Quarterly Technical Summary

Air Traffic Control

15 May 1971

Prepared under Electronic Systems Division Contract F19628-70-C-0230 by

Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Lexington, Massachusetts

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INTRODUCTION

This report discusses the activities under way in Division 4 that are funded mainly by the Air Force. The progress on two other ATC tasks, namely, the preparation of a Technical Development Plan for the Discrete Address Beacon System for the FAA (OSEM) and studies relating to Fourth Generation ATC System Concepts for the DoT/Transportation Systems Center, is reported separately.

A highlight of this quarter was the successful conclusion of the testing phase of a laser warning system for Logan Airport.

15 May 1971

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AIR TRAFFIC CONTROL

I. SUMMARY

The Lincoln Laboratory Air Traffic Control program includes investigations to develop an improved surveillance and communications capability to support the needs of the automated air traffic control system. Recent work on the beacon system and tracking studies is reported in Sec. II.

The system engineering and simulation studies for an airborne traffic situation display which will provide pilots with a suitably edited and formatted display of traffic information in the terminal area are continuing. This work is described in Sec. III.

Field testing has been completed on a laser warning system to alert the tower controllers at Boston's Logan Airport of the presence of a ship with a tall mast in the shipping channel which crosses the approach path to Runway 4R. This test program is supported by the Massachusetts Port Authority and is reported in Sec. IV.

Technical studies on topics related to Fourth Generation Air Traffic Control System Concepts are continuing under the sponsorship of the Transportation Systems Center of DoT as an integral part of their in-house concept formulation studies.

Working in close collaboration with the members of the Office of Systems Engineering Management and the Systems Research and Development Service of the Federal Aviation Administration, we are assisting in the preparation of a Technical Development Plan for a Discrete Address Beacon System (DABS).

II. SURVEILLANCE TECHNOLOGY

While the major emphasis on surveillance technology during the past quarter has concentrated on DABS, we continue to investigate certain topics related to the ATC Radar Beacon System (ATCRBS) and the general problem of radar tracking. In the latter area, we are applying the results of other programs at Lincoln Laboratory to the radar surveillance problem.

The performance of the high-resolution, electronically scanned radar system currently being assembled by the MTI Radar Group for a ground surveillance application will be evaluated in detecting aircraft in flight and on the ground in the presence of ground clutter. The choice of wavelength and use of a digital processing terminal for extracting doppler information and rejecting clutter for this system should provide a radar test bed with superior performance as an all-weather, clutter-free monitor of air traffic. During the past quarter, the major components of the antenna have been installed and work on the assembly of the radar is continuing. Plans are being developed for a demonstration of the surveillance capability of this system by observing targets in the approach zone to the instrument runway at Hanscom Field [see Figs. 1(a) and (b)].

A. ATC Radar Beacon System (ATCRBS) Development

1. Interrogator Antenna Studies

The antenna studies have focused on topics related to the development of an electronically scanned array and to the application of monopulse techniques to improve the angular resolution of interrogators.

Fig. 1(a). Electronically scanned antenna for use with advanced MTI radar.

In contemporary cylindrical arrays, only a limited sector of elements of the cylindrical array is excited at any one time. Electronic beam scanning is achieved by "sliding" the excited sector around the cylinder. At present, there does not exist any complete synthesis technique for cylindrical array sectors. As a first step in this direction, a new method of pattern synthesis for general circular arc arrays of antenna elements with arbitrary directivity has been developed and was reported in the last quarterly technical summary.* Previous investigators had speculated that closed-form results were not possible even in the case of an omnidirectional element. However, our method analytically inverts the relevant matrix to yield explicit simple closed-form formulas, and is believed to be capable of generalization to cylindrical sectors. In the past quarter, numerical results for a variety of circumstances have been obtained using the above method.

Attempts at using a small number (possibly only one) of transponder replies for azimuth angle determination will require the use of monopulse (or pseudomonopulse) systems with the capability of accurate angle-of-arrival measurement for off-boresight aircraft. A theory for accurately calculating a reasonable lower bound on the angle estimation accuracy of monopulse systems, even in the nonlinear portion of the monopulse "error curve," has been extended to the case where the noise power in the sum and difference channels is unequal.

2. Transponder Studies

The study of the problem of false triggering of the present generation ATCRBS transponders by various proposed DABS modulation formats continued during this report period. Experience gained during initial testing of a general aviation transponder had clearly indicated the difficulty of predicting its performance from circuit diagrams or specifications alone, and therefore the importance of experimental verification of performance under various conditions.

