Safety and Performance Requirements for new possible altitude capture laws

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Abstract

The current report aims at presenting the safety and performance requirements for new altitude capture laws taking into account TCAS II thresholds to prevent the triggering of RAs in level-off encounters. These new altitude capture laws consist in reducing the own vertical speed automatically at the approach of the own selected flight level.

The requirements developed in this report are divided into 5 areas. The first one is related to TCAS, as the new altitude capture law is triggered with conditions among which the triggering of a TA. The second one is related to the availability of the new altitude capture law, as it shall be available under some circumstances. The third one is related to eligible encounter geometries on which the new altitude capture law has to apply. The fourth one is related to the behaviour of the new altitude capture law. The last one is related to the interface with the crew.

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Intellectual Property Rights (foreground)

The foreground of this deliverable is owned by the SJU.
The new altitude capture law assessed within [6] and from which part of the following requirements are derived, is patented by Airbus S.A.S. through the following references:

- Patent 1:
  - French application number: FR20080005212
  - French publication number: FR2936344

- U.S. application number: 12/563661
- U.S. publication number: US2010076626

- Patent 2:

  - French application number: FR20080005211
  - French publication number: FR2936343
  - U.S. application number: 12/562808
  - U.S. publication number: US2010076686

- Patent 3:

  - French application number: FR20100050719
  - French publication number: FR2955960
  - U.S. application number: 13/016154
  - U.S. publication number: US2011187561

- Patent 4:

  - French application number: FR20100050718
  - French publication number: FR2955961
  - U.S. application number: 13/015938
  - U.S. publication number: US2011187562
  - PCT filing number: PCT/FR2011/051827

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Executive summary

During 1000 ft level-off encounters, TCAS II triggers Resolution Advisories (RAs) which are often perceived as operationally undesired by air traffic controllers and flight crews. These RAs are caused by TCAS II predicting a risk of collision if the involved aircraft maintain their high vertical speeds. Indeed, the instantaneous vertical convergence is such that in case of an altitude bust, there are only a few seconds remaining before a possible collision.

In the past, some operational solutions based on the modification of departure procedures were developed locally and they contributed in reducing the number of these RAs in some TMAs. Although efficient, these solutions are not widely implemented. There are also several recommendations for reduced vertical speeds when approaching the cleared flight level, such as ICAO Doc 8168, PANS-OPS, recommending a vertical speed of less than 1500 fpm throughout the last 1000 ft of climb or descent to the cleared flight level. However, these recommendations are not always applied. In the case of the ICAO recommendation, it only applies when the pilot is made aware of another aircraft at (or approaching) an adjacent altitude or flight level, and it remains a recommendation to operators and flight crews.

The current report aims at presenting the safety and performance requirements for new altitude capture laws taking into account the TCAS II thresholds. These new altitude capture laws consist in reducing the own vertical speed automatically at the approach of the own selected flight level, so as to avoid the triggering of RAs in 1000 ft level-off encounters.

The requirements developed in this report are divided into 5 areas. The first one is related to TCAS, as the new altitude capture law is triggered with conditions among which the triggering of a TA. The second one is related to the availability of the new altitude capture law, as it shall be available under some circumstances. The third one is related to eligible encounter geometries on which the new altitude capture law has to apply. The fourth one is related to the behaviour of the new altitude capture law. The last one is related to the interface with the crew.

1 Introduction

1.1 Purpose of the document

This Safety and Performance Requirements (SPR) document provides the safety and performance requirements for a new autopilot mode introducing an altitude capture law aiming at reducing the vertical speed of aircraft approaching their own selected flight level to avoid the triggering of TCAS RAs.

This new altitude capture law is defined and assessed in the validation plan [5] and in the validation report [6].

1.2 Scope

This document supports the operational services and concept elements identified in [5] and [6]. These services are expected to be operational (IOC) in the *2011-2013* time frame.

1.3 Intended audience

This document is intended to the partners involved in the project. It is also intended to input Projects 4.2/5.2 and 4.8.3.

It may also serve to initiate coordination with standardisation bodies (EUROCAE WG75, RTCA SC147, RTCA SC220).

1.4 Structure of the document

The document is structured in four main parts. The operational concept is summarized in Section 2 based on the descriptions provided in [5] and [6].

The safety and performance requirements are listed in Section 3 and their allocation to system functions presented in Section 4.

Finally, Appendix A presents the safety and performance assessments which were performed to extract the requirements listed in Section 3.

1.5 Background

During 1000 ft level-off encounters, TCAS II triggers RAs which are often perceived as operationally undesired by air traffic controllers and flight crews. These RAs can cause unnecessary deviations from trajectories, and result in unnecessary stress for the flight crews.

These RAs are caused by TCAS II predicting a risk of collision if the involved aircraft maintain their high vertical speeds. Indeed, the instantaneous vertical convergence is such that in case of an altitude bust, there are only a few seconds remaining before a possible collision.

A technical solution, which consists in implementing new altitude capture laws taking into account TCAS II thresholds, was studied in [5] and [6]. This new altitude capture law consists in reducing the own vertical speed automatically at the approach of the own selected flight level, after the triggering of a Traffic Advisory by TCAS II.

The purpose of the new altitude capture laws is to reduce the number of RAs during 1000 ft level-off encounters, while not debasing the situation for other geometries of encounters.

This report is related to such new altitude capture laws.

1.6 Glossary of terms

Term	Definition
ACAS	Airborne Collision Avoidance System – a system standardised in the ICAO SARPs that uses transponder replies from other aircraft to warn the pilot of a

Term	Definition
	risk of impending collision Hereafter, ACAS always refers to ACAS II – a system that generates traffic advisories (TAs) and also generates resolution advisories (RAs) in the vertical plane.
ACASA safety encounter model	A safety encounter model developed in the ACASA project which characterised close encounters occurring in European airspace before the introduction of RVSM.
ASARP (or European) safety encounter model	An update of the ACASA safety encounter model developed in the ASARP project, following the introduction of RVSM operations in European airspace.
ATM encounter model	A mathematical model which reproduces the distributions and interdependencies of the parameters characterising risk bearing encounters likely to occur in ATM operations. The encounters that matters are those in which (at least) two aircraft are on trajectories which may trigger STCA alerts.
NMAC	Near Mid Air Collision – a pair of aircraft for which, at some point, the horizontal separation is less than 500ft and simultaneously the vertical separation is less than 100ft.
RA	Resolution Advisory – an ACAS alert providing advice to a pilot on how to modify or regulate the vertical speed to avoid a potential mid-air collision. For an individual aircraft in a multiple aircraft encounter, the RAs issued by the ACAS logic can either consist of: - sequential RAs against two distinct threats, or a composite RA against two simultaneous threats.
RVSM	Reduced Vertical Separation Minima – the regime by which the standard vertical separation between FL285 and FL415 has been reduced from 2,000ft to 1,000ft.
Safety encounter model	A mathematical model which reproduces the distributions and interdependencies of the parameters characterising risk bearing encounters likely to occur in ATM operations. The encounters that matters are those in which (at least) two aircraft are on a close encounter course in which there exist a risk of mid-air collision or in which the response of pilots to RAs can result in a risk of mid-air collision. The ASARP project used post-RVSM radar data to update the ACASA safety encounter model and produced the post-RVSM European safety encounter model, viz. the ASARP safety encounter model. This model is for pair-wise close encounters. The project also developed a multiple aircraft safety encounter model (for three aircraft).
TA	Traffic Alert – an ACAS alert warning the pilot of the presence of another aircraft that may become the subject of an RA
TCAS	Traffic Alert and Collision Avoidance System – an aircraft equipment that is an implementation of an ACAS Hereafter, TCAS refers to TCAS II, version 7.1 – the equipment that complies with the ICAO SARPS, and whose carriage and operation is mandatory for many aircraft in Europe, except when specified.
VMD	Vertical Miss Distance

1.7 Acronyms and Terminology

Term	Definition
ACAS/TCAS	Airborne collision avoidance system / Traffic alert and collision avoidance system
ADD	Architecture Definition Document
ATM	Air Traffic Management
DOD	Detailed Operational Description
E-ATMS	European Air Traffic Management System
CPA	Closest Point of Approach
HMD	Horizontal Miss Distance
HMU	Height Monitoring Unit
INTEROP	Interoperability Requirements
IRS	Interface Requirements Specification
MTOM	Maximum Take Off Mass
OSED	Operational Service and Environment Definition
RA	Resolution Advisory
SARPS	Standards And Recommended Practices
SESAR	Single European Sky ATM Research Programme
SJU	SESAR Joint Undertaking (Agency of the European Commission)
SJU Work Programme	The programme which addresses all activities of the SESAR Joint Undertaking Agency.
SESAR Programme	The programme which defines the Research and Development activities and Projects for the SJU.
SPR	Safety and Performance Requirements
TS	Technical Specification
TA	Traffic Advisory
TAD	Technical Architecture Description
VP	Validation Plan
WA1	Work Area 1

2 Summary of Operational Concept

2.1 Description of the Concept Element

During 1000 ft level-off encounters, TCAS II triggers RAs which are often perceived as operationally undesired by air traffic controllers and flight crews. These RAs can cause unnecessary deviations from trajectories, and result in unnecessary stress for the flight crews.

