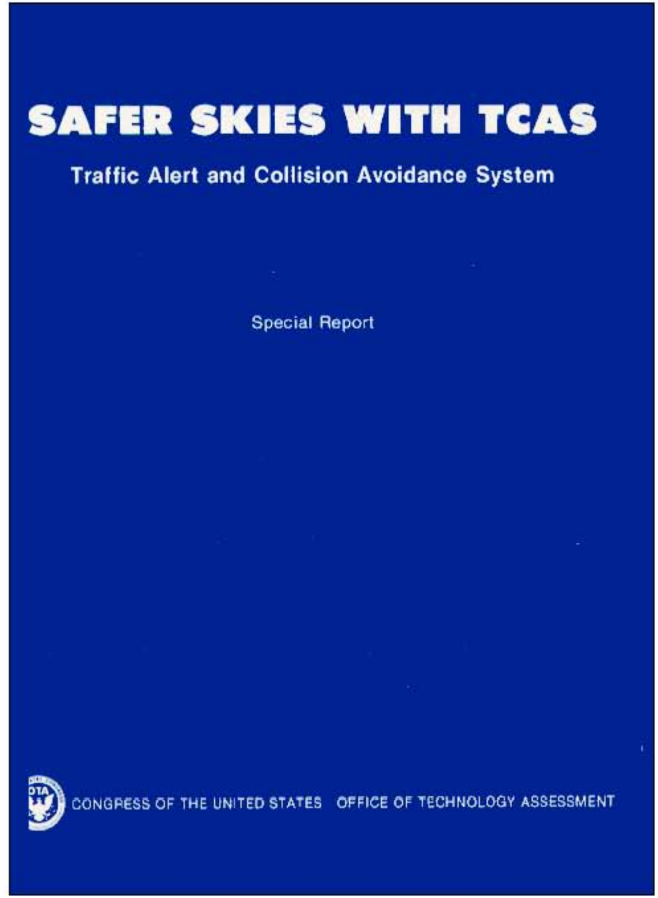
Safer Skies with TCAS: Traffic Alert and Collision Avoidance System—A Special Report

February 1989

NTIS order #PB89-169221



Recommended Citation:

U.S. Congress, Office of Technology Assessment, *Safer Skies With TCAS: Traffic* Alert *and Collision* Avoidance System–A *Special* Report, OTA-SET-431 (Washington, DC: U.S. Government Printing Office, February 1989).

Library of Congress Catalog Card Number 89-600725

For sale by the Superintendent of Documents
U.S. Government Printing Office, Washington, DC 20402-9325
(order form can be found in the back of this report)

FOREWORD

Because midair collisions between aircraft are nearly always catastrophic, the aviation community has been working for many years to develop technologies to help prevent such tragedies. Over the past 8 years, these efforts have culminated in a cooperative government-industry program to develop, evaluate, and implement a traffic alert and collision avoidance system (TCAS II) for commercial aviation.

Eager to reap the benefits of this important safety technology, the 100th Congress passed legislation requiring that most commercial passenger aircraft be equipped with TCAS II by December 1991, or they would not be permitted to fly in U.S. airspace. However, during the second half of 1988, questions arose about the safety implications of the certification and implementation schedule for TCAS 11. The Subcommittee on Aviation of the Senate Committee on Commerce, Science, and Transportation asked OTA to assess these implications and report in early 1989. The study was endorsed by the House Committee on Science, Space, and Technology, and the Subcommittee on Investigations and Oversight of the House Committee on Public Works and Transportation.

This special report contains the results of OTA's assessment. It also provides an admirable example of cooperative effort on the part of all segments of the aviation community in providing information to OTA and working to develop a common solution for a number of difficult issues.

Throughout the study, the Federal Aviation Administration, the airlines, equipment manufacturers, pilots, maintenance specialists, and airframe manufacturers played key roles in assisting OTA through interviews, site visits, and written comments. The workshop participants and numerous reviewers and contributors provided a broad and invaluable range of perspectives. OTA thanks all of them for their substantial commitment of time and energy. Their participation does not necessarily represent endorsement of the contents of the report, for which OTA bears sole responsibility.

John H Gibbons

JOHN H. GIBBONS
Director

Participants in **Workshop on** Getting Collision **Avoidance Airborne: TCAS Installation and Federal Deadlines, January 12, 1989**

Richard E. Rowberg, *Workshop Chair*
Science Policy Research Division
Congressional Research Service

Robert Buley
Flight Standards
Northwest Airlines

Sherry Chappell
NASA Ames Research Center

Jim Deckert
Marketing Manager
Sperry Commercial Flight Systems Group
Honeywell, Inc.

Joe Fee
AC ADS Program Manager
Federal Aviation Administration

John Fredericksen
Executive Vice President
Regional Airline Association

John Graham
Senior Staff Engineer
Flight Guidance and Control Engineering
Douglas Aircraft Co.

Ulf Gustafsson
Staff Engineer
Engineering Program
United Airlines

Jack D. Howell
Chairman, Air Traffic
Control Committee
Air Line Pilots Association

Thomas McSweeny
Deputy Director
Aircraft Certification Service
Federal Aviation Administration

John O'Brien
Director, Engineering and
Air Safety Department
Air Line Pilots Association

Carl Olberg
Director for Engineering
America West Airlines

Richard A. Peal
Director
Avionics/Flight Systems
Boeing Commercial Airplane Co.

Ron Smith
Vice President, Operations
Tracer Aviation, Inc.

Ray Valeika
Senior Vice President
Technical Operations
Continental Airlines

Frank White
Honeywell

Joe Wilson
TCAS Program
Air Transport Avionics Division
Bendix/King

TCAS
OTA PROJECT STAFF

John Andelin, *Assistant Director, OTA*
Science, Information, and Natural Resources Division

Nancy Carson, *Program Manager*
Science, Education, and Transportation Program

Edith B. Page, *Transportation Project Director*

Kevin Depart, Principal Analyst

Karen Mathiasen, Research *Assistant*

Marsha Fenn, *Administrative Assistant*

Madeline Gross, *Administrative Secretary*

Kimberley Gilchrist, *Secretary*

REVIEWERS AND CONTRIBUTORS

Aer Lingus
Aeronautical Radio, Inc.
Air Canada
Air France
Air Wisconsin
Air-India
Alaska Airlines
Alitalia
Allied-Signal Aerospace Co.
America West Airlines
American Airlines
Associated Air Center
Wayne J. Barlow,
Federal Aviation Administration
Boeing Commercial Airplane Co.
Braniff
British Airways
Anthony J. Broderick,
Federal Aviation Administration
Command Airways
Continental Airlines
Dalfort Aviation Services
Joseph M. Del Balzo,
Federal Aviation Administration
Delta Air Lines
Douglas Aircraft Co.
Eastern Air Lines
El Al Israel Airlines
Evergreen Air Center
Finnair
Roger Fleming, Air
Transport Association
L.R. Ganse, Trans World Airlines
Michel Guyard, French Embassy
Joseph Hawkins, Federal
Aviation Administration
Heli-Dyne Systems
Honeywell
Horizon Air
D.P. Huffman, American Airlines
Iberia
Larry James, Trans World Airlines
Japan Air Lines
KLM Royal Dutch Airlines
Keith H. King, international
Air Transport Association
Clyde Kizer, Air Transport Association
Hart A. Langer, Pan
American World Airways
Lufthansa German Airlines
David McMillan, British Embassy
C.R. Melugin, Jr., Federal
Aviation Administration
Northwest Airlines
Pan Am Express
Pan American World Airways
Michael Parkes, British Embassy
Philippine Airlines
B. Keith Potts, Federal
Aviation Administration
Qantas Airways
Jack Raia, Pan American World Airways
Francis C. Rock, Federal
Aviation Administration
Rockwell International
Sabena Belgian World Airlines
Daniel P. Salvano, Federal
Aviation Administration
Saudi Arabian Airlines
Scandinavian Airlines System
Southwest Airlines
William J. Sullivan, Federal
Aviation Administration
Swissair
Tracer Aviation
Tramco
Trans World Airlines
USAir
United Airlines

Table of Contents

Summary . . . 1

Part I: TCAS Development and the Federal Role . . . 3

BACKGROUND . . . 3
TCAS is Chosen . . . 5

TCAS CAPABILITIES AND COMPONENTS . . .
TCAS II Components . . . 7

THE FEDERAL ROLE . . .
Setting Standards . . . 14
Rule making . . . 17
Testing and Evaluation . . . 19

REMAINING CONCERNS 22

DEVELOPMENT FINDINGS . . .

Part II: Implementing TCAS . . . 28

INSTALLATION OVERVIEW . . . 29

INSTALLATION ISSUES . . .

TCAS II Equipment Manufacturing and Initial Certification . . . 31
Follow-up Certification of Airliner Modifications . . . 32
Installing TCAS II . . . 33
Technical Issues . . . 35

IMPLEMENTATION FINDINGS . . . 36

Part 111: Conclusions and Options . . . 40

THE ISSUES . . . 40
Safety and Technical Issues . . . 40
Economics . . . 42
International Issues . . . 43

CONCLUSIONS AND OPTIONS . . . 44

List of Acronyms . . . 51

BOXES

Box

A Minimum Operational Performance Standards for TCAS . 15
B Certification — A Complicated Process 18

FIGURES

Figures

1 TCAS Protected Airspace 8
2 Basic Components of a TCAS II System 9
3 TCAS II Resolution Advisory Example 11
4 Integrated Traffic and Resolution Advisory Display 12
5 TCAS II Traffic Display . 13
6 TCAS Implementation Flowchart 37
7 U.S. Fleet Equipped with TCAS and Possible Timing Options 48

TABLE

Table

1 Effects of TCAS Options 50

Summary

The pilots "felt naked without [TCAS] when
the evaluation was over. "
— United Airlines, Summary User Evaluation Report

The compliance deadline established in Public Law 100-223 for implementing the Traffic Alert and Collision Avoidance System (TCAS II) has safety, economic, and international consequences not fully foreseen at the time of enactment. The TCAS II program is unique in the combination of technological complexity, rapid introduction, and the number of aircraft affected. **OTA finds that aviation safety will be best served by introducing TCAS II on commercial aircraft as soon as possible, by requiring a phased implementation schedule, and by providing for a structured evaluation program carried out jointly by industry and the Federal Aviation Administration (FAA) to oversee the first year of operation.**

While evaluations to date have indicated that TCAS II works quite well, no more than two TCAS II equipped commercial aircraft have flown at any given time. The reactions and interactions of pilots, controllers, and TCAS II within the air traffic system cannot be understood until large numbers of aircraft equipped with TCAS are in operation. **OTA concludes that to ensure full safety benefits, a critical number of aircraft must be outfitted with TCAS II at an early date – possibly 15 to 30 percent (600 to 1,200 aircraft) of the commercial fleet by December 1990. Industry and FAA will need to cooperate in an evaluation that covers the spectrum of aircraft and airspace types and allocates sufficient resources for collecting, analyzing, and disseminating data.**

Public Law 100-223 requires that airlines meet a December 30, 1991, installation deadline for TCAS II. This will strain the resources of virtually every participating aviation organization. Manufacturers must produce and deliver equipment, airlines and others must redesign and modify aircraft, and FAA must certify equipment and altered aircraft. While many major airlines can probably meet the deadline, other critical maintenance and modification programs are likely to suffer. Airlines will have to remove about one-half of their fleets from scheduled service for at least a few days to install TCAS II. Faced with limited numbers of skilled technicians and engineering and maintenance resources, airlines plan to contract out TCAS II work, use overtime, cut discretionary maintenance, and petition for exemptions from other maintenance requirements, such as inspection and modification of aging aircraft. Development is still incomplete for some TCAS II display options, ground test equipment, and technology suitable for commuter aircraft, compounding the uncertainties surrounding installation time.

