Federal Aviation Administration

Summary of Studies of Area Navigation (RNAV/RNP) En Route Separation Along Adjacent Routes

June 2009

DOT-FAA-AFS-450-57

Flight Systems Laboratory
6500 S. MacArthur Blvd.
Systems Training Building Annex, RM 217
Oklahoma City, Oklahoma 73169
Phone: (405) 954-8191

OK-09-5057

NOTICE

This document is disseminated under the sponsorship of the U.S. Department of Transportation in the interest of information exchange. The United States Government assumes no liability for the contents or use thereof.

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the objective of this report.

DOT-FAA-AFS-450-57
Flight Systems Laboratory
Flight Technologies and Procedures
Division Flight Standards Service

Summary of Studies of Area Navigation (RNAV/RNP) En Route Separation Along Adjacent Routes

Released by:

for 13 JUL 2009

Michael J. Zenkovich **Date**
Manager, Flight Technologies and Procedures Division, AFS-400

June 2009

Technical Report

Technical Report Documentation Page

1. Report No. DOT-FAA-AFS-450-57	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Summary of Studies of Area Navigation (RNAV/RNP) En Route Separation Along Adjacent Routes		**5. Report Date** June 2009
6. Author(s) Dr. Richard Greenhaw Gerry McCartor Stephen Barnes		**7. Performing Organization Code**
8. Performing Organization Name and Address Department of Transportation/Federal Aviation Administration Flight Systems Laboratory, AFS-450 Systems Training Annex Bldg. 26 6500 S. MacArthur Blvd. Oklahoma City, OK 73169		**9. Type of Report and Period Covered** Technical report
10. Sponsoring Agency Name and Address Department of Transportation/Federal Aviation Administration Flight Systems Laboratory, AFS-450 Systems Training Annex Bldg. 26 6500 S. MacArthur Blvd. Oklahoma City, OK 73169		
11. Supplementary Notes		
12. Abstract The purpose of this study is to provide a summary of previous studies of risk assessment of lateral en route separation between parallel Area Navigation (RNAV/RNP) routes (including impromptu routes), such as Q-routes, with separation for both opposite and same direction traffic under radar surveillance and without radar surveillance.		
13. Key Words Lateral separation, Area Navigation (RNAV), RNP, en route, summary	**14. Distribution Statement** Controlled by AFS-450	
15. Security Classification of This Report Unclassified	**16. Security Classification of This Page** Unclassified	

Executive Summary

The purpose of this study is to summarize and to marginally extend the previous reports that assess midair collision risk for lateral en route separation between parallel Area Navigation (RNAV) routes. These include both impromptu routes and published routes such as Q-routes, with separation for both opposite and same direction traffic under radar surveillance and without radar surveillance. They include both Required Navigation Performance Level 2 (RNP-2) and RNP-1 protection levels.

The document provides answers for 8 questions dealing with midair collision risk for parallel, adjacent routes:

- RNP-2 Adjacent to RNP-2, Straight Segment, with Radar
- RNP-1 Adjacent to RNP-1, Straight Segment, with Radar
- RNP-2 Adjacent to RNP-2, Straight Segment, without Radar
- RNP-1 Adjacent to RNP-1, Straight Segment, without Radar
- RNP-2 Adjacent to RNP-2, Turns Segment, with Radar
- RNP-2 Adjacent to RNP-2, Turns Segment, without Radar
- RNP-2 Adjacent to VOR, Straight Segment, with Radar
- RNP-2 Adjacent to VOR, Straight Segment, without Radar

and one question dealing with route boundary penetration for impromptu routes:

- RNP-2 Impromptu, Straight Segment, without Radar.

