SAFETY FLASH

ACAS II bulletin No 8

EUROCONTROL

TCAS II operations in European RVSM airspace

Editorial

Before RVSM operations commenced in European airspace, work was carried out to ensure that TCAS II would be compatible with RVSM and would deliver the expected safety benefit.

TCAS II Version 7 successfully addressed compatibility issues related to the reduced vertical separation. As importantly, EUROCONTROL conducted an extensive safety study which used modelling of TCAS II encounters in RVSM. It concluded that, although there were instances when RAs could occur due to high vertical rates in level-off manoeuvres with 1000ft separation, or poor altitude station keeping, TCAS II would provide the expected additional safety benefit.

Now, following more than four years experience of TCAS II operations in European RVSM airspace, a further safety study (ASARP - ACAS Safety Analysis post-RVSM Project) has been completed using actual recorded TCAS operational encounters. This study has confirmed that TCAS II provides substantial safety benefit in European RVSM airspace.

The real events described in this Bulletin not only illustrate the safety performance of TCAS II in RVSM airspace, but also confirm that, as in any other airspace, the reduction in collision risk afforded by TCAS II relies on prompt and accurate responses to RAs.

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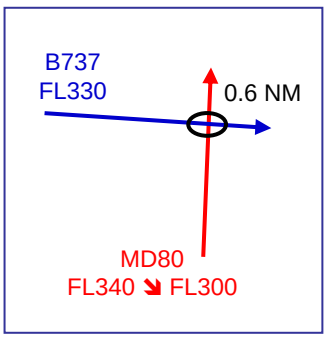
May 2006

Event 1: ATC error

An MD80 is level at FL340 heading North, about to descend.

The controller does not detect a converging eastbound B737 at FL330 and, therefore, clears the MD80 to descend to FL300.

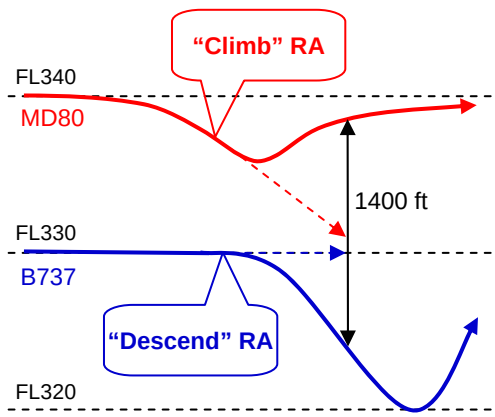
When the MD80 starts its descent, a Short Term Conflict Alert is triggered. In the attempt to rectify the error, the controller instructs the MD80 to stop the descent. Under stress, he issues a confusing instruction for the B737 to turn. The pilot does not respond.



At this point, both aircraft receive a coordinated RA:

- the MD80 pilot receives a "Climb" RA that he follows correctly while informing the controller
- the B737 pilot receives a "Descend" RA that it is also followed

As a result of the coordinated "Climb" and "Descend" RAs, the aircraft passed at 1400 ft and 0.6 NM. A simulation shows that **the vertical separation would have been 100 ft without these manoeuvres.**



Beware of unnecessary large deviations

*In the Event 1 described above, **the B737 pilot responded correctly to the "Descend" RA**. However, as the following illustrations show, he continued to descend despite receiving a subsequent weakening "Adjust Vertical Speed" RA, and even after the "Clear of Conflict". He eventually descended 1000 ft whereas an accurate reaction would have limited the deviation to only 300 ft.*

5 seconds after the "Descend" RA

5 seconds after the "Adjust Vertical Speed" RA

5 seconds after the "Clear of Conflict"

***A prompt and accurate response to all RAs** minimises the deviation and **reduces the likelihood of a domino effect** with a third aircraft.*