These RAs are caused by TCAS II predicting a risk of collision if the involved aircraft maintain their high vertical speeds. Indeed, the instantaneous vertical convergence is such that in case of an altitude bust, there are only a few seconds remaining before a possible collision.

The EUROCONTROL EMOTION-7 project [8] proposed some operational solutions based on the modification of arrival/departure procedures, which contributed reducing the number of these RAs in some TMAs. Even though efficient, these solutions are not widely implemented. There are also several recommendations for reduced vertical speeds approaching the cleared flight level, such as ICAO Doc 8168, PANS-OPS, recommending a vertical speed of less than 1500 fpm throughout the last 1000 ft of climb or descent to the cleared flight level. However, these recommendations are not always applied. In the case of the ICAO recommendation, it only applies when the pilot is made aware of another aircraft at (or approaching) an adjacent altitude or flight level, and it remains a recommendation.

Following an incident which occurred in March 2003 in France, the BEA (“Bureau d’Enquêtes et d’Analyses pour la sécurité de l’aviation civile”, which is the French body responsible for technical investigations into civil aviation accidents or incidents) made a recommendation stating that TCAS alert triggering threshold had to be taken into account into altitude capture laws [7].

For a greater performance when compared to already implemented operational solutions, a technical solution, which consists in implementing a new altitude capture law taking into account TCAS II thresholds, was studied in [6].

2.2 Description of Operational Services

The new altitude capture law consist in reducing the vertical speed automatically at the approach of the own selected flight level.

The principle of this solution is that, when a Traffic Advisory (TA) is triggered by TCAS II and under some conditions of the own aircraft trajectory, the vertical speed is automatically reduced through the autopilot, which enters into a new altitude capture mode. As a result, the likelihood that an RA is triggered is reduced. This mode can be activated in aircraft in TA/RA mode or TA-only mode, and remains active until the altitude capture is finished. Several configurations are available for the new altitude capture law. These configurations consist in optional features being enabled or not. Among the tested configurations [6], some offer an additional protection against multiple TAs, and some offer a protection against the triggering of induced RAs in a geometry called the “jump” geometry, in which an aircraft is climbing or descending passed another aircraft.

The new altitude capture law is associated to the following OSED requirements.

[REQ]

Identifier	REQ-04.08.02-OSED-TCAP.0001
Requirement	The new altitude capture law shall reduce the occurrences of operationally undesired RAs due to 1000 ft single level-off encounters (one aircraft level and the other one levelling-off 1000 ft beyond) as well as 1000 ft double level-off encounters (two aircraft levelling-off in the opposite direction vertically with targeted levels separated by 1000 ft). *Note: Extension to 500 ft level-off encounters, in particular with VFR aircraft not fitted with TCAS, could be considered but has not been assessed in the frame of SESAR WP 4.8.2.*
Title	Reducing the number of RAs in 1000 ft level-off geometries.
Status	<In Progress>
Rationale	Operationally undesired RAs represent more than half of RAs triggered by TCAS in the European airspace. They generate a lot of stress for the crew and can lead to unnecessary trajectory changes impacting air traffic management.
Category	<Performance>
Validation Method	<Fast Time Simulation>
Verification Method	<Test>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<APPLIES_TO>	<Application Process>	Application Service or Information Service or System Function Identifier	N/A

[REQ]

Identifier	REQ-04.08.02-OSED-TCAP.0002
Requirement	The new altitude capture law shall only be activated during altitude capture phases when presence of an intruder is confirmed in the close aircraft vicinity.
Title	Activation during altitude capture phases.
Status	<In Progress>
Rationale	Activation conditions aiming at detecting that the encounter geometry is likely a 1000 ft level-off are necessary so as to avoid modifying systematically aircraft trajectories during altitude captures, which would increase every altitude capture time, even when there is no risk for an operationally undesired RA to be triggered.
Category	<Performance>
Validation Method	<Fast Time Simulation>
Verification Method	<Test>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<APPLIES_TO>	<Application Process>	Application Service or Information Service or System Function Identifier	N/A

[REQ]

Identifier	REQ-04.08.02-OSED-TCAP.0003
Requirement	The new altitude capture law shall have a reasonable impact on the altitude capture time increase.
Title	Effect on altitude capture time.
Status	<In Progress>
Rationale	It is operationally not wished to remain a too long time in a level change situation.
Category	<Performance>
Validation Method	<Fast Time Simulation>
Verification Method	<Test>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<APPLIES_TO>	<Application Process>	Application Service or Information Service or System Function Identifier	N/A

[REQ]

Identifier	REQ-04.08.02-OSED-TCAP.0004
Requirement	The new altitude capture law shall favour a quick TA removal.
Title	Quick TA removal.
Status	<In Progress>
Rationale	This aims at favouring pilot confidence with the new altitude capture law effect.
Category	<Performance>
Validation Method	<Fast Time Simulation>
Verification Method	<Test>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<APPLIES_TO>	<Application Process>	Application Service or Information Service or System Function Identifier	N/A

[REQ]

Identifier	REQ-04.08.02-OSED-TCAP.0005
Requirement	The new altitude capture law shall minimize occurrence of self-produced TCAS TAs (multiple TA sequences) in the targeted encounter geometries (1000 ft simple/double level-off).
Title	Minimizing occurrence of multiple TAs.
Status	<In Progress>
Rationale	This aims at preventing as much as possible added TAs, which generates stress for the crew.
Category	<Performance>
Validation Method	<Fast Time Simulation>
Verification Method	<Test>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<APPLIES_TO>	<Application Process>	Application Service or Information Service or System Function Identifier	N/A

[REQ]

Identifier	REQ-04.08.02-OSED-TCAP.0006
Requirement	The new altitude capture law shall minimize occurrence of self-produced TCAS RAs in other encounter geometries than the targeted ones.
Title	Minimizing occurrence of self-produced TCAS RAs.
Status	<In Progress>
Rationale	This aims at preventing as much as possible added RAs, which generates stress for the crew and traffic perturbation.
Category	<Performance>
Validation Method	<Fast Time Simulation>
Verification Method	<Test>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<APPLIES_TO>	<Application Process>	Application Service or Information Service or System Function Identifier	N/A

[REQ]

Identifier	REQ-04.08.02-OSED-TCAP.0007
Requirement	The new altitude capture law should apply to 1000 ft level-off targeted geometries only.
Title	Application to level-off geometries only.
Status	<In Progress>
Rationale	This aims at avoiding added RAs possibly generated on non-targeted encounter geometries (e.g., jump geometry).
Category	<Performance>
Validation Method	<Fast Time Simulation>
Verification Method	<Test>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<APPLIES_TO>	<Application Process>	Application Service or Information Service or System Function Identifier	N/A

Table 1 – OSED requirements

2.3 Description of Operational Environment

The considered operational environment corresponds to any airspace in which TCAS is used, and with no specificity related to altitude requirements.

3 Requirements

3.1 The new altitude capture law

3.1.1 Performance Requirements

3.1.1.1 Interface prerequisite

[REQ]

Identifier	REQ-04.08.02-SPR-TCAP.0001
Requirement	The AutoPilot shall be informed of each occurrence of a Traffic Alert (TA) associated to the audio “Traffic Traffic” and preferably the intruder altitude.
Title	Knowledge of essential information
Status	<In Progress>
Rationale	
Category	<Performance>
Validation Method	<Fast Time Simulation>
Verification Method	<Test>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	<>	<Full>
<APPLIES_TO>	<Application Service> or <Information Service> or <System Function>	Application Service or Information Service or System Function Identifier	N/A
<APPLIES_TO>	<Operational Focus Area>	OFA03.04.02	N/A
<ALLOCATED_TO>	<Functional block>	Functional block Identifier	N/A
<CHANGED_BECAUSE_OF>	<Change Order>	Change reference	N/A

3.1.1.2 Availability of the new altitude capture law

[REQ]

Identifier	REQ-04.08.02-SPR-TCAP.0002
Requirement	The new altitude capture law shall be available when the AutoPilot is engaged.
Title	AutoPilot engaged.
Status	<In Progress>
Rationale	This aims at supporting the crew in preventing operationally undesired RAs through usual Auto Flight System function.
lCategory	<Performance>
Validation Method	<Fast Time Simulation>
Verification Method	<Test>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.08.02-OSED-TCAP.0001, REQ-04.08.02-OSED-TCAP.0002	<Full>
<APPLIES_TO>	<Application Service> or <Information Service> or <System Function>	Application Service or Information Service or System Function Identifier	N/A
<APPLIES_TO>	<Operational Focus Area>	OFA03.04.02	N/A
<ALLOCATED_TO>	<Functional block>	Functional block Identifier	N/A
<CHANGED_BECAUSE_OF>	<Change Order>	Change reference	N/A

[REQ]

Identifier	REQ-04.08.02-SPR-TCAP.0003
Requirement	The new altitude capture law shall be available when the TCAS system is in ‘TA/RA’ or ‘TA Only’ modes.

