Preview of TCAS II Version 7

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The Traffic Alert and Collision Avoidance System II (TCAS II) is an airborne system that uses active surveillance to alert the pilot of an equipped aircraft to the presence of other nearby aircraft. TCAS II is currently required in the United States on all commercial aircraft with more than 30 seats, and will soon be mandated in many European countries as well. An industry team recently completed the development of requirements for Version 7 of TCAS II. Version 7 is intended to address all known remaining problems and to optimize system performance; the system is also compliant with the ICAO Standards and Recommended Practices for airborne collision avoidance systems. This paper presents a high-level view of the changes that have been made in TCAS Version 7 and the reasons behind those changes. The paper focuses primarily on improvements to the collision avoidance logic.

INTRODUCTION

The Traffic Alert and Collision Avoidance System II (TCAS II) is an airborne system that uses active surveillance to alert the pilot of an equipped aircraft to the presence of other nearby aircraft. TCAS interrogates the transponders of other aircraft to determine their positions and altitudes, and shows these to the pilot of the TCAS aircraft by means of a traffic display. TCAS II issues two types of advisories: the Resolution Advisory (RA), which identifies an intruder that is considered a collision threat, and the Traffic Advisory (TA), which identifies an intruder that may soon cause an RA, and whose position should therefore be closely monitored. For each intruder causing an RA, TCAS II recommends a vertical escape maneuver to help maintain safe vertical separation from the threat aircraft. TCAS II is currently required in the United States on all commercial aircraft with more than 30 seats, and will soon be mandated in many European countries as well.

An industry team recently completed the development of requirements for Version 7 of TCAS II. This team was led by the Federal Aviation Administration (FAA), working through RTCA Special Committee 147 (SC-147), and in cooperation with the International Civil Aviation Organization's SSR Improvements and Collision Avoidance Systems Panel (ICAO/SICASP). Version 7, which is expected to be the last version of TCAS II, is intended to address all known remaining problems and to optimize system performance. In particular, it addresses many operational compatibility issues that have been identified over the last few years. The new version is also compliant with the ICAO Standards and Recommended Practices (SARPs) for airborne collision avoidance systems. Version 7 was developed under strict configuration management procedures and has been thoroughly tested. The latest safety studies show Version 7 to be marginally safer than the previous version of the system, Version 6.04A (Lejeune, 1997a).

The purpose of this paper is to present a high-level view of the changes that have been made in TCAS Version 7 and the reasons behind those changes. The paper focuses primarily on improvements in the collision avoidance logic, although other areas are covered as well.

ITEMS ADDRESSED IN VERSION 7

The development of TCAS II Version 7 was based on a long list of problem reports and change requests originating from the entire aviation community. The FAA, in collaboration with RTCA SC-147, decided that Version 7 would address only those items that were considered essential. Enhancements to the system were not generally considered unless there was a substantial operational or safety benefit to be gained at a reasonable cost. The approved list started with around 120 items in the first quarter of 1993, but the number of items had more than doubled by the time the effort was completed.

Many of the changes to the TCAS logic were minor changes that would not be apparent except to someone studying the system requirements very closely. These included correcting small "bugs," removing dead and redundant code, eliminating output variables that were no longer used, making minor editorial changes, and the like. Although such changes are collectively important, they will not be discussed further here. This paper will describe only the more important changes, which are categorized into the following areas:

- Input Processing
- Coordination and Communication
- Surveillance
- Tracking
- Traffic Advisory Logic
- Threat Detection Logic
- Modeling of Escape Maneuvers
- Resolution Advisory Selection Logic
- Displays and Aural Annunciations

Input Processing

Version 7 includes a number of changes in the area of input processing. To begin with, there were several improvements in the processing of radar altimeter inputs:

- Failure of the radar altimeter now requires TCAS to fail itself. This helps to ensure that TCAS will not recommend an escape maneuver that will move an aircraft dangerously close to the terrain. This was standard industry practice before Version 7, but it has now been made an explicit requirement.

- A minimum startup period is now required to ensure that TCAS cannot issue a Descend RA before the radar altimeter has had time to establish a lock on the ground.

- The collision avoidance logic now uses radar altitude to determine when own aircraft is on the ground. Originally, the weight-on-wheels switch, also known as the "squat" switch, was used for this purpose. Because the squat switch is not always reliable, however, it was decided that radar altitude would be used instead.

Another change in the area of input processing is that a floor on the sensitivity level for an aircraft conflict is established when an RA is issued. The TCAS sensitivity level varies with altitude and determines the protection boundaries for issuing advisories. With the previous version of TCAS, it was possible to issue an RA, then, by coincidence, have the aircraft cross the altitude threshold for a lower sensitivity level, causing the RA to be removed from the display, only to be issued again a few seconds later when the smaller threat boundary was crossed. So in Version 7, once an RA has been issued, the sensitivity level for that conflict is not allowed to decrease.

