About 25,000 traffic-alert and collision avoidance system (TCAS) units aboard aircraft today protect lives worldwide during airline, cargo, business and government flights, including military missions, the U.S. Federal Aviation Administration (FAA) says in a recent advisory circular (AC) and technical report.[1,2] Together, the documents provide a comprehensive guide to the latest operational capabilities, limitations and requirements of TCAS II.

In explaining the evolution of TCAS hardware and its programmed logic — now up to Version 7.1 software (*ASW*, 4/09, p. 34), introduced in 2010 and seeing wider service this year — the FAA also has focused on the critical roles of pilots, air traffic controllers and operators in the effectiveness of TCAS, known internationally as the airborne collision avoidance system (ACAS II).

"TCAS II is a last-resort airborne system designed to prevent midair collisions and significantly reduce near-midair collisions between aircraft," the AC says. "It is intended to serve as a backup to visual collision avoidance, application of right-of-way rules and air traffic separation service.

Appreciating Value

BY WAYNE ROSENKRANS

Updated guidance helps flight crews and air traffic controllers to maximize the safety benefits that TCAS offers.

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"For TCAS to work as designed, immediate and correct crew response to TCAS advisories is essential. Delayed crew response or reluctance of a flight crew to adjust the aircraft's flight path as advised by TCAS due to air traffic control [ATC] clearance provisions, fear of later FAA scrutiny, or other factors could significantly decrease or negate the protection afforded by TCAS. … By not responding to a resolution advisory [RA], the flight crew effectively takes responsibility for achieving safe separation."

Flight crew confidence in the system is essential, the guidance reiterates, and should not be diminished by the fact that "certain incompatibilities between TCAS and air traffic control procedures or airspace design … exist today that will not change with Version 7.1." The AC and report explain how to ensure that flight crews maximize the protective benefits despite the few limitations, reduce the non-safety-critical alerts still generated at times, and continue to utilize voluntary and mandatory event/anomaly–reporting channels, as appropriate.[3]

"TCAS II is designed to provide collision-avoidance protection in the case of any two aircraft that are closing horizontally at any rate up to 1,200 kt and vertically up to 10,000 fpm," the report said. "Surveillance is compatible with both the ATC radar beacon system and Mode S transponders. … TCAS can simultaneously track up to 30 transponder-equipped aircraft within a nominal range of 30 nm [56 km, and] has a requirement to provide reliable surveillance out to a range of 14 nm [26 km] and in traffic densities of up to 0.3 aircraft per square nautical mile [24 aircraft within a 5-nm (9-km) radius, the highest traffic density envisioned over the next 20 years]."

The FAA recommends the installation of Version 7.1 software "as soon as practical … to ensure compatibility with international standards." With respect to pilot training, the agency considers the changes in this upgrade to be relatively transparent to flight crews, requiring a minimal information update such as operational bulletins or similar material. "The only significant change [from Version 7.0] for pilots is the change in one aural annunciation from 'adjust vertical speed, adjust' to 'level off, level off,'" the FAA said, although there are other examples (Table 1). "Version 6.04a and 7.0 units are expected to remain operating for the foreseeable future where authorized."

Version 7.1 also added reversal logic to address "the 'vertical chase with low vertical miss distance' geometry that can arise when either own aircraft or the threat [aircraft] maneuvers contrary to [its] RA in a coordinated encounter, or when an unequipped threat moves so as to thwart [the] own aircraft's RA," the report said.

Comprehensive Training

To be effective, TCAS has to be operated properly by pilots.[4] Approved training typically comprises academic study of the theory and logic, and complementary practice in responding to simulated TCAS traffic advisories (TAs) and RAs. "Many of the operational issues identified during the operation of TCAS can be traced to misunderstandings regarding the operation of TCAS, its capabilities and its limitations," the report said.

Initial and recurrent academic training are expected to explain or review the essential TCAS concepts of tau,[5] sensitivity level[6] and protected volume, and the results and limitations of each TCAS control panel selection. Regarding TCAS limitations in flight operations, for example, they typically include "some RA inhibit altitudes, certain RAs being inhibited by aircraft performance constraints, the inability to comply with an RA due to aircraft performance limitations after an engine failure, and appropriate response to RAs in limiting performance conditions, such as during heavy weight takeoff or while en route at maximum altitude for a particular weight," the report said.

