Validation of a Proposed Change to the TCAS II Version 7 Algorithm

MEETING No. 95

AEROSPACE CONTROL AND GUIDANCE SYSTEMS COMMITTEE

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A Brief History of TCAS (part 1)

▸ 30 Jun 1956 - A Lockheed Constellation and DC-7 collide in VFR conditions over the Grand Canyon

- The airline industry and aviation authorities initiate system development studies for a effective system
- Radar installed in all Air Route Traffic Control Centers

▸ 1958 - Two midair collisions within weeks lead to legislation creating the Federal Aviation Agency

▸ 16 Dec 1960 – United DC-8 and TWA Constellation collide over Brooklyn, New York

A Brief History of TCAS (part 2)

- **Development efforts in the late 1950s and early 1960s emphasized passive and noncooperating systems.**
  - Proved impractical:
    1. Could not provide complementary avoidance maneuvers which requires a high-integrity communications link between the aircraft
- **Development efforts in the late 1960s and early 1970s**
  - Based on interrogator/transponder and time/frequency techniques
    1. Functioned properly during staged aircraft encounter testing
    2. Determined to generate a high rate of unnecessary alarms in dense terminal areas.
    3. Required each protected aircraft to have the same equipage
    4. Bulky avionics

A Brief History of TCAS (part 3)

- **Early 1970's – MITRE proposes an airborne based system**
  - Transponder based proposal named BCAS "Beacon Collision Avoidance System"
  - Based on the Mode C transponder, 70% of all aircraft operating in the U.S. are immediately visible to the system.
  - BCAS works, but only in low density airspace!
- **1978 - The midair collision of a Boeing 727 and light aircraft over San Diego led the FAA to initiate the development of TCAS.**
  - Based on BCAS concept, but enhanced to operate in denser airspace.
- **1982 - Initial operational evaluation of TCAS conducted by Piedmont Airlines**
  - Approximately 900 hours in revenue service
  - Digital recordings and observer logs only, displays not visible to pilots

A Brief History of TCAS (part 4)

▸ 1986 - Collision between a DC-9 and private aircraft over Cerritos, California

- Congressional mandate requiring some categories of American and foreign aircraft be equipped with TCAS for operations in U.S. airspace

▸ 1987 - Second operational evaluation of TCAS conducted by Piedmont Airlines

- Upgraded version of the Dalmo Victor equipment
- Approximately 1200 hours in revenue service
- Pilots permitted to use displays & aurals for maneuvers
- Digital recorders and observer logs continued to be used.
- Provided basis for avionics certification criteria, validated pilot training guidelines and procedures for using the equipment, and provided the justification for improvements to the TCAS algorithms and displays.

A Brief History of TCAS (part 5)

➤ Limited Installation Program

- Pre-production TCAS II equipment in compliance with the TCAS II Minimum Operational Performance Standards (MOPS)
- Bendix-King avionics / United Airlines B737-200 & DC8-73 aircraft
  - over 2000 hours operating experience in revenue service
- Honeywell avionics / Northwest Airlines MD-80 (2 aircraft)
  - over 2500 hours of operating experience in revenue service
- Pilots permitted to use displays & aurals for maneuvers
- Digital recorders continued to be used
- Further enhancements to the TCAS logic

➤ Late 1991 – Mandated implementation begins.

- FAA initiates the largest evaluation of TCAS, the TCAS Transition Program (TTP)

A Brief History of TCAS (part 6)

- **1993 Version 6.04A mandated for use after 31 Dec 1994**
  - Reduction of nuisance alerts occurring at low altitudes
  - Reduction of alerts occurring during level-off encounters
    - the “Dallas Bump-Up”
  - Correction of a problem in the altitude crossing logic
- **Sep 1997 Mid-air collision between a German Air Force Tupolev 154 and U.S. Air Force C-141 (Namibia, Africa)**
  - Several countries, including the U.S., initiate or accelerate programs to equip their military tanker, transport and cargo aircraft with TCAS II Version 7 avionics.

