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Manual on a 300 m (1 000 ft) Vertical Separation Minimum Between FL 290 and FL 410 Inclusive

Approved by the Secretary General
and published under his authority

Third Edition — 2012

International Civil Aviation Organization

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AMENDMENTS

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GLOSSARY

ACRONYMS

AAD	assigned altitude deviation
ACAS	airborne collision avoidance system
ACC	area control centre
ADS-B	automatic dependent surveillance–broadcast
ASE	altimetry system error
ATC	air traffic control
ATS	air traffic services
CFL	cleared flight level
CMA	central monitoring agency
CRM	collision risk model
FAA	Federal Aviation Administration
FL	flight level
FTE	flight technical error
GMS	GPS-based monitoring system
GMU	GPS-based monitoring unit
GPS	global positioning system
GSPS	global system performance specification
HMU	height-monitoring unit
JAA	Joint Aviation Authority
LHD	large height deviation
MASPS	minimum aircraft system performance specification
MNPS	minimum navigation performance specification
NAT	North Atlantic
NAT SPG	North Atlantic Systems Planning Group
NOTAM	notice to airmen
PDF	probability density function
RGCSP	Review of the General Concept of Separation Panel
RMA	regional monitoring agency
RNAV	area navigation
RPG	regional planning group
RVSM	reduced vertical separation minimum
SMS	safety management system
SSE	static source error
SSR	secondary surveillance radar
TLS	target level of safety
TVE	total vertical error
VSM	vertical separation minimum

DEFINITIONS

The following definitions are intended to clarify certain specialized terms used in this manual.

Aberrant aircraft. Those aircraft which exhibit measured height-keeping performance that is significantly different from the core height-keeping performance measured for the whole population of aircraft operating in RVSM airspace.

Aircraft type groupings. Aircraft are considered to belong to the same group if they are designed and assembled by one manufacturer and are of nominally identical design and build with respect to all details which could influence the accuracy of height-keeping performance.

Airworthiness approval. The process of assuring the State authority that aircraft meet an RVSM MASPS. Typically, this would involve an operator meeting the requirements of the aircraft manufacturer service bulletin for that aircraft and having the State authority verify the successful completion of that work.

Altimetry system error (ASE). The difference between the altitude indicated by the altimeter display, assuming a correct altimeter barometric setting, and the pressure altitude corresponding to the undisturbed ambient pressure.

Altimetry system error stability. Altimetry system error for an individual aircraft is considered to be stable if the statistical distribution of altimetry system error is within agreed limits over an agreed period of time.

Altitude-keeping device. Any equipment which is designed to automatically control the aircraft to a referenced pressure altitude.

Assigned altitude deviation (AAD). The difference between the transponder Mode C altitude and the assigned altitude/flight level.

Automatic altitude-keeping device. Any equipment which is designed to automatically control the aircraft to a referenced pressure-altitude.

Collision risk. The expected number of mid-air aircraft accidents in a prescribed volume of airspace for a specific number of flight hours due to loss of planned separation.

Note.— One collision is considered to produce two accidents.

Flight technical error (FTE). The difference between the altitude indicated by the altimeter display being used to control the aircraft and the assigned altitude/flight level.

Height-keeping capability. The 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 cleared flight level.

Non-compliant aircraft. An aircraft configured to comply with the requirements of an RVSM MASPS which, through height monitoring, is found to have a total vertical error (TVE) or an assigned altitude deviation (AAD) of 90 m (300 ft) or greater or an altimetry system error (ASE) of 75 m (245 ft) or more.

NOTAM. A notice distributed by means of telecommunication containing information concerning the establishment, condition or change in any aeronautical facility, service, procedure or hazard, the timely knowledge of which is essential to personnel concerned with flight operations.

Occupancy. A parameter of the collision risk model which is twice the count of aircraft proximate pairs in a single dimension divided by the total number of aircraft flying the candidate paths in the same time interval.

Operational error. Any vertical deviation of an aircraft from the correct flight level as a result of incorrect action by air traffic control (ATC) or the aircraft crew.

Overall risk. The risk of collision due to all causes, which includes the technical risk (see definition) and all risk due to operational errors and in-flight contingencies.

Passing frequency. The frequency of events in which two aircraft are in longitudinal overlap when travelling in the opposite or same direction on the same route at adjacent flight levels and at the planned vertical separation.

RVSM approval. The term used to describe the successful completion of airworthiness approval and operational approval (if required).