Another academic element is ensuring that pilots know how TCAS may fail because of loss of data from

Examples of TCAS II Annunciation Updates by Software Version

TCAS Advisory	Version 6.04a Annunciation	Version 7.0 Annunciation	Version 7.1 Annunciation
Reduce Climb RA	Reduce Climb, Reduce Climb	Adjust Vertical Speed, Adjust	Level Off, Level Off
Reduce Descent RA	Reduce Descent, Reduce Descent	Adjust Vertical Speed, Adjust	Level Off, Level Off
Maintain Rate RA	Monitor Vertical Speed	Maintain Vertical Speed, Maintain	
Altitude Crossing, Maintain Rate RA (Climb and Descend)	Monitor Vertical Speed	Maintain Vertical Speed, Crossing Maintain	
Weakening of RA	Monitor Vertical Speed	Adjust Vertical Speed, Adjust	Level Off, Level Off

RA = resolution advisory; TCAS II = traffic-alert and collision avoidance system

Source: U.S. Federal Aviation Administration

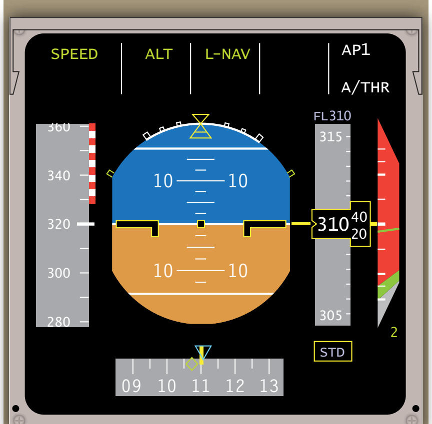
Table 1

other on-board systems, such as the inertial reference system or the attitude and heading reference system. Regarding flight maneuver training for TCAS responses, the FAA expects air carriers to provide practice in responding to corrective RAs, initial preventive RAs, maintain rate RAs, altitude crossing RAs, increase rate RAs, RA reversals, weakening RAs and multi-aircraft encounters.

Predictable Pilots

When responding to an RA, the typical excursion from the ATC-assigned altitude to satisfy the conflict should be 300 ft to 500 ft maximum. "[Vertical speed] responses should be made to avoid red arcs or outlined pitch avoidance areas [Figure 1] and, if applicable, to accurately fly to the green arc or outlined pitch guidance area," the AC said. "Evasive maneuvering must be limited to the minimum required to

TCAS Display on PFD Vertical Speed Tape



PFD = primary flight display; TCAS = traffic-alert and collision avoidance system

Note: Some airframe manufacturers now implement TCAS displays on the PFD vertical speed tape, as shown, or with pitch cues, or with both.

Source: U.S. Federal Aviation Administration

Figure 1

comply with the RA. Excessive responses to RAs are not desirable or appropriate because of other potential traffic and ATC consequences. … Deviations from rules or clearances should be kept to the minimum necessary to satisfy a TCAS RA."

Unexpected pilot responses, however, have prompted many of the upgrades since Version 6.04a was finalized in 1993. In recent years, cases of flight crews failing to respond as trained to a TCAS RA — such as by taking no action, delaying action or initiating climb/descent in the wrong direction — have reached a very low level, the report said. This is attributed to the gradually improving TCAS logic and to the quality and compliance of pilot and controller training programs.

"Most cases of 'no response' to an RA can be attributed to pilots having visual contact with the intruder or being on parallel approaches to runways during VFR [visual flight rules] operations and visual separation procedures," the report said. "Wrong-direction responses, though now rarely reported, must always be avoided. … The safety benefits provided by TCAS decrease significantly when pilots do not comply with RAs as the TCAS logic expects. … In no case should a pilot maneuver opposite to a TCAS RA."

The few known cases of no response or delayed response have occurred in situations where the flight crew did not visually acquire the intruder, misidentified the intruder or lost sight of the intruder after visual acquisition. If the intruder is TCAS-equipped (Figure 2, p. 29), either no response or a delayed response by the own airplane causes the crew of the other aircraft to maneuver more than for a correct response, and also may reduce the separation. The Version 7.1 software, for example, was designed "to make the intention of the corrective vertical speed limitation, i.e., a move toward level flight, unambiguously clear," the report said.

