

**DRAFT**

**OPERATIONS/AIRWORTHINESS APPROVAL MANUAL**

**FOR**

**REDUCED VERTICAL SEPARATION MINIMUM (RVSM)**

**IN THE MID REGION**

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## 1. PURPOSE

This manual provides a Minimum Aircraft Systems Performance Specification (MASPS) for altimetry to support the use of a 300m (1,000 ft) vertical separation above FL 290. It establishes an acceptable means, but not the only means, that can be used in the approval of aircraft and operators to conduct flights in airspace or on routes where Reduced Vertical Separation Minimum (RVSM) is applied. The manual contains guidance on airworthiness, continued airworthiness, and operational practices and procedures for RVSM airspace. RVSM airspace is any airspace or route between FL 290 and FL 410 inclusive where aircraft are separated vertically by 300m (1,000 ft).

## 2. RELATED REGULATIONS

National regulations relating to the granting of an approval for flight in RVSM airspace, testing and inspection of altimeter systems, and maintenance procedures.

## 3. REFERENCES:

EUROCONTROL Manual on Operational ATC Aspects in European RVSM airspace .

FAA Document 91 RVSM Interim Guidance Material on the approval of Operators/Aircraft for RVSM Operations.

ICAO Document 7030/4 (EUR), Regional Supplementary Procedures.

ICAO Document 9572, RGCSP, Seventh Meeting, Montreal 30 October - 20 November 1990.

ICAO Document 9574, Manual on the Implementation of a 300m (1,000 ft) Vertical Separation Minimum Between FL 290 - FL 410 Inclusive.

JAA Document Temporary Guidance Leaflet (TGL ) No.6 ; Guidance Material on the approval of aircraft and operators for flight in airspace above flight level 290 where a 300m (1,000 FT) vertical separation minimum is applied.

## 4. BACKGROUND:

In 1982 the International Civil Aviation Organization (ICAO) initiated a series of worldwide studies to assess the feasibility of a reduction of the vertical separation minimum (VSM) above FL 290 from 2000ft to 1000ft. The principal benefits, which the implementation of the VSM were expected to provide, were a theoretical doubling of the airspace capacity between FL 290 and FL 410, and the opportunity for aircraft to operate at or closer to their optimum flight levels, with resulting fuel economy and time savings.

Studies and data collections were conducted to determine the height deviations >300ft as well as to define corrective measures. As a result it was concluded that a 1000ft VSM between FL 290 and FL 410 was technically feasible without imposing unreasonably demanding technical or operational requirements.

The ICAO Air Navigation Commission (ANC) endorsed these findings in 1990. North Atlantic (NAT) was identified as the region best suited to the best application of the new minimum, because of the better than average height keeping accuracy shown by NAT Minimum Navigation Performance Specification (NAT MNPS) approved aircraft, together with the predominantly one-way traffic flow in the NAT region. The trials were successful and resulted in RVSM being adopted in 1997.



This concept has been introduced into designated European airspace since 24 January 2002 and to be introduced in the Middle East designated airspace (MID) and the western part of Asia Pacific designated airspace in 27 November 2003.

## 5. DEFINITIONS AND ABBREVIATIONS

**Aircraft Group** A group of aircraft that are of nominally identical design and build with respect to all details that could influence the accuracy of height keeping performance.

**Altimetry System Error (ASE)** The difference between the pressure altitude displayed to the flight crew when referenced to the International Standard Atmosphere ground pressure setting (1013.2 hPa /29.92 in.Hg) and free stream pressure altitude.

**Assigned Altitude Deviation (AAD)** The difference between the transmitted Mode C altitude and the assigned altitude/ flight level.

**Automatic Altitude Control System** Any system that is designed to automatically control the aircraft to a referenced pressure altitude.

**Avionics Error (AVE)** The error in the processes of converting the sensed pressure into an electrical output, of applying any static source error correction (SSEC) as appropriate, and of displaying the corresponding altitude.

**Basic RVSM Envelope** The range of Mach numbers and gross weights within the altitude ranges FL 290 to FL 410 (or maximum attainable altitude) where an aircraft can reasonably expect to operate most frequently.

**Full RVSM Envelope** The entire range of operational Mach numbers, W/ $\delta$ , and altitude values over which the aircraft can be operated within RVSM airspace.

**General Air Traffic (GAT)** Flights conducted in accordance with the rules and provisions of ICAO.

**Height keeping Capability** Aircraft height keeping performance that can be expected under nominal environmental operating conditions, with proper aircraft operating practices and maintenance.

**Height keeping Performance** The observed performance of an aircraft with respect to adherence to a flight level.

**Non-Group Aircraft** An aircraft for which the operator applies for approval on the characteristics of the unique airframe rather than on a group basis.

**Operational Air Traffic (OAT)** Flights which do not comply with the provisions stated for GAT and for which rules and procedures have been specified by appropriate authorities.

**RVSM Approval** The approval that is issued by the appropriate authority of the State in which the Operator is registered.

**Residual Static Source Error** The amount by which static source error (SSE) remains under-corrected or overcorrected after the application of SSEC.

**State Aircraft** Aircraft used in military, customs and police services shall be deemed to be State aircraft

**Static Source Error** The difference between the pressure sensed by the static system at the static port and the undisturbed ambient pressure.

**Static Source Error Correction (SSEC)** A correction for static source error.

**Total Vertical Error (TVE)** Vertical geometric difference between the actual pressure altitude flown by an aircraft and its assigned pressure altitude (flight level).

**W/δ** Aircraft weight, W, divided by the atmospheric pressure ratio, δ.

Abbreviation	Meaning
AAD	Assigned Altitude Deviation
ADC	Air Data Computer
AOA	Angle of Attack
AOC	Air Operator's Certificate
ASE	Altimetry System Error
ATS	Air Traffic Service
GAT	General Air Traffic
δ	Atmospheric Pressure Ratio
Hp	Pressure Altitude
hPa	Hecto-Pascals
in.Hg	Inches of Mercury
M	Mach number
MASPS	Minimum Aircraft System Performance Specification
MEL	Minimum Equipment List
MMEL	Master Minimum Equipment List
Mmo	Maximum Operating Limit Mach
MNPS	Minimum Navigation Performance Specification
NAT	North Atlantic
NOTAM	Notice to Airmen
OAT	Operational Air Traffic
OTS	Organised Track Structure
QFE	Atmospheric pressure at aerodrome elevation (or at runway threshold)
QNH	Altimeter sub-scale setting to obtain elevation when on ground
RTF	Radio Telephony
SSE	Static Source Error
SSEC	Static Source Error Correction
TVE	Total Vertical Error
VMO	Maximum Operating Limit Velocity
W	Weight

## 6. THE APPROVAL PROCESS

### 6.1 General

Airspace where RVSM is applied should be considered special qualification airspace. The specific aircraft type or types that the operator intends to use will need to be approved by the responsible authority before the operator conducts flight in RVSM airspace. In addition, where operations in specified airspace require approval in accordance with an ICAO Regional Navigation Agreement, an operational approval will be needed. This manual provides guidance for the approval of specific aircraft type or types, and for operational approval.



## 6.2 Approval of Aircraft

6.2.1 Each aircraft type that an operator intends to use in RVSM airspace should have received RVSM airworthiness approval from the responsible authority, in accordance with paragraph 9, prior to approval being granted for RVSM operations, including the approval of continued airworthiness programmes. Paragraph 9 provides guidance for the approval of newly built aircraft and for aircraft that have already entered service. Paragraph 10 contains guidance on the continued airworthiness (maintenance and repair) programmes for all RVSM operations.

6.2.2 It is accepted that aircraft which have been approved in compliance with JAA Information Leaflet No. 23, TGL No. 6 or FAA Interim Guidelines 91-RVSM satisfy the airworthiness criteria of this manual.

Note: Operators are advised to check existing approvals and the Aircraft Flight Manual for redundant regional constraints.

## 6.3 Operational Approval

For certain airspace, as defined by ICAO Regional Navigation Agreements, operators are required to hold State approval to operate in that airspace, which may or may not include RVSM. Paragraph 11 contains guidance on operational procedures that an operator may need to adopt for such airspace where RVSM is applied including advice on the operational material that may need to be submitted for review by the responsible authority.

## **7. RVSM PERFORMANCE**

### 7.1 General

The objectives set out by the RGCSP have been translated into airworthiness standards by assessment of the characteristics of altimetry system error (ASE) and automatic altitude control.

### 7.2 RVSM Flight Envelopes

For the purposes of RVSM approval, the aircraft flight envelope may be considered as two parts; the Basic RVSM flight planning envelope and the Full RVSM flight envelope (referred to as the Basic envelope and the Full envelope respectively), as defined in paragraph 5 and explained in 9.4. For the Full envelope, a larger ASE is allowed.

### 7.3 Altimetry System Error

7.3.1 To evaluate a system against the ASE performance statements established by RGCSP (see Appendix 5, paragraph 2), it is necessary to quantify the mean and three standard deviation values for ASE, expressed as  $ASE_{mean}$  and  $ASE_{3SD}$ . To do this, it is necessary to take into account the different ways in which variations in ASE can arise. The factors that affect ASE are:

- (a) Unit to unit variability of avionics equipment.
- (b) Effect of environmental operating conditions on avionics equipment.
- (c) Airframe to airframe variability of static source error.
- (d) Effect of flight operating conditions on static source error.

7.3.2 Assessment of ASE, whether based on measured or predicted data will need to consider sub-paragraphs (a) to (d) of 7.3.1. The effect of item (d) as a variable can be eliminated by evaluating ASE at the most adverse flight condition in an RVSM flight envelope.

7.3.3 The criteria to be met for the Basic envelope are:

- (a) At the point in the envelope where the mean ASE reaches its largest absolute value that value should not exceed 25 m (80 ft);
- (b) At the point in the envelope where absolute mean ASE plus three standard deviations of ASE reaches its largest absolute value, the absolute value should not exceed 60 m (200 ft).

