pensator (16TC). The theoretical limit for the number of terms that any aircraft can have is 16. Within three flights, the FOM is reduced to 2.5 gammas. At this time it became necessary to replace the 16-term computation procedure with a trim procedure. With the revised procedure, it should have been possible to decrease further the FOM to about 1.5 gammas. A FOM of this order would represent almost pure AN/ASQ-8 system noise. Once this level is reached, further work will be limited by the sensitivity of the present magnetometer.

Future Plans

The feasibility of an optically pumped magnetometer system for the helicopter is being investigated. With such a system, which has a sensitivity of 0.01 gamma, it will be possible to explore fully the potential of the CHSS-2 helicopter as a MAD platform.

References

[1] "CHSS-2 MAD—Feasibility of an Inboard Installation by Measurement of Aircraft Magnetic Fields," VX-10 Final Rept., Feb. 17, 1965, Experimental Squadron 10, Shearwater, Nova Scotia.

[2] Rept. H1037, Nov. 1, 1966, United Aircraft of Canada Ltd.

False Signal Rejection in Optical-Infrared Collision Warning Systems

John A. Decker Jr.* and Melvyn G. Morris†
Comstock and Wescott Inc., Cambridge, Mass.

AND

Martin O. Harwit‡
Cornell University, Ithaca, N.Y.

Introduction

The problem of mid-air aircraft collisions is becoming increasingly severe as the air traffic density grows, and is rapidly approaching a critical point in the airspace near major terminals.[1] Many collision-avoidance systems have been proposed in the past, ranging from sophisticated onboard automatic sensors directly coupled to the aircraft's autopilot, to an extension of positive control by radar-aided ground controllers to cover all aircraft movements. In general, the ground-based systems, although clearly the best long-term solution, would require major modifications to existing facilities, the attainment of which is years in the future, at best. In the meantime, there exists an immediate requirement for a simple, inexpensive collision-avoidance system, particularly for use by general aviation aircraft. This immediate, specific need has been recognized by both NASA and the FAA, and has led to a recent NASA request for proposals[2] designed to implement such a collision-avoidance system.

In this system, every aircraft is to be equipped with a Xenon-discharge beacon lamp that emits approximately one flash per second. This flash would produce both visible light and infrared radiation in the wavelength band from 0.8 to 1.0 μ. Every aircraft would also be equipped with a set of infrared detectors whose detection response would be optimized for this wavelength band; commercially available silicon semiconductor photodetectors will suffice. (This wavelength band, specifically the 0.9 μ region, provides the fortunate coincidence of an intense line-spectrum radiation emission from the Xenon lamp, the maximum sensitivity of silicon photodetectors, and a maximum transmission "window" of both dry and wet atmospheres.[3])

Infrared radiation emitted from the Xenon light on a "target" aircraft is thus transmitted through any atmospheric haze, etc., that may be present and is sensed by the photodetectors on the "protected" aircraft at ranges substantially greater than the normal visual range for the same atmospheric conditions. The signal from the infrared detectors is analyzed electronically and used to activate an audible-warning horn. In addition, the approximate location and range (determined by signal-strength techniques) of the target aircraft is displayed on a panel-mounted collision warning indicator. This alerts the pilot to the possibility of a collision and helps him visually to locate the intruder; any evasive action taken will normally be based on the pilot's final visual sighting of the target aircraft. The function of the collision-avoidance system is to alert the pilot to possible danger and to tell him approximately where to look for the source of this danger.

Problems

There are two major problems involved in setting up such a collision warning system.

1) The rejection of all signals other than those from aircraft Xenon-discharge lights involves the rejection or discrimination against direct or scattered sunlight, moonlight, artificial illumination from city lights, and atmospheric OH emission lines in the spectral region beyond about 8000Å.

2) The problem of self-illumination, namely that the light source on the protected plane is so strong that stray light from its own lamp reflected off parts of the plane, or even off nearby wisps of clouds, could produce false signals. These signals can be eliminated by discriminating against any signals received during the time when the aircraft's own Xenon flash tube is on. However, that would mean that roughly one target plane in 500 would emit a flash that would overlap in time with the flash from the protected plane and would therefore not be detected; one cannot afford to have this high a probability of a target plane remaining undetected.

