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Working Group Meeting
(GTE/23)**

Lima, Peru, 11 to 15 September 2023

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

MEXICO Area Airspace Vertical Safety Monitoring Report – 2022

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 2022. This report contains a summary of LHD reports received by the NAARMO for the calendar year 2022. There are forty-eight reported LHDs in calendar year 2022. 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:	Note and discuss the information provided.
<i>Strategic Objectives:</i>	<ul style="list-style-type: none">• Safety• Air Navigation Capacity and Efficiency
<i>References:</i>	<ul style="list-style-type: none">• 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 2022. 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 17 December 2022.

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.

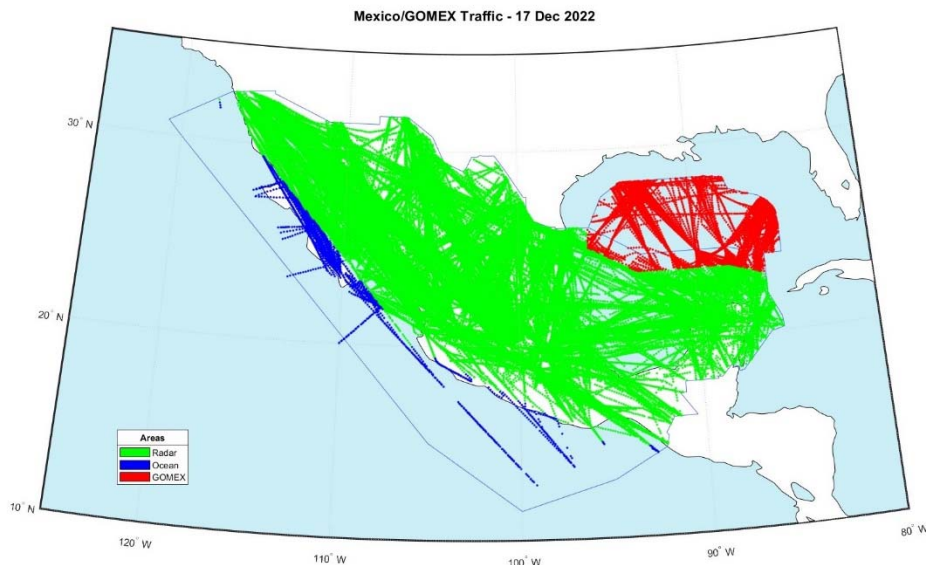


Figure 2-1. Aircraft Position Data Provided in TFMS – 17 December 2022

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 2022. 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 **3,409 flights per day**, this is an increase in the average 3,166 flights per day observed in December 2021.