Out-of-service time for aircraft raises equity issues separate from the direct costs of installing TCAS II. Airlines without extra aircraft are likely to lose passengers to other airlines for a short time, whereas companies with more resources can avoid canceling service. Airlines that fail to meet the deadline will be penalized severely if unequipped aircraft are not permitted to fly in **U.S.** airspace in **1992. However,** airlines that complete TCAS II installations on time will face indirect cost penalties if their competitors do not commit similar resources and are granted extensions.

Although OTA finds no reason to delay initial TCAS II implementation, sufficient airline resource limitations, economic inequities, and international implications stem from the present deadline for Congress to consider extending the installation schedule. If an extension is enacted, specific requirements in the same law will be needed to ensure that installation of TCAS II begins promptly after production equipment is available and proceeds at a reasonable pace over the span of any extension. Prompt congressional consideration of any change to Public Law 100-223 is also important. Indeed, the forcing effect of legislation is likely to be necessary to ensure maximum safety benefits as early as possible and to allow airlines to make appropriate plans for investments in personnel and equipment. Although requiring and linking an operational evaluation program, a phased compliance schedule, and an extended deadline places additional responsibilities on each affected party, this approach spreads economic burdens more equitably than other possible options and provides maximum safety benefits.

Part I

TCAS Development and the Federal Role

First we're going to crawl with TCAS,
then walk, then jog, then run.
— J. Lynn Helms, former FAA Administrator in announcing TCAS

BACKGROUND

Pilots are and always have been the first and foremost collision avoidance system. As pilots and aircraft became capable of flying "blind" by instruments in the 1930s, the need for air traffic control (ATC) and coordination increased. In the early days of commercial aviation (and to this day in oceanic airspace), air traffic was controlled procedurely, through reserved sections of airspace and radio reports from pilots verifying their positions. It was not until the development of radar during World War II that surveillance technology became available to assist air traffic controllers. By 1955 radar was in use at 2 of the 20 ATC enroute centers, and direct controller-pilot radio communication facilities had been established at all of them.[1] Most military and airline aircraft operated under visual flight rules, and the opportunities for collision multiplied as air traffic increased. In the wake of a catastrophic midair collision between two commercial transports over the Grand Canyon in 1956, the airline industry began the first concerted effort to develop an airborne collision avoidance system (CAS).[2] Only now, over 30 years later, are we on the verge of seeing the fruits of technology development that has continued amid industry and technical controversy.

---

1. Nick Komons, Aviation's *Indispensable* Partner Turns 50, (Washington, DC: U.S. Department of Transportation, 1986), pp. 12 and 14.
2. Frank C. White, "Where Does Aircraft Separation Assurance (or CAS) Now Stand?: An Historical Perspective and Project ion,'' in *Aircraft Collision Avoidance*, hearings before the Subcommittee on Transportation, Aviation and Communications of the Committee on Science and Technology, U.S. House of Representatives, June 27, 28; July 24, 1979 (Washington, DC: U.S. Government Printing Office, 1979), p. 360.

The physics of flight dictate that aircraft collisions will usually be catastrophic. Fortunately, midair collisions involving large transports are rare in U.S. airspace, having occurred just twice in the last 15 years. Thanks to continuing gradual improvements in ATC, two positively controlled airliners have not collided since 1965.[3] While the Federal Aviation Administration (FAA) followed and supported early airborne CAS efforts, it did not begin directly developing and evaluating collision avoidance technology until 1971, after congressional hearings on aircraft collisions. The Agency conducted a comprehensive evaluation of three different systems, collectively known as the Airborne Collision Avoidance System, between 1971 and 1975. FAA concluded that while the systems gave good protection in some airspace, they had severe limitations in high-density areas. Additionally, these systems required that dedicated collision avoidance equipment be installed on all aircraft.[4] Moreover, the establishment of ATC Terminal Control Areas and expanding computer automation, including conflict alert, made the ATC system much more versatile than existent airborne collision avoidance technology.

Every CAS devised for commercial aircraft requires compatible equipment installed on each aircraft to be protected or avoided. Using the radar signals from common ATC transponders installed on all commercial and military aircraft and the majority of the private fleet would eliminate the need to equip all aircraft with dedicated systems. First demonstrated in 1974, the beacon-based collision avoidance system (BCAS) relied on transponder replies for traffic data, immediately providing protection from all other transponder equipped aircraft. Aircraft without transponders were invisible to BCAS. However, BCAS development ran into difficulties. Self-contained airborne versions caused too much radio interference in high-density airspace, and solving that problem required expensive ground coordination equipment.[5]

---

3. Komons, op. cit., footnote 1, pp. 22.
4. Neal A. Blake, Acting Deputy Associate Administrator for Engineering and Development, Federal Aviation Administration, in testimony, *Aircraft Collision Avoidance,* op. cit., footnote 2, pp. 59-60.
5. U.S. Congress, Office of Technology Assessment, *Airport and Air Traffic Control*
(continued)

TCAS is Chosen

In June 1981, then FAA Administrator J. Lynn Helms announced that FAA would focus on an enhanced air-to-air version of BCAS called the Traffic Alert and Collision Avoidance System (TCAS). FAA assumed responsibility for supporting necessary research, developing prototype equipment, demonstrating the operational and technical feasibility of the TCAS concept, generating national standards for the equipment, and certificating TCAS-equipped aircraft for normal operation. TCAS is designed to:

- be compatible with the present ATC system and a logical extension of it;
- be suitable for use in high-density traffic;
- require no ground-based equipment;
- offer a range of capabilities suitable to the needs of various classes of airspace users.[6]

The 1987 Airport and Airways Capacity Expansion and Improvement Act, Public Law 100-223, established deadlines for completing development and installing the system known as TCAS II on commercial transports. By June 30, 1989, FAA must approve and validate the TCAS II performance standards. FAA finished its regulatory requirements for development on time in October 1988. The remaining FAA responsibility for establishing TCAS II is to test and evaluate TCAS II equipment that meets the latest standards. This testing is now scheduled to begin at the FAA Technical Center in early April 1989 and to be completed by Summer 1989.[7] Each passenger-carrying aircraft with more than 30 seats must be equipped with TCAS II to operate in U.S. airspace after December 30, 1991.

System, OTA-STI-175 (Washington, DC: U.S. Government Printing Office, January 1982), pp. 89-90.

6. Ibid., p. 91.

7. Joseph Fee, ACADS Program Manager, Federal Aviation Administration, in U.S. Congress, Office of Technology Assessment, “Transcript of Proceedings — Getting Collision Avoidance Airborne: TCAS Installation and Federal Deadlines,” unpublished typescript, Jan. 12, 1989.

TCAS will provide independent backup to ATC and flight crews by displaying range, bearing, and when possible, altitude of nearby aircraft and alerting the crew to conflicting traffic. To serve the varied needs of the aviation community, three versions of **TCAS —** TCAS I, TCAS II, and TCAS III – are being developed, each with distinct performance characteristics.

Prototypes of each version have been flight-tested. Designed for airline use and farthest along in development, TCAS II is the system addressed in Public Law 100-223. TCAS I, appropriate for general aviation and smaller commuter airlines, will be required along with TCAS II under FAA rule making. TCAS III, the most complex and sophisticated version, will probably not be fully specified until at least 1992.[8] In any case, TCAS III may be subject to separate rulemaking procedures.

TCAS I. Primarily intended to assist the pilot in visually acquiring nearby traffic, TCAS I is the simplest and least costly TCAS. TCAS I detects and displays range, approximate bearing, and altitude of traffic that is equipped with a Mode C or S transponder [9] within 4 nautical miles of the host aircraft. Traffic equipped with Mode A transponders is displayed without altitude information. TCAS I alerts the crew with a visual and aural traffic advisory to any intruding aircraft within about 40 seconds of closest approach. TCAS I **does not** offer guidance to the pilot for maneuvering away from potential collisions.

---

8. John M. Graham, Chairman, Special Committee 147 of the Radio Technical Commission for Aeronautics, personal communication, Feb. 7, 1989.

9. Three versions of air traffic radar transponders — Modes A, C, and S — are used by civilian aircraft. Mode A transponders reply to radar interrogations with a four-digit identification code. Mode C equipment includes the aircraft's altitude in the reply. The signal format for the newest transponder type, Mode S, allows radar interrogations and other information to be addressed to specific aircraft.

TCAS II. TCAS **II** does everything TCAS I does, but with greater range and bearing accuracies. The system also instructs the crew with a visual and aural resolution advisory (RA) on how to avoid threatening traffic, provided that the other aircraft is Mode C- or S- (altitude-encoding transponders) equipped and is typically less than 25 seconds[10] from a potential collision. Figure 1 depicts TCAS II protected airspace. TCAS II RAs are restricted to the vertical plane. Through Mode S air-to-air data links, TCAS II coordinates with other TCAS II-equipped aircraft to fly complementary avoidance maneuvers.

TCAS III. Not yet addressed directly in legislation or rulemaking, TCAS III will have all the features of TCAS II and will offer horizontal resolution maneuvers as well. To resolve conflicts with horizontal turns, TCAS III will measure the bearing of targets more accurately than required for TCAS II.

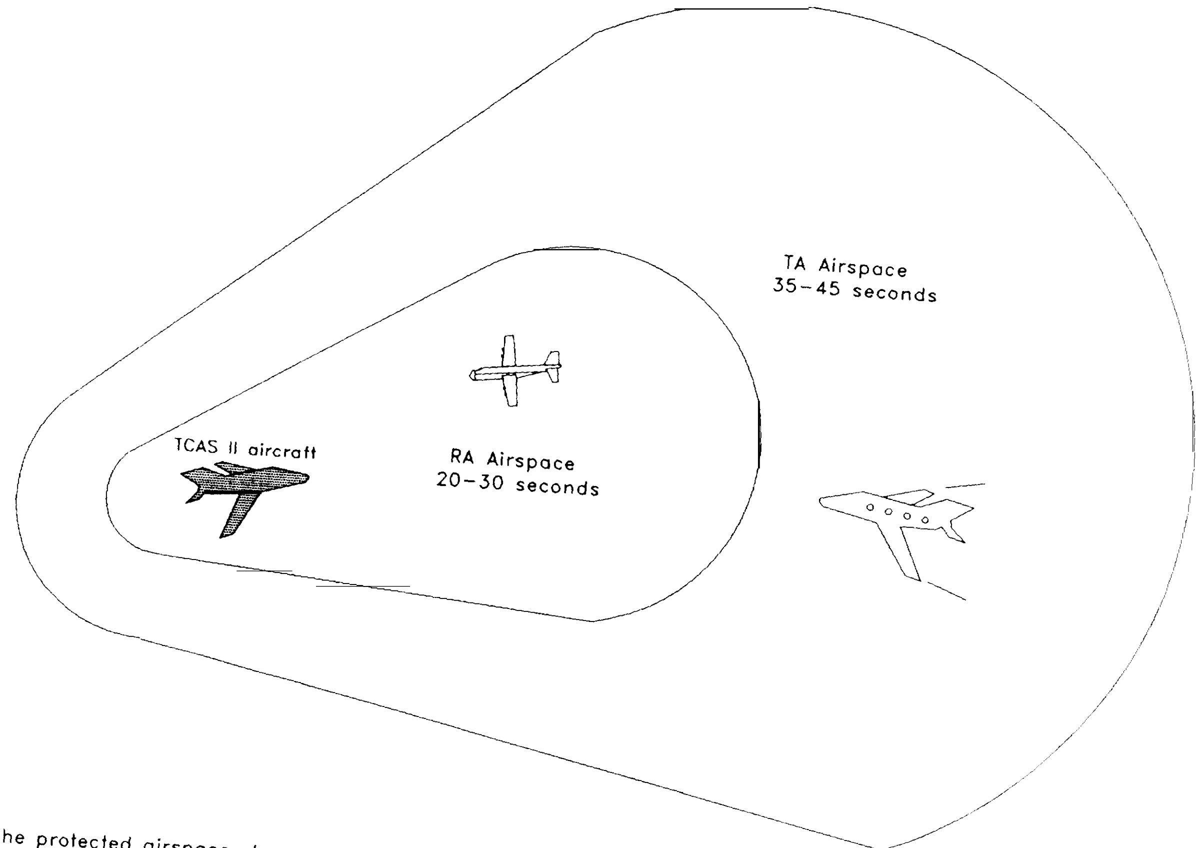
TCAS II **Components**

Each TCAS II unit is effectively a small, but versatile ATC-type radar station, consisting of a computer processor and software, a directional antenna system, a Mode S transponder, and cockpit displays, indicators, and controls. (See figure 2.) Although some TCAS II equipment options are still being developed, the principal features of the components as presently defined are described below.

