

The Ohio State University
Seventh International Symposium on Aviation Psychology

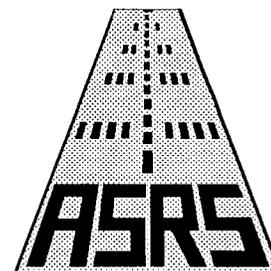
*Behavioral Impact of TCAS II on the
National Air Traffic Control System*

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April 27, 1993



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Research Report

THE BEHAVIORAL IMPACT OF TCAS II ON THE NATIONAL AIR TRAFFIC CONTROL SYSTEM

by

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BACKGROUND AND MOTIVATION

During the latter months of 1991 through mid-1992, the ASRS analyst staff were alerted to a significant increase in Traffic Alert and Collision Avoidance System (TCAS II)-related incident reporting. In July, 1992, both the Federal Aviation Administration (FAA) Office of Aviation Safety and the National Transportation Safety Board (NTSB) tasked the ASRS to complete a database analysis of TCAS II incident reports in preparation for a congressional subcommittee hearing on TCAS II issues.

ASRS Quick Response (QR) No. 235, TCAS Incident Reports Analysis was submitted to the FAA and the NTSB on July 29, 1992. During the coding and analysis of a random sampling of 170 reports used in QR 235, the ASRS research team identified evidence of increasing air traffic controller consternation with and resistance to the implementation of TCAS II technology into the national airspace system. There were also strong indications from the data set that the aviation community, government agencies, and industry may have unwittingly underestimated the impact of TCAS II avoidance maneuvers on both the air traffic controller and flight crew constituencies. The ASRS decided to undertake this study to verify or refute the impressions that emerged from QR 235.

OBJECTIVES AND SCOPE

The objectives of this research were to analyze the effects of TCAS II avoidance applications on pilot-controller interactions and to suggest strategies that could promote a more harmonious human-technology juncture.

Scope

The study was limited to a randomly selected data set of 174 ASRS reports from the January 1992-March 1993 period. The data set specifically included pilot and controller reports that involved Traffic Alert (TA) and Resolution Advisory (RA) incidents.

Specific Objectives

Our research addressed four issue areas:

- 1) Are there any significant changes in TCAS II reporting during the past three years?
- 2) Do TCAS II avoidance actions impact the Air Traffic Control (ATC) system?
- 3) Is there evidence of contention between pilots and controllers because of TCAS II applications?
- 4) Are there effective strategies that could be implemented to enhance pilot-controller cooperation?

APPROACH

Data Set

We coded and analyzed 174 ASRS reports from the January 1992- March 1993 period. The reports were randomly drawn from a universe of 780 TCAS II incidents from the same period involving TAs and RAs. The 174 reports accounted for approximately 11 % of the 1,522 TCAS II full-form reports in the ASRS database or awaiting analyst processing. For reasons of maximum currency, our data set included 55 unprocessed reports from the January-March 1993 period. There were a total of 109 pilot reports, 51 controller reports and 14 reports where both a pilot and controller submitted reports on the same TCAS II incident.

Methodology

A coding instrument was developed to extract pertinent information from the records. The coding instrument addressed several areas. The key points are described in Table 1.

Development of the coding form required a number of iterations of trial codings and inter-rater comparisons to validate the instrument. A team of experienced ASRS pilot and air traffic controller analysts was assigned to analyze and code 174 reports. The completed coding forms were subsequently keyed into a database program for statistical analysis. The data was reviewed, tabulated, and finally summarized for this document.

Table 1. Key TCAS II Coding Points

P1	Pilot Use of TCAS II Advisory
P2	Pilot Initiated Avoidance Actions
P3	ATC Initiated Avoidance Actions
P4	TA/RA Causal Factors
P5	Pilot Communications to ATC on TA/RA
P6	ATC Reactions to TA/RA
P7	Pilot Comments About TCAS II Incident
P8	TCAS II Application: Prevented-Caused
P9	Evidence of Pilot/Controller Contention

BACKGROUND ON TCAS II TECHNOLOGY

Since 1956, the aviation community has attempted, in the face of widely spaced, but successive commercial aircraft mid-air collisions, to conceive and implement an airborne collision avoidance system. In 1987, congressional legislation was passed that mandated the installation of TCAS II on all air carriers, with 30 or more passenger seats, by the end of 1993. To date, over 4,000 air carrier and business aircraft are TCAS II equipped.

