Faster is not always better

by Katarzyna Żmudzińska

It was a cold Sunday morning and, unusually for the route, we had only 26 passengers. We took off on schedule and were quite surprised when the departures controllers cleared us direct to XXXX [destination] and to FL230.
The First Officer [pilot flying] observed that there were not too many aircraft around as the frequency was remarkably quiet. When we were passing through FL215 we got a TA and noticed a target on the TCAS traffic display, above us, moving from left to right. The FO started to reduce the vertical rate which at this point was 5300 [ft/min]. At the same time, the controller reminded us that our cleared level is 230. While I was in the process of responding to her, I heard a TCAS RA command to "Level off". The FO disconnected the autopilot and performed a smooth level off at FL225. Suddenly, we got very busy: the FO flying the aircraft and me looking outside to see the intruder, talking to ATC and monitoring FO's actions. We never saw the other aircraft above due to haze. We told the controller we had an RA and would be filing a company report.
She said she has to do the same…

[A story from a Boeing B737 Captain]

As the story told by a Boeing 737 pilot indicates, TCAS RAs (Resolution Advisories) can be generated due to high vertical rates before an aircraft reaches its cleared level, against another aircraft at the adjacent level. Operationally, these RAs are unnecessary and cause additional workload and paperwork for all involved. They can also introduce new risks as pilots do not always correctly follow their RAs. Monitoring data indicates that approximately 40% of all RAs are generated due high vertical rates, regardless of TCAS version fitted on the aircraft. In line with ICAO recommendation some airlines published their own Standard Operating Procedures (SOP) to prevent these types of RAs. In this article we examine their effectiveness through simulations. Following these recommendations would help not only to prevent unwanted RAs but also to prevent the associated increase of the workload. That being said, these recommendations also involve additional workload.

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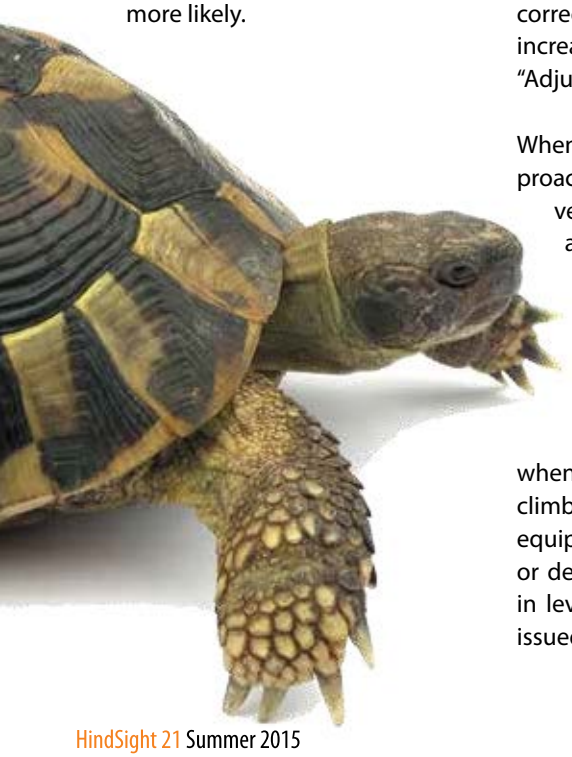
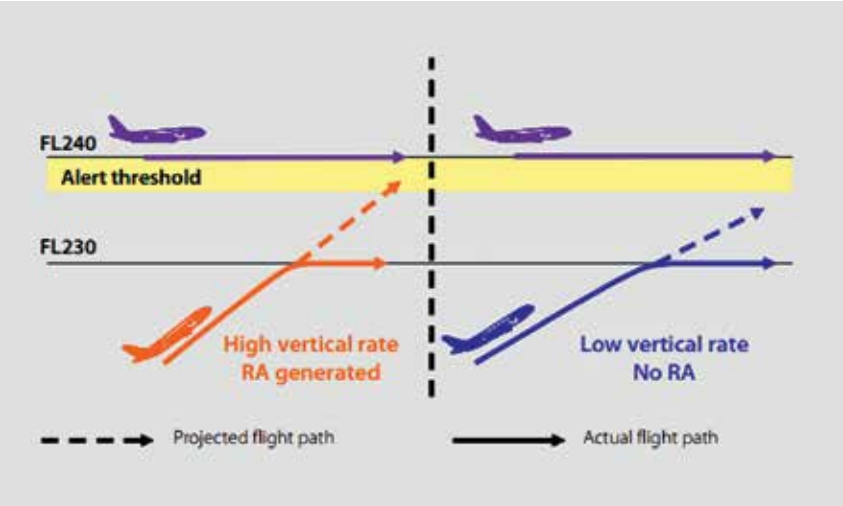
Unnecessary RAs due to high vertical rates before level-off

The performance of modern aircraft allows pilots to climb and descend with high vertical rates. While this can provide operational benefits (i.e. fuel or time savings), it can become problematic when aircraft continue to climb/descend with a high vertical rate close to their cleared level. TCAS will issue an RA when it calculates a risk of collision based on the closing speed and vertical rates. A high vertical rate before level-off may cause the TCAS logic to predict a conflict with another aircraft even when appropriate ATC instructions are being correctly followed by each crew. This is because TCAS does not know aircraft intentions – autopilot or flight management system inputs are not taken into account because TCAS must remain an independent safety net. If, simultaneously, another aircraft is approaching an adjacent level, the combined vertical rates make RAs are even more likely.