Ongoing ATC data analysis of the few cases of improper crew behaviors produces useful explanations and training improvements. "Aircraft [crews have] been observed making vertical or horizontal maneuvers based solely on the information shown on the traffic display, without visual acquisition by the flight crew and sometimes contrary to their existing ATC clearance," the report said. "Such maneuvers may not be consistent with controller plans, can cause a significant degradation in the level of flight safety and may be contrary to a limitation contained in the TCAS airplane flight manual supplement. … Pilots sometimes deviate significantly further from their original clearance than required or desired while complying with an RA. … Data analyses and simulator trials have shown that pilots often are not aware of the RA being weakened."

Pilot responses to a stall warning, wind shear warning or ground proximity warning system take precedence over a TCAS RA, particularly when the aircraft is less than 2,500 ft above ground level, the AC said, and TCAS and associated training are designed accordingly.

The latest guidance also reminds flight crews of ATC's perspective of RAs. Specifically, the controller initially remains unaware that an RA has been issued and may not understand the pilot's RA report to ATC because of its unexpected nature and/or nonstandard phraseology. "Pilots sometimes do not report, or are slow in reporting, TCAS-related clearance deviations to the controller," the report said. "This issue has been effectively addressed by pilot and controller training programs

TCAS Traffic Display Symbols

TCAS = traffic-alert and collision avoidance system

Source: U.S. Federal Aviation Administration

Figure 2

but deserves constant attention and continual monitoring.”

As the Version 7.1 software is adopted widely, air traffic controllers will see a higher incidence of unexpected level-offs during climbs and descents caused by flight crews responding to “level off, level off” RAs, according to the report. Related information currently is being incorporated into ATC training programs.

Non-Safety-Critical RAs

To reduce one of the most prevalent types of non-safety-critical RAs — sometimes called unwanted or nuisance RAs — the International Civil Aviation Organization and the FAA ask all pilots to follow the current guidance on reducing the aircraft’s vertical rate when approaching their cleared altitude, particularly when there is known traffic cleared to an adjacent altitude. This means limiting vertical speed during climb or descent to 1,500 fpm when within 2,000 ft of an ATC-assigned altitude. This practice should be followed, however, only if safe, practical and compliant with the air carrier’s approved operating procedures.

“Version 7.0 [or higher software] is required for operations in reduced vertical separation minimum airspace since it expands the use of [Version 6.04a] logic to higher altitudes to address the occurrence of [RAs related to high vertical rates] in the en route airspace structure,” the report noted. “In spite of these improvements, RAs related to high vertical rates still occur.”

As updating to Version 7.1 software proceeds, the FAA’s TCAS Operational Performance Assessment program has enabled comparison of this software version’s performance with that of the two previous versions still in use as permitted by regulations. The analyses of data downlinked to 21 U.S. Mode S interrogation ground sites, associated radar data and Internet pilot reports to the program have been used to develop mitigations for non-safety-critical RAs and to plan for the next generation of TCAS, called NextCAS.

The FAA’s Aviation Safety Information Analysis and Sharing (ASIAS) program, working with the U.S. Commercial Aviation Safety Team, a government-industry partnership, also analyzes dozens of data sources to monitor TCAS performance (*ASW*, 8/09, p. 32). Based on the ASIAS research, the FAA has been working to address the few areas of incompatibility between TCAS and ATC procedures or airspace design.

One example of a mitigation of the most prevalent types of non-safety-critical RAs has been a project to test modifications of local ATC equipment. This would alter the conventional TCAS functionality in a specific geographic area from the ground by broadcasting a sensitivity-level command at high-altitude airports or during approaches to some closely spaced parallel runways. Other mitigations in progress aim to resolve RAs that occur despite standard 500-ft vertical separation when aircraft operating under instrument flight rules are near aircraft operating under VFR.

“TCAS RAs are frequently generated during VFR operations and visual separation procedures since the TCAS logic does not consider the horizontal and vertical separations that occur in these situations,” the report said. “TCAS RAs may occur during approaches to airfields conducting VFR pattern operations. Also, altitude crossing clearances issued by a controller based on maintaining visual separation may result in RAs being issued, particularly if one … aircraft is level. Finally, nuisance RAs are often generated during visual approaches to closely spaced parallel runways; especially those separated by less than … 0.20

[nm, 0.37 km] or 0.35 nm [0.65 km] at lower altitudes."