TABLE OF CONTENTS

1.0 INTRODUCTION **1**

2 STATEMENT OF THE PROBLEM **2**

3. COMMON BACKGROUND AND ASSUMPTIONS **2**

4. QUESTIONS **3**

APPENDIX A **11**

REFERENCES **12**

LIST OF ILLUSTRATIONS

Tables

Table 1: RNAV / RNP-2 With Radar, 8 NM Separation 4
Table 2: RNAV / RNP-1 With Radar, 8 NM Lateral Separation 4
Table 3: RNAV / RNP-1 With Radar, 6 NM Lateral Separation 4
Table 4: RNAV / RNP-1 With Radar, 4 NM Lateral Separation 4
Table 5: RNAV / RNP-2 Without Radar, 10 NM Lateral Separation 5
Table 6: RNAV / RNP-2 Without Radar, 8 NM Lateral Separation 5
Table 7: RNAV / RNP-1 Without Radar, 8 NM Lateral Separation 6
Table 8: RNAV / RNP-1 Without Radar, 6 NM Lateral Separation 6
Table 9: RNAV / RNP-1 Without Radar, 4 NM Lateral Separation 6
Table 10: RNAV / RNP-2 With Radar, 8 NM Lateral Separation, 1 Turn ≤ 30º 7
Table 11: RNAV / RNP-2 Without Radar, 10 NM Lateral Separation, 1 Turn ≤ 30º 8
Table 12: RNAV / RNP-2 Without Radar, 8 NM Lateral Separation, 1 Turn ≤ 30º 8
Table 13: RNAV-2 Adjacent to VOR With Radar, 10 NM Lateral Separation 8
Table 14: RNAV-2 Adjacent to VOR With Radar, 8 NM Lateral Separation 9
Table 15: VOR Adjacent to VOR With Radar, 8 NM Lateral Separation 9
Table 16: RNAV-2 Adjacent to VOR With Radar, 10 NM Lateral Separation 9
Table 17: RNAV-2 Adjacent to VOR With Radar, 8 NM Lateral Separation 10
Table 18: VOR Adjacent to VOR With Radar, 8 NM Lateral Separation 10
Table 19: RNAV/RNP-2 Without Radar, 10 NM Route Width 10
Table 20: RNAV/RNP-2 Without Radar, 8 NM Route Width 10
Table 21: Response Probability Assumptions 11

1.0 Introduction

The purpose of this study is to summarize and to marginally extend the previous studies that assess midair collision risk for lateral en route separation between parallel, adjacent Area Navigation (RNAV) routes. These studies differ as to:

- whether the routes are impromptu or published routes (such as Q-Routes)
- whether the routes are under radar surveillance,
- whether turns greater than 15º are allowed,
- what type of adjacent routes are allowed (RNAV or conventional),
- and the level of RNP protection required (RNP-1 or RNP-2).

The seven reports summarized are:

[1] "Analysis of Area Navigation (RNAV) En Route Separation along Adjacent Straight Segments with Radar Surveillance (Phase I)" DOT-FAA-AFS-440-24, January 2007

[2] "Analysis of Area Navigation (RNAV) En Route Separation along Adjacent Straight Segments with Radar Surveillance and Turns (Phase II)" DOT-FAA-AFS-440-25, January 2007

[3] "Analysis of Area Navigation (RNAV) En Route Separation with Conventional Routes Including Turns and Special Use Airspace" DOT-FAA-AFS-440-26, January 2007

[4] "Analysis of Area Navigation (RNAV/RNP-1) En Route Separation Along Adjacent Straight Segments With Radar Surveillance Including Impromptu Routes (Phase III)" DOT-FAA-AFS-450-50, March 2009

[5] "Analysis of Area Navigation (RNAV/RNP-1 and RNP-2) En Route Separation Along Adjacent Straight Segments Without Radar Surveillance Including Impromptu Routes (Phase IV)" DOT-FAA-AFS-450-51, March 2009

[6] Analysis of Area Navigation (RNAV RNP-1 and RNP-2) En Route Separation Along Adjacent Segments With and Without Radar Surveillance and With Turns (Phase V) DOT-FAA-AFS-450-52, March 2009

[7] Analysis of Area Navigation (RNAV-2) En Route Separation With Conventional Routes Without Radar Surveillance Including Impromptu Routes, DOT-FAA-AFS-450-54, April 2009

The safety evaluations described in these reports were conducted by the Flight Systems Laboratory (AFS-450) of the Federal Aviation Administration (FAA) located at the Mike Monroney Aeronautical Center in Oklahoma City, Oklahoma.

