



The European Organisation for Civil Aviation Equipment
L'Organisation Européenne pour l'Équipement de l'Aviation Civile

VALIDATION OF THE FGS COUPLED TO TCAS MASPS REQUIREMENTS

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FOREWORD

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Since 2005, all civil turbine-engined aircraft with more than 19 passengers or weighing more than 5,700 kg flying in the European airspace are required to be equipped with TCAS II. This system has been introduced in order to reduce the risk of mid-air collisions between aircraft as a last-resort safety net and it has demonstrated its effectiveness.

However, the safety benefits provided by TCAS II depend on the pilots' responses to the triggered RAs and operational monitoring programmes have shown that some pilots do not follow their RAs and that for those responding to the RAs, the actual reactions vary from the expected ones (e.g. too slow, too aggressive, etc...).

To address this problem, Airbus has recently developed, certified and implemented a solution that links TCAS II to the Auto-Pilot for an automatic response to RAs.

Within the SESAR P04.08.02 project, it was shown that automatic responses to RAs can improve safety and operational acceptability of TCAS for all TCAS-equipped aircraft¹ ([4]). To achieve these objectives, some performance requirements were derived from the simulations and captured in a Safety and Performance Requirements (SPR) document ([5]).

1.2 CONTEXT

EUROCAE WG-75 has started the development of Minimum Aviation System Performance Specification (MASPS) for Flight Guidance System (FGS) coupled to Traffic alert and Collision Avoidance System (TCAS) (ED-224), with, as input, the material from SESAR P04.08.02 SPR document ([5]).

However, during the development of the MASPS, the requirements have been slightly modified compared to what had been simulated within SESAR project. In particular a recommendation for a 200 fpm margin in case of preventive RAs was added. Since this modification has not been validated within SESAR study, the impact, even if it is supposed to be minor, needs to be assessed.

Note that, additionally, in the SESAR work, the 'Maintain Vertical Speed' RAs were addressed as preventive RAs (i.e. maintain the current vertical speed) whereas in the MASPS they are considered as corrective RAs. This means that a 200 fpm margin should also be included for these RAs. The impact of this modification needs thus also to be assessed.

1.3 OBJECTIVE

The project consists in verifying that the requirements included in the MASPS under development (i.e. ED-224) are acceptable as they slightly vary from the simulations conducted in the context of the SESAR work that were used as the basis for the MASPS development.

This document describes the simulations conducted, the results obtained and concludes on the acceptability of the MASPS requirements.

¹ Not only Airbus aircraft

1.4 Acronyms and terminology

NOTE: For detailed description of TCAS RAs please refer to TCAS MOPS [2].

Term	Definition
ACAS	Airborne Collision Avoidance System
ALIM	Minimum vertical miss distance that TCAS II tries to achieve when generating an RA
AP/FD	Auto-Pilot / Flight Director
ATC	Air Traffic Control
ATM	Air Traffic Management
AVAL	ACAS on VLJs and LJs – a study commissioned by EUROCONTROL to assess the effect of equipping very light jets and light jets with TCAS II
CAS	Collision Avoidance System
CPA	Closest Point of Approach
EASA	European Aviation Safety Agency
EUROCAE	European Standardisation body that produces MOPS for TCAS
FGS	Flight Guidance System
HMD	Horizontal Miss Distance
IVSI	Instantaneous Vertical Speed Indicator
MASPS	Minimum Aviation System Performance Specification
MOPS	Minimum Operational Performance Standard
NMAC	Near Mid-Air Collision
RA	Resolution Advisory
SESAR	Single European Sky ATM Research Programme
SJU	SESAR Joint Undertaking
SPR	Safety and Performance Requirements
TCAS	Traffic alert and Collision Avoidance System
VMD	Vertical Miss Distance

CHAPTER 2

CONTEXT OF THE VALIDATION

2.1 MASPS AP/FD TCAS Requirements

2.1.1 Description

The table below gives the **API/FD TCAS requirements as currently written in the MASPS** (i.e. ED-224) and gives their validation status.