Title	Availability in 'TA/RA' or 'TA Only' modes.
Status	<In Progress>
Rationale	Even when in "TA only mode", an own aircraft can result in an RA being triggered onboard an intruder aircraft (at (or approaching) an adjacent Flight Level) in a 1000 ft level-off encounter. Therefore it is necessary for an aircraft in "TA only" mode to have the new altitude capture law available so as to avoid an RA being triggered onboard the intruder aircraft during a 1000 ft level-off encounters. This permits to ensure maximum efficiency of the new altitude capture law in a given airspace.
Category	<Performance>
Validation Method	<Fast Time Simulation>
Verification Method	<Test>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.08.02-OSED-TCAP.0001	<Full>
<APPLIES_TO>	<Application Service> or <Information Service> or <System Function>	Application Service or Information Service or System Function Identifier	N/A
<APPLIES_TO>	<Operational Focus Area>	OFA03.04.02	N/A
<ALLOCATED_TO>	<Functional block>	Functional block Identifier	N/A
<CHANGED_BECAUSE_OF>	<Change Order>	Change reference	N/A

[REQ]

Identifier	REQ-04.08.02-SPR-TCAP.0004
Requirement	The new altitude capture law shall be available when the AutoPilot intends to perform an altitude capture as per AutoPilot usual behaviour. *Note: Example of AutoPilot usual behaviour can be aircraft convergence towards own selected altitude and conventional 'altitude capture' mode armed.*
Title	Availability during altitude capture.
Status	<In Progress>
Rationale	The new altitude capture law aims at avoiding RAs in 1000 ft level-off encounters.
Category	<Performance>
Validation Method	<Fast Time Simulation>
Verification Method	<Test>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.08.02-OSED-TCAP.0002	<Full>
<APPLIES_TO>	<Application Service> or <Information Service> or <System Function>	Application Service or Information Service or System Function Identifier	N/A
<APPLIES_TO>	<Operational Focus Area>	OFA03.04.02	N/A
<ALLOCATED_TO>	<Functional block>	Functional block Identifier	N/A
<CHANGED_BECAUSE_OF>	<Change Order>	Change reference	N/A

[REQ]

Identifier	REQ-04.08.02-SPR-TCAP.0005
Requirement	Precautions shall be taken to avoid the new altitude capture law activation close to the ground. *Note: For example, inhibition in take-off and approach mode could be considered.*
Title	Ground proximity.
Status	<In Progress>
Rationale	Own vertical speed reduction can be conflicting with terrain clearance or can disturb approach phases.
Category	<Performance>
Validation Method	<Fast Time Simulation>
Verification Method	<Test>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	<>	<Full>
<APPLIES_TO>	<Application Service> or <Information Service> or <System Function>	Application Service or Information Service or System Function Identifier	N/A
<APPLIES_TO>	<Operational Focus Area>	OFA03.04.02	N/A
<ALLOCATED_TO>	<Functional block>	Functional block Identifier	N/A
<CHANGED_BECAUSE_OF>	<Change Order>	Change reference	N/A

[REQ]

Identifier	REQ-04.08.02-SPR-TCAP.0006
Requirement	The new altitude capture law shall only be activated if the radio altimeter altitude of own aircraft is higher than 900 ft.
Title	Inhibition below 900 ft.
Status	<In Progress>
Rationale	There is no need to activate the new altitude capture law below TCAS RA inhibition threshold because no RA can be issued.
Category	<Performance>
Validation Method	<Fast Time Simulation>
Verification Method	<Test>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.08.02-OSED-TCAP.0001	<Full>
<APPLIES_TO>	<Application Service> or <Information Service> or <System Function>	Application Service or Information Service or System Function Identifier	N/A
<APPLIES_TO>	<Operational Focus Area>	OFA03.04.02	N/A
<ALLOCATED_TO>	<Functional block>	Functional block Identifier	N/A
<CHANGED_BECAUSE_OF>	<Change Order>	Change reference	N/A

3.1.1.3 Eligible encounters

[REQ]

Identifier	REQ-04.08.02-SPR-TCAP.0007
Requirement	When the new altitude capture law is capable to acquire intruder altitude and if this altitude is available, it shall be available if intruder position at TA (ZTA_intruder) is at least 500 ft farther than own targeted altitude. In climb, the new altitude capture law is inhibited if ZTA_intruder < FLtarget + 500 ft and in descent, the new altitude capture law is inhibited if ZTA_intruder > FLtarget – 500 ft. *Note: The '500 ft' value has been assessed as a proper value to prevent induced-RA. Lower values may be considered to better address 500 ft level-off geometries.*
Title	Intruder's altitude logic - Threshold
Status	<In Progress>
Rationale	This should limit the new altitude capture law application to the intended encounters geometries (i.e. 1000ft separation level-off), and to avoid triggering of the new altitude capture law in the "jump" geometry.
Category	<Performance>
Validation Method	<Fast Time Simulation>
Verification Method	<Test>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.08.02-OSED-TCAP.0006, REQ-04.08.02-OSED-TCAP.0007	<Full>
<APPLIES_TO>	<Application Service> or <Information Service> or <System Function>	Application Service or Information Service or System Function Identifier	N/A
<APPLIES_TO>	<Operational Focus Area>	OFA03.04.02	N/A
<ALLOCATED_TO>	<Functional block>	Functional block Identifier	N/A
<CHANGED_BECAUSE_OF>	<Change Order>	Change reference	N/A

[REQ]

Identifier	REQ-04.08.02-SPR-TCAP.0008
Requirement	When the new altitude capture law is capable to acquire intruder altitude but when this altitude is not available, the new altitude capture law shall be inhibited.
Title	Intruder's altitude logic – Intruder's altitude unavailable
Status	<In Progress>
Rationale	TA alerts can be triggered even if intruder altitude is not reported but in this case RA alerts are inhibited.
Category	<Performance>
Validation Method	<Fast Time Simulation>
Verification Method	<Test>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.08.02-OSED-TCAP.0006, REQ-04.08.02-OSED-TCAP.0007	<Full>
<APPLIES_TO>	<Application Service> or <Information Service> or <System Function>	Application Service or Information Service or System Function Identifier	N/A
<APPLIES_TO>	<Operational Focus Area>	OFA03.04.02	N/A
<ALLOCATED_TO>	<Functional block>	Functional block Identifier	N/A
<CHANGED_BECAUSE_OF>	<Change Order>	Change reference	N/A

[REQ]

Identifier	REQ-04.08.02-SPR-TCAP.0009
Requirement	When the new altitude capture law is not capable to acquire intruder altitude, it shall be inhibited if current encounter geometry is considered as irrelevant. *Note: A possible way to identify an irrelevant geometry can be to rely on the difference between own altitude and targeted altitude and on own vertical speed at TA. An acceptable realization of this requirement can be to define 'the new altitude capture law availability threshold' beyond which it is relevant or not to activate the new altitude capture law.* *The new altitude capture law availability threshold' assessed in the frame of SESAR 4.8.2 is an estimation of the upper distance from targeted altitude where a TA can occur with an intruder targeting beyond own target.* *This threshold computation is based on targeted altitude Z_{TGT}, current aircraft altitude Z_{AC} at TA and current aircraft own vertical speed Vz at TA according the formula:* $DZ_{avail} = sign(Z_{AC}-Z_{TGT})\ Max(\ 2000ft;\ T_{TA}\ |Vz| + (0.05\ g/2)\ (60^2/0.3048)\ T_{TA}^2)$
Title	Inhibition logic.
Status	<In Progress>
Rationale	This aims at limiting the new altitude capture law application to the just necessary cases and particularly to avoid forcing an undue activation in case of TA occurring far from the targeted altitude with a current low own vertical speed.
Category	<Performance>
Validation Method	<Fast Time Simulation>
Verification Method	<Test>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.08.02-OSED-TCAP.0006,	<Full>

		REQ-04.08.02-OSED-TCAP.0007	
<APPLIES_TO>	<Application Service> or <Information Service> or <System Function>	Application Service or Information Service or System Function Identifier	N/A
<APPLIES_TO>	<Operational Focus Area>	OFA03.04.02	N/A
<ALLOCATED_TO>	<Functional block>	Functional block Identifier	N/A
<CHANGED_BECAUSE_OF>	<Change Order>	Change reference	N/A

