TCAP: an altitude capture enhancement to prevent TCAS RAs

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The 'Traffic Alert and Collision Avoidance System' – known as 'TCAS' was introduced in the 90's to prevent the risk of mid-air collisions. Today, this safety goal has been reached on a global scale. However, a recurrent side-effect of TCAS introduction can be observed. This side-effect is what we call the 'nuisance' RAs or the operationally 'undesired' RAs, which occur during 1000ft separation level-off manoeuvres. A new Safety Initiative has been launched by Airbus in response to BEA and EUROCONTROL recommendations as well as in response to airline requests to solve this issue.

What is an operationally 'undesired' TCAS RA?

What we call an operationally 'undesired' RA is an RA, which occurs during 1000ft level-off manoeuvres while everything is correctly done by the crew with regards to operations and clearance.

These 'undesired' RAs can be characterised by the following two typical encounter geometries:

- One aircraft (in red on Figure 1) is intending to level-off at a given level while another aircraft (in blue on Figure 1) is already levelled at the adjacent level (1000ft beyond the 1st aircraft intended level)
- One aircraft is climbing to level-off at a given level while another aircraft is descending to level-off at the adjacent level (1000ft beyond the 1st aircraft intended level) as on Figure 2

We know from EMOTION-7[1] and ASARP[2] European projects that this type of operationally 'undesired' RAs represent more than 50% of all RAs triggered by TCAS in Europe, and even more than 2/3 of RAs for some

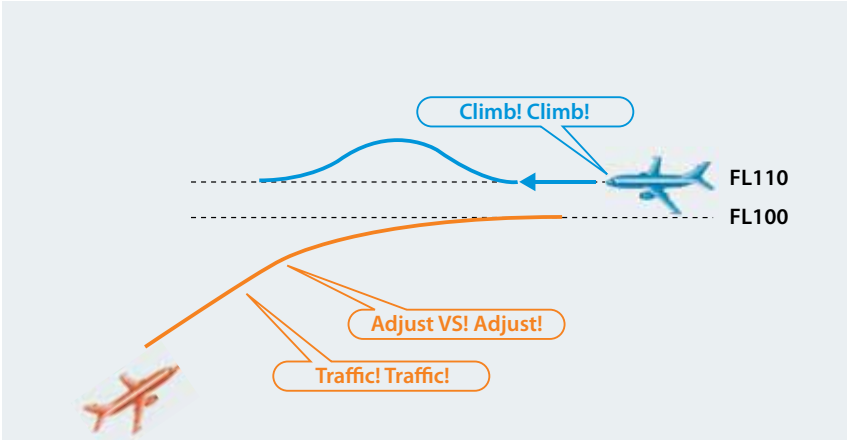

Figure 1 – 'Undesired' TCAS RAs occurring during a single 1000ft level-off manoeuvre