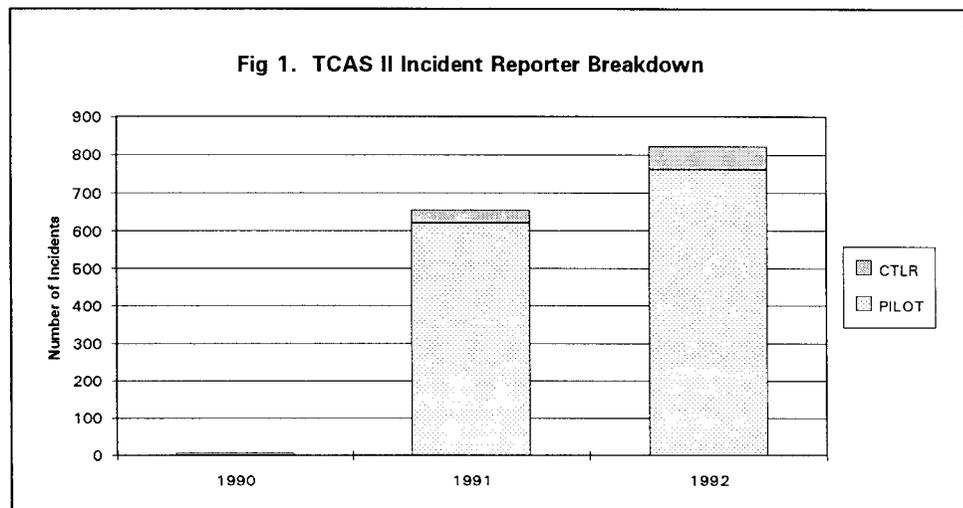
TCAS II is an aircraft-based airborne collision avoidance system that provides information, independent of the ground-based air traffic control (ATC) system, of the proximity of nearby aircraft. It alerts pilots, visually and aurally, to potentially threatening situations (intruders) by monitoring the position, closure rate, and altitude of nearby transponder-equipped aircraft. TCAS II offers the pilot both traffic advisories (TAs) and resolution advisories (RAs.) RAs are limited to vertical avoidance maneuvers if an intruder reaches within approximately 25-30 seconds of closure.

Initial testing of TCAS II in 1984-85 by two major air carriers, in a limited operational environment, determined that "...TCAS II is safe and operationally effective...operates harmoniously in the Air Traffic Control System..." The testing data indicated that "...approximately 50 percent of the alarms will be 'preventive' and the pilot will not deviate from his flight path...the average deviation will be approximately 300 feet based on a 1,500 foot-per-minute climb or descent."¹

PRINCIPAL FINDINGS

TCAS II Incident Reporting

The reporting of TCAS II incidents has undergone a significant increase in the past three years. (Figure 1). The increase included a total of 99 TCAS II incident reports from controllers. This is the largest number of controller reports to ASRS on a single topic since the August 1981 air traffic controllers' strike. The total breakdown of controller reporters on TCAS II incidents included 37 reports from enroute controllers, 58 reports from terminal radar controllers, and four reports from tower controllers. The overall increase in TCAS II incident reporting can also be attributed to the

