Introduction

Presented by the

Pacific Approvals Registry and Monitoring Organization (PARMO)

1. Reduced Vertical Separation Minimum (RVSM) history and implementation

   Why is continued safety monitoring needed?

2. RMA and EMA, Monitoring agency roles and responsibilities

3. Overview of safety monitoring processes for RVSM

APAC Safety Seminar

RVSM History and Implementation

Safety Seminar

RVSM History – Development of the Standard, Timeline

1

1954

Reevaluation of the vertical separation minimum

Due to the increase of commercial turbojet aircraft operating at high levels.

ICAO formed a Vertical Separation Panel, identified factors likely to contribute most to loss of vertical separation and proposed steps to be taken to reduce or eliminate their influence.

2

1958

2000-ft. separation standard established

Based on work of the Vertical Separation Panel “vertical separation minimum between IFR traffic shall be a nominal 1000 ft below flight level 290 and a nominal 2000 ft at or above this level”.

3

1970s

RVSM benefits are determined

A study of oceanic system improvement options, Oceanic Area System Improvement Study (OASIS), concluded that RVSM was single best thing to implement; fuel-burn reduction far outweighed that attributable to horizontal plane separation reductions.

- ✓ Aircraft fuel-burn penalty of about 1% for each 1000-ft below optimum cruise altitude
- ✓ RVSM provides doubling of capacity
- ✓ RVSM achievable without major changes to aircraft or ATC system

4

1982

RVSM feasibility assessment

ICAO Review of the General Concept of Separation Panel (RGCSP) agreed to begin work to determine RVSM technical feasibility

5

1988

RVSM determined to be technically feasible

RGCSP/6 concluded that the RVSM was technically feasible without placing undue burden on equipment.

6

1990

ICAO produced RVSM guidance a SARPs

RGCSP/7 produced draft RVSM guidance material

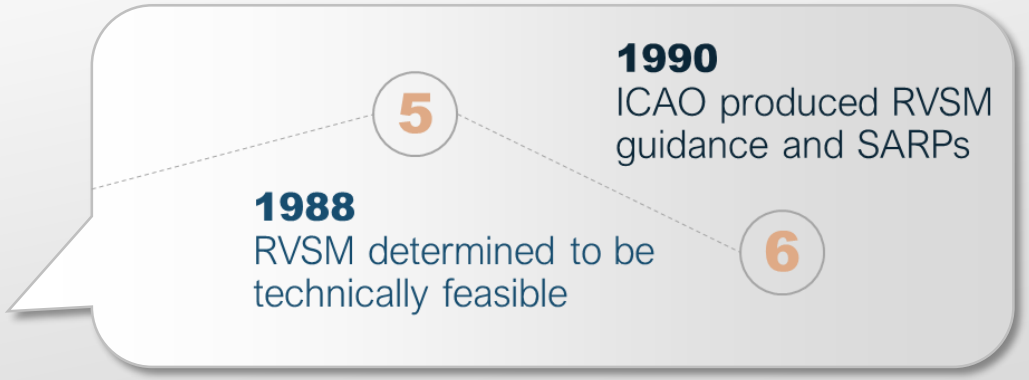
ICAO Air Navigation Commission approved guidance material and Standards and Recommended Practices (SARPS) - Amendment 31 to Annex 2

Aircraft Height-Keeping Performance

The Challenge

Accurately determining and maintaining aircraft altitudes and, therefore, the actual vertical distance between aircraft.

Aircraft maintain assigned flight level by sensing and measuring pressure and converting pressure to feet via the ICAO Standard Atmosphere.



Errors in the sensing and conversion process are not easily estimated

- Observed errors in pressure altitude on the flight deck or by ATC surveillance reflect only the differences between cleared pressure altitude and the pressure altitude flown
- The difference between aircraft-measured pressure and constant pressure surface defining flight level is what is needed - the difference is called **Altimetry System Error (ASE)**

Aircraft Height-Keeping Performance

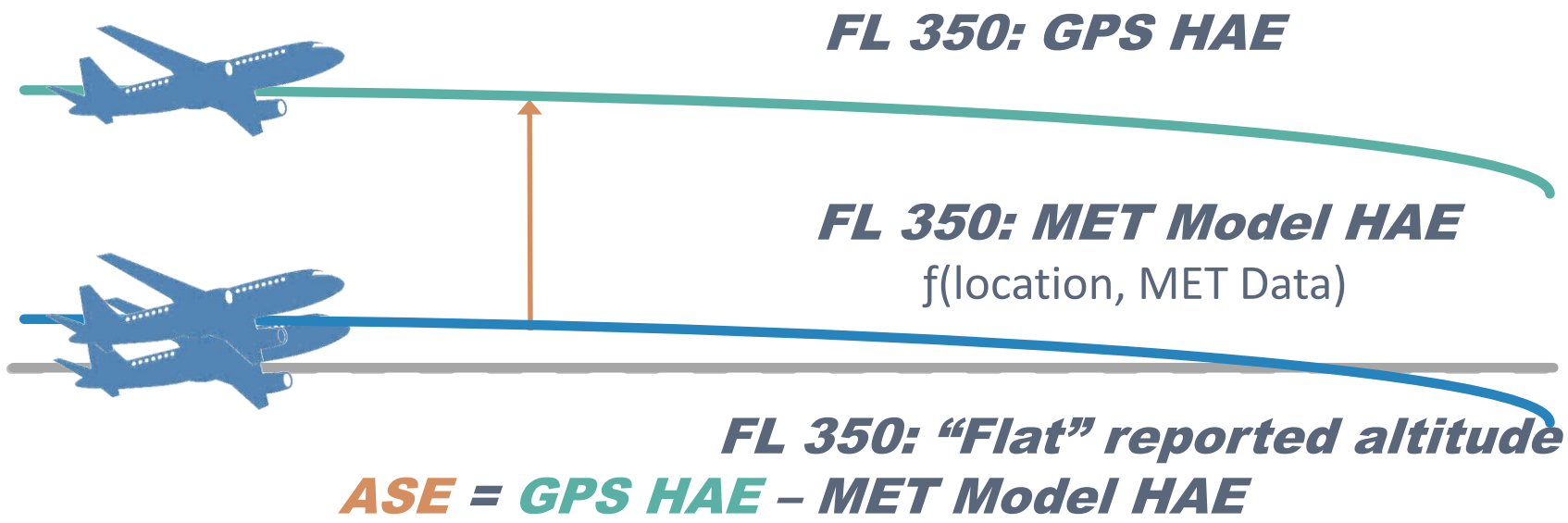
To determine errors in altimetry system, information about the geometric height of a flight level and the geometric height of aircraft is needed - neither of which were readily available.

- Flight levels are defined by constant pressure surfaces in the atmosphere
- Constant pressure surface over a geographic region is not at constant geometric (“tape measure”) height, in general:
  - constant-pressure surfaces increase in geometric height from pole to equator
    - Variations by latitude, season, weather patterns & time of day

      e.g. Generally higher in the summer (warmer expanded air) compared to winter

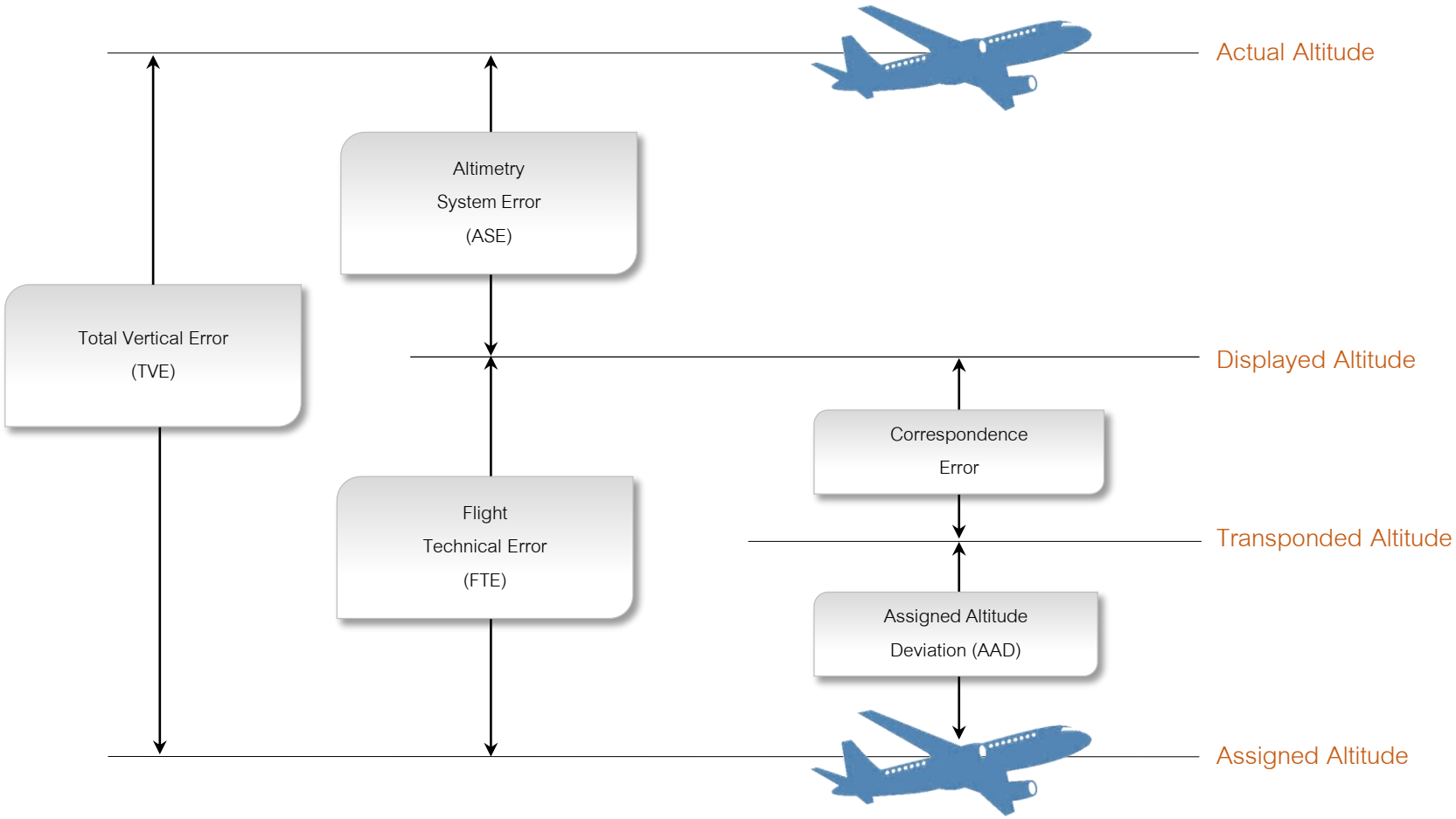
Aircraft Height-Keeping Performance

Altimetry System Error (ASE), undetectable discrepancies between the aircraft's assigned flight level and its actual altitude.



HAE = Height above ellipsoid

Aircraft Height-Keeping Performance



Development of the RVSM – The Solution in 3 Parts

Aircraft Equipment Requirements

- ✓ Provide flight crew information on the flight level being flown
- ✓ Automatic maintain a selected flight level
- ✓ Provide alert to the flight crew when a height deviation from the selected flight level occurs
- ✓ Report pressure-altitude automatically

Aircraft RVSM Specific Approval

RVSM specific approval indicating the State is satisfied that:

- ✓ the vertical navigation performance capability of the aircraft satisfies the requirements specified in Annex 6
- ✓ the operator has instituted procedures in respect of continued airworthiness (maintenance and repair) practices and programs

ASE Performance Monitoring

Establishment of a monitoring program for the height-keeping performance of aircraft operating at RVSM levels.

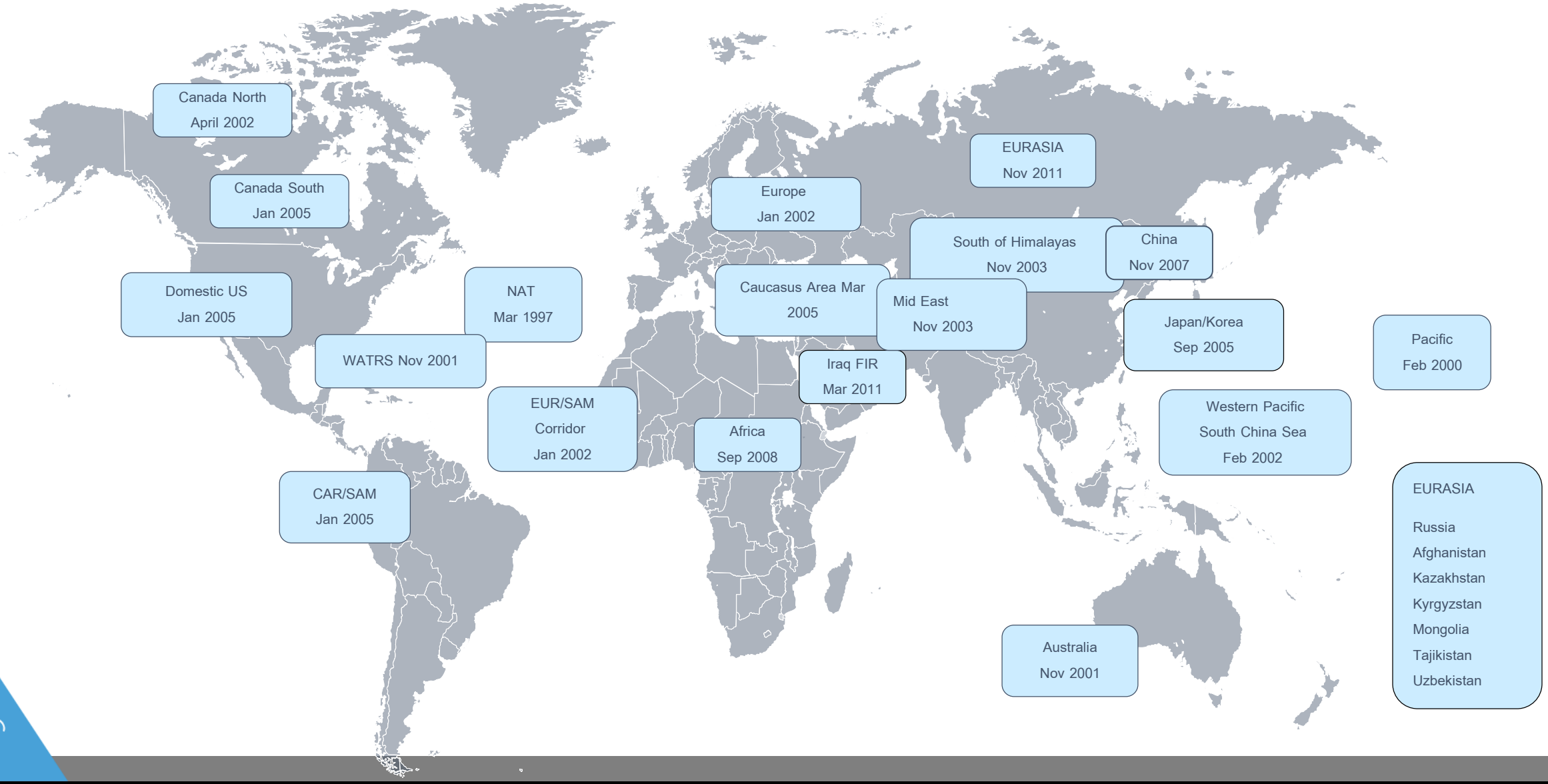
- ✓ The monitoring program can conduct analyses for individual aircraft and aircraft group performance and evaluate ASE stability