Beyond the realm of flight crew behavior, solutions can depend on correct diagnosis of external interference or avionics problems, sometimes traceable to transponders. "Alerts where there is no traffic, or phantoms [false indications of non-existent aircraft], have been generated by improper emissions from different types of ground stations (often during equipment testing) or by faulty installation or functioning of the TCAS equipment," the report said. "The improper altitude reporting by either own or intruder aircraft has been traced to the aircraft's air data or transponder systems. These issues have been greatly reduced, and since they can be easily corrected once identified, prompt reporting of these abnormalities is important."

Operator Responsibilities

The AC recommends that operators be proactive in mitigating TCAS issues related to their specific route environment, aircraft, procedures and TCAS display and mode-control features. For example, correct timing of flight crews' selection of TA and TA/RA modes during normal flight operations positively influences safety risks of frequency congestion.

"To preclude unnecessary transponder interrogations and possible interference with ground radar surveillance systems, do not activate TCAS (TA-only or TA/RA mode) until taking the active runway for departure," the AC said. "A transponder selected to 'XPDR' or 'ON' is adequate for ATC and nearby automatic dependent surveillance–broadcast–equipped aircraft to 'see' the aircraft while taxiing on the airport surface. Following landing and clearing of the runway, de-select TCAS from TA or TA/RA mode. Select 'XPNDR' or 'ON' while taxiing to the ramp area. Upon shutdown, select 'STBY' on the transponder."

The AC also reviewed situations in which operators should consider adopting procedures for when pilots will select TA mode (see "When TA Mode Makes Sense") and for pilot decision making responsibility regarding operation of TCAS controls and RA responses.

The FAA also recommended that aircraft operators evaluate their "unusual TCAS events" and take follow-up action as necessary, and periodically assess related training, checking and maintenance programs. Reporting events voluntarily to aviation databases or when mandated for certain RAs (*ASW*, 5/11, p. 18) and near-midair collisions is vital in improving TCAS. This basic principle extends to hazardous conditions, situations or events and problems with avionics or abnormal behavior that may have been induced by other aircraft, ATC procedures, ATC equipment or other factors.

21st Century Logic

Both guidance documents indirectly explain how operators that continue to use the nearly 20-year-old Version 6.04a software would gain significant benefits by upgrading. In Version 7.0 and Version 7.1 software, for example, modifications to the radio frequency interference–limiting algorithms take into account the distributions of TCAS aircraft in relation to terminal (high-density) areas or

When TA Mode Makes Sense

The U.S. Federal Aviation Administration lists the following examples of situations in which flight crews could enhance safety by selecting the traffic advisory–only (TA) mode of their traffic-alert and collision avoidance system (TCAS) to temporarily suppress resolution advisories (RAs):

- "During takeoff toward known nearby traffic that is in visual contact and which could cause an unwanted RA during initial climb, such as a visually identified helicopter passing near the departure end of the runway. Select the TA/RA mode after the potential for an unwanted RA ceases to exist, such as after climbing above a known visual flight rules corridor;
- "In instrument or visual [meteorological] conditions [VMC] during approaches to closely spaced parallel runways;
- "In [VMC], when flying in close proximity to other aircraft;
- "At certain airports, during particular procedures, or in circumstances identified by the operator as having a significant potential for unwanted or inappropriate RAs;
- "In the event of particular in-flight failures, such as engine failure, as specified by the aircraft flight manual or operator; [and,]
- "During takeoffs or landings outside of the nominal TCAS reference performance envelope for RAs, as designated by the airplane flight manual or operator. TCAS reference performance for RAs is typically attainable during takeoffs and landings at airports within the envelope of the International Standard Atmosphere plus/minus 50 degrees F [minus 46 degrees to 10 degrees C], sea level to 5,300 ft mean sea level."

