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Safety Analysis of Proposed Change to TCAS RA Reversal Logic

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Prepared by: SC-147

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Foreword

This document was prepared by RTCA Special Committee (SC-147) and approved by the RTCA Program Management Committee (PMC) on November 8, 2005.

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Executive Summary

A significant safety vulnerability has been identified in the TCAS Version 7 Resolution Advisory (RA) reversal logic. The vulnerability is termed SA01, and encompasses a class of encounters where a necessary reversal of RA sense is not issued in a timely manner (if at all), or where unnecessary RA reversals are issued that decrease separation. A total of 12 instances of SA01, including two that resulted in accidents, are known to have occurred worldwide since 2000. Based on observations in European airspace, it is estimated that SA01 events occur at a frequency of 4.7x10-6 per flight hour, corresponding to an estimated mid-air collision rate due to SA01 of 2.2x10-8 per flight hour. The U.S. monitoring indicates a rate consistent with European airspace. This risk is unacceptable because the observed frequency of SA01 exceeds that which is tolerated for catastrophic hazards.

A change to the RA reversal logic has been developed by the Safety Issue Rectification (SIR) Project of the EUROCONTROL ACAS Programme. This change (termed CP112E) was analyzed by several organizations participating in the RTCA SC-147 Requirements Working Group (RWG), which finds that CP112E would provide a substantial reduction in SA01 risk. Analyses indicate that CP112E would reduce the collision rate due to some types of SA01 events to 30-50% of the rate with Version 7.

While the evaluation shows the greatest improvement when all aircraft carry CP112E, improvement is even seen for airspace in which some aircraft carry CP112E while others carry other versions. No problems of interoperability between versions have been found.

Side effects and performance degradations are minimal for CP112E and are considered acceptable compared to the collision risk with current versions of TCAS II. No RA reversal logic can be perfect, given inherent limitations such as altitude tracking lag and variable pilot response. The evaluation effort compared CP112E to existing versions of TCAS using several complementary methods and airspace models. The evidence strongly indicates that the benefits of CP112E outweigh its limitations. A few areas have been identified for investigation towards final refinements to the proposed CP112E change. The evaluation work is underway, and it is anticipated that this work can be completed rapidly, without delaying early implementation of CP112E.

Based on the RWG's findings, it is recommended that FAA and international authorities commence work towards regulatory action that would expedite implementation of the revised logic. Safety would be improved as soon as the change can be installed in the TCAS fleet. Regulatory measures could include issuance of Airworthiness Directives, requirements to enhance pilot and controller training so as to minimize the occurrence of the observed problems, and mandatory equipage of the change by specific dates for both reverse and forward fit. It is further recommended that RTCA proceed with a revision to the TCAS II MOPS based on the CP112E change to the RA reversal logic.

Finally, it is recommended that airspace monitoring be expanded to assess the performance of TCAS in the changing airspace, and that resources of expertise in TCAS technical analysis be sustained.

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Table of Contents

Executive Summary i
1 Introduction 1
1.1 Problem Statement 1
2 History and Frequency of Operational Incidents 5
2.1 Identified SA01 Incidents 5
2.2 Monitoring approaches and results 7
2.3 Estimate of SA01a Frequency and Criticality 8
3 Approaches to Address Issue SA01 11
3.1 Displays and Aural annunciations 11
3.2 Control Coupling 11
3.3 Pilot Compliance 11
3.4 ATC Procedures 12
3.5 Airspace Design 12
4 Design of TCAS RA Reversal Logic 13
4.1 Principles 13
4.2 Summary of Change Proposal 112E (CP112E) 13
5 Evaluation Metrics 15
5.1 Concepts 15
5.2 Computation of Metrics 16
5.3 Key Metrics 17
6 Evaluation Results 19
6.1 MITRE 19
6.2 MIT Lincoln Laboratory 20
6.3 European 23
6.4 Fast Time Encounter Generator: William J. Hughes Technical Center and MIT Lincoln Laboratory 28
6.5 Code Evaluation 33
6.6 Next Steps in Implementing CP112E 33
7 Development of MOPS 35
8 Conclusions and Recommendations 37
8.1 Conclusions 37
8.2 Recommendations 37
9 References 39
Membership 41

