GTE/22 — IP/07
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CAR/SAM Planning and Implementation Regional Group (GREPECAS) Twenty Second Scrutiny Working Group Meeting (GTE/22)
Mexico City, Mexico, 26 to 30 September 2022

Agenda Item 3: Review of the Results of Large Height Deviation (LHD) Analysis
3.3 Results of the assessment project for safety in RVSM airspace for the CAR and SAM Regions

MEXICO AIRSPACE VERTICAL SAFETY MONITORING REPORT – 2021

(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 for Mexico and Gulf of Mexico (GOMEX) airspace for calendar year 2021. The purpose of this report is to compare actual performance to safety goals related to continued use of the RVSM in Mexico airspace. This report contains a summary of LHD reports received by the NAARMO for the calendar year 2021. There are thirty-five reported LHDs in calendar year 2021 for Mexico airspace. This report also contains an estimate of the vertical collision risk. The vertical collision risk estimate for Mexico airspace exceeds the target level of safety (TLS) value of 5.0×10^{-9} fatal accidents per flight hour.

Strategic Objectives:	• Strategic Objective 1 – Safety • Strategic Objective 2 – Air Navigation Capacity and Efficiency
References:	• Doc 9574, Manual on a 300 m (1 000 ft) Vertical Separation Minimum Between FL 290 and FL 410 Inclusive. • Doc 9937, Operating Procedures and Practices for Regional Monitoring Agencies in Relation to the Use of a 300 m (1 000 ft) Vertical Separation Minimum Between FL 290 and FL 410 Inclusive.

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 2021. 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 the Gulf of Mexico (GOMEX), Mexico domestic, and Mexico offshore/oceanic 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 13 December 2021.

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 three traffic flows. Portions of an individual flight operation might appear in multiple traffic flows

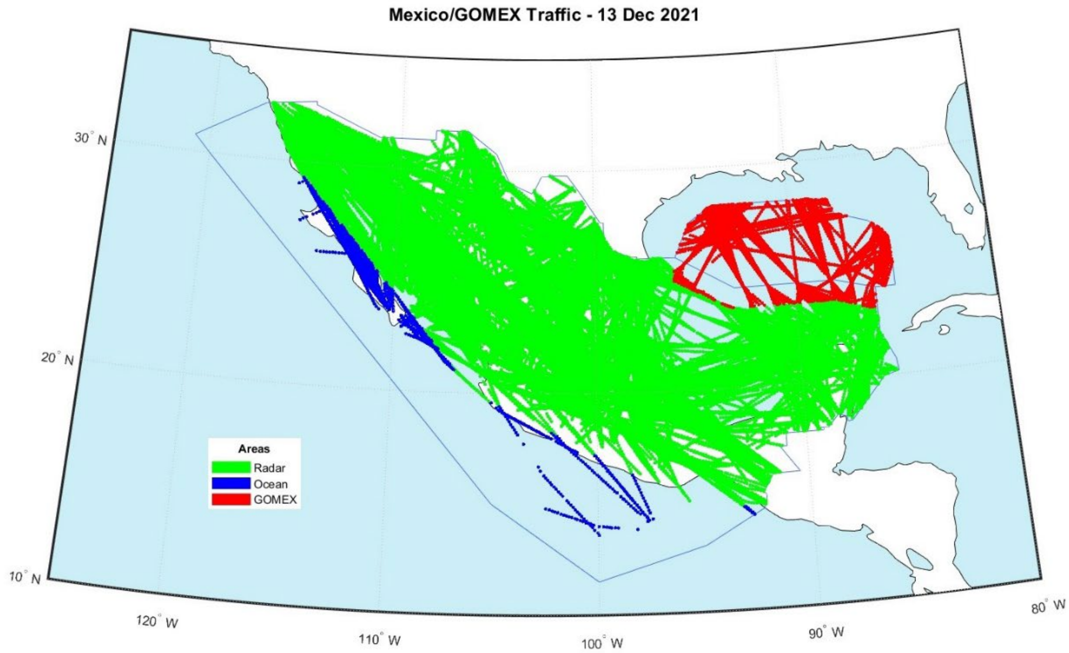

Figure 2-1. Aircraft Position Data Provided in TFMS – 13 December 2021

2.4 The three traffic flows are based on traffic volume and patterns. The three traffic flows include a portion of the Gulf of Mexico, Mexico offshore/oceanic, and Mexico domestic airspace. These three 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 (CTA)/flight information region (FIR) - Mexico FIR/CTA boundary over the Gulf of Mexico. In Figure 2-1, these are the operations shown in the color **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 the color **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 the color **green**.

