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Agenda Item 3: Review of the results of Large Height Deviation (LHD) analysis

MÉXICO AIRSPACE VERTICAL SAFETY MONITORING REPORT – 2018

(Presented by United States)

EXECUTIVE SUMMARY

This paper provides the vertical safety monitoring report for the continued-safe use of the Reduced Vertical Separation Minimum (RVSM) in México 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 sample data (TSD) provided by México to the NAARMO for calendar year 2018.

The purpose of this report is to compare actual performance to safety goals related to continued use of the RVSM in México airspace. This report contains a summary of large height deviation reports received by the NAARMO for the calendar year 2018. There are 75 reported large height deviations in calendar year 2018 for México airspace. This report also contains an estimate of the vertical collision risk. The vertical collision risk estimate for México airspace exceeds the target level of safety (TLS) value of 5.0 × 10-9 fatal accidents per flight hour.

Strategic Objectives:	• Safety
References:	• Reports of Large Height Deviations (LHD) in 2018 • December 2018 Mexican Traffic Sample Data (TSD) • FAA Traffic Flow Management System (TFMS) • ICAO Doc 9574 • ICAO Doc 9937

1. Introduction

1.1. The *Dirección General de Aeronáutica Civil* (DGAC Mexico) implemented the Reduced Vertical Separation Minimum (RVSM) between flight level 290 and flight level 410, inclusive, in all sovereign and delegated Mexican airspace on January 20, 2005. By mutual agreement, along with México, Canada, and the United States, the North American Aviation Trilateral States, implemented the RVSM simultaneously on the same date in all North American airspace.

1.2. The North American Approvals Registry and Monitoring Organization (NAARMO), a service provided by the 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 2018. Within this report, the reader will find a summary of the large height deviation (LHD) reports received by the NAARMO and the corresponding vertical collision risk estimate. There were 75 reported LHDs submitted to the NAARMO for calendar year 2018.

2. Traffic Sample Data

2.1. The NAARMO received a December 2018 traffic sample data (TSD) for México airspace. These data included flight observations from four area control centers (ACCs) – México (MMEX), Monterrey (MMTY), Mazatlán (MMZT), and Mérida (MMID). The information provided for each flight operation includes the date, aircraft call sign, aircraft registration mark, aircraft type, origin airport, destination airport, and aircraft position information.

2.2. In addition to the TSD received from the four ACCs, the NAARMO has access to the Federal Aviation Administration's (FAA's) Traffic Flow Management System (TFMS), which includes aircraft observations in México airspace. 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 15 December 2018.

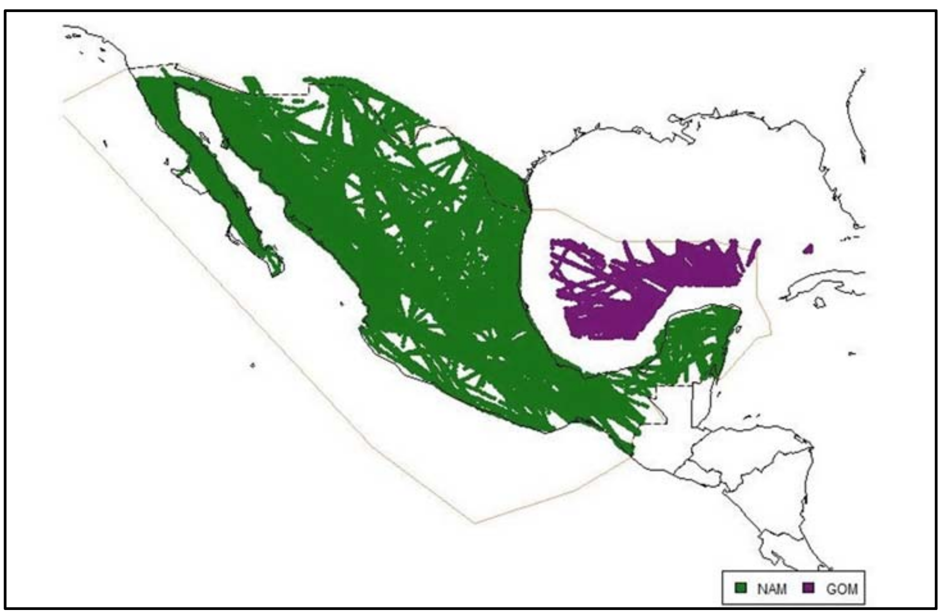

Figure 2-1. Aircraft Position Data Provided in TFMS – 15 December 2018

2.3 **Figure 2-2** shows the number of flights by day in the TFMS data for December 2018. The horizontal blue 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 2,710 flights per day. This value is about the same as observed in the 2017 data; **Table 2-1** shows the trend.

