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

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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

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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

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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

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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

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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

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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

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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
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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.**