2 Statement of the Problem

All studies were performed to address a request to determine whether, under assumptions of rather tight level of acceptable risk (target level of safety) and rather broad performance-based lateral deviation criteria (such as RNAV / RNP 95% lateral deviation performance specifications), certain lateral separation centerline-to-centerline distances were reasonable for various operational scenarios.

This paper's structure is based on those various scenarios. We will present the questions related to the scenarios (and their answers) immediately following a discussion of the common background and assumptions related to them. For details pertaining to the methodology, models, and data used see the specific study.

3. Common Background and Assumptions

These assumptions are common to all questions:

a. Unless otherwise stated all aircraft are assumed to be suitably equipped RNAV aircraft, as referenced in AC 90-100A.

b. These studies do not estimate the risk of wake exposures. The only hazard analyzed is midair collision (MAC).

c. Unless otherwise stated these studies address parallel adjacent routes at the same altitude. They do not address vertically adjacent routes, that is, routes adjacent bottom to top.

d. These studies do not address same track, longitudinal collision risks.

e. These studies do give credit for Traffic Collision Avoidance Systems (TCAS) in analyzing the risk.

f. The analysis in these studies does assume risk blunders and other anomalous types of flight technical error along with appropriate navigation error (unless otherwise specified).

g. The risk metric used is collisions per hour of flight.

h. Unless otherwise stated, en route aircraft are assumed to be flying at a 500 knot ground speed when they are on straight segments.

i. The overtake speed for aircraft flying in the same direction is assumed to be 100 knots.

j. All routes (or route segments) are assumed to be published unless otherwise specified. When we are dealing with unpublished, impromptu routes, we make that clear.

k. Longitudinal (in-trail) separation values of 5, 10, and 20 NM are used to analyze the various types of traffic density. Under radar surveillance, the worst case 5 NM density is assumed. Typically, without radar, 20 NM separation is assumed. The value assumed is described in the specific question.

l. These studies initially assumed the probability of vertical overlap (that is the probability that the adjacent aircraft are close enough to the same altitude to be overlapping in the vertical dimension) to be 1.0 in order to be conservative relative to future improves in altitude determination and aircraft performance. In this summary, we extend the previous results to include a less conservative (but still reasonably conservative[1]) probability value of 0.5.

m. These studies initially assumed, also, that no credit would be given for RNP alerting in non-surveillance operations. This was because we had no information describing a specific operational procedure for handling aircraft in a non-surveillance airspace in which the RNP aircraft had received an alert but an accurate estimate of its position could not be determined by air traffic. In this summary we extend the previous results to include a less conservative risk estimate for non-surveillance RNP operations based on an assumed operational procedure for handling such situations.

4. Questions

4.1 RNP-2 Adjacent to RNP-2, Straight Segment, with Radar (Reference [1])

What is the risk of an RNAV / RNP-2 aircraft flying a straight en route segment under radar surveillance colliding with an RNAV / RNP-2 aircraft flying a parallel, adjacent en route track, in a direction the same as that of the other aircraft, with track-to-track (centerline-to-centerline) separation distance of 8 NM? Also, what if the adjacent aircraft's direction of flight is opposite?

Comments

The summarized and extended results here include only 8 NM lateral (track-to-track) separation, 5 NM in-trail separation[2], and only two adjacent tracks. For more detailed results, see the study [1]. We do extend the study's results here to include both the initial vertical overlap probability of 1.0 and the less conservative value of 0.5.

