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Revised Pre-Implementation Collision Risk Assessment for RVSM in the Africa Indian Ocean Region

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Summary

This report presents a revised pre-implementation collision risk assessment of the implementation of a Reduced Vertical Separation Minimum (RVSM) in the Africa - Indian Ocean (AFI) Region. It addresses two of the AFI RVSM Safety Policy objectives, namely an assessment of the technical vertical risk against a Target Level of Safety (TLS) of 2.5×10^{-9} fatal accidents per flight hour, and an assessment of the total vertical risk against a TLS of 5×10^{-9} fatal accidents per flight hour. A revision was necessary since an initial assessment had shown that the total risk under RVSM would not meet the pertinent TLS without major improvements in the airspace performance. The assessments are pre-implementation assessments based on the latest data and information available from the existing airspace.

Collision risk models developed as a part of the initial assessment have been re-used with updated parameter values to estimate the vertical collision risk under AFI RVSM. The estimate of the technical vertical collision risk meets the technical vertical TLS of 2.5×10^{-9} fatal accidents per flight hour but the estimate of the total vertical collision risk does not meet the total vertical TLS of 5×10^{-9} fatal accidents per flight hour. The total TLS was found to be exceeded by a factor of three. Although this is a significant improvement over the result of the initial assessment, there are several factors that require the estimate of the total risk to be treated with caution.

The estimate of the technical vertical collision risk is affected by a number of limitations in the traffic flow data used for estimating the passing frequency parameter of the collision risk model. Steps must be taken to make the passing frequency estimates more reliable. The estimate of the total vertical collision risk is most likely affected by under-reporting of operational vertical incidents. Measures are required to ensure proper incident reporting.

List of acronyms

AAD	Assigned Altitude Deviation
ACAS	Airborne Collision Avoidance System
ACC	Area Control Centre
AFI	Africa - Indian Ocean
AIAG	ATS Incident Analysis working Group
ARMA	African Regional Monitoring Agency
ASE	Altimetry System Error
ASECNA	L'Agence pour la Sécurité de la Navigation Aérienne en Afrique et à Madagascar
ATC	Air Traffic Control
ATM	Air Traffic Management
ATS	Air Traffic Services
CAA	Civil Aviation Authority
CC	Crossing FL Crossing tracks
CNS	Communication Navigation and Surveillance
CO	Crossing FL Opposite direction tracks
CRA	Collision Risk Assessment
CS	Crossing FL Same direction tracks
CVSM	Conventional Vertical Separation Minimum
DDE	Double Double Exponential
DME	Distance Measuring Equipment
DRC	Democratic Republic of Congo
DS	Direct Speech
EUR	Europe(an)
FA	False Alert
FHA	Functional Hazard Assessment
FIR	Flight Information Region
FIS	Flight Information Service
FL	Flight Level
Ft	Foot
G	Gaussian
GDE	Gaussian Double Exponential
GNSS	Global Navigation Satellite System
H	Horizontal
H(SFL)	Horizontal (same route, following another aircraft)
IATA	International Air Transport Association

ICAO	International Civil Aviation Organisation
IFBP	In Flight Broadcasting Procedure
IFR	Instrument Flight Rules
LHD	Large Height Deviation
LoA	Letter of Agreement
MASPS	Minimum Aircraft System Performance Specification
MHz	Mega Hertz
NAT	North Atlantic
NDB	Non Directional Beacon
NLR	National Aerospace Laboratory
NM	Nautical Mile
OAG	Official Airline Guide
OB	Outside flight level Band
PISC	Pre Implementation Safety Case
RA	Resolution Advisory
RCF	Radio Communication Failure
RNAV	Area Navigation
RVSM	Reduced Vertical Separation Minimum
SAT	South Atlantic
SATMA	South Atlantic Monitoring Agency
TBD	To Be Defined
TLS	Target Level of Safety
UIR	Upper (Flight) Information region
VHF	Very High Frequency
VOR	Very high frequency Omni-directional Range
WC	Wrong level Crossing
WO	Wrong level Opposite
WS	Wrong level Same

Change record

Version	Issue date	Change description
0.8	230807	First issue for internal review (exclusive of TVE calculations).
0.9	290807	Processing of internal review comment. Inclusion of TVE calculations. Conclusions completed.
0.10	300807	Draft issue for ARMA
1.0	ddmmyy	Released issue.

Contents

(75 pages in total)

1 Introduction

This report presents a revised pre-implementation Collision Risk Assessment (CRA) for the implementation of a Reduced Vertical Separation Minimum, RVSM, in the Africa - Indian Ocean (AFI) Region. It supersedes the initial pre-implementation assessment of the vertical collision risk under RVSM in the AFI Region performed in 2005 and presented at the AFI RVSM TF/7 meeting in Dakar, 8-9 August 2005 (Refs. 1 and 2). The initial assessment showed that whilst the technical vertical collision risk under RVSM would meet the technical vertical Target Level of Safety (TLS) of $2.5 * 10^{-9}$ fatal accidents per flight hour, the total vertical collision risk would **not** meet the total vertical TLS of $5 * 10^{-9}$ fatal accidents per flight hour. On top of the latter result, it was concluded that the estimate of the total vertical collision risk was most likely affected by underreporting of large height deviations.

The findings of the initial CRA were subsequently presented at APIRG/15, 26-30 September 2005 (Ref. 3). With a view to a way ahead, the presentations emphasized the need for two steps to be taken:

- A reduction of the frequency and extent of incidents involving large height deviations; and
- An improvement of the incident reporting discipline.

The AFI RVSM programme recognised that implementation of the two steps would take some time and that a revised CRA would have to wait for the two steps to have become effective. It was concluded recently that a second CRA should be performed on the basis of data for the year 2006 where, in a similar manner as for the initial CRA, this data would comprise:

- Data collected by ARMA from States on a monthly basis; and
- Data collected by the AFI ATS Incident Analysis Working Group (AIAG).

The revised CRA has used essentially the same methods and models as the initial one. In this report, the pertinent collision risk models will simply be recalled from reference 1 to which the reader is referred for further details. Section 2 presents the assessment of the technical vertical collision risk and section 3 the assessment of the total vertical collision risk, i.e. the vertical collision risk due to all causes. Conclusions and recommendations are given in section 4. In accordance with the AFI RVSM Safety Policy (Ref. 4), the CRA results will form one of the major inputs to the AFI RVSM Pre Implementation Safety Case (PISC) (Ref. 5).

2 Assessment of technical vertical risk

2.1 Introduction

This section deals with the assessment of the technical vertical risk under RVSM in the AFI Region. Technical vertical risk represents the risk of a collision between aircraft on adjacent flight levels due to normal or typical height deviations of RVSM approved aircraft. In line with the AFI RVSM Safety Policy (Ref. 4), the technical vertical collision risk will be assessed against a technical TLS of 2.5×10^{-9} fatal accidents per flight hour using a suitable collision risk model. It should be remarked that a collision between two aircraft is counted as two accidents. Vertical collision risk due to other than typical aircraft height deviations will be examined in section 3.

Although the initial assessment showed that the technical vertical TLS was met, it has been decided to update also the technical vertical risk assessment taking into account the most recent information with respect to the planned RVSM operations in the AFI Region. For the technical vertical risk assessment, this concerns the aircraft population on the one hand and the traffic flows on the other. The aircraft population plays a part with regard to the overall Altimetry System Error (ASE) distribution, the lateral navigation accuracy, and the definition of average aircraft dimensions. Traffic flows (together with navigation accuracy) determine the exposure of the aircraft to the loss of vertical separation. All the information has been used to obtain revised estimates of the parameters of the collision risk model, where the model itself is the same as for the initial assessment.

Section 2.2 recalls the technical vertical collision risk model and its parameters. Revised estimates for the various model parameters are given in sections 2.3 – 2.6. Estimates of the technical vertical risk are then presented and compared with the TLS in section 2.7.

2.2 Collision risk model

Following reference 1, the vertical collision risk model for aircraft on adjacent flight levels of the <u>same route</u>, flying in either the <u>same</u> or the <u>opposite</u> direction is given by

$$N_{az} = 2P_z(S_z)P_y(0)\left[n_z(same)\left\{1+\frac{2\lambda_x}{2\lambda_y}\frac{\overline{|\dot{y}|}}{\overline{|\Delta V|}}+\frac{2\lambda_x}{2\lambda_z}\frac{\overline{|\dot{z}|}}{\overline{|\Delta V|}}\right\}+n_z(opp)\left\{1+\frac{2\lambda_x}{2\lambda_y}\frac{\overline{|\dot{y}|}}{2\overline{V}}+\frac{2\lambda_x}{2\lambda_z}\frac{\overline{|\dot{z}|}}{2\overline{V}}\right\}\right] \tag{2.1}$$

The left-hand side variable N_{az} represents the expected number of aircraft accidents due to normal technical height deviations of RVSM approved aircraft for the given traffic geometry.

All parameters in the model of eq. (2.1) are defined in table 2.1. The most important parameter is the probability of vertical overlap $P_z(S_z)$ with the vertical separation minimum S_z here being 1000 ft. The longitudinal overlap frequency parameters $n_z(same)$ and $n_z(opp)$ together with the kinematics factors in brackets (as functions of the relative speeds and aircraft dimensions) represent a major part of the different levels of exposure to the risk of the loss of vertical separation for the two traffic geometries covered by the collision risk model of eq. (2.1). (The subscript z in $n_z(same)$ and $n_z(opp)$ refers to aircraft on adjacent flight levels.)

Parameter	**Definition**
N_{az}	The expected number of fatal aircraft accidents per flight hour due to the loss of vertical separation
S_z	The vertical separation minimum
$P_z(S_z)$	The probability of vertical overlap for aircraft nominally flying on adjacent flight levels
$P_y(0)$	The probability of lateral overlap for aircraft nominally flying at the same route
$n_z(same)$	The frequency with which same direction aircraft on adjacent flight levels of the same route are in longitudinal overlap
$n_z(opp)$	The frequency with which opposite direction aircraft on adjacent flight levels of the same route are in longitudinal overlap
$\overline{\lvert\Delta V\rvert}$	The average of the absolute value of the relative along-track speed between two same direction aircraft flying at adjacent flight levels of the same route
$\overline{V}$	The average ground speed of a typical aircraft
$\overline{\lvert\dot{y}\rvert}$	The average of the absolute value of the relative cross-track speed between two typical aircraft flying at adjacent flight levels of the same route
$\overline{\lvert\dot{z}\rvert}$	The average of the absolute value of the relative vertical speed between two typical aircraft which have lost S_z feet of vertical separation
λ_x	The average length of a typical aircraft
λ_y	The average width of a typical aircraft
λ_z	The average height of a typical aircraft

Table 2.1 Definition of parameters of the vertical collision risk model of eq. (2.1)

Each of the terms within the accolades in eq. (2.1) represents one of the three ways in which a collision can originate, i.e. head/tail, sideways, or top/bottom for same direction traffic and similarly for opposite direction traffic. (Each term in fact equals the inverse of the ratio of the duration of an overlap in the pertinent dimension to the duration of a longitudinal overlap.)

The vertical collision risk model for aircraft on adjacent flight levels of two routes crossing at an angle θ and cylindrical aircraft models was expressed in reference 1 as

$$N_{az} = 2P_z(S_z)n_z(\theta)\left\{ 1 + \frac{\frac{\pi}{2}\lambda_{xy}}{2\lambda_z}\frac{\overline{|\dot{z}|}}{V_{rel}(\theta)} \right\} \tag{2.2}$$

where the relative speed $V_{rel}(\theta)$ is defined by

$$V_{rel}(\theta) = \overline{V}\sqrt{2(1-\cos\theta)} \tag{2.3}$$

The new parameters are defined in table 2.2. Notice that the lateral overlap probability $P_y(0)$ no longer appears explicitly in the model as it is effectively included within the crossing route frequency of horizontal overlap $n_z(\theta)$. Indeed, for crossing routes, it is more convenient to combine the head/tail and sideways collision directions into a combined horizontal direction The quantity $\frac{\pi}{2}\lambda_{xy}$ in eq. (2.2) represents the average length of a horizontal overlap between two typical aircraft on crossing routes as represented by cylinders with diameter λ_{xy}.

Parameter	**Definition**
θ	The angle of intersection between two routes
λ_{xy}	The average diameter of a standing cylinder representing a typical aircraft
$n_z(\theta)$	The frequency with which aircraft on adjacent flight levels of two routes intersecting at an angle of θ are in horizontal overlap
$V_{rel}(\theta)$	The average relative horizontal speed between aircraft flying at adjacent flight levels of two routes intersecting at an angle of θ

Table 2.2 Definition of additional parameters for vertical collision risk model of eq. (2.2)

For the case of n pairs of routes crossing at different angles $\theta_i, i = 1,...,n$, the collision risk model of eq. (2.2) was extended to

$$N_{az} = 2P_z(S_z)\sum_{i=1}^{n} n_z(\theta_i)\left\{1 + \frac{\frac{\pi}{2}\lambda_{xy}}{2\lambda_z}\frac{\overline{|\dot{z}|}}{V_{rel}(\theta_i)}\right\} \tag{2.4}$$

Combining the models in eqs. (2.1) and (2.4) gives the full technical vertical collision risk model for AFI RVSM:

$$N_{az} = 2P_z(S_z)P_y(0)\left[n_z(same)\left\{1 + \frac{2\lambda_{xy}}{2\lambda_{xy}}\frac{\overline{|\dot{y}|}}{|\Delta V|} + \frac{2\lambda_{xy}}{2\lambda_z}\frac{\overline{|\dot{z}|}}{|\Delta V|}\right\} + n_z(opp)\left\{1 + \frac{2\lambda_{xy}}{2\lambda_{xy}}\frac{\overline{|\dot{y}|}}{2\overline{V}} + \frac{2\lambda_{xy}}{2\lambda_z}\frac{\overline{|\dot{z}|}}{2\overline{V}}\right\}\right] + $$
$$+ 2P_z(S_z)\sum_{i=1}^{n} n_z(\theta_i)\left\{1 + \frac{\frac{\pi}{2}\lambda_{xy}}{V_{rel}(\theta_i)}\frac{\overline{|\dot{z}|}}{2\lambda_z}\right\} \tag{2.5}$$

Notice that for the same and opposite direction components the original aircraft length and width λ_x and λ_y have been replaced by a diameter λ_{xy}. The lateral overlap probability parameter $P_y(0)$ may be combined with the same direction and opposite direction longitudinal overlap frequencies $n_z(same)$ and $n_z(opp)$ respectively to give frequencies of horizontal overlap for these two traffic types (comparable to the horizontal overlap frequency $n_z(\theta_i)$ for crossing traffic).

Aside from $P_z(S_z)$, the impact of any opposite direction passing on the vertical collision risk is determined by the probability of lateral overlap $P_y(0)$ and the kinematic factor $\left\{1 + \overline{|\dot{y}|}/2\overline{V} + \lambda_{xy}/\lambda_z \times \overline{|\dot{z}|}/2\overline{V}\right\}$. Thus, any same direction passing event included in $n_z(same)$ and any crossing traffic passing included in $n_z(\theta_i)$ may be translated into an equivalent opposite direction passing by means of these two factors, i.e.

$$N_{az} = 2P_z(S_z)P_y(0)n_z(opp)\left\{1+\frac{\overline{|\dot{y}|}}{2\overline{V}}+\frac{\lambda_{xy}}{\lambda_z}\frac{\overline{|\dot{z}|}}{2\overline{V}}\right\}+$$

$$2P_z(S_z)P_y(0)n_z(same)\left\{1+\frac{\overline{|\dot{y}|}}{2\overline{V}}+\frac{\lambda_{xy}}{\lambda_z}\frac{\overline{|\dot{z}|}}{2\overline{V}}\right\}\frac{\left\{1+\frac{\overline{|\dot{y}|}}{\overline{\Delta V}}+\frac{\lambda_{xy}}{\lambda_z}\frac{\overline{|\dot{z}|}}{\overline{|\Delta V|}}\right\}}{\left\{1+\frac{\overline{|\dot{y}|}}{2\overline{V}}+\frac{\lambda_{xy}}{\lambda_z}\frac{\overline{|\dot{z}|}}{2\overline{V}}\right\}}+$$

$$2P_z(S_z)P_y(0)\frac{1}{P_y(0)}\sum_{i=1}^{n}n_z(\theta_i)\left\{1+\frac{\overline{|\dot{y}|}}{2\overline{V}}+\frac{\lambda_{xy}}{\lambda_z}\frac{\overline{|\dot{z}|}}{2\overline{V}}\right\}\frac{\left\{1+\frac{\frac{\pi}{2}\lambda_{xy}}{V_{rel}(\theta_i)}\frac{\overline{|\dot{z}|}}{2\lambda_z}\right\}}{\left\{1+\frac{\overline{|\dot{y}|}}{2\overline{V}}+\frac{\lambda_{xy}}{\lambda_z}\frac{\overline{|\dot{z}|}}{2\overline{V}}\right\}} \qquad (2.6)$$

or

$$N_{az} = 2P_z(S_z)P_y(0)\left\{n_z(opp)+n_z(same)\frac{\frac{\overline{|\dot{y}|}}{\overline{|\Delta V|}}+\frac{\lambda_{xy}}{\lambda_z}\frac{\overline{|\dot{z}|}}{\overline{\Delta V}}}{\left\{1+\frac{\overline{|\dot{y}|}}{2\overline{V}}+\frac{\lambda_{xy}}{\lambda_z}\frac{\overline{|\dot{z}|}}{2\overline{V}}\right\}}+\frac{1}{P_y(0)}\sum_{i=1}^{n}n_z(\theta_i)\frac{\left\{1+\frac{\frac{\pi}{2}\lambda_{xy}}{V_{rel}(\theta_i)}\frac{\overline{|\dot{z}|}}{2\lambda_z}\right\}}{\left\{1+\frac{\overline{|\dot{y}|}}{2\overline{V}}+\frac{\lambda_{xy}}{\lambda_z}\frac{\overline{|\dot{z}|}}{2\overline{V}}\right\}}\right\}\left\{1+\frac{\overline{|\dot{y}|}}{2\overline{V}}+\frac{\lambda_{xy}}{\lambda_z}\frac{\overline{|\dot{z}|}}{2\overline{V}}\right\} \qquad (2.7)$$

Defining

$$n_z(equiv) = n_z(opp)+n_z(same)\frac{\frac{\overline{|\dot{y}|}}{\overline{\Delta V}}+\frac{\lambda_{xy}}{\lambda_z}\frac{\overline{|\dot{z}|}}{\overline{|\Delta V|}}}{\left\{1+\frac{\overline{|\dot{y}|}}{2\overline{V}}+\frac{\lambda_{xy}}{\lambda_z}\frac{\overline{|\dot{z}|}}{2\overline{V}}\right\}}+\frac{1}{P_y(0)}\sum_{i=1}^{n}n_z(\theta_i)\frac{\left\{1+\frac{\frac{\pi}{2}\lambda_{xy}}{V_{rel}(\theta_i)}\frac{\overline{|\dot{z}|}}{2\lambda_z}\right\}}{\left\{1+\frac{\overline{|\dot{y}|}}{2\overline{V}}+\frac{\lambda_{xy}}{\lambda_z}\frac{\overline{|\dot{z}|}}{2\overline{V}}\right\}} \qquad (2.8)$$

eq. (2.7) can be written in the so-called equivalent opposite direction passing frequency form as

$$N_{az} = 2P_z(S_z)P_y(0)n_z(equiv)\left\{1+\frac{|\overline{\dot{y}}|}{2\overline{V}}+\frac{\lambda_{xy}}{\lambda_z}\frac{|\overline{\dot{z}}|}{2\overline{V}}\right\} \tag{2.9}$$

The last expression is precisely of the opposite direction traffic form, whereas numerically it takes account of all the different types of traffic geometries through the equivalent opposite direction passing frequency $n_z(equiv)$.