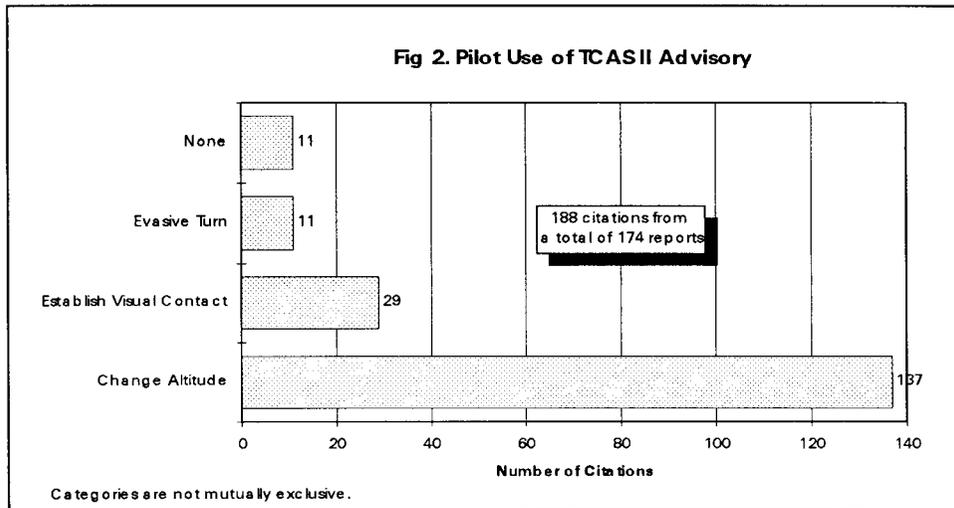


¹ Haines, The Journal of Air Traffic Control, Oct-Dec 90, p.25.

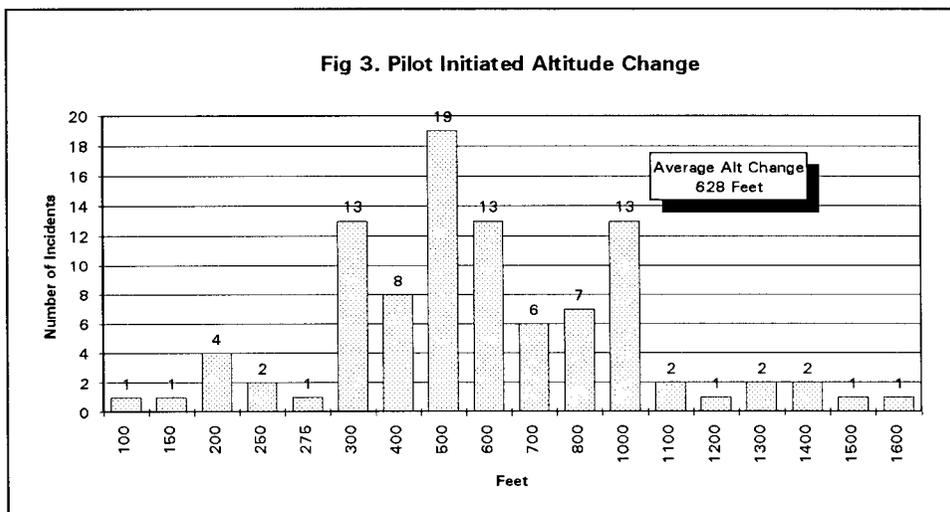
number of air carrier and business aircraft that are installing TCAS II equipment in accordance with the requirements of FAR 121.356 and, prospectively, FARs 91.221 and 135.180. As projected in QR 235, the reporting trend has continued upwards as flight crews and controllers experience various TCAS II avoidance advisory situations.

Actions Taken In Response to TAs and RAs

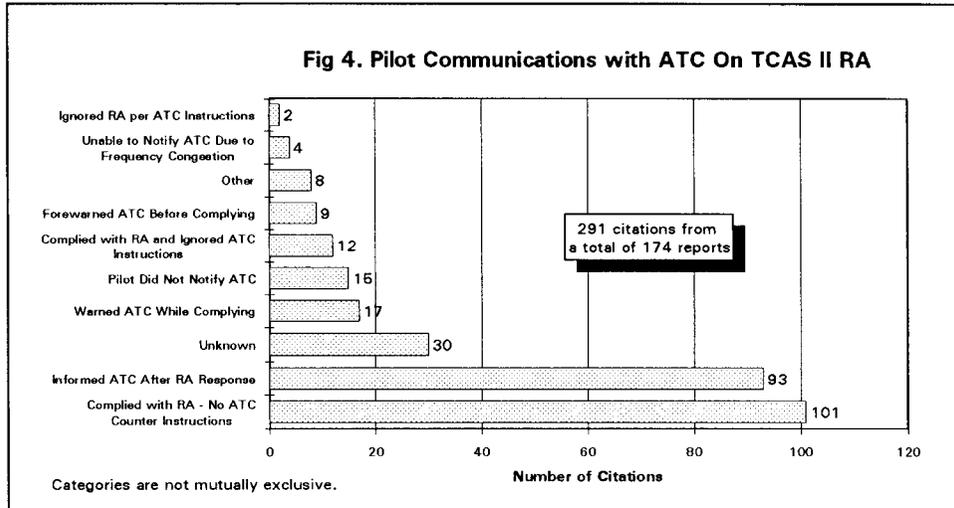
Figure 2 depicts the actions taken by pilots in conjunction with a TCAS II RA based on the data set. The majority of pilot actions were precipitated by RAs (92%).