RVSM Implementation – Regional Coordination and Harmonization

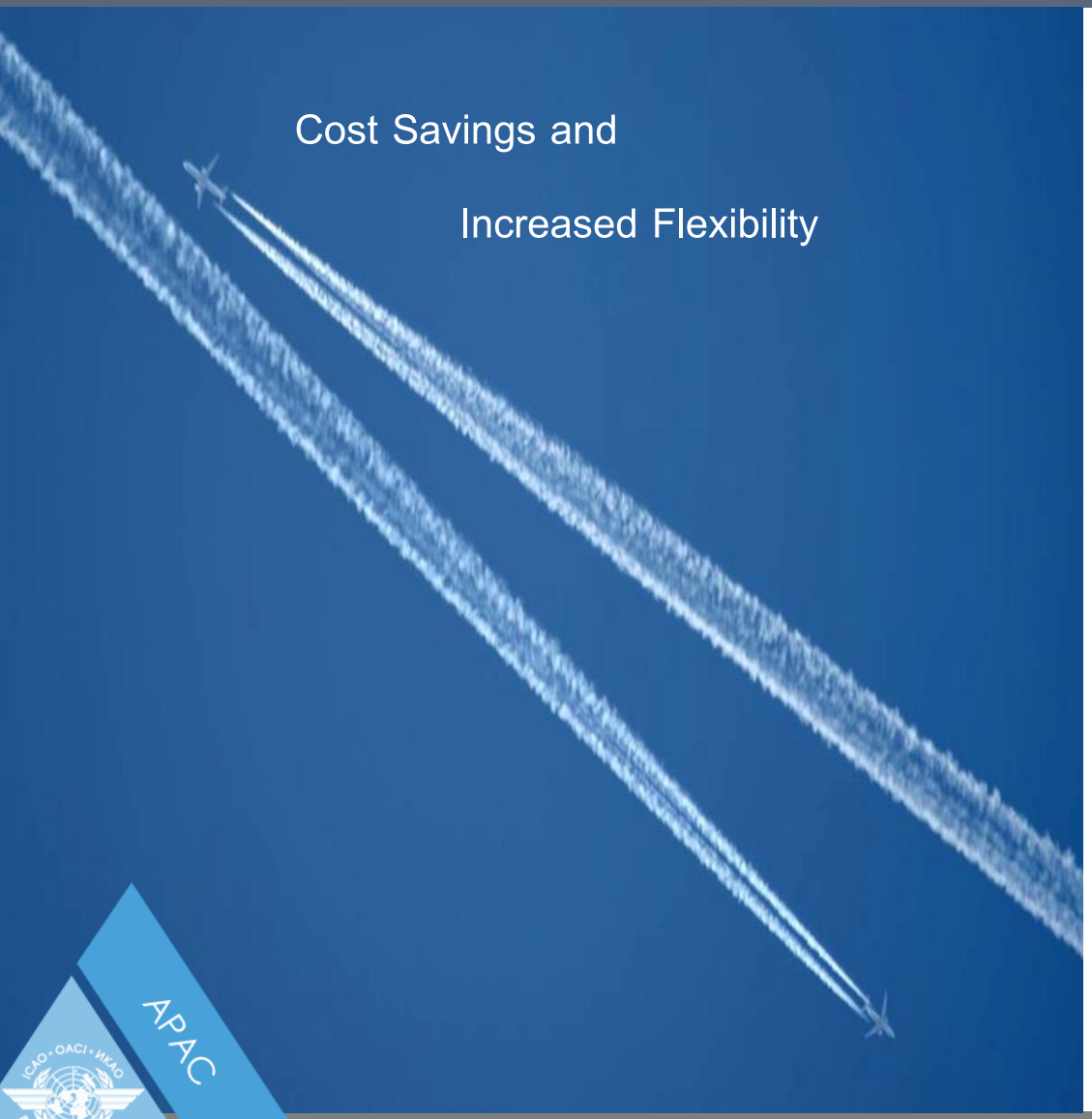
ICAO regional planning groups (PIRGs) were established to harmonize global guidance and regional requirements. RVSM implementation among Regions was coordinated through the PIRGs.

APANPIRG	Asia/Pacific Air Navigation Planning and Implementation Regional Group
APIRG	Africa-Indian Ocean Planning and Implementation Regional Group
EASPG	European Aviation System Planning Group
GREPECAS	Caribbean/South American Planning and Implementation Regional Group
MIDANPIRG	Middle East Air Navigation Planning and Implementation Regional Group
NATSPG	North Atlantic Systems Planning Group

RVSM Implementation Worldwide

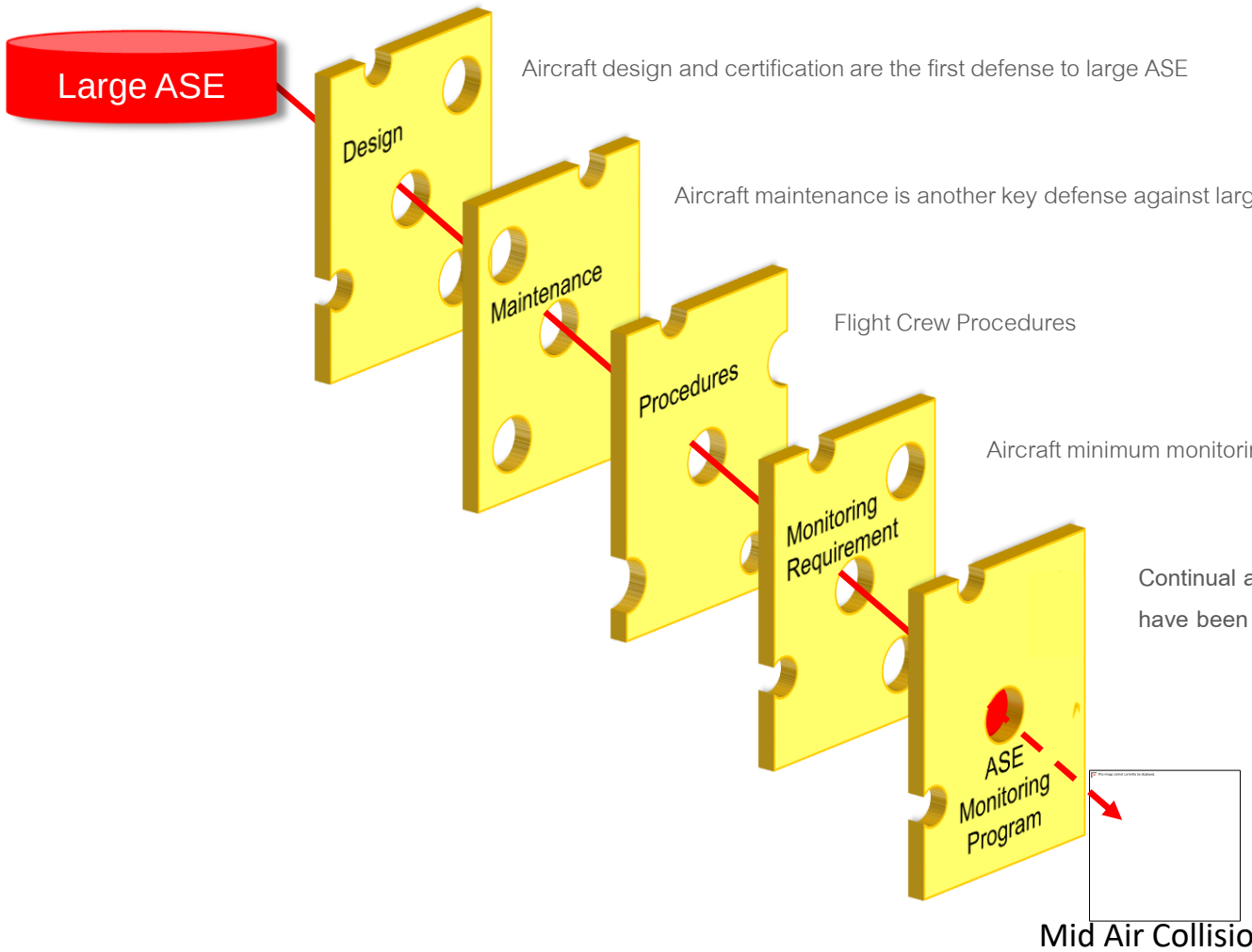


Initial RVSM Implementation Outcomes



- ✓ Operators found that the benefits were greater and the costs less than predicted.
- ✓ Most major oceanic operators recovered equipment costs within the first year of RVSM implementation based on fuel savings alone.
- ✓ ATC units reported little difficulty with RVSM procedures or RVSM/conventional VSM transitions.
- ✓ ATC units able to offer more desirable routings.
- ✓ ATC units report RVSM provides more operational flexibility.

Why is continued safety monitoring needed?



Aircraft design and certification are the first defense to large ASE

Aircraft maintenance is another key defense against large ASE

Flight Crew Procedures

Aircraft minimum monitoring requirements

Continual aircraft monitoring and verification that monitoring requirements have been met

RMA and EMA, Monitoring Agency Roles and Responsibilities

APAC Safety Seminar

Establishment of RMAs

To ensure the continued safe application of RVSM world-wide, standardized safety goals were established by ICAO:

- ✓ Monitoring of the effectiveness of the altimetry system modifications which have been implemented to enable aircraft to meet the required height-keeping performance criteria
- ✓ Evaluation of the stability of altimetry system error (ASE)
- ✓ Verification that the target level of safety will be met upon implementation of RVSM and will continue to be met thereafter

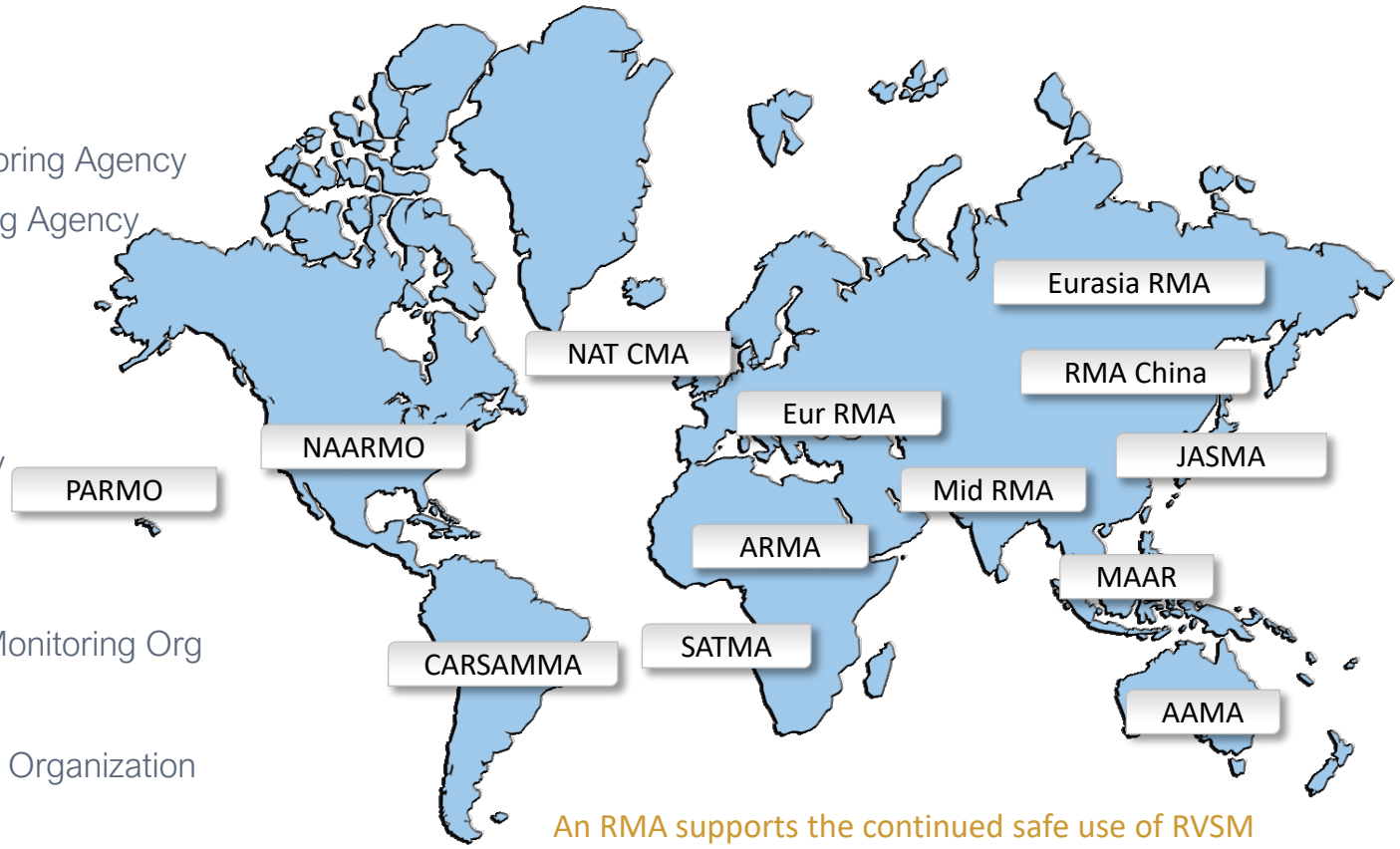
Safety oversight bodies termed Regional Monitoring Agencies (RMAs), were established world-wide to undertake these functions. (ICAO Annex 11)

Regional Monitoring Agencies (RMAs) Worldwide

In all regions where RVSM has been implemented, RMAs have been established by the appropriate PIRGs to satisfy the goals of the RVSM monitoring program.