With the form of the vertical collision risk model specified by eqs. (2.8) and (2.9), it remains to update the estimates of the various parameters in the model. This will be addressed in the subsequent subsections, starting with the probability of vertical overlap $P_z(S_z)$ in section 2.3 and followed by passing frequency $n_z(equiv)$ in section 2.4. The remaining parameters, i.e. the probability of lateral overlap for aircraft on the same route, and average aircraft dimensions and relative speeds will be dealt with in sections 2.5 and 2.6.

2.3 Probability of vertical overlap

The probability of vertical overlap for aircraft flying at adjacent flight levels of the same route or intersecting routes is calculated from the probability distribution of normal or typical height-keeping deviations of RVSM approved aircraft. These aircraft height-keeping deviations are usually defined in terms of Total Vertical Error (TVE) (in geometric feet) with:

$$TVE = actual\ \ pressure\,altitude\ \ flown\,by\,an\,aircraft - assigned\ altitude \tag{2.10}$$

In the same manner as for the initial CRA, the components approach has been used to express TVE as the (statistically independent) sum of Altimetry System Error (ASE) and Flight Technical Error (FTE) or Assigned Altitude Deviation (AAD), i.e.

$$TVE = ASE + FTE \tag{2.11}$$

$$TVE \approx ASE + AAD \tag{2.12}$$

The error components ASE, FTE and AAD are defined by

$$ASE = actual\ \ pressure\,altitude\ \ flown\,by\,an\,aircraft - displayed\ altitude \tag{2.13}$$

$$FTE = displayed\ altitude - assigned\ altitude \tag{2.14}$$

and

$$AAD = transponded\ altitude - assigned\ altitude \tag{2.15}$$

Within the components approach, the TVE probability density follows from the ASE and AAD probability densities by means of the convolution integral

$$f^{TVE}(z) = \int_{-\infty}^{\infty} f^{ASE}(a)\, f^{AAD}(z-a)\,da \tag{2.16}$$

The key part of the calculation is formed by the overall ASE probability density $f^{ASE}(a)$ of the RVSM approved aircraft population expected to be operating in AFI RVSM airspace. Assuming that this population is made up of n_{MG} aircraft monitoring groups with ASE probability densities $f_i^{ASE}(a)$, $i = 1,...,n_{MG}$, the overall ASE probability density can be written as a weighted mixture of the ASE densities by monitoring group, i.e.

$$f^{ASE}(a) = \sum_{i=1}^{n_{MG}} \beta_i f_i^{ASE}(a) \tag{2.17}$$

where the weighting factors β_i, $i = 1,...,n_{MG}$, are the proportions of flight time contributed by monitoring group i.

The candidate AFI RVSM aircraft population and the corresponding flight time proportions β_i, $i = 1,...,n_{MG}$, have been reviewed and updated as set out in Appendix A.

The types and parameter values of the monitoring groups' ASE probability densities $f_i^{ASE}(a)$, $i = 1,..., n_{MG}$, have been reviewed and updated on the basis of the latest results of the European height monitoring programme (Ref. 6). See Appendix A for details of the review and the resulting overall ASE probability density $f^{ASE}(a)$. Recall that the use of European height monitoring data is based on the assumption that typical height-keeping performance of RVSM approved aircraft is not dependent on the region of operation of the aircraft.

The type of AAD probability density and the corresponding parameter value(s) have also been reviewed. It was decided to retain the model used for the initial CRA, i.e. a double exponential AAD probability density with a standard deviation of typical AAD of $\sigma_{AAD} = 39.8$ ft.

Figures 2.1 and 2.2 show the revised TVE probability density $f^{TVE}(z)$, plotted against a linear and a logarithmic scale respectively.

Figure 2.1 TVE probability density defined by eq. (2.16)

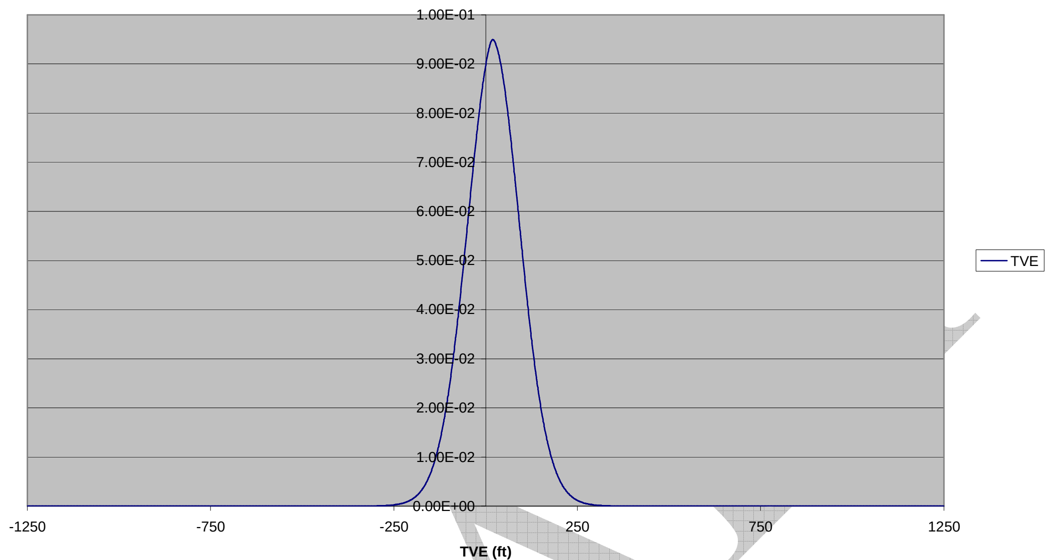
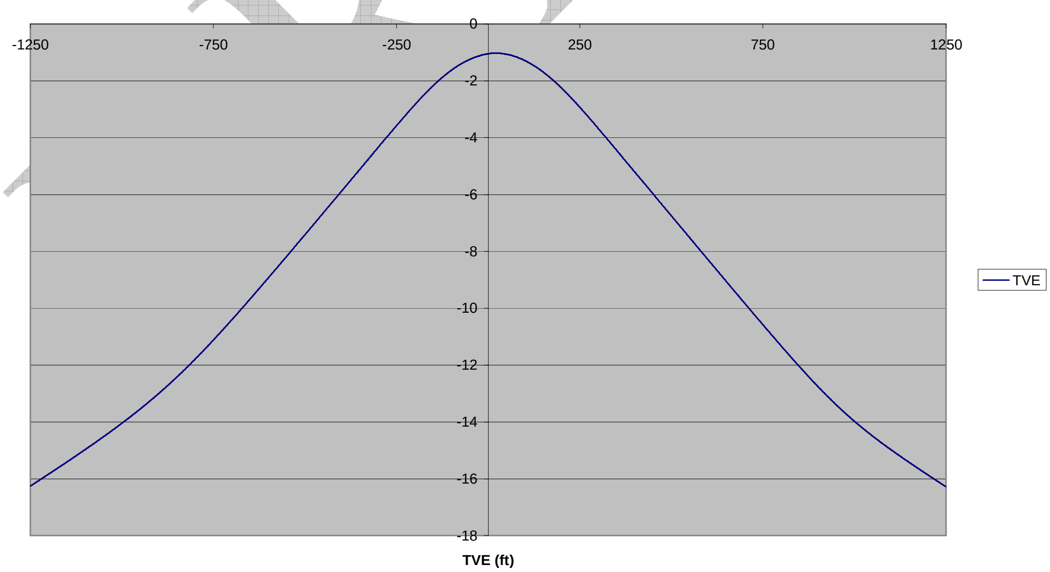


Figure 2.2 Logarithm (base 10) of TVE probability density defined by eq. (2.16)



The final step is to use the TVE probability density to calculate a revised estimate for the probability of vertical overlap for aircraft on adjacent flight levels separated by S_z by means of the formula

$$P_z(S_z) = \int_{-\lambda_z}^{\lambda_z} \int_{-\infty}^{\infty} f^{TVE}(z_1) f^{TVE}(S_z + z_1 - z) dz_1 dz \tag{2.18}$$

where $f^{TVE}(z)$ denotes the TVE probability of an aircraft given by eq. (2.16).

The probability of vertical overlap $P_z(1000)$ as calculated by means of eq. (2.18) was found to be

$$P_z(1000) = 1.0 \times 10^{-9} \tag{2.19}$$

This value is a factor of approximately 15 smaller than the value of 1.61 * 10^{-8} obtained in the initial CRA. As set out in Appendix A.4, the change in value is related to two factors, i.e. a new set of height monitoring data and the removal of a conservative analytical approximation in the process of combining within and between airframe ASE probability densities in favour of a numerical evaluation. New data sets tend to swell the estimate of the probability of vertical overlap whereas the removal of a conservative approximation reduces the estimate.

In addition to the technical TLS of 2.5×10^{-9} fatal accidents per flight hour which the collision risk estimate based on $P_z(1000)$ has to meet, the global system performance specification puts a direct constraint of 1.7×10^{-8} on the value of $P_z(1000)$ (Ref. 9). It is seen from eq. (2.19) that the current estimate of $P_z(1000)$ for the AFI RVSM aircraft population meets this constraint.

2.4 Passing frequency

2.4.1 Results

The distribution of the aircraft across the available flight levels of the route network in the AFI region determines the exposure to the risk due to the loss of vertical separation between aircraft on adjacent flight levels. This exposure is reflected in the frequencies of longitudinal and horizontal overlap, or passing frequencies, $n_z(same)$, $n_z(opp)$ and $n_z(\theta_i)$ in the collision risk model of eq. (2.5). Average values representative of AFI RVSM airspace are needed for each of these collision risk model parameters. To account for the fact that the exposure to the vertical collision risk varies greatly in space and time, the “RVSM Manual” (Ref. 9) dictates how the averaging should be performed. Based on the global system performance specification for RVSM, paragraph 6.2.13 of section 6, System Performance Monitoring, of reference 9 requires an assessment of the annual average passing frequency over the whole airspace of three adjacent area control centres (ACCs) covering the region’s busiest traffic flows or highest passing frequency. The use of these adjacent ACCs covering the highest passing frequency is to address the problem of high traffic flows where higher-than-average collision risk may pertain.

Ideally, the three different types of passing frequencies should be determined for each ACC in the AFI Region over a one year period and be used as a basis to identify the three busiest adjacent ACCs. Thus, as a part of the AFI RVSM programme, States in the AFI Region have been requested by ICAO State letter to provide monthly traffic flow data to the African Regional Monitoring Agency ARMA (Refs. 20, 21). Many, but not all, States have provided this data in one form or another. Prior to all the data being available, some judgement was applied to identify the three busiest adjacent ACCs by specifying the following four sets of adjacent States as candidates for the ultimate passing frequency calculations:

- Algeria, Libya, Egypt;
- Central African Republic, Nigeria, Egypt;
- Nigeria, Chad, Cameroon; and
- South Africa, Botswana, Democratic Republic of Congo (DRC)/Angola.

Each of the four sets provides a kind of east-west cross-section through the major north-south routes in the AFI Region. The associated FIR/UIRs are:

- Algiers, Tripoli, Cairo;
- Brazzaville/ N’Djamena, Kano, Cairo;
- Kano, N’Djamena, Brazzaville; and
- Johannesburg, Cape Town, Gaborone, Kinshasa/Luanda.

One more important aspect of the passing frequency estimation process needs to be mentioned before presenting some results. The traffic flow data has been collected in the AFI Region under the current conventional vertical separation minimum. Under RVSM, the traffic will be redistributed across the newly available flight levels and this leads, in principle, to fewer aircraft per flight level and, consequently, to lower passing frequency values. Since it is extremely difficult to forecast accurately how the traffic will reorganise, it will be assumed that the passing frequency values based on the current data are also applicable under AFI RVSM. This assumption, which is conservative, was also made in other RVSM safety assessments, see e.g. reference 22. To some extent, it may be taken as an (over) compensation for short term increases in traffic.

In accordance with the cruising levels (at or above FL290) currently in use in (most of) the FIR/UIRs in the AFI Region, no same direction passings between aircraft at adjacent flight levels were found, i.e. $n_z(same) = 0$ in the collision risk model of eqs. (2.8) and (2.9). Table 2.3 summarizes the opposite direction and equivalent opposite direction passing frequencies obtained from the ARMA Form 4 traffic flow data for the various FIR/UIRs. Details of the underlying calculations can be found in Appendix B. Recall that equivalent opposite direction passing frequency allows comparing the relative risk associated with an opposite direction passing and an aircraft passing on crossing tracks. For reference, the equivalent and opposite direction passing frequency values found in the initial CRA of reference 1 have also been included in the last two columns of table 2.3.

FIR/UIR	Revised CRA (CRA 2)		Initial CRA (CRA 1)	
	n_z(opp)	n_z(equiv)	n_z(equiv)	n_z(opp)
Accra	-	-	-	-
Addis Ababba	-	-	-	-
Algiers	0.1252	0.2105	0.1860	0.1280
Antananarivo	0.03485	0.04086	-	-
Asmara	-	-	-	-
Beira	0.1253	0.1314	-	-
Brazzaville	0.05006	0.05006	0.07876	0.06693
Cairo	0.02180	0.02601	-	-
Canarias	-	-	-	-
Cape Town	-	-	0.01114*	0.01114*
Casablanca	-	-	-	-
Dakar	-	-	-	-
Dakar Oceanic	-	-	-	-
Dar es Salaam	0.07099	0.1012	-	-
Entebbe	0.01515	0.03084	-	-
Gaborone	-	-	0.1981	0.1981
Harare	**	**	-	-
Johannesburg	-	-	0.01664	0.01594
Kano	0.1694	0.2233	0.2123	0.1470
Khartoum	-	-	-	-
Kinsasha	-	-	-	-
Lilongwe	-	-	-	-
Luanda	-	-	0.03856	0.01661
Lusaka	-	-	-	-

Mauritius	0.01690	0.01690	-	-
Mogadishu	0.03644	0.07294	-	-
Nairobi	-	-	-	-
N'Djamena	0.1125	0.1420	0.5802	0.5454
Niamey	-	-	-	-
Roberts	0.06018	0.06611	-	-
Sal Oceanic	-	-	-	-
Seychelles	0.01062	0.01062	-	-
Tripoli	-	-	-	-
Tunis	-	-	-	-
Windhoek	-	-	-	-

Table 2.3 Summary of passing frequency values for revised CRA and initial CRA

Remark *: Cape Town East only

Remark **: ARMA Form 4 traffic flow data provided in non-electronic form for 19 months

Notice that useful data for the passing frequency calculations was not obtained from 21 out of the 35 FIR/UIRs in the AFI Region. However, Canarias, Casablanca, Dakar Oceanic, Sal Oceanic, and Tunis are non-participating in the AFI RVSM Programme. Hence, effectively, ARMA Form 4 traffic flow data necessary for the passing frequency calculations was not received from 16 out of 30 participating FIR/UIRs.