Processor. The heart of each TCAS II is its processor, which contains the hardware and software for connecting all the components. The processor transmits and receives radar signals through the antennas, measures range, bearing, and altitude of nearby traffic, watches for conflicts, computes escape paths if necessary, and sends this information to the cockpit indicators. During an RA, the processor coordinates the maneuver through Mode S transponder datalink if the other aircraft is TCAS II equipped.

10. Resolution advisory sensitivity varies with own aircraft altitude: 20 seconds below 2,500 feet above the ground; 25 seconds between 2,500 feet and about 10,000 feet; and 30 seconds above 10,000 feet.

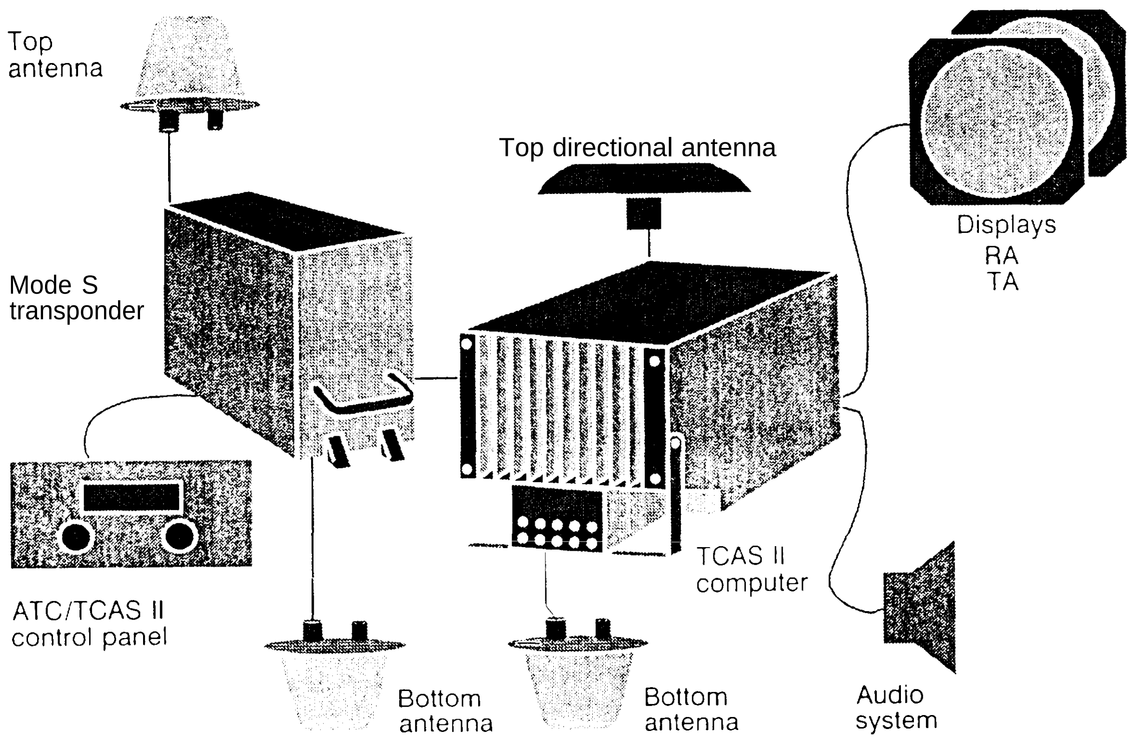
Figure 1.–TCAS Protected Airspace



[a] The protected airspace shown is for a TCAS II aircraft above 500 feet.

SOURCE: Office of Technology Assessment.

FIGURE 2. -- BASIC COMPONENTS OF A TCAS II SYSTEM



SOURCE: Boeing Commercial Airplane Co.

Antennas. Some TCAS II manufacturers are offering electronically-steered antennas accurate to about 3 degrees, far better than the 15 degree FAA minimum performance requirement.11 Each aircraft must have two antennas, typically mounted on the top and bottom of the fuselage, although the bottom one need not be a directional antenna. The TCAS II processor does not use bearing information in generating RAs, so directional antennas are needed only for cockpit traffic displays and for reducing radar interference.

Cockpit indicators. TCAS II provides two types of traffic-related information to the cockpit: 1) a representation of nearby traffic and its status, and 2) resolution advisories to prevent potential collisions. Each airline, depending on its aircraft types and cockpit configurations, will have a number of options for displaying TCAS II information to the flight crew.

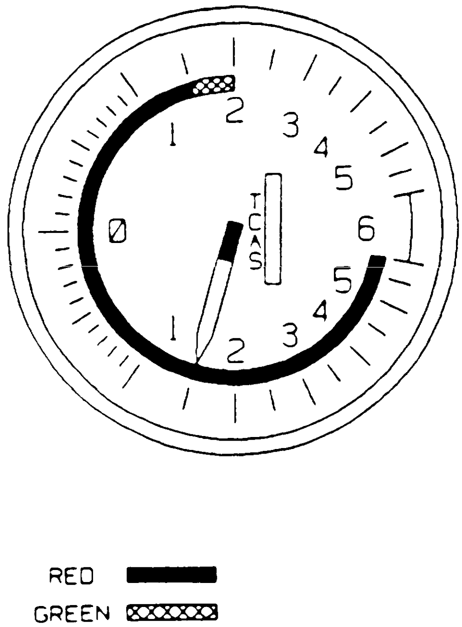
TCAS II will provide aural and visual advisories for all aircraft configurations. Visual RAs will be presented on modified instantaneous vertical speed indicators (IVSIs) for most existing aircraft. Red and green arcs appear during an RA, indicating vertical speeds to avoid (red) and to fly safely (green). (See figure 3 for an example.) Still under development are the RA indicator formats for "glass" cockpits, where many instruments are displayed on cathode ray tube (CRT) systems.

Four basic display options to indicate traffic location and threat status will be available. Airlines may install a dedicated TCAS II traffic display, modify weather radar display or an electronic flight instrument system, or replace the IVSI with one that will not only indicate RAs, but will also present traffic on a liquid crystal display in the center of the IVSI dial. Figure 4 shows a combined traffic display and IVSI, and figure 5 represents a traffic display for a CRT system. Human factors consideration are of crucial importance in the design of these links between TCAS II and the flight crew.

---

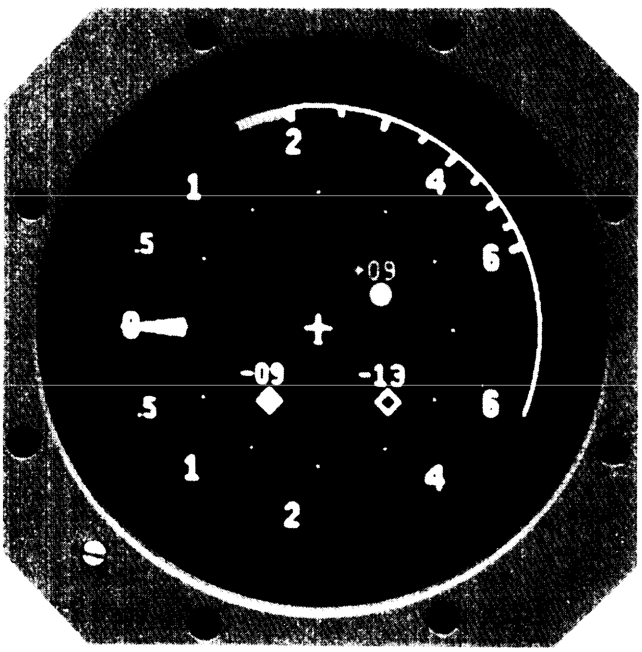
110 Federal Aviation Administration, "Airworthiness and Operational Approval of Traffic Alert and Collision Avoidance Systems (TCAS II) and Mode S Transponders, " Advisory Circular 20-131, Oct. 3, 1988, p. 18.

FIGURE 3. -- TCAS II RESOLUTION ADVISORY EXAMPLE



This instantaneous vertical speed indicator shows a corrective resolution advisory; the pilot should reverse the present 1,500 feet per minute (fpm) descent rate to a 1,500 to 2,000 fpm climb (the green area on the dial).

SOURCE: Federal Aviation Administration.



TCAS II traffic display symbols

−03
Resolution advisory
(solid red)

+09
Traffic advisory
(solid yellow)

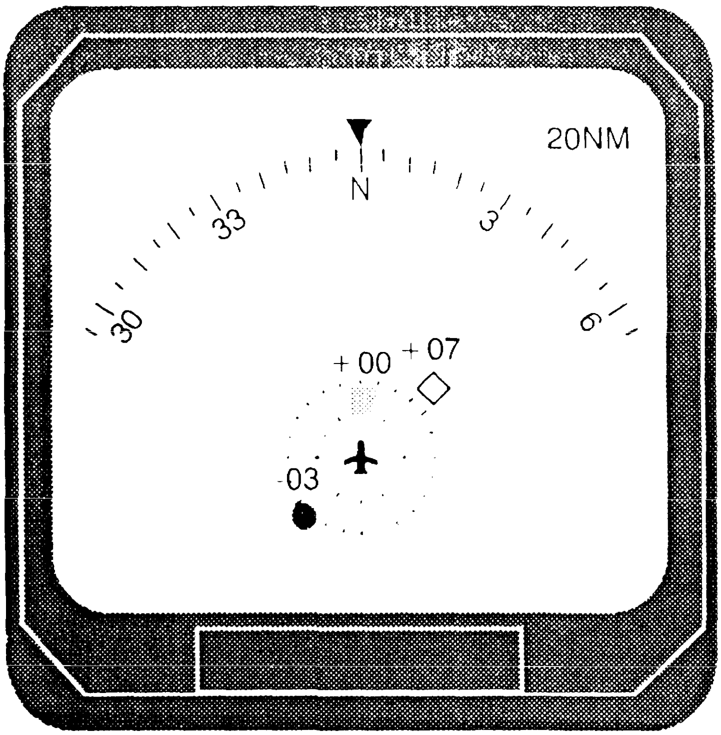
−09
Proximate traffic*
(solid white or solid blue)

−13
Non−threat
(hollow white or hollow blue)

* **Within 6 nautical miles and 1200** feet **relative altitude**

ımbers).

