Cir 343
AN/201

Guidelines for the Implementation of Performance-based Longitudinal Separation Minima

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ACRONYMS

A/C	Aircraft
AIC	Aeronautical information circular
AIP	Aeronautical information publication
AIRAC	Aeronautical information regulation and control
AIS	Aeronautical information service
ANSP	Air navigation service provider
ATC	Air traffic control
ATS	Air traffic services
CDI	Course deviation indicator
DCPC	Direct controller-pilot communications
DDE	Double double exponential
DME	Distance measuring equipment
DR	Dead reckoning
FAA	Federal Aviation Administration
FD	Fault detection
FDE	Fault detection and exclusion
FL	Flight level
FMS	Flight management system
FPL	Filed flight plan
GLONASS	GLObal NAvigation Satellite System
GNSS	Global navigation satellite system
GPS	Global positioning system
HPL	Horizontal protection limit
ICAO	International Civil Aviation Organization
IFR	Instrument flight rules
INS	Inertial navigation system
m	Meter
NDB	Non-directional radio beacon
NDE	Normal double exponential
NM	Nautical mile
NOPAC	North pacific
PANS-ATM	Procedures for Air Navigation Services – Air Traffic Management
RAIM	Receiver autonomous integrity monitoring
PBN	Performance-based navigation
RCP	Required Communication Performance
RGCSP	Review of the General Concept of Separation Panel
RLS	Reference level of safety
RNAV	Area navigation
RNP	Required navigation performance
RSP	Required Surveillance Performance
SASP	Separation and Airspace Safety Panel
SBAS	Satellite-based augmentation system
TSO	Technical standard order
VHF	Very high frequency
VOR	Very high frequency omnidirectional radio range
WGS-84	World Geodetic System – 1984
WP	Working paper

REFERENCES

The following documents are referred to in this circular or may provide additional guidance material.

ICAO DOCUMENTS

Doc 4444 — *Procedures for Air Navigation Services — Air Traffic Management* (PANS-ATM)

Doc 9613 — *Performance-based Navigation (PBN) Manual,* Volume II— *Implementing RNAV and RNP Operations*

Doc 9689 — *Manual on Airspace Planning Methodology for the Determination of Separation Minima*

Doc 9859 — *Safety Management Manual*

Doc 9869 — *Performance-based Communication and Surveillance (PBCS) Manual*

Doc 10037 — *Global Operational Data Link (GOLD) Manual*

Doc 10038 — *Satellite Voice Operations Manual*

Doc 10063 — *Manual on Monitoring the Application of Performance-based Horizontal Separation Minima*

OTHER DOCUMENTS

D. A. Hsu, *The Evaluation of Aircraft Collision Probabilities at Intersecting Air Routes*. Journal of Navigation, Vol. 34, No 1, 1981.

A. Osamu and N. Sakae, *Analysis on the Navigation Accuracy of GPS Equipped Aircraft on an Oceanic Route*, Journal of Japan Institute of Navigation, 102, pages 27–35, 2000.

M. Paglione, G. McDonald, I. Bayraktutar and J. Bronsvoort, *Lateral Intent Error's Impact on Aircraft Prediction*, Eighth USA/Europe Air Traffic Management Research and Development Seminar (ATM2009), 2009. http://www.atmseminar.org/seminarContent/seminar8/papers/p_141_TQM.pdf

Chapter 1

INTRODUCTION

1.1 PURPOSE

1.1.1. This circular provides guidance for the implementation of longitudinal separation minima intended for the separation of aircraft approved for performance-based operations (PBO). The guidance material is associated with the provisions previously included in the *Procedures for Air Navigation Services — Air Traffic Management* (PANS-ATM, Doc 4444), 5.4.2.6.3.1 and 5.4.2.6.4.3, which have now been moved to 5.4.2.9 Performance-based Longitudinal Separation Minima and includes a new 5 minute standard— see Chapter 2 of this circular.

1.1.2. To support the ICAO Global Air Navigation Plan Block 0 module B0-TBO – Improved Safety and Efficiency through the Initial Application of Data Link En-route, the 50 NM, 30NM and 5 minute longitudinal separations have been made conditional on Required Communication Performance 240 (RCP 240) and Required Surveillance Performance 180 (RSP 180) approvals. Application of the separation also requires an RNP approval.

1.2 GENERAL

1.2.1. Performance-based communications (PBC) and performance-based surveillance (PBS), as detailed in the *ICAO Performance-based Communication and Surveillance (PBCS) Manual* (Doc 9869), *Global Operational Data Link (GOLD) Manual* (Doc 10037) and *Satellite Voice Operations Manual* (Doc 10038), increase the robustness and safety of data link operations. This will enhance the usability of data link for application of separation.

1.2.2. The Separation and Airspace Safety Panel (SASP) has determined that some of the assumptions made in previous collision risk modelling for the 30 NM longitudinal separation needed to be reconsidered. This applies to:

a) the actual lateral track keeping performance of GNSS equipped aircraft. More accurate lateral track keeping increases the longitudinal collision risk. As a result, a conservative assumption is to assume observed GNSS lateral track keeping accuracy rather than the 95% RNP accuracy assumed in previous modelling; and

b) better information on speed error distributions enabled by extensive data collection from live operations.

1.2.3 The North Atlantic (NAT) Region has an operational requirement for the new 5 minute longitudinal separation. It was requested that the separation be made globally applicable rather than only regionally applicable in the NAT Region.

1.3 SCOPE

1.3.1. It is strongly advocated that, given the low speed variations used in the underlying assumptions for the modelling, appropriate air traffic control procedures and monitoring systems be in place to ensure the assumptions continue to be met in operations.

1.3.2. Attention for implementers is therefore directed to current ICAO provisions requiring speed control when aircraft are close to the longitudinal separation minimum, post-implementation monitoring of new separations as described in the *Manual on Monitoring the Application of Performance-based Horizontal Separation Minima* (Doc 10063), SMS practices as outlined in Annex 19 — *Safety Management* and also the Note below the new table in the revised 5.4.2.9.2.

Chapter 2

LONGITUDINAL SEPARATION MINIMA

2.1 This circular addresses the implementation of the performance-based longitudinal separation minima contained in the PANS-ATM which is reproduced below, Doc 4444, paragraph 5.4.2.9.

2.2 Since some separation minima in Chapter 5 are now reliant on data link, implementers need to take into account ICAO material concerning performance-based data link operations contained in the PANS-ATM, the *Performance-based Communication and Surveillance (PBCS) Manual* (Doc 9869), the *Global Operational Data Link (GOLD) Manual* (Doc 10037) and the *Satellite Voice Operations Manual* (Doc 10038).

2.3 The longitudinal separation has been changed to be applicable on crossing tracks where the relative angle between tracks is less than 90 degrees.

2.4 These separations are dependent on RNP, RCP, RSP and the length of the ADS-C periodic reporting interval.

EXTRACT FROM PANS-ATM

5.4.2.9 PERFORMANCE-BASED LONGITUDINAL SEPARATION MINIMA

Note.— Guidance material for implementation and application of the separation in this section is contained in the Performance-based Communication and Surveillance (PBCS) Manual *(Doc 9869), the* Global Operational Data Link (GOLD) Manual *(Doc 10037), the* Satellite Voice Operations Manual (SVOM) *(Doc 10038) and the* Guidelines for the Implementation of Performance-based Longitudinal Separation Minima *(Circular 343).*

5.4.2.9.1 Within designated airspace, or on designated routes, separation minima in accordance with the provisions of this section may be used, subject to regional air navigation agreements.

5.4.2.9.2 The following separation minima may be used for aircraft cruising, climbing or descending on:

a) the same track, or

b) crossing tracks provided that the relative angle between the tracks is less than 90 degrees.

Separation minima	*RNP*	*RCP*	*RSP*	*Maximum ADS-C periodic reporting interval*
93 km (50 NM)	10	240	180	27 minutes
	4	240	180	32 minutes
55.5 km (30 NM)	2 or 4	240	180	12 minutes
5 minutes	2 or 4 or 10	240	180	14 minutes

Note.— Detailed information on the analysis used to determine these separation minima and monitoring procedures is contained in the Guidelines for the Implementation of Performance-based Longitudinal Separation Minima *(Circular 343).*

5.4.2.9.3 Opposite-direction aircraft on reciprocal tracks may be cleared to climb or descend to or through the levels occupied by another aircraft provided that ADS-C reports show that the aircraft have passed each other by the applicable separation minimum in 5.4.2.9.2.

5.4.2.9.4 The five-minute separation shall be calculated to a resolution of one second without rounding.

5.4.2.9.5 Separation shall be applied so that the distance or time between the calculated positions of the aircraft is never less than the prescribed minimum. This distance or time shall be obtained by one of the following methods:

a) when the aircraft are on the same identical track, the distance or time may be measured between the calculated positions of the aircraft or may be calculated by measuring the distances or times to a common point on the track (see Figures 5-29 and 5-30);

Note.— Same identical tracks are a special case of same track defined in 5.4.2.1.5 a) where the angular difference is zero degrees or reciprocal tracks defined in 5.4.2.1.5 b) where the angular difference is 180 degrees.

b) when the aircraft are on same or reciprocal non-parallel tracks other than in a) above, or on crossing tracks, the distance or time shall be calculated by measuring the distances or times to the common point of intersection of the tracks or projected track (see Figures 5-31 to 5-33); and

c) when the aircraft are on parallel tracks whose protection areas overlap, the distance or time shall be measured along the track of one of the aircraft as in a) above using its calculated position and the point abeam the calculated position of the other aircraft (see Figure 5-34).

Note.— In all cases presented in Figures 5-29 to 5-34, "d" and "t" are calculated by subtracting the distance or time of the closer aircraft from the common point from the distance or time of the more distant aircraft from the common point, except in Figure 5-33 where the two distances or times are added and the order of the aircraft is not important in the calculation.

5.4.2.9.6 The communication system provided to enable the application of the separation minima in 5.4.2.9.2 shall allow a controller, within 4 minutes, to intervene and resolve a potential conflict by contacting an aircraft using the normal means of communication. An alternative means shall be available to allow the controller to intervene and resolve the conflict within a total time of 10.5 minutes, should the normal means of communication fail.

5.4.2.9.7 When an ADS-C periodic or waypoint change event report is not received within 3 minutes of the time it should have been sent, the report is considered overdue and the controller shall take action to obtain the report as quickly as possible, normally by ADS-C or CPDLC. If a report is not received within 6 minutes of the time the original report should have been sent, and there is a possibility of loss of separation with other aircraft, the controller shall take action to resolve any potential conflict(s) as soon as possible. The communication means provided shall be such that the conflict is resolved within a further 7.5 minutes.

5.4.2.9.8 When information is received indicating ground or aircraft equipment failure or deterioration below the communication, navigation and surveillance performance requirements, ATC shall then, as required, apply alternative separation minima.

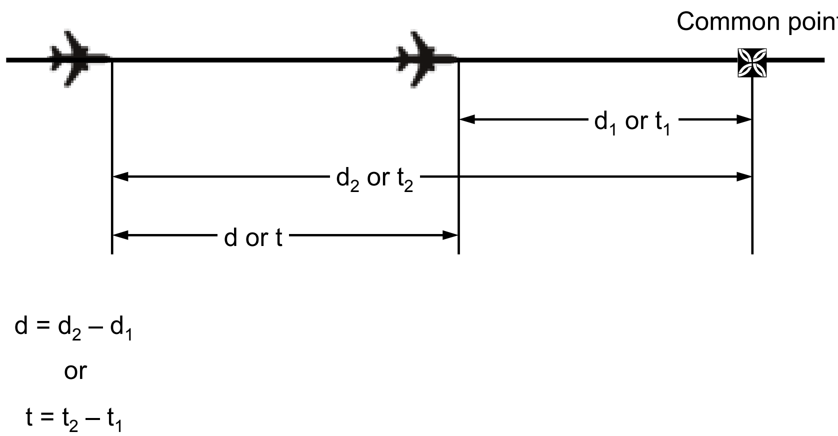


Figure 5-29. Calculation of longitudinal distance/time between aircraft — identical track, same direction (see 5.4.2.9.5 a))

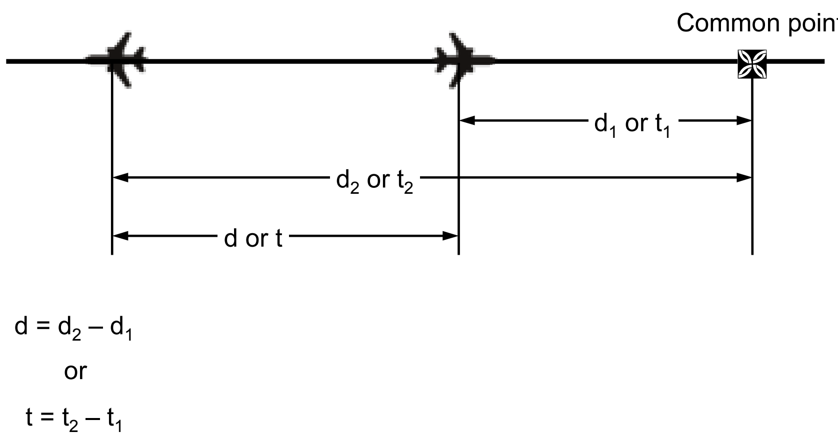
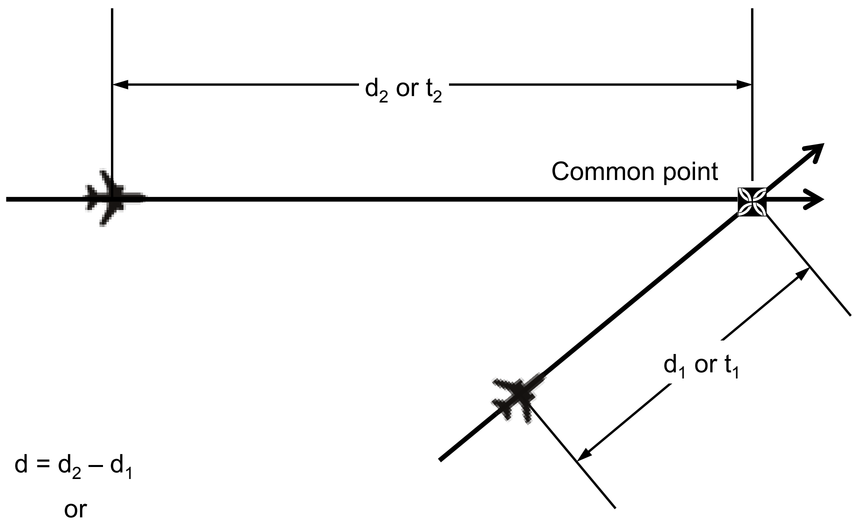


Figure 5-30. Calculation of longitudinal distance/time between aircraft — identical track, opposite direction (see 5.4.2.9.5 a))



$d = d_2 - d_1$

or

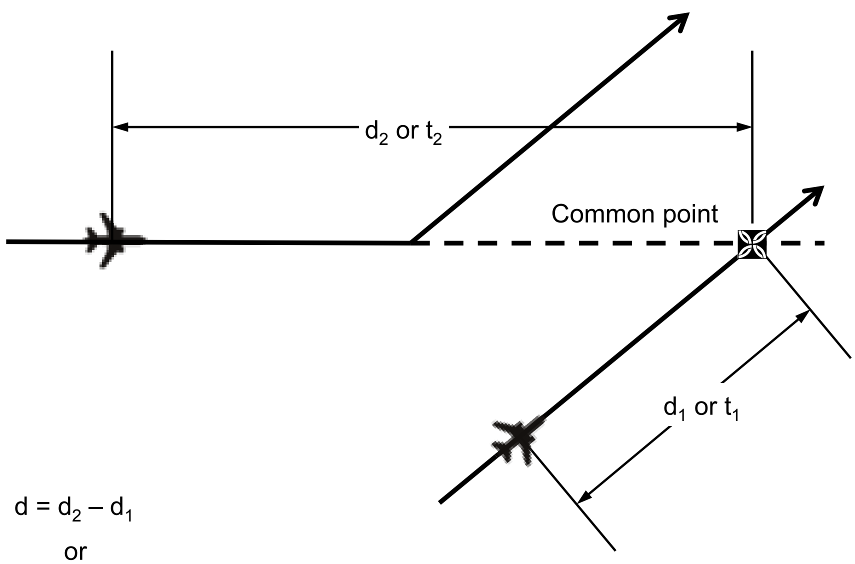
$t = t_2 - t_1$

$d = d_2 - d_1$

or

$t = t_2 - t_1$

Figure 5-31. Calculation of longitudinal distance/time between aircraft — same track, but not identical and crossing tracks (see 5.4.2.9.5 b))



$d = d_2 - d_1$

or

$t = t_2 - t_1$

Figure 5-32. Calculation of longitudinal distance/time between aircraft — same track projected, but not identical (see 5.4.2.9.5 b))

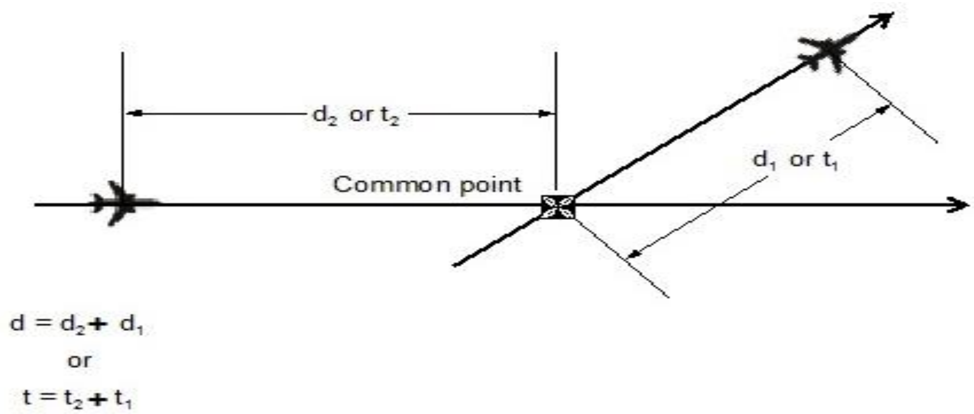


Figure 5-33. Calculation of longitudinal distance/time between aircraft — opposite sides of the common point (see 5.4.2.9.5 b))

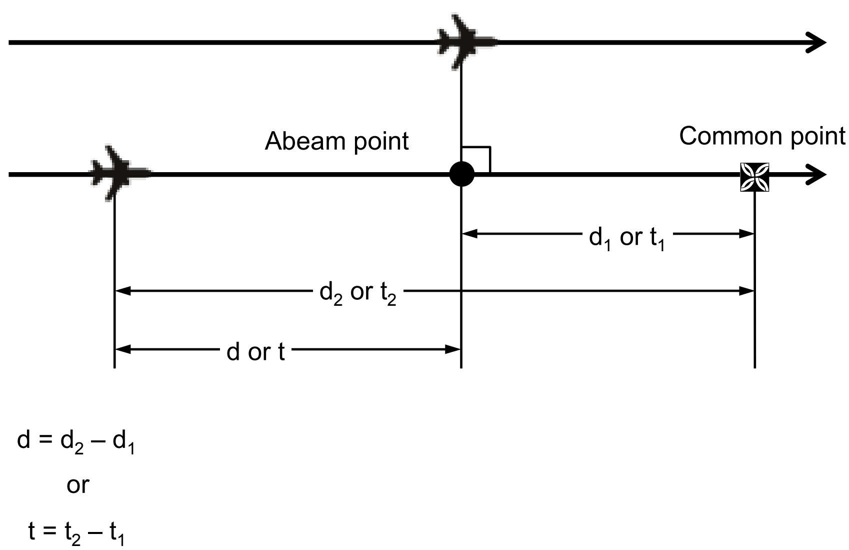


Figure 5-34. Calculation of longitudinal distance/time between aircraft – parallel tracks (see 5.4.2.9.5 c))

Chapter 3

SASP SAFETY ASSESSMENT

3.1 INTRODUCTION

This chapter summarizes the safety assessment performed by the SASP to determine the longitudinal separation minima, contained in the PANS-ATM, 5.4.2.9 Performance-based Longitudinal Separation Minima. In context, this chapter first describes the scope of any SASP safety assessment and then outlines the methodology used to arrive at the longitudinal separation minima.

3.2 SCOPE OF SASP SAFETY ASSESSMENT

3.2.1 In the context of the scope of the safety assessment, it is useful and necessary to distinguish between safety assessments undertaken by States for purposes of implementation at local or regional level and those undertaken by SASP from a *global perspective*. An assessment undertaken for global purposes does not always contain all the information required to address specific local implementation requirements.

3.2.2 The difference in assessment scope is depicted in Figure 3-1; it suggests, for example, that because the local operating environment into which performance-based longitudinal separation minima are to be integrated may have a significant effect on safety, the full safety assessment can only be completed for each local application. As such, the appropriate ATS authority needs to complement the SASP assessment with an implementation-focused assessment. It should be noted that a local implementation assessment may not necessarily require a regional assessment but may be initiated by an ANSP on a case-by-case basis.

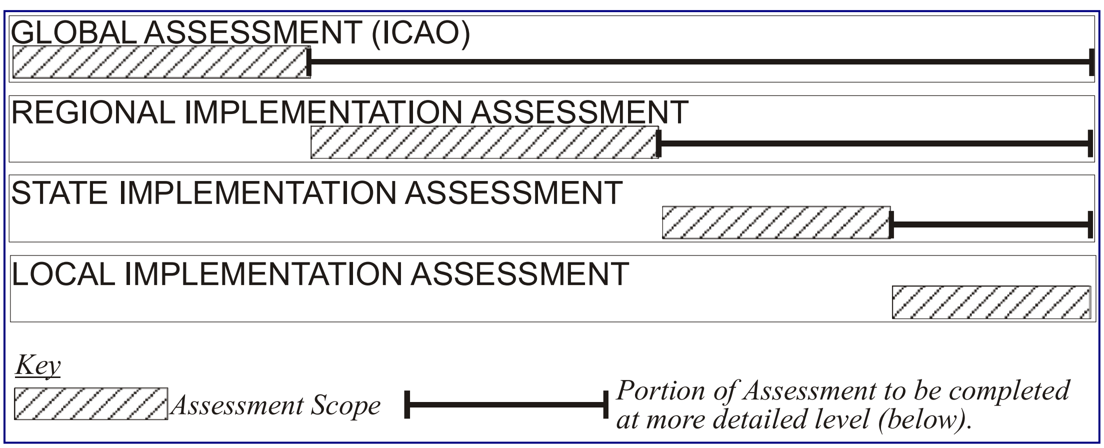


Figure 3-1: Safety Assessment Scope

3.2.3 SASP's assessment is based on a number of assumed characteristics related to either the airspace environment or aircraft performance. These characteristics may not necessarily be the same as those relevant to any particular regional, State or local implementation.

3.2.4 An implementation supporting safety assessment should begin with a review of SASP's global assessment taking particular note of the assumed characteristics used in that assessment. Where these characteristics are the same as or more stringent than those within the airspace being considered, the analysis only needs to focus on an assessment of matters related specifically to implementation.

3.3 SUMMARY OF KEY RESULTS FROM MODELLING

3.3.1 Monitoring Requirements

3.3.1.1 PANS-ATM, 5.4.2.1, specifies the following concerning Longitudinal Separation Application:

> 5.4.2.1.1 Longitudinal separation shall be applied so that the spacing between the estimated positions of the aircraft being separated is never less than a prescribed minimum. Longitudinal separation between aircraft following the same or diverging tracks may be maintained by application of speed control, including the Mach number technique. When applicable, use of the Mach number technique shall be prescribed on the basis of a regional air navigation agreement.
>
> *Note 1.— Attention is drawn to the guidance material contained in the* Air Traffic Services Planning Manual *(Doc 9426) regarding the application of the Mach number technique to separation of subsonic aircraft.*
>
> *Note 2.— The Mach number technique is applied using true Mach number.*
>
> 5.4.2.1.2 In applying a time- or distance-based longitudinal separation minimum between aircraft following the same track, care shall be exercised to ensure that the separation minimum will not be infringed whenever the following aircraft is maintaining a higher airspeed than the preceding aircraft. When aircraft are expected to reach minimum separation, speed control shall be applied to ensure that the required separation minimum is maintained.

3.3.1.2 Collision risk modeling done by the SASP for the longitudinal separation minima specified in this circular assumes that ATC apply the speed control methods referenced above. It has therefore been assumed that Mach numbers are assigned when aircraft are operating close to the separation minima even though this has not been explicitly specified in the separation minima due to the general requirements detailed in PANS-ATM, 5.4.2.1.

3.3.1.3 Monitoring of airspace features is necessary to satisfy the modeling assumptions:

a) where Mach is assigned, the speed estimates by the ATC system must be monitored with (distribution better than Laplace (2.5 knots)):

   i. 95 % of speed errors within 7.4 knots (0.012 Mach);

   ii. 99 % of speed errors within 11.5 knots (0.02 Mach); and

   iii. 99.9 % of speed errors within 17.2 knots (0.03 Mach).

b) where no Mach is assigned, the variation of aircraft speed estimates by the ATC system must be monitored for aircraft pairs close to the separation standard with (distribution better than Laplace (5.5 knots)):

i. 95 % of speed errors within 13 knots; and

ii. 99 % of speed errors within 22 knots.

c) no more than 2 per cent of all aircraft pairs should be within 5 NM of the separation standard;

d) no more than 4 per cent of all aircraft pairs should be within 10 NM of the separation standard;

e) no more than 6 per cent of all aircraft pairs should be within 15 NM of the separation standard; and

f) monitoring of required communication (RCP 240, 400) and surveillance performances (RSP 180).

3.3.1.4 Where airspace monitoring indicates one or some of these criteria is not met, then the standard may still be applicable given the full collision risk model is reproduced with the specific parameters of the airspace, and that this risk is still less than the TLS.

3.3.2 Summary of Key Concepts

3.3.2.1 This section summarizes the key concepts and assumptions used in the modelling.

3.3.2.2 **Mach limited**: Collision risk modeling assumes, in accordance with PANS-ATM section 5.4.2.1, that when aircraft are operating close to longitudinal separation minima that the speed of aircraft is assigned and monitored. A yearly analysis monitoring system must be in place to ensure aircraft maintain their speed within a distribution better than Laplace (2.5 knots) as indicated above. The parameter λ_v = 2.5 knots is assumed for Mach assigned and λ_v = 5.5 knots otherwise.

3.3.2.3 **Speed variability**: The speed variability is a key parameter and a yearly analysis monitoring regime should be in place to ensure this variability is acceptable.

3.3.2.4 **Maximum speed variability:** The speeds of aircraft are distributed around the nominal speed with the range truncated to $V \pm V_m$. For λ_v = 5.5 this truncation is V_m = 75 knots. For λ_v = 2.5 this truncation is V_m = 50 knots.

3.3.2.5 **Separation distributions**: Aircraft pairs are separated a distance S. The distribution of these distances should be monitored and analysed yearly to ensure compliance. Improved monitoring may allow for new modelling with a corresponding re-evaluation of separation standards (larger or smaller standards). The current model assumes a uniform distribution from S_X to $S_X + 250$ NM.

3.3.2.6 **Number of Pairs**: The model assumed NP=4 pairs per flight hour in the model for same-identical traffic and NP=1 for same track crossing at an angle.

3.3.2.7 **Aircraft sizes:** The assumed aircraft size is conservative and need not be monitored.

3.3.2.8 **Offset**: The modelling included offsets of 0.5 NM and 1.0 NM as well as random offsets (RO). For RO, the risk is assumed a factor of 4 lower than without RO. Here RO assumes aircraft offset randomly by either 0, 0.5, 1, 1.5 or 2 NM.

3.3.2.9 **Response time models**: The modelled assumptions for ADS-C failure rates, primary CPDLC communications and backup HF communications are conservative. Several different models are tested with the basic model being

$$CR = 0.9025\ CR(\tau = 4) + 0.0475\ CR(\tau = 10.5) + 0.05\ CR(\tau = 13.5) \quad (1)$$

This is denoted [4,10.5,13.5] minutes with weights [90.25,4.75,5] with NP=4. The range of models considered are:

a) Model 0: [4,10.5,13.5] minutes with weights [90.25,4.75,5] with NP=1;

b) Model 1: Gamma(4,2) with NP=1;

c) Model 2: [4,10.5,13.5] minutes with weights [90.25,4.75,5] with NP=4;

d) Model 3: Gamma(4,2) with NP=4;

e) Model 4: [4,11.5,14.5] minutes with weights [90.25,4.75,5] with NP=1;

f) Model 5: [4,7] minutes with weights [95,5] with NP=1;

g) Model 6: [4,7.5,10.5,13.5] minutes with weights [90.25,4.75,4.75,0.025] with NP=1; and

h) Model 7: [4,7.5,10.5,13.5] minutes with weights [90.25,4.75,4.75,0.025] with NP=4.

3.3.2.10 In evaluating the separation standards, Model 2 was used as it is the most conservative. Results were generally rounded **up** from this value to the nearest integer given this models over conservative nature. Model 5 is considered too liberal. Model 7 would be considered appropriate although this needs further consideration by SASP.

3.3.3 Key Graphical Results

3.3.3.1 This section uses Figures 3.3.1 and 3.2 to illustrate the key results.

3.3.3.2 Figure 3.1 gives the maximum tolerable duration of inter-report periods for a given separation standard when aircraft are RNP 2 and Mach speed restrictions are enforced, giving λ_v = 2.5 knots and V_m = 50 knots. Results are presented for either no offset, RO, 0.5 or 1 NM assigned offset. Figure 3.2 gives similar results for no speed restrictions (λ_v = 5.5 knots and V_m = 75 knots).

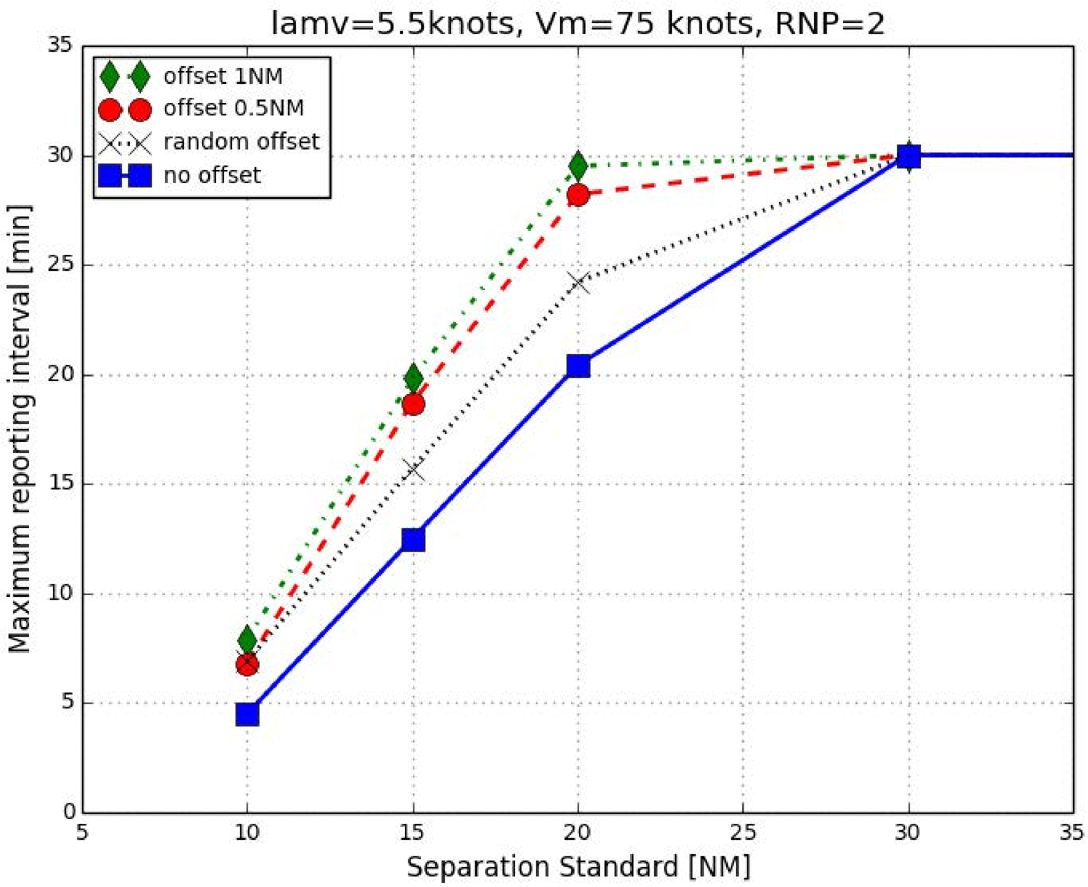


Figure 3.1. Maximum reporting interval in minutes, versus separation standard for either not offset, random offset (RO), 0.5 NM and 1 NM assigned offset. Here RNP =2 and aircraft are speed monitored (λv = 2.5 knots). For example: for 20 NM a maximum reporting interval of 20 minutes will give a risk below the TLS when no offset is in place. With RO this increases to 24 minutes. Note that the upper limit of 30 minutes is a constraint of these modelling results.

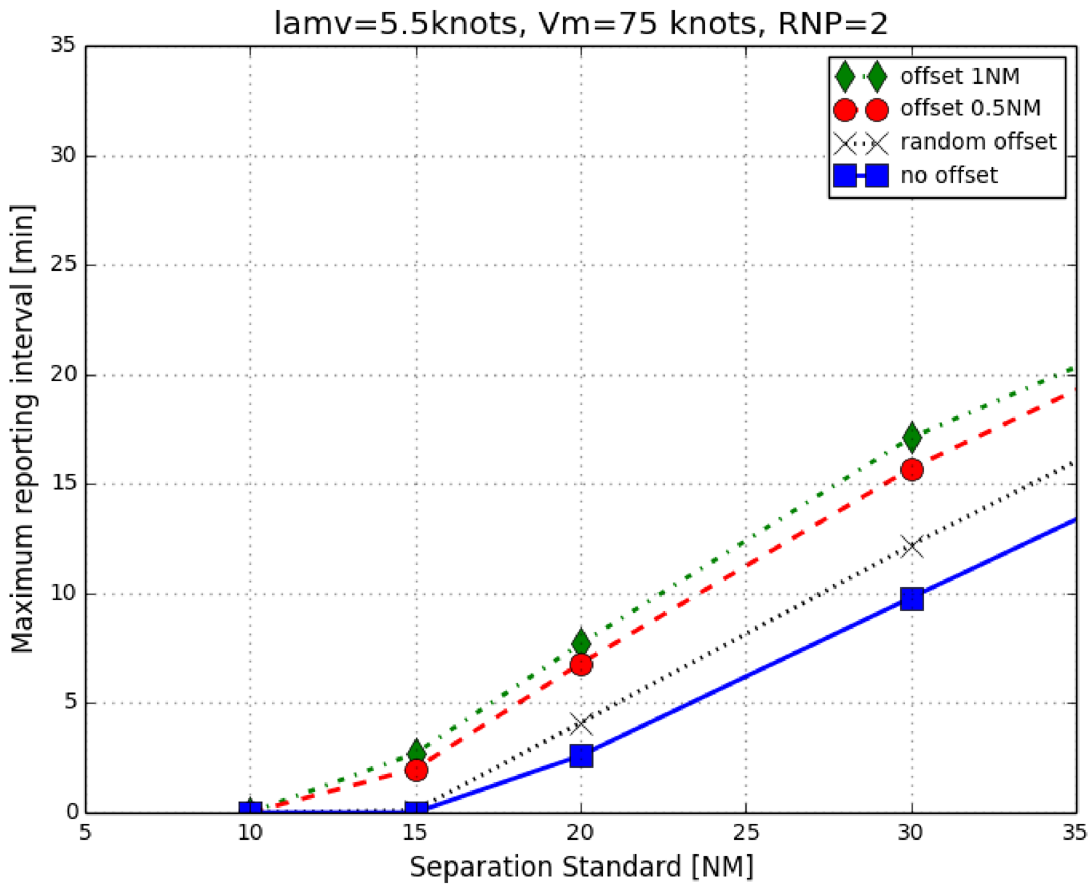


Figure 3.2. Maximum reporting interval in minutes, versus separation standard for either not offset, random offset (RO), 0.5 NM and 1 NM assigned offset. Here RNP =2 and aircraft are not speed monitored ($\lambda_v \approx$ 5.5 knots). For example: for 20 NM a maximum reporting interval of 2 minutes will give a risk below the TLS when no offset is in place. With an assigned 1.0 Nm offset this increases to 8 minutes.

3.3.3.3 Figures 3.3 and 3.4 give the maximum reporting times as a function of separation standard for the standard models: Model 0 uses response times τ = [4,10.5,13.5] minutes with proportions [90.25,4.75,5] and NP=1 while Model 2 has NP =4. Results are divided into angles either 1-90 degrees, 5-90 degrees or 5-45 degrees.

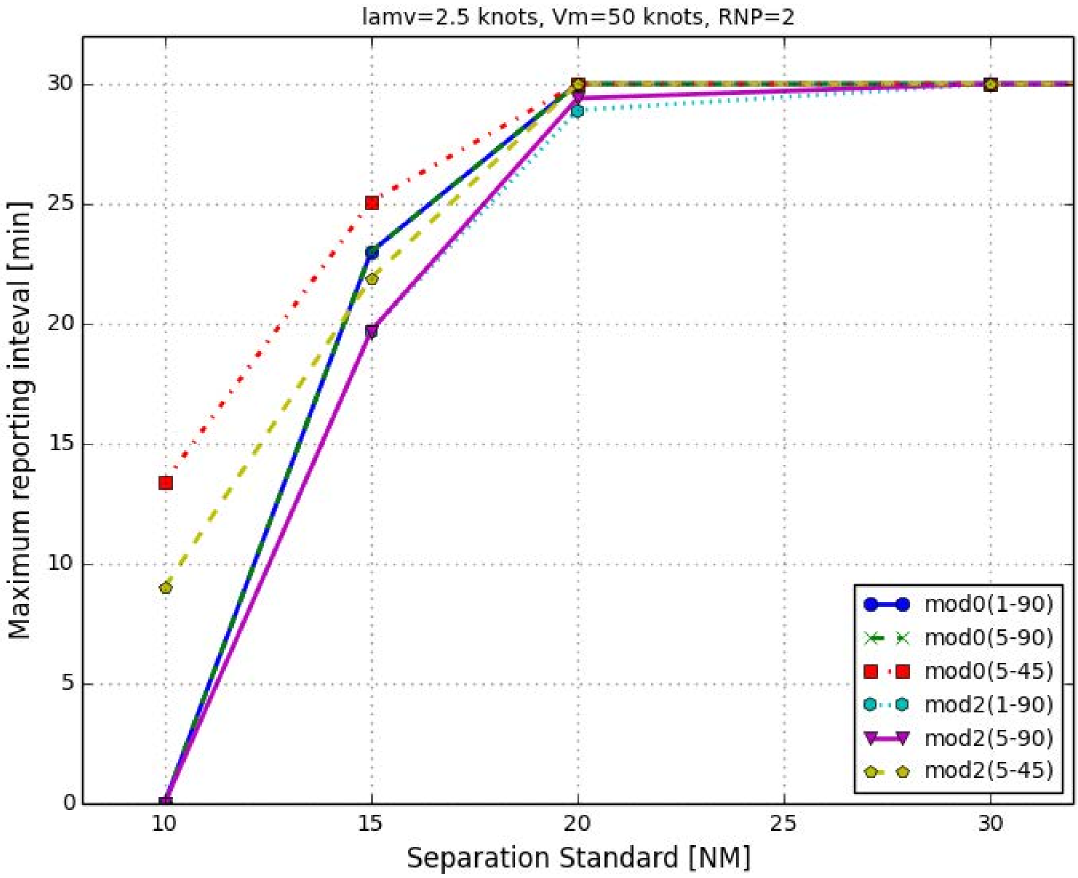


Figure 3.3. Maximum reporting interval in minutes, versus separation standard for aircraft on same track with crossing angles either 1-90 degrees, 5-90 degrees or 5-45 degrees. Model 0 uses response times τ = [4,10.5,13.5] minutes with proportions [90.25,4.75,5] and NP=1 while Model 2 has NP =4. Here RNP =2 and aircraft are speed monitored ($\lambda_v \approx 2.5$ knots, Vm = 50 knots). For example: for 15 NM a maximum reporting interval of 23 minutes will give a risk below the TLS for all angles 1-90 degrees, while if the angle is restricted to 5-45 degrees a large reporting time of 25 minutes can be used.

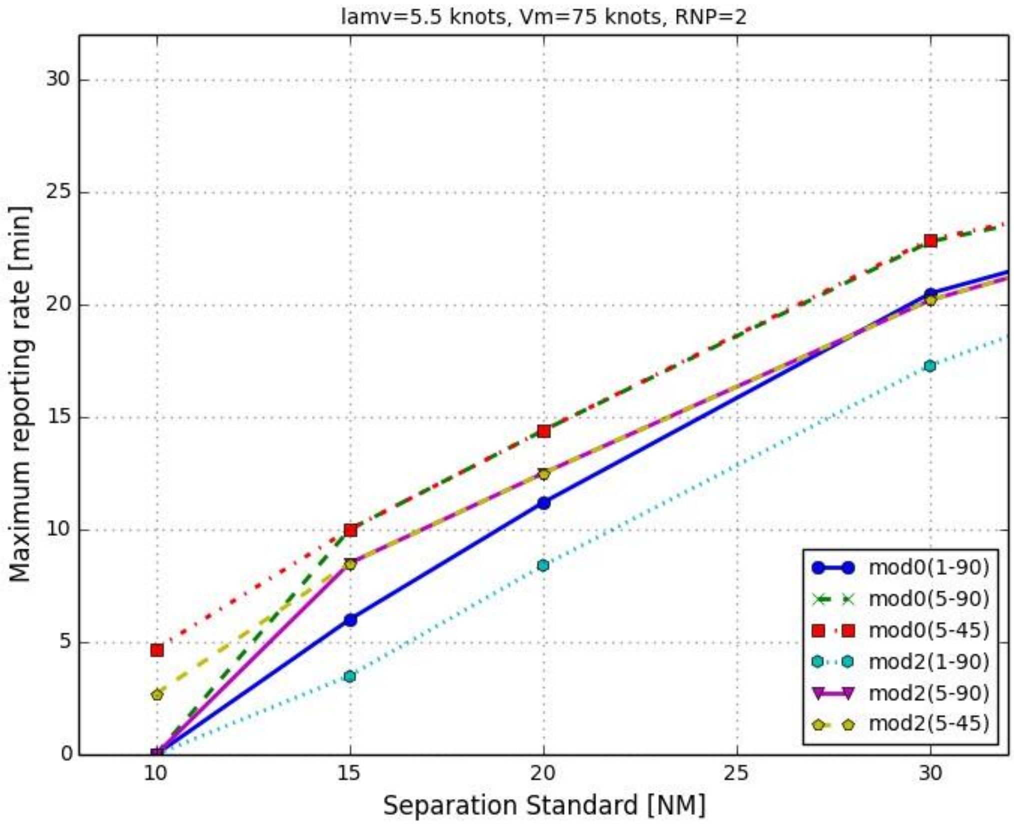


Figure 3.4. Maximum reporting interval in minutes, versus separation standard for aircraft on same track with crossing angles either 1-90 degrees, 5-90 degrees or 5-45 degrees. Model 0 uses response times τ = [4,10.5,13.5] minutes with proportions [90.25,4.75,5] and NP=1 while Model 2 has NP =4. Here RNP =2 and aircraft are not speed monitored ($\lambda_v \approx$ 2.5 knots, Vm = 75 knots). For example: for 20 NM a maximum reporting interval of 12 minutes will give a risk below the TLS for all angles 1-90 degrees, while if the angle is restricted to 5-45 degrees a large reporting time of 14 minutes can be used.

3.3.4 Summary and Conclusions

3.3.4.1 Speed variation and errors in speed estimation are a key factor in longitudinal risk analysis. Great care must be taken to monitor then analyze this value correctly.

3.3.4.2 Speed errors are well modelled by Laplace distributions. For Mach limited aircraft, or aircraft pairs close to the separation standard where closer monitoring of speed by ATC occurs, the scale parameter is $\lambda_v \approx 2.5$ knots. Where no monitoring occurs, this value is $\lambda_v \approx 5.5$ knots. Standards are defined here dependent of these criteria. Hence appropriate monitoring and analysis must occur to ensure the correct value is used.

3.3.4.3 An assigned and monitored offset of 0.5 NM or more greatly reduces the risk in same-identical track geometries. Random offsets (RO) also reduces the risk and allows for increases in reporting intervals.

3.3.4.4 Increased reporting time intervals will give results below the TLS for same track with crossing angles in the range of 1-90, 5-90 or 5-45 degrees.

3.3.4.5 These recommended combinations rely on an appropriate understanding of the underlying model and the assumptions used in the model. In particular, continued monitoring would be required to ensure that the aircraft and airspace using these standards have appropriate speed variations, Mach limitations, initial separation distributions and communications and surveillance performance.

3.3.4.6 Monitoring of the following airspace features is necessary in order to satisfy the assumptions in the modelling:

a) the variation of aircraft speed estimates as done by the ATC system must be monitored;

b) no more than 2 per cent of aircraft pairs should be within 5 NM of the separation standard;

c) no more than 4 per cent of aircraft pairs should be within 10 NM of the separation standard;

d) no more than 6 per cent of aircraft pairs should be within 15 NM of the separation standard; and

a. RCP 240 and RSP 180 are assumed with appropriate monitoring as described in Doc 9869, *PBCS Manual*.

3.3.4.7 Studies have shown [25] that a 5 minute longitudinal standard equivalent to the RLongSM trials in the North Atlantic [29, 30] can be maintained with a 14 minute reporting time. This standard is valid for all RNP 1, 4 or RNAV 10 aircraft. The same monitoring requirements are necessary with distance measures replaced by the equivalent time using the mean speed. For example, the requirement of no more than 2 per cent of aircraft should be separated by less than 5.6 min (S+5 NM at 480 knots).

3.4 MATHEMATICAL MODEL

3.4.1 Earlier papers [3, 5, 7, 8] give a derivation of a collision risk model based on reliability theory and the original Hsu model [35]. The collision risk in units of fatal accidents per flight hour during a time interval [t0, t1] is given by:

$$CR(t_0, t_1) = 2.\mathrm{NP}.\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{t_0}^{t_1} \mathrm{HOP}\,(t \mid V_1, V_2) P_z(h_z)\left(\frac{2V_{rel}}{\pi\lambda_{xy}} + \frac{\overline{|\dot{z}|}}{2\lambda_z}\right) f_1(V_1) f_2(V_2)\, dt\, dV_1\, dV_2. \qquad (2)$$

Here V_1 and V_2 are the speeds of the two aircraft, λ_z and λ_{xy} are the dimensions of the cylinder representing the aircraft, $V_{rel} = \sqrt{V_1^2 + V_2^2 - eV_1V_2\cos\theta}$ is the relative horizontal speed between the two aircraft, and HOP is the horizontal overlap probability. The integral over V_1 and V_2 with their respective probability distributions $f_1(V_1)$ and $f_2(V_2)$ is simply taking into account the variation in speeds around the pair of nominal speeds. In this analysis, we use a double exponential distribution with scale parameter 5.5 knots. The sensitivity to this parameter is analysed with results also presented for $\lambda_v = 4.5$ and 6.5 knots. The speed distribution is truncated at $\pm V_m$ knots with the distribution normalised to unity. The term $P_z(h_z)$ is the probability that two aircraft nominally vertically separated by h_z are in vertical overlap. NP is the number of aircraft pairs per flight hour. The term $\overline{|\dot{z}|}$ represents the average vertical aircraft speed in nominally level flight. The time interval $[t_0, t_1]$ covers the period when the two aircraft are close enough to each other near the intersection to make a non-negligible contribution to the collision risk.

3.4.2 Section 3.10 gives a listing of all notation. Section [AHdervn] gives a more complete derivation of the Anderson-Hsu model.

3.4.3 The vertical overlap probability Pz (hz) is a convolution of the vertical position error distributions for both aircraft. In line with [7, 8], we use:

$$P_z(h_z) = \exp(-0.5978 - h_z\,(1.908 \times 10^{-3} + h_z\,(2.063 \times 10^{-5} - h_z\,1.225 \times 10^{-8}))) \qquad (3)$$

for $h_z \leq 1000$ ft and $P_z(h_z) = P_z(1000)$ for $h_z > 1000$ feet.

3.4.4 The HOP term can be evaluated in terms of multiple integrals of the probability density functions for the along- and cross-track position errors of each aircraft. These are complicated expressions which form a main part of earlier papers [7, 8]. In general, HOP is:

$$\iiiint_{d_h < \lambda_{xy}} f_1^A(\epsilon_1^A) f_2^A(\epsilon_2^A) f_1^C(\epsilon_1^C) f_2^C(\epsilon_2^C)\, d\epsilon_1^A\, d\epsilon_2^A\, d\epsilon_1^C\, d\epsilon_2^C\,, \qquad (4)$$

with ε_1^A representing the along-track position error for aircraft 1 and the other terms representing along- and cross-track position errors for each aircraft in an obvious notation. The integral is over all values of the four ε variables such that the horizontal plane distance (denoted d_h) between the two aircraft is less than λ_{xy}. For an assumption of the same double exponential distribution for all the errors, and an angle of zero degrees, an equation for HOP is:

$$\mathrm{HOP}(t \mid V_1, V_2) = \frac{\pi\lambda_{xy}^2}{16\lambda^2} e^{-|D_x(t)|\frac{}{\lambda}} \left(\frac{|\,D_x(t)\,|}{\lambda} + 1\right), \qquad (5)$$

where $D_x(t)$ is the distance between the two aircraft and $\lambda = \rnp/\log(20)$ is the scale parameter of the along- and cross-track error distributions. Here $\rnp$ denotes the ONP or RNP accuracy of the aircraft. This is based on the central 0.95 probability region. The accuracy for RNP 2 is =2 NM. More complicated expressions for other angles were determined analytically using an algebraic manipulation package.

3.4.5 Note that recent work in [19] has shown Equation 5 is incorrect for small values of λ (this term is a probability but can become infinite for small λ). A correction was given in this paper replacing it by the correct cumulative distribution function. Appendix 3.12 contains copies of relevant sections of this paper.

3.4.6 The final CR is given as

$$\mathrm{CR} = \int_{S=S_x}^{S_x+250} H(S)\mathrm{CR}(t_0, t_1; S)\, S5 \qquad (6)$$

where H(S) is the initial distribution of separations in the airspace.

3.4.1 Mathematical Model – Time-Based Separation Model

3.4.1.1 This section gives information on how the Anderson-Hsu model was modified to account for time-based separation standards and used to vary the use of a 5 minute separation standard. The material is drawn from SASP/25-WP/16. The RLongSM model used in the North Atlantic requires a specific set of data monitoring to support the 18 minute standard. The modified Anderson-Hsu model for time-based separation is more general and with different assumptions shows with appropriate monitoring that a 14 minute separation standard meets the TLS.

3.4.1.2 A key element of this model is that each aircraft has a range of speeds around the nominal value V due to errors between what ATC believes the speed to be and what the speed actually is. This speed variation is given by distributions $f_1(V_1)$ and $f_2(V_2)$ which are usually well fitted by a Laplace distribution with scale parameter in the range 5.8 to 6.5 knots. The range of possible aircraft separations, S, needs to be integrated to find the overall risk. In the numerical modelling done by SASP, a uniform distribution is assumed for the aircraft separations:

$$\mathbf{CR}(t_0, t_1) = \int_0^{\infty} U(S, [S_x, S_x + 250])\, \mathbf{CR}(t_0, t_1 | S)\, dS \qquad (7)$$

with S_x to be the minimum longitudinal separation in distance, U(S) is the probability density function of initial separations – here a uniform distribution between S_x and $S_x + 250$ NM, and $CR(t_0, t_1 \mid S)$ is the collision risk during the time interval $[t_0, t_1]$ for given initial separation S.