[REQ]

Identifier	REQ-04.08.02-SPR-TCAP.0010
Requirement	When the new altitude capture law is capable to acquire intruder altitude, the intruder altitude logic shall be implemented. *Note: The two following inhibition logics have been assessed and validated in [6]:* · *-Intruder altitude logic together with the threshold inhibition logic* · *-Threshold inhibition logic only* *The intruder altitude logic alone has not been validated in [6] but is anticipated as a possible efficient implementation.*
Title	Intruder's altitude and inhibition logics combination.
Status	<In Progress>
Rationale	The intruder altitude logic has shown great benefits to avoid induced RAs.
Category	<Performance>
Validation Method	<Fast Time Simulation>
Verification Method	<Test>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.08.02-OSED-TCAP.0006, REQ-04.08.02-OSED-TCAP.0007	<Full>
<APPLIES_TO>	<Application Service> or <Information Service> or <System Function>	Application Service or Information Service or System Function Identifier	N/A
<APPLIES_TO>	<Operational Focus Area>	OFA03.04.02	N/A
<ALLOCATED_TO>	<Functional block>	Functional block Identifier	N/A
<CHANGED_BECAUSE_OF>	<Change Order>	Change reference	N/A

[REQ]

Identifier	REQ-04.08.02-SPR-TCAP.0011
Requirement	The new altitude capture law shall be automatically activated at the time a Traffic Alert (TA) associated to the audio "Traffic Traffic" is generated. *Note: For example, a 'residual' TA occurring at Clear of Conflict after an RA or a 'residual' TA following the loss of an RA due to TCAS setting to 'TA Only' shall not activate the new altitude capture law (no 'Traffic Traffic' audio in those cases).*
Title	The new altitude capture law activation at TA.
Status	<In Progress>
Rationale	The new altitude capture law objective being to prevent the RA, the new altitude capture law activation is based on the RA precursor, which is the TA.
Category	<Performance>
Validation Method	<Fast Time Simulation>
Verification Method	<Test>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.08.02-OSED-TCAP.0002	<Full>
<APPLIES_TO>	<Application Service> or <Information Service> or <System Function>	Application Service or Information Service or System Function Identifier	N/A
<APPLIES_TO>	<Operational Focus Area>	OFA03.04.02	N/A
<ALLOCATED_TO>	<Functional block>	Functional block Identifier	N/A
<CHANGED_BECAUSE_OF>	<Change Order>	Change reference	N/A

[REQ]

Identifier	REQ-04.08.02-SPR-TCAP.0012
Requirement	If the TA ceases while the new altitude capture law is active, the new altitude capture law shall be maintained till the end of the altitude capture to avoid temporary own vertical speed increase.
Title	The new altitude capture law behaviour at end of TA.
Status	<In Progress>
Rationale	Come back to conventional altitude capture could lead to trigger a new TA and possibly an RA.
Category	<Performance>
Validation Method	<Fast Time Simulation>
Verification Method	<Test>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.08.02-OSED-TCAP.0006	<Full>
<APPLIES_TO>	<Application Service> or <Information Service> or <System Function>	Application Service or Information Service or System Function Identifier	N/A
<APPLIES_TO>	<Operational Focus Area>	OFA03.04.02	N/A
<ALLOCATED_TO>	<Functional block>	Functional block Identifier	N/A
<CHANGED_BECAUSE_OF>	<Change Order>	Change reference	N/A

3.1.1.4 Behaviour of the new capture law

[REQ]

Identifier	REQ-04.08.02-SPR-TCAP.0013
Requirement	When activated, the new altitude capture law shall reduce the absolute value of the aircraft own vertical speed.

	Note: The own vertical speed can be reduced continuously or by step. The realisation below provides some values of vertical speed targets found acceptable. These values depends on the relative altitude to own target altitude DZTA and current own vertical speed VzTA at TA occurrence. •*Farther than 2000 ft from targeted altitude ('early TA'), a preliminary own vertical speed target is applied till reaching last 2000 ft.* •*Vertical speed target is refreshed to 1500 fpm when the aircraft reaches the last 2000 ft from own targeted altitude.* •*Inside the last 2000 ft, vertical speed target is function of the distance DZ.*
Title	Vertical speed reduction.
Status	<In Progress>
Rationale	Reducing the own vertical speed allows delaying time to collision and thus RA triggering.
Category	<Performance>
Validation Method	<Fast Time Simulation>
Verification Method	<Test>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.08.02-OSED-TCAP.0001	<Full>
<APPLIES_TO>	<Application Service> or <Information Service> or <System Function>	Application Service or Information Service or System Function Identifier	N/A
<APPLIES TO>	<Operational Focus Area>	OFA03.04.02	N/A
<ALLOCATED TO>	<Functional block>	Functional block Identifier	N/A
<CHANGED BECAUSE OF>	<Change Order>	Change reference	N/A

[REQ]

Identifier	REQ-04.08.02-SPR-TCAP.0014
Requirement	The absolute value of the own vertical speed commanded by the new altitude capture law shall never increase until reaching the targeted altitude (assuming no turbulent conditions).
Title	Vertical speed shall not increase.
Status	<In Progress>
Rationale	Prevention of operationally undesired RAs basically relies on a own vertical speed reduction.
Category	<Performance>
Validation Method	<Fast Time Simulation>
Verification Method	<Test>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.08.02-OSED-TCAP.0001	<Full>
<APPLIES_TO>	<Application Service> or <Information Service> or <System Function>	Application Service or Information Service or System Function Identifier	N/A
<APPLIES_TO>	<Operational Focus Area>	OFA03.04.02	N/A
<ALLOCATED_TO>	<Functional block>	Functional block Identifier	N/A
<CHANGED_BECAUSE_OF>	<Change Order>	Change reference	N/A

[REQ]

Identifier	REQ-04.08.02-SPR-TCAP.0015
Requirement	To ensure performance in term of operationally undesired RAs removal, the new altitude capture law shall command a own vertical speed of 1200 fpm for a TA occurring within the last 1000 ft from targeted altitude.
Title	Vertical speed reduction in the last 1000 ft.
Status	<In Progress>
Rationale	During the validation [6], this constraint was used. Using this constraint permits to have significant results in reducing the number of RAs in 1000 ft level-off encounters, without any major drawbacks [6]. The choice of own vertical speed was made through a compromise aiming at maximizing the RA speed reduction while minimizing the increase of the time to capture the selected flight level when compared to an usual capture law with a 0.05 g acceleration.
Category	<Performance>
Validation Method	<Fast Time Simulation>
Verification Method	<Test>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.08.02-OSED-TCAP.0001, REQ-04.08.02-OSED-TCAP.0003	<Full>
<APPLIES_TO>	<Application Service> or <Information Service> or <System Function>	Application Service or Information Service or System Function Identifier	N/A
<APPLIES_TO>	<Operational Focus Area>	OFA03.04.02	N/A
<ALLOCATED_TO>	<Functional block>	Functional block Identifier	N/A
<CHANGED_BECAUSE_OF>	<Change Order>	Change reference	N/A

[REQ]

Identifier	REQ-04.08.02-SPR-TCAP.0016
Requirement	To ensure performance in term of operationally undesired RAs removal, the new altitude capture law shall command a own vertical speed of no more than 1500 fpm for a TA occurring between 2000 ft and 1000 ft from targeted altitude.
Title	Vertical speed reduction in the last 2000 ft.
Status	<In Progress>
Rationale	During the validation [6], this constraint was used. Using this constraint permits to have significant results in reducing the number of RAs in 1000 ft level-off encounters, without any major drawbacks [6]. The choice of own vertical speed was made through a compromise aiming at maximizing the RA rate reduction while minimizing the increase of the time to capture the selected flight level when compared to an usual capture law with a 0.05 g acceleration.
Category	<Performance>
Validation Method	<Fast Time Simulation>
Verification Method	<Test>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.08.02-OSED-TCAP.0001, REQ-04.08.02-OSED-TCAP.0003	<Full>
<APPLIES_TO>	<Application Service> or <Information Service> or <System Function>	Application Service or Information Service or System Function Identifier	N/A
<APPLIES_TO>	<Operational Focus Area>	OFA03.04.02	N/A
<ALLOCATED_TO>	<Functional block>	Functional block Identifier	N/A
<CHANGED_BECAUSE_OF>	<Change Order>	Change reference	N/A

[REQ]

Identifier	REQ-04.08.02-SPR-TCAP.0017
Requirement	If a new Traffic Alert (TA) associated to the audio “Traffic Traffic” occurs while the new altitude capture law is already activated, the new altitude capture law commanded own vertical speed target shall be refreshed.
Title	Secondary TAs treatment.
Status	<In Progress>
Rationale	Previous own vertical speed target may be no more sufficient to prevent an RA.
Category	<Performance>
Validation Method	<Fast Time Simulation>
Verification Method	<Test>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.08.02-OSED-TCAP.0001	<Full>
<APPLIES_TO>	<Application Service> or <Information Service> or <System Function>	Application Service or Information Service or System Function Identifier	N/A
<APPLIES_TO>	<Operational Focus Area>	OFA03.04.02	N/A
<ALLOCATED_TO>	<Functional block>	Functional block Identifier	N/A
<CHANGED_BECAUSE_OF>	<Change Order>	Change reference	N/A