7.3.4 The criteria to be met for the Full envelope are:

- (a) At the worst point in the Full envelope where the mean ASE reaches its largest absolute value, the absolute value should not exceed 37 m (120 ft).
- (b) At the point in the Full envelope where the mean ASE plus three standard deviations of ASE reaches its largest absolute value, the absolute value should not exceed 75 m (245 ft).
- (c) If necessary, for the purpose of achieving RVSM approval for a group of aircraft (see 9.3), an operating limitation may be established to restrict aircraft from conducting RVSM operations in parts of the Full envelope where the absolute value of mean ASE exceeds 37 m (120 ft) and/or the absolute value of mean ASE plus three standard deviations of ASE exceed 75 m (245 ft). When such a limitation is established, it should be identified in the data submitted to support the approval application, and documented in appropriate aircraft operating manuals. However, visual or aural warning/indication associated with such a limitation need not be provided in the aircraft.

7.3.5 Aircraft types for which an application for a Type Certificate is made after 1 January 1997, should meet the criteria established for the Basic envelope in the Full RVSM envelope.

7.3.6 The standard for aircraft submitted for approval as non-group aircraft, as defined in subparagraph 9.3.2, is as follows:

- (a) For all conditions in the Basic envelope:
  - | Residual static source error + worst case avionics | ≤ 50 m (160 ft)
- (b) For all conditions in the Full envelope:
  - | Residual static source error + worst case avionics | ≤ 60 m (200 ft)

Note: Worst case avionics means that a combination of tolerance values, specified by the aircraft constructor for the altimetry fit into the aircraft, which gives the largest combined absolute value for residual SSE plus avionics errors.

#### 7.4 Altitude Keeping

about the selected altitude, when the aircraft is operated in straight and level flight under non-turbulent non-gust conditions. ft)

Note: Automatic altitude control systems with flight management system/ performance ft) under non-turbulent, non-gust conditions, installed in aircraft types for which an application for Type Certificate was made prior to January 1, 1997, need not be replaced or modified.

## 8. AIRCRAFT SYSTEMS

### 8.1 Equipment for RVSM Operations

The minimum equipment fit is:

8.1.1 Two independent altitude measurement systems. Each system will need to be composed of the following elements:

- (a) Cross-coupled static source/system, with ice protection if located in areas subject to ice accretion;
- (b) Equipment for measuring static pressure sensed by the static source, converting it to pressure altitude and displaying the pressure altitude to the flight crew;
- (c) Equipment for providing a digitally encoded signal corresponding to the displayed pressure altitude, for automatic altitude reporting purposes;
- (d) Static source error correction (SSEC), if needed to meet the performance criteria of sub-paragraphs 7.3.3, 7.3.4 or 7.3.6, as appropriate; and
- (e) Signals referenced to a pilot selected altitude for automatic control and alerting. These signals will need to be derived from an altitude measurement system meeting the criteria of this manual, and, in all cases, enabling the criteria of sub-paragraphs 8.2.6 and 8.3 to be met.

8.1.2 One secondary surveillance radar transponder with an altitude reporting system that can be connected to the altitude measurement system in use for altitude keeping.

8.1.3 An altitude alerting system.

8.1.4 An automatic altitude control system.

### 8.2. Altimetry

8.2.1 *System Composition* the altimetry system of an aircraft comprises all those elements involved in the process of sampling free stream static pressure and converting it to a pressure altitude output. The elements of the altimetry system fall into two main groups:

- (a) Airframe plus static sources.
- (b) Avionics equipment and/or instruments.

8.2.2 *Altimetry System Outputs* The following altimetry system outputs are significant for RVSM operations:

- (a) Pressure altitude (Baro-corrected) for display.
- (b) Pressure altitude reporting data.
- (c) Pressure altitude or pressure altitude deviation for an automatic altitude control device.

8.2.3 *Altimetry System Accuracy* The total system accuracy will need to satisfy the criteria of sub-paragraphs 7.3.3, 7.3.4 or 7.3.6 as appropriate.

8.2.4 *Static Source Error Correction* If the design and characteristics of the aircraft and its altimetry system are such that the criteria of sub-paragraphs 7.3.3, 7.3.4 or 7.3.6 are not satisfied by the location

and geometry of the static sources alone, then suitable SSEC will need to be applied automatically within the avionics equipment of the altimetry system. The design aim for static source error correction, whether applied by aerodynamic/ geometric means or within the avionics equipment, should be to produce a minimum residual static source error, but in all cases it should lead to compliance with the criteria of sub-paragraphs 7.3.3, 7.3.4 or 7.3.6, as appropriate.

8.2.5 *Altitude Reporting Capability* The aircraft altimetry system will need to provide an output to the aircraft transponder as required by applicable operating regulations.

8.2.6 *Altitude Control Output*

- (a) The altimetry system will need to provide a signal that can be used by an automatic altitude control system to control the aircraft to a selected altitude. The signal may be used either directly, or combined with other sensor signals. If SSEC is necessary to satisfy the criteria of sub-paragraph 7.3.3, 7.3.4 or 7.3.6, then an equivalent SSEC may be applied to the altitude control signal. The signal may be an altitude deviation signal, relative to the selected altitude, or a suitable absolute altitude signal.
- (b) Whatever the system architecture and SSEC system, the difference between the signal output to the altitude control system and the altitude displayed to the flight crew will need to be kept to the minimum.

8.2.7 *Altimetry System Integrity* The RVSM approval process will need to verify that the predicted rate of occurrence of undetected failure of the altimetry system does not exceed  $1 \times 10^{-5}$  per flight hour. All failures and failure combinations whose occurrence would not be evident from cross cockpit checks, and which would lead to altitude measurement /display errors outside the specified limits, need to be assessed against this value. Other failures or failure combinations need not be considered.

### 8.3 Altitude Alerting

The altitude deviation system will need to signal an alert when the altitude displayed to the flight crew deviates from selected altitude by more than a nominal threshold value. For aircraft for which an application for a Type Certificate is made before 1 January 1997, the nominal threshold value is 300 ft. For aircraft for which an application for a Type Certificate is made on or after 1 January 1997, the nominal threshold value is 200 m (656 ft). The overall equipment tolerance in implementing these nominal values will need to be not less than 10% of the nominal value.

### 8.4 Automatic Altitude Control System

8.4.1 As a minimum, a single automatic altitude control system with an altitude keeping performance complying with sub-paragraph 7.4, will need to be installed.

8.4.2 Where an altitude select/acquire function is provided, the altitude select/acquire control function exists between the value selected by, and displayed to, the flight crew, and the corresponding output to the control system.

## 8.5 System Limitations

8.5.1 The Aircraft Flight Manual should include a statement of compliance against this manual (or equivalent guidance material) quoting the applicable Service Bulletin or build standard of the aircraft. In addition the following statement should be included:-

approval alone does not authorise flight into airspace for which an RVSM

8.5.2 Non-compliant aspects of the installed systems and any other limitations will need to be identified in the approved Aircraft Flight Manual amendment or supplement, and in the applicable and approved Operations Manual.

For example:-

- Non-compliant altimeter systems, e.g. standby altimeter;
- Non-Compliant modes of the automatic pilot, e.g. altitude hold, vnav, altitude select;
- Weight Limit;
- Mach Limit;
- Altitude Limit.

## 9. AIRWORTHINESS APPROVAL

### 9.1 General

9.1.1 Obtaining RVSM airworthiness approval is a two step process which may involve more than one authority.

9.1.2 For the first step:

- in the case of a newly built aircraft, the aircraft constructor develops and submits to the responsible authority of the state of manufacture, the performance and analytical data that supports RVSM airworthiness approval of a defined build standard. The data will be supplemented with maintenance and repair manuals giving associated continued airworthiness instructions. Compliance with RVSM criteria will be stated in the Aircraft Flight Manual including reference to the applicable build standard, related conditions and limitations. Approval by the responsible authority, and, where applicable, validation of that approval by other authorities, indicates acceptance of newly built aircraft, conforming to that type and build standard, as complying with the RVSM airworthiness criteria.
- in the case of an aircraft already in service, the aircraft constructor (or an approved design organisation), submits to the responsible authority, either in the state of manufacture or the state in which the aircraft is registered, the performance and analytical data that supports RVSM airworthiness approval of a defined build standard. The data will be supplemented with a Service Bulletin, or its equivalent, that identifies the work to be done to achieve the build standard, continued airworthiness instructions, and an amendment to the Aircraft Flight Manual stating related conditions and limitations. Approval by the responsible authority, and, where applicable, validation of that approval by other authorities, indicates acceptance of that aircraft type and build standard as complying with the RVSM airworthiness criteria.

9.1.3 The combination of performance and analytical data, Service Bulletin(s) or equivalent, continued airworthiness instructions, and the approved amendment or supplement to the Aircraft Flight Manual is known as the RVSM approval data package.

9.1.4 For the second step, an aircraft operator may apply to the responsible authority of the state in which the aircraft is registered, for airworthiness approval of specific aircraft. The application will need to be supported by evidence confirming that the specific aircraft has been inspected and, where necessary, modified in accordance with applicable Service Bulletins, and is of a type and



build standard that meets the RVSM airworthiness criteria. The operator will need to confirm also that the continued airworthiness instructions are available and that the approved Aircraft Flight Manual amendment or supplement (see paragraph 8.5) has been incorporated. Approval by the authority indicates that the aircraft is eligible for RVSM operations. The authority will notify the designated monitoring cell accordingly.

For RVSM airspace for which an operational approval is prescribed, airworthiness approval alone does not authorise flight in that airspace.

#### 9.2 Contents of the RVSM Approval Data Package

As a minimum, the data package will need to consist of the following items:

- (a) A statement of the aircraft group or non-group aircraft and applicable build standard to which the data package applies.
- (b) A definition of the applicable flight envelope(s).
- (c) Data showing compliance with the performance criteria of paragraphs 7 and 8.
- (d) The procedures to be used to ensure that all aircraft submitted for airworthiness approval comply with RVSM criteria. These procedures will include the references of applicable Service Bulletins and the applicable approved Aircraft Flight Manual amendment or supplement.
- (e) The maintenance instructions that ensure continued airworthiness for RVSM approval.

The above items are explained further in the following sub-paragraphs.

#### 9.3 Aircraft Groupings

9.3.1 For aircraft to be considered as members of a group for the purposes of RVSM approval, the following conditions should be satisfied:

- (a) Aircraft should have been constructed to a nominally identical design and be approved on the same Type Certificate (TC), TC amendment, or Supplemental TC, as applicable.