2.8 Figure 2-2 shows the number of flights by day in the TFMS data for December 2021. 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 3,166 flights per day, this is an observed increase of 22 percent over traffic in December 2020.

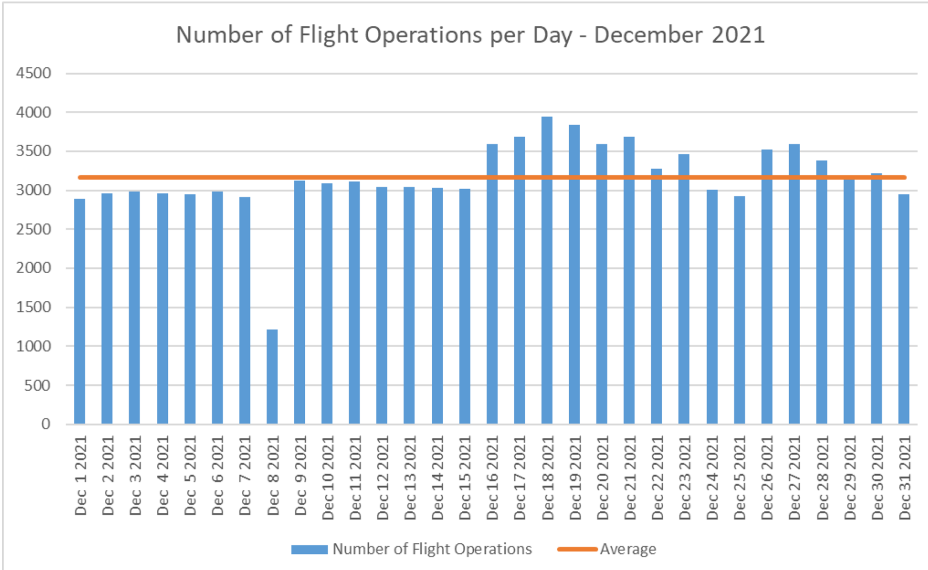

Figure 2-2. Number of Flight Operations per Day – December 2021

2.9 Reported Large Height Deviations (LHDs)

2.10 The NAARMO receives monthly LHD reports for Mexico and GOMEX airspace. There were forty-nine reported occurrences during calendar year 2021. This total includes two reported occurrences from Houston CTA/FIR. After review, thirty-five of the forty-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 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 – 2021

Month	Count	Duration at Incorrect FL (min)	Number of FLs Crossed
January 2021	0	0	0
February 2021	2	2	0
March 2021	16	16	0
April 2021	0	0	0
May 2021	3	6	0
June 2021	2	2	0
July 2021	2	2	0
August 2021	0	0	0
September 2021	4	4	0

October 2021	1	0	0
November 2021	3	1	0
December 2021	2	2	0
Total 2021	**35**	**35**	**0**

2.11 NAARMO did not organize virtual scrutiny reviews of the reported occurrences between Houston and Mexico. Confirmation of the reported LHDs was conducted via email. Based on preference, NAARMO will initiate scrutiny group reviews for reported occurrences for calendar year 2022. Thirty-four of the thirty-five LHD reports involve coordination errors in the ATC transfer (LHD categories E and F). Table 2-2 summarizes the qualifying LHD reports by cause.

Table 2-2. Qualifying LHD Reports by Cause – 2021

LHD Category Code	LHD Category Description	Number of LHD	Duration at Incorrect FL (min)	Number of FLs Crossed
E	Coordination errors in the ATC -to-ATC transfer of control responsibility as a result of human factors issues	32	33	0
F	Coordination errors in the ATC -to-ATC transfer of control responsibility as a result of an outage or technical issues	2	2	0
G	Aircraft contingency event leading to sudden inability to maintain assigned flight level (e.g. pressurization failure, engine failure)	1	0	0
	TOTALS	**35**	**35**	**0**

2.12 Figure 2-3 shows the approximate aircraft locations the thirty-five qualifying reported LHDs in 2021. The size of the circle represents the duration at incorrect or unexpected flight levels.