Finally, a ground site can no longer terminate an RA by commanding TCAS to go into a lower sensitivity level. TCAS includes the capability for a Mode S ground site to uplink a command to reduce TCAS's sensitivity level, all the way down to TA-only mode, presumably according to a site-adaptation map. However, in previous versions of TCAS this could cause the inadvertent removal of an RA for a conflict in progress. RTCA SC-147 decided that this was undesirable, and should not be allowed in Version 7.

Coordination and Communication

A number of changes were made in the area of coordination and communication. Mostly, these are new message requirements that were agreed to in the international (ICAO) arena. For example, it was felt that additional information should be downlinked to ground stations for the purpose of monitoring TCAS activity (Vallauri and Casaux, 1997). Some of these changes to TCAS require corresponding changes in the Mode S transponder. A number of meetings were held under the auspices of RTCA that resulted in the development of new protocols to allow a Version 7 TCAS unit to work with a pre-Version 7 transponder, and vice-versa. This is important in that it frees the airlines and manufacturers from having to upgrade both the TCAS unit and the transponder at the same time.

It should also be pointed out here that Version 7 now permits coordinated RA sense reversals in TCAS-TCAS conflicts. This change is discussed later, in the section on the RA selection logic. It is important to note that implementing this capability did not require changes in the air-to-air coordination protocols, so that Version 7 is fully compatible with previous versions of the system already in use.

Surveillance

A number of improvements have been made in the surveillance subsystem of TCAS to address specific problems. First of all, measurements of activity on the 1030 and 1090 MHz frequencies have shown that in areas of high traffic density, TCAS can cause somewhat more interference to ground and airborne sensors than was originally estimated. To alleviate this problem, several changes to the surveillance and interference-limiting algorithms were made in Version 7. These include:

- More efficient scheduling of surveillance interrogations, using adaptive interrogation rates based on the Mode C transponder density (for

Mode C interrogations) and the threat potential of individual Mode S intruders (for Mode S interrogations).

- Greater interference limiting for TCAS aircraft operating on the ground, where the required surveillance range is relatively small.

While these new features can result in reduced surveillance range at times, other changes help to ensure adequate range in areas of high traffic density for both collision avoidance and the display of targets of interest. These include:

- Limits on power reduction to ensure a surveillance range of at least 6 nmi when airborne and 3 nmi when operating on the ground.

- An exemption from interference limiting for enroute aircraft above 18,000 ft flying over high-density terminal areas. With the previous version of TCAS, surveillance range could conceivably have been reduced to as little as 4 nmi in this circumstance.

- Expansion of the minimum vertical surveillance range from ± 3000 ft to ± 10,000 ft for Mode S targets.

- The removal of "dormancy" for Mode S targets, whereby no regular interrogations were scheduled for some targets. This has been replaced by a reduced-surveillance mode, with more distant targets being interrogated at a five-second update rate instead of the normal one-second update rate.

Test results show that the surveillance changes in Version 7 will reduce TCAS utilization of aircraft transponders by more than 50%, while ensuring adequate surveillance range for collision avoidance in terminal areas. Compared with Version 6.04A, tests show that Version 7 will actually increase the TCAS surveillance range above 18,000 ft and in airspace more than 6 nmi from high-density airports (Sandholm, 1997).

Another interesting development in the surveillance area is that the Minimum Operational Performance Standards (MOPS) for Version 7 will allow some optional new capabilities for future use. These consist of the ability to receive and decode extended Mode S squitter messages, which may contain Automatic Dependent Surveillance-Broadcast (ADS-B) position reports and an intruder's flight ID. In addition, TCAS can request and receive air-to-air Mode S messages containing new information, such as an aircraft's intended flight path. These optional capabilities pave the way for new applications of ADS-B and Cockpit Display of Traffic Information (CDTI), as well as future enhancements to the collision avoidance function.

More detailed information on surveillance improvements in Version 7 can be found in Sandholm (1998).

Tracking

Version 7 introduces some significant changes in the area of tracking. First of all, a number of improvements were made to the 100-foot vertical tracker (the algorithms that track standard ATCRBS altitude reports quantized to 100-foot increments). Among other things, these improvements provide more accurate tracking of high vertical rates (above 6000 ft/min). In addition, a new 25-foot vertical tracker has been developed. The 25-foot tracker allows TCAS to produce significantly better estimates of the vertical rate for Mode S-equipped aircraft that report altitude in 25-foot increments (which includes most airline aircraft). Tests have shown that this improved tracking can help to reduce the number of corrective RAs (which require a change in the aircraft's flight path), as well as the number of altitude-crossing RAs and the number of unresolved encounters, when compared with the 100-foot tracker (Lejeune, 1997b). Furthermore, Version 7 provides the ability to switch between trackers and handle unexpected changes in quantization. Finally, the TCAS horizontal (range) tracker has been upgraded to support a new RA detection filter, which will be described later.