ICAO-Endorsed Regional Monitoring Agencies

AAMA	Australian Airspace Monitoring Agency
ARMA	African and Indian Ocean Regional Monitoring Agency
CARSAMMA	Caribbean and South American Monitoring Agency
China RMA	China Regional Monitoring Agency
EurAsia RMA	Regional Monitoring Agency Eurasia
EUR RMA	European Regional Monitoring Agency
JASMA	Japan Airspace Safety Monitoring Agency
MAAR	Monitoring Agency for Asia Region
MIDRMA	Middle East Regional Monitoring Agency
NAARMO	North American Approvals Registry and Monitoring Org
NAT CMA	North Atlantic Central Monitoring Agency
PARMO	Pacific Approvals Registry and Monitoring Organization
SATMA	South Atlantic Monitoring Agency

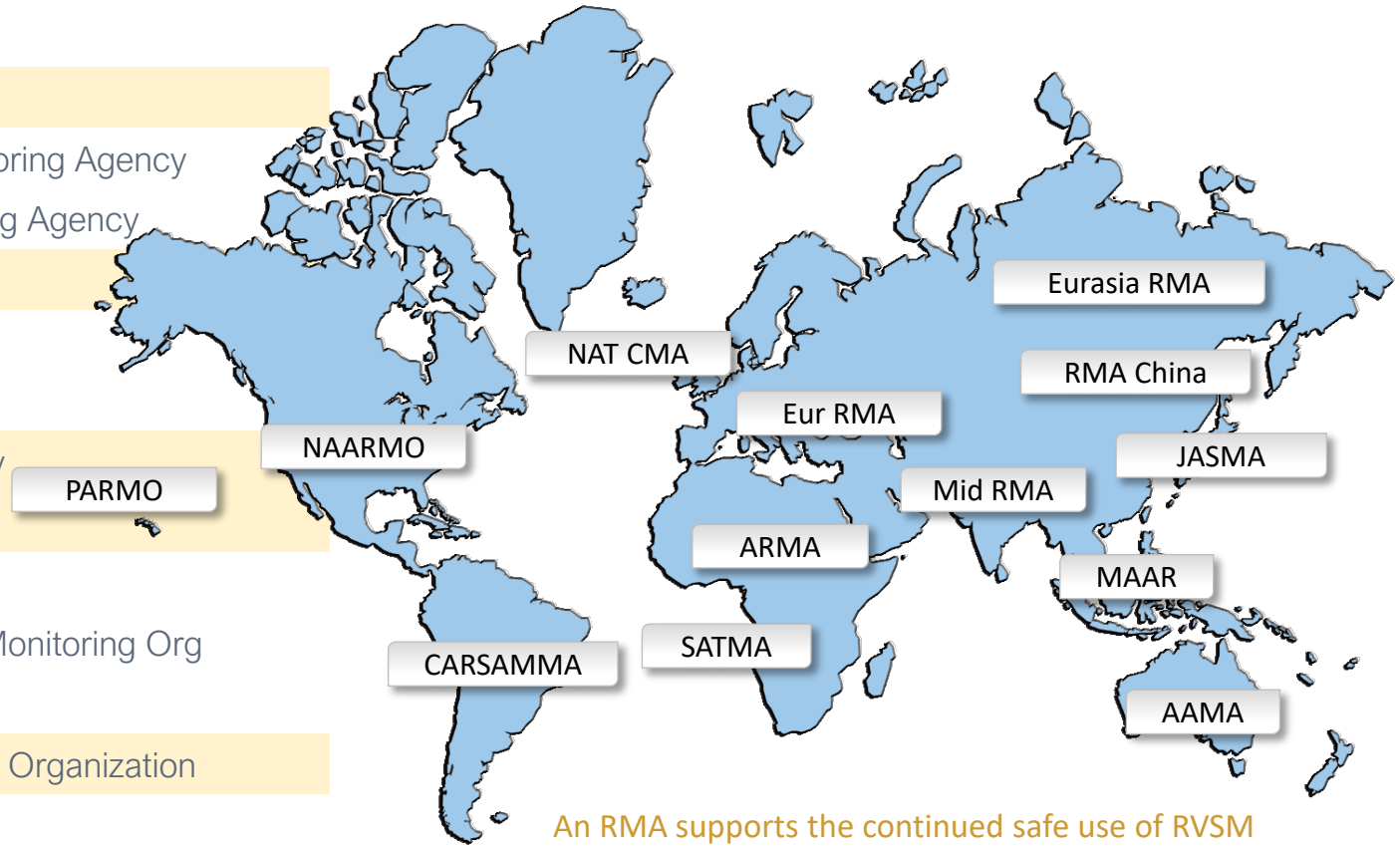


An RMA supports the continued safe use of RVSM within a designated airspace.

Regional Monitoring Agencies (RMAs) Worldwide

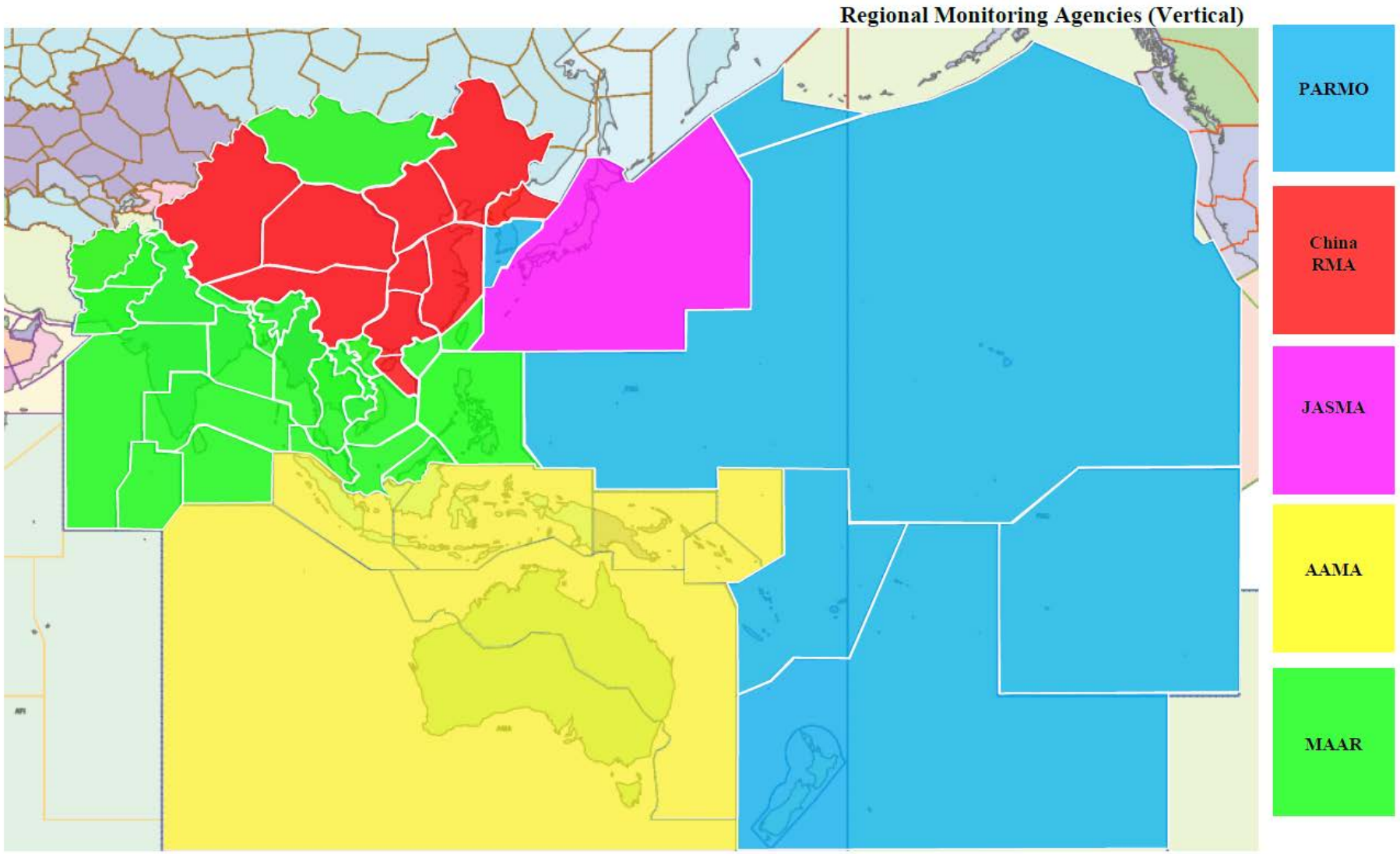
In all regions where RVSM has been implemented, RMAs have been established by the appropriate PIRGs to satisfy the goals of the RVSM monitoring program.

ICAO-Endorsed Regional Monitoring Agencies	
AAMA	Australian Airspace Monitoring Agency
ARMA	African and Indian Ocean Regional Monitoring Agency
CARSAMMA	Caribbean and South American Monitoring Agency
China RMA	China Regional Monitoring Agency
EurAsia RMA	Regional Monitoring Agency Eurasia
EUR RMA	European Regional Monitoring Agency
JASMA	Japan Airspace Safety Monitoring Agency
MAAR	Monitoring Agency for Asia Region
MIDRMA	Middle East Regional Monitoring Agency
NAARMO	North American Approvals Registry and Monitoring Org
NAT CMA	North Atlantic Central Monitoring Agency
PARMO	Pacific Approvals Registry and Monitoring Organization
SATMA	South Atlantic Monitoring Agency



An RMA supports the continued safe use of RVSM within a designated airspace.

Asia Pacific RMAs



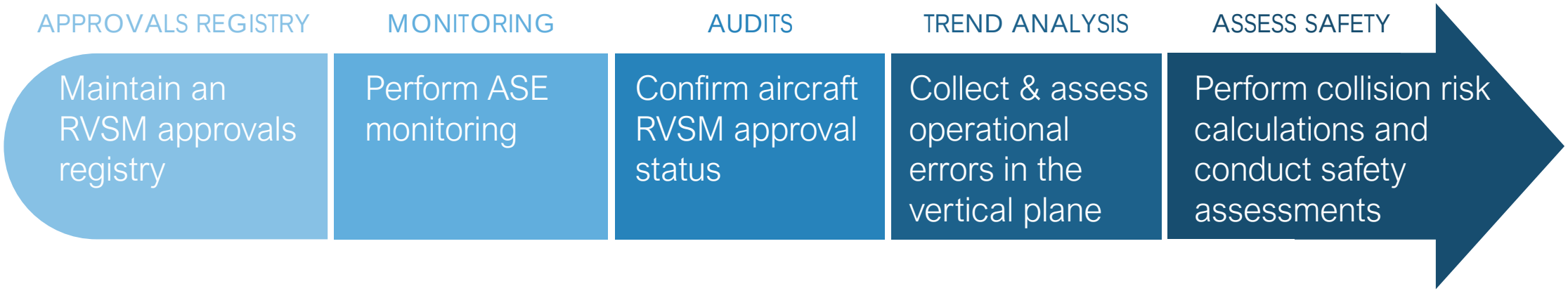
Regional Monitoring Agency Coordination Group (RMACG)

In 2002, the ICAO RMACG was established

- RMACG convenes annually
- Provides forum for the harmonization and standardization of RMA processes and best practices
- All RMAs are expected to participate and:
  - ✓ Report RVSM approvals compliance and monitoring burden
  - ✓ Report risk trends and safety concerns associated with RVSM operations
  - ✓ Maintain and update RVSM minimum monitoring requirements
  - ✓ Support development of advanced systems and processes to improve safety, efficiency and effectiveness of RMA operating procedures and practices

RMA Duties and Responsibilities Overview

In general, RMA duties include:



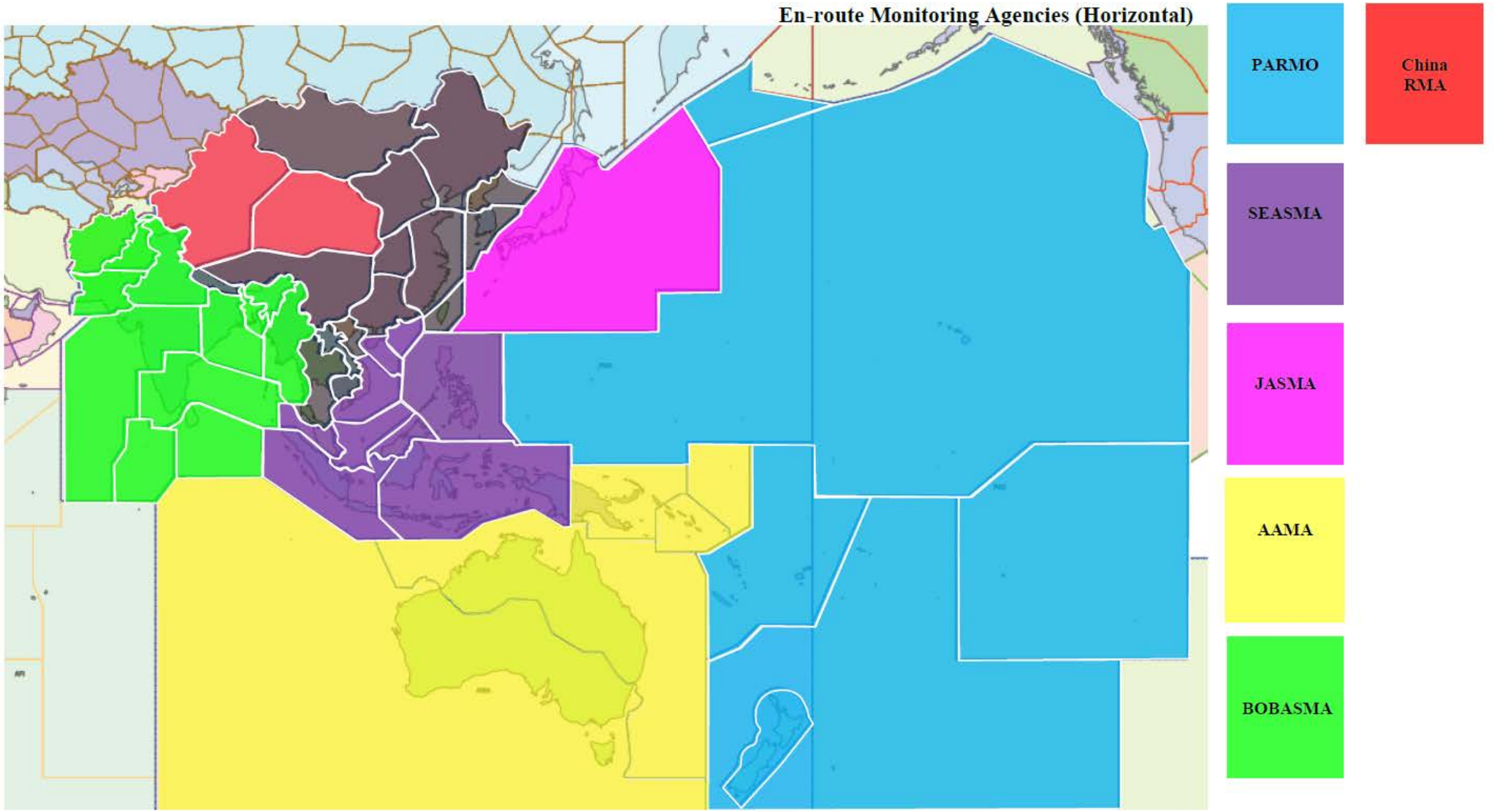
EMAs: Monitoring the Application of Performance-based Horizontal Separation Minima

- In Asia Pacific airspace where:
  - required communication performance (RCP),
  - required navigation performance (RNP), and
  - required surveillance performance (RSP) are utilized for the application of reduced horizontal separation minima, Enroute Monitoring Agencies (EMAs) were established to monitor the related safety performance to ensure that operations continue to meet safety objectives.