[1] The value of 0.5 is based on data and analysis in [8] and [9]. The values there are 0.39 and 0.49 respectively. Higher values are more conservative relative to risk.

[2] We will, in this summary, report 5 NM in-trail separation results for radar surveillance situations and 20 NM in-trail separation results for non-radar situations. More detailed results can be found in the studies, or can be easily calculated (see later footnotes).

Results

Table 1: RNAV / RNP-2 With Radar, 8 NM Separation

Vertical Overlap Probability	Same Direction Collisions / Hour	Opposite Direction Collisions / Hour
1.0	8.2 E-11	8.2 E-10
0.5	4.1 E-11	4.1 E-10

4.2 RNP-1 Adjacent to RNP-1, Straight Segment, with Radar (Reference [4])

What is the risk of an RNAV / RNP-1 aircraft flying a straight en route segment under radar surveillance colliding with an RNAV / RNP-1 aircraft flying a parallel, adjacent en route track, in a direction the same as that of the other aircraft, with track-to-track (centerline-to-centerline) separation distance of 8 NM? Also, what if the adjacent aircraft's direction of flight is opposite?

Comments

The summarized and extended results here also include only 8, 6, and 4 NM lateral (track-to-track) separation, 5 NM in-trail separation[3], and only two adjacent tracks. For more detailed results, see the study [4]. Again, we extend the study's results here to include both the initial vertical overlap probability of 1.0 and the less conservative value of 0.5.

Results

Table 2: RNAV / RNP-1 With Radar, 8 NM Lateral Separation

Vertical Overlap Probability	Same Direction Collisions / Hour	Opposite Direction Collisions / Hour
1.0	2.4 E-17	2.4 E-16
0.5	1.2 E-17	1.2 E-16

Table 3: RNAV / RNP-1 With Radar, 6 NM Lateral Separation

Vertical Overlap Probability	Same Direction Collisions / Hour	Opposite Direction Collisions / Hour
1.0	5.2 E-13	5.2 E-12
0.5	2.6 E-13	2.6 E-12

Table 4: RNAV / RNP-1 With Radar, 4 NM Lateral Separation

Vertical Overlap Probability	Same Direction Collisions / Hour	Opposite Direction Collisions / Hour
1.0	1.1 E-08	1.1 E-07
0.5	5.5 E-09	5.5 E-08

[3] For 10 NM in-trail separation, the 5 NM collision rates in Tables 2 through 4 should be divided by 2. And for 20 NM in-trail separation, they should be divided by 4. In general, for a NM in-trail separation of x, the 5 NM tabular value should be divided by x/5.

4.3 RNP-2 Adjacent to RNP-2, Straight Segment, without Radar (Reference[5])

What is the risk of an RNAV / RNP-2 aircraft flying a straight en route segment without radar surveillance colliding with an RNAV / RNP-2 aircraft flying a parallel, adjacent en route track, in a direction the same as that of the other aircraft, with track-to-track (centerline-to-centerline) separation distance of 8 NM? Also, what if the adjacent aircraft's direction of flight is opposite?

Comments

The summarized and extended results here also include only 10 and 8 NM lateral (track-to-track) separation, 20 NM in-trail separation[4], and only two adjacent tracks. For more detailed results, see the study [5]. Again, we extend the study's results here to include both the initial vertical overlap probability of 1.0 and the less conservative value of 0.5.

We also extend the study's results to give credit for RNP alerting. Appendix A describes the alerting operational scenario we assume.