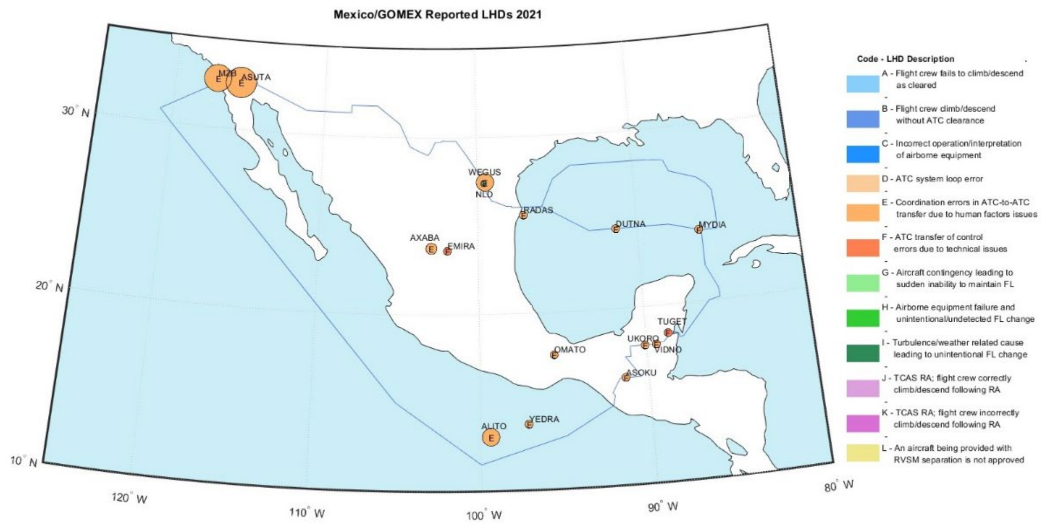

Figure 2-3. Qualifying LHD Reports – 2021

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

2.14 GOMEX Airspace

2.15 NAARMO did not organize scrutiny group teleconferences between Mexico ATC and Houston ATC to review the events reported during 2021. There were five reported LHDs for the GOMEX traffic flow in 2021. The details of these reported occurrences were communicated via emails. All five of the reported LHDs involved category E LHDs. The current Letter of Agreement (LOA) for the transfer of aircraft operations between Mexico and the United States requires verbal coordination in non-radar airspace. When automatic dependent surveillance – broadcast (ADS-B) data are available at both the U.S. and Mexico ATC facilities, the LOA might change to allow automated transfers. The U.S. ADS-B rule became effective in January 2020; Mexico indicated the ADS-B mandate is expected soon.

2.16 The five category E reported LHDs in 2021 were an increase over the three category E reported LHDs in 2020 for GOMEX airspace. For comparison, there were fourteen category E LHDs for GOMEX airspace in calendar year 2019.

2.17 Offshore/Oceanic Airspace

2.18 There were zero reported LHDs within the oceanic traffic flow in 2021. In calendar year 2020, there were also zero reported occurrences within the oceanic traffic flow. For comparison, there were three reported LHDs in calendar year 2019.

2.19 Mexico Domestic Airspace

2.20 There were thirty reported LHDs for Mexico airspace in 2021. 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 twenty-eight minutes.

2.21 One the reported LHDs involve a contingency event (category G) with the pilot reporting an auto-pilot failure and request to descend below RVSM flight levels.

2.22 Figure 2-4 shows the observed trend in the number of reported LHDs related to ATC causes from 2017 through 2021 for Mexico Domestic airspace. The data show the increase in the number of reported LHDs due to ATC causes in calendar year 2021.

