VR-TCAP Validation report for new possible altitude capture laws

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Abstract

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 rates. 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 rates when approaching the cleared flight level, such as ICAO Doc 8168, PANS-OPS, recommending a vertical rate 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.

ICAO has recommended that a technical solution, which consists in implementing new altitude capture laws taking into account TCAS II thresholds, should also be studied. The current report aims at presenting the validation report for such new altitude capture laws. These new altitude capture laws consist in reducing the vertical rate automatically at the approach of the selected flight level. The validation was conducted using the encounter model methodology with operationally realistic assumptions in terms of proportion of aircraft equipped with TCAS II and with these new altitude capture laws, as well as the types of pilot behaviour when RAs are triggered. The validation was made computing key performance indicators on two encounter models (i.e. "safety" and "ATM)" and for several configurations of the new altitude capture laws. These key performance indicators are grouped in four different areas: safety, pilot acceptance, compatibility with ATC and trajectory modification.

The validation has shown that the new altitude capture law (referred to as "AltCapt" in this report) is very effective in reducing the number of RAs triggered in 1000 ft level-off encounters. Assuming an RA is currently triggered every 800 flight hours in European airspace, and one RA out of two triggered is operationally undesired, we can assume that the current situation in Europe is one operationally undesired RA triggered every 1,600 flight hours. With the new altitude capture law, this figure would become roughly 50,000 flight hours, as the likelihood to receive an RA during a 1000 ft level-off encounter is reduced by a factor of 30, and even 70 with one given configuration.

Some side effects were discovered. One of these effects was observed on very specific geometries referred to as the "jump" geometry, in which an aircraft is climbing or descending passed another aircraft. In this geometry (which can only be observed in some specific areas) the new altitude capture law can add RAs. However, it was observed that these RAs occur mainly in

situations in which there are losses of separation even without the new altitude capture law. Several options to the new altitude capture law are available, and one of them solves the issue of added RAs. It consists in taking into account the altitude of the intruder in the activation of the new altitude capture law. Having this option implemented cancels this side effect, however this option would require some modifications in the output format of TCAS, therefore this is not considered as a short term solution. Given the very specific character of the geometry in which RAs can be added, the low probability of occurrence of this geometry (confirmed by a preliminary study conducted by NATS on radar data) and the benefits brought by the new altitude capture law, this issue can be considered as acceptable.

Another side effect of the new altitude capture law results from the fact that it can add multiple TAs. Multiple TAs have never been reported as an operational issue in any monitoring, and in addition, the rate by which the likelihood to receive multiple TAs is increased is not sufficiently high for this issue to be considered as more than minor.

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Executive summary

During 1000 ft level-off encounters, TCAS triggers Resolution Advisories which are often perceived as operationally undesired by air traffic controllers and by the crews. These Resolution Advisories cause unnecessary deviation from trajectories, and result in an unnecessary stress for the crews.

These RAs are caused by TCAS II predicting a risk collision if one of the involved aircraft maintain their high vertical rates.

In the past, some operational solutions based on the modification of arrival/departure procedures were developed locally and they contributed towards 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 rates approaching the cleared flight level, such as ICAO Doc 8168, PANS-OPS, recommending a vertical rate 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.

The ICAO ACAS manual recommends that a technical solution, which consists in implementing new altitude capture laws taking into account TCAS II thresholds, should also be studied. The current report aims at presenting the validation made for such new altitude capture laws. These new altitude capture laws consist in reducing the vertical rate automatically at the approach of the selected flight level.

The new altitude capture law (referred to as “AltCapt” in this report), which was validated in this study, is engaged when a Traffic Advisory is triggered, and under conditions related to the vertical distance to the selected flight level and to the vertical rate. If these conditions are passed, the vertical rate of the aircraft is decreased, so as to reduce the likelihood that a Resolution Advisory will be triggered. Several configurations are available for the new altitude capture law. These configurations consist in optional features being enabled or not. Four configurations were validated and compared.

The validation was conducted using the encounter model methodology. The validation was built on the methodology and tools that supported previous ACAS studies in Europe. These tools include a set of models that allow replicating the environment in which ACAS is being operated. These models consist essentially of a ‘safety encounter model’ (with aircraft on a close encounter course in which there exists a risk of mid-air collision) and an ‘ATM encounter model’ (in which the aircraft are not necessarily on a close encounter course but with trajectories which may trigger STCA alerts).

The validation was made on encounter models making realistic assumptions on the equipage of the aircraft. It was considered that a percentage of jets heavier than 5700 kg were able to use such a new altitude capture law. ACAS equipped aircraft were assumed to have TCAS II logic version 7.1 on-board and pilot responses were simulated as close as possible to what has been observed during monitoring.

Key performance indicators were computed on these models. These indicators can be gathered in 4 areas, safety, Pilot acceptance, Compatibility with ATC, and trajectory modification. Safety indicators aim at demonstrating that the new law does not debase the safety brought by ACAS. Pilot acceptance and compatibility with ATC indicators aim at demonstrating that the new law does not debase the current situation, and can even improve it. Trajectory modification indicators aim at comparing the configurations of the new altitude capture law between themselves in terms of impact on the trajectories.

The validation has shown that the new altitude capture law is very effective in reducing the number of RAs triggered in 1000 ft level-off encounters. Assuming an RA is currently triggered every 800 flight hours in the European airspace, and one RA out of two triggered is operationally undesired, we can assume that the current situation in Europe is one operationally undesired RA triggered every 1,600 flight hours. With the new altitude capture law and assuming most of these RAs are triggered during 1000 ft level-off encounters, this last figure would become roughly 50,000 flight hours, as the likelihood to receive an RA during a 1000 ft level-off encounter is reduced by a factor of 30, and even 70 with one given configuration.

Some side effects were discovered. One of these effects was observed on very specific geometries referred to as the “jump” geometry, in which an aircraft is climbing or descending passed another aircraft. In this geometry, which can only be observed in some specific areas, the new altitude capture law can add RAs. However, it was observed that these RAs occur mainly in situations in which there are losses of separation even without the new altitude capture law. Several options to the new altitude capture law are available, and one of them solves the issue of added RA. It consists in taking into account the altitude of the intruder in the activation of the new altitude capture law. Having this option implemented cancels this side effect, however this option would require some modifications in the output format of TCAS, therefore this is not considered as a short term solution. However given the very specific character of the geometry in which RAs can be added, the low probability of occurrence of this geometry (confirmed by a preliminary study conducted by NATS on radar data) and the benefits brought by the new altitude capture law, this issue can be considered as acceptable.

Another side effect of the new altitude capture law results from the fact that it can add multiple TAs. Multiple TAs have never been reported as an operational issue in any monitoring, and in addition the rate by which the likelihood to receive multiple TAs is increased is not sufficiently high for this issue to be considered as more than minor.

The implementation of AltCapt should be made in two steps:

- For a first step for short term implementation, it is recommended to implement AltCapt in its basic form plus additionally an available design option aiming at improving the protection against multiple TAs.
- For a second step for medium term implementation, it is recommended to implement AltCapt taking into account the altitude of the intruder, still with the improved protection against multiple TAs. A more suitable format of TCAS output is highly recommended at first opportunity.

1 Introduction

1.1 Purpose of the document

This document aims at presenting the 4.8.2.1 validation report for a technical solution to the issue of TCAS Resolution Advisories (RAs) in 1000 ft level-off encounters[1]. This solution aims at decreasing the vertical rate of aircraft at the approach of the selected flight level when a TCAS Traffic Advisory (TA) is triggered, so as to decrease the likelihood that a subsequent TCAS RA will be triggered.

1.2 Intended readership

This document is intended for the readership of the partners involved in the project. It is also intended to provide input to 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).

1.3 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 rates. 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 [1] proposed some operational solutions based on the modification of arrival/departure procedures, which contributed towards 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 rates approaching the cleared flight level, such as ICAO Doc 8168, PANS-OPS, recommending a vertical rate 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 French 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 altitude capture laws [2].

For greater performance when compared to already implemented operational solutions, a technical solution, which consists in implementing new altitude capture laws taking into account TCAS II thresholds, should be studied. These new altitude capture laws consist in reducing the vertical rate automatically at the approach of the 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.

[1] An encounter in which two aircraft are leveling-off 1000 ft apart vertically, or in which an aircraft is leveling-off 1000 ft apart from a level aircraft.

1.4 Glossary

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 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.
Acceptance criteria	If those criteria are met, the change is acceptable without discussion.
AEM	Altimetry error model – a mathematical model which defines altimetry system errors of aircraft as a series of distributions that depend on altitude. - The ASARP project determined an AEM applicable to the European RVSM airspace using HMU monitoring data.
ALIM	Distance (in feet) at CPA that is targeted by TCAS when choosing a resolution advisory sense and strength.
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.
Encounter	A traffic situation involving two (or more) aircraft. Distinction is hence made between a pair-wise encounter (involving two aircraft only) and a multiple aircraft encounter (with at least three aircraft). Furthermore, an encounter can either be: - an 'actual' encounter extracted from radar data recordings according to agreed capture criteria, or - a encounter generated from a safety encounter model.
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.
Pilot response model	A set of parameters which characterise the pilot responses to ACAS RAs and which can be used to simulate pilot behaviour during ACAS simulations. The ASARP project determined a 'typical pilot response' model applicable to ACAS operations in Europe using recent on-board recorded data.
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. As ACAS can update the advisories (each second) depending on the evolution of the situation, there can be a sequence of RAs related to the same encounter. The first RA of the sequence is called the initial RA. A sequence

Term	Definition
	ends with a 'Clear of Conflict' announcement. In rare cases, another RA can reappear for the same threat a few seconds after a 'Clear of Conflict' announcement. This situation is called a multiple RA. 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.
Risk ratio	The ratio of the risk of mid-air collision when ACAS is deployed to the risk that would exist without ACAS. A risk ratio of 0% would indicate a perfect system that eliminated the risk of collision; a risk ratio of 100% would indicate an ineffective system that made no change to the risk of collision
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).
Standard pilot response	The pilot response model described in the ACAS SARPS and implicitly assumed in the ACAS collision avoidance algorithms, viz an initial delay of 5s before the pilot responds with an acceleration of 0.25g to achieve the required vertical rate.
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.
VMD	Vertical Miss Distance

1.5 Acronyms and Terminology

Term	Definition
ACAS/TCAS	Airborne collision avoidance system / Traffic alert and collision avoidance system
ATM	Air Traffic Management
CPA	Closest Point of Approach
HMD	Horizontal Miss Distance
HMU	Height Monitoring Unit
MTOM	Maximum Take Off Mass
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
TA	Traffic Advisory
VP	Validation Plan
WA1	Work Area 1

2 Proposed solutions and options

2.1 Introduction

A possible solution to the issue of RAs triggered during 1000 ft level-off geometries consists of a new altitude capture law aimed at automatically reducing the vertical rate at the approach of the selected flight level. The benefits of such a new law are multiple:

- Less unnecessary traffic perturbation;
- Flight crew workload not increased.

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 rate is automatically reduced through the autopilot, which enters in to a new altitude capture mode (referred to as “AltCapt” in this report). As a result, the likelihood that an RA is triggered is reduced. This mode can be activated in aircraft operating in TA/RA mode or TA-only mode, and remains active until the altitude capture is finished.

2.2 New control law description

2.2.1 Introduction

AltCapt has a design including a basis and several options which have to be evaluated. The general principle of the design of AltCapt is presented hereafter. Then the options available are also presented.

2.3 Activation conditions

AltCapt can only be activated under some conditions.

First, a TA associated with an audio alert must be triggered. This condition is required, as the objective is not to modify the altitude capture law for all captures of the selected flight level: the laws currently used in aircraft have been optimized from a flight profile perspective and they should be used as often as possible. The new law should only be used in the situations where there is a risk of RA to be triggered. It is similar to the ICAO recommendation which refers to situations when “another aircraft is at or approaching an adjacent altitude or flight level”.

Then, some pre-conditions have to be satisfied:

- The autopilot and/or the flight director must be engaged; and
- The own aircraft must be converging towards its selected flight level; and
- The distance to the selected flight level must be lower than a threshold which depends on vertical rate and altitude; and
- The vertical rate must be higher (in absolute value) than the vertical rate AltCapt would choose; and
- The altitude must be higher than 1100 ft.

2.3.1 Basis

Once the activation conditions are passed, AltCapt is engaged, and remains engaged until the selected flight level is captured.

AltCapt chooses a vertical rate depending on the relative altitude to the selected flight level and on the vertical rate at the time of the TA and it reduces the vertical rate to the chosen value with an acceleration of 0.15 g in absolute value. The chosen vertical rate is updated at each new TA (if any).

AltCapt always ensures that the vertical rate is not higher than 1500 fpm in the last 2000 ft before the selected flight level.

The choice of 1500 fpm in the last 2000 ft was initially made by Airbus for AltCapt, and the justification is presented in [3].

2.3.2 Option 1: Protection against multiple TAs

An option adding a protection against multiple TAs generated against the same intruder has been designed. Indeed, initial tests by Airbus with AltCapt have shown that it is efficient at removing RAs; however it could lead to some situations where multiple TAs are triggered. This means that in some situations there is the risk that, AltCapt, after having been engaged following a TA, is efficient at removing a possible subsequent RA (and should even shorten the duration of the TA), but will cause the TA to start again a few seconds later, against the same intruder (i.e. multiple TA).

For that reason, a protection against these secondary TAs can be added. It consists in an additional reduction of the vertical rate, so that the time to be at the same height remains higher than the TCAS TA threshold. In practical terms, this protection further reduces the vertical rate, to avoid triggering of secondary TAs when AltCapt is already engaged.

The principle of the protection against multiple TAs is shown hereafter.

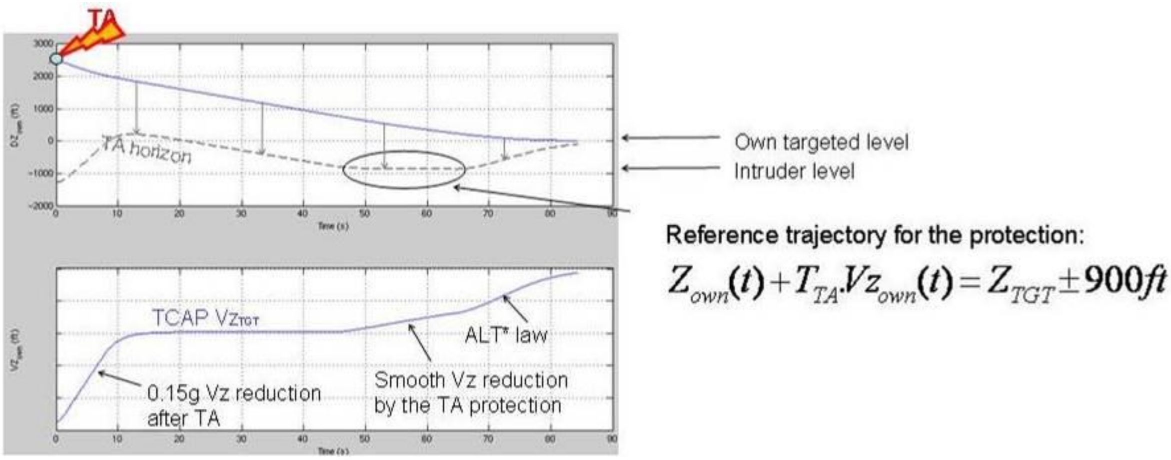


Figure 1: Multiple TA protection

A TA horizon[2] is computed, and whenever this horizon goes within 900 ft of the selected level of the own aircraft, the vertical rate is reduced according to the formula above.

This formula contains a threshold equal to 900 ft. It is possible to modify this threshold to change the efficiency of this protection. Changing the threshold to 500 ft was tested in this validation. This variant is referenced to as “Improved Protection against multiple TAs” below. The goal of setting the threshold to 500 ft instead of 900 ft is to make the condition to trigger the protection easier to pass.

2.3.3 Option 2: Absolute protection against RAs

A second option has been designed so as to ensure that an RA will not be triggered in the case of a second TA being received (so as to avoid sequences in the form of TA, TA ending, TA, RA).

In this case, it is assumed that the protection against multiple TAs has failed, and the vertical rate is further reduced using the same principle than for the protection against multiple TAs, but with a more stringent threshold.

This option was abandoned in favour of option 4 described hereafter.

2.3.4 Option 3: Reinforced acceleration

In the basis, the acceleration for the reduction of the vertical rate is 0.15 g. In option 3, the acceleration is reinforced to 0.3 g, allowing a faster reduction of the vertical rate, and consequently a possible better efficiency to reach the targeted vertical rate when compared to what occurs with 0.15g. It can be pointed out that such acceleration is greater than the standard acceleration required by a pilot to meet an RA.

[2] The TA horizon is the altitude where a level intruder should be to trigger a TA.

2.3.5 Option 4: Taking into account intruder's altitude

In the basic configuration of AltCapt, the altitude of the intruder is not taken into account.

In situations during which ATC decides to make an aircraft jump over another aircraft level at an adjacent flight level, if AltCapt triggers and decreases the vertical rate of the evolving aircraft, then it may cause an RA.

With option 4, the altitude of the intruder is taken into account so as to avoid the triggering of AltCapt when it is likely that such a situation is going on.

With this option, AltCapt will only be triggered, for a climbing aircraft, if the intruder is at least 500 ft above the altitude targeted by own aircraft. This should avoid AltCapt triggering in situations in which the aircraft are expected to cross in the vertical plane.

2.4 Configurations to be validated

Four configurations of AltCapt were fully validated and one was partially validated. When compared to the validation plan, configuration 3 has been changed to include option 4.

Configuration 1	Configuration 2	Configuration 2b	Configuration 3	Configuration 4
Basis	Basis & Protection against multiple TAs (option 1)	Basis & Improved Protection against multiple TAs (option 1)	Basis & Taking into account intruder's altitude (option 4)	Basis & Protection against multiple TAs (option 1) & Reinforced acceleration (option 3)

Figure 2: AltCapt configurations

3 Summary of the results

3.1 Introduction

The goal of this part is to provide a short summary of the findings of this study, and to provide some links to the detailed analysis provided in part 4.

3.2 Safety performance indicators

The following table shows a summary of the key performance indicators computed on the European safety encounter model. Green zones are used when the acceptance criteria is met without discussion for a given indicator, orange zones are used when the acceptance criteria are not met but an analysis estimates that the negative side effect is acceptable, and red zones are used when the acceptance criteria are not met and the negative side-effect is considered as unacceptable. White zones are used when a given metric has not been computed, because considered not relevant.

		Basis	Protection against mult. TAs	Improved protection against mult. TAs	Taking into account int. altitude	Protection against mult. TA+ reinforced
Safety	risk Ratio	green	green	green	green	green
	VMDs	green	green	green	green	green
	ALIM	green	green	green	green	green
	Increase RAs	green	green	green	green	green
	Reversal RAs	green	green	green	green	green

Table 1: Summary - Indicators computed on the European safety model

All the acceptance criteria are passed on the European safety model, and AltCapt has no negative effect on safety. Details about the analysis are shown in 4.2.

The following table shows a summary of the key performance indicators computed on the European ATM encounter model. The configurations are followed by a letter, S standing for the airspace perspective, A for the aircraft perspective, LLO for the level-off geometry perspective, and the ~~LLO~~ for the geometries which are not level-off.

		Basis				Protection against mult. TAs				Improved protection against mult. TAs				Taking into account int. altitude				Protection against mult. TA+ reinforced acceleration			
		S	A	LLO	~~LLO~~	S	A	LLO	~~LLO~~	S	A	LLO	~~LLO~~	S	A	LLO	~~LLO~~	S	A	LLO	~~LLO~~
	VMDs	green		green	orange	green		green	orange	green		green	orange	green		green	green	green		green	orange
Safety	ALIM	orange	orange	green	orange	orange	orange	green	orange	orange	orange	green	orange	green	green	green	green	orange	orange	green	orange
	Increase RAs	green	orange	green	orange	green	orange	green	orange	green	orange	green	orange	green	green	green	green	green	orange	green	orange
	Reversal RAs	orange	orange	green	orange	orange	orange	green	orange	orange	orange	green	orange	green	green	green	green	orange	orange	green	orange
Pilot Acceptance	Crossing RAs	orange	orange	green	orange	orange	orange	green	orange	orange	orange	green	orange	green	green	green	green	orange	orange	green	orange
	Positive RAs	green	green	green	orange	green	green	green	orange	green	green	green	orange	green	green	green	green	green	green	green	orange
	Init.opposite RAs	green	green	green	orange	green	green	green	orange	green	green	green	orange	green	green	green	green	green	green	green	orange
	split RAs	green	green	green	green	green	green	green	green	green	green	green	green	green	green	green	green	green	green	green	green
	Complex RAs	green	green	green	orange	green	green	green	orange	green	green	green	orange	green	green	green	green	green	green	green	orange
	Op.undesired Ras	green	green	green	green	green	green	green	green	green	green	green	green	green	green	green	green	green	green	green	green
	RA duration	green		green	green	green		green	green	green		green	green	green		green	green	green		green	green
	Number of TAs	green	green	green	green	green	green	green	green	green	green	green	green	green	green	green	green	green	green	green	green
	Multiple TAs	orange	orange	orange	orange	orange	orange	orange	orange	orange	orange	orange	orange	orange	orange	orange	orange	orange	orange	orange	orange
	TA duration	green		green	orange	green		green	orange	green		green	orange	green		green	green	green		green	orange
Compatibility with ATC	Number of Ras	green	green	green	orange	green	green	green	orange	green	green	green	orange	green	green	green	green	green	green	green	orange
	Positive RAs	green	green	green	orange	green	green	green	orange	green	green	green	orange	green	green	green	green	green	green	green	orange
	Op.undesired Ras	green	green	green	green	green	green	green	green	green	green	green	green	green	green	green	green	green	green	green	green
	Deviations	green		green	orange	green		green	orange	green		green	orange	green		green	green	green		green	orange
	Incompatible sense	orange	orange	green	orange	orange	orange	green	orange	orange	orange	green	orange	green	green	green	green	orange	orange	green	orange

Table 2: Summary - Indicators computed on the European ATM model

All the indicators were not computed for all the perspectives. Indeed, they were first all computed for the airspace perspective only. Then some indicators (SA2, PA7, PA11, CA3, CA5, and TM1 to TM7 as described in [3]) were not computed for the other perspectives because it was considered they would not bring more information than that brought by the airspace perspective, and because showing them would have resulted in repetitions in the report.

All configurations have one or more negative aspects, which all have been estimated as acceptable in view of their magnitude. The comparison between configurations can be further refined by looking at the actual figures (which are provided in section 4.2).

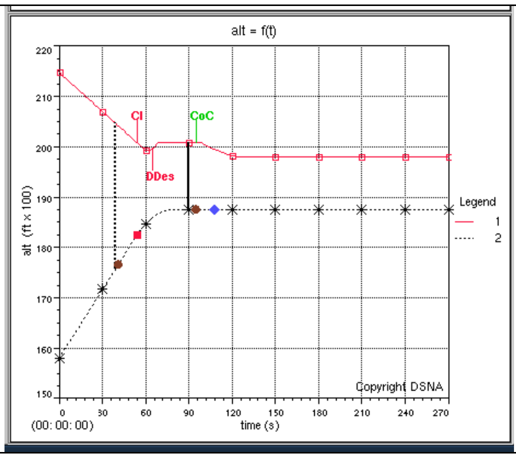
Overall, AltCapt results in very significant benefits when considering RAs triggered in 1000 ft level-off encounters. Assuming an RA is triggered every 800 flight hours [1], and one RA out of two is operationally undesired, we can assume that the current situation in Europe is one operationally undesired RA triggered every 1,600 flight hours. With AltCapt, this figure would become roughly 50,000 flight hours, as the likelihood to receive an RA during a 1000 ft level-off encounter is reduced by a factor of 30 when introducing AltCapt (and in fact even 70 with the improved protection against multiple TAs). On an aircraft perspective, even assuming a rate of equipage of 25% would result in aircraft fitted with AltCapt receiving 47% less RAs.

The configuration of AltCapt which has the best performance on level-off geometries is the configuration with an improved protection against TAs, as shown in part 4.4.1.2.6. In this configuration, the benefit is doubled, because of the additional vertical rate decrease afforded.

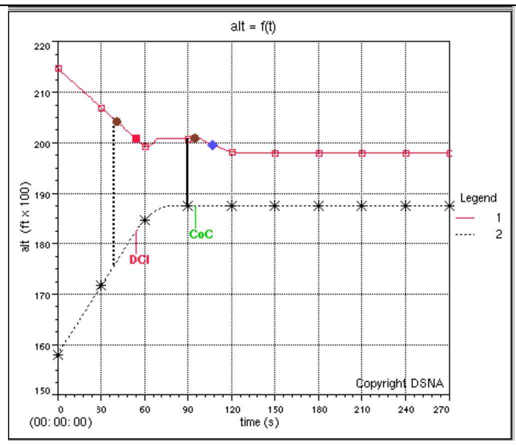
The benefits of AltCapt are illustrated on the following figure.