FIGURE 5. -- TCAS II TRAFFIC DISPLAY



Traffic may be displayed on a CRT system, such as a dedicated display, a weather radar, or an electronic flight instrument system.

SOURCE: Boeing Commercial Airplane Co.

While several airlines have ordered the combined traffic display/IVSI, which has not yet been used in any of the operational evaluations of TCAS II,[12] some others and some pilots, through the Air Line Pilots Association (ALPA), oppose these displays. Traffic displays for glass cockpits are still being developed.

THE FEDERAL ROLE

Much of the basic research and fundamental technology development used in the FAA's TCAS II program was completed in earlier collision avoidance projects. These set the stage for current Federal efforts requiring TCAS II on some categories of aircraft. In coordination with industry, three interrelated Federal activities to establish TCAS II have proceeded in parallel: setting national standards defining TCAS II; mandating TCAS II implementation through rulemaking; and testing and evaluating TCAS II technology.

Setting Standards

The characteristics of aircraft equipment covered under the Federal Aviation Regulations are usually defined by national standards published in Technical Standard Orders (TSOs), the ". . . minimum performance standard for a specified material, part, process, or appliance."[13] FAA has approval authority for standards governing aviation system designs. The Agency works in consort with members of the aviation community to establish the standards, often incorporating directly the findings of independent committees such as the Society of Automotive Engineers or the Radio Technical Commission for Aeronautics (RTCA). FAA does not specify design specifications in a TSO, but states the minimum performance requirement for the equipment and grants TSO "authorization" to manufacturers of articles that meet the TSO.

---

12. John O'Brien, Director, Engineering and Air Safety Department, Air Line Pilots Association, in Office of Technology Assessment, op. cit., footnote 7.
13. 14 CFR 21.601 (Jan. 1, 1988)

Since TCAS involves the application of electronics and telecommunications, RTCA developed the minimum operational performance standards (MOPS) for TCAS II, which formed the basis of the TSO[14] issued by FAA in October 1988. (See Box A for an explanation of the MOPS.) The bulk of the MOPS deal with computer algorithms and have been revised a number of times as the result of analyses, simulations, and tests. However, the latest revision of the MOPS, referred to as "Change 6," has not yet been approved by RTCA; consequently FAA's TSO is based also on an FAA report prepared by MITRE Corporation,[15] which established Change 6.

Also in October 1988, FAA released an Advisory Circular (AC)[16] which provides guidance for the airworthiness and operational approval of TCAS II. An AC is not mandatory, but following its guidance ensures compliance with the Federal Aviation Regulations.

BOX A: Minimum Operational Performance Standards for TCAS

RTCA, established in 1935 to solve aviation problems involving electronics and telecommunications, is the joint government/industry advisory committee that is developing and recommending MOPS for TCAS I, II, and III. RTCA recommendations are usually incorporated directly into TSOs or otherwise accepted by FAA.

The MOPS for TCAS II are the most mature, first published in 1983 and then followed by a series of changes. Since a large part of the MOPS deal with TCAS computer instructions, such as resolving conflicts and coordinating maneuvers between aircraft, software changes to fix problems or enhance performance are not unusual.

14. U.S. Department of Transportation, "Traffic Alert and Collision Avoidance System (TCAS) Airborne Equipment, TCAS II," TSO-C119, Oct. 14, 1988.
15. Federal Aviation Administration, "Required Modifications to the Traffic Alert and Collision Avoidance System (TCAS II) Minimum Operational Performance Standards (MOPS)," DOT/FAA/SA-88/3, October 1988.
16. Federal Aviation Administration, op. cit., footnote 11.

TCAS II MOPS including Changes 1 through 5 are incorporated into FAA's TCAS II TSO and advisory circular, and Change 6 will be added following its formal approval by RTCA, expected in June 1989. FAA will likely accept additional changes to the MOPS, but will not require them unless FAA decides they are warranted for safety. RTCA plans to include a Change 7 to enhance TCAS II.

Recently, two United and two Northwest jets were outfitted with pre-production TCAS II units, incorporating MOPS Changes 1 to 5, for operational evaluation under a limited installation program (LIP). At the same time, work continued on Change 6 to incorporate some changes identified before these evaluation flights began. The main issue was that once TCAS II issued an RA, if the other aircraft changed its path, TCAS II would not be able to resolve the new conflict and would issue a TCAS "invalid" warning, leaving the flight crew to fend for itself. Change 6 removes the invalid option and permits TCAS II to calculate additional maneuvers if the initial RA is not sufficient. Change 6 also biases against maneuvers that cross through (instead of staying above or below) the other aircraft's altitude and simplifies logic for air-to-air TCAS II coordination.

Findings from the LIPs[17] suggest further TCAS enhancements, including reducing the low-altitude traffic alert rate during approaches and in areas with many Mode A targets. By November 1989, RTCA plans to finish Change 7 addressing the LIP results. This version of the MOPS will be used for equipment purchased by most airlines. RTCA plans to make the MOPS compatible with the international collision avoidance standards now being reviewed by the International Civil Aviation Organization (ICAO) by the end of 1990.

END BOX

17. United Airlines completed its limited installation program (LIP) in October 1988; Northwest Airlines will report on its LIP in May 1989.

Rule making

Congress gave strong guidance to FAA for implementing TCAS II in the Airport and Airway Safety and Capacity Expansion Act of 1987 (Public Law 100-223) on December 30, 1987. The Act required FAA to complete TCAS II "certification" (see Box B) within 18 months and mandated that each aircraft capable of carrying more than 30 passengers have TCAS II installed and operating in the subsequent 30 months. This implied a December 30, 1991, deadline for TCAS II installation and implementation for domestic and foreign aircraft operating in U.S. airspace.

Public Law 100-223 also required FAA to promulgate a final rule expanding requirements for aircraft to be equipped with Mode C (altitude encoding) transponders. In response, FAA adopted Amendment 91-203, "Transponder Automatic Altitude Reporting Capability Requirement," in June 1988,[18] requiring Mode C transponder use within and above each terminal control area (TCA) and airport radar service area; within 30 miles of a TCA, and above 10,000 feet above mean sea level. Additionally, Public Law 100-223 requires that TCAS II be "upgradable" to the performance standards of the future TCAS III, although these are still being developed. FAA's final rule for TCAS states that other than air-to-air coordination logic, TCAS II may have a variety of designs, and TCAS III may be addressed through separate rulemaking.[19]

Prior to enactment of Public Law 100-223, FAA had issued Notice of Proposed Rulemaking (NPRM) 87-8[20] intending to require either TCAS I or TCAS 11 on various classes of passenger aircraft. Public Law 100-223 was generally similar to the NPRM, which proposed a 3-year deadline for TCAS II implementation on large passenger transports. At the time Public Law 100-223 was passed, the final rule was expected to be released in late 1988; it was actually issued in January 1989.

---

18. 53 *Federal Register 23356-23374* (June 21, 1988).
19. 54 *Federal Register 944* (Jan. 10, 1989).
20. 52 *Federal Register 32268-32277* (Aug. 26, 1987).

FAA received 70 separate comments to the NPRM; about half expressed concerns over the implementation schedule. Bound by Public Law 100-223, FAA could not address these concerns in the final rule and set the dates as required by the legislation. However, in response to public comment, FAA did change the requirement for 20- to 30-passenger aircraft from TCAS II to TCAS I and extended the TCAS I compliance date from 5 years to 6 years.[21]

BOX B: Certification — A Complicated Process

Public Law 100-223 requires FAA to complete ". . . certification of the collision avoidance system known as TCAS-II . . ." by June 30, 1989. The law's intent was to ensure TCAS validation, authorization, and implementation in a timely manner. Although FAA certification results in authorization, FAA can approve equipment standards, such as those for TCAS II, without certification. **Additionally, FAA may formally approve equipment performance standards, before those standards are tested and evaluated on an aircraft in flight.** Thus, FAA certification as required in Public Law 100-223 is open to interpretation.

FAA certificates the major components of the aviation system — people, such as pilots and mechanics, aircraft, and organizations, such as airlines and repair stations. Through these categories of certification, FAA approves aircraft design and production, operations, and airworthiness. For example, each specific design or make and model of airframe, engine, and propellor is manufactured under a unique Type Certificate (TC).[22] Altering an aircraft's design in a way that could affect flight safety, such as installing TCAS, requires obtaining an amended TC or a Supplemental Type Certificate (STC).[23] Extensive design changes require a **completely new TC.**[24]

---

21. 54 *Federal* Register 941 (Jan. 10, 1988).
22. 14 CFR Part 21, Subpart B (Jan. 1, 1988).
23. 14 CFR 21.113 (Jan. 1, 1988).
(continued)

Before the STC or TC process begins, the design requirements and performance standards for equipment such as TCAS are usually approved and validated separately. Then an engineering analysis is conducted as a basis for an STC that need only be undertaken once for each aircraft make and model to change its design. For example, an airline that receives an STC for one B727-200 will be able to use that approved procedure for modifying the rest of its 727-200 fleet, provided all its 727-200s are the same. However, additional engineering work and FAA approval are required to address individual differences among aircraft within a single make and model category. Moreover, because approved production equipment will not be available, none of the numerous varieties of aircraft equipped with TCAS II can be certificated before July 1989 at the earliest. Complicating the process, most aircraft types in airline fleets are slightly dissimilar.

STCs are proprietary, but could be shared or sold to other organizations, although doing so would require time-consuming and costly coordination. New aircraft types will likely have TCAS II installations covered by TCs.

END BOX

Testing **and Evaluation**

Much of the basic collision avoidance technology used for TCAS was developed during the past two decades by FAA at its Technical Center and by its contractors, the MITRE Corporation and the Lincoln Laboratory of the Massachusetts Institute of Technology. As for TCAS itself, limited numbers of TCAS II systems have been operated on scheduled airline flights since 1987, TCAS I will be evaluated in the operational environment later this year, and development testing is ongoing for TCAS III at the FAA Technical Center.

---

24. 14 CFR 21.19 (Jan. 1, 1988).

To observe and record TCAS II performance and pilot interaction with the equipment during normal operations, FAA sponsored and partly funded four evaluation programs carried out by industry. Each participating airline and TCAS II manufacturer contributed substantial time, manpower, and financial support for these programs. Two types of data were collected in each program — electronic output from the TCAS II equipment and comments from pilots and other observers. These programs included:

Piedmont Phase I. Collision avoidance equipment developed under the BCAS program was modified to incorporate some TCAS elements and installed on two Piedmont Airlines B727 aircraft. These aircraft were flown in scheduled service from November 1981 to March 1982. The purpose of Phase I was to measure TCAS II performance; flight crews could not see or use any TCAS II-generated information.[25]

Piedmont Phase II. TCAS II prototype equipment was first operated in regular airline service in this program, whose purpose was to assess the effects of TCAS II on both the flight crew and the ATC system. However, the TCAS equipment, built by Dalmo Victor/Singer prior to full development of the MOPS and Aeronautical Radio, Inc. (A RI NC) characteristics, lacked many of the capabilities of present systems. While the pilots had TCAS displays in the cockpit, they could use the information only in visual flight conditions. Additionally, the equipment lacked Mode S capability and could not coordinate with another TCAS-equipped aircraft. A single TCAS-equipped B727 operated from March 1987 to January 1988.[26]

Assisting flight crews in visually locating nearby aircraft was found to be a major benefit of TCAS II, garnering positive acceptance by Piedmont's pilots. TCAS II had no noticeable effect on ATC or on pilot workload. Higher than expected alert rates and minor problems with aural and visual TCAS II information suggested numerous

---

25. 52 Federal Register 32271 (Aug. 26, 1987).
26. ARINC Research Corp., In-Service Evaluation of the Traffic *Alert and Collision Avoidance System (TCAS) Industry Prototype,* prepared for the Federal Aviation Administration, DOT/FAA/SA-88/2 (Springfield, VA: National Technical Information Service, May 1988), pp. vii-x.

improvements.[27] The Piedmont programs are analogous to the crawling stage described by Administrator Helms in announcing TCAS.