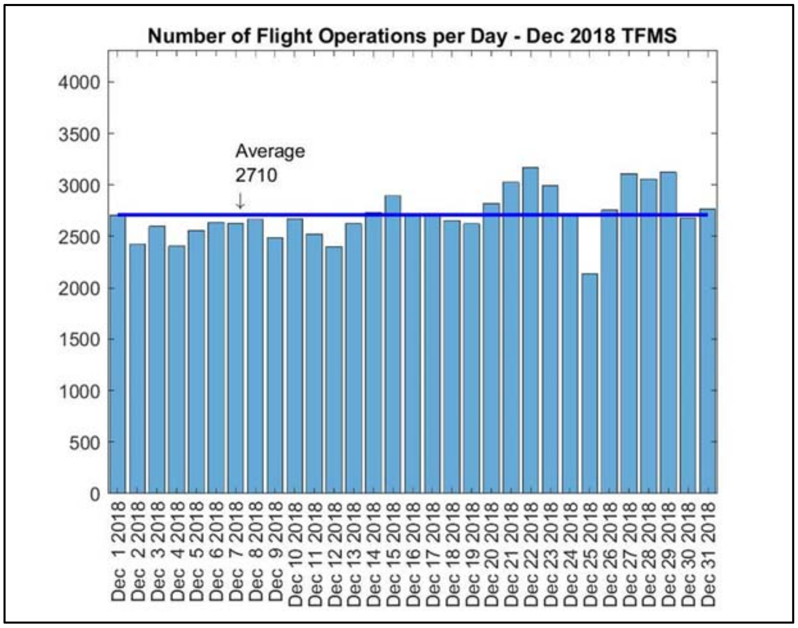

Figure 2-2. Number of Flight Operations Observed by Day - TFMS December 2018

Table 2-1. Average Number of Daily Flight Operations – Trend

Month-Year	Average Number of Daily Flight Operations
December 2015	2,378
December 2016	2,508
December 2017	2,732
December 2018	2,710

3. RVSM Airspace Audit

3.1 The December 2018 TSD received from México for the MMEX, MMTY, MMZT, and MMID ACCs are used to identify the operations operating within RVSM airspace. These data total approximately 148,000 operations in the month of December 2018.

3.2 The December 2018 TSD for México airspace was compared with the collective approvals database as of 31 August 2019 to determine the approval status of each observed operation. The operations for which no approval or an expired approval is found are identified for further verification. **Table 3-1** provides a summary of the results of the México RVSM Airspace Audit following the initial verification process. The results are listed alphabetically by the State of the Operator/Registry. This list contains 176 civilian non-approved operations from ten different States observed within RVSM airspace in México. This is a significant increase from the same verification results in 2017. There were 58 civilian non-approved operations reported in December 2017. The observed increase in the number of non-approved operations is due to process improvements made to the NAARMO approvals database.

3.3 There are twenty-one aircraft operations identified as non-approved in the December 2018 TSD were also observed as non-approved in 2017. These twenty-one operations observed to be non-approved in 2017 and 2018 are highlighted in Table 3-1 in Yellow.

Table 3-1. México RVSM Airspace Audit – 2018

State of Operator/Registry	Aircraft Registration	RMA	Count of Observations
México	XBMSZ	NAARMO	49
México	XBNPF	NAARMO	46
México	***XBVFJ***	***NAARMO***	***43***
México	XBNZS	NAARMO	43
México	XALRD	NAARMO	42
México	XBPND	NAARMO	42
México	XACAL	NAARMO	38
United States	N43PJ	NAARMO	38
México	***XAUZD***	***NAARMO***	***37***
United States	N464FG	NAARMO	36
México	***XALAU***	***NAARMO***	***32***
México	XBSYT	NAARMO	32
México	XCDGO	NAARMO	32
México	XACZG	NAARMO	31
United States	N31EA	NAARMO	30
México	XBOHX	NAARMO	28
México	XCBJG	NAARMO	28
México	***XAJAO***	***NAARMO***	***25***
México	***XAHEL***	***NAARMO***	***23***
México	XALTS	NAARMO	23
México	XAOLI	NAARMO	23
México	XAUWF	NAARMO	23
México	XBOYD	NAARMO	23
México	XBNZW	NAARMO	22
México	XCHIX	NAARMO	22
México	XAARR	NAARMO	21
México	XALRM	NAARMO	21
México	XCGDT	NAARMO	21
México	XARCL	NAARMO	20
México	XARKY	NAARMO	20
México	XASOF	NAARMO	20
México	XASSE	NAARMO	19
México	XAVCM	NAARMO	19
México	XAVYE	NAARMO	19
México	XBOEC	NAARMO	19