The first figure shows a typical 1000 ft level-off encounter, during which RAs are triggered onboard both aircraft. The left view shows the perspective of aircraft 1 with TCAS simulated, whereas the right view shows the perspective of aircraft 2 with TCAS simulated.

Aircraft 1



Aircraft 2

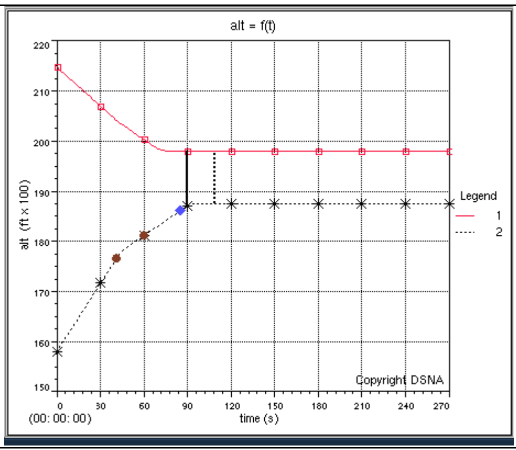


CPA: 0.04NM/1330ft

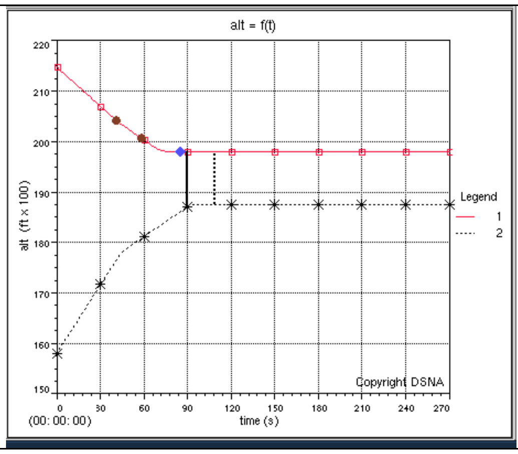
Figure 3: Encounter without AltCapt contribution

Legend: CL: Climb RA, DDes: “Level-off” RA, DCL: “Level-off” RA, CoC: clear of conflict

Aircraft 1



Aircraft 2



CPA: 0.04NM/1100ft

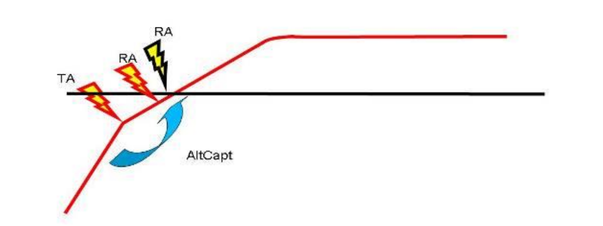
Figure 4: Encounter with AltCapt contribution

When introducing AltCapt, the vertical rate of the climbing aircraft is decreased after the triggering of the TA, and as a result, there are no RA triggered onboard the two aircraft. Consequently, the upper aircraft no longer deviates from its flight level.

Overall, the configuration which takes into account the altitude of the intruder performs much better than the other configurations.

The issues observed on the other configurations (additional reversal, increase and crossing RAs, increase of encounters which do not satisfy ALIM) are all linked to the “jump” geometry, in which additional RAs can be triggered (representing 95% of the added RAs). The following figure illustrates this geometry, and how AltCapt can affect the triggering of RAs in this geometry.

Jump encounter without AltCapt



Jump encounter with AltCapt

Figure 5: Jump geometry

In the “jump” geometry, the vertical rate reduction by AltCapt results in the aircraft passing closer than expected in the vertical plane, which results in RAs being triggered.

In addition, this geometry is only observed in very specific airspaces, and the added RAs are triggered in 94% of the cases in encounters which are already losses of separation without AltCapt. Details about this geometry are given in 4.2.3.1.2.

Furthermore, the configuration of AltCapt taking into account the altitude of the intruder solves this issue completely. Indeed, this configuration does not result in added RAs being triggered on this geometry, as shown in parts 4.4.2, 4.4.2.2 and 4.4.2.3.

Whatever the configuration, the acceptance criteria are not passed for multiple TAs, as AltCapt increases their number (see 4.2.2.9). However, the proportion of TAs which are multiple remains acceptable. In addition, multiple TAs have never been observed as an issue in any operational monitoring. Therefore, when considering the significant benefits brought by AltCapt, it can be assumed that multiple TAs are not considered as an issue.

The analysis of all the results, as detailed hereafter, has shown that the best solution would be to implement the configuration which takes into account the altitude of the intruder, because it solves completely the issue of the "jump" geometry. However this solution requires modifying the format of the TCAS outputs. Therefore it is not considered as a short term solution, but rather as a mid term or long term solution.

The analysis has also shown that the second best solution is the configuration which uses an improved protection against multiple TAs. This solution has the advantage of being immediately implementable, and provides significant benefits in 1000 ft level-off encounters.

3.3 Validation objectives achievement

3.3.1 Introduction

The validation plan [3] defines a set of validation objectives. The following sections present these validation objectives, and make an assessment of the achievement of these objectives dependant on taking into account the intruder's altitude.

3.3.2 Using AltCapt without taking into account the altitude of intruder

Validation objective	Achievement	Comments
Verify that **the safety performance of TCAS II is not debased** by the use of the new altitude capture laws in the European airspace	**Yes**	The overall safety performance of TCAS II is not debased, and can even be very slightly improved (see parts 4.2.1.1, 4.2.1.2, 4.2.1.3, 4.2.1.4, 4.2.1.5).
Verify that the **number of RAs triggered during 1000 ft level-off geometries decreases**	**Yes**	The number of RAs triggered during 1000 ft level-off geometries is dramatically reduced, by a factor of around 30, and even 70 with the improved protection against multiple TAs (see parts 4.2.2.2, 4.2.2.6, 4.2.3.1, 4.2.3.2, 4.2.3.3, 4.2.3.4, 4.3.2.2, 4.3.3.1, 4.3.3.2, 4.3.3.3, 4.4.1.2, 4.4.1.3).
Verify that **the use of the new altitude capture laws does not debase the way TCAS II behaves** for other types of encounters, especially by verifying that it does not add additional RAs	**Partial**	For a very specific geometry (named as "jump" in the report), occurring in some very specific situations, AltCapt can add RAs. Given the specificity of this geometry, the low probability of occurrence and the fact that they correspond in 94% of the cases to losses of separation without TCAS, the validation objective is not considered as not achieved (see parts 4.2.2.1, 4.2.3.1.2, 4.4.2.2, 4.4.2.3).
Perform an additional **comparison based on the way the trajectories are modified**, between several altitude capture laws available	**Yes**	The effect of AltCapt on the trajectories is limited, and the different configurations of AltCapt show very small differences between themselves (see part 4.2.4).

Table 3: Validation objectives achievement - Without taking into account the altitude of the intruder

3.3.3 Using AltCapt taking into account the altitude of intruder

Validation objective	Achievement	Comments
Verify that **the safety performance of TCAS II is not debased** by the use of the new altitude capture laws in the European airspace	**Yes**	The safety performance of TCAS II is not debased, and can even be very slightly improved (see parts 4.2.1.1, 4.2.1.2, 4.2.1.3, 4.2.1.4, 4.2.1.5).
Verify that the **number of RAs triggered during 1000 ft level-off geometries decreases**	**Yes**	The number of RAs triggered during 1000 ft level-off geometries is dramatically reduced, by a factor of around 30, and even 70 with the improved protection against multiple TAs (see parts 4.2.2.2, 4.2.2.6, 4.2.3.1, 4.2.3.2, 4.2.3.3, 4.2.3.4, 4.3.2.2, 4.3.3.1, 4.3.3.2, 4.3.3.3, 4.4, 4.4.1.2, 4.4.1.3).
Verify that **the use of the new altitude capture laws does not debase the way TCAS II behaves** for other types of encounters, especially by verifying that it does not add additional RAs	**Yes**	When AltCapt is used with the option permitting to take into account the altitude of the intruder, it does not add RAs (see parts 4.2.2.1, 4.2.3.1.2, 4.4.2.2, 4.4.2.3).
Perform an additional **comparison based on the way the trajectories are modified**, between several altitude capture laws available	**Yes**	The effect of AltCapt on the trajectories is limited, and the different configurations of AltCapt show very small differences between themselves (see part 4.2.4).

Table 4: Validation objectives achievement - Taking into account the altitude of intruder

4 Detailed validation results

4.1 Introduction

This part aims at presenting the results of the validation conducted according to [3].

[3] defines a set of key performance indicators. This part presents, for each scenario simulated, the key performance indicators computed, and the comparison with the reference scenarios, which accurately reflect the current TCAS contribution to safety in the European airspace.

It must be pointed out that a key performance indicator defined in [3] is not used in this report as it is now considered as irrelevant for this study. This indicator is the number of operationally undesired TAs. Indeed, it was considered during the validation that the notion of operationally undesired TA was difficult to define.

The configuration of AltCapt including the improved protection against multiple TAs has been assessed only for a level of equipage of 100%, and only on the European ATM encounter model, therefore it will not appear in the tables showing safety performance indicators in the following parts.

4.2 Airspace perspective

4.2.1 Indicators related to safety

4.2.1.1 Risk ratios

The following table shows the risk ratios with the four configurations fully simulated, with the proportion of aircraft equipped with the AltCapt function varying from 0% (reference scenario) to 100% (full equipage) in steps of 25%.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	34.2%	34.3%	34.0%	33.9%	34.0%
Basis+Protection against multiple TAs	34.2%	34.3%	34.0%	33.9%	34.0%
Basis+Taking into account intruder's altitude	34.2%	34.2%	34.0%	33.9%	33.9%
Basis+Protection against multiple TAs+reinforced acc.	34.2%	34.3%	34.0%	33.9%	34.0%

Table 5: Risk ratios – airspace perspective – European safety model

The risk ratios are, overall, unchanged or nearly unchanged, whatever the level of equipage of AltCapt. Only a very slight increase can be noticed for a level of equipage of 25%. However, the difference may result from the error margin of the simulation: indeed it is considered in TCAS studies that a difference of 0.1% on a risk ratio is insignificant.

As a result, it can be assessed that AltCapt does not debase the safety brought by TCAS II to the European airspace.

4.2.1.2 Vertical Miss Distances

The tables below present the VMD ratios, computed as the ratio of VMDs increased by AltCapt, divided by the number of VMDs decreased by AltCapt. A VMD ratio of 100% means that overall, the number of VMDs increased is equal to the number of VMDs decreased.

The following figure shows a VMD diagram to illustrate what a VMD ratio is.

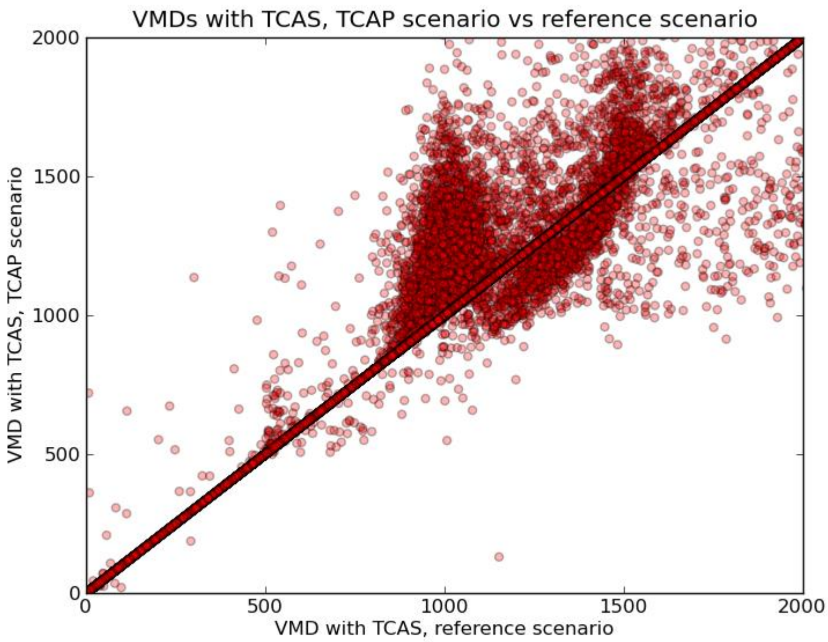


Figure 6: VMD diagram - airspace perspective – European ATM model – AltCapt plus option taking into account intruder's altitude

It is obvious on this diagram that the number of plots above the diagonal is higher than the number of plots below the diagonal. This is materialised by a VMD ratio of 389.0% in Table 7.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	100.0%	140.7%	145.4%	150.0%	152.4%
Basis+Protection against multiple TAs	100.0%	140.7%	145.4%	141.9%	152.4%
Basis+Taking into account intruder's altitude	100.0%	165.3%	169.6%	176.4%	163.9%
Basis+Protection against multiple TAs+reinforced acc.	100.0%	140.7%	145.4%	150.8%	159.5%

Table 6: VMD ratio – airspace perspective – European safety model

Whatever the level of equipage, the VMD ratios are well over 100%, which means the number of VMDs increased is higher than the number of VMDs decreased.

It is noticeable that the configuration taking into account the altitude of the intruder has a better performance than the other configurations. In fact, this better performance is explained by the number of VMDS decreased which is lower than with the other configurations.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	100.0%	220.4%	214.7%	215.8%	216.9%
Basis+Protection against multiple TAs	100.0%	220.4%	214.7%	215.8%	216.9%
Basis+Taking into account intruder's altitude	100.0%	388.9%	379.3%	384.2%	389.0%
Basis+Protection against multiple TAs+reinforced acc.	100.0%	253.8%	246.0%	250.8%	251.5%
Basis+improved Protection against multiple TAs	100.0%				264.1%

Table 7: VMD ratios – airspace perspective – European ATM model

Whatever the level of equipage, the VMD ratios are over 200%, which means the number of VMDs increased is always at least twice as high as the number of VMDs decreased.

4.2.1.3 Number of RAs without ALIM provision

The following table shows the proportion of RAs which result in a vertical separation lower than the CAS logic objective referred to as ALIM, which is the target vertical separation which TCAS II aims at achieving at the closest point of approach. These proportions are expressed as a percentage of the number of RAs in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	1.1%	1.1%	1.1%	1.1%	1.1%
Basis+Protection against multiple TAs	1.1%	1.1%	1.1%	1.1%	1.1%
Basis+Taking into account intruder's altitude	1.1%	1.1%	1.1%	1.1%	1.1%
Basis+Protection against multiple TAs+reinforced acc.	1.1%	1.1%	1.1%	1.1%	1.1%

Table 8: % of RAs without ALIM – airspace perspective – European safety model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	0.0%	0.3%	-0.3%	-0.8%
Basis+Protection against multiple TAs	0.0%	0.0%	0.3%	-0.3%	-0.8%
Basis+Taking into account intruder's altitude	0.0%	0.0%	-0.3%	-0.3%	-0.8%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	0.0%	0.3%	-0.3%	-0.8%

Table 9: RAs without ALIM - Variation – airspace perspective – European safety model

Small variations are observed, however they are not noticeable with the accuracy used here (1 digit).

The proportion of RAs failing to achieve ALIM remains unchanged, whatever the AltCapt configuration and level of equipage.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	4.5%	4.7%	4.6%	4.7%	4.8%
Basis+Protection against multiple TAs	4.5%	4.7%	4.6%	4.7%	4.8%
Basis+Taking into account intruder's altitude	4.5%	4.5%	4.5%	4.5%	4.5%
Basis+Protection against multiple TAs+reinforced acc.	4.5%	4.8%	4.8%	4.8%	5.0%
Basis+improved Protection against multiple TAs	4.5%				4.8%

Table 10: % of RAs without ALIM – airspace perspective – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	2.7%	2.3%	3.0%	6.7%
Basis+Protection against multiple TAs	0.0%	2.7%	2.3%	3.0%	6.7%
Basis+Taking into account intruder's altitude	0.0%	-1.0%	-1.7%	-1.0%	-1.0%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	4.7%	6.3%	6.0%	10.7%
Basis+improved Protection against multiple TAs	0.0%				5.0%

Table 11: RAs without ALIM - Variation – airspace perspective – European ATM model

For all the configurations, except the one that takes into account intruder's altitude, one notices a slight increase of the proportion of RAs failing to achieve ALIM. The configuration that takes into account intruder's altitude decreases insignificantly the proportion of RAs failing to achieve ALIM. This means that not taking into account the altitude of the intruder results, although rarely, in AltCapt debasing some situations.

These situations correspond to specific geometries. These are encounters in which ATC decides to make an aircraft climb and cross the altitude of the intruder aircraft before levelling-off. In that kind of situation, which is referred to as the "jump" geometry in this report, ATC requires the evolving aircraft to maintain a specified vertical rate.

In this geometry, AltCapt decreases the vertical rate of the evolving aircraft, and as a result the VMD is decreased, which can result in additional RAs, or in sequences of RAs made more complex, as it will be shown in this report. This implies that in a few situations, the vertical separation at CPA is slightly decreased, and can become lower than ALIM.

With the configuration with a reinforced acceleration, the proportion of RAs failing to achieve ALIM is very slightly worse than for the other configurations. This is explained by the fact that, due to the increased acceleration, in the "jump" geometries, the evolving aircraft has its vertical rate decreasing faster, therefore the VMD can be further reduced.

4.2.1.4 Number of increase RAs

The following table shows the proportion of RAs which are increase RAs[3]. These proportions are expressed as a percentage of the number of RAs in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.8%	0.8%	0.8%	0.7%	0.7%
Basis+Protection against multiple TAs	0.8%	0.8%	0.8%	0.7%	0.7%
Basis+Taking into account intruder's altitude	0.8%	0.8%	0.8%	0.8%	0.8%
Basis+Protection against multiple TAs+reinforced acc.	0.8%	0.8%	0.8%	0.7%	0.7%

Table 12: % of RAs which are increase RAs – airspace perspective – European safety model

[3] An RA requiring an increase of the strength of the manoeuvre to be performed, to 2500fpm.

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	0.0%	-1.2%	-2.3%	-5.0%
Basis+Protection against multiple TAs	0.0%	0.0%	-1.2%	-2.3%	-5.0%
Basis+Taking into account intruder's altitude	0.0%	0.0%	-0.8%	-1.2%	-1.2%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	0.0%	-1.2%	-2.3%	-5.0%

Table 13: Increase RAs - Variation – airspace perspective – European safety model

With the European safety model, the proportion of increase RAs decreases or remains unchanged, whatever the configuration and level of equipage.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	1.5%	1.5%	1.5%	1.5%	1.5%
Basis+Protection against multiple TAs	1.5%	1.5%	1.5%	1.5%	1.5%
Basis+Taking into account intruder's altitude	1.5%	1.5%	1.4%	1.4%	1.4%
Basis+Protection against multiple TAs+reinforced acc.	1.5%	1.5%	1.5%	1.5%	1.6%
Basis+improved Protection against multiple TAs	1.5%				1.5%

Table 14: % of RAs which are increase RAs - airspace perspective – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	4.2%	4.2%	4.2%	6.3%
Basis+Protection against multiple TAs	0.0%	4.2%	4.2%	4.1%	6.3%
Basis+Taking into account intruder's altitude	0.0%	0.0%	-1.0%	-1.0%	-1.0%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	5.2%	5.2%	6.3%	9.4%
Basis+improved Protection against multiple TAs	0.0%				6.3%

Table 15: Increase RAs – Variation - airspace perspective – European ATM model

With the European ATM model, the proportion of increase RAs remains unchanged or decreases with the configuration taking into account the altitude of the intruder, and increases slightly with the other configurations. However the increase is not noticeable at the level of accuracy of 1 digit used here when looking at the absolute values.

4.2.1.5 Number of Reversal RAs

The following table shows the proportion of RAs which are reversal RAs[4]. These proportions are expressed as a percentage of the number of RAs in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.7%	0.7%	0.7%	0.7%	0.7%
Basis+Protection against multiple TAs	0.7%	0.7%	0.7%	0.7%	0.7%
Basis+Taking into account intruder's altitude	0.7%	0.7%	0.7%	0.7%	0.7%
Basis+Protection against multiple TAs+reinforced acc.	0.7%	0.7%	0.7%	0.7%	0.7%

Table 16: % of RAs which are reversal RAs – airspace perspective – European safety model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	0.8%	-1.2%	-4.0%	-7.2%
Basis+Protection against multiple TAs	0.0%	0.8%	-1.2%	-4.0%	-7.2%
Basis+Taking into account intruder's altitude	0.0%	-0.4%	-2.8%	-5.2%	-7.2%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	-0.4%	-2.4%	-5.2%	-8.4%

Table 17: Reversal RAs – Variation - airspace perspective – European safety model

With the European safety model, the proportion of reversal RAs remains unchanged or decreases, whatever the configuration and level of equipage.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.5%	0.5%	0.5%	0.6%	0.7%
Basis+Protection against multiple TAs	0.5%	0.5%	0.5%	0.6%	0.7%
Basis+Taking into account intruder's altitude	0.5%	0.5%	0.5%	0.5%	0.5%
Basis+Protection against multiple TAs+reinforced acc.	0.5%	0.5%	0.5%	0.7%	0.7%
Basis+improved Protection against multiple TAs	0.5%				0.7%

Table 18: % of RAs which are reversal RAs – airspace perspective – European ATM model

[4] An RA requesting a change of sense when compared to the sense initially chosen by the CAS logic (for example, a descend RA where a climb sense RA was initially chosen).

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	6.7%	13.3%	33.3%	53.3%
Basis+Protection against multiple TAs	0.0%	6.7%	13.3%	33.3%	53.3%
Basis+Taking into account intruder's altitude	0.0%	0.0%	0.0%	0.0%	6.6%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	10.0%	16.6%	46.6%	60.0%
Basis+improved Protection against multiple TAs	0.0%				53.3%

Table 19: Reversal RAs - Variation - airspace perspective – European ATM model

With the European ATM model, the proportion of reversal RAs increases with the configurations which do not take into account the altitude of the intruder. This can be explained by the "jump" geometry, in which AltCapt can add RAs, which can be sometimes reversed. Indeed these RAs are usually triggered just before or at the time when the aircraft are at co-altitude and this can lead to a reversal RA once the aircraft have actually crossed in the vertical plane.

When the altitude of the intruder is taken into account, there are no more or nearly no more added reversal RAs. It must be mentioned that the proportion of reversal RAs remains negligible (see Table 18) when compared to the overall number of RAs, showing that reversal RAs would remain rarely triggered.

4.2.2 Indicators related to pilot acceptance

4.2.2.1 Number of crossing RAs

The following table shows the proportion of RAs which are crossing RAs[5]. These proportions are expressed as a percentage of the number of RAs in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	1.5%	2.0%	2.3%	2.5%	2.9%
Basis+Protection against multiple TAs	1.5%	2.0%	2.3%	2.5%	2.9%
Basis+Taking into account intruder's altitude	1.5%	1.5%	1.5%	1.5%	1.5%
Basis+Protection against multiple TAs+reinforced acc.	1.5%	2.1%	2.4%	2.8%	3.3%
Basis+improved Protection against multiple TAs	1.5%				2.9%

Table 20: % of RAs which are crossing RAs - airspace perspective – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	30.4%	48.0%	63.7%	90.2%
Basis+Protection against multiple TAs	0.0%	30.4%	48.0%	63.7%	90.2%
Basis+Taking into account intruder's altitude	0.0%	-1.0%	-2.0%	-2.9%	-3.9%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	35.3%	53.9%	83.3%	112.8%
Basis+improved Protection against multiple TAs	0.0%				88.2%

Table 21: Crossing RAs – Variation - airspace perspective – European ATM model

With the European ATM model, the proportion of crossing RAs increases with the configurations which do not take into account the altitude of the intruder, and remains unchanged with the configuration taking into account the altitude of the intruder.

The increase of the number of crossing RAs is explained by geometries in which AltCapt, when not taking into account the altitude of the intruder, adds RAs whereas no RAs are triggered without AltCapt.

It must be mentioned however, that the proportion of crossing RAs remains small when compared to the overall number of RAs (see Table 20).

In 75% of the cases, these crossing RAs are compatible with the sense initially chosen by ATC. The remaining 25% correspond to the following situation. The first figure shows an encounter without TCAS and without AltCapt contribution.

[5] An RA which will require aircraft trajectories to cross in the vertical plane.