Note: For derivative aircraft it may be possible to use the data from the parent configuration to minimise the amount of additional data required to show compliance. The extent of additional data required will depend on the nature of the differences between the parent aircraft and the derivative aircraft.

- (b) The static system of each aircraft should be nominally identical. The SSE corrections should be the same for all aircraft of the group.
- (c) The avionics units installed on each aircraft to meet the minimum RVSM equipment criteria of sub-paragraph 8.1 should comply with the manufacturer's same specification and have the same part number.

Note: Aircraft that have avionic units that are of a different manufacturer or part number may be considered part of the group, if it can be demonstrated that this standard of avionic equipment provides equivalent system performance.

9.3.2 If an airframe does not meet the conditions of sub-paragraphs 9.3.1(a) to (c) to qualify as a member of a group, or is presented as an individual airframe for approval, then it will need to be considered as a non-group aircraft for the purposes of RVSM approval.



9.4 Flight Envelopes

The RVSM operational flight envelope, as defined in paragraph 5, is the Mach number,  $W/\delta$ , and altitude ranges over which an aircraft can be operated in cruising flight within the RVSM airspace. Appendix 1 gives an explanation of  $W/\delta$ . The RVSM operational flight envelope for any aircraft may be divided into two parts as explained below:

9.4.1 *Full RVSM Flight Envelope* The Full envelope will comprise the entire range of operational Mach number,  $W/\delta$ , and altitude values over which the aircraft can be operated within RVSM airspace. Table 1 establishes the parameters to be considered.

**TABLE 1 - FULL RVSM ENVELOPE BOUNDARIES**

	Lower Boundary is defined by	Upper Boundary is defined by
Level		The lower of:  buffet; other aircraft flight limitations
Mach or Speed	The lower of :	The lower of: $M_{MO}/V_{MO}$ limited by cruise thrust; buffet; other aircraft flight limitations
Gross Weight	with operations in RVSM airspace	with operations in RVSM airspace

9.4.2 *Basic RVSM Flight Planning Envelope* The boundaries for the Basic envelope are the same as those for the Full envelope except for the upper Mach boundary.

9.4.3 For the Basic envelope, the upper Mach boundary may be limited to a range of airspeeds over which the aircraft group can reasonably be expected to operate most frequently. This boundary should be declared for each aircraft group by the aircraft constructor or the approved design organisation. The boundary may be equal to the upper Mach/airspeed boundary defined for the Full envelope or a lower value. This lower value should not be less than the Long Range Cruise Mach Number plus 0.04 Mach, unless limited by available cruise thrust, buffet, or other flight limitations.

9.5 Performance Data

The data package should contain data sufficient to show compliance with the accuracy criteria set by paragraph 7.

9.5.1 *General* ASE will generally vary with flight condition. The data package should provide coverage of the RVSM envelope sufficient to define the largest errors in the Basic and Full envelopes. In the case of group aircraft approval, the worst flight condition may be different for each of the criterion of sub-paragraph 7.3.3 and 7.3.4. Each should be evaluated.

9.5.2 Where precision flight calibrations are used to quantify or verify altimetry system performance they may be accomplished by any of the following methods. Flight calibrations should be performed only when appropriate ground checks have been completed. Uncertainties in application of the method will need to be assessed and taken into account in the data package.

- (a) Precision tracking radar in conjunction with pressure calibration of atmosphere at test altitude.
- (b) Trailing cone.
- (c) Pacer aircraft.
- (d) Any other method acceptable to the responsible authority.

Note: When using pacer aircraft, the pacer aircraft will need to be calibrated directly to a known standard. It is not acceptable to calibrate a pacer aircraft by another pacer aircraft.

9.5.3 *Altimetry System Error Budget* It is implicit in the intent of sub-paragraph 7.3, for group aircraft approvals and for non-group approvals, that a trade-off may be made between the various error sources which contribute to ASE. This manual does not specify separate limits for the various error sources that contribute to the mean and variable components of ASE as long as the overall ASE accuracy criteria of sub-paragraph 7.3 are met. For example, in the case of an aircraft group approval, the smaller the mean of the group and the more stringent the avionics standard, the larger the available allowance for SSE variations. In all cases, the trade-off adopted should be presented in the data package in the form of an error budget that includes all significant error sources. This is discussed in more detail in the following sections. Altimetry system error sources are discussed in Appendix 2.

9.5.4 *Avionic Equipment* should be identified by function and part number. A demonstration will need to show that the avionic equipment can meet the criteria established by the error budget when the equipment is operated in the environmental conditions expected to be met during RVSM operations.

9.5.5 *Groups of Aircraft* Where approval is sought for an aircraft group, the associated data package will need to show that the criteria of sub-paragraph 7.3.3 and 7.3.4 are met. Because of the statistical nature of these criteria, the content of the data package may vary considerably from group to group.

- (a) The mean and airframe-to-airframe variability of ASE should be established, based on precision flight test calibration of a number of aircraft. Where analytical methods are available, it may be possible to enhance the flight test data base and to track subsequent changes in the mean and variability based on geometric inspections and bench test, or any other method acceptable to the responsible authority. In the case of derivative aircraft it may be possible to use data from the parent as part of the data base. This may be applicable to a fuselage stretch where the only difference in mean ASE between groups could be reliably accounted for by analytical means.
- (b) An assessment of the aircraft-to-aircraft variability of each error source should be made. The error assessment may take various forms as appropriate to the nature and magnitude of the source and the type of data available. For example, for some error sources (especially small ones), it may be acceptable to use specification values to represent three standard deviations. For other error sources (especially larger ones) a more comprehensive assessment may be required. This is especially true for airframe error sources where specification values of ASE contribution may not have been previously established.
- (c) In many cases, one or more of the major ASE error sources will be aerodynamic in nature, such as variations in the airframe surface contour in the vicinity of the static pressure source. If evaluation of these errors is based on geometric measurements, substantiation should be provided that the methodology used is

adequate to ensure compliance. An example of the type of data that could be used to provide this substantiation is provided in Appendix 3, figure 3-2.

- (d) An error budget should be established to ensure that the criteria of sub-paragraphs 7.3.3 and 7.3.4 are met. As noted in 9.5.1, the worst condition experienced in flight may differ for each criterion and therefore the component error values may also differ.
- (e) In showing compliance with the overall criteria, the component error sources should be combined appropriately. In most cases this will involve the algebraic summation of the mean components of the errors, Root-Sum-Square (RSS) combination of the variable components of the errors, and summation of the RSS value with the absolute value of the overall mean. Care should be taken that only variable component error sources that are independent of each other are combined by RSS.
- (f) The methodology described above for group approval is statistical. This is the result of the statistical nature of the risk analysis and the resulting statements of Appendix 5 sub-paragraphs 5(a) and 5(b). In the context of a statistical method, the statements of Appendix 5, sub-paragraph 5(c) need further explanation. This item states that 'each individual aircraft in the group shall be built to have an ASE of  $\pm$  ft'. This statement has not been taken to mean that every airframe should be calibrated with a trailing cone or equivalent to  $\pm$  ft). Such an interpretation would be unduly onerous considering that the risk analysis allows for a small proportion of aircraft to exceed 60m (200 ft). However, it is accepted that if any aircraft is found to exceed  $\pm$  ft) then it should receive corrective action.

**9.5.6 Non-group Aircraft** When an aircraft is submitted for approval as a non-group aircraft, as explained in sub-paragraph 9.3.2, the data should be sufficient to show that the criteria of sub-paragraph 7.3.6 are met. The data package should specify how the ASE budget has been allocated between residual SSE and avionics error. The operator and responsible authority should agree on what data is needed to satisfy approval criteria. The following data should be established:

- (a) Precision flight test calibration of the aircraft to establish its ASE or SSE over the RVSM envelope. Flight calibration should be performed at points in the flight envelope(s) as agreed by the responsible authority. One of the methods listed in sub-paragraphs 9.5.2 (a) to (d) should be used.
- (b) Calibration of the avionics used in the flight test as required to establish residual SSE. The number of test points should be agreed by the responsible authority. Since the purpose of the flight test is to determine the residual SSE, specially calibrated altimetry equipment may be used.
- (c) Specifications for the installed altimetry avionics equipment, identifying the largest allowable errors.

Using the foregoing, compliance with the criteria of sub-paragraph 7.3.6 should be demonstrated. If, subsequent to aircraft approval for RVSM operation, avionics units that are of a different manufacturer or part number are fitted, it should be demonstrated that the standard of avionics equipment provides equivalent altimetry system performance.

## 9.6 Compliance Procedures

The data package will need to define the procedures, inspections and tests, and the limits that will be used to ensure that all aircraft approved against the data package 'conform to type'; that is all future approvals, whether of new build or in-service aircraft, meet the budget allowances developed according to sub-paragraph 9.5.3. The budget allowances will be established by the data package and include a methodology that allows for tracking the mean and standard deviation for new build aircraft. Limits will need to be defined for each potential source of error. A discussion of error sources is provided in Appendix 2. Examples of procedures are presented in Appendix 3. Where an operating limitation has been applied, the package should contain the data and information necessary to document and establish that limitation.

#### 9.7 Continued Airworthiness

9.7.1 The following items should be reviewed and updated as applicable to RVSM:

- (a) The Structural Repair Manual with special attention to the areas around each static source, angle of attack sensors, and doors if their rigging can affect airflow around the previously mentioned sensors.
- (b) The Master Minimum Equipment List (MMEL).

9.7.2 The data package should include details of any special procedures that are not covered in sub-paragraph 9.7.1, but may be needed to ensure continued compliance with RVSM approval criteria. Examples follow:

- (a) For non-group aircraft, where airworthiness approval has been based on flight test, the continuing integrity and accuracy of the altimetry system will need to be demonstrated by ground and flight tests of the aircraft and its altimetry system at periods to be agreed with the responsible authority. However, alleviation of the flight test requirement may be given if it can be demonstrated that the relationship between any subsequent airframe/system degradation and its effects on altimetry system accuracy is understood and that it can be compensated or corrected.
- (b) In-flight defect reporting procedures should be defined to aid identification of altimetry system error sources. Such procedures could cover acceptable differences between primary and alternate static sources, and others as appropriate.
- (c) For groups of aircraft where approval is based on geometric inspection, there may be a need for periodic re-inspection, and the interval required should be specified.