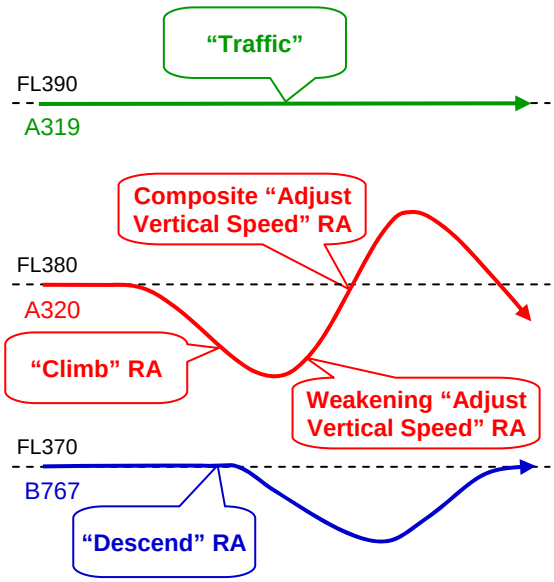
Event 2: initial ATC error resulting in a multiple aircraft encounter

A northbound A320 is level at FL380. Its track is crossing two aircraft heading South-West: a B767 below at FL370 and an A319 above at FL390.

Shortly before crossing the B767, the A320 is cleared in error by the controller to descend to FL320. The descent triggers a Short Term Conflict Alert and in response, the controller issues an immediate 20 degree left turn instruction to the B767. The B767 pilot replies that he is turning and he also reports responding to a TCAS descent.

A coordinated "Climb" RA is issued to the A320 and the pilot responds correctly. However, he does not respond to a subsequent weakening "Adjust Vertical Speed" RA and continues climbing. As a result, TCAS declared the A319 above to be a threat and **a composite "Adjust Vertical Speed" RA requiring neither to climb nor to descend (i.e. to level-off) is triggered in the A320**. The pilot responds by stopping the climb. The A320 receives a "Clear of Conflict" for both threats when it is levelling off. The A320 pilot then resumes the descent to FL320 as previously cleared.

Despite the lack of response by the A320 pilot to the weakening RA, the correct response to the subsequent composite RA ensures that no domino effect RA is triggered for the A319, which only receives a Traffic Advisory.



At the closest point, the A320 passed approximately 1700 ft from the B767 and 700 ft from the A319. **Without TCAS, the A320 would have passed through the level of the B767 at a distance of only 1.4 NM**.

Event 3: Incorrect altitude reporting

A B737, heading North-East, is level at FL350. Its track is crossing two northwest bound aircraft: an A320 above at FL360 which is almost on top of a B757 below at FL340.

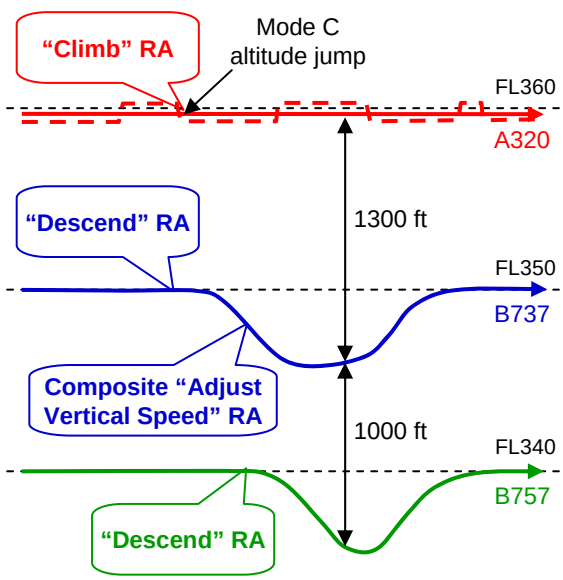
However, the A320 transponder is incorrectly reporting its altitude. Although the aircraft is level, **the altitude reports indicate frequent abnormal 100-foot "jumps"**. As this aircraft is reporting altitude in 25-foot increments, the TCAS on the B737 is tracking some high vertical rate variations for the A320.