Altitude changes ranged from 100 feet to 1600 feet as indicated in Figure 3 with an average altitude change of 628 feet. By contrast, the designers of TCAS II expected altitude deviations to average 200 to 300 feet. Initial TCAS II simulation testing did not reveal that aircraft would deviate by 1000 feet or more and intrude upon other occupied altitudes.

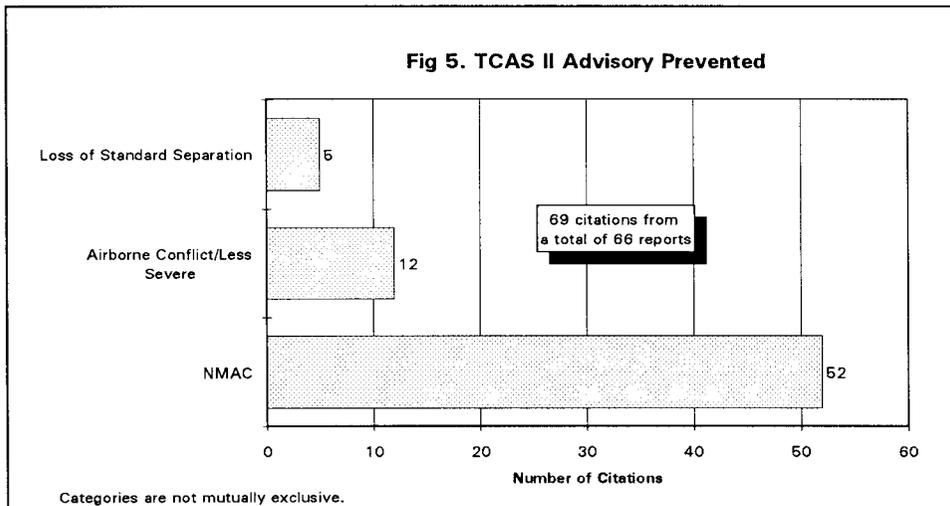


As can be seen in Figure 4, in the majority of incidents (93), the pilot informed ATC after reacting to the RA. In 15 incidents, the pilot did not notify ATC at all of the RA maneuver. In 26 incidents, the pilot either forewarned ATC (9) or warned ATC while complying with the RA (17). A number of controller reports indicate that this response pattern is a major source of their concern because of the impact of the unanticipated avoidance deviations upon the controller's air traffic situation.