#### 9.8 Post Approval Modification

Any variation/modification from the initial installation that affects RVSM approval should be referred to the aircraft constructor or approved design organisation, and accepted by the responsible authority.

### **10. CONTINUED AIRWORTHINESS (MAINTENANCE PROCEDURES)**

#### 10.1 General

- (a) The integrity of the design features necessary to ensure that altimetry systems continue to meet RVSM approval criteria should be verified by scheduled tests and inspections in conjunction with an approved maintenance programme. The operator should review its maintenance procedures and address all aspects of continued airworthiness that may be relevant.

- (b) Adequate maintenance facilities will need to be available to enable compliance with the RVSM maintenance procedures.

#### 10.2 Maintenance Programmes

Each operator requesting RVSM operational approval should establish RVSM maintenance and inspection practices acceptable to, and as required by, the responsible authority, that include any required maintenance specified in the data package (sub-paragraph 9.2). Operators of aircraft subject to maintenance programme approval will need to incorporate these practices in their maintenance programme.

### 10.3 Maintenance Documents

The following items should be reviewed, as appropriate:

- (a) Maintenance Manuals.
- (b) Structural Repair Manuals.
- (c) Standard Practices Manuals.
- (d) Illustrated Parts Catalogues.
- (e) Maintenance Schedule.
- (f) MMEL

### 10.4 Maintenance Practices

If the operator is subject to an approved maintenance programme, that programme should include, for each aircraft type, the maintenance practices stated in the applicable aircraft and component manufacturers' maintenance manuals. In addition, for all aircraft, including those not subject to an approved maintenance programme, attention should be given to the following items:

- (a) All RVSM equipment should be maintained in accordance with the component manufacturers' maintenance instructions and the performance criteria of the RVSM approval data package.
- (b) Any modification or design change which in any way affects the initial RVSM approval, should be subject to a design review acceptable to the responsible authority.
- (c) Any repairs, not covered by approved maintenance documents, that may affect the integrity of the continuing RVSM approval, e.g. those affecting the alignment of pitot/static probes, repairs to dents or deformation around static plates, should be subject to a design review acceptable to the responsible authority.
- (d) Built-in Test Equipment (BITE) testing should not be used for system calibration unless it is shown to be acceptable by the aircraft constructor or an approved design organisation, and with the agreement of the responsible authority.
- (e) An appropriate system leak check (or visual inspection where permitted) should be accomplished following reconnection of a quick-disconnect static line.
- (f) Airframe and static systems should be maintained in accordance with the aircraft constructor's inspection standards and procedures.
- (g) To ensure the proper maintenance of airframe geometry for proper surface contours and the mitigation of altimetry system error, surface measurements or skin waviness checks will need to be made, as specified by the aircraft constructor, to ensure adherence to RVSM tolerances. These checks should be performed following repairs, or alterations having an effect on airframe surface and airflow.
- (h) The maintenance and inspection programme for the autopilot will need to ensure continued accuracy and integrity of the automatic altitude control system to meet the height keeping standards for RVSM operations. This requirement will typically be satisfied with equipment inspections and serviceability checks.



- (i) Whenever the performance of installed equipment has been demonstrated to be satisfactory for RVSM approval, the associated maintenance practices should be verified to be consistent with continued RVSM approval. Examples of equipment to be considered are:
  - (i) Altitude alerting.
  - (ii) Automatic altitude control system.
  - (iii) Secondary surveillance radar altitude reporting equipment.
  - (iv) Altimetry systems.

10.4.1 *Action for Non-compliant Aircraft* Those aircraft positively identified as exhibiting height keeping performance errors that require investigation, as discussed in sub-paragraph 11.7, should not be operated in RVSM airspace until the following actions have been taken:

- (a) The failure or malfunction is confirmed and isolated; and,
- (b) Corrective action is taken as necessary to comply with sub-paragraph 9.5.5 (f) and verified to support RVSM approval.

10.4.2 *Maintenance Training* New training may be necessary to support RVSM approval. Areas that may need to be highlighted for initial and recurrent training of relevant personnel are:

- (a) Aircraft geometric inspection techniques.
- (b) Test equipment calibration and use of that equipment.
- (c) Any special instructions or procedures introduced for RVSM approval.

10.4.3 *Test Equipment*

- (a) The test equipment should have the capability to demonstrate continuing compliance with all the parameters established in the data package for RVSM approval or as approved by the responsible authority.
- (b) Test equipment should be calibrated at periodic intervals as agreed by the responsible authority using reference standards whose calibration is certified as being traceable to national standards acceptable to that authority. The approved maintenance programme should include an effective quality control programme with attention to the following:
  - (i) Definition of required test equipment accuracy.
  - (ii) Regular calibrations of test equipment traceable to a master standard. Determination of the calibration interval should be a function of the stability of the test equipment. The calibration interval should be established using historical data so that degradation is small in relation to the required accuracy.
  - (iii) Regular audits of calibration facilities both in-house and outside.
  - (iv) Adherence to approved maintenance practices.
  - (v) Procedures for controlling operator errors and unusual environmental conditions which may affect calibration accuracy.

## 11. OPERATIONAL APPROVAL

### 11.1 Purpose and Organization

Paragraph 6 of this manual gives an overview of the RVSM approval processes. For airspace where operational approval is required, this paragraph describes steps to be followed and gives detailed guidance on the required operational practices and procedures. Appendices 4 and 5 are related to this paragraph and contain essential information for operational programmes.

### 11.2 RVSM Operations

Approval will be required for each aircraft group and each aircraft to be used for RVSM operations. Approval will be required for each operator and the responsible authority will need to be satisfied that

- (a) each aircraft holds airworthiness approval according to paragraph 9;
- (b) each operator has continued airworthiness programmes (maintenance procedures) according to paragraph 10;
- (c) where necessary, operating procedures unique to the airspace have been incorporated in operations manuals including any limitations identified in paragraph 8.5.
- (d) high levels of aircraft height keeping performance can be maintained.

### 11.3 Content of Operator RVSM Application

The following material should be made available to the responsible authority, in sufficient time to permit evaluation, before the intended start of RVSM operations.

- (a) *Airworthiness Documents* Documentation that shows that the aircraft has RVSM airworthiness approval. This should include an Approved Flight Manual amendment or supplement.
- (b) *Description of Aircraft Equipment* A description of the aircraft appropriate to operations in an RVSM environment.
- (c) *Training Programmes and Operating Practices and Procedures* Holders of Air Operators Certificates (AOC) may need to submit training syllabi for initial, and where appropriate, recurrent training programmes together with other appropriate material to the responsible authority. The material will need to show that the operating practices, procedures and training items, related to RVSM operations in airspace that requires State operational approval, are incorporated. Non-AOC operators will need to comply with local procedures to satisfy the responsible authority that their knowledge of RVSM operating practices and procedures is equivalent to that set for AOC Holders, sufficient to permit them to conduct RVSM operations. Guidance on the content of training programmes and operating practices and procedures is given in Appendix 4. In broad terms, this covers flight planning, pre-flight procedures, aircraft procedures before RVSM airspace entry, in-flight procedures, and flight crew training procedures. The procedures used within airspace of the EUR region and the procedures unique to the North Atlantic Airspace for which specific State operational approval is required are stated in Doc 7030/4.
- (d) *Operations Manuals and Checklists* The appropriate manuals and checklists should be revised to include information/guidance on standard operating procedures as detailed in Appendix 4. Manuals should include a statement of the airspeeds, altitudes and weights considered in RVSM aircraft approval; including identification

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of any operating limitations or conditions established for that aircraft group. Manuals and checklists may need to be submitted for review by the authority as part of the application process.

- (e) *Past Performance* Relevant operating history, where available, should be included in the application. The applicant should show that changes needed in training, operating or maintenance practices to improve poor height keeping performance, have been made.
- (f) *Minimum Equipment List* Where applicable, a minimum equipment list (MEL), adapted from the master minimum equipment list (MMEL) and relevant operational regulations, should include items pertinent to operating in RVSM airspace.
- (g) *Maintenance* When application is made for operational approval, the operator should establish a maintenance programme acceptable to the responsible authority, as detailed in paragraph 10.
- (h) *Plan for Participation in Verification/Monitoring Programmes* The operator should establish a plan acceptable to the responsible authority, for participation in any applicable verification/ monitoring programme (See 11.6). This plan will need to include, as a minimum, a check on a sample of the operator's fleet by an independent height monitoring system.

#### 11.4 Demonstration Flight(s)

The content of the RVSM application may be sufficient to verify the aircraft performance and procedures. However, the final step of the approval process may require a demonstration flight. The responsible authority may appoint an inspector for a flight in RVSM airspace to verify that all relevant procedures are applied effectively. If the performance is satisfactory, operation in RVSM airspace may be permitted.

#### 11.5 Form of Approval Documents

- (a) *Holders of an Air Operator's Certificate* Approval to operate in designated RVSM airspace areas will be granted by an Approval issued by the responsible authority in accordance with their national regulations where operational approval is required by an ICAO Regional Agreement. Each aircraft group for which the operator is granted approval will be listed in the Approval.
- (b) *Non AOC Holders* These operators will be issued with an Approval as required by their national regulations. These approvals will be valid for a period specified in national regulations which may require renewal.

Note: Subject to compliance with applicable criteria, an RVSM Approval combining the airworthiness approval of sub-paragraph 9.1.4 and the operational approval of paragraph 11.2 may be available from some authorities.

#### 11.6 Height Monitoring

The introduction of 300 m (1,000 ft) RVSM separation is conditional upon the principal consideration that the risk of collision as a consequence of a loss of vertical separation, from any cause, is less than the agreed target level of safety. Accordingly, height monitoring is carried out using a system comprised of fixed ground-based Height Monitoring Units (HMU) and a GPS-based monitoring system comprising portable GPS Monitoring Units (GMU), GPS reference stations, post-flight processing facilities and logistic support. Air Operators are required to have a number of their aircraft height monitored within six months of receiving RVSM approval. Information on the

location of Height Monitoring Units can be found in ICAO Document 7030/4 Regional Supplementary Procedures (for appropriate region)

Note: The frequency of monitoring and the establishment of global continued monitoring requirements is to be determined at an ICAO Regional Monitoring Agencies coordination meeting in November 2002.