The duties and responsibilities of EMAs are similar to RMAs and, in general, include:

Collect and analyze LLD/LLE reports	Monitor level of risk as a consequence of reported LLDs/LLEs	Coordinate with State and ATC POCs for PBCS Underperformance reports

Asia Pacific Enroute Monitoring Agencies (EMAs)



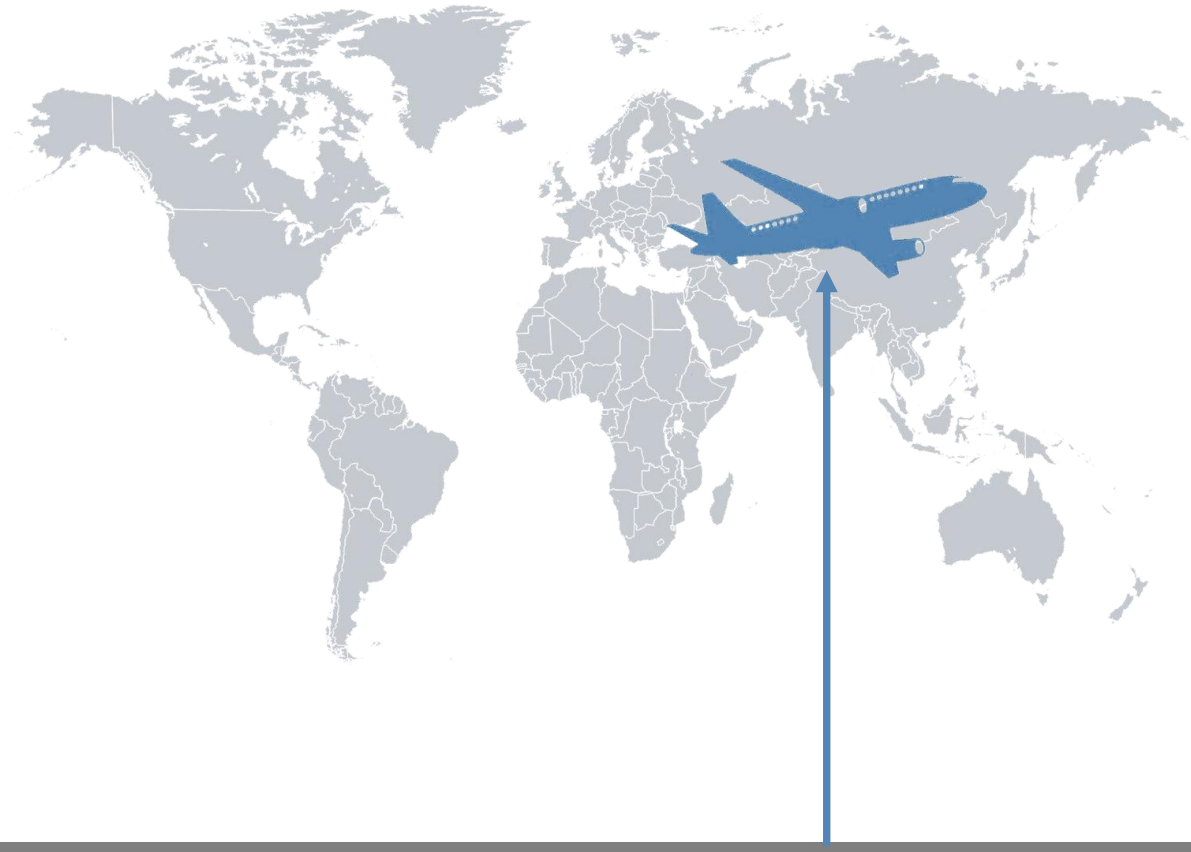
RVSM Safety Monitoring Processes

APAC Safety Seminar

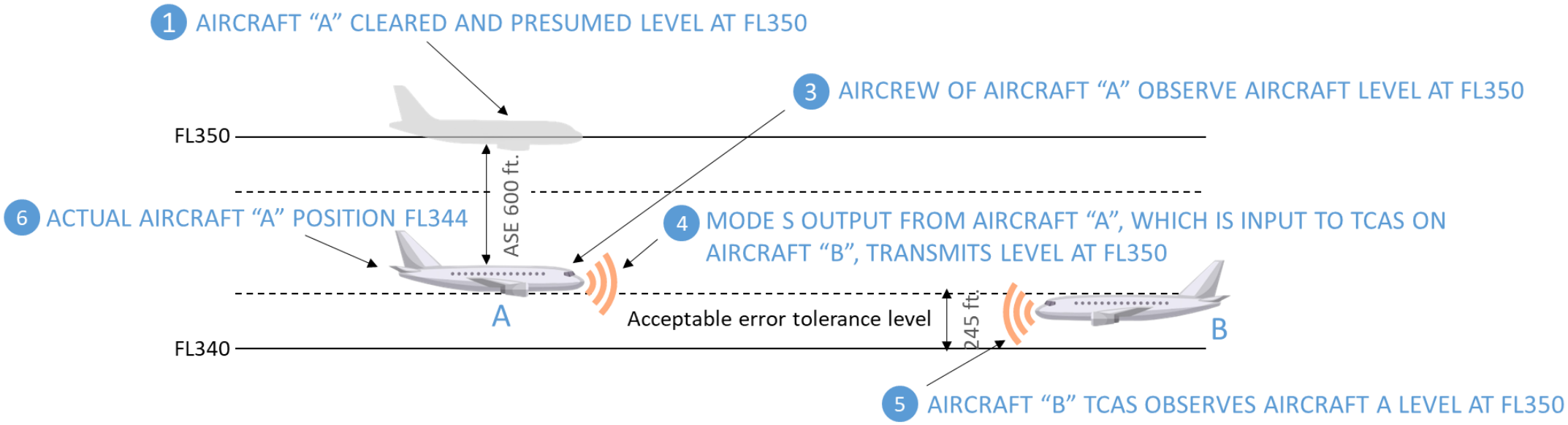
Height-Keeping Performance Technical Objectives

A key role of an RMA is to establish a height-keeping performance monitoring program to provide ongoing assessment of ASE performance of aircraft and aircraft groups so that adverse trends can be identified quickly

The primary function of the monitoring system is to estimate the ASE of an aircraft by comparing the actual height of the aircraft to the height of the flight level as indicated by the aircraft's altimetry system.

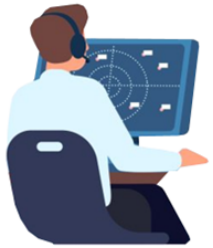


ASE is an Invisible Risk



2 ATC OBSERVES AIRCRAFT "A" LEVEL AT FL350

Datablock indicates aircraft A is level at FL350



ASE IS UNDETECTABLE BY AIRCREW, TCAS AND ATC AND HAS A SIGNIFICANT EFFECT ON RISK

- ASE is ONLY detectable by height monitoring systems.
- Although ASE is typically relatively stable over periods of many months, individual aircraft can evidence dramatic change in ASE value due to damage, airframe modification, or other factors.
- ASE of individual aircraft or groups can change slowly over periods of many months.

Height-Keeping Performance Monitoring Methods

The height keeping performance of an aircraft is measured by equipment independent of the aircraft's altimetry system.

- ✓ Aircraft must be airborne and operating at an RVSM altitude for the performance to be measured.
- ✓ Height keeping performance monitoring requires meteorological and aircraft position information

GPS-based Monitoring Unit (GMU) – a portable device brought on board an aircraft and operated by trained technicians. This method uses GPS data to collect the aircraft's position that is then used in the ASE process.

Ground-based Height Monitoring Unit (HMU) – ground-based antennas, configured in a constellation and installed at a fixed location. This method uses multilateration to passively calculate the ASE of all aircraft within the coverage area.

Automatic Dependent Surveillance-Broadcast (ADS-B) Height Monitoring System (AHMS) – provides a source of aircraft position data for use in the ASE calculations. In airspace where ADS-B is available, all properly equipped aircraft are monitored automatically.

RVSM Minimum Monitoring Requirements (MMR)

MMR was established to reduce monitoring burden on operators

- All aircraft operators approved for RVSM are required RVSM height monitoring program
- The number of aircraft that require monitoring operator's fleet, and the variety of aircraft types
- Most aircraft types are eligible for RVSM airworthiness approval provisions
- Aircraft monitoring groups consist of aircraft types that assembled by the same manufacturer, are of have common elements that influence the accuracy of performance

It is not necessary to monitor all airframes within a monitoring group

Category 1: Operators must monitor at least 2 airframes of each group in their fleet

Category 2: Operators must monitor at least 60% of the airframes of each group in their fleet

Category 3: Non-group, experimental, or test aircraft: all aircraft must be monitored

The MMR is updated annually to include new aircraft types, adjust monitoring group composition, or revise the monitoring category of existing monitoring groups

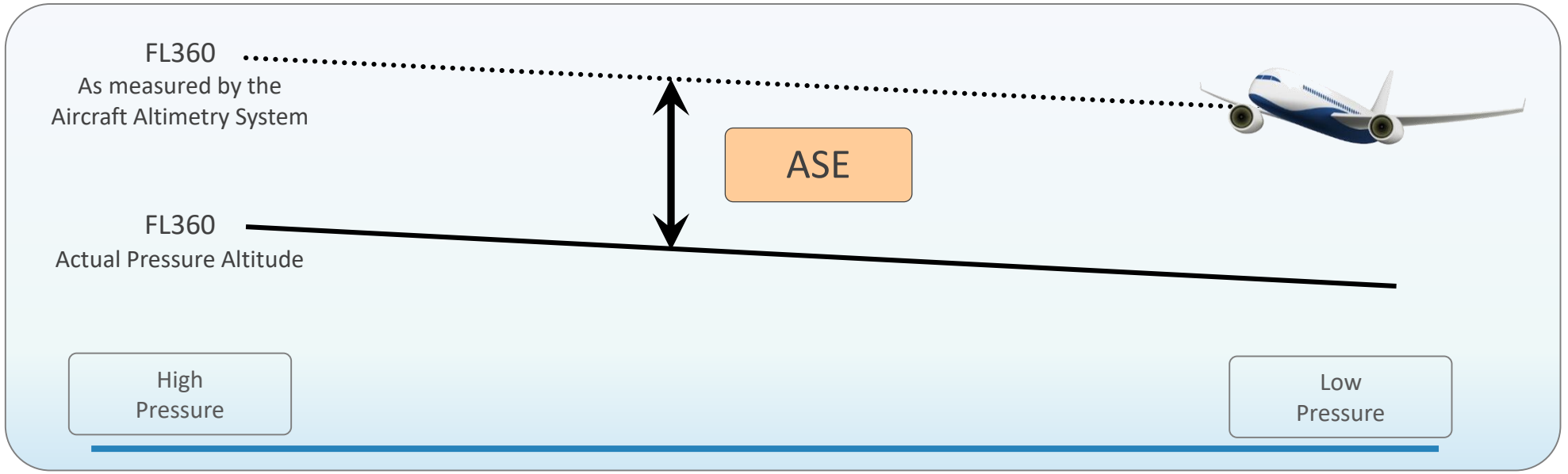
Long-term Monitoring Requirements

- ICAO SASP identified that height-keeping performance monitoring results for RVSM approved aircraft had, in some cases, demonstrated long-term adverse trends in altimetry system error (ASE) stability
- Accordingly, to ensure that adverse trends in ASE stability were detected, it was recognized that globally applicable RVSM long-term height monitoring requirements would be necessary
- As a result, in 2007 ICAO amended Annex 6 – Operation of Aircraft:

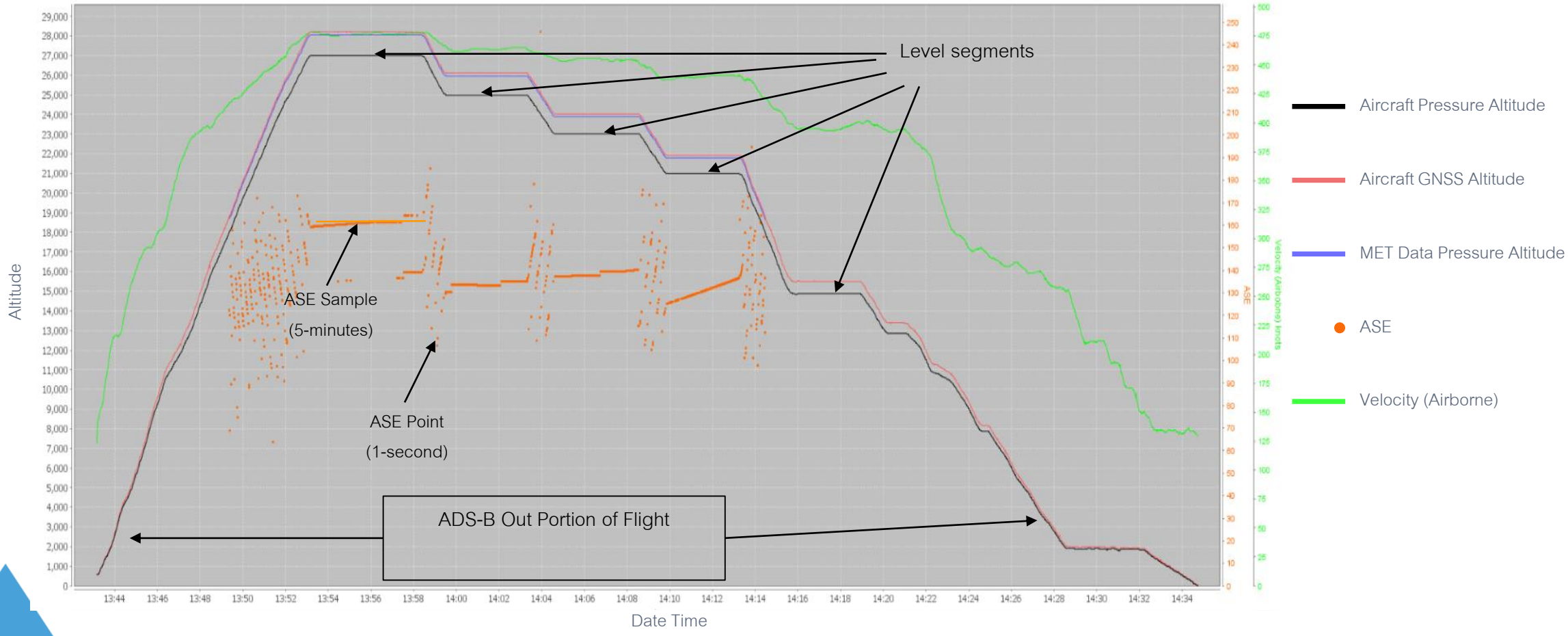
> *"a minimum of two airframes of each aircraft type grouping of the operator have their height-keeping performance monitored, at least once every two years or within intervals of 1 000 flight hours per aeroplane, whichever period is longer. If an operator aircraft type grouping consists of a single aeroplane, monitoring of that aeroplane shall be accomplished within the specified period."*