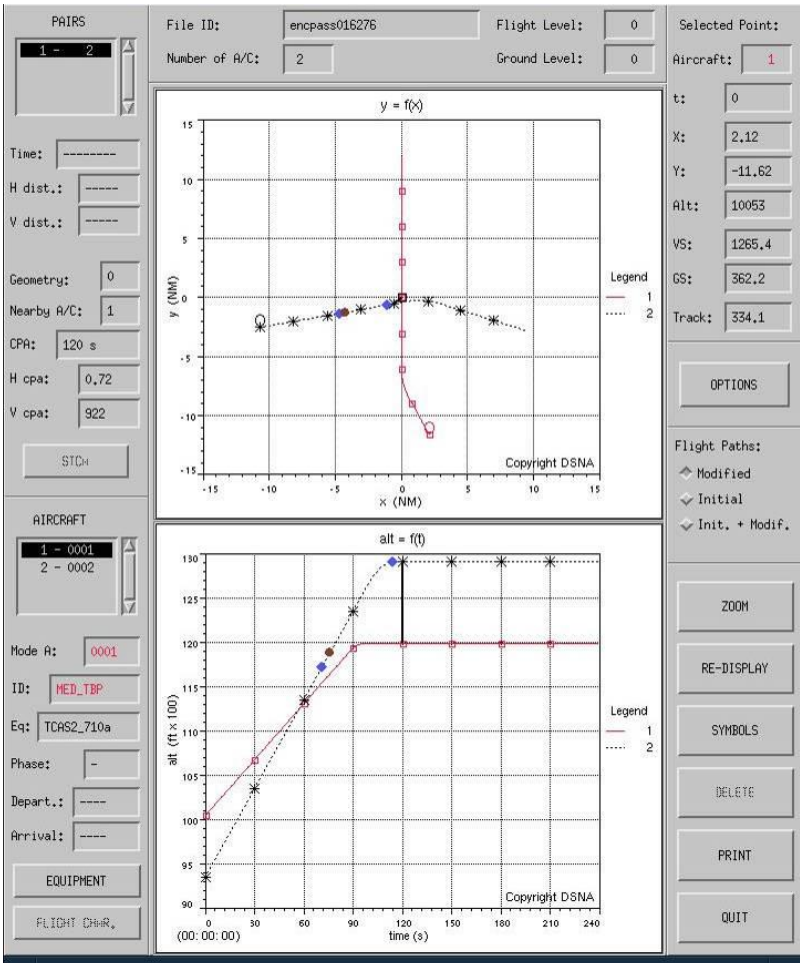


Figure 7: Encounter without TCAS and AltCapt contribution

The following figure shows the encounter without TCAS and with AltCapt contribution.

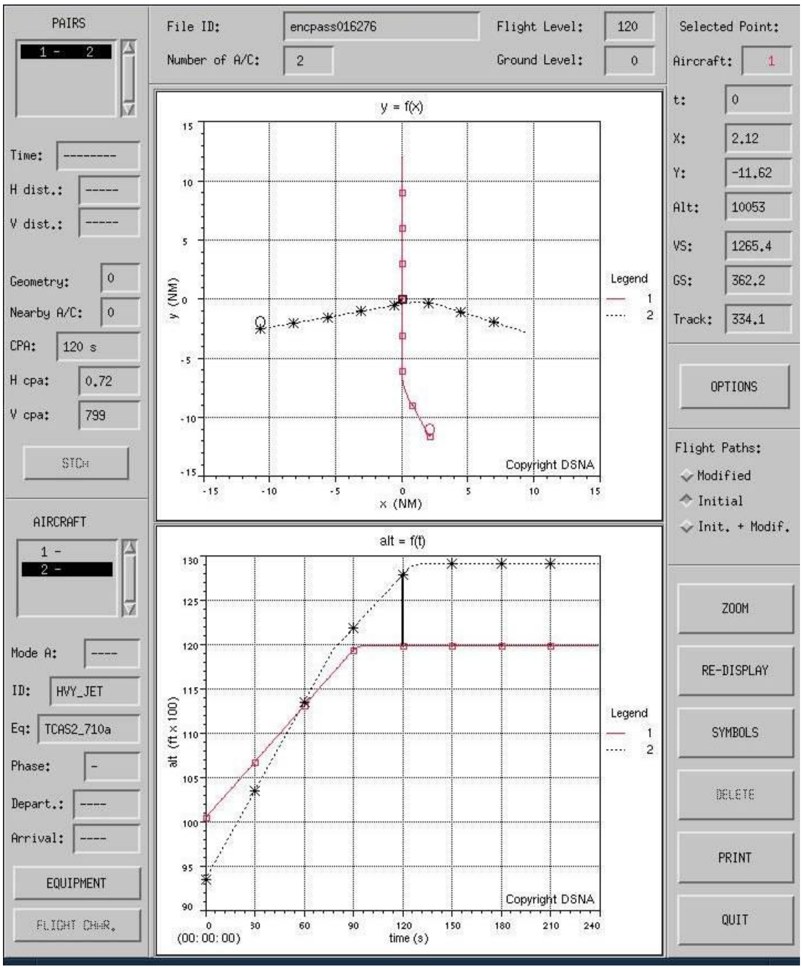


Figure 8: Encounter with AltCapt contribution and without TCAS contribution

The following figure shows the encounter with TCAS and with AltCapt contribution.

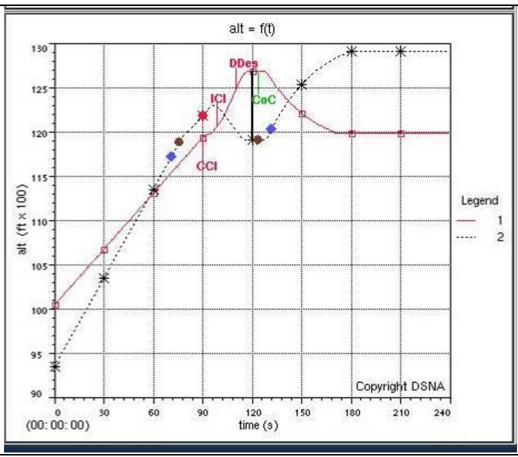
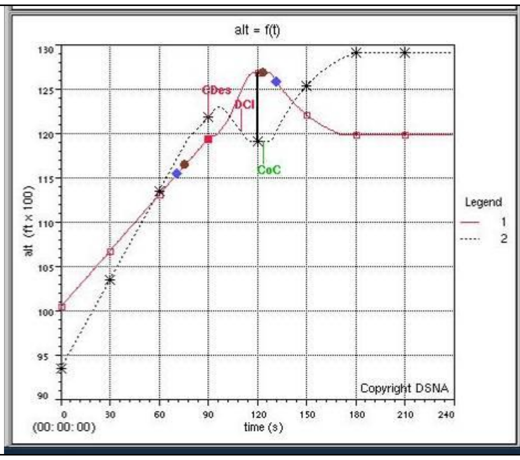
Aircraft 1	Aircraft 2
	
CPA: 0.72NM/770ft	

Figure 9: Encounter with AltCapt contribution and with TCAS contribution

Legend: CCl: crossing climb RA, ICl: increase climb RA, DDES: “Level-off” RA, CDEs: crossing descend RA, DCL: “Level-off” RA, CoC: Clear of Conflict

Crossing RAs are triggered after the trajectories of the aircraft cross in the vertical plane. Resulting from this, the trajectories cross again, and the encounter is classified as incompatible for ATC because the aircraft which ATC intended to be above comes out below after the RA.

4.2.2.2 Number of positive RAs

The following table shows the proportion of RAs which are positive RAs[6]. These proportions are expressed as a percentage of the number of RAs in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	85.0%	74.6%	63.5%	51.9%	38.2%
Basis+Protection against multiple TAs	85.0%	74.6%	63.5%	51.9%	38.2%
Basis+Taking into account intruder's altitude	85.0%	72.3%	59.1%	45.1%	29.9%
Basis+Protection against multiple TAs+reinforced acc.	85.0%	74.6%	63.6%	52.1%	38.9%
Basis+improved Protection against multiple TAs	85.0%				37.0%

Table 22: % of RAs which are positive RAs - airspace perspective – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	-12.2%	-25.3%	-39.0%	-55.0%
Basis+Protection against multiple TAs	0.0%	-12.2%	-25.3%	-39.0%	-55.0%
Basis+Taking into account intruder's altitude	0.0%	-14.9%	-30.5%	-47.0%	-64.8%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	-12.3%	-25.2%	-38.7%	-54.3%
Basis+improved Protection against multiple TAs	0.0%				-56.5%

Table 23: Positive RAs – Variation - airspace perspective – European ATM model

Whatever the configuration tested, the proportion of positive RAs decreases, and the decrease is correlated to the level of equipage. With a level of equipage of 100%, the proportion of positive RAs is divided by more than two.

The best performance is obtained when taking into account the altitude of the intruder. This results from the fact that, when not taking into account this information, a proportion of the remaining RAs are in fact additional RAs. When taking into account the altitude of the intruder, these RAs are no more present, and as a result the overall number of RAs is even more decreased.

This will be illustrated in details further when presenting results about the number of RAs in 4.2.3.1.

[6] An RA which requires an action from the pilot (e.g., a climb RA)

4.2.2.3 Number of initial RAs opposite to the aircraft trajectory

The following table shows the proportion of RAs which are initial RAs and opposite to the trajectory. These proportions are expressed as a percentage of the number of RAs in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	13.8%	12.4%	10.6%	8.8%	6.9%
Basis+Protection against multiple TAs	13.8%	12.4%	10.6%	8.8%	6.9%
Basis+Taking into account intruder's altitude	13.8%	11.8%	9.6%	7.3%	5.0%
Basis+Protection against multiple TAs+reinforced acc.	13.8%	12.4%	10.6%	8.9%	7.1%
Basis+improved Protection against multiple TAs	13.8%				6.7%

Table 24: % of RAs which are initial opposite RAs - airspace perspective – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	-10.0%	-23.1%	-35.97%	-49.7%
Basis+Protection against multiple TAs	0.0%	-10.0%	-23.1%	-35.97%	-49.7%
Basis+Taking into account intruder's altitude	0.0%	-13.97%	-30.3%	-46.8%	-63.4%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	-9.7%	-22.99%	-35.1%	-48.6%
Basis+improved Protection against multiple TAs	0.0%				-51.5%

Table 25: Initial opposite RAs – Variation - airspace perspective – European ATM model

Whatever the configuration tested, the proportion of initial opposite RAs decreases, and the decrease is correlated to the level of equipage. With a level of equipage of 100%, the proportion of such RAs is divided by two.

Here again, the best performance is obtained when taking into account the altitude of the intruder, which is explained by additional RAs not being triggered in the “jump” geometry.

4.2.2.4 Number of multiple RAs

The following table shows the proportion of multiple RAs. These proportions are expressed as a percentage of the number of RAs in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.2%	0.2%	0.1%	0.1%	0.0%
Basis+Protection against multiple TAs	0.2%	0.2%	0.1%	0.1%	0.0%
Basis+Taking into account intruder's altitude	0.2%	0.2%	0.1%	0.1%	0.0%
Basis+Protection against multiple TAs+reinforced acc.	0.2%	0.2%	0.1%	0.1%	0.0%
Basis+improved Protection against multiple TAs	0.2%				0.0%

Table 26: % of RAs which are multiple RAs - airspace perspective – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	-31.3%	-43.8%	-62.5%	-87.5%
Basis+Protection against multiple TAs	0.0%	-31.3%	-43.8%	-62.5%	-87.5%
Basis+Taking into account intruder's altitude	0.0%	-31.3%	-43.8%	-56.3%	-81.3%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	-31.3%	-43.8%	-62.5%	-87.5%
Basis+improved Protection against multiple TAs	0.0%				-87.5%

Table 27: Multiple RAs – Variation - airspace perspective – European ATM model

Whatever the configuration, the proportion of multiple RAs can be considered as unchanged, considering that the proportion is very low.

4.2.2.5 Number of complex RA sequences

The following table shows the proportion of sequences of RAs which are considered as complex. These proportions are expressed as a percentage of the number of RAs in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	4.6%	4.5%	4.4%	4.5%	4.3%
Basis+Protection against multiple TAs	4.6%	4.5%	4.4%	4.5%	4.3%
Basis+Taking into account intruder's altitude	4.6%	4.3%	4.0%	3.9%	3.6%
Basis+Protection against multiple TAs+reinforced acc.	4.6%	4.5%	4.5%	4.7%	4.5%
Basis+improved Protection against multiple TAs	4.6%				4.3%

Table 28: % of RAs which are complex RAs - airspace perspective – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	-0.7%	-3.3%	-1.0%	-6.3%
Basis+Protection against multiple TAs	0.0%	-0.7%	-3.3%	-1.0%	-6.3%
Basis+Taking into account intruder's altitude	0.0%	-6.3%	-12.6%	-15.2%	-22.2%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	-0.7%	-1.3%	2.7%	-1.3%
Basis+improved Protection against multiple TAs	0.0%				-7.0%

Table 29: Complex RAs – Variation - airspace perspective – European ATM model

Whatever the configuration, the proportion of complex sequences remains unchanged or decreases, especially when taking into account the altitude of the intruder.

4.2.2.6 Number of operationally undesired RAs

The following table shows the proportion of RAs which are considered as operationally undesired. These proportions are expressed as a percentage of the number of RAs in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	54.5%	42.4%	29.7%	16.4%	1.7%
Basis+Protection against multiple TAs	54.5%	42.4%	29.7%	16.4%	1.7%
Basis+Taking into account intruder's altitude	54.5%	42.4%	29.7%	16.5%	1.9%
Basis+Protection against multiple TAs+reinforced acc.	54.5%	27.1%	29.5%	16.1%	1.6%
Basis+improved Protection against multiple TAs	54.5%				0.8

Table 30: % of RAs which are operationally undesired RAs - airspace perspective – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	-22.2%	-45.5%	-70.0%	-96.7%
Basis+Protection against multiple TAs	0.0%	-22.2%	-45.5%	-70.0%	-96.7%
Basis+Taking into account intruder's altitude	0.0%	-22.2%	-45.5%	-69.7%	-96.6%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	-22.4%	-45.9%	-70.5%	-97.1%
Basis+improved Protection against multiple TAs	0.0%				-98.5%

Table 31: Operationally undesired RAs – Variation - airspace perspective – European ATM model

Whatever the configuration, the proportion of RAs considered as operationally undesired is significantly decreased by the introduction of AltCapt. **With a level of equipage of 100%, the number of operationally undesired RAs is cut by a factor of around 30, and even 70 with the improved protection against multiple TAs.**

Assuming an RA is triggered every 800 flight hours [1], and one RA out of two is operationally undesired, we can assume that the current situation in Europe is one operationally undesired RA triggered every 1,600 flight hours. With AltCapt, this figure would become roughly 50,000 flight hours, which means that such RAs would become very rare in the European Airspace.

4.2.2.7 RA durations

The table below presents the RA duration ratios, computed as the ratio of RA durations decreased by AltCapt, divided by the number of RA durations increased by AltCapt. A ratio of 100% means that overall, the number of RA duration increased is equal to the number of RA durations decreased.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	100.0%	316.7%	339.7%	335.9%	336.4%
Basis+Protection against multiple TAs	100.0%	316.7%	339.7%	335.9%	336.4%
Basis+Taking into account intruder's altitude	100.0%	1350.0%	1700.0%	1787.5%	1683.3%
Basis+Protection against multiple TAs+reinforced acc.	100.0%	314.3%	311.8%	309.8%	313.5%
Basis+improved Protection against multiple TAs	100.0%	-	-	-	254.7%

Table 32: RA duration ratio - airspace perspective – European ATM model

Overall, the durations of RAs are decreased. The best performance is obtained, once more, when taking into account the altitude of the intruder.

In order to illustrate the effect of the AltCapt on the distribution of RA durations, the following figure presents the distributions of the durations of RAs with two configurations, knowing that the distributions for the Basis, for Basis+Protection against multiple TAs, and for Basis+Protection against multiple TAs+reinforced acceleration are very close, and therefore not worth showing.

On this figure, the reference scenario is shown in red, the AltCapt scenario in green, and where the two distributions are superimposed, in dark green (which may print as brown). The bins used are 5 s long, and shown with the minimum value of the bin (i.e., 5 stands for [5;10[)

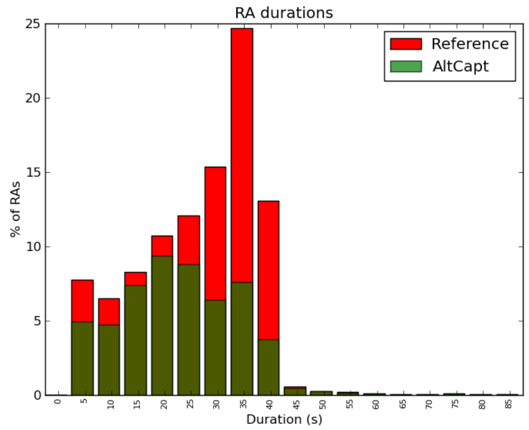
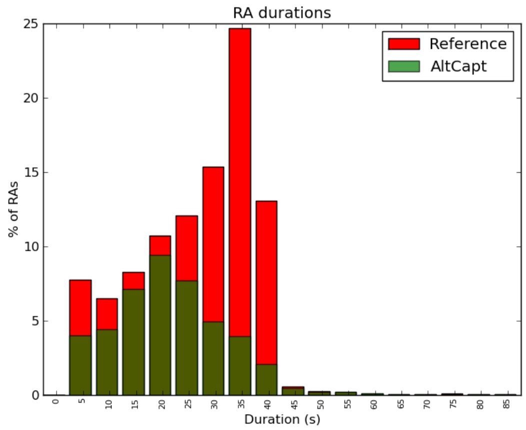
Basis	AltCapt Basis+Taking into account intruder's altitude
	

Figure 10: RA durations distributions

The shape of the distribution changes significantly when introducing AltCapt. Indeed, the peak around 35 s disappears.

The difference between the two configurations of AltCapt can be observed above 20 s. When taking into account the altitude of the intruder, the proportion of these RAs is lower.

4.2.2.8 Number of TAs

The following table shows the proportion of TAs expressed as a percentage of the number of TAs in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	100.0%	99.9%	99.8%	99.8%	99.7%
Basis+Protection against multiple TAs	100.0%	99.9%	99.8%	99.8%	99.7%
Basis+Taking into account intruder's altitude	100.0%	99.9%	99.8%	99.7%	99.7%
Basis+Protection against multiple TAs+reinforced acc.	100.0%	99.8%	99.5%	99.2%	98.9%
Basis+improved Protection against multiple TAs	100.0%				99.6%

Table 33: % of TAs - airspace perspective – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	-0.1%	-0.2%	-0.2%	-0.3%
Basis+Protection against multiple TAs	0.0%	-0.1%	-0.2%	-0.2%	-0.3%
Basis+Taking into account intruder's altitude	0.0%	-0.1%	-0.2%	-0.3%	-0.3%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	-0.2%	-0.5%	-0.8%	-1.1%
Basis+improved Protection against multiple TAs	0.0%				-0.4%

Table 34: TAs – Variation - airspace perspective – European ATM model

With AltCapt, the number of TAs remains unchanged or very slightly decreases.

4.2.2.9 Number of multiple TAs

The following table shows the proportion of multiple TAs expressed as a percentage of the number of TAs in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	1.1%	2.2%	3.7%	5.7%	7.9%
Basis+Protection against multiple TAs	1.1%	2.2%	3.7%	5.7%	7.9%
Basis+Taking into account intruder's altitude	1.1%	2.2%	3.5%	5.5%	7.7%
Basis+Protection against multiple TAs+reinforced acc.	1.1%	2.2%	3.5%	5.5%	7.6%
Basis+improved Protection against multiple TAs	1.1%				6.1%

Table 35: % of multiple TAs - airspace perspective – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	94.5%	223.4%	403.6%	600.4%
Basis+Protection against multiple TAs	0.0%	94.3%	223.2%	403.4%	600.2%
Basis+Taking into account intruder's altitude	0.0%	90.1%	209.5%	384.8%	576.8%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	91.5%	213.1%	385.4%	570.7%
Basis+improved Protection against multiple TAs	0.0%				439.8%

Table 36: Multiple TAs – Variation - airspace perspective – European ATM model

AltCapt makes multiple TAs more frequent. The option which is designed to prevent the triggering of multiple TAs seems to be of little effect.

However, **it must be pointed out that multiple TAs have never been reported as an issue during any operational monitoring. In addition, multiple TAs are a minor concern when compared to the benefits brought by AltCapt.**

The configuration improving the protection against multiple TAs results in the number of multiple TAs being reduced by 23% when compared to the Basis, with the only drawback of rare cases where the time to reach the selected flight level is slightly increased (by 10 s at worst).

4.2.2.10 TA durations

The table below present the TA duration ratios, computed as the ratio of TA durations decreased by AltCapt, divided by the number of TA durations increased by AltCapt. A ratio of 100% means that overall, the number of TA durations increased is equal to the number of TA durations decreased.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	100.0%	414.0%	393.9%	379.6%	372.3%
Basis+Protection against multiple TAs	100.0%	414.4%	394.1%	379.7%	372.5%
Basis+Taking into account intruder's altitude	100.0%	1074.2%	977.6%	922.0%	886.3%
Basis+Protection against multiple TAs+reinforced acc.	100.0%	428.6%	408.0%	388.6%	380.3%
Basis+improved Protection against multiple TAs	100.0%				280.3%

Table 37: TA duration ratio - airspace perspective – European ATM model

Overall, the durations of TAs are decreased. The best performance is obtained, once more, when taking into account the altitude of the intruder.

In order to illustrate the effect of the AltCapt on the distribution of TA durations, the following figure presents the distributions of the durations of TAs with two configurations, knowing that the distributions for the Basis, for Basis+Protection against multiple TAs, and for Basis+Protection against multiple TAs+reinforced acc. are very close, and therefore not worth showing.

On this figure, the reference scenario is shown in red, the AltCapt scenario in green, and where the two distributions are superimposed, in dark green. The bins used are 5 s long, and shown with the minimum value of the bin (i.e., 5 stands for [5;10[).

Basis	**AltCapt Basis+Taking into account intruder's altitude**

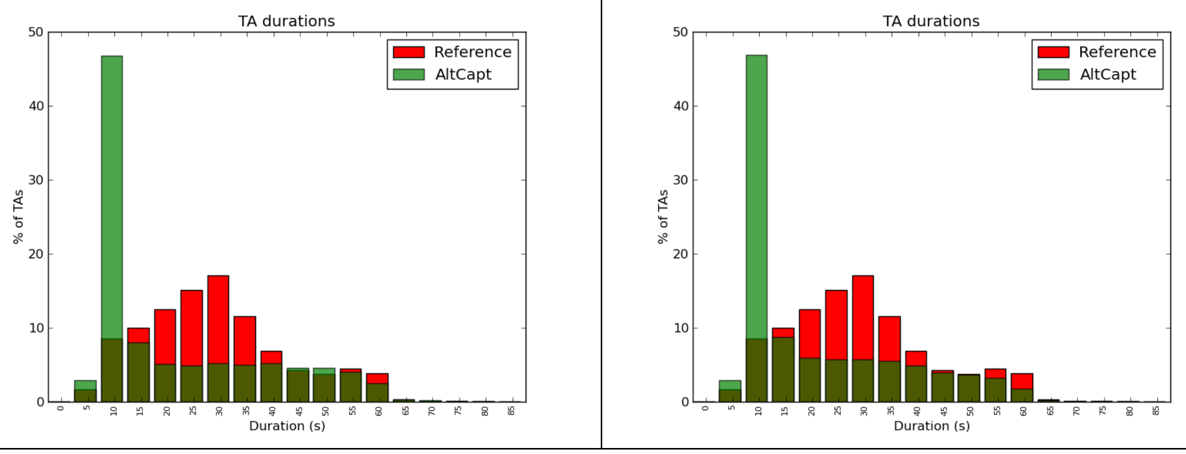


Figure 11: TA durations distributions

The shape of the distributions changes when introducing AltCapt. Many TA durations are reduced to 9 or 10 s. Indeed, when triggered, a TA will always last at least 9 s, with TCAS II logic version 7.0 and 7.1. With AltCapt, a noticeable part (i.e., 17.5% compared to 3.2% without AltCapt) of the TAs last less than 11 s. A majority of TAs (58.9%) last less than 20 s with AltCapt, whereas they are less than half the proportion (22.5%) without AltCapt.

The differences between the two AltCapt configurations are only visible for the longest durations, as taking into account the altitude of the intruder seems to reduce, slightly, the proportion of TAs lasting more than 40 s.

4.2.2.11 Distribution of the RA types

The following figure shows, for each configuration and with a level of equipage of 100%, the distribution of RA types in an airspace, reproducing European operations, in which AltCapt has been introduced. It must be kept in mind that, overall, AltCapt decreases the overall number of RAs by a factor of nearly two, which does not appear on this figure.