Traffic Advisory (TA) Logic

Version 7 includes several changes in the TCAS TA logic. The most extensive change is that the criteria for removing a TA have been made more stringent, to reduce the likelihood that TCAS will issue multiple TAs against the same target. With the previous version of TCAS, pilots found that parallel approaches to certain airports, such as LAX, sometimes produced these multiple TAs. Figure 1 illustrates how slight variations in the flight path can cause this to happen—although the lateral variations are exaggerated in this figure. Each Traffic Advisory is accompanied by the annunciation, "Traffic, traffic," and repeated occurrences can be distracting to the flight crew—so much so, in fact, that some pilots switch TCAS into standby mode when executing a parallel approach into one of the problem airports. This problem has been corrected in Version 7, with the tradeoff that TAs may last a few seconds longer (as an amber symbol on the traffic display) when the two aircraft are diverging satisfactorily.

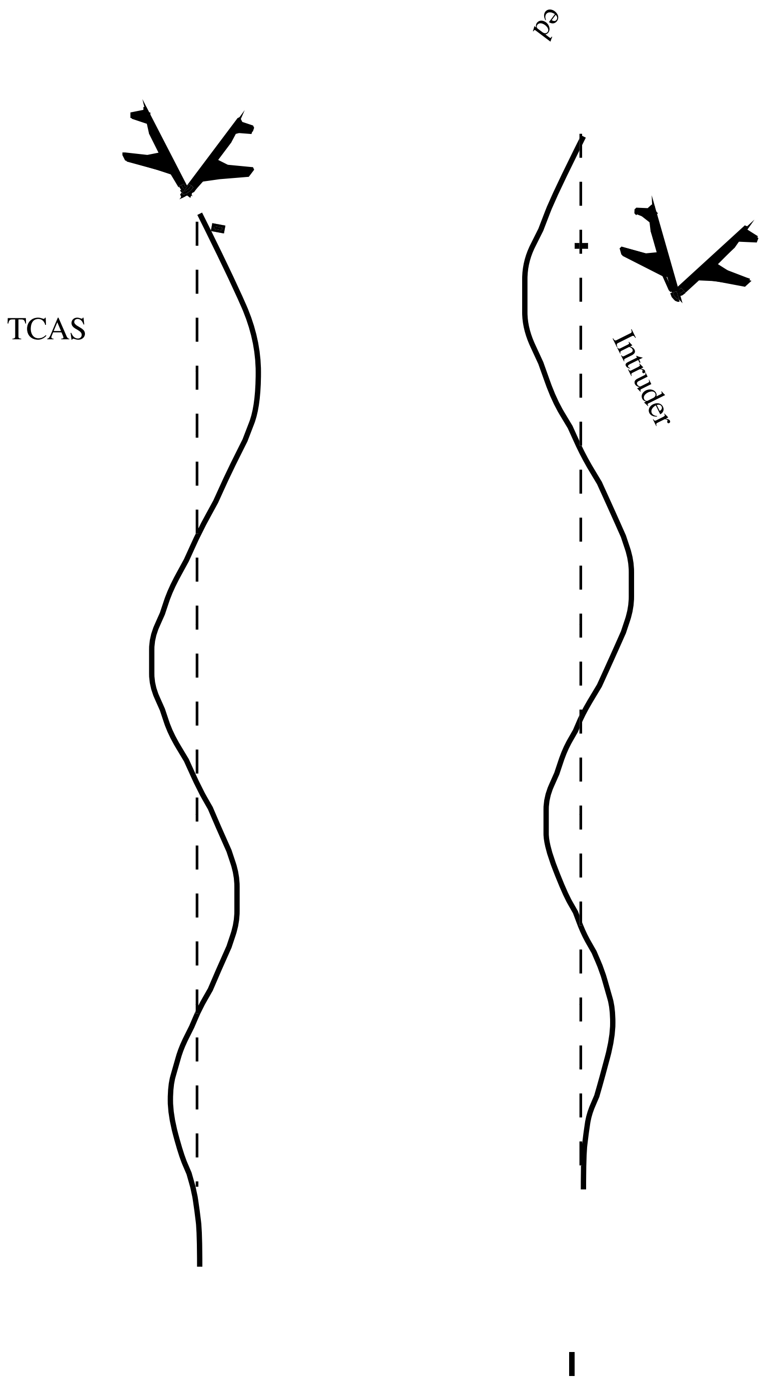

Figure 1. Multiple Traffic Advisories During Parallel Approach

In addition, the TA altitude threshold has been reduced (from 1200 ft to 850 ft) for altitudes between 30,000 and 42,000 ft. This change is intended to support reduced vertical separation minima (RVSM) for altitudes above 29,000 ft. Without this change, many unnecessary TAs may occur in areas, such as oceanic track systems, where RVSM is being phased in (Casaux and Vallauri, 1995).

Threat Detection Logic

A number of improvements were made in the detection logic for determining when to issue a Resolution Advisory.

General Changes

Improvements to the threat detection logic include the following:

- In a TCAS-TCAS conflict, if one TCAS issues an RA that will require the two aircraft to cross in altitude, the Version 7 logic will see to it that the second TCAS also issues an RA shortly thereafter. This helps to ensure that both aircraft maneuver in a coordinated fashion, even in cases where the two TCAS units don't have exactly the same picture of the situation.