State of Operator/Registry	Aircraft Registration	RMA	Count of Observations
México	XADON	NAARMO	18
México	XAUBI	NAARMO	18
México	XBODW	NAARMO	18
México	XBPGQ	NAARMO	18
México	XBRSC	NAARMO	18
México	XAOOI	NAARMO	17
México	XASRD	NAARMO	17
United States	N145MB	NAARMO	17
United States	***N875HB***	***NAARMO***	***16***
México	XAARB	NAARMO	16
México	XABEG	NAARMO	16
México	XACTL	NAARMO	16
México	XBMNV	NAARMO	16
Panama	HP2010DA	CARSAMMA	16
United States	N375TC	NAARMO	16
United States	N800CJ	NAARMO	16
México	XABNG	NAARMO	15
México	XAUUW	NAARMO	15
México	XASYJ	NAARMO	14
México	XAUPX	NAARMO	14
México	XBGCU	NAARMO	14
México	XBJOA	NAARMO	14
México	XBPGP	NAARMO	14
México	XBSMV	NAARMO	14
México	XCHIE	NAARMO	14
México	XAVRF	NAARMO	13
México	XBGTH	NAARMO	13
United States	N428P	NAARMO	13
México	***XBNVE***	***NAARMO***	***12***
México	XAEBM	NAARMO	12
México	XBVXS	NAARMO	12
México	XCPFT	NAARMO	12
United States	N214DV	NAARMO	12
México	***XAOFM***	***NAARMO***	***11***
México	XAQLO	NAARMO	11
México	XBNXX	NAARMO	11
United States	N440AZ	NAARMO	11
United States	N723LK	NAARMO	11
México	XARJT	NAARMO	10
México	XAUZO	NAARMO	10
México	XBPEB	NAARMO	10
United States	N145GL	NAARMO	10
United States	N43AG	NAARMO	10
México	***XAEGU***	***NAARMO***	***9***

State of Operator/Registry	Aircraft Registration	RMA	Count of Observations
México	***XAUFF***	***NAARMO***	***9***
México	XAAMI	NAARMO	9
México	XAFRC	NAARMO	9
México	XAUSF	NAARMO	9
México	XBGFI	NAARMO	9
México	XBJHV	NAARMO	9
México	***XAXTR***	***NAARMO***	***8***
México	***XBMBP***	***NAARMO***	***8***
United States	***N38VC***	***NAARMO***	***8***
México	XANZF	NAARMO	8
México	XBFCR	NAARMO	8
México	XBGOE	NAARMO	8
México	XBOTZ	NAARMO	8
México	XBPGY	NAARMO	8
México	XBRGB	NAARMO	8
México	XCGDC	NAARMO	8
United States	N337CM	NAARMO	8
México	***XADHM***	***NAARMO***	***7***
México	***XAUZF***	***NAARMO***	***7***
México	***XBELJ***	***NAARMO***	***7***
México	XAHCR	NAARMO	7
México	XARAB	NAARMO	7
México	XAVCO	NAARMO	7
México	XBOAE	NAARMO	7
México	XCHIF	NAARMO	7
United States	N195ME	NAARMO	7
United States	N397MG	NAARMO	7
México	***XAGDQ***	***NAARMO***	***6***
Canada	CFBWS	NAARMO	6
Canada	CFZUB	NAARMO	6
México	XAPAG	NAARMO	6
México	XARIB	NAARMO	6
México	XBDGA	NAARMO	6
México	XBJTG	NAARMO	6
México	XBNVN	NAARMO	6
México	XBRAY	NAARMO	6
Panama	HP1910DA	CARSAMMA	6
United States	N994EA	NAARMO	6
Canada	CCAXZ	NAARMO	5
Canada	CFTXW	NAARMO	5
Canada	CFZUR	NAARMO	5
Canada	CGKOD	NAARMO	5
Canada	CGTXV	NAARMO	5
México	XAPMH	NAARMO	5

State of Operator/Registry	Aircraft Registration	RMA	Count of Observations
México	XAYCC	NAARMO	5
México	XBMAM	NAARMO	5
United States	N949CL	NAARMO	5
México	***XARED***	***NAARMO***	***4***
México	***XATFR***	***NAARMO***	***4***
México	***XBMTG***	***NAARMO***	***4***
Canada	CGTVC	NAARMO	4
México	XABZN	NAARMO	4
México	XADIJ	NAARMO	4
México	XAERM	NAARMO	4
México	XAGRB	NAARMO	4
México	XAMMD	NAARMO	4
México	XARFB	NAARMO	4
México	XBCAF	NAARMO	4
México	XBCYA	NAARMO	4
México	XBGSM	NAARMO	4
México	XBNYV	NAARMO	4
México	XBODN	NAARMO	4
México	XBOKR	NAARMO	4
México	XBOXV	NAARMO	4
México	XBPHP	NAARMO	4
México	XBTTT	NAARMO	4
México	XCLJS	NAARMO	4
United States	N102ES	NAARMO	4
United States	N2112	NAARMO	4
United States	N253RM	NAARMO	4
United States	N77MA	NAARMO	4
United States	N813NA	NAARMO	4
Venezuela	YV3333	CARSAMMA	4
Guatemala	***TGDAE***	***CARSAMMA***	***3***
Brazil	PRODF	CARSAMMA	3
Canada	CGJWO	NAARMO	3
Canada	CGKOE	NAARMO	3
México	XALFJ	NAARMO	3
México	XBCSI	NAARMO	3
México	XBOUZ	NAARMO	3
México	XCVSA	NAARMO	3
United States	N357MJ	NAARMO	3
United States	N476MM	NAARMO	3
United States	N767CB	NAARMO	3
United States	N863JB	NAARMO	3
Algeria	7TVPS	ARMA	2
Canada	CFXCD	NAARMO	2
Canada	CGZEH	NAARMO	2

State of Operator/Registry	Aircraft Registration	RMA	Count of Observations
México	XBCRL	NAARMO	2
México	XBJFV	NAARMO	2
México	XBLWW	NAARMO	2
Panama	HP1810DA	CARSAMMA	2
United States	N106PA	NAARMO	2
United States	N269RC	NAARMO	2
United States	N31YA	NAARMO	2
United States	N898AW	NAARMO	2
Venezuela	YV484T	CARSAMMA	2

4. Reported Large Height Deviations (LHDs)

4.1 The NAARMO receives monthly LHD reports for México airspace. There were 75 reported LHDs during calendar year 2018. After scrutiny group review, fifteen of the 75 reported LHDs were determined to be risk-bearing. **Table 4-1** contains a summary of all the qualifying reported LHDs by month. The last row of Table 4-1 shows there were 85.5 minutes of flying time at an unexpected/incorrect flight levels and ten flight levels crossed without clearance/incorrectly.