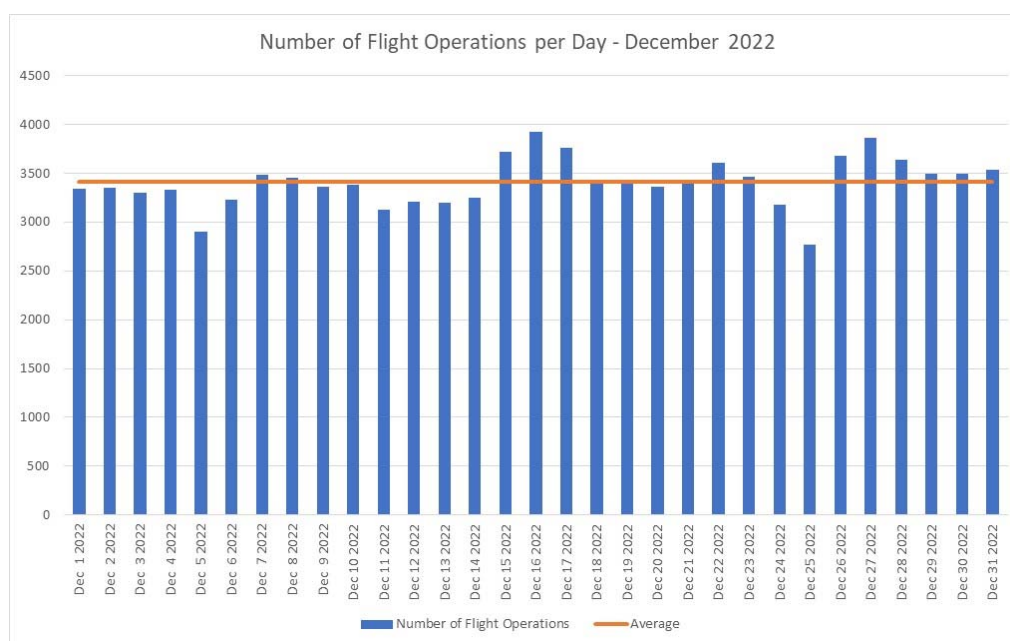


Figure 2-2. Number of Flight Operations per Day – December 2022

2.9 *Reported Large Height Deviations (LHDs)*

2.10 The NAARMO receives LHD reports from Mexico and USA ARTCCs. There were seventy-six reported occurrences during calendar year 2022. After review, forty-eight of the seventy-six reported occurrences were determined to be risk-bearing events. The set of forty-eight reports includes two reports from Houston CTA/FIR, three reports from Los Angeles ARTCC and one report from Albuquerque 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 – 2022

Month	Count	Duration at Incorrect FL (min)	Number of FLs Crossed
January 2022	0	0	0
February 2022	3	14.5	0
March 2022	2	6	0
April 2022	3	4	0
May 2022	2	2.5	0
June 2022	2	1	0
July 2022	10	8.5	1
August 2022	9	8	0
September 2022	7	7	10
October 2022	3	2.5	0
November 2022	3	15	0
December 2022	4	13	0
Total 2022	48	82	11

2.11 Forty-four of the forty-eight 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 – 2022

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	3	6	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)	30	38.5	0
E2	Negative coordination in the ATC-to-ATC transfer of control responsibility	12	28.5	0
F	Coordination errors in the ATC -to-ATC transfer of control responsibility as a result of an outage or technical issues	2	9	0

LHD Category Code	LHD Category Description	Number of LHD	Duration at Incorrect FL (min)	Number of FLs Crossed
G	Aircraft contingency event leading to sudden inability to maintain assigned flight level (e.g. pressurization failure, engine failure)	1	0	10
	TOTALS	48	82	11

2.12 **Figure 2-3** shows the approximate aircraft locations the forty-eight reported LHDs in 2022. The size of the circle represents the vertical risk estimate for each reported LHD.