List of Appendices

Appendix A: Specific SA01 Incidents
Appendix B: Design of TCAS RA Reversal Logic
Appendix C: U.S. Monitoring
Appendix D: MIT Lincoln Laboratory Analysis
Appendix E: European Analysis
Appendix F: Fast-Time Encounter Generator / FAA William J. Hughes Technical Center Analysis
Appendix G: Fast-Time Encounter Generator / MIT Lincoln Laboratory Analysis
Appendix H: Code Evaluation
Appendix I: Decision Tables for TCAS II Version 7 Threat Declaration, Initial Sense Selection and RA Reversal Logic and for CP112E Changes to Reversal Logic

List of Figures

Figure 1-1: SA01a Encounter 2

Figure 1-2: SA01c Encounter 3

Figure 2-1: Vertical Profile of November 2001 SA01 Event 6

Figure 2-2: Vertical Rate During vs. Prior to RA (Climb RAs) Nov 2004 – May 2005 8

Figure 6-1: Status-Quo and Upgrade Risk Rate (European model) 23

Figure 6-2: VMD Change from CP112E (US-like Model, Responding/Non-Responding Condition) 25

Figure 6-3: Separation Difference Plots (FTEG) 30

Figure 6-4: Induced NMAC Rates for TCAS-TCAS Non-Responding Encounters (FTEG) 32

Figure B-1: Version 7.0 – The Intruder is Causing the Crossing RA 58

Figure B-2: Version 7.0 – Crossing Encounters – Condition on the Current Certical Separation to Reverse 59

Figure B-3: Version 7.0 – Crossing Encounter – Condition to Reverse 59

Figure B-4: Version 7.0 – Non Crossing Encounter – Condition to Reverse 60

Figure B-5: Version 7.0 – Non Crossing Encounter – Conditions to Reverse When Own Takes a Long Time to Follow His RA – Unequipped Intruder 61

Figure B-6: Version 7.0 – Non Crossing Encounter – Condition to Reverse When Both Aircraft Are in the Same Sense – Unequipped Intruder 62

Figure B-7: Illustration of the VMD Test 65

Figure B-8: Issue SA01b – Encounter Without TCAS Contribution 67

Figure B-9: Issue SA01b – Encounter Simulated with TCAS II Logic Version 7.0 – RAs Onboard Aircraft 2 Sequence of RAs: Des: Descend RA, Ides: Increase Descend RA, CoC: Clear of Conflict 68

Figure B-10: Issue SA01b – Encounter Simulated With TCAS II Logic Version 7.0+CP112E – RAs Onboard Aircraft 2 Sequence of RAs: Des: Descend RA, Ides: Increase Descend RA, RCl: Reversal Climb RA, CoC: Clear of Conflict 69

Figure B-11: Issue SA01a – Encounter Without TCAS Contribution 71

Figure B-12: Issues SA01a – Encounter Simulated With TCAS II Version 7.0 – RAs Onboard Aircraft 2 72

Figure B-13: Issue SA01a – Encounter Simulated With TCAS II Version 7.0+CP112E - RAs Onboard Aircraft 2 Sequence of RAs: Des: Descend RA, RCl: Reversal climb RA, ICl: Increase climb RA, DDes: Don't descend Ra, CoC: Clear of Conflict 73

Figure B-14: Issue SA01c – Encounter Without TCAS Contribution 75

Figure B-15: Issue SA01c – Encounter Simulated With TCAS II Version 7.0 RAs Onboard Aircraft 2 Sequence of RAs: MCl: Maintain Climb RA, RDes: Reversal Descent RA CoC: Clear of Conflict 76

Figure B-16: Issue SA01c – Encounter Simulated With TCAS II Version 7.0 and Without Reversal RAs (using CP112E) – RAs Onboard Aircraft 2 Sequence of RAs: MCl: Maintain Climb RA, CoC: Clear of Conflict 77

Figure C-1: Vertical Rate During vs. Prior to RA (Climb RAs) Nov 2004 – May 2005 81

Figure C-2: Vertical rate during vs. prior to RA (Descend RAs) Nov 2004 – May 2005 82

Figure D-1: Effect of CP112E on VMD (European Model, all layers, TCAS-TCAS, Standard vs. No Response) 84