- TCAS must now be RA-capable for at least two seconds before it declares a TCAS-equipped intruder to be a threat. This ensures that if one of the TCAS units has just been switched to RA mode, it will have enough time for full coordination with the intruder before selecting an RA. Otherwise, TCAS may not be aware that the threat has already issued an RA, and it could choose an RA that inadvertently and unnecessarily reverses the directional sense of the threat's RA.

- TCAS will no longer issue an RA against a target with a vertical rate in excess of 10,000 ft/min. Such high vertical rates are rare, but are considered to be beyond the reliable operating limits of TCAS's vertical tracker. However, TCAS can still issue a Traffic Advisory against such a target.

- There are now minimum requirements on the projected vertical separation that can be achieved before TCAS will issue an RA. In the past, TCAS could issue an RA in some rare cases where neither directional sense was projected to provide minimal separation. It was determined through testing that it was sometimes better to have TCAS wait momentarily until the correct choice becomes clearer.

- Vertical detection thresholds have been reduced for altitudes between 30,000 and 42,000 ft to support reduced separation minima in certain airspaces. (See the discussion of RVSM under Traffic Advisory Logic, above.)

- A high-altitude range detection threshold has been reduced to help eliminate so-called “bump-up” RAs above 20,000 ft. Figure 2 illustrates the geometry of a “bump-up” RA. Here a TCAS aircraft is flying level, and an intruder comes up rapidly from below, apparently in conflict with the TCAS aircraft. Then, at the last moment, the intruder levels off safely below the TCAS aircraft, but not before TCAS generates a Climb RA that forces the TCAS aircraft to deviate from its cleared altitude. This situation used to occur frequently in certain airspaces, caused in part by local air traffic control procedures. The TCAS detection logic includes special tests to recognize this type of geometry and to wait a bit longer before issuing an RA; the added delay (typically several seconds) is considered an acceptable tradeoff in such cases, because it allows many unnecessary RAs to be avoided.

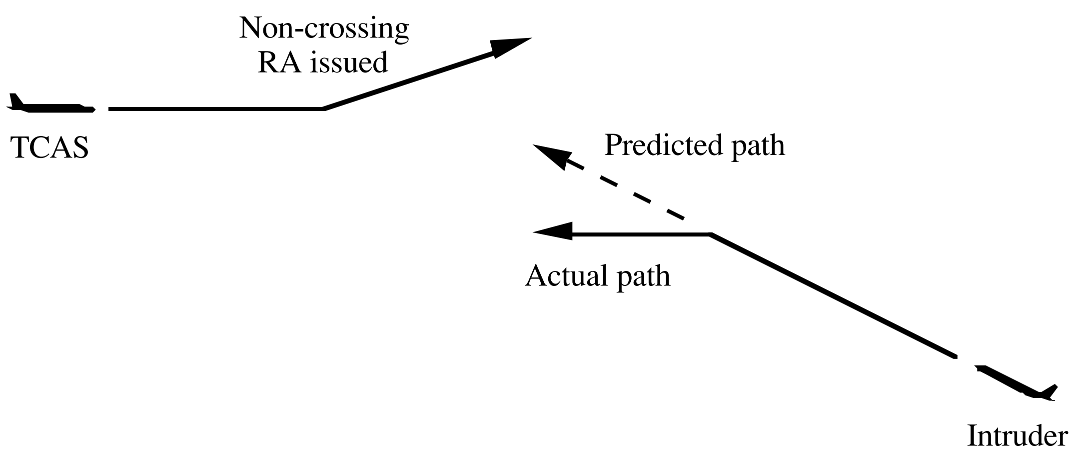

Figure 2. “Bump-up” Encounter Geometry

Horizontal Miss Distance Filter

Perhaps the most important new feature in the TCAS detection logic is the horizontal miss distance filter (Hammer, 1996). The previous version of TCAS could issue RAs even in cases where there was adequate horizontal separation; this problem was considered to be especially significant in Europe (Vallauri and Casaux, 1997). The possibility of developing a filter to eliminate such unnecessary RAs has been a subject of investigation for a number of years in both Europe and the United States, and these efforts have been brought to fruition in Version 7. The new filter estimates the horizontal range of an intruder at closest approach, using the tracked range, range rate, and range acceleration. A second estimate of horizontal miss distance, derived from a bearing-based tracker, is used as a cross-check. If the projected miss distance is great enough (0.2 to 1.1 nmi, depending on altitude), the issuance of an unnecessary RA can be prevented. The filter makes use of a new alpha-beta-gamma range tracker and includes intruder maneuver and speed-change detectors that can shut the filter off in situations where it could otherwise be fooled. It has been estimated that this new filter will reduce the TCAS alert rate by 20-25% in the U.S., and by 40% in European airspace (Hammer, 1997). This is considered an acceptable tradeoff for the slight increase in risk associated with occasional delays in issuing RAs against real threats.

