TIME AND FREQUENCY RELATING TO COLLISION AVOIDANCE SYSTEM

by

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This paper is a discussion of the history of the collision avoidance program and the current status of FAA plans and requirements. First, however, some basic definitions will be presented. A collision avoidance system (CAS) is an all-weather system which detects all potentially dangerous intruders, automatically evaluates the degree of the threat, and, if necessary, indicates a safe, evasive manuever to the pilot. A cooperative system is one which is only capable of detecting those aircraft which are equipped with the same cooperating system; that is, there is an active exchange of information between the aircraft. A non-cooperative system would protect against any other aircraft, equipped or not. While our objective is the development of non-cooperative systems, it is a fact today that the most promising CAS is a cooperative system.

The primary mission of the FAA is the safe and efficient movement of air traffic, with the emphasis on safety; as such the entire traffic control system can be thought of as a collision avoidance system. However, the philosophy behind our CAS program has been to search for a collision avoidance capability independent of the ground base air traffic control (ATC) system which could serve as a backup in the event of a failure in the ATC system and which could provide protection to aircraft in areas not serviced by an ATC system. In addition, our search has been directed primarily toward a collision avoidance capability utilizing an air-to-air data transfer. Again, it should be emphasized that the ATC system is, and will remain, the primary method of controlling air traffic; a CAS will simply serve as a back-up, not as a substitute for it. Much research on the CAS has been done in government and industry and quite a long time ago it was realized that a forum was needed for a continuing exchange of information on the subject. As a result, in 1959, the FAA formed the Collision Prevention Advisory Group, commonly known as COPAG. Membership is made up of representatives from government agencies and from selected civil aviation associations which best represent the majority of the airspace users; that is, those who have demonstrated both an interest and a competence in areas pertinent to mid-air collisions. The present members are from the FAA, NASA, the National Transportation Safety Board, the Army, the Navy, the Air Force, the Air Transport Association, the Aircraft Owners and Pilots Association, the Airlines Pilots Association, the National Business Aircraft Association, the National Pilots Association, and the National Air Transportation Conferences, Inc. The representative from the FAA serves as chairman. The group consists of organizations that are not involved in the manufacture or selling of commercial hardware, so there are no conflicts in this respect. Their primary function is to advise FAA regarding aspects of the mid-air collision problem, unique requirements, proposed solutions, etc. There is no voting in COPAG; it just provides an opportunity to consider everyone's needs and opinions. Since its inception, COPAG has kept abreast of FAA programs in these areas, has influenced them, and has assisted in carrying them out.

In order to provide some knowledge of the background of CAS, some of the completed projects should be mentioned. In 1958 we contracted with Bendix Corporation for a collision avoidance system which, since then, has come to be known as the ground bounce system. This system called for the transmission of a planes' altitude on a to-whom-it-may-concern basis.

Reception was both by the direct path and by the indirect, reflection path from the earth or the ground bounce. Thus, the receiving aircraft, knowing its own altitude and having been informed of the intruder's altitude and taking into consideration the time difference between direct and reflective pulses, could compute the range to the intruder. Successive computations of ranges were then made to determine range rate. Range divided by range rate, τ , was then computed. This contract with Bendix produced flyable hardware in 1961 and established the feasibility of the τ evaluator for the non-accelerating flight regime. However, the data exchange technique was not reliable and too much computation time was required. The obvious recommendations were to continue to search for a better data exchange technique and to reduce the threat evaluation time required.

Our next hardware contract was with the Sperry-Rand Corporation for a CAS which utilized an interrogate-transpond data exchange technique. This system utilized both an omnidirectional and a scanning antenna and exchanged altitude and velocity information. With this exchanged information and range and bearing measurements, an attempt was made to solve the collision triangle for the normal velocity component; i.e., that velocity component normal to the closing rate vector or line of sight. The threat evaluation criteria employed were relative altitude, range divided by range rate (τ), and normal velocity. If normal velocity is zero, and the range is closing, a collision course exists. The evaluation of this equipment was limited to bench tests only, due to the status of other contractual efforts at the time. These were a hardware contract with National Radio Company to investigate a time-frequency (TF) data exchange concept and an analysis computer simulation contract with Collins Radio Company. The TF concept involves synchronization in time and frequency of all cooperative aircraft so that range and closing velocity could be determined from the one-way propagation time and doppler frequency respectively. This effectively allowed the threat evaluation to be accomplished in a very short period of time and eliminated any mutual interference considerations, since time synchronization permitted one, and only one aircraft, to transmit at any one given time. We concluded from this hardware effort that the TF concept was indeed feasible and appeared very promising.