#### 11.7 Airspace Monitoring

For airspace where a numerical Target Level of Safety is prescribed, monitoring of aircraft height keeping performance in the airspace by an independent height monitoring system is necessary to verify that the prescribed level of safety is being achieved. However, an independent monitoring check of an aircraft is not a prerequisite for the grant of an RVSM approval.

#### 11.8 Suspension, Revocation and Reinstatement of RVSM Approval

The incidence of height keeping errors that can be tolerated in an RVSM environment is small. It is expected of each operator to take immediate action to rectify the conditions that cause an error. The operator should report an occurrence involving poor height keeping to the responsible authority within 72 hours. The report should include an initial analysis of causal factors and measures taken to prevent repeat occurrences. The need for follow up reports will be determined by the responsible authority. Occurrences that should be reported and investigated are errors of:

- (a) ft),
- (b) ft), and
- (c) ft).

##### 11.8.1 *Height keeping Errors* Height keeping errors fall into two broad categories:

- errors caused by malfunction of aircraft equipment; and
- operational errors.

11.8.2 An operator that consistently experiences errors in either category will have approval for RVSM operations suspended or revoked. If a problem is identified which is related to one specific aircraft type, then RVSM approval may be suspended or revoked for that specific type within that operator's fleet.

Note: The tolerable level of collision risk in the airspace would be exceeded if an operator consistently experienced errors.

11.8.3 *Operators Actions* The operator should make an effective, timely response to each height keeping error. The responsible authority may consider suspending or revoking RVSM approval if the operator's responses to height keeping errors are not effective or timely. The responsible authority will consider the operator's past performance record in determining the action to be taken.

11.8.4 *Reinstatement of Approval* The operator will need to satisfy the responsible authority that the causes of height keeping errors are understood and have been eliminated and that the operator's RVSM programmes and procedures are effective. At its discretion and to restore confidence, the authority may require an independent height monitoring check of affected aircraft to be performed.

## 12. AVAILABILITY OF DOCUMENTS

- 12.1 Copies of EUROCONTROL documents may be requested from EUROCONTROL Documentation Centre, GS4, Rue de la Fusee, 96, B-1130 Brussels, Belgium: (Fax: 32 2 729 9109), and on the internet at < <http://www.eur-rvsm.com> > .
- 12.2 Copies of FAA documents may be obtained from Superintendent of Documents, Government Printing Office, Washington DC 20402-9325, USA.
- 12.3 Copies of ARINC documents may be obtained from Aeronautical radio Inc., 2551 Riva Road, Annapolis, Maryland 24101-7465, USA.
- 12.4 Copies of RTCA documents may be obtained from RTCA Inc., 1140 Connecticut Avenue, N.W., Suite 1020, Washington, DC 20036-4001, USA,. (Tel: 1 202 833 9339).
- 12.5 Information for obtaining ICAO and JAA doc national authority. (Information for obtaining the North Atlantic MNPS Airspace Operational Manual may be found in UK CAA AIC 149/1998).

**APPENDIX 1 - EXPLANATION OF W/δ**

1 Sub-paragraph 9.4 describes the range of flight conditions over which conformity with the ASE criteria should be shown. The description includes reference to the parameter W/δ. The following discussion is provided for the benefit of readers who may not be familiar with the use of this parameter.

2 It would be difficult to show all of the gross weight, altitude, and speed conditions which constitute the RVSM envelope(s) on a single plot. This is because most of the speed boundaries of the envelopes are a function of both altitude and gross weight. As a result, a separate chart of altitude versus Mach would be required for each aircraft gross weight. Aircraft performance engineers commonly use the following technique to solve this problem.

3 For most jet transports the required flight envelope can be collapsed to a single chart with good approximation, by the use of the parameter W/δ (weight divided by atmospheric pressure ratio). This fact is due to the relationship between W/δ and the fundamental aerodynamic variables M and lift coefficient as shown below.

$$W/\delta = 1481.4C_L M^2 S_{REF}, \text{ where:}$$

δ = ambient pressure at flight altitude divided by sea level standard pressure of 1013.25 hPa

W/δ = Weight over Atmospheric Pressure Ratio

C<sub>L</sub> = Lift Coefficient

M = Mach Number

S<sub>REF</sub> = Reference Wing Area

4 As a result, the RVSM flight envelope(s) may be collapsed into one chart by simply plotting W/δ, rather than altitude, versus Mach Number. Since δ is a fixed value for a given altitude, weight can be obtained for a given condition by simply multiplying the W/δ value by δ.

5 Over the RVSM altitude range, it is a good approximation to assume that position error is uniquely related to Mach Number and W/δ for a given aircraft.

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## APPENDIX 2 - ALTIMETRY SYSTEM ERROR COMPONENTS

### 1. INTRODUCTION

Sub-paragraph 9.5.3 states that an error budget should be established and presented in the approval data package. The error budget is discussed in some detail in subsequent paragraphs for group and non-group aircraft. The purpose of this appendix is to provide guidance to help ensure that all the potential error sources are identified and included in the error budget for each particular model.

### 2. OBJECTIVE OF ASE BUDGET

2.1 The purpose of the ASE budget is to demonstrate that the allocation of tolerances amongst the various parts of the altimetry system is, for the particular data package, consistent with the overall statistical ASE criteria. These individual tolerances within the ASE budget also form the basis of the procedures, defined in the airworthiness approval data package, which will be used to demonstrate that aircraft satisfy the RVSM criteria.

2.2 It is necessary to ensure that the budget takes account of all contributory components of ASE.

2.3 For group approval it is necessary to ensure either that the budget assesses the combined effect of the component errors in a way that is statistically realistic, or that the worst case specification values are used.

### 3. ALTIMETRY SYSTEM ERROR

#### 3.1 Breakdown

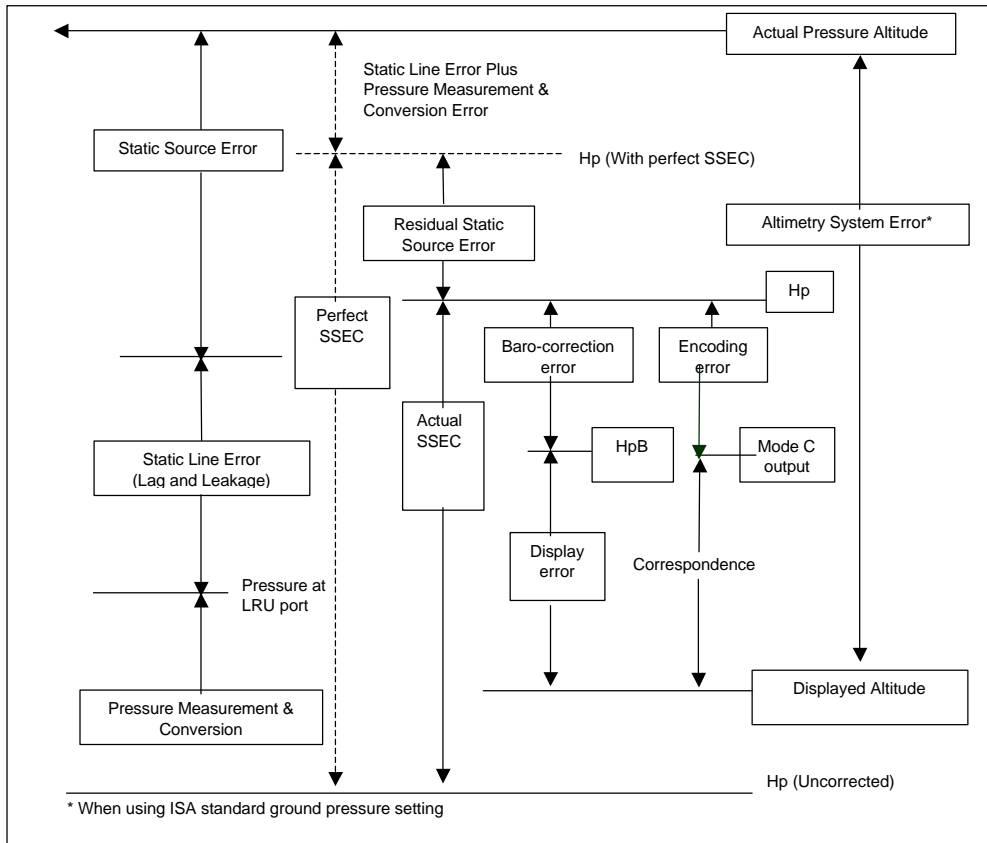
Figure 2-1 shows the breakdown of total ASE into its main components, with each error block representing the error associated with one of the functions needed to generate a display of pressure altitude. This breakdown encompasses all altimetry system errors that can occur, although different system architectures may combine the components in slightly different ways.

- (a) The 'Actual Altitude' is the pressure altitude corresponding to the undisturbed ambient pressure.
- (b) 'Static Source Error' is the difference between the undisturbed ambient pressure and the pressure within the static port, at the input end of the static pressure line.
- (c) 'Static Line Error' is any difference in pressure along the length of the line.
- (d) 'Pressure Measurement and Conversion Error' is the error associated with the processes of sensing the pneumatic input seen by the avionics, and converting the resulting pressure signal into altitude. As drawn, Figure 2-1 represents a self-sensing altimeter system in which the pressure measurement and altitude conversion functions would not normally be separable. In an air data computer system the two functions would be separate, and SSEC would probably then be applied before pressure altitude (Hp) was calculated.
- (e) 'Perfect SSEC' would be that correction that compensated exactly for the SSE actually present at any time. If such a correction could be applied, then the resulting value of Hp

calculated by the system would differ from the actual altitude only by the static line error plus the pressure measurement and conversion error. In general this cannot be achieved, so although the 'Actual SSEC' can be expected to reduce the effect of SSE, it will do so imperfectly.



FIGURE 2-1 ALTIMETRY SYSTEM ERRORS



(f) 'Residual Static Source Error' is applicable only in systems applying an avionic SSEC. It is the difference between the SSE and the correction actually applied. The corrected value of Hp will therefore differ from actual pressure altitude by the sum of static line error, pressure measurement and conversion error, and residual SSE.