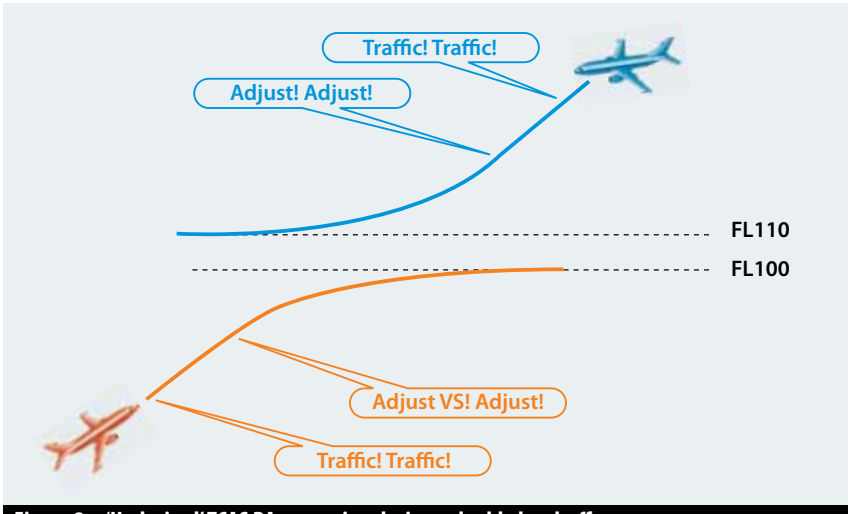

Figure 2 – 'Undesired' TCAS RAs occurring during a double level-off manoeuvre

1- EMOTION-7: European Maintenance Of TCAS II logic version 7.0 - Project commissioned by EUROCONTROL to provide the Agency with the adequate tool and structure to minimize any possible risk associated with the ACAS II implementation in Europe (Jan 2000 - Dec 2002).

2- ASARP: ACAS Safety Analysis post-RVSM Project – Project commissioned by EUROCONTROL to investigate the safety of ACAS following the introduction of RVSM in Europe (Oct 2004 – May 2006).

major European airlines which use to frequently operate very high density TMAs like Paris or London.

Although these RAs do not imply a 'real' collision risk (as far as aircraft intentions are to level-off), they remain very stressful alerts and above all, they impose - by procedure - an avoidance manoeuvre to both aircraft, leading to unnecessary deviations from initial trajectories and to traffic perturbations.

Let's take the example of an A320 (medium weight/CG, selected speed 300kt) climbing to FL130 with a vertical speed of 2800ft/min, while an A340-600 (light weight / medium CG, selected speed VMO-20kt) is descending to FL140 with a vertical speed of 2200 ft/min as shown on Figure 3. In such an encounter, TCAS system will trigger a TA at FL116 in the A320 and simultaneously a TA at FL153 in the A340-600 followed by an RA at FL123 in the A320 and an RA at FL147 in the A340-600.

Recommendations to prevent these RAs

Several recommendations have been made to prevent these 'undesired' RAs. The first of them directly addresses the pilots and consists of reducing the vertical rate when approaching an assigned altitude or a flight level, when pilots are aware of traffic converging in altitude. Indeed, this preventive action enables us to limit the vertical convergence between aircraft and thus to prevent passing TCAS alert triggering thresholds.

As shown in Table 1, we can observe that the preventive rates to apply lightly vary depending on who is expressing the rule. For example, in PANS-OPS Doc. 8168, ICAO recommends adopting a rate less than 1500ft/min throughout the last 1000ft of climb or descent to the assigned altitude when the pilot is made aware of another aircraft at or approaching an adjacent altitude.

In the Airbus FCOM, we recommend that pilots limit the vertical speed to 1500 ft/min during the last 2000ft of a climb or descent, especially when they are aware of traffic that is converging in altitude and intending to level off 1000ft above or below the pilot's assigned altitude.

	Vz	Dist. to level
AI FCOM	1500 ft/min	2000 ft
FAA	500-1500 ft/min	1000-2000 ft
ICAO	1500 ft/min	1000 ft
DLH	2000 ft/min	2000 ft
	1000 ft/min	1000 ft
EUROCONTROL ACAS and RVSM Programs	1000 ft/min	1000 ft
Swiss regulation	1500 ft/min	1500 ft