[REQ]

Identifier	REQ-04.08.02-SPR-TCAP.0018
Requirement	To allow final end of the capture, conventional altitude capture control law shall be used when its command induces a stronger own vertical speed reduction than the new altitude capture law command.
Title	Final capture.
Status	<In Progress>
Rationale	This aims at allowing final end of the capture.
Category	<Performance>
Validation Method	<Fast Time Simulation>
Verification Method	<Test>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.08.02-OSED-TCAP.0003	<Full>
<APPLIES_TO>	<Application Service> or <Information Service> or <System Function>	Application Service or Information Service or System Function Identifier	N/A
<APPLIES_TO>	<Operational Focus Area>	OFA03.04.02	N/A
<ALLOCATED_TO>	<Functional block>	Functional block Identifier	N/A
<CHANGED_BECAUSE_OF>	<Change Order>	Change reference	N/A

[REQ]

Identifier	REQ-04.08.02-SPR-TCAP.0019
Requirement	The targeted load factor for the new altitude capture law control law shall not be less than 0.15 g. *Note: It has been shown that an authority of 0.3g does not bring any benefits compared to 0.15 g. Values below 0.15 g have not been evaluated. Implementation with an acceleration lower than this value should be evaluated properly before use.*
Title	Load factor.
Status	<In Progress>
Rationale	Choosing such a value higher than the usual 0.05 g aims at reaching faster the targeted own vertical speed for a better RA prevention performance.
Category	<Performance>
Validation Method	<Fast Time Simulation>
Verification Method	<Test>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.08.02-OSED-TCAP.0001	<Full>
<APPLIES_TO>	<Application Service> or <Information Service> or <System Function>	Application Service or Information Service or System Function Identifier	N/A
<APPLIES_TO>	<Operational Focus Area>	OFA03.04.02	N/A
<ALLOCATED_TO>	<Functional block>	Functional block Identifier	N/A
<CHANGED_BECAUSE_OF>	<Change Order>	Change reference	N/A

[REQ]

Identifier	REQ-04.08.02-SPR-TCAP.0020
Requirement	Usual speed protection logics applying to conventional altitude capture shall remain active when the new altitude capture law is activated.
Title	Active speed protection.
Status	<In Progress>
Rationale	This aims at maintaining aircraft own vertical speed within the normal flight envelop.
Category	<Performance>
Validation Method	<Fast Time Simulation>
Verification Method	<Test>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	<>	<Full>
<APPLIES_TO>	<Application Service> or <Information Service> or <System Function>	Application Service or Information Service or System Function Identifier	N/A
<APPLIES_TO>	<Operational Focus Area>	OFA03.04.02	N/A
<ALLOCATED_TO>	<Functional block>	Functional block Identifier	N/A
<CHANGED_BECAUSE_OF>	<Change Order>	Change reference	N/A

[REQ]

Identifier	REQ-04.08.02-SPR-TCAP.0021
Requirement	The new altitude capture law shall command a own vertical speed depending on the relative altitude to the own selected flight level and on the own vertical speed at the time of the TA. *Note: An example of acceptable solution tested is shown in Appendix A, in tables 6 and 7.*
Title	Vertical speed target.
Status	<In Progress>
Rationale	This method was chosen so as to decrease the likelihood to have an RA while minimizing the effect on altitude capture time.
Category	<Performance>
Validation Method	<Fast Time Simulation>
Verification Method	<Test>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.08.02-OSED-TCAP.0001	<Full>
<APPLIES_TO>	<Application Service> or <Information Service> or <System Function>	Application Service or Information Service or System Function Identifier	N/A
<APPLIES_TO>	<Operational Focus Area>	OFA03.04.02	N/A
<ALLOCATED TO>	<Functional block>	Functional block Identifier	N/A
<CHANGED BECAUSE OF>	<Change Order>	Change reference	N/A

[REQ]

Identifier	REQ-04.08.02-SPR-TCAP.0022
Requirement	The new altitude capture law control law should include an additional protection preventing the occurrence of self-produced TAs due to the same intruder, especially to avoid multiple-TAs sequences in the case of the simple level-off encounter geometry (which is the most preponderant geometry in European airspace). *Note: Example of realization for multi-TA protection:* *In order to protect the aircraft against another TA caused by the same intruder cruising at an adjacent level, the new altitude capture law own vertical speed target can be reduced if TA horizon, located at the altitude* $Z(t)+T_{TA}.Vz(t)$*, exceeds intended altitude target by more than 500 ft according to the formula:* $T_{TA}\ |Vz_{TGT}| < |\ Z_{TGT} - Z_{AC}\ | - 500ft$ *with ZAC: current aircraft altitude, ZTGT: targeted altitude and TTA: TCAS TA threshold.*
Title	Multiple TA protection.
Status	<In Progress>
Rationale	This aims at preventing as much as possible nuisance TCAS TA alerts, which generate stress for the crew.
Category	<Performance>
Validation Method	<Fast Time Simulation>
Verification Method	<Test>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	REQ-04.08.02-OSED-TCAP.0005	<Full>
<APPLIES_TO>	<Application Service> or <Information Service> or <System Function>	Application Service or Information Service or System Function Identifier	N/A
<APPLIES_TO>	<Operational Focus Area>	OFA03.04.02	N/A
<ALLOCATED_TO>	<Functional block>	Functional block Identifier	N/A
<CHANGED_BECAUSE_OF>	<Change Order>	Change reference	N/A

3.1.1.5 Compatibility with other modes

[REQ]

Identifier	REQ-04.08.02-SPR-TCAP.0023
Requirement	The new altitude capture mode shall interact compatibly with Autothrust modes and engagement status.
Title	Compatibility with Autothrust modes and engagement status.
Status	<In Progress>
Rationale	
Category	<Performance>
Validation Method	<Fast Time Simulation>
Verification Method	<Test>

[REQ Trace]

Relationship	Linked Element Type	Identifier	Compliance
<SATISFIES>	<ATMS Requirement>	<>	<Full>
<APPLIES_TO>	<Application Service> or <Information Service> or <System Function>	Application Service or Information Service or System Function Identifier	N/A
<APPLIES_TO>	<Operational Focus Area>	OFA03.04.02	N/A
<ALLOCATED TO>	<Functional block>	Functional block Identifier	N/A
<CHANGED BECAUSE OF>	<Change Order>	Change reference	N/A

Table 2 – Requirements capture layout

4 Traceability matrix

Requirement Identification	Requirement title	Functional block Id < xxxxx >	System Function Identifier	Information Service or Application Service Identifier
REQ-04.08.02-SPR-TCAP.0001	Knowledge of essential information	*tbd*	*tbd*	*tbd*
REQ-04.08.02-SPR-TCAP.0002	AutoPilot engaged.	*tbd*	*tbd*	*tbd*
REQ-04.08.02-SPR-TCAP.0003	Availability in 'TA/RA' or 'TA Only' modes.	*tbd*	*tbd*	*tbd*
REQ-04.08.02-SPR-TCAP.0004	Availability during altitude capture.	*tbd*	*tbd*	*tbd*
REQ-04.08.02-SPR-TCAP.0005	Ground proximity.	*tbd*	*tbd*	*tbd*
REQ-04.08.02-SPR-TCAP.0006	Inhibition below 900 ft.	*tbd*	*tbd*	*tbd*
REQ-04.08.02-SPR-TCAP.0007	Intruder's altitude logic - Threshold	*tbd*	*tbd*	*tbd*
REQ-04.08.02-SPR-TCAP.0008	Intruder's altitude logic – Intruder's altitude unavailable	*tbd*	*tbd*	*tbd*
REQ-04.08.02-SPR-TCAP.0009	Inhibition logic.	*tbd*	*tbd*	*tbd*
REQ-04.08.02-SPR-TCAP.0010	Intruder's altitude and inhibition logics combination.	*tbd*	*tbd*	*tbd*
REQ-04.08.02-SPR-TCAP.0011	The new altitude capture law activation at TA.	*tbd*	*tbd*	*tbd*
REQ-04.08.02-SPR-TCAP.0012	The new altitude capture law behaviour at end of TA.	*tbd*	*tbd*	*tbd*
REQ-04.08.02-SPR-TCAP.0013	Vertical speed reduction.	*tbd*	*tbd*	*tbd*
REQ-04.08.02-SPR-TCAP.0014	Vertical speed shall not increase.	*tbd*	*tbd*	*tbd*
REQ-04.08.02-SPR-TCAP.0015	Vertical speed reduction in the last 1000 ft.	*tbd*	*tbd*	*tbd*
REQ-04.08.02-SPR-TCAP.0016	Vertical speed reduction in the last 2000 ft.	*tbd*	*tbd*	*tbd*
REQ-04.08.02-SPR-TCAP.0017	Secondary TAs treatment.	*tbd*	*tbd*	*tbd*