Crossing traffic is seen to have a significant effect for most of the FIR/UIRs, particularly for Mogadishu, Algiers, and Dar es Salaam. In general, passing frequency increases with the amount of traffic and this seems to be in line with the increase in the equivalent opposite direction passing frequency for Algiers and Kano. For Brazzaville and N'Djamena, however, the estimates of equivalent opposite direction passing frequency have decreased significantly.
The reduction by a factor of approximately four for N'Djamena is the result of an increase in the calculated number of flight hours by a factor of approximately 1.4 together with a decrease in the calculated number of opposite direction passings by a factor of about 0.3, the combined effect being a reduction by a factor of approximately $1.4/0.3 \approx 4.67$. The reason for the decrease in the number of opposite direction passings is unknown.

As follows from table 2.3, the required traffic flow data had not been received from all the ACCs involved in the preliminary clusters of busiest ACCs at the time of drafting of this report. As a result, the intended averaging over the ACCs included in each cluster has only been applied to the ACCs for which data was available. In principle, averaging over fewer ACCs in a cluster tends to be conservative (less smoothing) unless the ACC(s) excluded from the averaging have the larger passing frequencies. Table 2.4 summarises the equivalent opposite direction passing frequencies for the four clusters specified above. The names of the ACCs for which no data was available have been put in brackets.

Cluster of busy ACCs	Equivalent opposite direction passing frequency values
Algiers, (Tripoli), Cairo	0.2105, 0.02601
Brazzaville/ N'Djamena, Kano, Cairo	0.05006/0.1420, 0.2233, 0.02601
Kano, N'Djamena, Brazzaville	0.2233, 0.1420, 0.05006
(Johannesburg), (Cape Town), Gaborone, (Kinshasa)/Luanda	0.1981*, 0.03856*

Table 2.4 Summary of equivalent opposite direction passing frequency values for four clusters of busy ACCs
Remark *: CRA 1 values

Based on the available data and the resulting values in table 2.4, it follows that the three busiest adjacent ACCs are Kano, N'Djamena and Brazzaville. Thus, the overall value that will be used for the vertical collision risk assessment for the AFI Region is a (weighted) average across these three ACCs, i.e.

$$n_z^{AFI}(equiv) = w_1 \times n_z(equiv)_{Kano} + w_2 \times n_z(equiv)_{N'Djamena} + w_3 \times n_z(equiv)_{Brazzaville} \qquad (2.20)$$

where the weighting factors w_1, w_2 and w_3 are the proportions of annual flying time ($\approx 0.17, 0.48$ and 0.35) in the respective FIR/UIRs. Substitution of the various parameter values finally gives

$$n_z^{AFI}(equiv) = 0.1241 \qquad (2.21)$$

This value is approximately a factor of three smaller than the one obtained for the initial CRA. The main reason for the lower value is the much smaller equivalent opposite direction passing frequency for N'Djamena, i.e. 0.1420 rather than 0.5802, cf. table 2.3. The value for the Kano, N'Djamena, Brazzaville cluster is approximately 14% larger than the next largest value of

0.1090 for the Algiers and Cairo cluster. The values for the remaining two clusters are approximately 0.05.

2.4.2 Summary of Data limitations

It should be clear that in order to produce a representative pre-implementation estimate of the technical vertical collision risk in AFI RVSM airspace, it is necessary to collect data on all flights currently operating on all routes in the flight level band FL290 to FL410 inclusive. This data is needed to estimate the number of flying hours in the band FL290 - FL410 on the one hand and the number of horizontal passing events (of each of the different types) on the other. The collection is done via ARMA Form 2 (monthly movements) and ARMA Form 4 (traffic flow data). Provided the information in ARMA Form 4 is complete, flying time can be derived from it and can be cross-checked against the flying time reported in ARMA Form 2.

A key element of the traffic flow data information in ARMA Form 4 is the actual flight progress information, i.e. waypoint identification, reporting time at waypoint, and FL at waypoint. It should be clear that even for a single route segment bounded by a waypoint at either side, the reporting times at both waypoints are needed to determine whether a (longitudinal) passing has occurred between two aircraft flying at adjacent flight levels, independent of their flying in the same or opposite direction. More generally, to be able to handle all possible route configurations, the flight progress information at all the waypoints along an aircraft's flight path through a FIR/UIR is required.

Data has only been received from a limited number of FIR/UIRs. For 13 FIR/UIRs, the quality of the data was such that the passing frequency and aircraft population could be determined. In total, 121 months worth of data have been processed. The quality of the submitted information varied strongly. Specifics on the determination of the passing frequency are given in Appendix B (sections B.1 and B.2). Section B.2, in particular, lists per FIR/UIR all the limitations of the data. In Appendix A (sections A.2 and A.3), more details are given concerning the determination of the aircraft population.

Figure 2.3 below illustrates the amount of data received from each State. The blue colour indicates that more than 8 months worth of data from the year 2006 could be processed. Pink indicates those States for which some data was received, but less than 8 months from the year 2006. Grey indicates that no information was received or could be processed. It should be noted that this map is used for illustration purposes only. The borders represent States' borders rather than FIR/UIR borders.

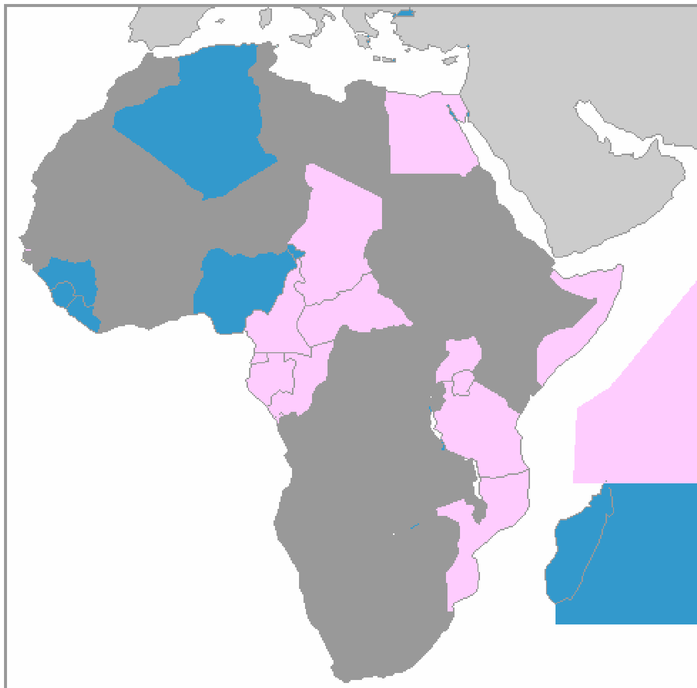


Figure 2.3 Summary of available data.
Blue means more than 8 months of information for 2006. Pink means some information, but less than 8 months. Grey means no information was submitted or could be processed.

Based on the available data, a total of 368,424 flight hours for the AFI region has been estimated for the year 2006. This is a very limited set. The total flight hours in Johannesburg and Cape Town FIR (not included in this set) in the RVSM band for 2006 is estimated to be 372,000 hours. Furthermore, in the initial CRA report (Ref. 1), it has been estimated that in 2003 there have been 1,108,000 scheduled flights in the AFI region. It must be concluded that the available set of information represents only a fraction of all flights in the AFI region.

2.5 Probability of lateral overlap

Lateral navigation accuracy has an essential influence on the likelihood of a collision between two aircraft once vertical separation has been lost. This influence is expressed as the probability of lateral overlap for aircraft nominally flying on (adjacent flight levels of) the same route, $P_y(0)$, and is defined by

$$P_y(0) = \int_{-\lambda_y}^{\lambda_y} \int_{-\infty}^{\infty} f_Y(y_1) f_Y(y_1 - y) dy_1 dy \qquad (2.22)$$

where λ_y denotes the average width of the aircraft (cf. table 2.1) and $f_Y(y)$ denotes the probability density of the lateral deviations from track centre line. The probability density $f_Y(y)$ is dependent on the type of navigation equipment being used in the airspace under consideration. To quantify $P_y(0)$, the same approach has been followed as for the initial CRA.

The approach followed was to assume that a proportion α, $0 \le \alpha \le 1$, of the AFI RVSM airspace users is using GNSS navigation and that the remaining proportion $1-\alpha$ is using VOR/DME navigation. The following mixture distribution was then specified

$$f_Y(y) = (1-\alpha)\frac{1}{\sigma_{VOR/DME}\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{y}{\sigma_{VOR/DME}}\right)^2} + \alpha\frac{1}{\sigma_{GNSS}\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{y}{\sigma_{GNSS}}\right)^2} \quad (2.23)$$

with

$$\sigma_{VOR/DME} = 0.3NM \quad (2.24)$$

$$\sigma_{GNSS} = 0.06123NM \quad (2.25)$$

and used to calculate the probability of lateral overlap as a function of the proportion α of the AFI RVSM airspace users using GNSS navigation. Table 2.5 below has been reproduced from reference 1.

Proportion α of GNSS flying time	**$P_y(0)$**
0	0.0491
0.05	0.0513
0.1	0.0544
0.2	0.0627
0.25	0.0679
0.5	0.106
0.75	0.162
1	0.237

Table 2.5 The probability of lateral overlap, $P_y(0)$, as a function of the proportion α of GNSS flying time

The initial CRA used a value of $\alpha = 0.5$ for the proportion of GNSS flying time. At the time, this value was judged to be slightly conservative. Following the presentation of the initial CRA at the AFI RVSM TF/7 meeting in Dakar, August 2005, it was suggested to assume that the full aircraft population would be using GNSS and to take $\alpha = 1.0$ correspondingly. This suggestion, however, is believed to be overly optimistic and it has been decided to use the same value of $\alpha = 0.5$ for the proportion of GNSS flying time as in the initial CRA.

$P_y(0)$ multiplied by $n_z(equiv)$ determines the exposure to the risk of collision due to the loss of vertical separation. When the aircraft height-keeping performance just meets the limit value of $P_z(1000) = 1.7 \times 10^{-8}$, the exposure needs to be less than $0.058 \times 2.5 = 0.145$ to be able to meet the technical vertical TLS of 2.5×10^{-9} fatal accidents per flight hour. This global upper bound of 0.145, applied to the local value of $P_y(0) = 0.106$, gives a local upper bound of only 1.36 for the (equivalent) opposite direction passing frequency for RVSM in the AFI Region. This is a direct consequence of the product of passing frequency and probability of lateral overlap being constrained by the global system performance specification. Put simply, the better the lateral navigation accuracy the fewer passings are allowed.

A means to reduce the increase in the probability of lateral overlap $P_y(0)$ due to very accurate GNSS based navigation is the use of lateral offsets under certain conditions as set out in an ICAO State letter (Ref. 10). To be able to take the risk mitigating effect of lateral offsets on $P_y(0)$ into account, it needs to be known to what extent the offsets are actually used in practice. Since this knowledge is currently unavailable, the beneficial effects of lateral offsets have not been taken into account in this report.

2.6 Aircraft dimensions and relative speeds

2.6.1 Relative speeds

The vertical collision risk model of eqs. (2.8) and (2.9) contains four basic relative speed parameters, $2|V|$, $|\Delta V|$, $|\dot{y}|$ and $|\dot{z}|$. A revised estimate of the average aircraft speed has been calculated in Appendix A as $\overline{V} = 464$ kts, i.e. 2kts smaller than the value of 466 kts used in the initial CRA. The other relative speed parameter values have not been revised since no data directly from AFI RVSM airspace was available. Thus the following intial values have been retained: $\overline{|\Delta V|} = 20$ kts, $\overline{|\dot{y}|} = 20$ kts, and $\overline{|\dot{z}|} = 1.5$ kts.

2.6.2 Aircraft dimensions

Revised weighted average aircraft dimensions have been calculated as described in Appendix A. The resulting dimensions for a typical aircraft in AFI RVSM airspace are shown in Table 2.6. Notice that the revised values are virtually the same as the initial values. The values for the AFI region are larger than those for the EUR Region and smaller than those for the NAT Region (see reference 1, table 3.18).

Aircraft dimension	Parameter	Value (ft)		Value (NM)	
		Initial CRA	Revised CRA	Initial CRA	Revised CRA
Length	λ_x	168.72	173.51	0.02777	0.02856
Width	λ_y	158.71	163.35	0.02612	0.02689
Height	λ_z	49.25	51.07	0.008106	0.008404
Diameter	λ_{xy}	168.72	173.51	0.02777	0.02856

Table 2.6 Typical aircraft dimensions for AFI Region

2.7 Technical vertical risk

Recall the technical vertical collision risk model specified in eq. (2.8) of section 2.2, i.e.

$$N_{az} = 2P_z(S_z)P_y(0)n_z(equiv)\left\{1+\frac{\overline{|\dot{y}|}}{2\overline{V}}+\frac{\lambda_{xy}}{\lambda_z}\frac{\overline{|\dot{z}|}}{2\overline{V}}\right\} \qquad (2.9)$$

Table 2.7 summarises the main parameter estimates for this model. Substitution of these values into eq. (2.9) gives

$$N_{az} = 2\times 1.0\times 10^{-9}\times 0.106\times 0.1241\times 1.0270 = 2.70\times 10^{-11} \qquad (2.26)$$

This risk estimate is expressed in fatal accidents per flight hour and is to be compared with the technical vertical TLS of 2.5×10^{-9} fatal accidents per flight hour. It can be concluded that the technical vertical TLS is met. Moreover, it is being met with a factor of approximately 90. The significant reduction in the current estimate of 2.7×10^{-11} compared with the estimate of 1.35×10^{-9} obtained for the initial CRA is due to two factor mentioned in sections 2.3 and 2.4, i.e. a reduction in the probability of vertical overlap by a factor of approximately 15 and a reduction in the average passing frequency for the AFI Region by a factor of approximately three. Notice that the same value of 0.106 was used for the probability of lateral overlap in the initial and revised CRAs, based on a 50% GNSS flight time contribution.

The margin between the technical TLS and the current estimate of the technical risk needs to be considered in the context of several uncertainties like the data limitations summarised in section 2.4.2, the proportion of GNSS navigation and increases in traffic volume. The effect of the proportion of GNSS navigation can easily be quantified, see table 2.5 and would be a factor of approximately two when nearly all aircraft would be using GNSS navigation. In first approximation, passing frequency growth proportionally to traffic volume. For example, a 5% annual traffic growth over ten years would, in first approximation, lead to a 60% increase in passing frequency. The uncertainty associated with the data limitations is rather difficult to quantify but is not believed to be an order of magnitude. Moreover, there will be some reduction in passing frequency due to the redistribution of the traffic over the additional RVSM flight levels. Finally, the proper use of the Strategic Lateral Offset Procedure under RVSM would counteract the adverse effect on the vertical risk of GNSS navigation accuracy. Thus, the current margin is deemed to be sufficient to cover the effect of the data limitations from section 2.4.2 and the other uncertainties..

Parameter	**Value**
S_z	1000
$P_z(S_z)$	1.0×10^{-9}
$P_y(0)$	0.106
$n_z(equiv)$	0.1241
$\left\{1+\frac{\overline{\lvert\dot{y}\rvert}}{2\bar{V}}+\frac{\lambda_{xy}}{\lambda_z}\frac{\overline{\lvert\dot{z}\rvert}}{2\bar{V}}\right\}$	1.0270

Table 2.7 Summary of parameter values for vertical collision risk model of eq. (2.9)

3 Assessment of total vertical risk

3.1 Introduction

Section 2 dealt with the assessment of the technical vertical collision risk under RVSM in the AFI Region. There may exist additional causes of vertical collision risk, however, and the combined effect of all these potential causes and the normal technical cause is to be assessed against the total vertical TLS of 5×10^{-9} fatal accidents per flight hour. Suitable collision risk models for the risk due to all the additional causes developed for the initial CRA have been re-used for the current CRA.

Section 3.2 recalls the pertinent models. This is followed by a detailed examination of the data available for the revised CRA in section 3.3. Data on large atypical height deviations in the current 2000 ft CVSM environment between FL290 and FL410 inclusive have been obtained via ARMA from the African States and from IATA. Based on the nature of the underlying events, it will be assumed that similar events could occur equally well in a 1000 ft RVSM environment. Finally, section 3.4 will present estimates of the total vertical collision risk under AFI RVSM.

3.2 Total vertical collision risk models

In the same manner as for the initial CRA, incident data will be used to estimate the vertical collision risk due to causes other than the normal typical height-deviations of RVSM approved aircraft. The following broad categories of potential causes of total vertical collision risk have been distinguished in reference 1:

- ATC error;
- Pilot error;
- ACAS;
- Non-RVSM approved aircraft;
- Equipment failure;
- Turbulence/weather;
- Unknown civil aircraft;
- Unknown military aircraft operating outside designated military areas; and
- Aircraft contingency events.

Each category may be subdivided further dependent on the specific nature of the error or problem. From a collision risk assessment point of view, the importance of these causes is that they may lead to large or atypical height deviations of 300 ft or more, say. It is essentially the vertical risk due to this type of height deviations that is to be modelled for comparison with the total vertical TLS of 5×10^{-9} fatal accidents per flight hour.

The resulting height deviations have been classified into

- large height deviations involving whole numbers of flight levels; and
- large height deviations not involving whole numbers of flight levels.

For example, an ATC error in issuing a clearance may lead to an aircraft levelling off at a wrong flight level leading to two types of risk. Firstly, it may lead to a risk for any aircraft that may already correctly be flying at that level. Secondly, on its way towards the wrong flight level, the pertinent aircraft may have traversed through one or more intermediate flight levels. As another example, ATC misjudging the climb speed of an aircraft may lead to the aircraft passing through another aircraft's flight level too late. From a risk point of view, this is very similar to passing through a level without a proper clearance.

A pilot error in following a correct ATC clearance may also lead to a large height deviation of the whole number of flight levels type. On the other hand, a level bust is an example of a pilot error not involving a whole number of flight levels. It involves an overshoot over a certain short period of time after which the aircraft levels off correctly at the intended flight level.