4.2 The ten flight levels crossed without clearance were associated with a single contingency event. The assumed descend rate for this event corresponds to a rapid emergency descent and is 5000 ft/min.

Table 4-1. Qualifying Reported LHDs for México Airspace – 2018

Month	Count	Duration at Incorrect FL	Number of FLs Crossed
January 2018	1	1	0
February 2018	0	0	0
March 2018	1	0.5	0
April 2018	2	0.5	0
May 2018	1	23	0
June 2018	1	0.5	0
July 2018	1	0	0
August 2018	1	22	0
September 2018	1	0	0
October 2018	2	3	10
November 2018	2	1	0
December 2018	2	34	0
Total 2018	**15**	**85.5**	**10**

4.3 An LHD event with a duration of twenty minutes or more is considered to be a long duration event. There were three reported long duration LHD events in 2018. Because long duration LHDs have a larger effect on the vertical collision risk estimate, a de-identified summary of each long duration event is below.

4.3.1 The longest reported LHD duration was twenty-three minutes. This event took place in area without radar surveillance. The cause of the reported occurrence is an error in ATC coordination. The flight was coordinated, but was coordinated at the wrong altitude.

4.3.2 Another event had an LHD duration of twenty-two minutes. This event occurred in offshore airspace without radar surveillance. The cause of the reported occurrence was an error in ATC coordination, in this case there was no flight plan message received.

4.3.3 The final long duration LHD report was twenty minutes in duration. This event occurred in airspace without radar surveillance. The cause of the reported occurrence was an error in ATC coordination. The flight was coordinated, but the coordination was for a different FL than occupied by the aircraft.

4.4 The scrutiny review determined the cause for each of the fifteen qualifying LHD reports in 2018. Eleven of the qualifying LHD reports involve coordination errors in the ATC transfer. **Table 4-2** summarizes the qualifying LHD reports by cause.

Table 4-2. Qualifying LHD Reports by Cause – 2018

LHD Category Code	LHD Category Description	Number of LHD	Duration at Incorrect FL	Number of FLs Crossed
E	Coordination errors in the ATC-unit-to-ATC-unit transfer of control responsibility as a result of human factors issues (e.g. late or non-existent coordination, incorrect time estimate/actual, flight level, ATS route etc.)	11	85.5	0
G	Aircraft contingency event leading to sudden inability to maintain assigned flight level (e.g. pressurization failure, engine failure)	1	0	10
H	Airborne equipment failure leading to unintentional or undetected change of flight level (e.g. altimetry errors)	1	0	0
I	Turbulence or other weather related causes	1	0	0
J	TCAS resolution advisory; flight crew correctly following the resolution advisory	1	0	0
	TOTALS	**15**	**85.5**	**10**

4.5 **Figure 4-1** shows the aircraft locations for the fifteen qualifying reported LHDs in 2018. Eleven of the qualifying events classified as category E, coordination errors in the ATC-unit-to-ATC-unit transfer of control.