Except at low altitudes, the horizontal miss distance filter can also remove an RA before closest approach if safe separation is predicted in the horizontal dimension. This feature helps to reduce the magnitude of vertical deviations from the intended flight path. The down side is that such an early "clear of conflict" decision can occasionally result in a "split" RA sequence, where an RA is removed and then reissued several seconds later against the same target. This could be potentially confusing or distracting to the pilot. However, it is estimated that such splits will occur for less than 2% of all RAs (Hammer, 1997).

Modeling of Escape Maneuvers

The modeling of potential escape maneuvers is an important part of the TCAS logic for determining the best RA for each conflict geometry. Modeling results are also used by the threat detection logic. In Version 7, the modeling logic has been restructured to simplify the interface with the rest of the logic and to make it more easily understood. The modeling logic has also been improved in terms of accuracy, in the handling of slow-closure geometries, and in modeling the effects of RAs that were issued previously. All of these are important in terms of choosing the correct RA at the right time and avoiding unnecessary changes in RA strength or direction as a conflict progresses.

Resolution Advisory Selection Logic

A wide range of improvements has been made in TCAS's Resolution Advisory selection logic.

General Changes

To begin with, the TCAS logic includes numerous biases against selecting an RA that will cause own aircraft to cross through the altitude of an intruder. In Version 7 this logic has been enhanced, but it has also been made smarter in recognizing geometries where an altitude crossing is actually unavoidable.

Logic has also been added to prevent unnecessary rate-reversing RAs in TCAS-TCAS encounters. For example, consider the case illustrated in Figure 3, where one aircraft is descending at a significant vertical rate towards an intruder below. Assuming that an altitude-crossing RA is unnecessary, the previous version of TCAS may issue a positive Climb RA where a level-off (Don't Descend) would have been sufficient. This type of situation has been the subject of a number of pilot complaints (Tillotson and Love, 1996). The main reason why TCAS issues a Climb RA in this case is because it normally projects an intruder as continuing its current vertical rate for the duration of the encounter. But new logic in Version 7 determines that if the intruder is TCAS-equipped and has a modest vertical rate, then it is safe for TCAS to issue a Don't Descend RA initially. This is because the first few seconds of the escape maneuver are spent in leveling off the aircraft, regardless of whether the strength of the RA is positive or negative. In addition, the threat will be getting a complementary RA of its own. The new logic includes tests that allow TCAS to quickly revert to positive strength if an adverse maneuver by either aircraft is detected.

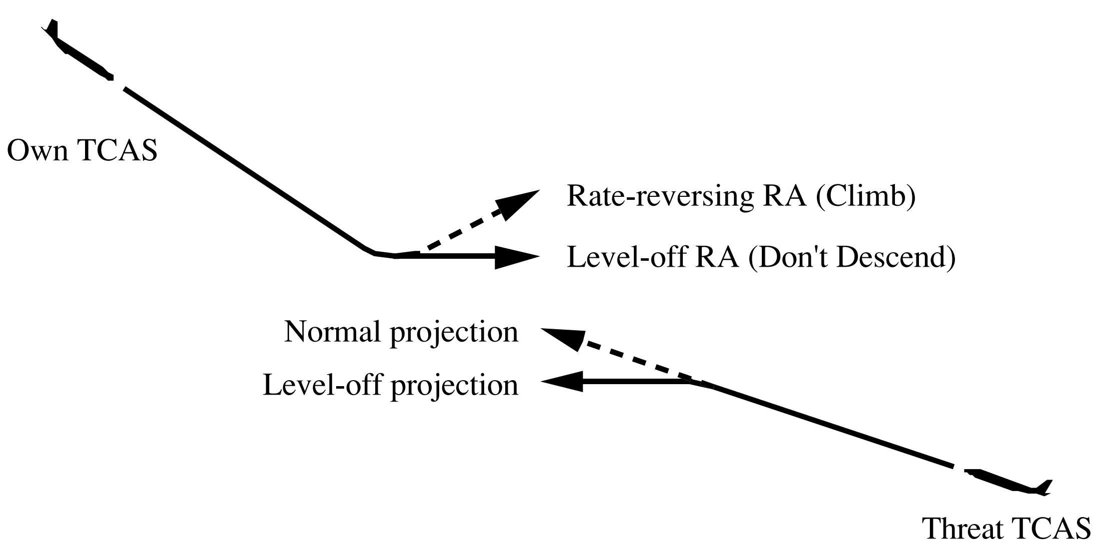

Figure 3. Conflict Geometry Leading to a Rate-Reversing RA

Another significant improvement is that Version 7 now allows the optional input of data from an onboard altitude alerter. If available in a particular installation, this information will be used to help ensure that a TCAS RA does not unnecessarily divert the aircraft from its intended level-off altitude.