Target level of safety (TLS). A generic term representing the level of risk which is considered acceptable in particular circumstances.

Technical risk. The risk of collision associated with aircraft height-keeping performance.

Total vertical error (TVE). The vertical geometric difference between the actual pressure altitude flown by an aircraft and its assigned pressure altitude (flight level).

Track. The projection on the earth's surface of the path of an aircraft, the direction of which path at any point is usually expressed in degrees from North (true, magnetic or grid).

Vertical separation. The spacing provided between aircraft in the vertical plane to avoid collision.

Vertical separation minimum (VSM). VSM is documented in the *Procedures for Air Navigation Services — Air Traffic Management* (PANS-ATM, Doc 4444) as being a nominal 300 m (1 000 ft) below FL 290 and 600 m (2 000 ft) above FL 290 except where, on the basis of regional agreement, a value of less than 600 m (2 000 ft) but not less than 300 m (1 000 ft) is prescribed for use by aircraft operating above FL 290 within designated portions of the airspace.

Chapter 1

INTRODUCTION

1.1 BACKGROUND

1.1.1 In the late 1950s it was recognized that, as a result of the reduction in pressure-sensing accuracy of barometric altimeters with increasing altitude, there was a need above a certain flight level (FL) to increase the prescribed vertical separation minimum (VSM) of 300 m (1 000 ft). In 1960, an increased VSM of 600 m (2 000 ft) was established for use between aircraft operating above FL 290 except where, on the basis of regional air navigation agreement, a lower flight level was prescribed for the increase. The selection of FL 290 as the vertical limit for the 300 m (1 000 ft) VSM was not so much an empirically-based decision but rather a function of the operational ceiling of the aircraft at that time. In 1966, this changeover level was established at FL 290 on a global basis. At the same time, it was considered that the application of a reduced VSM above FL 290, on a regional basis and in carefully prescribed circumstances, was a distinct possibility in the not too distant future. Accordingly, ICAO provisions stated that such a reduced VSM could be applied under specified conditions within designated portions of airspace on the basis of regional air navigation agreement.

1.1.2 It has long been recognized that any decision concerning the feasibility of reducing the VSM above FL 290 could not be based upon operational judgement alone, but would need to be supported by a rigorous assessment of the risk associated with such a reduction of separation. The lack of a clear-cut method of achieving such an assessment was the primary cause of the failure of various attempts to determine the feasibility of a reduced VSM.

1.1.3 In the mid-1970s, the series of world fuel shortages and the resultant rapid escalation of fuel costs, allied to the growing demand for a more efficient use of the available airspace, emphasized the need for a detailed appraisal of the proposal to reduce the VSM above FL 290. Thus, at its fourth meeting (in 1980), the ICAO Review of the General Concept of Separation Panel (RGCSP) concluded that, despite the cost and time involved, the potential benefits of reducing the VSM above FL 290 to 300 m (1 000 ft) were so great that States should be encouraged to conduct the necessary major evaluations.

1.1.4 In 1982, coordinated by the RGCSP, States initiated programmes to study comprehensively the question of reducing the VSM above FL 290. Studies were carried out by Canada, Japan, Member States of EUROCONTROL (France, Federal Republic of Germany, Kingdom of the Netherlands and United Kingdom), Union of Soviet Socialist Republics and United States, and in December 1988 the results were considered by the RGCSP at its sixth meeting (RGCSP/6).

1.1.5 These studies employed quantitative methods of risk assessment to support operational decisions concerning the feasibility of reducing the VSM. The risk assessment consisted of two elements: first, risk estimation, which concerns the development and use of methods and techniques with which the actual level of risk of an activity can be estimated; and second, risk evaluation, which concerns the level of risk considered to be the maximum tolerable value for a safe system. The level of risk that is deemed acceptable was termed the target level of safety (TLS).

1.1.6 The process for estimating risk in the vertical plane using the collision risk model (CRM) assumed that collisions result solely from vertical navigation errors of aircraft to which procedural separation had been correctly applied. The TLS was derived to apply to this source of collision risk alone; it does not address risk from other sources, such as height deviations due to turbulence, responses to airborne collision avoidance system alerts, emergency descents and operational errors in the issuance of, or compliance with, air traffic control (ATC) instructions.