Table 1 – Recommendations to prevent 'undesired' TCAS RAs

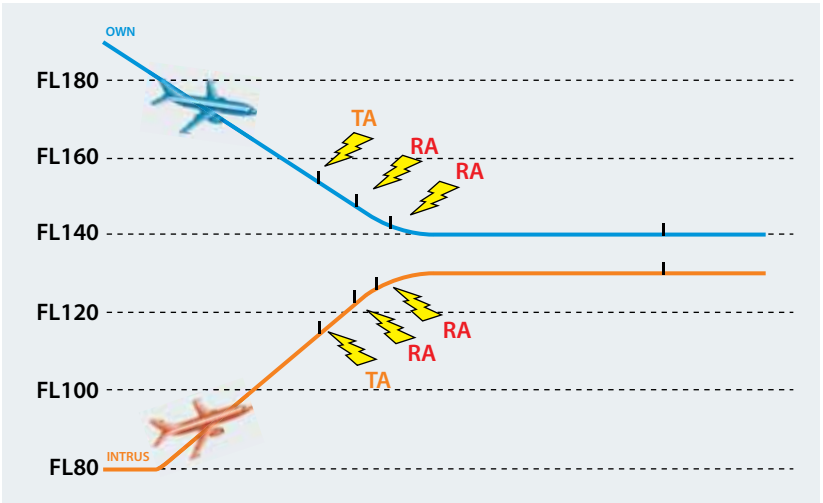

Figure 3 – Example of nuisance TCAS alerts occurring during a double level-off manoeuvre

This last recommendation meets FAA one within AC 20-151A (appendix A section III), which advises to reduce the vertical velocity to a rate between 500 and 1500ft/min, when approaching an altitude between 1000 and 2000ft above or below the altitude assigned.

As a matter of fact, those recommendations are rarely applied. Some pilots confess it is difficult to apply as it requires a lot of anticipation. As a result, there is still a significant number of undesired RAs observed during 1000ft level-off manoeuvres.

TCAP: an altitude capture enhancement to prevent TCAS RAs (cont'd)

Another kind of recommendation – more "medium-term" – has been expressed by BEA following a mid-air incident in March 2003, where a wrong response to an "ADJUST V/S" RA was observed in the context of a 1000ft level-off encounter. BEA requested aircraft manufacturers to study the capability to take into account TCAS alert triggering thresholds into their altitude capture laws.

This recommendation has been followed by EUROCONTROL within the ACAS Bulletins and by several airlines who requested a modification of the altitude capture control laws with an earlier reduction of the vertical rate to prevent such recurrent undesired RAs.

The Airbus Solution: TCAP function

In response to these requests for improvement, Airbus has launched the feasibility study of a new system called 'TCAS Alert Prevention' or 'TCAP'.

The objective of this new 'TCAP' feature is twofold:

1) To reduce the number of undesired TCAS RAs occurring during 1000ft level-off encounters by introducing a new altitude capture law which soften aircraft arrival to an intended altitude when traffic is confirmed in the nearby vicinity.

2) Not to unduly degrade the aircraft performance, in particular in descent, by a premature and excessive reduction of the vertical speed before reaching the altitude target, when it is not justified.

TCAP activation logic is based on the Traffic Advisory (TA) triggered by TCAS system, which clearly confirms the presence of traffic in the aircraft vicinity. This triggering condition is associated to a set of necessary pre-conditions including:

- The Auto Pilot and/or the Flight Director must be engaged,
- The aircraft is converging towards its selected altitude,
- The distance to the selected altitude at the time of the TA is lower than what we called the 'TCAP availability threshold' DZ_{avail} (see below).

The concept of a 'TCAP availability threshold' has been introduced in order to limit TCAP activation to the only TAs corresponding to our targeted encounter geometries, i.e. to the 1000ft level-off encounters.

To avoid any TCAP activation upon a TA occurring in other circumstances (e.g. far from selected altitude), TCAP availability threshold DZ_{avail} has been defined as the upper distance from the selected altitude where a TA can occur with an intruder capturing the same altitude in the opposite sense (with a 'conventional' altitude capture control law). This DZ_{avail} value depends both on the aircraft vertical speed at the time of the TA and on its altitude.

For example, with a vertical speed of +3000ft/min at FL130, DZ_{avail} is around 4000ft. This means that in case of a TA, TCAP will activate if the aircraft intend to capture a flight level lower than FL170. TCAP will be inhibited if the aircraft intend to capture a flight level greater than FL170.