Height deviations due to ACAS do not normally involve whole numbers of flight levels but may be much larger than an aircraft's typical height deviations. Height deviations of non-RVSM approved aircraft will generally not involve whole numbers of flight levels either but may be expected to have a larger probability of relatively large height deviations, larger than 300 ft, say. Height deviations due to equipment failure, turbulence or other adverse weather conditions will also generally lead to large height deviations not involving whole numbers of flight levels.

Unknown civil or military aircraft operating at an AFI RVSM flight level involve by definition height deviations of the whole number of flight levels type as they should simply not be flying where they are. When such aircraft also happen to be non-RVSM approved, they may also cause the other type of large height deviation. Aircraft contingency procedures should be designed in such a way that they do not involve any significant risk when executed properly. Due to the nature of the situation, however, it may occasionally not be possible to fully comply with the procedure as a result of which one or more flight levels may be crossed without a proper clearance before levelling off at a new level.

Following reference 1, three sub-models will be used for:

- Large height deviations not involving whole numbers of flight levels;
- Aircraft climbing or descending through a flight level; and

- Aircraft levelling off at a wrong level.

The last two cases concern large height deviations involving whole numbers of flight levels.

The vertical collision risk due to large height deviations not involving whole numbers of flight levels can be modelled in the same way as the technical vertical collision risk, i.e.

$$N_{az}^{*} = 2P_z(S_z)^{*}P_y(0)n_z(equiv)\left\{1+\frac{\overline{|\dot{y}|}}{2\overline{V}}+\frac{\lambda_{xy}}{\lambda_z}\frac{\overline{|\dot{z}|}}{2\overline{V}}\right\} \tag{3.1}$$

A superscript "*" is used to distinguish this type of vertical risk from the technical vertical collision risk. The probability of vertical overlap $P_z(S_z)^{*}$ can be calculated by means of eqs. (2.16) and (2.18). The AAD probability density $f^{AAD}(a)$ would be taken of the form of eq. (4.1) of reference 1[1] and the ASE probability density is given by eq. (2.17) of section 2 of this report.

The conventional vertical collision risk model for aircraft climbing or descending through a flight level is given by:

$$N_{az}^{cl/d} = 2P_z(S_z)^{cl/d}P_y(0)n_z(equiv)\left\{1+\frac{\overline{|\dot{y}|}}{2\overline{V}}+\frac{\lambda_{xy}}{\lambda_z}\frac{\overline{|\dot{z}|}}{2\overline{V}}\right\} \tag{3.2}$$

where the superscript "cl/d" refers to an aircraft climbing or descending through a flight level without a proper clearance and $P_z(S_z)^{cl/d}$ is given by

$$P_z(S_z)^{cl/d} = \frac{n^{cl/d}\times 2\lambda_z/\overline{|\dot{z}_c|}}{T} \tag{3.3}$$

The new parameters are defined in table 3.1. Information on the number of incorrect flight level crossings and the pertinent vertical speeds is to be obtained from the incident reports. When no information on the vertical speed is included in a particular report, a default value will have to be used. Default values for a number of cases are given in references 11 and 12, for example, 20 kts and 15 kts respectively for a normal climb/descent. Both references specify a value of 50 kts in case of pressurisation failure, and 2 – 5 kts for engine failures. Since the probability of vertical overlap in eq. (3.3) is inversely proportional to the vertical speed, a value of 15 kts will

[1] The model of eq. (3.1) for large height deviations not involving whole numbers of flight levels is included for completeness, but will not actually be used, see section 3.3.2.

be used for normal climb/descents when specific information is missing in the incident report. The common reference 11 and 12 values will be used for the other cases, where the distinction between 2 kts and 5 kts depends on the aircraft being triple (or more) engined or twin engined.

Parameter	Definition
$N_{az}^{cl/d}$	Expected number of fatal aircraft accidents per flight hour due to aircraft climbing or descending through a flight level without a proper clearance
$P_z(S_z)^{cl/d}$	Probability of vertical overlap due to aircraft climbing or descending through a flight level without a proper clearance
$n^{cl/d}$	Number of aircraft climbing or descending through a flight level without a proper clearance during a period of time with T flying hours
$\overline{\lvert \dot{z}_c \rvert}$	Average climb or descent rate for aircraft climbing or descending through a flight level without a proper clearance
T	Amount of flying time during the period of time the incident data were collected

Table 3.1 Definition of additional parameters of the vertical collision risk model of eq. (3.2)

Finally, the conventional vertical collision risk model for aircraft levelling off at a wrong flight level is given by

$$N_{az}^{wl} = 2P_z(S_z)^{wl} P_y(0) n_z(equiv) \left\{ 1 + \frac{\overline{|\dot{y}|}}{2\overline{V}} + \frac{\lambda_{xy}}{\lambda_z} \frac{\overline{|\dot{z}|}}{2\overline{V}} \right\} \tag{3.4}$$

where the superscript "wl" refers to levelling off at a wrong level and $P_z(S_z)^{wl}$ is given by

$$P_z(S_z)^{wl} = \frac{P_z(0) \times n^{wl} \times \bar{t}^{wl}}{T} \tag{3.5}$$

The additional new collision risk model parameters are defined in table 3.2. Not surprisingly, the number of times an aircraft levels off at a wrong level and the average duration of its stay at the wrong level are a part of the probability of vertical overlap for this particular type of event. Information on these two parameters is to be obtained from the incident reports. The probability of vertical overlap $P_z(0)$ accounts for the normal technical height deviations of aircraft that, in this case, are flying at the same flight level after the incorrect levelling off. $P_z(0)$ can be calculated in a similar manner as the probabilities of vertical overlap $P_z(S_z)$ or $P_z(S_z)^*$ due to technical or large height deviations by putting $S_z = 0$ in the pertinent formulae.

Parameter	Definition
N_{az}^{wl}	Expected number of fatal aircraft accidents per flight hour due to aircraft levelling off at a wrong flight level
$P_z(S_z)^{wl}$	Probability of vertical overlap due to aircraft levelling off at a wrong flight level
$P_z(0)$	Probability of vertical overlap for aircraft nominally flying at the same flight level
n^{wl}	Number of aircraft levelling off at a wrong flight level during a period of time with T flying hours
$\bar{t}^{wl}$	Average sojourn time (hours) of an aircraft at a wrong flight level after incorrectly levelling off

Table 3.2 Definition of additional parameters of the vertical collision risk model of eq. (3.5)

Each of the three collision risk models of eqs. (3.1), (3.2) and (3.4) might, in principle, be extended with some intervention factor. This has not been done as AFI RVSM airspace is essentially procedurally controlled airspace and the risk mitigating effect of ACAS (and IFBP) as a safety net is not allowed to be accounted for in collision risk assessment (Ref. 13).

3.3 Data

3.3.1 Introduction

This subsection examines the data from the current 2000 ft vertical separation minimum environment that were available for the assessment of the total vertical collision risk under AFI RVSM. Data collected by ARMA from States in the monthly forms will be presented first, i.e. Form 1, large height deviations. Following that, some data from the AFI ATS Incident Analysis Working Group (AIAG) will be presented and analysed. It will be argued that only the AIAG data is useable for the assessment of the total vertical collision risk under AFI RVSM.

An important issue with regard to the data is whether or not it is affected by under-reporting. The fact that a State may not be reporting any large height deviations or reports precisely zero deviations over a certain period of time does not necessarily mean that the true rate of occurrence of large height deviations is zero, cf. references 14 and 15.

As regards the type of data, data on the occurrence frequency of each type of cause is needed in the first place. Secondly, the data needed on the resulting effects is dependent on the type of large height deviation. For large height deviations involving whole numbers of flight levels, the numbers of flight levels crossed without proper clearance at what vertical speed are needed and also the time spent at a resulting incorrect flight level. For large height deviations not involving whole numbers of flight levels, the magnitude and duration of the deviations are needed.

3.3.2 ARMA Form 1 – large height deviations

Recall that Form 1 is to be used for the reporting of **all** height deviations of 300 ft or more on the basis of conclusion 3/4 of the RVSM/RNAV/RNP/TF/3 meeting (Ref. 16). Where applicable, this data should be collected by radar (conclusion 3/13 of the same meeting) and otherwise by the institution of suitable procedures for reporting data, incidents and conditions necessary for the vertical collision risk assessment.

Only two events have been reported to ARMA by the African States in Form 1 over the period June 2005 – December 2006 as is illustrated in table 3.3. The two reports from the Nairobi FIR concerned certain co-ordination issues between the Nairobi and Khartoum FIRs and have been concluded not to concern operational errors relevant to the CRA.

Based on table 3.3, it is hypothesized that there exists a serious problem of under-reporting by States. For example, the zero number of large height deviations is not consistent with the number of pilot reported incidents in the AIAG data set for the AFI Region to be examined in section 3.3.3. It does not seem to be consistent with the experience from other ICAO Regions such as the NAT either (Ref. 17).

FIR/UIR	**Underlying Countries**	**Deviations reported**	
		2005	**2006**
		June - Dec	**Jan - Dec**
Accra	Ghana / Togo / Benin	0	0
Addis Abbaba	Ethiopia/Djibouti	0	0
Algeria	Algeria	0	0
Anthanarivo	Madagascar/Comores	0	0
Asmara	Eritrea	0	0
Beira	Mozambique	0	0

Brazzaville	Cameroon/Congo ASECNA/E_Guinea/Gabon/CAR/Sao Tome	0	0
Cairo	Egypt	0	0
Cape Town	Republic of South Africa	0	0
Dakar	Mauritania/Mali/The Gambia/ Ivory Coast/Guinea Bissau/Senegal	0	0
Dar Es Salaam	Tanzania / Rwanda / Burundi	0	0
Entebbe	Uganda	0	0
Gaborone	Botswana	0	0
Harare	Zimbabwe	0	0
Johannesburg	Republic of South Africa/Lesotho/Swaziland	0	0
Kano	Nigeria	0	0
Khartoum	Sudan	0	0
Kinshasa	Democratic republic of Congo	0	0
Lilongwe	Malawi	0	0
Luanda	Angola	0	0
Lusaka	Zambia	0	0
Mauritius	Mauritius	0	0
Mogadishu	Somalia	0	0
Nairobi	Kenya	2	0
Niamey	Niger Niamey/Burkina Faso/Mali	0	0
N'Djamena	Cameroon/Chad ASECNA/Car	0	0
Roberts	Liberia/Guinea/Sierra Leone	0	0
Seychelles	Seychelles	0	0
Tripoli	Libya	0	0
Windhoek	Namibia	0	0
Canarias	Canary Island	0	0
Casablanca	Morocco	0	0
Sal Oceanic	Cape Verde	0	0
Tunis	Tunisia	0	0

Table 3.3 Summary of height deviations reported in ARMA Form 1

Remark: The last four FIR/UIRs are non-participating in the AFI RVSM Programme

By comparison, table 4.1 of reference 1 showed that for the initial CRA a number of 31 height deviations had been reported by the African States for the period September 2004 to May 2005 inclusive. Twenty-four deviations were equal to 100 ft or 200 ft and were classified as representing typical performance. The remaining seven deviations were classified as large height deviations. One of these deviations occurred during an emergency descent and was further classified as of the "whole numbers of flight levels" type. The other six large height deviations were of the "not involving whole numbers of flight levels" type and were shown to have a dramatic impact on the probability distributions of AAD and TVE and hence on the safety of RVSM operations due to their size and magnitude (see table 4.20 in reference 1).

It was noted in reference 1 that the identification and elimination of the causes of those large height deviations was fundamental to the safety of RVSM in the AFI Region. Thus, the question arises as to what extent this has actually happened or, in other words, to what extent is the seven older data still representative of the AFI upper airspace in 2006 and beyond. Table 3.3 might suggest that the older data is not representative anymore. However, as noted above, the nil reported height deviations but two in table 3.3 are suspect. On the other hand, based on APIRG/15 conclusion 15/51, it might be speculated that measures have been taken to prevent the (re-)occurrence of the above type of large height deviations.

Taking all factors into account, the position taken here is that the older data should not be considered representative for the revised CRA. The implication of this in conjunction with table 3.3 is that the component of the total vertical collision risk due to large height deviations not involving whole numbers of flight levels will be taken as zero for the revised CRA. **This implication should be kept in mind in the final judgement of the estimate of the total vertical risk as compared with the total TLS.**

It follows from the above that an additional source of data on incidents/large height deviations is needed for the CRA. This source will be the AFI ATS Incident Analysis Working Group (AIAG) data to be presented below in section 3.3.3.

3.3.3 AFI ATS Incident Analysis Working Group (AIAG) data

3.3.3.1 The incident data

Airmiss queries for the year 2006 have been made available by ARMA and IATA (Refs. 18 and 19). The queries concerned various phases of flight and types of airspace and were numbered from 795-907. The first event queried occurred on 6 January 2006 and the last event occurred on 29 December 2006. A total of 17 queries are currently missing from the series of 113 events, most likely due to some delay in processing. Some of the missing queries may pertain to the year 2005 and will be excluded on that basis once they will have become available. In addition, some other queries concerning events that occurred late in the year 2006 may be missing. The missing-queries issue is currently being followed up by ARMA and IATA. It is not certain that this issue can be resolved before the completion of this report. **Hence, the possibility of some missing airmiss queries needs to be kept in mind when judging the final estimate of the total vertical risk in comparison with the total TLS.** A total number of 32 queries pertained to events that occurred outside of the FL290-FL410 band, leaving 64 events to be further processed.

The available airmiss queries concerning vertical events will be seen not to cover all the FIR/UIRs in the AFI Region (see section 3.2.3.3, table 3.8), and **there may be some concern as to the completeness and representation of this operational incident data.**

In a similar manner as for the initial CRA, the airmiss queries have been classified into a number of categories as shown in table 3.4. The first six categories concern "vertical events". The "crossing through FL" category should be self-explanatory. For the "wrong FL" category, the incorrectness of the flight level was inferred from the airmiss query and the applicable cruising levels.

There are two "horizontal categories". The first category, coded H, concerns aircraft at the same flight level of intersecting tracks. When the flight directions were in conformity with the applicable cruising levels, it was assumed that the aircraft were to be horizontally separated at the intersection unless the airmiss query indicated that the aircraft had actually been intended to be vertically separated at the intersection (in which case the classification WC was applied). Two examples of the latter are the airmiss queries no 876 and no 894. The second "horizontal" category, coded H(SFL), concerns pairs of in-trail aircraft on the same flight path where the actual longitudinal separation was less than the applicable longitudinal separation minimum.

Event type	Event Code
Crossing through FL, opposite direction	CO
Crossing through FL, same direction	CS
Crossing through FL, intersecting routes	CC
Wrong FL, opposite direction	WO
Wrong FL, crossing traffic	WC
Joining wrong FL, same direction	WS
Horizontal (intersecting routes)	H
Horizontal (same route, following another a/c)	H(SFL)
Other	Various

Table 3.4 Event types and coding

Table 3.5 provides the results of the classification applied to the 64 airmiss queries, namely 27 vertical events, 35 horizontal events and two other events. One of the two other events, airmiss query no 828, was concluded not to involve a loss of separation and the second one, airmiss query no 861, was found to involve a flight efficiency issue rather than a separation issue.

Table 3.5 also lists some additional information, particularly with respect to ACAS and IFBP. The last column in table 3.5 is based on the information provided in the pertinent field of the airmiss query forms and suggests that ACAS was in use in 35 out of 64 events. The other information in the forms suggests that ACAS was in use in at least 7 more events. (This information sometimes contradicts a “No” in the TCAS field.) Similarly, the last column but one of table 3.5 suggests that IFBP was in use for 28 out of the 64 events whereas the other information indicated that IFBP was in use (at least by the reporting airline) in 12 more events at least. (Empty cells indicate that no information was provided in the airmiss query report.)

Specifically for the vertical events, the numbers on the use of ACAS and IFBP are 18 (23)[2] and 8 (13) out of 28 events respectively. The corresponding percentages of 64.3% (82.1%) and 28.6.0% (46.4%) are rather different from those found in the initial CRA, namely 90.5% (19/21*100%) and 23.8% (5/21*100%). The reason for the differences is not known at the moment.

The airmiss queries no 830, 845, and 905 concern events that occurred in the EUR/SAM corridor. They have been excluded from further processing for the AFI RVSM CRA since they are to be included in the annual RVSM CRA conducted by SATMA for the EUR/SAM corridor.

Reference	**Event code**	**Phase of flight**	**Type of airspace**	**IFBP use**	**ACAS**
813	CO	Cruise	FIR	No	Yes
823	CC	Cruise	FIR	Yes	Yes
826	WC	Cruise	FIR	No	Unkn
827	CO	Cruise	FIR	No	Yes
830	CO	Cruise	FIR*	No	Yes
831	CS	Cruise	FIR	No	Yes
833	CO	Cruise	FIR	No	Yes
834	CO	Cruise	FIR	No	No
839	CC	Climb	FIR	N/A	Yes

[2] Numbers in brackets refer to the use of all the information on ACAS and IFBP in the airmiss query reports.