Results

Table 5: RNAV / RNP-2 Without Radar, 10 NM Lateral Separation

Vertical Overlap Probability	RNP Alerting	Same Direction Collisions / Hour	Opposite Direction Collisions / Hour
1.0	No Alerting[5]	1.0 E-12	1.0 E-11
0.5	No Alerting	5.0 E-13	5.0 E-12
1.0	4 NM Alerting	5.0 E-13	5.0 E-12
0.5	4 NM Alerting	2.5 E-13	2.5 E-12

Table 6: RNAV / RNP-2 Without Radar, 8 NM Lateral Separation

Vertical Overlap Probability	RNP Alerting	Same Direction Collisions / Hour	Opposite Direction Collisions / Hour
1.0	No Alerting	4.8 E-10	4.8 E-09
0.5	No Alerting	2.4 E-10	2.4 E-09
1.0	4 NM Alerting	2.4 E-10	2.4 E-09
0.5	4 NM Alerting	1.2 E-10	1.2 E-09

[4] For 10 NM in-trail separation, the 20 NM collision rates in Tables 5 through 8 should be multiplied by 2. And for 5 NM in-trail separation, they should be multiplied by 4. In general, for a NM in-trail separation of x, the 20 NM tabular value should be multiplied by 20/x.

[5] "No Alerting" values are appropriate for RNAV aircraft without RNP alerting capabilities and for RNP aircraft that cannot be assumed to follow the scenario described in Appendix A. "4 NM Alerting" and "2 NM Alerting" values are calculated assuming the operational scenario described in Appendix A. The tabular values' calculation assumes that vertical overlap amount and alerting events are independent.

4.4 RNP-1 Adjacent to RNP-1, Straight Segment, without Radar (Reference [5])

What is the risk of an RNAV / RNP-1 aircraft flying a straight en route segment without radar surveillance colliding with an RNAV-1 / RNP-1 aircraft flying a parallel, adjacent en route track, in a direction the same as that of the other aircraft, with track-to-track (centerline-to-centerline) separation distance of 8 NM? Also, what if the adjacent aircraft's direction of flight is opposite?

Comments

The summarized and extended results here also include 4, 6, and 8 NM lateral (track-to-track) separation, 20 NM in-trail separation, and only two adjacent tracks. For more detailed results, see the study [5]. Again, we extend the study's results here to include both the initial vertical overlap probability of 1.0 and the less conservative value of 0.5.

We also extend the study's results to give credit for RNP alerting. Appendix A describes the alerting operational scenario we assume.

Results

Table 7: RNAV / RNP-1 Without Radar, 8 NM Lateral Separation

Vertical Overlap Probability	RNP Alerting	Same Direction Collisions / Hour	Opposite Direction Collisions / Hour
1.0	No Alerting	1.4 E-16	1.4 E-15
0.5	No Alerting	7.0 E-17	7.0 E-16
1.0	2 NM Alerting	7.0 E-17	7.0 E-16
0.5	2 NM Alerting	3.5 E-17	3.5 E-16

Table 8: RNAV / RNP-1 Without Radar, 6 NM Lateral Separation

Vertical Overlap Probability	RNP Alerting	Same Direction Collisions / Hour	Opposite Direction Collisions / Hour
1.0	No Alerting	3.0 E-12	3.0 E-11
0.5	No Alerting	1.5 E-12	1.5 E-11
1.0	2 NM Alerting	1.5 E-12	1.5 E-11
0.5	2 NM Alerting	7.5 E-13	7.5 E-12

Table 9: RNAV / RNP-1 Without Radar, 4 NM Lateral Separation

Vertical Overlap Probability	RNP Alerting	Same Direction Collisions / Hour	Opposite Direction Collisions / Hour
1.0	No Alerting	6.0 E-08	6.0 E-07
0.5	No Alerting	3.0 E-08	3.0 E-07
1.0	2 NM Alerting	3.0 E-08	3.0 E-07
0.5	2 NM Alerting	1.5 E-08	1.5 E-07

4.5 RNP-2 Adjacent to RNP-2, Turns Segment, with Radar (Reference [2])

What is the risk of an RNAV / RNP-2 aircraft flying an en route segment with turns greater than 15º under radar surveillance colliding with an RNAV / RNP-2 aircraft flying a parallel, adjacent en route track, in a direction the same as that of the other aircraft, with track-to-track (centerline-to-centerline) separation distance of 8 NM? Also, what if the adjacent aircraft's direction of flight is opposite?