1.1.7 The recognition of several sources of risk in addition to vertical navigation errors played a role in the choice of TLS values made by various States during their studies. Several approaches were followed in order to establish an appropriate range of values, including all en-route mid-air collisions and the implicit period between collisions, and adjusting the TLS until the period of time became acceptable. Nevertheless, the primary approach, and the traditional manner, was to use historical data from global sources, predicted forward to approximately the year 2000 to provide safety improvement and to apportion resultant risk budgets to derive the vertical collision risk element.

1.1.8 The derived values for the TLS ranged between 1×10^{-8} and 1×10^{-9} fatal accidents per aircraft flight hour. On the basis of these figures, it was agreed that an assessment TLS of 2.5×10^{-9} fatal accidents per aircraft flight hour would be used to assess the technical feasibility of a 300 m (1 000 ft) VSM above FL 290 and also to develop aircraft height-keeping capability requirements for operating in a 300 m (1 000 ft) VSM.

1.1.9 Using the assessment TLS of 2.5×10^{-9} fatal accidents per aircraft flight hour, RGCSP/6 concluded that a 300 m (1 000 ft) VSM above FL 290 was technically feasible. This technical feasibility refers to the fundamental capability of aircraft height-keeping systems, which could be built, maintained and operated in such a manner that the expected, or typical, performance is consistent with safe implementation and use of a 300 m (1 000 ft) VSM above FL 290. In reaching this conclusion on technical feasibility, the panel found it necessary to establish:

- a) airworthiness performance requirements embodied in a comprehensive minimum aircraft system performance specification (MASPS) for all aircraft utilizing the reduced separation;
- b) new operational procedures; and
- c) a comprehensive means of monitoring the safe operation of the system.

1.1.10 It is important to emphasize that the assessment TLS did not address all causes of risk of collision in the vertical plane. In the first edition of this guidance material, regional planning authorities were advised of the necessity to institute measures to ensure that the risks associated with operational errors and emergency actions did not increase in the 300 m (1 000 ft) VSM environment. In the North Atlantic (NAT) Region, which on 27 March 1997 became the first ICAO region to implement the reduced vertical separation minimum (RVSM), it was agreed that a more formal approach was necessary to assessing all causes of risk in the vertical plane. On the basis of the experience gained in the monitoring and analysis of the causes of operational errors in NAT minimum navigation performance specification (MNPS) airspace, the NAT Systems Planning Group (NAT SPG) agreed that limiting the risk of collision due to the loss of planned vertical separation as a consequence of such events should receive attention at least equal to that devoted to limiting the effects of technical errors (errors of aircraft height-keeping systems). Therefore, in addition to the TLS for technical errors, i.e. 2.5×10^{-9} fatal accidents per aircraft flight hour, an overall TLS of 5×10^{-9} fatal accidents per aircraft flight hour resulting from a loss of vertical separation due to any cause was adopted.

1.2 PURPOSE OF THE MANUAL

1.2.1 The basic purpose of this manual is to provide regional planning groups (RPGs) with a basis for the revision of documents, procedures and programmes to enable the maintenance of a 300 m (1 000 ft) VSM between FL 290 and FL 410 inclusive within their particular regions in accordance with the criteria and requirements developed by ICAO.

1.2.2 This manual also provides:

- a) guidance to State aviation authorities on those measures necessary to ensure that the criteria and requirements are met within their area of responsibility; and

- b) background information for operators to assist them in the development of operating manuals and flight crew procedures.

1.3 CONTENT AND PRESENTATION

1.3.1 The title of this manual and the sequence of material in this third edition reflect amended content and presentation that focus on continuing RVSM operations, in contrast to the first and second editions that focused on implementation. These changes have been made on the basis that RVSM has been successfully implemented globally. Chapter 2 describes the general RVSM requirements in terms of inter alia, safety, required aircraft height-keeping performance, and operating aspects. Chapter 3 describes specific aircraft RVSM requirements and approval aspects, Chapter 4 gives general guidance on procedures, for both ATC and flight crew, and Chapter 5 provides information on system monitoring, including the responsibilities and tasks of authorities in RVSM performance monitoring. Appendix A contains guidance on the quantitative aspects of system performance monitoring, and Appendix B provides a list of reference documentation, such as regional documentation developed in the context of regional RVSM implementation programmes.

1.3.2 In this manual, RVSM refers to a vertical separation minimum of 300 m (1 000 ft) between FL 290 and FL 410 inclusive.