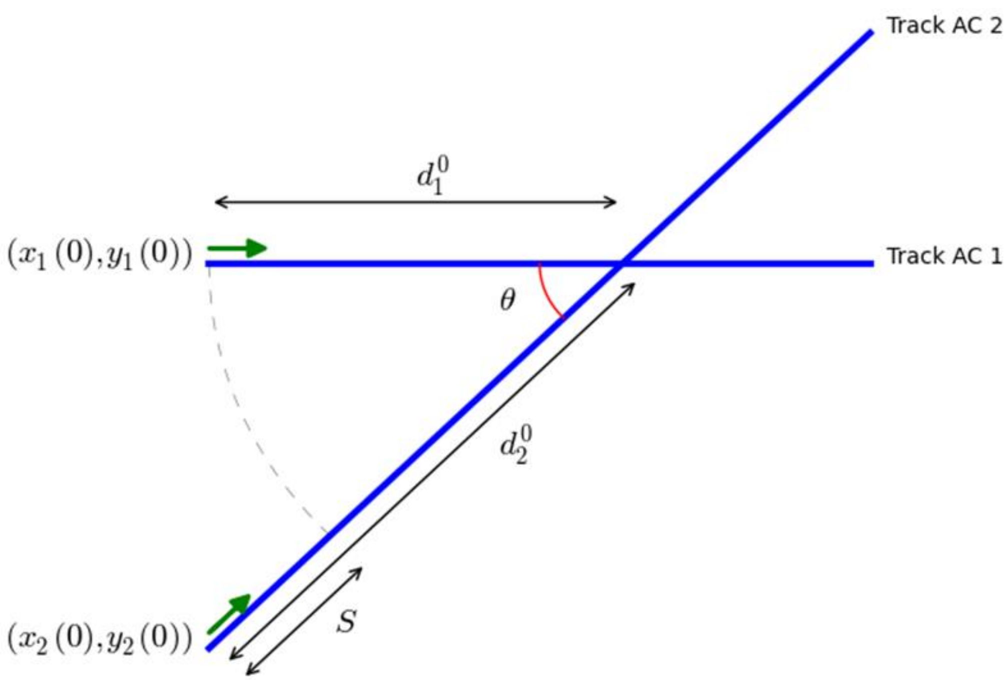


Figure 3.5. Nominal positions of aircraft on intersecting tracks at time t_0 (usually assumed 0)

3.4.1.3 Figure 3.5 shows the scenario of two aircraft on tracks crossing at an angle θ. At time t_0 (often set to $t_0 = 0$), aircraft 1 with speed V_1 and aircraft 2 with speed V_2 have nominal distances d_1^0 and d_2^0 respectively to the intersection. The initial distance difference is denoted as $S = d_2^0 - d_1^0$. The time separation at the intersecting point is denoted as T_s and measured as the time difference between the two aircraft arrival times at the intersection:

$$T_s = \frac{d_2^0}{V_2} - \frac{d_1^0}{V_1}. \tag{8}$$

3.4.1.4 Let $W = V_1 - V_2$ and assume $| W | \ll V_2$ then

$$\begin{aligned} T_s &= \frac{S + d_1^0}{V_2} - \frac{d_1^0}{V_2 + W} && (9) \\ &= \frac{1}{V_2}\left(S + d_1^0 - \frac{d_1^0}{1 + \frac{W}{V_2}}\right) && (10) \\ &\approx \frac{1}{V_2}\left(S + d_1^0 - d_1^0\left[1 - \frac{W}{V_2}\right]\right) && (11) \\ &= \frac{1}{V_2}\left(S + \frac{W d_1^0}{V_2}\right). && (12) \end{aligned}$$

3.4.1.5 Therefore, the given initial separation distance S is related to the time separation T_s by:

$$S \approx T_s V_2 - \frac{W d_1^0}{V_2}. \tag{13}$$

3.4.1.6 The model usually assumes that the speeds of both aircraft are the same, as this gives the greatest risk. It is assumed that if aircraft are near the separation standard then no controller would allow nominal speeds V2 >V1. If nominal speeds are such that V2 <V1, then the risk is small. Thus maximum risk is obtained if V2 =V1.

3.4.1.7 To extend the model to a time-based model, we would need to add another integral of the nominal speeds of the aircraft:

$$\mathbf{CR}(t_0, t_1 | T_s) = \int_{\overline{V}} \int_{V_1=-\infty}^{\infty} \int_{V_2=-\infty}^{\infty} \int_{t=t_0}^{t_1} [\ldots] f_1(V_1|\overline{V})\, f_2(V_2|\overline{V})\, f_v(\overline{V}) dt\, dV_1\, dV_2\, d\overline{V}. \tag{14}$$

This is clearly cumbersome.

3.4.1.8 As the relative speeds of the aircraft are the main risk, we can well approximate the double speed integrals as:

$$\int_{V_1=-\infty}^{\infty} \int_{V_2=-\infty}^{\infty} [\ldots] f_1(V_1|\overline{V})\, f_2(V_2|\overline{V})\, dV_1\, dV_2 \approx \int_{W} [\ldots]\, f_W(W|\overline{V})\, dW \tag{15}$$

with W the relative speed and f_W the distribution of relative speeds. The latter is easily done by a convolution of f_1 and f_2. The integrals are reduced to:

$$\mathrm{CR}(t_0, t_1|T_s) = \int_{\overline{V}} \int_{W=-\infty}^{\infty} \int_{t=t_0}^{t_1} [\ldots] f_W(W|\overline{V}) f_v(\overline{V})\, dt\, dW\, d\overline{V} \qquad (16)$$

where we now only consider the variation in the speed difference between the aircraft. This makes for an easier comparison with the RLongSM work as well as the results found recently which considered speed difference in aircraft pairs.

3.4.1.9 The recent work analysed two large sets of ADS-C speed prediction data to find that aircraft speeds were well matched by combinations of two Laplace Convolution functions:

$$f_W(W) \approx 0.86\, C(3.3) + 0.14\, C(12.9) \qquad (17)$$

(with 3.3 and 12.9 in knots), with

$$C(W, \lambda_1) \approx L(W, \lambda_1) \circ L(W, \lambda_1) = \frac{1}{4\lambda_1} e^{-|W|/\lambda_1} \left(\frac{|W|}{\lambda_1} + 1 \right) \qquad (18)$$

and L the Laplace distribution:

$$L(v, \lambda_1) = \frac{1}{2\lambda_1} e^{-|v|/\lambda_1}. \qquad (19)$$

3.4.1.10 The risk for a given time separation is then:

$$\begin{aligned} \mathrm{CR}(t_0, t_1|T_s) \;&=\; 2\mathrm{NP} \int_{\overline{V}} \int_{W=-\infty}^{0} \int_{t_0}^{t_1} \mathrm{HOP}(t|W, V_r, Ts) P_z(h_z) \left(\frac{2V_r}{\pi \lambda_{xy}} + \frac{\overline{|\dot{z}|}}{2\lambda_z} \right) \\ &\quad \times f_W(W|\overline{V}) f_{\overline{V}}(\overline{V})\, dt\, dW\, d\overline{V}. \end{aligned} \qquad (20)$$

with f_V the probability density function of nominal speeds. From Equation (7):

$$\mathrm{CR}(t_0, t_1) \;=\; \int_{T_s} H^*(T_s)\, \mathrm{CR}(t_0, t_1|T_s)\, dT_s \qquad (21)$$

where $H^*(T_S)$ is the probability density function of the initial separation in time T_s.

3.4.1.11 In summary, the distance-based model is Equations 6 and 7. The time-based model is Equations 20 and 21.

3.4.1.12 Figure 3.6 shows an example comparison of how use of a uniform distribution for the time-based separations ($H^*(T_S)$) gives a non-uniform distance separation distribution. Here a uniform distribution for distance is compared with the resulting distance distribution from the model, calculated using 100 000 random samples values drawn from a uniform distribution in time multiplied by a uniform distribution in speed.

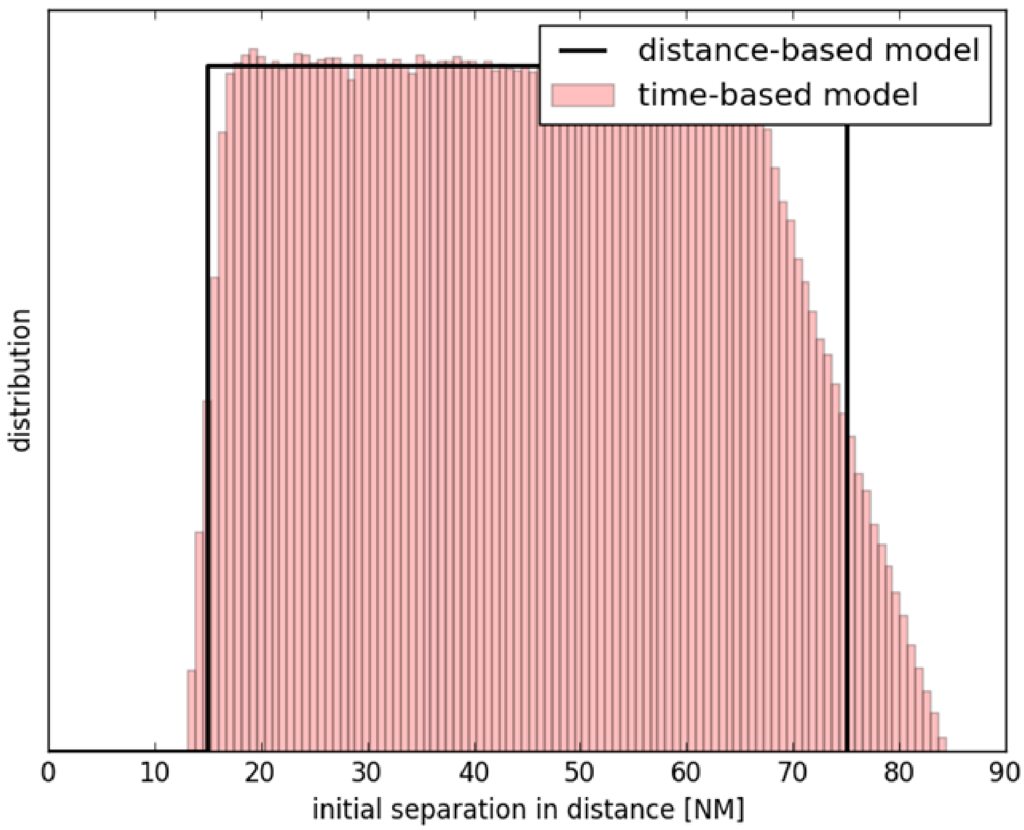


Figure 3.6. An example comparison of the initial distance separation distributions for the \dbAH model (black solid line) and the \tbAH model (red histogram, derived by multiplying samples from uniform distributions for time and speed). The histogram was generated from random samples drawn from a uniform separation distribution from 1.875-9.375 minutes and a uniform speed distribution from 420 to 540 knots.

3.5 NUMERICAL METHODOLOGY

3.5.1 The numerical scheme outlined in [8] is followed, and the computer code used was based on the original C code written by Dr. David Anderson. The difficult integrals were calculated in [8] using a computational algebra system. The scheme involves a quadruple integral over time, speeds of both aircraft and initial separation distance. The methodology is illustrated here using the same identical track case.

3.5.2 Numerical integration is used to evaluate the two speed integrals and the time integral. As in [7, 8] results are integrated over an interval of initial aircraft separation from the standard S = Sx to S = Sx + 250 NM. A uniform distribution for S is assumed. Since the major contribution to the error comes from the smallest separation distances, it is only necessary to carry out the integration for:

S ∈ [Sx, Sx + 75] with the contribution being effectively 0 for S ∈ [Sx + 75, Sx + 250].

3.5.3 This assumption of a uniform distribution for S is conservative. Later sections in this chapter discuss this assumption in more detail.

3.5.4 The time integral was performed using Boole's rule with NT points given by:

$$\mathrm{NT} = 4(\mathrm{int}[60(\mathrm{t}_1 - \mathrm{t}_0) + 0.5], \qquad (22)$$

where t_1 and t_0 are the time limits of the integral and 'int' is the integer value. The factor of 4 is to ensure that there are the correct multiple of points necessary for Boole's rule.

3.5.5 This was tested for speed and numerical accuracy and this discretisation gave results adequate to three significant figures.

3.5.6 The spatial integral was done assuming a uniform distribution between a given Sx and Sx + 250 and integrated using Simpson's rule. The collision risk is dominated when the distance is smallest hence the numerical integral uses a finer discretisation for the smaller values of S. The number of subdivisions for the distance S integral was NS = 60.

3.5.7 The scale parameter in the double exponential distribution used for the position estimate is given by:

$$\lambda = \frac{\mathrm{Acc}}{\ln(20)} \approx \frac{\mathrm{Acc}}{3}. \qquad (23)$$

3.5.8 The value of log 20 is chosen to fit the requirement that Pr(d<Acc) >0.95, since for a double exponential distribution this is:

$$\Pr(d < x) = 1 - e^{-x/\lambda} \rightarrow \Pr(d < \mathrm{Acc}) = 0.95 \qquad (24)$$

This gives Pr(d < 2Acc) = 0.9975 which does not meet the RNP requirement of Pr(d < 2Acc) > 0.99999 where d is the distance from the nominal position [9].

3.5.9 A value of λ ≈ Acc/5.75 is needed for a double exponential distribution to fit the requirement of Pr(d < 2Acc) > 0.99999.

3.5.10 Figure 3.7 gives the distributions for a double exponential with scale parameters λ = (Acc2)/ ln 20, λ = (Acc4)/ ln 20, λ = (Acc2)/5.75, and a Gaussian distribution with σ = (Acc2)/1.96 which fits the requirement that P r(d < Acc) > 0.95. Here Acc2 denotes accuracy for RNP 2.

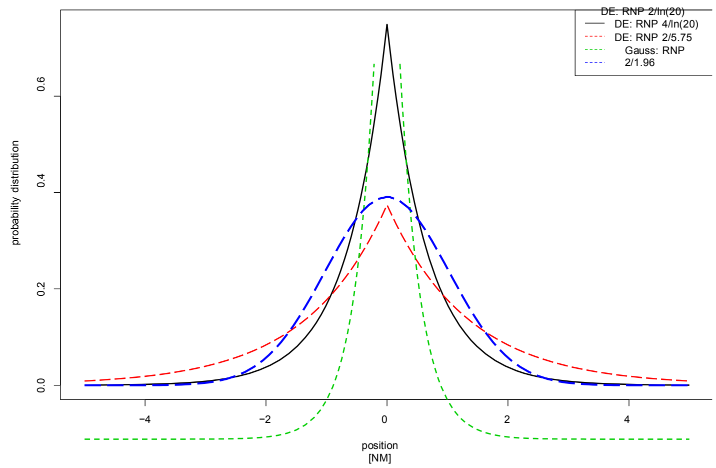


Figure 3.7: Double exponential (DE) probability density ** for position error for RNP 2. The decay parameter is λ = Acc2/ log(20) NM. Also shown is the DE distribution for RNP 4, a more stringent DE with scaling parameter Acc2/5.75 and a Gaussian with scaling parameter σ = Acc2/1.96 (chosen to give P r(d < Acc) = 0.95).

3.6 MODELLING ASSUMPTIONS

3.6.1 This section explores some of the major assumptions used in the modelling.

3.6.1 Parameters

3.6.1.1 There are numerous parameters in the model, and it is impossible to explore and document the full variation of the model for all possible sets of parameters. Table 3.1 contains a list of parameters used, their default value and the range of values explored. Thus, depending on the problem, different combinations of parameters will be used to interpret the behaviour of the system and aid in understanding the fundamental characteristics of the system.

3.6.1.2 The next section explores some of the assumptions regarding these parameters in more detail.

Table 3.1. Fixed and variable parameters for the calculations in this paper

parameter	*meaning*	*units*	*default*	*range explored*
λ_V	speed decay	knots	5.5	[4.5,5.5,6.5]
V_m	maximum speed var'n	knots	100	[20 - 100]
S_X	separation standard	NM	20	[10,15,20,25,30]
RNP	navigation performance	NM	2	[2,4]
ONP	observed nav. perf.	NM	0.05	[0.05 - RNP]
τ	response times	mins	[4,10.5,13.5]	various models
T	reporting time	mins	14	[4 - 30]
V_1, V_2	aircraft speeds mean	knots	480	[300 - 600]
$\lvert\dot{z}\rvert$	vertical speed var'n	knots	1.5	fixed
$P_Z(0)$	vertical overlap	probability	0.55	fixed
λ_{xy}	aircraft length or span	ft	231.8 ft	fixed
λ_Z	aircraft height	ft	63.2	fixed
NP	number of pairs	per Fl. hr	1	[1, 4, 1/T]

3.6.2 Aircraft size

3.6.2.1 This section considers the relevance of the use of parameters: $\lambda xy = 231.8$ ft, the diameter of the assumed cylinder for the aircraft and $\lambda_z = 63.2$ ft, the height of the assumed cylinder for the aircraft. These correspond to a B747. In nautical miles, these are 0.038153 NM and 0.0104 NM, respectively.

3.6.2.2 Previous studies have used the following assumptions:

a) (192.2 ft, 54.8ft) [4, 5, 7, 8] for RNP 10 studies;

b) (231.8 ft, 63.4 ft) [7, 8] for RNP 4 studies;

c) (220.6 ft, 61.36 ft) [30]: Anchorage airspace;

d) (218 ft, 60.71 ft) [39]: a study of NOPAC routes; and

e) a study [29] of Anchorage and New York airspaces showed a (33 ft, 8 ft) difference in mean aircraft dimensions.

3.6.2.3 In the Hsu model, there are two places where these parameters occur: as a ratio λ_{xy}/λ_z, which will not change significantly, and λ_{xy}^2 which is a proportional constant in the equations. Thus using the A388 dimensions will increase the risk by 3.65 per cent over the use of our B744 value. Similarly, use of the mean size (220 ft) would reduce the risk by 10 per cent.

3.6.2.4 Table 3.2 shows results from an analysis of ADS-C data using 25 339 flights, with 180 103 way-point reports from four months of Australian airspace covering approximately 90 664 flight hours. It shows a mean aircraft size (weighted by flight hour) of $\lambda_{xy} = 219$ ft, the diameter of the assumed cylinder for the aircraft and $\lambda_z = 61$ ft for the height.

3.6.2.5 Hence our use of 231.8 ft can be considered a reliable and conservative estimate for the risk.

Table 3.2: Aircraft flight hours and dimensions from four months of 2013 ADS-C and CPDLC data sourced from Airservices Australia

Type	*Flights*	*Reports*	*Flight Hrs*	*per cent*	*Weight ’000 kg*	*Span m*	*Length m*	*Height m*	*S ft*	*L ft*	*H ft*
Total	25339	180103	90663	100	312	63.22	66.77	18.57	207	219	60
A333	5626	30421	19551	21.56	233	60.30	63.60	16.74	197	208	54
B772	4457	34587	17398	19.19	263	60.93	63.73	18.51	199	209	60
A332	4749	21816	14324	15.80	230	60.30	59.00	16.83	197	193	55
A388	2664	29730	12049	13.29	586	79.80	76.01	24.10	261	249	79
B773	2547	28447	11455	12.64	300	60.93	73.86	18.51	199	242	60
B744	2238	13363	6203	6.84	385	64.44	70.67	19.41	211	231	63
B77W	1284	7551	4613	5.09	341	60.93	73.86	18.51	199	242	60
A346	312	4165	1436	1.58	365	63.70	75.30	17.80	208	247	58
A343	404	4592	1109	1.22	275	60.30	59.39	16.74	197	194	54
B77L	282	1567	734	0.81	297	60.93	63.73	18.51	199	209	60
MD11	271	1067	686	0.76	273	51.66	61.21	17.60	169	200	57
A330	57	282	236	0.26	230	60.30	59.00	16	197	193	55
B763	132	582	218	0.24	175	47.57	54.94	15	156	180	52
A320	151	593	201	0.22	77	34.09	37.57	11	111	123	38
GLF5	44	454	133	0.15	41	28.50	29.39	7.87	93	96	25
GLEX	32	250	85	0.09	43	28.65	30.30	7.57	93	99	24
A345	11	210	82	0.09	365	63.70	67.86	17.80	208	222	58
B748	12	25	46	0.05	987	76.25	68.45	19.35	250	224	63
B738	25	123	30	0.03	70	34.31	39.47	12.55	112	129	41
GLF4	8	90	16	0.02	33	23.72	26.92	7.45	77	88	24
FA7X	6	37	16	0.02	29	25.13	23.19	7.77	82	76	25
A319	19	77	16	0.02	64	34.09	33.84	11.76	111	111	38
GL5T	6	63	10	0.01	40	28.65	29.51	7.57	93	96	24
A342	1	1	3	0.00	260	60.30	59.39	16.74	197	194	54
B752	1	10	2	0.00	105	38.05	47.32	13.56	124	155	44

3.6.3 Vertical Speed Variation

3.6.3.1 This section considers the relevance of taking the vertical speed variation in cruising level flight as 1.5 knots, as with most previous publications. Although commonly used, no recent reference to data or analysis supporting this value could be found. This term is part of mathematical Hsu model equation as:

$$\left(1+\frac{\overline{|\dot{z}|}\pi\lambda_{xy}}{4\lambda_z V_{rel}}\right) \approx \left(1+\frac{\overline{|\dot{z}|}\pi}{V_{rel}}\right) \qquad (25)$$

3.6.3.2 An approximate estimate of the effect on risk of changing the vertical speed can be done by considering Equation 25. As λ_{xy}/λ_z is approximately 4, we can simplify the left hand side of Equation 25 to that shown. The relative speeds necessary for an overlap to occur in same-identical track cases are related to a trailing aircraft catching a leading aircraft in approximately 20 minutes over a distance of approximately 20-30 NM. This gives an order of magnitude for speed of 20/20 = 1 NM per minute or 60 knots. Hence the ratio term will be of the order of 4/60 ≈ 0.07; this is for the same-identical track scenario where the majority of the risk occurs. Increasing $\overline{|\dot{z}|}$ from 1.5 to 15 changes the overall term above from approximately 1.07 to 1.7, an increase of 50 per cent. Note that 1.5 knots is approximately 151 ft per minute or 2.5 ft per second. A 15 knot vertical speed would be a dramatic vertical motion of 25 ft per second. Even with an extreme change from 1.5 to 15 knots, the relative increase in risk by a factor of 50 per cent does not change the order of magnitude of the risk estimates; that is 1×10^{-0} to 1.5×10^{-0} is small on the log scales appropriate to these problems.

3.6.3.3 Hence the assumption of 1.5 knots is considered reasonable.

3.6.4 Vertical Overlap Probability

3.6.4.1 This section considers the relevance of taking the vertical overlap probability as $P_z(0) = 0.55$ consistent with earlier studies. From altimetry system error calculations (Figure 3.8) in RVSM airspace, the height keeping is approximately Gaussian with standard deviation of $\sigma = 58$ ft. The overlap probability for airframes of height $\lambda_z = 63$ both nominally at the same flight level is:

$$Pz(0) = \int_{-\lambda_z}^{\lambda_z} \int_{x=-\infty}^{\infty} N(\mu = x, \sigma)\, N(\mu = z - x, \sigma)\, dx\, dz \qquad (26)$$

which by standard convolution results is $N(\lambda_z, \sigma\sqrt{2}) - N(-\lambda_z, \sigma\sqrt{2})$.

3.6.4.2 This gives an upper limit value of $Pz(0) = 0.72$ due to the improved height keeping performance of RVSM aircraft. However, this result is not weighted by the distribution of aircraft in the airspace. As $P_z(0)$ is a linear factor in the calculations, it is a simple matter to increase the collision risk by the additional 30 per cent if required; this will have little impact on risk applied to a logarithmic scale.

3.6.4.3 Assigned Altitude Deviation (AAD) is also included in the analysis and recent papers on RVSM risk analysis detail how $P_z(0)$:is calculated and support the estimate of $Pz(0) \approx 0.55$.

3.6.4.4 Previous studies have used the following values of $P_z(0)$:

a) 0.48; [4, 5, 7, 8] for RNP 10 studies;

b) 0.41; [39]: a study of NOPAC routes;

c) 0.55; [7, 8] for RNP 4 studies; and

d) 0.538 and 0.471; [29, 30] for Anchorage and New York airspaces.

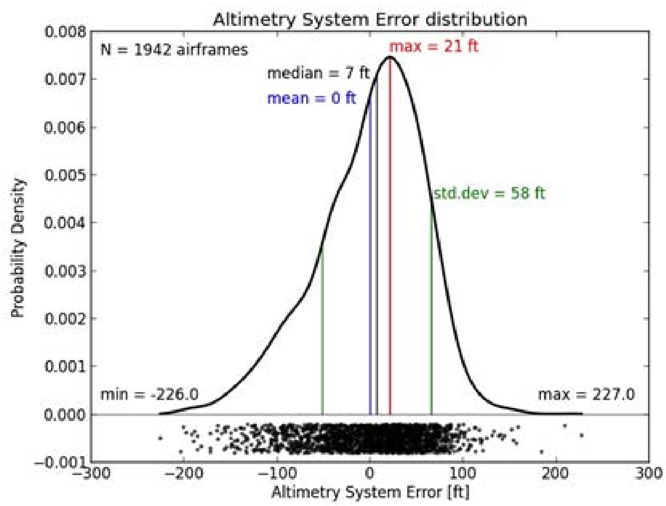


Figure 3.8. Distribution of alitmetry system error from Australian AAMA data to 29-9-2013

3.6.4.5 Hence the use of 0.55 is considered appropriate and is assumed throughout.

3.6.5 RNP and ONP

3.6.5.1 This section explores the relationship between observed navigational performance (ONP) and required navigational performance (RNP). In particular, it examines the evidence and need for modelling aircraft risk using a range of values from ONP = 0.05 NM up to RNP of 2 or 4 NM.

3.6.5.2 RNP 2 oceanic is taken to mean that navigation performance for cross-track and along-track position errors satisfy conservative PBN-based requirements of at least 95% within 2 NM cross-track of the nominal position, and a probability of at most 0.00001 of being outside 4 NM cross-track of the nominal position. This is in line with the *Performance-based Navigation (PBN) Manual,* Volume II— *Implementing RNAV and RNP Operations* (Doc 9613), which requires:

> **2.3.3.3** ***On-board performance monitoring and alerting***
>
> 2.3.3.3.1 Accuracy: During operations in airspace or on routes designated as RNP 2, the lateral TSE must be within ±2 NM for at least 95 per cent of the total flight time. The along-track error must also be within ±2 NM for at least 95 per cent of the total flight time. To satisfy the accuracy requirement, the 95 per cent FTE should not exceed 1 NM.
>
> *Note.— The use of a deviation indicator with 2 NM full-scale deflection is an acceptable means of compliance.*

Note that this quote only relates to the 95% requirement for navigational performance.

3.6.5.3 Modelling based only on minimum PBN requirements would not capture the increased collision risk due to accurate centreline tracking by GNSS-equipped aircraft. The concept of ONP X addresses this issue.

3.6.5.4 Observed navigation performance (ONP) X is considered to have the same position error distribution as RNP X. An aircraft approved as RNP X may have an ONP which is much lower than X.

3.6.5.5 This analysis uses the methodology of [7, 8, 10, 11, 12, 15] for a range of ONP values from ONP 4 down to ONP 0.05 NM.

3.6.5.6 The collision risk evaluated is taken as the largest collision risk over the range ONP=0.05 to ONP= RNP for any given parameter.

3.6.5.7 To model RNP X, we assume a cross-track position distribution as a double exponential with scale parameter $\lambda = X/\log 20$. For RNP 2, this gives $\lambda \approx 0.67$ and for RNP 4, $\lambda \approx 1.34$.

3.6.5.8 Previous work on cross-track aircraft performance includes:

a) a study of 2 298 aircraft on RNAV approaches to Kagoshim standard terminal arrival route [2] showing distribution with standard deviation 0.0771 NM (Gaussian fit), double exponential scale factor of 0.06 NM, and maximum deviations of approximately 0.39 NM. Fits with mixes of distributions had parameter values of the order of 0.07-0.08 NM for scale parameters;

b) a study of RNAV approaches into Brisbane airport [23] indicating an apparent cross track error of the order of 150 m (approximate standard deviation) on some arrival waypoints and 250 m (approximate standard deviation) on other waypoints;

c) a study of 778 flights and 26 731 aircraft position reports using ADS-C data [24] recorded a standard deviation of lateral position of 0.026 NM (160 ft);

d) a study of Japanese data [33] from NOPAC route system showed cross-track deviations were well fitted by a Gaussian core and exponential tails;

e) a study of Gulf of Mexico data [34] showed lateral track deviations with standard deviations of the order of 0.14-0.19 NM for GNSS aircraft and 0.28 for non-GNSS aircraft;

f) a study of 26 731 Australian ADSC position reports [41] showed lateral deviations well contained within 0.1 NM with standard deviation of 0.026 NM or 160 ft;

g) a 2007 study of 39 012 USA ADSC position reports [quoted in [41]] showed lateral deviation with standard deviation of 0.184 NM; and

h) a 2010 study of 7 532 RNP-special flights using ADS-B on approach[45] showed a cross-track 0.02179 NM (27.4 m). Maximum deviations were of the order 0.25 NM.

3.6.5.9 Given these previous studies it seems appropriate to use a low ONP=0.05 NM in this analysis.

3.6.6 Communication Performance

3.6.6.1 This sections explores the history and relevance of key communication parameters and probabilities, notably the use of [4, 10.5, 13.5] as communication response times in minutes with relative probabilities of [90.25, 4.75, 0.5], respectively.

3.6.6.2 Communications between ATC and a pilot are assumed to be by CPDLC as primary means (assumed RCP 240) with HF voice as a secondary backup (assumed RCP 400). Surveillance is assumed to be by periodic ADS-C reporting and meeting the RSP 180 specification. Both CPDLC messages and ADS-C reports are assumed to be delivered by satellite. Both surveillance and communications contribute to the parameter τ .

3.6.6.3 Communication performance is based on historic values [3, 7] for the proportion of responses within certain time frames. This is:

$$\mathrm{CR} = 0.95(0.95\,\mathrm{CR}(\tau = 4) + 0.05\,\mathrm{CR}(\tau = 10.5)) + 0.05\,\mathrm{CR}(\tau = 13.5), \qquad (27)$$

where CR is the collision risk for a delay of τ minutes and reporting time T. This reflects an ATC-pilot CPDLC communication time, pilot and aircraft response times, and additional times if the primary then secondary communication methods fail. This section also discusses the three times 4, 10.5, 13.5 in terms of RCP and RSP.

3.6.6.4 In RGCSP/1, arguments were made for these [4, 10.5, and 13.5] values.

> 7.1 On occasions it will be necessary for the controller to communicate with an aircraft to ensure separation is maintained or for other reasons. As with the original methodology, a buffer is included in the current mathematical analysis to allow time for the controller to intervene, convey instructions to the pilot and for the pilot to react and cause the aircraft to achieve a change of trajectory sufficient to ensure that a collision will be averted. The previous methodology had a confusing mixture of ADS and non-ADS components in the buffer. In the present methodology the components are made explicit to an ADS environment. One major change from the previous methodology is that the extrapolation error is included with the navigation error, so the buffer no longer includes the ADS downlink time, as it is included with the extrapolation error (which is assumed to have its maximal value). The current methodology assumes that CPDLC will be used as the primary communications medium, with HF backup. Recent experience in Australia indicates that for CPDLC messages the uplink plus message assurance time to the aircraft and the downlink time should not exceed 90 seconds 95 per cent of the time, allowing for the cases when CPDLC fails. These values are assumed in the analysis, and should be somewhat conservative as the uplink time already includes the message assurance time. It is assumed that the response to the uplink message will be received by the controller within 3 minutes 95 per cent of the time, allowing for non-availability of CPDLC and failure of the message to be delivered. Because of the nature of modern ground systems and the ease with which CPDLC messages can be composed, the controller message composition time has been reduced from 30 seconds to 15 seconds. It was also felt that the previous value of 45 seconds for the pilot reaction time to a time critical ATC instruction was too large. In the present analysis a value of 30 seconds is assumed.

7.2 The current methodology utilizes three different values of the buffer, for the following cases:

a) periodic ADS reports are received and response to CPDLC uplink is received within 3 minutes. For this case, a value of τ = 4 minutes is used. Note that the downlink time is not included in the buffer because this is not necessary for the aircraft to begin its change of trajectory. The components are itemized in Table 1;

b) periodic ADS reports are received and response to CPDLC uplink is not received within 3 minutes. It is assumed that after 3 minutes from when the CPDLC message was sent, the controller would contact the aircraft via HF. If contact with the aircraft concerned cannot be made the controller would need to contact one or more other aircraft to ensure separation is maintained. For this case, a value of τ = 10 minutes is used. Note that the 3 minutes occurs in parallel with the CPDLC uplink. The components are itemized in Table 2; and

c) a periodic ADS report has been lost. In this case it is assumed that after 3 minutes from when the periodic ADS message should have been sent from the aircraft a position report will be requested by the controller via CPDLC or ADS, but that the request will always fail, so after a further 3 minutes the controller will contact the aircraft via HF. If contact with the aircraft concerned cannot be made the controller would need to contact one or more other aircraft to ensure separation is maintained. It is conservatively assumed that the controller will always attempt to contact the aircraft in this situation regardless of the existence of a potential conflict. Thus neither the screen update time, nor the controller conflict recognition time are included in the buffer. However, to allow ease of implementation, an additional allowance of 30 seconds is included. The components are itemized in Table 3.

3.6.6.5 In Equation 27, the first 0.95 and the last 0.05 relate to RSP, the middle 0.95 and 0.05 relate to RCP. The values of τ in the equation are determined by (the DT 95% and OT) RSP 180 and (the TRN) RCP 240 parameters as described in the GOLD document, Appendices C and B.

3.6.6.6 The model used in previous papers and in Equation 27 makes numerous assumptions about pilot, aircraft and controller performance. These are detailed in the tables below.

3.6.6.7 The contributions to τ = 4 minutes were assumed to be the values shown in Table 3.3, for 10.5 minutes in Table 3.4 and 13.5 minutes in Table 3.5. They are the same used in [7]. CPDLC actual communication values from the Brisbane FIR in 2012 are shown in Table 3.6 and Figure 3.12.

Table 3.3. Time delay assumptions for CR(τ = 4). These apply to the "normal ADS" case in which the ADS report is received within 90 seconds and a response to a CPDLC message sent by ATC is received within 3 minutes

time	*component*
30 seconds	screen update and conflict resolution
15 seconds	message composition
90 seconds	for 95 % CPDLC uplink (RCP 240)
30 seconds	pilot reaction
75 seconds	aircraft inertia plus climb/descent

Table 3.4. Time delay assumptions for CR(τ = 10.5). These apply to the case in which the periodic ADS report is received within 90 seconds of its due time, but the response to a CPDLC message sent by ATC is not received within 3 minutes, and HF communication is initiated

time	*component*
30 seconds	screen update and conflict resolution
15 seconds	message composition
180 seconds	CPDLC uplink and response (RCP 240)
300 seconds	HF communication (RCP 400)
30 seconds	pilot reaction
75 seconds	aircraft inertia plus climb/descent

Table 3.5. Time delay assumptions for CR(τ = 13.5). These apply to cases in which the periodic ADS report is delayed by more than 3 minutes or lost

time	*component*
180 seconds	wait for ADS message (RSP 180)
15 seconds	message composition
180 seconds	CPDLC uplink and response (RCP 240)
300 seconds	HF communication (RCP 400)
30 seconds	pilot reaction
75 seconds	aircraft inertia plus climb or descent
30 seconds	extra allowance

Table 3.6. Typical CPDLC Actual Communication Performance [ACP] from the Brisbane FIR (2012) [1]

response time	*Satellite/VHF*	*HF*
30 seconds	90%	-
60 seconds	97%	92%
90 seconds	98.5%	95%
120 seconds	99%	97%
150 seconds	99,5%	98%
180 seconds	99.6%	99%

3.6.6.8 Figure 3.9 shows schematically the decision and probability tree for the values [4,10.5,13.5] minutes and the respective probabilities (as percentages) [90.25,4.75,5] of each response time occurring. Note that the obvious branch of using CPDLC when an ADS-C messages is delayed is not used. At the left of the diagram, an ADS-C message is either received (95%) or lost (5%) of the time. If received a CPDLC message is sent and if received the top branch is used resulting in a time of 4 min, 90.25% of the time. If this CPDLC message is lost and HF communication is used the second branch from the top is used resulting in a time of 10.5 minutes, 4.75% of the time.

3.6.6.9 The lower branches in Figure 3.9 shows the case of and ADS-C message being delayed and an alternative method of action occurred. The diagram mirrors the top two branches where CPDLC or HF options are used. However, the upper CPDLC branch is shaded in gray since this was not included in the original models. Historically, when the original models were developed CPDLC was not as common and hence the HF option was only considered here. However, in modern aviation this would be considered a viable option which is illustrated in Figure 3.10.

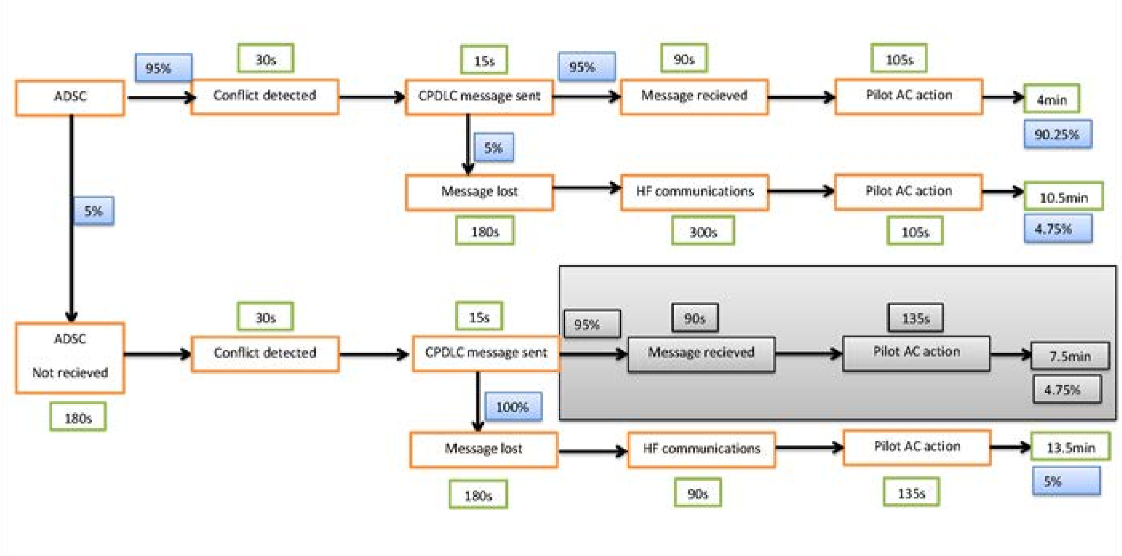


Figure 3.9. Schematic of the decision tree corresponding to response times and probabilities in the standard A-H model. Note that the obvious branch of using CPDLC when an ADS-C message is delayed is not used. This is discussed in the text.

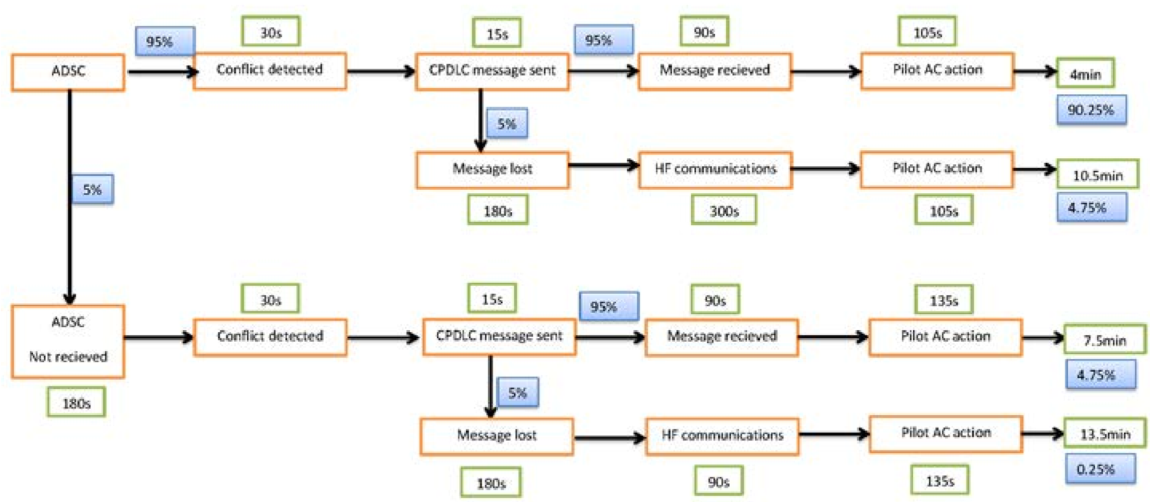


Figure 3.10. Schematic of the decision tree corresponding to response times and probabilities in the modified A-H model. Here the branch of using CPDLC when an ADS-C message is delayed is used.

3.6.6.10 Figure 3.11 shows another version of Figure 3.10 which may clarify the process. The top part of the figure shows the different options when ADS-C messages are received correctly or not, and when CPDLC messages are received correctly or not. The percentages and times are shown simplistically by the coloured boxes resulting the in the full model of [4,10.5,7.5,13.5] minutes occurring with percentages [90.25,4.75,4.75,0.25]. The bottom bar chart illustrates the relative values of these times and weights. As in Figure 3.10, the traditional A-H model excluded the third branch from the top resulting in the [4,10.5,13.5] minutes and the respective probabilities (as percentages) [90.25,4.75,5] of each response time occurring.

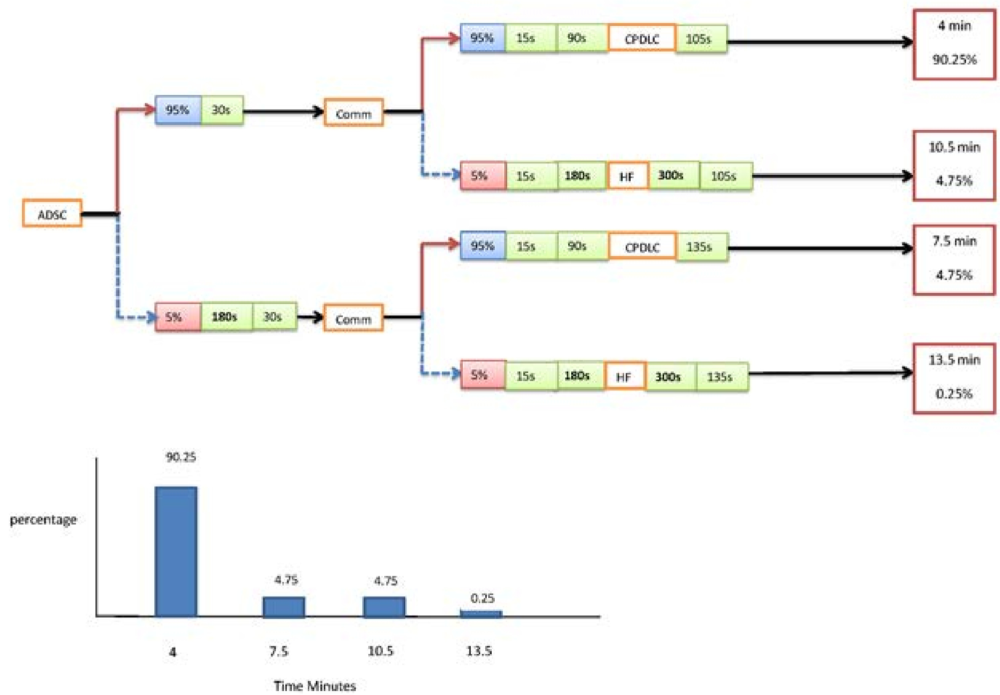


Figure 3.11. Schematic of the decision tree corresponding to response times and probabilities in the modified A-H model. Here the branch of using CPDLC when an ADS-C message is delayed is used.

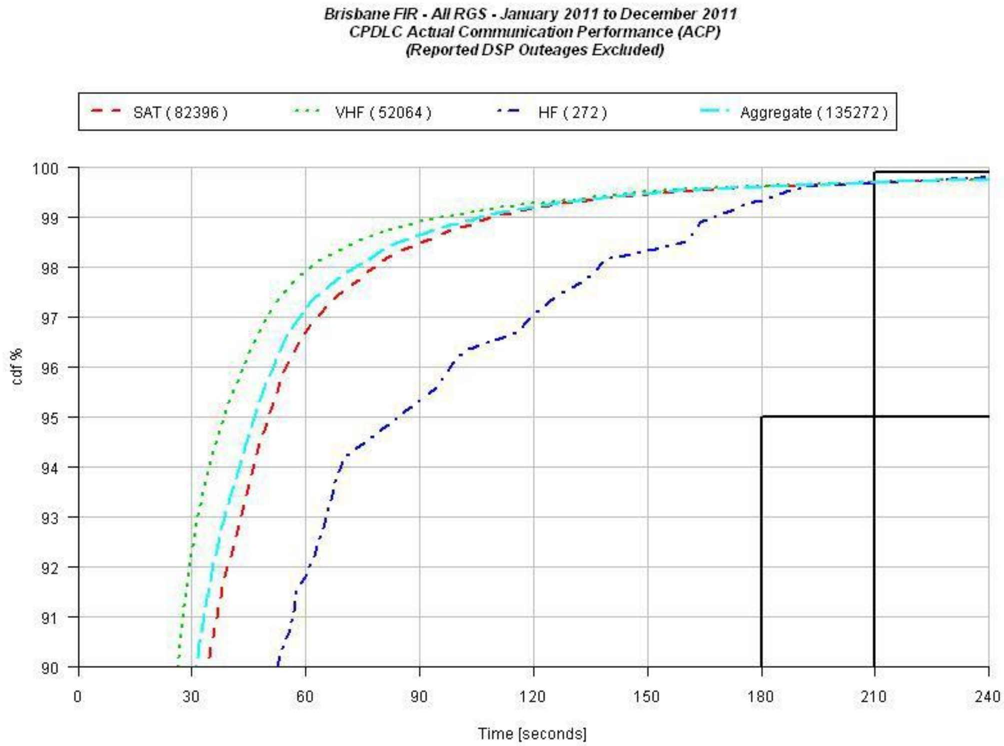


Figure 3.12. CPDLC actual communication performance results from Brisbane FIR [1]

3.6.6.11 Typical CPDLC Actual Communication Performance (ACP which accounts for the 90 seconds and 180 second components of Tables 3 and 4) from the Brisbane FIR in 2012 are shown in Table 6. These and example communications and surveillance performance data in Appendix D of the GOLD document are noticeably better than the minimum required (GOLD document 2nd Edition, Appendix D). However, the sensitivity of collision risk to surveillance and communications performance is studied below.

3.6.6.12 The *Procedures for Air Navigation Services — Air Traffic Management* (PANS-ATM, Doc 4444) (reference 4) provides the following communication and surveillance performance requirements for the application of 55.5 km (30-NM) and 93 km (50-NM) longitudinal separation minima:

> 5.4.2.6.4.3.2 The communication system provided to enable the application of the separation minima in 5.4.2.6.4.3 shall allow a controller, within 4 minutes, to intervene and resolve a potential conflict by contacting an aircraft using the normal means of communication. An alternative means shall be available to allow the controller to intervene and resolve the conflict within a total time of 10.5 minutes, should the normal means of communication fail.
>
> 5.4.2.6.4.3.3 When an ADS-C periodic or waypoint change event report is not received within 3 minutes of the time it should have been sent, the report is considered overdue and the controller shall take action to obtain the report as quickly as possible, normally by ADS-C or CPDLC. If a report is not received within 6 minutes of the time the original report should have been sent, and there is a possibility of loss of separation with other aircraft, the controller shall take action to resolve any potential conflict(s) as soon as possible. The communication means provided shall be such that the conflict is resolved within a further 7.5 minutes. All of the time information highlighted in bold above were directly taken from the collision risk model and the controller intervention buffer cases, provided in reference 3 and Tables 1 through 3, used in the initial development of these separation minima.

3.6.6.13 SASP-WG/WHL/21 (Seattle, United States, November 2012) noted that:

> The controller intervention buffer [..] was then used by the joint RTCA Special Committee (SC) 189/EUROCAE Working Group (WG) 53 to develop performance specifications for communication and surveillance capabilities supporting the application of the 30-NM and 50-NM longitudinal separation minima. These results were published in 2007 in RTCA DO-306/EUROCAE ED-122, Safety and Performance Standard for Air Traffic Data Link Services in Oceanic and Remote Airspace (Oceanic SPR Standard). In 2010, the Global Operational Data Link Document (GOLD) (reference 5), defined required communica- tion performance (RCP) specifications and surveillance performance (RSP) specifications. The GOLD also contains guidance material for post-implementation monitoring for the RCP/RSP specifications. The GOLD, has been endorsed as guidance material in the North Atlantic and Asia-Pacific Regions.

3.6.6.14 SASP-WG/WHL/20 (Montréal, Canada, May 2012) noted that:

> According to the guidance in the GOLD, the ACP, ACTP and PORT for applicable CPDLC transactions are required to meet the Required Communication Performance (RCP) 240 criteria when sent via satellite and VHF, and are required to meet RCP400 criteria when sent via HF. Similarly, the ADS-C downlink latency is required to meet Required Surveillance Performance (RSP) 180 criteria for ADS-C downlink messages sent via satellite and VHF, and is required to meet RSP400 criteria when sent via HF. For the application of the 30 NM lateral and longitudinal separation minima, the RCP240 and RSP180 criteria are the applicable performance targets for the necessary data link communication performance. Table 12 outlines the appropriate performance targets for the reduced horizontal separation minima.

3.6.6.15 One limitation of Equation 27 is the very discrete nature of the assumed time values, each of which will actually be drawn from a distribution. The 90 second CPDLC time along with 0.95% weighting is conservative relative to the values from the Brisbane FIR which indicate a 98% take up at 90 seconds and 90% within 30 seconds.

3.6.6.16 It is impractical to measure every possible time variable listed above along with their distributions; such values would be unreliable and differ widely in different regions. Instead, it is important to ensure that the overall behaviour of the system is not critically sensitive to these values.

Note the acronyms in these quotes for: actual communication performance (ACP); actual communication technical performance (ACTP); pilot operator response times (PORT); very high frequency (VHF); and high frequency (HF). Note also the reference [50] for the GOLD document.

3.6.6.17 To model the sensitivity of the system simply, a Gamma distribution with shape a and location b was used to mimic the approximate behaviour of the discrete model. This is shown in Figure 3.13. The top graph shows the three discrete times $T + 4$, $T + 10.5$ and $T + 13.5$ for $T = 6$, all in minutes. The height of each blue column is the relative weighting of each value, here 0.95^2, 0.95×0.05 and 0.05 respectively. The red shaded region is a Gamma distribution with $(a = 4, b = 2 + T)$. The black line represents the scaled collision risk as a function of $T + \tau$ for RNP=2, $S_x = 20$ NM, $V_m = 20$ knots and $T = 6$ minutes. That is, the collision risk increases exponentially with increased time, since over a large time period of $T + \tau$ trailing aircraft may be able to catch leading aircraft. However, this collision risk is weighted by the probabilities of the time being $T + \tau$. Thus the product of the black and blue lines gives the blue result in the lower plot, and the product of the black and red curve give the red bars in the lower plot.

3.6.6.18 The bottom graph on Figure 3.13 represents the relative contribution of each of these factors to the overall risk. This shows that the risk due to the $\tau = 13.5$ minute component is the main contributor to the risk, despite the 0.05 weighting. Similarly, the red columns show the contribution from each minute taken from the Gamma distribution. Here the overall risk is similar for both as log10 CR = -12.4. The risk contribution shown by the red columns from the Gamma distribution mimics the behaviour of the blue discrete value; that is, there is little contribution from the $T + \tau \approx 14$ minute region, with more and roughly even contributions from the $\tau = 10.5$ and 13.5 regions. Eventually the contribution from the tail of the Gamma distribution decays faster than the collision risk increase for large τ .

3.6.6.19 The values of ($a = 4$, $b = 2+T$) for the Gamma distribution were chosen arbitrarily, with the aim of simply mimicking the discrete distribution results. Clearly one can vary the three parameters (shape, scale and location) of the Gamma distribution endlessly to fit any desired criteria. However, our goal here is simply to demonstrate that approximately similar results can be found using a very different set of values than the assumed discrete equation.

3.6.6.20 Table 3.7 gives a summary of Data Link Performance Requirements:

Table 3.7. Summary of data link performance requirements [30]

Performance Measure	*Percentage messages*	*RSP 180 sec*	*RCP 240 sec*
ADS-C Latency	95.0	90	-
ADS-C Latency	99.9	180	-
ACTP	95.0	-	120
ACTP	99.9	-	150
ACP	95.0	-	180
ACP	99.9	-	210
PORT	95.0	-	60

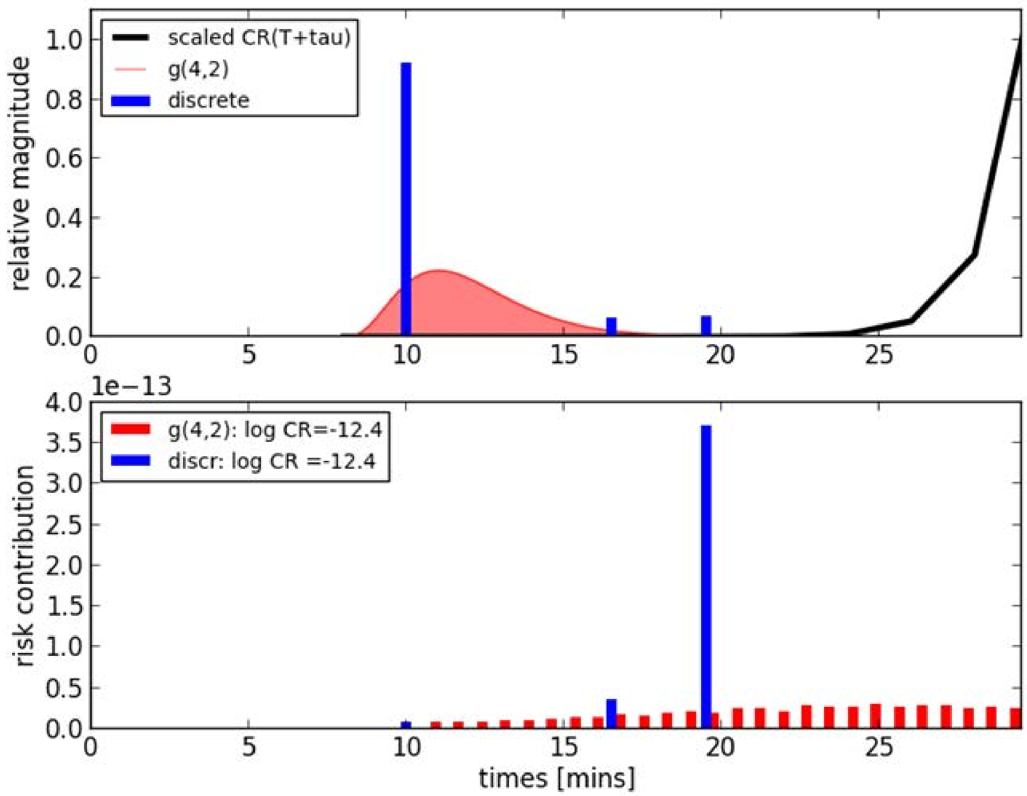


Figure 3.13. Visual representation of Equation 27. The blue vertical bars on the top graph represent the weights and positions of the discrete values in Equation 27. The red curve shows a Gamma distribution with shape 4 and location (2+T =12). The black line is the scaled collision risk versus T +τ with RNP=2, S_x = 20 NM, V_m = 20 knots, T = 6 minutes. The bottom graph shows the contributions of the overall risk from each of the discrete and Gamma distribution elements. The overall collision risk is the same in both models, CR = $10^{-=1}$.