Multiaircraft Logic

No single part of the TCAS logic has been modified in Version 7 more extensively than the multiaircraft logic—the part of the logic that deals with simultaneous, multiple threats. Multiple-threat situations are rare—it has been variously estimated that out of 1000 conflicts producing TCAS RAs, anywhere from three to ten will become true multiple-threat conflicts. But when a multiple-threat conflict occurs, it can be difficult to deal with. In previous versions of TCAS, the multiaircraft logic was relatively primitive. TCAS dealt with threats strictly on a pairwise basis, and if opposite senses happened to be chosen for two different threats, TCAS would immediately issue a Don't Climb/Don't Descend RA with no further consideration of the vertical separation against each individual threat.

The new multiaircraft logic in Version 7 is much more versatile and robust than the old multiaircraft logic. The new logic allows both sense reversals and Increase Rate RAs to deal with worsening situations. When a new threat is declared, optimum resolution against all threats is not constrained by the initial RAs against existing threats (Yang, 1997).

Figure 4 shows an example of a multiple-threat encounter. In this example, a TCAS-equipped aircraft is descending as two intruders approach. TCAS detects a conflict with the lower aircraft first, at which time it chooses a Climb RA. A few seconds later, TCAS declares the second intruder to be a threat, but determines that a Climb RA will not work against the second threat. The previous version of TCAS would immediately issue a Don't Climb/Don't Descend RA at this point. If the pilot responds promptly according to his TCAS training, this *could* result in a level-off that does not provide adequate separation against the first threat. The new multiaircraft logic, however, has some new options, which include delaying the level-off annunciation until adequate separation has been assured against the lower threat, or reversing the directional sense against the lower threat if sufficient time remains for this to be effective.

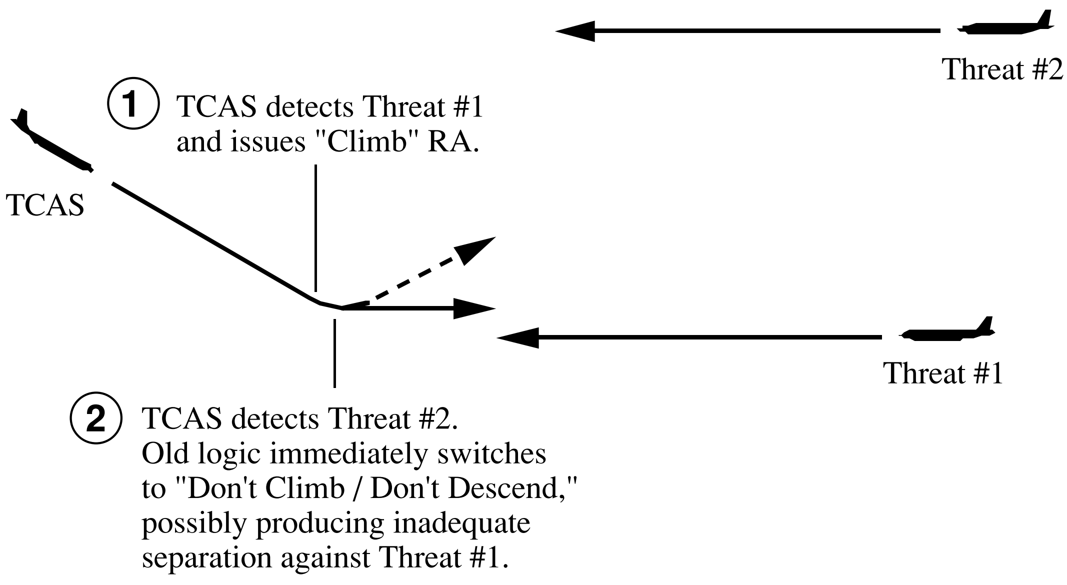

Figure 4. Multiple-Threat Encounter

Sense Reversal Logic

In Version 7, a number of improvements have been made to the sense reversal logic—the logic that decides when TCAS should change the directional sense of an RA (from Climb to Descend, for instance). In general, the changes to this portion of the logic have been geared toward optimizing performance. As a result, Version 7 is more likely to use sense reversals in situations where they will really help, and this has been linked to simulation results that show improved safety (Arino and Casaux, 1997). But some of the changes to this portion of the logic are intended to reduce the likelihood of a sense reversal if this will not result in better separation at closest approach. For example, the effect of a sense reversal is now always modeled to ensure that it will be effective. In the old reversal logic, the directional sense could be reversed if certain trigger mechanisms were satisfied, but without any projections being made to estimate the effectiveness of the reversal. This could occasionally result in a reversal that did nothing to improve the situation.

But probably the most significant change in the reversal logic is that sense reversals are now permitted in TCAS-TCAS conflicts if the situation warrants it. In previous versions of the logic, such reversals were not allowed—it had always been assumed that both pilots would follow their RAs, and a reversal would never be necessary. But one thing that was learned from the TCAS Transition Program was that, for various reasons, pilots often ignore RAs (Steenblik, 1996; FAA, 1996). Therefore, it was decided that TCAS should be allowed to reverse its directional sense if the situation changes and the original sense has clearly become the wrong thing to do. However, since both aircraft may be maneuvering in response to an RA, the reversal logic will be more conservative against a TCAS-equipped threat.