One of these erroneous altitude reporting jumps occurred some 30 seconds before the crossing, consequently the TCAS on the B737 computes that the A320 is descending at 3300 fpm and is a threat. **A "Descend" RA is then triggered for the B737**. This is not a normal TCAS event where aircraft in level flight are separated by 1000 ft.

The incorrect altitude data is also provided to the A320's own TCAS, which triggers a coordinated "Climb" RA that is not followed by the pilot.

The B737 pilot initiates a descent in response to the RA and informs the controller. This manoeuvre induces a vertical convergence with the B757 and coordinated RAs are also triggered between these two aircraft. The B757 receives a "Descend" RA (domino effect), while the initial RA in the B737 is changed to a composite RA requiring level-off, which provides collision avoidance against both threats.

The B737 pilot stops descending and levels off accurately while the B757 pilot descends and informs the controller. As a result, **the B737 passes 1300 ft below the A320 and 1000 ft above the B757**.



Multiple aircraft encounters in RVSM airspace

The EUROCONTROL ASARP safety study (see editorial) has investigated in depth the TCAS II performances in multiple aircraft encounters. It shows that:

- ***These are rare situations**. Although two events are described in this Bulletin, operational data obtained from TCAS II operational monitoring programmes shows that there are very few cases each year in Europe.*
- *The RAs generated during multiple aircraft encounters are **effective** and are typically composite "Adjust Vertical Speed" RAs.*
- *Good aircraft altitude station keeping performances and correct altitude reporting are essential to avoid undesirable RAs in RVSM.*
- ***Prompt and accurate pilot response to all RAs is a key element** in reducing the likelihood of a TCAS domino effect with a third aircraft at an adjacent flight level.*

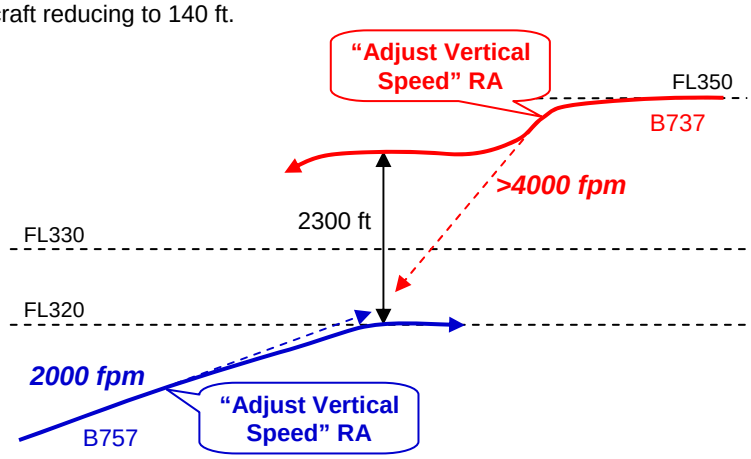
*Finally, the ASARP safety study shows that in RVSM airspace, **TCAS II contributes positively to the safety of the flights involved in multiple aircraft encounters**.*

Event 4: RA due to high vertical rate

A B757, heading North-West, is climbing to FL320 at about 2000 fpm.

In the opposite direction, a B737 is maintaining FL350 approaching its top of descent. It is cleared to descend to FL330 initially because of the B757 which is at 12 o'clock 15 NM.

The B737 starts descending at about 500 fpm and then increases the rate of descent to more than 4000 fpm. Soon after, a coordinated RA is generated on-board each of the aircraft – **they are separated by 3000 ft and 7 NM but are converging at more than 6000 fpm vertically and 880 kts horizontally**. The high rate of closure causes the TCAS to extrapolate the separation between the aircraft reducing to 140 ft.



The B737, which has received an "Adjust Vertical Speed" RA to reduce the vertical rate to less than 2000 fpm, actually stops the descent by levelling off and reports the RA to the controller. The B757 also informs the controller about an RA and modifies its trajectory accordingly.

At the crossing, the two aircraft pass at 2300 ft and 0.2 NM.