A Brief History of TCAS (part 7)

- **Dec 1997 Version 7 MOPS Approved**
  - Reduction of altitude thresholds resulting in lower alert rates and better compatibility in RVSM operations
  - Includes the capability for TCAS to issue Resolution Advisory (RA) reversals in coordinated encounters if the encounter geometry changes after the initial RA is issued
  - Only one reversal based on changes in the encounter geometry can be issued
- **1999 Version 7 avionics become available**
- **1 Jan 2000 Eurocontrol mandate goes into effect**
  - All aircraft, operating in European airspace, having a maximum take-off mass exceeding 15,000 kg or a maximum approved passenger seating configuration of more than 30 must be equipped with TCAS Version 7.
- **Jul 2002 Mid-air collision over Űberlingen, Germany**

Change Proposal Background

The FAA is concerned over the performance of the V7 TCAS-TCAS RA sense reversal logic in various airspaces resulting from the preliminary work performed by the RTCA SC-147 Requirements Working Group since May of 2004. Evaluation of this logic has been elevated to the highest priority of study under RTCA SC-147 with the goal of validating European studies and the establishment of appropriate metrics.

The Issues

- **Late reversal RAs or no reversal RAs in coordinated encounters**
  - Observed in European operational airspace
- **Late reversal RAs or no reversal RAs in uncoordinated encounters**
- **Undesirable reversal RAs in coordinated encounters**
  - Decreased vertical separation at Closest Point of Approach (CPA)

The Change Proposal (CP112E)

- **Allow early modeling of sense reversals in TCAS-TCAS encounters, when a maneuver opposite to the RA sense is detected onboard one aircraft.**
- **Forbid the issuance of reversal RAs when they are likely to induce two altitude crossings.**

FAA Objectives

- Verify that the proposed change is effective in all airspaces and is robust for all potential encounters without introducing undesired effects elsewhere.
- Determine if a change is necessary to improve the safety of the TCAS II Version 7 TCAS-TCAS coordinated RA sense reversals.

Strategy – Divide and Conquer

- **Analysis of the reversal logic**

  Identification of all the TCAS II V7 code modules and state charts involved in the RA sense reversal logic, including a detailed understanding of the pseudocode, underlying assumptions and coupling to other parts of the collision avoidance logic.

- **Evaluation of the issue in the airspace**

  Detailed analysis of the Eurocontrol proposal (CP112E) on the existing US airspace model to determine the Risk Ratio impact in U.S. airspace in addition to validating European analysis results with the European and ICAO airspace models.

  Stress test comparison of baseline V7 with V7 implementing CP112E

  # NMACs by encounter class, # RA reversals

- **Establishment of decision criteria supporting the implementation of CP112E to include metrics, thresholds and associated rationale.**

Strategy – Roles and Responsibilities

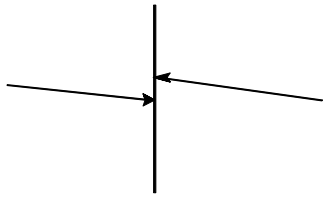
- **FAA Wm J Hughes Technical Center**
  - Perform simulation stress testing & analysis
  - Produce metrics to show if change is beneficial
- **MIT Lincoln Laboratory**
  - Run TCAS logic simulation with real radar data and airspace models
  - Review WJHTC stress testing results
- **MITRE**
  - Produce Risk Ratio Metrics
  - Review WJHTC stress testing results
- **Eurocontrol / Sovreavia / CENA**
  - Safety assessment with CP112E
- **ALL -** Produce a final unified report to RTCA with recommendations

SCENARIO DEFINITIONS FOR TCAS II TESTING

Class	Parameter Variations	Simulations per Class	Total
0,10	84	2,520	5,040
1,11	252	7,560	15,120
2,12	3,024	90,720	181,440
3,13	3,888	116,640	233,280
4,14	504	15,120	30,240
5,15	6,018	181,440	362,880
6,16	6,018	181,440	362,880
7,17	9,072	272,160	544,320
8,18	9,072	272,160	544,320
9,19	7,776	233,280	466,560
		Total Simulations	**2,746,080**