844	WC	Cruise	FIR	Unkn	Unkn
847	CS	Cruise	FIR	Yes	
851	1300ft LHD	Cruise	FIR	No	Yes
860	CO	Climb	CTA	N/A	No
868	CC	Cruise	FIR	Unkn	Yes
871	WC	Cruise	FIR	Yes	
873	WO	Cruise	FIR	Unkn	Yes
876	WC	Cruise	FIR	Unkn	
877	CO	Cruise	FIR	Yes	Yes
878	WC	Cruise	FIR	Unkn	No
889	CS	Cruise	FIR	Yes	Yes
890	CO	Climb	FIR	Unkn	No
893	WC	Cruise	FIR	Yes	Yes
894	WC	Cruise	FIR	Yes	No
896	CO	Cruise	FIR	Yes	Yes
898	WC	Cruise	FIR	Unkn	Yes
905	WC	Cruise	FIR*	Unkn	Yes
907	CO		FIR		Yes
795	H	Cruise	FIR	No	Yes
796	H	Cruise	FIR	Yes	No
798	H	Cruise	FIR	Yes	Yes
804	H	Cruise	FIR	Yes	No
808	H	Cruise	FIR	Yes	No
814	H	Cruise	FIR	Yes	No
817	H	Cruise	TMA	No	No
822	H	Cruise	FIR	Unkn	Unkn
824	H	Cruise	FIR	Yes	Yes
825	H	Cruise	FIR	No	Unkn
829	H	Cruise	FIR	No	Yes
832	H	Cruise	FIR	Yes	Unkn
835	H	Cruise	FIR	Yes	No
838	H	Cruise	FIR	N/A	No
841	H	Cruise	FIR	Unkn	Unkn
842	H	Cruise	FIR	Unkn	Unkn
845	H	Cruise	UIR*	No	Yes
848	H	Cruise	FIR	Yes	Unkn
855	H	Cruise	FIR	No	Yes

856	H	Cruise	FIR	Yes	Yes
862	H	Cruise	FIR	Yes	Yes
863	H	Cruise	FIR	Yes	No
864	H	Cruise	FIR	Yes	Yes
866	H (SFL)	Cruise	FIR	Unkn	
867	H	Cruise	FIR	Unkn	
869	H	Cruise	FIR	Unkn	
880	H	Cruise	FIR	Yes	Yes
881	H (SFL)	Cruise	FIR	Unkn	Yes
884	H	Cruise	FIR	Yes	Yes
885	H	Cruise	FIR	Yes	No
895	H	Cruise	FIR	Unkn	Yes
899	H	Cruise	FIR	Yes	Yes
900	H	Cruise	FIR	Yes	Yes
903	H	Cruise	FIR*	Unkn	Yes
904	H	Cruise	FIR	Yes	Yes
828	No loss of separation	Cruise	FIR	No	Yes
861	Flight efficiency	Cruise	FIR	Yes	

Table 3.5 Some details of the 64 airmiss queries for the FL290-FL410 band
Note *: EUROSAM Corridor

Consider now the vertical events in some more detail. Recall from section 3.1 that two types of large height deviations involving whole numbers of flight levels are distinguished, namely aircraft climbing/descending incorrectly through another aircraft's flight level and aircraft levelling off at an incorrect flight level. Table 3.6 shows in the second column that 16 out of the 27 vertical events are of the former type where most of the queries concerned aircraft flying in the opposite direction. In one case, i.e. query no 833, it was impossible to infer from the query which of the three traffic situations, opposite direction, same direction, or crossing traffic, applied. For the CRA, therefore, this query will be treated conservatively as an opposite direction event.

All but one of the queries involving an aircraft flying at a wrong level involved crossing traffic events, i.e. events where both aircraft were flying at the same level at the crossing point, but one aircraft should have been flying at a different level according to either its flight direction or ATC instructions.

An airmiss query of the incorrect flight level crossing type (CO, CS, or CC) may involve the crossing of more than a single flight level and, hence, multiple exposure of other aircraft to the risk of a collision. For example, when an aircraft in the current CVSM environment would incorrectly change level from FL290 to FL370, it would traverse three intermediate levels. Therefore, the number of flight levels crossed needs to be determined for each airmiss query of this type. The resulting numbers of flight levels crossed are shown in the third to fifth column in table 3.6, together with a value for the climb/descent rate of the aircraft during the event if that information was available in the airmiss query report. Default values will be used for the remaining cases.

Reference	Airmiss query event code	Number of FLs crossed for CRA			Climb/descent rate (kts)	Crossing angle
		Same	Opposite	crossing		
823	CC	1	2	4	Unkn	120°
839	CC	0	0	1	Unkn	Unkn
868	CC	0	0	1	Unkn	120°
813	CO	0	1	0	Unkn	180°
827	CO	0	1	0	Unkn	180°
830*	CO	0	1	0	Unkn	180°
834	CO	0	1	0	Unkn	180°
860	CO	0	1	0	Unkn	180°
877	CO	0	1	0	Increased rate of climb	180°
890	CO	0	2	0	Expedite climb	180°
896	CO	0	1	0	Unkn	180°
907	CO	0	1	0	1000ft/min	180°
833	CO	0	1	0	Unkn	180°
831	CS	2	2	0	ROD 2500ft/min	0°
847	CS	2	2	0	Unkn	0°
889	CS	1	2	0	Unkn	0°
826	WC	-	-	-	-	Unkn
844	WC	-	-	-	-	Unkn
871	WC	-	-	-	-	56°
876	WC	-	-	-	-	75°
878	WC	-	-	-	-	37°

893	WC	-	-	-	-	Unkn
894	WC	-	-	-	-	24°
898	WC	-	-	-	-	152°
905*	WC	-	-	-	-	Unkn
873	WO	-	-	-	-	180°
851	1300 ft LHD	0	1	0	Steep climb back	180°

Table 3.6 Some further details of the 27 vertical airmiss queries
Note *: EUROSAM corridor (not included in AFI RVSM CRA)

3.3.3.2 Translating the incident data to the proposed RVSM environment

For any pre-implementation RVSM CRA, data collected in the CVSM environment have to be translated into data representative of the RVSM environment. In the same manner as for the initial CRA, it has been assumed firstly that the events queried in the AIAG 2006 data set could equally well have occurred under RVSM in the AFI Region, albeit possibly with different effects. Therefore, as a second step, the extent of the pertinent large height deviations under RVSM has been evaluated.

With regard to incorrect flight level crossings, it has been assumed that the same number of flight levels per event would be crossed in an RVSM environment as in a CVSM environment. For aircraft having levelled off at an incorrect level, the duration of the event has been assumed to be the same under RVSM as under CVSM.

The main problem with the translation occurs for large height deviations not involving a whole number of flight levels. In that context, airmiss query no 851 in table 3.5 needs to be considered. Following a flight level change clearance, this involved an extreme overshoot up to 1300 ft, followed by a return to the cleared level. It is difficult to unambiguously translate this event from the CVSM environment to an RVSM environment. One way would be to assume that the minimum vertical distance of 700 ft to the adjacent flight level would also have existed in an RVSM environment. However, this would effectively mean that the maximum deviation of 1300 ft would have reduced to the limiting value of a typical height deviation, i.e. 300 ft. Another way would be to assume that the size of the maximum deviation would have been exactly the same in an RVSM environment, i.e. 1300 ft. This would then imply crossing through the adjacent flight level and back, plus an additional height deviation of 300 ft towards the next adjacent flight level. The approach taken here has been to scale the 1300 ft large height deviation with the 2000 ft CVSM to obtain a maximum large height deviation of 650 ft under

RVSM. Assuming a default climb/descent speed for the aircraft involved, the maximum deviation has been used to calculate a probability of vertical overlap for this particular type of airmiss query similar to eqs. (3.3) and (3.5).

Table 3.7 summarises the incident data to be utilised in section 3.4 for the assessment of the total vertical collision risk under AFI RVSM. It differs from table 3.6 only in that the EUROSAM airmiss queries no 830 and no 905 have been dropped and the extent of the large height deviation of airmiss query 851 has been adjusted.

Reference	Airmiss query event code	Number of FLs crossed for CRA			Climb/descent rate (kts)	Crossing angle
		Same	Opposite	crossing		
823	CC	1	2	4	Unkn	120°
839	CC	0	0	1	Unkn	Unkn
868	CC	0	0	1	Unkn	120°
813	CO	0	1	0	Unkn	-
827	CO	0	1	0	Unkn	-
834	CO	0	1	0	Unkn	-
860	CO	0	1	0	Unkn	-
877	CO	0	1	0	Increased rate of climb	-
890	CO	0	2	0	Expedite climb	-
896	CO	0	1	0	Unkn	-
907	CO	0	1	0	1000ft/min	-
833	CO	0	1	0	Unkn	-
831	CS	2	2	0	ROD 2500ft/min	-
847	CS	2	2	0	Unkn	-
889	CS	1	2	0	Unkn	-
826	WC	-	-	-	-	Unkn
844	WC	-	-	-	-	Unkn
871	WC	-	-	-	-	56°
876	WC	-	-	-	-	75°
878	WC	-	-	-	-	37°
893	WC	-	-	-	-	Unkn
894	WC	-	-	-	-	24°

898	WC	-	-	-	-	153°
873	WO	-	-	-	-	180°
851	650 ft LHD	-	-	-	Steep climb back	-

Table 3.7 Summary of 25 vertical incidents for AFI RVSM CRA

3.3.3.3 Matching flight hours

Since the vertical collision risk is measured in fatal accidents per flight hour, an estimate of the total amount of flight hours during which the incident reports were generated is also needed. In principle, this estimate can be obtained from the flight hours in the FIR/UIRs concerned by means of the information as collected in ARMA Form 2 and Form 4 for the year 2006. However, as mentioned in section 2.4.2 on data limitations, the required information was not provided by a significant number of States.

Table 3.8 lists the 13 FIR/UIRs concerned together with some data. As can be seen in the third and fourth columns, the number of flight hours in 2006 was available from ARMA Form 4 for only four out of the thirteen FIR/UIRs and from Form 2 for three more FIR/UIRs. For Kano, flight hours were available from both Form 4 and Form 2, albeit with a significant difference. Since the Form 4 information is believed to be more reliable, the Form 4 information will be utilised whenever available. For three out of the remaining six FIR/UIRs, flight hour information from the initial CRA has been included in table 3.8. This flight hour information pertained to the years 2004 - 2005 and is outdated, i.e. the real number of flight hours in 2006 is most likely to be higher. For the estimate of the risk, however, an underestimation of the flight hours is conservative since the amount of flying time appears in the denominator of the equations for the probability of vertical overlap, cf. eqs. (3.3) and (3.5). ARMA has kindly provided an estimate for the Cape Town and Johannesburg FIR/UIRs. The only remaining issue, therefore, was Kinshasa. Given that more or less reliable flight hour information was available for the other FIR/UIRs, it has been decided to exclude the 2 vertical airmiss queries for Kinshasa from the estimation of the total vertical risk under RVSM in the AFI region. **It is important that this decision and the consequent uncertainty about the estimate of the total vertical risk under RVSM in the AFI Region is kept in mind when this estimate will be compared with the total vertical TLS in section 3.4.**

Thus, the estimate of the annual number of flying hours in the year 2006 for the twelve FIR/UIRs of which the vertical airmiss queries have been taken into account amounts 603390 hours. It should be noted that this value is dominated by the flight hours, approximately 60%, from the Cape Town and Johannesburg FIRs. Combined with 23 vertical airmiss queries, a vertical airmiss query rate is obtained of approximately 3.8×10^{-5} queries per flight hour. This value may be compared with the rate estimated in the initial CRA, which ranged from 8.8×10^{-6} to 2.6×10^{-4} incidents per flight hour, the range being due to uncertainty in the flight hour estimate. Although more flight hour information was available for the current CRA, it should be noted that the current airmiss query rate is very sensitive to the annual flight hour estimate for the Cape Town and Johannesburg FIRs. Without the airmiss query and the flight hours from these two FIRs, the airmiss query rate would be estimated at a level of $22/231390 \approx 10.0 \times 10^{-5}$, i.e. a factor of 2.5 larger.

FIR/UIR	No. of vertical airmiss queries	Estimated number of flight hours in 2006				
		ARMA Form 4 2006	ARMA Form 2 2006	ARMA Form 4 2004-2005	ARMA Form 2 2004-2005	Other source
Beira	1	18386	-			
Brazzaville	6	20695	-			
Brazzaville/ Kano	1	20695/ 10890	-/13774			
Cape Town/ Johannesburg	1	-	-	-	-	372000
Dakar	1	-	18865			
Gaborone	1	-	-	12041		
Kano/ Niamey	1	10890/-	13774/-		/27724	
Kinshasa	2	-	-	-	-	
Luanda	2	-	27408			
Nairobi	3	-	-	-	32535	
N'Djamena	2	28535	-			
Niamey	2	-	-	-	27724	
Harare	2	-	34311			

Table 3.8 Estimated number of flight hours in 2006 for FIR/UIRs with vertical airmiss queries in the AIAG 2006 data set

3.4 Total vertical collision risk

In this sub-section, the conventional vertical collision risk model will be applied to obtain a revised (as compared to the initial CRA) pre-implementation estimate of the total vertical collision risk under AFI RVSM. The estimated total vertical collision risk is to be compared with the total vertical TLS of 5×10^{-9} fatal accidents per flight hour.

The total vertical risk estimate is made up of the following contributions:

1. Risk due to airmiss queries coded CC, CO, and CS;
2. Risk due to airmiss queries coded WC and WO;
3. Risk due to airmiss query no. 851; and
4. Technical vertical risk, see eq. (2.26).

Airmiss queries coded CC, CO, and CS

The probability of vertical overlap $P_z(S_z)^{cl/d}$ given by eq. (3.3) applies to each of the airmiss queries coded CC, CO, and CS as it does not depend on the horizontal geometry of the individual events but only on the duration of their vertical passing. The exposure to this probability of vertical overlap is given by the collision risk model of eq. (3.2) for the CO and CC cases since $n_z(equiv)$ covers opposite direction and crossing traffic only (there is no same direction passings at adjacent flight levels). For a CS event, an additional same direction passing frequency is needed for same direction aircraft nominally separated by twice the vertical separation minimum S_z.

The full collision risk model for the airmiss queries coded CC, CO, and CS thus becomes

$$N_{az}^{cl/d} = 2P_z(S_z)^{cl/d} P_y(0) \left[n_z(equiv) \left\{ 1 + \frac{\overline{|\dot{y}|}}{2\overline{V}} + \frac{\lambda_{xy}}{\lambda_z} \frac{\overline{|\dot{z}_c|}}{2\overline{V}} \right\} + n_z^*(same) \left\{ 1 + \frac{\overline{|\dot{y}|}}{\overline{|\Delta V|}} + \frac{\lambda_{xy}}{\lambda_z} \frac{\overline{|\dot{z}_c|}}{\overline{|\Delta V|}} \right\} \right] \quad (3.6)$$

where $n_z^*(same)$ denotes the same direction passing frequency for same direction aircraft nominally separated by twice the vertical separation minimum.

Table 3.9 summarises the parameter values for the collision risk model of eq. (3.6), the most important one being $P_z(S_z)^{cl/d} = 5.76 \times 10^{-8}$. This value is approximately 30% larger than its counterpart in the initial CRA. Notice that $n^{cl/d}$ is equal to the sum of the flight levels crossed in table 3.7. Substitution of the table 3.9 values into the model gives

$$N_{az}^{cl/d} = 2 \times 5.76 \times 10^{-8} \times 0.106 \times (0.1241 \times 1.0765 + 0.04894 \times 4.5481) = 4.35 \times 10^{-9} \quad (3.7)$$

The risk estimate of $N_{az}^{cl/d} = 4.35 \times 10^{-9}$ is slightly larger than its counterpart in the initial CRA.

Eq. (3.7) suggests that this individual component of the total vertical risk just meets the total vertical TLS of 5×10^{-9} fatal accidents per flight hour. However, some care is necessary with regard to the sensitivity of $P_z(S_z)^{cl/d}$ to both the number of airmiss queries (and thus the number of flight levels crossed wrongly) and the annual number of flying hours. For example, without the data from the Cape Town and Johannesburg FIRs, one fewer opposite direction flight level would have been crossed and the number of flight hours would have been smaller by approximately 60%. As a result, the $P_z(S_z)^{cl/d} = 5.76\times10^{-8}$ value from table 3.9 would **increase** by a factor of approximately 2.5 to a value of $P_z(S_z)^{cl/d} = 14.5\times10^{-8}$. Based on that, the risk estimate would also **increase** by the same factor.

Parameter	Estimated value	Parameter	Estimated value
$n^{cl/d}$	31	$n_z(equiv)$	0.1241
λ_z (NM)	0.008404	$n_z^*(same)$	0.04894
$\overline{\lvert\dot{z}_c\rvert}$ (kts)	15	$\left\{1+\frac{\overline{\lvert\dot{y}\rvert}}{2\overline{V}}+\frac{\lambda_{xy}}{\lambda_z}\frac{\overline{\lvert\dot{z}_c\rvert}}{2\overline{V}}\right\}$	1.0765
T (hrs)	603390	$\left\{1+\frac{\overline{\lvert\dot{y}\rvert}}{\overline{\lvert\Delta V\rvert}}+\frac{\lambda_{xy}}{\lambda_z}\frac{\overline{\lvert\dot{z}_c\rvert}}{\overline{\lvert\Delta V\rvert}}\right\}$	4.5481
$P_z(S_z)^{cl/d}$	5.76×10^{-8}	λ_{xy} (NM)	0.002856
		$\overline{V}$ (kts)	464
$P_y(0)$	0.106	$\overline{\lvert\Delta V\rvert}$ (kts)	20
		$\overline{\lvert\dot{y}\rvert}$ (kts)	20

Table 3.9 Summary of parameter estimates for collision risk model of eq. (3.6)

Airmiss queries coded WC and WO

The probability of vertical overlap $P_z(S_z)^{wl}$ given by eq. (3.5) applies to each of the airmiss queries coded WC, WO, and WS. Its parameters n^{wl} and $\bar{t}^{wl}$ need to be inferred from the reports for the airmiss queries 826 – 873 in the lower half of table 3.7, where n^{wl} denotes the number of queries of this type and $\bar{t}^{wl}$ denotes the average value of the times spent by the aircraft at a wrong level. This is more difficult than for the airmiss queries of the flight level crossings type. The time spent at a wrong level is rarely present in an airmiss query and some judgement is generally necessary. Since there is no airmiss query of the WS-type, only the WC and WO airmiss queries need to be considered.