(g) Between Hp and displayed altitude occur the baro-correction error and the display error. Figure 2-1 represents their sequence for a self-sensing altimeter system. Air data computer systems can implement baro-correction in a number of ways that would modify slightly this part of the block diagram, but the errors would still be associated with either the baro-correction function or the display function. The only exception is that those systems that can be switched to operate the display directly from the Hp signal can eliminate baro-correction error where standard ground pressure setting is used, as in RVSM operations.

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### 3.2 Components

The altimetry system errors presented in Figure 2-1 and described in 3.1 are discussed below in greater detail.

3.2.1 *Static Source Error* The component parts of SSE are presented in Table 2-1, with the factors that control their magnitude.

- (a) The reference SSE is the best estimate of actual SSE, for a single aircraft or an aircraft group, obtained from flight calibration measurements. It is variable with operating condition characteristically reducing to a family of  $W/\delta$  curves that are functions of Mach. It includes the effect of any aerodynamic compensation that may have been incorporated in the design. Once determined, the reference SSE is fixed for the single aircraft or group, although it may be revised when considering subsequent data.
- (b) The test techniques used to derive the reference SSE will have some measurement of uncertainty associated with them, even though known instrumentation errors will normally be eliminated from the data. For trailing-cone measurements the uncertainty arises from limitations on pressure measurement accuracy, calibration of the trailing-cone installation, and variability in installations where more than one are used. Once the reference SSE has been determined, the actual measurement error is fixed, but as it is unknown it can only be handled within the ASE budget as an estimated uncertainty.
- (c) The airframe variability and probe/port variability components arise from differences between the individual airframe and probe/port, and the example(s) of airframe and probe port used to derive the reference SSE.

3.2.2 *Residual Static Source Error*

- (a) The components and factors are presented in Table 2-1. Residual SSE is made up of those error components which make actual SSE different from the reference value, components 2, 3, and 4 from Table 2-1, plus the amount by which the actual SSEC differs from the value that would correct the reference value exactly, components 2(a), (b) and (c) from Table 2-2.
- (b) There will generally be a difference between the SSEC that would exactly compensate the reference SSE, and the SSEC that the avionics is designed to apply. This arises from practical avionics design limitations. The resulting error component 2(a) will therefore be fixed, for a particular flight condition, for the single aircraft or group. Additional variable errors 2(b) and 2(c) arise from those factors that cause a particular set of avionics to apply an actual SSEC that differs from its design value.
- (c) The relationship between perfect SSEC, reference SSEC, design SSEC and actual SSEC is illustrated in Figure 2-2, for the case where static line errors and pressure measurements and conversion errors are taken as zero.
- (d) Factors that create variability of SSE relative to the reference characteristic should be accounted for twice. First, as noted for the SSE itself in Table 2-2, and secondly for its effect on the corruption of SSEC as in factor 2(a)(i) of Table 2-2. Similarly the static pressure measurement error should be accounted for in two separate ways. The main effect will be by way of the 'pressure measurement and

conversion' component, but a secondary effect will be by way of factor 2(a)(ii) of Table 2-2.

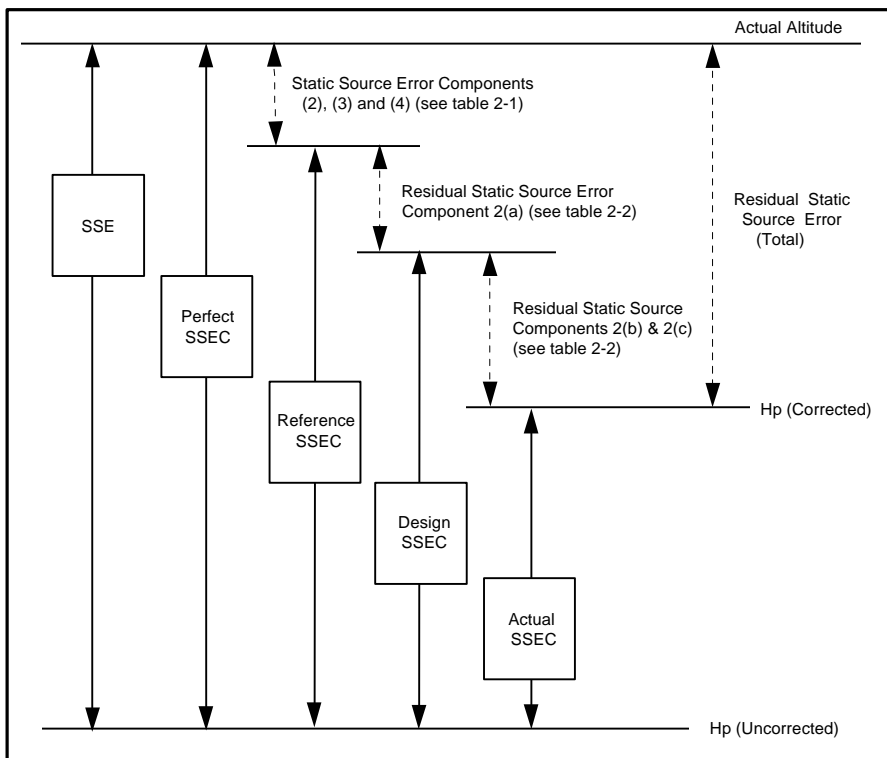
**TABLE 2-1 STATIC SOURCE ERROR**  
(Cause: Aerodynamic Disturbance to Free-Stream Conditions)

Factors	Error Components
Airframe Effects  Operating Condition (Speed, altitude, angle of attack, sideslip)  Geometry: Size and shape of airframe; Location of static sources; Variations of surface contour near the sources; Variations in fit of nearby doors, skin panels or other items.	1) Reference SSE values from flight calibration measurements.  2) Uncertainty of flight calibration measurements.
Probe/Port Effects  Operating Condition (Speed, altitude, angle of attack, sideslip)  Geometry: Shape of probe/port; Manufacturing variations; Installation variations.	3) Airframe to airframe variability.  4) Probe/port to probe/port variability.

**TABLE 2-2 RESIDUAL STATIC SOURCE ERROR: (AIRCRAFT WITH AVIONIC SSEC)**  
(Cause: Difference between the SSEC actually applied and the actual SSE)

Factors	Error Components
(1) As for Static Source Error PLUS  (2) Source of input data for SSEC function (a) Where SSEC is a function of Mach: (i) $P_S$ sensing: difference in SSEC from reference SSE. (ii) $P_S$ measurement: pressure transduction error. (iii) $P_T$ errors: mainly pressure transduction error.  (b) Where SSEC is a function of angle of attack:  (i) geometric effects on alpha: -sensor tolerances; -installation tolerances; -local surface variations. (ii) measurement error: -angle transducer accuracy.  (3) Implementation of SSEC function  (a) Calculation of SSEC from input data; (b) Combination of SSEC with uncorrected height.	1) Error Components (2), (3), and (4) from table 2-1 PLUS  2(a) Approximation in fitting design SSEC to flight calibration reference SSE.  2(b) Effect of production variability (sensors and avionics) on achieving design SSEC.  2(c) Effect of operating environment (sensors and avionics) on achieving design SSEC.

FIGURE 2-2 SSE/SSEC RELATIONSHIPS FOR ASE WHERE STATIC LINE, PRESSURE MEASUREMENT AND CONVERSION ERRORS ARE ZERO



3.2.3 *Static Line Error* Static line errors arise from leaks and pneumatic lags. In level cruise these can be made negligible for a system that is correctly designed and correctly installed.

3.2.4 *Pressure Measurement and Conversion Error*

- (a) The functional elements are static pressure sensing, which may be mechanical, electromechanical or solid-state, and the conversion of pressure signal to pressure altitude.
- (b) The error components are:
  - (i) calibration uncertainty;
  - (ii) nominal design performance;
  - (iii) unit to unit manufacturing variations; and

- (iv) effect of operating environment.
- (c) The equipment specification is normally taken to cover the combined effect of the error components. If the value of pressure measurements and conversion error used in the error budget is the worst case specification value, then it is not necessary to assess the above components separately. However, calibration uncertainty, nominal design performance and effect of operating environment can all contribute to bias errors within the equipment tolerance. Therefore if it is desired to take statistical account of the likely spread of errors within the tolerance band, then it will be necessary to assess their likely interaction for the particular hardware design under consideration.
- (d) It is particularly important to ensure that the specified environmental performance is adequate for the intended application.

3.2.5 *Baro-Setting Error* This is the difference between the value displayed and the value applied within the system. For RVSM operation the value displayed should always be the International Standard Atmosphere ground pressure, but setting mistakes, although part of TVE, are not components of ASE.

- (a) The components of Baro-Setting Error are:
  - (i) resolution of setting knob/display;
  - (ii) sensing of displayed value; and
  - (iii) application of sensed value.
- (b) The applicability of these factors and the way that they combine depend on the particular system architecture.
- (c) For systems in which the display is remote from the pressure measurement function there may be elements of the sensing and/or application or sensed value error components which arise from the need to transmit and receive the setting between the two locations.

3.2.6 *Display Error* The cause is imperfect conversion from altitude signal to display.

The components are:

- (a) conversion of display input signal;
- (b) graticule/format accuracy, and
- (c) readability.

3.2.7 In self-sensing altimeters the first of these would normally be separate from the pressure measurement and conversion error.

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**APPENDIX 3 - ESTABLISHING AND MONITORING STATIC SOURCE ERRORS****1. INTRODUCTION**

The data package is discussed in sub-paragraph 9.2. It is stated, in sub-paragraph 9.5.5 (c) that the methodology used to establish the static source error should be substantiated. It is further stated in sub-paragraph 9.6 that procedures be established to ensure conformity of newly manufactured aeroplanes. There may be many ways of satisfying these objectives; two examples are discussed below.

**2. EXAMPLE 1**

2.1 One process for showing compliance with RVSM criteria is shown in Figure 3-1. Figure 3-1 illustrates those flight test calibrations and geometric inspections will be performed on a given number of aircraft. The flight calibrations and inspections will continue until a correlation between the two is established. Geometric tolerances and SSEC will be established to satisfy RVSM criteria. For aircraft being manufactured, every Nth aircraft will be inspected in detail and every Mth aircraft will be flight test calibrated, where 'N' and 'M' are determined by the aircraft constructor and agreed to by the responsible authority. The data generated by 'N' inspections and 'M' flight calibrations can be used to track the mean and three standard deviation values to ensure continued compliance of the model with the criteria of paragraph 7. As additional data are acquired, they should be reviewed to determine if it is appropriate to change the values of N and M as indicated by the quality of the results obtained.

