boundary fix between the MMID and MMTY ACCs. As a result of these occurrences, MMID and MMTY ACCs amended their letter of agreement (LOA) and it was signed on 15 September 2023. There have been zero repeat occurrences at NOTEM since the modified LOA was signed.

2.18.2 There were three category B LHDs reported in 2023. These events contributed 30 seconds of LHD duration, and 3 flight levels crossed without clearance.

2.18.3 There were three category A LHDs reported in 2023. These events contributed 2 minutes of LHD duration, and 2 flight levels crossed without clearance.

2.18.4 There were 4 reported LHDs involving contingency events (category G) where the pilot needed to descend due to equipment failure, there was zero LHD duration on whole flight levels and 21 flight levels crossed for these occurrences.

2.19 Mexico-USA Corridor Airspace

2.19.1 There were 7 reported LHDs affecting the Mexico-USA corridor airspace in calendar year 2023. Six of these occurrences involved errors in the ATC transfer of control responsibility between adjacent FIRs; 5 reported LHDs were category E1 and 1 LHD report was category E2.

2.19.2 There was one reported LHD with assigned category D, ATC system loop error, and a sub-category J, TCAS RA. In this occurrence ATC cleared a 1000 ft climb to an aircraft that eventually caused an TCAS RA with another aircraft. Moments after issuing the climb clearance, the controller realized the mistake and turned both aircraft, but the ATC action was too late to avoid the TCAS RA. For this occurrence, the contribution towards vertical operational risk is the incorrect climb clearance. Therefore, one flight level crossed is accounted for in the vertical risk estimate.

2.19.3 There were two reported occurrences where the data block was dropped erroneously by the receiving ATC unit. In these cases, the aircraft proceeds through the airspace as a limited data block on the controller screen. The available surveillance, both radar and ADS-B, update the ATC automation system which still contains the flight plan although the data block was dropped. These cases are not ideal; however, the surveillance information continues to update the conflict alert functions. The ATC unit is working with the automation system engineers to modify the ATC display for limited data blocks within the system. It is noted that these automation changes will take time to implement, in the meantime the ATC units have updated the ATC refresher training related to these occurrences. Two corrective action plans (CAPs) have been opened because of these occurrences.

2.20 Observed Trends

2.21 Figure 2-4 shows the observed trend in the number of reported LHDs related to ATC causes from 2018 through 2023. The data show the increase in the number of reported LHDs due to ATC causes in calendar year 2023.