Requirement Identification	Requirement title	Functional block Id < xxxxx >	System Function Identifier	Information Service or Application Service Identifier
REQ-04.08.02-SPR-TCAP.0018	Final capture.	*tbd*	*tbd*	*tbd*
REQ-04.08.02-SPR-TCAP.0019	Load factor.	*tbd*	*tbd*	*tbd*
REQ-04.08.02-SPR-TCAP.0020	Active speed protection.	*tbd*	*tbd*	*tbd*
REQ-04.08.02-SPR-TCAP.0021	Vertical speed target.	*tbd*	*tbd*	*tbd*
REQ-04.08.02-SPR-TCAP.0022	Multiple TA protection.	*tbd*	*tbd*	*tbd*
REQ-04.08.02-SPR-TCAP.0023	Compatibility with Autothrust modes and engagement status.	*tbd*	*tbd*	*tbd*

Table 3 - Requirement traceability matrix

5 References and Applicable Documents

5.1 Applicable Documents

This SPR complies with the requirements set out in the following documents:

[1] SESAR SEMP 2.0
[2] Template Toolbox 03.00.00
[3] Requirements and V&V Guidelines 02.00.00
[4] Toolbox User Manual 02.00.00

5.2 Reference Documents

The following documents were used to provide input / guidance / further information / other:

[5] **SESAR 4.8.2.1** – Validation Plan – Deliverable 5, edition 00.00.01, August 2010
[6] **SESAR 4.8.2.1** – Validation Report – Deliverable 6, edition 00.00.01, April 2010
[7] **BEA,** Incident grave survenu en vol le 23 mars 2003 aux avions immatriculés F-GPMF et F-GHQA exploités par Air France – rapport f-mf030323 f-qa030323, mars 2003
[8] **EMOTION-7,** Final report, WP5/107/D, version 1.3, January 2003
[9] **BEA,** Incident grave survenu en vol le 23 mars 2003 aux avions immatriculés F-GPMF et F-GHQA exploités par Air France – rapport f-mf030323 f-qa030323, mars 2003

Appendix A Assessment / Justifications

A.1Safety and Performance Assessments

A.1.1Functional requirements

The following section defines functional requirements identified for the TCAS Alert Prevention (AltCapt) function as derived from the operational requirements.

A.1.1.1 General

A.1.1.2 Assumptions

Assumption: The validation of several new altitude capture law implementations [6] was performed with TCAS II logic version 7.1. The behaviour of these implementations was not assessed with other CAS logic versions. The new altitude capture law is therefore assumed to be used with TCAS II logic version 7.1.

Assumption: The new altitude capture law is only available onboard an aircraft with a TCAS operating in TA/RA or “TA only” mode. The new altitude capture law is activated with several conditions among which the triggering of a TA.

Assumption: All the requirements below assume that the autopilot is engaged and therefore apply to the AutoPilot function. It is anticipated that extension to the Flight Director would not result in any difference, but this was not evaluated.

Assumption: As the new altitude capture law may command a significant vertical speed reduction at a distance to targeted altitude possibly greater than usually, thrust shall be adapted accordingly to ensure an appropriate speed control.

A.1.1.3Interface prerequisites

Requirement 1) The AutoPilot shall be informed of each occurrence of a Traffic Alert (TA) associated to the audio “Traffic Traffic” and preferably the intruder altitude.

A.1.1.4New altitude capture law availability

Requirement 2) The new altitude capture law shall be available when the AutoPilot is engaged.
Rationale: This aims at supporting the crew in preventing operationally undesired RAs through usual Auto Flight System function.

Requirement 3) The new altitude capture law shall be available when the TCAS system is in ‘TA/RA’ or ‘TA Only’ modes.
Rationale: Even when in “TA only mode”, an own aircraft can result in an RA being triggered onboard an intruder aircraft (at (or approaching) an adjacent Flight Level) in a 1000 ft level-off encounter. Therefore it is necessary for an aircraft in “TA only” mode to have the new altitude capture law available so as to avoid an RA being triggered onboard the intruder aircraft during a 1000 ft level-off encounters. This permits to ensure maximum efficiency of the new altitude capture law in a given airspace.

Requirement 4) The new altitude capture law shall be available when the AutoPilot intends to perform an altitude capture as per AutoPilot usual behaviour.
Note: Example of AutoPilot usual behaviour can be aircraft convergence towards own selected altitude and conventional ‘altitude capture’ mode armed.
Rationale: The new altitude capture law aims at avoiding RAs in 1000 ft level-off encounters.

Requirement 5) Precautions shall be taken to avoid the new altitude capture law activation close to the ground.
Note: For example, inhibition in take-off and approach mode could be considered.
Rationale: Own vertical speed reduction can be conflicting with terrain clearance or can disturb approach phases.

Requirement 6) The new altitude capture law shall only be activated if the radio altimeter altitude of own aircraft is higher than 900 ft.
Rationale: There is no need to activate the new altitude capture law below TCAS RA inhibition threshold because no RA can be issued.

A.1.1.5 Eligible encounter geometries

Requirement 7) When the new altitude capture law is capable to acquire intruder altitude and if this altitude is available, it shall be available if intruder position at TA (ZTA_intruder) is at least 500 ft farther than own targeted altitude. In climb, the new altitude capture law is inhibited if ZTA_intruder < FLtarget + 500 ft and in descent, the new altitude capture law is inhibited if ZTA_intruder > FLtarget – 500 ft.
Note: The '500 ft' value has been assessed as a proper value to prevent induced-RA. Lower values may be considered to better address 500 ft level-off geometries.

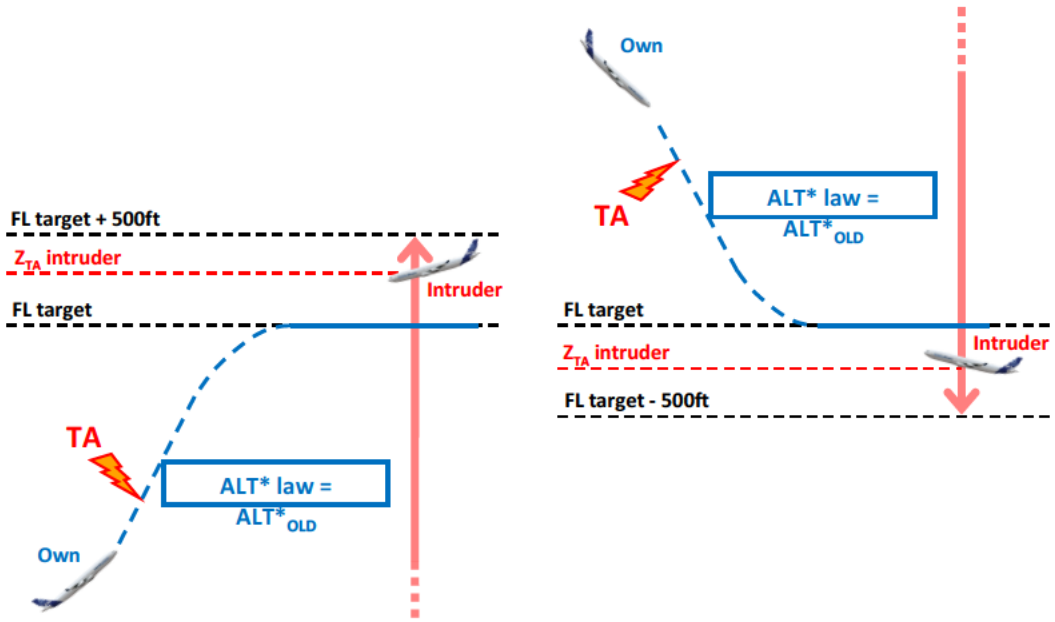
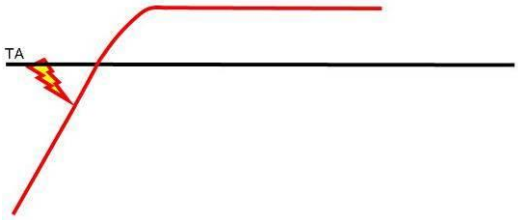
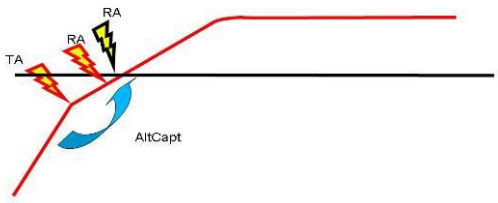


Figure 1 – Use of Intruder altitude

Rationale:This should limit the new altitude capture law application to the intended encounters geometries (i.e. 1000ft separation level-off), and to avoid triggering of the new altitude capture law in the "jump" geometry.