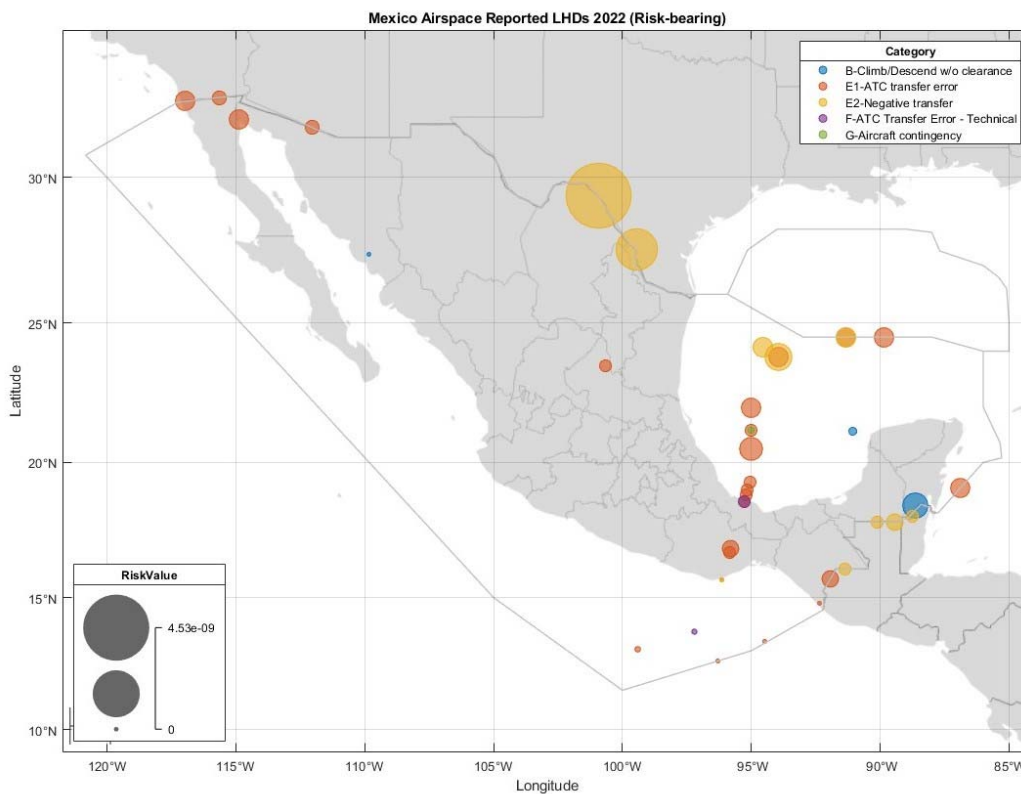


Figure 2-3. Qualifying LHD Reports – 2022

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 three reported LHDs for the GOMEX traffic flow in 2022. The details of these reported occurrences were communicated via emails and via teleconference. All three of the reported LHDs involved category E LHDs, there were two category E1 LHDs reported and one 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 six reported LHDs within the oceanic traffic flow in 2022. All 6 reported LHDs were errors in the ATC transfer of aircraft. There were four category E1, one category E2 and one category F occurrences. Category F indicates errors in the ATC-unit transfer due to technical problems.

2.18 *Mexico Domestic Airspace*

2.18.1 There were thirty-three reported LHDs for Mexico airspace in 2022. Twenty-nine of these reported LHDs involved errors in the ATC transfer of control responsibility between adjacent FIRs classified as category E or F. The total duration associated with the category E and F LHDs was thirty minutes.

2.18.2 There were three category B LHDs reported in 2022. These three events contributed 6 minutes of LHD duration and 1 flight level crossed without clearance. The largest contribution towards vertical risk for category B was an occurrence was a reported category B LHD where the aircraft descended without clearance with an estimated six minutes spent at the wrong FL. The contribution towards the risk estimate from this occurrence was 0.67×10^{-9} fapfh.

2.18.3 One the reported LHDs involve a contingency event (category G) with the pilot reporting a pressurization failure and descend below RVSM flight levels.

2.19 *Mexico-USA Corridor Airspace*

2.19.1 The largest contribution towards the risk estimate for Mexico airspace was a category E2 LHD from Houston ARTCC. For this occurrence, the transferring ATC-unit was Monterrey ARTCC. The duration for this occurrence was 12.5 minutes, which accounts for the unprotected time spent within Houston airspace. The vertical risk estimate from this occurrence was 4.53×10^{-9} fapfh. A few weeks later, a similar E2 LHD occurred with a duration of 5 minutes. The vertical risk contribution from the second occurrence was 1.83×10^{-9} fapfh. These two occurrences prompted a revision of the LOA between Houston and Monterrey. The revised LOA between Houston ARTCC and Monterrey ARTCC clarifies the procedures to be used along the USA/Mexico Control Area (CTA)/Flight Information Region (FIR) between Monterrey Center and Houston Center. The revised LOA was effective 24 March 2022. There have been no repeat occurrences since the LOA was revised in March 2022.

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 2022. The data show the increase in the number of reported LHDs due to ATC causes in calendar year 2022.

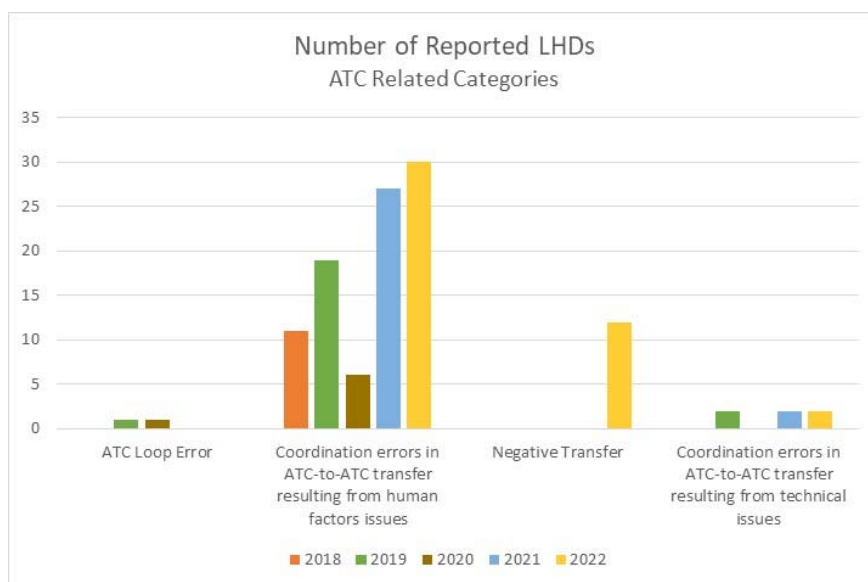


Figure 2-4. Observed Trend in Number of Reported LHDs – ATC Related Causes

2.22 *Communication Failure Reports*

2.23 In calendar year 2022, there were seventeen reported occurrences specifying communication failures between ATC and the aircraft. Sixteen reported occurrences from Mexico and one reported occurrence from Houston center. There were no indications of pilot deviation from either the 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.