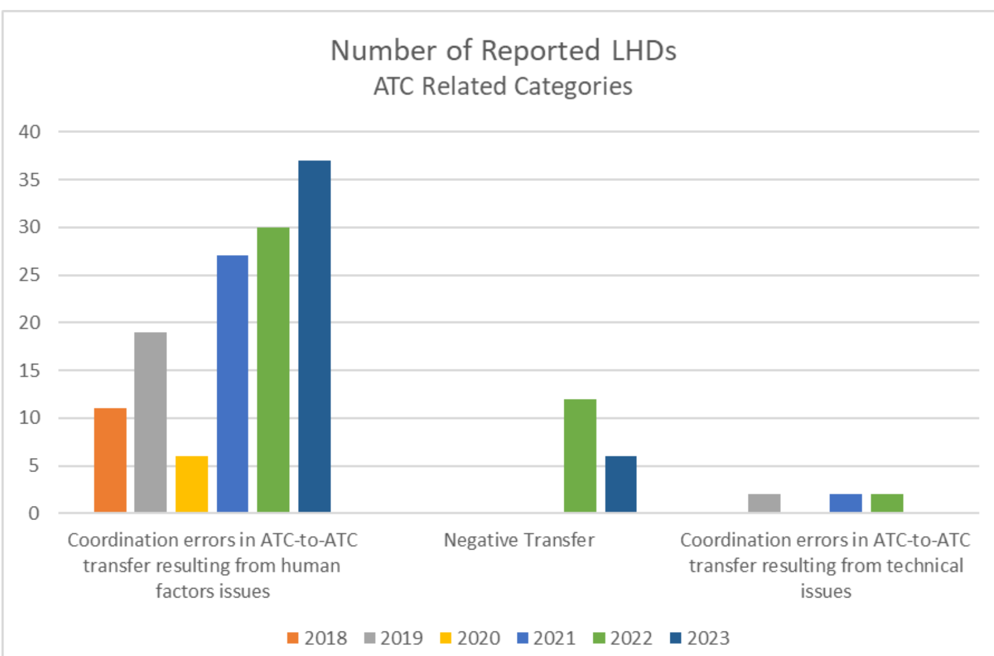

Figure 2-4. Observed Trend in Number of Reported LHDs – ATC Related Causes

2.22 Communication Failure Reports

2.23 In calendar year 2023, there were 31 reported occurrences specifying communication failures between ATC and the aircraft. Twenty-nine reported occurrences from Mexico and two reported occurrences from US ARTCCs. 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.

2.24 The trend in the number of communication failure reports has increased from the previous year. Figure 2-5 shows the observed trend

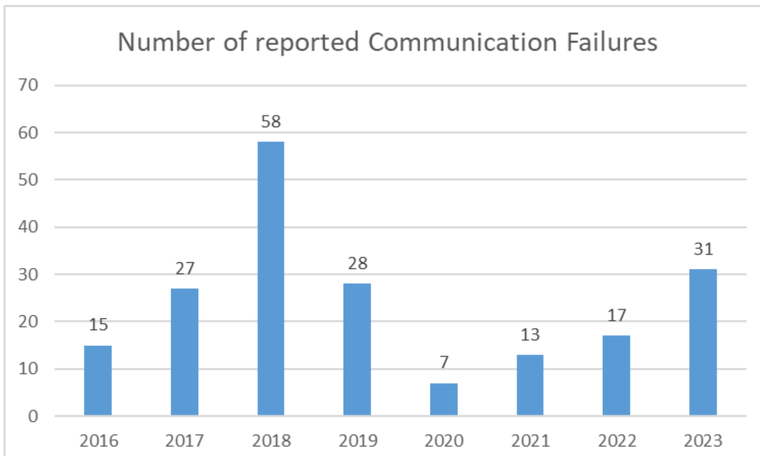

Figure 2-5. Numbers of reported communication failures by year

2.25 Figure 2-6 shows the locations associated with the reported communication failures. There were five reports at the airspace fix MATOL and four reports at the airspace fix LIDAM. The number of minutes in which ATC could not communicate with an aircraft was 827 minutes in calendar year 2023. This is an increase from calendar year 2022 where there were 508 minutes in which ATC could not communicate with an aircraft.