Comments

The summarized and extended results here also include 8 NM lateral (track-to-track) separation, 20 NM in-trail separation, only two adjacent tracks, turns up to 30º, and one turn per hour of flight. For more detailed results, see the study [6]. Again, we extend the study's results here to include both the initial vertical overlap probability of 1.0 and the less conservative value of 0.5.

We also extend the study's results to give credit for RNP alerting. Appendix A describes the alerting operational scenario we assume.

Results

Table 10: RNAV / RNP-2 With Radar, 8 NM Lateral Separation, 1 Turn ≤ 30º

Vertical Overlap Probability	Same Direction Collisions / Hour	Opposite Direction Collisions / Hour
1.0	3.8 E-11	4.0 E-10
0.5	1.9 E-11	2.0 E-10

4.6 RNP-2 Adjacent to RNP-2, Turns Segment, without Radar (Reference [6])

What is the risk of an RNAV / RNP-2 aircraft flying an en route segment with turns greater than 15º not under radar surveillance colliding with an RNAV / RNP-2 aircraft flying a parallel, adjacent en route track, in a direction the same as that of the other aircraft, with track-to-track (centerline-to-centerline) separation distance of 8 NM? Also, what if the adjacent aircraft's direction of flight is opposite?

Comments

The summarized and extended results here also include 8 and 10 NM lateral (track-to-track) separation, 20 NM in-trail separation, only two adjacent tracks, turns up to 30º, and one turn per hour of flight. For more detailed results, see the study [6]. Again, we extend the study's results here to include both the initial vertical overlap probability of 1.0 and the less conservative value of 0.5. We also extend the study's results to give credit for RNP alerting. Appendix A describes the alerting operational scenario we assume.

Results

Table 11: RNAV / RNP-2 Without Radar, 10 NM Lateral Separation, 1 Turn ≤ 30º

Vertical Overlap Probability	RNP Alerting	Same Direction Collisions / Hour	Opposite Direction Collisions / Hour
1.0	No Alerting	1.7 E-12	1.8 E-11
0.5	No Alerting	8.5 E-13	9.0 E-12
1.0	2 NM Alerting	8.5 E-13	9.0 E-12
0.5	2 NM Alerting	4.3 E-13	4.5 E-12

Table 12: RNAV / RNP-2 Without Radar, 8 NM Lateral Separation, 1 Turn ≤ 30º

Vertical Overlap Probability	RNP Alerting	Same Direction Collisions / Hour	Opposite Direction Collisions / Hour
1.0	No Alerting	3.7 E-09	4.3 E-08
0.5	No Alerting	1.9 E-09	2.2 E-08
1.0	2 NM Alerting	1.9 E-09	2.2 E-08
0.5	2 NM Alerting	8.0 E-10	1.1 E-08

4.7 RNP-2 Adjacent to VOR, Straight Segment, with Radar (Reference [3])

What is the risk of an RNAV / RNP-2 aircraft flying a straight en route segment under radar surveillance colliding with an aircraft flying a parallel, adjacent conventional (VOR) en route track, in a direction the same as that of the other aircraft, with track-to-track (centerline-to-centerline) separation distance of 8 NM? Also, what if the adjacent aircraft's direction of flight is opposite?

Comments

The summarized and extended results here also include 8 and 10 NM lateral (track-to-track) separation, 5 NM in-trail separation, crossover point (COP) distance not more than 51 NM, and only two adjacent tracks. For more detailed results, see the study [3]. Again, we extend the study's results here to include both the initial vertical overlap probability of 1.0 and the less conservative value of 0.5.

We also include, for comparison purposes, our results for the risk of two conventional parallel, adjacent routes assuming 8 NM lateral separation and 5 NM in-trail separation with crossover point (COP) distance not more than 51 NM.