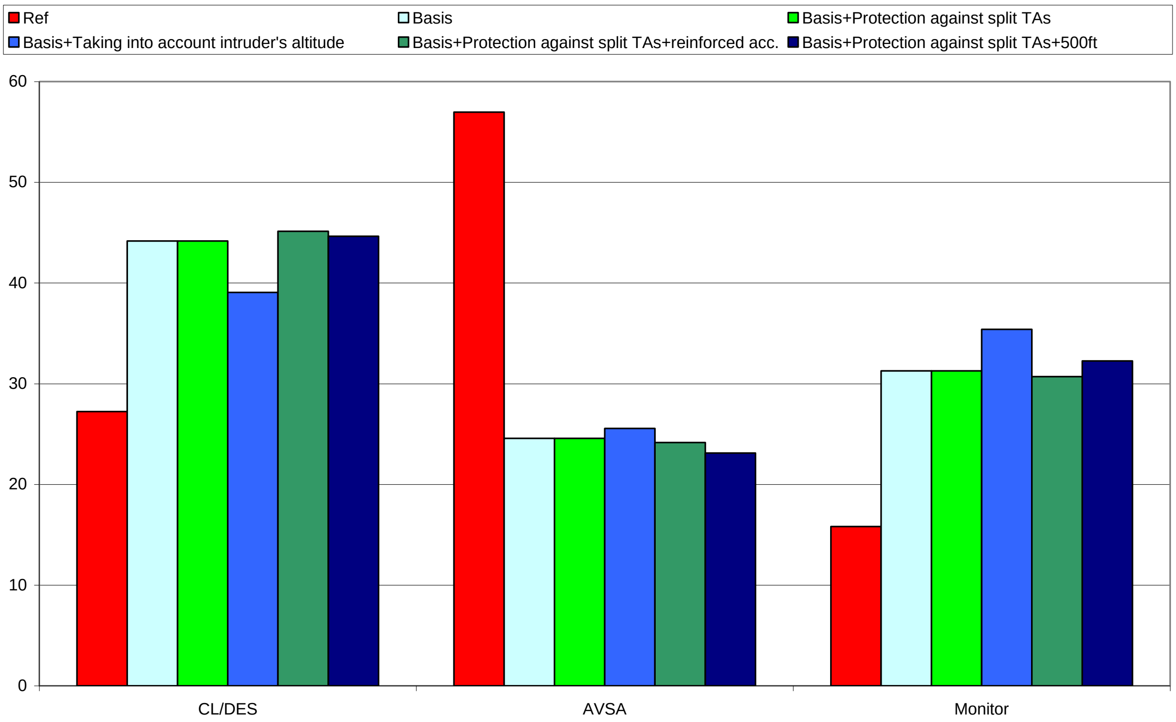


Figure 12: Distribution of the RA types without and with AltCapt

Without AltCapt, 57% of RAs are an “adjust vertical speed, adjust”. 27% of RAs are climb or descend RAs, and the remaining 16% are monitor vertical speed RAs.

When introducing AltCapt, this distribution changes. “Adjust vertical speed, adjust” RAs represent only 25% of the RAs triggered. Climb or descend RAs represent around 40% of RAs, and monitor vertical speed RAs around 30%, depending on the AltCapt configuration.

Introducing AltCapt in a given airspace would change the distribution of RAs significantly and therefore the perception of TCAS by people using it.

4.2.3 Indicators related to ATC compatibility

4.2.3.1 Number of RAs

4.2.3.1.1 Results

The following table shows the proportion of RAs expressed as a percentage of the number of RAs in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	100.0%	89.8%	79.0%	67.7%	54.3%
Basis+Protection against multiple TAs	100.0%	89.8%	79.0%	67.7%	54.3%
Basis+Taking into account intruder's altitude	100.0%	87.3%	74.1%	60.2%	45.0%
Basis+Protection against multiple TAs+reinforced acc.	100.0%	89.9%	79.0%	67.7%	54.8%
Basis+improved Protection against multiple TAs	100.0%				53.3%

Table 38: % of RAs - airspace perspective – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	-10.2%	-21.0%	-32.3%	-45.7%
Basis+Protection against multiple TAs	0.0%	-10.2%	-21.0%	-32.3%	-45.7%
Basis+Taking into account intruder's altitude	0.0%	-12.7%	-25.9%	-39.8%	-55.0%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	-10.1%	-21.0%	-32.3%	-45.2%
Basis+improved Protection against multiple TAs	0.0%				-46.7%

Table 39: RAs – Variation - airspace perspective – European ATM model

With AltCapt, the proportion of RAs can be decreased by a factor which can be as high as 55%, if taking into account the intruder’s altitude.

If this information is not taken into account, the magnitude of the decrease of the number of RAs is 46%, which is still significant.

Even a level of equipage of 25% would decrease the number of RAs by a factor of at least 10%, which is a noticeable benefit of AltCapt.

The following table shows the proportion of RAs removed and added by each of the AltCapt configurations, as a proportion of the initial number of RAs.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	-	2.74%	5.56%	8.60%	10.72%
Basis+Protection against multiple TAs	-	2.74%	5.56%	8.60%	10.72%
Basis+Taking into account intruder's altitude	-	0.06%	0.11%	0.14%	0.21%
Basis+Protection against multiple TAs+reinforced acc.	-	2.91%	6.01%	9.27%	11.80%
Basis+improved Protection against multiple TAs	-				10.90%

Table 40: RAs added - airspace perspective – European ATM model

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	-	12.95%	26.59%	40.91%	56.41%
Basis+Protection against multiple TAs	-	12.95%	26.59%	40.91%	56.41%
Basis+Taking into account intruder's altitude	-	12.78%	26.00%	39.98%	55.16%
Basis+Protection against multiple TAs+reinforced acc.	-	13.17%	27.03%	41.47%	56.95%
Basis+improved Protection against multiple TAs	-				57.62%

Table 41: RAs removed - airspace perspective – European ATM model

The better performance obtained by taking into account the altitude of the intruder results from the fact that the configurations not taking into account this information remove a significant part of RAs, but add some.

Indeed, with AltCapt basis, 19% of the remaining RAs are RAs which were not present without AltCapt, which represents around 10% of the initial number of RAs.

4.2.3.1.2 The jump geometry

4.2.3.1.2.1 Example

The following figure shows an example of the jump geometry, without AltCapt.

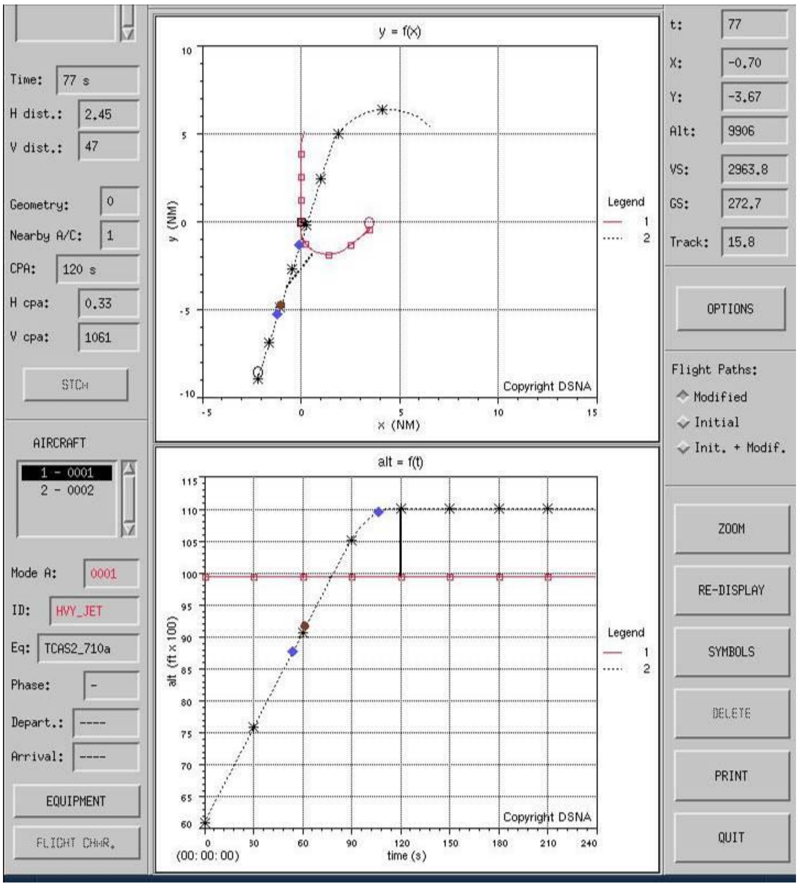


Figure 13: Encounter without AltCapt contribution – Jump geometry

This encounter, which is a loss of ATC separation, results in only TAs being triggered onboard the two aircraft. The horizontal distance is 2.5 NM when the aircraft are at co-altitude.

The following figures show the same encounter once AltCapt has been applied.

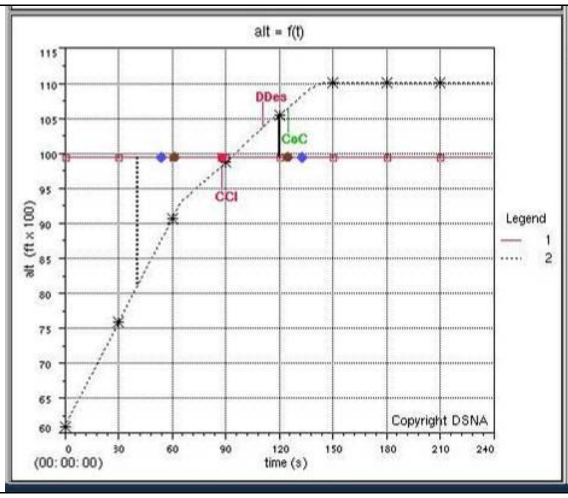
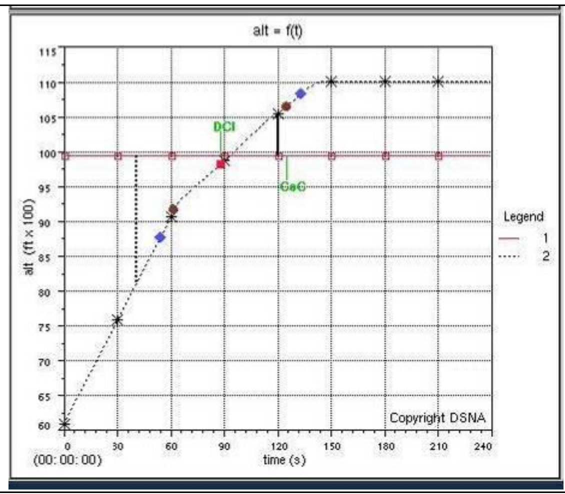
Aircraft 1	Aircraft 2
	
CPA: 0.33NM/590ft	

Figure 14: Encounter with AltCapt contribution

Legend: CCL: crossing climb RA, DDES: level-off RA, CoC: Clear of Conflict, DCl: monitor vertical speed RA

When AltCapt is applied, the reduction of the vertical rate just before the altitude crossing induces the triggering of a crossing climb RA onboard the climbing aircraft and a monitor vertical speed RA onboard the level aircraft. The vertical separation at CPA is reduced to 590 ft.

4.2.3.1.2.2 Detailed geometries

The following figure shows the distribution of the geometries in which these RAs are added. The geometries are shown with a format such as "xy-ab-crossing". The four letters x, y, a and b can take the value of L (for "Level"), C (for "Climb") and D (for "Descend"). The indication of crossing or not crossing indicates whether the trajectories cross in the vertical plane in the encounter without AltCapt and TCAS simulated. For the most represented geometries, the shape of the corresponding geometry in the vertical plane is shown with an arrow, to illustrate to what trajectories the four letter code corresponds (for example DL-CL crossing corresponds to a geometry in which two aircraft are leveling-off 1000ft apart, but with their trajectories crossing in the vertical plane).

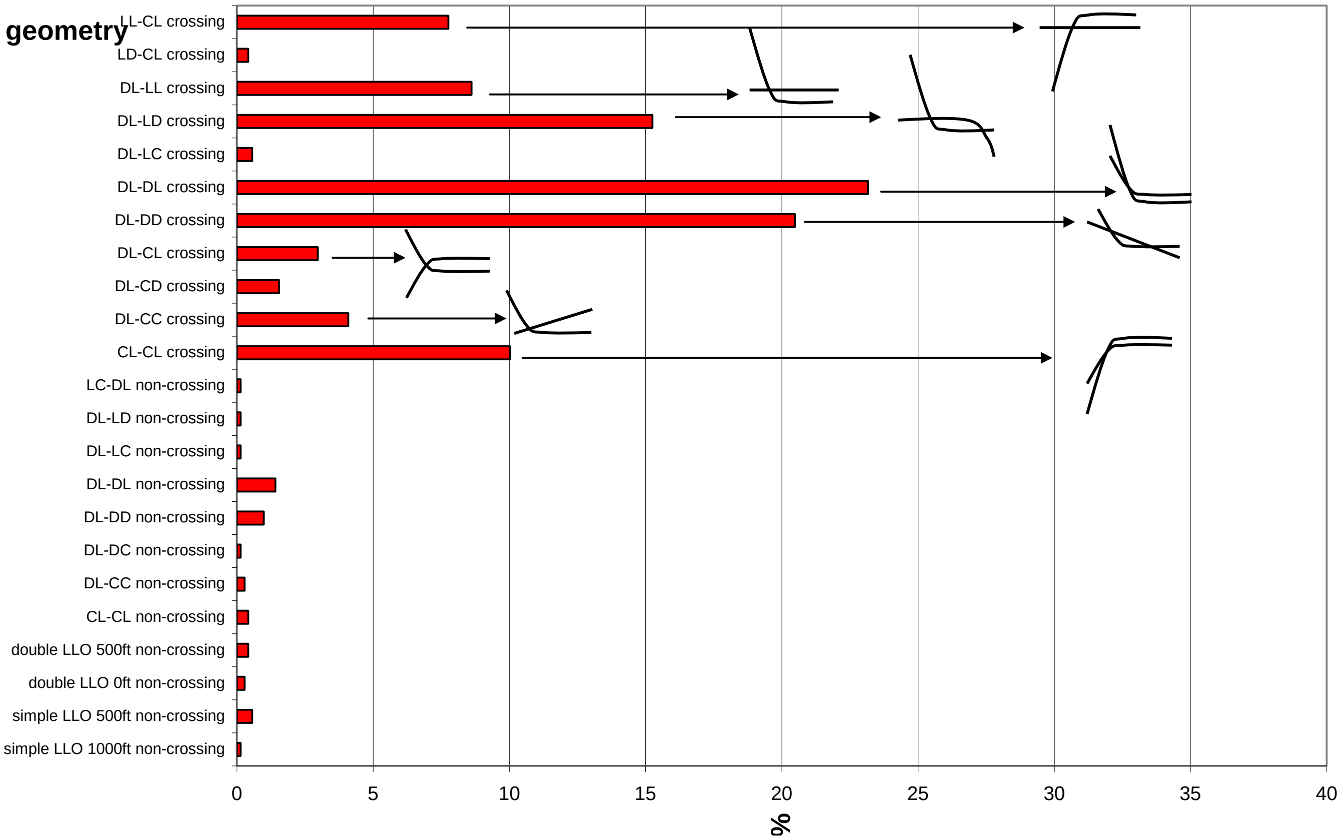


Figure 15: Geometries in which RAs are added by AltCapt when not taking into account the altitude of the intruder

Legend: L: Level, C: Climb, D: Descent (e.g. CL: Climb then Level)

95% of the added RAs are triggered during encounters which geometry corresponds to the "jump" geometry (i.e. all the crossing geometries in the figure above). For the 5% remaining, the geometry is non crossing, meaning the trajectory of the involved aircraft never cross in the vertical plane. In the case of non-crossing geometries, AltCapt can very rarely add RAs because decreasing a vertical rate increases the duration of a vertical convergence, therefore the thresholds to trigger an RA may pass for one cycle, whereas they were not passed without AltCapt.

94% of the added RAs are triggered during encounters which are initially losses of ATC separation without AltCapt.

4.2.3.1.2.3 VMD diagram

The following figure shows the safety perspective only for encounters in which RAs are added (which are in 95% of the cases triggered in a jump geometry), through a VMD diagram.

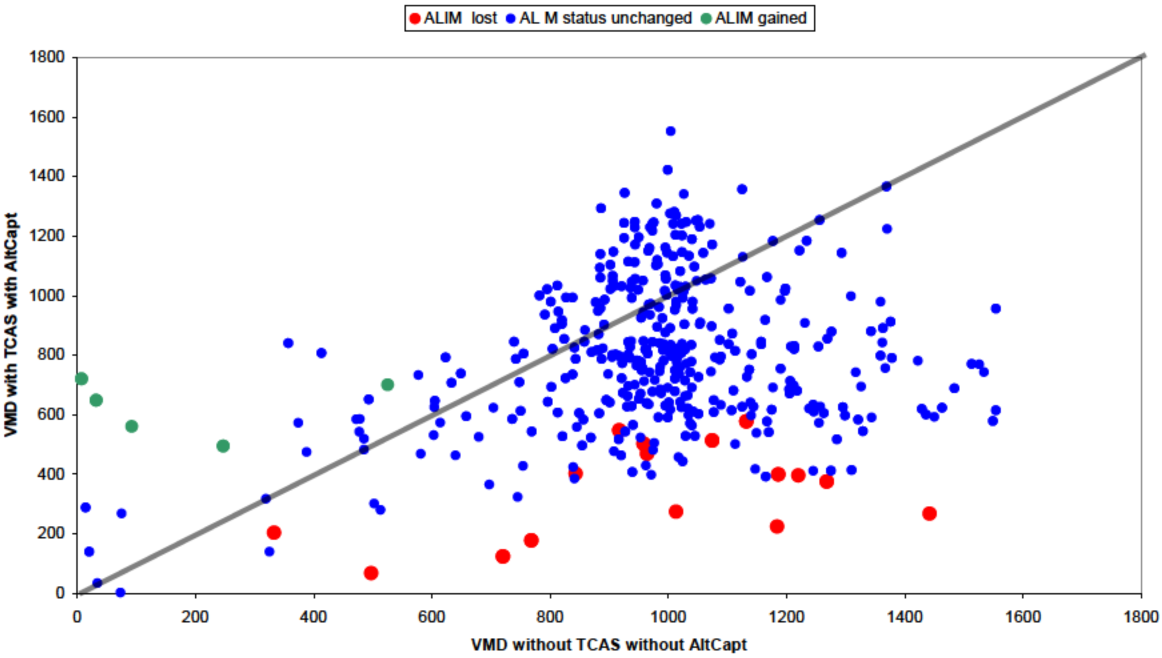


Figure 16: VMD diagram – added RAs

Overall, there are more encounters for which the VMD is decreased than for which the VMD is increased.

The proportion of these added RAs resulting in a vertical separation at CPA becoming lower than ALIM, where it was higher than ALIM without AltCapt is equal to 3.7% (red plots).

The proportion of these added RAs resulting in a vertical separation at CPA becoming higher than ALIM, where it was lower than ALIM without AltCapt is equal to 1.1% (green plots).

4.2.3.1.2.4 Added RAs

The following figure shows the distribution of the added RAs. The RAs of both aircraft involved are shown, using the format A/B, where A is the RA for one aircraft, and B for the intruder.

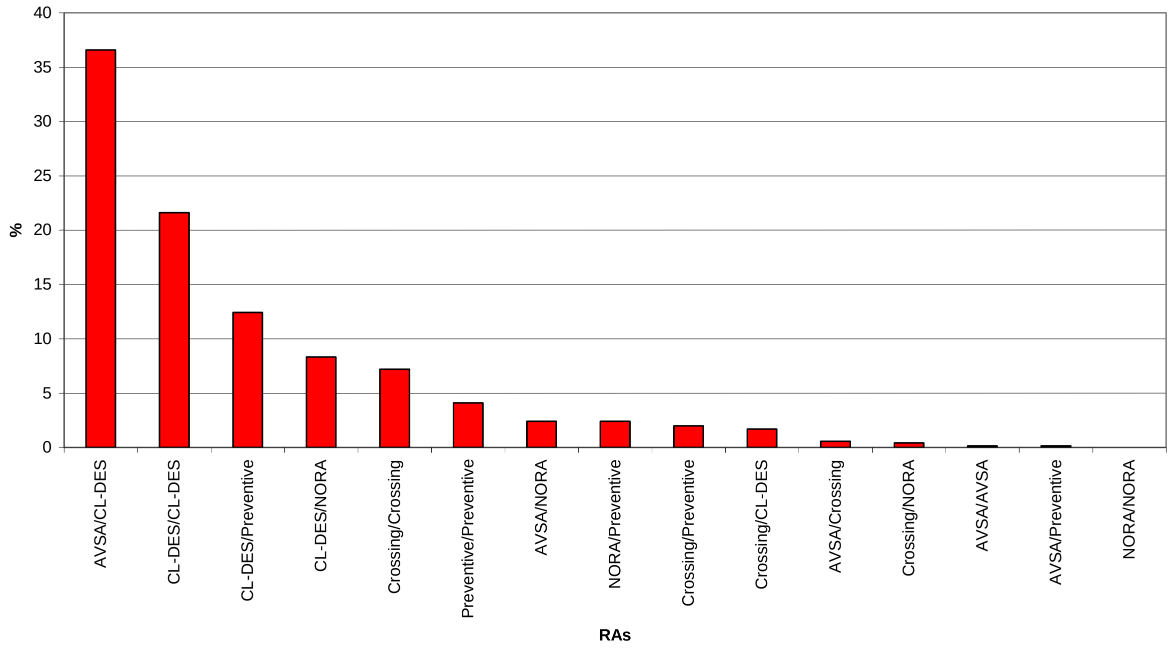


Figure 17: Added RAs

This figure shows that crossing RAs are far from being the majority of the added RAs. Indeed, the crossing status of an RA depends on the tracked vertical distance between own and the intruder. If this distance is below 100 ft, an RA is not announced as a crossing RA. As a result, one can assess from the above figure that for the major part of the added RAs, the RA is triggered when the aircraft are at co-altitude or when they have already crossed vertically.

4.2.3.1.2.5 NATS Study

NATS has performed an analysis of UK radar data in order to find actual occurrences of the jump geometry, in which AltCapt could possibly result in added RAs being triggered [5].

Criteria corresponding to the activation conditions of AltCapt were used on vertical "cross" geometries, so as to filter those on which AltCapt would possibly trigger. Additionally, a filter was added to keep only the encounters for which there was no actual RA but on which a TA was eligible, because only such encounters can possibly result in AltCapt adding an RA.

In total, ten possible AltCapt activations were observed from the analysed data. Of these ten, it is noted that all of them occurred once within a pair file (i.e. only one aircraft would receive a TCAP within the pair).

The AltCapt and TCAS simulator used by DSNA was passed on these encounters. None of the AltCapt simulations resulted in RAs being induced to either aircraft.

As a conclusion to this study, it is considered that the issue of the jump geometry is acceptable.

4.2.3.2 Number of positive RAs

This safety indicator has been presented in 4.2.2.2.

4.2.3.3 Distribution of RAs vs. altitude

The following figure shows the distribution of each RA type vs. altitude for the reference scenario. The FL shown are 2000 ft wide (as an example, the bin indicated as 25 is going from FL25 to FL 45 not comprised).

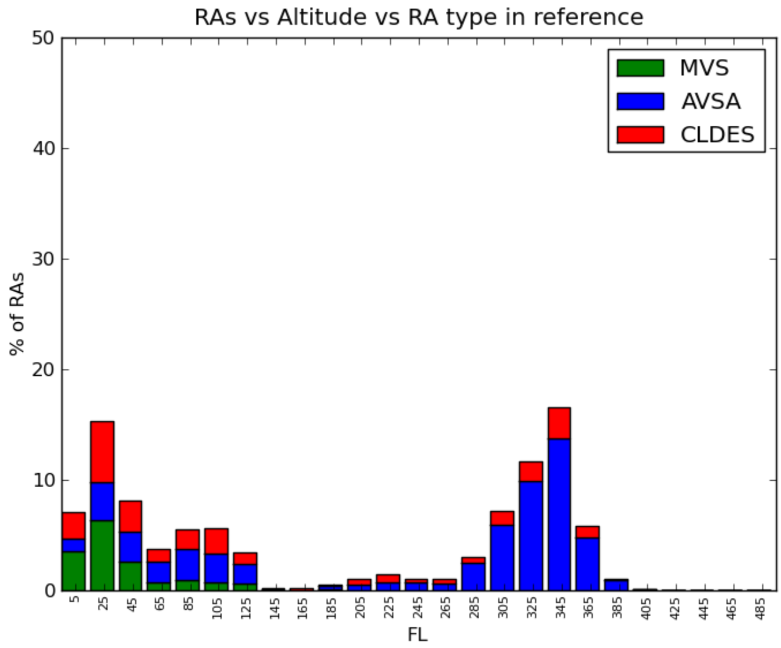


Figure 18: Distribution of RA vs altitude – Reference

In the reference scenario, at low altitudes, a noticeable part of RAs are monitor vertical speed RAs, triggered in encounters with 500 ft of vertical separation, between VFR and IFR aircraft. Another noticeable part of RAs are climb or descend RAs.

At higher altitudes, the majority of RAs are “adjust vertical speed, adjust” RAs triggered during 1000 ft level-off encounters. Sometimes, climb or descend RAs are triggered in these encounters.

The following figure shows the distribution of each RA type vs altitude for the AltCapt Basis scenario.

On the following figures, the number of RAs used as a reference to compute the percentage shown is constant (unlike what is shown in 4.2.2.11), and equal to the number of RAs in the reference scenario, so as to permit to better assess the actual effect of AltCapt.