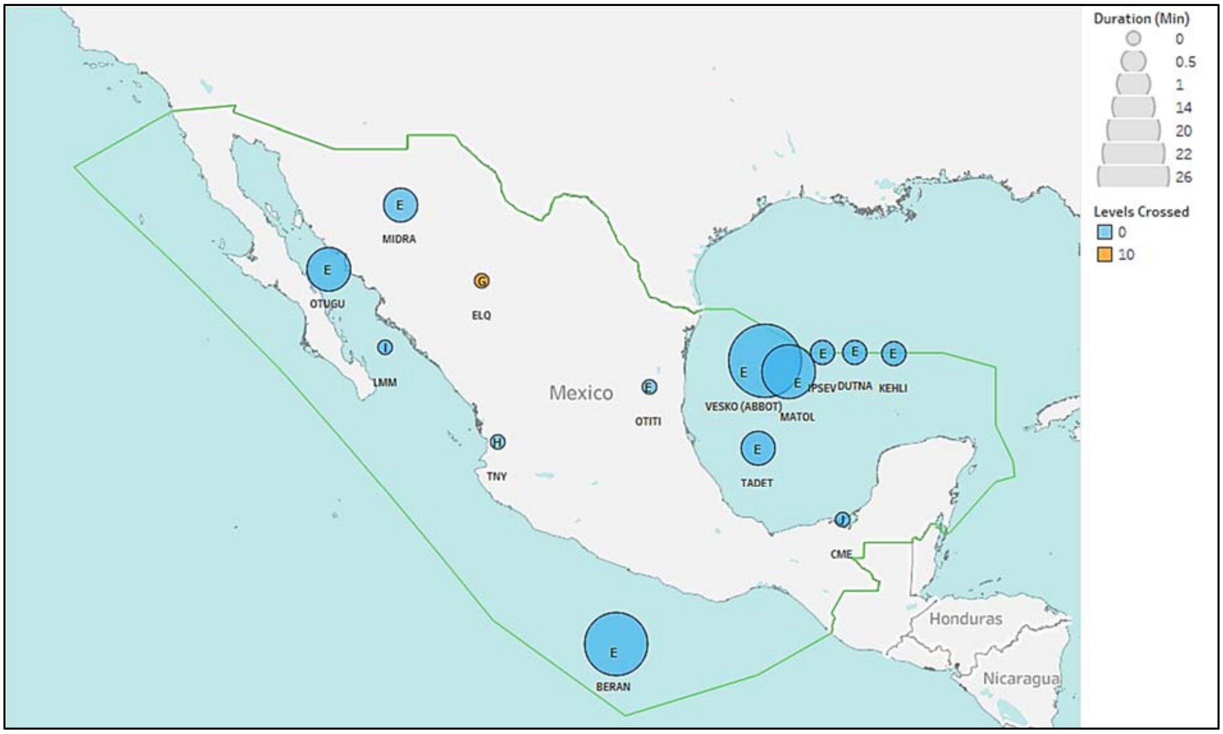

Figure 4-1. Qualifying LHD Reports - 2018

4.6 The NAARMO organized scrutiny group teleconferences between México ATC and Houston ATC to review the events reported during 2018. However, the scrutiny review took place several months after the end of the calendar year. This time lapse did not permit the scrutiny team to obtain responses from the aircraft operators and limited any additional information from ANSPs. In the future, in order to solicit as much information as possible, the NAARMO will arrange for scrutiny meetings earlier in the calendar year.

4.7 Communication Failure Reports

4.7.1 There were 58 reported occurrences specifying communication failures between ATC and the aircraft over a period of time. One of these reports indicated the pilot deviated from the cleared route of flight, this report involved an international general aviation (IGA) aircraft operation. In the remaining 57 cases, 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.

4.7.2 The trend in the number of communication failure reports is increasing. During the previous calendar years 2017 and 2016, there were 27 and 15 such reports, respectively. Due to the numerous reported cases of communication failures, DGAC México, SENEAM and NAARMO agreed there should be some further study on these data.

4.7.3 In calendar year 2017, the 27 communication failure reports accounted for 805 minutes in which ATC could not communicate with an aircraft. In calendar year 2018, the 58 communication failure reports accounted for 1,587 minutes in which ATC was not able to communicate with an aircraft.

4.7.4 The top two locations, in terms of the communication failure duration, are airspace fixes ELURA and AXOMU. These two airspace fix locations are consistent with communication failure reports from calendar year 2017. **Figure 4-2** highlights the locations of the top locations included in the communication failure reports.