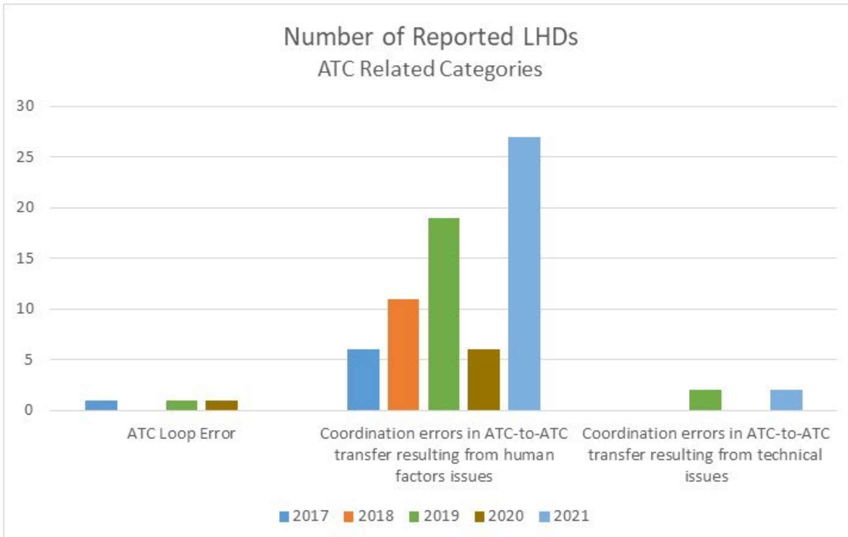

Figure 2-4. Observed Trend in Number of Reported LHDs – ATC Related Causes

2.23 Communication Failure Reports

2.24 In calendar year 2021, there were thirteen reported occurrences specifying communication failures between ATC and the aircraft. Twelve reported occurrences from Mexico and one reported occurrence from Albuquerque 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.

2.25 The trend in the number of communication failure reports has increased from 2020. Figure 2-5 shows the trend.

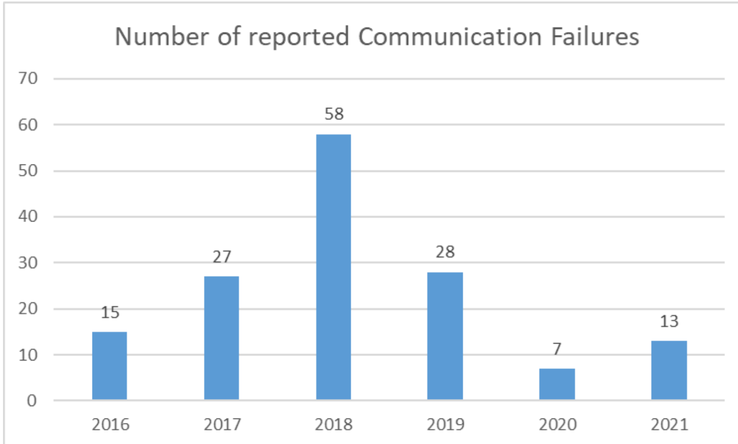

Figure 2-5. Numbers of reported communication failures by year

2.26 Figure 2-6 shows the locations associated with the reported communication failures. There were three reports at the airspace fix AVIVI and another three reports at the airspace fix ELURA. The number of minutes in which ATC could not communicate with an aircraft was 323 minutes in calendar year 2021. This is an increase from calendar year 2020 where there were 258 minutes in which ATC could not communicate with an aircraft from seven reports of communication failures.