Monitoring Aircraft Height-keeping Performance

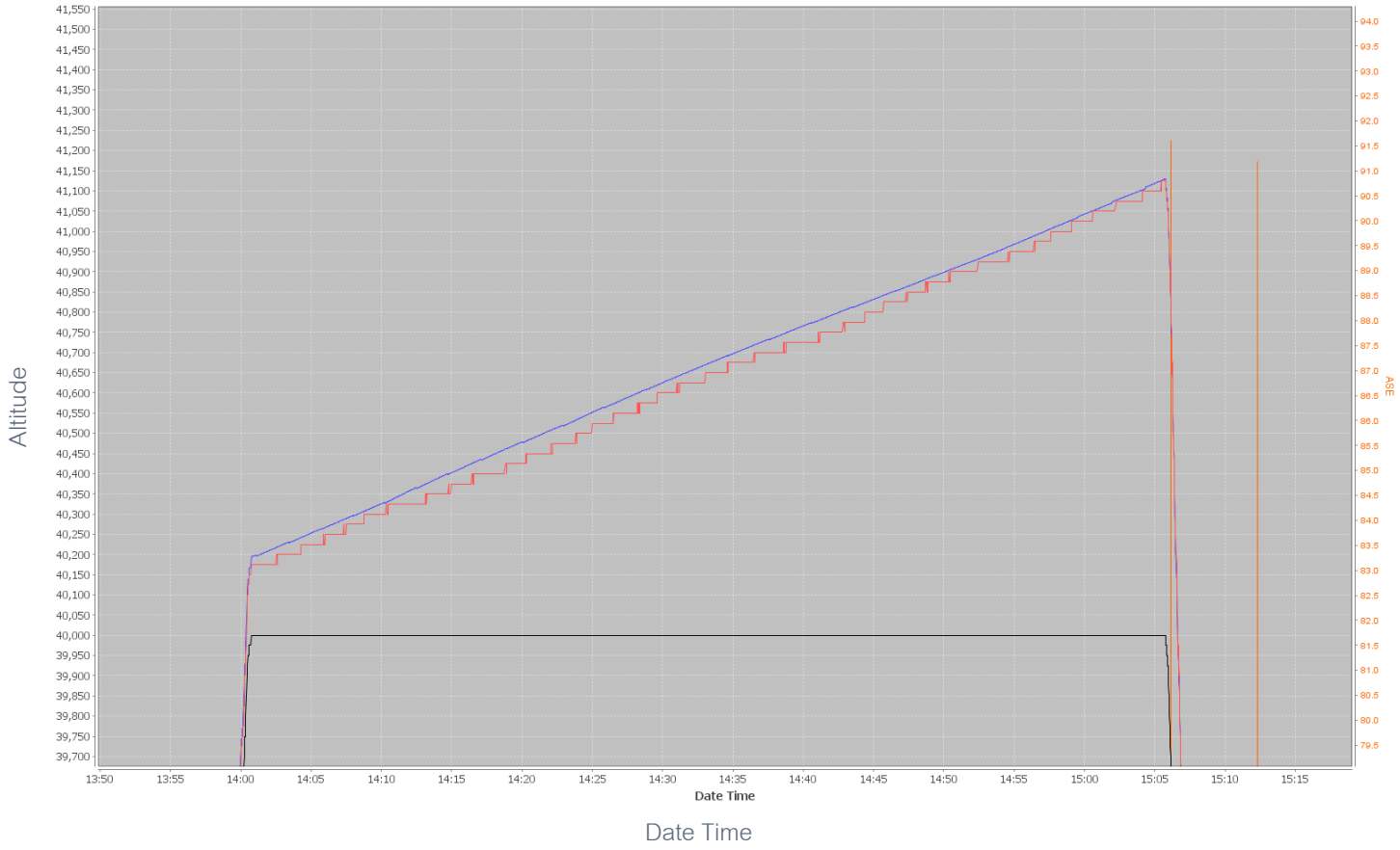
- Altimetry system error is:
  - often referred to as an invisible risk. It is undetectable by aircrew, TCAS and ATC and has a significant effect on risk
  - only detectable by use of specialized monitoring systems
  - determined by comparing the geometric height of an aircraft and the geometric height of the barometric pressure surface associated with the altimetry measurement



Example: Vertical Track Profile



Data Visualization – Zoom to Altitude Data

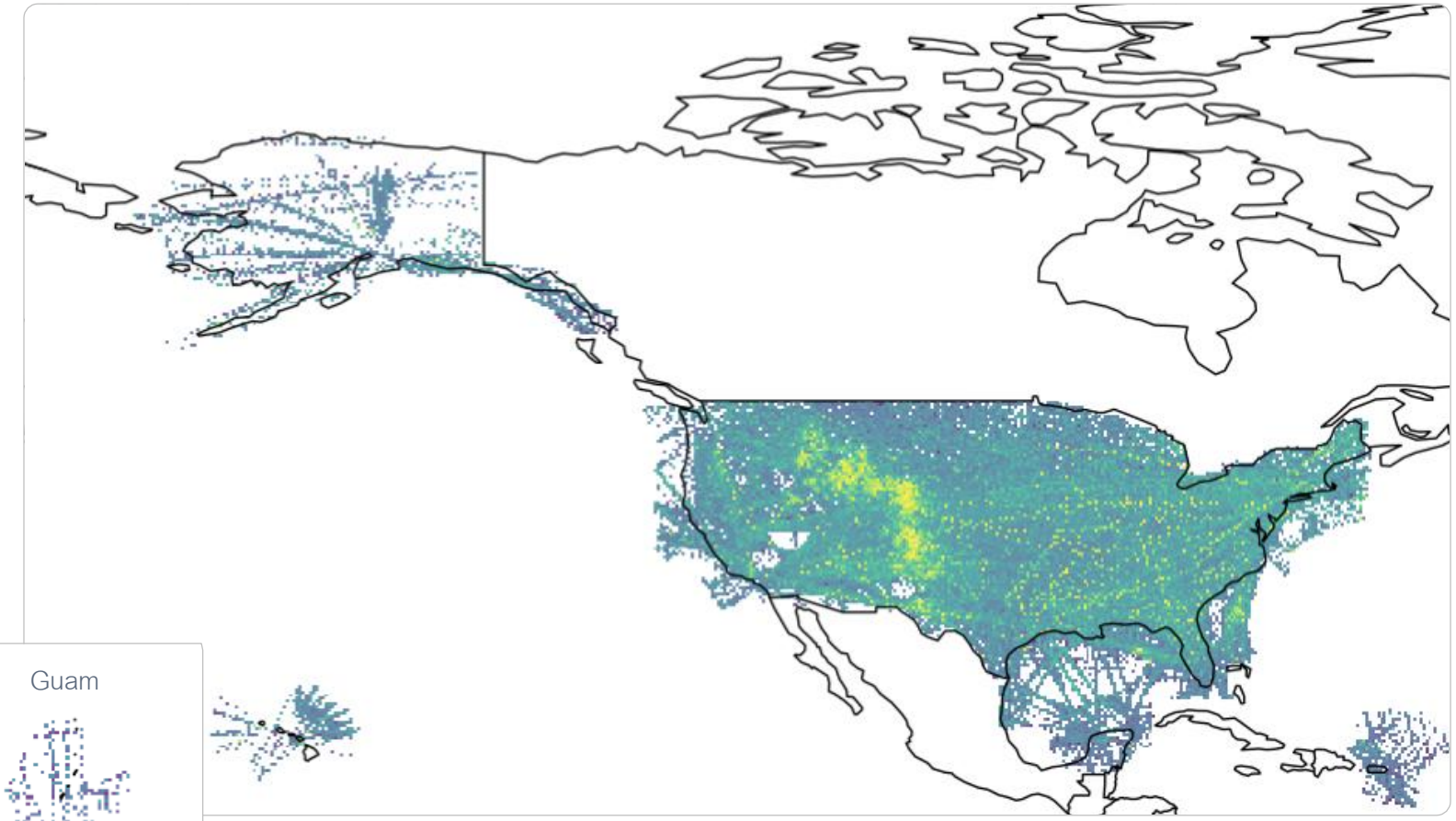


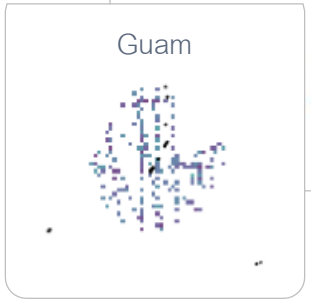
This graph depicts aircraft altitude- keeping information using ADS-B Out.

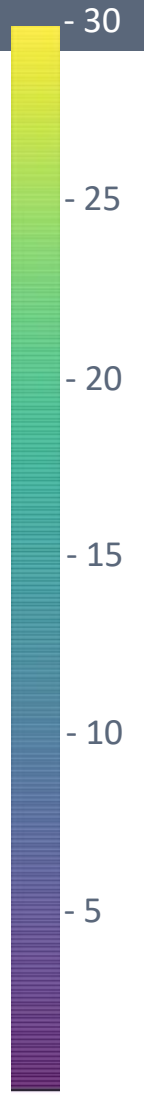
- The aircraft is maintaining FL400 (reported pressure altitude) (black line, left scale).
- The blue line is the modeled meteorological data.
- The red line is the GPS reported altitude.

This aircraft is on its cleared flight level.

ASE Standard Deviation and Terrain





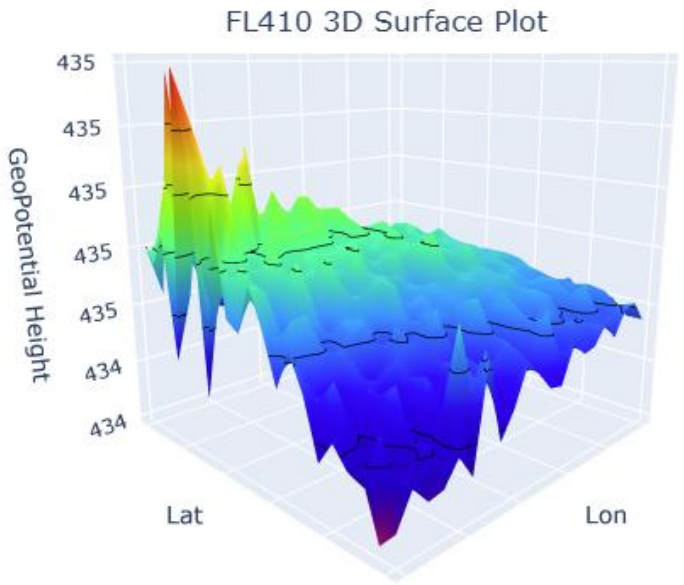


U.S. Air Traffic Control ADS-B Data Coverage

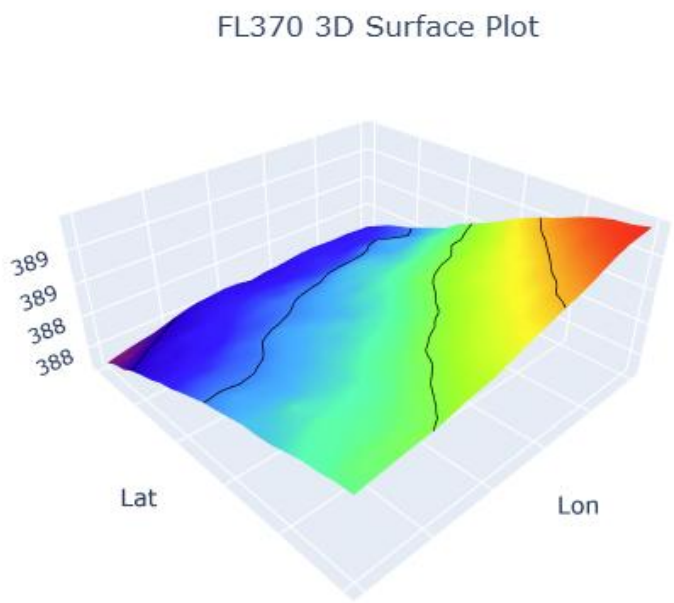
Meteorological (MET) Data Quality Control

- ASE is calculated from independent GPS and MET data
- The MET data elements, such as pressure, temperature, and geopotential heights, contribute to the calculation of ASE
- PARMO has developed a method to identify areas within unstable meteorological conditions
- This method helps to reduce false positive identification of high ASE