One task of the contract with Collins Radio Company was to consider all the promising CAS proposals and to recommend the most promising for concentrated effort. As a result of this analysis, the time-frequency concept was selected as the most promising. It still may be considered the best method, although several proponents of interrogated transpond techniques contend that the data processing state-of-the-art is now such that the inherent mutual interference problem of those techniques can now be overcome. Having decided that time-frequency was the best method, we prepared an engineering requirement for procurement of a time-frequency test bed whose initial primary purpose was the investigation of collision avoidance. This engineering requirement was reviewed by the members of COPAG and was supported by them. In late 1966, however, the Air Transport Association, a COPAG member, had second thoughts on the subject and in a letter to our administrator, requested cancellation of the planned procurement. As an alternate, they offered the following: the ATA would create the CAS Technical Working Group composed of representatives from the major avionic firms, interested government agencies, and industry experts in the TF technology. This group would convene and jointly prepare a CAS specification to which interested manufacturers would build equipment, at their own expense, for flight testing by the ATA. Because of certain obvious advantages in this arrangement, such as no government funding, we participated in the Technical Working Group. During the course of the Technical Working Group deliberations, it became apparent that a network of master time-disseminating ground stations would greatly simplify system operation. After discussion and analysis of the problem, it was determined that a synchronization requirement for these ground stations would be $\pm \frac{1}{2}$

microsecond between any ground station in the network and a master time. After considering this, the FAA went on record to the effect that, should the ATA system prove successful and become implemented, we would procure, install, and maintain the required ground stations.

It is now estimated that participating manufacturers have invested in excess of ten million dollars into the program. Equipment has been built by Bendix, McDonnell-Douglas, Sierra Research, and Wilcox to the specification prepared by the Technical Working Group. Flight test and evaluation of this equipment has been completed and no major technical problems appear to have been encountered. Based on the results of these flight tests, and on fast-time computer simulations by both FAA and the Technical Working Group, the CAS threat evaluation and manuever logics have been changed. However, operational questions which are impossible to evaluate with a limited number of equipments remained unanswered. For instance, what is the impact of the CAS on the ATC system in the area of false alarms? What is the effect on arrival and departure rates and what is the effect on the air traffic controller when aircraft make a sudden, perhaps unexpected, manuever? These questions and other questions are being investigated in a dynamic simulation, with controllers in the loop, at our Atlantic City Test Facility. The exploratory phase of this simulation was completed in late July, and the final report is due in February 1972. Tentative conclusions reached indicate that controllers can adapt to the effects of the CAS by modifying their control techniques. However, under certain configurations, this can result in a slight decrease in the rate of take-offs and landings per hour. While preliminary indications lead us to be optimistic, detailed analyses of the data and additional simulation are necessary before an optimum manuever logic for terminal area operations can be formulated. Follow-up simulation activity in this area is planned for the 1st or 2nd quarter of FY73. Hopefully, after follow-up simulation, our air traffic service will be in a position to state just what the significance of the CAS ATC interaction is and how a CAS can be used to supplement and assist the air traffic control system.

A Senate hearing on the subject of collision avoidance systems is scheduled for November 30. It was brought about by a bill, introduced for consideration by Senator Moss, to make collision avoidance systems and pilot warning instruments a requirement in aircraft in the very near future. However, Senator Moss, in an entry into the Congressional Records, indicated that one of the primary purposes of the introduction of the bill was simply to get expert testimony on the subject before Congress. The point is that the FAA and the Air Transport Association are doing quite a bit of work in preparation for that hearing.