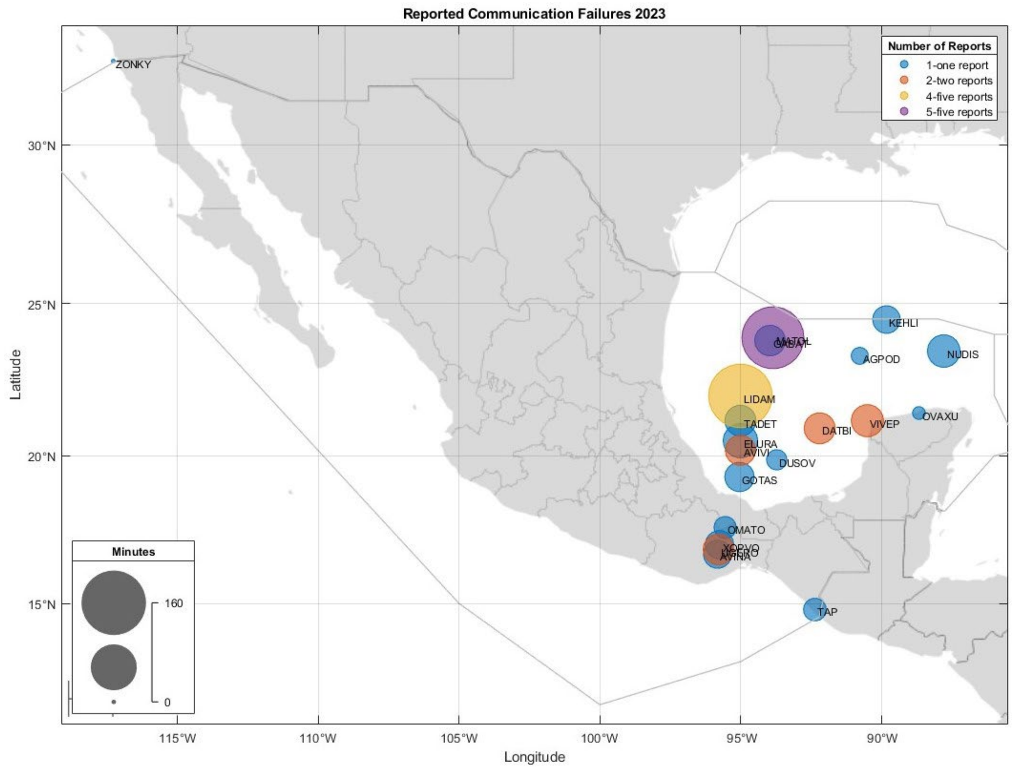

Figure 2-6. Reported Communication Failures – 2023

2.26 There were five international general aviation (IGA) aircraft and twenty-six commercial aircraft operators involved in the reported communication failure reports from 2023.

2.27 Vertical Collision Risk Estimation

2.28 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.

2.29 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 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 109 flying hours, and, simultaneously,
- collision risk due to aircraft height-keeping systems does not exceed 2.5 fatal accidents in 109 flying hours.

2.30 Based on the December 2023 TFMS data, the NAARMO estimates approximately 1,650,294 annual flying hours for 2023 in Mexico airspace where the RVSM is applied. Table 2-4 shows the flying hours within each identified traffic flow. Since a collision due to the loss of 1,000-ft vertical separation is assumed to result in two fatal accidents, the TLS can be expressed as 2.5 fatal midair collisions due to all causes in 109 flying hours.

Table 2-4. Flying Hours by Traffic Flow – 2023

Traffic Flow	2023 Flying hours	Proportion of Traffic
GOMEX	341,585	20.70%
Offshore/Oceanic	13,783	0.84%
Domestic	1,145,951	69.44%
Mexico-USA Corridor	148,975	9.03%
Total	**1,650,294**	**100%**

2.31 Mexico 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:

2.32 $N_{az}=N_{az}(same)+N_{az}(opp)+N_{az}(cross)$ (1)

2.33 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 on the same, opposite and crossing routes, respectively due to the loss of vertical separation between aircraft at adjacent flight levels.

2.34 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.

2.35 Aircraft Types

2.36 Figure 2-7 provides the top 25 aircraft types observed in the December 2023 TFMS traffic data by flying hours. The aircraft types listed in Figure 2-5 account for 85 percent of total flying hours observed in the traffic sample.

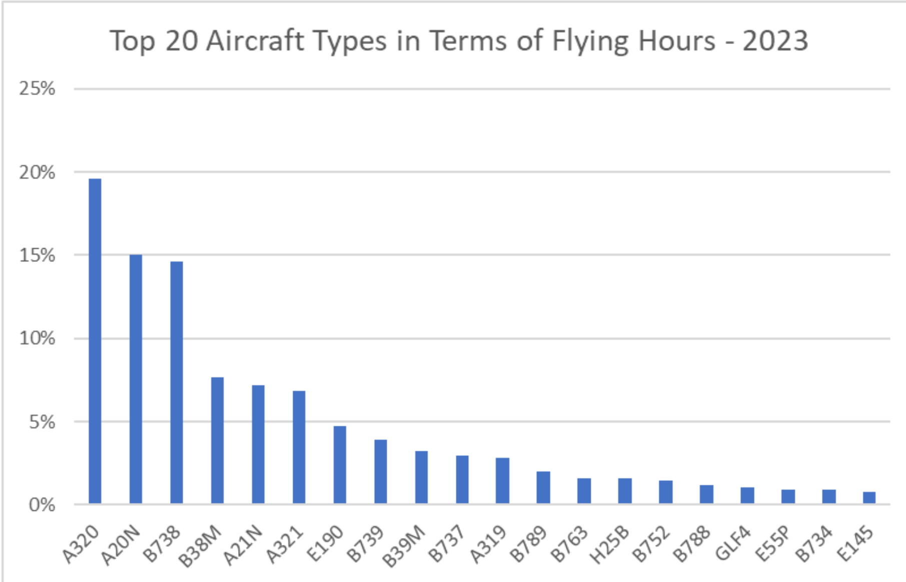

Figure 2-7. Observed Aircraft Types in Terms of Flying Hours - 2023

2.37 Aircraft Size

2.38 The collision risk model parameters related to the aircraft size are: length, wingspan, and height. These parameters are estimated directly from the December 2023 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 2-5.