3.6.6.21 Hence, in light of this extensive examination of the literature for response times, results are presented and compared using the following different parameters:

a) Standard A-H: [4,10.5,13.5] minutes with probabilities [90.25,4.75,5] %;

b) Modified A-H: [4,7.5,10.5,13.5] minutes with probabilities [90.25,4.75,4.75,0.25] %; and

c) Continuous A-H: Gamma(a=4,b=2+T).

3.6.6.22 To be conservative, results and separation standards reflect the traditional [4,10.5,13.5] minutes with probabilities [90.25,4.75,5] % scenario, with further work required to investigate developing these models further.

3.6.7 Initial Separation Distribution

3.6.7.1 This section explores the validity of using a uniform distribution of aircraft separations in the risk calculations.

3.6.7.2 The two aircraft in the simulations are assumed to have a separation S NM at the start of a reporting period. This separation varies uniformly from S_x to S_x + 250 NM where S_x is the separation standard. This recognises that ATC would not place all aircraft exactly S_x distance apart. Figure 3.14 illustrates this concept where the blue line indicates the assumed distribution of aircraft pair separations from 30 NM to 280 NM. The red shaded region schematically shows the relative contribution to the risk: that is most contribution to risk comes from aircraft pairs with small separations, and the risk decays approximately exponentially with distance.

3.6.7.3 An assumption in this model is that no aircraft pairs start the at-risk time interval with a separation below the standard. This is because any such pairs would not have to be wait to the end of another reporting interval T_r before being intervened and would be acted upon by ATC immediately. In effect, any pairs below the separation standard would have T = 0 resulting in a much lower risk. Additionally, these pairs violating the separation standard would have had an acceptable separation at an earlier time $-r$ and hence been correctly addressed by this model at an earlier stage.

3.6.7.4 Hence the critical component to risk arises from those aircraft within 20 NM of the separation standard.

3.6.7.5 Figure 3.15 illustrates the separation distribution from 480 aircraft pairs using four months of Australian ADS-C data. It shows a roughly gamm type distribution from 50 NM to 450 NM which supports the assumptions used in our model. The uniform distribution model is conservative as it assumed all aircraft are distributed within 200 NM not 400 NM and has a higher proportion of aircraft close to the separation standard.

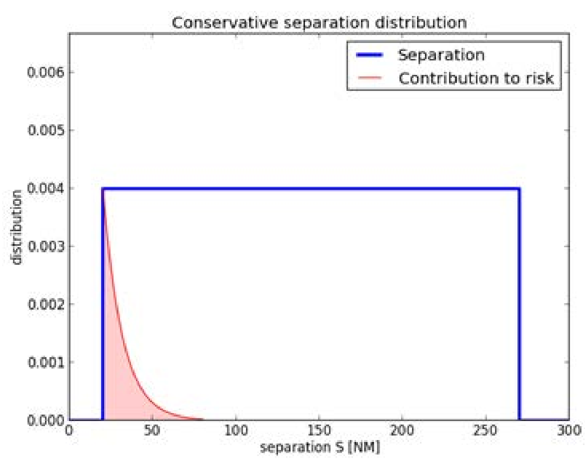


Figure 3.14. The separation distribution is assumed uniformly distributed from S_x to S_x + 250 NM. The major contribution to the risk comes from low values of S. Note, that when two aircraft are separated by S_x NM they are assumed to have the same nominal (assumed) speed. In this close separation a speed variation which is unknown to ATC could contribute significantly to increase risk.

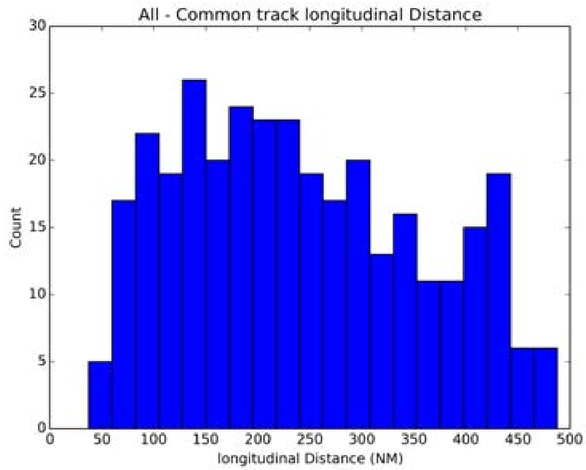


Figure 3.15. Separation distance distribution between 960 aircraft on the same route from four months of Australian ADS-C data. Here each count is two aircraft. Some aircraft pairs have separation distances greater than the 500 NM limit shown.

3.6.7.6 RGCSP/10 (Montréal, Canada, November 2000) noted that:

> As with the original model (References 1, 10, 11 and 12), it is assumed that a conservative estimate of the use by controllers of separations close to the minimum can be approximated by a uniform density with height 0.004. This has subsequently been termed "the four per-cent rule", since 4 per cent of the separations will occur within any 10 NM band under this assumption. The assumption can be relaxed somewhat, as with the original, albeit at the expense of complication. Furthermore, if the model is used as a post-implementation verification of the collision risk in a particular airspace, then the actual distribution of separations should be determined from a traffic sample and used in the model.

3.6.7.7 The actual distribution of aircraft separations is a data gathering exercise that must be continually monitored and analysed appropriately.

3.6.7.8 SASP-WG/WHL/1 (Canberra, Australia, May 2002) gives a result shown in Figure 3.16 for NOPAC routes. These exceed the 0.04 rule and go up to 0.06 for some separation distances. This figure corresponds to 10-15 minute separation standards which gives roughly 80-120 NM separation distance.

3.6.7.9 UK Nats [25] showed separations approximately followed a Gamma type distribution similar to that shown above.

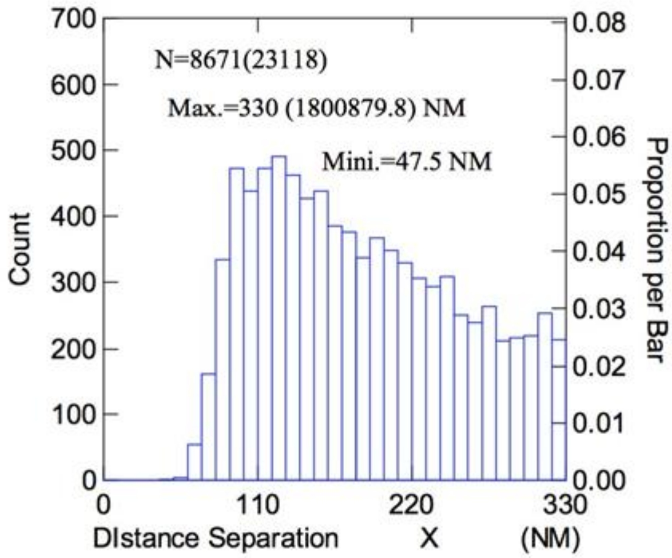


Figure 3.16. SASP-SG/WHL/1 (Canberra, Australia, May 2002). Frequency distribution of distance separation X (actual value of s in w(s)). Width of interval is 10NM. N stands for the sample size. The figures in parentheses show the values for the whole data.

3.6.7.10 The uniform distribution assumed here is conservative since the majority of the risk is for aircraft separated by distances near the separation standard, and empirical data shows that few aircraft are within the first 20 NM of the separation standard. There is scope to further reduce separation standards with closer monitoring of separation distributions, and use of a more realistic aicraft separation distribution.

3.6.8 Speed Distribution

3.6.8.1 The distribution of aircraft speeds assumed in the model is a crucial component of the modelling, and one that has been studied in great depth by the SASP. This section examines this key assumption and the appropriate value for the speed decay parameter.

3.6.8.2 In the modelling, both aircraft are assigned a random speed around their nominal speed for the duration of a calculation ($T + \tau$). That is, the aircraft may be assumed by ATC to have a speed V but in reality this speed is randomly distributed around this nominal value. Even with Mach restrictions, the exact speed of an aircraft can only be approximated by ATC.

3.6.8.3 The speeds are assumed to follow a double exponential distribution with nominal parameter λ_V=5.5 knots (illustrated in Figure 3.17)

$$P(V) = \frac{1}{2\lambda_v} e^{-|V-V_0|/\lambda_V}. \qquad (28)$$

The distribution is truncated at $V = V_0 \pm V_m$ knots and then normalized to one.

3.6.8.4 This section explores the evidence for the value 5.5 knots.

3.6.8.5 The truncation of the speed to V_m is necessary since aircraft are not physically able to fly at extremely low or high speeds, or may have controls to minimize speed variation.

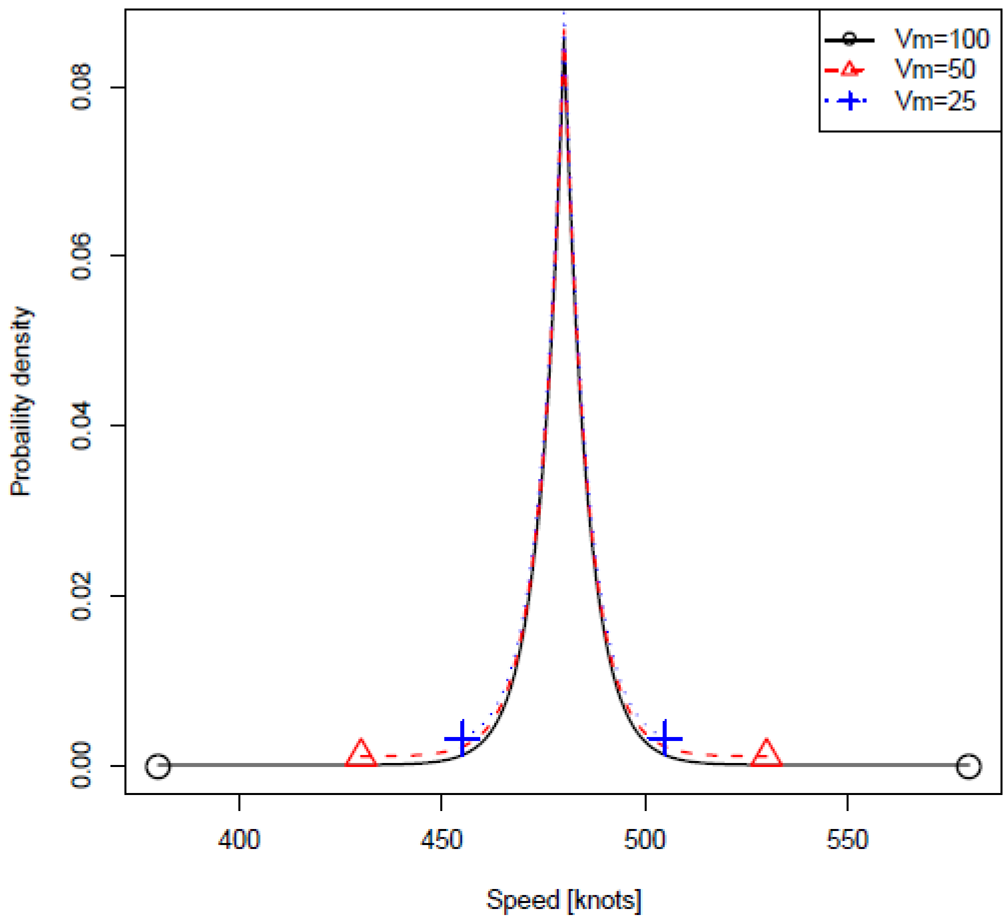


Figure 3.17. Double exponential probability distribution for speed around V = 480 knots. The scale(decay) parameter shown here is _v = 5:82 knots. The distribution is truncated at Vm in (2 100; 50; 25) knots either side of 480. Note that the distributions for Vm = 50 and Vm = 25 knots have had their vertical scaling exaggerated for visual purposes; in reality, the normalisation of the distribution increases the values by amounts which are not visible.

3.6.8.6 Many previous studies have used λ_v = 5.82 knots [5, 7, 8, 10, 11, 12, 13, 14, 15, 30].

3.6.8.7 An analysis [32] showed a double exponential decay scale parameter of 6.5 knots (Oakland), 6.16 knots (New York).

3.6.8.8 A recent paper by the FAA [31] considered data on the speed distributions of aircraft in two FIRs. For the New York FIR a typical value for the decay parameter was 4.22 knots. The paper noted that although this fit the tails well it did not fit the core of the distribution and a combination of Gaussian core with exponential tail was more appropriate.

3.6.8.9 Airservices recently analysed [17] 25 339 flights, with 180 103 way-point reports from

Australian airspace covering approximately 90 664 flight hours. A consistent pattern across four months of data emerged with the difference between reporting time and actual arrival time at waypoints being distributed as a double exponential distribution with decay parameter of 1.13 (in per cent). For the four months this parameter was 1.10, 1.15, 1.12, 1.15 percent. For a typical airspeed of 480 knots, this corresponds to a speed distribution decaying with scale parameter 5.5 knots.

3.6.8.10 However, careful analysis [17] of this data showed that if data was filtered to include only predictions within 15 minutes ahead (the time-scale of importance in this modelling), the scale parameter was 6.5 knots (1.34 percent). That is, the speed prediction is worse for small times than for moderate times. This is thought to be due to inability to predict local wind variations, which will average out over longer time scales.

3.6.8.11 Hence the previous papers [10, 11, 12, 13, 14, 15] which considered a parameter of 5.82 knots may not have been conservative enough.

3.6.8.12 Figure 3.18 shows the distribution of speed variation from four months of ADS-C data [17]. The data is well represented by a Laplace distribution with decay parameter 5.35 knots. However, if data is restricted to estimated position reports within 15 minutes, Figure 3.19, then the scale parameter increases to 6.21 knots. That is, speed estimates are more inaccurate for short-time predictions than for longer-time predictions, possible due to the inability to predict local wind variations; these errors will average out over longer time frames.

3.6.8.13 The large extremes in this data set, which are shown later to strongly affect the risk outcome for same-identical track geometries, imply that particular care and monitoring must be undertaken in using separation standards. Assuming Mach-limitations or physical limits on aircraft speeds may not be sufficient to exclude the risk associated with these tails, a clear understanding of how ATC systems interpret and model aircraft speed estimates is necessary.

3.6.8.14 SASP-WG/WGH/11 considered ADS-C data to estimate speed errors. Their results indicate an exponential decay with standard deviation of 9.81 knots and extremes of -58 to 72 knots. An extract of this paper is shown in Figure 3.20.

3.6.8.15 SASP-WGA quoted studies of 10318 ADS reports during 1994 and 2000 to obtain a decay scale parameter of λ_v = 5.82 knots.

3.6.8.16 Evidence from SASP-WG/WHL/23 indicates that this speed distribution may have decay parameter as high as 9 knots, although this data may need to be considered in more detail; this magnitude may be an artifact of large prediction times not appropriate to the 14 minute time intervals considered here.

3.6.8.17 Evidence from SASP-WG/WHL/23 indicates an exponential speed decay parameter of the order of 3 knots. This work was from instantaneous Mach data and hence may not reflect the additional error due to ATC predictions of speed based on wind models. Some results are reproduced in Figures 3.21 and 3.22. Please see this paper for full context.

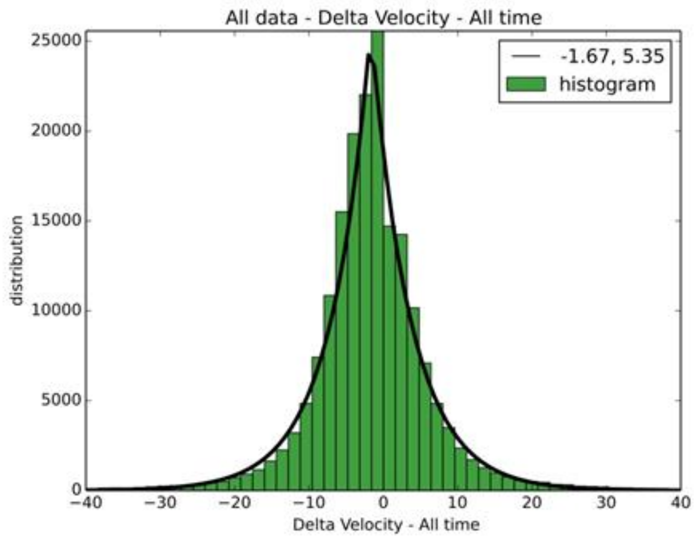


Figure 3.18. Double exponential probability distribution for aircraft predicted speed. The scale (decay) parameter is λ_v = 5.35 knots. Some data exists in the tails of the distribution up to 100 knots.

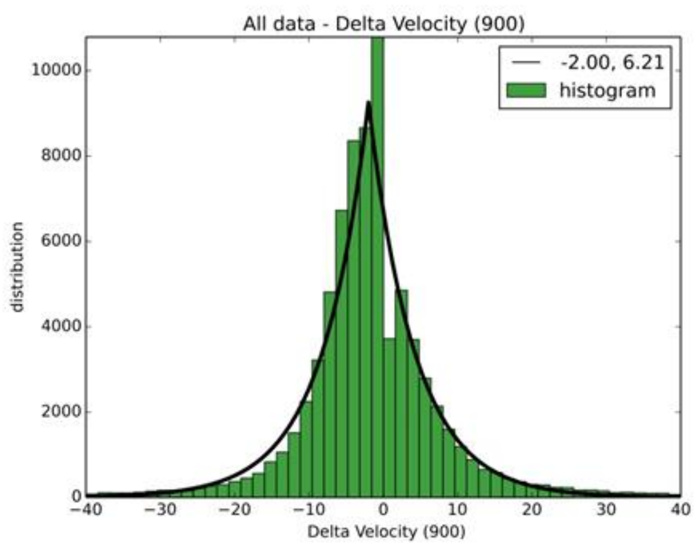


Figure 3.19. Double exponential probability distribution for aircraft predicted speed. Here data is restricted to predicted waypoint position reports within 15 minutes (900 seconds). The scale(decay) parameter is λ_v = 6.21 knots. Some data exists in the tails of the distribution up to 100 knots.

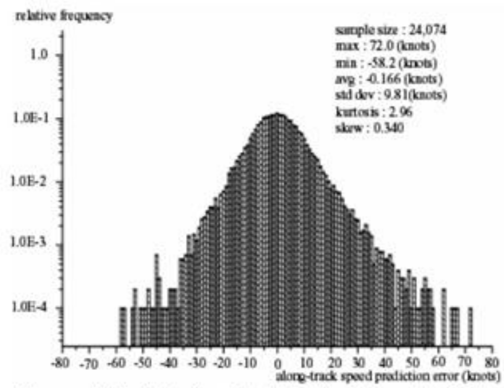


Figure 12 : *Along-track Prediction Error for Pairs Whose Interval ≥ 26 min and <27 min*
(Basic Report Data without '*Fixed Projected Intent Group*' Were Omitted)

Figure 3.20. Extract from SASP-WG/WHL/11 showing the speed distribution from ADS-C data.

3.6.8.18 SASP-WGA/2 (Montréal, November 2001) gives results that show that forward position estimates (related to speed) can vary due to time of day, most likely due to the time-based interpolation of meteorological data. This paper makes some useful points:

> 4.6 It appears that the accuracy of the FDPS forward estimates varies periodically. Weather updates are input into FDPS twice a day (round about 0600 and 1800). These times correspond to the worst predictions.
>
> 4.9 The increase in estimated in-trail risk appears to have come about as a result of fitting an exponential distribution to the tail of the gain/loss distribution. Previously, the tail had been assumed to decay at the rate of a Gaussian distribution.
>
> 4.11 It may be possible to set up a monitoring system to identify large deviations from planned time and large gains or losses in separation as they occur. Such incidents could then be validated (to check that they really occurred) and the causes investigated.
>
> 5.2 The distribution of deviations from planned time of arrival made the largest contribution to risk, largely due to the effect of the weather model used to calculate FDPS forward estimates.

3.6.8.19 In SASP-WG/WHL/1, a double exponential shape parameter of 7.16 knots was found based on South Pacific data. Their data extended to a 48 knot limit in the speed variation.

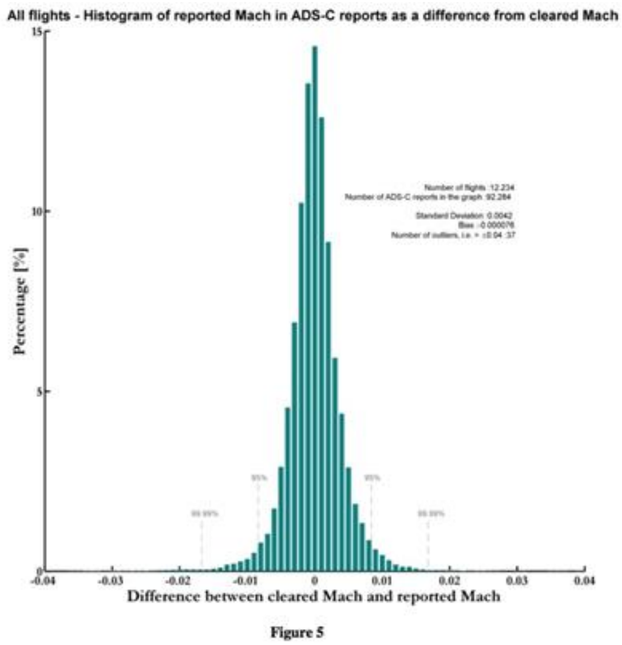


Figure 3.21: Extract from SASP-WG/WHL/23 showing speed variation from assigned Mach.

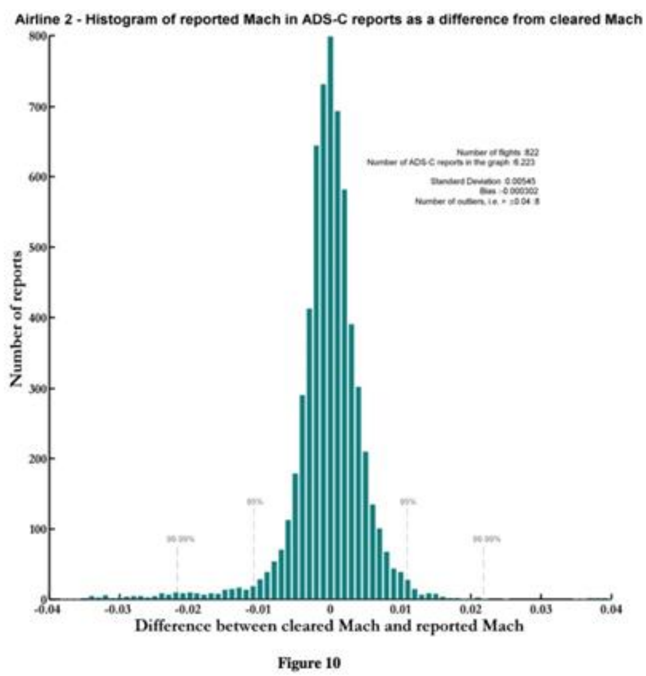


Figure 3.22. Extract from SASP-WG/WHL/23 showing speed variation from assigned Mach for a particular airline.

3.6.8.20 Recent work [18] showed that close to the separation standards the scale parameter $\lambda \to 2.5$ knots and that Mach limited aircraft had $\lambda \approx 1.9$ knots. Hence the work in this circular also shows results for $\lambda = 2.5$ knots with key provision that this value must be monitored and demonstrated by a monitoring agency. This paper [18] showed that although individual aircraft may exhibit estimated speed errors with scale parameter up to 8 knots, the value is reduced for pairs of aircraft closely separated or if an aircraft is

Mach limited. Results for the actual speed errors from aircraft crossing waypoints showed a reduction in speed error for aircraft closely separated.

3.6.8.21 In accordance with PANS-ATM, 5.4.2.1, it is expected that ATC will closely monitor aircraft speeds closer to the separation standard, and ensure that speeds are constrained so a break-down of separation does not occur. The results from [18] appear to indicate this. Some key results from this paper are included here for completeness.

3.6.8.22 The key element in the analysis of [18] is the grouping of aircraft pairs separated by a given distance (say within 40-45 NM) and the estimation of the relative closing speed for these aircraft. By varying the distance ranges (40-45,45-50, etc.) and varying the width of the ranges (40-42,42-44,44-46, etc.) it is possible to obtain a smooth approximation of the speed variation and extrapolate this for a range of separation distances. Data was obtained using a large sample of Atlantic and Pacific data provided by the FAA.

3.6.8.23 Estimating speed variation is usually done by reference to arrival times at successive waypoints. Mathematically, the leading aircraft is denoted AC1 and is followed by aircraft 2 (AC2). At waypoint A they are separated by a time dt_A. At waypoint B they are separated by a time dt_B. The change in separation is $dt = dt_B - tt_A$ which is negative if the separation is reduced. The distance between the two waypoints is denoted d. The positions of the two aircraft at any time, t can be given by

$$x_1 = V_1 t \quad (29)$$
$$x_2 = V_2(t - dt_A) \quad (30)$$

with V_1 and V_2 the speeds of the aircraft. Time $t = 0$ is when aircraft AC1 reaches waypoint A positioned at $x = 0$.

Hence each aircraft reaches waypoint B (at times t_B):

$$x_1 = d = V_1 t_B \quad (31)$$
$$x_2 = d = V_2(t_B + dt_B - dt_A) = V_2(t_B + dt) \quad (32)$$

Thus using $W = V_1 - V_2$ be the speed difference we are calculating

$$V_1 t_B = V_2(t_B + dt) \quad (33)$$
$$\rightarrow \quad V_1 t_B = (V_1 - W)(t_B + dt) \quad (34)$$
$$\rightarrow \quad W = \frac{V_1 dt}{dt + d/V_1} \quad (35)$$
$$= V_1 - \frac{1}{dt/d + 1/V_1} \quad (36)$$
$$\approx \frac{dt}{d} V_1^2 \quad (37)$$

with each of the last expressions simply algebraic reformulations for convenience. The last expressions assumes the speed variation (of order 10 knots) is much less than the aircraft speeds (of order 480 knots).

3.6.8.24 For each pair of aircraft (AC1,AC2) a value W is obtained at each waypoint pair A, B. Hence data W_i is obtained for $i = 1, \ldots, N$ with N the number of samples. Each W_i corresponds to an approximate separation distance (or time) denoted s. Hence in the analysis the data is broken down into $W_i(s)$ and all aircraft within a particular separation range s are grouped. A grouping of $ds = 3$ minutes (approximately 24 NM) is used. That is all the W_i values for aircraft separated by between [10,13) minutes will be grouped together. If ds is too small then insufficient aircraft are available to form a sample. If ds is too large then the sample will be skewed since aircraft may behave differently for different s.

3.6.8.25 Figure 3.23 illustrates the grouping.

a) Aircraft pairs are separated by a time s. This is represented as the histogram in the top plot. The red region is all those data points from aircraft pairs separated between 5 and 8 minutes. That is a slice ds = 3 minutes centred on 4.5 minutes.

b) Aircraft pairs will change their separation between waypoints. This is represented in the middle plot with each dot the separation times for one aircraft pair at successive waypoints. The change in this separation time δt for each aircraft pair can be converted to a speed difference dw based on aircraft nominal speeds.

c) Collecting all the speed differences for the aircraft within the red region gives a distribution (example shown in Figure 3.24). This distribution can be fitted by a Laplace distribution with scale parameter λ in knots. This value of λ may change with difference slices we take from the upper plots. The large red square shows the value for λ for all aircraft separations within the red region.

d) (5-8 minutes) are collected together. The lighter lines indicate values against the separation and with different slice widths from 1 to 5 minutes. If 1 minute is chosen then there are insufficient aircraft in the sample and the resulting line is jagged with considerable error. If the slice width is too large (i.e., 5 minutes) then we are including aircraft pairs with different characteristics. The red dashed line shows a smooth fit through the 3 minute slice line. The fitting function is of the form:

$$\lambda = a_1 + a_2\left(1 - e^{-x/a_3}\right) \tag{38}$$

with a_1, a_2, a_3 parameters found by least square regression through the data lines.

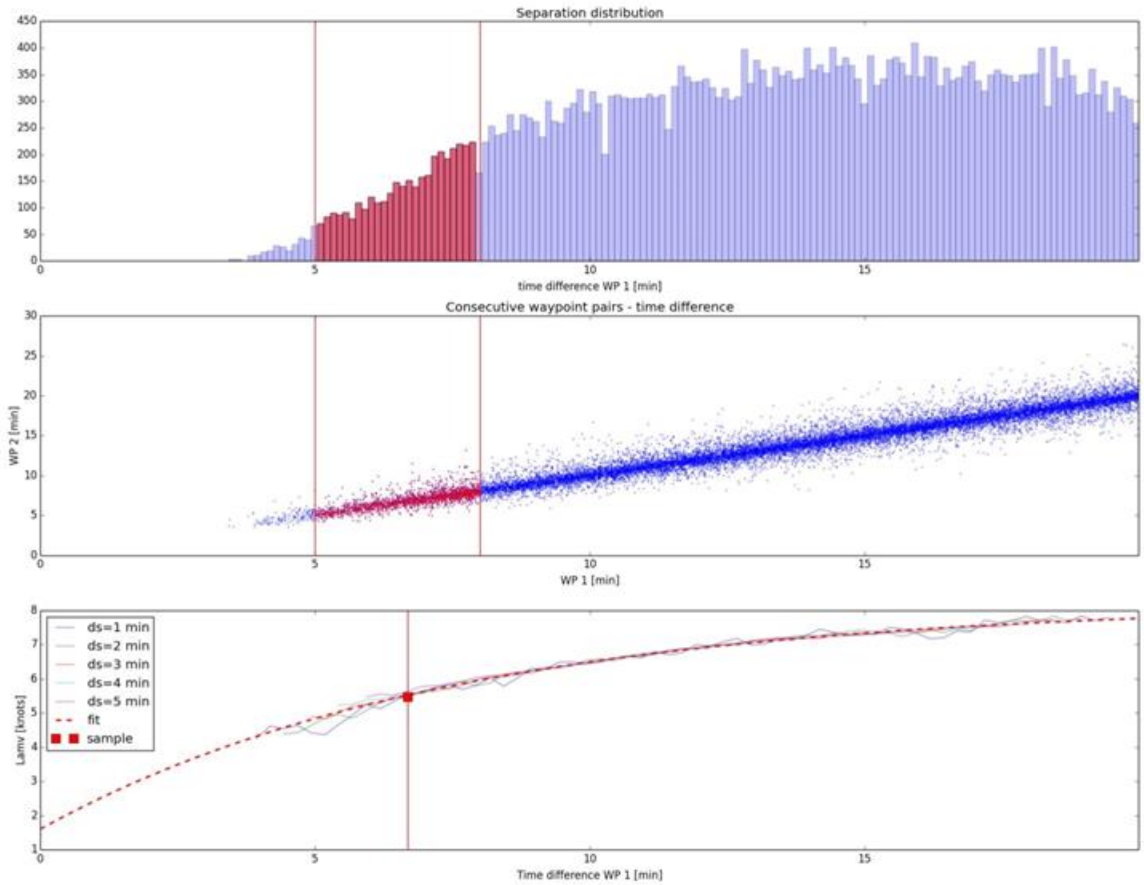


Figure 3.23. Example of calculation of speed variation for aircraft pairs within a distance ds. The top plot is the distribution of aircraft pairs separated by a time s: all aircraft pairs separated within 5 and 8 minutes of each other are highlighted. The middle plot is the separation at one waypoint and then then the separation at the next waypoint. The bottom plot has the scale parameter of separations (fitting a Laplacian) expressed in knots. The red dot is the scale parameter including all aircraft in the red samples above. Each line ds = [1, 2, 3, 4, 5] represents averaging over slices of width 1 minute, 2 minutes and so on. The red line is a curve fit through the data.

3.6.8.26 Figure 3.24 shows the type of distribution for speed variation from the sliced data in Figure 3.23.

a) The top left graph shows the speed variation distribution. The speed variation is a measure of the speed difference between the two aircraft. The data is well fitted by a Laplace distribution with scale parameter λ = 6.8 knots as shown by the cdf and Q-Q plots on the bottom.

b) The risk bearing component is when the speed difference is negative. To avoid contamination by the positive speed component, which may be allowed by ATC, an exponential distribution is fitted to this side – equivalent to creating a mirror (fold) of the negative side and fitting another Laplace. The scale parameter here is smaller, 6.5 knots, which may reflect that the ATC would allow increases in separation but not decreases in separation.

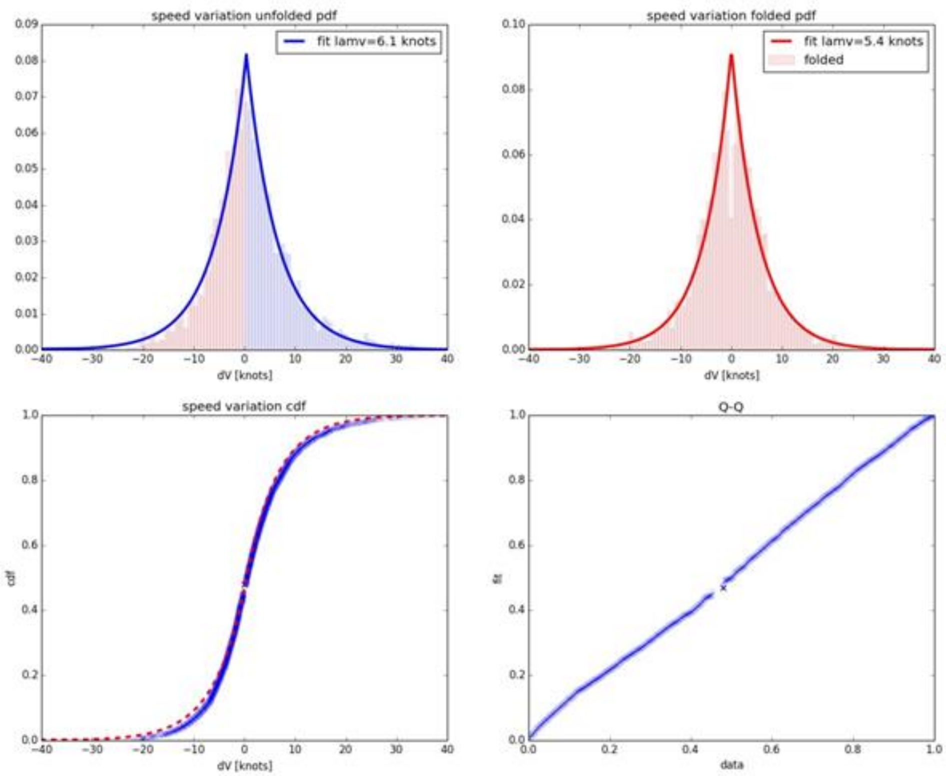


Figure 3.24. Example of fitting data through the speed variation dw. Here we have selected all aircraft pairs separated by 10 to 13 minutes. The top left graph shows the distribution and Laplace fit with scale parameter 6.8 knots. The left side of the distribution is more critical as this is aircraft closing on each other. The right plot "folds" this left hand side and then fits the distribution (essentially fitting an exponential distribution) giving a slightly different scale parameter shown in the top right plot. The bottom left shows the excellent fit to the cdf function and the Q-Q plot.

3.6.8.27 Figure 3.25 shows the errors in assigned Mach speeds and speeds calculated from aircraft position estimates using data from the North Atlantic where Mach speed restrictions apply. Unusual results using the aircraft speed estimates are seen with a distinct 80-20% bias and 7.4 to 12.5 knot variability. In this case, the majority of aircraft are arriving before their estimated time at each waypoint. The overall Mach (expressed in knots) and ground speed are shown. Note the variation in x− axis scales.

3.6.8.28 Figure 3.25 clearly shows that Mach limited aircraft have a much lower range of speed variation (as expected). This will be critical in collision risk modelling.

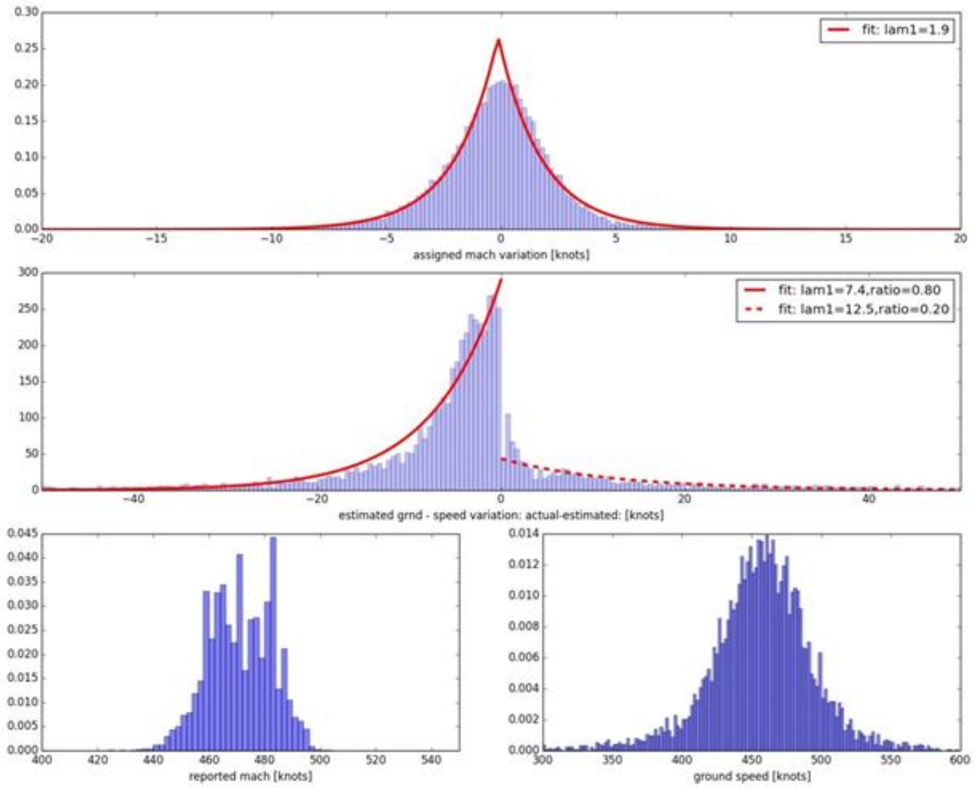


Figure 3.25. Iceland data. The top plot shows the variation from assigned Mach which is well fitted with scale parameter 1.8 knots. The middle plots show the speed error calculated from aircraft position estimates. This shows an unusual biased behaviour with Laplace scale parameters of 7.4 and 12.5 knots with the data split to a ratio of 80 to 20 % respectively. Note the variation in x−axis scales.

3.6.8.29 Numerical results from [18] are shown in Table 3.8 with the data sources being from Airservices (ASA), North Atlantic supplied from Iceland or Gander; and Anchorage (ZAN) or Oakland (ZOA) supplied from the FAA. Data considered as "individual" represent the traditional method for estimating speed error, using only a single aircraft speed variation. This does not take into account any correlation in error between adjacent aircraft pairs or that ATC naturally monitor aircraft pairs close to separation limits.

3.6.8.30 Table 8 also demonstrates results looking at estimation of aircraft speeds for pairs of aircraft, and that these actually are modeled using two distributions - one with small speed variation (3.2 knots) and the other with large speed variation (12.9 knots). However, these again do not account for aircraft pairs near the separation limit with ATC that will have enhanced monitoring.

3.6.8.31 Table 8 shows some key results based on actual arrival times. These show that for large separations, speed errors may be as large as 5.1 knots; however, closer to the separation standard, evidence shows this reduces to 2.5 knots.

Table 3.8. Summary of relevant speed errors calculated in this report. The scale parameter $\lambda_i \approx 0.64\lambda_p$

data	*individual λ_i knots*	*comment*
ASA Gander Iceland	4.9 8.2 7.4	individual: from arrival estimates individual: from arrival estimates individual: from arrival estimates
ASA ASA	3.2 (86%) 12.9 (14%)	from pairs: arrival estimates from pairs: arrival estimates
Gander Gander	3.9 (67%) 12.9 (33%)	from pairs: arrival estimates from pairs: arrival estimates
ASA Gander	3.2 7	from pairs: actual arrival times from pairs: actual arrival times
ZAN ZAN	4.5 2.5	from pairs: actual arrival times s large from pairs: actual arrival times s small
ZOA ZOA	5.1 2.5	from pairs: actual arrival times s large from pairs: actual arrival times s small
Iceland	1.9	individual: from reported Mach

3.6.8.32 A key result from Table 3.8 is that for Mach limited aircraft the speed error parameters is as low as 1.9 knots.

3.6.8.33 The speed error λ_v is a key parameter in the risk analysis, and has promoted considerable discussion within the SASP members over many years. This has led to the detailed studies outlined earlier in this section. The final results now match with the experience of the controllers and members of the SASP.

3.6.8.34 In summary, the key results are:

a) the speed error can be modelled using a Laplace distribution with parameter λ_v;

b) the parameter λ_v can be conservatively taken as 2.5 knots where appropriate Mach speed restrictions are in place and associated monitoring is performed; and

c) without a monitoring regime, the speed variation parameter is assumed to be a higher value of 5.5 knots, representative of independent aircraft with unknown methods of speed estimation by the ATC system.

3.6.9 Speed Restriction Limit V_m

3.6.9.1 This section explores the relevance of placing a restriction of Vm = ±50 knots on the speed error.

3.6.9.2 Previous studies [11, 12] considered a long tailed distribution for the speeds of both aircraft as a double exponential distribution with decay parameter 5.82 knots and truncated to ± 100 knots from a mean speed, V_0.

3.6.9.3 In a truncation of less than 100 knots was considered. The probability distribution is truncated at $V = V_0 \pm V_m$ and the resulting distribution normalised to one. The rationale for this truncation was that:

a) aircraft are not able to fly at extreme high and low speeds; and

b) aircraft may be Mach-limited.

3.6.9.4 The cruise speed for typical oceanic aircraft are: Mach 0.82-Mach 0.85 (denoted here as M 0.82-M 0.85) for an A380 and B747; M 0.78-M 0.81 for a B767 and A320; M 0.74 - M 0.82 for a B737; and, M 0.79-M 0.82 for an A330. The physical lower limit of these aircraft is approximately M 0.02-M 0.03 lower than this [37].

3.6.9.5 The speed of sound varies with altitude up to 36 000 ft from approximately 592 knots to 570 knots at cruising levels. Above 36 000 ft, the speed of sound is approximately constant. This variation does not significantly affect our modelling calculations.

3.6.9.6 If two aircraft are nominally flying the same speed (say M 0.82), the figures quoted above indicate that without strict Mach limitation, there could be a range of M 0.03 - M 0.06 for each aircraft. In our notation, this corresponds to approximately V_m = 17 - 34 knots, depending on interpretation of the range of possible aircraft speeds.

3.6.9.7 An additional scenario to consider is the operational error when a controller fails to notice that two aircraft have different speeds. For example, an A330 following a B767 could easily give rise to a M 0.07 difference in speeds. In our notation, this would be covered by the case of V_m = 50 knots.

3.6.9.8 Evidence from SASP-WG/WHL/23 indicates that this limit may be of the order of 70-90 knots. Whilst this data may need to be re-interpreted, it does provide evidence that this limit of speed must at least be considered. Figures 3.26 and 3.27 give extracts from this paper giving some indication of the speed distributions. Please see this paper for full context.

3.6.9.9 Evidence from SASP-WG/WHL/23 also indicates that there may be a possibility of large speed variation in a sample. In this paper, instantaneous Mach readings from aircraft were compared to assigned Mach. Whilst this instantaneous Mach may be subject to turbulence, or data errors, there is still some evidence (for example page 16, entry 44) of large speed variations. Whilst this level of variation may not be physically possible (i.e., aerodynamically too slow) the key issue is how does ATC handle these speeds in prediction of waypoint arrival times, and future separations. Whether real speeds or data errors, this paper shows there is evidence of large entries in the tails of the speed distributions which must be accounted for by the use of V_m in the model.

Table 3. Summary Statistics for the Along Track Predicted Speed Error – 14 Minutes

	Along Track Predicted Speed Error – New York	**Along Track Predicted Speed Error - Oakland**
Number of data points	69,070	145,597
Mean (knots)	0.93	1.69
Standard Deviation (knots)	9.08	8.52
Minimum Value (knots)	-86.80	-93.23
Maximum Value (knots)	86.92	71.87
Skewness	0.1990	0.1909
Kurtosis	7.0704	6.7473

Figure 3.26. Extract from SASP-WG/WHL/23 showing possible extremes of speeds.

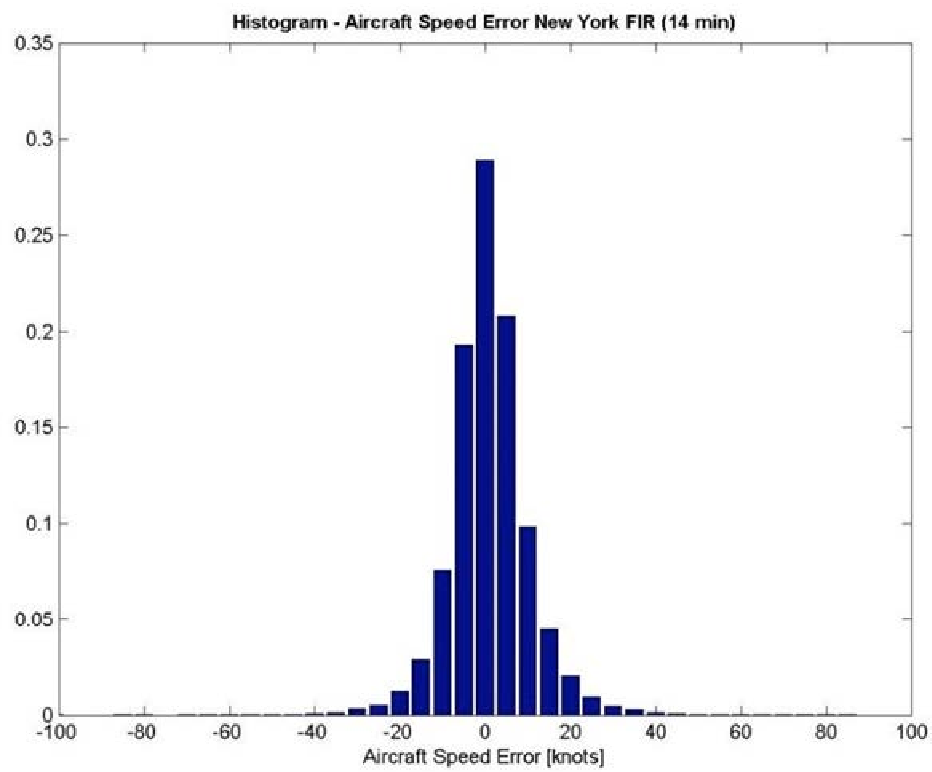


Figure 3.27. Extract from Figure 5, SASP-WG/WHL/23 showing distribution and possible extremes of speeds.

3.6.9.10 However, care must be taken in the interpretation of V and the distribution of speed around V.

Of interest in the risk assessment is that ATC believes an aircraft has a speed V_0, but it actually has a speed of V . Hence other variables such as unknown winds, data errors, malfunction and inadequate ATC software need to be considered. Thus the limit V_m may correspond to inaccuracies in aircraft speed prediction, not in variability in the actual aircraft speed. In the analysis of four months of Australian ADS-C data (25 339 flights) there were numerous data entries with up to 100 per cent variation between reported and actual time. In terms of speed, this would be equivalent to a 240 knot variation in predicted versus actual speed. Whilst these are probably "erroneous" data, it is still an open question as to how ATC systems interpret this.

3.6.9.11 For aircraft which are Mach limited it can be argued that increased vigilance by both aircrew and ATC will force the range of speed errors to be constrained to realistic levels of V_m = 50 knots.

3.6.9.12 The results and data within [18] show that the speed variation for aircraft pairs close to the separation standard will not be as high as 100 knots.

3.6.9.13 For completeness and future reference, results are presented in this circular for a range of V_m from 20 to 100 knots.

3.6.9.14 The value used for separation standard is a realistic and slightly conservative V_m = 50 knots.

3.6.10 Number of Pairs

3.6.10.1 This section explores a simple factor in the governing equations, NP, the number of pairs per flight hour. This is not a trivial exercise and can be contentious, particularly for traffic on same-identical tracks.

3.6.10.2 Some original models used NP = 1/T with T the reporting period 14, 30 or 40 minutes. However, as T becomes small, say 1.5 seconds for ADS-B, this relationship becomes nonsensical. Hence the following discussion considers this parameter.

3.6.10.3 Early meetings of the SASP recognized issues with the controller intervention buffer τ if the periodic reporting interval T became small [5, 6, 28, 38]. Anderson [6] argued that for small T it was not necessary to include an intervention buffer with every reporting period. A controller would adjust the scrutiny of position reports to concentrate on a small number of aircraft pairs. The discussion in [28] and [38] gives a summary of some points made in the debate. The work in [7, 8] assumed that NP was 1/T valid for values of T of order 15 minutes and not appropriate for small values of T. The issue was never resolved by the SASP. Attention at following meetings turned to an appropriate breakdown (by time) of the intervention buffers used to determine RNP 4 separation standards.

3.6.10.4 SASP-WG/WHL/1 (Canberra, Australia, May 2002) stated that:

> 2.1 The modification proposed in WP/17 to the collision risk model involved the application of the communication and controller intervention buffer (tau) only once in every 15 minutes or so. This was based on the assumption that controllers would not be anticipating the need to intervene after every ADS report where the reporting time intervals were

> significantly shorter than the 14.5 minute interval determined for the 30 NM standard. It was assumed that with a reporting interval of 21.5 minutes and a separation of 20 NM, that once the controller had checked a particular pair of aircraft, they would look ahead and not anticipate the need for intervention during the next 15 minutes.
>
> 2.2 During the project team discussions on WP/17, one member suggested that the assumption of the 15-minute "look ahead" time may need to be further examined. Since the Montréal meeting, a survey of controllers working procedural sectors in Australia confirmed that the assumption of 15 minutes was conservative.

3.6.10.5 The model used as recently as [15] implicitly assumes that (on average) every aircraft is contacted by ATC for an intervention at the end of every T. This is evident since the smallest τ in Equation 27 of this paper is 4 minutes. For a reporting period T = 20 minutes this degree of intervention (to every aircraft) could be regarded as very conservative: for T = 4 very unrealistic and for T = 1/60 (ADS-B) as an impossible intervention scenario.

3.6.10.6 Modelling NP as 1/T is one option. Assuming the worst case of synchronous reporting, a pair of aircraft fly for T minutes before their positions are known again. The collision risk for the pair would be CR(T , τ = 0). With adequate separation, perfect ATC scrutiny and no intervention needed, each aircraft would be involved in 1/T such pairs per flight hour. Each reporting period then represents a random trial from an acceptable starting configuration. Without the need for intervention, the risk per flight hour (in FAPFH) from NP repeated trials by each aircraft in an hour would be given to high accuracy by 2NP=2/T times the collision risk for a single trial over T by an aircraft pair.

3.6.10.7 The lower the value of T, the greater the certainty a controller has about aircraft position. Rather than modelling a small T as extra workload to controllers, it should be modelled as enabling controllers to concentrate on the aircraft pairs needing the most attention. It is appropriate that as T $\rightarrow$ 0 most aircraft pairs would not be checked at the end of each reporting interval.