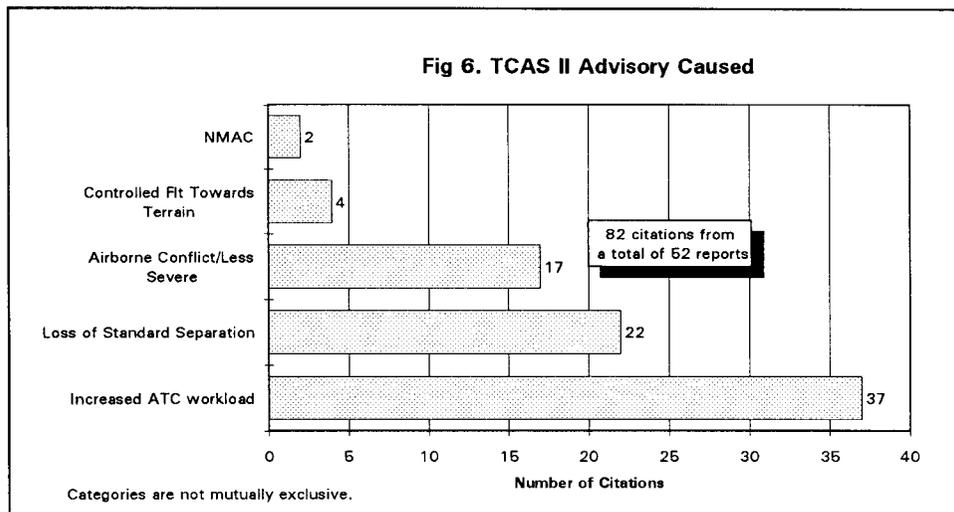


TCAS II Causal Factors

Here is where we see the dual impacts of TCAS II applications. Analysis of the reporter narratives verify that TCAS II has been instrumental in preventing many Near Mid-Air Collisions (NMACs) and other conflicts. (Figure 5)

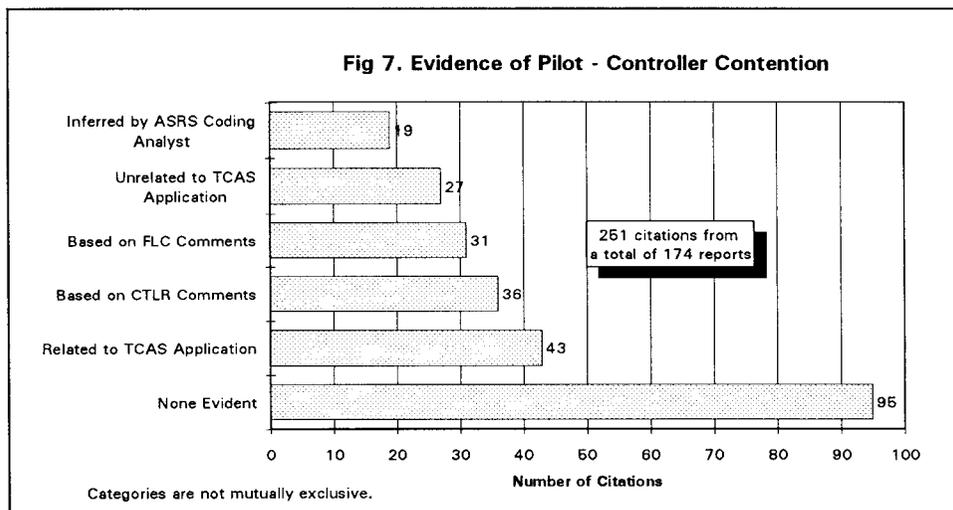


Reporter narratives also confirm that ATC workload has increased. Pilot actions to avoid one conflict, allegedly, precipitated a loss of separation or airborne conflict with another non-intruder aircraft in the same vicinity (Figure 6).



Evidence of Pilot-Controller Contention

Emerging from the previous findings of QR 235 were indications in the reporter narratives that the process of assimilating TCAS II into the ATC system was effecting pilot-controller interactions. Our subsequent intensive coding analysis of the 174 reports verified that a degree of contentiousness existed in approximately 24% of the reports. Figure 7 denotes that, in a majority of the incidents (95), disagreement was not evident in the reporter's narrative. However, in the 43 episodes, related to TCAS II applications, and 27 episodes unrelated to TCAS II applications, there was inferred or stated evidence of contention based on the narrative comments of the reporter.



DISCUSSION

The Emerging Issues

TCAS II has definitely prevented, or reduced the threat of countless airborne conflicts as reflected by the majority of favorable ASRS reports and evidenced by the following quotes:

- "It is the captain's opinion that TCAS II saved about 100 lives today. I am a firm believer in TCAS II forever." (ASRS Pilot Report # 212377)
- "Gap in updating of radar displayed Mode C misled me to think Air Carrier X was still level at Flight Level 310. Situation was resolved by TCAS." (ASRS Controller Report # 225920)

However, there have been side-effects related to the controllers' sense of a loss of control over the aircraft nominally under their jurisdiction. Apprehensive controllers increasingly wonder "Who's in control?" when TCAS II equipped aircraft execute avoidance maneuvers or apply non-standard uses of TCAS II without prior notification or coordination with ATC.