Table 2-5. CRM Parameter Estimates for Aircraft Size

Length λ_x (NM)	Wingspan λ_y (NM)	Height λ_z (NM)
0.0213 *[129.4 ft]*	0.0188 *[114.3 ft]*	0.0064 *[39.2 ft]*

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

2.40 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 2-6 provides the same and opposite direction vertical occupancies by traffic flow.

Table 2-6. Vertical Occupancies by Traffic Flow - 2023

Traffic Flow	Same Direction Vertical Occupancy	Opposite Direction Vertical Occupancy
GOMEX	0.094	0.247
Offshore/Oceanic	0.000	0.001
Domestic	0.029	0.055
Mexico-USA Corridor	0.063	0.195

2.41 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 2023 is 317,062 aircraft pairs. This value is roughly equivalent to that observed in the 2022 traffic data sample.

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

2.43 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.

2.44 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.

2.45 The NAARMO estimate for the probability of vertical overlap for aircraft pairs operating on adjacent flight levels, Pz(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, Pz(0),used in the estimation of vertical operational risk is 0.42.

2.46 Time spent at Unexpected FL

2.47 The proportion of flying time spent at incorrect levels, Pi, 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 2023 contain 34.5 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 2-7 provides the breakdown of reported LHD duration and flight levels crossed by identified traffic flow.

Table 2-7. Reported LHD Duration and Flight Levels Crossed by Traffic Flow

Traffic Flow	Reported LHD duration (min)	Number of FLs crossed without clearance
GOMEX	6	2
Offshore/Oceanic	4.3	0
Mexico Domestic	19.7	34
Mexico-USA Corridor	4.5	1
TOTAL	**34.5**	**37**

2.48 Collision Risk Model Parameters

2.49 The individual parameters of the models, their definitions, estimates, and sources are given in Table 2-8. These parameters are common to the vertical risk estimate for all identified traffic flows.

Table 2-8. 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 *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 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.	0.0208 NM	Estimated using December 2023 Mexico TFMS sample
λy	Average aircraft wingspan.	0.0184 NM	Estimated using December 2023 Mexico TFMS sample
λz	Average aircraft height with undercarriage retracted.	0.0063 NM	Estimated using December 2023 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

Term	Definition	Estimate	Source
$\overline{\lvert V \rvert}$	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

2.50 Results and Conclusions

2.51 Table 2-9 provides 2023 estimates of technical and operational vertical risk by traffic flow for the airspace.

Table 2-9. 2023 Vertical Risk Estimates for RVSM Airspace (× 10^{-9} fapfh)

Traffic Flow	Technical Risk Estimate	Operational Risk Estimate	Total Risk Estimate
GOMEX	0.04	2.73	2.77
Offshore/Oceanic	0.00	0.01	0.01
Mexico Domestic	0.03	2.33	2.36
Mexico-USA Corridor	0.01	0.82	0.83
TOTAL	**0.08**	**5.89**	**5.97**

2.52 The estimated technical risk in the RVSM airspace is 0.08 × 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.

2.53 The total risk estimate for the RVSM airspace, 5.97 × 10-9 fapfh, exceeds the overall safety target of 5.0 × 10-9 fapfh. A major contribution towards the vertical collision risk estimate were the ATC coordination occurrences categories E1 and E2. Figure 2-8 shows the contribution towards the vertical collision risk estimate by LHD category, together, categories E1 and E2 account for 89% of the risk estimate. Many of the category E reports occurred at the NOTEM airspace fix, a boundary fix between the MMID and MMTY ACCs. The reported E1 and E2 LHDs over NOTEM account for 19% of the vertical collision risk estimate for the airspace in 2023. As a result of these occurrences, MMID and MMTY ACCs amended their letter of agreement (LOA) and it was signed on 15 September 2023. There have been zero repeat occurrences at NOTEM since the modified LOA was signed.