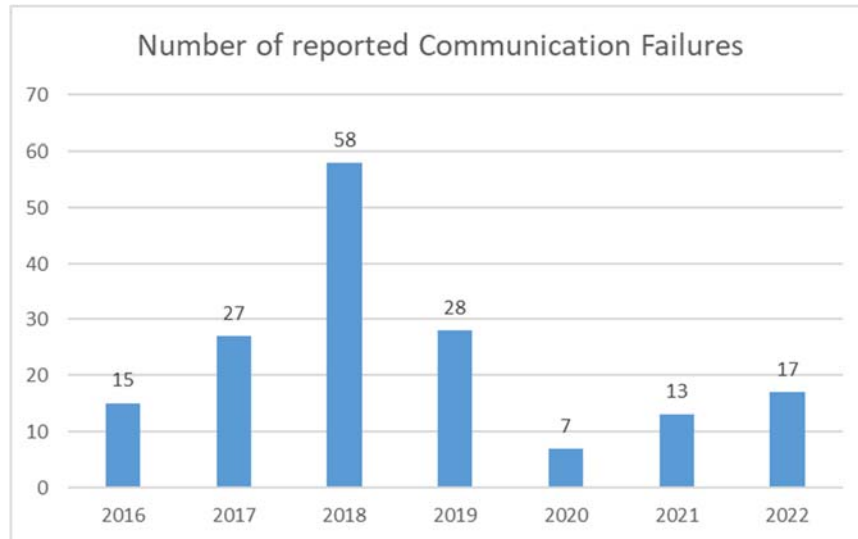


Figure 2-5. Numbers of reported communication failures by year

2.25 **Figure 2-6** shows the locations associated with the reported communication failures. There were two reports at the airspace fix TADET and another five reports at the airspace fix ELURA. The number of minutes in which ATC could not communicate with an aircraft was 508 minutes in calendar year 2022. This is an increase from calendar year 2021 where there were 323 minutes in which ATC could not communicate with an aircraft from seven reports of communication failures.

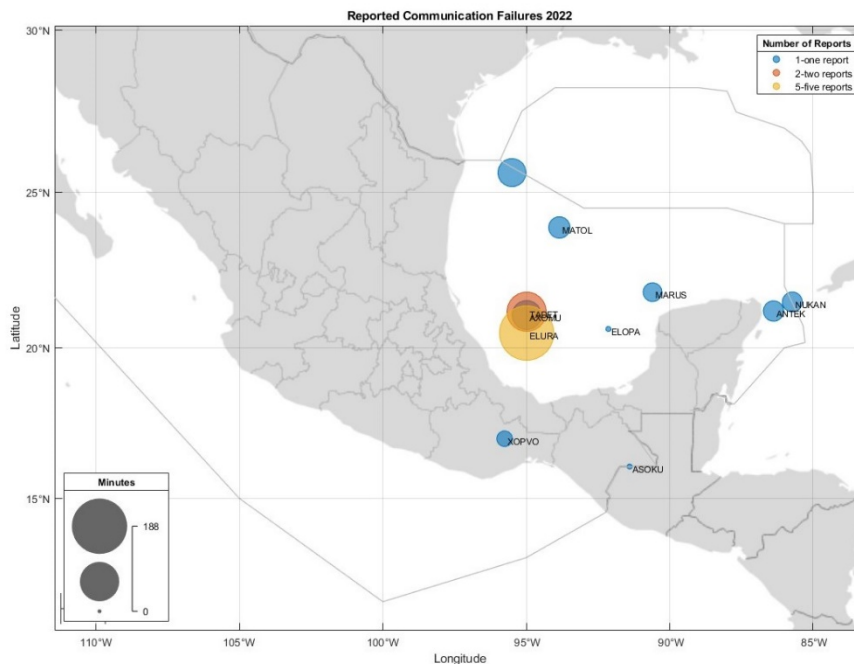


Figure 2-6. Reported Communication Failures – 2022

2.26 There are three international general aviation (IGA) aircraft and fourteen commercial aircraft operators involved in the reported communication failure reports from 2022.