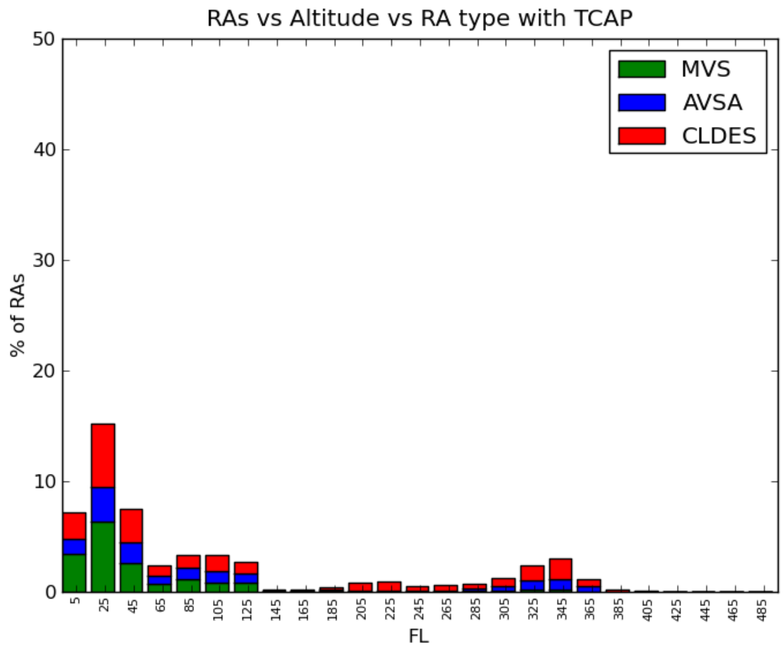


Figure 19: Distribution of RA vs altitude – AltCapt Basis

The following figure shows the distribution of each RA type vs altitude for the AltCapt scenario taking into account the intruder's altitude. The FL shown are 2000 ft wide (as an example, the bin indicated as 25 going from FL25 to FL 45 not comprised).

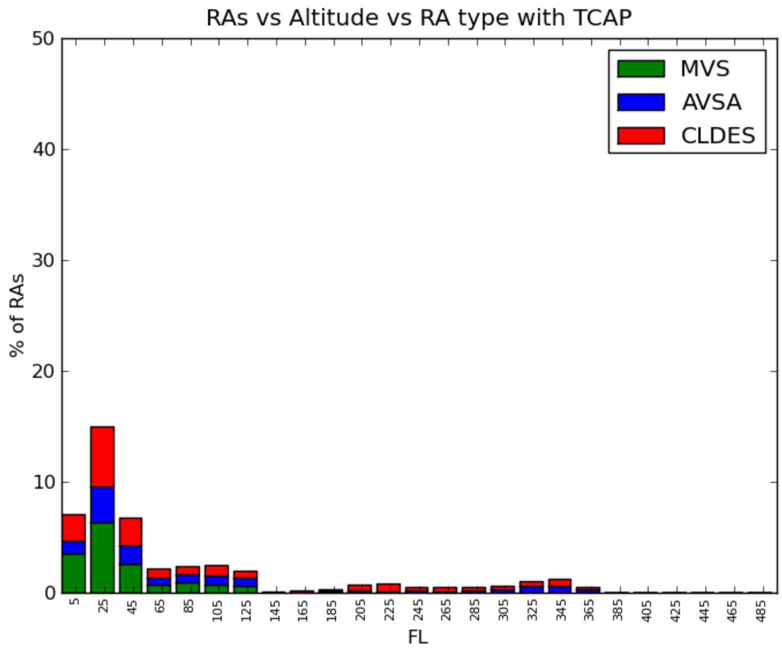


Figure 20: Distribution of RA vs altitude – AltCapt Basis+Taking into account intruder's altitude

As shown on the last two figures, AltCapt has a significant effect above FL 200, and on the peak around FL100. At these altitudes, the number of "Adjust Vertical Speed, Adjust" is significantly decreased, so are the numbers of climb and descend RAs.

Taking into account the altitude of the intruder reduces the number of RAs around FL100 and above FL200. This is explained by the fact that taking into account the altitude of the intruder reduces very significantly the number of added RAs.

It must be pointed out that the distribution for the two configurations not shown are very close to that shown in Figure 19, and are therefore not worth showing.

4.2.3.4 Number of operationally undesired RAs

This safety indicator has been presented in 4.2.2.6.

4.2.3.5 Distribution of vertical deviations

The table below present the deviation ratios, computed as the ratio of deviations decreased by AltCapt, divided by the number of deviations increased by AltCapt. A ratio of 100% means that overall, the number of deviations decreased is equal to the number of deviations increased. For a level of equipage of 0%, the ratio is not computed: comparing a simulation to itself presents little interest.

The following table presents the deviation ratios computed on the European ATM model.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	-	150.0%	185.2%	184.7%	210.5%
Basis+Protection against multiple TAs	-	150.0%	185.2%	184.7%	210.5%
Basis+Taking into account intruder's altitude	-	547.6%	830.0%	875.0%	1436.1%
Basis+Protection against multiple TAs+reinforced acc.	-	143.8%	166.0%	169.5%	186.8%
Basis+improved Protection against multiple TAs	-				215.5%

Table 42: Deviation ratios – airspace perspective – European ATM model

Whatever the AltCapt configuration and level of equipage, the number of deviations decreased is higher than the number of deviations increased, but much more when taking into account the altitude of the intruder.

4.2.3.6 Number of RAs with incompatible sense selection

The following table shows the proportion of RAs with an incompatible sense selection when compared to what ATC had planned.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	5.0%	5.9%	6.3%	6.6%	6.6%
Basis+Protection against multiple TAs	5.0%	5.9%	6.3%	6.6%	6.6%
Basis+Taking into account intruder's altitude	5.0%	5.0%	4.9%	4.9%	4.8%
Basis+Protection against multiple TAs+reinforced acc.	5.0%	4.5%	6.7%	7.0%	7.2%
Basis+improved Protection against multiple TAs	5.0%				6.5%

Table 43: % of RAs with incompatible sense selection - airspace perspective – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	17.6%	26.4%	32.2%	31.6%
Basis+Protection against multiple TAs	0.0%	17.6%	26.4%	32.2%	31.6%
Basis+Taking into account intruder's altitude	0.0%	0.0%	-1.8%	-2.1%	-3.0%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	-10.0%	33.7%	41.3%	43.8%
Basis+improved Protection against multiple TAs	0.0%				29.8%

Table 44: RAs with incompatible sense selection – Variation - airspace perspective – European ATM model

All the configurations, except the one taking into account the altitude of intruder, lead to an increase of the proportion of RAs with an incompatible sense selection. This is explained by the “jump” geometry, in which the reduction of vertical rate with AltCapt leads, for the encounters in which an RA is triggered even without AltCapt, to a change of sense of the RAs (e.g., climb sense RA turning into descend sense RA).

4.2.4 Indicators related to the trajectory modification

4.2.4.1 Distance to selected FL at the time of the TA

The following figure shows the distribution of the distance to the selected flight level at the time of TAs. This figure was plotted using AltCapt Basis, however the distribution is identical whatever the AltCapt options used.

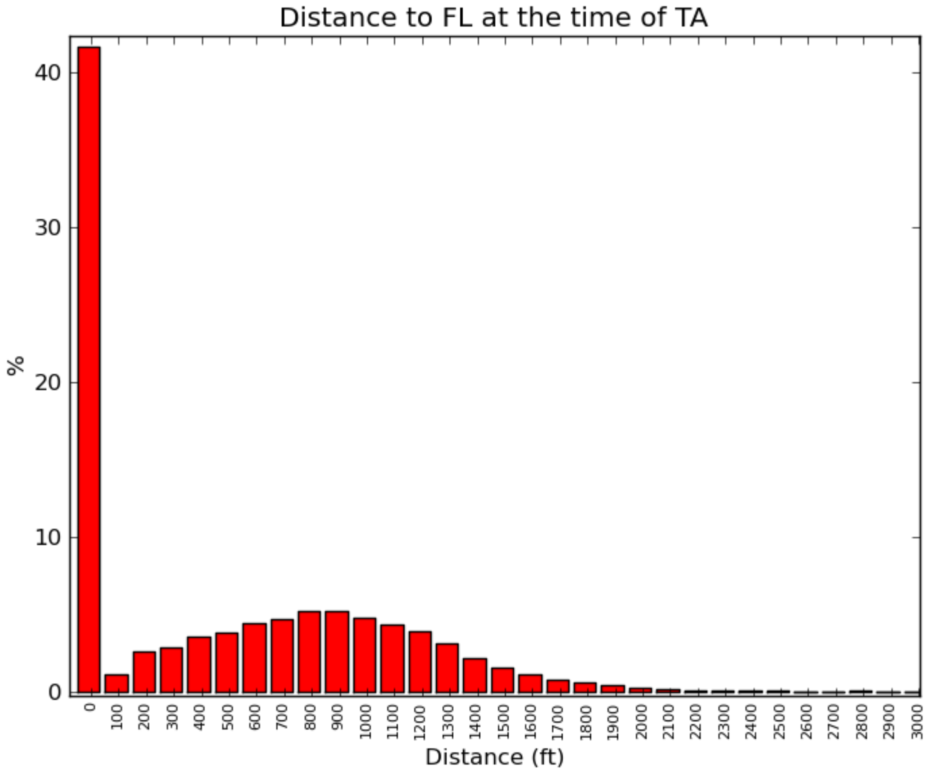


Figure 21: Distance to selected FL at TA

75.5% of the TAs triggered on aircraft having a trajectory with a level-off are triggered at less than 1000 ft from the selected flight level. 98.5% of them are triggered at less than 2000 ft of the selected flight level.

It is also interesting to notice that over 40% of TAs are triggered in level aircraft.

4.2.4.2 Distance to selected FL at the time of the initial RA

The following figure shows the distribution of the distance to the selected flight level at the time of RAs (without AltCapt).

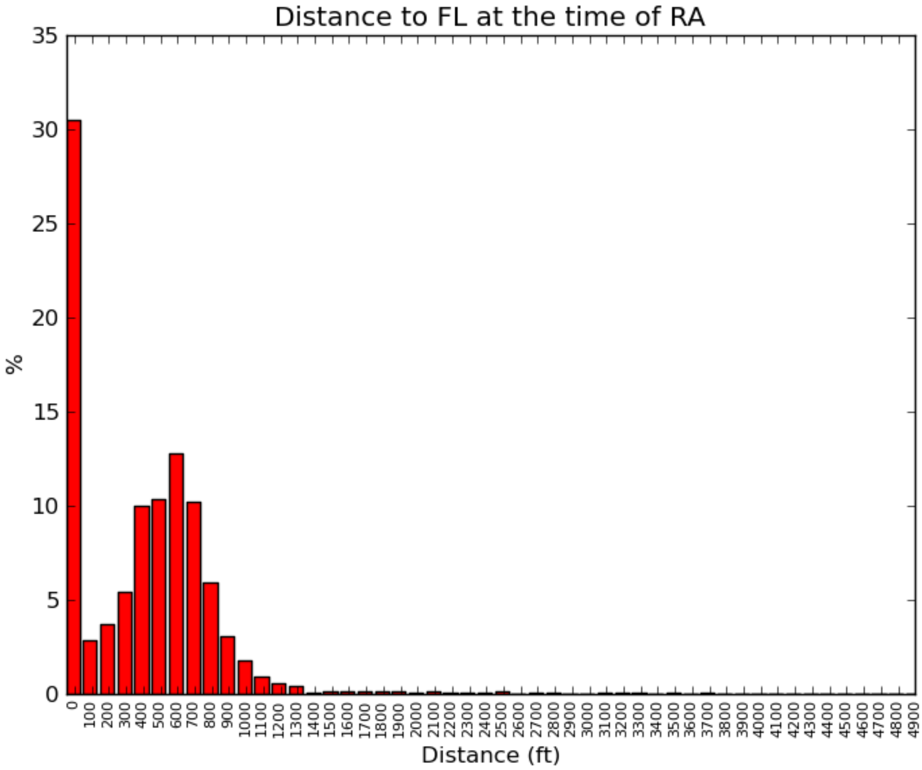


Figure 22: Distance to selected FL at RA

As shown on this figure, the major part of the RAs are triggered while the aircraft is less than 1000 ft from the selected flight level.

4.2.4.3 Vertical rate at the time of the TA

The following figure shows the distribution of the vertical rates at the time of TAs.

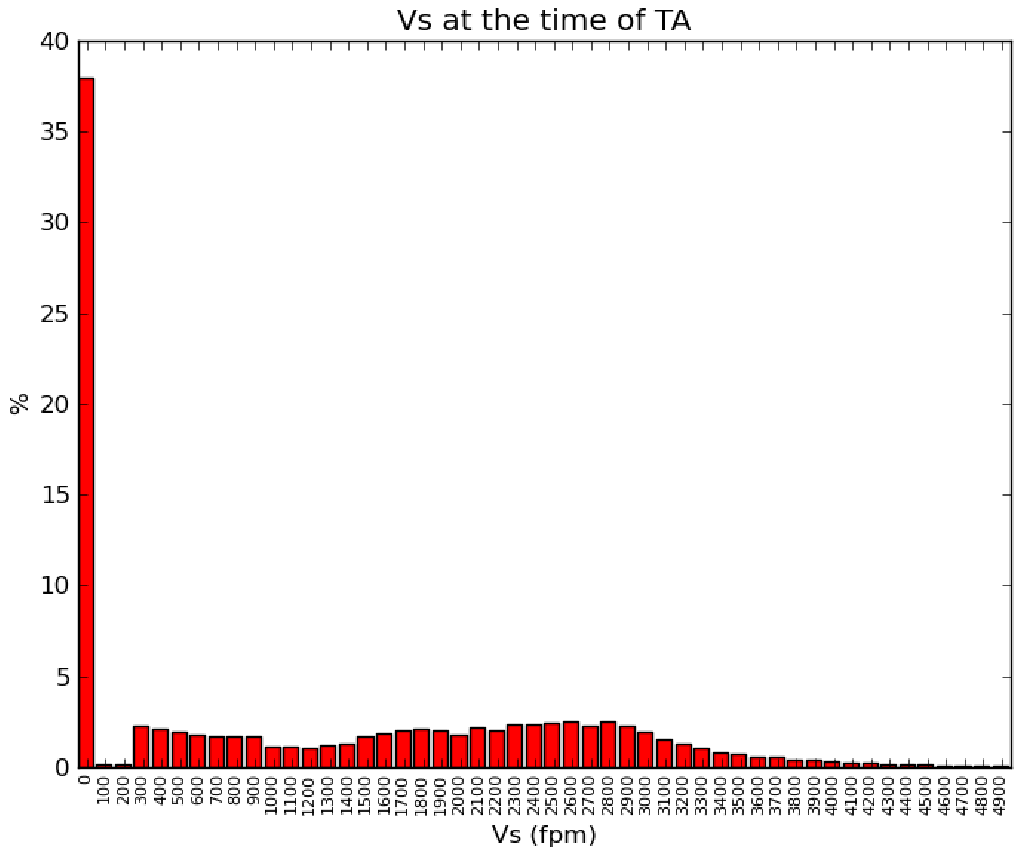


Figure 23: Vertical rates at the time of TAs

4.2.4.4 Vertical rate at the time of the initial RAs

The following figure shows the distribution of the vertical rates at the time of RAs.

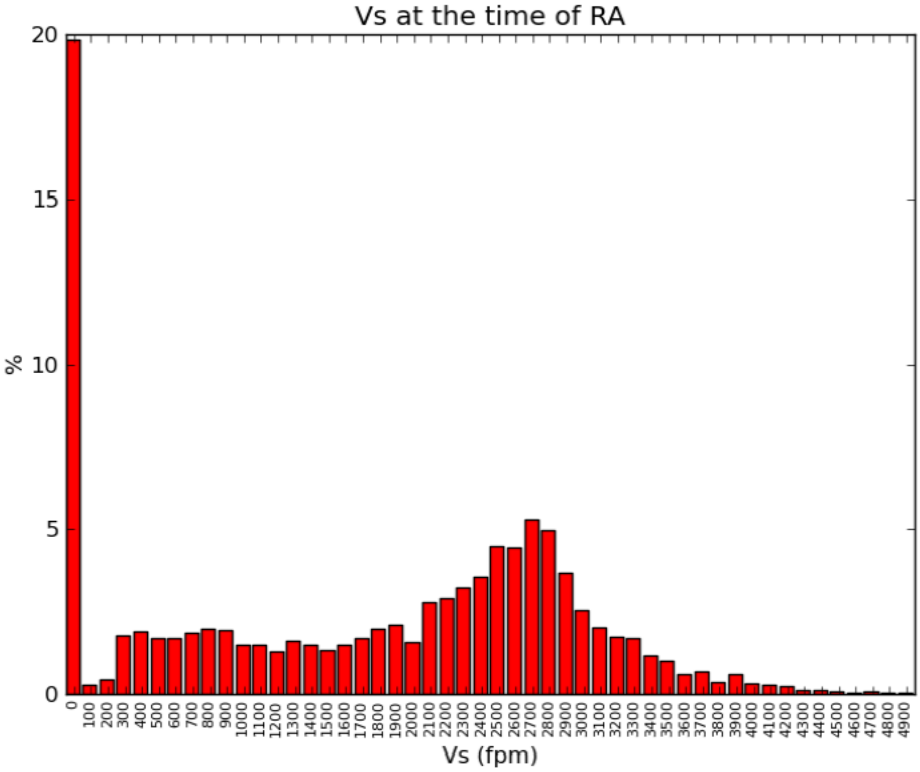


Figure 24: Vertical rates at the time of RAs

4.2.4.5 Difference between the times to reach the selected Flight level

The following figures show the distributions of the difference of times to reach the selected flight level for each AltCapt configuration and 100% of equipage. The meaning of this indicator is illustrated hereafter.

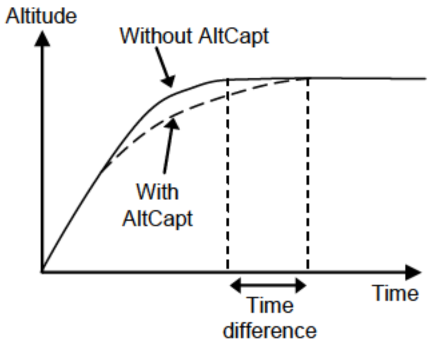
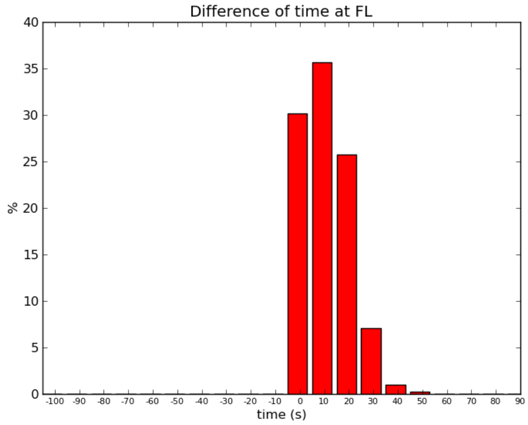
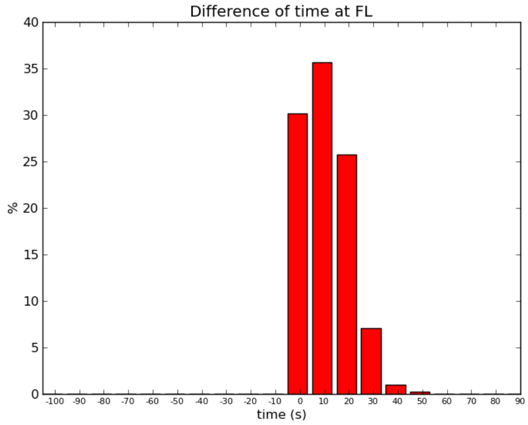
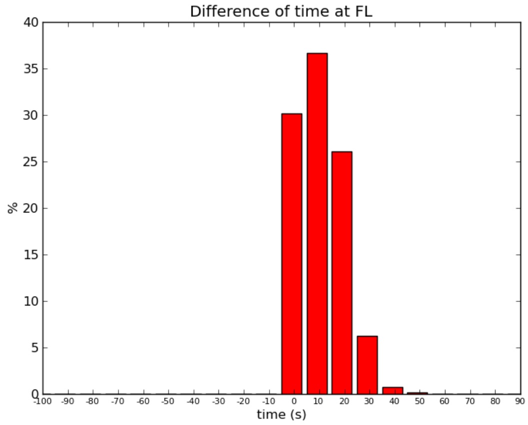


Figure 25: Indicator explanation

AltCapt Configuration	Distribution
Basis	
Basis+Protection against multiple TAs	
Basis+Taking into account intruder's altitude	

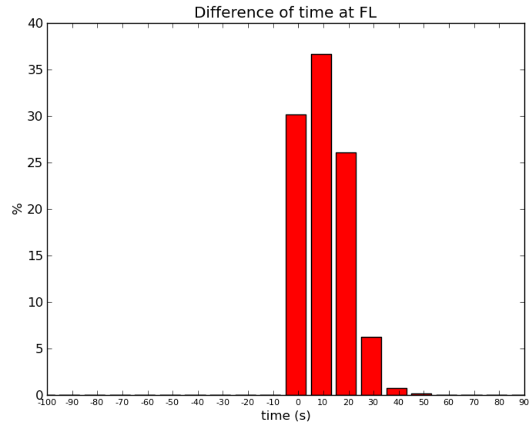
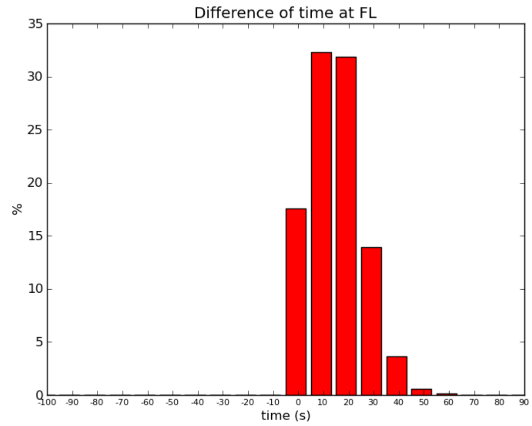
Basis+Protection against multiple TAs+reinforced acc.	
Basis+improved Protection against multiple TAs	

Table 45: Difference of time to reach selected flight level

These figures show that whatever the configuration, the additional time to reach the selected flight level with AltCapt is always below 70s. In more than 99% of the cases, this additional time is below 60 s.

With the 4 first configurations, in over 90% of the cases, the time is below 30s. With the last configuration, one notices a 10s shift of the distribution to the right. In fact, this configuration aims at decreasing the number of multiple TAs by reducing the vertical rate. This has a little cost in terms of time to capture the selected flight level. This cost is considered minimal.

4.2.4.6 Difference of altitude at the time of level-off at the selected flight level

The following figures show the distributions of the difference of altitude at the time of level-off at the selected flight level for each AltCapt configuration and 100% of equipage. The meaning of this indicator is illustrated hereafter.