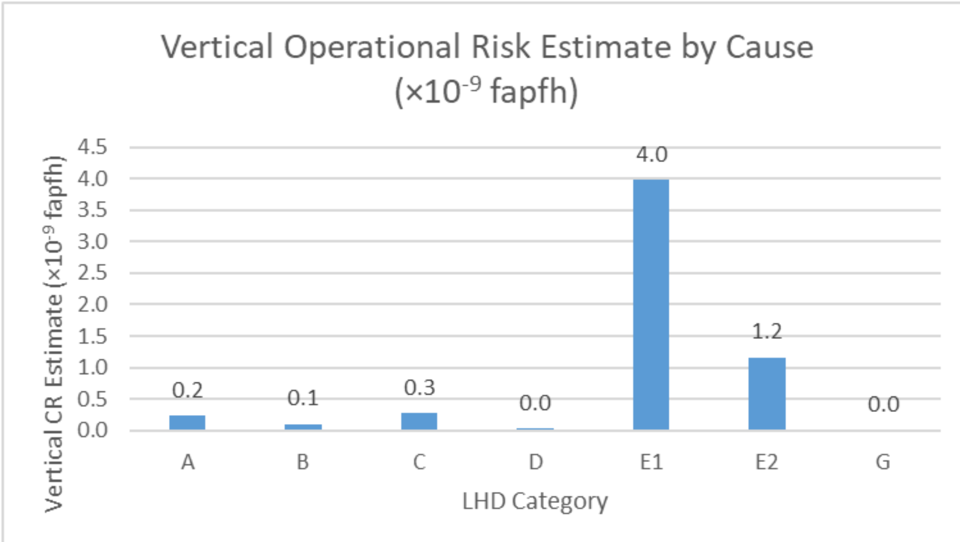

Figure 2-8. Vertical Collision Risk Estimates by LHD Category - 2023

2.54 Mexico RVSM Airspace

2.55 Table 2-10 and Figure 2-9 provide the overall vertical risk estimates for calendar years 2015 – 2023 for the Mexico Area RVSM airspace, excluding the Mexico-USA corridor 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 2-10. 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	12.21
2023	5.97

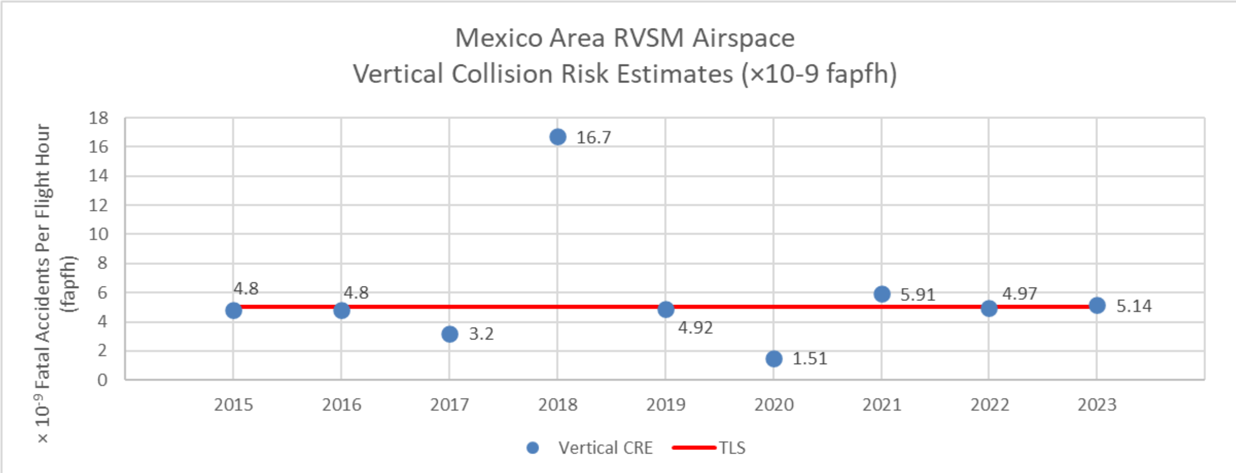

Figure 2-9. Vertical Collision Risk Estimates, Mexico Area RVSM Airspace 2015 - 2023

2.56 The vertical risk estimate for Mexico RVSM airspace, calculated from the sum of the first three rows in Table 2-9, is 5.14 × 10-9 fapfh. This value exceeds the overall safety target of 5.0 × 10-9 fapfh for Mexico RVSM airspace.

3 Suggested Action

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 —