In a recent congressional hearing on TCAS II, ALPA President, J. Randolph Babbit testified that, "Line pilots have strongly endorsed TCAS II and would emphatically resist any efforts to reduce its operational effectiveness."² In contrast, at the same hearing, NATCA President, Barry Krasner ominously warned that TCAS II "...is an airborne system that works improperly and erodes an already precarious margin of safety in the skies."³ The pilot community, particularly ALPA, sees TCAS II as a "...last ditch, they-may-have-hit-if-something-is-not-done, piece of equipment that gives [the pilot] a way out if the rest of our ATC system has somehow unaccountably failed."⁴

With 20/20 Hindsight

Looking back on the road toward implementing TCAS II, it appears that the TCAS II designers may not have fully anticipated all the ways that pilots would act, and controllers would react, once TCAS II was broadly implemented. Over two and one-half million revenue miles later with TCAS II installed in over 70% of the air carrier fleet and with several hundred RAs reported, the following issues have become evident:

Training and Preparation Have Not Been Adequate

Both pilot and controller initial TCAS II training has been inadequate for the unexpected avoidance actions being encountered. A recent NTSB declaration to the FAA recommended that "...both controllers and pilots need more training in the traffic alert and collision avoidance system."⁵ There appears to have been a lack of operational human factors impact analysis preparatory to implementing TCAS II system-wide.

One major air carrier's TCAS II flight crew indoctrination video indicated that resolution command altitude changes would typically require a 200 to 300 foot maneuver. The initial FAA controller TCAS II training video tape conveyed that the implementation of TCAS II would be "...transparent to the controllers" and the resolution advisories would be limited to "200 to 300 feet" in altitude changes. However, both FAA and ASRS Resolution Advisory altitude change data now confirm that the average altitude change has been more than double what was originally anticipated.

- "Air traffic controllers have expressed major concern about the magnitude of the altitude displacements in response to some corrective RA's...The data provide evidence that a problem exists in the way the pilot's use of the system or in the way pilot training is implemented."⁶
- "Senior FAA officials admitted during the [International TCAS Conference, January 7-9, 1992, Washington, DC] that TCAS training for controllers and controller involvement...have been too little, too late."⁷

² Air Safety Week, Aug 10, 92, p.3

³ NATCA News, Jul/Aug 92, p.6

⁴ Hanson, Delta MEC Safety Newsletter, Second Quarter 92, p.8

⁵ Aviation Daily, Mar 26, 92, p.477

⁶ FAA Interim Report, "Results of the TCAS Transition Program (TTP)", AIRINC Research Corp., Dec 31, 91 p. 4-16

⁷ Steenblik, Air Line Pilot, "How Fares TCAS? Part I", Apr 92, p.16

Ad Hoc Fixes Have Been Necessary

Subsequent "fixes" to arising unanticipated TCAS II logic deficiencies convey an "after-the-fact approach" to the overall problems with the technology, i.e., nuisance RAs, phantom intruders, RA commands being contradicted by counter instructions from controllers, etc.

- "The GENOT [FAA General Notice RWA 3/14] is riddled with ambiguities and contradictions that decrease the safety margin...TCAS is not reliable enough for the FAA to order controllers to take such a hands off position."⁸

Recently, the FAA announced its intentions of mandating TCAS II software logic changes (Change 6.04) through the release of a Notice of Proposed Rule Making (NPRM) and the subsequent issuance of an Airworthiness Directive (AD) by December 31, 1993. This fine tuning of TCAS II software logic should eliminate a majority of the nuisance RAs. However, the changes will, in some instances, reduce RA warning time and has provoked strong reservations from ALPA, and others, as illustrated below:

- "There is some industry concern that proposed modifications...will further complicate TCAS implementation and safety risks."⁹

Pilots Are in A Quandary Over How To Respond to TCAS II Alerts

Pilots are being placed in a quandary over making split-second decisions whether to ignore controller advisories on separated traffic or to follow RA commands:

- "Center later admonished us for descending from altitude and stated traffic was level..." (ASRS Pilot Report # 205812)
- "We did not inform the controller of the evasive action in a timely manner." (ASRS Pilot Report # 212715)
- "ATC took offense to TCAS and its use in the air traffic system. I have been finding that ATC...is not too fond of TCAS because it takes away their authority." (ASRS Pilot Report # 206966)

Controllers Feel Conflict Over the Appropriate Response to RA-Commanded Deviations

Controllers have recently been instructed by the FAA to not countermand RAs which could contradict avoidance commands. In some instances, the controller becomes a passive observer to potential loss of separation situations. This is contrary to all their prior training and basic instincts as air traffic controllers:

- "TCAS should only be used as an advisory tool for pilots and should not override Air Traffic Control instructions." (ASRS Controller Report # 232487)
- "Pilot of Air Taxi X elected to respond to RA from Aircraft Y and descended into Aircraft Z...This is insane at best and a blatant misuse of technology..." (ASRS Controller Report # 209177)

There Are Indications of Non-Standard Use of TCAS II By Pilots

The ASRS has received a number of TCAS II incident reports that clearly identify non-standard applications of TCAS II:

- "I cannot have pilots using TCAS II for visual separation...There is no TCAS II separation." (ASRS Controller Report # 202301)
- "Approach appeared to not have the 'big picture'...TCAS was used to ensure safe traffic separation." (ASRS Pilot Report # 183286)
- "Cannot have pilot using TCAS II...to maintain spacing." (ASRS Controller Report # 202301)
- "ALPA's ATC Committee cautions pilots...not to use TCAS to provide their own air traffic control and self-separation."¹⁰

⁸ NATCA News, Mar 93, p.2

⁹ Flight Safety Foundation, Airport Operations Bulletin, Sept/Oct 92, p.4

IN SUMMARY

The conclusions of our TCAS II incident analysis verified the following points:

- TCAS II has definitely enhanced flight safety and is widely supported by the commercial pilot community.
- Air traffic controllers have been confused and occasionally alarmed by the variety of RA applications being experienced in terminal and enroute airspace.
- The requirements associated with the implementation and subsequent nurturing of TCAS II may not have fully anticipated the "growing pains" that have impacted both pilots and controllers.
- Initial TCAS II training did not adequately prepare pilots and controllers for the "surprises" generated during RA situations.
- TCAS II applications have had an impact on the respective roles of the pilot and the controller.
- Behavioral ramifications need to be fully evaluated in concert with ergonomic issues.

SUGGESTED TCAS II ENHANCEMENTS

Information provided to the ASRS by pilots and controllers suggest that the following enhancements should be given serious consideration:

- Mandate a requirement for high performance turbojet aircraft to reduce their vertical speed below 1500 feet per minute when 1000 feet from their assigned level off altitude.
- Require pilots to select TA mode only when established on the final approach for parallel approaches, in VMC conditions, at airports where the parallel runways are less than 4300 feet apart.
- Require pilots to notify ATC whenever a TA becomes a "yellow circle intruder" to forewarn ATC of a probable RA situation. As flight crew workload and frequency congestion permits, the pilot should also cite the clock position, direction of flight, and altitude of the intruder.
- Require ATC to issue the pilot all Mode C traffic in his vicinity upon being informed of a "yellow circle intruder."
- Direct pilots not to exceed a 500 foot altitude change during an RA response unless the intruder is displayed to be climbing or descending within 500 feet of the TCAS II aircraft's altitude.
- Expand and vigorously promote TCAS II simulation training for flight crews and controllers. The FAA Training Academy should consider developing and distributing ATC TCAS II situational training scenarios for immediate use at all Terminal Radar and Enroute Center dynamic simulation training labs.
- The FAA and major aviation organizations (ALPA, AOPA, APA, NBAA, and NATCA) should sponsor joint pilot-controller area and regional TCAS II workshops to promote cooperative dialogue between the constituencies.
- ATC facility managers, through the support of the air carriers and the Air Transport Association (ATA), should actively promote TCAS II familiarization flights for controllers. The opportunity to ride jumpseat, observe TCAS II situations, and engage in constructive dialogue with flight crews should promote a better understanding of their respective professional concerns.

¹⁰ Steenblik, Air Line Pilot, Apr 92, pp. 41-42