3.6.10.8 A model which prevents a "runaway" level of controller intervention as $T \rightarrow 0$ is

$$\begin{aligned} \mathrm{CR} \;&=\; (1-\rho)\mathrm{CR}(\tau=0) \\ &\quad +\rho\left[0.95(0.95\,\mathrm{CR}(\tau=4)+0.05\,\mathrm{CR}(\tau=10.5))+0.05\,\mathrm{CR}(\tau=13.5)\right], \qquad (39) \end{aligned}$$

where CR(τ) is defined according to over the time period T + τ for an intervention delay of τ minutes and reporting time T minutes; and ρ is an intervention factor.

3.6.10.9 An intervention factor ρ = 3T is proposed for aircraft cruising in en-route airspace with T $\leq$ 20 minutes. With NP= 1/T , the combination NPρ = 3 is a constant for any reporting period T. This corresponds to a controller intervention to every aircraft every 20 minutes (in the mean). Since CR(T , 0) is relatively small, the results of modelling with Equation 39, NP = 1/T and ρ = 3T are almost identical to results from Equation 27 with NP = 3 in Equation 2.

3.6.10.10 Other natural system frequencies support a value like NP=3. For example, with relatively small T, the total time T + $\tau \approx$ T + 13.5 $\approx$ 20 giving NP=3. If aircraft have a separation standard of 20 NM, the initial separations used here are distributed in [20,270] NM with mean 145 NM or approximately one aircraft every 18 minutes giving NP ≈ 3.3. Similarly, a North Atlantic time separation in the range 10-20 minutes gives a time scale of 15 minutes and an equivalent NP = 4.

3.6.10.11 In previous papers, results were studied where Equation 27 is used with NP taken as either NP=1, NP=4 and NP=1/T in order to conservatively cover all reasonable possibilities. The papers also use the three values [4,10.5,13.5] and [4.5, 11.5, 13.5] in Equation 27 to conservatively model cases where these response times are poor. Although Equation 39 was proposed to extend the modelling down to very small T it was not needed for the results below.

3.6.10.12 Reference [30] uses NP=1 based on 438 aircraft pairs observed to have separations within the range 50 - 80 NM at an average of 37 per month.

3.6.10.13 A related argument for NP being of order 1 to 4 (and not becoming large as reporting time decreases) is the non-independence of risk for two similar scenarios a small time apart. For example, setting NP=4 (per flight hour), is assuming that two risk events (aircraft crossing), are independent and hence their risk can be linearly added. For a reporting period of 1 minute, the risk of a collision for an aircraft pair is not independent; their speeds and relative positions will be mostly unchanged. Hence the value of NP (per flight hour) relates to the time scale for independence of aircraft pairs. If the natural variation of aircraft speeds is of order 2.5 knots (NM/hour) and a change in relative speeds of aircraft of 5 knots is significant, or change in position of 5 NM is significant, then this gives a typical time-scale for independence of approximately 15-30 minutes. Hence NP = 4 would seem appropriate given this scenario. To clarify this argument: it is not necessary for ATC to re-assess an aircraft pair after 1 minute since their relative speeds and positions would be relatively unchanged; however, after 15 minutes there has been sufficient time elapsed for the speeds and positions to again require a new assessment by ATC (they again become independent events).

3.6.10.14 Some of the preceding discussion on NP is speculation on the part of SASP members, since a mathematical foundation for occupancy in crossing and same-track scenarios is still under development. However, SASP members consider the current model and use of NP to be satisfactory and conservative in its application here.

3.6.10.15 Hence, for the separation standards defined here a conservative value of NP=1 is used throughout, with results for other values of NP included for completeness. As risk is linear with NP, it is a trivial matter to multiply risk by a factor.

3.6.11 Offset

3.6.11.1 This section explores the assumptions made in applying offsets of random offsets (RO) to the model.

3.6.11.2 The model was simulated using either 0.5, 1.0, 1.5, or 2.0 NM offsets. That is, two aircraft are considered to have an applied offset by ATC of this amount.

3.6.11.3 Random offsets were also modelled with aircraft randomly taking an offset of either 0, 0.5, 1, 1.5 or 2 NM offsets.

3.6.11.4 The risk was calculated using basic probability assuming aircraft take one of the 5 possible positions on offer, denoted [0,0.5,1,1.5,2] respectively. Hence if aircraft 1 (AC1) is at position 0, the total risk is calculated due to the second aircraft is:

$$\mathrm{CR}(AC1 = 0) = \frac{1}{5}\left(\mathrm{CR}(o = 0) + \mathrm{CR}(o = 0.5) + \mathrm{CR}(o = 1) + \mathrm{CR}(o = 1.5) + \mathrm{CR}(o = 2)\right) \quad (40)$$

where o = 0.5 denotes aircraft 2 being offset from aircraft 1 by 0.5 NM. Hence counting for all possible positions:

$$\begin{aligned}
\mathrm{CR}(AC1 = 0) &= \frac{1}{5}[\mathrm{CR}(o = 0) + \mathrm{CR}(o = 0.5) + \mathrm{CR}(o = 1) + \mathrm{CR}(o = 1.5) + \mathrm{CR}(o = 2)] \\
\mathrm{CR}(AC1 = 0.5) &= \frac{1}{5}[\mathrm{CR}(o = 0.5) + \mathrm{CR}(o = 0) + \mathrm{CR}(o = 0.5) + \mathrm{CR}(o = 1) + \mathrm{CR}(o = 1.5)] \\
\mathrm{CR}(AC1 = 1) &= \frac{1}{5}[\mathrm{CR}(o = 1) + \mathrm{CR}(o = 0.5) + \mathrm{CR}(o = 0) + \mathrm{CR}(o = 0.5) + \mathrm{CR}(o = 1)] \\
\mathrm{CR}(AC1 = 1.5) &= \frac{1}{5}[\mathrm{CR}(o = 1.5) + \mathrm{CR}(o = 1) + \mathrm{CR}(o = 0.5) + \mathrm{CR}(o = 0) + \mathrm{CR}(o = 0.5)] \\
\mathrm{CR}(AC1 = 2) &= \frac{1}{5}[\mathrm{CR}(o = 2) + \mathrm{CR}(o = 1.5) + \mathrm{CR}(o = 1) + \mathrm{CR}(o = 0.5) + \mathrm{CR}(o = 0)]
\end{aligned}$$

3.6.11.5 The final summation of the probabilities is then:

$$\mathrm{CR} = \frac{1}{25}\left(5\,\mathrm{CR}(o = 0) + 8\,\mathrm{CR}(o = 0.5) + 6\,\mathrm{CR}(o = 1) + 4\,\mathrm{CR}(o = 1.5) + 2\,\mathrm{CR}(o = 2)]\right). \quad (41)$$

3.7 SAME IDENTICAL TRACK

3.7.1 This section explores the same-identical track situation that is where one aircraft is following the other. The aircraft are assumed to have the same nominal speed (assumed by ATC) but their speed may vary around this according to a double exponential distribution. This is shown in Figure 3.28.

3.7.2 Part of the aim of the following sections is to explore the variation of collision risk as different parameters change, to enable an understanding of the dynamics of the collision risk model. These also provide assurance that the results are "reasonable" and behaving as expected.

3.7.1 Geometry

3.7.1.1 The separation S relates to the initial distances $\hat{d}_1$ and $\hat{d}_2$ to the intersection of the aircraft via the relationships:

$$\hat{d}_1 = V_1 T, \quad (42)$$
$$\hat{d}_2 = \hat{d}_1 + S, \quad (43)$$

where T is the reporting time and S is the initial separation. The "intersection" is the position of aircraft 1 at $t = T$. The time integral is evaluated over $t \in [0, T + \tau]$ where τ is the buffer time incorporating the time for a controller to receive an ADS report, assess the information, contact the aircraft and for the aircraft to complete a manoeuvre.

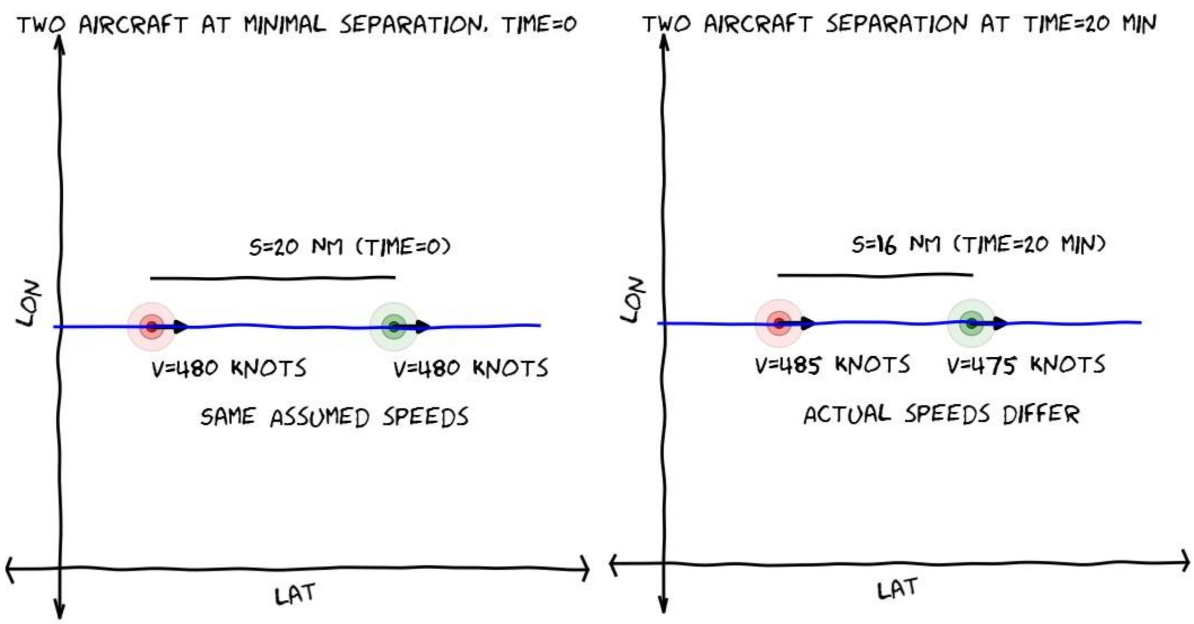


Figure 3.28. Two same-identical track aircraft separated by S = 20 NM (say) will always be assumed to have the same speeds. However, they may actually have different speeds within the next reporting period time which could cause a breakdown of separation.

3.7.2 Variation with ONP

3.7.2.1 Figure 3.29 shows the variation of collision risk (log10 CR) versus ONP ∈ [0.05 , 0.1, 0.5, 1, 2, 4 , 6 , 8, 10] for a variety of reporting times T = [4, 6, 8, 10, 12, 14] minutes. Here S = 20 NM, λ_v = 5.5 knots,V_m = 75 knots, angle = 0, τ = [4, 10.5, 13.5] minutes, offset = 0, and all other parameters are standard.

3.7.2.2 If ONP is small, aircraft track the centerline closely and if the speeds are such that the trailing aircraft "catches up" to the lead aircraft, a collision is likely to occur. Hence risk is large for small ONP. As ONP increases the risk decreases. However, if ONP is very large, then the longitudinal error in position can mean aircraft again may intersect. Thus risk increases for large ONP. The results shown in Figure 3.29 are therefore reasonable.

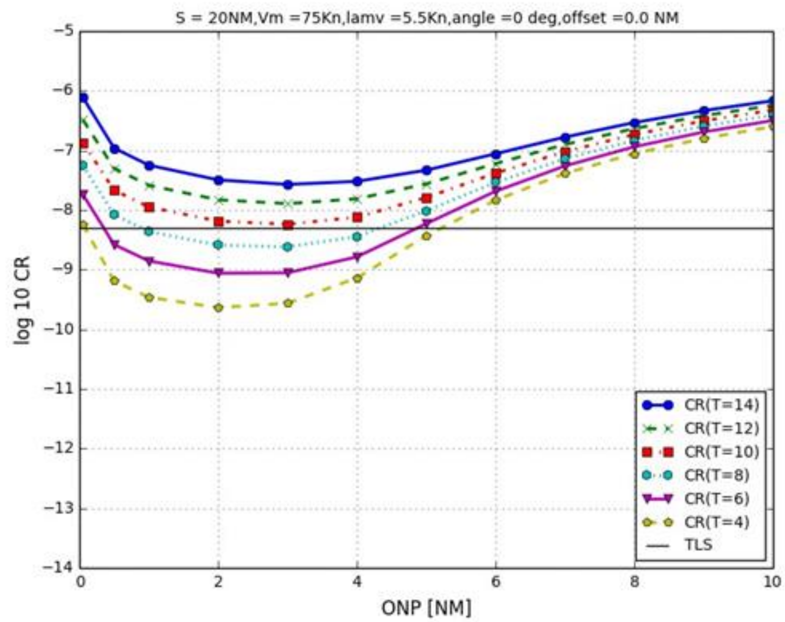


Figure 3.29: log10 CR versus ONP [NM] for a range of reporting times T [mins]. Parameters are Sx = 20 NM, NP=1, λv = 5.5 knots and τ ≡ [4, 10.5, 13.5] minutes. Note that the maximum risk is when ONP is small or ONP large. The geometry is "same-identical track".

3.7.2.3 Hence for same-identical track:

a) the risk is highest either when ONP = 0.05 or when ONP = RNP; and

b) the risk when ONP = 0.05 dominates when RNP is approximately less than 8-10 NM.

3.7.3 Variation with Speed Decay λ_V

3.7.3.1 An aircraft with a nominal speed of V = 480 knots may have a quite different speed during the time interval of the interaction T + τ (from 6 to 27 minutes). This may be due to wind changes or inaccurate estimates of speed by either ATC or the aircraft. Estimates have shown that this decay fits a double exponential decay with scale parameter of the order of 2.5 or 5.5 knots. Here we vary this parameter as 4.5, 5.5 and 6.5 to illustrate the effect on the risk.

3.7.3.2 Figure 3.30 shows the variation of collision risk (log10 C R) versus λ_v ∈ [4.5, 5.5, .5] knots for a variety of reporting times T = [4, 6, 8, 10, 12, 14] minutes. Importantly, our calculation of collision risk is the maximum risk over the range of ONP ∈ [0.05,RNP]. Here S = 20 NM, angle = 0, τ = [4, 10.5, 13.5] minutes, offset = 0, and all other parameters are standard.

3.7.3.3 This near linear behavior is to be expected. The majority of the risk arises from the tail-ends of the speed distribution, since these are the speeds where trailing aircraft are able to "catch-up" to leading aircraft. An exponential decay in the distribution and increase of 1 in the scale parameter (from 4.5 to 5.5 knots) implies an exponential increase in the proportion of traffic with large speed differentials. When a logarithm is applied, this increases the risk linearly. Hence the results presented here are reasonable and consistent.

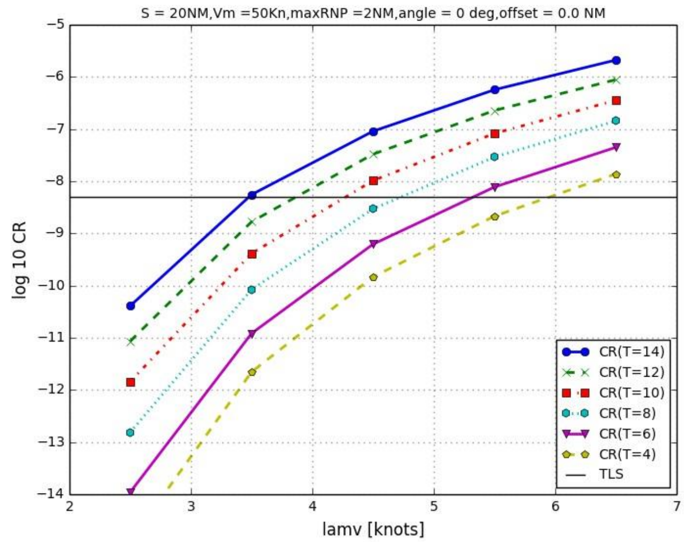


Figure 3.30. log10 CR versus λv [knots] for a range of reporting times T [mins]. Parameters are $S_x = 20$ NM, NP=1, λ_v = 5.5 knots and $\tau \equiv [4, 10.5, 13.5]$ minutes. The geometry is "same-identical track".

3.7.3.4 Hence same-identical track results for different λ_v affect the results linearly and predictably.

3.7.4 CR versus *T* with Vm Variation

3.7.4.1 This section explores log10 CR versus reporting time T for different speed limitations Vm . This helps to understand the underlying behavior of the risk.

3.7.4.2 Figure 3.31 shows our "default" situation where S_x = 20 NM, RNP=2 NM, NP=1, λ_v = 5.5 knots and $\tau \equiv [4, 10.5, 13.5]$ minutes. The plot shows that if the speed is restricted to ±20 knots which may be considered to be Mach limited aircraft, then a reporting time up to 15 minutes is possible. However, if speeds are less restricted to ±40 knots then a reporting time of 4 minutes is required.

3.7.4.3 Note that in these graphs "T0" refers to our parameter τ , and "lamv" refers to λ_v .

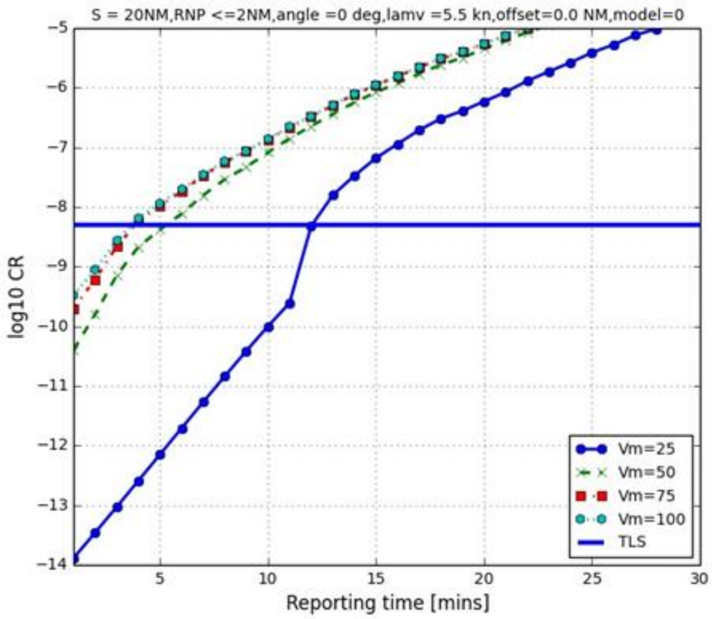


Figure 3.31. log10 CR versus reporting time T [minutes] for a range of speed restrictions V_m [knots]. Parameters are S_x = 20 NM, RNP=2 NM, NP=1, λv = 5.5 knots and τ ≡ [4, 10.5, 13.5] minutes. The geometry is "same-identical track".

3.7.4.4 Hence for same-identical track:

a) speed restrictions of Vm ∈ [40, 100] knots give similar results and benefit is only observed when Vm is reduced below 30 knots;

b) very low reporting times (4 minutes or less) are needed to obtain a CR < TLS when V_m is large; and

c) moderate reporting times of 10-14 minutes may be applied so long as strict Mach limitations are considered and data demonstrates the performance of ATC and aircraft in speed prediction.

3.7.5 Variation with Communication Performance τ distribution

3.7.5.1 This section illustrates the effect of changing the distribution and weights associated with response times τ . The discrete case is represented by Equation 27 denoted using the shorthand notation τ = [4, 10.5, 13.5] with the respective weights given in the equation [90.25,4.75,5] in per cent. Results are shown approximating this discrete case by a Gamma distribution denoted g(4,2) as discussed earlier. The aim is to show that results are not non-linearly sensitive to the precise values in the discrete case. Note that the τ values and distribution are a mixture of RCP and RSP values.

3.7.5.2 Figure 3.32 shows the situation where Sx = 20 NM, RNP=2 NM, NP=1, λ_v = 5.5 knots and where τ ≡ [4, 11.5, 14.5] (left plot) and τ ≡ g(4, 2) (right plot).

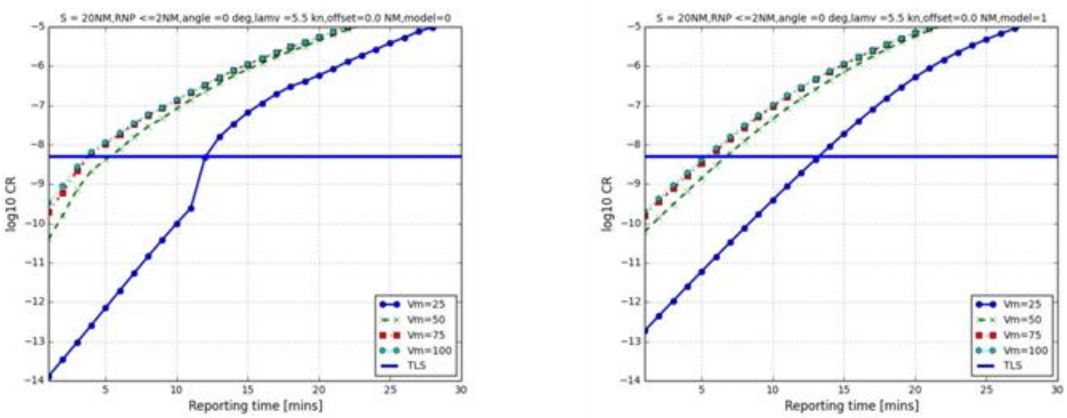


Figure 3.32. log10 CR versus reporting time T [minutes] for a range of speed restrictions V_m [knots]. Parameters are S_x = 20 NM, RNP=2 NM, NP=1, λ_v = 5.5 knots and $\tau \equiv$ [4, 11.5, 14.5] minutes or $\tau \equiv$ g(4, 2). The geometry is "same-identical track".

3.7.5.3 The results between the left and right plots in Figure 3.32 are similar apart from the "kinks" being eliminated from the discrete case. The kink represents the critical turnover from being not able to catch a leading aircraft to being able catch it. This will disappear with a smoother τ distribution. In this regard, the use of a smooth Gamma distribution is possibly more realistic than the discrete model.

3.7.5.4 Use of a Gamma distribution (G(4,2)) would make results smoother and more realistic, but is not used here. Significant variation of the model for response times is beyond the scope of this circular and should be the subject of further research.

3.7.5.5 Hence for same-identical track:

a) the models are not highly sensitive to the precise values of NP (1, 4 or 1/T), communication performance model ($\tau \equiv$ [4, 10.5, 13.5]; [4, 11.5, 14.5]; or g(4, 2)); and

b) the default case of NP=1, $\tau \equiv$ [4, 10.5, 13.5] minutes is representative of the system although NP=4 would be more conservative.

3.7.6 Variation with Offset

3.7.6.1 This section explores the reduction in risk due to lateral offset between the leading and trailing aircraft. Since aircraft move in the same direction, the offset would need to be assigned and managed to ensure aircraft pairs have an offset; a random offset would have little effect for same direction aircraft since even with five offset options (0.5,1,1.5,2,2.5) NM there is still a 0.2 chance of an aircraft-pair having the same offset.

3.7.6.2 Figure 3.33 shows the effect of offset on the collision risk for different reporting times T. Note that an offset of 0.5 NM is sufficient to reduce the risk significantly, since this prevents a large component of the risk for small ONP.

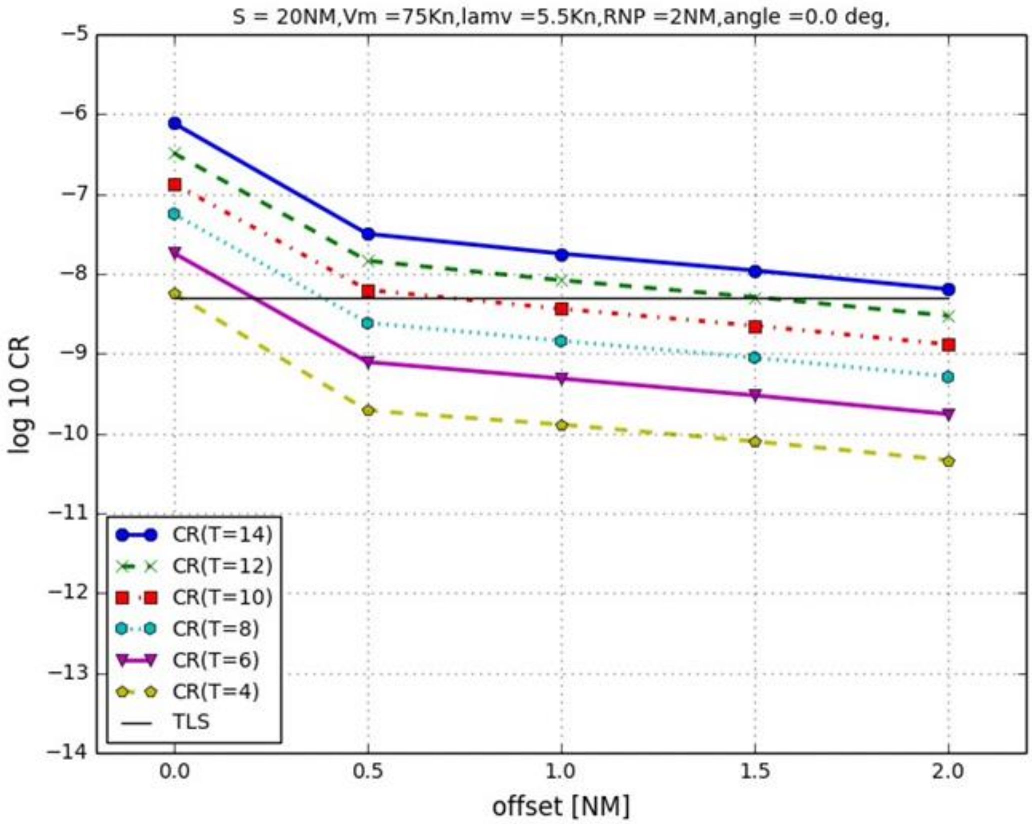


Figure 3.33. log10 CR versus offset for a variety of models. Parameters are S_x = 20 NM, RNP=2 NM, λ_v = 5.5 knots, NP=1, reporting times T ∈ [4, 6, 8, 10, 12, 14] minutes. The geometry is "same-identical track".

3.7.6.3 Figure 3.34 shows the log10 CR versus reporting time T [mins] for an offset of 1 NM. Shown on the left is the result with no offset from Figure 3.31.

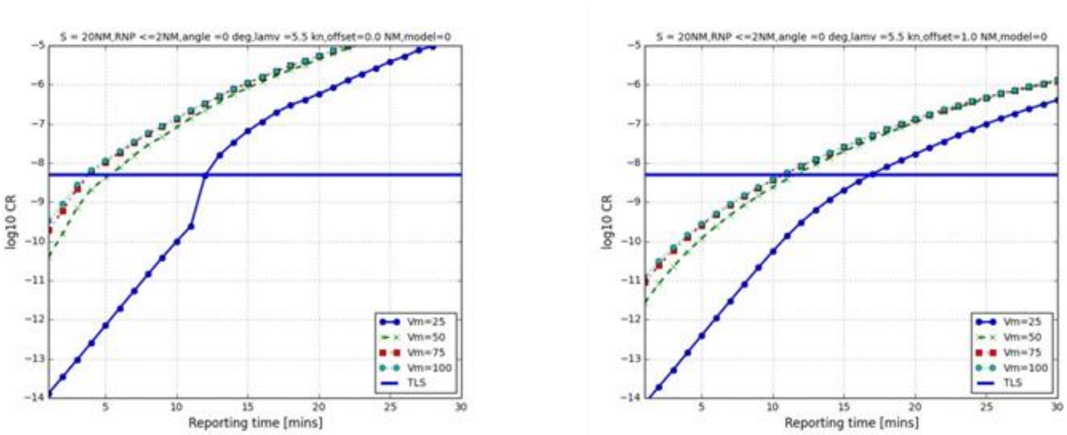


Figure 3.34. log10 CR versus reporting time T [mins] for a range of maximum speed variation V_m . Parameters are S_x = 20 NM, RNP=2, NP=1, λ_v = 5.5 knots and $\tau \equiv [4, 10.5, 13.5]$ minutes. The left figure has no offset and the right has offset of 1 NM. The geometry is "same-identical track".

3.7.6.4 Hence for same-identical track:

a) an offset of 0.25 NM is sufficient to reduce the risk by over one order of magnitude; and

b) moderate decreases in risk are obtained if offset is further reduced.

3.7.7 Discussion

3.7.7.1 The results demonstrated that for same-identical track:

a) NP ≈ 4 is an appropriate and conservative value for the number of pairs;

b) NP linearly influences the risk. Increasing NP from 1 to 4 increases the log10 risk by 0.6;

c) a τ response time of [4,10.5,13.5] with weights [90.25,4.75,5.0] % is appropriate although over-conservative. Further reduction in separation standards could result with an improvement in this model;

d) a uniform distribution in separation distances between aircraft pairs for 250 NM beyond the separation standard is appropriate but overly conservative. Use of a Gamma function with a reduction of aircraft pairs distances near the separation standard is appropriate and would result in lower separation standards. This should be the subject of further research;

e) a speed variation parameter of 2.5 knots is appropriate so long as Mach Restrictions, speed control and/or associated monitoring is in place. Without this restriction, a parameter of 5.5 knots should be used;

f) the limit to the speed variation can be assumed to be 50 knots.

3.7.7.2 Table 3.9 gives a list of different combinations of separation standard S_x, RNP, speed distribution scale parameter λ_v, reporting time T and speed restrictions V_m. Results using a discrete and continuous τ distribution are shown. Key values are highlighted.

Table 3.9. **Combinations of separation standard Sx, RNP, speed variation scale λ_v , reporting time T and speed restriction V_m . Negative times indicate that no reporting time interval will give a risk below the TLS. Results larger than 14 minutes are shown as > 14 since this was the maximum value used in the modelling. The geometry is "same-identical track".**

Std	*RNP*	*λv*	*Vm* knots	*T discrete NP=1* mins	*T gamma NP=1* mins	*T discrete NP=4* mins	*T gamma NP=4* mins
10	2	2.5	25	6.2	7.7	4.6	5.7
10	2	2.5	75	5.4	6.8	3.7	4.7
15	2	2.5	25	>14	>14	13.1	>14
15	2	2.5	75	>14	>14	11.7	12.7
20	2	2.5	25	>14	>14	>14	>14
20	2	2.5	75	>14	>14	>14	>14

20	2	4.5	50	8.5	9.7	6.5	7.7
20	2	4.5	80	7.3	8.7	5.2	6.7
20	2	4.5	100	7.3	8.7	5.2	6.6
30	4	4.5	50	>14	>14	>14	>14
30	4	4.5	80	>14	>14	13.8	>14
30	4	4.5	100	>14	>14	13.8	>14
20	2	5.5	50	4.8	6.3	3.2	4.5
20	2	5.5	80	3.4	5	2.2	3.1
20	2	5.5	100	3.3	4.9	2.1	3.1
30	4	5.5	50	13.4	>14	10.9	12.6
30	4	5.5	80	10.9	12.5	9.1	10.5
30	4	5.5	100	10.8	12.3	8.9	10.2
20	2	6.5	50	2.8	4	1.8	2.2
20	2	6.5	80	1.5	2.4	0.1	0.6
20	2	6.5	100	1.2	2.3	<0	0.4
30	4	6.5	50	10.1	11.7	8.6	9.8
30	4	6.5	80	8	9.3	6.3	7.3
30	4	6.5	100	7.6	8.9	5.7	6.9

3.7.7.3 Where an offset of 1 NM is considered, the combinations of times and speed restrictions are shown in Table 3.10.

Table 3.10. **Combinations of separation standard S_x, RNP, NP=1, speed variation scale λ_v , reporting time T and speed restriction V_m for an assigned offset of 1NM. The geometry is "same-identical track".**

Std	*RNP*	λ_V	*Vm* knots	*T discrete NP=1 mins*	*T gamma NP=1 mins*	*T discrete NP=4 mins*	*T gamma NP=4 mins*
20	2	4.5	50	>14	>14	12.6	13.5
20	2	4.5	80	>14	>14	12.1	12.7
20	2	4.5	100	>14	>14	12.1	12.7
30	4	4.5	50	>14	>14	>14	>14
30	4	4.5	80	>14	>14	>14	>14
30	4	4.5	100	>14	>14	>14	>14
20	2	5.5	50	11.6	12.3	8.7	9.9
20	2	5.5	80	10.7	11.3	7.7	8.8
20	2	5.5	100	10.7	11.2	7.7	8.7
30	4	5.5	50	>14	>14	>14	>14
30	4	5.5	80	>14	>14	>14	>14
30	4	5.5	100	>14	>14	>14	>14
20	2	6.5	50	8.6	9.6	6	7.4
20	2	6.5	80	7.2	8.2	4.6	6
20	2	6.5	100	7.2	8.1	4.5	5.9
30	4	6.5	50	>14	>14	>14	>14
30	4	6.5	80	>14	>14	12.5	13.1
30	4	6.5	100	>14	>14	12.3	12.9

3.8 SAME DIRECTION TRACK – ANGLE [1-90]

3.8.1 This section explores the overall behaviour of results for same direction track geometry crossing at some angle θ. Detailed results are tabulated and graphed in the appendices.

3.8.1 Geometry

3.8.1.1 The same scenario, parameters, analysis and computer code used in are reproduced for same-track longitudinal separation. This is outlined in Figure 3.35. The separation S relates to the initial distances $\hat{d}_1$ and $\hat{d}_2$ to the intersection of the aircraft via the relationships

$$\hat{d}_1 = V_1 T, \quad (44)$$

$$\hat{d}_2 = \hat{d}_1 + S, \quad (45)$$

where T is the reporting time and S is the initial separation. The time integral is evaluated over $t \in [0, T + \tau]$ where τ is the buffer time incorporating the time for a controller to receive an ADS report, assess the information, contact the aircraft and for the aircraft to complete a manoeuvre.

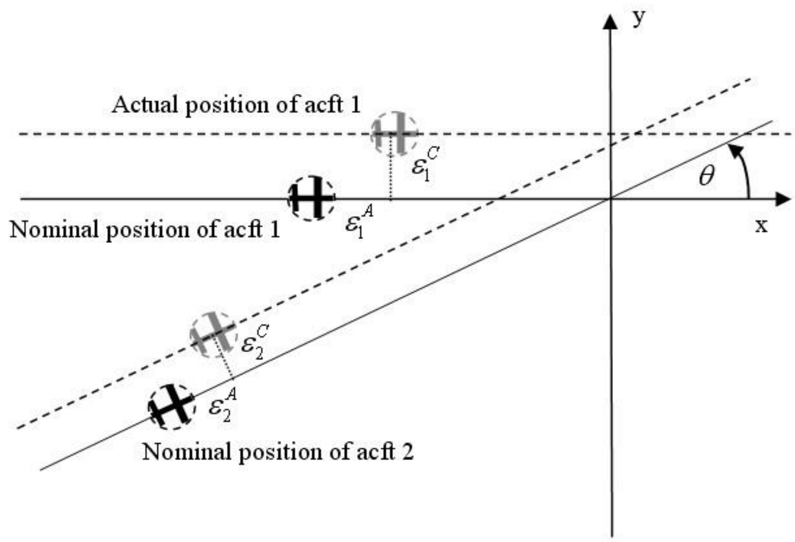


Figure 3.35. **Schematic of two aircraft approaching an intersection with an angle θ between the approach tracks. Both nominal and actual positions are shown and position errors (d) relate to along-track and cross-track errors [7].**

3.8.2 Variation of CR with angle

3.8.2.1 Figure 3.36 shows the collision risk versus RNP for different reporting times. Here S_x = 20 NM, NP=1, λ_v = 5.5 knots and $\tau \equiv [4, 10.5, 13.5]$ minutes.

3.8.2.2 In this result, we do not see the large increase in collision risk when ONP is small. This is to be expected since small ONP can only really increase collision risk if the aircraft are on identical tracks.

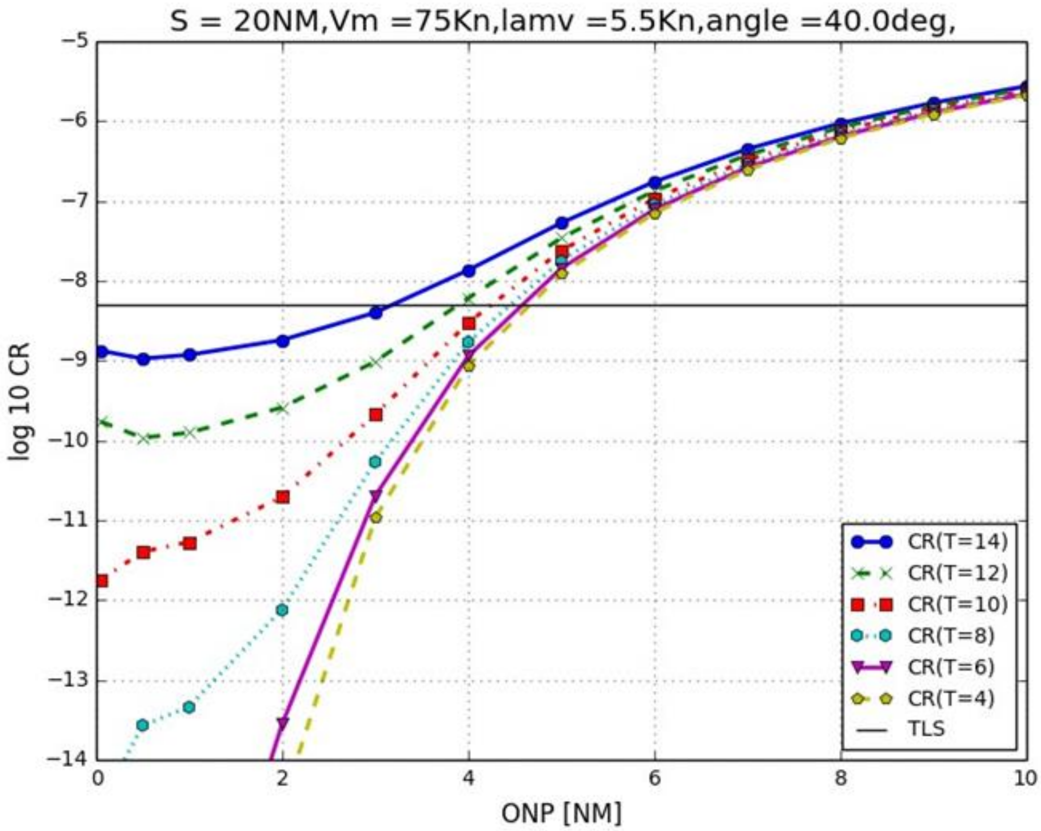


Figure 3.36. log10 CR versus ONP [NM] for a range of reporting times T [mins]. Parameters are S_x = 20 NM, NP=1, λ_v = 5.5 knots and $\tau \equiv$ [4, 10.5, 13.5] minutes. Note that the maximum risk is now only when ONP large. Geometry is same track angle 40 degrees.

3.8.2.3 Hence for same track 1-45 degree crossing:

a) when the angle is large the ONP down to 0.05 NM does not increase the collision risk; and

b) the maximum collision risk occurs when ONP = RNP.

3.8.3 Variation with Angle

3.8.3.1 Figure 3.37 shows the collision risk versus angle for different reporting times. Here Sx = 20 NM, NP=1, λ_v = 5.5 knots, V_m = 75 knots and $\tau \equiv$ [4, 10.5, 13.5] minutes.

3.8.3.2 Figure 3.38 shows the similar plot as Figure 3.37 but with λ_v = 2.5 knots and V_m = 50 knots.

3.8.3.3 The risk is largest for angle 1 degree, dropping rapidly at five degrees to a minima around 20-30 degrees. The risk then rises again as angle increases to 90 degrees.

3.8.3.4 Due to the behavior with angle, tabulated results are split into three groups. The maximum risk over:

a) 1-90 degrees;

b) 5-90 degrees;

c) 5-45 degrees.

Under some circumstances, it may be useful to define separation standards separately for these regions, if the broader region 1-90 degrees does not provide a low enough reporting interval.

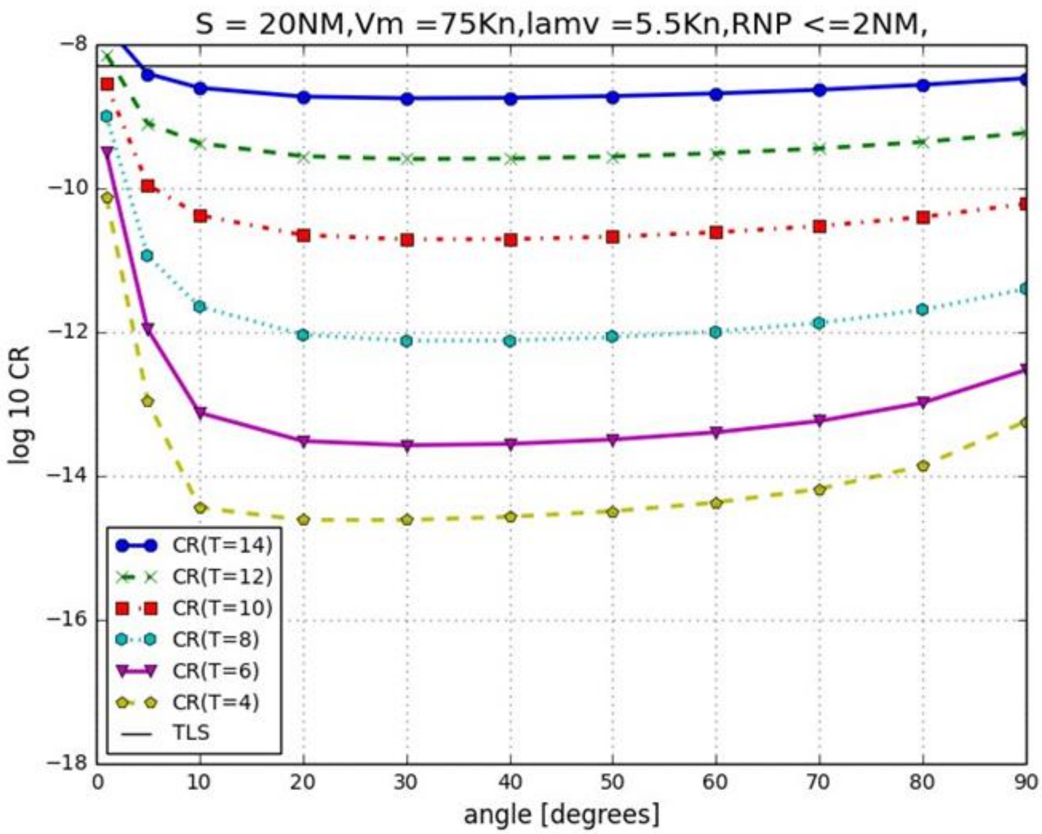


Figure 3.37. log10 CR versus angle for a range of reporting times T [mins]. Parameters are S_x = 20 NM, RNP =2, NP=1, λ_v = 5.5 knots, V_m = 75 knots and $\tau \equiv$ [4, 10.5, 13.5] minutes. Geometry is same direction track, angle 1-90 degrees.

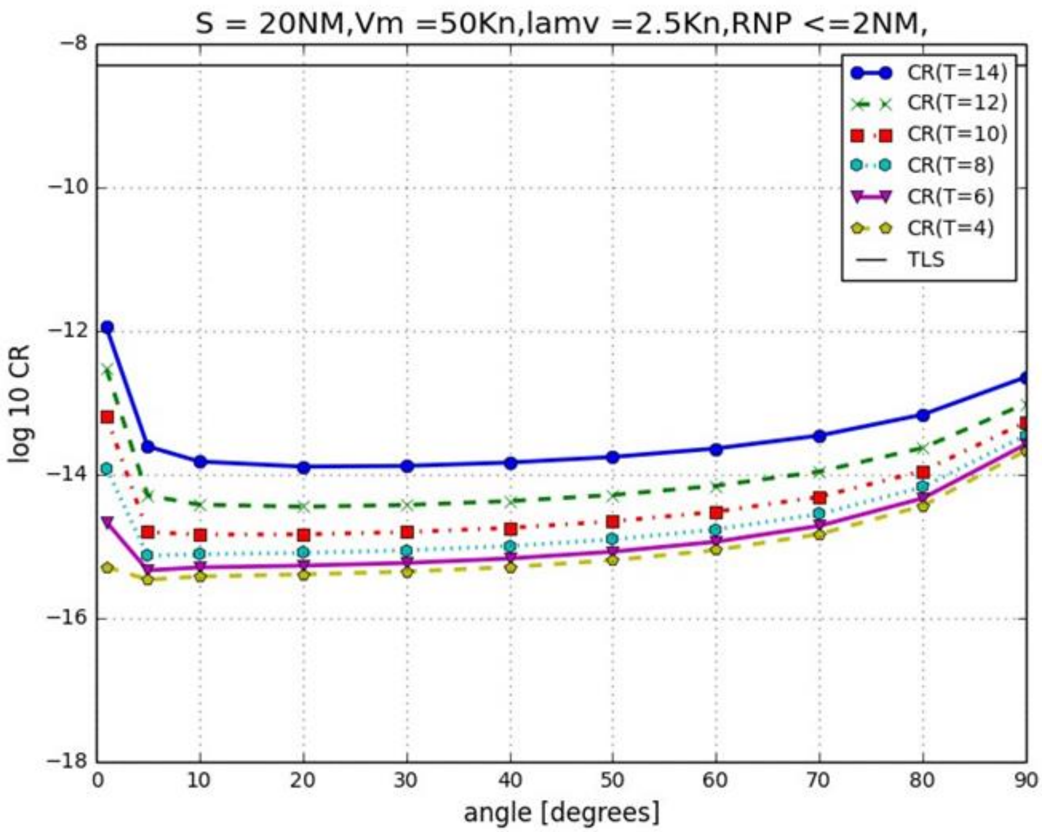


Figure 3.38. **log10 CR versus angle for a range of reporting times T [mins]. Parameters are S_x = 20 NM, RNP =2, NP=1, λ_v = 2.5 knots, V_m = 50 knots and $\tau \equiv$ [4, 10.5, 13.5] minutes. Geometry is same direction track, angle 1-90 degrees.**

3.8.3.5 Hence for same direction track 1-90 degree crossing:

a) the risk is highest when the angle is small (1 degree);

b) the risk is lowest around 30-40 degrees;

c) the risk rises again around 90 degrees.

3.8.4 CR Versus *T*

3.8.4.1 Figure 3.39 shows the log10 CR versus reporting time T for key angles $\theta \in$ [1, 5, 90] knots. Parameters are S_x = 20 NM, RNP=2, NP=1, λ_v = 5.5 knots, V_m = 75 knots and $\tau \equiv$ [4, 10.5, 13.5] minutes.

3.8.4.2 In the tabulated results in the appendices, the time where these lines cross the TLS (horizontal line) is recorded. Hence θ = 5 degrees gives a reporting time of 14.4 minutes while the 1 degree gives a maximum reporting interval of 11.2 seconds.

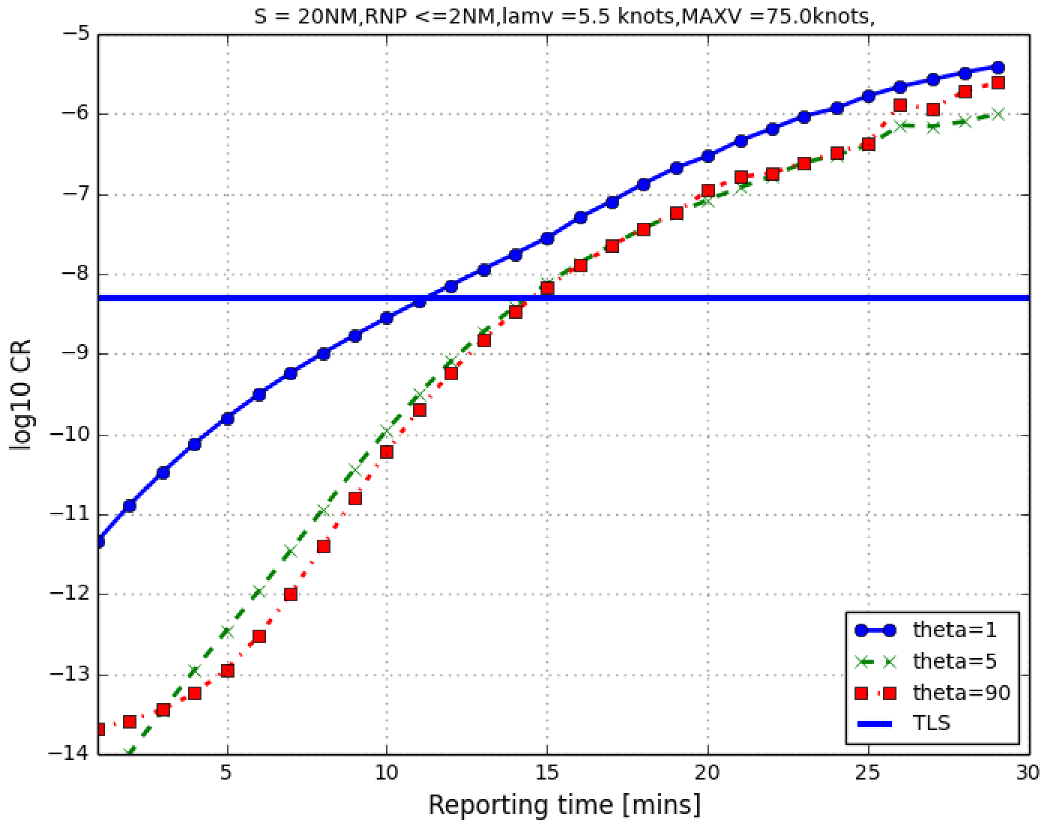


Figure 3.39. log10 CR versus angle for a range of reporting times T [mins]. Parameters are S_x = 20 NM, RNP ≤ 2, NP=1, λ_v = 5.5 knots, V_m = 75 knots, and $\tau \equiv$ [4, 10.5, 13.5] minutes. Geometry is same track angle 1-90 degrees.

3.8.5 Discussion

3.8.5.1 This section discusses the main results for same track 1-90 degree. Table 3.11 shows combinations of separation standard (Std [NM]), RNP [NM] and maximum speed variation limit λv . The maximum reporting time T which gives a risk below the TLS is shown for four different models used in previous results. Here the NP=4 case is not used as for crossing tracks the number of pairs is countable (as opposed to same-identical track where NP is a debatable concept), and NP=1 is more appropriate and conservative. The NP=4 case is given for completeness.

Table 3.11. Combinations of separation standard Sx, RNP, NP, speed variation scale λv , reporting time T and speed restriction Vm . The geometry is same-track 1-90 degrees.

Std *NM*	*RNP* *NM*	λ_v *knots*	*Vm* *knots*	*T discrete NP=1 mins*	*angles*	*comment*
10	2	2.5	50	13	5-45	Mach limited
15	2	2.5	50	23	1-90	Mach limited
20	2	2.5	50	≥ 30	1-90	Mach limited
20	4	2.5	50	29	1-45	Mach limited
30	2 or 4	2.5	50	≥ 30	1-90	Mach limited
10	2	5.5	75	4	5-45	
15	2	5.5	75	6	1-90	
15	2	5.5	75	10	5-90	
20	2	5.5	75	11	1-90	
20	2	5.5	75	14	5-90	
20	4	5.5	75	11	5-45	
30	2 or 4	5.5	75	20	1-90	

3.8.5.2 For aircraft considered to be same-track on angles 1-90 degrees:

a) the collision risk is highest at either 1 or 90 degrees;

b) for 20 NM, RNP 2 separation standard a reporting time of 11 minutes will give a risk below the separation standard;

c) when aircraft are Mach limited then for 20 NM, RNP 2 separation standard a reporting time of 30 minutes will give a risk below the separation standard;

d) when aircraft are Mach limited then a 15 NM, RNP 2 separation standard a reporting time of 23 minutes will give a risk below the separation standard; and

e) when aircraft are Mach limited then a 10 NM, RNP 2 separation standard a reporting time of 13 minutes will give a risk below the separation standard only for 5-45 degree angles.

3.9 RECIPROCAL TRACK LONGITUDINAL SEPARATION

3.9.1 Geometry

3.9.1.1 This section deals with the situation depicted in Figure 3.40. There is no need for a response time τ in this scenario. Here the angle is set to 180 degrees, which gave the greatest risk. The vertical separation standard, S_z, is either 1 000 or 2 000 feet. In the methodology $P_z(h_z > 1000\text{ft}) = P_z(h_z = 1000\text{ft})$, climb rates are fixed at 1 000 ft per minute.

3.9.1.2 In this situation, aircraft two is cleared to change flight level when it is at least a distance S_x^R from aircraft one and the distance between them is increasing. The distance $S_x^R \geq S_x$ is a choice but is at least as large as the separation standard. The aircraft are said to have an intersection point when the two planes are in overlap in the horizontal plane (for θ = 180 degrees), or when their extrapolated paths are in overlap for θ /= 180.