Jump encounter without the new altitude capture law



Jump encounter with the new altitude capture law

Figure 2 - Jump Geometry

It must be noted that for the new altitude capture law to trigger in this geometry, a TA must be triggered. This means that the new altitude capture law would not trigger each time this geometry is observed, but only when this geometry results in a TA being triggered. In addition it was observed [6] that the RAs triggered in this geometry occur mainly in situations in which there are losses of separation even without the new altitude capture law.

Requirement 8) When the new altitude capture law is capable to acquire intruder altitude but when this altitude is not available, the new altitude capture law shall be inhibited.
Rationale: TA alerts can be triggered even if intruder altitude is not reported but in this case RA alerts are inhibited.

Requirement 9) When the new altitude capture law is not capable to acquire intruder altitude, it shall be inhibited if current encounter geometry is considered as irrelevant.

Note: A possible way to identify an irrelevant geometry can be to rely on the difference between own altitude and targeted altitude and on own vertical speed at TA. An acceptable realization of this requirement can be to define 'the new altitude capture law availability threshold' beyond which it is relevant or not to activate the new altitude capture law.

The new altitude capture law availability threshold' assessed in the frame of SESAR 4.8.2 is an estimation of the upper distance from targeted altitude where a TA can occur with an intruder targeting beyond own target.

This threshold computation is based on targeted altitude Z_{TGT}, current aircraft altitude Z_{AC} at TA and current aircraft own vertical speed Vz at TA according the formula:

$$DZ_{avail} = sign(Z_{AC}-Z_{TGT})\ Max(\ 2000ft;\ T_{TA}\ |Vz| + (0.05\ g/2)\ (60^2/0.3048)\ T_{TA}^2)$$

with T_{TA}: the linear interpolation of the following table of values, depending on the maximum altitude Z_{MAX} between Z_{TGT} and Z_{AC}:

Z_{MAX} (ft)	2350	5000	10000	20000
T_{TA} (min)	0.5	2/3	0.75	0.8

Table 4 – TTa thresholds

The following table gives examples of the new altitude capture law availability thresholds according to aircraft own vertical speed and altitude:

|Vz| (fpm)		2000	3000	4000	5000	6000	7000	8000
$\|DZ_{AVAIL}\|$ (ft)	FL 200	3450	4250	5050	5850	6650	7450	8250
	FL 100	3130	3880	4630	5380	6130	6880	7630
	FL 50	2620	3290	3950	4620	5290	5950	6620
	2350ft	2000	2220	2720	3220	3720	4220	4720

Table 5 –Availability Thresholds

If a TA alert occurs while distance to targeted altitude is greater than the new altitude capture law availability threshold ($|DZ_{TA}| > |DZ_{AVAIL}|$), the new altitude capture law is inhibited. Inversely, if a TA occurs while distance to targeted altitude is lower than DZ_{AVAIL} ($|DZ_{TA}| <= |DZ_{AVAIL}|$), the new altitude capture law is activated.

In this type of realization, if the aircraft crosses the new altitude capture law threshold while a TA is still active, the new altitude capture law remains inhibited until a new TA.

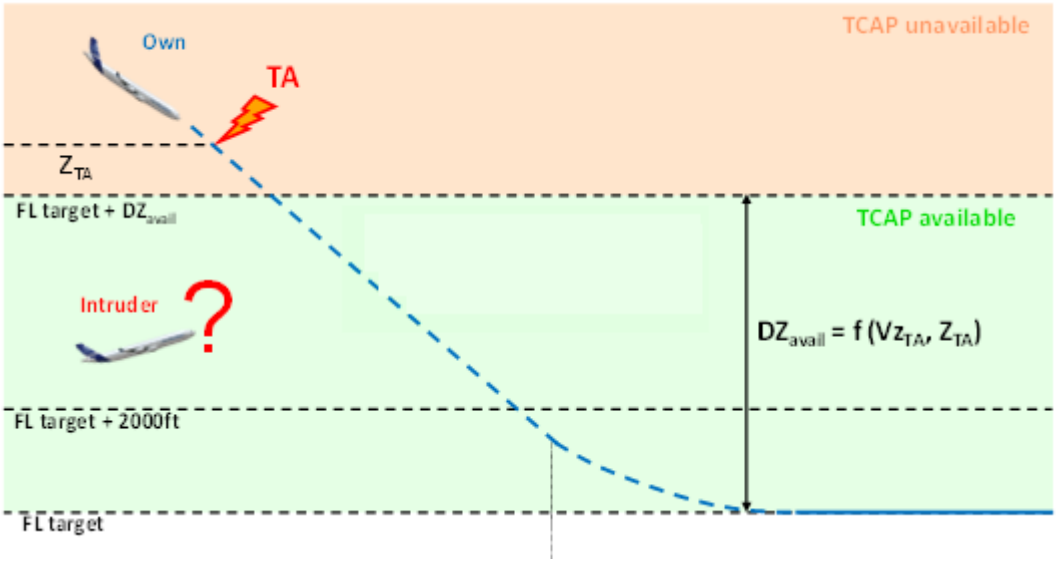


Figure 3 – Availability threshold

Rationale: This aims at limiting the new altitude capture law application to the just necessary cases and particularly to avoid forcing an undue activation in case of TA occurring far from the targeted altitude with a current low own vertical speed.

Requirement 10) When the new altitude capture law is capable to acquire intruder altitude, the intruder altitude logic shall be implemented.

Note: The two following inhibition logics have been assessed and validated in [6]:

- *-Intruder altitude logic together with the threshold inhibition logic*
- *-Threshold inhibition logic only*

The intruder altitude logic alone has not been validated in [6] but is anticipated as a possible efficient implementation.

Rationale: The intruder altitude logic has shown great benefits to avoid induced RAs.

A.1.1.6New altitude capture law activation

Requirement 11) The new altitude capture law shall be automatically activated at the time a Traffic Alert (TA) associated to the audio “Traffic Traffic” is generated.

Note: For example, a ‘residual’ TA occurring at Clear of Conflict after an RA or a ‘residual’ TA following the loss of an RA due to TCAS setting to ‘TA Only’ shall not activate the new altitude capture law (no ‘Traffic Traffic‘ audio in those cases).

Rationale: The new altitude capture law objective being to prevent the RA, the new altitude capture law activation is based on the RA precursor, which is the TA.

Requirement 12) If the TA ceases while the new altitude capture law is active, the new altitude capture law shall be maintained till the end of the altitude capture to avoid temporary own vertical speed increase.

Rationale: Come back to conventional altitude capture could lead to trigger a new TA and possibly an RA.

A.1.1.7New altitude capture law control law

Requirement 13) When activated, the new altitude capture law shall reduce the absolute value of the aircraft own vertical speed.

Note: The own vertical speed can be reduced continuously or by step. The realisation below provides some values of vertical speed targets found acceptable. These values depends on the relative altitude to own target altitude DZTA and current own vertical speed VzTA at TA occurrence.

- *Farther than 2000 ft from targeted altitude ('early TA'), a preliminary own vertical speed target is applied till reaching last 2000 ft.*
- *Vertical speed target is refreshed to 1500 fpm when the aircraft reaches the last 2000 ft from own targeted altitude.*
- *Inside the last 2000 ft, vertical speed target is function of the distance DZ.*

Rationale: Reducing the own vertical speed allows delaying time to collision and thus RA triggering.

Requirement 14) The absolute value of the own vertical speed commanded by the new altitude capture law shall never increase until reaching the targeted altitude (assuming no turbulent conditions).

Rationale: Prevention of operationally undesired RAs basically relies on a own vertical speed reduction.

Requirement 15) To ensure performance in term of operationally undesired RAs removal, the new altitude capture law shall command a own vertical speed of 1200 fpm for a TA occurring within the last 1000 ft from targeted altitude.

Rationale: During the validation [6], this constraint was used. Using this constraint permits to have significant results in reducing the number of RAs in 1000 ft level-off encounters, without any major drawbacks [6]. The choice of own vertical speed was made through a compromise aiming at maximizing the RA speed reduction while minimizing the increase of the time to capture the selected flight level when compared to an usual capture law with a 0.05 g acceleration.

Requirement 16) To ensure performance in term of operationally undesired RAs removal, the new altitude capture law shall command a own vertical speed of no more than 1500 fpm for a TA occurring between 2000 ft and 1000 ft from targeted altitude.

Note: if no new TA occurs, there is no need to refresh the target vertical speed when passing 1000 ft from targeted altitude.