Certain airlines have expressed a desire to proceed with fleet implementation of a collision avoidance system on a voluntary basis. In fact, Piedmont Airlines has already signed a letter of intent to procure collision avoidance system equipment from McDonnell-Douglas, and United Airlines is flying two sets of McDonnell-Douglas equipment in order to obtain maintenance and other associated data. In conformance with the desire of United Airlines, McDonnell-Douglas has petitioned the Federal Communications Commission for an operational frequency license in the provisional U.S. allocated CAS frequency band which is 1592.5 megahertz to 1622.5 megahertz, a total of 30 megahertz. While an experimental license already exists, the operational license will mean that a buyer of CAS equipment of the type specified by the Technical Working Group will be assured of receiving a regular FCC license to radiate and be protected against any harmful radio interference from other systems in accordance with the applicable FCC and Office of Telecommunication policy rules and regulations. The FAA's position on that frequency application is being reviewed.

The most promising systems proposed are cooperative in nature. Therefore, only one system is desired wherein all airplanes carrying collision avoidance equipment work with each other. However, there has been no decision reached in the agency on the matter of picking a system. The FAA does support the voluntary use of the equipment by the airlines, but it is felt that there are too many unanswered questions to predict if, or when, such a system would become a requirement.

Within the FAA, time-frequency is the main directed effort. However, the agency, in conjunction with other government agencies is monitoring other efforts in this field, one being a contract that the Navy has with RCA to test a portion of their collision avoidance system. Action is now underway to develop a time-frequency ground station. The FAA has a contract with Sierra Research Corporation to investigate the possibility of utilizing DME stations, suitably modified, to provide a ground-air synchronization capability. We are also about to request proposals for a more accurate and sophisticated form of ground station which, along with providing the ground-air synchronization function, will provide a performance check of the CAS equipment. Complementing these hardware efforts, the FAA is about to request proposals for a ground station network configuration study which will determine the optimum number, location, and type of ground station required, along with the best implementation priority. If the T/F system is approved, the schedule calls for the installation of the ground network between 1974 and 1978. This reasonably fits with the airline implementation schedule set up previously.

Another effort being made, which will be continued through FY72 is the investigation of techniques for the synchronization of a ground station network with master time. It is felt that the synchronization, at least of the developmental ground station network, will be accomplished by the fly-by technique; that is, synchronization with a standard carried by an aircraft specifically for that purpose. Ultimately, a more efficient method, such as satellite relay will be necessary. In relation to this, the FAA is in the preliminary discussion phase with NASA, Goddard to try to set up a joint program to investigate satellite usage for synchronization. The objective of the experiment is to evaluate a method of disseminating precise time and time interval from a master reference time station to a large number of ground stations. This would be done by time synchronizing the clocks at the ground station, via a communication relay satellite to the clocks at the master station. The operating data obtained from the experiment will be of value in designing the ground facilities for the T/F collision avoidance system, will augment radio astronomical studies, and will add to the data needed for the precise synchronization of national and international clocks. As stated before, the requirement for the time-frequency ground station synchronization network is to maintain time in all ground stations to within $\pm \frac{1}{2}$ microsecond, 3σ, of a master time reference. The rms value then is 167 nanoseconds and, if we permit a 100-nanosecond drift in each ground station between synchronization periods, we are looking for at least 60-nanosecond synchronization accuracy. There is the additional requirement that the synchronization be absolute, rather than relative, timing accuracy. It is hoped that the achievable level of synchronization accuracy will be shown for (1) laboratory conditions, (2) a situation where a satellite transponder with a common transmitter-receiver on the ground is used, and (3) a situation where two widely separated ground stations are used via the satellite transponder. As we said before, this is still in the preliminary discussion phases.

In summary, the FAA hopes to issue an RFP in the immediate future to determine the number, type, location, and implementation priority of the required synchronizing ground stations. An existing contract is for study of the possibility of providing a ground-air synchronization function via suitably modified distance measuring equipment (DME). The results of this study are expected in mid-1972. An RFP will be issued fairly soon for development of a more accurate and sophisticated ground station which will be capable of testing the operation of the airborne CAS equipment. The FAA is participating with other government agencies--the Navy in particular--in the testing and evaluation of the RCA correlator which is the data processing heart of their system.

Just recently an inter-departmental group on collision avoidance and pilot warning has been formed. Members are from the Department of Defense, FAA, and NASA. There has been one meeting which was primarily an introductory meeting. The purpose of the group is to accomplish more work in the collision avoidance area, in technologies other than TF, in an effort to determine the best system, and to make use of other government expertise, facilities, etc.