NOTE: *In this document, 'SESAR AP/FD TCAS' will refer to automatic response to RA implementations as simulated within SESAR P04.08.02 project; whereas 'MASPS AP/FD TCAS' will refer to automatic response to RA implementations as defined within the MASPS.*

TABLE 1: MASPS AP/FD TCAS REQUIREMENTS

Type of RA		API/FD TCAS Requirement (MASPS)	Validation status
Corrective	Climb, Descend, AVSA (500, 1000, 2000 fpm)	"In response to a corrective Resolution Advisory prescribing a positive vertical speed, when engaged in the normal flight envelope and while not limited by speed protection (if any), the Autopilot/Flight Director TCAS RA mode shall fly the aircraft towards a target vertical speed equal to the vertical speed prescribed by the current RA plus a 200 fpm margin (within the range of allowed vertical speeds) to help flight crew monitoring of the RA response."	Validated within SESAR P04.08.02 ([4])
	Maintain Vertical Speed		Margin not validated within SESAR P04.08.02 ² – to be analysed in this report
	Level-off	"In response to a corrective Resolution Advisory prescribing a null vertical speed, when engaged in the normal flight envelope and while not limited by speed protection (if any), the Autopilot/Flight Director TCAS RA mode shall fly the aircraft towards a target vertical speed equal to the vertical speed prescribed by the current RA (i.e. 0 fpm)."	Validated within SESAR P04.08.02 ([4])
Preventive	Monitor Vertical Speed	"In response to a preventive Resolution Advisory that does or does not include the aircraft current vertical speed in its range of prohibited vertical speeds, when engaged in the normal flight envelope and while not limited by speed protection (if any), the Autopilot/Flight Director TCAS RA mode shall continue to fly the intended trajectory while maintaining the current vertical speed outside the range of forbidden vertical speeds. Note: It might be preferable to apply a margin of 200 fpm. Some other margins could also be used but this has not been evaluated."	Margin not validated within SESAR P04.08.02 – to be analysed in this report

As it can be seen in the table above, **two requirements are still to be validated** on the response to 'Maintain' and 'Monitor' vertical speed RAs. The effects of these requirements are illustrated in the next sub-section.

²

Because considered as Preventive RAs within SESAR P04.08.02 project.

2.1.2

Illustrations

The two following figures illustrate the differences between an encounter simulated with a SESAR AP/FD TCAS response to RA versus a MASPS AP/FD TCAS response to RA: the first encounter illustrates the difference of behaviour on 'Maintain vertical speed' RAs (FIGURE 1) and the second figure illustrates the difference of behaviour on 'Monitor vertical speed' RAs (FIGURE 2).

On these figures, the upper views represent the altitude of aircraft versus time, whereas the lower views represent what the pilots see on their IVSI for each encounter and scenario of AP/FD TCAS.