SCENARIO DEFINITIONS FOR TCAS II TESTING

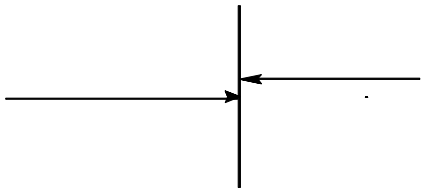
ENCOUNTER CLASS 0



Aircraft 1 : LEVEL LEVEL
Vertical rates : -400, 0, 400 fpm

Aircraft 2 LEVEL LEVEL CROSS
Vertical rates : -400, 0, 400 fpm

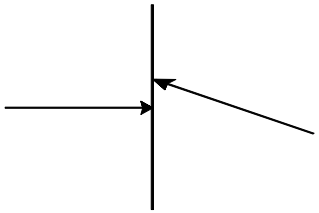
ENCOUNTER CLASS 10



Aircraft 1 : LEVEL LEVEL
Vertical rates : -400, 0, 400 fpm

Aircraft 2 LEVEL LEVEL
Vertical rates : -400, 0, 400 fpm

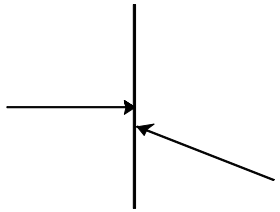
ENCOUNTER CLASS 1



Aircraft 1 : LEVEL LEVEL
Vertical rates : -400, 0, 400 fpm

Aircraft 2 TRANSITIONING TRANSITIONING CROSS
Vertical rates : 1000, 3000, 5000 fpm

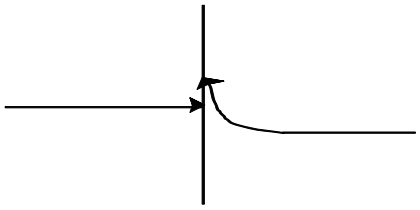
ENCOUNTER CLASS 11



Aircraft 1 : LEVEL LEVEL
Vertical rates : -400, 0, 400 fpm

Aircraft 2 TRANSITIONING TRANSITIONING
Vertical rates : 1000, 3000, 5000 fpm

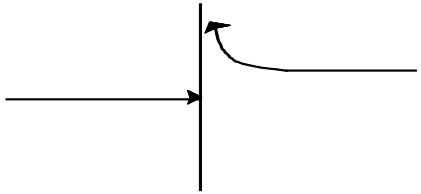
ENCOUNTER CLASS 2



Aircraft 1 : LEVEL LEVEL
Vertical rates : -400, 0, 400 fpm

Aircraft 2 : LEVEL TRANSITIONING CROSS
Vertical rates : 1000, 3000, 5000 fpm

ENCOUNTER CLASS 12

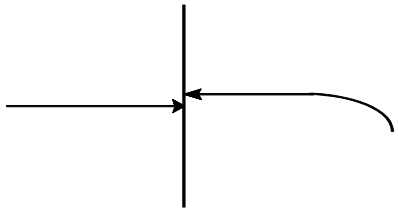


Aircraft 1 : LEVEL LEVEL
Vertical rates : -400, 0, 400 fpm

Aircraft 2 : LEVEL TRANSITIONING
Vertical rates : 1000, 3000, 5000 fpm

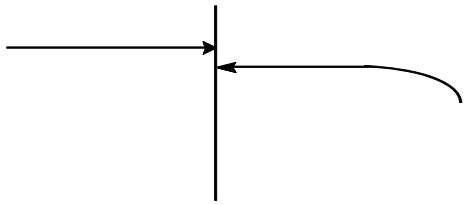
SCENARIO DEFINITIONS FOR TCAS II TESTING

ENCOUNTER CLASS 3



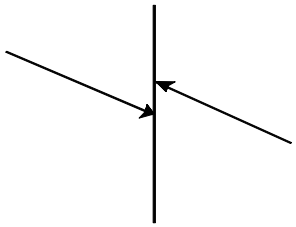
Aircraft 1: LEVEL LEVEL Aircraft 2 : TRANSITIONING LEVEL CROSS
Vertical rates : -400, 0, 400 fpm Vertical rates : 1000, 3000, 5000 fpm