Limited Installation Programs. The TCAS II installations used in the LIPs are fully certified for the full range of airline operations. Incorporating the latest available MOPS (Change 5) and ARINC characteristics, the equipment used in the LIPs was intended to match closely in performance and appearance the versions to be installed fleetwide. The equipment operated on two United Airlines aircraft, a B737 and **a** DC8, from January through July 1988, were built by the Bendix/King Air Transport Division of the Allied-Signal Aerospace Company. Honeywell teamed with Northwest Airlines for the ongoing operational evaluation onboard two MD80s, which began in October 1988 and is expected to be completed in March 1989.

The Bendix/United LIP found that TCAS II substantially enhanced air traffic safety, and is highly desirable for routine airline operations, provided certain CAS logic changes are made to prevent disruptive and unnecessary advisories.[28] Additionally, United assessed TCAS II's readiness for full implementation. The final report raises concerns about:

- integrating TCAS II into glass cockpit aircraft,
- the lack of ramp test equipment for efficient installation testing,
- the fact that no airline experience with CAS logic beyond Change 5 will precede certification,
- incorporating ICAO requirements into U.S. standards,
- the engineering, mechanic, and facility resources required for full fleet retrofit, and

---

27. Ibid., pp. x-xvi.
28. George K. Schwind et al., United Airlines, Inc., "Summary User Evaluation Report on the Traffic Alert and Collision Avoidance System (TCAS II) Limited Installation Program, " prepared for Bendix/King Air Transport Avionics Division, October 1988, p. vii.

- high traffic advisory/RA rates and the need to eliminate unnecessary alerts.[29]

Other evaluation programs will begin in the near future. British Airways will begin an operational evaluation with a Bendix/King TCAS II with Change 6 in March 1989.[30] FAA is currently testing Change 6 in computer simulations and will conduct flight tests in April 1989 at the Tech Center. The three TCAS II manufacturers will begin flight tests and other certification procedures to obtain TSO and STC approval. These are now scheduled for March 1989. FAA also expects to contract for a (31 to 60 seat) turboprop commuter LIP by October 1989.[31] The LIPs are analogous to walking for TCAS.

REMAINING CONCERNS

FAA and industry agree that closely monitoring the initial implementation of TCAS II will help ensure adequate TCAS II, flight crew, and air traffic system performance. FAA has established a TCAS II Transition Program to coordinate data collection and analysis among industry and FAA certification, ATC, and the TCAS Program office.[32] However, the Agency has not yet clearly defined how the program will work, or what the scope and timing of its efforts will be.

There is widespread agreement in the aviation community that cockpit human factors and air traffic system effects need further attention. From the inception of TCAS, pilots, airlines, and manufacturers have been concerned about possible human factors implications of traffic displays, warnings, and maneuver advisories in the

29. Ibid., pp. 99-103.
30. Buzz Hefti, Allied Signal, personal communication, Feb. 9, 1989.
31. Joseph Fee, Federal Aviation Administration, in Office of Technology Assessment, op. cit., footnote 7.
32. C.R. Melugin, Jr., Executive Director for Regulatory Standards, Federal Aviation Administration, personal communication, Jan. 10, 1988.

cockpit. While pilot responses to TCAS have been studied at the National Aeronautics and Space Administration (NASA) Ames Research Center and during the LIPs, the full effect of TCAS on other pilot duties is unclear.

The reactions and interactions of pilots, controllers, and TCAS will affect the safety and operation of the entire ATC system. While the air traffic system can be modeled to include TCAS on a simple basis, the human dimension escapes prediction. Using past and predicted traffic patterns and TCAS detection and avoidance algorithms, the number and extent of TCAS alerts, warnings, and conflict resolution maneuvers can be studied along with the potential for electromagnetic interference. However, pilot and controller performance could change due to TCAS, ranging from complacency to interference with normal duties. The following issues need to be more fully addressed: 1) changes in the amount of pilot/controller communications; 2) pilot/controller attention to other duties due to workload or complacency; and 3) the effect of pilots using or reacting to TCAS information outside design boundaries — maneuvering in traffic without an RA or over/underflying an RA.

These issues cannot be resolved until TCAS is implemented widely; if a problem requiring TCAS modification exists, it must be uncovered early if changes are to be effected economically. An early implementation period and evaluation program (equivalent to jogging in Administrator Helms' statement) could accomplish this. The present schedule for TCAS implementation is unusual in that new technology will be introduced to the full air transport fleet over a short timespan.

DEVELOPMENT FINDINGS

TCAS II technology has been proven feasible and is sufficiently developed to justify Federal actions requiring airline implementation. Pre-production TCAS II technology has been successfully demonstrated, and airline evaluations to date have uncovered no fundamental flaws preventing industry-wide implementation. OTA concludes that TCAS **II is likely to be practical and beneficial for all transports; however, this will not be confirmed until sufficient numbers of TCAS II are installed on airliners and operated in the air traffic system.**

FAA has approved the minimum performance standards for TCAS II, and if all goes well, will complete simulation and flight test validation by June 30, 1989, thereby "certifying" TCAS by the deadline set in Public Law 100-223. The last revision of the TCAS software required by FAA, known as Change 6 to the MOPS, is being tested extensively in computer simulations and will be flown at the FAA Technical Center beginning in March 1989. No problems that would prohibit approval and validation are anticipated.

OTA **concludes that an evaluation program that includes early implementation of TCAS in a substantial portion of the fleet would benefit safety.** Without such a program, the worst case scenario is that the airlines could completely outfit their fleets only to learn that a technical glitch requires major modification of the current TCAS equipment. A structured evaluation phase would allow problems to be identified early, preventing further installation of flawed units and permitting modifications soon enough in the installation program to minimize costs.

In the best case, TCAS II works perfectly in all respects. However, most airlines will not take delivery of TCAS II equipment until 1991 (see page 35) unless early implementation is required. A monitoring program requiring early implementation for part of the fleet could provide added protection to a portion of the traveling public earlier than it would otherwise receive. As part of the program, industry and FAA will want to consider ways to incorporate modifications identified through the evaluation.

According to LIP findings, software modification is desirable; however, only some of the changes will be addressed in the baseline TCAS II requirements established by FAA. The FAA position is that Change 6 is sufficient for safety, and no information has

been provided that disproves this claim. Moreover, airlines may add changes as "enhancements" to the baseline TCAS II equipment, although absent FAA requirements or widespread industry support, such enhancements will be very costly. A monitoring program could open lines of communication within the aviation community and provide the necessary information to support TCAS II modification decisions for all parties involved.

OTA concludes that a basic requirement for a successful operational evaluation program is having a critical mass of aircraft outfitted with TCAS II at an early date. If 15 to 30 percent of the commercial fleet (about 600 to 1,200 aircraft) were equipped with **TCAS II during 1990, a reasonable operational evaluation of system effects would be possible.** Operations under the evaluation should cover the full spectrum of geographical locations and aircraft and airspace types, including sufficient numbers at hubs to address high-density issues. FAA and industry must cooperate to plan and allocate sufficient resources for collecting, analyzing, and disseminating TCAS data. A wide range of expertise is required, including certification, air traffic, aviation medicine, safety, and TCAS program officials from FAA, airlines, TCAS and aircraft manufacturers, pilots' and controllers unions, and aviation human factors experts from NASA.

Although some TCAS II technology is still being developed, this need not prevent introducing TCAS. The major technology concerns that remain unresolved include:

- Displays: Only two display option types, the dedicated display and modified weather radar, have been flight tested. The combination traffic display/IVSI incorporates liquid crystal/flat panel technology that is new to commercial aviation. The small size and combination of functions in the traffic display/IVSI is opposed by ALPA, whose members cite human factors concerns. Some new glass cockpit aircraft have only one display option available — modifying the CRT systems. The display modifications for earlier electronic cockpit aircraft (such as the Boeing 757), will be very expensive, almost doubling installation costs for TCAS.[33] The aircraft manufacturers have not defined the necessary changes and are not expected to do so until summer 1989.

- **Ground test equipment:** While not required for TCAS, acceptable ground test equipment can reduce or eliminate flight test requirements and expedite installation check-out. Such equipment may prove necessary to meet the installation deadline, and none is yet available.

- **TCAS II for commuter aircraft:** Initial production versions **of** TCAS II may not fit in some Part 121 commuter aircraft (31 to 60 passengers) and questions remain about the effect the propellers and high wings that characterize most commuter aircraft will have on **TCAS** signals. The results of FAA testing, scheduled for late 1989, may come too late to give commuter airlines any reasonable chance of meeting the installation deadline.

Public Law 100-223 requires TCAS II systems to be upgradable to the performance standards for TCAS III. These performance standards give TCAS III a more accurate surveillance capability and an alternative escape maneuver selection in the horizontal plane. Even though these performance standards are currently under development, a number of common elements between TCAS II and TCAS III have been identified. Two manufacturers are advertising their TCAS II units as upgradable. Thus, it can be assumed that there will be some hardware and software commonality between TCAS II and

33. Ulf Gustafsson, United Airlines, personal communication, Feb. 8, 1989.

TCAS III, and that TCAS engineers will strive for minimum aircraft modifications for TCAS III.

However, OTA finds that a Federal specification of TCAS II upgradability is inappropriate at this time. Since FAA gives wide latitude for TCAS II designs, there is no reason to expect one manufacturer's TCAS II components to be compatible with another's, except for air-to-air coordination logic. Presently, there are no regulatory requirements for TCAS III.

Part II

Implementing TCAS

If you ask me if I would like to see . . . a good
collision avoidance system implemented . . .
I would say tomorrow. . . . Dealing with what we
now have, 1 cannot vote yes for the '91 deadline.
— Ulf Gustafsson, Staff Engineer, United Airlines, OTA Workshop

The commercial aviation industry fosters and adopts technological advances. Nonetheless, the proposed TCAS II implementation is unique in the combination of technological complexity, rapid introduction, and the number of aircraft affected. The introduction of technology such as jet engines, radar, or electronic cockpits pale in comparison since they arrived gradually over many years. Based on present airline plans, the proportion of the fleet equipped with TCAS II may go from less than 10 percent to over 80 percent in a 12-month period.

The closest analogy to this rapid introduction of a complex new technology is probably the ground proximity warning system (GPWS) requirement. Following a series of accidents in which airplanes flew into the ground — controlled flight into terrain or (C FIT) accidents — and congressional pressure, FAA issued a rule in December 1974, allowing U.S. airlines 1 year to outfit their fleets with electronic devices that warn of impending collisions with the ground. GPWS technology was sufficiently mature, but the program was initially plagued by technical problems, including excessive false alarms that eroded pilot confidence in the equipment. FAA had to extend the deadline by 6 months, and some airlines still did not comply until the end of 1976.[34] **However,** the **safety benefits out weighed these problems — the C FIT rate plummeted. Subsequent crashes were caused by pilots who ignored or turned off the GPWS.**

---

34. Edmund Preston, *Troubled Passage: The Federal Aviation Administration During the Nixon-Ford Term* (Washington, DC: U.S. Government Printing Office, 1987), pp. 156-158.