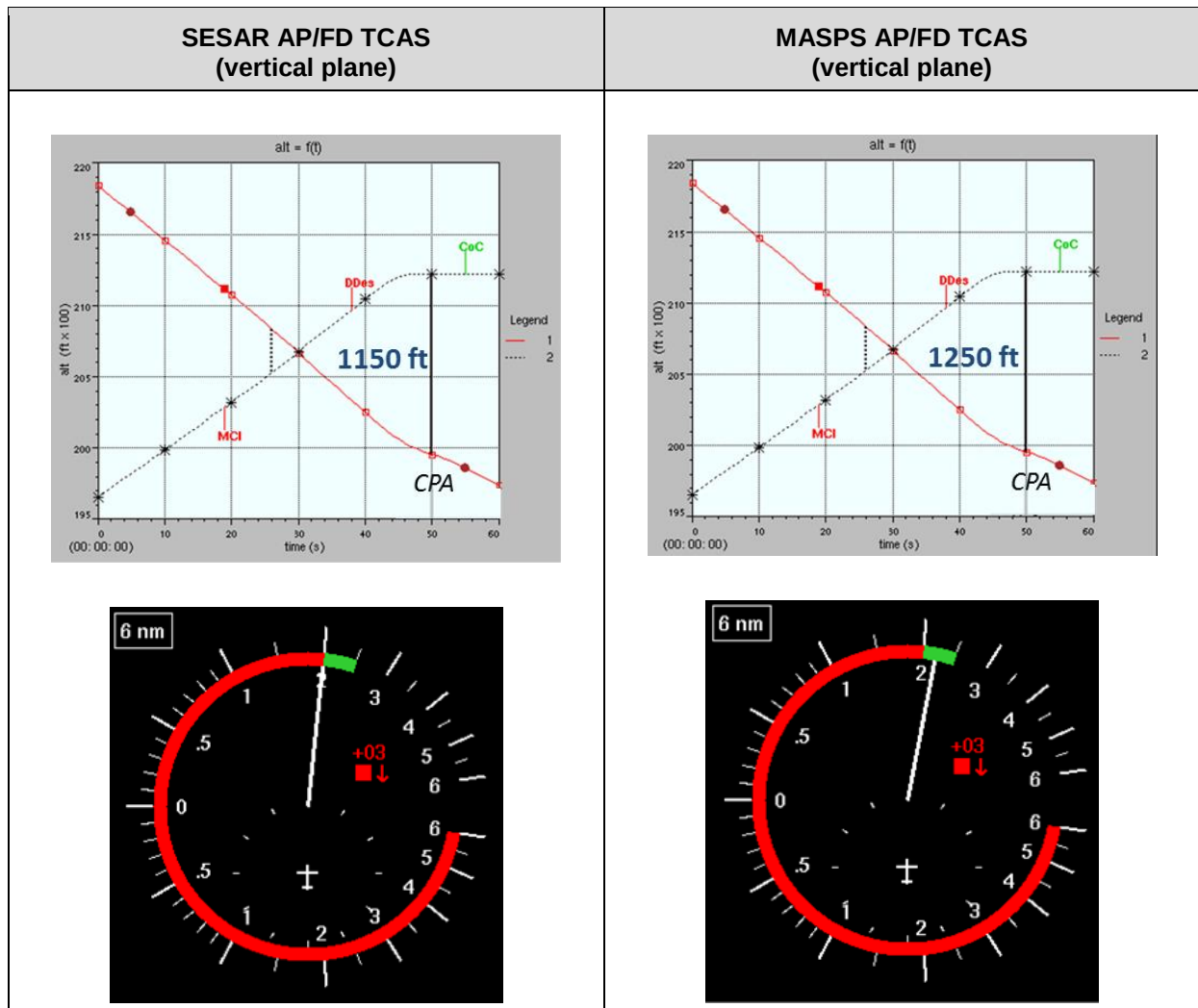


FIGURE 1: ILLUSTRATION OF MASPS AP/FD TCAS RESPONSE TO 'MAINTAIN VERTICAL SPEED' RA (VS. SESAR)

With SESAR AP/FD TCAS response, the climbing aircraft remains at 2,000 fpm after its RA is triggered; whereas with MASPS AP/FD TCAS response, the aircraft climbs at 2,200 fpm (200 fpm margin added). As a result, in this example, the vertical separation at closest point of approach (CPA) is slightly increased with MASPS response.