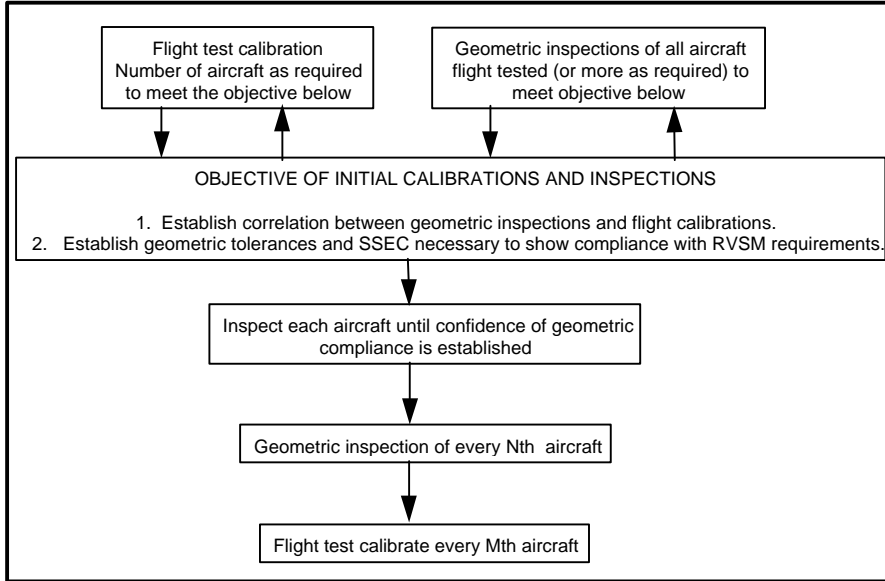
2.2 There are various ways in which the flight test and inspection data might be used to establish the correlation. The example shown in Figure 3-2 is a process in which each of the error sources for several aeroplanes is evaluated based on bench tests, inspections and analysis. Correlation between these evaluations and the actual flight test results would be used to substantiate the method.

2.3 The method illustrated in Figures 3-1 and 3-2 is appropriate for new models since it does not rely on any pre-existing data base for the group.

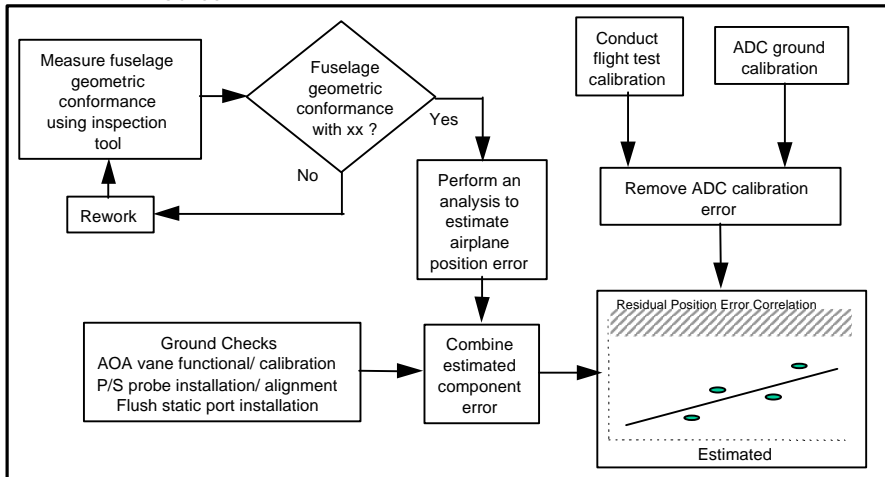
**3. EXAMPLE 2**

3.1 Figure 3-3 illustrates that flight test calibrations should be performed on a given number of aircraft and consistency rules for air data information between all concerned systems verified. Geometric tolerances and SSEC should be established to satisfy the criteria. A correlation should be established between the design tolerances and the consistency rules. For aircraft being manufactured, air data information for all aircraft should be checked for consistency in cruise conditions and every Month aircraft should be calibrated, where M is determined by the manufacturer and agreed to by the responsible authority. The data generated by the M flight calibrations should be used to track the mean and three standard deviation values to ensure continued compliance of the group with the criteria of paragraph 7.

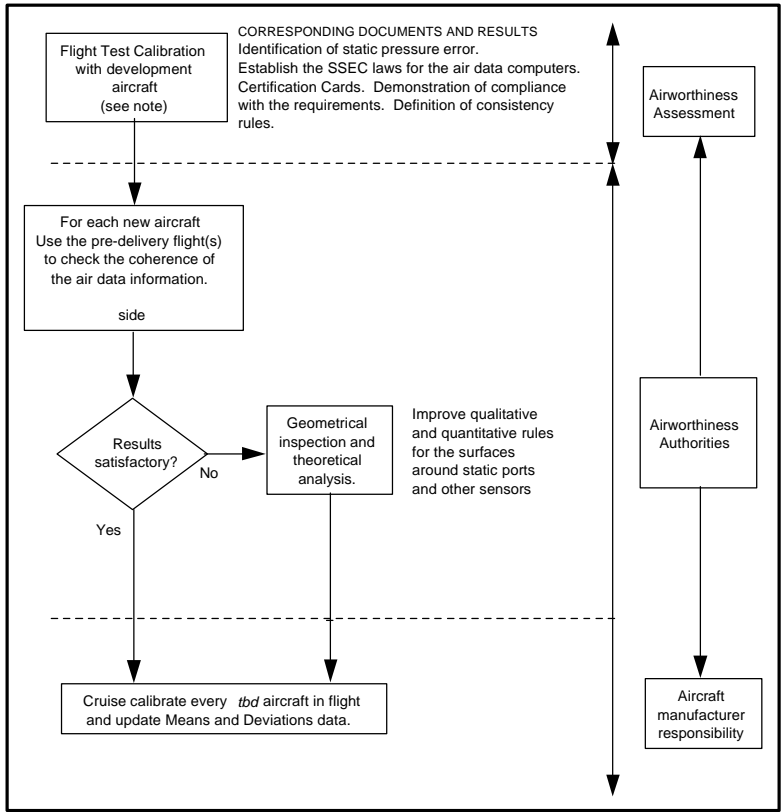
**FIGURE 3-1 PROCESS FOR SHOWING INITIAL AND CONTINUED COMPLIANCE OF AIRFRAME STATIC PRESSURE SYSTEMS**



**FIGURE 3-2 COMPLIANCE DEMONSTRATION GROUND - TO FLIGHT TEST CORRELATION PROCESS EXAMPLE**



**FIGURE 3-3 PROCESS FOR SHOWING INITIAL AND CONTINUED COMPLIANCE OF AIRFRAME STATIC PRESSURE SYSTEMS FOR NEW MODEL AIRCRAFT.**



Note : The flight test installation chosen to get the calibration data will need to have an accuracy compatible with the level of performance to be demonstrated and an analysis of this accuracy will need to be provided. Any possible degradation of this accuracy will need to be monitored and corrected during the flight test period.



## APPENDIX 4 TRAINING PROGRAMMES AND OPERATING PRACTICES AND PROCEDURES

### 1. INTRODUCTION

Flight crews will need to have an awareness of the criteria for operating in RVSM airspace and be trained accordingly. The items detailed in paragraphs 2 to 6 of this appendix should be standardised and incorporated into training programmes and operating practices and procedures. Certain items may already be adequately standardised in existing procedures. New technology may also remove the need for certain actions required of the flight crew. If this is so, then the intent of this guidance can be considered to be met.

Note: This document is written for all users of RVSM airspace, and as such is designed to present all required actions. It is recognised that some material may not be necessary for larger public transport operators.

### 2. FLIGHT PLANNING

During flight planning the flight crew should pay particular attention to conditions that may affect operation in RVSM airspace.

These include, but may not be limited to:

- (a) verifying that the airframe is approved for RVSM operations;
- (b) reported and forecast weather on the route of flight;
- (c) minimum equipment requirements pertaining to height keeping and alerting systems; and
- (d) any airframe or operating restriction related to RVSM approval.

### 3. PRE-FLIGHT PROCEDURES AT THE AIRCRAFT FOR EACH FLIGHT

The following actions should be accomplished during the pre-flight procedure:

- (a) review technical logs and forms to determine the condition of equipment required for flight in the RVSM airspace. Ensure that maintenance action has been taken to correct defects to required equipment;
- (b) during the external inspection of aircraft, particular attention should be paid to the condition of static sources and the condition of the fuselage skin near each static source and any other component that affects altimetry system accuracy. This check may be accomplished by a qualified and authorised person other than the pilot (e.g. a flight engineer or ground engineer);
- (c) before takeoff, the aircraft altimeters should be set to the QNH of the airfield and should display a known altitude, within the limits specified in the aircraft operating manuals. The two primary altimeters should also agree within limits specified by the aircraft operating manual. An alternative procedure using QFE may also be used. Any required functioning checks of altitude indicating systems should be performed.

Note. The maximum value for these checks cited in operating manuals should not exceed 23m (75ft).

- (d) before take-off, equipment required for flight in RVSM airspace should be operative, and any indications of malfunction should be resolved.

### 4. PROCEDURES PRIOR TO RVSM AIRSPACE ENTRY

The following equipment should be operating normally at entry into RVSM airspace:

- (a) Two primary altitude measurement systems.
- (b) One automatic altitude-control system.
- (c) One altitude-alerting device.

Note: Dual equipment requirements for altitude-control systems will be established by regional agreement after an evaluation of criteria such as mean time between failures, length of flight segments and availability of direct pilot-controller communications and radar surveillance.

- (d) Operating Transponder. An operating transponder may not be required for entry into all designated RVSM airspace. The operator should determine the requirement for an operational transponder in each RVSM area where operations are intended. The operator should also determine the transponder requirements for transition areas next to RVSM airspace.