Recommendation for reduction in vertical rate before level-off

Before implementation of RVSM in European airspace, the EUROCONTROL ACAS Programme distributed a training package to pilots and controllers that addressed TCAS II performance in the RVSM airspace. In particular, the expected RVSM and TCAS II interaction was clearly described.

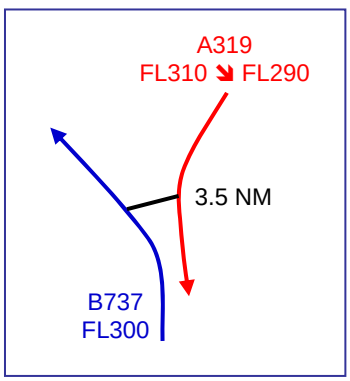
Based on the TCAS II experience at lower altitudes, it was anticipated that RAs could be generated in 1000 ft level-off geometries with high vertical rates.

*To prevent such RAs, EUROCONTROL has recommended that pilots **climb or descend at a rate less than 1000 fpm in the last 1000 ft before reaching the cleared flight level** when they are aware of traffic in close vicinity at the adjacent flight level. This is equally important in RVSM airspace.*

However, operational monitoring programmes show that this recommendation has not been universally adopted. There are still a significant number of RAs being triggered during 1000 ft level-off manoeuvres in RVSM airspace because of aircraft with high vertical rates of climb and descent.

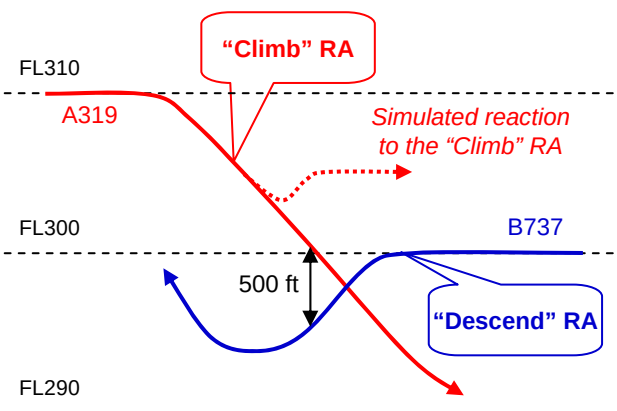
Event 5: Opposite manoeuvre to RA to follow ATC clearance

An A319 at FL310 requests descent to FL290 because of turbulence. The controller issues the descent clearance overlooking a B737, level at FL300, on opposite track, about 20 NM ahead.



The controller quickly detects his mistake and instructs the A319 to turn 30 degrees left and the B737 to turn 20 degrees left. Both pilots read back correctly and comply with the instructions. A short term conflict alert is triggered and the controller instructs the B737 to turn left another 20 degrees.

Due to the combined horizontal and vertical convergence, both aircraft receive coordinated RAs: a "Climb" RA for the A319 and a "Descend" RA for the B737. However, only the B737 pilot correctly follows the RA. **The A319 pilot disregards the "Climb" RA and continues his descent, following the last ATC clearance, but manoeuvring in the opposite sense of the RA**. As a result, the aircraft eventually pass at 500 ft and 3.5 NM.



The horizontal instructions provided by the controller were complementary to the RAs triggered by TCAS II. Simulations show that the aircraft would have crossed at 0.8 NM without the turns and at 0 ft without the manoeuvre of the B737 in response to the "Descend" RA.

If the A319 pilot had reacted to the "Climb" RA, the vertical separation at the crossing would have 850 ft. However, the non-compliance and opposite manoeuvre to the RA by the A319 pilot caused the vertical distance to be limited to 500 ft at the crossing.

A manoeuvre in the opposite sense of an RA can have very serious consequences. It must be re-emphasised that ICAO PANS-OPS Doc 8168 clearly states that "***pilots shall follow the RA even if there is a conflict between the RA and an ATC instruction to manoeuvre***" (cf. ACAS Bulletins 5 and 7).