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 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.

2.30 Based on the December 2022 TFMS data, the NAARMO estimates approximately 1,548,075 annual flying hours for 2022 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 10^9 flying hours.

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:

$$2.32 \quad N_{oz} = N_{oz}(same) + N_{oz}(opp) + N_{oz}(cross) \quad (1)$$

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.

Table 2-4. Flying Hours by Traffic Flow - 2022

Traffic Flow	2022 Flying hours	Proportion of Traffic
GOMEX	334,820	21.22%
Offshore/Oceanic	15,618	0.99%
Domestic	1,093,708	69.31%
Mexico-USA Corridor	133,928	8.49%
Total	1,578,075	100%

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 2022 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.

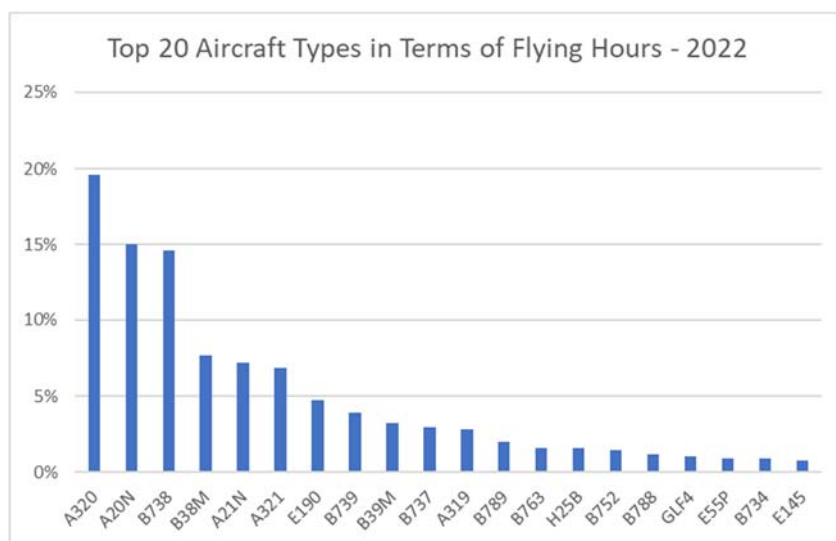


Figure 2-7. Observed Aircraft Types in Terms of Flying Hours - 2022

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 2022 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	0.0188	0.0064
[129.4 ft]	[114.3 ft]	[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 - 2022

Traffic Flow	Same Direction Vertical Occupancy	Opposite Direction Vertical Occupancy
GOMEX	0.063	0.207
Offshore/Oceanic	0.000	0.005
Domestic	0.027	0.069
Mexico-USA Corridor	0.063	0.207

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 2022 is 346,962 aircraft pairs. This value is approximately fifty-two percent higher than the number of crossing pairs observed in the previous calendar year.

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 U.S. Aircraft Geometric Height Measurement Element (AGHME), 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, $P_z(1,000)$, 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.

2.46 *Time spent at Unexpected FL*

2.47 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 2022 contain 35 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	3	0
Offshore/Oceanic	22.5	0
Mexico Domestic	36	11
Mexico-USA Corridor	20.5	0
TOTAL	82	11

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
$P_y(0)$	Probability that two aircraft on the same track are in lateral overlap.	0.1	Value used in the vertical risk estimates for Pacific airspace
λ_x	Average aircraft length.	0.0208 NM	Estimated using December 2022 Mexico TFMS sample
λ_y	Average aircraft wingspan.	0.0184 NM	Estimated using December 2022 Mexico TFMS sample
λ_z	Average aircraft height with undercarriage retracted.	0.0063 NM	Estimated using December 2022 Mexico TFMS sample
$ \overline{\Delta V} $	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{V} $	Average absolute aircraft ground speed.	480 knots	Value used in the North Atlantic, Pacific, and US Domestic airspace vertical risk estimates

Term	Definition	Estimate	Source
$ \bar{y} $	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
$ \bar{z} $	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 2022 estimates of technical and operational vertical risk by traffic flow for the airspace.