Results

Table 13: RNAV-2 Adjacent to VOR With Radar, 10 NM Lateral Separation

Vertical Overlap Probability	Same Direction Collisions / Hour	Opposite Direction Collisions / Hour
1.0	5.9 E-10	5.9 E-09
0.5	3.5 E-10	3.5 E-09

Table 14: RNAV-2 Adjacent to VOR With Radar, 8 NM Lateral Separation

Vertical Overlap Probability	Same Direction Collisions / Hour	Opposite Direction Collisions / Hour
1.0	6.8 E-07	6.8 E-06
0.5	3.4 E-07	3.4 E-06

Table 15: VOR Adjacent to VOR With Radar, 8 NM Lateral Separation

Vertical Overlap Probability	Same Direction Collisions / Hour	Opposite Direction Collisions / Hour
1.0	1.4 E-05	1.4 E-04
0.5	7.0 E-06	7.0 E-05

4.8 RNP-2 Adjacent to VOR, Straight Segment, without Radar (Reference [7])

What is the risk of an RNAV / RNP-2 aircraft flying a straight en route segment without radar surveillance colliding with an aircraft flying a parallel, adjacent conventional (VOR) en route track, in a direction the same as that of the other aircraft, with track-to-track (centerline-to-centerline) separation distance of 8 NM? Also, what if the adjacent aircraft's direction of flight is opposite?

Comments

The summarized and extended results here also include 8 and 10 NM lateral (track-to-track) separation, 20 NM in-trail separation, crossover point (COP) distance not more than 51 NM, and only two adjacent tracks. For more detailed results, see the study [7]. Again, we extend the study's results here to include both the initial vertical overlap probability of 1.0 and the less conservative value of 0.5.

Again, we include, for comparison purposes, our results for the risk of two conventional parallel, adjacent routes assuming 8 NM lateral separation and 20 NM in-trail separation with crossover point (COP) distance not more than 51 NM.

Results

Table 16: RNAV-2 Adjacent to VOR With Radar, 10 NM Lateral Separation

Vertical Overlap Probability	RNP Alerting	Same Direction Collisions / Hour	Opposite Direction Collisions / Hour
1.0	No Alerting	6.7 E-10	6.7 E-09
0.5	No Alerting	3.4 E-10	3.4 E-09
1.0	2 NM Alerting	3.4 E-10	3.4 E-09
0.5	2 NM Alerting	1.7 E-10	1.7 E-09

Table 17: RNAV-2 Adjacent to VOR With Radar, 8 NM Lateral Separation

Vertical Overlap Probability	RNP Alerting	Same Direction Collisions / Hour	Opposite Direction Collisions / Hour
1.0	No Alerting	3.6 E-07	3.6 E-06
0.5	No Alerting	1.8 E-07	1.8 E-06
1.0	2 NM Alerting	1.8 E-07	1.8 E-06
0.5	2 NM Alerting	9.0 E-08	9.0 E-07

Table 18: VOR Adjacent to VOR With Radar, 8 NM Lateral Separation

Vertical Overlap Probability	Same Direction Collisions / Hour	Opposite Direction Collisions / Hour
1.0	3.6 E-06	3.6 E-05
0.5	1.8 E-06	1.8 E-05

4.9 RNP-2 Impromptu, Straight Segment, without Radar (Reference [7])

What is the risk of an RNAV / RNP-2 aircraft exiting a single, straight, impromptu route boundary assuming no radar surveillance?

Comments

The summarized and extended results here include 8 and 10 NM route widths. For more detailed results, see the study [7]. Neither in-trail distances, vertical overlap, nor the alerting operations of Appendix A apply since the hazards assessed is route boundary penetration and not midair collision. A route width of 8 NM would mean centerline ± 4 NM. Penetration is not typically considered to be a catastrophic event. Penetration rates for impromptu routes with radar surveillance can be found in reference [4].