Upon TCAP activation at TA:

- If the aircraft is initially in a vertical guidance mode other than the altitude capture mode (for example in a climb or a descent mode), the vertical mode automatically reverts to the altitude capture mode (ALT* for Airbus HMI) with the new TCAP altitude control law active (ALT^*_{TCAP} control law).
  See figure 5.

- If the vertical mode is initially the altitude capture mode (ALT* with the conventional altitude capture control law active), the vertical mode remains the altitude capture mode but with the new ALT^*_{TCAP} control law active. The flight mode annunciator, 'ALT*' remains displayed.
  See figure 6.

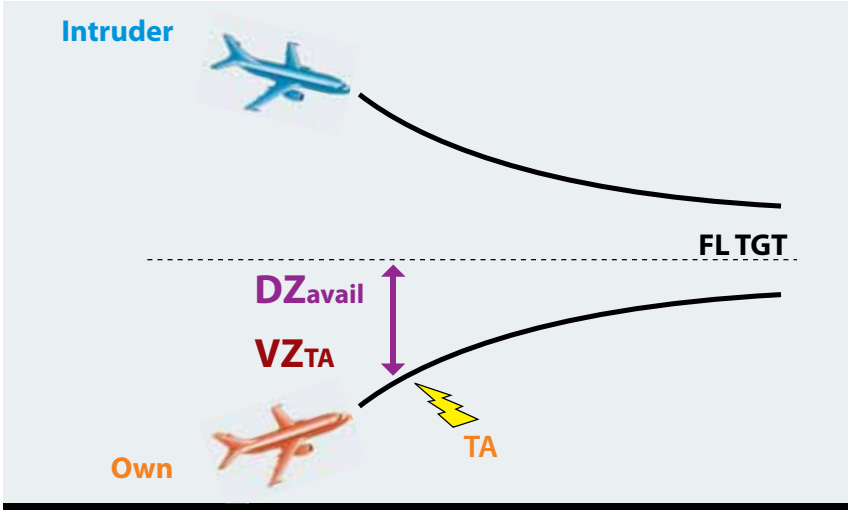

Figure 4 – TCAP availability threshold DZ_{avail}

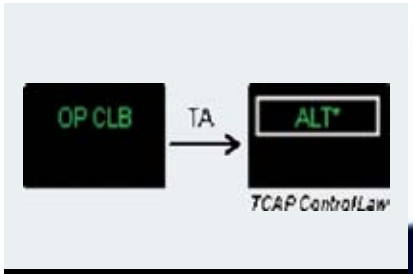

Figure 5 – FMA upon TCAP activation when initially in OP CLB

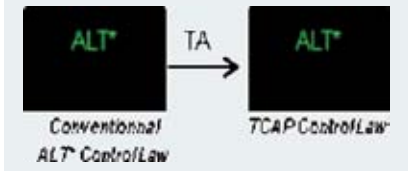

Figure 6 – FMA upon TCAP activation when initially in ALT*

Once activated, the ALT*$_{TCAP}$ control law remains active until the end of the capture (with ALT* mode engaged), even if the triggering TA ceases. This is to avoid triggering a new TA.

Finally, it is important to note that TCAP activation has no impact on the lateral trajectory and associated lateral guidance mode as well as no impact on Auto-Pilot, Flight Director and Auto-Thrust engagement status.

New TCAP ALTITUDE capture control law (ALT*$_{TCAP}$)

ALT*$_{TCAP}$ control law objective is to acquire and hold one or several consecutive vertical speed targets until the aircraft reaches its intended altitude by resuming a classical 0.05g parabola profile.

When in ALT*$_{TCAP}$ control law, a vertical load factor of 0.15g is applied to ensure a rapid reduction of the vertical speed, and therefore a more efficient prevention of the RAs. It also gives a reliable sensorial feedback to the crew to indicate TCAP function activation if ALT* mode was previously engaged.