Solutions

1) Perhaps the best way of attaining the necessary degree of false signal discrimination is through an electronic scheme which effectively measures the light pulse duration. All the natural "false" light sources mentioned previously vary slowly with time; the sun, for instance, may disappear behind clouds, but the time scale involved is quite slow compared to the millisecond-duration flash of a Xenon discharge. Artificial lights, on the other hand, can be turned on quite rapidly. Once turned on, however, these lights tend to remain lit for some time. This means that a circuit requiring both a fast turn-on and a subsequent turn-off, 1 msec later, can be used to discriminate against most natural and artificial lights. From time to time a false signal will, of course, be registered; one might think, for instance, of sunlight reflected off a distant moving automobile windshield. Such events, however, are rare and will simply contribute to the over-all system noise. This is not too serious, because the presence of a target plane will generally be characterized by a series of signals spaced at approximately 1-sec intervals, while the noise sources would usually lack this repetition rate.

2) We have already mentioned that one can eliminate difficulties arising from self illumination by discriminating against signals received during the flash of the protected plane's own lamp. There are a number of ways of doing this electronically, the simplest being merely to turn off the detector for the duration of the flash; more sophisticated

Received September 17, 1968.

* Director, Physics Group, Space Physics Division. Member AIAA.

† Director of Electrical Engineering, Space Physics Division.

‡ Professor of Astronomy, Center for Radiophysics and Space Research.

systems would have an identical effect. No suitable optical means seem to exist for eliminating this interference. Even if great pains were taken to baffle the receiving optics against stray radiation reflected off the plane itself, one would not be able to discriminate against radiation reflected from nearby clouds; such clouds could easily lie directly in the detector's field of view and would therefore appear as genuine targets. Electronic discrimination against self illumination, therefore, is much to be preferred. It does raise one difficulty, however, if the duration of the Xenon discharge flash is about 1 msec and the repetition rate is one flash/sec, there exists approximately one chance in 500 that an aircraft on a collision course with the protected plane would have a coincident flash occurring while the protected plane's detectors were turned off; the aircraft would therefore remain undetected. A probability of one in 500 aircraft remaining undetected is far too high.

The main purpose of our Note is to show that this difficulty can be reduced to inconsequentially small proportions. This can be done quite simply by introducing a certain amount of random "jitter" into the timing of the Xenon flashes. If the Xenon light source is deliberately made to fire at a random time within an interval of, say, 20 msec around the one flash/sec repetition period, individual flashes that were exactly coincidental would still be ignored, but the chances of ignoring all the flashes from any given target plane are reduced by a factor of approximately $n^{(\Delta t_j/\Delta t_f)}$, where n is the number of flashes one would normally expect to detect during a collision course approach and where the exponent represents the ratio of the time uncertainty introduced by the jitter to the duration of the flash. Thus, if n were as low as 10 (in very unfavorable circumstances) and if $\Delta t_j/\Delta t_f$ were 10 also, there would be only about one chance in 10^{10} that no flash at all would be detected by either plane before colliding. In addition, there would be only one chance in 100 that the signals from the two planes would be that closely phased anyhow, and the over-all odds are therefore reduced to about one in 10^{12}; this represents satisfactorily high odds. In actual practice, the odds could be somewhat higher still, because one would expect n to be considerably higher than 10. On the other hand, the pilot would like to register more than just one flash from an approaching plane before a collision, if at all possible. These two factors more or less cancel, and representative system odds therefore appear to be about one chance in 10^{12} that two planes headed for a collision would not see each other because of coincidences in their own flashing rates. If even greater safety factors are considered desirable, a slight increase in $\Delta t_j/\Delta t_f$ can improve these odds substantially.