ENCOUNTER CLASS 13



Aircraft 1 : LEVEL LEVEL Aircraft 2 : TRANSITIONING LEVEL
Vertical rates : -400, 0, 400 fpm Vertical rates : 1000, 3000, 5000 fpm

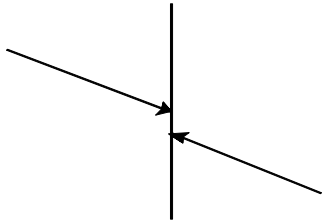
ENCOUNTER CLASS 4



Aircraft 1 : TRANSITIONING TRANSITIONING
Vertical rates : -5000, -3000,-1000,1000,3000,5000 fpm

Aircraft 2 : TRANSITIONING TRANSITIONING CROSS
Vertical rates : -5000, -3000,-1000, 1000,3000,5000 fpm

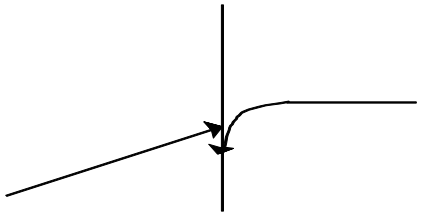
ENCOUNTER CLASS 14



Aircraft 1 : TRANSITIONING TRANSITIONING
Vertical rates : -5000, -3000,-1000,1000,3000,5000 fpm

Aircraft 2 : TRANSITIONING TRANSITIONING
Vertical rates : -5000, -3000,-1000, 1000,3000,5000 fpm

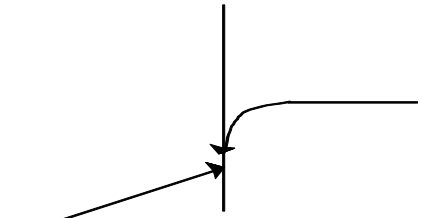
ENCOUNTER CLASS 5



Aircraft 1 :TRANSITIONING TRANSITIONING
Vertical rates : 1000,3000,5000 fpm

Aircraft 2 LEVEL TRANSITIONING CROSS
Vertical rates : -5000,-3000,-1000, 1000, 3000, 5000 fpm

ENCOUNTER CLASS 15

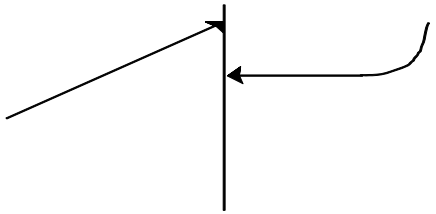


Aircraft 1 :TRANSITIONING TRANSITIONING
Vertical rates : 1000,3000,5000 fpm

Aircraft 2 LEVEL TRANSITIONING
Vertical rates : -5000,-3000,-1000, 1000, 3000, 5000 fpm

SCENARIO DEFINITIONS FOR TCAS II TESTING

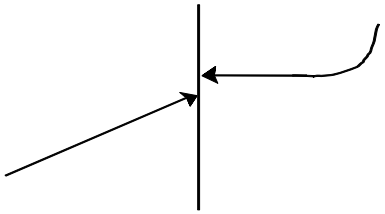
ENCOUNTER CLASS 6



Aircraft 1 : TRANSITIONING TRANSITIONING
Vertical rates : -5000,-3000,-1000,1000,3000,5000 fpm

Aircraft 2 : TRANSITIONING LEVEL CROSS
Vertical rates : -5000,-3000,-1000 fpm

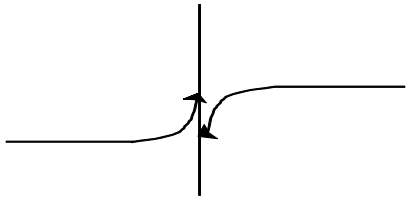
ENCOUNTER CLASS 16



Aircraft 1 : TRANSITIONING TRANSITIONING
Vertical rates : -5000,-3000,-1000,1000,3000,5000 fpm