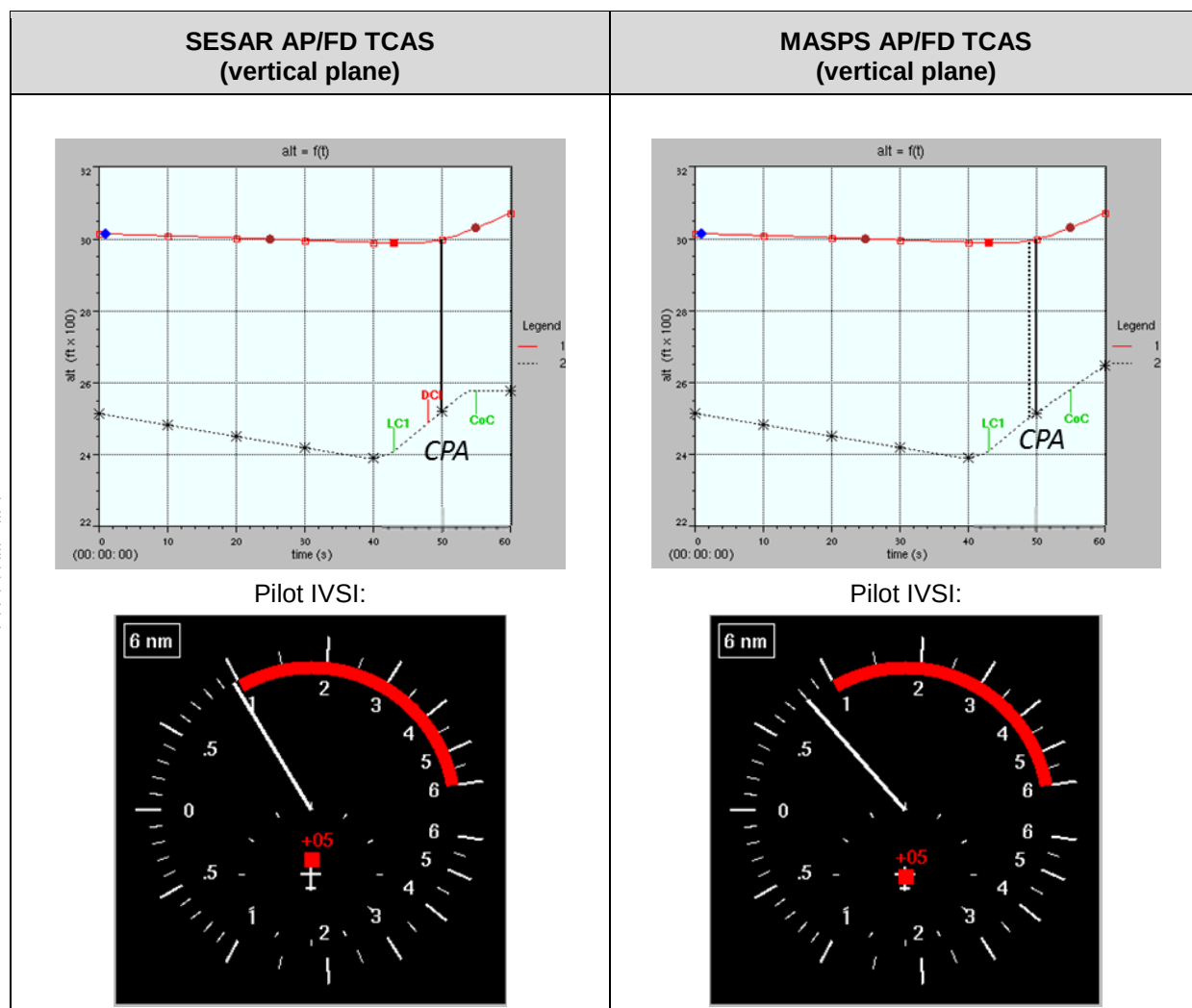


FIGURE 2: ILLUSTRATION OF MASPS AP/FD TCAS RESPONSE TO 'MONITOR VERTICAL SPEED' RA (VS. SESAR)

With SESAR AP/FD TCAS response, the climbing aircraft remains at 1,000 fpm after its RA is triggered; whereas with MASPS AP/FD TCAS response, the aircraft reduces its climb rate at 800 fpm (200 fpm margin added). As a result, in this example, the secondary RA is no more triggered.

2.2 IMPLEMENTATIONS OF PILOT RESPONSE TO RAs

The following table compares the vertical rates as expected by TCAS and SESAR AP/FD TCAS with the ones defined within the MASPS. The differences between SESAR and MASPS implementations are highlighted in blue in the table.