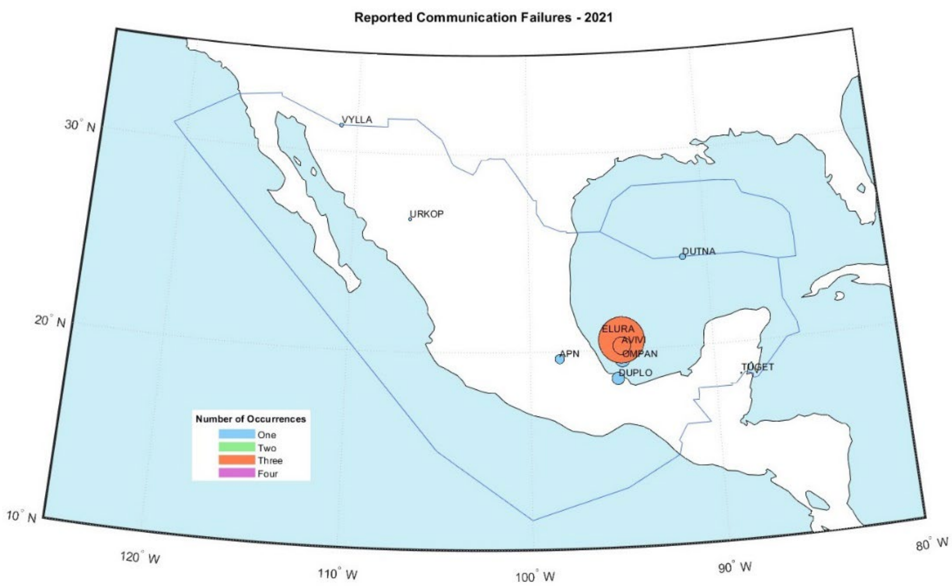

Figure 2-6. Reported Communication Failures – 2021

2.27 There are four international general aviation (IGA) aircraft and nine commercial aircraft operators involved in the reported communication failure reports from 2021.

2.28 Vertical Collision Risk Estimation

2.29 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.

2.30 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

2.31 Based on the December 2021 TFMS data, the NAARMO estimates approximately 1,444,874 annual flying hours for 2021 in Mexico and GOMEX 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.

2.32 Mexico and GOMEX 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:

2.33 $$N_{az}=N_{az}(same)+N_{az}(opp)+N_{az}(cross) \quad (1)$$

2.34 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 - 2021

Traffic Flow	2021 Flying hours	Proportion of Traffic
GOMEX	320,652	22.19%
Offshore/Oceanic	26,916	1.86%
Domestic	1,097,397	75.95%
Total	**1,444,874**	**100%**

2.35 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.

2.36 Aircraft Types

2.37 Figure 2-7 provides the top 25 aircraft types observed in the December 2021 TFMS traffic data by flying hours. The aircraft types listed in Figure 2-5 account for 89 percent of total flying hours observed in the traffic sample.

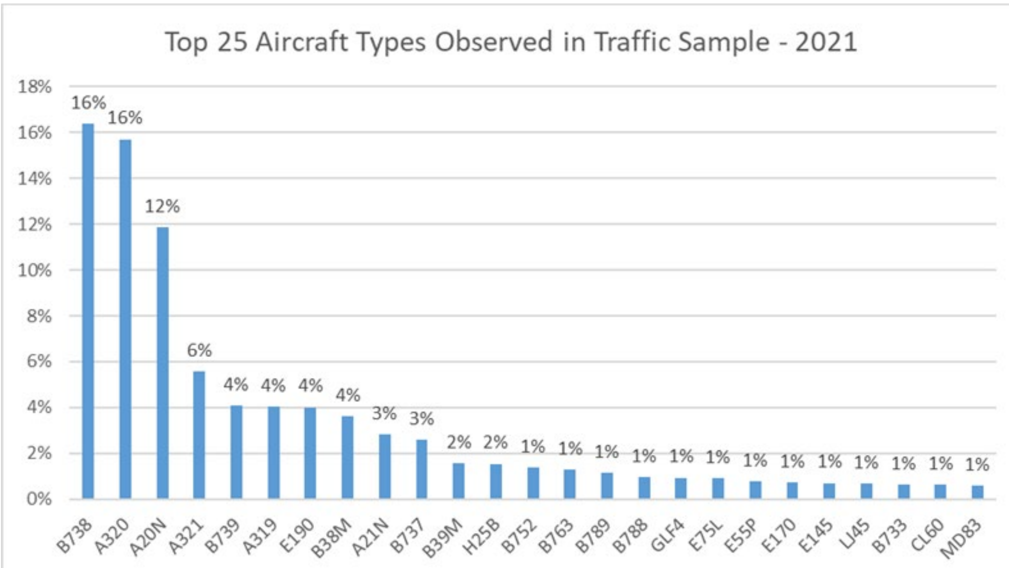

Figure 2-7. Observed Aircraft Types in Terms of Flying Hours - 2021

2.38 Aircraft Size

2.39 The collision risk model parameters related to the aircraft size are: length, wingspan, and height. These parameters are estimated directly from the December 2021 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)
0.0208 *[126.2 ft]*	0.0184 *[112.0 ft]*	0.0063 *[38.4 ft]*

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

2.41 The TFMS data is used to estimate the number of vertical aircraft passings per hour for each of the three traffic flows; GOMEX, offshore/oceanic, and domestic. The traffic is separated into three 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. The traffic flow with the lowest traffic density is the offshore/oceanic traffic flow, followed by the GOMEX airspace. As expected, the Mexico domestic airspace has the highest vertical occupancy values compared to the other two traffic flows. The occupancy estimates for calendar year 2021 increased slightly from the occupancy estimates calculated for calendar year 2020.