Two cases can be distinguished with regard to the wrong flight level when two aircraft appear to be flying at the same level whereas they were supposed to be vertically separated. Firstly, the level flown by each individual aircraft is in compliance with the applicable flight direction, but one aircraft should simply have been at a different level in the same direction (e.g. the next adjacent flight level). Secondly, the level flown by one of the aircraft is not in compliance with the prevailing flight direction. Notice that a WO airmiss query is always of the latter type.

For the first case, the time spent at a wrong level pertains only to the crossing situation and has essentially been inferred from the "lack of time-based longitudinal separation at the crossing". For example, when an airmiss query report would state that the aircraft passed at only 6 minutes time difference, it would be assumed that one of the aircraft was 4 minutes late in achieving vertical separation (for a 10 minutes longitudinal separation minimum). If no information on minimum time or distance at the crossing was included in a report, the time spent at a wrong level was taken equal to the longitudinal separation minimum. For the second case, it was assumed that a conflicting aircraft had been on the wrong flight level since its last-passed reporting point when no other information was available in the report.

The distinction between the two cases is of importance with regard to the exposure to the vertical collision risk associated with the airprox query. For the first case, the non-genuine case, say, exposure to the vertical risk exists at the crossing only whereas for the second case, the genuine one, exposure exists at crossings as well as on route segments. It is necessary, therefore, to consider two different vertical overlap probabilities, $P_z(S_z)^{wl}_{non-gen}$ and $P_z(S_z)^{wl}_{genuine}$, and to multiply these with the appropriate exposure factors. Thus, the pertinent collision risk model becomes

$$N^{wl}_{az} = 2P_z(S_z)^{wl}_{non-gen}\, n_z(cross)\{1+\ldots cross\} + 2P_z(S_z)^{wl}_{genuine}\, P_y(0)\, n_z(equiv)\left\{1+\frac{\overline{|\dot{y}|}}{2\overline{V}}+\frac{\lambda_{xy}}{\lambda_z}\frac{\overline{|\dot{z}|}}{2\overline{V}}\right\} \tag{3.8}$$

where

$$n_z(cross)\{1+\ldots cross\} = P_y(0)\big(n_z(equiv)-n_z(opp)\big)\left\{1+\frac{\overline{|\dot{y}|}}{2\overline{V}}+\frac{\lambda_{xy}}{\lambda_z}\frac{\overline{|\dot{z}|}}{2\overline{V}}\right\} \tag{3.9}$$

Analysis of the nine airmiss queries from the lower half of table 3.7 showed that four of them were of the genuine type, namely the queries 826, 844, 878, and 873. The difference in their coding only reflects that they were detected in a different way, i.e. the first three were detected when an aircraft pair was approaching a crossing and the last one on a single route segment. Hence, these four queries are to be used for the estimation of $P_z(S_z)^{wl}_{genuine}$.

Unfortunately, it was not possible to make any reasonable estimate of the time spent at a wrong level for the queries 826 and 844 that concerned events in oceanic airspace inside the Luanda FIR. Both events concerned the same call signs, at approximately (?) the same location, with a time interval of approximately 3 months. Rather than making unjustified estimates, it was decided to exclude these two airmiss queries from the estimation of the average time $\bar{t}^{wl}$ spent at a wrong level, also on the basis that it was not clear whether or not flying time on oceanic routes inside the Luanda FIR had been included in the ARMA Form 2 information. ARMA Form 4 traffic flow data was not available for the Luanda FIR. **As noted before, this decision should be kept in mind when judging the final estimate of the total vertical risk against the total vertical TLS.** Thus, only the two airmiss queries 878 and 898 have been used to obtain a value of $\bar{t}^{wl}_{genuine} = 0.2073$ hours for the average sojourn time at a genuinely wrong flight level, see table 3.10.

The remaining five airprox queries were of the non-genuine wrong flight level type and have been used for the estimation of $P_z(S_z)^{wl}_{non-gen}$ with $\bar{t}^{wl}_{non-gen} = 0.1130$. Notice that this average delay of 0.1130 hours or 6.77 minutes in achieving vertical separation is relatively large compared to a 10 minutes longitudinal separation minimum. This is due to two events for which minimum distances between the aircraft of 5 NM and 8 NM were reported.

Table 3.10 summarises the parameter values for the probabilities of vertical overlap $P_z(S_z)^{wl}_{genuine}$ and $P_z(S_z)^{wl}_{non-gen}$ as well as for the collision risk model of eq. (3.8).

One parameter in table 3.10 needs some discussion, viz. $P_z(0)$. Recall from eq. (3.5) that the probability of vertical overlap for aircraft flying at a wrong level ($P_z(S_z)^{wl}_{non-gen}$ and $P_z(S_z)^{wl}_{genuine}$ in eq. (3.8)) is directly proportional to $P_z(0)$. Based on the then available height monitoring data, the initial CRA used a value of 0.1 for $P_z(0)$ but noted that this value was rather small compared to the values used elsewhere (see reference 1, page 100). It was suggested this was correlated with the relatively large value of 1.61×10^{-8} for $P_z(1000)$ in the initial CRA due to a relatively widely spread TVE distribution. The current TVE distribution is narrower and a larger value for $P_z(0)$ is then appropriate. In accordance with the values in use in Europe, the North Atlantic, and the Caribbean/South American regions, and based on an average aircraft height of $\lambda_z = 50$ ft, a value of $P_z(0) = 0.45$ is used in the current CRA (cf. references 20 and 21).

Parameter	Estimated value	Parameter	Estimated value
$n^{wl}_{genuine}$	2	$n_z(opp)$	0.1005
$\bar{t}^{wl}_{genuine}$ (hrs)	0.2073	$\left\{1+\frac{\overline{\lvert\dot{y}\rvert}}{2\overline{V}}+\frac{\lambda_{xy}}{\lambda_z}\frac{\overline{\lvert\dot{z}\rvert}}{2\overline{V}}\right\}$	1.0270
$P_z(0)$	0.45	$\left\{1+\frac{\overline{\lvert\dot{y}\rvert}}{\overline{\lvert\Delta V\rvert}}+\frac{\lambda_{xy}}{\lambda_z}\frac{\overline{\lvert\dot{z}\rvert}}{\overline{\lvert\Delta V\rvert}}\right\}$	2.2548
T (hrs)	575982	$\overline{V}$ (kts)	464
$P_z(S_z)^{wl}_{genuine}$	3.24 * 10^{-7}	$\overline{\lvert\Delta V\rvert}$ (kts)	20
$n^{wl}_{non-gen}$	5	$\overline{\lvert\dot{y}\rvert}$ (kts)	20
$\bar{t}^{wl}_{non-gen}$ (hrs)	0.1130	$\overline{\lvert\dot{z}\rvert}$ (kts)	1.5
and $P_z(S_z)^{wl}_{non-gen}$	4.42 * 10^{-7}	λ_{xy} (NM)	0.002856
$P_y(0)$	0.106	λ_z (NM)	0.008404
$n_z(equiv)$	0.1241		

Table 3.10 Summary of parameter estimates for collision risk model of eq. (3.8)

Substitution of all the parameter values into the collision risk model of eq. (3.8) results in

$$N^{wl}_{az} = 2\times 4.42\times 10^{-7}\times 0.002568 + 2\times 3.24\times 10^{-7}\times 0.106\times 0.1241\times 1.0270 \qquad (3.10)$$

or

$$N^{wl}_{az} = 2.27\times 10^{-9} + 8.75\times 10^{-9} = 11.0\times 10^{-9} \qquad (3.11)$$

The risk estimate of $N^{wl}_{az} = 11.0\times 10^{-9}$ is smaller than its counterpart in the initial CRA by a factor of approximately 2.5. This is mainly caused by the decrease in the passing frequency described in section 2.4.1.

Eq. (3.11) shows that this individual component of the total vertical risk does not meet the total vertical TLS of 5×10^{-9} fatal accidents per flight hour. Moreover, some care is again necessary with regard to the sensitivity of $P_z(S_z)^{wl}_{genuine}$ and $P_z(S_z)^{wl}_{non-gen}$ to the annual number of flying hours. Without the data from the Cape Town and Johannesburg FIRs, the number of flight hours would have been smaller by approximately 60%. As a result, the $P_z(S_z)^{wl}_{genuine}$ and $P_z(S_z)^{wl}_{non-gen}$ values from table 3.10 would both **increase** by a factor of approximately 2.8. Similarly, the risk estimate would also **increase** by this very same factor to $N^{wl}_{az} = 31.9\times10^{-9}$, i.e. a value well above the total vertical TLS of 5×10^{-9} fatal accidents per flight hour.

Airmiss query no 851

For this airmiss query, the large height deviation of the non-whole number of flight levels type has been modelled as a very significant deviation from and back to a correctly assigned RVSM flight level. The corresponding probability of vertical overlap $P_z(S_z)^{**}$, say, may be calculated by

$$P_z(S_z)^{**} = 2\frac{2\lambda_z/|\dot{z}|}{T}\int_{S_z - z_{\max}}^{S_z} f^{TVE}(z)dz \tag{3.12}$$

where $f^{TVE}(z)$ is given by eqs. (2.16) ff. from section 2 and $z_{\max}$ denotes the maximum deviation from the assigned flight level. With the maximum deviation smaller than the vertical separation minimum S_z, the exposure to the above probability of vertical overlap is essentially given by the collision risk model of eq. (3.2) (but with $|\dot{z}|$ referring to the climb/descent speed of the subject aircraft), since $n_z(equiv)$ fully covers opposite direction and crossing traffic. Thus, the collision risk model for the airmiss query no 851 becomes

$$N^{**}_{az} = 2P_z(S_z)^{**}P_y(0)n_z(equiv)\left\{1+\frac{\overline{|\dot{y}|}}{2\overline{V}}+\frac{\lambda_{xy}}{\lambda_z}\frac{\overline{|\dot{z}|}}{2\overline{V}}\right\} \tag{3.13}$$

Table 3.11 summarises the parameter values for this collision risk model. Substitution of the various parameter values into the model gives for the risk due to airmiss query no 851

$$N^{**}_{az} = 2\times2.24\times10^{-11}\times0.106\times0.1241\times1.0765 = 6.34\times10^{-13} \tag{3.14}$$

Eq. (3.14) shows that this individual component of the total vertical risk is negligible compared with the total vertical TLS of 2.5 * 10^{-9} fatal accidents per flight hour and this conclusion is not affected by the flight hour sensitivity issue discussed for the previous two components of the total vertical risk. The reason for the negligibly small value of this risk component is that it concerns only a single event and that the aircraft involved remains more than 350 ft away from the adjacent flight level.

Parameter	Estimated value
λ_z (NM)	0.008404
$\overline{\lvert\dot{z}\rvert}$ (kts)	15
T (hrs)	603390
$P_z(S_z)^{**}$	2.24×10^{-11}
$P_y(0)$	0.106
$n_z(equiv)$	0.1241
$\left\{1+\frac{\overline{\lvert\dot{y}\rvert}}{2\overline{V}}+\frac{\lambda_{xy}}{\lambda_z}\frac{\overline{\lvert\dot{z}\rvert}}{2\overline{V}}\right\}$	1.0765

Table 3.11 Summary of parameter estimates for collision risk model of eq. (3.13)

<u>Total vertical collision risk</u>

The total vertical collision risk due to all causes under AFI RVSM is the sum of the three risk components $N_{az}^{cl/d}$, N_{az}^{wl}, and N_{az}^{851} and the technical vertical risk given by eq. (2.26), i.e.

$$N_{az}^{total} = N_{az}^{cl/d} + N_{az}^{wl} + N_{az}^{851} + N_{az} \qquad (3.15)$$

Substitution of the risk estimates given by eqs. (3.7), (3.11), (3.14), and (2.26) into eq. (3.15) gives the following estimate for the total vertical risk:

$$N_{az}^{total} = 4.35\times10^{-9} + 11.0\times10^{-9} + 6.34\times10^{-13} + 2.70\times10^{-11} \qquad (3.16)$$

or

$$N_{az}^{total} = 15.4\times10^{-9} \qquad (3.17)$$

fatal accidents per flight hour. This estimate exceeds the total vertical TLS of 5×10^{-9} fatal accidents per flight hour by a factor of three. It should be noted that, intentionally, the risk estimate of eq. (3.17) does not include the risk mitigating effect of ACAS.

It should be clear that the above result is conditional on many factors, the most important one being the completeness and representation of the data available to the assessment. As mentioned at several places, there is a need for considerable caution in this respect. Two more specific factors will be elaborated briefly below.

As remarked under the development of the collision risk models for the different components of the total vertical collision risk in the foregoing part of this section, the estimates for $N_{az}^{cl/d}$ and N_{az}^{wl} are very sensitive to the value of the annual flying time for the Cape Town and Johannesburg FIRs, see the summary in table 3.12. Unfortunately, it has not been possible to verify that value against traffic flow data from ARMA Form 4. The sensitivity of the risk components will propagate into the estimate of the total vertical collision risk under AFI RVSM.

Risk component	Cape Town and Johannesburg data included	Cape Town and Johannesburg data excluded
$N_{az}^{cl/d}$	4.35×10^{-9}	10.9×10^{-9}
N_{az}^{wl}	11.00×10^{-9}	31.9×10^{-9}

Table 3.12 Sensitivity of total vertical risk components to Cape Town and Johannesburg data

The other factor to be mentioned is the effect of increased lateral navigation accuracy, i.e. the proportion of aircraft using GNSS-based navigation. As follows from the various collision risk models, the risk increases approximately proportionally to $P_y(0)$, the probability of horizontal overlap for aircraft on the same track. Table 2.5 showed $P_y(0)$ as a function of the proportion α of aircraft using GNSS. The current assessment assumed that 50% of the aircraft population would be using GNSS with a corresponding value of $P_y(0) = 0.106$. If the proportion of GNSS users would increase to 75%, the value of $P_y(0)$ would increase to 0.162. Consequently, the risk estimates would increase by a factor of approximately 1.5.

4 Conclusions

4.1 Overall

Two collision risk assessments have been conducted to meet the AFI RVSM Safety Policy objectives concerning the technical vertical collision risk and the total vertical collision risk. The two risk estimates have been compared with the technical and total vertical TLSs of 2.5×10^{-9} and 5×10^{-9} fatal accidents per flight hour respectively. Based on the data available to the assessments, the technical vertical TLS was found to be met, but the total vertical TLS was found not yet to be met. The total vertical TLS was found to be exceeded by a factor of three. Although this is a significant improvement over the result obtained in the initial CRA, there are several factors that require the estimate of the total vertical risk to be treated with caution.

The estimation of the total vertical risk requires data on large height deviations of 300 ft or more, say. The reporting of such data in ARMA Form 2 is completely inconsistent with airmiss query reports available from the AFI ATS Incident Analysis Working Group (AIAG). This inconsistency needs to be resolved prior to the implementation of RVSM to obtain sufficient credibility for the process.

Analysis of the AIAG data showed a significant number of airmiss queries concerning aircraft at the same flight level of intersecting tracks. It was generally unclear whether the aircraft had been intended to be separated vertically or horizontally. The pertinent queries have been classified as “horizontal” events unless there was a clear indication in the reports that the aircraft were actually intended to be vertically separated at the intersection. The resulting classification may well be too optimistic with regard to the vertical risk. Apart from that, the “horizontal” events need to be addressed as a matter of urgency.

The AIAG airmiss query data have been used as the only source for the estimation of the probability of vertical overlap due to all causes other than normal technical height-keeping deviations. Although this data has been found to be very useful, there remains considerable concern as to whether a complete and fully representative sample of incident data has been obtained. All the stakeholders involved with AFI RVSM must take the necessary steps to ensure that sufficient and reliable data on operational issues becomes available prior to the implementation of AFI RVSM.

The next important parameter of the vertical collision risk model is passing frequency. This is estimated from traffic flow data collected by ARMA from the African States on a monthly basis in ARMA Form 4. A considerable amount of data limitations has been identified. These limitations must be eliminated in order to make the passing frequency estimation process more precise and reliable.

The limitations in the ARMA Form 4 and Form 2 data do not only affect the passing frequency estimation, but also that of the annual flying time in the RVSM band. This in turn affects the estimation of the rate of large height deviations and, consequently, that of the total vertical collision risk under AFI RVSM.

It is recommended that (at least) one more pre-implementation collision risk assessment is performed based on data for the year 2007 in order to confirm the current results.

4.2 Technical vertical collision risk

Based on current traffic levels, the technical vertical collision risk was estimated as 2.70×10^{-11} fatal accidents per flight hour, i.e. well below the technical TLS of 2.5×10^{-9} fatal accidents per flight hour. Opposite direction traffic is the main contributor to the risk. The precision of lateral navigation is an important factor with regard to the vertical collision risk. It has been assumed that 50% of the flying time in AFI RVSM airspace would be made with GNSS navigation and the remaining 50% with VOR/DME navigation.