Increase Rate Logic

The Increase Rate logic allows TCAS to advise the flight crew to increase its vertical rate to 2500 ft/min if the current RA escape rate does not appear to be sufficient to resolve a conflict. In Version 7, the Increase Rate logic has been improved. Changes have been made to reduce the number of unnecessary Increase Rate RAs. For instance, the trigger thresholds now have to be satisfied on two out of three consecutive processing cycles for an Increase to be issued; this helps to prevent unnecessary Increases caused by momentary fluctuations in the threat's vertical track. Other changes have been made to ensure that a timely Increase Rate RA can be issued when it is really needed (Lejeune, 1997b). And, like the reversal logic, the effect of an Increase Rate RA is now always modeled to ensure that it will produce improvement in the vertical separation at closest approach.

Displays and Aural Annunciations

In Version 7, numerous changes have been made in the area of displays and aural annunciations—these are the changes most visible to the flight crew. Before these changes were finalized, they were reviewed carefully by human factors experts (Adam, 1995; Domino, et al., 1996) and tested thoroughly with line pilots in aircraft simulators. Described below are some of the more significant changes in this area.

Elimination of Display Deferral

In conflicts with TCAS-equipped threats, the previous version of TCAS could defer the display of an RA for up to three seconds until air-to-air coordination was completed between the two aircraft. The reason for this is that if an RA is announced before coordination is completed, there is a small chance that the two TCAS units will select incompatible RA senses, and a sense reversal will then have to be announced on one of the aircraft. It was ultimately determined, however, that the display deferral itself was causing some problems. For example, if one of the aircraft is accelerating vertically when the conflict starts, it is possible for the conflict geometry to change significantly during the three-second delay period, making the selected RA a poor choice by the time the flight crew can see and react to it. Fortunately, analysis indicated that even without a display deferral, the chances of a reversal having to be announced because incompatible senses are selected at almost the same instant is quite small—less, in fact, than the chances of a sense reversal for other reasons. Therefore, it was decided that the display deferral could be eliminated without a major effect on operational compatibility.

Changes for Human Factors Reasons

Several changes in aural annunciations have been implemented in Version 7 for human factors reasons. The annunciation for Maintain Rate RAs, for example, has been changed from "Monitor Vertical Speed" to "Maintain Vertical Speed, Maintain" because the newer aural is easier for the pilot to understand without having to look immediately at the RA display. (If the RA requires an altitude crossing, the new annunciation is "Maintain Vertical Speed, Crossing Maintain.") And for corrective Vertical Speed Limits, the annunciation has been changed from "Reduce Climb" or "Reduce Descent" to "Adjust Vertical Speed, Adjust". A problem with the old annunciation was that the pilot would occasionally hear only the final word—so instead of hearing "Reduce Climb," he might only hear the word "Climb." Note that with both of these new annunciations, the most important word is now voiced last. And finally, some other phrases that were previously announced multiple times, such as "Climb, Climb, Climb," are now announced one time less to reduce distraction.

Changes Related to Weakening RAs

In Version 7, a lot of thought went into how to display a weakening RA once adequate vertical separation has been attained. Following are some of the changes that resulted.

First, it was decided that all positive RAs would only be weakened to Don't Climb or Don't Descend, and not to a Vertical Speed Limit (VSL) that allows the pilot to reestablish a safe vertical rate toward the threat aircraft's altitude. This simplifies the logic and reflects the actual behavior of pilots—because in practice, it was found that once an RA has been issued and the TCAS aircraft is moving away from the threat's altitude, pilots are extremely reluctant to reestablish a vertical rate toward the threat's altitude until safe separation in the horizontal dimension has been assured and the RA removed.

Second, a VSL, once issued, is not allowed to weaken at all. This prevents the annunciation of many strength changes caused by variations in the track of an intruder, and again reflects the reluctance of pilots to increase their vertical rate toward a threat aircraft's altitude before safe separation has been assured in the horizontal dimension.