Note: Should any of the required equipment fail prior to the aircraft entering RVSM airspace, the pilot should request a new clearance to avoid entering this airspace;

## 5. IN-FLIGHT PROCEDURES

5.1 The following practices should be incorporated into flight crew training and procedures:

- (a) Flight crews will need to comply with any aircraft operating restrictions, if required for the specific aircraft group, e.g. limits on indicated Mach number, given in the RVSM airworthiness approval.
- (b) Emphasis should be placed on promptly setting the sub-scale on all primary and standby altimeters to 1013.2 (hPa) /29.92 in.Hg when passing the transition altitude, and rechecking for proper altimeter setting when reaching the initial cleared flight level;
- (c) In level cruise it is essential that the aircraft is flown at the cleared flight level. This requires that particular care is taken to ensure that ATC clearances are fully understood and followed. The aircraft should not intentionally depart from cleared flight level without a positive clearance from ATC unless the crew are conducting contingency or emergency manoeuvres;
- (d) When changing levels, the aircraft should not be allowed to overshoot or undershoot the cleared flight level by more than 45 m (150 ft);

Note: It is recommended that the level off be accomplished using the altitude capture feature of the automatic altitude-control system, if installed.

- (e) An automatic altitude-control system should be operative and engaged during level cruise, except when circumstances such as the need to re-trim the aircraft or turbulence require disengagement. In any event, adherence to cruise altitude should be done by reference to one of the two primary altimeters. Following loss of the automatic height keeping function, any consequential restrictions will need to be observed.
- (f) Ensure that the altitude-alerting system is operative;
- (g) At intervals of approximately one hour, cross-checks between the primary  
m  
ft). Failure to meet this condition will require that the altimetry system be reported as defective and notified to ATC;

- (i) The usual scan of flight deck instruments should suffice for altimeter cross-checking on most flights.
- (ii) Before entering RVSM airspace, the initial altimeter cross check of primary and standby altimeters should be recorded  
Note: Some systems may make use of automatic altimeter comparators.
- (h) In normal operations, the altimetry system being used to control the aircraft should be selected for the input to the altitude reporting transponder transmitting information to ATC.
- (i) If the pilot is advised in real time that the aircraft has been identified by a height-  
m ft) and/or an ASE  
m ft) then the pilot should follow established regional procedures to protect the safe operation of the aircraft. This assumes that the monitoring system will identify the TVE or ASE within the set limits for accuracy.
- (j) If the pilot is notified by m  
ft) then the pilot should take action to return to cleared flight level as quickly as possible.

5.2 Contingency procedures after entering RVSM airspace are:

5.2.1 The pilot should notify ATC of contingencies (equipment failures, weather) which affect the ability to maintain the cleared flight level, and co-ordinate a plan of action appropriate to the airspace concerned. Appendices 6 and 7 are relevant to EUR and NAT airspace.

Note: Other appendices may be added as necessary to address additional areas of operation.

5.2.2 Examples of equipment failures which should be notified to ATC are:

- (a) failure of all automatic altitude-control systems aboard the aircraft;
- (b) loss of redundancy of altimetry systems;
- (c) loss of thrust on an engine necessitating descent; or
- (d) any other equipment failure affecting the ability to maintain cleared flight level;

5.2.3 The pilot should notify ATC when encountering greater than moderate turbulence.

5.2.4 If unable to notify ATC and obtain an ATC clearance prior to deviating from the cleared flight level, the pilot should follow any established contingency procedures and obtain ATC clearance as soon as possible.

**6. POST FLIGHT**

6.1 In making technical log entries against malfunctions in height keeping systems, the pilot should provide sufficient detail to enable maintenance to effectively troubleshoot and repair the system. The pilot should detail the actual defect and the crew action taken to try to isolate and rectify the fault.

6.2 The following information should be recorded when appropriate:

- (a) Primary and standby altimeter readings.

- (b) Altitude selector setting.
- (c) Subscale setting on altimeter.
- (d) Autopilot used to control the aeroplane and any differences when an alternative autopilot system was selected.
- (e) Differences in altimeter readings, if alternate static ports selected.
- (f) Use of air data computer selector for fault diagnosis procedure.
  
- (g) The transponder selected to provide altitude information to ATC and any difference noted when an alternative transponder was selected.

#### **7. SPECIAL EMPHASIS ITEMS: FLIGHT CREW TRAINING**

7.1 The following items should also be included in flight crew training programmes:

- (a) knowledge and understanding of standard ATC phraseology used in each area of operations;
- (b) importance of crew members cross checking to ensure that ATC clearances are promptly and correctly complied with;
- (c) use and limitations in terms of accuracy of standby altimeters in contingencies. Where applicable, the pilot should review the application of static source error correction/ position error correction through the use of correction cards;

Note: Such correction data will need to be readily available on the flight deck.

- (d) problems of visual perception of other aircraft at 300m (1,000 ft) planned separation during darkness, when encountering local phenomena such as northern lights, for opposite and same direction traffic, and during turns; and
- (e) characteristics of aircraft altitude capture systems which may lead to overshoots;
- (f) relationship between the aircraft's altimetry, automatic altitude control and transponder systems in normal and abnormal conditions;
- (g) any airframe operating restrictions, if required for the specific aircraft group, related to RVSM airworthiness approval.

#### **8. SPECIFIC REGIONAL OPERATIONAL PROCEDURES**

8.1 The areas of applicability by Flight Information Region (FIR) of RVSM airspace in identified ICAO regions is contained in the relevant sections of ICAO Document 7030/4. In addition these sections contain operational and contingency procedures unique to the regional airspace concerned, specific flight planning requirements, and the approval requirements for aircraft in the designated region.

8.2 For the North Atlantic Minimum Navigation Performance Specification (MNPS) airspace, where RVSM have been in operation since 1997, further guidance (principally for State Approval Agencies) is contained in ICAO Document NAT 001 T13/5NB.5 with comprehensive operational guidance (aimed specifically at aircraft operators) in the North Atlantic MNPS Airspace Operational Manual.

8.3 Comprehensive guidance on operational matters for European RVSM Airspace is contained in EUROCONTROL Document ASM ET1.ST.5000 enti

Publications.

8.4 During the life of this document, it is expected that additional ICAO regions or parts of regions may introduce RVSM into their airspace. For example, plans are well in hand to introduce RVSM into parts of the Pacific region. The area of applicability and associated procedures will be published in Document 7030/4 where reference will be made to additional material as necessary.

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**APPENDIX 5 - REVIEW OF ICAO DOCUMENT 9574 - HEIGHT KEEPING PARAMETERS**

1. ICAO Document 9574 Manual on the implementation of a 300m (1,000 ft) Vertical Separation Minimum Between FL 290-FL 410 Inclusive, covers the overall analysis of factors for achieving an acceptable level of safety in a given airspace system. The major factors are passing frequency, lateral navigation accuracy, and vertical overlap probability. Vertical overlap probability is a consequence of errors in adhering accurately to the assigned flight level, and this is the only factor covered in this document.

2. In ICAO Doc. 9574, Section 2.1.1.3, the vertical overlap probability requirement is restated as the aggregate of height keeping errors of individual aircraft that must lie within the total vertical error (TVE) distribution, expressed as the simultaneous satisfaction of the following four criteria:

- (a) " the proportion of height keeping errors beyond 90 m (300 ft) in magnitude must be less than  $2.0 \times 10^{-3}$ ; and
- (b) the proportion of height keeping errors beyond 150 m (500 ft) in magnitude must be less than  $3.5 \times 10^{-6}$ ; and
- (c) the proportion of height keeping errors beyond 200 m (650 ft) in magnitude must be less than  $1.6 \times 10^{-7}$ ; and
- (d) the proportion of height keeping errors between 290 m (950 ft) and 320 m (1,050 ft) in magnitude must be less than  $1.7 \times 10^{-8}$ . "

3. The following characteristics presented in ICAO Doc. 9574 were developed in accordance with the conclusions of ICAO Doc. 9536. They are applicable statistically to individual groups of nominally identical aircraft operating in the airspace. These characteristics describe the performance that the groups need to be capable of achieving in service, exclusive of human factors errors and extreme environmental influences, if the airspace system TVE criteria are to be satisfied. The following characteristics are the basis for development of this document:

- (a) and ft);
- (b) The sum of the absolute value of the mean ASE for the group and three standard deviations of ASE within the group shall not exceed 75 m (245 ft); and
- (c) Errors in altitude keeping shall be symmetric about a mean of 0 m (0 ft) and shall have a standard deviation not greater than 13 m (43 ft) and should be such that the error frequency decreases with increasing error magnitude at a rate which is at least exponential.'

4. ICAO Doc. 9574 recognises that specialist study groups would develop the detailed specifications, to ensure that the TVE objectives can be met over the full operational envelope in RVSM airspace for each aircraft group. In determining the breakdown of tolerances between the elements of the system it was considered necessary to set system tolerances at levels that recognise that the overall objectives must be met operationally by aircraft and equipment subject to normal production variability, including that of the airframe static source error, and normal in-service degradation. It was also recognised that it would be necessary to develop specifications and procedures covering the means for ensuring that in-service degradation is controlled at an acceptable level.

5. On the basis of studies reported in ICAO Doc. 9536, Volume 2, ICAO Doc. 9574 recommended that the required margin between operational performance and design capability

should be achieved by ensuring that the performance criteria are developed to fulfil the following, where the narrower tolerance in sub-paragraph 5 (b) is specifically intended to allow for some degradation with increasing age:

- (a) 'the mean uncorrected residual position error (static source error) of the group shall ft); and
- (b) the sum of the absolute value of the mean ASE for the group and three standard deviations of ASE within the group, shall not exceed 60 m (200 ft); and
- (c) each individual aircraft in the group shall be built to have ASE contained within ft); and
- (d) an automatic altitude control system shall be required and will be capable of ft) about selected altitude when operated in the altitude hold mode in straight and level flight under non-turbulent, non-gust conditions.'

6. These standards provide the basis for the separate performance aspects of airframe, altimetry, altimetry equipment and automatic altitude control system. It is important to recognise that the limits are based on studies (Doc. 9536, Volume 2), which show that ASE tends to follow a normal distribution about a characteristic mean value for the aircraft group and that the in-service performances of the separate groups aggregate together to give an overall performance spread which is distributed about the population mean TVE that is nominally zero. Consequently, controls should be provided which will preclude the possibility that individual aircraft approvals could create clusters operating with a mean significantly beyond 25 m (80 ft) in magnitude, such as could arise where elements of the altimetry system generate bias errors additional to the mean corrected static source error.

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