Once an RA has been issued it must be followed without delay and it takes precedence over any ATC instructions. Any deviation from the intended flight path, resulting from the RA, causes additional workload to all involved and can be disruptive to ATC traffic flow and planning and in congested airspace there is a risk for follow up conflicts. Moreover, several cases have been observed where pilots did not correctly follow their RAs and instead increase their vertical rate following an "Adjust vertical speed, adjust" RA.

When a TCAS-equipped aircraft is approaching its cleared level with a high vertical rate, TCAS will generate an RA advising the reduction of vertical rate (e.g. "Adjust vertical speed, adjust" or "Level off, level off" RA, depending on the TCAS software version). It might even change the vertical direction (i.e. "Climb" when descending or "Descend" when climbing). If both aircraft are TCAS-equipped and one aircraft is climbing or descending while the other one is in level flight, an RA will typically be issued first to the climbing/descending aircraft and only to the aircraft in level flight if a response to the initial RA is not satisfactory. However, in cases of very high rates or when both aircraft are climbing and descending, RAs will be issued to both aircraft. The precise sequence of RAs may be different if one of the aircraft is not TCAS-equipped.

In order to reduce the number of RAs caused by high vertical rates before level-off, ICAO recommends under certain conditions a reduction of vertical rate while approaching the cleared level. A major European airline has introduced a Standard Operational Procedure (SOP) requiring their crews to approach the cleared level with a specified maximum vertical rate in all cases (see the adjacent text box for details). The workload implications of the two approaches are different: the ICAO recommendation requires routine monitoring for

ICAO Annex 6:
Max. 1500 ft/min. in the last 1000 ft (when the pilot is aware of another aircraft at or approaching an adjacent altitude or flight level).

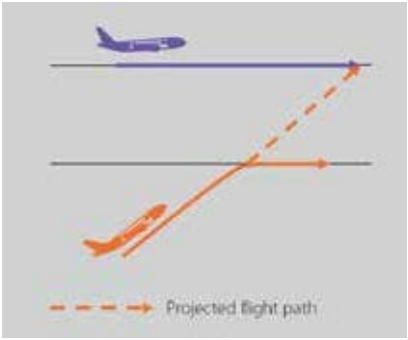
Major European airline SOP:
Always max. 1000 ft/min. in the last 1000 ft.

Faster is not always better (cont'd)

potential conflicts and occasional vertical rate reduction whilst the airline SOP only requires routine vertical rate reduction. This airline experienced a reduction of nuisance level-off RAs by a factor of 10 (the effectiveness of the ICAO recommendation is unknown). Additionally, some States have introduced specific vertical rate reduction requirements or recommendations applicable in their airspace. "While these provisions prescribe the vertical speed during the last 1000 ft before the level off, the vertical speed of the aircraft may dictate that these reductions start to take place earlier." In this article, for simplicity, only the ICAO recommendation and the above mentioned airline SOP are examined.

Effectiveness of vertical rate reduction if correctly applied

The number of possible conflict geometries is infinite; therefore it is impossible to examine the effectiveness of these recommendations in all cases. Therefore, a small number of encounters were created to test simplified level-off geometries in computer-based simulations. These scenarios assumed perfect surveillance and virtually the same speed for both aircraft in all cases. Heading, as well as altitude of either aircraft were not subject to normal variations (due to wind etc.). Analyses were conducted at various altitude bands, based on TCAS sensitivity levels[1], varying the initial vertical rate of the climbing aircraft.



In each scenario one aircraft was always in level flight, while the other was climbing towards it, either head-on or on a crossing track. These scenarios assumed a projected track with no horizontal or vertical miss-distance at the Closest Point of Approach[2], i.e. a collision; however, the climbing aircraft would start to reduce its vertical rate to achieve the required vertical rate 2000 ft before the other, to level off, subsequently, 1000 ft below. The vertical rate in the last 1000 ft before level off will be either 1500 (ICAO recommendation) or 1000 ft/min (major European airline SOP) and, subsequently, the climbing aircraft will level-off 1000 ft below the aircraft in level flight. The vertical rate reduction deceleration was set to varying values from 0.1 g to 0.3 g (in 0.05 g increments).

To determine their effectiveness, these scenarios were compared to a baseline scenario where the aircraft only reduces its vertical rate in order to level-off 1000 ft below the other aircraft.

If no vertical rate reductions are applied at all (i.e. the aircraft starts reducing its vertical rate only in order to level off), it is likely that an RA will be triggered, especially at the higher levels, with relatively low vertical rate. The maximum vertical rates (ft/min) at which no RA will occur for different load factors are shown in Table 1 below. For example, an aircraft climbing at 1,800 ft/min will not generate an RA if it just reduces its rate for level-off (e.g. ignores the ICAO recommendation), with deceleration of 0.20 g in the altitude band between FL200 and FL420.