One can augment this action of the jitter by systematically making the flash repetition period different for different aircraft, so that the repetition period for two arbitrary approaching planes would differ by some 20 to 50 msec. This can be done either by using a relatively crude timing system design which would statistically assure that the repetition periods of individual lights were randomly distributed within, say, a 50-msec range around 1 cps, or by using a high-quality flasher design with repetition rates that are systematically distributed within the same 50-msec range. The first method, presumably, is much less expensive and should be equally effective.

References

[1] Thompson, F. L., "Air Safety?," *Aeronautics and Astronautics*, Vol. 6, No. 7, July 1968, p. 25.

[2] "Request for Proposal No. ERC/R&D SA-8-001," July 1968, NASA Electronics Research Center, Cambridge, Mass.

[3] Elterman, L., "Parameters for Attenuation in the Atmospheric Windows for Fifteen Wavelengths," *Applied Optics*, Vol. 3, No. 6, June 1964, pp. 745–749; also Hedelman, S. and Nelson, D. C., "A Direct-Reading Comparison Spectroradiometer," *Applied Optics*, Vol. 5, No. 4, April 1966, pp. 537–544.

A Comparison of Access Systems to Present World Airports

SECOR D. BROWNE*

Massachusetts Institute of Technology, Cambridge, Mass.

THIS Note deals with existing airport access systems and basically utilizes data compiled by the Port of New York Authority and published in July 1968. This report was based on a survey conducted by the Authority beginning in November of 1966 to which 23 of the world's major airports responded.

Since, in all cases, an access system by rail is competitive with highways, the distances, travel times, and frequency of service at both peak and off-peak periods are the basic data for comparison. Unfortunately, the questionnaire did not request highway journey times for private automobile and taxi.

There is every indication that in the choice of an airport access mode there is relatively little fare sensitivity or preference for vehicle type compared with such matters as exclusive right-of-way, transfers, baggage conveyance and handling, number of stops, or the actual distance the passenger must walk with or without luggage between the access vehicle and the aircraft.

It will be perhaps useful here to quote from the Port of New York Authority's summary:

> The questionnaires reveal that about one-half million daily airport travelers of all types enter the 23 airports surveyed in this study of ground access between central business districts and airports. Practically all of them use highway transport modes: automobile, taxis, coach-limo services, and to a considerably lesser extent, public bus, subway-bus combinations, and helicopter services.
>
> Rail passenger services link 11 of the 23 airports with the central business districts, but collectively serve few airport travelers. Several of the rail lines reach only the peripheries of the airports, and not all of these have bus connections to the airline passenger terminal buildings, drastically limiting their value. Only four of the 23 airports actually have direct rapid transit rail service to the airline passenger terminal buildings. One, Berlin-Tempelhof, is a station on one of the city's subway lines. Two of the airports, Brussels and London-Gatwick, have special railroad service connections. The fourth, Tokyo International (Haneda), has a monorail link.
>
> A rail rapid transit line extension into Cleveland Hopkins International Airport will be completed in late 1968. By early-to-mid 1970's, a railroad link and possibly the Underground are proposed to be extended into London-Heathrow. And by 1980, six other airport railroad or rail rapid transit links will be in operation—all in Europe—if present plans and proposals are consummated.
>
> Central business districts (CBD) now generate 17 to 50 per cent of total airport traffic at the ten airports reporting this information. Most airports are within 30 minutes of their central business districts during midday and evening hours, but 30-to-60 minute travel times are much more common during peak hours.† The London-Gatwick rail service is a real time saver, being 15 to 45 minutes faster than highway travel. Travel time on the rail ser-

Presented as Paper 68-1072 at the AIAA 5th Annual Meeting and Technical Display, Philadelphia, Pa., October 21–24, 1968; submitted September 11, 1968; revision received November 14, 1968. The author would like to acknowledge the assistance of C. N. Peavey of the Port of New York Authority and N. J. Payne of the British Airports Authority.

* Professor, Department of Aeronautics and Astronautics.

† It should be noted that travel times cited in this report generally reflect time spent between the downtown airline terminal and the airport, for both rail and bus modes and do not include travel time to reach the downtown terminal, baggage checking time or distribution time within the terminal. These times, however, are usually reflected in data for automobile and taxicab modes.