ALT*$_{TCAP}$ vertical speed targets (VzTGT) have been defined so as to efficiently prevent 'undesired' RAs while not to unbearably increase the altitude capture phase duration, based on an optimisation algorithm applied to 100.000 encounters.

When TCAP is active, ALT*$_{TCAP}$ vertical speed targets are computed in decreasing sequence and refreshed as long as the TA is active, so as to comply with the operational requirement to "kill" the triggering TA for pilot confidence in TCAP effect.

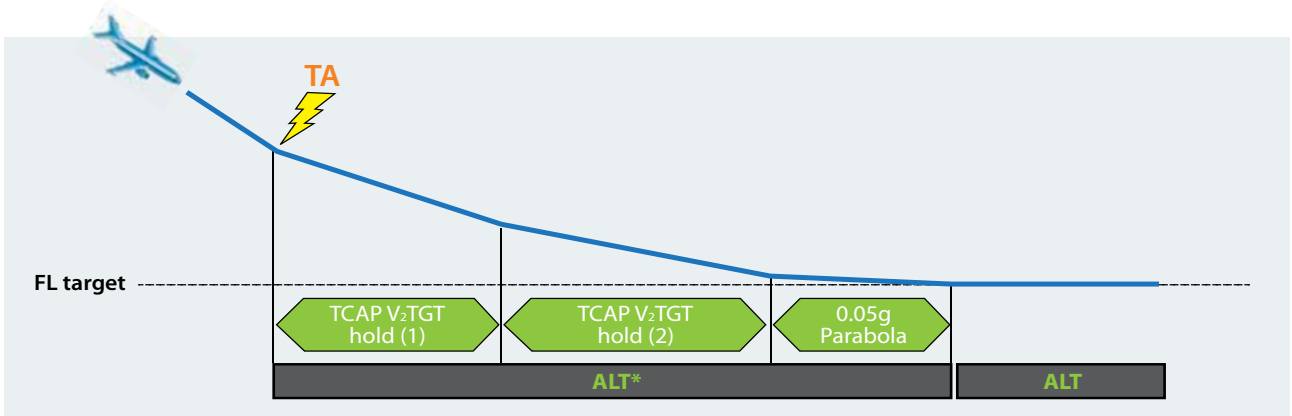

Figure 7 – TCAP Profile

TCAP: an altitude capture enhancement to prevent TCAS RAs (cont'd)

In the case of a TA occurring farther than the last 2000ft from intended altitude (also called "early-TA"), the preliminary TCAP vertical speed target is the function both of the current aircraft vertical speed at the time of the TA (VzTA) and of the distance to the targeted altitude. Its value is comprised between 1500ft/min and Vz_{TA} (assuming Vz_{TA} > 1500 ft/min). When entering the last 2000ft from targeted altitude, the vertical speed target automatically becomes 1500ft/min till the final capture (see Figure 8).

In the case of a TA occurring within the last 2000ft of an altitude capture, the TCAP vertical speed target is the function of the distance to the targeted altitude at the time of the TA. Its value is comprised between 1200ft/min and 1500ft/min (see Figure 9).

The average impact on the altitude capture time is an increase of 40 seconds, compared to the conventional altitude capture law, remembering that TCAP control law activation is limited to a TA occurrence.

EXAMPLES

"Early-TA" occurring when the aircraft is in descent

The aircraft is descending in OP DES mode when a TA occurs farther than the last 2000ft. The ALT* mode immediately engages with $ALT*_{TCAP}$ control law active: the rate of descent is then continuously reduced while the TA is active (few seconds) with a vertical load factor of 0.15g. Once the TA is off, the vertical rate is frozen on current vertical speed target (>1500ft/min) until reaching the last 2000ft where the vertical speed target becomes 1500ft/min.

TA occurring during an altitude capture (in ALT*)

The aircraft is performing an altitude capture on the conventional 0.05g parabola capture profile (ALT* mode) when a TA occurs. The $ALT*_{TCAP}$ law automatically activates to quickly reduce the rate of descent, shortcutting the parabola with a vertical load factor of 0.15g (ALT* mode remains engaged).