Examples of geopotential height variations

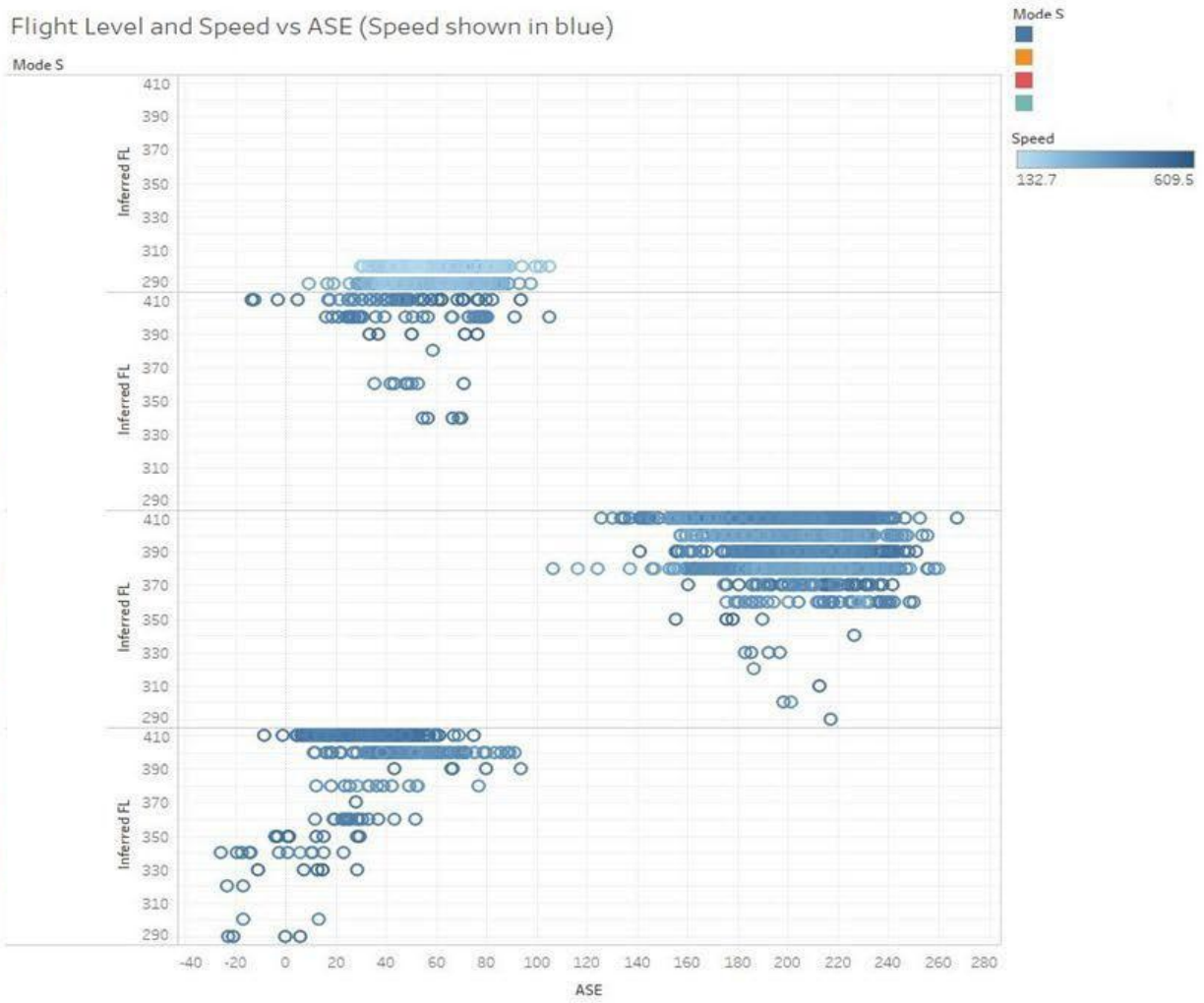


Geopotential heights appear irregular. These variations may result from localized turbulence, convection, or other short-lived atmospheric processes.



Geopotential heights show a smooth and continuous distribution, indicating more structured and predictable atmospheric behavior.

Sample Database Output: Operator Report with Poor Performer

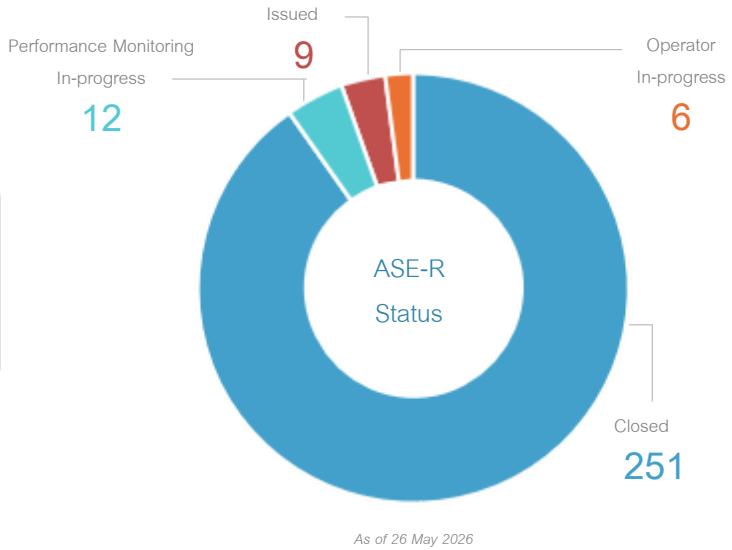


Large ASE Statistics – United States Domestic

OVERVIEW

278
Total initiated since March 2016

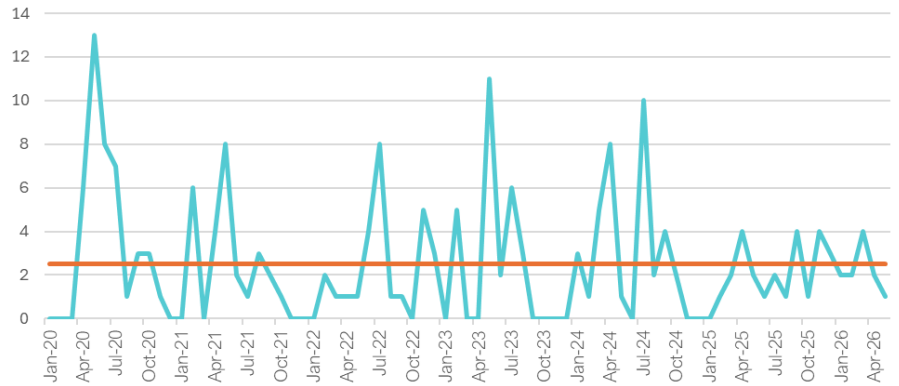
2.27
Average initiated per month



As of 26 May 2026

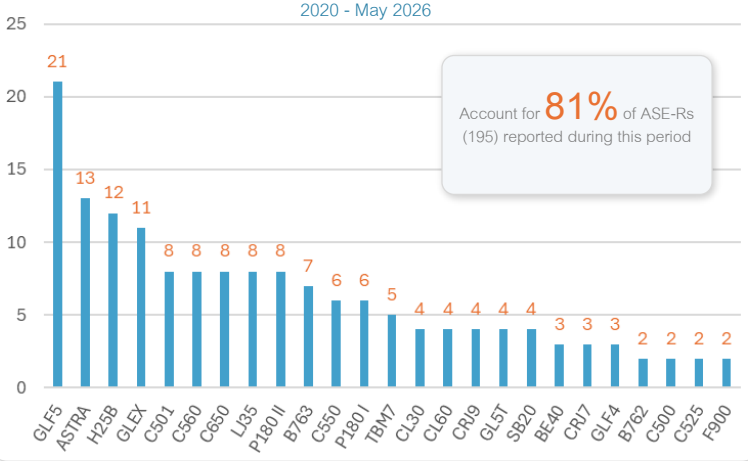
Number of ASE-Rs Initiated by Month

2020 - May 2026



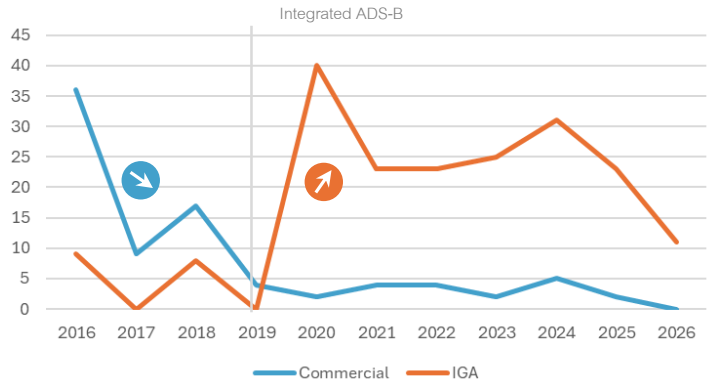
Top 25 Aircraft Types

2020 - May 2026

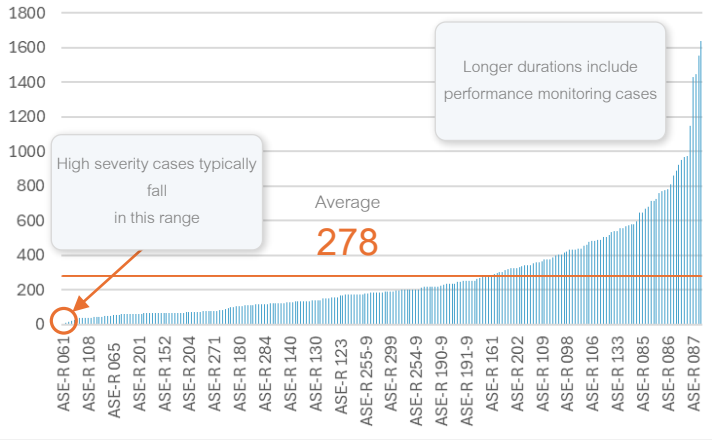


Number of ASE-Rs by Operator Type

2016 – May 2026



Number of Days between Issued Date and Closed



Large ASE Example 1

- 600 ft

Measured ASE

11

Days between issued and closed

Identified 10 and 14 April 2025 in the NAS

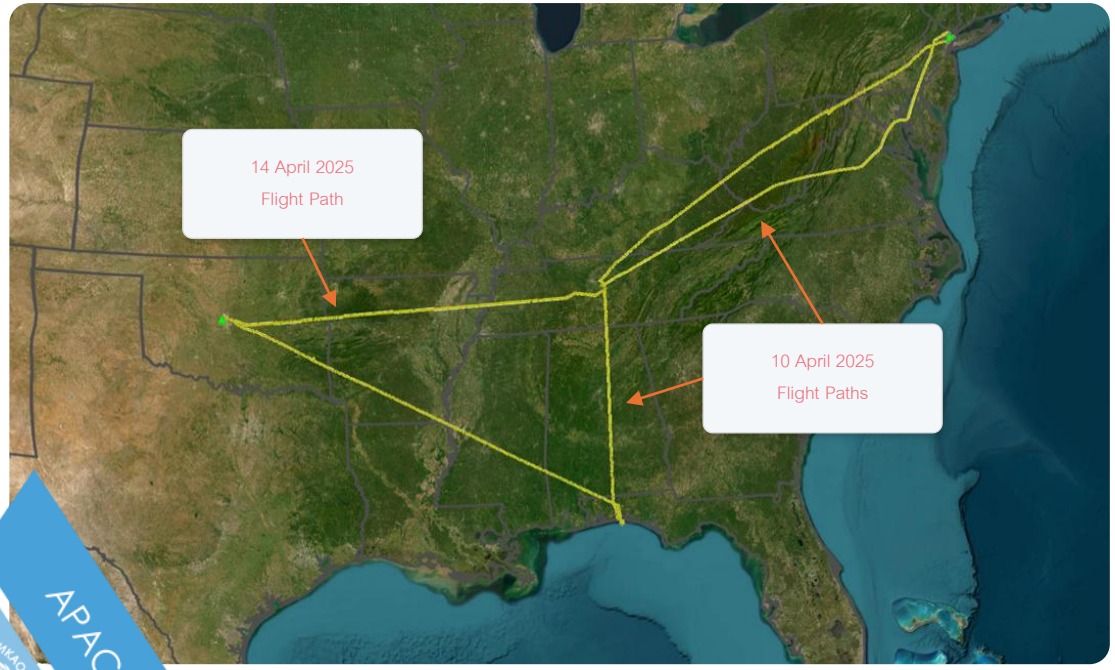
Section 3, RVSM Approval under Part 135
or Part 91-Appendix G

Corrective action 21 April 2025

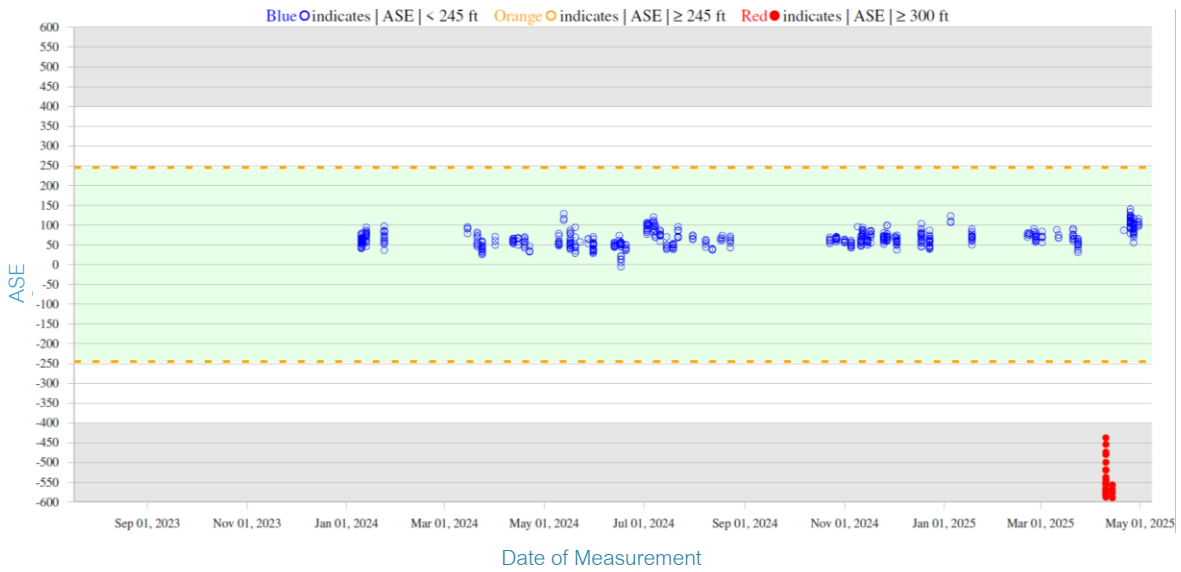
Found co-pilot ADC pitot line disconnected; reconnected to the co-pilots ADC.

Conducted pitot/static leak checks.