TCAS II is considerably more complex than the GPWS, interacting electronically with other TCAS II systems and providing pilots with a display of nearby traffic, warning of potential conflicts, and suggesting maneuvers for avoiding possible collisions — all new types of cockpit information. The aviation community is following closely the way each TCAS II design will meet the basic technical performance standards. Attention is increasingly focusing on the higher order or “system" effects of TCAS II, such as its influence on pilots and air traffic controllers (human factors) and the air traffic system. Most troublesome system effects could be identified within a few months under a structured operational evaluation program.

INSTALLATION OVERVIEW

Adapting TCAS II to the complex and diverse U.S. and worldwide transport fleets will require dedicated efforts by avionics and airframe manufacturers, FAA, NASA, ICAO, industry/government advisory groups, and most importantly, the airlines. The airlines and their contractors must redesign each aircraft presently in their fleets to accept additional new antennas, wiring, computers, and cockpit instruments and displays and complete the installations by December 30, 1991.35 Each aircraft type and model, such as the 13727-200, will require about 1,000 hours of engineering work.[36] Other configurations of a given type and model will require additional retrofit engineering (for example, United has 6 aircraft types, but will need about 14 STCs). Aircraft design changes, such as those needed for TCAS II, must be approved by FAA under the STC process. The first STC for each manufacturer's TCAS II will require extensive testing and analysis. Other aircraft types must have any differences in aircraft configuration

35. The airframe manufacturers have taken responsibility for redesigning in-production and future aircraft for TCAS.
36. Ulf Gustafsson, Staff Engineer, United Airlines, in Office of Technology Assessment, op. cit., footnote 7.

from previous TCAS II STCs analyzed and approved even though the TCAS II equipment is the same. This will take less analysis and time, but the effort will still be extensive. Efficiently addressing the myriad changes made to older airliners throughout their service lives will be especially troublesome.

Airlines may begin installing some provisions for TCAS II in advance, and many are planning to do so since the industry, through ARINC, has defined the form, fit, and function specifications for TCAS II, standardizing the size of components, the interwiring, and the location of plugs and connectors. Provisions include building equipment racks, cutting holes for antennas,[37] running wire bundles, and reconfiguring cockpits, as necessary.[38] Final provisions cannot be installed until STCs are granted following the delivery of production Change 6 TCAS II equipment in late 1989. Change 7 equipment will not be available until early 1990.

Modifying each aircraft and installing the TCAS II equipment will take 500 to 1,000 hours of labor, depending on the skills and experience of the technicians and the aircraft type and configuration.[39] The U.S. airline industry will need about 1,000 additional technicians[40] to meet the TCAS II workload without overtime or cutting back on other maintenance. TCAS II installation activities alone will require each aircraft to be grounded for about 5 days,[41] although these will not necessarily be consecutive days.

Each installation must be tested to ensure proper operation. The airlines expect to check out TCAS II on the ground. No test equipment is yet available, although two manufacturers have said they can provide it in early-1990.[42] Each TCAS II-outfitted

37. Airlines are expecting engineering data from manufacturers within the next few months establishing TCAS antenna locations for existing aircraft types.
38. At least three traffic display options are available, and few airlines have made final decisions.
39. OTA data; and Office of Technology Assessment, op. cit., footnote 7.
40. Ibid.
41. Page Avjet has stated it can commit to accomplishing TCAS retrofit during four overnight stays of the aircraft. Joe Wilson, Bendix/King, personal communication, Feb. 7, 1989.
42. Ibid.

aircraft could be flight tested, but doing so would add substantially to the total installation time and cost.

INSTALLATION ISSUES

TCAS II implementation issues include a need to start installation procedures before equipment is fully validated, a fast-paced installation rate, and a deadline for installation completion that will require aircraft to be out of service. The established timeframe will strain the resources of virtually every participating aviation organization. TCAS II manufacturers must produce and deliver equipment, airlines and others must redesign and modify aircraft, and FAA must certify equipment and altered aircraft. Questions about the technical quality, safety effects, and economic consequences accompany the introduction of any new and complex technology. However, such concerns are amplified in the case of TCAS II by the time pressure and number and variety of aircraft covered. TCAS II hardware and software, while successful to date in limited operations, are still being developed and may encounter "intermix"[43] obstacles. More so than for most other aviation technologies, understanding cockpit human factors and air traffic system effects is essential for TCAS II.

TCAS II **Equipment Manufacturing and Initial Certification**

In response to OTA inquiries, the three main TCAS II equipment manufacturers — Bendix/King, Honeywell, and Rockwell/Collins — indicated that they will be able to meet worldwide TCAS II needs during the next 3 years. These companies will begin an

43. While manufacturers will provide complete TCAS systems to their customers, some airlines may intermix components from different companies. For example, the communication link between the TCAS computer and the Mode S transponder is critical; each different combination of a Mode S transponder from one company and a TCAS computer from another will require a separate certification from the Federal Aviation Administration.

equipment demonstration and evaluation program using Change 6 logic with FAA in April 1989 leading to TSO and STC approval by Autumn 1989. Currently initial equipment delivery to airlines is scheduled for late 1989.

FAA set the baseline performance standards for TCAS II, including the latest version of the collision avoidance software known as MOPS Change 6. Change 6 and production versions of TCAS II have yet to be flight tested. Although few surprises are expected from the flight tests, airlines are expected to request further software changes to address concerns raised in the LIPs and to meet international standards, which are still being deliberated. FAA views software changes beyond Change 6 as enhancements, and any changes must be compatible with FAA's baseline TCAS II for approval.

Follow-up Certification of Airliner Modifications

With each aircraft type requiring an STC, a heavy load of engineering changes for review and approval will confront FAA Aircraft Certification Offices (ACOs). Moreover, approval of most STCs will require flight testing. FAA has designated a TCAS II certification team and has pledged to provide trained personnel to meet the requirements. The agency informed OTA that its ACOs should have sufficient numbers of engineers and inspectors to accomplish all TCAS II certifications, and ". . . does not anticipate at this time that it would need to relocate personnel or resources for TCAS II certification."[44] However, the magnitude of the burden on FAA will be partly a function of how many airlines independently pursue STCs instead of seeking a common source and partly of the number of variations necessary to cover the Nation's civilian aircraft fleet.

FAA needs validated engineering and performance data to certificate a retrofit. Once data have been certified for one aircraft type, only the data addressing the differences in other aircraft require confirmation and review. Industry coordination and cooperation to reduce redundant STC support work could lower the burden for FAA and

44. Melugin, op. cit., footnote 32.

industry. However, because such coordination is complicated and will require time consuming and extensive negotiation, it is not clear that cooperation will be cost-effective.

Turboprop transports, known as larger “commuters," may face TCAS II certification delays. Three major issues remain to be addressed including: the effect of high wings and propellers on TCAS II signals, necessary changes in the TCAS II algorithm to address the low maneuvering performance of some commuter aircraft, and whether TCAS II equipment designed for large jets will fit in the smaller commuters. FAA plans to sponsor a LIP for commuter aircraft later this year to seek answers to some of these questions.

Other special performance or limited production aircraft that operate now in U.S. airspace face difficulties in installing TCAS II. For example, the TCAS II computer logic and antenna design are incompatible with the supersonic Concorde.

installing TCAS II

The bulk of the airlines’ TCAS II installation workload will be in modifying aircraft. Many preparations for installing TCAS II can and will be made before the TCAS 11 equipment is delivered. Installing the TCAS II equipment itself will not be an undue burden, although system validation may prove cumbersome unless acceptable ground test equipment is available. Many of the large U.S. airlines informed OTA they ". . . will meet the deadline if (they) have to;"[45] other large and many small airlines could face difficulties.

The ARINC Characteristic 735 and antenna location data will be available to the airlines by June 1989, leaving about 2 1/2 years to complete all installations. To complete installation by December 1991, best industry estimates indicate that airlines and aircraft modification companies must add about 1,000 skilled technicians to their

45. Office of Technology Assessment, op. cit., footnote 7.

work forces. Airline expansion in recent years has drastically reduced the number of available technicians. Those airlines now hiring for TCAS II told OTA that they are encountering substantial difficulties finding experienced personnel and that to keep those technicians they have hired, they must raise salary levels. Because many mechanics are relatively inexperienced, they will require substantial extra time and supervision for their work. Additionally, some airlines indicated that their own maintenance facilities may be insufficient for the extra tasks. Faced with these shortages, airlines plan to contract out some TCAS II work, use more overtime, cut back on other discretionary maintenance, and petition for exemptions from other maintenance requirements, such as modifications of aging aircraft.[46]

Even if all testing and certification procedures proceed smoothly, uneventfully and promptly, most airlines will have to pull aircraft out of normal scheduled service to meet the deadline. Heavy maintenance periods (“D” checks) for large jets, which are long enough to permit TCAS II installation without disrupting scheduled passenger service, occur about once every 4 years. **Since the deadline leaves roughly 2 years for installations, about** 50 **percent of the U.S. fleet will have to be removed from service for at least a few days to have TCAS II installed if routine procedures are used** Other installation scheduling options are being explored by some airlines. Some airlines have suggested a phased approach using "C" checks, but none indicated to OTA that they have firm plans for such a program. During 1990 and 1991, on average an additional 1 percent of the U.S. fleet not previously scheduled for heavy maintenance will be on the ground each day due to TCAS II.

Contractors perform heavy maintenance and modifications for many airlines. These airlines, as well as those that will not have the capacity to handle the increased workload, must turn to independent modification companies to perform TCAS II

46. Ibid.

installations. Modification companies will face many of the same labor and resource limitations as the airlines in the face of this heavy demand for their services.

The airlines must install windshear warning systems during the same period as they are working on TCAS II. While requiring only about one-half the labor of TCAS II,[47] installing windshear systems requires using the same technicians and will make it difficult to accomplish other cockpit work concurrently. However, the airlines will find it most efficient to do windshear and TCAS II cockpit work during the same out-of-service period to minimize the number of times the sensitive cockpit instruments have to be disturbed.

Resource availability and the implementation deadline may have both direct and indirect safety and economic consequences. One direct effect of economics will manifest itself in the rate the airlines outfit their fleets with TCAS II. While the airlines must begin installing TCAS II wiring and other provisions as soon as possible in 1989, they can postpone the TCAS II equipment delivery (and therefore payment) until late in 1991, since installing the equipment is a much simpler task than installing provisions.[48] By delaying delivery, airlines also can minimize other costs if the TCAS II design should require early modifications. The effect of these circumstances is that over a few months between 1991 and early 1992, the commercial fleet and U.S. airspace may go from limited TCAS II exposure to almost total coverage. This would effectively eliminate the possibility of benefits from an operational evaluation program for TCAS II. It also postpones sales income for TCAS II manufacturers until the end of the demand period, creating possible cash flow problems during the time of heaviest production.

Technical Issues

The two technical issues facing TCAS II implementation, meeting the equipment

---

47. For some older aircraft, windshear warning and guidance system installation may take twice as long as the TCAS work.
48. Office of Technology Assessment, op. cit., footnote 7.

performance specifications and system effects from TCAS II operations, were discussed in the previous chapter. While most experts believe that TCAS II technology is fundamentally sound, questions remain as to whether TCAS II can be adapted satisfactorily to every commercial transport in the time allowed. Additionally, airlines will intermix different Mode S transponders, TCAS II computers, displays, antenna locations, and other equipment characteristics. This raises questions about the need for further evaluation and time for certification.

Everyone agrees that system or secondary effects of TCAS II on the traffic system will remain unknown until implementation of TCAS II in a substantial portion of the operating fleet. The complexity added by the human factor in the system prohibit suitable pre-implementation analysis and make realistic simulation extremely difficult.