The risk increasing effect of an extended use of GNSS navigation has not been taken into account in the current risk estimate. An increase of the GNSS flight time proportion to 75%, for example, would cause the estimate of the technical risk to increase by a factor of approximately 1.5. The risk mitigating effect of strategic lateral offsets has not been incorporated either.

The decrease in the estimate of the technical risk compared with the initial CRA is due to two factors. Firstly, extended modelling capabilities have resulted in a considerable reduction of the probability of vertical overlap due to normal technical height-keeping deviations of RVSM approved aircraft. Secondly, a lower estimate was obtained for the passing frequency parameter of the collision risk model. The reason for the decrease in passing frequency is unclear and should be investigated further.

The estimate for the technical vertical collision risk is considered to be conservative with regard to no credits having been taken for the redistribution of the traffic under RVSM. The risk estimate is considered to be not conservative with regard to the data limitations affecting the passing frequency estimation. The risk increasing effect of future traffic growth has not been considered. The margin between the technical TLS and the estimate of the technical vertical risk is believed to be sufficient to cater for these factors.

4.3 Total vertical collision risk

Total vertical collision risk is the risk due to all causes including normal technical height-keeping performance. Causes of vertical risk other than normal technical height-keeping performance generally lead to large, atypical height deviations. These large height deviations have been classified into large height deviations involving whole numbers of flight levels and those not involving whole numbers of flight levels. Appropriate models for the risk due to such deviations developed for the initial CRA have been re-used, but with their parameters updated on the basis of the data available for the year 2006.

A number of specific assumptions, observations, and decisions have been made during the assessment, which have a bearing on the estimate of the total vertical collision risk under AFI RVSM:

- Data provided by States in ARMA Form 1 for the initial CRA have not been included (section 3.3.2);
- The set of AIAG airmiss queries was not complete (section 3.3.3.1);
- Two vertical airmiss queries in the Kinshasa FIR/UIR have not been included due to a lack of data on the corresponding annual flying hours in the FIR/UIR (section 3.3.3.3); and
- Two vertical airmiss queries concerning events in oceanic airspace inside the Luanda FIR/UIR have not been included due to a lack of detail on the actual events (section 3.4).

Since not any large height deviations were reported by States through ARMA Form 1 for the year 2006, the estimation of the vertical risk due to such deviations has been based solely on the available AIAG airmiss queries for 2006.

Based on current traffic levels and 50% GNSS flying time, the total vertical collision risk was estimated to be 15.4×10^{-9} fatal accidents per flight hour, i.e. three times as large as to the total vertical TLS of 5×10^{-9} fatal accidents per flight hour. However, the estimate was found to be very sensitive to the annual flight hour estimate for the Cape Town and Johannesburg FIRs. The latter could not be computed from the ARMA Form 4 traffic flow data but was provided externally. Excluding the Cape Town and Johannesburg data from the assessment increased the estimate of the total vertical risk by a factor of nearly three.

The decrease in the estimate of the total vertical collision risk under AFI RVSM compared with the initial CRA is essentially due to two factors. Firstly, there is the effect of a lower passing frequency estimate in a similar manner as for the technical risk. Secondly, there is a significant reduction in the estimate of the probability of vertical overlap for the risk component due to large height deviations not involving whole numbers of flight levels. There is also a reduction in the technical risk component of the total vertical risk.

Given the limited distribution of the AIAG airmiss queries over the FIRs in the AFI Region and across the airline population, there is considerable concern as regards the completeness and representation of the AIAG data set. Hence, there continues to be a need for improvements in incident reporting.

The effect of redistribution of traffic under RVSM, data limitations, traffic growth, extended use of GNSS navigation, and the potential use of lateral offsets on the estimate of the total vertical risk is essentially similar to that on the technical vertical risk.

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APPENDIX A: Aircraft population

A.1 Introduction

Flight time proportions are needed with respect to two parameters of the vertical collision risk model, namely the overall ASE probability distribution and the average aircraft dimensions.

The traffic flow data collection form (Form 4) includes for each flight the aircraft type by ICAO aircraft designator. In principle, therefore, the flight time by ICAO aircraft designator can be calculated for each FIR in the AFI Region for the flight level band FL290 – FL410 and be combined to give the precise flight time proportions by ICAO aircraft designator for the AFI Region. An implicit assumption is that all flights between FL290 and FL410 inclusive have been included in the Forms 4.

A.2 Aircraft population data

All 35 FIR/UIRs were requested by the ARMA to submit flight progress information (Form 4) for flight level band FL290 – FL410 for the period June 2005 to December 2006. For 13 FIR/UIRs, the flight progress information for one or more months has been processed. In total, 121 months have been processed with a total of flight time of 261551.20 hrs.

Using the available data, an estimate of the total flight time in the year 2006 is estimated. For Roberts FIR and Kano FIR all data of 2006 was available. For Algiers FIR and Mauritius FIR, only the last one or two months from 2006 were missing and the estimate has been made by taking the missing months from 2005. For the other FIR/UIRs, the estimate was obtained by taking the available months in 2006 and scaling it with the appropriate factor. If no data from 2006 was available, the data from 2005 was taken.

FIR/UIR	**No of months processed**	**Flight time estimate for 2006 (hrs)**
Algiers	18	88804.67
Mauritius	16	13916.93
Roberts	17	8060.03
Antananarivo	12	30963.65
Cairo	2	106539.50
Brazzaville	3	20695.13
N’Djamena	2	28534.50
Beira	1	18386.00
Mogadishu	3	17013.60
Seychelles	7	10494.09

Entebbe	13	2323.20
Dar es Salaam	8	22150.80
Kano	19	10889.83
Total	121	368424.37

Table A.1 Annual flight time estimate by FIR/UIR for the year 2006

A.3 Flight time proportions for the overall ASE distribution

The flight time proportions β_i, $i = 1,...,n_{MG}$, in the overall ASE probability density model of eq. (2.17) are needed by monitoring group.

The total flight time for the year 2006 for all the aircraft types in the traffic flow data collection forms (Form 4) was 368424.37 hours. However, some of the aircraft types included in Form 4 were not valid ICAO aircraft designators. Some of these have been regarded as typing errors and have been corrected. The following corrections have been made:
A232 → A332, A43 → A343, AN124 → A124, B1-11, BAC11, BAC1-11 → BA11, B44 → B744, C502 → C500, CL604 → CL60, EA33 → A330, FK100 → F100, FK28 →F28, GII, G2 → GLF2, GIII, G3 → GLF3, GIV, G4 → GLF4, GV, G5 → GLF5, HS25A → H25A, HS25B → H25B, L11, L1011 → L101, LR24 → LJ24, LR25 → LJ25, LR31 → LJ31, LR35 → LJ35, LR45 → LJ45, LR55 → LJ55, LR60 → LJ60, TU154 → T154, TU204 → T204, TU54 → T154, 737 → B737, AB733 → B733, B7333 → B733, DV86 → DC86, F200 → FA20, MB82 → MD82, MDII → MD11, ND82 → MD82, SBRI → SBR1, CL601 → CL60, FA900 → F900, FK70 → F70, GLAX → GALX, MD8 → MD80, A34 → A340, A3433 → A343, B74/24 → B744, 19 → A319, 319 → A319, A3116 → A316, A32 → A320, A346A → A346, B7444 → B744, DC83 → MD83, EI135 → E135, FRTH → F2TH, TU24 → T224, BE02 → BE20, BE35 → B350, EA30, EA300 → A300, EA31 → A310, EA32 → A320, EA33 → A330, EA34 → A340, A25A → H25A, BJ40 → BE40, GULF → GLF, M090 → MD90, C506 → C500, GLEXM → GLEX, HS25C → H25C, RJ1HM, RJ1HN, RJHI → RJ1H, A036 → A306, A308 → A30B, A32 → A320, A324 → A332, A736 → B736, A742 → B742, A745 → B745, A763 → B763, A772 → B772, B46 → B746, B73G → B738, C756 → C750, CC60 → CL60, CLEX → GLEX, D752 → B752, D90 → F900, DN24 → AN24, E70 → F70, FA20 → F200, F2RH, F2TA → F2TH, FA59 → FA50, GALA → GALX, GL4O → GLF4, GFL2 → GLF2, IC76 → IL76, PK100 → F100 N772 → B772 Q319 → A319, Q321 → A321, Q342 → A342, TV54 → T154, V772 → B772, Z342 → A342.

After these corrections there are still some cases in which the aircraft type was empty or clearly an invalid ICAO aircraft designator.

Next, the ICAO aircraft designators were mapped onto the monitoring groups. The latest set of monitoring groups is taken from the EUR RVSM Safety Monitoring Report 2006 (Ref. 6). In total, 99.21% of the total flight time estimate for 2006 could be assigned to a monitoring group. In case a particular ICAO aircraft designator appeared in more than one monitoring group, the flight time of that particular aircraft designator was equally distributed among the monitoring groups.

To obtain an estimate of the aircraft population in the flight level band FL290 – FL410, a distinction is made between African resident and non-African resident operator. For the candidate non-African resident and registered AFI RVSM population the same set as in the initial first Collision Risk Assessment report (Ref. 1) has been used to represent the population of non-African resident operators.

To determine the African resident operators, the current set of RVSM approved aircraft provided by the African Regional Monitoring Agency (ARMA) has been used. If a particular group of aircraft has at least one RVSM approved aircraft, the whole group has been included. The third and forth column of Table A.2 indicate with a checkmark (√) whether the monitoring group is used by an African or non-African resident operator respectively. Based on the set of potential Monitoring Groups, the flight time proportion is determined using the flight time estimates for 2006.

Compared to the first Collision Risk Assessment report, the following monitoring groups have been excluded: B461, B701, BE40, C130, C500, C501-1, C550-B, C550-II, D228, E135-145, F2TH, FA10, FA20, GLF3, GLF5, IL76, L29B-2, PC12, YK40, YK42, BN2, C212, E120, SW4 and SF34. Furthermore, the following monitoring groups have been included: B737C, B747LCF, B74S, DC86-7-1, C750, CL600, GLF2, GLF2-G, GLF2-3, GLF2B and GLF2B-G. It should be noted that the last six monitoring groups in table A.2 (presented in italic) are non-group aircraft .

Monitoring Group	**ICAO aircraft designator**	**AFI operator**	**Non-AFI operator**	**Total Flight time**	**Flight time proportion**
A300	A30B	√	√	1474.78	0.004068
A306	A306	√	√	4876.89	0.013453
A310-GE	A310	√	√	3214.10	0.008866
A310-PW	A310		√	3214.10	0.008866
A320	A319,A320, A321	√	√	49087.92	0.135409

A330	A332, A333	√	√	35114.08	0.096862
A340	A342, A343	√	√	41224.15	0.113716
A345	A345		√	109.32	0.000302
A346	A346	√	√	11117.38	0.030667
ATR	AT43, AT44, AT45, AT72		√	9.97	0.000027
AVRO	RJ1H, RJ70, RJ85		√	4.87	0.000013
B703	B703	√		147.86	0.000408
B712	B712		√	2.43	0.000007
B727	B721, B722	√	√	1579.67	0.004358
B732	B732	√	√	7106.33	0.019603
B737C	B737		√	5981.46	0.016500
B737CL	B733, B734, B735	√	√	16530.28	0.045599
B737NX	B736, B737, B738, B739	√	√	22441.73	0.061905
B744-10	B744	√	√	11820.01	0.032605
B744-5	B744	√	√	11820.01	0.032605
B747CL	B741, B742, B743	√	√	9419.63	0.025984
B747LCF	B744		√	11820.01	0.032605
B74S	B74S		√	1400.72	0.003864
B752	B752	√	√	13580.40	0.037461
B764	B764		√	763.74	0.002107
B767	B762, B763	√	√	35792.40	0.098733
B772	B772	√	√	30615.87	0.084454
B773	B773		√	8494.30	0.023431
BE20	BE20, BE30, B350		√	110.70	0.000305
C750	C750	√		39.43	0.000109
CARJ	CRJ1, CRJ2		√	4.32	0.000012
CRJ-900	CRJ9		√	30.70	0.000085
CL600	CL60	√		654.82	0.001806
CL600-1	CL60	√		654.82	0.001806
DC10	DC10	√	√	4706.17	0.012982
DC86-7	DC86, DC87	√	√	634.69	0.001751
DC86-7-1	DC86, DC87	√	√	634.69	0.001751
DC93	DC93	√	√	404.51	0.001116
DC94	DC94		√	335.41	0.000925
DC95	DC95		√	513.51	0.001417

F100	F100		√	238.80	0.000659
GLF2	GLF2	√		40.61	0.000112
GLF2-G	GLF2	√		40.61	0.000112
GLF2-3	GLF2, GLF3	√		227.09	0.000626
GLF2B	GLF2	√		40.61	0.000112
GLF2B-G	GLF2	√		40.61	0.000112
GLF4	GLF4	√		1449.26	0.003998
H25B-700	H25B	√		418.04	0.001153
H25B-700-A	H25B	√		418.04	0.001153
H25B-800	H25B	√		418.04	0.001153
L101	L101	√	√	1254.08	0.003459
LJ45	LJ45	√		86.90	0.000240
MD11	MD11		√	6832.36	0.018847
MD80	MD81, MD82, MD83, MD87, MD88	√	√	1989.57	0.005488
T154	T154		√	80.68	0.000223
T204	T204, T224, T234	√		42.66	0.000118
BA11	BA11		√	66.55	0.000184
DC85	DC85	√	√	399.71	0.001103
IL62	IL62		√	266.65	0.000736
DH8	DHC8		√	0.43	0.000001
F50	F50		√	40.76	0.000112
F28	F28	√	√	636.74	0.001756

Table A.2 Population of (partially) RVSM approved aircraft

The set of African and non-African resident operators with RVSM approved aircraft operating in the AFI region for 2006 corresponds to 95.84% (353113.90 hrs) of the total flight time estimate for 2006.

A.4 Overall ASE distribution

This appendix summarizes the modelling of the overall ASE distribution for the RVSM aircraft population expected to be operating in AFI RVSM airspace.

Assume that n_{MG} aircraft monitoring groups (see e.g. Ref. 18) will be operating in AFI RVSM airspace. Each monitoring group's ASE probability density $f_i^{ASE}(a)$, $i = 1,...,n_{MG}$, say, is the result of both within and between airframe ASE variability of all the airframes making up the group. An overall ASE probability density $f^{ASE}(a)$, say, for the full RVSM aircraft population is then found as a weighted mixture of the ASE densities by monitoring group, i.e.

$$f^{ASE}(a) = \sum_{i=1}^{n_{MG}} \beta_i f_i^{ASE}(a) \tag{A.1}$$

where the weighting factors β_i, $i = 1,...,n_{MG}$, are the proportions of flight time contributed by monitoring group i. Both the weighting factors and the monitoring group's ASE probability densities need to be inferred from monitoring data pertaining to the AFI RVSM airspace. (See Appendix A.3 for a discussion on the estimation of the weighting factors.)

The monitoring groups' probability densities $f_i^{ASE}(a)$, $i = 1,...,n_{MG}$ are to be estimated on the basis of height monitoring data of RVSM approved aircraft. Height monitoring data can be collected by ground-based Height Monitoring Units (HMUs) or by air portable GPS Monitoring Units (GMUs). Ground-based HMUs are not available in the AFI region. However, as the normal height-keeping performance of RVSM approved aircraft is not dependent on the region of operation, HMU data collected in other ICAO Regions may be used for the modelling of a monitoring group's ASE probability density $f_i^{ASE}(a)$. Notice that the overall ASE probability density defined by eq. (A.1) will vary from region to region due to differences in the weighting factors β_i resulting from the particular composition of each region's aircraft population.

For the current CRA, height monitoring data from the EUR RVSM Safety Monitoring Report 2006 have been used, i.e. monitoring data recorded between 1 June 2004 and 31 May 2006 by the Linz, Nattenheim, Geneva, and Strumble HMUs in the EUR and NAT regions as well as by GMUs from all ICAO regions.

In addition, the modelling of the monitoring groups' ASE probability densities has been refined in accordance with the latest developments for the EUR Region. This refinement concerns two parts.

Firstly, the families of within and between airframe ASE probability densities have been extended to mixtures of up to three Generalised Laplace probability densities, i.e.

$$f^{ASE}(x) = (1-\alpha_2-\alpha_3)\frac{1}{2a_1b_1\Gamma(b_1)}e^{-\left|\frac{x-\mu}{a_1}\right|^{1/b_1}} + \alpha_2\frac{1}{2a_2b_2\Gamma(b_2)}e^{-\left|\frac{x-\mu}{a_2}\right|^{1/b_2}} + \alpha_3\frac{1}{2a_3b_3\Gamma(b_3)}e^{-\left|\frac{x-\mu}{a_3}\right|^{1/b_3}}$$

(A.2)

The parameters $a_1, a_2,$ and a_3 are usually referred to as scale parameters and the parameters $b_1, b_2,$ and b_3 as shape parameters and μ represents the mean of the random variable x, i.e. either within airframe ASE or between airframe ASE. $\Gamma(b)$ denotes the gamma function of b. All parameters are dependent on the monitoring group under consideration.

A Generalised Laplace probability reduces to a Gaussian probability density when the scale parameter b is set to a value of 0.5, and it reduces to a Double Exponential probability density when the shape parameter is given a value of 1.0. A single probability density, be it Gaussian, Double Exponential or Generalised Laplace, is obtained by putting $\alpha_2 = \alpha_3 = 0.0$ and a mixture of two probability densities may be obtained by putting $\alpha_3 = 0$.