C650



ASE Performance



APAC

Large ASE Example 2

≥ 900 ft

Measured ASE

5

Days between issued and closed

Identified 23 Sep 2025 in NAS

Section 9, Domestic RVSM Authorization, Part 91-Appendix G

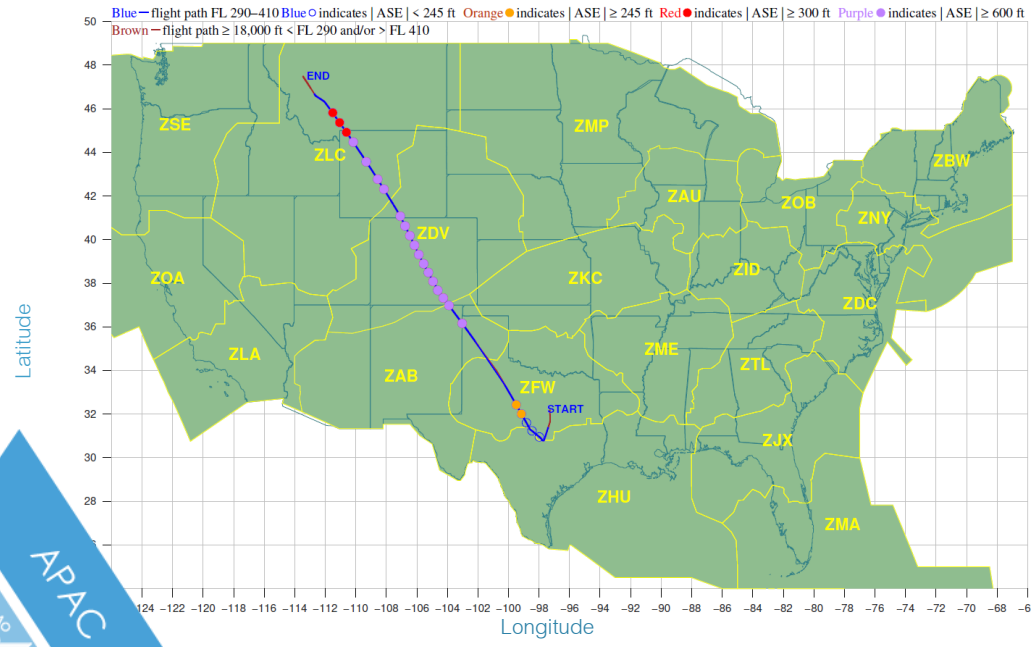
Oceanic Transmittal Sheet filed, May 2025

Corrective action 28 Sep 2025

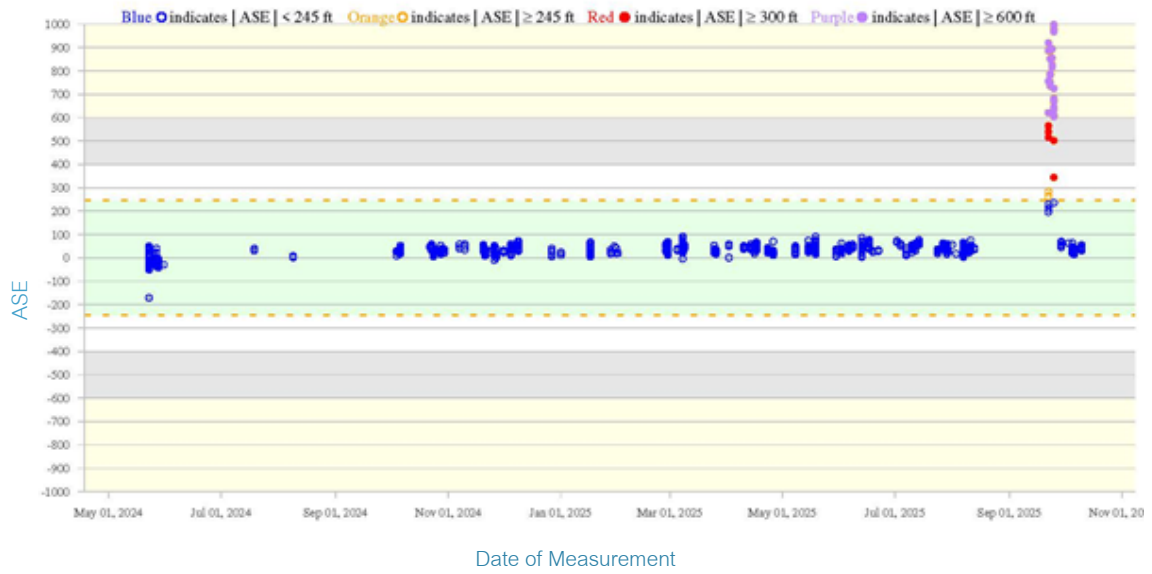
Repaired failed static system rubber hoses, tested for leaks

C560

ASE Performance



ASE Performance



Date of Measurement

APAC

Large ASE Example 3

≥ 900 ft

Measured ASE

3

Days between issued and closed

Identified 1 Oct 2025 in NAS and Canadian airspace

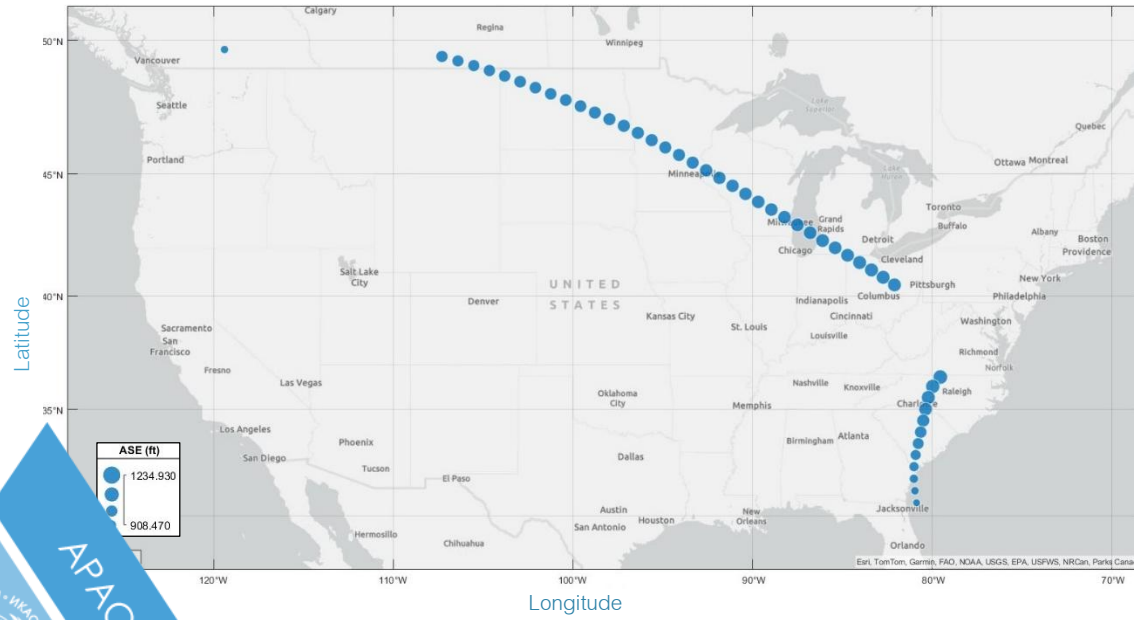
Section 3, RVSM Approval under Part 135 or Part 91-Appendix G

Corrective action 4 Oct 2025

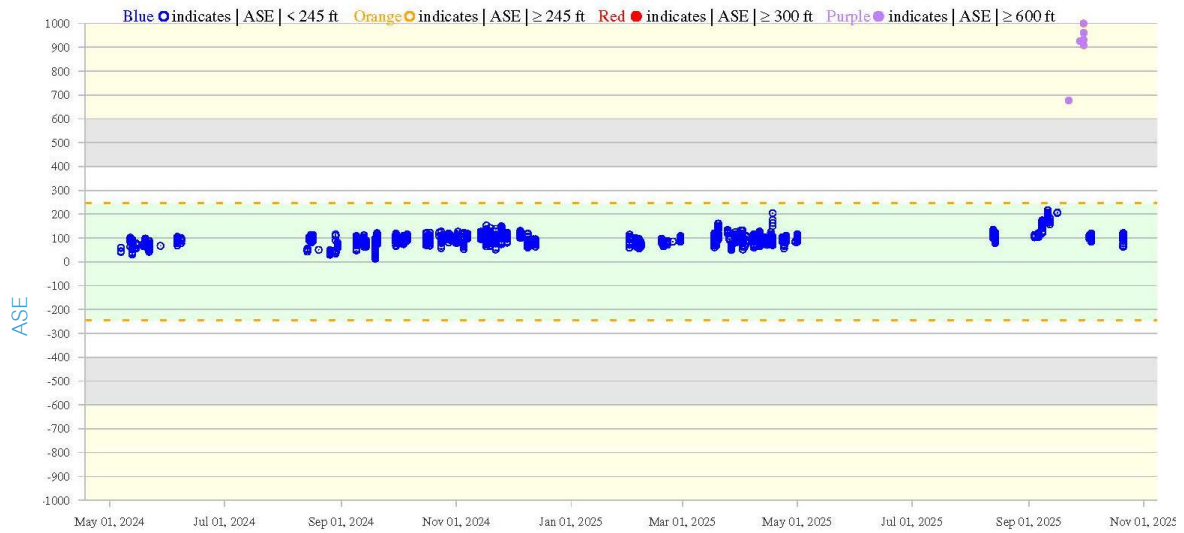
Repaired a leak in the pitot/static system

LJ35

ASE Performance



ASE Performance



Date of Measurement

APAC

Large ASE Example 4

+ 350 ft

Measured ASE

TBD

Days between issued and closed

Identified 1 May 2024 in NAS

Aberrant ASE performance observed, ASE-R issued on 10 October 2024

RVSM approval status unknown; aircraft is not listed in the Mexico RVSM approvals registry

The aircraft's ADS-B system is not broadcasting

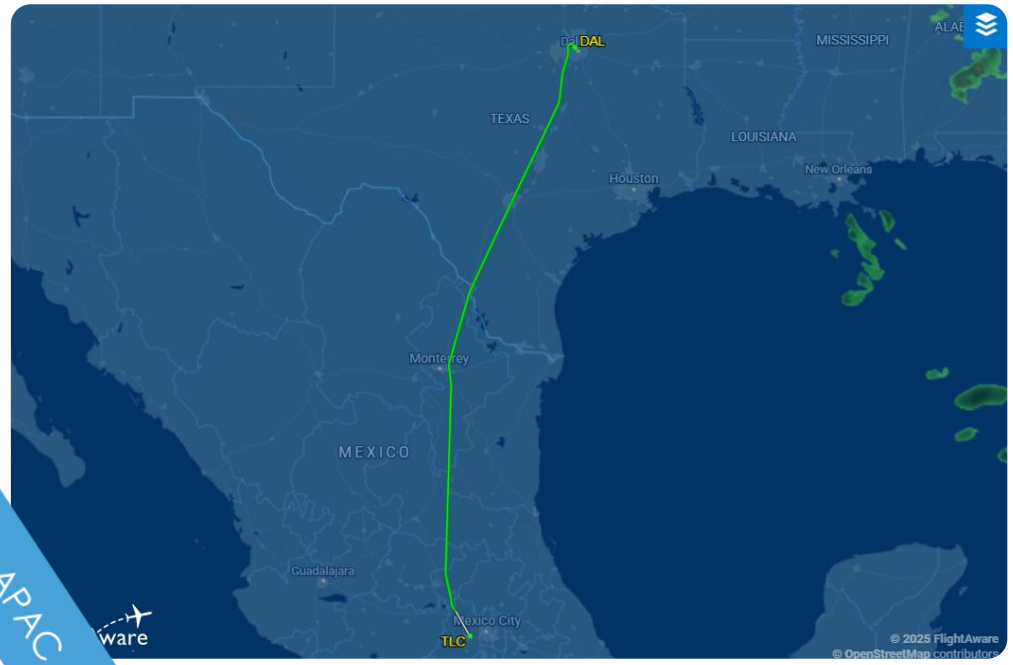
Corrective action TBD

Pending, remains in "Issued" status

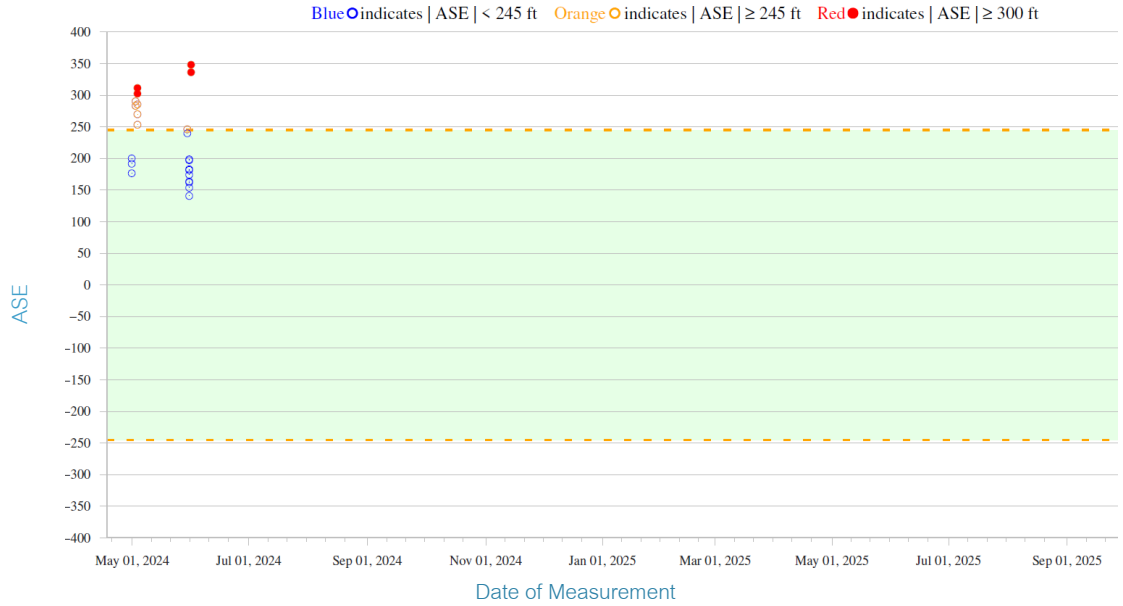
NAARMO attempted coordination with Agencia Federal de Aviación Civil (AFAC)

C650

ASE Performance



ASE Performance



Large ASE Example 5

+ 400 ft

Measured ASE

35

Days between issued and fixed

Identified 17 December 2025 in NAS

- After initial maintenance, ASE appeared to improve but still did not meet performance requirements
- ASE-R remained open until March just to confirm steady performance. (82 days)