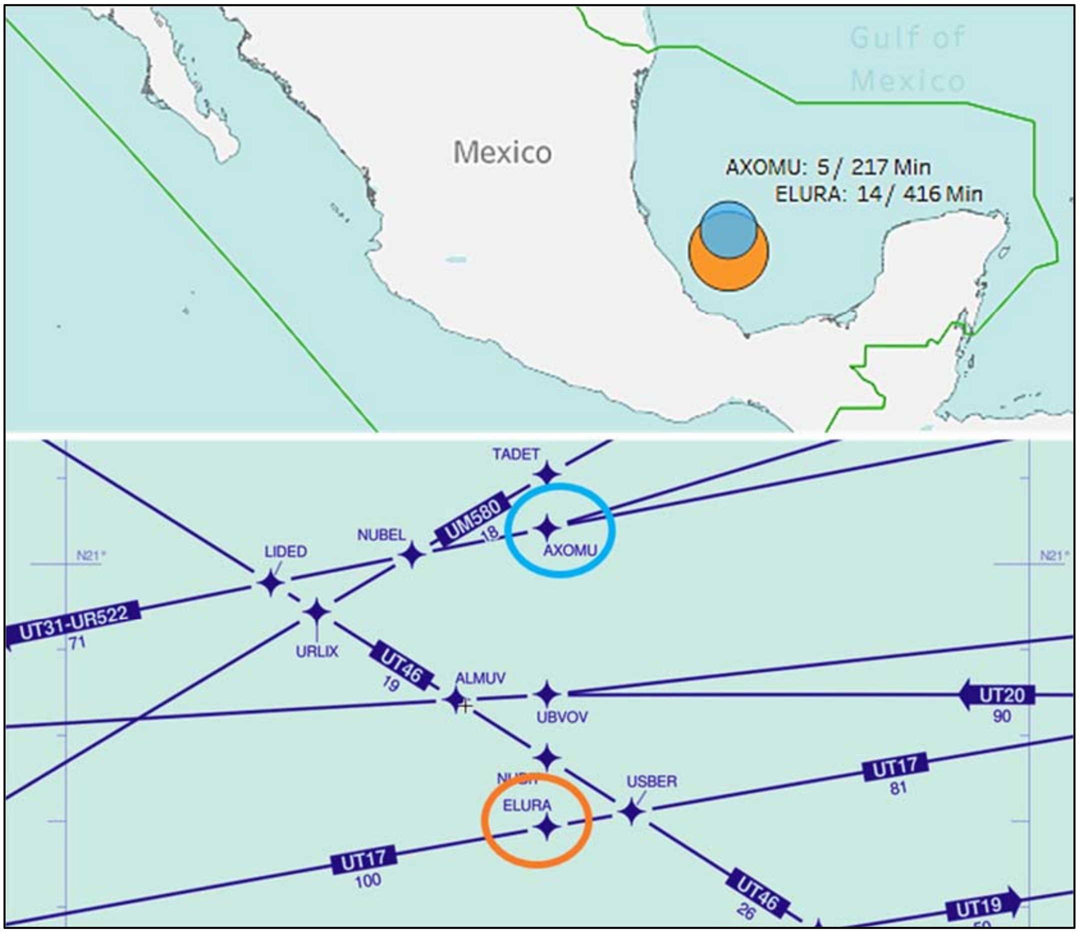

Figure 4-2. Top Locations Provided in Communication Failure Reports – 2018

4.7.5 There were 14 reports of communication failure near the airspace fix ELURA, accounting for 416 minutes of ATC unable to communicate with an aircraft. There were 5 reports near the airspace fix AXOMU, which is close to ELURA accounting for 217 minutes. **Figure 4-3** provides the general location for all the reported communication failure reports. The size of the icon reflects the total duration of reported communication failures at the airspace fix location.

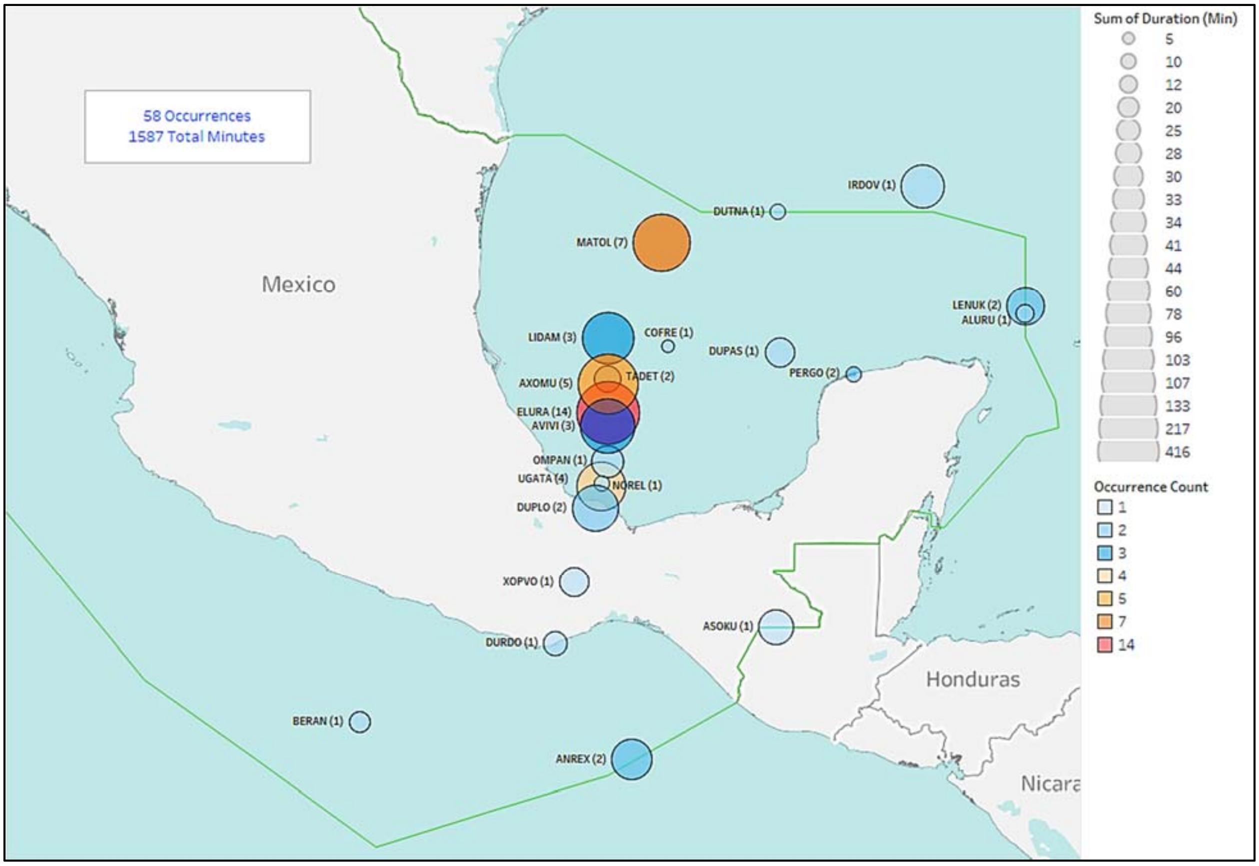

Figure 4-3. Reported Communication Failures - 2018

4.7.6 The aircraft operators involved in the communication failure reports are listed in **Table 4-3**. The aircraft operator ABC Aerolíneas (AIJ) had eleven communication failure reports accounting for 394 minutes. The aircraft operator Aerovías de México (AMX) were involved in ten communication failure reports accounting for 275 minutes. **Table 4-3** contains all the operator details associated with the 2018 communication failure reports.