The rate of descent is continuously reduced while the TA is active (a few seconds). Once the TA is off, the vertical rate is frozen on the current vertical speed target (1300ft/min) until the end of the capture.

3- INCAS: INteractive Collision Avoidance Simulator: EUROCONTROL tool allowing to simulate encounters and resulting TCAS alerts (Input = aircraft trajectories / Output = TCAS alerts)

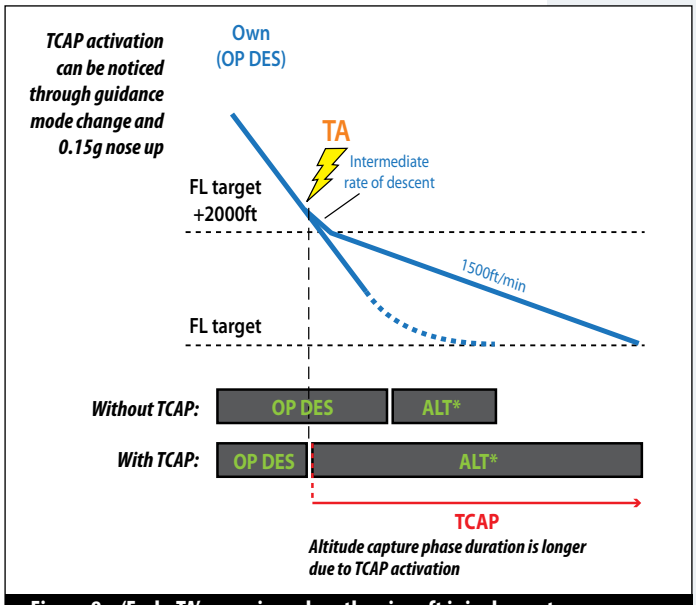

Figure 8 – 'Early-TA' occurring when the aircraft is in descent

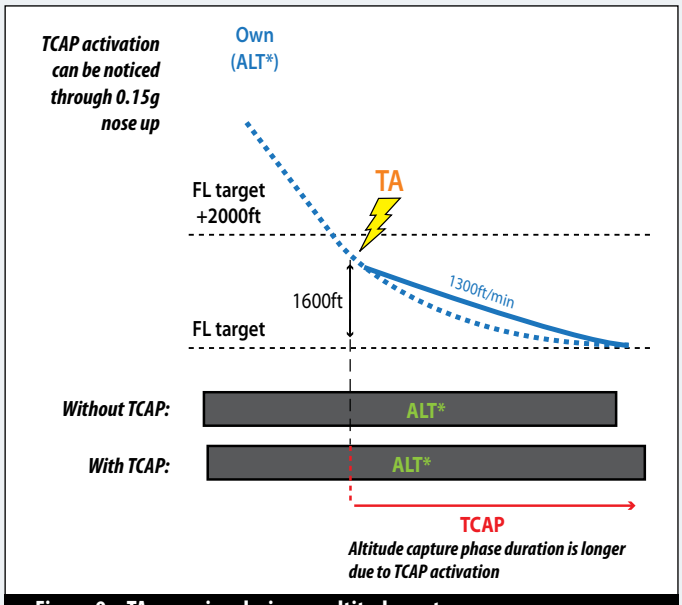

Figure 9 – TA occurring during an altitude capture

Expected benefits

A performance assessment has been carried out thanks to EUROCONTROL INCAS³ tool coupled to Airbus simulation tools in order to measure the benefits of the new Airbus TCAP solution in terms of prevention of 'undesired' TCAS RAs.

For that purpose, several hundreds of encounters, single level-off and double level-off ones, at several flight levels with random initial vertical rate conditions, were tested.

The resulting performance is significant - not to say optimal - with 100% of 'undesired' RAs prevented among the overall simulated cases. Based on this very exhaustive assessment, Airbus is very confident about TCAP efficiency in the current airspace environment.