Chapter 2

GENERAL REQUIREMENTS

2.1 SAFETY OBJECTIVES

2.1.1 Continuity of RVSM operations can be based on safety assessments undertaken at least annually, demonstrating that RVSM safety objectives are being maintained. Where practicable, assessments may be undertaken on a more frequent basis to ensure any change to system risk is identified and controlled as early as possible. The safety assessment may include using a CRM for the airspace in accordance with the guidance provided in this manual (more detailed information on CRM methodologies is contained in the documents referenced in Appendix B). Alternatively, safety assessments may be part of a continuing monitoring process based on a safety management system (SMS) approach to monitoring safety. This ongoing process seeks to capture data on a continuing basis and is aimed at identifying system risk at its earliest stages. This SMS process aims to capture safety performance indicators in order to measure their levels of safety when compared to safety performance targets. These safety performance targets are set in agreement with oversight authorities in order to meet higher-level acceptable levels of safety.

2.1.2 Safety objectives for RVSM implementation have been set for both technical risk and overall risk and are as follows.

Safety objective for technical risk

2.1.3 Technical risk is the risk of collision associated with aircraft height-keeping performance. Risk associated with operational errors (e.g. controller/pilot errors) and in-flight contingencies is not included.

2.1.4 The RVSM safety objective for technical risk is a TLS of 2.5×10^{-9} fatal accidents per aircraft flight hour. This value for technical risk was used to derive the global system performance specification and the global height-keeping performance specification, which are detailed in 2.2 and 2.3, respectively.

Safety objective for overall risk

2.1.5 Overall risk is the risk of collision due to all causes, which includes the technical risk (see above) and all risk due to operational errors and in-flight contingencies, such as but not limited to pilot/controller errors, height deviations due to emergency procedures, and turbulence.

2.1.6 The RVSM safety objective for overall risk should be set by regional agreement. Due account should be taken of existing ICAO guidance on safety objectives and of safety objectives applied in other regions. To this end, attention is drawn to:

- a) the guidance provided in the *Performance-based Navigation (PBN) Manual* (Doc 9613) which, with regard to spacing between parallel tracks or between parallel RNAV route centre lines based on RNP type, recommends that for implementation of en-route systems after the year 2000, a TLS of 5×10^{-9} fatal accidents per flying hour per dimension should be applied;
- b) SMS-based metrics and methods of qualitative assessment providing an acceptable level of safety performance may be established by States and, as appropriate, implemented by regional agreement;

- c) the overall safety objective applied for RVSM implementation globally, i.e. a TLS of 5×10^{-9} fatal accidents per aircraft flight hour resulting from a loss of vertical separation due to any cause (see 1.1.10); and
- d) the reference list in Appendix B to this manual.

2.1.7 Guidance on the methodologies to estimate risk associated with RVSM is contained in Chapter 5, system performance monitoring.

2.1.8 Regional authorities should take into account all possible means of quantifying and reducing the level of risk of collision resulting from operational errors and in-flight contingencies in RVSM airspace. Whilst the frequency of occurrence of these events is not considered to be a function of the separation minimum applied, it will be essential for RPGs to institute measures to ensure that the risk due to operational errors and in-flight contingencies does not increase. Guidance on the type of measures to be taken by RPGs, ATC and flight crews is outlined in Chapters 5 and 6.

2.1.9 The results of safety assessments compared against the accepted TLS will provide RPGs with an indication of the current risk within the airspace in which an assessment was undertaken. In the event this risk exceeds the accepted TLS, the RPG should initiate remedial actions in order to attempt to reduce the level of risk to at least the TLS. For it to do so, an RPG will need to have a clear understanding of the reasons driving the risk increase. Therefore it is important that any safety assessments undertaken are of such detail that underlying causes of risk in the airspace are identified. As a result, a qualitative analysis of operational errors and large height deviations is an important activity to be included in the safety assessment process.

2.2 GLOBAL SYSTEM PERFORMANCE SPECIFICATION

2.2.1 The global system performance specification is a statement of the parameters that form the basis for defining the integrated set of requirements for aircraft height-keeping, aircraft systems, aircraft operating procedures, ATC procedures and monitoring practices presented in this manual. The global system performance specification defines the height-keeping performance necessary to meet the safety goal for RVSM technical risk (see 2.1). This level of height-keeping performance depends on specific values of important airspace parameters affecting the risk of collision should vertical separation be lost. The height-keeping performance requirement of the system performance specification is expressed as the maximum value for the probability that aircraft will lose vertical separation equal to the RVSM value, $P_z(1\ 000)$. The important airspace parameters concern the frequency with which aircraft pass while having procedural vertical separation equal to RVSM and actual horizontal separation less than the horizontal size of an aircraft. These important airspace parameters may be expressed in different ways, depending on the route structure of the airspace.