Table 2-9. 2022 Vertical Risk Estimates for RVSM Airspace ($\times 10^{-9}$ fapfh)

Traffic Flow	Technical Risk Estimate	Operational Risk Estimate	Total Risk Estimate
GOMEX	0.03	1.06	1.09
Offshore/Oceanic	0.00	0.04	0.04
Mexico Domestic	0.03	3.81	3.84
Mexico-USA Corridor	0.01	7.23	7.24
TOTAL	0.07	12.14	12.21

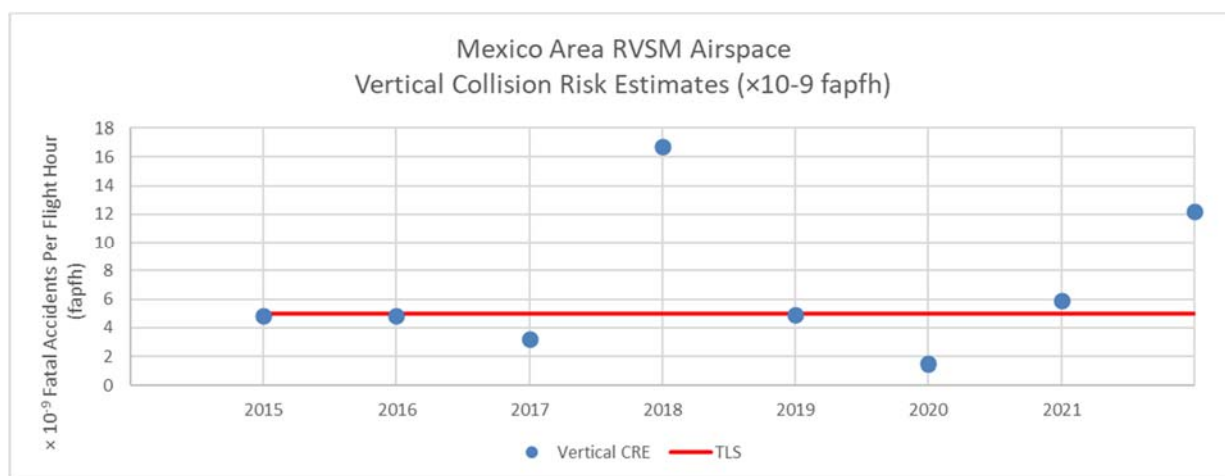
2.52 The estimated technical risk in the RVSM airspace is 0.07×10^{-9} fatal accidents per flight hour (fapfh). This estimate is significantly below 2.5×10^{-9} fapfh, which is the portion of the TLS set as the safety target for technical height-keeping performance.

2.53 The total risk estimate for the RVSM airspace, 12.21×10^{-9} fapfh, exceeds the overall safety target of 5.0×10^{-9} fapfh. The results provided in Table 2-9 show that the largest contribution to the risk estimate is within the Mexico-USA Corridor airspace. There were two significant LHD reports during calendar year 2022 that prompted a revision of the LOA between Houston and Monterrey ARTCCs. The revised LOA between Houston ARTCC and Monterrey ARTCCs clarifies the procedures to be used along the USA/Mexico Control Area (CTA)/Flight Information Region (FIR) between Monterrey Center and Houston Center. The revised LOA was effective 24 March 2022. There have been no repeat occurrences since the LOA was revised in March 2022.

2.54 **Table 2-10** and **Figure 2-8** provide the overall vertical risk estimates for calendar years 2015 – 2022 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 2-10. Overall Vertical Risk Estimates for Mexico Area RVSM Airspace

Calendar Year	Vertical Collision Risk Estimate ($\times 10^{-9}$ 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

**Figure 2-8.** Vertical Collision Risk Estimates, Mexico Area RVSM Airspace 2015 - 2022

2.55 In calendar year 2022, occurrences reported along the Mexico-USA boundary area were separated from the LHD reports occurring within Mexico airspace. Prior to GTE/23 the Mexico-USA Corridor traffic flow was not considered. In 2022, there were 6 reported LHDs contributing 20.5 minutes of time spent at an unexpected flight level within the Mexico-USA corridor airspace.

2.56 The vertical risk estimate for **Mexico RVSM airspace**, calculated from the sum of the first three rows in Table 2-9, is **4.97×10^{-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.