Aircraft 2 : TRANSITIONING LEVEL
Vertical rates : -5000,-3000,-1000 fpm

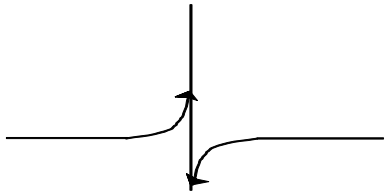
ENCOUNTER CLASS 7



Aircraft 1 : LEVEL TRANSITIONING
Vertical rates : 1000, 3000, 5000 fpm

Aircraft 2 LEVEL TRANSITIONING CROSS
Vertical rates : -1000, - 3000, -5000 fpm

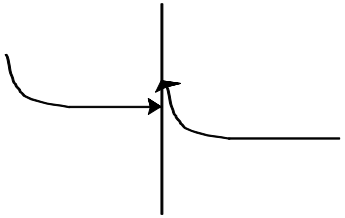
ENCOUNTER CLASS 17



Aircraft 1 : LEVEL TRANSITIONING
Vertical rates : 1000, 3000, 5000 fpm

Aircraft 2 LEVEL TRANSITIONING
Vertical rates : -1000, - 3000, -5000 fpm

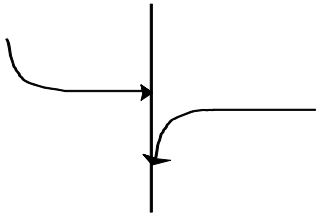
ENCOUNTER CLASS 8



Aircraft 1 : TRANSITIONING LEVEL
Vertical rates : -5000, -3000, -1000, 1000, 3000, 5000 fpm

Aircraft 2 : LEVEL TRANSITIONING CROSS
Vertical rates : -5000,-3000,-1000,1000,3000,5000 fpm

ENCOUNTER CLASS 18

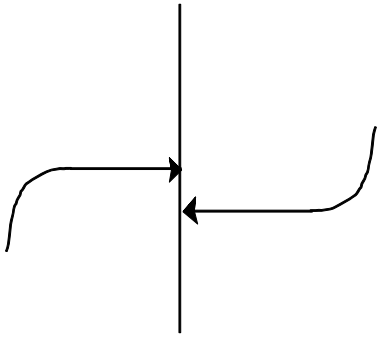


Aircraft 1 : TRANSITIONING LEVEL
Vertical rates : -5000, -3000, -1000, 1000, 3000, 5000 fpm

Aircraft 2 : LEVEL TRANSITIONING
Vertical rates : -5000,-3000,-1000,1000,3000,5000 fpm

SCENARIO DEFINITIONS FOR TCAS II TESTING

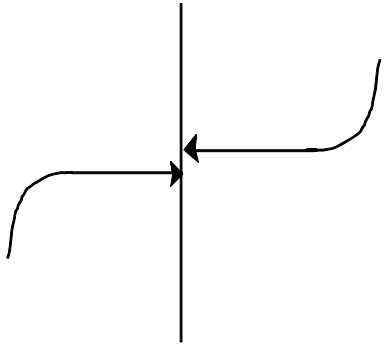
ENCOUNTER CLASS 9



Aircraft 1 : TRANSITIONING LEVEL
Vertical rates : 1000, 3000, 5000 fpm

Aircraft 2 : TRANSITIONING LEVEL CROSS
Vertical rates : -5000,-3000,-1000 fpm

ENCOUNTER CLASS 19



Aircraft 1 : TRANSITIONING LEVEL
Vertical rates : 1000, 3000, 5000 fpm

Aircraft 2 : TRANSITIONING LEVEL
Vertical rates : -5000,-3000,-1000 fpm

REFERENCES

"Introduction to TCAS II Version 7" FAA, November 2000

"Aviation Disasters" www.multied.com/av.html

www.aviationtoday.com

"SIR Final Report", version 1.2, 16 July 2004, Sofreavia/CENA, Chabert, Arino

"Independent Validation and Verification of the TCAS II Collision Avoidance Subsystem", 18th Annual Digital Avionics Systems Conference, Rannoch Corporation, Abdul-Baki, Baldwin, Rudel

"Fast Time Encounter Generator Operations", internal memo and communication with Kathryn Ciaramella, FAA William J Hughes Technical Center