Finally, a weakening RA is now displayed as a "corrective" RA, with a green arc on the RA display to give the pilot positive guidance to level off, once adequate vertical separation has been achieved. One problem that was discovered early in the TCAS program was that in responding to corrective RAs, pilots often deviate more than necessary from their cleared altitudes (FAA, 1991a; FAA, 1991b). This raised a concern in various segments of the aviation community about the possibility of TCAS inducing "domino" conflicts with aircraft at adjacent flight levels. One suggested solution to this problem was to remove the RA early (before the point of minimum range) if adequate vertical separation has been achieved (Arino and Casaux, 1995), but this raised concerns over split RA sequences. Another possibility was to treat the problem strictly as a training issue. Eventually it was decided that the problem would be addressed through changes to the TCAS display logic. Although this decision was a controversial one, tests in simulators did show that displaying a weakening RA as corrective would help to reduce unnecessary displacement. As an example, Figure 5 illustrates a weakening RA with both the old logic and Version 7. In this conflict, TCAS only needs a little additional altitude to achieve safe separation; so TCAS first issues a Climb RA. On the RA display, a red arc is displayed for all negative rates and for positive rates up to 1500 ft/min. A green arc is displayed between 1500 and 2000 ft/min. The pilot responds by initiating a climb and establishing a vertical rate that moves the needle out of the red area and into the green. When adequate vertical separation has been achieved, TCAS weakens the RA to a Don't Descend. With the previous version of TCAS, this would be announced as "Monitor Vertical Speed," the green arc would disappear, and the red arc would retreat to 0 ft/min. With Version 7, the annunciation will be "Adjust Vertical Speed, Adjust," the red arc will be set to prohibit negative vertical speeds, and a green arc will be displayed around 0 ft/min. Since pilots are trained to put the needle in the green area, they are more likely to level off promptly, avoiding unnecessary vertical displacement.

SUMMARY

Version 7 is intended by the FAA to be the last change to TCAS II. This new version deals with all the known problems of the previous design, and affects almost all parts of the system. As with any new design, compromises and difficult decisions had to be made each step of the way. Nonetheless, the result is a clear improvement over previous versions of the system. Version 7 can be expected to generate fewer unnecessary alerts, and the RAs it issues will be more operationally compatible and marginally safer. Just as with previous versions of TCAS, it will be necessary to monitor the safety, effectiveness, and operational compatibility of Version 7 as it is introduced into service. However, great care has been taken in developing the changes to the system, and those changes have been thoroughly tested. Version 7 represents a substantial and important advance in airborne collision avoidance.

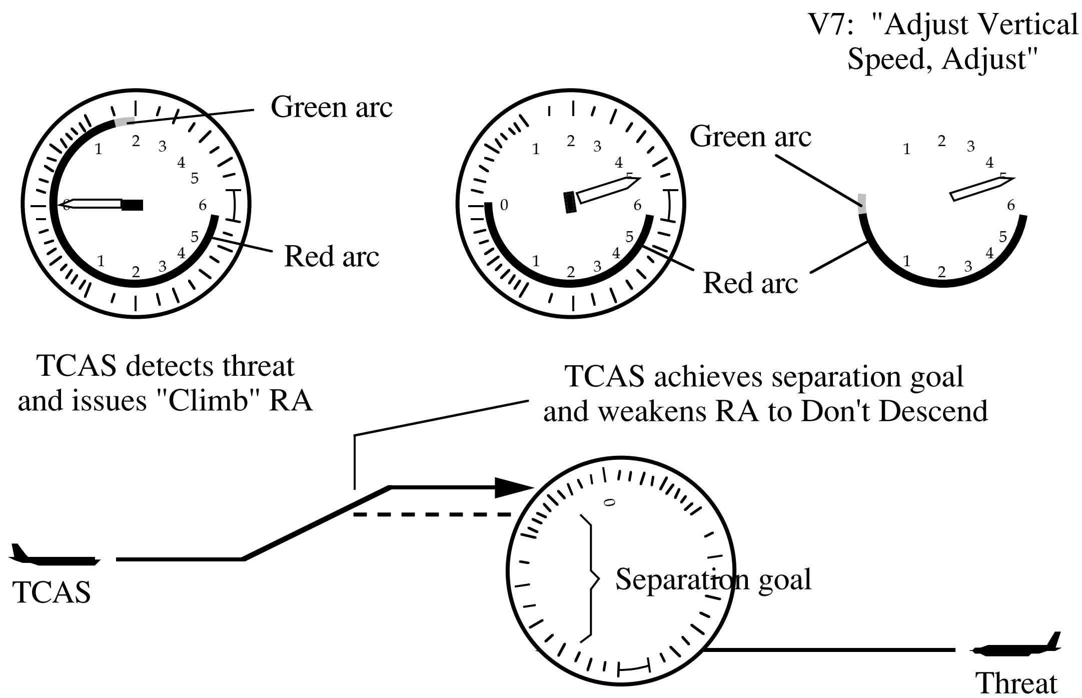

Figure 5. Example of a Weakening RA

ACRONYMS

ADS-B	Automatic Dependent Surveillance-Broadcast
ATCRBS	Air Traffic Control Radar Beacon System
CDTI	Cockpit Display of Traffic Information
FAA	Federal Aviation Administration
ICAO	International Civil Aviation Organization
ID	Identifier
LAX	Los Angeles International Airport
MOPS	Minimum Operational Performance Standards
RA	Resolution Advisory
RVSM	Reduced Vertical Separation Minima
SARPs	Standards and Recommended Practices
SC	Special Committee
SICASP	SSR Improvements and Collision Avoidance Systems Panel
SSR	Secondary Surveillance Radar
TA	Traffic Advisory
TCAS	Traffic Alert and Collision Avoidance System
TTP	TCAS Transition Program
VSL	Vertical Speed Limit
WG	Working Group

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