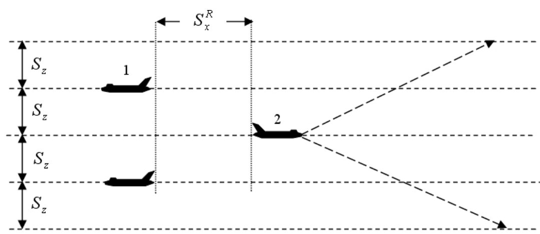


Figure 3.40. **Schematic of aircraft on a reciprocal track scenario. Here aircraft 2 is not clear to change flight level until a separation distance S = S^R_x achieved [7]. The scenario represented is Reciprocal Track Longitudinal Separation.**

3.9.1.3 Figure 3.41 shows the variation of collision risk against reporting time for different combinations of aircraft speed. The case of both aircraft having very low speeds of 300 knots gives the highest risk and hence this is the case used in the remaining results.

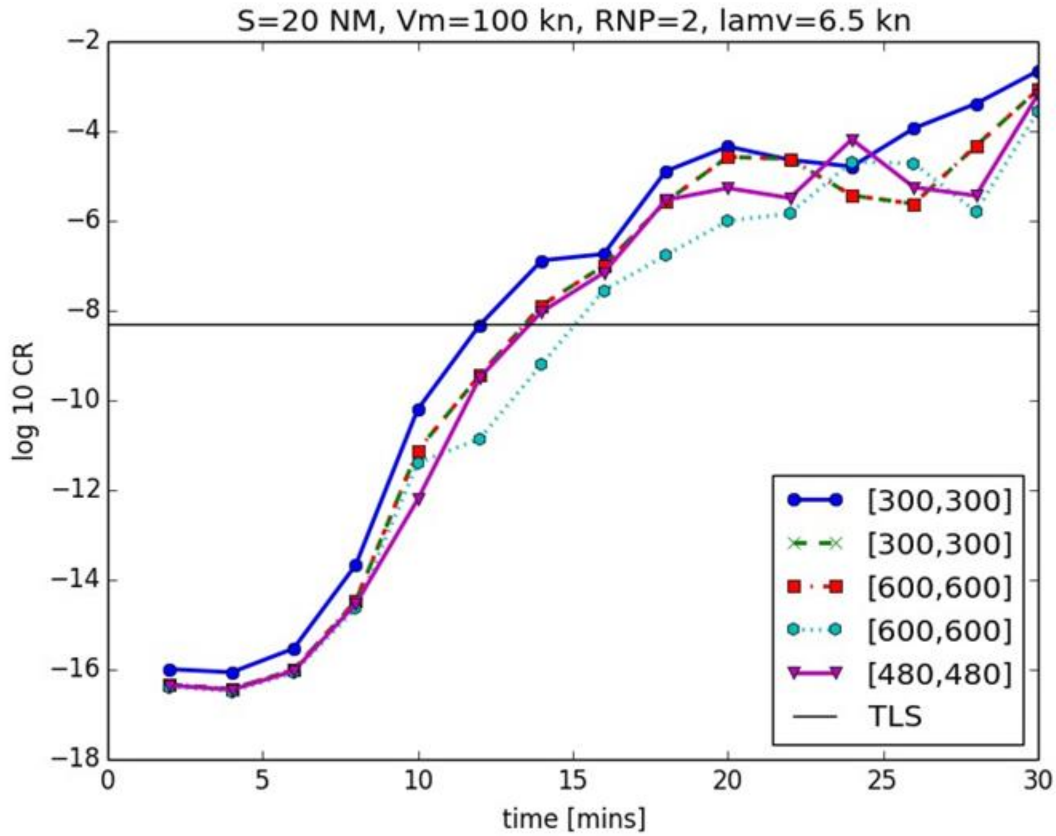


Figure 3.41. log10 of collision risk versus reporting time T [mins] for a range of aircraft speed combinations. Parameters are RNP=2, λ_v = 6.5 and 1000 ft vertical separation. Geometry is reciprocal track.

3.9.2 Variation with Reporting Time

3.9.2.1 Figure 3.42 shows the log10 CR versus reporting time T [mins] for the reciprocal geometry. The left figure shows results are shown for RNP=2, Sx = 20 NM and either 1 000 ft or 2 000 ft separation. Similarly results for RNP=4, Sx = 30 NM and either 1 000 ft or 2 000 ft separation are shown. The right figure shows the equivalent result with an assigned offset of 0.5 NM.

3.9.2.2 Figure 3.43 shows log10 CR with the same result as Figure 3.42 but with λ_v = 6.5.

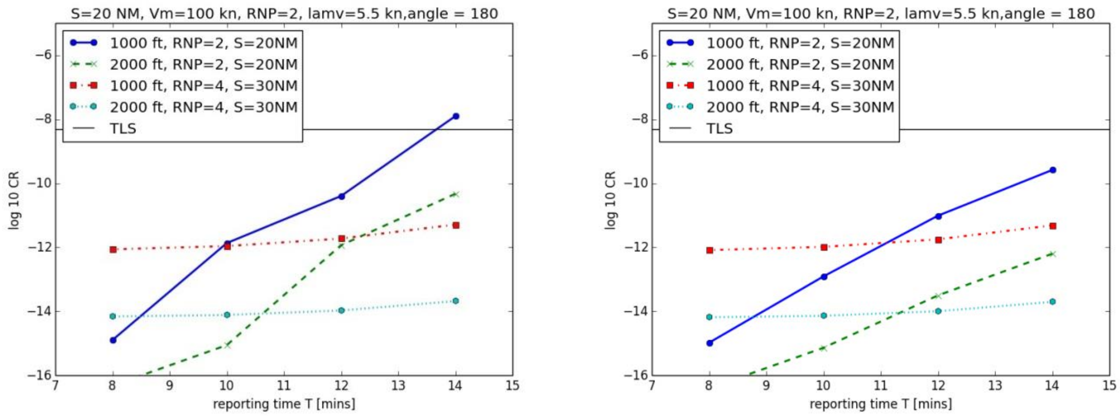


Figure 3.42. log10 CR versus reporting time T [mins] for a range of maximum speed variation Vm. Parameters are Sx = 20 NM, RNP=2, NP=1, λ_v = 5.5 knots and $\tau \equiv$ [4, 10.5, 13.5] minutes. The left figure has no offset and the right has offset of 0.5 NM. Geometry is reciprocal track.

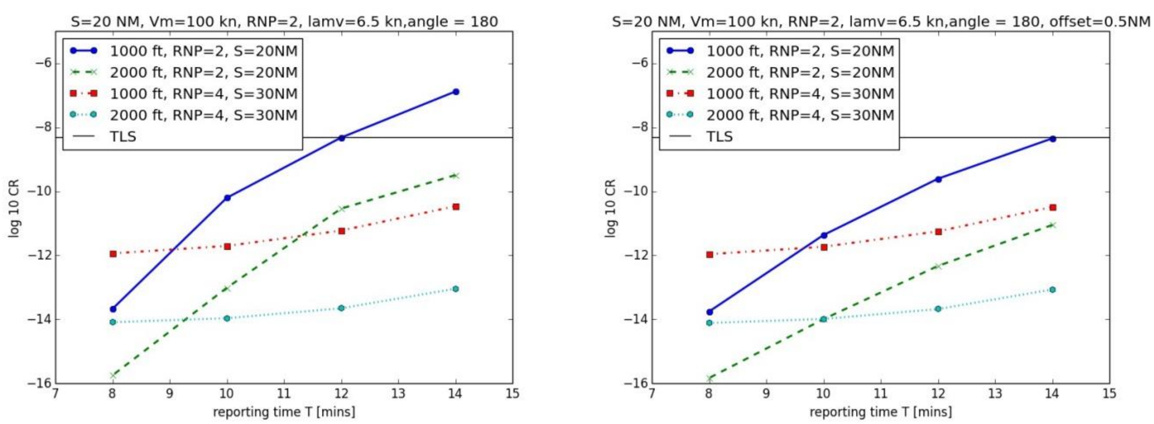


Figure 3.43. log10 CR versus reporting time T [mins] for a range of maximum speed variation Vm. Parameters are Sx = 20 NM, RNP=2, NP=1, λ_v = 6.5 knots and $\tau \equiv$ [4, 10.5, 13.5] minutes. The left figure has no offset and the right has offset of 0.5 NM. Geometry is reciprocal track.

3.9.3 Variation with Separation Standard

3.9.3.1 Figure 3.44 shows a result from [10] for log10 CR versus longitudinal separation standard for a range of reporting times. It illustrates that for this geometry a large reporting time can be used for relatively small separation standards S_x.

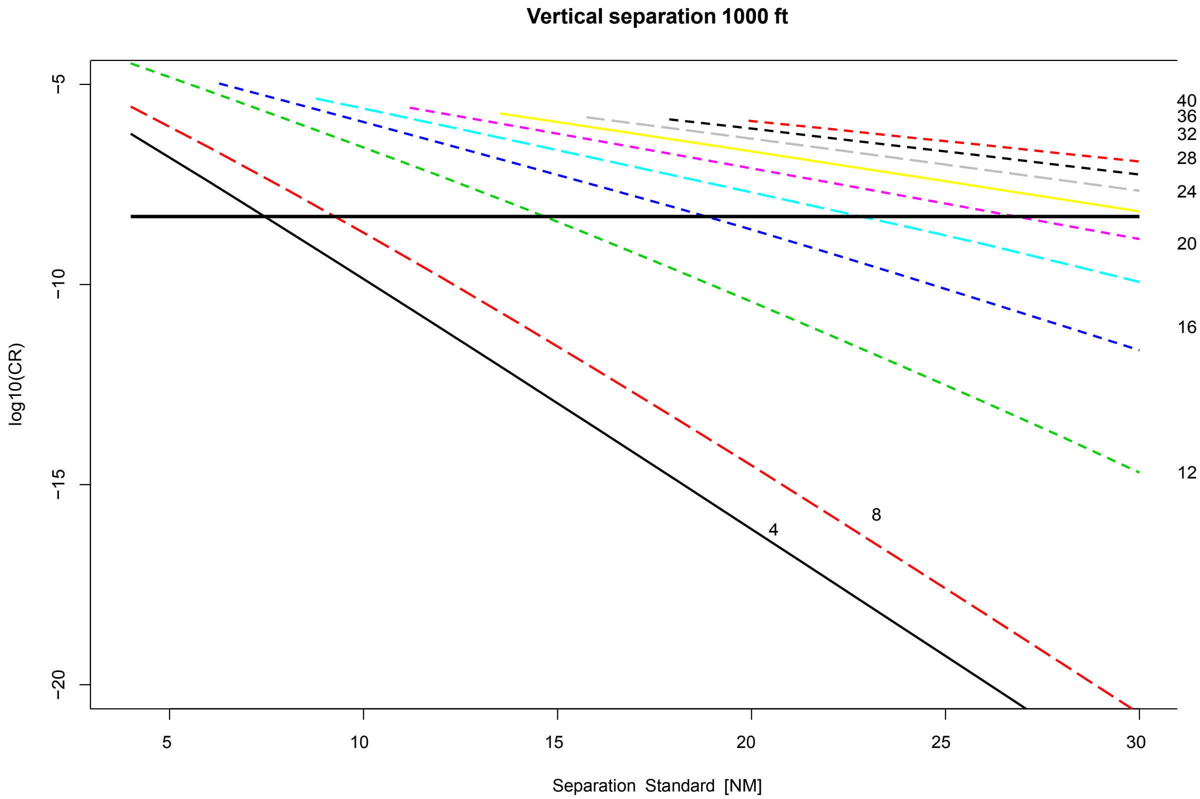


Figure 3.44. **log10 of collision risk versus separation standard for a range of reporting times [10]. Parameters are RNP=2, λ_v = 5.84 and 1 000 ft vertical separation. Geometry is reciprocal track.**

3.9.4 Discussion

3.9.4.1 Table 3.12 shows the combinations of key parameters which meet the target level of safety. Parameters are λ_v = 6.5 knots, NP=1 and the geometry is reciprocal. For example: with no offset, a reporting time of 12 minutes or less is sufficient to allow a 20 NM separation standard for RNP 2 aircraft. The geometry is reciprocal.

Table 3.12. Combinations of separation standard, RNP, offset, vertical standard and maximum reporting time which allows the risk to below the TLS. Here λ_v = 6.5 knots, NP=1 and the geometry is reciprocal.

Std NM	*RNP NM*	*offset NM*	*Vert Std ft*	*TLS Min*
20	2	0	1000	12.0
20	2	0	2000	16.1
20	2	0.5	1000	14.1
20	2	0.5	2000	19.7
20	2	1.0	1000	14.5
20	2	1.0	2000	20.3
30	4	0	1000	16.3
30	4	0	2000	22.3
30	4	0.5	1000	19.6
30	4	0.5	2000	25.5
30	4	1.0	1000	19.7
30	4	1.0	2000	26.2

Table 3.13. Risk results for RNP 4 and RNP 2 reciprocal track longitudinal separation. The risk figures are in units of fatal accidents per flight hour. This table is taken from [10]. Parameters are λ_v = 5.84, NP=1/T .

Longitudinal Separation Minimum (NM)	*Vertical Separation Minimum (feet)*	*Maximum ADS Reporting Interval (minutes)*	*Vertical Rate (feet per minute)*	*Risk estimate (RNP 4)*	*Risk estimate (RNP 2)*
30	2000	14	1000	3.1×10^{-14}	2.2×10^{-16}
30	1000	14	1000	9.0×10^{-12}	2.5×10^{-13}
20	2000	14	1000	-	1.8×10^{-12}
20	1000	14	1000	-	8.5×10^{-10}

3.10 NOTATION

3.10.1 This section summaries key notation:

a) ε_1^A: along-track position error for aircraft 1;

b) $f_1(V_1)$, $f_2(V_2)$: variation in speeds around the aircraft speed;

c) $g(4,2)$: Gamma distribution with shape $a = 4$ and location $b = 2 + T$;

d) HOP: horizontal overlap probability - the probability of two aircraft overlapping horizontally if nominally separated by a distance x;

e) h_z: vertical separation of aircraft (e.g. 1 000 ft);

f) $\lambda = \rnp/\log(20)$: scale parameter of the along- and cross-track error distributions;

g) λ_v: scale factor in double exponential decay of aircraft speed distributions (e.g. 5.5 knots);

h) lamv: is the same as λ_v and used in graphs;

i) λ_z: height of the cylinder representing an aircraft (e.g. 63.2 ft);

j) λ_{xy}: diameter of the cylinder representing an aircraft (e.g. 231.8 ft)

k) $P_z(h_z)$: probability that two aircraft nominally vertically separated by h_z are in vertical overlap;

l) S: initial longitudinal separation of aircraft (e.g. 20 NM);

m) S_x: longitudinal separation standard (e.g. 20 NM);

n) t_0, t_1: time interval for integration of risk (e.g. 0, 10 minutes);

o) τ: : delay of τ minutes (e.g. [4,10.5,13.5] minutes). For example:

– $\tau \equiv [4,10.5,13.5]$ implies

$$\mathrm{CR} = 0.95(0.95\,\mathrm{CR}(\tau = 4) + 0.05\,\mathrm{CR}(\tau = 10.5)) + 0.05\,\mathrm{CR}(\tau = 13.5) \quad (46)$$

– $\tau \equiv g(4,2)$ denotes

$$\mathrm{CR} = \int_0^\infty \Gamma(\tau; 4, 2) CR(\tau)\, d\tau \quad (47)$$

where $\Gamma(\tau; 4,2)$ is a Gamma distribution with shift $T + 2$ minutes and decay scale 4 [minutes]

p) T0: is the same as τ and used in graphs;

q) T: reporting time (e.g. 14 minutes);

r) V_1, V_2: speeds of the two aircraft (e.g. 480 knots);

s) V_m: maximum limit of speed distribution (e.g. 30 knots);

t) V_{rel}: relative horizontal speed between the two aircraft (e.g. 40 knots);

u) $\overline{|\dot{z}|}$: average relative vertical aircraft speed during nominal level flight;

v) ACP: actual communication performance;

w) ADS-C: automatic dependent surveillance – contract;

x) CPDLC: controller-pilot data link communication;

y) CR: collision risk in units of accidents per flight hour;

z) FIR: flight information region;

aa) ONP: observed navigation performance, for example ONP 0.1 implies a position performance equivalent to RNP 0.1 in NM;

bb) NP: Number of aircraft pairs per flight hour (eg NP=1, or NP=1/T);

cc) RCP: required communication performance;

dd) RNP: required navigation performance: navigation performance for cross-track and along-track position errors satisfy conservative PBN-based requirements. For RNP 2, at least 95% within 2 NM cross-track of the nominal position, and probability no more than 0.00001 of being outside 4 NM cross-track of the nominal position; and

ee) RSP: required surveillance performance.

3.11 PREVIOUS COLLISION RISK CALCULATIONS

3.11.1 This section explores some risk calculations from earlier publications as a guide only. Please refer to the relevant publications for context, details and assumptions.

3.11.1 Same Track

Table 3.14. Example risk assessments for same-track geometry from the referenced literature. Please see the references for context and detail.

RNP	*S*	*T*	*CR*	*cite*
10	50	27	4.4×10^{-9}	[4, 5]
10	50	27	4.3×10^{-9}	[7, 8]
4	30	14	3.9×10^{-9}	[4, 5, 7, 8]
4	50	32	3.3×10^{-9}	[4, 5, 7, 8]
4	30	14	2.0×10^{-8}	[29] (ONP=0.3 NM)
4	30	10	3.7×10^{-9}	[29, 30] (ONP=0.3 NM)
4	50	16	4.3×10^{-9}	[39] ($\tau = 9$ minutes

3.11.2 Reciprocal track

Table 3.15. Example risk assessments for reciprocal-track geometry from the referenced literature. Please see the references for context and detail.

RNP	*S*	*T*	*CR*	*cite*
10	50	27	3.2×10^{-9}	[4, 5]
10	50	27	3.4×10^{-9}	[7, 8] (900 ft/min rate)
4	30	14	1.1×10^{-12}	[4, 5]
4	30	14	2.2×10^{-11}	[7, 8]

3.12 DERIVATION OF ANDERSON-HSU MATHEMATICAL MODEL

3.12.1 Earlier papers give a derivation of a collision risk model based on reliability theory and the original Hsu model. This section gives an overview of this model and includes large sections of text copied directly from SASP papers.

3.12.2 Let $t = 0$ denote the time the simultaneous position reports are sent from the two aircraft. Let the nominal distances before the intersection at time $t = 0$ of aircraft 1 and 2, respectively, be denoted $\hat{d}_1^0$ and $\hat{d}_2^0$. These are the distances, according to their navigation instruments, the aircraft have to run to the intersection at time $t = 0$. If either aircraft has already passed the intersection (according to their navigation instruments), then the corresponding distance will be negative. It is assumed that the aircraft report simultaneously because this increases the uncertainty in the positions and tends to increase the risk of collision. If this is not true, then suitable adjustments may be made to either $\hat{d}_1^0$ or $\hat{d}_2^0$. For longitudinal separation, $\hat{d}_2^0 = \hat{d}_1^0 + S$ where S is the difference between the nominal distances of the two aircraft to the intersection at time $t = 0$ and will be assumed to be distributed according to a particular probability density function, for example a uniform density function.

3.12.3 Suppose that a randomly chosen pair of aircraft, not necessarily at the same level, is flying along either the same tracks or on tracks that intersect. Assume that for a particular application of the methodology $\hat{d}_1^0$ and $\hat{d}_2^0$. Suppose that their nominal speeds given by V_1 and V_2 are known and are constant during a time interval $[t_0, t_1]$ during which it is desired to estimate the risk of collision. The interval $[t_0, t_1]$ may, as in the case of longitudinal separation, include a controller communication and intervention buffer τ. The collision risk for given values of V_1 and V_2 the true speeds of the two aircraft, is firstly determined and then the probability of collision during time interval $[t_0, t_1]$ is calculated by multiplying by the probability density functions of V_1 and V_2 and integrating with respect to V_1 and V_2. The final collision risk estimate is obtained by integrating out the conditional risk estimates with respect to V_1 and V_2, and also where appropriate, by multiplying by an appropriate probability density function for $S = \hat{d}_2^0 - \hat{d}_1^0$. and integrating with respect to S.

3.12.4 Let the notation $\Pr\{X\}$ mean the probability of X occurring, and define

$$\mathrm{CR}(t_0, t_1 | V_1, V_2) = \Pr\{\text{pair collides during time interval}[t_0, t_1] \text{ given } V_1, V_2 \qquad (48)$$

3.12.5 As in the Reich model, aircraft are represented by simple geometric shapes. In this paper, it is assumed the aircraft are circular cylinders of diameter λ_{xy} and height λ_z . Again, as in the Reich model an equivalent geometry is used where one aircraft, aircraft 1 in this explanation, is a cylinder of radius λ_{xy} and height $2\lambda_z$, denoted by C, and the other aircraft, aircraft 2, is a point particle, denoted by P. It is clear that for a collision to occur P must enter C through its vertical side or through the top or bottom. It is also clear that a horizontal overlap of the two aircraft occurs when P enters the infinite cylinder, which we denote C_∞ , of radius λ_{xy} obtained by extending upwards and downwards the cylinder representing aircraft 1. Thus,

$$\mathrm{CR}(t_0, t_1|V_1, V_2) = \Pr\{P \text{ enters } C|P \text{ enters } C_\infty\}[t_0, t_1] \times \mathrm{HOP}(t_0, t_1|V_1, V_2) \qquad (49)$$

where HOP(t0,t1 |V1, V2) denotes the probability, the pair of aircraft will have a horizontal overlap during the time interval $[t_0, t_1]$ given V_1 and V_2.

3.12.6 Now to calculate Pr{Penters C | Penters C_∞}, note that the average horizontal path length through a cylinder of radius λ_{xy} is given by:

$$l = \frac{\pi\lambda_{xy}}{2}. \qquad (50)$$

3.12.7 Since P has relative speed $V_r = \sqrt{V_1^2 + V_2^2}$, it takes time

$$\delta t = \frac{\pi\lambda_{xy}}{2V_r} \qquad (51)$$

to pass through the cylinder. During this time, P moves vertically a distance z. Thus, the effective thickness of the cylinder representing a collision is:

$$2\lambda_z \times \left(1 + \frac{\overline{|\dot{z}|}\pi\lambda_{xy}}{2\lambda_z 2V_r}\right). \qquad (52)$$

3.12.8 Thus, if the instantaneous vertical overlap probability of the two aircraft of height λ_z, nominally separated vertically by distance h_z when the horizontal overlap occurs, is given by $P_z(h_z)$, then:

$$\Pr\{P \text{ enters } C|P \text{ enters } C_\infty\} = P_z(h_z) \times \left(1 + \frac{\overline{|\dot{z}|}\pi\lambda_{xy}}{2\lambda_z 2V_r}\right) \qquad (53)$$

since $P_z(h_z)$ may be assumed to vary linearly with λ_z over the small distances involved.

3.12.9 The factor NP is introduced to convert to units of collisions per flight hour and the final collision risk in units of fatal accidents per flight hour is then:

$$\mathrm{CR}(t_0, t_1|V_1, V_2) = 2\mathrm{NP}P_z(h_z) \times \left(1 + \frac{\overline{|\dot{z}|}\pi\lambda_{xy}}{2\lambda_z 2V_r}\right).$$

3.12.10 The collision risk in units of fatal accidents per flight hour during time interval is $[t_0, t_1]$ is given by:

$$\mathrm{CR}(t_0, t_1) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \mathrm{CR}(t_0, t_1 | V_1, V_2)\, f_1(V_1) f_2(V_2)\, dt\, dV_1\, dV_2 \quad (55)$$

where $f_1(V_1)$ is the probability density function of V_1 and similarly for V_2.

3.12.11 The Hsu methodology is based on reliability theory. Define $\lambda(t)$ as the number of entries into horizontal overlap per pair per hour at time t. This corresponds to the hazard rate in reliability theory. From reliability theory, the horizontal overlap probability during time interval $[t_0, t_1]$ is given by:

$$\begin{aligned} \mathrm{HOP}(t_0, t_1 | V_1, V_2) &= 1 - \exp\{-\int_{t_0}^{t_1} \lambda(t|V_1, V_2)\, dt\} && (56) \\ &\approx \int_{t_0}^{t_1} \lambda(t|V_1, V_2)\, dt && (57) \\ &= \int_{t_0}^{t_1} \frac{\lambda(t|V_1, V_2)\delta t}{\delta t}\, dt. && (58) \end{aligned}$$

3.12.12 Now, if the true positions (i.e. centres) of the two aircraft in cartesian coordinates, are $(x_1(t)y_1(t))$, and $(x_2(t)y_2(t))$, the probability that the two aircraft are actually in horizontal overlap at time t is:

$$\mathrm{HOP}(t|V_1, V_2) = \Pr\{(x_1^2(t) - x_2^2(t))^2 + (y_1^2(t) - y_2^2(t))^2\}. \quad (59)$$

This probability is just the probability the pair commenced horizontal overlap in the time interval $[t - \delta t, t]$, which is just $\lambda(t|V_1, V_2)$. Thus:

$$\mathrm{HOP}(t|V_1, V_2) = \int_{t_0}^{t_1} \frac{1}{\delta t} \mathrm{HOP}(t|V_1, V_2)\, dt. \quad (60)$$

and so

$$\begin{aligned} &\mathrm{CR}(t_0, t_1) = && (61) \\ &2\mathrm{NP} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \mathrm{HOP}(t_0, t_1 | V_1, V_2) \times P_z(h_z) \left(1 + \frac{\overline{|\dot{z}|}\pi\lambda_{xy}}{2\lambda_z 2V_r}\right) f_1(V_1) f_2(V_2)\, dV_1\, dV_2 && (62) \\ = \; &2\mathrm{NP} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \int_{t_0}^{t_1} \frac{2V_r}{\pi\lambda_{xy}} \mathrm{HOP}(t|V_1, V_2) P_z(h_z) \left(1 + \frac{\overline{|\dot{z}|}\pi\lambda_{xy}}{2\lambda_z 2V_r}\right) f_1(V_1) f_2(V_2)\, dt\, dV_1\, dV_2 && (63) \\ = \; &2\mathrm{NP} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \int_{t_0}^{t_1} \mathrm{HOP}(t|V_1, V_2) P_z(h_z) \left(\frac{2V_r}{\pi\lambda_{xy}} + \frac{\overline{|\dot{z}|}}{2\lambda_z}\right) f_1(V_1) f_2(V_2)\, dt\, dV_1\, dV_2. && (64) \end{aligned}$$

3.12.13 If ε_1^A and ε_2^A denote the along-track errors of the two aircraft, and ε_1^C and ε_2^C the cross-track errors, then the coordinates of the actual positions of the two aircraft at time t will be given by:

$$
\begin{aligned}
x_1(t) &= -\hat{d}_1^0 + \epsilon_1^A + V_1 t && (65)\\
y_1(t) &= \epsilon_1^C && (66)\\
x_2(t) &= -(\hat{d}_2^0 - \epsilon_2^A)\cos\theta - \epsilon_2^C \sin\theta + V_2 t\cos\theta && (67)\\
y_2(t) &= -(\hat{d}_2^0 - \epsilon_2^A)\sin\theta + \epsilon_2^C \cos\theta + V_2 t\sin\theta. && (68)
\end{aligned}
$$

3.12.14 Let $\Delta x = x_1(t) - x_2(t)$ be the true difference in x-coordinates which is given by:

$$
\begin{aligned}
\Delta x(t) &= (V_1 - V_2\cos\theta)t - \hat{d}_1^0 + \hat{d}_2^0\cos\theta + \epsilon_1^A - \epsilon_2^A\cos\theta + \epsilon_2^C\sin\theta && (69)\\
&= D_x(t) + \epsilon_1^A - \epsilon_2^A\cos\theta + \epsilon_2^C\sin\theta && (70)
\end{aligned}
$$

where

$$D_x(t) = (V_1 - V_2\cos\theta)t - \hat{d}_1^0 + \hat{d}_2^0\cos\theta \qquad (71)$$

is the nominal difference in x-coordinates at time t given V_1, V_2 and S.

3.12.15 Similarly, $\Delta y = y_1(t) - y_2(t)$ be the true difference in y-coordinates which is given by:

$$
\begin{aligned}
\Delta y(t) &= -V_2(t - t_0)\sin\theta + \hat{d}_2^0\sin\theta + \epsilon_1^C - \epsilon_2^A\sin\theta - \epsilon_2^C\cos\theta && (72)\\
&= D_y(t) + \epsilon_1^C - \epsilon_2^A\sin\theta - \epsilon_2^C\cos\theta && (73)
\end{aligned}
$$

where

$$D_y(t) = -V_2(t - t_0)\sin\theta + \hat{d}_2^0\sin\theta \qquad (74)$$

is the nominal difference in y-coordinates at time t given V_1, V2 and S. Thus:

$$
\begin{aligned}
\text{HOP}(t|V_1, V_2, S) &= P_r\{\Delta x(t)^2 + \Delta y(t)^2 \le \lambda_{xy}^2\} && (75)\\
&= \underset{\Delta x(t)^2+\Delta y(t)^2\le\lambda_{xy}^2}{\int_{\epsilon_1^A}\int_{\epsilon_2^A}\int_{\epsilon_1^C}\int_{\epsilon_2^C}} f_1^A(\epsilon_1^A) f_2^A(\epsilon_2^A) f_1^C(\epsilon_1^C)) f_2^C(\epsilon_2^C)\, d\epsilon_2^C\, d\epsilon_1^C\, d\epsilon_2^A\, d\epsilon_1^A && (76)
\end{aligned}
$$

where $f_i^A(x)$ and $f_i^C(x)$ are the probability density functions for along-track and cross-track navigational error, respectively, for aircraft=1,2.

3.12.16 The assumption that the region $\Delta x(t)^2 + \Delta y(t)^2 \le \lambda_{xy}^2$ is small has been taken and in the following derivation:

$$\text{HOP}(t|V_1, V_2, S) \quad (77)$$

$$= \int_{\substack{\epsilon_1^A \\ \Delta x(t)^2+\Delta y(t)^2 \le \lambda_{xy}^2}} \int_{\epsilon_2^A} \int_{\epsilon_1^C} \int_{\epsilon_2^C} f_1^A(\epsilon_1^A) f_2^A(\epsilon_2^A) f_1^C(\epsilon_1^C)) f_2^C(\epsilon_2^C)\, d\epsilon_2^C\, d\epsilon_1^C\, d\epsilon_2^A\, d\epsilon_1^A \quad (78)$$

$$= \int_{\epsilon_2^A} \int_{\epsilon_2^C} f_1^A(\epsilon_2^A \cos\theta - \epsilon_2^C \sin\theta - D_x(t)) f_2^A(\epsilon_2^A) f_1^C(\epsilon_2^A \sin\theta - \epsilon_2^C \cos\theta \quad (79)$$

$$-D_y(t)) f_2^C(\epsilon_2^C)\, d\epsilon_2^C\, d\epsilon_2^A \int_{\substack{\epsilon_1^A \\ \Delta x(t)^2+\Delta y(t)^2 \le \lambda_{xy}^2}} \int_{\epsilon_1^C} d\epsilon_1^C\, d\epsilon_1^A, \quad (80)$$

$$= \pi\lambda_{xy}^2 \int_{\epsilon_2^A} \int_{\epsilon_2^C} f_1^A(\epsilon_2^A \cos\theta - \epsilon_2^C \sin\theta - D_x(t)) f_2^A(\epsilon_2^A) f_1^C(\epsilon_2^A \sin\theta - \quad (81)$$

$$\epsilon_2^C \cos\theta - D_y(t)) f_2^C(\epsilon_2^C)\, d\epsilon_2^C\, d\epsilon_2^A \quad (82)$$

the constraint $\Delta x(t)^2 + \Delta y(t)^2 \le \lambda_{xy}^2$ is missing for the integration of ε_2^A and ε_2^C.

3.12.17 The density functions f_i^C and f_i^A are assumed to be double exponential distributions which allows exact evaluation of the integrals for different scenarios. For example, in the case where track angle $\theta = 0$ and assuming $f_1^A = f_1^C = f_2^A = f_2^C = f$ and $\lambda_1^A = \lambda_2^A = \lambda_1^C = \lambda_2^C = \lambda$ then:

$$\text{HOP}(t|V_1, V_2, S) \approx \frac{\pi\lambda_{xy}^2}{16\lambda^2} e^{-\frac{|D_x(t)|}{\lambda}} \left(\frac{|D_x(t)|}{\lambda} + 1\right). \quad (83)$$

Note that this formula is invalid for small λ and this is addressed in the next section.

3.13 AN IMPORTANT LIMITATION OF THE HSU COLLISION RISK MODEL FOR SMALL ONP

3.13.1 Reference [19] proposed an amendment for the Anderson-Hsu model appropriate for aircraft with a high position accuracy. This paper discusses the mathematics behind the amendment and some of the implications. Further work may be required to generalize the correction.

3.14 PAIRED VERSUS INDIVIDUAL SPEED ERROR

3.14.1 Assume each individual aircraft has an independent speed error dv fitted by a Laplace distribution with rate λ_i (for example 6 knots):

$$L_i(dv; \lambda_i) = \frac{e^{-|dv|/\lambda_i}}{2\lambda_i}.$$

3.14.2 The distribution of speed difference w between a pair of aircraft will then have a distribution:

$$C_p(w;\lambda_i) = \frac{e^{-|w|/\lambda_i}}{4\lambda_i}\left(\frac{|\,w\,|}{\lambda_i}+1\right).$$

3.14.3 If we fit a simple Laplace distribution to the paired speed distribution then we would have:

$$L_p(w;\lambda_p) = \frac{e^{-|w|/\lambda_p}}{2\lambda_p} \approx \frac{e^{-|w|/\lambda_i}}{4\lambda_i}\left(\frac{|\,w\,|}{\lambda_i}+1\right).$$

where we have now related the two distributions. The approximate relationship between λ_i and λ_p is now needed.

3.14.4 Figure 3.48 shows the direct comparison between $L_p(w;\lambda_p)$ and $C_p(w;\lambda_i)$ for $\lambda_i = 3.2$ and $\lambda_p = 5.0$. Also shown is the relationship between them for different values of λ. The ROe of the line is approximately 0.64 indicating that for typical values of speed parameters

$$L(\lambda) \approx C(0.64\lambda).$$

That is, if we measure the Laplace scale parameter for speed differences (λ_p), then this is equivalent to each aircraft having speed variability $\lambda_i \approx 0.64\lambda_p$.

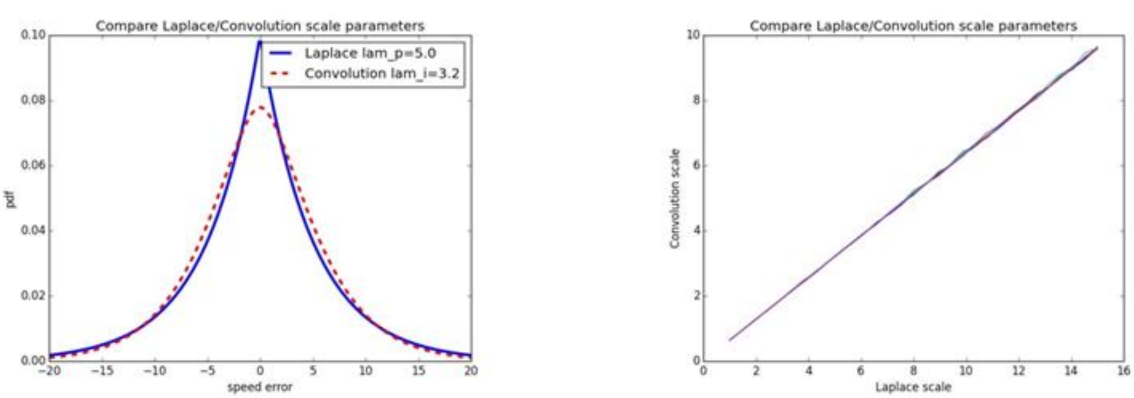


Figure 3.48. Comparison of scale parameters for Laplace and Convolution distributions. The left plot shows the comparison of the two distributions with scale parameters given. The right graph shows the relationship between the parameters for a range of λ derived from 5 simulations each with 100 000 randomly generated values. The ROe of the line is 0.64. Thus if the speed difference for a pair has scale λp, then this is equivalent to each aircraft having scale parameter $\lambda_i = 0.64\lambda_p$.

3.15 TABULATED RESULTS - SAME - IDENTICAL TRACK

3.15.1 This section gives tabulated results for main parameter sets which are detailed in the

Attachment A.

3.15.2 The following tables shows the minimum reporting rate T in minutes for a range of parameter values. These are:

a) Std: the separation standard as either 10,15,20,30 or 50 NM;

b) RNP: the maximum required navigational performance as either 0.05,0.5,1,2,3,4,5,6,7,9, 10 NM;

c) λ_v : the exponential decay speedparameter as either 2.5, 5.5 or 6.5 knots;

d) offset: the assigned lateral offset in NM (as either 0, ...);

e) mod0 (model 0): response times τ = [4, 10.5, 13.5] minutes with respective weights=[0.9025, 0.0475, 0.05];

f) mod1 (model 1): Gamma(4,2) response time, weight distribution;

g) mod2 (model 2): NP =4 and response times τ = [4, 10.5, 13.5] minutes with respective weights=[0.9025, 0.0475, 0.05];

h) mod3 (model 3): NP=4 and Gamma(4,2) response time, weight distribution;

i) mod4 (model 4): response times τ = [5, 11.5, 14.5] minutes with respective weights=[0.9025, 0.0475, 0.05];

j) mod5 (model 5): response times τ = [4, 7] minutes with respective weights=[0.95,0.05];

k) mod6 (model 6): response times τ = [4, 7.5, 10.5, 13.5] minutes with respective weights=[0.9025, 0.0475, 0.0475, 0.0025]; and

l) mod7 (model 7): NP=4 and response times τ = [4, 7.5, 10.5, 13.5] minutes with respective weights=[0.9025, 0.0475, 0.0475, 0.0025].

3.15.3 Results are limited to a maximum 30 minute reporting time and hence values larger than 30 are reports as $\geq$ 30.

3.15.4 Results with times indicated as "nan" mean that no sensible reporting rate gives results which meet the TLS.

3.15.5 A summary of key results from the tables are listed below.

Table 3.16. Key results from the following tables. For combinations of separation standards (in NM), RNP (in NM), λv in (knots) and assigned offset (in NM) the maximum allowable reporting time (in minutes) to meet the TLS is given using a range of different models for communication performance. Model 2 (mod2) is the standard model.

Std [NM]	*RNP* [NM]	*λv* [knots]	*Vm* [knots]	*offset* [NM]	*mod0* [min]	*mod1* [min]	*mod2* [min]	*mod3* [min]	*mod4* [min]	*mod5* [min]	*mod6* [min]	*mod7* [min]
10	2	2.5	50	0.0	6.6	7.9	4.5	5.8	5.6	11.8	9.2	7.1
15	2	2.5	50	0.0	15.3	16.1	12.6	13.7	14.3	19.1	17.7	15.2
20	2	2.5	50	0.0	23.7	23.9	20.4	21.0	22.7	26.7	25.5	22.7
20	4	2.5	50	0.0	23.7	23.9	20.4	21.0	22.7	26.7	25.5	22.5
30	2	2.5	50	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	4	2.5	50	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
10	2	5.5	75	0.0	nan	nan	nan	nan	nan	2.5	nan	0.0
15	2	5.5	75	0.0	nan	1.3	nan	nan	nan	6.4	2.7	1.3
20	2	5.5	75	0.0	3.9	5.5	2.6	3.6	2.9	10.0	6.6	5.2
20	4	5.5	75	0.0	3.9	5.5	2.6	3.6	2.9	10.0	6.6	5.2
30	2	5.5	75	0.0	11.8	13.2	9.8	11.2	10.8	17.0	14.5	12.5
30	4	5.5	75	0.0	11.8	13.2	9.8	11.2	10.8	17.0	14.5	12.5
10	2	2.5	50	0.5	10.7	10.8	6.8	7.2	9.7	13.6	12.4	8.7
15	2	2.5	50	0.5	22.7	22.3	18.7	18.8	21.7	24.8	23.9	20.4
20	2	2.5	50	0.5	≥ 30	≥ 30	28.2	27.9	≥ 30	≥ 30	≥ 30	29.5
20	4	2.5	50	0.5	29.4	28.6	22.3	21.7	28.4	≥ 30	≥ 30	23.3
30	2	2.5	50	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	4	2.5	50	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
10	2	5.5	75	0.5	nan	nan	nan	nan	nan	3.9	1.1	nan
15	2	5.5	75	0.5	4.3	5.6	2.0	3.5	3.3	9.2	7.0	4.8
20	2	5.5	75	0.5	9.5	10.4	6.8	8.1	8.5	13.7	11.9	9.5
20	4	5.5	75	0.5	9.0	9.3	5.5	6.1	8.0	12.2	10.9	7.6
30	2	5.5	75	0.5	19.1	19.2	15.7	16.5	18.1	22.0	20.8	18.0
30	4	5.5	75	0.5	19.1	19.2	15.7	16.5	18.1	22.0	20.8	18.0
10	2	2.5	50	1.0	11.8	11.8	7.9	8.3	10.8	14.5	13.4	9.8
15	2	2.5	50	1.0	23.9	23.4	19.8	19.7	22.9	25.9	25.0	21.3
20	2	2.5	50	1.0	≥ 30	≥ 30	29.5	29.0	≥ 30	≥ 30	≥ 30	≥ 30
20	4	2.5	50	1.0	≥ 30	29.2	23.1	22.4	29.0	≥ 30	≥ 30	24.0
30	2	2.5	50	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	4	2.5	50	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
10	2	5.5	75	1.0	nan	0.5	nan	nan	nan	4.3	1.8	nan
15	2	5.5	75	1.0	5.2	6.3	2.7	4.1	4.2	9.7	7.8	5.4
20	2	5.5	75	1.0	10.8	11.3	7.7	8.9	9.8	14.4	12.9	10.3
20	4	5.5	75	1.0	9.4	9.6	5.8	6.4	8.4	12.5	11.2	7.9
30	2	5.5	75	1.0	20.7	20.5	17.1	17.5	19.7	23.2	22.2	19.1
30	4	5.5	75	1.0	20.5	20.2	16.7	17.0	19.5	22.8	21.9	18.6
10	2	2.5	50	RO	9.3	10.4	6.9	7.8	8.3	13.7	11.8	9.3
15	2	2.5	50	RO	18.9	19.3	15.7	16.5	17.9	22.0	21.0	18.1
20	2	2.5	50	RO	27.9	27.7	24.2	24.4	26.9	≥ 30	29.4	26.1
20	4	2.5	50	RO	27.9	27.7	22.9	22.2	26.9	≥ 30	29.4	23.8
30	2	2.5	50	RO	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	4	2.5	50	RO	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
10	2	5.5	75	RO	nan	nan	nan	nan	nan	3.6	nan	nan
15	2	5.5	75	RO	2.1	3.5	0.1	1.6	1.1	7.9	4.8	2.9
20	2	5.5	75	RO	6.5	7.9	4.1	5.8	5.5	11.8	9.3	6.9
20	4	5.5	75	RO	6.5	7.9	4.1	5.8	5.5	11.8	9.3	6.9
30	2	5.5	75	RO	15.0	15.9	12.2	13.6	14.0	19.1	17.5	14.8
30	4	5.5	75	RO	15.0	15.9	12.2	13.6	14.0	19.1	17.5	14.8

3.16 TABULATED RESULTS: SAME DIRECTION TRACK, CROSSING ANGLE

3.16.1 This section gives tabulated results for main parameter sets.

3.16.2 The following tables shows the minimum reporting rate T in minutes for a range of parameter values. These are:

a) Std: the separation standard as either 10,15,20 or 30 NM;

b) RNP: the maximum required navigational performance as either 0.05,0.5,1,2,3,4,5,6,7,9, 10 NM;

c) λ_v : the exponential decay speed parameter as either 2.5 knots (Mach limited) or 5.5 knots;

d) mod0 (model 0): response times τ = [4, 10.5, 13.5] minutes with respective weights=[0.9025, 0.0475, 0.05];

e) mod2 (model 2): NP =4 and response times τ = [4, 10.5, 13.5] minutes with respective weights=[0.9025, 0.0475, 0.05];

f) 1-90 degrees: the time considers all angles between 1 and 90 degrees;

g) 5-90 degrees: the time considers all angles between 5 and 90 degrees;

h) 5-45 degrees: the time considers all angles between 1 and 45 degrees.

3.16.3 Results are limited to a maximum 30 minute reporting time and hence values larger than 30 are reports as ≥ 30.

3.16.4 Results with times indicated as "nan" mean that no sensible reporting rate gives results which meet the TLS.

Std	*RNP*	λ_v	*Vm*	*mod0*	*mod0*	*mod0*	*mod2*	*mod2*	*mod2*
				1-90 deg	*5-90 deg*	*5-45 deg*	*1-90 deg*	*5-90 deg*	*5-45 deg*
[NM]	*[NM]*	*[knots]*	*[knots]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*
10	2	2.5	50	nan	nan	13.4	nan	nan	9.0
15	2	2.5	50	23.0	23.0	25.1	19.7	19.7	21.9
20	2	2.5	50	≥ 30	≥ 30	≥ 30	28.9	29.4	≥ 30
20	4	2.5	50	nan	nan	29.2	nan	nan	21.2
30	2	2.5	50	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	4	2.5	50	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
10	2	5.5	75	nan	nan	4.7	nan	nan	2.7
15	2	5.5	75	6.0	10.0	10.0	3.5	8.5	8.5
20	2	5.5	75	11.2	14.4	14.4	8.4	12.5	12.5
20	4	5.5	75	nan	nan	11.6	nan	nan	7.8
30	2	5.5	75	20.5	22.8	22.9	17.3	20.2	20.2
30	4	5.5	75	20.1	20.1	22.2	16.8	17.1	19.1

3.17 TABULATED RESULTS: SAME-IDENTICAL TRACK

3.17.1 This section gives tabulated results for main parameter sets. The following tables shows the minimum reporting rate T in minutes for a range of parameter values. These are:

a) Std: the separation standard as either 10,15,20 or 30 NM;

b) RNP: the **maximum** required navigational performance as either 0.05,0.5,1,2,3,4,5,6,7,9, 10 NM;

c) λ_v: the exponential decay speed parameter as either 2.5 knots (Mach limited) or 5.5 knots;

d) mod0 (model 0): response times $\tau = [4{,}10.5{,}13.5]$ minutes with respective weights=[0.9025, 0.0475, 0.05];

e) mod2 (model 2): NP =4 and response times $\tau = [4{,}10.5{,}13.5]$ minutes with respective weights=[0.9025, 0.0475, 0.05];

f) 1-90 degrees: the time considers all angles between 1 and 90 degrees;

g) 5-90 degrees: the time considers all angles between 5 and 90 degrees; and

h) 5-45 degrees: the time considers all angles between 1 and 45 degrees.

3.17.2 Results are limited to a maximum 30 minute reporting time and hence values larger than 30 are reported as ≥ 30. Results with times indicated as “nan”, mean that no sensible reporting rate gives results which meet the TLS.

3.17.1 Main results

3.17.1.1 Key results from the following tables. For combinations of separation standards (in NM), RNP (in NM), λ_v in (knots) and assigned offset (in NM), the maximum allowable reporting time (in minutes) to meet the TLS is given.

Std	*RNP*	λ_v	*Vm*	*offset*	*mod0*	*mod1*	*mod2*	*mod3*	*mod4*	*mod5*	*mod6*	*mod7*
[NM]	*[NM]*	*[knots]*	*[knots]*	*[NM]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*
10	2	2.5	50	0.0	6.6	7.9	4.5	5.8	5.6	11.8	9.2	7.1
15	2	2.5	50	0.0	15.3	16.1	12.6	13.7	14.3	19.1	17.7	15.2
20	2	2.5	50	0.0	23.7	23.9	20.4	21.0	22.7	26.7	25.5	22.7
20	4	2.5	50	0.0	23.7	23.9	20.4	21.0	22.7	26.7	25.5	22.5
30	2	2.5	50	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	4	2.5	50	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
10	2	5.5	75	0.0	nan	nan	nan	nan	nan	2.5	nan	0.0
15	2	5.5	75	0.0	nan	1.3	nan	nan	nan	6.4	2.7	1.3
20	2	5.5	75	0.0	3.9	5.5	2.6	3.6	2.9	10.0	6.6	5.2
20	4	5.5	75	0.0	3.9	5.5	2.6	3.6	2.9	10.0	6.6	5.2
30	2	5.5	75	0.0	11.8	13.2	9.8	11.2	10.8	17.0	14.5	12.5
30	4	5.5	75	0.0	11.8	13.2	9.8	11.2	10.8	17.0	14.5	12.5
10	2	2.5	50	0.5	10.7	10.8	6.8	7.2	9.7	13.6	12.4	8.7
15	2	2.5	50	0.5	22.7	22.3	18.7	18.8	21.7	24.8	23.9	20.4
20	2	2.5	50	0.5	≥ 30	≥ 30	28.2	27.9	≥ 30	≥ 30	≥ 30	29.5
20	4	2.5	50	0.5	29.4	28.6	22.3	21.7	28.4	≥ 30	≥ 30	23.3
30	2	2.5	50	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	4	2.5	50	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
10	2	5.5	75	0.5	nan	nan	nan	nan	nan	3.9	1.1	nan
15	2	5.5	75	0.5	4.3	5.6	2.0	3.5	3.3	9.2	7.0	4.8
20	2	5.5	75	0.5	9.5	10.4	6.8	8.1	8.5	13.7	11.9	9.5
20	4	5.5	75	0.5	9.0	9.3	5.5	6.1	8.0	12.2	10.9	7.6
30	2	5.5	75	0.5	19.1	19.2	15.7	16.5	18.1	22.0	20.8	18.0
30	4	5.5	75	0.5	19.1	19.2	15.7	16.5	18.1	22.0	20.8	18.0
10	2	2.5	50	1.0	11.8	11.8	7.9	8.3	10.8	14.5	13.4	9.8
15	2	2.5	50	1.0	23.9	23.4	19.8	19.7	22.9	25.9	25.0	21.3
20	2	2.5	50	1.0	≥ 30	≥ 30	29.5	29.0	≥ 30	≥ 30	≥ 30	≥ 30
20	4	2.5	50	1.0	≥ 30	29.2	23.1	22.4	29.0	≥ 30	≥ 30	24.0
30	2	2.5	50	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	4	2.5	50	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
10	2	5.5	75	1.0	nan	0.5	nan	nan	nan	4.3	1.8	nan
15	2	5.5	75	1.0	5.2	6.3	2.7	4.1	4.2	9.7	7.8	5.4
20	2	5.5	75	1.0	10.8	11.3	7.7	8.9	9.8	14.4	12.9	10.3
20	4	5.5	75	1.0	9.4	9.6	5.8	6.4	8.4	12.5	11.2	7.9
30	2	5.5	75	1.0	20.7	20.5	17.1	17.5	19.7	23.2	22.2	19.1
30	4	5.5	75	1.0	20.5	20.2	16.7	17.0	19.5	22.8	21.9	18.6
10	2	2.5	50	RO	9.3	10.4	6.9	7.8	8.3	13.7	11.8	9.3
15	2	2.5	50	RO	18.9	19.3	15.7	16.5	17.9	22.0	21.0	18.1
20	2	2.5	50	RO	27.9	27.7	24.2	24.4	26.9	≥ 30	29.4	26.1
20	4	2.5	50	RO	27.9	27.7	22.9	22.2	26.9	≥ 30	29.4	23.8
30	2	2.5	50	RO	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	4	2.5	50	RO	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
10	2	5.5	75	RO	nan	nan	nan	nan	nan	3.6	nan	nan
15	2	5.5	75	RO	2.1	3.5	0.1	1.6	1.1	7.9	4.8	2.9
20	2	5.5	75	RO	6.5	7.9	4.1	5.8	5.5	11.8	9.3	6.9
20	4	5.5	75	RO	6.5	7.9	4.1	5.8	5.5	11.8	9.3	6.9
30	2	5.5	75	RO	15.0	15.9	12.2	13.6	14.0	19.1	17.5	14.8
30	4	5.5	75	RO	15.0	15.9	12.2	13.6	14.0	19.1	17.5	14.8

3.17.2 Separation 10 NM, λv = 2.5 knots, offset = 0

Std [NM]	*RNP* [NM]	*λv* [knots]	*Vm* [knots]	*offset* [NM]	*mod0* [min]	*mod1* [min]	*mod2* [min]	*mod3* [min]	*mod4* [min]	*mod5* [min]	*mod6* [min]	*mod7* [min]
10	0.05	2.5	25	0.0	7.6	9.0	5.9	7.1	6.6	13.2	10.4	8.5
10	0.05	2.5	50	0.0	6.6	7.9	4.5	5.9	5.6	11.8	9.2	7.1
10	0.05	2.5	75	0.0	6.6	7.9	4.5	5.8	5.6	11.8	9.2	7.1
10	0.05	2.5	100	0.0	6.6	7.9	4.5	5.8	5.6	11.8	9.2	7.1
10	0.50	2.5	25	0.0	7.6	9.0	5.9	7.1	6.6	13.2	10.4	8.5
10	0.50	2.5	50	0.0	6.6	7.9	4.5	5.9	5.6	11.8	9.2	7.1
10	0.50	2.5	75	0.0	6.6	7.9	4.5	5.8	5.6	11.8	9.2	7.1
10	0.50	2.5	100	0.0	6.6	7.9	4.5	5.8	5.6	11.8	9.2	7.1
10	1	2.5	25	0.0	7.6	9.0	5.9	7.1	6.6	13.2	10.4	8.5
10	1	2.5	50	0.0	6.6	7.9	4.5	5.9	5.6	11.8	9.2	7.1
10	1	2.5	75	0.0	6.6	7.9	4.5	5.8	5.6	11.8	9.2	7.1
10	1	2.5	100	0.0	6.6	7.9	4.5	5.8	5.6	11.8	9.2	7.1
10	2	2.5	25	0.0	7.6	9.0	5.8	7.0	6.6	13.2	10.4	8.3
10	2	2.5	50	0.0	6.6	7.9	4.5	5.8	5.6	11.8	9.2	7.1
10	2	2.5	75	0.0	6.6	7.9	4.5	5.8	5.6	11.8	9.2	7.1
10	2	2.5	100	0.0	6.6	7.9	4.5	5.8	5.6	11.8	9.2	7.1
10	3	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	3	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	3	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	3	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	4	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	4	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	4	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	4	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	5	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	5	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	5	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	5	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	6	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	6	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	6	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	6	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	7	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	7	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	7	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	7	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	8	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	8	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	8	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	8	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	9	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	9	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	9	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	9	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	10	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	10	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	10	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	10	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0

10NM, speed limited (λv = 2.5 **knots**), **no offset**: Separation standard of 10 NM, no offset and with speed monitoring (λv = 2.5 knots). For RNP 2, a reporting rate of 5 minutes would meet the TLS.