Table 2-6. Vertical Occupancies by Traffic Flow - 2021

Traffic Flow	Same Direction Vertical Occupancy	Opposite Direction Vertical Occupancy
GOMEX	0.071	0.195
Offshore/Oceanic	0.000	0.001
Domestic	0.024	0.054

2.42 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 2021 is 228,000 aircraft pairs. This value is approximately fifty-six percent higher than the number of crossing pairs observed in calendar year 2020.

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

2.44 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.

2.45 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.

2.46 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.

2.47 Time spent at Unexpected FL

2.48 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 2021 contain 35 minutes of flying time spend at unexpected flight level. This time is split into the three 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	7	0
Offshore/Oceanic	0	0
Domestic	28	0
TOTAL	**35**	**0**

2.49 Collision Risk Model Parameters

2.50 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
$P_z(S_z)$	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 2021 Mexico TFMS sample**
λy	Average aircraft wingspan.	0.0184 NM	Estimated using December 2021 Mexico TFMS sample
λz	Average aircraft height with undercarriage retracted.	0.0063 NM	Estimated using December 2021 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

2.51 Results and Conclusions

2.52 Table 2-9 provides 2021 estimates of technical and operational vertical risk for Mexico and GOMEX airspace.

Table 2-9. 2021 Vertical Risk Estimates for Mexico and GOMEX RVSM Airspace

Description	Risk Estimate ($\times 10^{-9}$ fapfh)
Estimate of Technical Risk	**0.06**
Estimate of Risk Due to Operation at Incorrect Flight Levels	**5.85**
Estimate of Overall Risk	**5.91**

2.53 The estimated technical risk in the Mexico and GOMEX RVSM airspace is 0.05 × 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.

2.54 The operational risk estimate for Mexico and GOMEX RVSM airspace 5.85 × 10-9 fapfh. The sum of this value and the technical risk estimate for Mexico airspace is 5.91 × 10-9 fapfh, which exceeds the overall safety target of 5.0 × 10-9 fapfh.

2.55 Table 2-10 and Figure 2-8 provide the overall vertical risk estimates for calendar years 2015 – 2021 for Mexico 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 three 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 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

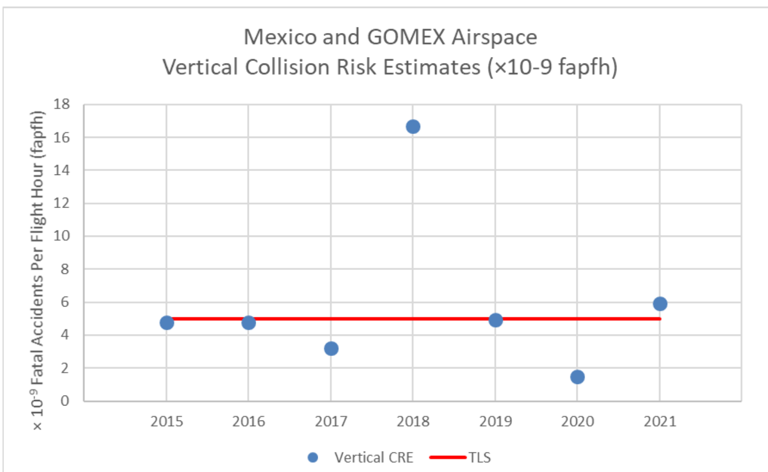

Figure 2-8. Vertical Collision Risk Estimates, Mexico and GOMEX Airspace 2015 - 2021

2.56 With the exception of 2018 as noted above and the drop in the estimate in 2020 due to traffic reduction related to COVID, the estimated level of risk has been consistent.

3 Action by the meeting

3.1 The GTE is invited to note and discuss the information provided.

— END —