Traffic Alert and Collision Avoidance System (TCAS)
1981-1985
By Emory Reed

Background

Bendix Radio's work in phased-array radar had progressed to the point where beam forming for circular arrays was well understood and several projects had employed this innovative technique. Government agencies had been looking for a backup for ground based air traffic control since the 1950s. In the 1970s Bendix was one of three companies that submitted Airborne Collision Avoidance (ACAS) equipments. All three failed because the intruder as well as the protected aircraft had to carry the ACAS equipment. In the 1980s it was proposed to use the Air Traffic Control Beacon System (ATCRBS) as part of ACAS since the ATCRBS transponders were already installed on all aircraft that entered dense traffic areas. The first designs used the altitude response and velocity change to estimate collision probability, but not all beacons reported altitude. Also, without some visual correlation the pilot would not trust the blind commands to climb or dive. Bendix proposed to the FAA a small flat circular array that would provide angle information on the intruder with sufficient accuracy to present an accurate position and velocity vector of an intruder on a pilot's display. Collision avoidance commands could be given and believed by the pilot.

Program Summary

The Bendix Radio TCAS program consisted of two contracts with the Federal Aviation Administration (FAA). The first was to show, by feasibility study, that a system flying on an airplane in the year 2000 environment could make angle measurements on other aircraft with sufficient accuracy and in time combined with beacon altitude to calculate miss distances and avoid collisions by warning or commanding the pilot to take timely evasive action. The second contract was to build and test an Engineering Test Evaluation Unit (ETEU) to prove the analysis.

The proposal for Full Beacon Collision Avoidance (BCAS) was submitted to FAA in July 1979. The contract was awarded 14 January 1981. The first Design Management Plan and Monthly Management Report was submitted 15 February 1981. About that time, a proposal was made to the FAA for Bendix to build an ETEU based on the expected results of the study. Study results were good enough to persuade the FAA to award the ETEU contract by September 1981. The BCAS was renamed Traffic Alert and Collision Avoidance (TCAS). The ETEU was shipped to the FAA's Atlantic City Test Center in March 1983 for flight testing on the FAA's aircraft, the testing was completed in 1985, and the design information was forwarded to the Bendix Avionics Division in Fort Lauderdale for production. By this time, Bendix had been absorbed by Allied Signal. The production run was very successful, in part, because the Bendix equipment provided excellent angle information to the pilot displays - thus gaining pilot acceptance.

During the project, the Bendix equipment was called TCAS-II then Enhanced TCAS-II to differentiate it from the Lincoln Laboratory development. The Bendix Enhanced TCAS-II added angle information to the calculations, provided turn commands in addition to the change-altitude commands, and included other features.

Competition

Two years before the FAA awarded the contract to Bendix to include angle measurements, Dalmo Victor was awarded a contract to manufacture a system designed by Lincoln Laboratories. That system used beacon altitude and the Tau factor to estimate the threat and issue change-altitude commands. The Tau factor, invented by Dr. S. Morrell of Bendix Radio during the 1970s ACAS development, uses the change in velocity of the intruder to estimate collision probability.

It is the writer's opinion that angle information introduced by the Bendix Radio design was an absolute necessity for pilot acceptance of TCAS. Although horizontal commands provided by the Bendix ETEU were not incorporated in the TCAS system approved for international implementation, the angle measurements provided information suitable for displaying the plan view of all aircraft in the vicinity of interest. TCAS performance is extolled by pilots and installation is mandated by the FAA on all commercial aircraft.

Other features introduced by Bendix Radio that were included in the final ARINC approved system are: adaptive threat-driven controls, contoured surveillance, garble reduction, beam sharpening, beam splitting, monopulse measurements and receive sidelobe suppression, stabilized coordinate system, relative-motion display, aural alarm, false-alarm reduction, and threat detection and resolution.

Engineering Test Unit - ETEU

The directional antenna as shown in figure 1 was the primary hardware development that allowed angle measurements of one degree accuracy to be made on intruders within 20 miles. Eight electronically steerable elements were included in the one-inch high by fourteen-inch diameter antennas curved to fit top and bottom of the FAA's Boeing 727.

No effort was made to package the ETEU design in a form representative of airline operational needs. Rather, the emphasis was placed on flexible packaging and computer programming that facilitated the test and evaluation. Although allowance was made for changes, very few hardware changes were required after the initial check-out of wire wrapped cards. Control and visual display was provided by an Apple computer. Test data was recorded on a commercially available tape recorder. Figure 2 shows the ETEU equipment mounted on four racks as installed on the FAA's N-40 Boeing 727. In addition to the rack-mounted equipment, a weather radar monitor mounted in the cockpit displayed relative altitudes and velocity vectors, and collision threat levels of all aircraft in the vicinity.

ETEU Test Results

Tests were run on the system mounted in the FAA's N-40 to validate its ability to reduce unnecessary alarms, to provide relative motion on traffic advisories, and to give appropriate horizontal resolution advisories. To measure angular accuracy, two aircraft were flown in both linear encounters and circular orbits over the Technical Center's instrumented test range. The FAA's Convair 580 with a regular ATCRBS transponder on board was used as the target aircraft (intruder). The FAA's precision trackers provided accurate position of one aircraft relative to the other as a function of time. Since the trackers were reported to be five times more accurate than the TCAS, all errors were attributed to the TCAS. After flying many tests, it was shown to have the accuracy necessary for calculating correct resolution advisories.

To test the ETEU in high-density environments, both test aircraft were flown to the Los Angeles Basin and sixty-eight encounters were flown over an accumulative fifteen hours in five days. Peak densities ranged up to 0.26 aircraft per square mile or 13 aircraft within four miles. In all 68 encounters, Enhanced TCAS-II (ETEU) acquired the Convair near the edge of coverage, maintained an accurate track on the target through closest point of approach (CPA), displayed relative position and velocity vector of the threatening aircraft, and generated timely and appropriate resolution advisories even for fake-out maneuvers. Of most interest were resolution advisories on threatening aircraft of opportunity. In the Air-Traffic-Controller controlled environment, that should not happen - thus showing the need for TCAS. The FAA pilots, after flying in the high-density environments of the LA Basin, claimed they would not fly there without TCAS.

By 1995, all commercial aircraft carrying 19 passengers or more were mandated to have TCAS. All private jet pilots wanted the streamlined version. Bendix (Allied Signal) commanded a major portion of the estimated 4,000 installations and thus made valuable profits.

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