Rationale: During the validation [6], this constraint was used. Using this constraint permits to have significant results in reducing the number of RAs in 1000 ft level-off encounters, without any major drawbacks [6]. The choice of own vertical speed was made through a compromise aiming at maximizing the RA rate reduction while minimizing the increase of the time to capture the selected flight level when compared to an usual capture law with a 0.05 g acceleration.

Requirement 17) If a new Traffic Alert (TA) associated to the audio "Traffic Traffic" occurs while the new altitude capture law is already activated, the new altitude capture law commanded own vertical speed target shall be refreshed.

Rationale: Previous own vertical speed target may be no more sufficient to prevent an RA.

Requirement 18) To allow final end of the capture, conventional altitude capture control law shall be used when its command induces a stronger own vertical speed reduction than the new altitude capture law command.

Rationale: This aims at allowing final end of the capture.

Requirement 19) The targeted load factor for the new altitude capture law control law shall not be less than 0.15 g.

Note: It has been shown that an authority of 0.3g does not bring any benefits compared to 0.15 g. Values below 0.15 g have not been evaluated. Implementation with an acceleration lower than this value should be evaluated properly before use.

Rationale: Choosing such a value higher than the usual 0.05 g aims at reaching faster the targeted own vertical speed for a better RA prevention performance.

Requirement 20) Usual speed protection logics applying to conventional altitude capture shall remain active when the new altitude capture law is activated.
Rationale: This aims at maintaining aircraft own vertical speed within the normal flight envelop.

Requirement 21) The new altitude capture law shall command a own vertical speed depending on the relative altitude to the own selected flight level and on the own vertical speed at the time of the TA.
Note: Example of realization for the new altitude capture law Control law:

Possible own vertical speed targets for the new altitude capture law control law (Vz_{TGT}) can be defined based on current aircraft own vertical speed at TA (Vz_{TA}) and distance to targeted altitude at the time of the TA (DZ_{TA}) as proposed in tables below.

In SESAR WP4.8.2 assessed realization, own vertical speed targets are computed as follow:

- *Inside the last 2000 ft, own vertical speed target is function of the distance DZ only:*

DZ_{TA} (ft)	2000	1900	1600	1000
Vz_{TGT} (fpm)	1500	1350	1300	1200

Table 6 – Own vertical speed choice in the last 2000ft

Note: For "intermediate" input values, output is computed by linear interpolation. Output is saturated to extreme values of second row if the input is out of bounds.

- *Farther than 2000 ft from targeted altitude ('early TA'), a preliminary the new altitude capture law own vertical speed target is applied till reaching last 2000 ft. This target is function of DZ_{TA} and Vz_{TA} and is defined so as to efficiently prevent RAs while not unbearably increasing the altitude capture duration.*

DZ_{TA} (ft) \ Vz_{TA} (fpm)	2000	3000	4000	5000	8000
2000	1500	1500	1500	1500	1500
3500	1550	2100	2550	2900	3750
4250	1550	2250	2720	3150	4150
5000	1550	2250	2850	3350	4450
5850	1550	2250	2850	3500	4750
8250	1550	2250	2850	3500	5400

Table 7 – Own vertical speed choice outside 2000ft

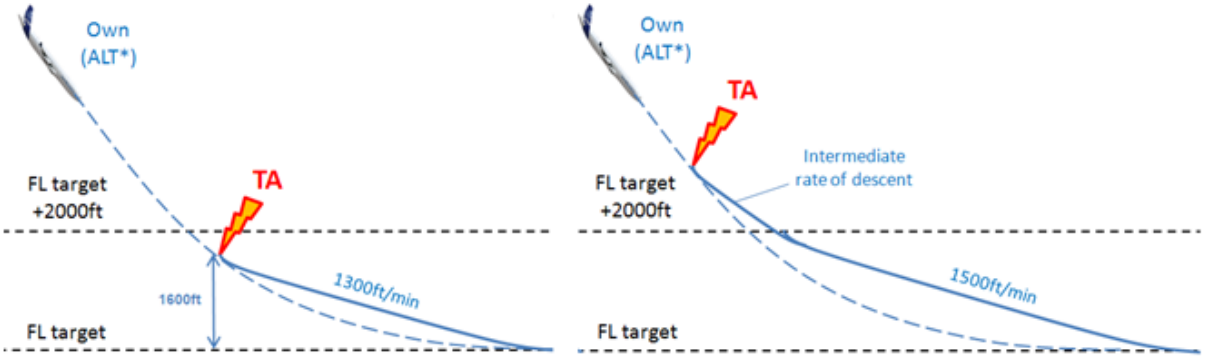
The new altitude capture law own vertical speed target is refreshed to 1500 fpm when the aircraft reaches the last 2000 ft from targeted altitude.

In both cases (farther or within the last 2000 ft), the new altitude capture law own vertical speed target is refreshed according tables 3 and 4 at each new TA.

Examples

Own is performing an altitude capture at around 0.05 g when a TA arises. The new altitude capture law control law reduces immediately the rate of descent and parabola is shortcut with an authority of 0.15g.

- *If the TA arises within the last 2000 ft, rate of descent is reduced between 1200 fpm and 1500 fpm according to table 3.*
- *If the TA arises farther the last 2000 ft, an intermediate rate of descent is commanded until crossing FL target +2000 ft where own vertical speed target becomes 1500 fpm.*



TA within the last 2000ft TA farther than 2000ft

Figure 4 – Own vertical speed choice

Rationale: This method was chosen so as to decrease the likelihood to have an RA while minimizing the effect on altitude capture time.

Requirement 22) The new altitude capture law control law should include an additional protection preventing the occurrence of self-produced TAs due to the same intruder, especially to avoid multiple-TAs sequences in the case of the simple level-off encounter geometry (which is the most preponderant geometry in European airspace).

Rationale: This aims at preventing as much as possible nuisance TCAS TA alerts, which generate stress for the crew.

Note: Example of realization for multi-TA protection:

In order to protect the aircraft against another TA caused by the same intruder cruising at an adjacent level, the new altitude capture law own vertical speed target can be reduced if TA horizon, located at the altitude $Z(t)+T_{TA}.Vz(t)$, exceeds intended altitude target by more than 500 ft according to the formula:

$$T_{TA} \, |Vz_{TGT}| < | \, Z_{TGT} - Z_{AC} \, | - 500ft$$

with ZAC: current aircraft altitude, ZTGT: targeted altitude and TTA: TCAS TA threshold.

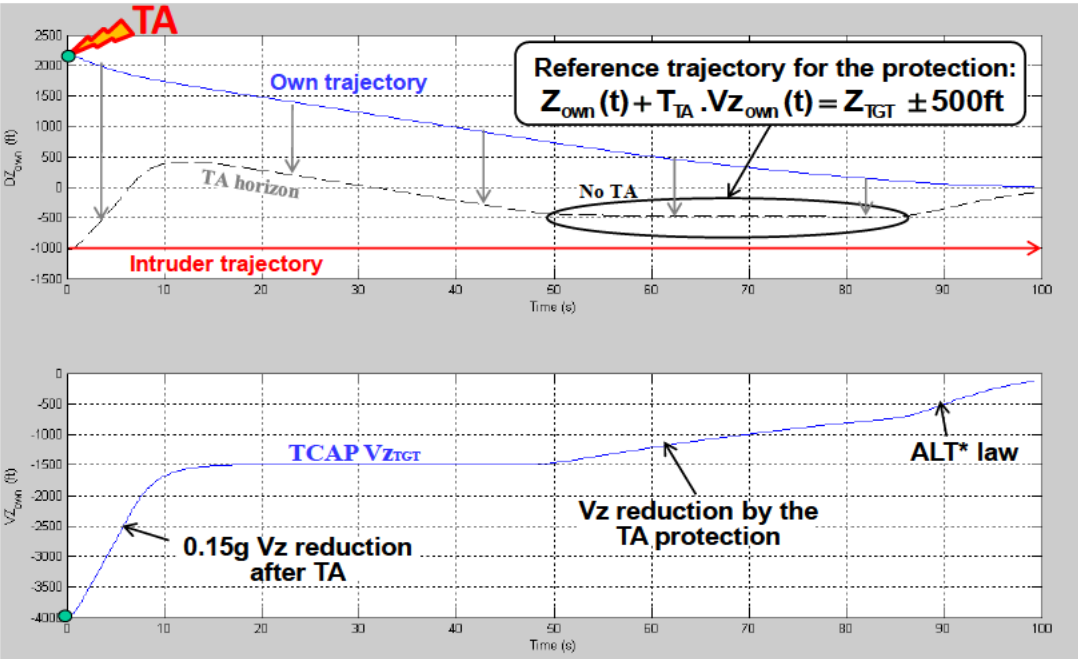


Figure 5 – Multiple TA protection

A.1.1.8Compatibility with other modes

Requirement 23) The new altitude capture mode shall interact compatibly with Autothrust modes and engagement status.

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