The second refinement concerns the combination of a monitoring group's between and within airframe ASE probability densities. The problem here is that any combination of a between airframe ASE probability density and a within airframe ASE probability other than two Gaussians (or Gaussian mixtures) produces a non-standard combined ASE probability density, i.e. a probability density that cannot be expressed in a standard analytical form. Its evaluation, therefore, must be performed either by purely numerical means or by the use of a suitable analytical approximation. The latter approach was followed form the start of the technical vertical risk assessments for RVSM, where it was shown that a Double Exponential probability density provided a conservative approximation. More recently, however, it was found that for certain combinations this Double Exponential approximation resulted in unrealistically conservative results. As a result, algorithms and software have been developed for the proper numerical evaluation of all combinations of within and between airframe ASE probability densities.

Figures A.1 and A.2 show the resulting overall ASE probability density $f^{ASE}(a)$ given by eq. (A.1) based on the above mentioned height monitoring data and the latest software. The logarithmic scale of figure A.2 provides a better indication of the tail of the overall ASE probability density for the RVSM approved aircraft population operating in AFI RVSM airspace.

It is remarked that height monitoring data was available from the European height monitoring programme for all but the following monitoring groups: ATR, B747LCF, CRJ-900, DC85, DC93, DC94, DH8, F28, F50, IL62. For all the monitoring groups for which no data was available, a default Gaussian ASE density has been assumed with mean zero and a standard deviation of 81.7 ft based on the MASPS.

Figure A.1 Overall ASE probability density for the AFI RVSM aircraft population

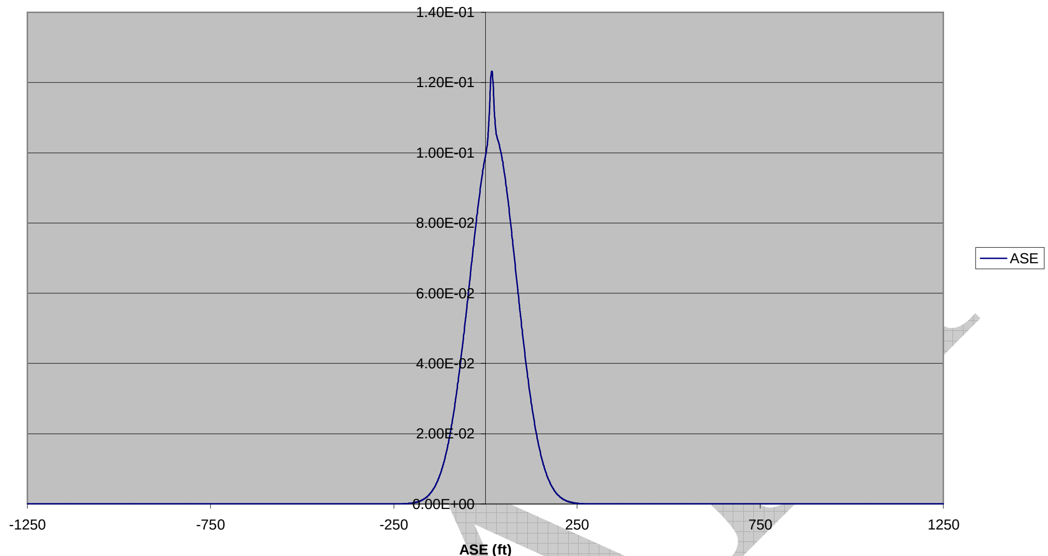
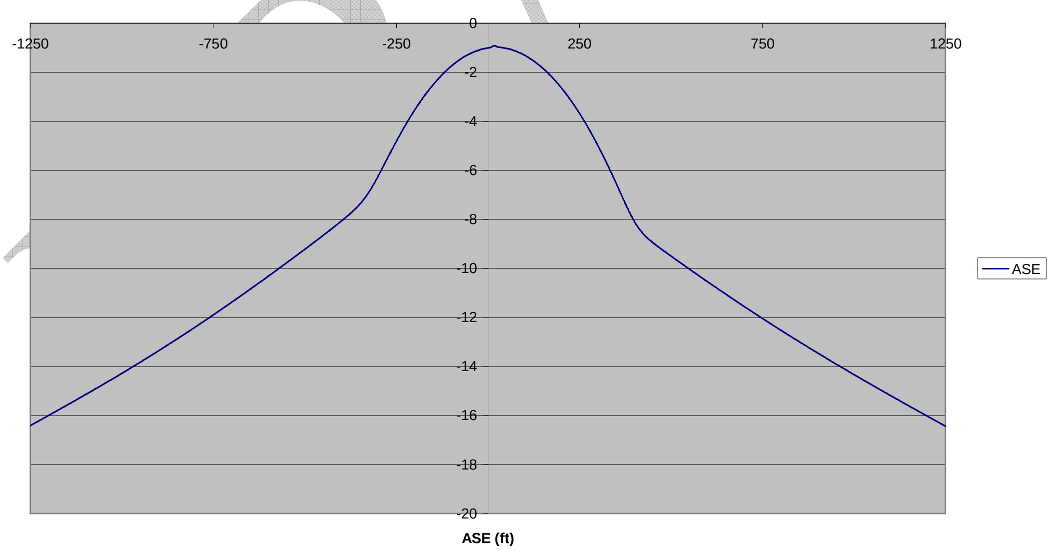


Figure A.2 Logarithm (base 10) of the overall ASE probability density for the AFI RVSM aircraft population



A.5 Flight time proportions for average aircraft dimensions and cruising speed

Each ICAO aircraft designator represents a particular aircraft name or model that may be made up of different aircraft types and/or series. The dimensions may vary by type and series of a given name or model. Since the traffic flow data collected in Form 4 does not distinguish between aircraft types or series under a given ICAO aircraft designator, the variation in dimensions by type or series needs to be accounted for in some manner. Two straightforward possibilities are an un-weighted average or the maximum dimensions. The latter option has been adopted here. Following that, the proportions of flight time by ICAO aircraft designator have been used as weighting factors for the calculation of average aircraft dimensions. For 95.1% of the total flight time estimate of 2006, the given aircraft designator could be linked particular aircraft dimension. The resulting weighted average dimensions are given in Table A.3.

An average cruising speed has been calculated as 464 kts.

Aircraft Dimension	**Value (ft)**
Length	173.51
Width	163.35
Height	51.07

Table A.3 Average aircraft dimensions projected for AFI RVSM airspace

APPENDIX B: Aircraft population

B.1 Introduction

In order to estimate the passing frequency, States have been requested by the ARMA to submit monthly flight progress information (Form 4) for all aircraft in the flight level band FL290 – FL410 for the period June 2005 to December 2006 (19 months).

Form 4 contains for each flight besides the aircraft type, operator, origin and destination, for all waypoints that flight passes the name of the waypoint, the time at which the aircraft passes and the flight level.

Besides the traffic flow data, monthly movements for each FIR/UIR should have been provided through Form 2.

Before the passing frequency was computed some pre-processing was preformed on the information that has been received electronically. The following steps were performed:

1. The information for a flight was brought in a format which has all the information on one line.
2. For the different FIR/UIRs conversion scripts have been written depending on the submitted format. The specifics for each FIR/UIR are given in Section B.2 below.
3. Only flights have been included that had flight progress complete information respect to waypoint name, time and FL[3].
4. Only segments of the flights in the FL290-FL410 flight level band have been taken into account.
5. Segments with an unrealistic flight time (e.g. more than 5 hours) have been removed manually.

B.2 FIR/UIR specific aspects

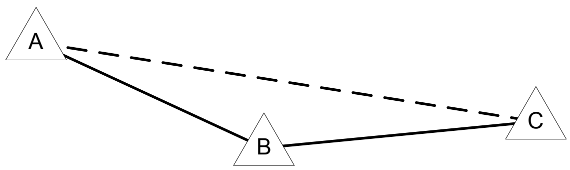
Algiers

For 18 of the 19 months, Form 4 as well as Form 2 information has been received. Compared to the number of flights reported in Form 2, Form 4 contains 71% of the flights. About 2% of the flights have been removed due to the pre-processing. Hence, the passing frequency was based on 69% of the flights.

The traffic flow data contains for each flight several waypoints. A closer analysis showed, however, that not all waypoints have been reported. As a result we have the following problem. Suppose an aircraft should traverse for a specific route from waypoint A via B to C. If for a first aircraft all three waypoints have been reported, but for a second aircraft only waypoint A and C,

[3] For some FIR/UIR only one flight level was given. It was assumed that this flight level holds for all waypoints. It is indicated in section B.2 if this has been the case.

then the two aircraft are considered as following two different routes, namely the second aircraft follows directly from A to C. As a result, a potential passing on a specific segment (in opposite or same direction) is not counted, since the two aircraft have been considered to fly different routes. Moreover, when the two aircraft pass each other near waypoint C, the passing could be incorrectly counted as a crossing.



The artefacts of this problem were observed served in the analysis of the Algiers traffic flow data, but may exist for other FIR/UIRs as well.

Mauritius

For 18 months of the 19 months (only May 2006 is missing), Form 2 information has been received. For Form 4, only the last three months (October 2006 up to December 2006) could not be processed due to the incorrect format. For the months in which both Form 2 and Form 4 have been received, Form 2 reports 14062 flights in the FL290 – FL410 flight level band whereas Form 4 reports 14255 flights. After pre-processing Form 4, this number is reduced to 10946. Hence, 77% of the flights have been taken into account. For the computation of the passing frequency all months for which Form 4 was available has been used. Form 4 contains only one flight level for a specific aircraft. It was assumed that this flight level holds for all waypoints of that flight.

Roberts

For Roberts FIR, Form 2 and Form 4information has been received for August 2005 up to December 2006. For June 2005 and July 2005 also Form 2 has been received. For the months for which both Form 2 and Form 4 was available Form 2 reported in total 14236 flights and Form 4 14237 flight. The amounts per months, however, differ for some months between 0 and 100 flights. After pre-processing 14032 flights remain (99%). Form 4 contains only one flight level for a specific aircraft. It was assumed that this flight level holds for all waypoints of that flight.

Luanda

For 9 months information was received via Form 4 (16500 flights in total). This information was consistent with the information received via Form 2 for the months April 2006 to

September 2006. However, Form 4 contained for each flight the information for one or sometimes two waypoints. Hence, no flight progress could be computed for Luanda.

Antananarivo

For 12 of the 19 months both From 2 and Form 4 have been received electronically. For June 2005 Form 2 has been received additionally, but in the corresponding Form 4 only the time and FL for one unknown waypoint was given. Form 2 reports 42671 flights in the FL290-FL410 flight level band, but Form 4 contains only 24882 (58%). Pre-processing reduced the number of flights obtained in Form 4 to 24753, removing 0.5% of the flights. Form 4 contains only one flight level for a specific aircraft. It was assumed that this flight level holds for all waypoints of that flight. Furthermore, Form 4 contains only 2 or 3 waypoints for each flight. Hence, it is possible that not all waypoints have been logged.

Harare

For all 19 months, Form 2 and Form 4 have been received. However, Form 4 was submitted in hardcopy and not electronically. Hence, no progress information was processed. Form 2 reports a total of 47555 flights in the FL290-FL410 flight level band in this period with an average of 47 minutes in the FIR per flight. For the year 2006, 30726 flights have been reported. This would yield a total flight time of 24068.7 hrs in the Harare FIR.

Accra

For the months July 2005 up to January 2006, Form 4 information has been received electronically. June 2005 was only available in a Word format. For Form 2 only June 2005 was available. In the 7 months 32442 flights have been reported through Form 4. This includes also flights outside the FL290-FL410 flight level band. Since the information in Form 4 only contain one waypoint per flight, no progress information could be derived.

Lusaka

For the period October 2005 up to December 2006 Form 2 information has been received. For that period a total of 25606 flights have been reported in the FL290-FL410 flight level band. The average climbing and decent time was reported as 20 minutes and the average time of level flight varied between 42 and 47 minutes. For the year 2006, 21015 flights have been reported in theFL290-FL410 flight level band. With an average flight time of 45 minutes, the total flight time for 2006 is estimated to be 15761.25 hrs. Form 4 was only received for June 2005, July 2005, Aug 2005 and Oct 2005, but the form contained only one waypoint. Hence, no progress information could be derived.

Tunis

For the Tunis FIR no information was received.

Casablanca

For the Casablanca FIR no information was received.

Cairo

For Cairo, Form 2 has only been received for October 2005. Form 4 has been received for April 2006 and August 2006. Form 2 reports 15893 flight in the FL290-FL410 flight level band. From Form 4 an average of 15274 flights per month. After pre-processing, less than 0.1% of the flights have been removed.

Gaborone

Form 4 is received for June 2005, July 2005, January 2006, February 2006 and March 2006. Form 4 contains only one waypoint per flight, so no progress information could be derived.

Nairobi

For all 19 months Form 4 has been received, but the forms contain only one waypoint per flight, so no progress information could be derived.

Brazzaville

Only Form 4 information is received for three months: June 2005, July 2005 and August 2005. The forms contains only 2 waypoints (an in and out waypoint of the FIR). It is assumed that the flight was a direct flight from the in waypoint to the out waypoint. From the 7651 reported flights in Form 4, 6853 remain after pre-processing (89%).

Sal Oceanic

For the Sal Oceanic FIR no information was received. Sal Oceanic is part of the EUR-SAM corridor.

N'Djamena

Only Form 4 information is received for two months: September 2006 and October 2006. Of the total 4006 reported flights in Form 4, 3640 remain after pre-processing (91%).

Kinsasha

No information has been received for the Kinsasha FIR.

Addis Ababba
No information has been received for the Addis Ababba FIR.

Tripoli
No information has been received for the Tripoli FIR.

Lilongwe
No information has been received for the Lilongwe FIR.

Dakar
For three months (June 2005, November 2005 and December 2005) Form 2 and Form 4 information has been received. Based on Form 2, there have been 3536 flights in the FL290-FL410 flight level band for these months. The available Form 4, were in Word format with limited information and only one waypoint per flight. Hence, no flight progress information could be derived.

Beira
Only one Form 4 (October 2006) has been submitted with 1485 flights. After pre-processing no flights have been removed.

Windhoek
For 9 months, Form 4 information has been received with a total of 4018 flights. Form 4 has a VIA waypoint without time/FL, so only two waypoints remain. A quick scan of the submitted forms revealed that the forms are very incomplete. Due to these limitations, no (reliable) flight progress information could be derived.

Niamey
Form 2 has been received for June 2005 and September 2005 up to April 2006 (9 months) with a total of 15086 flights in the FL290-FL410 flight level band. For Jun 2005 up to April 2006, Form 4 information has been received. Form 4 for June 2005 and July 2005 contain only one waypoint. Form 4 for the other months contain two waypoints. Hence, no flight progress information has been derived.

Mogadishu
Form 4 has been received for January 2006, February 2006 and March 2006. Form 2 has been received for these three months plus June 2005 and July 2005. For the January 2006 up to March 2006, Form 2 reports 3556 flights in the FL290-FL410 flight level band. Form 4 contains 3552 flights. After pre-processing 3536 remain (99.5%) of the flights.

Seychelles

For the Seychelles FIR, Form 4 information has been received for June 2005 up to December 2005. After pre-processing the 5155 flights were reduced to 4898 (95%). Form 4 of September 2005 contains only data up to September 4th. Form 4 of October 2005 seems to be missing a lot of data and Form 4 of December 2005 is about half of the month. The other months contain about 860 to 900 flights per month.

Entebbe

For 13 months, Form 4 has been received. Form 2 has been received for 12 months, but only for 8 months Form 2 as well as Form 4 have been received. For these 8 months, Form 2s report a total of 10533 flights in the FL290-FL410 flight level band. The corresponding Form 4s report only 6280 flights (60%). After pre-processing only 2395 flights remain. This is 38% of the flights in Form 4 and 23% of the number of flights from Form 2. Furthermore, Form 4 of August 2005 misses 1, 2 and 3 August and Form 4 of December 2005 is up to 12 December.

Khartoum

No information has been received for the Khartoum FIR.

Dar es Salaam

For the Dar es Salaam FIR 8 months of flight progress information (Form 4) has been received. Form 2 has been received for 6 months. Based on the 5 months for which Form 2 and Form 4 have been received, Form 2 reports 12263 flights in the FL290-FL410 flight level band. Form 4 reports 11330 flights (92%) which have been reduced tot 11081 flights after pre-processing. Hence, 98% of the flights of Form 4 remain.

Canarias

For the Canarias FIR no information was received. Canarias is part of the EUR-SAM corridor.

Dakar Oceanic

For Dakar Oceanic no information was received. Dakar Oceanic is part of the EUR-SAM corridor.

Asmara

For all months Form 2 information has been received with a total of 4917 flights in the FL290-FL410 flight level band. Form 4 has been received for all months except that June 2005 and July 2005 are in Word format and contain only part of the information. Based on the remaining months Form 2 reports 4565 flights, but Form 4 contain only 1972 flights (43%). Furthermore, Form 4 contains 2 waypoints in a “/”-format: A/B X/Y U/V. Hence, no flight progress information was derived.

Kano

Form 2 and Form 4 has been received for all 19 months! Form 2 reports 21660 flights in the FL290-FL410 flight level band. This is in good agreement with the 21553 flights reported in Form 4. After pre-processing 21252 remain (99%). In Form 4, 3 July is missing.

Form 4 contains only one flight level for each flight. Sometimes the flight level is given in an X/Y format. If that was the case Y has been taken.

Johannesburg

Form 4 was received for almost all months. However Form 4 contains only part of the flights and has only one waypoint format. Hence, no flight progress information could be retrieved.

Cape Town

No information was received.