Table 4-3. Operators involved in the communication failure reports – 2018

ICAO Operator Code	Operator Name	State of the Operator/ Registry	Number of Reports	Duration (minutes)
AIJ	ABC AEROLÍNEAS S.A. DE C.V.	México	11	394
AMX	AEROVIAS DE MÉXICO S.A. DE C.V.	México	10	275
VIV	AEROENLACES NACIONALES S.A. DE C.V.	México	6	134
VOI	Volaris	México	6	86
-	International General Aviation (IGA) Operators	México	5	159
CMP	COMPAÑÍA PANAMEÑA DE AVIACIÓN, S.A.	Panama	5	130
AAL	American Airlines	United States	4	152

ICAO Operator Code	Operator Name	State of the Operator/ Registry	Number of Reports	Duration (minutes)
LAN	LATAM Airlines	Chile	2	45
UAL	United Airlines	United States	2	16
DAL	Delta Air Lines, Inc.	United States	1	43
GMT	Magnicharters	México	1	39
RPN	---		1	35
UAE	Emirates	United Arab Emirates	1	30
SWA	Southwest Airlines	United States	1	27
JBU	JetBlue Airways Corporation	United States	1	12
WJA	WestJet Airlines Ltd.	Canada	1	10

4.7.7 The scrutiny review of the reported LHDs for 2018 took place several months after the end of the calendar year. This time lapse did not permit the scrutiny team to obtain responses from the aircraft operators. In the future, in order to solicit an operator response for a communication failure event, it may be possible for IATA to relay the communication failure report to the airline operator. Many airline operators clear the data from their systems within a month of the flight, having more timely reports will provide them an opportunity to respond. This information should help in determining the related cause(s).

5. Vertical Collision Risk Estimation

5.1 This section of the paper provides the parameter estimates used in the ICAO vertical risk model. The collision risk methodology consists of a mathematical model to estimate risk for comparison to the safety criterion, the target level of safety (TLS). The section also provides information on the sources of data used to estimate risk model parameters.

5.2 The internationally agreed TLS for the 1 000-ft vertical separation standard is specified for technical and operational risk separately. The vertical technical risk provides the risk associated the effects of turbulence, loss of altitude holds 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 provides the risk associated with operational errors. The risk due to all causes is the sum of the vertical operational and technical risk estimates. The TLS for the 1 000-ft vertical separation standard is specified as:

a) collision risk due to all causes does not exceed 5 fatal accidents in 10^9 flying hours, and, simultaneously,
b) collision risk due to aircraft height-keeping systems does not exceed 2.5 fatal accidents in 10^9 flying hours

5.3 Based on the December 2018 TFMS data, the NAARMO estimates approximately 955,000 annual flying hours for 2018 in México airspace where the RVSM is applied. 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.

5.4 México 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:

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

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.

5.5 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.

5.6 Aircraft Types Observed in México Airspace

5.6.1 **Figure 5-1** provides the top 25 aircraft types observed in the December 2018 TFMS México traffic data by flying hours. These aircraft types account for 90 percent of total flying hours observed in México airspace. The flying hours associated with the Airbus A320 aircraft type represent 30 percent of all the flying hours observed in the traffic sample. The percentage of flying hours observed for the Airbus A320 family; including the A319, A320, and A321, account for 41 percent of all the flying hours observed in the traffic data. The Boeing 737-800 is the second most observed aircraft in México airspace. The percentage of flying hours observed for the Boeing 737 NGX family; including B737, B738, and B739, is 25 percent of all the flying hours observed in the traffic data.

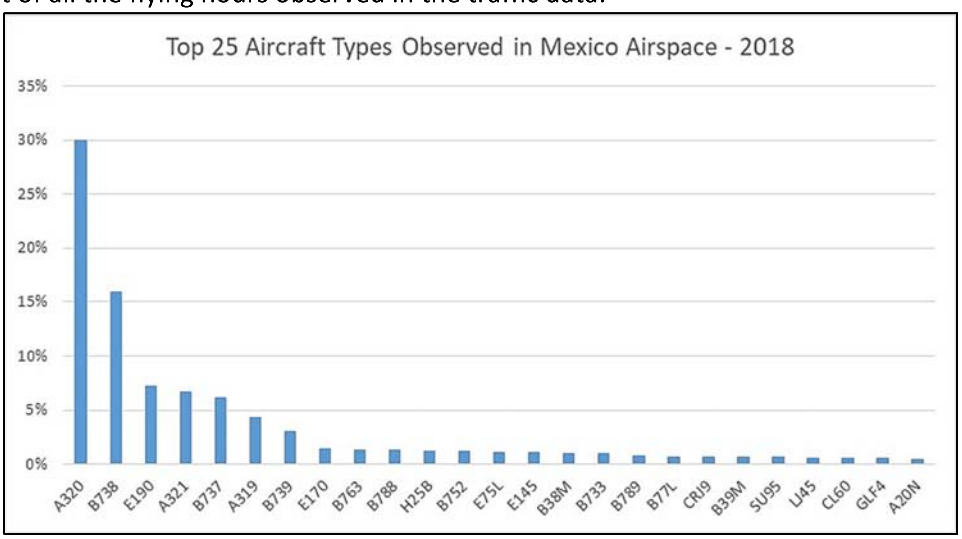

Figure 5-1. Observed Aircraft Types in Terms of Flying Hours in México Airspace (2018)