Figure D-2: Risk Ratios (TCAS-TCAS, European Model) 86

Figure D-3: Risk Ratios (TCAS-Unequipped, European Model) 86

Figure D-4: Induced Risk Rate (TCAS-TCAS, European Model) 87

Figure D-5: Induced Risk Rate (TCAS-Unequipped, European Model) 88

Figure D-6: Status-Quo and Upgrade Risk Rate 90

Figure D-7: Risk Ratios (TCAS-TCAS, ICAO Model) 90

Figure D-8: Risk Ratios (TCAS-Unequipped, ICAO Model) 91

Figure D-9: Induced Risk Rate (TCAS-TCAS, ICAO Model) 91

Figure D-10: Induced Risk Rate (TCAS-Unequipped, ICAO Model) 92

Figure D-11: Status-Quo and Upgrade Risk Rate (ICAO Model) 92

Figure D-12: Change in VMD Due to CP112E (TCAS-TCAS, Standard Response, SA01a Model) 93

Figure D-13: Change in VMD Due to CP112E (TCAS-TCAS, Slow Response, SA01a Model) 94

Figure D-14: P(NMAC) for Version 7 and CP112E in the SA01a Encounter Model (Standard Response) 94

Figure D-15: Relative Reduction in NMAC Rate Due to CP112E (SA01a Encounter Model, Standard Response) (1 = complete elimination of NMACs) 95

Figure D-16: P(NMAC) for Version 7 and CP112E in the SA01a Encounter Model (Slow Response) 95

Figure D-17: Relative Reduction in NMAC Rate Due to CP112E (SA01a Encounter Model, Slow Response) (1 = Complete Elimination of NMACs) 96

Figure D-18: SA01a Triplet Outcomes – Standard Response ([101] and [001] Together Represent 0.13% and Are Not Shown) 97

Figure D-19: SA01a Triplet Outcomes – Slow Response 98
Figure D-20: SA01 Rate Estimates 99
Figure E-1: US-like Model, Responding / Non-Responding Scenario 105
Figure E-2: European model – Responding/non-responding scenario 106
Figure E-3: ICAO model – Responding/non-responding scenario 106
Figure E-4: SA01a model – Responding/non-responding scenario 107
Figure E-5: US-like Model – Responding/Unequipped Scenario 109
Figure E-6: European model– Responding/unequipped scenario 109
Figure E-7: ICAO model– Responding/unequipped scenario 110
Figure E-8: US-like model – Responding/responding scenario 111
Figure E-9: ICAO model – Responding/responding scenario 112
Figure E-10: Decision risk vs. airspace RA response rate – US-like model 114
Figure E-11: US-like model – Responding/non-responding scenario 117
Figure E-12: European model – Responding/non-responding scenario 117
Figure E-13: ICAO model – Responding/non-responding scenario 118
Figure E-14: SA01 model – Responding/non-responding scenario 118
Figure E-15: US-like model – Responding/Unequipped Scenario 121
Figure E-16: European model – Responding/unequipped scenario 121
Figure E-17: ICAO model – Responding/unequipped scenario 122
Figure E-18: US-like model – Responding/Responding Scenario 125
Figure E-19: ICAO model – Responding/responding scenario 125
Figure F-1: Unresolved NMACs Responding Data (Low Altitude) 129
Figure F-2: Induced NMACs Responding Data (Low Altitude) 129
Figure F-3: Unresolved NMACS Non-Responding Data (Low Altitude) 130
Figure F-4: Induced NMACS Non-Responding Data (Low Altitude) 130
Figure F-5: Unresolved NMACS Responding data (High altitude) 131
Figure F-6: Induced NMACS Responding Data (High altitude) 131
Figure F-7: Unresolved NMACS Non-Responding data (High altitude) 132
Figure F-8: Induced NMACS Non-Responding Data (High altitude) 132
Figure F-9: NMAC TOTAL Summary for All Data 133