Another very relevant result observed is the following: only one aircraft of the encounter needs to be equipped with TCAP to allow RAs prevention on both aircraft (see Figure 10).

As far as 'undesired' RAs represent more than 50% of the totality of RAs produced by TCAS system and as far as we anticipate a huge efficiency of TCAP on this RA family, we can assume a major effect on the global airspace perspective with significantly fewer RAs and the following associated outcomes:

- **For the crew:**
  less stress due to RA situations,
- **For ATC:**
  fewer unnecessary traffic perturbations owing to 'undue' avoidance manoeuvres.

Finally, TCAP solution will efficiently contribute to alleviating the crew workload. Pilots will not have to anticipate the FCOM recommendation to prevent 'undesired' RAs any longer, knowing they are flying an aircraft equipped with the TCAP system, they will just have to monitor the Auto Pilot or the Flight Director adopting the proper strategy in the event of a TA.

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Next steps

This new TCAP altitude capture enhancement will be available on A380, A350 and on fly-by-wire aircraft families in the near future. The certification targets are anticipated between end 2011 and mid 2013 depending on the aircraft type.

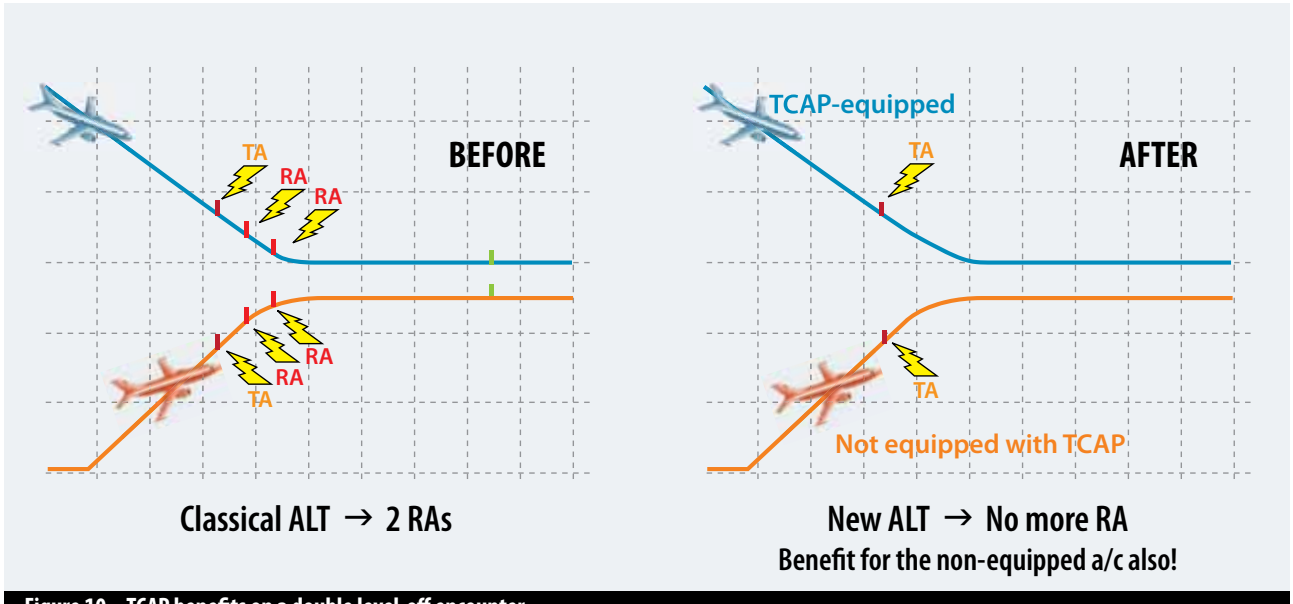

Figure 10 – TCAP benefits on a double level-off encounter