Events 6 & 7: Limited aircraft performances

- An A320 is cruising at FL390. A converging Falcon 900 is climbing to FL400 with a rate of climb requirement that will ensure separation from the A320. However, the F900 pilot unexpectedly informs the controller that the rate of climb cannot be maintained (due to an increase of the air temperature). Consequently, to resolve what has become a conflict, the controller issues appropriate instructions telling both aircraft to turn left 30 degrees.

  A few seconds later, despite complying with the turn instructions, both aircraft receive coordinated RAs: a "Climb" RA for the A320 and a "Descend" RA for the F900. **Although the A320 was at its maximum certified flight level and in the turn, the pilot follows the RA and starts to climb, achieving a 800 fpm climb rate**. The F900 pilot responds to the RA as well and starts to descend. As a result of these manoeuvres, the aircraft pass at **1370 ft** and 1.1 NM.

- An A340 is cleared to climb to FL340 with a requirement to reach this flight level within three minutes. This restriction is due to a converging A320 climbing to FL330. However, due to performance limitations, the A340 climb rate reduces from 1700 fpm to 300 fpm and, consequently, the time requirement cannot be met.

  As the A340 passes FL335, its TCAS triggers a "Climb" RA against the A320 which has just levelled off at FL330. **The A340 pilot cannot increase the rate of climb to 1500 fpm as required by the RA. Nevertheless, he continues climbing at 300 fpm**. The A320 has received a coordinated "Descend" RA, which is correctly followed by the pilot. As a result of the combined climb and descent, the aircraft pass at **930 ft** and 1.5 NM.

Reactions to "Climb" RAs at high altitudes

TCAS does not usually take into account the possible aircraft performance limitations when generating an RA. Even at the maximum certified flight level, aircraft should have the ability to climb, albeit maybe at less than 1500 fpm, for a short period of time – the RA duration is about 30 seconds at high altitudes.

In Event 6, the A320 pilot responded to the "Climb" RA even though the aircraft was at its maximum certified flight level. Such response is already stipulated in many airline standard operating practices. The aircraft was also turning, which further limited the climb performance. Despite both limitations, the pilot was still able to partially comply with the RA.

In Events 6 & 7, the aircraft which received the "Climb" RAs could not achieve the required rate of climb (i.e. 1500 fpm). Nevertheless, ***the limited climb combined with the response to the coordinated "Descend" RA by the other pilot provided a safe vertical distance****.*

As almost all aircraft in RVSM airspace are TCAS II equipped, the coordinated RA of the other aircraft will provide an additional protection. This also emphasises that pilots must never manoeuvre opposite to a RA. Even if they are not able to achieve the required climb rate, they should apply the best possible.

Conclusion

The recent ASARP safety study concludes that **TCAS II provides substantial safety benefits in the European RVSM airspace**. This has been confirmed by operational monitoring.

Prompt and accurate pilot response to all RAs is key to achieve maximum safety benefits in all airspace, including European RVSM airspace. This will also minimise the risk of a domino effect with a third aircraft at an adjacent RVSM flight level.

"Climb" RAs should be complied with even at high altitudes, albeit that aircraft performance might dictate a climb rate lower than required by the RA.

Multiple aircraft encounters in RVSM airspace are rare. However, TCAS II provides significant safety benefits in these encounters.

As can happen at lower altitudes, RAs can be triggered in 1000 ft level-off geometries due to high vertical rate or as a result of poor altitude reporting or altitude keeping. It is recommended that **the vertical rate should be reduced to less than 1000 fpm in the last 1000 ft before reaching the cleared flight level**. This will reduce the number of RAs generated in such geometries.

Finally, aircraft operators are reminded that **accurate altitude reporting is a fundamental requirement** for effective TCAS safety performance.

TCAS II is very effective in the European RVSM airspace, provided pilots respond correctly to all RAs

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This is one of a series of ACAS II Bulletins addressing specific TCAS operational issues. They are available on the Mode S and ACAS Programme website, as well as an ACAS II brochure and some training material.