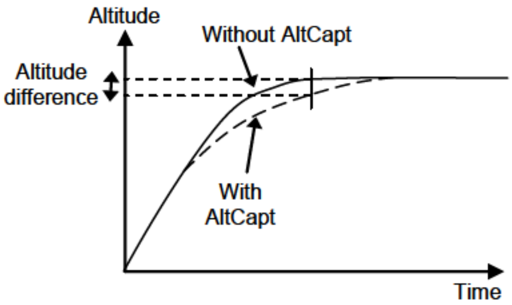
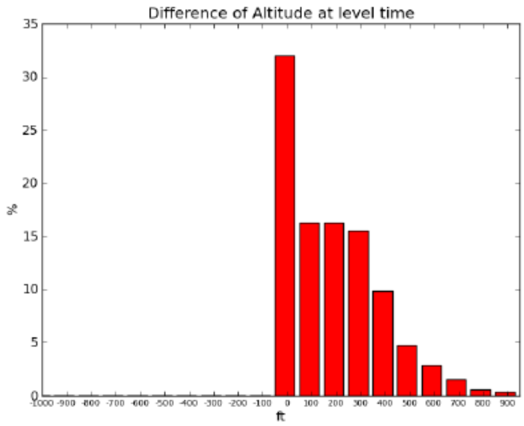
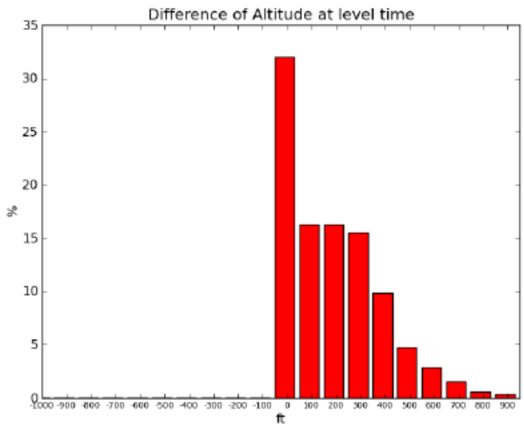


Figure 26: Indicator explanation

AltCapt Configuration	Distribution
Basis	
Basis+Protection against multiple TAs	

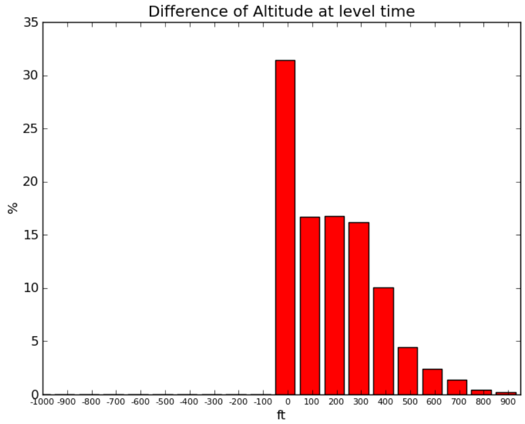
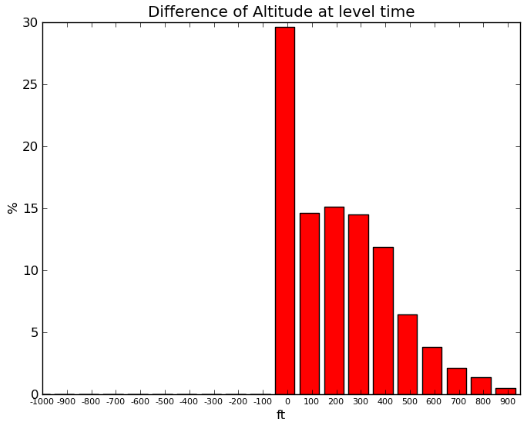
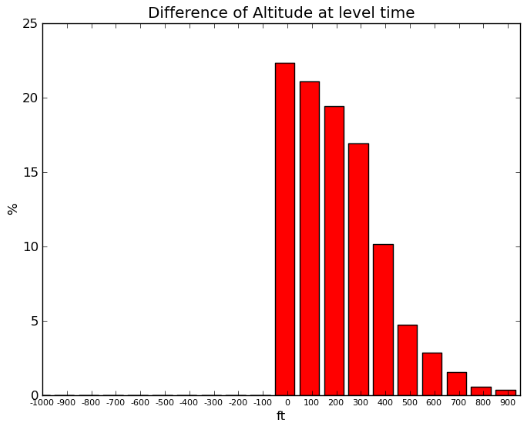
<table>
<tr><td>Basis+Taking into account intruder's altitude</td><td>
</td></tr>
<tr><td>Basis+Protection against multiple TAs+reinforced acc.</td><td>
</td></tr>
<tr><td>Basis+improved Protection against multiple TAs</td><td>
</td></tr>
</table>

Table 46: Difference altitude at the time of level-off at the selected flight level

Whatever the configuration, the difference of altitude is below 500 ft in 95% of the cases.

4.2.4.7 Horizontal distance at the preceding selected FL

The following figures show the distributions of the horizontal distance at the preceding selected FL for each AltCapt configuration and 100% of equipage. The meaning of this indicator is illustrated hereafter.

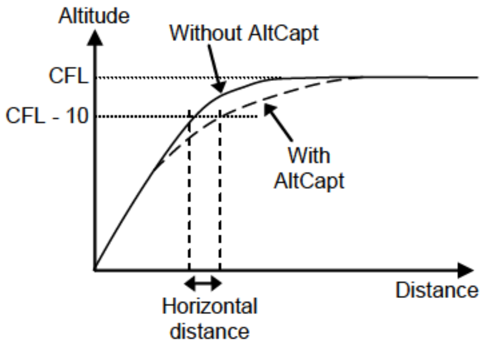
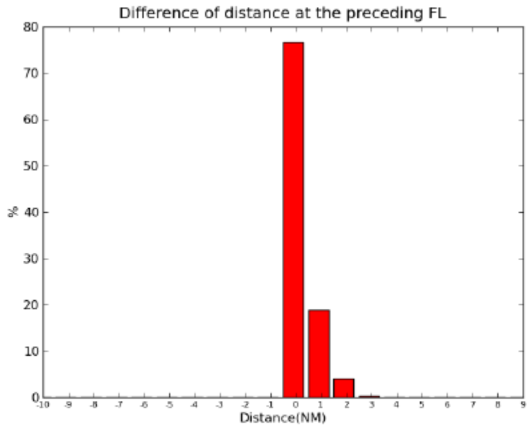
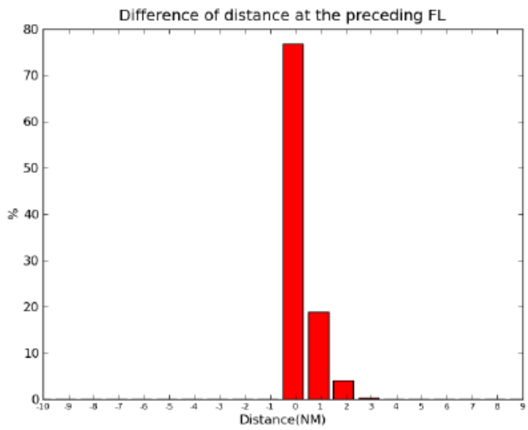


Figure 27: Indicator explanation

AltCapt Configuration	Distribution
Basis	
Basis+Protection against multiple TAs	

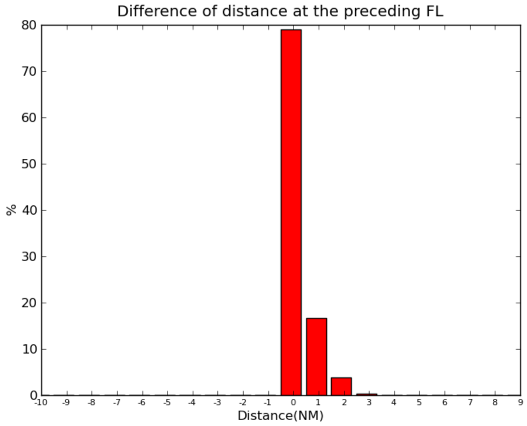
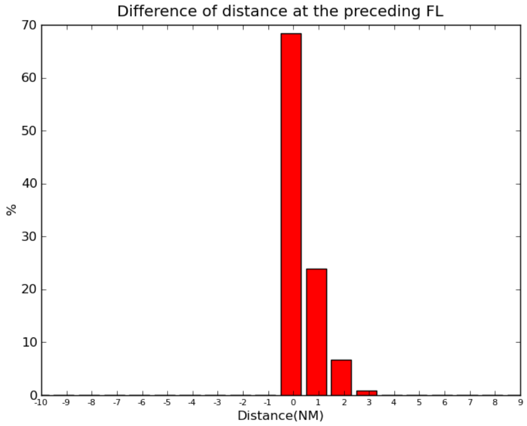
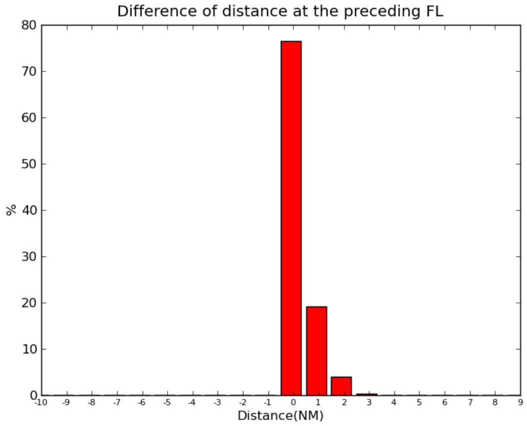
Basis+Taking into account intruder's altitude	
Basis+Protection against multiple TAs+reinforced acc.	
Basis+improved Protection against multiple TAs	

Table 47: Difference of horizontal distance at the preceding selected FL

Whatever the configuration, the horizontal distance is below 4 NM in all the cases.

4.3 Aircraft perspective

4.3.1 Indicators related to safety

4.3.1.1 Number of RAs without ALIM provision

The following table shows the increase or decrease, expressed as a percentage, of RAs without ALIM that an aircraft would receive by equipping with the AltCapt functionality.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	-	9.7%	6.9%	5.1%	10.8%
Basis+Protection against multiple TAs	-	9.7%	6.9%	5.1%	10.8%
Basis+Taking into account intruder's altitude	-	-3.9%	-2.97%	-1.9%	-1.4%
Basis+Protection against multiple TAs+reinforced acc.	-	17.7%	17.8%	11.4%	16.4%
Basis+improved Protection against multiple TAs	-				8.4%

Table 48: RAs without ALIM – aircraft perspective – European ATM model

For all the configurations, except the one taking into account intruder's altitude, one notices a slight increase of the number of RAs failing to achieve ALIM.

The configuration taking into account intruder's altitude results in a very slight decrease of the RAs without ALIM.

4.3.1.2 Number of increase RAs

The following table shows the increase or decrease, expressed as a percentage, of increase RAs an aircraft would receive by equipping with the AltCapt functionality.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	-	13.3%	0.0%	0.0%	6.0%
Basis+Protection against multiple TAs	-	13.3%	0.0%	0.0%	6.0%
Basis+Taking into account intruder's altitude	-	0.0%	-3.0%	0.0%	-1.5%
Basis+Protection against multiple TAs+reinforced acc.	-	20.0%	6.1%	0.0%	11.9%
Basis+improved Protection against multiple TAs	-				6.0%

Table 49: Increase RAs - aircraft perspective – European ATM model

When the altitude of the intruder is not taken into account, the number of increase RAs an aircraft would receive by equipping with the AltCapt functionality would remain nearly unchanged or slightly increased, taking into account that, especially for the rates of equipage of 25% and 50%, the absolute numbers of increase RAs are small when compared to the overall number of RAs received (below 2%).

The configuration with a reinforced acceleration has slightly worse results than the other solutions.

The configuration taking into account the altitude of the intruder results in a decrease of the number of increase RAs received, confirming once again that this solution is very efficient to avoid situations in which AltCapt would add RAs.

4.3.1.3 Number of Reversal RAs

The following table shows the increase or decrease, expressed as a percentage, of reversal RAs an aircraft would receive by equipping with the AltCapt functionality.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	-	20.0%	40.0%	71.4%	66.7%
Basis+Protection against multiple TAs	-	20.0%	40.0%	71.4%	66.7%
Basis+Taking into account intruder's altitude	-	0.0%	0.0%	0.0%	8.3%
Basis+Protection against multiple TAs+reinforced acc.	-	0.0%	50.0%	92.9%	75.0%
Basis+improved Protection against multiple TAs	-				66.7%

Table 50: Reversal RAs - aircraft perspective – European ATM model

Overall, the number of reversal RAs is increased for all the configurations, except the one taking into account the altitude of the intruder.

It must be taken into account that absolute numbers of reversal RAs are small when compared to the overall number of RAs received (below 1%).

4.3.2 Indicators related to pilot acceptance

4.3.2.1 Number of crossing RAs

The following table shows the increase or decrease, expressed as a percentage, of crossing RAs an aircraft would receive by equipping with the AltCapt functionality.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	-	105.0%	135.5%	111.8%	134.3%
Basis+Protection against multiple TAs	-	105.0%	135.5%	111.8%	134.3%
Basis+Taking into account intruder's altitude	-	-5.0%	0.0%	-5.9%	-6.0%
Basis+Protection against multiple TAs+reinforced acc.	-	130.0%	154.8%	147.1%	168.7%
Basis+improved Protection against multiple TAs	-				131.3%

Table 51: Crossing RAs - aircraft perspective – European ATM model

Overall, the number of crossing RAs is increased for all the configurations except the one taking into account the altitude of the intruder.

However, it must be taken into account that absolute numbers of crossing RAs are small when compared to the overall number of RAs received (below 3%).

Once again, the configuration taking into account the altitude of the intruder results in the number of crossing RAs not increasing.

4.3.2.2 Number of positive RAs

The following table shows the increase or decrease, expressed as a percentage, of positive RAs an aircraft would receive by equipping with the AltCapt functionality.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	-	-53.7%	-55.8%	-56.96%	-59.3%
Basis+Protection against multiple TAs	-	-53.7%	-55.8%	-56.96%	-59.3%
Basis+Taking into account intruder's altitude	-	-62.3%	-65.2%	-67.5%	-69.6%
Basis+Protection against multiple TAs+reinforced acc.	-	-53.7%	-55.8%	-56.6%	-58.5%
Basis+improved Protection against multiple TAs					-61.0%

Table 52: Positive RAs - aircraft perspective – European ATM model

Whatever the configuration, the proportion of positive RAs decreases significantly. Even at a proportion of equipped aircraft equal to 25%, the decrease is above 50%.

4.3.2.3 Number of initial RAs opposite to the aircraft trajectory

The following table shows the increase or decrease, expressed as a percentage, of RAs opposite to the trajectory an aircraft would receive by equipping with the AltCapt functionality.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	-	-25.5%	-34.9%	-45.5%	-52.6%
Basis+Protection against multiple TAs	-	-25.5%	-34.9%	-45.5%	-52.6%
Basis+Taking into account intruder's altitude	-	-44.7%	-52.6%	-61.3%	-66.8%
Basis+Protection against multiple TAs+reinforced acc.	-	-24.2%	-33.7%	-43.97%	-51.4%
Basis+improved Protection against multiple TAs	-				-61.0

Table 53: Initial opposite RAs - aircraft perspective – European ATM model

Whatever the configuration tested, the proportion of initial opposite RAs decreases, and the decrease is correlated to the level of equipage. With a level of equipage of 100%, the proportion of such RAs is divided by two.

Here again, the best performance is obtained when taking into account the altitude of the intruder, which is explained by additional RAs not being triggered in the “jump” geometry.

4.3.2.4 Number of multiple RAs

The following table shows the increase or decrease, expressed as a percentage, of multiple RAs an aircraft would receive by equipping with the AltCapt functionality.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	-	-75.0%	-100.0%	-100.0%	-100.0%
Basis+Protection against multiple TAs	-	-75.0%	-100.0%	-100.0%	-100.0%
Basis+Taking into account intruder's altitude	-	-75.0%	-100.0%	-90.0%	-92.9%
Basis+Protection against multiple TAs+reinforced acc.	-	-75.0%	-100.0%	-90.0%	-92.9%
Basis+improved Protection against multiple TAs	-				-100%

Table 54: Multiple RAs - aircraft perspective – European ATM model

Whatever the configuration, the proportion of multiple RAs decreases but can be considered is unchanged, considering that the proportion is very low.

4.3.2.5 Number of complex RA sequences

The following table shows the increase or decrease, expressed as a percentage, of complex sequences of RAs an aircraft would receive by equipping with the AltCapt functionality.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	-	10.2%	-6.5%	-2.9%	-8.98%
Basis+Protection against multiple TAs	-	10.2%	-6.5%	-2.9%	-8.98%
Basis+Taking into account intruder's altitude	-	-14.3%	-25.0%	-24.1%	-27.4%
Basis+Protection against multiple TAs+reinforced acc.	-	10.2%	-6.5%	-2.9%	-8.98%
Basis+improved Protection against multiple TAs	-				-9.8%

Table 55: Complex sequences of RAs - aircraft perspective – European ATM model

Whatever the configuration, the proportion of complex sequences remains nearly unchanged or decreases, especially when taking into account the altitude of the intruder.

4.3.2.6 Number of operationally undesired RAs

The following table shows the increase or decrease, expressed as a percentage, of operationally undesired RAs an aircraft would receive by equipping with the AltCapt functionality.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	-	-89.8%	-92.4%	-94.8%	-96.9%
Basis+Protection against multiple TAs	-	-89.8%	-92.4%	-94.8%	-96.9%
Basis+Taking into account intruder's altitude	-	-89.8%	-92.3%	-94.6%	-96.6%
Basis+Protection against multiple TAs+reinforced acc.	-	-90.3%	-93.1%	-95.3%	-97.2%
Basis+improved Protection against multiple TAs	-				-98.6%

Table 56: Operationally undesired RAs - aircraft perspective – European ATM model

Whatever the configuration, the proportion of RAs considered as operationally undesired is significantly decreased by the introduction of AltCapt. With a level of equipage of 100%, the number of such RAs is cut by around 30, and even 70 with the improved protection against multiple TAs.

4.3.2.7 Number of TAs

The following table shows the increase or decrease, expressed as a percentage, of TAs aircraft would receive by equipping with the AltCapt functionality.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	-	-0.1%	-0.2%	-0.2%	-0.3%
Basis+Protection against multiple TAs	-	-0.1%	-0.2%	-0.2%	-0.3%
Basis+Taking into account intruder's altitude	-	-0.1%	-0.2%	-0.2%	-0.3%
Basis+Protection against multiple TAs+reinforced acc.	-	-0.3%	-0.5%	-0.7%	-1.1%
Basis+improved Protection against multiple TAs	-				-1.1%

Table 57: TAs - aircraft perspective – European ATM model

With AltCapt, the proportion of TAs remains unchanged or very slightly decreases.

4.3.2.8 Number of multiple TAs

The following table shows the increase or decrease, expressed as a percentage, of multiple TAs an aircraft would receive by equipping with the AltCapt functionality.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	-	94.5%	223.4%	403.6%	600.4%
Basis+Protection against multiple TAs	-	94.3%	223.2%	403.4%	600.2%
Basis+Taking into account intruder's altitude	-	90.1%	209.5%	384.8%	576.8%
Basis+Protection against multiple TAs+reinforced acc.	-	91.5%	213.1%	385.4%	570.7%
Basis+improved Protection against multiple TAs	-				471.9%

Table 58: Multiple TAs - aircraft perspective – European ATM model

AltCapt makes multiple TAs more frequent. However and as said for the airspace perspective, multiple TAs have never been reported as an operational issue in any operational monitoring.

4.3.3 Indicators related to ATC compatibility

4.3.3.1 Number of RAs

The following table shows the increase or decrease, expressed as a percentage, of RAs an aircraft would receive by equipping with the AltCapt functionality.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	-	-47.4%	-49.3%	-49.7%	-51.9%
Basis+Protection against multiple TAs	-	-47.4%	-49.3%	-49.7%	-51.9%
Basis+Taking into account intruder's altitude	-	-55.1%	-57.8%	-59.9%	-62.0%
Basis+Protection against multiple TAs+reinforced acc.	-	-47.4%	-49.4%	-49.6%	-51.3%
Basis+improved Protection against multiple TAs	-				-53.1%

Table 59: % of TAs - aircraft perspective – European ATM model

Whatever the configuration, the number of RAs an aircraft would receive would be cut by around two, even at a level of equipage of 25%.

At a level of equipage of 100%, the gain afforded by AltCapt only increases marginally when compared to a level of equipage of 25%, showing that having AltCapt onboard one aircraft only (as with a level of equipage of 25%, the probability to have two aircraft equipped with AltCapt in the same encounter is low) is already sufficient to observe noticeable benefits.

4.3.3.2 Number of positive RAs

This safety indicator has been presented in 4.3.2.2.

4.3.3.3 Number of operationally undesired RAs

This safety indicator has been presented in 4.3.3.3.

4.3.3.4 Number of RAs with incompatible sense selection

The following table shows the increase or decrease, expressed as a percentage, of RAs with incompatible sense selection an aircraft would receive by equipping with the AltCapt functionality.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	-	66.1%	60.5%	47.5%	36.0%
Basis+Protection against multiple TAs	-	66.1%	60.5%	47.5%	36.0%
Basis+Taking into account intruder's altitude	-	0.0%	-2.5%	-3.5%	-3.6%
Basis+Protection against multiple TAs+reinforced acc.	-	76.8%	60.5%	58.1%	49.5%
Basis+improved Protection against multiple TAs	-				34.2%

Table 60: % of RAs with incompatible sense selection - aircraft perspective – European ATM model

All the configurations, except the one that takes into account the altitude of intruder, lead to an increase of the proportion of RAs with an incompatible sense selection. This is explained by the “jump” geometry, in which the reduction of vertical rate with AltCapt leads, for the encounters in which an RA is triggered even without AltCapt, to a change of sense of the RAs (e.g., climb sense RA turning into descend sense RA).

4.4 Geometry perspective

4.4.1 Level-off encounters

4.4.1.1 Indicators related to safety

4.4.1.1.1 Vertical Miss Distances

The table below presents the VMD ratios, computed as the ratio of VMDs increased by AltCapt, divided by the number of VMDs decreased by AltCapt. A VMD ratio of 100% means that overall, the number of VMDs increased is equal to the number of VMDs decreased.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	100.0%	344.9%	333.8%	340.8%	344.2%
Basis+Protection against multiple TAs	100.0%	344.9%	333.8%	340.8%	344.2%
Basis+Taking into account intruder's altitude	100.0%	344.9%	333.8%	340.8%	344.2%
Basis+Protection against multiple TAs+reinforced acc.	100.0%	439.1%	415.2%	433.9%	435.7%
Basis+improved protection against multiple TAs	100.0%				458.4%

Table 61: VMD ratios – geometry perspective - Level-off encounters – European ATM model

Whatever the level of equipage, the VMD ratios are over 300%, which means the number of VMDs increased is always at least three times as high as the number of VMDs decreased.

It is noticeable that the configurations with the improved protections against multiple TAs and with the reinforced acceleration have the best performance, as the ratio is the highest. In fact, this better performance is explained by the number of VMDs increased which is higher than with the other configurations, because the improved protection against multiple TAs decreases the vertical rates even more, resulting in higher VMDs.

Indeed, having more VMDs increased than VMDs decreased is explained by the fact that in many encounters, often without RAs, AltCapt reduces the vertical rate of one or two aircraft, therefore increasing the VMD.

Having VMDs decreased is explained by encounters in which RAs are triggered without AltCapt, and no more triggered with AltCapt.

4.4.1.1.2 Number of RAs without ALIM provision

The following table shows the proportion of RAs failing to achieve the CAS logic threshold referred to as ALIM, which is the target vertical separation which TCAS II aims at achieving at the closest point of approach. These proportions are expressed as a percentage of the number of RAs in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+Protection against multiple TAs	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+Taking into account intruder's altitude	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+improved Protection against multiple TAs	0.0%				0.0%

Table 62: % of RAs without ALIM - geometry perspective - Level-off encounters – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+Protection against multiple TAs	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+Taking into account intruder's altitude	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+improved Protection against multiple TAs	0.0%				0.0%

Table 63: RAs without ALIM – Variation - geometry perspective - Level-off encounters – European ATM model

As expected, AltCapt does not result in encounters ending with a vertical separation at CPA below ALIM, for level-off geometries.

4.4.1.1.3 Number of increase RAs

The following table shows the proportion of RAs which are increase RAs. These proportions are expressed as a percentage of the number of RAs in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+Protection against multiple TAs	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+Taking into account intruder's altitude	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+improved Protection against multiple TAs	0.0%				0.0%

Table 64: % of Increase RAs - geometry perspective - Level-off encounters – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+Protection against multiple TAs	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+Taking into account intruder's altitude	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+improved Protection against multiple TAs	0.0%				0.0%

Table 65: Increase RAs – Variation - geometry perspective - Level-off encounters – European ATM model

As expected, AltCapt does not result in increase RAs being triggered in level-off encounters.

4.4.1.1.4 Number of Reversal RAs

The following table shows the proportion of RAs which are reversal RAs. These proportions are expressed as a percentage of the number of RAs in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+Protection against multiple TAs	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+Taking into account intruder's altitude	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+improved Protection against multiple TAs	0.0%				0.0%

Table 66: % of Reversal RAs - geometry perspective - Level-off encounters – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+Protection against multiple TAs	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+Taking into account intruder's altitude	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+improved Protection against multiple TAs	0.0%				0.0%

Table 67: Reversal RAs – Variation - geometry perspective - Level-off encounters – European ATM model

As expected, AltCapt does not result in reversal RAs being triggered in level-off encounters.

4.4.1.2 Indicators related to pilot acceptance

4.4.1.2.1 Number of crossing RAs

The following table shows the proportion of RAs which are crossing RAs. These proportions are expressed as a percentage of the number of RAs in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+Protection against multiple TAs	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+Taking into account intruder's altitude	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+improved Protection against multiple TAs	0.0%				0.0%

Table 68: % of Crossing RAs - geometry perspective - Level-off encounters – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+Protection against multiple TAs	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+Taking into account intruder's altitude	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+improved Protection against multiple TAs	0.0%				0.0%

Table 69: Crossing RAs – Variation - geometry perspective - Level-off encounters – European ATM model

As expected, AltCapt does not result in crossing RAs being triggered in level-off encounters.