3.17.3 Separation 15 NM, λv = 2.5 knots, offset = 0

Std *[NM]*	*RNP* *[NM]*	*λv* *[knots]*	*Vm* *[knots]*	*offset* *[NM]*	*mod0* *[min]*	*mod1* *[min]*	*mod2* *[min]*	*mod3* *[min]*	*mod4* *[min]*	*mod5* *[min]*	*mod6* *[min]*	*mod7* *[min]*
15	0.05	2.5	25	0.0	17.1	18.1	14.7	15.8	16.1	21.5	19.4	17.4
15	0.05	2.5	50	0.0	15.3	16.1	12.6	13.7	14.3	19.1	17.7	15.2
15	0.05	2.5	75	0.0	15.3	16.1	12.5	13.7	14.3	19.1	17.7	15.2
15	0.05	2.5	100	0.0	15.3	16.1	12.5	13.7	14.3	19.1	17.7	15.2
15	0.50	2.5	25	0.0	17.1	18.1	14.7	15.8	16.1	21.5	19.4	17.4
15	0.50	2.5	50	0.0	15.3	16.1	12.6	13.7	14.3	19.1	17.7	15.2
15	0.50	2.5	75	0.0	15.3	16.1	12.5	13.7	14.3	19.1	17.7	15.2
15	0.50	2.5	100	0.0	15.3	16.1	12.5	13.7	14.3	19.1	17.7	15.2
15	1	2.5	25	0.0	17.1	18.1	14.7	15.8	16.1	21.5	19.4	17.4
15	1	2.5	50	0.0	15.3	16.1	12.6	13.7	14.3	19.1	17.7	15.2
15	1	2.5	75	0.0	15.3	16.1	12.5	13.7	14.3	19.1	17.7	15.2
15	1	2.5	100	0.0	15.3	16.1	12.5	13.7	14.3	19.1	17.7	15.2
15	2	2.5	25	0.0	17.1	18.1	14.7	15.8	16.1	21.5	19.4	17.4
15	2	2.5	50	0.0	15.3	16.1	12.6	13.7	14.3	19.1	17.7	15.2
15	2	2.5	75	0.0	15.3	16.1	12.5	13.7	14.3	19.1	17.7	15.2
15	2	2.5	100	0.0	15.3	16.1	12.5	13.7	14.3	19.1	17.7	15.2
15	3	2.5	25	0.0	17.1	18.1	14.5	14.7	16.1	21.5	19.4	16.3
15	3	2.5	50	0.0	15.3	16.1	12.6	13.6	14.3	19.1	17.7	15.2
15	3	2.5	75	0.0	15.3	16.1	12.5	13.6	14.3	19.1	17.7	15.2
15	3	2.5	100	0.0	15.3	16.1	12.5	13.6	14.3	19.1	17.7	15.2
15	4	2.5	25	0.0	6.6	5.6	nan	nan	5.6	7.6	7.1	0.0
15	4	2.5	50	0.0	6.6	5.6	nan	nan	5.6	7.6	7.1	0.0
15	4	2.5	75	0.0	6.6	5.6	nan	nan	5.6	7.6	7.1	0.0
15	4	2.5	100	0.0	6.6	5.6	nan	nan	5.6	7.6	7.1	0.0
15	5	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	5	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	5	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	5	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	6	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	6	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	6	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	6	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	7	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	7	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	7	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	7	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	8	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	8	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	8	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	8	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	9	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	9	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	9	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	9	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	10	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	10	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	10	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	10	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0

15NM, speed limited (λv = 2.5 **knots**), **no offset**: Separation standard of 15 NM, no offset and with speed monitoring (λv = 2.5 knots). For RNP 2, a reporting rate of 12 minutes would meet the TLS.

3.17.4 Separation 20 NM, λv = 2.5 knots, offset = 0

Std *[NM]*	*RNP* *[NM]*	*λv* *[knots]*	*Vm* *[knots]*	*offset* *[NM]*	*mod0* *[min]*	*mod1* *[min]*	*mod2* *[min]*	*mod3* *[min]*	*mod4* *[min]*	*mod5* *[min]*	*mod6* *[min]*	*mod7* *[min]*
20	0.05	2.5	25	0.0	26.1	26.6	23.3	24.0	25.1	29.7	28.1	25.6
20	0.05	2.5	50	0.0	23.7	23.9	20.4	21.0	22.7	26.7	25.5	22.7
20	0.05	2.5	75	0.0	23.7	23.8	20.4	21.0	22.7	26.7	25.4	22.6
20	0.05	2.5	100	0.0	23.7	23.8	20.4	21.0	22.7	26.7	25.4	22.6
20	0.50	2.5	25	0.0	26.1	26.6	23.3	24.0	25.1	29.7	28.1	25.6
20	0.50	2.5	50	0.0	23.7	23.9	20.4	21.0	22.7	26.7	25.5	22.7
20	0.50	2.5	75	0.0	23.7	23.8	20.4	21.0	22.7	26.7	25.4	22.6
20	0.50	2.5	100	0.0	23.7	23.8	20.4	21.0	22.7	26.7	25.4	22.6
20	1	2.5	25	0.0	26.1	26.6	23.3	24.0	25.1	29.7	28.1	25.6
20	1	2.5	50	0.0	23.7	23.9	20.4	21.0	22.7	26.7	25.5	22.7
20	1	2.5	75	0.0	23.7	23.8	20.4	21.0	22.7	26.7	25.4	22.6
20	1	2.5	100	0.0	23.7	23.8	20.4	21.0	22.7	26.7	25.4	22.6
20	2	2.5	25	0.0	26.1	26.6	23.3	24.0	25.1	29.7	28.1	25.6
20	2	2.5	50	0.0	23.7	23.9	20.4	21.0	22.7	26.7	25.5	22.7
20	2	2.5	75	0.0	23.7	23.8	20.4	21.0	22.7	26.7	25.4	22.6
20	2	2.5	100	0.0	23.7	23.8	20.4	21.0	22.7	26.7	25.4	22.6
20	3	2.5	25	0.0	26.1	26.6	23.3	24.0	25.1	29.7	28.1	25.6
20	3	2.5	50	0.0	23.7	23.9	20.4	21.0	22.7	26.7	25.5	22.7
20	3	2.5	75	0.0	23.7	23.8	20.4	21.0	22.7	26.7	25.4	22.6
20	3	2.5	100	0.0	23.7	23.8	20.4	21.0	22.7	26.7	25.4	22.6
20	4	2.5	25	0.0	26.1	26.6	22.7	22.0	25.1	29.7	28.1	23.6
20	4	2.5	50	0.0	23.7	23.9	20.4	21.0	22.7	26.7	25.5	22.5
20	4	2.5	75	0.0	23.7	23.8	20.4	20.9	22.7	26.7	25.4	22.5
20	4	2.5	100	0.0	23.7	23.8	20.4	20.9	22.7	26.7	25.4	22.5
20	5	2.5	25	0.0	17.5	16.5	3.3	2.1	16.5	18.5	18.0	3.6
20	5	2.5	50	0.0	17.4	16.4	3.3	2.1	16.4	18.4	17.9	3.6
20	5	2.5	75	0.0	17.4	16.4	3.3	2.1	16.4	18.4	17.9	3.6
20	5	2.5	100	0.0	17.4	16.4	3.3	2.1	16.4	18.4	17.9	3.6
20	6	2.5	25	0.0	1.5	0.3	nan	nan	0.5	2.2	1.9	0.0
20	6	2.5	50	0.0	1.5	0.3	nan	nan	0.5	2.2	1.9	0.0
20	6	2.5	75	0.0	1.5	0.3	nan	nan	0.5	2.2	1.9	0.0
20	6	2.5	100	0.0	1.5	0.3	nan	nan	0.5	2.2	1.9	0.0
20	7	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	7	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	7	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	7	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	8	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	8	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	8	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	8	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	9	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	9	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	9	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	9	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	10	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	10	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	10	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	10	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0

20NM, speed limited (λv = 2.5 **knots**), **no offset**: Separation standard of 20 NM, no offset and with speed monitoring (λv = 2.5 knots). For RNP 4 and RNP 2, a reporting rate of 20 minutes would meet the TLS.

3.17.5 Separation 30 NM, λv = 2.5 knots, offset = 0

Std [NM]	RNP [NM]	λv [knots]	Vm [knots]	offset [NM]	mod0 [min]	mod1 [min]	mod2 [min]	mod3 [min]	mod4 [min]	mod5 [min]	mod6 [min]	mod7 [min]
30	0.05	2.5	25	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	0.05	2.5	50	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	0.05	2.5	75	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	0.05	2.5	100	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	0.50	2.5	25	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	0.50	2.5	50	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	0.50	2.5	75	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	0.50	2.5	100	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	1	2.5	25	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	1	2.5	50	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	1	2.5	75	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	1	2.5	100	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	2	2.5	25	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	2	2.5	50	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	2	2.5	75	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	2	2.5	100	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	3	2.5	25	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	3	2.5	50	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	3	2.5	75	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	3	2.5	100	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	4	2.5	25	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	4	2.5	50	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	4	2.5	75	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	4	2.5	100	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	5	2.5	25	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	5	2.5	50	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	5	2.5	75	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	5	2.5	100	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	6	2.5	25	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	6	2.5	50	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	6	2.5	75	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	6	2.5	100	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	30.0
30	7	2.5	25	0.0	≥ 30	≥ 30	17.2	16.0	≥ 30	≥ 30	≥ 30	17.5
30	7	2.5	50	0.0	≥ 30	≥ 30	17.1	16.0	≥ 30	≥ 30	≥ 30	17.5
30	7	2.5	75	0.0	≥ 30	≥ 30	17.1	16.0	≥ 30	≥ 30	≥ 30	17.5
30	7	2.5	100	0.0	≥ 30	≥ 30	17.1	16.0	≥ 30	≥ 30	≥ 30	17.5
30	8	2.5	25	0.0	18.6	17.4	1.9	0.7	17.6	19.3	18.9	2.3
30	8	2.5	50	0.0	18.5	17.4	1.9	0.7	17.5	19.3	18.9	2.3
30	8	2.5	75	0.0	18.5	17.4	1.9	0.7	17.5	19.3	18.9	2.3
30	8	2.5	100	0.0	18.5	17.4	1.9	0.7	17.5	19.3	18.9	2.3
30	9	2.5	25	0.0	4.8	3.6	nan	nan	3.8	5.4	5.1	0.0
30	9	2.5	50	0.0	4.8	3.6	nan	nan	3.8	5.4	5.1	0.0
30	9	2.5	75	0.0	4.8	3.6	nan	nan	3.8	5.4	5.1	0.0
30	9	2.5	100	0.0	4.8	3.6	nan	nan	3.8	5.4	5.1	0.0
30	10	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
30	10	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
30	10	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
30	10	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0

30NM, speed limited (λv = 2.5 **knots**), **no offset**: Separation standard of 30 NM, no offset and with speed monitoring (λv = 2.5 knots). For RNP 4 and RNP 2, a reporting rate of 30 minutes would meet the TLS.

3.17.6 Separation 10 NM, λv = 5.5 knots, offset = 0

Std	*RNP*	*λv*	*Vm*	*offset*	*mod0*	*mod1*	*mod2*	*mod3*	*mod4*	*mod5*	*mod6*	*mod7*
[NM]	*[NM]*	*[knots]*	*[knots]*	*[NM]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*
10	0.05	5.5	25	0.0	nan	nan	nan	nan	nan	6.2	1.7	0.6
10	0.05	5.5	50	0.0	nan	nan	nan	nan	nan	3.0	nan	0.0
10	0.05	5.5	75	0.0	nan	nan	nan	nan	nan	2.5	nan	0.0
10	0.05	5.5	100	0.0	nan	nan	nan	nan	nan	2.4	nan	0.0
10	0.50	5.5	25	0.0	nan	nan	nan	nan	nan	6.2	1.7	0.6
10	0.50	5.5	50	0.0	nan	nan	nan	nan	nan	3.0	nan	0.0
10	0.50	5.5	75	0.0	nan	nan	nan	nan	nan	2.5	nan	0.0
10	0.50	5.5	100	0.0	nan	nan	nan	nan	nan	2.4	nan	0.0
10	1	5.5	25	0.0	nan	nan	nan	nan	nan	6.2	1.7	0.6
10	1	5.5	50	0.0	nan	nan	nan	nan	nan	3.0	nan	0.0
10	1	5.5	75	0.0	nan	nan	nan	nan	nan	2.5	nan	0.0
10	1	5.5	100	0.0	nan	nan	nan	nan	nan	2.4	nan	0.0
10	2	5.5	25	0.0	nan	nan	nan	nan	nan	5.6	1.7	0.6
10	2	5.5	50	0.0	nan	nan	nan	nan	nan	3.0	nan	0.0
10	2	5.5	75	0.0	nan	nan	nan	nan	nan	2.5	nan	0.0
10	2	5.5	100	0.0	nan	nan	nan	nan	nan	2.4	nan	0.0
10	3	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	3	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	3	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	3	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	4	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	4	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	4	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	4	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	5	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	5	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	5	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	5	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	6	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	6	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	6	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	6	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	7	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	7	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	7	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	7	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	8	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	8	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	8	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	8	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	9	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	9	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	9	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	9	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	10	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	10	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	10	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	10	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0

10NM, (λv = 5.5 knots), no offset: Separation standard of 15 NM, no offset and no speed monitoring (λv = 5.5 knots). A 10 NM standard for RNP 2 will not conservatively meet the TLS .

3.17.7 Separation 15 NM, λv = 5.5 knots, offset = 0

Std	*RNP*	*λv*	*Vm*	*offset*	*mod0*	*mod1*	*mod2*	*mod3*	*mod4*	*mod5*	*mod6*	*mod7*
[NM]	*[NM]*	*[knots]*	*[knots]*	*[NM]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*
15	0.05	5.5	25	0.0	6.0	6.6	5.4	4.9	5.0	12.7	8.4	7.1
15	0.05	5.5	50	0.0	1.0	2.1	nan	0.3	0.2	7.3	3.5	2.2
15	0.05	5.5	75	0.0	nan	1.3	nan	nan	nan	6.4	2.7	1.3
15	0.05	5.5	100	0.0	nan	1.2	nan	nan	nan	6.2	2.5	1.1
15	0.50	5.5	25	0.0	6.0	6.6	5.4	4.9	5.0	12.7	8.4	7.1
15	0.50	5.5	50	0.0	1.0	2.1	nan	0.3	0.2	7.3	3.5	2.2
15	0.50	5.5	75	0.0	nan	1.3	nan	nan	nan	6.4	2.7	1.3
15	0.50	5.5	100	0.0	nan	1.2	nan	nan	nan	6.2	2.5	1.1
15	1	5.5	25	0.0	6.0	6.6	5.4	4.9	5.0	12.7	8.4	7.1
15	1	5.5	50	0.0	1.0	2.1	nan	0.3	0.2	7.3	3.5	2.2
15	1	5.5	75	0.0	nan	1.3	nan	nan	nan	6.4	2.7	1.3
15	1	5.5	100	0.0	nan	1.2	nan	nan	nan	6.2	2.5	1.1
15	2	5.5	25	0.0	6.0	6.6	5.4	4.9	5.0	12.6	8.4	7.1
15	2	5.5	50	0.0	1.0	2.1	nan	0.3	0.2	7.3	3.5	2.2
15	2	5.5	75	0.0	nan	1.3	nan	nan	nan	6.4	2.7	1.3
15	2	5.5	100	0.0	nan	1.2	nan	nan	nan	6.2	2.5	1.1
15	3	5.5	25	0.0	5.9	6.6	3.9	4.4	4.9	10.8	8.4	5.9
15	3	5.5	50	0.0	1.0	2.1	nan	0.3	0.2	7.3	3.5	2.2
15	3	5.5	75	0.0	nan	1.3	nan	nan	nan	6.4	2.7	1.3
15	3	5.5	100	0.0	nan	1.2	nan	nan	nan	6.2	2.5	1.1
15	4	5.5	25	0.0	1.1	0.5	nan	nan	0.1	2.8	2.1	0.0
15	4	5.5	50	0.0	0.7	nan	nan	nan	0.2	2.5	1.6	0.0
15	4	5.5	75	0.0	nan	nan	nan	nan	nan	2.4	1.5	0.0
15	4	5.5	100	0.0	nan	0.2	nan	nan	nan	2.4	1.5	0.0
15	5	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	5	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	5	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	5	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	6	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	6	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	6	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	6	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	7	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	7	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	7	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	7	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	8	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	8	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	8	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	8	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	9	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	9	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	9	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	9	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	10	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	10	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	10	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	10	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0

15NM, (λv = 5.5 knots), no offset: Separation standard of 15 NM, no offset and no speed monitoring (λv = 5.5 knots). No acceptable reporting period will give a risk below the TLS unless improved communication models are demonstrated.

3.17.8 Separation 20 NM, λv = 5.5 knots, offset = 0

Std [NM]	*RNP* [NM]	*λv* [knots]	*Vm* [knots]	*offset* [NM]	*mod0* [min]	*mod1* [min]	*mod2* [min]	*mod3* [min]	*mod4* [min]	*mod5* [min]	*mod6* [min]	*mod7* [min]
20	0.05	5.5	25	0.0	12.0	13.2	11.6	11.4	11.0	18.8	14.7	13.5
20	0.05	5.5	50	0.0	5.3	6.7	3.5	4.8	4.3	11.2	7.9	6.2
20	0.05	5.5	75	0.0	3.9	5.5	2.6	3.6	2.9	10.0	6.6	5.2
20	0.05	5.5	100	0.0	3.7	5.3	2.3	3.4	2.7	9.7	6.5	4.9
20	0.50	5.5	25	0.0	12.0	13.2	11.6	11.4	11.0	18.8	14.7	13.5
20	0.50	5.5	50	0.0	5.3	6.7	3.5	4.8	4.3	11.2	7.9	6.2
20	0.50	5.5	75	0.0	3.9	5.5	2.6	3.6	2.9	10.0	6.6	5.2
20	0.50	5.5	100	0.0	3.7	5.3	2.3	3.4	2.7	9.7	6.5	4.9
20	1	5.5	25	0.0	12.0	13.2	11.6	11.4	11.0	18.8	14.7	13.5
20	1	5.5	50	0.0	5.3	6.7	3.5	4.8	4.3	11.2	7.9	6.2
20	1	5.5	75	0.0	3.9	5.5	2.6	3.6	2.9	10.0	6.6	5.2
20	1	5.5	100	0.0	3.7	5.3	2.3	3.4	2.7	9.7	6.5	4.9
20	2	5.5	25	0.0	12.0	13.2	11.5	11.4	11.0	18.8	14.7	13.5
20	2	5.5	50	0.0	5.3	6.7	3.5	4.8	4.3	11.2	7.9	6.2
20	2	5.5	75	0.0	3.9	5.5	2.6	3.6	2.9	10.0	6.6	5.2
20	2	5.5	100	0.0	3.7	5.3	2.3	3.4	2.7	9.7	6.5	4.9
20	3	5.5	25	0.0	12.0	13.2	11.3	11.4	11.0	18.5	14.7	13.5
20	3	5.5	50	0.0	5.3	6.7	3.5	4.8	4.3	11.2	7.9	6.2
20	3	5.5	75	0.0	3.9	5.5	2.6	3.6	2.9	10.0	6.6	5.2
20	3	5.5	100	0.0	3.7	5.3	2.3	3.4	2.7	9.7	6.5	4.9
20	4	5.5	25	0.0	12.0	13.1	8.8	8.8	11.0	15.9	14.4	10.4
20	4	5.5	50	0.0	5.3	6.7	3.5	4.8	4.3	11.2	7.9	6.2
20	4	5.5	75	0.0	3.9	5.5	2.6	3.6	2.9	10.0	6.6	5.2
20	4	5.5	100	0.0	3.7	5.3	2.3	3.4	2.7	9.7	6.5	4.9
20	5	5.5	25	0.0	6.9	6.3	nan	nan	5.9	8.6	7.9	0.4
20	5	5.5	50	0.0	5.2	5.2	nan	nan	4.2	7.6	6.8	0.2
20	5	5.5	75	0.0	3.8	5.0	nan	nan	2.8	7.5	6.3	0.2
20	5	5.5	100	0.0	3.7	5.0	nan	nan	2.7	7.5	6.2	0.1
20	6	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	6	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	6	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	6	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	7	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	7	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	7	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	7	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	8	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	8	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	8	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	8	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	9	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	9	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	9	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	9	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	10	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	10	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	10	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	10	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0

20NM, (λv = 5.5 knots), no offset: Separation standard of 20 NM, no offset and with no speed control (λv = 5.5 knots). A reporting period of 3 minutes would give a risk below the TLS for RNP 2 and RNP 4.

3.17.9 Separation 30 NM, λv = 5.5 knots, offset = 0

Std	*RNP*	*λv*	*Vm*	*offset*	*mod0*	*mod1*	*mod2*	*mod3*	*mod4*	*mod5*	*mod6*	*mod7*
[NM]	*[NM]*	*[knots]*	*[knots]*	*[NM]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*
30	0.05	5.5	25	0.0	24.7	26.2	23.9	24.4	23.7	≥ 30	27.4	26.3
30	0.05	5.5	50	0.0	13.8	15.0	11.4	13.0	12.8	18.7	16.5	14.2
30	0.05	5.5	75	0.0	11.8	13.2	9.8	11.2	10.8	17.0	14.5	12.5
30	0.05	5.5	100	0.0	11.4	12.7	9.3	10.6	10.4	16.4	14.1	11.9
30	0.50	5.5	25	0.0	24.7	26.2	23.9	24.4	23.7	≥ 30	27.4	26.3
30	0.50	5.5	50	0.0	13.8	15.0	11.4	13.0	12.8	18.7	16.5	14.2
30	0.50	5.5	75	0.0	11.8	13.2	9.8	11.2	10.8	17.0	14.5	12.5
30	0.50	5.5	100	0.0	11.4	12.7	9.3	10.6	10.4	16.4	14.1	11.9
30	1	5.5	25	0.0	24.7	26.2	23.9	24.4	23.7	≥ 30	27.4	26.3
30	1	5.5	50	0.0	13.8	15.0	11.4	13.0	12.8	18.7	16.5	14.2
30	1	5.5	75	0.0	11.8	13.2	9.8	11.2	10.8	17.0	14.5	12.5
30	1	5.5	100	0.0	11.4	12.7	9.3	10.6	10.4	16.4	14.1	11.9
30	2	5.5	25	0.0	24.7	26.2	23.9	24.4	23.7	≥ 30	27.4	26.3
30	2	5.5	50	0.0	13.8	15.0	11.4	13.0	12.8	18.7	16.5	14.2
30	2	5.5	75	0.0	11.8	13.2	9.8	11.2	10.8	17.0	14.5	12.5
30	2	5.5	100	0.0	11.4	12.7	9.3	10.6	10.4	16.4	14.1	11.9
30	3	5.5	25	0.0	24.7	26.2	23.8	24.4	23.7	≥ 30	27.4	26.3
30	3	5.5	50	0.0	13.8	15.0	11.4	13.0	12.8	18.7	16.5	14.2
30	3	5.5	75	0.0	11.8	13.2	9.8	11.2	10.8	17.0	14.5	12.5
30	3	5.5	100	0.0	11.4	12.7	9.3	10.6	10.4	16.4	14.1	11.9
30	4	5.5	25	0.0	24.7	26.2	23.7	24.4	23.7	≥ 30	27.4	26.3
30	4	5.5	50	0.0	13.8	15.0	11.4	13.0	12.8	18.7	16.5	14.2
30	4	5.5	75	0.0	11.8	13.2	9.8	11.2	10.8	17.0	14.5	12.5
30	4	5.5	100	0.0	11.4	12.7	9.3	10.6	10.4	16.4	14.1	11.9
30	5	5.5	25	0.0	24.7	26.2	22.8	22.7	23.7	29.6	27.4	24.3
30	5	5.5	50	0.0	13.8	15.0	11.4	13.0	12.8	18.7	16.5	14.2
30	5	5.5	75	0.0	11.8	13.2	9.8	11.2	10.8	17.0	14.5	12.5
30	5	5.5	100	0.0	11.4	12.7	9.3	10.6	10.4	16.4	14.1	11.9
30	6	5.5	25	0.0	24.1	23.6	17.7	17.1	23.1	26.0	25.2	18.7
30	6	5.5	50	0.0	13.8	15.0	11.4	12.9	12.8	18.7	16.5	14.2
30	6	5.5	75	0.0	11.8	13.2	9.8	11.2	10.8	17.0	14.5	12.5
30	6	5.5	100	0.0	11.4	12.7	9.3	10.6	10.4	16.4	14.1	11.9
30	7	5.5	25	0.0	18.2	17.4	7.7	6.7	17.2	19.6	19.0	8.3
30	7	5.5	50	0.0	13.8	14.8	6.9	6.0	12.8	17.2	16.2	7.6
30	7	5.5	75	0.0	11.8	13.2	6.8	6.0	10.8	16.8	14.5	7.5
30	7	5.5	100	0.0	11.4	12.7	6.8	6.0	10.4	16.2	14.1	7.5
30	8	5.5	25	0.0	8.7	7.7	nan	nan	7.7	9.7	9.3	0.0
30	8	5.5	50	0.0	8.0	7.1	nan	nan	7.0	9.2	8.6	0.0
30	8	5.5	75	0.0	8.0	7.0	nan	nan	7.0	9.1	8.6	0.0
30	8	5.5	100	0.0	8.0	7.0	nan	nan	7.0	9.1	8.6	0.0
30	9	5.5	25	0.0	1.2	nan	nan	nan	nan	1.9	1.5	0.0
30	9	5.5	50	0.0	1.0	nan	nan	nan	nan	1.8	1.4	0.0
30	9	5.5	75	0.0	1.0	nan	nan	nan	nan	1.8	1.4	0.0
30	9	5.5	100	0.0	1.0	nan	nan	nan	nan	1.8	1.4	0.0
30	10	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
30	10	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
30	10	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
30	10	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0

30NM, (λv = 5.5 knots), no offset: Separation standard of 30 NM, no offset and with no speed monitoring (λv = 5.5 knots). A reporting period of 10 minutes would give a risk below the TLS for RNP 2 and RNP 4.

3.17.10 Separation 10 NM, λv = 2.5 knots, offset = 0.5 NM

Std [NM]	RNP [NM]	λv [knots]	Vm [knots]	offset [NM]	mod0 [min]	mod1 [min]	mod2 [min]	mod3 [min]	mod4 [min]	mod5 [min]	mod6 [min]	mod7 [min]
10	0.05	2.5	25	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
10	0.05	2.5	50	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
10	0.05	2.5	75	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
10	0.05	2.5	100	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
10	0.50	2.5	25	0.5	14.3	14.7	11.2	12.2	13.3	17.7	16.3	13.7
10	0.50	2.5	50	0.5	13.6	13.9	10.4	11.2	12.6	16.8	15.5	12.7
10	0.50	2.5	75	0.5	13.6	13.9	10.4	11.2	12.6	16.8	15.5	12.7
10	0.50	2.5	100	0.5	13.6	13.9	10.4	11.2	12.6	16.8	15.5	12.7
10	1	2.5	25	0.5	13.0	13.7	10.1	11.2	12.0	16.7	15.2	12.6
10	1	2.5	50	0.5	12.4	12.8	9.3	10.2	11.4	15.7	14.4	11.7
10	1	2.5	75	0.5	12.4	12.8	9.3	10.2	11.4	15.7	14.4	11.7
10	1	2.5	100	0.5	12.4	12.8	9.3	10.2	11.4	15.7	14.4	11.7
10	2	2.5	25	0.5	11.1	11.3	7.2	7.6	10.1	14.1	12.9	9.1
10	2	2.5	50	0.5	10.7	10.8	6.8	7.2	9.7	13.6	12.4	8.7
10	2	2.5	75	0.5	10.7	10.8	6.8	7.2	9.7	13.6	12.4	8.7
10	2	2.5	100	0.5	10.7	10.8	6.8	7.2	9.7	13.6	12.4	8.7
10	3	2.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	3	2.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	3	2.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	3	2.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	4	2.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	4	2.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	4	2.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	4	2.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	5	2.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	5	2.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	5	2.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	5	2.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	6	2.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	6	2.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	6	2.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	6	2.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	7	2.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	7	2.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	7	2.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	7	2.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	8	2.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	8	2.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	8	2.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	8	2.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	9	2.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	9	2.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	9	2.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	9	2.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	10	2.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	10	2.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	10	2.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	10	2.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan

10NM, (λv = 2.5 knots), 0.5NM offset: Separation standard of 10 NM, 0.5NM offset and with speed monitoring (λv = 2.5 knots). A reporting period of 7 minutes would give a risk below the TLS for RNP 2 and RNP 4.

3.17.11 Separation 15 NM, λv = 2.5 knots, offset = 0.5 NM

Std [NM]	*RNP* [NM]	*λv* [knots]	*Vm* [knots]	*offset* [NM]	*mod0* [min]	*mod1* [min]	*mod2* [min]	*mod3* [min]	*mod4* [min]	*mod5* [min]	*mod6* [min]	*mod7* [min]
15	0.05	2.5	25	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
15	0.05	2.5	50	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
15	0.05	2.5	75	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
15	0.05	2.5	100	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
15	0.50	2.5	25	0.5	25.4	25.3	21.8	22.1	24.4	28.1	27.0	23.7
15	0.50	2.5	50	0.5	24.2	23.8	20.2	20.3	23.2	26.2	25.4	21.9
15	0.50	2.5	75	0.5	24.2	23.7	20.2	20.3	23.2	26.2	25.4	21.9
15	0.50	2.5	100	0.5	24.2	23.7	20.2	20.3	23.2	26.2	25.4	21.9
15	1	2.5	25	0.5	24.3	24.2	20.7	21.1	23.3	26.9	25.8	22.7
15	1	2.5	50	0.5	22.9	22.6	19.1	19.3	21.9	25.2	24.3	21.0
15	1	2.5	75	0.5	22.9	22.6	19.1	19.3	21.9	25.2	24.3	21.0
15	1	2.5	100	0.5	22.9	22.6	19.1	19.3	21.9	25.2	24.3	21.0
15	2	2.5	25	0.5	23.8	23.5	20.0	20.1	22.8	26.1	25.2	21.8
15	2	2.5	50	0.5	22.7	22.3	18.7	18.8	21.7	24.8	23.9	20.4
15	2	2.5	75	0.5	22.7	22.3	18.7	18.8	21.7	24.8	23.9	20.4
15	2	2.5	100	0.5	22.7	22.3	18.7	18.8	21.7	24.8	23.9	20.4
15	3	2.5	25	0.5	21.0	20.5	15.4	15.1	20.0	22.9	22.1	16.7
15	3	2.5	50	0.5	20.3	19.8	14.9	14.6	19.3	22.2	21.4	16.2
15	3	2.5	75	0.5	20.3	19.8	14.9	14.5	19.3	22.2	21.4	16.2
15	3	2.5	100	0.5	20.3	19.8	14.9	14.5	19.3	22.2	21.4	16.2
15	4	2.5	25	0.5	7.1	6.1	nan	nan	6.1	8.1	7.6	nan
15	4	2.5	50	0.5	7.1	6.0	nan	nan	6.1	8.1	7.6	nan
15	4	2.5	75	0.5	7.1	6.0	nan	nan	6.1	8.1	7.6	nan
15	4	2.5	100	0.5	7.1	6.0	nan	nan	6.1	8.1	7.6	nan
15	5	2.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	5	2.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	5	2.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	5	2.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	6	2.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	6	2.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	6	2.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	6	2.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	7	2.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	7	2.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	7	2.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	7	2.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	8	2.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	8	2.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	8	2.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	8	2.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	9	2.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	9	2.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	9	2.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	9	2.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	10	2.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	10	2.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	10	2.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	10	2.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan

Separation standard of 15 NM, 0.5NM offset and with speed monitoring (λv = 2.5 knots). A reporting period of 18 minutes would give a risk below the TLS for RNP 2.

3.17.12 Separation 20 NM, λv = 2.5 knots, offset = 0.5 NM

Std [NM]	*RNP [NM]*	*λv [knots]*	*Vm [knots]*	*offset [NM]*	*mod0 [min]*	*mod1 [min]*	*mod2 [min]*	*mod3 [min]*	*mod4 [min]*	*mod5 [min]*	*mod6 [min]*	*mod7 [min]*
20	0.05	2.5	25	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
20	0.05	2.5	50	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
20	0.05	2.5	75	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
20	0.05	2.5	100	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
20	0.50	2.5	25	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
20	0.50	2.5	50	0.5	≥ 30	≥ 30	29.4	29.0	≥ 30	≥ 30	≥ 30	≥ 30
20	0.50	2.5	75	0.5	≥ 30	≥ 30	29.4	29.0	≥ 30	≥ 30	≥ 30	≥ 30
20	0.50	2.5	100	0.5	≥ 30	≥ 30	29.4	29.0	≥ 30	≥ 30	≥ 30	≥ 30
20	1	2.5	25	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
20	1	2.5	50	0.5	≥ 30	≥ 30	28.2	27.9	≥ 30	≥ 30	≥ 30	29.5
20	1	2.5	75	0.5	≥ 30	≥ 30	28.2	27.9	≥ 30	≥ 30	≥ 30	29.5
20	1	2.5	100	0.5	≥ 30	≥ 30	28.2	27.9	≥ 30	≥ 30	≥ 30	29.5
20	2	2.5	25	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
20	2	2.5	50	0.5	≥ 30	≥ 30	28.2	27.9	≥ 30	≥ 30	≥ 30	29.5
20	2	2.5	75	0.5	≥ 30	≥ 30	28.2	27.9	≥ 30	≥ 30	≥ 30	29.5
20	2	2.5	100	0.5	≥ 30	≥ 30	28.2	27.9	≥ 30	≥ 30	≥ 30	29.5
20	3	2.5	25	0.5	≥ 30	≥ 30	28.9	28.6	≥ 30	≥ 30	≥ 30	≥ 30
20	3	2.5	50	0.5	≥ 30	≥ 30	27.4	26.9	≥ 30	≥ 30	≥ 30	28.5
20	3	2.5	75	0.5	≥ 30	≥ 30	27.4	26.9	≥ 30	≥ 30	≥ 30	28.5
20	3	2.5	100	0.5	≥ 30	≥ 30	27.4	26.9	≥ 30	≥ 30	≥ 30	28.5
20	4	2.5	25	0.5	≥ 30	29.5	23.0	22.3	29.3	≥ 30	≥ 30	23.9
20	4	2.5	50	0.5	29.4	28.6	22.3	21.7	28.4	≥ 30	≥ 30	23.3
20	4	2.5	75	0.5	29.4	28.6	22.3	21.7	28.4	≥ 30	≥ 30	23.3
20	4	2.5	100	0.5	29.4	28.6	22.3	21.7	28.4	≥ 30	≥ 30	23.3
20	5	2.5	25	0.5	17.9	16.9	3.5	2.4	16.9	19.0	18.5	3.9
20	5	2.5	50	0.5	17.8	16.8	3.5	2.4	16.8	18.9	18.4	3.9
20	5	2.5	75	0.5	17.8	16.8	3.5	2.4	16.8	18.9	18.4	3.9
20	5	2.5	100	0.5	17.8	16.8	3.5	2.4	16.8	18.9	18.4	3.9
20	6	2.5	25	0.5	1.7	0.5	nan	nan	0.7	2.4	2.0	nan
20	6	2.5	50	0.5	1.7	0.5	nan	nan	0.7	2.4	2.0	nan
20	6	2.5	75	0.5	1.7	0.5	nan	nan	0.7	2.4	2.0	nan
20	6	2.5	100	0.5	1.7	0.5	nan	nan	0.7	2.4	2.0	nan
20	7	2.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	7	2.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	7	2.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	7	2.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	8	2.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	8	2.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	8	2.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	8	2.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	9	2.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	9	2.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	9	2.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	9	2.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	10	2.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	10	2.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	10	2.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	10	2.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan

Separation standard of 20 NM, 0.5NM offset and with speed monitoring (λv = 2.5 knots). A reporting period of 28 minutes would give a risk below the TLS for RNP 2 and 22 minutes for RNP 4.

3.17.13 Separation 30 NM, λv = 2.5 knots, offset = 0.5 NM

Std *[NM]*	*RNP* *[NM]*	*λv* *[knots]*	*Vm* *[knots]*	*offset* *[NM]*	*mod0* *[min]*	*mod1* *[min]*	*mod2* *[min]*	*mod3* *[min]*	*mod4* *[min]*	*mod5* *[min]*	*mod6* *[min]*	*mod7* *[min]*
30	0.05	2.5	25	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.05	2.5	50	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.05	2.5	75	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.05	2.5	100	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.50	2.5	25	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.50	2.5	50	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.50	2.5	75	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.50	2.5	100	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	1	2.5	25	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	1	2.5	50	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	1	2.5	75	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	1	2.5	100	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	2	2.5	25	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	2	2.5	50	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	2	2.5	75	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	2	2.5	100	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	3	2.5	25	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	3	2.5	50	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	3	2.5	75	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	3	2.5	100	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	4	2.5	25	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	4	2.5	50	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	4	2.5	75	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	4	2.5	100	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	5	2.5	25	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	5	2.5	50	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	5	2.5	75	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	5	2.5	100	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	6	2.5	25	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	6	2.5	50	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	6	2.5	75	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	6	2.5	100	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	7	2.5	25	0.5	≥ 30	≥ 30	17.5	16.3	≥ 30	≥ 30	≥ 30	17.9
30	7	2.5	50	0.5	≥ 30	≥ 30	17.4	16.3	≥ 30	≥ 30	≥ 30	17.8
30	7	2.5	75	0.5	≥ 30	≥ 30	17.4	16.3	≥ 30	≥ 30	≥ 30	17.8
30	7	2.5	100	0.5	≥ 30	≥ 30	17.4	16.3	≥ 30	≥ 30	≥ 30	17.8
30	8	2.5	25	0.5	18.8	17.7	2.0	0.8	17.8	19.6	19.2	2.4
30	8	2.5	50	0.5	18.8	17.7	2.0	0.8	17.8	19.6	19.2	2.4
30	8	2.5	75	0.5	18.8	17.7	2.0	0.8	17.8	19.6	19.2	2.4
30	8	2.5	100	0.5	18.8	17.7	2.0	0.8	17.8	19.6	19.2	2.4
30	9	2.5	25	0.5	4.9	3.7	nan	nan	3.9	5.6	5.2	nan
30	9	2.5	50	0.5	4.9	3.7	nan	nan	3.9	5.6	5.2	nan
30	9	2.5	75	0.5	4.9	3.7	nan	nan	3.9	5.6	5.2	nan
30	9	2.5	100	0.5	4.9	3.7	nan	nan	3.9	5.6	5.2	nan
30	10	2.5	25	0.5	nan	nan	nan	nan	nan	0.1	nan	nan
30	10	2.5	50	0.5	nan	nan	nan	nan	nan	0.1	nan	nan
30	10	2.5	75	0.5	nan	nan	nan	nan	nan	0.1	nan	nan
30	10	2.5	100	0.5	nan	nan	nan	nan	nan	0.1	nan	nan

Separation standard of 30 NM, 0.5NM offset and with speed monitoring (λv = 2.5 knots). A reporting period of 30 minutes would give a risk below the TLS for RNP 2 and RNP 4.

3.17.14 Separation 10 NM, λv = 5.5 knots, offset = 0.5 NM

Std [NM]	*RNP* [NM]	*λv* [knots]	*Vm* [knots]	*offset* [NM]	*mod0* [min]	*mod1* [min]	*mod2* [min]	*mod3* [min]	*mod4* [min]	*mod5* [min]	*mod6* [min]	*mod7* [min]
10	0.05	5.5	25	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
10	0.05	5.5	50	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
10	0.05	5.5	75	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
10	0.05	5.5	100	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
10	0.50	5.5	25	0.5	2.6	4.2	1.0	2.3	1.6	8.7	5.3	3.6
10	0.50	5.5	50	0.5	nan	1.4	nan	nan	nan	5.8	2.6	0.8
10	0.50	5.5	75	0.5	nan	1.1	nan	nan	nan	5.2	2.2	0.3
10	0.50	5.5	100	0.5	nan	1.0	nan	nan	nan	5.2	2.2	0.3
10	1	5.5	25	0.5	1.9	3.5	0.2	1.6	0.9	8.0	4.6	2.9
10	1	5.5	50	0.5	nan	0.8	nan	nan	nan	5.2	1.9	0.2
10	1	5.5	75	0.5	nan	0.4	nan	nan	nan	4.8	1.6	nan
10	1	5.5	100	0.5	nan	0.4	nan	nan	nan	4.7	1.6	nan
10	2	5.5	25	0.5	0.8	2.1	nan	nan	nan	5.9	3.4	1.2
10	2	5.5	50	0.5	nan	0.1	nan	nan	nan	4.2	1.4	Nan
10	2	5.5	75	0.5	nan	nan	nan	nan	nan	3.9	1.1	Nan
10	2	5.5	100	0.5	nan	nan	nan	nan	nan	3.9	1.1	Nan
10	3	5.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	3	5.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	3	5.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	3	5.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	4	5.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	4	5.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	4	5.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	4	5.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	5	5.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	5	5.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	5	5.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	5	5.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	6	5.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	6	5.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	6	5.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	6	5.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	7	5.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	7	5.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	7	5.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	7	5.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	8	5.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	8	5.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	8	5.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	8	5.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	9	5.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	9	5.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	9	5.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	9	5.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	10	5.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	10	5.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	10	5.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
10	10	5.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan

Separation standard of 10 NM, 0.5NM offset and with no speed monitoring (λv = 5.5 knots). No realistic RNP meets the TLS.

3.17.15 Separation 15 NM, λv = 5.5 knots, offset = 0.5 NM

Std [NM]	*RNP* [NM]	*λv* [knots]	*Vm* [knots]	*offset* [NM]	*mod0* [min]	*mod1* [min]	*mod2* [min]	*mod3* [min]	*mod4* [min]	*mod5* [min]	*mod6* [min]	*mod7* [min]
15	0.05	5.5	25	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
15	0.05	5.5	50	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
15	0.05	5.5	75	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
15	0.05	5.5	100	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
15	0.50	5.5	25	0.5	9.8	11.4	7.8	9.4	8.8	15.3	12.6	10.5
15	0.50	5.5	50	0.5	5.7	7.0	3.5	5.0	4.7	10.7	8.4	6.2
15	0.50	5.5	75	0.5	5.0	6.3	2.7	4.2	4.0	9.8	7.7	5.4
15	0.50	5.5	100	0.5	5.0	6.2	2.7	4.1	4.0	9.7	7.7	5.4
15	1	5.5	25	0.5	9.1	10.7	7.1	8.7	8.1	14.7	11.8	9.8
15	1	5.5	50	0.5	5.0	6.4	2.9	4.4	4.0	10.2	7.7	5.6
15	1	5.5	75	0.5	4.3	5.7	2.1	3.6	3.3	9.3	7.0	4.8
15	1	5.5	100	0.5	4.3	5.6	2.0	3.5	3.3	9.2	7.0	4.8
15	2	5.5	25	0.5	8.8	10.1	6.5	7.9	7.8	13.7	11.4	9.2
15	2	5.5	50	0.5	5.0	6.3	2.7	4.1	4.0	9.9	7.6	5.4
15	2	5.5	75	0.5	4.3	5.6	2.0	3.5	3.3	9.2	7.0	4.8
15	2	5.5	100	0.5	4.3	5.6	2.0	3.4	3.3	9.1	7.0	4.7
15	3	5.5	25	0.5	7.3	7.9	4.1	4.7	6.3	11.0	9.4	6.2
15	3	5.5	50	0.5	4.3	5.2	1.6	2.5	3.3	8.5	6.7	3.9
15	3	5.5	75	0.5	3.9	4.8	1.1	2.2	2.9	8.1	6.3	3.6
15	3	5.5	100	0.5	3.9	4.8	1.1	2.2	2.9	8.0	6.3	3.5
15	4	5.5	25	0.5	1.3	0.7	nan	nan	0.3	3.0	2.3	nan
15	4	5.5	50	0.5	0.5	0.2	nan	nan	nan	2.7	1.8	nan
15	4	5.5	75	0.5	0.4	0.2	nan	nan	nan	2.7	1.7	nan
15	4	5.5	100	0.5	0.4	0.2	nan	nan	nan	2.7	1.7	nan
15	5	5.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	5	5.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	5	5.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	5	5.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	6	5.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	6	5.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	6	5.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	6	5.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	7	5.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	7	5.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	7	5.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	7	5.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	8	5.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	8	5.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	8	5.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	8	5.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	9	5.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	9	5.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	9	5.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	9	5.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	10	5.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	10	5.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	10	5.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
15	10	5.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan

Separation standard of 15 NM, 0.5NM offset and with **no** speed monitoring (λv = 5.5 knots). A reporting period of 2 minutes would give a risk below the TLS for RNP 2.

3.17.16 Separation 20 NM, λv = 5.5 knots, offset = 0.5 NM

Std	*RNP*	*λv*	*Vm*	*offset*	*mod0*	*mod1*	*mod2*	*mod3*	*mod4*	*mod5*	*mod6*	*mod7*
[NM]	*[NM]*	*[knots]*	*[knots]*	*[NM]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*
20	0.05	5.5	25	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
20	0.05	5.5	50	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
20	0.05	5.5	75	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
20	0.05	5.5	100	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
20	0.50	5.5	25	0.5	16.8	18.2	14.4	16.1	15.8	21.7	19.6	17.2
20	0.50	5.5	50	0.5	11.3	12.2	8.6	9.9	10.3	15.4	13.7	11.2
20	0.50	5.5	75	0.5	10.3	11.1	7.5	8.7	9.3	14.2	12.6	10.1
20	0.50	5.5	100	0.5	10.3	11.0	7.4	8.6	9.3	14.1	12.5	10.0
20	1	5.5	25	0.5	16.0	17.5	13.8	15.4	15.0	21.2	18.8	16.5
20	1	5.5	50	0.5	10.5	11.5	7.9	9.3	9.5	14.8	13.0	10.6
20	1	5.5	75	0.5	9.5	10.4	6.8	8.1	8.5	13.7	11.9	9.5
20	1	5.5	100	0.5	9.4	10.3	6.7	8.0	8.4	13.5	11.8	9.4
20	2	5.5	25	0.5	16.0	17.1	13.5	14.9	15.0	20.5	18.6	16.2
20	2	5.5	50	0.5	10.5	11.5	7.9	9.3	9.5	14.8	13.0	10.6
20	2	5.5	75	0.5	9.5	10.4	6.8	8.1	8.5	13.7	11.9	9.5
20	2	5.5	100	0.5	9.4	10.3	6.7	8.0	8.4	13.5	11.8	9.4
20	3	5.5	25	0.5	15.4	16.1	12.5	13.4	14.4	19.2	17.6	14.8
20	3	5.5	50	0.5	10.5	11.3	7.7	8.8	9.5	14.4	12.8	10.2
20	3	5.5	75	0.5	9.5	10.4	6.8	7.9	8.5	13.5	11.9	9.4
20	3	5.5	100	0.5	9.4	10.3	6.7	7.8	8.4	13.4	11.8	9.3
20	4	5.5	25	0.5	13.3	13.3	9.0	9.0	12.3	16.0	14.9	10.6
20	4	5.5	50	0.5	9.6	9.9	6.0	6.5	8.6	12.8	11.5	8.0
20	4	5.5	75	0.5	9.0	9.3	5.5	6.1	8.0	12.2	10.9	7.6
20	4	5.5	100	0.5	9.0	9.3	5.4	6.0	8.0	12.1	10.9	7.5
20	5	5.5	25	0.5	7.1	6.5	nan	nan	6.1	8.8	8.1	0.5
20	5	5.5	50	0.5	5.7	5.4	nan	nan	4.7	7.8	6.9	0.3
20	5	5.5	75	0.5	5.5	5.2	nan	nan	4.5	7.7	6.8	0.3
20	5	5.5	100	0.5	5.5	5.2	nan	nan	4.5	7.7	6.8	0.3
20	6	5.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	6	5.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	6	5.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	6	5.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	7	5.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	7	5.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	7	5.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	7	5.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	8	5.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	8	5.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	8	5.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	8	5.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	9	5.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	9	5.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	9	5.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	9	5.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	10	5.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	10	5.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	10	5.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
20	10	5.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan

Separation standard of 20 NM, 0.5NM offset and with **no** speed monitoring (λv = 5.5 knots). A reporting period of 6 minutes would give a risk below the TLS for RNP 2 and RNP 4.

3.17.17 Separation 30 NM, λv = 5.5 knots, offset = 0.5 NM

Std [NM]	RNP [NM]	λv [knots]	Vm [knots]	offset [NM]	mod0 [min]	mod1 [min]	mod2 [min]	mod3 [min]	mod4 [min]	mod5 [min]	mod6 [min]	mod7 [min]
30	0.05	5.5	25	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.05	5.5	50	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.05	5.5	75	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.05	5.5	100	0.5	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.50	5.5	25	0.5	≥ 30	≥ 30	27.5	29.1	29.5	≥ 30	≥ 30	≥ 30
30	0.50	5.5	50	0.5	21.6	21.7	18.3	18.9	20.6	24.5	23.4	20.5
30	0.50	5.5	75	0.5	20.0	20.0	16.5	17.1	19.0	22.7	21.6	18.7
30	0.50	5.5	100	0.5	19.8	19.7	16.3	16.8	18.8	22.5	21.4	18.3
30	1	5.5	25	0.5	29.5	≥ 30	26.8	28.4	28.5	≥ 30	≥ 30	29.5
30	1	5.5	50	0.5	20.7	21.0	17.5	18.2	19.7	23.8	22.6	19.8
30	1	5.5	75	0.5	19.1	19.2	15.7	16.5	18.1	22.0	20.8	18.0
30	1	5.5	100	0.5	18.9	18.9	15.5	16.1	17.9	21.7	20.6	17.6
30	2	5.5	25	0.5	29.5	≥ 30	26.7	28.1	28.5	≥ 30	≥ 30	29.4
30	2	5.5	50	0.5	20.7	21.0	17.5	18.2	19.7	23.8	22.6	19.8
30	2	5.5	75	0.5	19.1	19.2	15.7	16.5	18.1	22.0	20.8	18.0
30	2	5.5	100	0.5	18.9	18.9	15.5	16.1	17.9	21.7	20.6	17.6
30	3	5.5	25	0.5	29.5	≥ 30	26.4	27.3	28.5	≥ 30	≥ 30	28.8
30	3	5.5	50	0.5	20.7	21.0	17.5	18.2	19.7	23.8	22.6	19.8
30	3	5.5	75	0.5	19.1	19.2	15.7	16.5	18.1	22.0	20.8	18.0
30	3	5.5	100	0.5	18.9	18.9	15.5	16.1	17.9	21.7	20.6	17.6
30	4	5.5	25	0.5	29.0	29.0	25.3	25.7	28.0	≥ 30	≥ 30	27.2
30	4	5.5	50	0.5	20.7	21.0	17.5	18.1	19.7	23.8	22.6	19.7
30	4	5.5	75	0.5	19.1	19.2	15.7	16.5	18.1	22.0	20.8	18.0
30	4	5.5	100	0.5	18.9	18.9	15.5	16.1	17.9	21.7	20.6	17.6
30	5	5.5	25	0.5	27.4	27.1	22.9	22.8	26.4	29.7	28.7	24.4
30	5	5.5	50	0.5	20.7	20.5	16.8	16.9	19.7	23.1	22.2	18.5
30	5	5.5	75	0.5	19.1	19.2	15.6	15.8	18.1	21.9	20.8	17.4
30	5	5.5	100	0.5	18.9	18.9	15.5	15.6	17.9	21.7	20.6	17.2
30	6	5.5	25	0.5	24.3	23.7	17.8	17.2	23.3	26.1	25.3	18.8
30	6	5.5	50	0.5	19.1	18.8	14.1	13.9	18.1	21.3	20.4	15.5
30	6	5.5	75	0.5	18.3	17.9	13.4	13.3	17.3	20.4	19.5	14.9
30	6	5.5	100	0.5	18.2	17.8	13.3	13.2	17.2	20.3	19.5	14.8
30	7	5.5	25	0.5	18.4	17.6	7.9	6.9	17.4	19.8	19.2	8.4
30	7	5.5	50	0.5	15.5	14.9	7.0	6.2	14.5	17.3	16.5	7.8
30	7	5.5	75	0.5	15.0	14.5	6.9	6.1	14.0	16.9	16.1	7.7
30	7	5.5	100	0.5	15.0	14.4	6.9	6.1	14.0	16.8	16.0	7.7
30	8	5.5	25	0.5	8.9	7.8	nan	nan	7.9	9.9	9.4	nan
30	8	5.5	50	0.5	8.2	7.2	nan	nan	7.2	9.3	8.8	nan
30	8	5.5	75	0.5	8.1	7.2	nan	nan	7.1	9.3	8.7	nan
30	8	5.5	100	0.5	8.1	7.1	nan	nan	7.1	9.3	8.7	nan
30	9	5.5	25	0.5	1.2	nan	nan	nan	0.1	2.0	1.6	nan
30	9	5.5	50	0.5	1.1	nan	nan	nan	nan	1.9	1.5	nan
30	9	5.5	75	0.5	1.1	nan	nan	nan	nan	1.9	1.5	nan
30	9	5.5	100	0.5	1.1	nan	nan	nan	nan	1.9	1.5	nan
30	10	5.5	25	0.5	nan	nan	nan	nan	nan	nan	nan	nan
30	10	5.5	50	0.5	nan	nan	nan	nan	nan	nan	nan	nan
30	10	5.5	75	0.5	nan	nan	nan	nan	nan	nan	nan	nan
30	10	5.5	100	0.5	nan	nan	nan	nan	nan	nan	nan	nan

Separation standard of 30 NM, 0.5NM offset and with **no** speed monitoring (λv = 5.5 knots). A reporting period of 15 minutes would give a risk below the TLS for RNP 2 and RNP 4.