Figure F-10: Separation Difference Plot for Unequipped Intruders(Low Altitude) 134
Figure F-11: Separation Difference Plot for TCAS-TCAS Responding Intruders (Low and High Altitude) 135
Figure F-12: Separation Difference Plot for TCAS-TCAS Non-Responding Intruders (Low and High Altitude) 135
Figure F-13: Metric B4 for Low Altitude Data Set 137
Figure F-14: Metric B4 for High Altitude Data Set 137
Figure F-15: Reversal RA Quadruplet Table 139
Figure F-16: Reversal Quadruplets for Low Altitude Data Set 140
Figure F-17: Reversal Quadruplets for High Altitude Data Set 141
Figure G-1: TCAS – TCAS One Pilot Non-Responding 144
Figure G-2: TCAS – TCAS One Pilot Non-Responding 145
Figure G-3: TCAS – TCAS One Pilot Non-Responding 145
Figure G-4: TCAS – TCAS One Pilot Non-Responding 146
Figure G-5: TCAS – Unequipped 147
Figure G-6: TCAS – Unequipped 147
Figure G-7: TCAS – Unequipped 148
Figure G-8: TCAS – Unequipped 148
Figure G-9: Both Pilots Responding 149
Figure G-10: Both Pilots Responding 149
Figure G-11: Both Pilots Responding 150
Figure G-12: Both Pilots Responding 150
Figure G-13: One Pilot Non-Responding 154
Figure G-14: One Pilot Non-Responding 154
Figure G-15: One Pilot Non-Responding 155
Figure G-16: Both Pilots Responding 156
Figure G-17: Both Pilots Responding 156
Figure G-18: Both Pilots Responding 157
Figure G-19: Sample Encounter, Version 7 159
Figure G-20: Sample Encounter, CP112E 159

Figure G-21: Representative NMAC 8, Version 7 163
Figure G-22: Representative NMAC 8, CP112E..... 163
Figure G-23: Representative NMAC 16, Version 7 164
Figure G-24: Representative NMAC 16, CP112E..... 164
Figure H-1: Version 7 and CP112E Logic Flow Diagram Based on Pseudo-Code. 171
Figure H-2: Version 7 Top-Level Reversal Logic Flow Diagram Based on a Simple Realization of State Chart. 172
Figure H-3: Top-Level Logic Flow Diagram Based on CP112E Changes to Figure H-2..... 173
Figure H-4: Version 7 Data Flow Diagram for "Reversal_Check". 174
Figure H-5: CP112E Data Flow Diagram for "Reversal_Check". 175

List of Tables

Table 2-1: Identified SA01 Events 5

Table 6-1: Risk Ratios for TCAS-TCAS Encounters, U.S. Encounter Model 19

Table 6-2: Risk Ratios for TCAS-Unequipped Encounters, U.S. Encounter Model 19

Table 6-3: Risk Ratios for TCAS-TCAS Encounters (non-TCAS probability of NMAC per encounter = 0.0028 for European model, 0.0043 for ICAO model) 21

Table 6-4: Risk Ratios for TCAS-Unequipped Encounters 21

Table 6-5: Key Metrics – Responding/Non-Responding Scenario 24

Table 6-6: Status-Quo and Upgrade Risk Rates – Responding/Non-Responding Scenario 26

Table 6-7: Key Metrics – Responding/Unequipped Scenario 26

Table 6-8: Key Metrics – Responding/Responding Scenario 27

Table 6-9: NMAC Effects Summary for all FTEG Data 29

Table C- 1: Monitoring statistics for the Boston airspace Nov 2004 – May 2005 80

Table D-1: CP112E Effect on VMD Relative to Version 7 (European Model, weighted across altitude layers) 85

Table D-2: Derived Metrics (European Encounter Model) 88

Table E-1: Key Metrics – Responding/Non-Responding Scenario 104

Table E-2: Status-Quo and Upgrade Risk Rates – RespondingNnon-Responding Scenario 108

Table E-3: Key Metrics – Responding/Unequipped Scenario 108

Table E-4: Status-Quo and Upgrade Risk Rates: Responding/unequipped scenario 110

Table E-5: Key metrics – Responding/responding scenario 111

Table E-6: Status-quo and upgrade risk rates – Responding/responding scenario 113

Table E-7: Risk ratio breakdown – Responding/non-responding scenario 115

Table E-8: Supporting metrics – Responding/non-responding scenario 115

Table E-9: Key metrics – Responding/non-responding scenario 116

Table E-10: Risk ratio Breakdown – Responding/Non-Responding Scenario 116

Table E-11: Status-Quo and Upgrade Risk Rates – Responding/Non-Responding Scenario 119