4.4.1.2.2 Number of positive RAs

The following table shows the proportion of RAs which are positive RAs. These proportions are expressed as a percentage of the number of RAs in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	99.9%	78.0%	54.5%	30.1%	3.1%
Basis+Protection against multiple TAs	99.9%	78.0%	54.5%	30.1%	3.1%
Basis+Taking into account intruder's altitude	99.9%	78.0%	54.5%	30.1%	3.1%
Basis+Protection against multiple TAs+reinforced acc.	99.9%	77.7%	54.1%	29.6%	2.8%
Basis+improved Protection against multiple TAs	99.9%				1.4%

Table 70: % of Positive RAs - geometry perspective - Level-off encounters – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	-21.9%	-45.4%	-69.9%	-96.9%
Basis+Protection against multiple TAs	0.0%	-21.9%	-45.4%	-69.9%	-96.9%
Basis+Taking into account intruder's altitude	0.0%	-21.9%	-45.4%	-69.9%	-96.9%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	-22.2%	-45.9%	-70.4%	-97.2%
Basis+improved Protection against multiple TAs	0.0%				-98.6%

Table 71: Positive RAs – Variation - geometry perspective - Level-off encounters – European ATM model

Whatever the configuration tested, the proportion of positive RAs decreases, and the decrease is correlated to the level of equipage. With a level of equipage of 100%, the proportion of positive RAs is divided by around 30, and even 70 with the improved protection against multiple TAs.

This reduction rate is very significant, and pleads for the implementation of the AltCapt functionality as it would almost fully remove the issue of RAs triggered during 1000 ft level-off geometries.

4.4.1.2.3 Number of initial RAs opposite to the aircraft trajectory

The following table shows the proportion of RAs which are initial RAs and opposite to the trajectory. These proportions are expressed as a percentage of the number of RAs in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	15.7%	12.5%	8.3%	4.5%	0.4%
Basis+Protection against multiple TAs	15.7%	12.5%	8.3%	4.5%	0.4%
Basis+Taking into account intruder's altitude	15.7%	12.5%	8.3%	4.5%	0.4%
Basis+Protection against multiple TAs+reinforced acc.	15.7%	12.4%	8.3%	4.4%	0.3%
Basis+improved Protection against multiple TAs	15.7%				0.3%

Table 72: % of Initial opposite RAs - geometry perspective - Level-off encounters – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	-20.5%	-47.0%	-71.5%	-97.4%
Basis+Protection against multiple TAs	0.0%	-20.5%	-47.0%	-71.5%	-97.4%
Basis+Taking into account intruder's altitude	0.0%	-20.5%	-47.0%	-71.5%	-97.4%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	-20.7%	-47.2%	-71.9%	-98.0%
Basis+improved Protection against multiple TAs	0.0%				-98.2%

Table 73: Initial opposite RAs – Variation - geometry perspective - Level-off encounters – European ATM model

Whatever the configuration tested, the proportion of initial RAs opposite to the trajectory decreases, and the decrease is correlated to the level of equipage. With a level of equipage of 100%, the proportion of initial RAs opposite to the trajectory is divided by more than 30.

The option with an improved protection against multiple TAs has an even better performance, as the number of initial opposite RAs is cut by 56.

4.4.1.2.4 Number of multiple RAs

The following table shows the proportion of multiple RAs. These proportions are expressed as a percentage of the number of RAs in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.3%	0.2%	0.1%	0.1%	0.0%
Basis+Protection against multiple TAs	0.3%	0.2%	0.1%	0.1%	0.0%
Basis+Taking into account intruder's altitude	0.3%	0.2%	0.1%	0.1%	0.0%
Basis+Protection against multiple TAs+reinforced acc.	0.3%	0.2%	0.1%	0.1%	0.0%
Basis+improved Protection against multiple TAs	0.3%				0.0%

Table 74: % of Multiple RAs - geometry perspective - Level-off encounters – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	-30.0%	-50.0%	-60.0%	-100.0%
Basis+Protection against multiple TAs	0.0%	-30.0%	-50.0%	-60.0%	-100.0%
Basis+Taking into account intruder's altitude	0.0%	-30.0%	-50.0%	-50.0%	-100.0%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	-30.0%	-50.0%	-60.0%	-90.0%
Basis+improved Protection against multiple TAs	0.0%				-100.0%

Table 75: Multiple RAs – Variation - geometry perspective - Level-off encounters – European ATM model

Whatever the configuration, the proportion of multiple RAs decreases but can be considered as unchanged, considering that the absolute number is very low.

4.4.1.2.5 Number of complex RA sequences

The following table shows the proportion of sequences of RAs which are considered as complex. These proportions are expressed as a percentage of the number of sequences in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	2.0%	1.5%	1.0%	0.7%	0.1%
Basis+Protection against multiple TAs	2.0%	1.5%	1.0%	0.7%	0.1%
Basis+Taking into account intruder's altitude	2.0%	1.5%	1.0%	0.7%	0.1%
Basis+Protection against multiple TAs+reinforced acc.	2.0%	1.5%	1.0%	0.7%	0.1%
Basis+improved Protection against multiple TAs	2.0%				0.0%

Table 76: % of Complex sequences of RAs - geometry perspective - Level-off encounters – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	-26.1%	-50.7%	-62.3%	-95.7%
Basis+Protection against multiple TAs	0.0%	-26.1%	-50.7%	-62.3%	-95.7%
Basis+Taking into account intruder's altitude	0.0%	-26.1%	-50.7%	-62.3%	-95.7%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	-26.1%	-50.7%	-63.8%	-95.7%
Basis+improved Protection against multiple TAs	0.0%				-100.0%

Table 77: Complex sequences of RAs – Variation - geometry perspective - Level-off encounters – European ATM model

Whatever the configuration tested, the proportion of complex sequences of RAs decreases, and the decrease is correlated to the level of equipage. With a level of equipage of 100%, the proportion of positive RAs is divided by around 20.

The option with an improved protection against multiple TAs has an even better performance, as the number of complex sequences becomes nill.

4.4.1.2.6 Number of operationally undesired RAs

The following table shows the proportion of RAs which are considered as operationally undesired. These proportions are expressed as a percentage of the number of sequences in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	99.3%	77.5%	54.1%	30.0%	3.1%
Basis+Protection against multiple TAs	99.3%	77.5%	54.1%	30.0%	3.1%
Basis+Taking into account intruder's altitude	99.3%	77.5%	54.1%	30.0%	3.1%
Basis+Protection against multiple TAs+reinforced acc.	99.3%	77.3%	53.6%	30.0%	2.7%
Basis+improved Protection against multiple TAs	99.3%				1.4%

Table 78: % of operationally undesired RAs - geometry perspective - Level-off encounters – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	-22.0%	-45.6%	-69.8%	-96.9%
Basis+Protection against multiple TAs	0.0%	-22.0%	-45.6%	-69.8%	-96.9%
Basis+Taking into account intruder's altitude	0.0%	-22.0%	-45.6%	-69.8%	-96.9%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	-22.2%	-46.0%	-69.8%	-97.3%
Basis+improved Protection against multiple TAs	0.0%				-98.6%

Table 79: Operationally undesired RAs – Variation - geometry perspective - Level-off encounters – European ATM model

Whatever the configuration tested, the proportion of operationally undesired RAs decreases, and the decrease is correlated to the level of equipage. With a level of equipage of 100%, the proportion of operationally undesired RAs is divided by around 30, and even 70 with the improved protection against multiple TAs. The option with an improved protection against multiple TAs has an even better performance, as the number of operationally undesired RAs is cut by 70.

As said before, this reduction rate is very significant, and pleads for the implementation of the AltCapt functionality as it would almost fully remove the issue of RAs triggered during 1000 ft level-off geometries.

4.4.1.2.7 RA durations

The table below presents the RA duration ratios, computed as the ratio of RA durations decreased by AltCapt, divided by the number of RA durations increased by AltCapt. A ratio of 100% means that overall, the number of RA durations increased is equal to the number of RA durations decreased. For a level of equipage of 0%, the ratio is not computed because comparing a simulation to itself presents little interest.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	-	1160.00%	∞	1500.00%	∞
Basis+Protection against multiple TAs	-	1160.00%	∞	1500.00%	∞
Basis+Taking into account intruder's altitude	-	1450.00%	∞	1500.00%	3500.00%
Basis+Protection against multiple TAs+reinforced acc.	-	1100.00%	infinite ∞	1057.14%	∞
Basis+improved Protection against multiple TAs	-				∞

Table 80: RA duration ratio - geometry perspective – Level-off geometries - European ATM model

Overall, a large majority of the RA durations that are modified by AltCapt introduction(sometimes all of them) are decreased.

4.4.1.2.8 Number of TAs

The following table shows the proportion of TAs expressed as a percentage of the number of TAs in the reference scenario. It must be noticed that for this indicator, a TA is counted once for an aircraft. Therefore an aircraft which receives two TAs is only counted once.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	100.0%	99.9%	99.7%	99.6%	99.5%
Basis+Protection against multiple TAs	100.0%	99.9%	99.7%	99.6%	99.5%
Basis+Taking into account intruder's altitude	100.0%	99.9%	99.7%	99.6%	99.5%
Basis+Protection against multiple TAs+reinforced acc.	100.0%	99.6%	99.2%	98.8%	98.3%
Basis+improved Protection against multiple TAs	100.0%				99.4%

Table 81: % of TAs - geometry perspective - Level-off encounters – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	-0.2%	-0.3%	-0.4%	-0.5%
Basis+Protection against multiple TAs	0.0%	-0.2%	-0.3%	-0.4%	-0.5%
Basis+Taking into account intruder's altitude	0.0%	-0.2%	-0.3%	-0.4%	-0.5%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	-0.4%	-0.8%	-1.2%	-1.7%
Basis+improved Protection against multiple TAs	0.0%				-0.7%

Table 82: TAs – Variation - geometry perspective - Level-off encounters – European ATM model

With AltCapt, the proportion of TAs remains unchanged or very slightly decreases.

4.4.1.2.9 Number of multiple TAs

The following table shows the proportion of multiple TAs expressed as a percentage of the number of TAs in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	1.5%	2.6%	4.5%	7.6%	11.0%
Basis+Protection against multiple TAs	1.5%	2.6%	4.5%	7.6%	11.0%
Basis+Taking into account intruder's altitude	1.5%	2.6%	4.5%	7.6%	11.0%
Basis+Protection against multiple TAs+reinforced acc.	1.5%	2.6%	4.3%	7.2%	10.4%
Basis+improved Protection against multiple TAs	1.5%				8.4%

Table 83: % of Multiple TAs - geometry perspective - Level-off encounters – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	79.4%	208.3%	419.2%	653.4%
Basis+Protection against multiple TAs	0.0%	79.1%	208.0%	418.9%	653.1%
Basis+Taking into account intruder's altitude	0.0%	79.4%	208.3%	419.2%	653.4%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	78.2%	196.8%	395.3%	613.9%
Basis+improved Protection against multiple TAs	0.0%				472.3%

Table 84: Multiple TAs – Variation - geometry perspective - Level-off encounters – European ATM model

The proportion of multiple TAs increases whatever the AltCapt configuration. Only the configuration with an improved protection against multiple TAs performs significantly better than the other options.

4.4.1.2.10 TA durations

The table below presents the RA duration ratios, computed as the ratio of TA durations decreased by AltCapt, divided by the number of TA durations increased by AltCapt. A ratio of 100% means that overall, the number of TA duration increased is equal to the number of TA durations decreased. For a level of equipage of 0%, the ratio is not computed because comparing a simulation to itself presents little interest.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	-	1287.87%	1124.97%	1038.21%	988.65%
Basis+Protection against multiple TAs	-	1291.62%	1126.43%	1039.05%	990.30%
Basis+Taking into account intruder's altitude	-	1290.57%	1124.97%	1038.21%	988.65%
Basis+Protection against multiple TAs+reinforced acc.	-	1430.54%	1256.76%	1126.39%	1066.33%
Basis+improved Protection against multiple TAs	-				1642.72%

Table 85: RA duration ratio - geometry perspective – Level-off geometries – European ATM model

Overall, the durations of TAs are decreased.

4.4.1.3 Geometry perspective – Level-off encounters - Indicators related to ATC compatibility

4.4.1.3.1 Number of RAs

The following table shows the proportion of RAs expressed as a percentage of the number of RAs in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	100.0%	78.0%	54.6%	30.1%	3.1%
Basis+Protection against multiple TAs	100.0%	78.0%	54.6%	30.1%	3.1%
Basis+Taking into account intruder's altitude	100.0%	78.0%	54.6%	30.1%	3.1%
Basis+Protection against multiple TAs+reinforced acc.	100.0%	78.0%	54.2%	29.6%	2.8%
Basis+improved Protection against multiple TAs	100.0%				1.4%

Table 86: % of RAs - geometry perspective - Level-off encounters – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	-22.0%	-45.4%	-69.9%	-96.9%
Basis+Protection against multiple TAs	0.0%	-22.0%	-45.4%	-69.9%	-96.9%
Basis+Taking into account intruder's altitude	0.0%	-22.0%	-45.4%	-69.9%	-96.9%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	-22.0%	-45.8%	-70.4%	-97.3%
Basis+improved Protection against multiple TAs	0.0%				-98.6%

Table 87: RAs – Variation - geometry perspective - Level-off encounters – European ATM model

Whatever the configuration tested, the number of RAs decreases, and the decrease is correlated to the level of equipage. With a level of equipage of 100%, the proportion of positive RAs is divided by around 30, and even 70 with the improved protection against multiple TAs. Here again, the best performance is obtained by the configuration with an improved protection against multiple TAs.

The following figures illustrate this phenomenon.

The first figure shows the VMD diagram comparing the VMDs in the reference scenario, with and without TCAS.

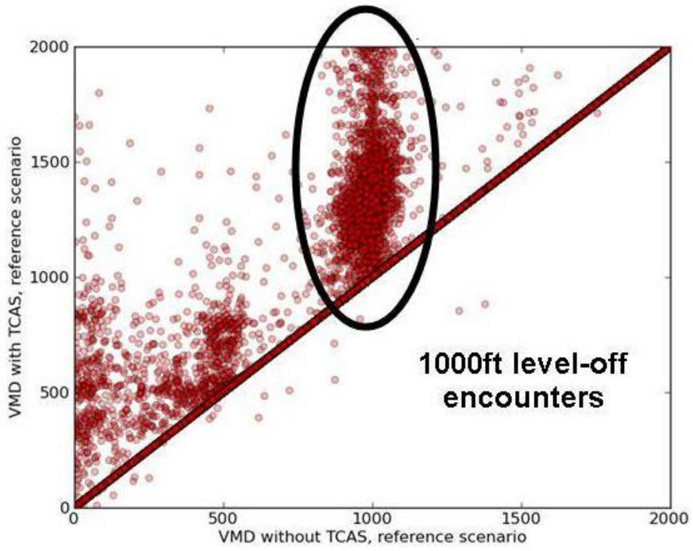


Figure 28: VMD diagram – reference scenario

The second figure shows the VMD diagram comparing the VMDs with AltCapt, with and without TCAS.

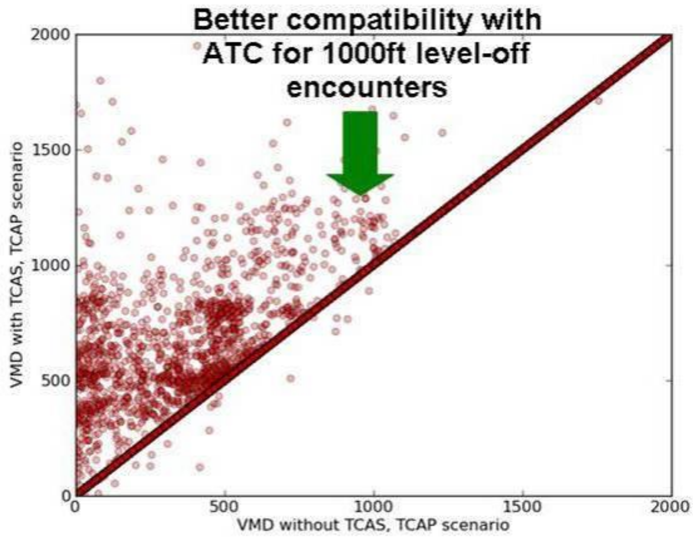


Figure 29: VMD diagram – AltCapt basis scenario

The diagram for the reference scenario has many points above the diagonal for VMDs without TCAS around 1000 ft, meaning that many encounters have RAs for which a manoeuvre is made.

The diagram for the AltCapt scenario has few points above the diagonal for VMDs without TCAS around 1000 ft, showing that for the majority of encounters, the RA is no longer triggered.

4.4.1.3.2 Number of positive RAs

This safety indicator has been presented in 4.4.1.2.2.

4.4.1.3.3 Number of operationally undesired RAs

This safety indicator has been presented in 4.4.1.2.6.

4.4.1.3.4 Distribution of vertical deviations

The table below present the deviation ratios, computed as the ratio of deviations decreased by AltCapt, divided by the number of deviations increased by AltCapt. A ratio of 100% means that overall, the number of deviations decreased is equal to the number of deviations increased.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	-	715.4%	1161.1%	1421.7%	4911.1%
Basis+Protection against multiple TAs	-	715.4%	1161.1%	1421.7%	4911.1%
Basis+Taking into account intruder's altitude	-	723.1%	1161.1%	1426.1%	4900.0%
Basis+Protection against multiple TAs+reinforced acc.	-	715.4%	1100.0%	1557.1%	5525.0%
Basis+improved Protection against multiple TAs	-				11125.0%

Table 88: Deviation ratios – geometry perspective - Level-off encounters – European ATM model

Whatever the AltCapt configuration and level of equipage, the number of deviations decreased is higher than the number of deviations increased.

In 48% of the cases, a deviation which decreases becomes a non-deviation (0-foot deviation).

4.4.1.3.5 Number of RAs with incompatible sense selection

The following table shows the proportion of RAs with an incompatible sense selection when compared to what ATC had planned.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+Protection against multiple TAs	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+Taking into account intruder's altitude	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+improved Protection against multiple TAs	0.0%				0.0%

Table 89: % of RAs with incompatible sense selection - geometry perspective - Level-off encounters – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+Protection against multiple TAs	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+Taking into account intruder's altitude	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+improved Protection against multiple TAs	0.0%				0.0%

Table 90: RAs with incompatible sense selection – Variation - geometry perspective - Level-off encounters – European ATM model

As expected, AltCapt does not result in RAs with an incompatible sense selection being triggered in level-off encounters.

4.4.2 Non level-off encounters

4.4.2.1 Indicators related to safety

4.4.2.1.1 Vertical miss distances

The table below present the VMD ratios, computed as the ratio of VMDs increased by AltCapt, divided by the number of VMDs decreased by AltCapt. A VMD ratio of 100% means that overall, the number of VMDs increased is equal to the number of VMDs decreased.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	100.0%	99.1%	97.9%	97.3%	96.1%
Basis+Protection against multiple TAs	100.0%	99.1%	97.9%	97.3%	96.1%
Basis+Taking into account intruder's altitude	100.0%	833.3%	873.8%	833.9%	881.4%
Basis+Protection against multiple TAs+reinforced acc.	100.0%	104.5%	105.0%	106.5%	96.1%
Basis+improved Protection against multiple TAs	100.0%				104.8%

Table 91: VMD ratios – geometry perspective - Non level-off encounters – European ATM model

The configurations which do not take into account the altitude of the intruder have an average performance, with VMD ratios around or little lower than 100%.

When taking into account the altitude of the intruder, the VMD ratio is well over 100%. This high ratio results from the low number of encounters for which the VMD is decreased. This high ratio confirms the very good performance of the configuration taking into account the altitude of the intruder.

4.4.2.1.2 Number of RAs without ALIM provision

The following table shows the proportion of RAs failing to achieve the CAS logic threshold referred to as ALIM, which is the target vertical separation which TCAS II aims at achieving at the closest point of approach. These proportions are expressed as a percentage of the number of RAs in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	9.6%	9.9%	9.9%	9.9%	10.3%
Basis+Protection against multiple TAs	9.6%	9.9%	9.9%	9.9%	10.3%
Basis+Taking into account intruder's altitude	9.6%	9.5%	9.5%	9.5%	9.5%
Basis+Protection against multiple TAs+reinforced acc.	9.6%	10.1%	10.2%	10.2%	10.7%
Basis+improved Protection against multiple TAs	9.6%				10.1%

Table 92: % of RAs without ALIM – geometry perspective - Non level-off encounters – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	2.7%	2.3%	3.0%	6.7%
Basis+Protection against multiple TAs	0.0%	2.7%	2.3%	3.0%	6.7%
Basis+Taking into account intruder's altitude	0.0%	-1.0%	-1.7%	-1.0%	-1.0%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	4.7%	6.3%	6.0%	10.7%
Basis+improved Protection against multiple TAs	0.0%				5.0%

Table 93: RAs without ALIM – Variation - geometry perspective - Non level-off encounters – European ATM model

For all the configurations, except the one that takes into account intruder's altitude, one notices a slight increase of the proportion of RAs failing to achieve ALIM. The configuration that takes into account intruder's altitude decreases insignificantly the proportion of RAs failing to achieve ALIM. This means that not taking into account the altitude of the intruder results, although rarely, in AltCapt debasing some situations.

These situations correspond to specific geometries. These are encounters in which ATC decides to make an aircraft climb and cross the altitude of the intruder aircraft before levelling-off. In that kind of situation, ATC requires the evolving aircraft to maintain a specified vertical rate.

In this geometry, AltCapt decreases the vertical rate of the evolving aircraft, and as a result the vertical separation at CPA is decreased, which can result in additional RAs, or in sequences of RAs made more complex. This implies that in a few situations, the vertical separation at CPA is slightly decreased, and can become lower than ALIM.

With the configuration with a reinforced acceleration, the proportion of RAs failing to achieve ALIM is very slightly worse than for the other configurations. This is explained by the fact that, due to the increased acceleration, in the "jump" geometries, the evolving aircraft has its vertical rate decreasing faster, therefore the VMD can be even more reduced than with a normal acceleration.

4.4.2.1.3 Number of increase RAs

The following table shows the proportion of RAs which are increase RAs. These proportions are expressed as a percentage of the number of RAs in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	3.1%	3.2%	3.2%	3.2%	3.3%
Basis+Protection against multiple TAs	3.1%	3.2%	3.2%	3.2%	3.3%
Basis+Taking into account intruder's altitude	3.1%	3.1%	3.0%	3.0%	3.0%
Basis+Protection against multiple TAs+reinforced acc.	3.1%	3.2%	3.2%	3.3%	3.4%
Basis+improved Protection against multiple TAs	3.1%				3.3%

Table 94: % of Increase RAs - geometry perspective - Non level-off encounters – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	4.2%	4.2%	4.2%	6.3%
Basis+Protection against multiple TAs	0.0%	4.2%	4.2%	4.2%	6.3%
Basis+Taking into account intruder's altitude	0.0%	0.0%	-1.0%	-1.0%	-1.0%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	5.2%	5.2%	6.3%	9.4%
Basis+improved Protection against multiple TAs	0.0%				6.3%

Table 95: Increase RAs – Variation - geometry perspective - Non level-off encounters – European ATM model

The proportion of increase RAs increases with the configurations not taking into account the altitude of the intruder.

When taking into account this information, the proportion of increase RAs remains unchanged or decreases very slightly, showing the efficiency of this solution.

4.4.2.1.4 Number of Reversal RAs

The following table shows the proportion of RAs which are reversal RAs. These proportions are expressed as a percentage of the number of RAs in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	1.0%	1.0%	1.1%	1.3%	1.5%
Basis+Protection against multiple TAs	1.0%	1.0%	1.1%	1.3%	1.5%
Basis+Taking into account intruder's altitude	1.0%	1.0%	1.0%	1.0%	1.0%
Basis+Protection against multiple TAs+reinforced acc.	1.0%	1.1%	1.1%	1.4%	1.5%
Basis+improved Protection against multiple TAs	1.0%				1.5%

Table 96: % of Reversal RAs - geometry perspective - Non level-off encounters – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	6.7%	13.3%	33.3%	53.3%
Basis+Protection against multiple TAs	0.0%	6.7%	13.3%	33.3%	53.3%
Basis+Taking into account intruder's altitude	0.0%	0.0%	0.0%	0.0%	0.0%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	10.0%	16.7%	46.7%	60.0%
Basis+improved Protection against multiple TAs	0.0%				53.3%

Table 97: Reversal RAs – Variation - geometry perspective - Non level-off encounters – European ATM model

The proportion of reversal RAs increases with the configurations not taking into account the altitude of the intruder.

When taking into account this information, the proportion of such RAs remains unchanged, showing the efficiency of this solution.

4.4.2.2 Indicators related to pilot acceptance

4.4.2.2.1 Number of crossing RAs

The following table shows the proportion of RAs which are crossing RAs. These proportions are expressed as a percentage of the number of RAs in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	3.3%	4.3%	4.8%	5.4%	6.2%
Basis+Protection against multiple TAs	3.3%	4.3%	4.8%	5.4%	6.2%
Basis+Taking into account intruder's altitude	3.3%	3.2%	3.2%	3.2%	3.1%
Basis+Protection against multiple TAs+reinforced acc.	3.3%	4.4%	5.0%	6.0%	7.0%
Basis+improved Protection against multiple TAs	3.3%				6.2%

Table 98: % of Crossing RAs - geometry perspective - Non level-off encounters – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	30.4%	48.0%	63.7%	90.2%
Basis+Protection against multiple TAs	0.0%	30.4%	48.0%	63.7%	90.2%
Basis+Taking into account intruder's altitude	0.0%	-1.0%	-2.0%	-2.9%	-3.9%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	35.3%	53.9%	83.3%	112.8%
Basis+improved Protection against multiple TAs	0.0%				88.3%

Table 99: Crossing RAs – Variation - geometry perspective - Non level-off encounters – European ATM model

The proportion of crossing RAs increases with the configurations not taking into account the altitude of the intruder. When taking into account this information, the proportion of such RAs remains unchanged or decreases very slightly, showing the efficiency of this solution.

