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Safety Analysis of Proposed Change to TCAS RA Reversal Logic

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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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- Analyzing and recommending solutions to the system technical issues that aviation faces as it continues to pursue increased safety, system capacity and efficiency;
- Developing consensus on the application of pertinent technology to fulfill user and provider requirements, including development of minimum operational performance standards for electronic systems and equipment that support aviation; and
- Assisting in developing the appropriate technical material upon which positions for the International Civil Aviation Organization and the International Telecommunications Union and other appropriate international organizations can be based.

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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

List of Appendices

List of Figures

List of Tables

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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