TABLE 2: IMPLEMENTATIONS OF PILOT RESPONSE TO RAs

Type of RA	Required vertical rates		
	TCAS	SESAR AP/FD TCAS	MASPS AP/FD TCAS
Climb (including reversal and crossing)	1500 fpm	1700 fpm	1700 fpm
Increase Climb	2500 fpm	2700 fpm	2700 fpm
Descend (including reversal and crossing)	-1500 fpm	-1700 fpm	-1700 fpm
Increase Descend	-2500 fpm	-2700 fpm	-2700 fpm
Maintain Vertical Speed (while climbing)	Current vertical rate	Current vertical rate	Current vertical rate + 200 fpm
Maintain Vertical Speed (while descending)	Current vertical rate	Current vertical rate	Current vertical rate – 200 fpm
Level-off	0 fpm	0 fpm	0 fpm
Monitor Vertical Speed (downward sense prohibited)	Current vertical rate	Current vertical rate	Current vertical rate + 200 fpm
Monitor Vertical Speed (upward sense prohibited)	Current vertical rate	Current vertical rate	Current vertical rate – 200 fpm

2.3 Validation objective

The objective of this report is to verify that the performance of TCAS when considering Automatic-Pilot responses to RAs as defined in the MASPS (i.e. ED-224) is at least as good as when considering Automatic-Pilot responses to RAs as validated within SESAR (refer to [4]).

The same list of indicators as in the SESAR validation activity on the TCAS AP/FD function will be computed (refer to Appendix A for the list of indicators to be computed) on various scenarios. The main indicator is the risk ratio, but other indicators will be computed to check that the new requirements do not debase other areas such as deviations. The objective of this validation is, among others, to check that the effect caused by the modification of requirement on deviations is minor.

The simulations will also allow the update of TCAS safety and operational indicators comparing manual versus automated responses to RA as defined in the MASPS (as performed within SESAR study).

CHAPTER 3

DESCRIPTION OF THE SIMULATIONS

3.1 INTRODUCTION ON THE MODEL-BASED METHODOLOGY

The validation built on the model-based methodology that is used in TCAS II studies conducted in Europe for more than a decade. It relies on a set of tools including several models and scenarios to allow replicating the environment in which TCAS is being operated.

This methodology is a powerful technique by which a very large set of risk bearing encounters (which are rare events) can be stochastically generated to assess the safety benefits of TCAS or any other ATM safety nets.

As shown in the figure below, these models are used in particular to determine the risk, or 'logic system risk', which remains when TCAS is being operated (which results from the risk ratio³ achieved by TCAS and the underlying risk in the absence of TCAS). The 'logic system risk' is usually determined through the performance of TCAS simulations that include the modelling of pilot response to RAs in a very large set of modelled encounters.

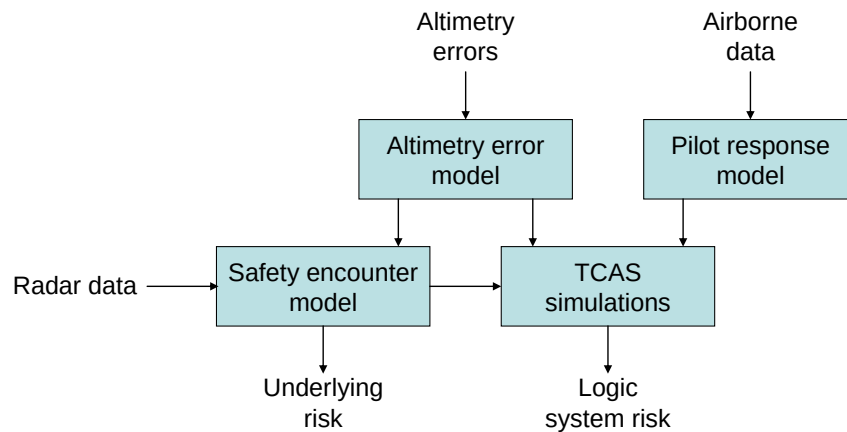


FIGURE 3: METHODOLOGY AND TOOLS FOR TCAS STUDIES

The tables in the following sub-sections summarise the models and scenarios used for the validation of MASPS automatic response to TCAS RAs scenarios. For more detail on the models and scenarios mentioned in these tables please refer to SESAR P04.08.02 AP/FD Validation Plan [3] where these are thoroughly described.

³

The risk ratio is the ratio between the rate of Near Mid-Air Collisions with TCAS II and the rate without TCAS II. A risk ratio less than 1 indicates that TCAS II improves safety. See Appendix A for a detailed description.