1 - The TCAS sensitivity level is a function of the altitude and defines the level of protection. The warning time is greater at higher altitude.
2 - The Closest Point of Approach is the instant at which the slant range between own TCAS II equipped aircraft and the intruder is at a minimum.

Table 1: RA triggering thresholds if **no vertical rate reductions** are applied

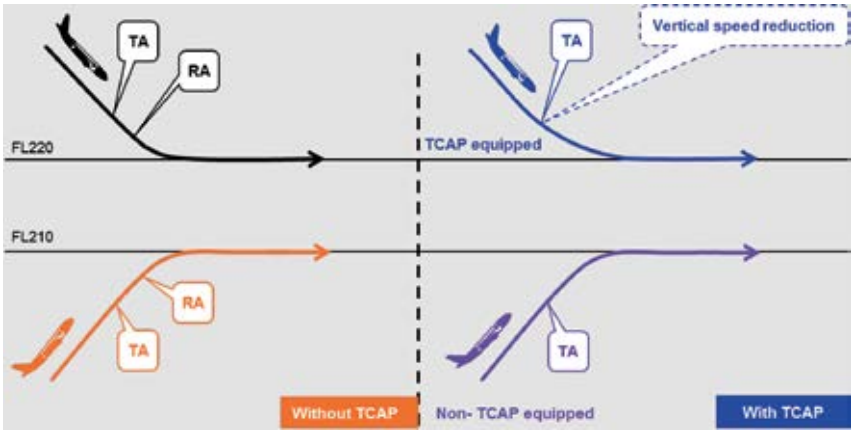
Altitude band	0.10 g	0.15 g	0.20 g	0.25 g	0.3 g
FL200 – FL420	2,000	1,850	1,800	1,850	1,750
FL100 – FL200	2,550	2,300	2,200	2,150	2,100
FL50 – FL100		3,000	2,800	2,700	2,600
2350 ft AGL – FL50			4,050	3,700	3,500
1000 ft – 2350 ft AGL					6,250

However, if the ICAO recommendation or airline SOP is applied, unwanted RAs in level-off geometries will be prevented with much higher vertical rates until 2000 ft below the other aircraft. These maximum vertical rates (ft/min) at which no RA will occur are shown respectively in Tables 2 and 3 below. For example, an aircraft climbing at 3,900 ft/min will not generate an RA if it just reduces its rate for level-off in line with the ICAO recommendation (Table 2), with deceleration of 0.20 g in the altitude band between FL200 and FL420.

Not surprisingly, more aggressive vertical rates deceleration (higher g-load) will make the ICAO recommendation and airline SOP less effective. However, higher decelerations are less likely to be used in normal operations due to passenger comfort.

TCAP

Aircraft manufacturers recognise that unwanted RAs are an operational problem and try to supplement procedures with technology which would prevent unwanted RAs. An example of a technological solution to the problem is the TCAS Alert Prevention (TCAP) functionality which has been introduced by Airbus to prevent the generation of RAs in 1000-foot level-off geometries (see Hindsight 12). The functionality uses a new altitude capture law for flight guidance computers, which decreases the aircraft's vertical rate towards the selected altitude, once a TA has been generated and the auto-pilot and/or flight director are engaged, and when another aircraft is known to be in the vicinity.



Summary

TCAS II will generate RAs in 1000-ft level-off encounters if aircraft approach their cleared levels with high vertical rates as autopilot inputs or pilot intentions are not known to TCAS. RAs caused by high vertical rates result in unnecessary workload to flight crews and can be disruptive for ATC. Any unexpected departure from ATC clearance carries a risk of a follow up conflict. Monitoring data indicates that as much as 40% RAs are generated due high vertical rates and 75% of the aircraft getting an RA in the level-off geometry approach their cleared level with a rate above 1500 ft/min. These RAs are not operationally needed and can be avoided in many cases if vertical rate reductions are applied.

Although the simulations conducted assume a perfect environment, they indicate that reductions in vertical rates in the last 1000 feet before level-off are effective in preventing RAs due to high vertical rates before level off.

Table 2: RA triggering thresholds **when ICAO-recommended** vertical rate reductions are applied

Altitude band	0.10 g	0.15 g	0.20 g	0.25 g	0.3 g
FL200 – FL420	5,500	4,150	3,900	3,750	3,700
FL100 – FL200		5,800	4,950	4,650	4,500
FL50 – FL100			8,000	6,450	5,950
2350 ft AGL – FL50					
1000 ft – 2350 ft AGL					

Table 3: RA triggering thresholds **when airline SOP-recommended** vertical rate reductions are applied

Altitude band	0.10 g	0.15 g	0.20 g	0.25 g	0.3 g
FL200 – FL420	6,200	4,250	3,950	3,800	3,750
FL100 – FL200		6,050	5,050	4,700	4,550
FL50 – FL100			8,450	6,500	6,000
2350 ft AGL – FL50					
1000 ft – 2350 ft AGL					