DISCUSSION

LCDR SEELEY: I wonder just what interface on an international nature might you have had in this area. I understood the French might be doing some work in this area.

MR. BRENNAN: We have heard the same thing. In fact several months ago, a telegram was sent to our representative in France in an attempt to determine exactly what they were doing and in a followup just recently, another telegram was sent, but just what the French are doing, what they're accomplishing, I don't know. However, this subject has been informally discussed in various ICAO conferences and it is an item for discussion at the Seventh ANC Conference in Montreal, which is next spring. So, there has been informal coordination on an international level.

LCDR SEELEY: The second question I had pertains to the candidate systems or references for this master time reference which you mentioned had not yet been chosen.

MR. BRENNAN: No decision has been made and on an informal basis the only two candidates I know of are the Naval Observatory and the National Bureau of Standards. We haven't thought about operational problems involved one way or the other, I think it's a little preliminary at this time in the program to discuss that.

LCDR SEELEY: My final question is in regard to the shift that is coming on January 1, 1972; how that might affect your plans?

MR. BRENNAN: I don't know any of the details but certainly the shift shouldn't affect us, because we have no ground stations to be affected.

MR. WATSON: The ATA specification is set up for A-1 frequency. This is a very good thing, in going to the A-1 frequency and the new UTC specification. Our interfaces are very smooth compared to what it would have been with the offset.

DR. HAFELE: You mentioned a network of coordinated time on the ground for synchronization. Are you thinking of stations every hundred miles on a grid work? How far, throughout the United States, throughout the world? I have some ideas on coordinating time on the ground like that and I wondered what extent you had in mind.

MR. BRENNAN: The RFP that I mentioned, will give the number, location, and implementation priority of ground stations, considering the system characteristics that have been described by the Technical Working Group. These considerations are the power, the time hierarchy system, and the altitude coverage that would be required or that we would want. It will be similar to a grid network, but not exactly located on a square grid or rectangular grid. It would be a function of coverage required and utility to be gained by certain locations; for instance, you will service more aircraft with a ground station at Idlewild than possibly another location. This study, we hope will come up with those answers.

DR. HAFELE: You said that these stations should be synchronized to within one-half millisecond.

MR. BRENNAN: Plus or minus $\frac{1}{2}$ microsecond of a master time. Such master time will be decided upon in the future.

MR. GATTERER: I would like to read again some comments I made in my talk the other day with regard to the Synchronous Meteorological Satellite (SMS), Geostationary Operational Environmental Satellite (GOES) which is a Department of Commerce (DOC) satellite to be operated by NOAA after a launch sometime in early 1973. It is still in the planning stage but we hope to provide one-tenth microsecond timing at 29 hertz.

MR. BRENNAN: While the frequency band for the collision avoidance system developed by the ATA is L band, 1592.5 to 1622.5 megahertz, the subject of synchronizing the ground stations is left open. The proposer that got this contract would analyze this a little further. In other words we're not saying you have to do it on that frequency and we're not saying you can't do it either, this will be one of the things to look into.

MR. FOSQUE: Some time ago, questions were raised regarding the CAS and how it might inter-act with the ordinary control procedures. I understood you to say that the FAA position was to encourage the ATA to implement some sort of system and to try this out. If so, how do you plan to take care of the possible interference with normal control procedures?

MR. BRENNAN: The agency position is that they are for the voluntary use of collision avoidance systems by anybody. However, that depends on the formulation of some rules, guidelines, and regulations, as to how a collision avoidance system would fit into the air traffic system with the least disruptive effect and the most beneficial effect. The simulation that we've been accomplishing at our Atlantic City facility is towards that end. However, as I understand the situation right now, there are still unanswered questions which we hope to answer with followup simulation early next year. Subsequent to that simulation we are hoping the air traffic service will be in a position to state just how a collision avoidance system utilizing range, range rate, altitude information, threat evaluation, and manuever logic of that type can fit into the air traffic system. You are quite right; that is the critical path item right now. On an operational basis, I don't think collision avoidance systems can be implemented until the air traffic service makes the decision.