4.4.2.2.2 Number of positive RAs

The following table shows the proportion of RAs which are positive RAs. These proportions are expressed as a percentage of the number of RAs in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	68.4%	70.9%	73.6%	76.3%	77.6%
Basis+Protection against multiple TAs	68.4%	70.9%	73.6%	76.3%	77.6%
Basis+Taking into account intruder's altitude	68.4%	66.0%	64.2%	61.8%	60.0%
Basis+Protection against multiple TAs+reinforced acc.	68.4%	71.1%	74.3%	77.3%	79.4%
Basis+improved Protection against multiple TAs	68.4%				76.8%

Table 100: % of Positive RAs - geometry perspective - Non level-off encounters – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	3.6%	7.6%	11.5%	13.4%
Basis+Protection against multiple TAs	0.0%	3.6%	7.6%	11.5%	13.4%
Basis+Taking into account intruder's altitude	0.0%	-3.5%	-6.2%	-9.7%	-12.3%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	3.9%	8.5%	12.95%	16.0%
Basis+improved Protection against multiple TAs	0.0%				12.3%

Table 101: Positive RAs – Variation - geometry perspective - Non level-off encounters – European ATM model

The proportion of positive RAs increases with the configurations that do not take into account the altitude of the intruder.

When taking into account this information, the proportion of such RAs remains unchanged or decreases, showing the efficiency of this solution to avoid added RAs in non level-off geometries.

4.4.2.2.3 Number of initial RAs opposite to the aircraft trajectory

The following table shows the proportion of RAs which are initial RAs and opposite to the trajectory. These proportions are expressed as a percentage of the number of RAs in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	14.4%	15.5%	16.4%	17.2%	17.7%
Basis+Protection against multiple TAs	14.4%	15.5%	16.4%	17.2%	17.7%
Basis+Taking into account intruder's altitude	14.4%	14.0%	13.9%	13.4%	13.1%
Basis+Protection against multiple TAs+reinforced acc.	14.4%	15.6%	16.7%	17.7%	18.4%
Basis+improved Protection against multiple TAs	14.4%				13.8%

Table 102: % of Initial opposite RAs - geometry perspective - Non level-off encounters – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	7.1%	13.8%	18.9%	22.7%
Basis+Protection against multiple TAs	0.0%	7.1%	13.8%	18.9%	22.7%
Basis+Taking into account intruder's altitude	0.0%	-3.3%	-4.0%	-7.6%	-9.6%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	7.8%	15.3%	22.7%	27.6%
Basis+improved Protection against multiple TAs	0.0%				19.1%

Table 103: Initial opposite RAs – Variation - geometry perspective - Non level-off encounters – European ATM model

The proportion of initial RAs opposite to the trajectory increases with the configurations that do not take into account the altitude of the intruder.

When taking into account this information, the proportion of such RAs decreases, showing the efficiency of this solution.

4.4.2.2.4 Number of multiple RAs

The following table shows the proportion of multiple RAs. These proportions are expressed as a percentage of the number of RAs in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.2%	0.1%	0.1%	0.1%	0.1%
Basis+Protection against multiple TAs	0.2%	0.1%	0.1%	0.1%	0.1%
Basis+Taking into account intruder's altitude	0.2%	0.1%	0.1%	0.1%	0.1%
Basis+Protection against multiple TAs+reinforced acc.	0.2%	0.1%	0.1%	0.1%	0.1%
Basis+improved Protection against multiple TAs	0.2%				0.1%

Table 104: % of Multiple RAs - geometry perspective - Non level-off encounters – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	-33.3%	-33.3%	-66.7%	-66.7%
Basis+Protection against multiple TAs	0.0%	-33.3%	-33.3%	-66.7%	-66.7%
Basis+Taking into account intruder's altitude	0.0%	-33.3%	-33.3%	-66.7%	-66.7%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	-33.3%	-33.3%	-66.7%	-66.7%
Basis+improved Protection against multiple TAs	0.0%				-66.7%

Table 105: Multiple RAs – Variation - geometry perspective - Non level-off encounters – European ATM model

Whatever the configuration, the proportion of multiple RAs is unchanged, considering that the proportion is very low.

4.4.2.2.5 Number of complex RA sequences

The following table shows the proportion of sequences of RAs which are considered as complex. These proportions are expressed as a percentage of the number of sequences in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	7.5%	8.0%	8.3%	8.8%	9.0%
Basis+Protection against multiple TAs	7.5%	8.0%	8.3%	8.8%	9.0%
Basis+Taking into account intruder's altitude	7.5%	7.4%	7.4%	7.4%	7.4%
Basis+Protection against multiple TAs+reinforced acc.	7.5%	8.0%	8.5%	9.1%	9.5%
Basis+improved Protection against multiple TAs	7.5%				9.0%

Table 106: % of Complex sequences of RAs - geometry perspective - Non level-off encounters – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	6.9%	10.7%	17.2%	20.2%
Basis+Protection against multiple TAs	0.0%	6.9%	10.7%	17.2%	20.2%
Basis+Taking into account intruder's altitude	0.0%	-0.4%	-1.3%	-1.3%	-0.4%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	6.9%	13.3%	22.3%	26.6%
Basis+improved Protection against multiple TAs	0.0%				20.6%

Table 107: Complex sequences of RAs – Variation - geometry perspective - Non level-off encounters – European ATM model

The proportion of complex sequences of RAs increases with the configurations that do not take into account the altitude of the intruder.

When taking into account this information, the proportion of such RAs remains unchanged, showing the efficiency of this solution.

4.4.2.2.6 Number of operationally undesired RAs

The following table shows the proportion of RAs which are considered as operationally undesired. These proportions are expressed as a percentage of the number of sequences in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	4.3%	3.1%	2.4%	1.1%	0.3%
Basis+Protection against multiple TAs	4.3%	3.1%	2.4%	1.1%	0.3%
Basis+Taking into account intruder's altitude	4.3%	3.1%	2.4%	1.4%	0.5%
Basis+Protection against multiple TAs+reinforced acc.	4.3%	3.1%	2.4%	1.1%	0.3%
Basis+improved Protection against multiple TAs	4.3%				0.2%

Table 108: % of Operationally undesired RAs - geometry perspective - Non level-off encounters – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	-27.6%	-43.3%	-73.9%	-94.0%
Basis+Protection against multiple TAs	0.0%	-27.6%	-43.3%	-73.9%	-94.0%
Basis+Taking into account intruder's altitude	0.0%	-27.6%	-43.3%	-67.9%	-87.3%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	-27.6%	-43.3%	-73.9%	-94.0%
Basis+improved Protection against multiple TAs	0.0%				-95.5%

Table 109: Operationally undesired RAs – Variation - geometry perspective - Non level-off encounters – European ATM model

Whatever the solution, the proportion of operationally undesired RAs decreases significantly, showing that AltCapt is not only efficient in level-off encounters with one of the aircraft being level, but also in other geometries involving one aircraft levelling-off (for example, an aircraft climbing and levelling-off, and an intruder descending from above).

4.4.2.2.7 RA durations

The table below presents the RA duration ratios, computed as the ratio of RA durations decreased by AltCapt, divided by the number of RA durations increased by AltCapt. A ratio of 100% means that overall, the number of RA duration increased is equal to the number of VMDs decreased. For a level of equipage of 0%, the ratio is not computed because comparing a simulation to itself presents little interest.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	-	180.6%	197.1%	254.7%	272.7%
Basis+Protection against multiple TAs	-	180.6%	197.1%	254.7%	272.7%
Basis+Taking into account intruder's altitude	-	2300.0%	622.2%	960.0%	1100.0%
Basis+Protection against multiple TAs+reinforced acc.	-	177.4%	186.8%	248.2%	264.2%
Basis+improved Protection against multiple TAs	-				243.6%

Table 110: RA duration ratio - geometry perspective – Non level-off geometries – European ATM model

Overall, the durations of RAs are decreased.

4.4.2.2.8 Number of TAs

The following table shows the proportion of TAs expressed as a percentage of the number of TAs in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	100.0%	100.0%	99.9%	99.9%	99.9%
Basis+Protection against multiple TAs	100.0%	100.0%	99.9%	99.9%	99.9%
Basis+Taking into account intruder's altitude	100.0%	100.0%	99.9%	99.9%	99.8%
Basis+Protection against multiple TAs+reinforced acc.	100.0%	99.9%	99.8%	99.7%	99.7%
Basis+improved Protection against multiple TAs	100.0%				99.8%

Table 111: % of TAs - geometry perspective - Non level-off encounters – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	0.0%	-0.1%	-0.1%	-0.1%
Basis+Protection against multiple TAs	0.0%	0.0%	-0.1%	-0.1%	-0.1%
Basis+Taking into account intruder's altitude	0.0%	-0.0%	-0.1%	-0.1%	-0.2%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	-0.1%	-0.2%	-0.3%	-0.4%
Basis+improved Protection against multiple TAs	0.0%				-0.15%

Table 112: TAs – Variation - geometry perspective - Non level-off encounters – European ATM model

With AltCapt, the proportion of TAs remains unchanged or very slightly decreases.

4.4.2.2.9 Number of multiple TAs

The following table shows the proportion of multiple TAs expressed as a percentage of the number of TAs in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.8%	1.7%	2.7%	3.6%	4.6%
Basis+Protection against multiple TAs	0.8%	1.7%	2.7%	3.6%	4.6%
Basis+Taking into account intruder's altitude	0.8%	1.6%	2.4%	3.2%	4.0%
Basis+Protection against multiple TAs+reinforced acc.	0.8%	1.7%	2.7%	3.6%	4.5%
Basis+improved Protection against multiple TAs	0.8%				3.7%

Table 113: % of Multiple TAs - geometry perspective - Non level-off encounters – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	125.3%	254.2%	371.7%	492.2%
Basis+Protection against multiple TAs	0.0%	125.3%	254.2%	371.7%	492.2%
Basis+Taking into account intruder's altitude	0.0%	112.1%	212.1%	314.5%	420.5%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	118.7%	246.4%	365.1%	482.5%
Basis+improved Protection against multiple TAs	0.0%				373.5%

Table 114: Multiple TAs – Variation - geometry perspective - Non level-off encounters – European ATM model

As for level-off geometries, AltCapt results in an increased number of multiple TAs. The configuration with an improved protection against multiple TAs has a better performance than the other configurations.

4.4.2.2.10 TA durations

The table below presents the TA duration ratios, computed as the ratio of TA durations decreased by AltCapt, divided by the number of TA durations increased by AltCapt. A ratio of 100% means that overall, the number of TA durations increased is equal to the number of TA durations decreased. For a level of equipage of 0%, the ratio is not computed because comparing a simulation to itself presents little interest.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	-	71.2%	71.2%	69.6%	68.0%
Basis+Protection against multiple TAs	-	71.2%	71.2%	69.6%	68.0%
Basis+Taking into account intruder's altitude	-	459.7%	479.9%	488.3%	483.4%
Basis+Protection against multiple TAs+reinforced acc.	-	73.8%	73.3%	70.8%	69.4%
Basis+improved Protection against multiple TAs	-				77.3%

Table 115: TA duration ratio - geometry perspective – Non level-off geometries - European ATM model

Only the configuration taking into account the altitude of the intruder reduces, overall, the TA durations. The other configuration increase, overall, the durations of TAs.

4.4.2.3 Indicators related to ATC compatibility

4.4.2.3.1 Number of RAs

The following table shows the proportion of RAs expressed as a percentage of the number of RAs in the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	100.0%	103.0%	106.3%	109.7%	111.6%
Basis+Protection against multiple TAs	100.0%	103.0%	106.3%	109.7%	111.6%
Basis+Taking into account intruder's altitude	100.0%	97.6%	96.0%	93.8%	92.0%
Basis+Protection against multiple TAs+reinforced acc.	100.0%	103.1%	106.8%	110.5%	113.2%
Basis+improved Protection against multiple TAs	100.0%				111.4%

Table 116: % of RAs - geometry perspective - Non level-off encounters – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	3.0%	6.3%	9.7%	11.7%
Basis+Protection against multiple TAs	0.0%	3.0%	6.3%	9.7%	11.7%
Basis+Taking into account intruder's altitude	0.0%	-2.4%	-4.0%	-6.2%	-8.0%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	3.1%	6.8%	10.5%	13.2%
Basis+improved Protection against multiple TAs	0.0%				11.4%

Table 117: RAs – Variation - geometry perspective - Non level-off encounters – European ATM model

The following tables show the proportion of RAs added and removed by each of the AltCapt configurations, as a proportion of the initial number of RAs.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	-	5.8%	11.8%	18.2%	22.7%
Basis+Protection against multiple TAs	-	5.8%	11.8%	18.2%	22.7%
Basis+Taking into account intruder's altitude	-	0.1%	0.2%	0.3%	0.4%
Basis+Protection against multiple TAs+reinforced acc.	-	6.2%	12.7%	19.6%	25.0%
Basis+improved Protection against multiple TAs	-	5.8%	11.8%	18.2%	22.7%

Table 118: RAs added - geometry perspective - Non level-off encounters – European ATM model

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	-	2.8%	5.5%	8.5%	11.0%
Basis+Protection against multiple TAs	-	2.8%	5.5%	8.5%	11.0%
Basis+Taking into account intruder's altitude	-	2.5%	4.2%	6.5%	8.4%
Basis+Protection against multiple TAs+reinforced acc.	-	3.0%	5.9%	9.&%	11.8%
Basis+improved Protection against multiple TAs	-	2.8%	5.5%	8.5%	11.0%

Table 119: RAs removed - geometry perspective - Non level-off encounters – European ATM model

The solutions that do not take into account the altitude of the intruder add RAs, whereas the solution that takes into account the altitude of the intruder adds nearly no RAs.

The solution taking into account the altitude of the intruder removes slightly less RAs, which is a small price to pay for the benefit afforded.

It is also noticeable from these results that AltCapt removes RAs not only for level-off encounters.

4.4.2.3.2 Number of positive RAs

This safety indicator has been presented in 4.4.2.2.2.

4.4.2.3.3 Number of operationally undesired RAs

This safety indicator has been presented in 4.4.2.2.6.

4.4.2.3.4 Distribution of vertical deviations

The table below present the deviation ratios, computed as the ratio of deviations decreased by AltCapt, divided by the number of deviations increased by AltCapt. A ratio of 100% means that overall, the number of deviations decreased is equal to the number of deviations increased. For a level of equipage of 0%, the ratio is not computed because it is the reference scenario, and because comparing a simulation to itself presents little interest.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	-	65.5%	74.1%	68.6%	72.2%
Basis+Protection against multiple TAs	-	65.5%	74.1%	68.6%	72.2%
Basis+Taking into account intruder's altitude	-	275.0%	333.3%	276.2%	277.8%
Basis+Protection against multiple TAs+reinforced acc.	-	62.0%	66.3%	70.2%	63.3%
Basis+improved Protection against multiple TAs	-				72.5%

Table 120: Deviation ratios – geometry perspective - Non level-off encounters – European ATM model

Once again, the configuration taking into account the altitude of the intruder has a significantly better performance on non level-off geometries than the other configurations.

4.4.2.3.5 Number of RAs with incompatible sense selection

The following table shows the proportion of RAs with an incompatible sense selection when compared to what ATC had planned.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	10.6%	12.4%	13.4%	14.0%	13.9%
Basis+Protection against multiple TAs	10.6%	12.4%	13.4%	14.0%	13.9%
Basis+Taking into account intruder's altitude	10.6%	10.6%	10.4%	10.3%	10.2%
Basis+Protection against multiple TAs+reinforced acc.	10.6%	9.5%	14.1%	14.9%	15.2%
Basis+improved Protection against multiple TAs	10.6%				13.7%

Table 121: % of RAs with incompatible sense selection - geometry perspective - Non level-off encounters – European ATM model

The following table shows the variation relative to the reference scenario.

Configuration	Ref.	25% eq.	50% eq.	75% eq.	100% eq.
Basis	0.0%	17.6%	26.4%	32.2%	31.6%
Basis+Protection against multiple TAs	0.0%	17.6%	26.4%	32.2%	31.6%
Basis+Taking into account intruder's altitude	0.0%	0.0%	-1.8%	-2.1%	-3.0%
Basis+Protection against multiple TAs+reinforced acc.	0.0%	-10.0%	33.7%	41.3%	43.8%
Basis+improved Protection against multiple TAs	0.0%				29.8%

Table 122: RAs with incompatible sense selection – Variation - geometry perspective - Non level-off encounters – European ATM model

The proportion of RAs with an incompatible sense selection increases with the configurations that do not take into account the altitude of the intruder.

When taking into account this information, the proportion of such RAs remains unchanged or decreases, showing the efficiency of this solution.

5 Conclusions

AltCapt is very efficient in avoiding operationally undesired RAs. The likelihood to receive an RA during a level-off encounter when equipped with AltCapt is reduced by a factor of 30 (and even 70 with the improved protection against multiple TAs). Assuming an RA is currently triggered every 800 flight hours, and one RA out of two triggered is operationally undesired, we can assume that the current situation in Europe is one operationally undesired RA triggered every 1,600 flight hours. With the new altitude capture law, this last figure would become roughly 50,000 flight hours.

TCAS safety performance is not affected in an adverse manner by AltCapt. In addition, it has only a very slight effect on the vertical trajectories and it will not affect ATC operations in an adverse manner.

Introducing AltCapt in a given airspace would change the distribution of RAs significantly and therefore the perception of TCAS by people using it.

Some side effects were discovered. One of these effects was observed on very specific geometries referred to as the “jump” geometry, in which an aircraft is required to maintain a specified vertical rate to go above or below another aircraft. In this geometry, which can only be observed in some specific areas, and predominantly in losses of separation, the new altitude capture law can add RAs. Several options to the new altitude capture law are available, and one of them solves this issue. It consists in taking into account the altitude of the intruder in the activation of the new altitude capture law. Having this option implemented removes this side effect, however this option would require some modifications in the output format of TCAS, therefore this is not considered as a short term solution. However given the very specific character of the geometry in which RAs can be added, the low probability of occurrence of this geometry (confirmed by a preliminary study conducted by NATS on radar data) and the benefits brought by the new altitude capture law, this issue is considered as acceptable.

Another side effect of the new altitude capture law results from the fact that it can add multiple TAs. Multiple TAs have never been reported as an operational issue in any monitoring, and in addition the rate by which the likelihood to receive multiple TAs is increased is not sufficiently high for this issue to be considered as more than minor.

6 Recommendations

The French BEA should be made aware of this report, as in the past they made a recommendation stating that the TCAS alert triggering threshold had to be taken into account for altitude capture laws [2].

The implementation of AltCapt should be made in two steps:

- In a first step for short term implementation, it is recommended to implement AltCapt in its basic form plus additionally the improved protection against multiple TAs. This configuration will result in no safety impact and major operational benefits with few and acceptable downsides;

- In a second step for medium term implementation, it is recommended to implement AltCapt taking into account the altitude of the intruder, still with the improved protection against multiple TAs. A more suitable format of TCAS output is highly recommended at first opportunity.

7 References

[1] **EMOTION-7,** Final report, WP5/107/D, version 1.3, January 2003

[2] **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

[3] **SESAR 4.8.2.1** – Validation Plan – D02, edition 00.01.00, August 2010

[4] **NATS Operational Analysis** – Frequency of "cross" scenarios Analysis Summary, September 2011

8 Appendix A: General description of OSCAR displays

The OSCAR test bench is a set of integrated tools to prepare, execute and analyse scenarios of encounters involving TCAS II equipped aircraft. It includes an implementation of the TCAS II Version 7.0 and Version 7.1.

For each encounter, the most relevant results of the TCAS II simulations are provided by screen dumps of OSCAR windows. Several types of information are displayed:

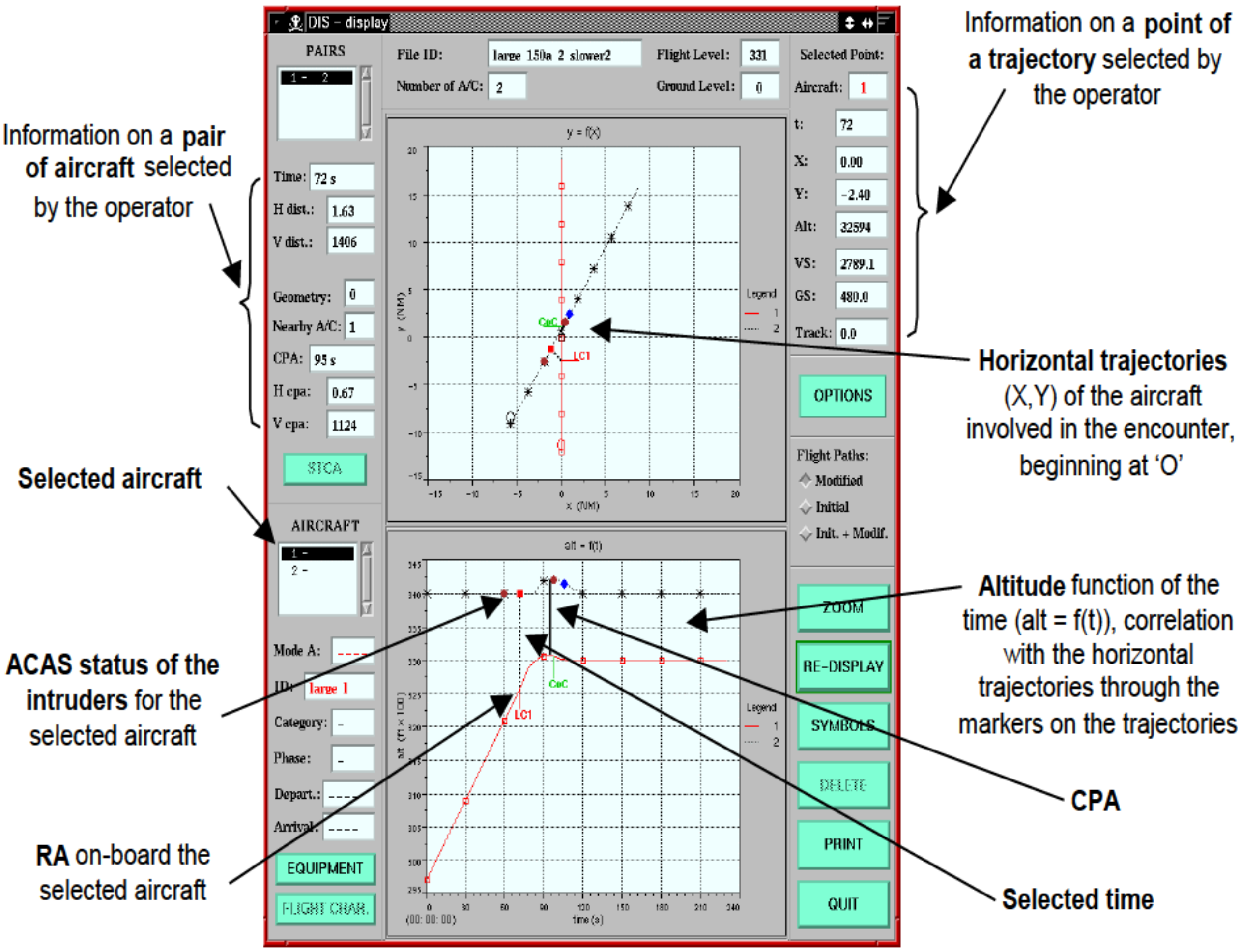


Figure 30: OSCAR display

TCAS II simulation results are displayed on the horizontal and vertical trajectories. RAs are displayed on the trajectory of the selected aircraft and ACAS status of the intruders on their respective trajectories, according to the symbols and labels described hereafter:

Figure 31: OSCAR symbols

Label	Advisory
CoC	Clear of Conflict
Cl	Climb (1500 fpm)
DDes	Don't Descend
LD5 / LD1 / LD2	Limit Descent 500 / 1000 / 2000 fpm
Des	Descend (1500 fpm)
DCl	Don't Climb
LC5 / LC1 / LC2	Limit Climb 500 / 1000 / 2000 fpm
CCl	Crossing Climb (1500 fpm)
RCl	Reverse Climb (1500 fpm)
ICl	Increase Climb (2500 fpm)
MCl	Maintain Climb
CDes	Crossing Descend (-1500 fpm)
RDes	Reverse Descent (-1500 fpm)
IDes	Increase Descent (-2500 fpm)
MDes	Maintain Descent

Table 123: OSCAR labels