Results

Table 19: RNAV/RNP-2 Without Radar, 10 NM Route Width

Aircraft Ground Speed	Boundary Penetrations / Hour
200 knots	4.8 E-09
300 knots	7.1 E-09
400 knots	9.5 E-09
500 knots	1.2 E-08

Table 20: RNAV/RNP-2 Without Radar, 8 NM Route Width

Aircraft Ground Speed	Boundary Penetrations / Hour
200 knots	7.1 E-07
300 knots	1.1 E-06
400 knots	1.4 E-06
500 knots	1.8 E-06

Appendix A

RNP Alerting Credit Assumptions

We assume that RNP aircraft are equipped with alerting capabilities so that the pilot is alerted whenever the total system error (TSE) exceeds 2 times the RNP value (i.e., 2 NM for RNP 1 and 4 NM for RNP 2) as specified in AC 90-105 [10].

We assume that if the pilot of an RNP aircraft (the target aircraft) receives an alert he or she will respond (with a certain probability of *pilot response*) by communicating with air traffic control. If the aircraft is operating under radar surveillance, the controller will handle the situation in the same way as if the controller had detected a route deviation. Therefore, the credit given in the surveillance case is the same as the credit given for controller initiated action.

However, if the aircraft is operating without radar surveillance, we assume that the controller will respond (with a certain probability *controller response*) by alerting other aircraft in the appropriate airspace to clear the airspace for the target RNP aircraft.

We also assume that this controller action will be effective (with a certain probability *other aircraft response*). And therefore, eliminate exposure of the target aircraft to other aircraft during the period of controller action.

We assume that the probabilities of each of the three responses are:

Table 21: Response Probability Assumptions

Response	Probability
pilot response	0.8
controller response	0.8
other aircraft response	0.8

If these three responses are assumed to be independent, the probability of elimination of exposure of the target aircraft to other aircraft will be the product of the three probabilities, or about 0.5.

References

[1] "Analysis of Area Navigation (RNAV) En Route Separation along Adjacent Straight Segments with Radar Surveillance (Phase I)" DOT-FAA-AFS-440-24, January 2007

[2] "Analysis of Area Navigation (RNAV) En Route Separation along Adjacent Straight Segments with Radar Surveillance and Turns (Phase II)" DOT-FAA-AFS-440-25, January 2007

[3] "Analysis of Area Navigation (RNAV) En Route Separation with Conventional Routes Including Turns and Special Use Airspace" DOT-FAA-AFS-440-26, January 2007

[4] "Analysis of Area Navigation (RNAV/RNP-1) En Route Separation Along Adjacent Straight Segments With Radar Surveillance Including Impromptu Routes (Phase III)" DOT-FAA-AFS-450-50, March 2009

[5] "Analysis of Area Navigation (RNAV/RNP-1 and RNP-2) En Route Separation Along Adjacent Straight Segments Without Radar Surveillance Including Impromptu Routes (Phase IV)" DOT-FAA-AFS-450-51, March 2009

[6] "Analysis of Area Navigation (RNAV RNP-1 and RNP-2) En Route Separation Along Adjacent Segments With and Without Radar Surveillance and With Turns (Phase V)" DOT-FAA-AFS-450-52, March 2009

[7] "Analysis of Area Navigation (RNAV-2) En Route Separation With Conventional Routes Without Radar Surveillance Including Impromptu Routes", DOT-FAA-AFS-450-54, April 2009

[8] "Manual on Airspace Planning Methodology for the Determination of Separation Minima", First Edition, 1998, ICAO Document 9689-AN/953, p. 50

[9] "Determination of $P_z(0)$ for Domestic RVSM", FAA Working Paper, Christine Falk, personal correspondence, 2009

[10] "Approval Guidance for RNP Operations and Barometric Vertical Navigation in the U.S. National Airspace System", AC 90-105, January, 2009