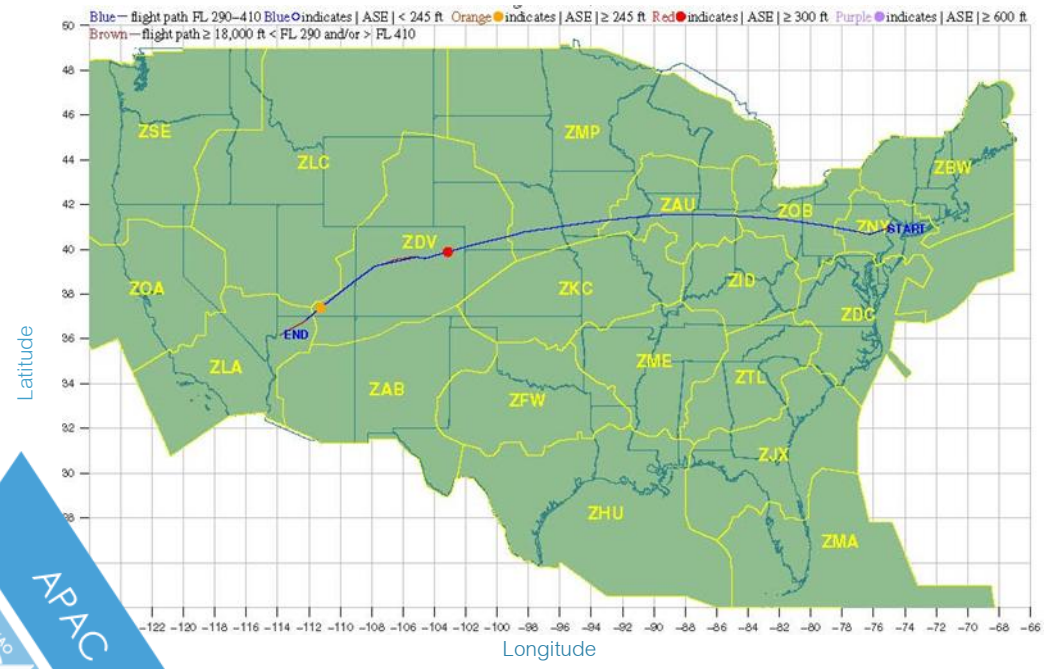
Corrective action 14 January 2026

17 Dec 2025: Replaced #1 pitot static probe

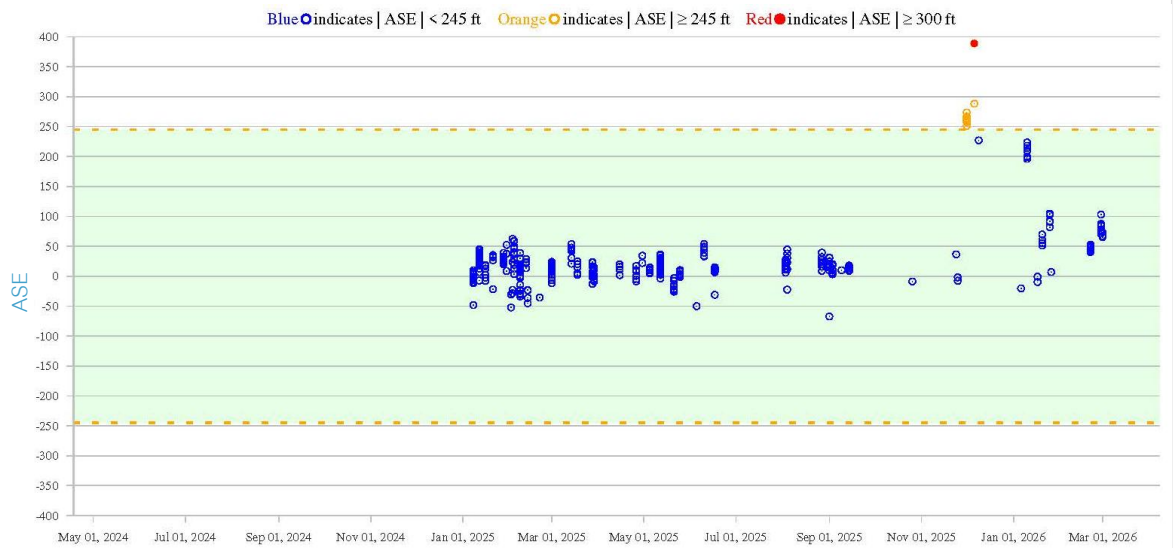
14 Jan 2026: Replaced #2 and #3 Pitot Probes

GLEX

ASE Performance



ASE Performance



Large ASE Example 6

+ 301 ft

Measured ASE

TBD

Days between issued and closed

Identified 9 May 2026 in NAS

Aberrant ASE performance observed, ASE-R issued on 9 May 2026

Altimeters were reading outside of tolerances. Troubleshooting revealed a significant amount of water in the static system lines.

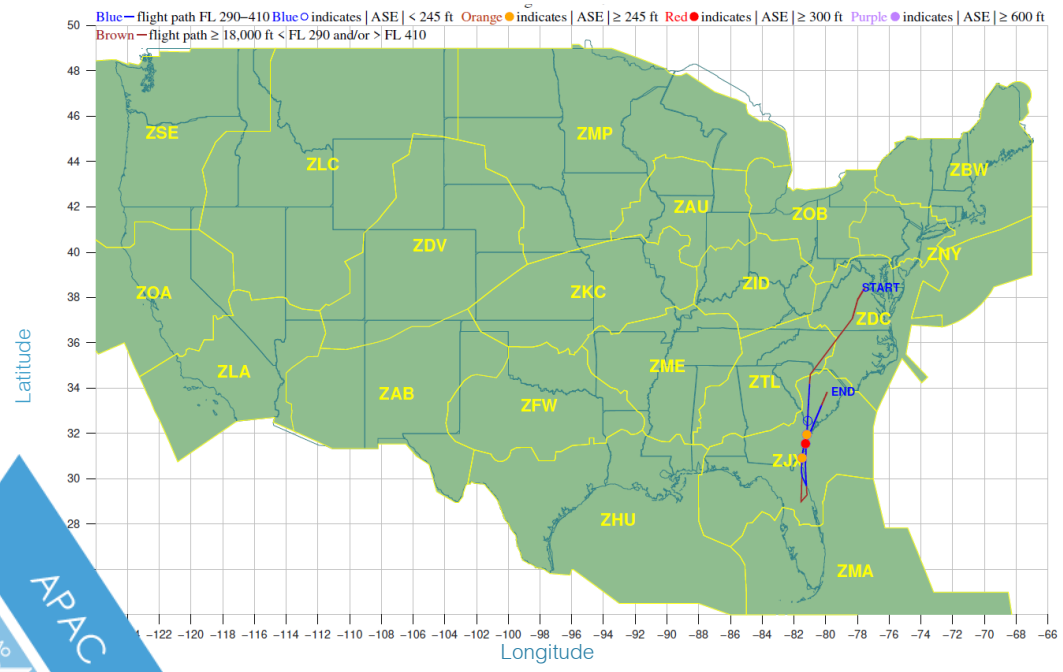
Corrective action, follow-on monitoring TBD

Drained water from static system lines

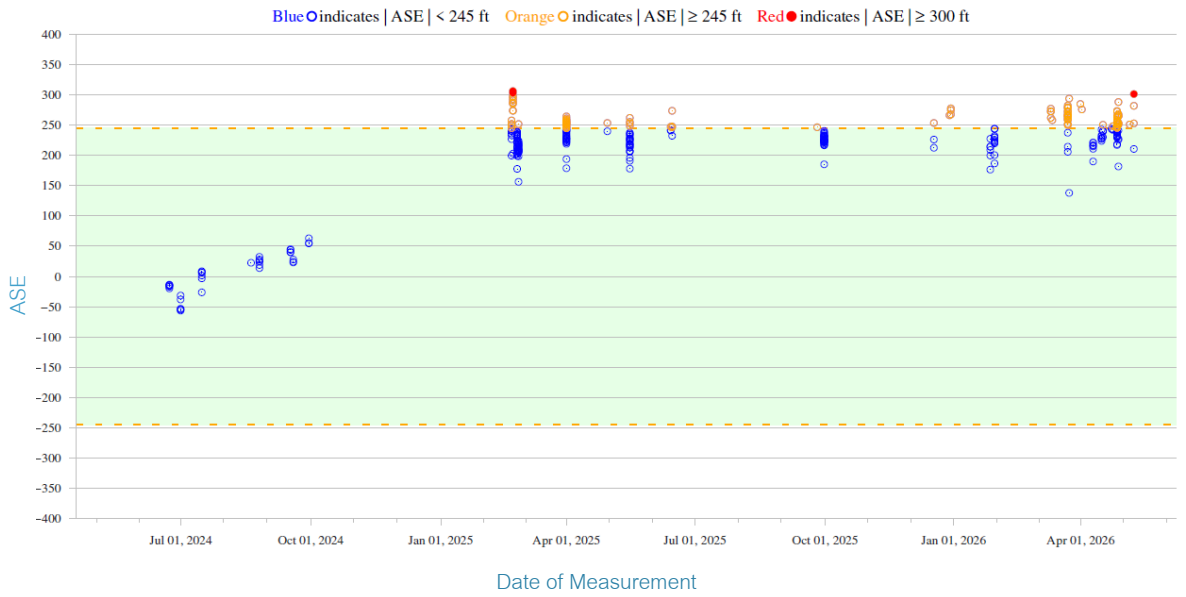
Pitot-static and transponder system inspections were performed and found to be satisfactory

C650

ASE Performance



ASE Performance



Possible High ASE Resolutions

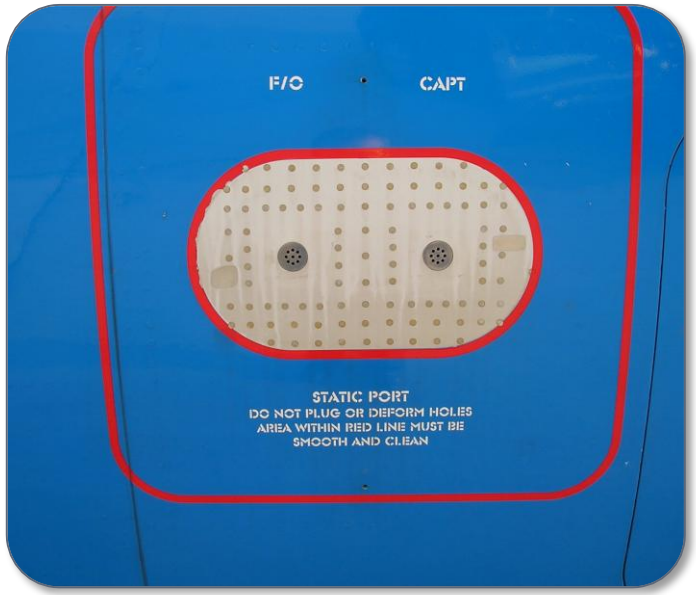
- Corrosion or Erosion: Deterioration in pitot tubes and static vents.
- Humidity and Leaks: Moisture or leaks in static lines affect accuracy.
- Air Data Computers (ADCs) Drift: Variations due to changes in electrical components, such as transducers.
- Altimeter Drift: Gradual deviation from tolerance levels over time.
- Mechanical and Electrical Faults: Issues in components which contribute to the altimetry performance
- Flying an aircraft outside of the speed limits defined for RVSM operations: Each RVSM MASPS solution has a defined performance envelope.

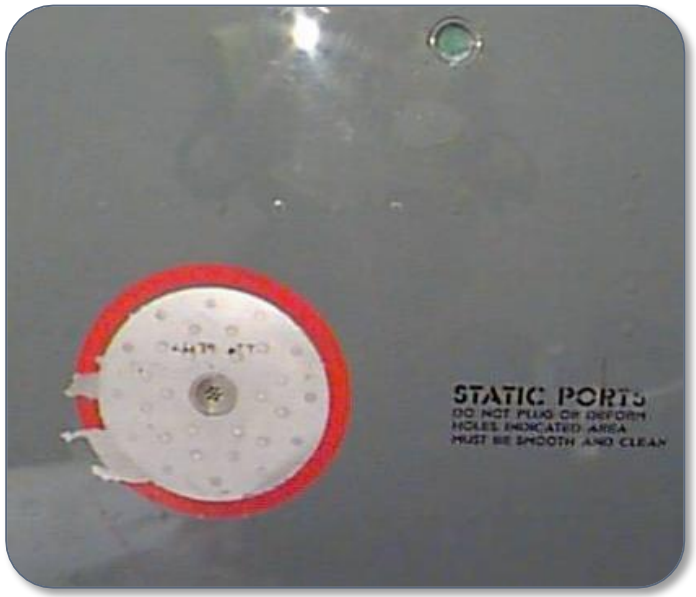
  Basic RVSM Envelope: The range of Mach numbers and gross weights within the altitude ranges FL 290 to FL 410 (or maximum available altitude) where an aircraft is expected to operate most frequently.

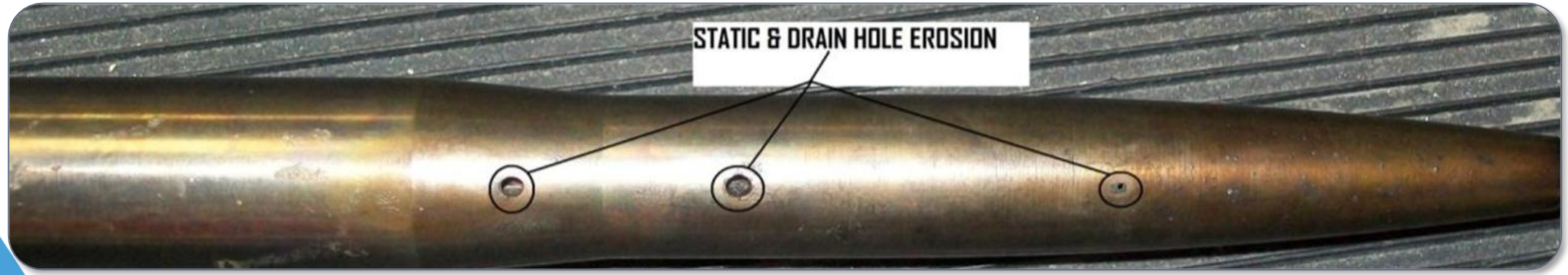
  Full RVSM Envelope: The entire range of operational Mach numbers, W/δ, and altitude values over which the aircraft is operated within RVSM airspace.

Examples of Probe Corrosion

Examples of Other Reported Issues







Questions?

APAC Safety Seminar