Table E-12: Supporting Metrics – Responding/Non-Responding Scenario 119

Table E-13: Risk Ratio Breakdown – Responding/Unequipped Scenario 119

Table E-14: Supporting metrics – Responding/unequipped scenario 120
Table E-15: Key metrics – Responding/unequipped scenario 120
Table E-16: Risk Ratio Breakdown – RespondingUunequipped Scenario 122
Table E-17: Status-Quo and Upgrade Risk Rates – Responding/Unequipped Scenario 123
Table E-18: Supporting Metrics – Responding/Unequipped Scenario 123
Table E-19: Risk ratio breakdown – Responding/responding scenario 123
Table E-20: Supporting metrics – Responding/responding scenario 124
Table E-21: Key metrics – Responding/responding scenario 124
Table E-22: Risk ratio breakdown – Responding/unequipped scenario 124
Table E-23: Status-quo and upgrade risk rates – Responding/responding scenario 126
Table E-24: Supporting metrics – Responding/responding scenario 126
Table G-1: Example Separation Differences Output Non-Reversed RAs, CP112E, Classes 9/19 152
Table G-2: Example Separation Differences Output Reversed RAs, CP112E, Classes 9/19 153
Table G-3: Sample NMAC Analysis Output 158
Table G-4: Representative NMACs 160
Table G-5: Representative Saves 161
Table G-6: Representative NMACs 162
Table G-7: Representative Saves 165
Table H-1: Reversal Logic Variables 170
Table I-1: TCAS II Version 7 Criteria for Threat Declaration 183
Table I-2: TCAS II Version 7 Criteria for Initial Sense Selection Against a Single Threat 188
Table I-3: TCAS II Version 7 Criteria for Sense Reversal Against a Single Threat 193
Table I-4: TCAS II Version 7 Plus CP112E Criteria for Sense Reversal Against a Single Threat 194
Table I-5: Changes to Reversal_modeling 201

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1 Introduction

This report, a product of the SC-147 Requirements Working Group (RWG), presents the examination of an identified safety issue and the analysis of a proposed change to the TCAS II Resolution Advisory (RA) reversal logic that addresses this issue. The report provides a history of the issue, an analysis of known incidents and accidents that develops the expected frequency of events, a description of the problem, both operational and technical, and a detailed analysis of the safety considerations of the proposed change, with comparison to the present logic known as Version 7.

The report also discusses the body of evaluation techniques and metrics that were considered by the committee. With the benefit of its considerable experience in evaluating alternative designs for TCAS, the committee has determined several primary metrics that best convey the evaluation. These are accompanied by a larger number of supporting metrics.

The conclusions and recommendations of the RWG are presented in Section 0. Appendices A-I contain details on the history of the safety issue, the design of the RA reversal logic, and the evaluations performed by various teams working within the RWG.

1.1 Problem Statement

TCAS II Version 7, as specified in RTCA DO-185A, provides the capability to reverse the sense of RAs (e.g., from climb to descend) to resolve deteriorating conditions during an encounter. A reversal may be needed after the initial RA when one pilot does not respond to TCAS RA guidance, or worse, maneuvers in the opposite direction. An RA reversal enables the other aircraft, which is following its RA, to take different action to avert a collision. The effectiveness of the reversal logic was an area of particular concern during Version 7 development, with requirements evolving as the performance of the reversal logic was evaluated. Ultimately, best engineering judgment was used to resolve trade-offs and reach consensus on an acceptable implementation. Operational experience attained since the deployment of Version 7 has challenged some of the earlier judgments and assumptions and compels reevaluation of some areas of the reversal logic.

In early 2000, the EUROCONTROL ACAS Programme, under its European Maintenance of TCAS II Version 7.0 project (EMOTION-7), identified specific safety issues related to the Version 7 reversal logic [EMO2]. These safety issues, known as SA01, are published in the EMOTION–7 final report [EMO1] and further expanded in the Safety Issue Rectification (SIR) Final Report [SIR1]. Specific changes to the Version 7 reversal logic have been proposed and are documented as Version 7 Change Proposal 112E (CP112E) [SIRE3].

The SA01 issue was originally predicted by European analyses and simulations early in 2000, and was subsequently observed during European monitoring efforts from 2001 to 2005. Additionally, analysis indicates that the SA01 issue has been a factor contributing to two major events: a near mid-air collision in Japanese airspace between a B-747 and a DC-10-40 on 31 January 2001, and the mid-air collision between a B-757 and a Tu-154 over Überlingen, Germany on 1 July 2002. In both these accidents, TCAS failed to reverse the sense of its initial RA even though a reversal might have prompted action to avoid the accident. Since 2000, a total of eight SA01 events have been observed in European airspace, one has occurred in Japanese airspace, and at least three have occurred in U.S. airspace. Eleven of these twelve events are

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