3.17.18 Separation 10 NM, λv = 2.5 knots, offset = 1.0 NM

Std [NM]	*RNP* [NM]	*λv* [knots]	*Vm* [knots]	*offset* [NM]	*mod0* [min]	*mod1* [min]	*mod2* [min]	*mod3* [min]	*mod4* [min]	*mod5* [min]	*mod6* [min]	*mod7* [min]
10	0.05	2.5	25	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
10	0.05	2.5	50	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
10	0.05	2.5	75	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
10	0.05	2.5	100	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
10	0.50	2.5	25	1.0	21.1	20.5	17.1	16.9	20.1	22.8	22.0	18.6
10	0.50	2.5	50	1.0	20.6	19.9	16.4	16.2	19.6	22.3	21.6	17.8
10	0.50	2.5	75	1.0	20.6	19.9	16.4	16.2	19.6	22.3	21.6	17.8
10	0.50	2.5	100	1.0	20.6	19.9	16.4	16.2	19.6	22.3	21.6	17.8
10	1	2.5	25	1.0	15.7	15.7	12.2	13.0	14.7	18.5	17.4	14.5
10	1	2.5	50	1.0	15.1	15.0	11.5	12.1	14.1	17.7	16.7	13.7
10	1	2.5	75	1.0	15.1	15.0	11.5	12.1	14.1	17.7	16.7	13.7
10	1	2.5	100	1.0	15.1	15.0	11.5	12.1	14.1	17.7	16.7	13.7
10	2	2.5	25	1.0	12.2	12.3	8.3	8.7	11.2	15.0	13.9	10.2
10	2	2.5	50	1.0	11.8	11.8	7.9	8.3	10.8	14.5	13.4	9.8
10	2	2.5	75	1.0	11.8	11.8	7.9	8.3	10.8	14.5	13.4	9.8
10	2	2.5	100	1.0	11.8	11.8	7.9	8.3	10.8	14.5	13.4	9.8
10	3	2.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	3	2.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	3	2.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	3	2.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	4	2.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	4	2.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	4	2.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	4	2.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	5	2.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	5	2.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	5	2.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	5	2.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	6	2.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	6	2.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	6	2.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	6	2.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	7	2.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	7	2.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	7	2.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	7	2.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	8	2.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	8	2.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	8	2.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	8	2.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	9	2.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	9	2.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	9	2.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	9	2.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	10	2.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	10	2.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	10	2.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	10	2.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan

Separation standard of 10 NM, 1 NM offset and with speed monitoring (λv = 2.5 knots). A reporting period of 8 minutes would give a risk below the TLS for RNP 2.

3.17.19 Separation 15 NM, λv = 2.5 knots, offset = 1.0 NM

Std *[NM]*	*RNP* *[NM]*	*λν* *[knots]*	*Vm* *[knots]*	*offset* *[NM]*	*mod0* *[min]*	*mod1* *[min]*	*mod2* *[min]*	*mod3* *[min]*	*mod4* *[min]*	*mod5* *[min]*	*mod6* *[min]*	*mod7* *[min]*
15	0.05	2.5	25	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
15	0.05	2.5	50	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
15	0.05	2.5	75	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
15	0.05	2.5	100	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
15	0.50	2.5	25	1.0	≥ 30	≥ 30	28.6	28.1	≥ 30	≥ 30	≥ 30	29.6
15	0.50	2.5	50	1.0	≥ 30	≥ 30	27.5	26.8	≥ 30	≥ 30	≥ 30	28.5
15	0.50	2.5	75	1.0	≥ 30	≥ 30	27.5	26.8	≥ 30	≥ 30	≥ 30	28.5
15	0.50	2.5	100	1.0	≥ 30	≥ 30	27.5	26.8	≥ 30	≥ 30	≥ 30	28.5
15	1	2.5	25	1.0	27.3	26.9	23.4	23.3	26.3	29.3	28.5	24.9
15	1	2.5	50	1.0	26.0	25.5	21.9	21.7	25.0	28.0	27.2	23.4
15	1	2.5	75	1.0	26.0	25.5	21.9	21.7	25.0	28.0	27.2	23.4
15	1	2.5	100	1.0	26.0	25.5	21.9	21.7	25.0	28.0	27.2	23.4
15	2	2.5	25	1.0	25.0	24.6	21.0	21.0	24.0	27.1	26.2	22.7
15	2	2.5	50	1.0	23.9	23.4	19.8	19.7	22.9	25.9	25.0	21.3
15	2	2.5	75	1.0	23.9	23.4	19.8	19.7	22.9	25.9	25.0	21.3
15	2	2.5	100	1.0	23.9	23.4	19.8	19.7	22.9	25.9	25.0	21.3
15	3	2.5	25	1.0	21.8	21.3	16.3	16.0	20.8	23.7	22.9	17.6
15	3	2.5	50	1.0	21.1	20.5	15.7	15.4	20.1	23.0	22.2	17.0
15	3	2.5	75	1.0	21.1	20.5	15.7	15.4	20.1	23.0	22.2	17.0
15	3	2.5	100	1.0	21.1	20.5	15.7	15.4	20.1	23.0	22.2	17.0
15	4	2.5	25	1.0	8.3	7.3	nan	nan	7.3	9.3	8.8	nan
15	4	2.5	50	1.0	8.2	7.2	nan	nan	7.2	9.3	8.8	nan
15	4	2.5	75	1.0	8.2	7.2	nan	nan	7.2	9.3	8.8	nan
15	4	2.5	100	1.0	8.2	7.2	nan	nan	7.2	9.3	8.8	nan
15	5	2.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	5	2.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	5	2.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	5	2.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	6	2.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	6	2.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	6	2.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	6	2.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	7	2.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	7	2.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	7	2.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	7	2.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	8	2.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	8	2.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	8	2.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	8	2.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	9	2.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	9	2.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	9	2.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	9	2.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	10	2.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	10	2.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	10	2.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	10	2.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan

Separation standard of 15 NM, 1 NM offset and with speed monitoring (λv = 2.5 knots). A reporting period of 20 minutes would give a risk below the TLS for RNP 2.

3.17.20 Separation 20 NM, λv = 2.5 knots, offset = 1.0 NM

Std [NM]	RNP [NM]	λv [knots]	Vm [knots]	offset [NM]	mod0 [min]	mod1 [min]	mod2 [min]	mod3 [min]	mod4 [min]	mod5 [min]	mod6 [min]	mod7 [min]
20	0.05	2.5	25	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
20	0.05	2.5	50	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
20	0.05	2.5	75	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
20	0.05	2.5	100	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
20	0.50	2.5	25	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
20	0.50	2.5	50	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
20	0.50	2.5	75	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
20	0.50	2.5	100	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
20	1	2.5	25	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
20	1	2.5	50	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
20	1	2.5	75	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
20	1	2.5	100	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
20	2	2.5	25	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
20	2	2.5	50	1.0	≥ 30	≥ 30	29.5	29.0	≥ 30	≥ 30	≥ 30	≥ 30
20	2	2.5	75	1.0	≥ 30	≥ 30	29.5	29.0	≥ 30	≥ 30	≥ 30	≥ 30
20	2	2.5	100	1.0	≥ 30	≥ 30	29.5	29.0	≥ 30	≥ 30	≥ 30	≥ 30
20	3	2.5	25	1.0	≥ 30	≥ 30	29.6	29.2	≥ 30	≥ 30	≥ 30	≥ 30
20	3	2.5	50	1.0	≥ 30	≥ 30	28.1	27.6	≥ 30	≥ 30	≥ 30	29.2
20	3	2.5	75	1.0	≥ 30	≥ 30	28.1	27.6	≥ 30	≥ 30	≥ 30	29.2
20	3	2.5	100	1.0	≥ 30	≥ 30	28.1	27.6	≥ 30	≥ 30	≥ 30	29.2
20	4	2.5	25	1.0	≥ 30	≥ 30	23.8	23.1	≥ 30	≥ 30	≥ 30	24.7
20	4	2.5	50	1.0	≥ 30	29.2	23.1	22.4	29.0	≥ 30	≥ 30	24.0
20	4	2.5	75	1.0	≥ 30	29.2	23.0	22.4	29.0	≥ 30	≥ 30	24.0
20	4	2.5	100	1.0	≥ 30	29.2	23.0	22.4	29.0	≥ 30	≥ 30	24.0
20	5	2.5	25	1.0	19.0	17.9	4.3	3.1	18.0	20.0	19.5	4.6
20	5	2.5	50	1.0	18.8	17.8	4.3	3.1	17.8	19.9	19.4	4.6
20	5	2.5	75	1.0	18.8	17.8	4.3	3.1	17.8	19.9	19.4	4.6
20	5	2.5	100	1.0	18.8	17.8	4.3	3.1	17.8	19.9	19.4	4.6
20	6	2.5	25	1.0	2.1	0.9	nan	nan	1.1	2.8	2.5	nan
20	6	2.5	50	1.0	2.1	0.9	nan	nan	1.1	2.8	2.5	nan
20	6	2.5	75	1.0	2.1	0.9	nan	nan	1.1	2.8	2.5	nan
20	6	2.5	100	1.0	2.1	0.9	nan	nan	1.1	2.8	2.5	nan
20	7	2.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
20	7	2.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
20	7	2.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
20	7	2.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan
20	8	2.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
20	8	2.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
20	8	2.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
20	8	2.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan
20	9	2.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
20	9	2.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
20	9	2.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
20	9	2.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan
20	10	2.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
20	10	2.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
20	10	2.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
20	10	2.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan

Separation standard of 20 NM, 1 NM offset and with speed monitoring (λv = 2.5 knots). A reporting period of 30 minutes would give a risk below the TLS for RNP 2 and for RNP 4 a period of 23 minutes is required.

3.17.21 Separation 30 NM, λv = 2.5 knots, offset = 1.0 NM

Std	*RNP*	*λv*	*Vm*	*offset*	*mod0*	*mod1*	*mod2*	*mod3*	*mod4*	*mod5*	*mod6*	*mod7*
[NM]	*[NM]*	*[knots]*	*[knots]*	*[NM]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*
30	0.05	2.5	25	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.05	2.5	50	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.05	2.5	75	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.05	2.5	100	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.50	2.5	25	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.50	2.5	50	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.50	2.5	75	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.50	2.5	100	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	1	2.5	25	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	1	2.5	50	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	1	2.5	75	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	1	2.5	100	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	2	2.5	25	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	2	2.5	50	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	2	2.5	75	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	2	2.5	100	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	3	2.5	25	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	3	2.5	50	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	3	2.5	75	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	3	2.5	100	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	4	2.5	25	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	4	2.5	50	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	4	2.5	75	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	4	2.5	100	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	5	2.5	25	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	5	2.5	50	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	5	2.5	75	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	5	2.5	100	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	6	2.5	25	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	6	2.5	50	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	6	2.5	75	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	6	2.5	100	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	7	2.5	25	1.0	≥ 30	≥ 30	18.3	17.1	≥ 30	≥ 30	≥ 30	18.7
30	7	2.5	50	1.0	≥ 30	≥ 30	18.2	17.1	≥ 30	≥ 30	≥ 30	18.6
30	7	2.5	75	1.0	≥ 30	≥ 30	18.2	17.1	≥ 30	≥ 30	≥ 30	18.6
30	7	2.5	100	1.0	≥ 30	≥ 30	18.2	17.1	≥ 30	≥ 30	≥ 30	18.6
30	8	2.5	25	1.0	19.6	18.4	2.3	1.1	18.6	20.3	19.9	2.6
30	8	2.5	50	1.0	19.5	18.4	2.3	1.1	18.5	20.3	19.9	2.6
30	8	2.5	75	1.0	19.5	18.4	2.3	1.1	18.5	20.3	19.9	2.6
30	8	2.5	100	1.0	19.5	18.4	2.3	1.1	18.5	20.3	19.9	2.6
30	9	2.5	25	1.0	5.2	4.0	nan	nan	4.2	5.9	5.5	nan
30	9	2.5	50	1.0	5.2	4.0	nan	nan	4.2	5.9	5.5	nan
30	9	2.5	75	1.0	5.2	4.0	nan	nan	4.2	5.9	5.5	nan
30	9	2.5	100	1.0	5.2	4.0	nan	nan	4.2	5.9	5.5	nan
30	10	2.5	25	1.0	nan	nan	nan	nan	nan	0.3	nan	nan
30	10	2.5	50	1.0	nan	nan	nan	nan	nan	0.3	nan	nan
30	10	2.5	75	1.0	nan	nan	nan	nan	nan	0.3	nan	nan
30	10	2.5	100	1.0	nan	nan	nan	nan	nan	0.3	nan	nan

Separation standard of 30 NM, 1 NM offset and with speed monitoring (λv = 2.5 knots). A reporting period of 30 minutes would give a risk below the TLS for RNP 2 and RNP 4.

3.17.22 Separation 10 NM, λv = 5.5 knots, offset = 1.0 NM

Std [NM]	*RNP [NM]*	*λv [knots]*	*Vm [knots]*	*offset [NM]*	*mod0 [min]*	*mod1 [min]*	*mod2 [min]*	*mod3 [min]*	*mod4 [min]*	*mod5 [min]*	*mod6 [min]*	*mod7 [min]*
10	0.05	5.5	25	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
10	0.05	5.5	50	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
10	0.05	5.5	75	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
10	0.05	5.5	100	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
10	0.50	5.5	25	1.0	7.0	7.9	4.2	5.7	6.0	11.2	9.5	7.0
10	0.50	5.5	50	1.0	4.3	5.2	1.5	3.0	3.3	8.4	6.8	4.2
10	0.50	5.5	75	1.0	4.2	4.9	1.2	2.6	3.2	8.0	6.5	4.0
10	0.50	5.5	100	1.0	4.1	4.9	1.2	2.6	3.1	8.0	6.5	3.9
10	1	5.5	25	1.0	3.4	4.9	1.5	3.0	2.4	9.0	6.1	4.1
10	1	5.5	50	1.0	0.7	2.3	nan	0.3	nan	6.2	3.5	1.5
10	1	5.5	75	1.0	0.4	1.9	nan	nan	nan	5.8	3.2	1.1
10	1	5.5	100	1.0	0.4	1.9	nan	nan	nan	5.7	3.2	1.1
10	2	5.5	25	1.0	1.5	2.7	nan	0.4	0.5	6.5	4.1	1.8
10	2	5.5	50	1.0	nan	0.7	nan	nan	nan	4.6	2.0	nan
10	2	5.5	75	1.0	nan	0.5	nan	nan	nan	4.3	1.8	nan
10	2	5.5	100	1.0	nan	0.5	nan	nan	nan	4.3	1.8	nan
10	3	5.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	3	5.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	3	5.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	3	5.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	4	5.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	4	5.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	4	5.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	4	5.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	5	5.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	5	5.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	5	5.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	5	5.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	6	5.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	6	5.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	6	5.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	6	5.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	7	5.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	7	5.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	7	5.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	7	5.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	8	5.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	8	5.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	8	5.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	8	5.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	9	5.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	9	5.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	9	5.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	9	5.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	10	5.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	10	5.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	10	5.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
10	10	5.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan

Separation standard of 10 NM, 1 NM offset and with **no** speed monitoring (λv = 5.5 knots). No reporting rate currently gives a risk below the TLS unless improved models for communication performance are demonstrated.

3.17.23 Separation 15 NM, λv = 5.5 knots, offset = 1.0 NM

Std [NM]	RNP [NM]	λv [knots]	Vm [knots]	offset [NM]	mod0 [min]	mod1 [min]	mod2 [min]	mod3 [min]	mod4 [min]	mod5 [min]	mod6 [min]	mod7 [min]
15	0.05	5.5	25	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
15	0.05	5.5	50	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
15	0.05	5.5	75	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
15	0.05	5.5	100	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
15	0.50	5.5	25	1.0	15.4	15.5	11.9	13.0	14.4	18.3	17.2	14.6
15	0.50	5.5	50	1.0	11.2	11.3	7.7	8.7	10.2	14.2	13.0	10.2
15	0.50	5.5	75	1.0	10.8	10.8	7.3	8.1	9.8	13.5	12.4	9.6
15	0.50	5.5	100	1.0	10.7	10.8	7.2	8.0	9.7	13.5	12.4	9.6
15	1	5.5	25	1.0	11.0	12.2	8.5	10.1	10.0	15.7	13.7	11.3
15	1	5.5	50	1.0	6.9	8.0	4.4	5.8	5.9	11.4	9.5	7.1
15	1	5.5	75	1.0	6.4	7.4	3.7	5.1	5.4	10.6	8.9	6.4
15	1	5.5	100	1.0	6.4	7.3	3.7	5.0	5.4	10.6	8.8	6.4
15	2	5.5	25	1.0	9.5	10.7	7.1	8.5	8.5	14.2	12.1	9.8
15	2	5.5	50	1.0	5.7	6.9	3.3	4.7	4.7	10.4	8.3	6.0
15	2	5.5	75	1.0	5.2	6.3	2.7	4.1	4.2	9.7	7.8	5.4
15	2	5.5	100	1.0	5.2	6.3	2.6	4.0	4.2	9.6	7.7	5.3
15	3	5.5	25	1.0	7.8	8.4	4.6	5.2	6.8	11.4	9.9	6.7
15	3	5.5	50	1.0	4.8	5.6	2.0	3.0	3.8	8.9	7.1	4.4
15	3	5.5	75	1.0	4.4	5.2	1.5	2.6	3.4	8.4	6.7	4.0
15	3	5.5	100	1.0	4.4	5.2	1.5	2.6	3.4	8.4	6.7	3.9
15	4	5.5	25	1.0	1.9	1.3	nan	nan	0.9	3.6	2.9	nan
15	4	5.5	50	1.0	1.0	0.8	nan	nan	nan	3.2	2.3	nan
15	4	5.5	75	1.0	0.9	0.7	nan	nan	nan	3.2	2.2	nan
15	4	5.5	100	1.0	0.8	0.7	nan	nan	nan	3.2	2.2	nan
15	5	5.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	5	5.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	5	5.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	5	5.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	6	5.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	6	5.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	6	5.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	6	5.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	7	5.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	7	5.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	7	5.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	7	5.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	8	5.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	8	5.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	8	5.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	8	5.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	9	5.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	9	5.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	9	5.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	9	5.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	10	5.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	10	5.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	10	5.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
15	10	5.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan

Separation standard of 15 NM, 1 NM offset and with **no** speed monitoring (λv = 5.5 knots). A reporting rate of 3 minutes will give a risk below the TLS for RNP 2.

3.17.24 Separation 20 NM, λv = 5.5 knots, offset = 1.0 NM

Std *[NM]*	*RNP* *[NM]*	*λv* *[knots]*	*Vm* *[knots]*	*offset* *[NM]*	*mod0* *[min]*	*mod1* *[min]*	*mod2* *[min]*	*mod3* *[min]*	*mod4* *[min]*	*mod5* *[min]*	*mod6* *[min]*	*mod7* *[min]*
20	0.05	5.5	25	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
20	0.05	5.5	50	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
20	0.05	5.5	75	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
20	0.05	5.5	100	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
20	0.50	5.5	25	1.0	23.1	22.7	19.3	19.9	22.1	25.3	24.3	21.6
20	0.50	5.5	50	1.0	17.4	17.1	13.7	14.1	16.4	19.8	18.8	15.7
20	0.50	5.5	75	1.0	16.6	16.2	12.9	13.1	15.6	18.8	17.9	14.7
20	0.50	5.5	100	1.0	16.6	16.2	12.8	13.0	15.6	18.8	17.9	14.6
20	1	5.5	25	1.0	18.3	19.1	15.4	16.9	17.3	22.3	20.8	18.1
20	1	5.5	50	1.0	12.7	13.3	9.8	10.9	11.7	16.4	14.9	12.3
20	1	5.5	75	1.0	11.9	12.3	8.7	9.8	10.9	15.3	13.9	11.3
20	1	5.5	100	1.0	11.8	12.2	8.7	9.7	10.8	15.2	13.8	11.2
20	2	5.5	25	1.0	16.9	17.8	14.1	15.5	15.9	21.1	19.4	16.8
20	2	5.5	50	1.0	11.6	12.3	8.7	9.9	10.6	15.4	13.8	11.3
20	2	5.5	75	1.0	10.8	11.3	7.7	8.9	9.8	14.4	12.9	10.3
20	2	5.5	100	1.0	10.7	11.2	7.7	8.7	9.7	14.2	12.8	10.2
20	3	5.5	25	1.0	15.9	16.5	12.9	13.8	14.9	19.5	18.0	15.2
20	3	5.5	50	1.0	11.1	11.7	8.1	9.1	10.1	14.7	13.2	10.6
20	3	5.5	75	1.0	10.4	10.8	7.3	8.3	9.4	13.8	12.5	9.8
20	3	5.5	100	1.0	10.4	10.8	7.2	8.2	9.4	13.7	12.4	9.7
20	4	5.5	25	1.0	13.7	13.7	9.4	9.5	12.7	16.4	15.3	11.0
20	4	5.5	50	1.0	9.9	10.2	6.3	6.9	8.9	13.1	11.8	8.4
20	4	5.5	75	1.0	9.4	9.6	5.8	6.4	8.4	12.5	11.2	7.9
20	4	5.5	100	1.0	9.4	9.6	5.8	6.3	8.4	12.4	11.2	7.9
20	5	5.5	25	1.0	7.6	7.0	0.3	nan	6.6	9.3	8.6	1.0
20	5	5.5	50	1.0	6.1	5.8	nan	nan	5.1	8.3	7.3	0.8
20	5	5.5	75	1.0	5.9	5.6	nan	nan	4.9	8.1	7.2	0.7
20	5	5.5	100	1.0	5.8	5.6	nan	nan	4.8	8.1	7.2	0.7
20	6	5.5	25	1.0	nan	nan	nan	nan	nan	0.2	nan	nan
20	6	5.5	50	1.0	nan	nan	nan	nan	nan	0.1	nan	nan
20	6	5.5	75	1.0	nan	nan	nan	nan	nan	0.1	nan	nan
20	6	5.5	100	1.0	nan	nan	nan	nan	nan	0.1	nan	nan
20	7	5.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
20	7	5.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
20	7	5.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
20	7	5.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan
20	8	5.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
20	8	5.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
20	8	5.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
20	8	5.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan
20	9	5.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
20	9	5.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
20	9	5.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
20	9	5.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan
20	10	5.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
20	10	5.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
20	10	5.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
20	10	5.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan

Separation standard of 20 NM, 1 NM offset and with **no** speed monitoring (λv = 5.5 knots). A reporting rate of 9 minutes will give a risk below the TLS for RNP 2 and for RNP 4 a rate of 6 minutes.

3.17.25 Separation 30 NM, λv = 5.5 knots, offset = 1.0 NM

Std [NM]	*RNP* [NM]	*λv* [knots]	*Vm* [knots]	*offset* [NM]	*mod0* [min]	*mod1* [min]	*mod2* [min]	*mod3* [min]	*mod4* [min]	*mod5* [min]	*mod6* [min]	*mod7* [min]
30	0.05	5.5	25	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.05	5.5	50	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.05	5.5	75	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.05	5.5	100	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.50	5.5	25	1.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.50	5.5	50	1.0	28.7	28.1	24.5	24.2	27.7	≥ 30	29.8	25.9
30	0.50	5.5	75	1.0	27.4	26.7	22.9	22.5	26.4	29.0	28.3	24.2
30	0.50	5.5	100	1.0	27.3	26.6	22.8	22.4	26.3	28.9	28.3	24.1
30	1	5.5	25	1.0	≥ 30	≥ 30	28.7	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	1	5.5	50	1.0	23.4	23.3	19.8	20.2	22.4	26.0	24.9	21.8
30	1	5.5	75	1.0	21.8	21.6	18.1	18.4	20.8	24.2	23.2	20.1
30	1	5.5	100	1.0	21.7	21.4	17.9	18.1	20.7	24.0	23.1	19.8
30	2	5.5	25	1.0	≥ 30	≥ 30	27.5	28.8	29.9	≥ 30	≥ 30	≥ 30
30	2	5.5	50	1.0	22.2	22.2	18.8	19.3	21.2	25.0	23.9	20.8
30	2	5.5	75	1.0	20.7	20.5	17.1	17.5	19.7	23.2	22.2	19.1
30	2	5.5	100	1.0	20.5	20.3	16.9	17.2	19.5	23.0	22.0	18.8
30	3	5.5	25	1.0	≥ 30	≥ 30	26.9	27.7	29.4	≥ 30	≥ 30	29.2
30	3	5.5	50	1.0	22.1	22.0	18.6	19.0	21.1	24.7	23.7	20.6
30	3	5.5	75	1.0	20.7	20.4	17.0	17.4	19.7	23.1	22.1	19.0
30	3	5.5	100	1.0	20.5	20.3	16.8	17.1	19.5	22.9	21.9	18.7
30	4	5.5	25	1.0	29.4	29.3	25.6	26.0	28.4	≥ 30	≥ 30	27.5
30	4	5.5	50	1.0	21.8	21.6	18.1	18.4	20.8	24.3	23.3	20.0
30	4	5.5	75	1.0	20.5	20.2	16.7	17.0	19.5	22.8	21.9	18.6
30	4	5.5	100	1.0	20.4	20.1	16.6	16.7	19.4	22.7	21.7	18.4
30	5	5.5	25	1.0	27.7	27.4	23.2	23.1	26.7	≥ 30	29.0	24.7
30	5	5.5	50	1.0	21.0	20.8	17.0	17.1	20.0	23.4	22.4	18.7
30	5	5.5	75	1.0	19.9	19.6	15.9	16.0	18.9	22.2	21.2	17.6
30	5	5.5	100	1.0	19.8	19.5	15.8	15.8	18.8	22.0	21.1	17.5
30	6	5.5	25	1.0	24.6	24.0	18.2	17.6	23.6	26.4	25.6	19.2
30	6	5.5	50	1.0	19.4	19.0	14.3	14.1	18.4	21.5	20.6	15.7
30	6	5.5	75	1.0	18.6	18.1	13.7	13.5	17.6	20.6	19.8	15.1
30	6	5.5	100	1.0	18.5	18.0	13.6	13.4	17.5	20.5	19.7	15.0
30	7	5.5	25	1.0	18.7	17.9	8.3	7.3	17.7	20.1	19.5	8.9
30	7	5.5	50	1.0	15.8	15.2	7.4	6.6	14.8	17.5	16.8	8.1
30	7	5.5	75	1.0	15.3	14.7	7.3	6.5	14.3	17.1	16.4	8.0
30	7	5.5	100	1.0	15.3	14.7	7.2	6.5	14.3	17.1	16.3	8.0
30	8	5.5	25	1.0	9.3	8.2	nan	nan	8.3	10.3	9.8	nan
30	8	5.5	50	1.0	8.5	7.5	nan	nan	7.5	9.6	9.1	nan
30	8	5.5	75	1.0	8.4	7.5	nan	nan	7.4	9.6	9.1	nan
30	8	5.5	100	1.0	8.4	7.5	nan	nan	7.4	9.6	9.0	nan
30	9	5.5	25	1.0	1.4	0.2	nan	nan	0.3	2.2	1.8	nan
30	9	5.5	50	1.0	1.3	nan	nan	nan	0.2	2.1	1.7	nan
30	9	5.5	75	1.0	1.3	nan	nan	nan	0.2	2.1	1.7	nan
30	9	5.5	100	1.0	1.3	nan	nan	nan	0.2	2.1	1.7	nan
30	10	5.5	25	1.0	nan	nan	nan	nan	nan	nan	nan	nan
30	10	5.5	50	1.0	nan	nan	nan	nan	nan	nan	nan	nan
30	10	5.5	75	1.0	nan	nan	nan	nan	nan	nan	nan	nan
30	10	5.5	100	1.0	nan	nan	nan	nan	nan	nan	nan	nan

Separation standard of 30 NM, 1 NM offset and with **no** speed monitoring (λv = 5.5 knots). A reporting rate of 17 minutes will give a risk below the TLS for both RNP 2 and RNP 4.

3.17.26 Separation 10 NM, λv = 2.5 knots, offset = RO

Std [NM]	RNP [NM]	λv [knots]	Vm [knots]	RO [NM]	mod0 [min]	mod1 [min]	mod2 [min]	mod3 [min]	mod4 [min]	mod5 [min]	mod6 [min]	mod7 [min]
10	0.05	2.5	25	0.0	10.4	11.5	7.9	9.4	9.4	15.1	12.9	10.7
10	0.05	2.5	50	0.0	9.3	10.4	6.9	8.2	8.3	13.8	11.8	9.6
10	0.05	2.5	75	0.0	9.3	10.4	6.9	8.2	8.3	13.8	11.8	9.6
10	0.05	2.5	100	0.0	9.3	10.4	6.9	8.2	8.3	13.8	11.8	9.6
10	0.50	2.5	25	0.0	10.4	11.5	7.9	9.4	9.4	15.1	12.9	10.7
10	0.50	2.5	50	0.0	9.3	10.4	6.9	8.2	8.3	13.8	11.8	9.6
10	0.50	2.5	75	0.0	9.3	10.4	6.9	8.2	8.3	13.8	11.8	9.6
10	0.50	2.5	100	0.0	9.3	10.4	6.9	8.2	8.3	13.8	11.8	9.6
10	1	2.5	25	0.0	10.4	11.5	7.9	9.4	9.4	15.1	12.9	10.7
10	1	2.5	50	0.0	9.3	10.4	6.9	8.2	8.3	13.8	11.8	9.6
10	1	2.5	75	0.0	9.3	10.4	6.9	8.2	8.3	13.8	11.8	9.6
10	1	2.5	100	0.0	9.3	10.4	6.9	8.2	8.3	13.8	11.8	9.6
10	2	2.5	25	0.0	10.4	11.5	7.8	8.2	9.4	14.6	12.9	9.7
10	2	2.5	50	0.0	9.3	10.4	6.9	7.8	8.3	13.7	11.8	9.3
10	2	2.5	75	0.0	9.3	10.4	6.9	7.8	8.3	13.7	11.8	9.3
10	2	2.5	100	0.0	9.3	10.4	6.9	7.8	8.3	13.7	11.8	9.3
10	3	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	3	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	3	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	3	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	4	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	4	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	4	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	4	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	5	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	5	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	5	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	5	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	6	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	6	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	6	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	6	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	7	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	7	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	7	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	7	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	8	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	8	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	8	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	8	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	9	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	9	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	9	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	9	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	10	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	10	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	10	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
10	10	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0

Separation standard of 10 NM, random offset (RO) and with speed monitoring (λv = 2.5 knots). A reporting rate of 7 minutes will give a risk below the TLS for RNP 2.

3.17.27 Separation 15 NM, λv = 2.5 knots, offset = RO

Std	*RNP*	*λv*	*Vm*	*RO*	*mod0*	*mod1*	*mod2*	*mod3*	*mod4*	*mod5*	*mod6*	*mod7*
[NM]	*[NM]*	*[knots]*	*[knots]*	*[NM]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*
15	0.05	2.5	25	0.0	20.5	21.1	17.7	18.5	19.5	24.3	22.6	19.8
15	0.05	2.5	50	0.0	18.9	19.3	15.7	16.5	17.9	22.0	21.0	18.1
15	0.05	2.5	75	0.0	18.9	19.3	15.7	16.5	17.9	22.0	21.0	18.1
15	0.05	2.5	100	0.0	18.9	19.3	15.7	16.5	17.9	22.0	21.0	18.1
15	0.50	2.5	25	0.0	20.5	21.1	17.7	18.5	19.5	24.3	22.6	19.8
15	0.50	2.5	50	0.0	18.9	19.3	15.7	16.5	17.9	22.0	21.0	18.1
15	0.50	2.5	75	0.0	18.9	19.3	15.7	16.5	17.9	22.0	21.0	18.1
15	0.50	2.5	100	0.0	18.9	19.3	15.7	16.5	17.9	22.0	21.0	18.1
15	1	2.5	25	0.0	20.5	21.1	17.7	18.5	19.5	24.3	22.6	19.8
15	1	2.5	50	0.0	18.9	19.3	15.7	16.5	17.9	22.0	21.0	18.1
15	1	2.5	75	0.0	18.9	19.3	15.7	16.5	17.9	22.0	21.0	18.1
15	1	2.5	100	0.0	18.9	19.3	15.7	16.5	17.9	22.0	21.0	18.1
15	2	2.5	25	0.0	20.5	21.1	17.7	18.5	19.5	24.3	22.6	19.8
15	2	2.5	50	0.0	18.9	19.3	15.7	16.5	17.9	22.0	21.0	18.1
15	2	2.5	75	0.0	18.9	19.3	15.7	16.5	17.9	22.0	21.0	18.1
15	2	2.5	100	0.0	18.9	19.3	15.7	16.5	17.9	22.0	21.0	18.1
15	3	2.5	25	0.0	20.5	21.0	16.0	15.7	19.5	23.5	22.4	17.3
15	3	2.5	50	0.0	18.9	19.3	15.4	15.1	17.9	22.0	21.0	16.7
15	3	2.5	75	0.0	18.9	19.3	15.4	15.1	17.9	22.0	21.0	16.7
15	3	2.5	100	0.0	18.9	19.3	15.4	15.1	17.9	22.0	21.0	16.7
15	4	2.5	25	0.0	8.0	6.9	nan	nan	7.0	9.0	8.5	0.0
15	4	2.5	50	0.0	7.9	6.9	nan	nan	6.9	9.0	8.5	0.0
15	4	2.5	75	0.0	7.9	6.9	nan	nan	6.9	9.0	8.5	0.0
15	4	2.5	100	0.0	7.9	6.9	nan	nan	6.9	9.0	8.5	0.0
15	5	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	5	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	5	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	5	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	6	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	6	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	6	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	6	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	7	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	7	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	7	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	7	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	8	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	8	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	8	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	8	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	9	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	9	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	9	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	9	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	10	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	10	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	10	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
15	10	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0

Separation standard of 15 NM, random offset (RO) and with speed monitoring (λv = 2.5 knots). A reporting rate of 16 minutes will give a risk below the TLS for both RNP 2.

3.17.28 Separation 20 NM, λv = 2.5 knots, offset = RO

Std [NM]	RNP [NM]	λv [knots]	Vm [knots]	RO [NM]	mod0 [min]	mod1 [min]	mod2 [min]	mod3 [min]	mod4 [min]	mod5 [min]	mod6 [min]	mod7 [min]
20	0.05	2.5	25	0.0	≥ 30	≥ 30	26.7	27.1	29.2	≥ 30	≥ 30	28.8
20	0.05	2.5	50	0.0	27.9	27.7	24.2	24.4	26.9	≥ 30	29.4	26.1
20	0.05	2.5	75	0.0	27.9	27.7	24.2	24.3	26.9	≥ 30	29.4	26.1
20	0.05	2.5	100	0.0	27.9	27.7	24.2	24.3	26.9	≥ 30	29.4	26.1
20	0.50	2.5	25	0.0	≥ 30	≥ 30	26.7	27.1	29.2	≥ 30	≥ 30	28.8
20	0.50	2.5	50	0.0	27.9	27.7	24.2	24.4	26.9	≥ 30	29.4	26.1
20	0.50	2.5	75	0.0	27.9	27.7	24.2	24.3	26.9	≥ 30	29.4	26.1
20	0.50	2.5	100	0.0	27.9	27.7	24.2	24.3	26.9	≥ 30	29.4	26.1
20	1	2.5	25	0.0	≥ 30	≥ 30	26.7	27.1	29.2	≥ 30	≥ 30	28.8
20	1	2.5	50	0.0	27.9	27.7	24.2	24.4	26.9	≥ 30	29.4	26.1
20	1	2.5	75	0.0	27.9	27.7	24.2	24.3	26.9	≥ 30	29.4	26.1
20	1	2.5	100	0.0	27.9	27.7	24.2	24.3	26.9	≥ 30	29.4	26.1
20	2	2.5	25	0.0	≥ 30	≥ 30	26.7	27.1	29.2	≥ 30	≥ 30	28.8
20	2	2.5	50	0.0	27.9	27.7	24.2	24.4	26.9	≥ 30	29.4	26.1
20	2	2.5	75	0.0	27.9	27.7	24.2	24.3	26.9	≥ 30	29.4	26.1
20	2	2.5	100	0.0	27.9	27.7	24.2	24.3	26.9	≥ 30	29.4	26.1
20	3	2.5	25	0.0	≥ 30	≥ 30	26.7	27.1	29.2	≥ 30	≥ 30	28.8
20	3	2.5	50	0.0	27.9	27.7	24.2	24.4	26.9	≥ 30	29.4	26.1
20	3	2.5	75	0.0	27.9	27.7	24.2	24.3	26.9	≥ 30	29.4	26.1
20	3	2.5	100	0.0	27.9	27.7	24.2	24.3	26.9	≥ 30	29.4	26.1
20	4	2.5	25	0.0	≥ 30	≥ 30	23.6	22.9	29.2	≥ 30	≥ 30	24.5
20	4	2.5	50	0.0	27.9	27.7	22.9	22.2	26.9	≥ 30	29.4	23.8
20	4	2.5	75	0.0	27.9	27.7	22.9	22.2	26.9	≥ 30	29.4	23.8
20	4	2.5	100	0.0	27.9	27.7	22.9	22.2	26.9	≥ 30	29.4	23.8
20	5	2.5	25	0.0	18.7	17.7	4.1	3.0	17.7	19.8	19.3	4.5
20	5	2.5	50	0.0	18.6	17.6	4.1	2.9	17.6	19.7	19.2	4.5
20	5	2.5	75	0.0	18.6	17.6	4.1	2.9	17.6	19.7	19.2	4.5
20	5	2.5	100	0.0	18.6	17.6	4.1	2.9	17.6	19.7	19.2	4.5
20	6	2.5	25	0.0	2.1	0.9	nan	nan	1.1	2.8	2.4	0.0
20	6	2.5	50	0.0	2.1	0.9	nan	nan	1.1	2.8	2.4	0.0
20	6	2.5	75	0.0	2.1	0.9	nan	nan	1.1	2.8	2.4	0.0
20	6	2.5	100	0.0	2.1	0.9	nan	nan	1.1	2.8	2.4	0.0
20	7	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	7	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	7	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	7	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	8	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	8	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	8	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	8	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	9	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	9	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	9	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	9	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	10	2.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	10	2.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	10	2.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	0.0
20	10	2.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	0.0

Separation standard of 20 NM, Random offset (RO) and with speed monitoring (λv = 2.5 knots). A reporting rate of 22 minutes will give a risk below the TLS for both RNP 2 and RNP 4.

3.17.29 Separation 30 NM, λv = 2.5 knots, offset = RO

Std [NM]	RNP [NM]	λv [knots]	Vm [knots]	RO [NM]	mod0 [min]	mod1 [min]	mod2 [min]	mod3 [min]	mod4 [min]	mod5 [min]	mod6 [min]	mod7 [min]
30	0.05	2.5	25	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.05	2.5	50	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.05	2.5	75	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.05	2.5	100	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.50	2.5	25	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.50	2.5	50	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.50	2.5	75	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.50	2.5	100	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	1	2.5	25	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	1	2.5	50	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	1	2.5	75	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	1	2.5	100	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	2	2.5	25	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	2	2.5	50	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	2	2.5	75	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	2	2.5	100	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	3	2.5	25	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	3	2.5	50	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	3	2.5	75	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	3	2.5	100	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	4	2.5	25	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	4	2.5	50	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	4	2.5	75	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	4	2.5	100	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	5	2.5	25	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	5	2.5	50	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	5	2.5	75	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	5	2.5	100	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	6	2.5	25	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	6	2.5	50	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	6	2.5	75	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	6	2.5	100	0.0	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	7	2.5	25	0.0	≥ 30	≥ 30	18.2	17.0	≥ 30	≥ 30	≥ 30	18.6
30	7	2.5	50	0.0	≥ 30	≥ 30	18.1	17.0	≥ 30	≥ 30	≥ 30	18.5
30	7	2.5	75	0.0	≥ 30	≥ 30	18.1	17.0	≥ 30	≥ 30	≥ 30	18.5
30	7	2.5	100	0.0	≥ 30	≥ 30	18.1	17.0	≥ 30	≥ 30	≥ 30	18.5
30	8	2.5	25	0.0	19.5	18.3	2.3	1.1	18.5	20.2	19.8	2.6
30	8	2.5	50	0.0	19.4	18.3	2.3	1.1	18.4	20.2	19.8	2.6
30	8	2.5	75	0.0	19.4	18.3	2.3	1.1	18.4	20.2	19.8	2.6
30	8	2.5	100	0.0	19.4	18.3	2.3	1.1	18.4	20.2	19.8	2.6
30	9	2.5	25	0.0	5.1	3.9	nan	nan	4.1	5.8	5.5	nan
30	9	2.5	50	0.0	5.1	3.9	nan	nan	4.1	5.8	5.5	nan
30	9	2.5	75	0.0	5.1	3.9	nan	nan	4.1	5.8	5.5	nan
30	9	2.5	100	0.0	5.1	3.9	nan	nan	4.1	5.8	5.5	nan
30	10	2.5	25	0.0	nan	nan	nan	nan	nan	0.2	nan	nan
30	10	2.5	50	0.0	nan	nan	nan	nan	nan	0.2	nan	nan
30	10	2.5	75	0.0	nan	nan	nan	nan	nan	0.2	nan	nan
30	10	2.5	100	0.0	nan	nan	nan	nan	nan	0.2	nan	nan

Separation standard of 30 NM, random offset (RO) and with speed monitoring (λv = 2.5 knots). A reporting rate of 30 minutes will give a risk below the TLS for both RNP 2 and RNP 4.

3.17.30 Separation 10 NM, λv = 5.5 knots, offset = RO

Std	RNP	λv	Vm	RO	mod0	mod1	mod2	mod3	mod4	mod5	mod6	mod7
[NM]	[NM]	[knots]	[knots]	[NM]	[min]	[min]	[min]	[min]	[min]	[min]	[min]	[min]
10	0.05	5.5	25	0.0	0.5	1.7	nan	nan	nan	7.2	3.2	1.9
10	0.05	5.5	50	0.0	nan	nan	nan	nan	nan	4.2	0.3	nan
10	0.05	5.5	75	0.0	nan	nan	nan	nan	nan	3.6	nan	nan
10	0.05	5.5	100	0.0	nan	nan	nan	nan	nan	3.5	nan	nan
10	0.50	5.5	25	0.0	0.5	1.7	nan	nan	nan	7.2	3.2	1.9
10	0.50	5.5	50	0.0	nan	nan	nan	nan	nan	4.2	0.3	nan
10	0.50	5.5	75	0.0	nan	nan	nan	nan	nan	3.6	nan	nan
10	0.50	5.5	100	0.0	nan	nan	nan	nan	nan	3.5	nan	nan
10	1	5.5	25	0.0	0.5	1.7	nan	nan	nan	7.2	3.2	1.9
10	1	5.5	50	0.0	nan	nan	nan	nan	nan	4.2	0.3	nan
10	1	5.5	75	0.0	nan	nan	nan	nan	nan	3.6	nan	nan
10	1	5.5	100	0.0	nan	nan	nan	nan	nan	3.5	nan	nan
10	2	5.5	25	0.0	0.5	1.7	nan	nan	nan	6.2	3.2	1.5
10	2	5.5	50	0.0	nan	nan	nan	nan	nan	4.2	0.3	nan
10	2	5.5	75	0.0	nan	nan	nan	nan	nan	3.6	nan	nan
10	2	5.5	100	0.0	nan	nan	nan	nan	nan	3.5	nan	nan
10	3	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	nan
10	3	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	nan
10	3	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	nan
10	3	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	nan
10	4	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	nan
10	4	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	nan
10	4	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	nan
10	4	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	nan
10	5	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	nan
10	5	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	nan
10	5	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	nan
10	5	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	nan
10	6	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	nan
10	6	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	nan
10	6	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	nan
10	6	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	nan
10	7	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	nan
10	7	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	nan
10	7	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	nan
10	7	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	nan
10	8	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	nan
10	8	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	nan
10	8	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	nan
10	8	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	nan
10	9	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	nan
10	9	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	nan
10	9	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	nan
10	9	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	nan
10	10	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	nan
10	10	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	nan
10	10	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	nan
10	10	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	nan

Separation standard of 10 NM, random offset (RO) and with **no** speed monitoring (λv = 5.5 knots). No reporting rate gives risk below the TLS.

3.17.31 Separation 15 NM, λv = 5.5 knots, offset = RO

Std	*RNP*	*λv*	*Vm*	*RO*	*mod0*	*mod1*	*mod2*	*mod3*	*mod4*	*mod5*	*mod6*	*mod7*
[NM]	*[NM]*	*[knots]*	*[knots]*	*[NM]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*
15	0.05	5.5	25	0.0	7.2	8.7	6.1	6.9	6.2	13.8	9.8	8.6
15	0.05	5.5	50	0.0	2.9	4.3	1.3	2.4	1.9	8.8	5.6	3.8
15	0.05	5.5	75	0.0	2.1	3.5	0.1	1.6	1.1	7.9	4.8	2.9
15	0.05	5.5	100	0.0	2.0	3.4	nan	1.5	1.0	7.7	4.7	2.8
15	0.50	5.5	25	0.0	7.2	8.7	6.1	6.9	6.2	13.8	9.8	8.6
15	0.50	5.5	50	0.0	2.9	4.3	1.3	2.4	1.9	8.8	5.6	3.8
15	0.50	5.5	75	0.0	2.1	3.5	0.1	1.6	1.1	7.9	4.8	2.9
15	0.50	5.5	100	0.0	2.0	3.4	nan	1.5	1.0	7.7	4.7	2.8
15	1	5.5	25	0.0	7.2	8.7	6.1	6.9	6.2	13.8	9.8	8.6
15	1	5.5	50	0.0	2.9	4.3	1.3	2.4	1.9	8.8	5.6	3.8
15	1	5.5	75	0.0	2.1	3.5	0.1	1.6	1.1	7.9	4.8	2.9
15	1	5.5	100	0.0	2.0	3.4	nan	1.5	1.0	7.7	4.7	2.8
15	2	5.5	25	0.0	7.2	8.7	6.1	6.9	6.2	13.7	9.8	8.6
15	2	5.5	50	0.0	2.9	4.3	1.3	2.4	1.9	8.8	5.6	3.8
15	2	5.5	75	0.0	2.1	3.5	0.1	1.6	1.1	7.9	4.8	2.9
15	2	5.5	100	0.0	2.0	3.4	nan	1.5	1.0	7.7	4.7	2.8
15	3	5.5	25	0.0	7.2	8.2	4.5	5.0	6.2	11.3	9.6	6.5
15	3	5.5	50	0.0	2.9	4.3	1.3	2.4	1.9	8.7	5.6	3.8
15	3	5.5	75	0.0	2.1	3.5	0.1	1.6	1.1	7.9	4.8	2.9
15	3	5.5	100	0.0	2.0	3.4	nan	1.5	1.0	7.7	4.7	2.8
15	4	5.5	25	0.0	1.8	1.2	nan	nan	0.8	3.5	2.7	nan
15	4	5.5	50	0.0	0.9	0.6	nan	nan	nan	3.1	2.2	nan
15	4	5.5	75	0.0	0.7	0.6	nan	nan	nan	3.1	2.1	nan
15	4	5.5	100	0.0	0.7	0.6	nan	nan	nan	3.1	2.1	nan
15	5	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	nan
15	5	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	nan
15	5	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	nan
15	5	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	nan
15	6	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	nan
15	6	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	nan
15	6	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	nan
15	6	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	nan
15	7	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	nan
15	7	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	nan
15	7	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	nan
15	7	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	nan
15	8	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	nan
15	8	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	nan
15	8	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	nan
15	8	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	nan
15	9	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	nan
15	9	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	nan
15	9	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	nan
15	9	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	nan
15	10	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	nan
15	10	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	nan
15	10	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	nan
15	10	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	nan

Separation standard of 15 NM, random offset (RO) and with **no** speed monitoring (λv = 5.5 knots). No reporting rate gives acceptable risk unless new communication models are assumed.

3.17.32 Separation 20 NM, λv = 5.5 knots, offset = RO

Std [NM]	RNP [NM]	λv [knots]	Vm [knots]	RO [NM]	mod0 [min]	mod1 [min]	mod2 [min]	mod3 [min]	mod4 [min]	mod5 [min]	mod6 [min]	mod7 [min]
20	0.05	5.5	25	0.0	13.6	15.4	12.2	13.5	12.6	20.1	16.3	14.9
20	0.05	5.5	50	0.0	7.8	9.0	5.7	7.0	6.8	12.8	10.5	8.3
20	0.05	5.5	75	0.0	6.5	7.9	4.1	5.8	5.5	11.8	9.3	6.9
20	0.05	5.5	100	0.0	6.4	7.7	3.9	5.6	5.4	11.5	9.1	6.7
20	0.50	5.5	25	0.0	13.6	15.4	12.2	13.5	12.6	20.1	16.3	14.9
20	0.50	5.5	50	0.0	7.8	9.0	5.7	7.0	6.8	12.8	10.5	8.3
20	0.50	5.5	75	0.0	6.5	7.9	4.1	5.8	5.5	11.8	9.3	6.9
20	0.50	5.5	100	0.0	6.4	7.7	3.9	5.6	5.4	11.5	9.1	6.7
20	1	5.5	25	0.0	13.6	15.4	12.2	13.5	12.6	20.1	16.3	14.9
20	1	5.5	50	0.0	7.8	9.0	5.7	7.0	6.8	12.8	10.5	8.3
20	1	5.5	75	0.0	6.5	7.9	4.1	5.8	5.5	11.8	9.3	6.9
20	1	5.5	100	0.0	6.4	7.7	3.9	5.6	5.4	11.5	9.1	6.7
20	2	5.5	25	0.0	13.6	15.4	12.2	13.5	12.6	20.1	16.3	14.9
20	2	5.5	50	0.0	7.8	9.0	5.7	7.0	6.8	12.8	10.5	8.3
20	2	5.5	75	0.0	6.5	7.9	4.1	5.8	5.5	11.8	9.3	6.9
20	2	5.5	100	0.0	6.4	7.7	3.9	5.6	5.4	11.5	9.1	6.7
20	3	5.5	25	0.0	13.6	15.4	12.2	13.5	12.6	19.4	16.3	14.7
20	3	5.5	50	0.0	7.8	9.0	5.7	7.0	6.8	12.8	10.5	8.3
20	3	5.5	75	0.0	6.5	7.9	4.1	5.8	5.5	11.8	9.3	6.9
20	3	5.5	100	0.0	6.4	7.7	3.9	5.6	5.4	11.5	9.1	6.7
20	4	5.5	25	0.0	13.4	13.6	9.3	9.3	12.4	16.3	15.2	10.9
20	4	5.5	50	0.0	7.8	9.0	5.7	6.8	6.8	12.7	10.5	8.2
20	4	5.5	75	0.0	6.5	7.9	4.1	5.8	5.5	11.8	9.3	6.9
20	4	5.5	100	0.0	6.4	7.7	3.9	5.6	5.4	11.5	9.1	6.7
20	5	5.5	25	0.0	7.5	6.9	0.2	nan	6.5	9.2	8.5	0.9
20	5	5.5	50	0.0	6.0	5.7	nan	nan	5.0	8.2	7.3	0.7
20	5	5.5	75	0.0	5.8	5.5	nan	nan	4.8	8.0	7.1	0.6
20	5	5.5	100	0.0	5.8	5.5	nan	nan	4.8	8.0	7.1	0.6
20	6	5.5	25	0.0	nan	nan	nan	nan	nan	0.1	nan	nan
20	6	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	nan
20	6	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	nan
20	6	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	nan
20	7	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	nan
20	7	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	nan
20	7	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	nan
20	7	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	nan
20	8	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	nan
20	8	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	nan
20	8	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	nan
20	8	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	nan
20	9	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	nan
20	9	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	nan
20	9	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	nan
20	9	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	nan
20	10	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	nan
20	10	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	nan
20	10	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	nan
20	10	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	nan

Separation standard of 20 NM, random offset (RO) and with **no** speed monitoring (λv = 5.5 knots). A reporting rate of 4 minutes will give a risk below the TLS for both RNP 2 and RNP 4.