2.2.2 The global system performance specification was originally derived for opposite-direction traffic. In that case, the important airspace parameters are the frequency with which aircraft pass while having procedural vertical separation equal to RVSM and no nominal horizontal separation, and the standard deviation of the error with which aircraft maintain assigned track in the lateral dimension. The quantitative statements of the global system performance specification are:

- a) a passing frequency equal to 2.5 opposite-direction passings per aircraft flight hour;
- b) a standard deviation of lateral path-keeping error equal to 550 m (0.3 NM); and
- c) a probability that two aircraft will lose procedural vertical separation of RVSM value, $P_z(1\ 000)$, equal to 1.7×10^{-8} .

The values for passing frequency and the standard deviation of lateral path-keeping were chosen to forecast future global airspace conditions. These choices reflect the intention to ensure that the TLS will continue to be met with the anticipated increase in global traffic volume and expected technological improvements in navigation.

2.2.3 The global system performance specification in 2.2.2 is based on factoring the frequency with which aircraft pass, with an actual horizontal separation of less than the horizontal size of an aircraft, into a longitudinal and a lateral component. A standard deviation of lateral path-keeping error of 550 m (0.3 NM) produces a probability of lateral overlap of 0.058 for aircraft on the same track. The combined effect of the requirements of 2.2.2 a) and b) on vertical collision risk is equal to $2.5 \times 0.058 = 0.145$. Therefore, an equivalent but more generally applicable quantitative statement of the global system performance specification is:

- a) a frequency of opposite-direction passing events involving lateral overlap equal to 0.145 passings per aircraft flight hour; and
- b) a probability that two aircraft will lose procedural vertical separation of RVSM value, $P_z(1\ 000)$, equal to 1.7×10^{-8} .

2.2.4 Although the global system performance specification was derived and formulated in terms of opposite-direction traffic, it also applies to other route structures, e.g. same-direction traffic, crossing traffic and combinations thereof. For each type of route structure, an equivalent form of the global system performance specification exists (for further details see Chapter 5, 5.2.5 and Appendix A).

Trade-off between global system performance specification parameters

2.2.5 The parameters of the global system performance specification consist of the height-keeping performance on the one hand and the specified airspace parameters on the other. This allows for two types of trade-offs between these parameters, depending on the value of the probability of vertical overlap, $P_z(1\ 000)$, i.e. whether $P_z(1\ 000)$ is equal to or well below the value of 1.7×10^{-8} , as defined in the global system performance specification. However, $P_z(1\ 000)$ may never be allowed to exceed the value of 1.7×10^{-8} .

2.2.6 The first type of trade-off that may be used is between the airspace parameters of passing frequency and the standard deviation of lateral path-keeping error, provided that the probability of vertical overlap is not greater than 1.7×10^{-8} . These two airspace parameters may be traded off against one another provided that their joint effect on vertical collision risk is not greater than that due to an opposite-direction passing frequency of 2.5 passings per aircraft flight hour and a lateral path-keeping error standard deviation of 550 m (0.3 NM). The numerical bound for this joint effect is 0.145 (see also 2.2.3). Thus, either a higher passing frequency in combination with less accurate lateral path-keeping or a lower passing frequency in combination with more accurate lateral path-keeping would be allowed as long as the bound of 0.145 was not exceeded. Note that this trade-off for opposite-direction traffic is implicit in the more general form of the global system performance specification in 2.2.3.

2.2.7 The second type of trade-off is between the probability of vertical overlap, $P_z(1\ 000)$, and the airspace parameters, provided that the probability of vertical overlap is well below the value of 1.7×10^{-8} . The margin provided by $P_z(1\ 000)$ may then be used to increase the upper bound of 0.145 for the combined effect of passing frequency and lateral path-keeping error standard deviation. Within this larger upper bound, the two airspace parameters may be varied as set out in 2.2.6. This second type of trade-off should be performed with great care since the height-keeping performance of the aircraft population may change over time, e.g. aircraft new to the airspace under consideration are only required to meet the global $P_z(1\ 000)$ value of 1.7×10^{-8} and not a lower value.

2.2.8 It should be noted that conducting the trade-off process is more complex than carrying out a straightforward check against a fixed upper bound. The benefit, however, is more flexibility with regard to the allowable parameter values.