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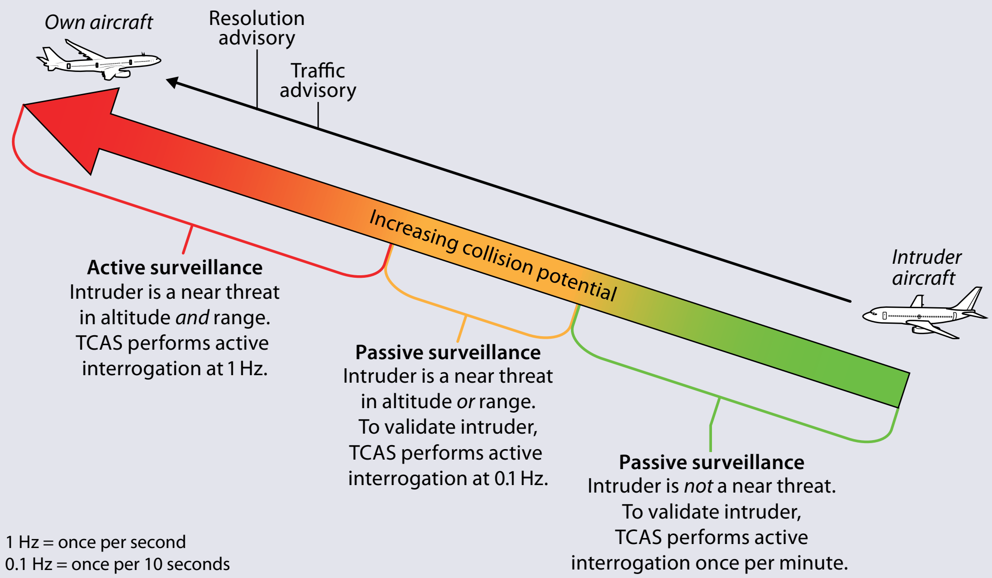
en-route areas, rather than just counting these aircraft. Other enhancements enable longer surveillance ranges for aircraft above Flight Level 180 (approximately 18,000 ft) overflying high density traffic areas. Another improves management of automatic transmit-power reductions by TCAS to "ensure that the TCAS surveillance range is always adequate for collision avoidance," the report said.

"[Versions after 6.04a have] the capability for TCAS to issue RA reversals in coordinated encounters if the encounter geometry changes after the initial RA is issued," the report said. "A new feature was implemented … to reduce the frequency of initial RAs that reverse the existing vertical rate of own aircraft (e.g., displayed a climb RA for a descending aircraft) because pilots did not follow a majority of these RAs, and those that were followed, were considered to be disruptive by controllers."

While envisioning ever more crowded airspace and the associated interference potential, Version 7.0/7.1 software also incorporates hybrid surveillance (Figure 3), an optional way of further reducing the likelihood of data link–radar frequency saturation.

Hybrid surveillance offers, in addition to the normal TCAS active-surveillance mode, a passive-surveillance mode that relies on continuously receiving positions updated from an intruder aircraft's Mode S transponder. These positions originate from an on-board navigation source, typically data from a global positioning system receiver. A limited number of operators so far take advantage of this existing feature of TCAS, however, the FAA said.

Hybrid Surveillance in Traffic-Alert and Collision Avoidance Systems (TCAS)



Note: The intent is to reduce the rate of interrogations by TCAS units to prevent radio frequency congestion and interference with air traffic control radars "without any degradation of the safety and effectiveness of TCAS," the FAA said.

Source: U.S. Federal Aviation Administration (FAA)

Figure 3

Notes

1. FAA. "Air Carrier Operational Approval and Use of TCAS II." AC 120-55C, Feb. 23, 2011.
2. FAA. "Introduction to TCAS II Version 7.1." Feb. 28, 2011.
3. U.S. pilots must consider which of the following reports, if any, are appropriate: ATC clearances and instructions report; captain's report to the operator; pilot/observer questionnaire; logbook entry; aircraft communications addressing and reporting system message; near-midair collision report; report to the Aviation Safety Reporting System; and/or mandatory RA report if the RA fits criteria of U.S. National Transportation Safety Board Part 830, "Notification and Reporting of Aircraft Accidents or Incidents and Overdue Aircraft, and Preservation of Aircraft Wreckage, Mail, Cargo, and Records."
4. "In modeling aircraft response to RAs, the expectation is [that] the pilot will begin the initial 0.25 g acceleration [that is, one-fourth of standard gravitational acceleration] maneuver within 5 seconds to an achieved rate of 1,500 fpm," the report noted. "Pilot response with 0.35 g acceleration to an achieved rate of 2,500 fpm is expected within 2.5 seconds for subsequent RAs."
5. Tau is an approximation, in seconds, of the time to the closest point of approach, known as range tau, or of the time to the own aircraft and intruder being at the same altitude, or co-altitude, known as vertical tau.
6. Sensitivity level controls the dimensions of the protected airspace around each TCAS-equipped aircraft.