IMPLEMENTATION FINDINGS

If TCAS II production rate is sufficient, FAA certification resources are available, and no technical barriers develop, TCAS II could be installed in most of the U.S. airline fleet by December 30, 1991. However, **OTA concludes that delays, especially those facing commuter and special configuration aircraft will probably prevent 100 percent compliance. Moreover, some airlines will endure greater economic hardship than others in meeting the deadline.** Figure 6 shows the conditions that must be met if installation is to be completed by the current deadline.

Installing TCAS II on an airliner is a complex process requiring substantial aircraft modification and FAA certification of the design changes. Airline fleets are diverse, making the FAA certification process potentially both time consuming and difficult and requiring more FAA personnel than the Agency has planned. FAA states that it has sufficient resources to meet demand; however, airlines may not be able to obtain certification quickly and move ahead with modifying their aircraft in a timely manner.

Figure 6. TCAS Implementation Flowchart

```
Sufficient numbers of
TCAS units are delivered to  ------------------ NO ---------------------> ALL INSTALLATIONS WILL NOT
the airline Industry                                                      BE COMPLETED BY 12/30/91
            |
           YES
           \|/
Each airline has
sufficient labor and
facilities to outfit         ------------------ NO ---------------------> ALL INSTALLATIONS WILL NOT
its aircraft by                                                           BE COMPLETED BY 12/30/91
December 30, 1991.
            |
           YES
           \|/
FAA certification resources
and process provide enough
time for the airlines,       ------------------ NO --------------------> ALL INSTALLATIONS WILL NOT
given their resources,                                                   BE COMPLETED BY 12/30/91
to meet the deadline.
            |
           YES
           \|/
Operational and
technological problems are   ------------------- NO --------------------> ALL INSTALLATIONS WILL NOT
minimal and do not delay                                                  BE COMPLETED BY 12/30/91
or lengthen installations.
            |
           YES
           \|/
The safety, technical , and,
economic consequences of     ------------------- NO --------------------> ALL INSTALLATIONS WILL NOT
the current schedule are                                                  BE COMPLETED BY 12/30/91
acceptable to Congress.
            |
           YES
           \|/
INSTALLATION FOR ThE ENTIRE FLEET
CAN BE COMPLETED BY DECEMBER 30, 1991
```

Moreover, as some airlines are intermixing TCAS II equipment from one manufacturer and Mode S transponders from another, each intermixed system will require full certification. OTA concludes that delays in certification are likely.

The airlines will have about 2 years to meet the congressional deadline. Most airlines, domestic and foreign, view the deadline as difficult at best and unachievable at worst, since installing TCAS II will double the rate at which airlines ground their aircraft for heavy maintenance. The major U.S. airlines should be able to meet the deadline if required, although other maintenance and modifications may suffer. However, those airlines late in planning or those with limited facilities and financial resources are likely to be unable to meet the deadline for the following reasons. Additional technicians will be needed for the installation work force, and the supply of trained technicians will probably not be adequate to meet all the needs for every airline. Limited ramp and hangar space and other maintenance requirements may compound the labor shortage. Additionally, support equipment that could help speed installation, such as ground testing equipment, is still being developed.

Depending on start-up and learning curve rates and equipment delivery dates, the aviation system may encounter high TCAS II installation rates in 1991 — with more than two-thirds of the fleet being equipped in less than 1 year. Most aviation experts familiar with TCAS II believe such a high installation rate is not a sufficiently prudent course for implementing such a complex safety technology.[49] While the fundamental technological concepts of TCAS II have been tested extensively, certain difficulties with complex aircraft systems often develop only in an operational setting. Thus an initial evaluation program for TCAS II has gained widespread industry and FAA support.

OTA finds that the cost consequences of out-of-service time for outfitting their fleets will not affect all **airlines equally.** The airline industry as a whole will suffer financially from out-of-service time only if some potential airline passengers decide not

49. OTA data; and Office of Technology Assessment, op. cit., footnote 7.

to fly at all. However it is likely that most passengers will switch airlines or travel time if their desired flight is pulled out of service. During 1990 and 1991, on average approximately 1 percent of the U.S. fleet (not previously scheduled for heavy maintenance) will be on the ground each day due to TCAS II, although these numbers may be much greater for some airlines during certain periods. This makes economic equity a major concern.

Airlines that plan and structure their programs to complete TCAS II installation by December 1991 will incur substantial costs to do so, although those airlines with the ability and schedule flexibility to minimize their passenger losses while capturing passengers turned away by other airlines may come out ahead in the long run. Airlines with financial or cash flow constraints may lose substantial revenue, especially if they are unable to obtain adequate financial, personnel, or facility resources to outfit their entire fleets by 1992 when unequipped aircraft will not be permitted to fly in U.S. airspace. While the effect on major transportation centers will be virtually invisible to the traveling public, a few smaller communities may find themselves with fewer and less convenient flights.

The airlines must install windshear warning systems and undertake major maintenance on older aircraft during the same period as they install TCAS II. The same technicians will be used to install windshear systems, and accomplishing other cockpit work will be difficult because of limited space. Maintenance of aging aircraft will also draw on ramp and hangar space. **OTA finds that out-of--service time and economic penalties due to TCAS II will be compounded by the windshear and aging aircraft requirements.**

Part III

Conclusions and Options

I think all of us have to acknowledge somewhere that while having safety legislated is not the ideal way to go, the fact .* . that Congress set a deadline has been a very significant piece of this program, and . . . for that, I think we owe the Congress a thanks.
— Robert Buley, Northwest Airlines, OTA Workshop

THE ISSUES

The basic issues associated with TCAS II legislation include the safety, technical, and economic consequences of rapid installation — by 1992 — in the Nation% commercial fleet. All three are interrelated; however the safety and technical issues are so closely connected that they will be summarized together. A fourth issue is the impact on international relations.

Safety and Technical Issues

The safety concerns related to TCAS II are twofold: 1) the as-yet-unknown effect of full TCAS II implementation on system safety, and 2) the possibility of reduced safety because resources are strained or diverted from other maintenance needs in order to implement TCAS II by December 30, 1991. FAA has not developed a well-defined plan for evaluating operational performance in a setting that includes a substantial portion of the Nation's fleet equipped with TCAS II. The limited installation programs undertaken to date have involved no more than two commercial aircraft and did not provide an adequate assessment of the effects of a fully-equipped fleet on the air traffic system. TCAS II technology is now well developed, and a more widespread operational evaluation is justified to determine whether software or hardware modifications are called for or whether pilot or air traffic control procedures must be changed. Without such a program, a worst case scenario is that the airlines would completely outfit their fleets only to learn that a technical problem requires major modification of TCAS II equipment. A structured evaluation program would allow most problems to be identified quickly, preventing further installation of flawed units and permitting equipment modifications to be made early in the installation program.

A successful operational evaluation would require a critical mass of aircraft to be outfitted with TCAS II at an early date. Operations under the evaluation should cover the full spectrum of geographical locations and aircraft and airspace types, including sufficient numbers at hubs to address high-density issues and assess the impact on air traffic controllers in heavily used airspace. The effects of TCAS II on pilot and controller performance are still unknown and must be carefully analyzed during the evaluation.

Regardless of the results of an evaluation period, airlines are aware that some upgrades to TCAS II will probably occur over the next 30 months, and they may postpone taking delivery of TCAS II equipment until near the installation deadline. This would permit airlines to avoid possible costs associated with removing TCAS and installing a modified version, but it would confront equipment manufacturers with serious cash flow problems. Moreover, this also means the air traffic system could suddenly be saturated with new equipment, and the resulting effects on the system are virtually impossible to predict.

Supplies of skilled labor, as well as ramp and hangar space, are limited. Thus, airlines may need to divert maintenance attention from other programs to install TCAS II on time. These strains on resources could degrade the quality of both TCAS II installations and other important maintenance and safety activities, such as those associated with aging aircraft.

Economics

The economic consequences of the implementation deadline will affect each airline differently. TCAS II installation would be least disruptive for airlines if it could be accomplished during the normal heavy maintenance cycle that occurs about every 4 years for each aircraft. However, the December 1991 deadline leaves the airlines only 2 years for fleetwide implementation, because production equipment of TCAS II will not be available until December 1989. To complete the work in 2 rather than 4 years will require airlines to hire additional labor, schedule more overtime, and take more aircraft out-of-service time. The increased workload may cause sequencing problems with other programs, such as aging aircraft requirements and windshear equipment installation. Airlines that are financially healthy are much better able to meet these demands than airlines with cash flow or labor problems.

Out-of-service time for aircraft raises equity issues for the various airlines. Some of these equity issues are separate from the direct costs of installing TCAS II. Airlines without any extra aircraft may have to eliminate some flights for short periods. These airlines are likely to lose passengers to other airlines, whereas companies that have extra aircraft in their fleets or the resources to lease them can avoid canceling any service. In addition, some communities served by airlines without extra aircraft may be inconvenienced during down time for the aircraft that normally serve them. Finally, the costs associated with the multiple maintenance requirements now in place may cause some airlines with older fleets to retire aircraft rather than complete the programs, further compounding out-of-service problems.

Airlines that do not meet the deadline for any reason will be penalized severely if unequipped aircraft are not permitted to fly in U.S. airspace in 1992. However, airlines that complete TCAS II installations on time will face substantial indirect cost penalties if their competitors do not commit similar resources and are granted extensions. If problems occur in early 1992 and TCAS equipment should need to be modified, all airlines will face substantial costs.

The TCAS II installation requirement has a different effect on the various U.S. TCAS manufacturers. Expecting over 6,000 orders from domestic and foreign airlines by the end of 1991, these companies have invested accordingly.[50] Under the current schedule, airlines may postpone taking delivery of equipment until late in 1991 to allow modifications to be made before their purchases are effective. Equipment manufacturers that were not early supporters of TCAS II development may reap benefits from such postponements, while those that invested heavily in development and testing programs will face cash flow problems as they gear up for production. A simple extension of the deadline could heighten cash flow problems by further postponing purchases.

International Issues

Foreign airlines contend that the installation of collision avoidance systems in international air transports should occur on the basis of agreed international standards and recoin mended practices. Such standards are under consideration in the International Civil Aviation Organization and are currently scheduled for adoption in 1990. Many question the appropriateness of the United States action in including foreign carriers within the scope of its TCAS II requirements, claiming this undermines the basic objectives of ICAO in producing international standards. Moreover, critics claim the United States may have abrogated Article 37 of the Convention on International Civil Aviation by its actions.[51]

An extended TCAS II implementation schedule could help ensure that U.S. and ICAO standards are compatible. If international airborne collision avoidance standards

---

50. Joe Wilson, Bendix/King, personal communication, Feb. 7, 1989.
51. Office of Technology Assessment, op. cit., footnote 7.

are completed and approved as expected by mid-1990, an international implementation schedule can then be established.[52]

CONCLUSIONS AND OPTIONS

OTA concludes that the TCAS II compliance deadline established in Public Law 100-223 (TCAS section) has some safety, economic, and international consequences not fully foreseen at the time of enactment. The TCAS II requirement is unique in the combination of technological complexity, rapid implementation, and the number of aircraft affected. Moreover, the extensive maintenance requirements associated with the aging of the national fleet were not anticipated when the legislation was enacted. Maintenance for aging aircraft will place severe demands on airline personnel and facilities resources concurrently with those needed for TCAS II.

Different groups concerned with aviation matters recognized some or many of the issues summarized in this report several months ago. Three possible congressional approaches were being discussed as OTA began this study in October 1988. The tradeoffs associated with each option are discussed below and summarized in Table 1 at the end of this section.