3.17.33 Separation 30 NM, λv = 5.5 knots, offset = RO

Std [NM]	RNP [NM]	λv [knots]	Vm [knots]	RO [NM]	mod0 [min]	mod1 [min]	mod2 [min]	mod3 [min]	mod4 [min]	mod5 [min]	mod6 [min]	mod7 [min]
30	0.05	5.5	25	0.0	26.6	28.4	24.9	26.5	25.6	≥ 30	29.3	27.6
30	0.05	5.5	50	0.0	17.2	17.7	14.2	15.4	16.2	20.8	19.4	16.9
30	0.05	5.5	75	0.0	15.0	15.9	12.2	13.6	14.0	19.1	17.5	14.8
30	0.05	5.5	100	0.0	14.8	15.5	11.8	13.1	13.8	18.7	17.1	14.4
30	0.50	5.5	25	0.0	26.6	28.4	24.9	26.5	25.6	≥ 30	29.3	27.6
30	0.50	5.5	50	0.0	17.2	17.7	14.2	15.4	16.2	20.8	19.4	16.9
30	0.50	5.5	75	0.0	15.0	15.9	12.2	13.6	14.0	19.1	17.5	14.8
30	0.50	5.5	100	0.0	14.8	15.5	11.8	13.1	13.8	18.7	17.1	14.4
30	1	5.5	25	0.0	26.6	28.4	24.9	26.5	25.6	≥ 30	29.3	27.6
30	1	5.5	50	0.0	17.2	17.7	14.2	15.4	16.2	20.8	19.4	16.9
30	1	5.5	75	0.0	15.0	15.9	12.2	13.6	14.0	19.1	17.5	14.8
30	1	5.5	100	0.0	14.8	15.5	11.8	13.1	13.8	18.7	17.1	14.4
30	2	5.5	25	0.0	26.6	28.4	24.9	26.5	25.6	≥ 30	29.3	27.6
30	2	5.5	50	0.0	17.2	17.7	14.2	15.4	16.2	20.8	19.4	16.9
30	2	5.5	75	0.0	15.0	15.9	12.2	13.6	14.0	19.1	17.5	14.8
30	2	5.5	100	0.0	14.8	15.5	11.8	13.1	13.8	18.7	17.1	14.4
30	3	5.5	25	0.0	26.6	28.4	24.9	26.5	25.6	≥ 30	29.3	27.6
30	3	5.5	50	0.0	17.2	17.7	14.2	15.4	16.2	20.8	19.4	16.9
30	3	5.5	75	0.0	15.0	15.9	12.2	13.6	14.0	19.1	17.5	14.8
30	3	5.5	100	0.0	14.8	15.5	11.8	13.1	13.8	18.7	17.1	14.4
30	4	5.5	25	0.0	26.6	28.4	24.8	25.9	25.6	≥ 30	29.3	27.3
30	4	5.5	50	0.0	17.2	17.7	14.2	15.4	16.2	20.8	19.4	16.9
30	4	5.5	75	0.0	15.0	15.9	12.2	13.6	14.0	19.1	17.5	14.8
30	4	5.5	100	0.0	14.8	15.5	11.8	13.1	13.8	18.7	17.1	14.4
30	5	5.5	25	0.0	26.6	27.3	23.1	23.0	25.6	29.9	28.9	24.6
30	5	5.5	50	0.0	17.2	17.7	14.2	15.4	16.2	20.8	19.4	16.9
30	5	5.5	75	0.0	15.0	15.9	12.2	13.6	14.0	19.1	17.5	14.8
30	5	5.5	100	0.0	14.8	15.5	11.8	13.1	13.8	18.7	17.1	14.4
30	6	5.5	25	0.0	24.5	24.0	18.1	17.5	23.5	26.4	25.6	19.1
30	6	5.5	50	0.0	17.2	17.7	14.1	14.1	16.2	20.8	19.4	15.7
30	6	5.5	75	0.0	15.0	15.9	12.2	13.3	14.0	19.1	17.5	14.8
30	6	5.5	100	0.0	14.8	15.5	11.8	13.1	13.8	18.7	17.1	14.4
30	7	5.5	25	0.0	18.7	17.9	8.2	7.2	17.7	20.1	19.5	8.8
30	7	5.5	50	0.0	15.7	15.1	7.3	6.5	14.7	17.5	16.7	8.1
30	7	5.5	75	0.0	15.0	14.7	7.2	6.4	14.0	17.1	16.3	8.0
30	7	5.5	100	0.0	14.7	14.6	7.2	6.4	13.7	17.0	16.3	8.0
30	8	5.5	25	0.0	9.2	8.2	nan	nan	8.2	10.2	9.7	nan
30	8	5.5	50	0.0	8.4	7.5	nan	nan	7.4	9.6	9.1	nan
30	8	5.5	75	0.0	8.4	7.4	nan	nan	7.4	9.5	9.0	nan
30	8	5.5	100	0.0	8.4	7.4	nan	nan	7.4	9.5	9.0	nan
30	9	5.5	25	0.0	1.4	0.2	nan	nan	0.3	2.2	1.8	nan
30	9	5.5	50	0.0	1.3	nan	nan	nan	0.2	2.0	1.7	nan
30	9	5.5	75	0.0	1.2	nan	nan	nan	0.2	2.0	1.6	nan
30	9	5.5	100	0.0	1.2	nan	nan	nan	0.2	2.0	1.6	nan
30	10	5.5	25	0.0	nan	nan	nan	nan	nan	nan	nan	nan
30	10	5.5	50	0.0	nan	nan	nan	nan	nan	nan	nan	nan
30	10	5.5	75	0.0	nan	nan	nan	nan	nan	nan	nan	nan
30	10	5.5	100	0.0	nan	nan	nan	nan	nan	nan	nan	nan

Separation standard of 30 NM, random offset (RO) and with no speed monitoring (λv = 5.5 knots). A reporting rate of 12 minutes will give a risk below the TLS for both RNP 2 and RNP 4.

3.18 TABULATED RESULTS: SAME DIRECTION TRACK, CROSSING ANGLE

3.18.1 This section gives tabulated results for main parameter sets.

3.18.2 The following tables show the minimum reporting rate T in minutes for a range of parameter values. These are:

a) Std: the separation standard as either 10,15,20 or 30 NM;

b) RNP: the maximum required navigational performance as either 0.05,0.5,1,2,3,4,5,6,7,9, 10 NM;

c) λv : the exponential decay speedparameter as either 2.5 knots (Mach limited) or 5.5 knots;

d) mod0 (model 0): response times τ = [4, 10.5, 13.5] minutes with respective weights=[0.9025, 0.0475, 0.05];

e) mod2 (model 2): NP =4 and response times τ = [4, 10.5, 13.5] minutes with respective weights=[0.9025, 0.0475, 0.05];

f) 1-90 degrees: the time considers all angles between 1 and 90 degrees;

g) 5-90 degrees: the time considers all angles between 5 and 90 degrees; and

h) 5-45 degrees: the time considers all angles between 1 and 45 degrees.

3.18.3 Results are limited to a maximum 30 minute reporting time and hence values larger than 30 are reports as ≥ 30.

3.18.4 Results with times indicates as “nan”, mean that no sensible reporting rate gives results which meet the TLS.

3.18.1 Main results

Std	*RNP*	*λv*	*Vm*	*mod0*	*mod0*	*mod0*	*mod2*	*mod2*	*mod2*
				1-90 deg	*5-90 deg*	*5-45 deg*	*1-90 deg*	*5-90 deg*	*5-45 deg*
[NM]	*[NM]*	*[knots]*	*[knots]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*
10	2	2.5	50	nan	nan	13.4	nan	nan	9.0
15	2	2.5	50	23.0	23.0	25.1	19.7	19.7	21.9
20	2	2.5	50	≥ 30	≥ 30	≥ 30	28.9	29.4	≥ 30
20	4	2.5	50	nan	nan	29.2	nan	nan	21.2
30	2	2.5	50	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	4	2.5	50	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
10	2	5.5	75	nan	nan	4.7	nan	nan	2.7
15	2	5.5	75	6.0	10.0	10.0	3.5	8.5	8.5
20	2	5.5	75	11.2	14.4	14.4	8.4	12.5	12.5
20	4	5.5	75	nan	nan	11.6	nan	nan	7.8
30	2	5.5	75	20.5	22.8	22.9	17.3	20.2	20.2
30	4	5.5	75	20.1	20.1	22.2	16.8	17.1	19.1

Key results from the following tables. For combinations of separation standards (in NM), RNP (in NM), λv in (knots) and assigned offset (in NM) the maximum allowable reporting time (in minutes) to meet the TLS is given.

3.18.2 Separation 10 NM, λv = 2.5 knots

Std	*RNP*	*λv*	*Vm*	*mod0 1-90 deg*	*mod0 5-90 deg*	*mod0 5-45 deg*	*mod2 1-90 deg*	*mod2 5-90 deg*	*mod2 5-45 deg*
[NM]	*[NM]*	*[knots]*	*[knots]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*
10	0.05	2.5	25	17.4	18.7	20.0	15.7	17.8	17.8
10	0.05	2.5	50	15.8	16.9	17.6	14.3	15.6	15.6
10	0.05	2.5	75	15.8	16.9	17.6	14.3	15.6	15.6
10	0.05	2.5	100	15.8	16.9	17.6	14.3	15.6	15.6
10	0.50	2.5	25	16.4	18.6	18.7	14.6	16.9	16.9
10	0.50	2.5	50	15.3	17.5	17.6	13.4	15.6	15.6
10	0.50	2.5	75	15.3	17.5	17.6	13.4	15.6	15.6
10	0.50	2.5	100	15.3	17.5	17.6	13.4	15.6	15.6
10	1	2.5	25	15.5	17.5	18.0	13.2	15.6	16.1
10	1	2.5	50	14.6	16.7	17.1	12.2	14.7	15.0
10	1	2.5	75	14.6	16.7	17.1	12.2	14.7	15.0
10	1	2.5	100	14.6	16.7	17.1	12.2	14.7	15.0
10	2	2.5	25	nan	nan	13.8	nan	nan	9.1
10	2	2.5	50	nan	nan	13.4	nan	nan	9.0
10	2	2.5	75	nan	nan	13.4	nan	nan	9.0
10	2	2.5	100	nan	nan	13.4	nan	nan	9.0
10	3	2.5	25	nan	nan	nan	nan	nan	nan
10	3	2.5	50	nan	nan	nan	nan	nan	nan
10	3	2.5	75	nan	nan	nan	nan	nan	nan
10	3	2.5	100	nan	nan	nan	nan	nan	nan
10	4	2.5	25	nan	nan	nan	nan	nan	nan
10	4	2.5	50	nan	nan	nan	nan	nan	nan
10	4	2.5	75	nan	nan	nan	nan	nan	nan
10	4	2.5	100	nan	nan	nan	nan	nan	nan
10	5	2.5	25	nan	nan	nan	nan	nan	nan
10	5	2.5	50	nan	nan	nan	nan	nan	nan
10	5	2.5	75	nan	nan	nan	nan	nan	nan
10	5	2.5	100	nan	nan	nan	nan	nan	nan
10	6	2.5	25	nan	nan	nan	nan	nan	nan
10	6	2.5	50	nan	nan	nan	nan	nan	nan
10	6	2.5	75	nan	nan	nan	nan	nan	nan
10	6	2.5	100	nan	nan	nan	nan	nan	nan
10	7	2.5	25	nan	nan	nan	nan	nan	nan
10	7	2.5	50	nan	nan	nan	nan	nan	nan
10	7	2.5	75	nan	nan	nan	nan	nan	nan
10	7	2.5	100	nan	nan	nan	nan	nan	nan
10	8	2.5	25	nan	nan	nan	nan	nan	nan
10	8	2.5	50	nan	nan	nan	nan	nan	nan
10	8	2.5	75	nan	nan	nan	nan	nan	nan
10	8	2.5	100	nan	nan	nan	nan	nan	nan
10	9	2.5	25	nan	nan	nan	nan	nan	nan
10	9	2.5	50	nan	nan	nan	nan	nan	nan
10	9	2.5	75	nan	nan	nan	nan	nan	nan
10	9	2.5	100	nan	nan	nan	nan	nan	nan
10	10	2.5	25	nan	nan	nan	nan	nan	nan
10	10	2.5	50	nan	nan	nan	nan	nan	nan
10	10	2.5	75	nan	nan	nan	nan	nan	nan
10	10	2.5	100	nan	nan	nan	nan	nan	nan

10NM, speed limited (λv = 2.5 knots): Separation standard of 10 NM, no offset and with speed monitoring (λv = 2.5 knots).

3.18.3 Separation 15 NM, λv = 2.5 knots

Std	*RNP*	*λv*	*Vm*	*mod0 1-90 deg*	*mod0 5-90 deg*	*mod0 5-45 deg*	*mod2 1-90 deg*	*mod2 5-90 deg*	*mod2 5-45 deg*
[NM]	*[NM]*	*[knots]*	*[knots]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*
15	0.05	2.5	25	25.8	≥ 30	≥ 30	23.4	26.9	26.9
15	0.05	2.5	50	23.9	25.7	26.7	21.4	24.0	24.0
15	0.05	2.5	75	23.9	25.7	26.4	21.4	24.0	24.0
15	0.05	2.5	100	23.9	25.7	26.4	21.4	24.0	24.0
15	0.50	2.5	25	25.6	27.9	27.9	23.2	25.1	25.8
15	0.50	2.5	50	23.9	26.1	26.6	21.2	23.6	23.6
15	0.50	2.5	75	23.9	26.1	26.6	21.2	23.6	23.6
15	0.50	2.5	100	23.9	26.1	26.6	21.2	23.6	23.6
15	1	2.5	25	25.5	27.6	27.8	22.7	24.7	25.1
15	1	2.5	50	23.9	25.9	26.3	20.9	23.1	23.3
15	1	2.5	75	23.9	25.9	26.3	20.9	23.1	23.3
15	1	2.5	100	23.9	25.9	26.3	20.9	23.1	23.3
15	2	2.5	25	23.9	23.9	26.3	20.5	20.5	23.2
15	2	2.5	50	23.0	23.0	25.1	19.7	19.7	21.9
15	2	2.5	75	23.0	23.0	25.1	19.7	19.7	21.9
15	2	2.5	100	23.0	23.0	25.1	19.7	19.7	21.9
15	3	2.5	25	nan	nan	21.6	nan	nan	15.0
15	3	2.5	50	nan	nan	21.1	nan	nan	14.8
15	3	2.5	75	nan	nan	21.1	nan	nan	14.8
15	3	2.5	100	nan	nan	21.1	nan	nan	14.8
15	4	2.5	25	nan	nan	nan	nan	nan	nan
15	4	2.5	50	nan	nan	nan	nan	nan	nan
15	4	2.5	75	nan	nan	nan	nan	nan	nan
15	4	2.5	100	nan	nan	nan	nan	nan	nan
15	5	2.5	25	nan	nan	nan	nan	nan	nan
15	5	2.5	50	nan	nan	nan	nan	nan	nan
15	5	2.5	75	nan	nan	nan	nan	nan	nan
15	5	2.5	100	nan	nan	nan	nan	nan	nan
15	6	2.5	25	nan	nan	nan	nan	nan	nan
15	6	2.5	50	nan	nan	nan	nan	nan	nan
15	6	2.5	75	nan	nan	nan	nan	nan	nan
15	6	2.5	100	nan	nan	nan	nan	nan	nan
15	7	2.5	25	nan	nan	nan	nan	nan	nan
15	7	2.5	50	nan	nan	nan	nan	nan	nan
15	7	2.5	75	nan	nan	nan	nan	nan	nan
15	7	2.5	100	nan	nan	nan	nan	nan	nan
15	8	2.5	25	nan	nan	nan	nan	nan	nan
15	8	2.5	50	nan	nan	nan	nan	nan	nan
15	8	2.5	75	nan	nan	nan	nan	nan	nan
15	8	2.5	100	nan	nan	nan	nan	nan	nan
15	9	2.5	25	nan	nan	nan	nan	nan	nan
15	9	2.5	50	nan	nan	nan	nan	nan	nan
15	9	2.5	75	nan	nan	nan	nan	nan	nan
15	9	2.5	100	nan	nan	nan	nan	nan	nan
15	10	2.5	25	nan	nan	nan	nan	nan	nan
15	10	2.5	50	nan	nan	nan	nan	nan	nan
15	10	2.5	75	nan	nan	nan	nan	nan	nan
15	10	2.5	100	nan	nan	nan	nan	nan	nan

15NM, speed limited (λv = 2.5 knots): Separation standard of 15 NM, no offset and with speed monitoring (λv = 2.5 knots).

3.18.4 Separation 20 NM, λv = 2.5 knots

Std	*RNP*	*λv*	*Vm*	*mod0 1-90 deg*	*mod0 5-90 deg*	*mod0 5-45 deg*	*mod2 1-90 deg*	*mod2 5-90 deg*	*mod2 5-45 deg*
[NM]	*[NM]*	*[knots]*	*[knots]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*
20	0.05	2.5	25	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
20	0.05	2.5	50	≥ 30	≥ 30	≥ 30	28.5	≥ 30	≥ 30
20	0.05	2.5	75	≥ 30	≥ 30	≥ 30	28.5	≥ 30	≥ 30
20	0.05	2.5	100	≥ 30	≥ 30	≥ 30	28.5	≥ 30	≥ 30
20	0.50	2.5	25	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
20	0.50	2.5	50	≥ 30	≥ 30	≥ 30	28.9	≥ 30	≥ 30
20	0.50	2.5	75	≥ 30	≥ 30	≥ 30	28.9	≥ 30	≥ 30
20	0.50	2.5	100	≥ 30	≥ 30	≥ 30	28.9	≥ 30	≥ 30
20	1	2.5	25	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
20	1	2.5	50	≥ 30	≥ 30	≥ 30	29.1	≥ 30	≥ 30
20	1	2.5	75	≥ 30	≥ 30	≥ 30	29.1	≥ 30	≥ 30
20	1	2.5	100	≥ 30	≥ 30	≥ 30	29.1	≥ 30	≥ 30
20	2	2.5	25	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
20	2	2.5	50	≥ 30	≥ 30	≥ 30	28.9	29.4	≥ 30
20	2	2.5	75	≥ 30	≥ 30	≥ 30	28.9	29.4	≥ 30
20	2	2.5	100	≥ 30	≥ 30	≥ 30	28.9	29.4	≥ 30
20	3	2.5	25	29.2	29.2	≥ 30	23.3	23.3	≥ 30
20	3	2.5	50	28.4	28.4	≥ 30	22.7	22.7	28.9
20	3	2.5	75	28.4	28.4	≥ 30	22.7	22.7	28.9
20	3	2.5	100	28.4	28.4	≥ 30	22.7	22.7	28.9
20	4	2.5	25	nan	nan	≥ 30	nan	nan	21.6
20	4	2.5	50	nan	nan	29.2	nan	nan	21.2
20	4	2.5	75	nan	nan	29.2	nan	nan	21.2
20	4	2.5	100	nan	nan	29.2	nan	nan	21.2
20	5	2.5	25	nan	nan	3.6	nan	nan	nan
20	5	2.5	50	nan	nan	3.6	nan	nan	nan
20	5	2.5	75	nan	nan	3.6	nan	nan	nan
20	5	2.5	100	nan	nan	3.6	nan	nan	nan
20	6	2.5	25	nan	nan	nan	nan	nan	nan
20	6	2.5	50	nan	nan	nan	nan	nan	nan
20	6	2.5	75	nan	nan	nan	nan	nan	nan
20	6	2.5	100	nan	nan	nan	nan	nan	nan
20	7	2.5	25	nan	nan	nan	nan	nan	nan
20	7	2.5	50	nan	nan	nan	nan	nan	nan
20	7	2.5	75	nan	nan	nan	nan	nan	nan
20	7	2.5	100	nan	nan	nan	nan	nan	nan
20	8	2.5	25	nan	nan	nan	nan	nan	nan
20	8	2.5	50	nan	nan	nan	nan	nan	nan
20	8	2.5	75	nan	nan	nan	nan	nan	nan
20	8	2.5	100	nan	nan	nan	nan	nan	nan
20	9	2.5	25	nan	nan	nan	nan	nan	nan
20	9	2.5	50	nan	nan	nan	nan	nan	nan
20	9	2.5	75	nan	nan	nan	nan	nan	nan
20	9	2.5	100	nan	nan	nan	nan	nan	nan
20	10	2.5	25	nan	nan	nan	nan	nan	nan
20	10	2.5	50	nan	nan	nan	nan	nan	nan
20	10	2.5	75	nan	nan	nan	nan	nan	nan
20	10	2.5	100	nan	nan	nan	nan	nan	nan

20NM, speed limited (λv = 2.5 knots): Separation standard of 20 NM, no offset and with speed monitoring (λv = 2.5 knots).

3.18.5 Separation 30 NM, λv = 2.5 knots

Std	*RNP*	*λv*	*Vm*	*mod0 1-90 deg*	*mod0 5-90 deg*	*mod0 5-45 deg*	*mod2 1-90 deg*	*mod2 5-90 deg*	*mod2 5-45 deg*
[NM]	*[NM]*	*[knots]*	*[knots]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*
30	0.05	2.5	25	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.05	2.5	50	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.05	2.5	75	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.05	2.5	100	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.50	2.5	25	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.50	2.5	50	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.50	2.5	75	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.50	2.5	100	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	1	2.5	25	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	1	2.5	50	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	1	2.5	75	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	1	2.5	100	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	2	2.5	25	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	2	2.5	50	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	2	2.5	75	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	2	2.5	100	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	3	2.5	25	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	3	2.5	50	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	3	2.5	75	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	3	2.5	100	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	4	2.5	25	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	4	2.5	50	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	4	2.5	75	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	4	2.5	100	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	5	2.5	25	≥ 30	≥ 30	≥ 30	20.6	20.6	≥ 30
30	5	2.5	50	≥ 30	≥ 30	≥ 30	20.4	20.4	≥ 30
30	5	2.5	75	≥ 30	≥ 30	≥ 30	20.4	20.4	≥ 30
30	5	2.5	100	≥ 30	≥ 30	≥ 30	20.4	20.4	≥ 30
30	6	2.5	25	nan	nan	≥ 30	nan	nan	≥ 30
30	6	2.5	50	nan	nan	≥ 30	nan	nan	≥ 30
30	6	2.5	75	nan	nan	≥ 30	nan	nan	≥ 30
30	6	2.5	100	nan	nan	≥ 30	nan	nan	≥ 30
30	7	2.5	25	nan	nan	≥ 30	nan	nan	0.7
30	7	2.5	50	nan	nan	≥ 30	nan	nan	0.7
30	7	2.5	75	nan	nan	≥ 30	nan	nan	0.7
30	7	2.5	100	nan	nan	≥ 30	nan	nan	0.7
30	8	2.5	25	nan	nan	0.7	nan	nan	nan
30	8	2.5	50	nan	nan	0.7	nan	nan	nan
30	8	2.5	75	nan	nan	0.7	nan	nan	nan
30	8	2.5	100	nan	nan	0.7	nan	nan	nan
30	9	2.5	25	nan	nan	nan	nan	nan	nan
30	9	2.5	50	nan	nan	nan	nan	nan	nan
30	9	2.5	75	nan	nan	nan	nan	nan	nan
30	9	2.5	100	nan	nan	nan	nan	nan	nan
30	10	2.5	25	nan	nan	nan	nan	nan	nan
30	10	2.5	50	nan	nan	nan	nan	nan	nan
30	10	2.5	75	nan	nan	nan	nan	nan	nan
30	10	2.5	100	nan	nan	nan	nan	nan	nan

30NM, speed limited (λv = 2.5 knots): Separation standard of 30 NM, no offset and with speed monitoring (λv = 2.5 knots).

3.18.6 Separation 10 NM, λv = 5.5 knots

Std	*RNP*	*λv*	*Vm*	*mod0 1-90 deg*	*mod0 5-90 deg*	*mod0 5-45 deg*	*mod2 1-90 deg*	*mod2 5-90 deg*	*mod2 5-45 deg*
[NM]	*[NM]*	*[knots]*	*[knots]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*
10	0.05	5.5	25	11.5	12.1	12.1	11.2	12.5	12.5
10	0.05	5.5	50	7.4	8.3	8.3	6.7	7.6	7.6
10	0.05	5.5	75	6.7	7.6	7.6	6.0	6.7	6.7
10	0.05	5.5	100	6.5	7.5	7.5	5.7	6.6	6.6
10	0.50	5.5	25	8.4	11.2	11.2	6.9	10.7	10.7
10	0.50	5.5	50	5.3	8.0	8.0	3.9	7.1	7.1
10	0.50	5.5	75	4.8	7.3	7.3	3.5	6.5	6.5
10	0.50	5.5	100	4.7	7.2	7.2	3.4	6.3	6.3
10	1	5.5	25	5.2	10.1	10.1	3.2	9.3	9.3
10	1	5.5	50	2.6	7.4	7.4	0.5	6.4	6.4
10	1	5.5	75	2.3	6.8	6.8	0.1	5.8	5.8
10	1	5.5	100	2.2	6.7	6.7	0.1	5.7	5.7
10	2	5.5	25	nan	nan	6.4	nan	nan	3.6
10	2	5.5	50	nan	nan	5.0	nan	nan	2.8
10	2	5.5	75	nan	nan	4.7	nan	nan	2.7
10	2	5.5	100	nan	nan	4.7	nan	nan	2.7
10	3	5.5	25	nan	nan	nan	nan	nan	nan
10	3	5.5	50	nan	nan	nan	nan	nan	nan
10	3	5.5	75	nan	nan	nan	nan	nan	nan
10	3	5.5	100	nan	nan	nan	nan	nan	nan
10	4	5.5	25	nan	nan	nan	nan	nan	nan
10	4	5.5	50	nan	nan	nan	nan	nan	nan
10	4	5.5	75	nan	nan	nan	nan	nan	nan
10	4	5.5	100	nan	nan	nan	nan	nan	nan
10	5	5.5	25	nan	nan	nan	nan	nan	nan
10	5	5.5	50	nan	nan	nan	nan	nan	nan
10	5	5.5	75	nan	nan	nan	nan	nan	nan
10	5	5.5	100	nan	nan	nan	nan	nan	nan
10	6	5.5	25	nan	nan	nan	nan	nan	nan
10	6	5.5	50	nan	nan	nan	nan	nan	nan
10	6	5.5	75	nan	nan	nan	nan	nan	nan
10	6	5.5	100	nan	nan	nan	nan	nan	nan
10	7	5.5	25	nan	nan	nan	nan	nan	nan
10	7	5.5	50	nan	nan	nan	nan	nan	nan
10	7	5.5	75	nan	nan	nan	nan	nan	nan
10	7	5.5	100	nan	nan	nan	nan	nan	nan
10	8	5.5	25	nan	nan	nan	nan	nan	nan
10	8	5.5	50	nan	nan	nan	nan	nan	nan
10	8	5.5	75	nan	nan	nan	nan	nan	nan
10	8	5.5	100	nan	nan	nan	nan	nan	nan
10	9	5.5	25	nan	nan	nan	nan	nan	nan
10	9	5.5	50	nan	nan	nan	nan	nan	nan
10	9	5.5	75	nan	nan	nan	nan	nan	nan
10	9	5.5	100	nan	nan	nan	nan	nan	nan
10	10	5.5	25	nan	nan	nan	nan	nan	nan
10	10	5.5	50	nan	nan	nan	nan	nan	nan
10	10	5.5	75	nan	nan	nan	nan	nan	nan
10	10	5.5	100	nan	nan	nan	nan	nan	nan

10NM, speed limited (λv = 2.5 knots): Separation standard of 10 NM, no offset and with speed monitoring (λv = 2.5 knots).

3.18.7 Separation 15 NM, λv = 5.5 knots

Std	RNP	λv	Vm	mod0 1-90 deg	mod0 5-90 deg	mod0 5-45 deg	mod2 1-90 deg	mod2 5-90 deg	mod2 5-45 deg
[NM]	[NM]	[knots]	[knots]	[min]	[min]	[min]	[min]	[min]	[min]
15	0.05	5.5	25	17.4	18.7	18.7	17.2	18.3	18.3
15	0.05	5.5	50	11.0	12.3	12.3	10.0	11.1	11.3
15	0.05	5.5	75	10.0	11.3	11.3	9.0	10.2	10.2
15	0.05	5.5	100	9.7	11.0	11.0	8.6	9.9	9.9
15	0.50	5.5	25	14.9	17.2	17.2	13.6	16.7	16.7
15	0.50	5.5	50	9.8	12.1	12.1	8.4	10.9	10.9
15	0.50	5.5	75	8.9	11.1	11.1	7.6	9.9	9.9
15	0.50	5.5	100	8.8	11.0	11.0	7.3	9.7	9.7
15	1	5.5	25	12.5	16.4	16.4	10.2	15.5	15.5
15	1	5.5	50	8.2	11.8	11.8	6.0	10.5	10.5
15	1	5.5	75	7.6	10.8	10.8	5.3	9.5	9.5
15	1	5.5	100	7.5	10.7	10.7	5.2	9.3	9.3
15	2	5.5	25	10.3	13.2	14.4	7.9	11.2	12.8
15	2	5.5	50	6.5	10.6	10.7	4.1	9.0	9.2
15	2	5.5	75	6.0	10.0	10.0	3.5	8.5	8.5
15	2	5.5	100	5.9	9.9	9.9	3.4	8.3	8.3
15	3	5.5	25	nan	nan	10.5	nan	nan	6.5
15	3	5.5	50	nan	nan	8.4	nan	nan	5.3
15	3	5.5	75	nan	nan	8.0	nan	nan	5.1
15	3	5.5	100	nan	nan	8.0	nan	nan	5.1
15	4	5.5	25	nan	nan	nan	nan	nan	nan
15	4	5.5	50	nan	nan	nan	nan	nan	nan
15	4	5.5	75	nan	nan	nan	nan	nan	nan
15	4	5.5	100	nan	nan	nan	nan	nan	nan
15	5	5.5	25	nan	nan	nan	nan	nan	nan
15	5	5.5	50	nan	nan	nan	nan	nan	nan
15	5	5.5	75	nan	nan	nan	nan	nan	nan
15	5	5.5	100	nan	nan	nan	nan	nan	nan
15	6	5.5	25	nan	nan	nan	nan	nan	nan
15	6	5.5	50	nan	nan	nan	nan	nan	nan
15	6	5.5	75	nan	nan	nan	nan	nan	nan
15	6	5.5	100	nan	nan	nan	nan	nan	nan
15	7	5.5	25	nan	nan	nan	nan	nan	nan
15	7	5.5	50	nan	nan	nan	nan	nan	nan
15	7	5.5	75	nan	nan	nan	nan	nan	nan
15	7	5.5	100	nan	nan	nan	nan	nan	nan
15	8	5.5	25	nan	nan	nan	nan	nan	nan
15	8	5.5	50	nan	nan	nan	nan	nan	nan
15	8	5.5	75	nan	nan	nan	nan	nan	nan
15	8	5.5	100	nan	nan	nan	nan	nan	nan
15	9	5.5	25	nan	nan	nan	nan	nan	nan
15	9	5.5	50	nan	nan	nan	nan	nan	nan
15	9	5.5	75	nan	nan	nan	nan	nan	nan
15	9	5.5	100	nan	nan	nan	nan	nan	nan
15	10	5.5	25	nan	nan	nan	nan	nan	nan
15	10	5.5	50	nan	nan	nan	nan	nan	nan
15	10	5.5	75	nan	nan	nan	nan	nan	nan
15	10	5.5	100	nan	nan	nan	nan	nan	nan

15NM, speed limited (λv = 2.5 knots): Separation standard of 10 NM, no offset and with speed monitoring (λv = 2.5 knots).

3.18.8 Separation 20 NM, λv = 5.5 knots

Std	RNP	λv	Vm	mod0 1-90 deg	mod0 5-90 deg	mod0 5-45 deg	mod2 1-90 deg	mod2 5-90 deg	mod2 5-45 deg
[NM]	[NM]	[knots]	[knots]	[min]	[min]	[min]	[min]	[min]	[min]
20	0.05	5.5	25	23.7	24.1	26.1	23.2	24.4	26.2
20	0.05	5.5	50	14.5	16.0	16.0	13.5	14.6	14.6
20	0.05	5.5	75	13.3	14.8	14.8	12.2	13.5	13.5
20	0.05	5.5	100	12.9	14.6	14.6	11.5	13.1	13.1
20	0.50	5.5	25	21.2	23.2	23.2	20.0	22.6	22.6
20	0.50	5.5	50	14.0	16.3	16.3	12.5	14.7	14.7
20	0.50	5.5	75	12.8	14.9	14.9	11.2	13.3	13.3
20	0.50	5.5	100	12.6	14.8	14.8	10.9	13.0	13.0
20	1	5.5	25	19.4	22.5	22.5	16.9	21.5	21.5
20	1	5.5	50	13.2	16.0	16.0	10.9	14.4	14.4
20	1	5.5	75	12.1	14.7	14.7	9.8	13.1	13.1
20	1	5.5	100	12.0	14.6	14.6	9.6	12.8	12.8
20	2	5.5	25	17.5	20.3	21.1	14.8	18.5	19.4
20	2	5.5	50	12.1	15.4	15.4	9.4	13.6	13.6
20	2	5.5	75	11.2	14.4	14.4	8.4	12.5	12.5
20	2	5.5	100	11.1	14.3	14.3	8.3	12.3	12.3
20	3	5.5	25	15.5	15.5	19.0	11.9	11.9	16.4
20	3	5.5	50	11.4	12.8	14.4	8.5	10.1	12.2
20	3	5.5	75	10.7	12.4	13.6	7.7	9.8	11.4
20	3	5.5	100	10.6	12.3	13.5	7.6	9.7	11.3
20	4	5.5	25	nan	nan	14.9	nan	nan	9.9
20	4	5.5	50	nan	nan	12.1	nan	nan	8.1
20	4	5.5	75	nan	nan	11.6	nan	nan	7.8
20	4	5.5	100	nan	nan	11.5	nan	nan	7.8
20	5	5.5	25	nan	nan	2.2	nan	nan	nan
20	5	5.5	50	nan	nan	2.1	nan	nan	nan
20	5	5.5	75	nan	nan	2.0	nan	nan	nan
20	5	5.5	100	nan	nan	2.0	nan	nan	nan
20	6	5.5	25	nan	nan	nan	nan	nan	nan
20	6	5.5	50	nan	nan	nan	nan	nan	nan
20	6	5.5	75	nan	nan	nan	nan	nan	nan
20	6	5.5	100	nan	nan	nan	nan	nan	nan
20	7	5.5	25	nan	nan	nan	nan	nan	nan
20	7	5.5	50	nan	nan	nan	nan	nan	nan
20	7	5.5	75	nan	nan	nan	nan	nan	nan
20	7	5.5	100	nan	nan	nan	nan	nan	nan
20	8	5.5	25	nan	nan	nan	nan	nan	nan
20	8	5.5	50	nan	nan	nan	nan	nan	nan
20	8	5.5	75	nan	nan	nan	nan	nan	nan
20	8	5.5	100	nan	nan	nan	nan	nan	nan
20	9	5.5	25	nan	nan	nan	nan	nan	nan
20	9	5.5	50	nan	nan	nan	nan	nan	nan
20	9	5.5	75	nan	nan	nan	nan	nan	nan
20	9	5.5	100	nan	nan	nan	nan	nan	nan
20	10	5.5	25	nan	nan	nan	nan	nan	nan
20	10	5.5	50	nan	nan	nan	nan	nan	nan
20	10	5.5	75	nan	nan	nan	nan	nan	nan
20	10	5.5	100	nan	nan	nan	nan	nan	nan

20NM, speed limited (λv = 2.5 knots): Separation standard of 20 NM, no offset and with speed monitoring (λv = 2.5 knots).

3.18.9 Separation 30 NM, λv = 5.5 knots

Std	*RNP*	*λv*	*Vm*	*mod0 1-90 deg*	*mod0 5-90 deg*	*mod0 5-45 deg*	*mod2 1-90 deg*	*mod2 5-90 deg*	*mod2 5-45 deg*
[NM]	*[NM]*	*[knots]*	*[knots]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*	*[min]*
30	0.05	5.5	25	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.05	5.5	50	21.7	24.6	24.6	20.0	21.9	21.9
30	0.05	5.5	75	19.9	21.8	21.8	18.1	20.1	20.1
30	0.05	5.5	100	19.5	21.8	21.8	17.5	19.8	19.8
30	0.50	5.5	25	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30	≥ 30
30	0.50	5.5	50	22.2	24.5	24.5	20.0	22.1	22.1
30	0.50	5.5	75	20.4	22.7	22.7	18.2	20.2	20.2
30	0.50	5.5	100	20.0	22.6	22.6	17.7	19.9	19.9
30	1	5.5	25	≥ 30	≥ 30	≥ 30	29.7	≥ 30	≥ 30
30	1	5.5	50	22.2	24.5	24.5	19.6	22.0	22.0
30	1	5.5	75	20.4	22.8	22.8	17.8	20.3	20.3
30	1	5.5	100	20.1	22.7	22.7	17.4	19.9	19.9
30	2	5.5	25	≥ 30	≥ 30	≥ 30	28.0	≥ 30	≥ 30
30	2	5.5	50	22.1	24.5	24.5	19.0	21.9	21.9
30	2	5.5	75	20.5	22.8	22.9	17.3	20.2	20.2
30	2	5.5	100	20.2	22.7	22.7	17.0	19.9	19.9
30	3	5.5	25	≥ 30	≥ 30	≥ 30	27.1	27.8	≥ 30
30	3	5.5	50	22.0	23.3	24.2	18.7	20.7	21.5
30	3	5.5	75	20.5	21.9	22.7	17.1	19.2	19.9
30	3	5.5	100	20.4	21.9	22.6	16.9	19.1	19.6
30	4	5.5	25	26.4	26.4	≥ 30	22.4	22.4	27.7
30	4	5.5	50	21.1	21.1	23.5	18.0	18.0	20.5
30	4	5.5	75	20.1	20.1	22.2	16.8	17.1	19.1
30	4	5.5	100	20.1	20.1	22.1	16.6	16.9	18.9
30	5	5.5	25	18.8	18.8	28.6	9.2	9.2	24.1
30	5	5.5	50	16.3	16.3	22.3	8.5	8.5	18.7
30	5	5.5	75	15.9	15.9	21.2	8.4	8.4	17.7
30	5	5.5	100	15.8	15.8	21.1	8.4	8.4	17.5
30	6	5.5	25	nan	nan	24.5	nan	nan	17.4
30	6	5.5	50	nan	nan	20.0	nan	nan	14.6
30	6	5.5	75	nan	nan	19.3	nan	nan	14.1
30	6	5.5	100	nan	nan	19.2	nan	nan	14.0
30	7	5.5	25	nan	nan	16.4	nan	nan	0.4
30	7	5.5	50	nan	nan	14.4	nan	nan	0.3
30	7	5.5	75	nan	nan	14.1	nan	nan	0.2
30	7	5.5	100	nan	nan	14.1	nan	nan	0.2
30	8	5.5	25	nan	nan	0.3	nan	nan	nan
30	8	5.5	50	nan	nan	0.3	nan	nan	nan
30	8	5.5	75	nan	nan	0.3	nan	nan	nan
30	8	5.5	100	nan	nan	0.3	nan	nan	nan
30	9	5.5	25	nan	nan	nan	nan	nan	nan
30	9	5.5	50	nan	nan	nan	nan	nan	nan
30	9	5.5	75	nan	nan	nan	nan	nan	nan
30	9	5.5	100	nan	nan	nan	nan	nan	nan
30	10	5.5	25	nan	nan	nan	nan	nan	nan
30	10	5.5	50	nan	nan	nan	nan	nan	nan
30	10	5.5	75	nan	nan	nan	nan	nan	nan
30	10	5.5	100	nan	nan	nan	nan	nan	nan

30NM, speed limited (λv = 2.5 knots): Separation standard of 30 NM, no offset and with speed monitoring (λv = 2.5 knots).

3.19 ACKNOWLEDGEMENTS AND ATTRIBUTION

3.19.1 This work is a combined effort of many ICAO Separation and Safety Panel (SASP) members. Dr. David Anderson did the original work on the Anderson-Hsu model and wrote the associated C programming code. This was modified by Dr. Geoffrey Aldis. Further extensive testing and modifications were done by Dr. Steven Barry. Later results were tested by independent Python code by Dr. Yuan Fang and Dr. Steven Barry. Rob Butcher and Dr. Geoff Aldis promoted this work within SASP and provided continued feedback into the modelling. Drs. Aldis, Anderson, Barry and Fang and Rob Butcher are all from Airservices Australia. Data supporting some of the results were provided by Bjarni Stefansson (Iceland) and co-workers, Christine Falk (FAA) and co-workers, and Peter Friedrichs (Nav Canada). The SASP Mathematics Sub Group provided input and discussions including Christine Falk, Bennet Flax, Jacky Civil and Peter Friedrichs. Bjarni Stefansson and Noel Dwyer from SASP provided valuable insight, as did many other SASP delegates.

3.20 HAZARD ASSESSMENT

3.20.1 In an effort to identify hazards that may affect the implementation and use of published separation minima and to develop effective controls for these hazards, SASP undertook a process of hazard identification. The intent of this activity was to bring operational experience and issues into the development of a separation minimum. The identified hazards are documented in the Implementation Hazard Log in Attachment A.

Note.— SASP hazard identification is limited in its scope, and is intended to identify significant globally applicable hazards and to develop specific controls that shall be considered in separation minima development. This activity should **not** *be considered as a formal hazard identification process that would normally include the determination of severity and estimates of likelihood and requires complementary regional, State or local implementation safety assessment action.*

3.21 CONCLUSIONS

3.21.1 The application of the SASP process demonstrated that the separation minima developed and detailed in this document have been determined as being safe. SASP also identified a number of hazards together with appropriate mitigations and controls.

3.21.2 Notwithstanding the above, there is a requirement for a region or State to undertake an implementation safety assessment. In principle, this comprises two parts, namely, a safety assessment for navigation performance and a hazard assessment. In practice, only a hazard assessment needs to be performed for any local implementation since the safety assessment for the navigation performance under the various navigation specifications is valid for any implementation. The hazard analysis is to identify hazards and related mitigation measures that are specific to the local situation.

3.21.3 To assist regions and States with their implementation safety assessment, a State implementation plan is provided in the next chapter. This plan relies upon the various outputs from the application of the SASP safety assessment.

Chapter 4

IMPLEMENTATION CONSIDERATIONS

4.1 INTRODUCTION

4.1.1 The successful implementation of the proposed separation minima is not possible at the regional, State or local level without undertaking an implementation safety assessment (see Chapter 3). When undertaking this activity, reference should be made to the requirements detailed in Annex 11 — *Air Traffic Services* (Chapter 2, 2.26), PANS-ATM (Chapter 2, 2.6), and the guidance material contained in the *Safety Management Manual* (Doc 9859) including the development of hazard identification, risk management and mitigation procedures tables.

4.1.2 This chapter provides an overview of the minimum steps that SASP considers necessary for a region, State or ANSP to undertake a safety assessment.

4.2 IMPLEMENTATION CONSIDERATIONS

4.2.1 When undertaking a regional, State or local safety assessment, the following process is provided as guidance:

Step 1: Undertake widespread regional consultation with all possible stakeholders and other interested parties.

Step 2: Develop an airspace design concept or ensure that the proposed separation minima being implemented will fit the current airspace system and regional or state airspace planning strategy.

Step 3: Review this circular noting specific assumptions, constraints, enablers and system performance requirements.

Step 4: Compare assumptions, enablers, and system performance requirements in this circular with the regional or State's operational environment, infrastructure and capability.

Step 5: If a region, State or ANSP has determined that the change proposal for that region or State is equal to or better than the reference, requirements and system performance in this circular, then the region or State must undertake safety management activities including:

a) formal hazard and consequence(s) identification, and safety risk analysis activities including identification of controls and mitigators;

b) implementation plan;

c) techniques for hazard identification/safety risk assessment which may include:

i. the use of data or experience with similar services/changes;

ii. quantitative modeling based on sufficient data, a validated model of the change, and analyzed assumptions;

iii. the application and documentation of expert knowledge, experience and objective judgment by specialist staff; and

iv. a formal analysis in accordance with appropriate safety risk management techniques as set out in the *Safety Management Manual* (Doc 9859).

d) identification and analysis of human factors issues identified with the implementation including those associated with Human Machine Interface matters;

e) simulation where appropriate;

f) operational training; and

g) regulatory approvals

Step 6: If a region or State has determined that the change proposal for that region or State is not equal to the requirements and system performance in this circular, then the region or State must:

a) consider alternative safety risk controls to achieve the technical and safety performance that matches the reference in this circular; or

b) conduct appropriate quantitative risk analysis for the development of a local standard in accordance with the *Manual on Airspace Planning Methodology for the Determination of Separation Minima* (Doc 9689).

Step 7: Develop suitable safety assessment documentation including a safety plan and associated safety cases.

Step 8: Implementation activities should include:

a) trial under appropriate conditions;

b) expert panel to undertake scrutiny of proposals and development of identified improvements to the implementation plan;

c) develop an appropriate backup plan to enable reversion if necessary; and

d) continuous reporting and monitoring results of incidents, events and observations.

Step 9: Develop suitable post-implementation monitoring and review processes.

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APPENDIX

IMPLEMENTATION HAZARD LOG

This section lists some hazards that were considered by the SASP when developing the PBN longitudinal separation minima. The pertinent ATS authority must, in its implementation safety assessment, review these hazards and reflect how they may affect its local implementation and additionally identify if there are other regional, state or local hazards that need to be considered (refer to 3.2 and 3.9of the main text).

Definitions:

Hazard:

A hazard is defined as a condition or an object with the potential to cause injuries to personnel, damage to equipment or structures, loss of material, or reduction of ability to perform a prescribed function.

Subject 1 — Filing of incorrect FPL information
Hazard Loss of separation.
Unsafe event (cause) An ineligible aircraft receives a clearance for one of the performance based separation minimum because equipment and/or capability were incorrectly filed in the FPL or incorrect flight information transmitted from an adjacent ATC unit.

Analysis The safety analysis used for determining the longitudinal separation standards was based on the assumption that the concerned aircraft and crew had and was operating the required on-board ADS-C and CPDLC equipment. If the equipment is filed in the FPL but not available or not used by the flight crew then the controller could apply inappropriate separation. Aircraft operators are required to correctly file the on-board navigation equipment that is serviceable and usable by the crew. It is important that aircrew also use the equipment that is filed. It may, for example, lead to loss of separation if CPDLC capability is filed in the flight plan but then subsequently not used by the pilot. ATC reads the navigation and equipment designators from the FPL and then plans for and applies separation accordingly. ATC normally does not question the data in the FPL and trusts that the filed data is correct. It is important that aircraft operators and aircrew understand the importance of filing correct data in the FPL and the adverse impact that incorrectly filing this information can have on airspace risk. It is also the responsibility of ATC to correct flight plan data that is found to be incorrect and subsequently pass corrected data in coordination messages to the next facility. For example if CPDLC is found to be inoperative in an aircraft that has filed CPDLC capability then that information must be passed to the next ATC unit.
SASP global controls and/or mitigations a) Establishment of ongoing system performance monitoring as defined in the *Manual on Monitoring the Application of Performance-Based Horizontal Separation Minima* (Doc 10063). b) PANS-ATM providing guidance for completing the FPL form. c) *Performance-based Communication and Surveillance Manual* (Doc 9869), *Global Operational Data Link Manual* (Doc 10037) providing guidance to aircraft operators.
Regional and local controls and/or mitigators required Monitoring of airspace in accordance with *Manual on Monitoring the Application of Performance-based Horizontal Separation Minima* (Doc10063) guidelines.

Subject 2 — Failure of ADS-C and/or CPDLC transfer
Hazard Loss of separation.
Unsafe event (cause) The receiving ANSP is unable to establish an ADS-C or CPDLC connection with one or both aircraft.

Analysis ADS-C and CPDLC services are intended to be seamless as connected aircraft move across flight information region (FIR) boundaries. However, experience has shown that, due to any one of a number of ground or airborne system problems or errors, the transfer of ADS-C and/or CPDLC connections may not occur. Examples of transfer failure include cases in which: a) the transferring ANSP fails to nominate the receiving ANSP as the Next Data Authority (NDA) for CPDLC; b) failure in the forwarding of the CPDLC connection to the receiving ANSP; c) inappropriate termination of the ADS-C connection by the flight crew when crossing the FIR boundary; and d) unintentional ADS-C disconnects due to or the ground system is unable to re-establish a lost ADS-C connection. When this occurs, ATC is expected to request the flight crew to follow procedures for re-establishment of the AFN Logon or CPDLC connection. If attempts to restore connectivity are unsuccessful, ATC is expected to apply an alternate form of separation between the aircraft pairs involved.
SASP global controls and/or mitigations Establishment of recommended data link procedures as defined in the *Global Operational Data Link (GOLD) Manual* (Doc 10037).
Regional and local controls and/or mitigations required A. Apply an alternate form of separation. B. Comply with guidelines provided in the *Global Operational Data Link (GOLD) Manual* (Doc 10037).

Subject 3 — Surveillance and/or Communication failure
Hazard Loss of Separation.
Unsafe event (cause) Failure within the data link system and/or supporting subnetworks.

Analysis

Performance-based longitudinal separations rely upon end to end connectivity of data link systems and subnetworks to ensure that required messages and information are sent, received and processed between the airborne equipment, communication service provider (CSP) networks and air traffic service unit (ATSU) ground system. Failure of individual components of the overall data link system can result in a necessary condition for separation application to not be available.

Examples of communication and surveillance system components that can fail individually include:

a) air navigation service provider (ANSP) gateway failure;

b) CSP network failure; and

c) ground-earth station (GES) failure.

SASP global controls and/or mitigations

Establishment of recommended data link procedures as defined in the *Global Operational Data Link (GOLD) Manual* (Doc 10037) and the *Performance-based Communication and Surveillance (PBCS) Manua*l (Doc 9869).

Regional and local controls and/or mitigations required

a) Apply an alternate form of separation.

b) Ensure redundancy of equipment, lines, power supply, etc.

c) Comply with guidelines provided in the *Global Operational Data Link Document (GOLD) Manual* (Doc 10037), the *Performance-based Communication and Surveillance (PBCS) Manual* (Doc 9869) and the *Satellite Voice Operations Manual* (Doc 10038).

Subject 4 — Ground system failure

Hazard

Loss of Separation.

Unsafe event (cause)

Failure of the (ANSP) flight data processing system (FDPS).

Analysis Performance-based longitudinal separations rely on ground system automation to process ADS-C reports to both calculate the distance between aircraft pairs and provide ATC alerts when the distance is in danger of falling below the minimum. Failure of FDPS hardware/software components or unavailability of power supply would negate this function and compromise the conditions for application of the separation.
SASP global controls and/or mitigations None.
Regional and local controls and/or mitigations required a) Where able, transition remaining pairs to other form of separation that is not data link dependent. b) Ensure redundancy of equipment, lines, power supply, etc. c) Suspend further use of the performance-based separation minima.

Subject 5 — GNSS system failure
Hazard Loss of separation.
Unsafe event (cause) GNSS failure affecting multiple aircraft or a failure of individual GNSS receivers.
Analysis Performance-based longitudinal separation rely on data link communications which have a requirement to be accurate to within one second of UTC. On most aircraft equipped with ADS-C and CPDLC, this accuracy is provided via the GNSS time source. GNSS outages are detected by RAIM equipment. For individual GNSS receivers, the pilot shall advise ATC of failure.
SASP global controls and/or mitigations PANS-ATM (Doc 4444), 5.2.2 Degraded Aircraft Performance

Regional and local controls and/or mitigations required

a) Make RAIM prediction a standard operation and suspend application of the performance-based separation minima in case of predicted RAIM outage.

b) Where able, transition remaining pairs to separation that is not reliant on GNSS.

c) Suspend further use of the performance-based separation minima.

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