5.7 Aircraft Size

5.7.1 The collision risk model parameters related to the aircraft size are: length, wingspan, and height. These parameters are estimated directly from the México December 2018 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 5-1**.

Table 5-1. CRM Parameter Estimates for Aircraft Size

Length λ_x (NM)	Wingspan λ_y (NM)	Height λ_z (NM)
0.0201	0.0184	0.0063

5.8 Same-Direction, Opposite-Direction, and Crossing-Route Vertical Passing Frequencies

5.8.1 The TFMS data is used to estimate the number of vertical aircraft passings per hour. The same and opposite direction vertical occupancy estimates are 0.040 and 0.060, respectively. Improvements in the TSD would help to provide better estimates of occupancy. NAARMO will examine the difference in vertical occupancy estimates for the domestic versus oceanic/offshore airspace.

5.8.2 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 observed in the December 2018 TFMS data was 19,774. This value, prorated from the 31-sample days for the calendar year 2018 is 232,823 aircraft pairs.

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

5.9.1 RVSM technical risk is considered to arise from the effects of turbulence, loss of altitude hold and crew response to airborne collision avoidance system alerts as well as from errors in aircraft altimetry and altitude-keeping system performance. Hence, estimation of the probability of vertical overlap must account for contributions to vertical error arising from all of these sources.

5.9.2 Currently, the U.S. Aircraft Geometric Height Monitoring Element (AGHME) and the GPS Monitoring Unit (GMU) systems provide the NAARMO with estimates of aircraft altimetry system error (ASE), an important contributor to estimated risk. Control of 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.

5.9.3 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 1.64×10^{-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.

5.10 Time spent at Unexpected FL

5.10.1 The proportion of flying time spent at incorrect levels, P_i, is determined as the ratio of the amount of time spent at incorrect levels to the total amount of flying time in the México airspace during the period when the wrong-flight-level events occurred. The qualifying LHDs for calendar year 2018 contain 85.5 minutes of flying time spend at unexpected flight level. The proportion of total flight time spent at unexpected flight levels is 1.49×10^{-6}.

5.11 Collision Risk Model Parameters

5.11.1 The individual parameters of the models, their definitions, estimates, and sources are given in **Table 5-2**.

Table 5-2. 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 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
$P_y(0)$	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.	0.0201 NM	Estimated using December 2018 México TFMS sample
λ_y	Average aircraft wingspan.	0.0184 NM	Estimated using December 2018 México TFMS sample
λ_z	Average aircraft height with undercarriage retracted.	0.0063 NM	Estimated using December 2018 México TFMS sample
$E_z(same)$	Same-direction vertical occupancy for a pair of aircraft at adjacent flight levels on same route.	0.040	Estimated using December 2018 México TFMS sample
$E_z(opp)$	Opposite-direction vertical occupancy for a pair of aircraft at adjacent flight levels on same route.	0.060	Estimated using December 2018 México 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

6. Results and Conclusions

6.1 **Table 6-1** provides 2018 estimates of technical and operational vertical risk for México airspace.

Table 6-1. 2018 Vertical Risk Estimates for México RVSM Airspace

Description	Risk Estimate (×10^{-9} fapfh)
Estimate of Technical Risk	**0.05**
Estimate of Risk Due to Operation at Incorrect Flight Levels	**16.67**
Estimate of Overall Risk	**16.7**

6.2 The estimated technical risk in the México RVSM airspace is 0.050 × 10^{-9} fatal accidents per flight hour (fapfh). This estimate is significantly below 2.5 × 10^{-9} fapfh, which is the portion of the TLS set as the safety goal for technical height-keeping performance.

6.3 The operational risk estimate for México RVSM airspace 16.7 × 10^{-9} fapfh. The sum of this value and the technical risk estimate for México airspace is 16.7 × 10^{-9} fapfh, or about 23 percent above the overall safety goal of 5.0 × 10^{-9} fapfh.

6.4 **Table 6-2** provides the overall vertical risk estimates for calendar years 2015 – 2018 for México RVSM airspace. The increase in the vertical risk estimate for calendar year 2018 occurs because of the occurrence of three long duration reported LHDs. Without these three reported LHDs, the estimated overall vertical risk would be 4.27 × 10^{-9} fapfh.

Table 6-2. Overall Vertical Risk Estimates for México RVSM Airspace

Calendar Year	Vertical Collision Risk Estimate (×10^{-9} fapfh)
2015	**4.8**
2016	**4.8**
2017	**3.2**
2018	**16.7**

— END —