The **first option was a signal from the congressional leadership that Public Law 100-223 would remain unchanged, thus ensuring rapid implementation of TCAS Il.** The signal would be necessary because uncertainty over whether Congress will make any change has led some airlines to postpone planning and committing resources to TCAS II. These airlines are likely to find that facilities and personnel are unavailable once they do begin to prepare for TCAS II, since both types of resources have already been committed. An early decision by Congress not to reconsider the legislation can minimize, but not eliminate economic penalties for some of the industry groups. If the

52. M. Parkes, Civil Air Attache, British Embassy, in ibid.

current deadline is clearly confirmed, airlines will not gamble on an extension and delay implementing TCAS II.

However, **OTA finds a critical and immediate need for FAA and the airlines to define and undertake an operational evaluation program.** The current deadline does not appear to allow adequate time for this, given the constraints on certification, production, and installation capabilities.

The second option included explicit indication by congressional leaders that the deadline in the law was not going to be changed and that Congress encourages FAA's vague plans for a TCAS II transition program. However, even if FAA and industry tried to undertake a more well-defined transition program during late-l **990** and early-1991, the deadline under this option does not allow time for adequate evaluation. Delays are likely during the certification process, which is complicated enough that it is likely to strain both industry and FAA resources, limiting the capabilities for evaluation. Further, since some airlines may fail to meet the current deadline, FAA would have to exercise its authority to grant exemptions under this option as well as under option one.

Moreover, under any circumstances, **OTA finds that the input of air traffic control personnel to the TCAS II program must be stepped up considerably from its level to date.** Full participation by FAA air traffic control personnel is an essential component of any evaluation. The effects on the air traffic system must be assessed, including the reactions of pilots and controllers to TCAS II, and any initial problems resolved, so that the full benefits can be realized.

Furthermore, and regardless of any decision on the deadline, Congress may wish to ensure that FAA has adequate resources for the installation period. These will be necessary for the Agency to evaluate TCAS and maintain adequate oversight of other airline maintenance and modification programs to prevent possible safety diminution indirectly related to TCAS II requirements.

The third option included amending the law to extend the deadline and encouraging an unspecified operational evaluation. (This was basically the airline industry's position.) In the view of both domestic and foreign airlines, the implementation deadline is the most pressing TCAS II issue. **However, OTA concludes that if the deadline is extended with no other specific, required actions, most TCAS II safety benefits will be delayed, and equipment manufacturers will be severely penalized.**

Yet, the present TCAS II implementation requirement is extremely difficult for some segments of the industry. Aircraft that cannot easily be fitted with TCAS II because of technical problems, such as some older commuter turboprops, would probably require extensions without a longer installation period. Moreover, the unilateral U.S. action in requiring TCAS II equipment of foreign airlines has created ill feelings around the world. Many foreign carriers are likely to install TCAS II voluntarily for safety and competitive reasons, once **ICAO** standards are established. **Extending the deadline could ease international concerns and help synchronize ICAO's activities with U.S. requirements.**

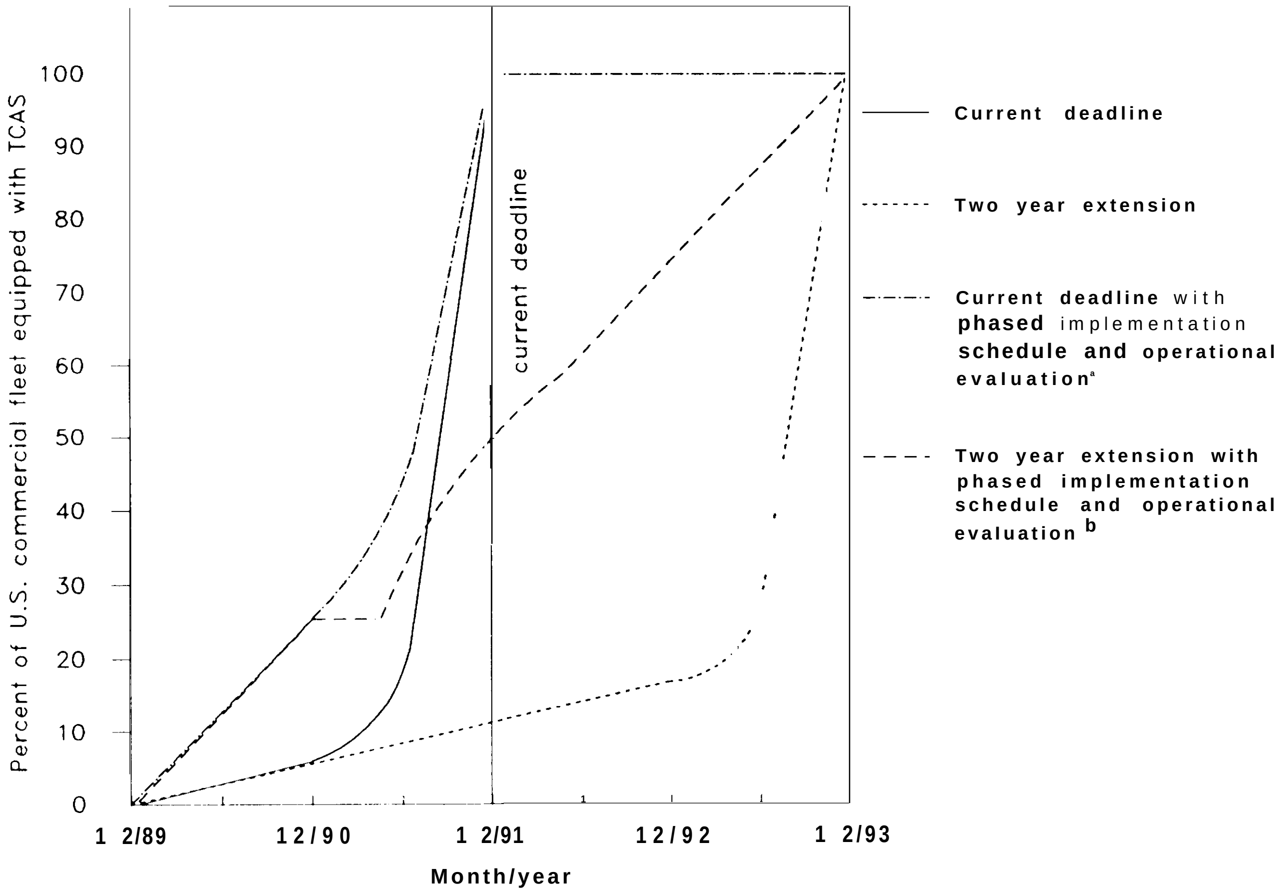
As OTA's study neared completion, a fourth option emerged — amending Public Law 100-223 to require a phased implementation schedule beginning in 1990 (to ensure early equipage of a substantial portion of the fleet) and a structured operational evaluation program, as well as extending the deadline. This would allow manufacturers to incorporate any necessary modifications before airlines took delivery of the balance of their orders. Sufficient airline resource limitations, economic inequities, and international implications stem from the present deadline for Congress to consider extending the installation schedule. **OTA finds that the fourth option is the best choice and that aviation safety will be best served by introducing TCAS II on commercial aircraft as soon as possible, by requiring a phased implementation schedule, and by providing for a structured evaluation program carried out jointly by industry and FAA to oversee the first year of operation.**

Prompt congressional consideration of any change to the law is important. OTA finds no reason to delay initial TCAS II implementation; yet, the forcing effect of legislation may well be necessary to ensure maximum safety benefits as early as possible and allow airlines to make appropriate plans for investments in personnel and equipment. Requiring and linking an operational evaluation program, a phased compliance schedule, and an extended deadline (the fourth option) will place additional responsibilities on each affected party, but it spreads the burdens more equitably than the other options.

OTA concludes that introducing TCAS early into a substantial portion of the commercial fleet and requiring a structured evaluation program conducted jointly between FAA and industry could ensure early safety benefits. Industry officials at OTA's workshop indicated that such an evaluation program might include a requirement that airlines purchase and install TCAS II equipment in 15 to 30 percent of the national fleet (600 to 1,200 aircraft) as soon as possible after production equipment is available (probably over the period from late spring to the end of 1990). The operational evaluation would be conducted over this time period, with the specific details and responsibilities to be worked out jointly under industry leadership. Congress could further require that 50 to 60 percent of the national fleet be equipped by the end of 1991 and fully equipped by the end of 1992 or sometime 1993. For an indication of the percent of the U.S. commercial fleet equipped with TCAS II over different time period options, see figure 7.

This combination of requirements and an extended deadline offers the opportunity for early identification of any technical and human factors problems during the operational evaluation. It also addresses economic and international issues more completely than simply extending the deadline. A phased compliance schedule balances greater safety from more TCAS II-equipped aircraft early in the program against a more lengthy period for full implementation. It minimizes the downside of a more flexible

Figure 7.– U.S. Fleet Equipped with TCAS and Possible Timing Options



[a] Time constraints with a 12/91 implementation deadline do not permit an installation level off during the operational evaluation and analysis.

[b] This curve suggests only one of several possibilities.

SOURCE: Office of Technology Assessment.

deadline for the TCAS II manufacturers by ensuring more early orders and permits identification of system safety effects and timely corrective actions.

An operational evaluation program also offers the airlines the equivalent of an insurance policy. For the relatively modest extra cost of early installation in portions of the fleet and analytical support, the industry and public gain peace of mind if TCAS II works well, and avert financial and safety penalties if TCAS II should need to be modified. Regardless of how well TCAS II works, early implementation and evaluation bring the most TCAS safety quickly to the public.

TABLE 1: EFFECTS OF TCAS OPTIONS

TCAS issues	No new legislative action	Same deadline and transition program	Deadline extension only	Phased implementation schedule, operational evaluation program, and deadline extension
	TCAS IMPLEMENTATION OPTIONS			
If TCAS performs adequately:				
(1) Level of TCAS safety benefits before 1992	+	+		+/-[a]
If TCAS equipment requires modification after initial implementation				
(2) Level of TCAS safety benefits before 1992		+		+
(3) Economic impact on industry		+	+	+
Regardless of actual TCAS performance:				
(4) System safety effects from TCAS identified by 1992	-	+	-	+
(5) Level of safety in other areas	-?	-?	+	+
(6) Economic impact on airlines	-	-	+	+
(7) Economic impact on TCAS manufacturers	+	+	-	+/-[b]
(8) Availability of TCAS component options and support equipment	-	-	+	+
(9) FAA certification resources	-	-	+	+
(10) International relations	-	-	+	+

KEY: (+) positive effect
- negative effect

a earlier initial benefits (+), but delayed full benefits (-)

b more early orders (+), but extended production run for same number of systems (-)

LIST OF ACRONYMS

AC	Advisory Circular
ACO	Aircraft Certification Offices
ALPA	Air Line Pilots Association
ARINC	Aeronautical Radio, Inc.
ATC	air traffic control
BCAS	beacon-based collision avoidance system
CAS	collision avoidance system
CFIT	controlled flight into terrain
CRT	cathode ray tube
FAA	Federal Aviation Administration
GPWS	ground proximity warning system
ICAO	International Civil Aviation Organization
IVSI	instantaneous vertical speed indicator
LIP	limited installation program
MOPS	minimum operational performance standards
NASA	National Aeronautics and Space Administration
NPRM	Notice of Proposed Rulemaking
RA	resolution advisory
RTCA	Radio Technical Commission for Aeronautics
STC	Supplemental Type Certificate
TA	traffic advisory
TC	Type Certificate
TCAS	Traffic Alert and Collision Avoidance System
TSO	Technical Standard Order