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* Air Traffic Control Quarterly Technical Summary, Lincoln Laboratory, M.I.T. (15 February 1971), pp. 2-3. DDC AD-721463.

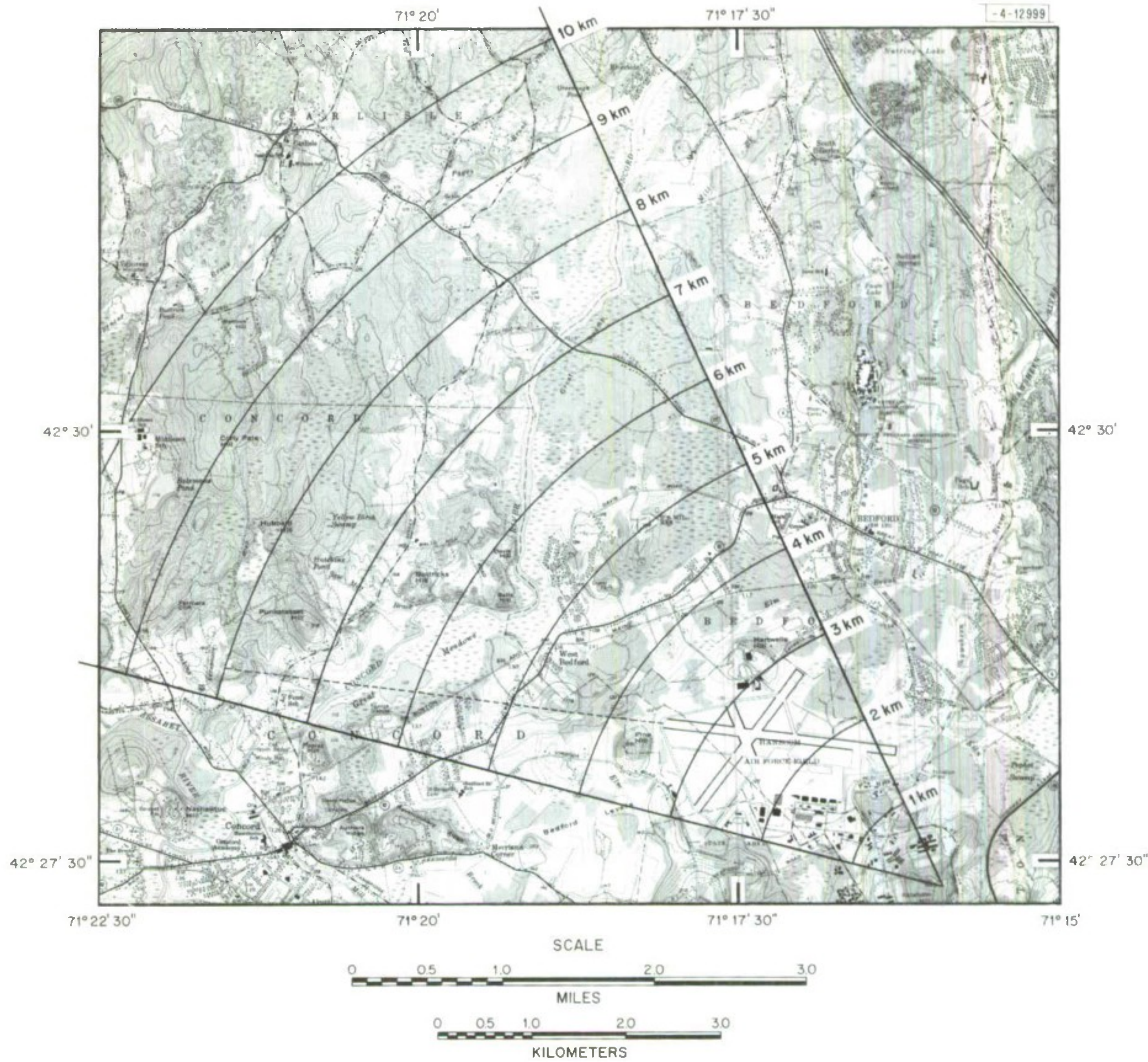

Fig. 1(b). Surveillance coverage diagram of MTI radar showing ILS Runway 11 at L. G. Hanscom Field.

During this reporting period, the program was expanded to include tests on a second general aviation transponder and a military transponder. Unlike the first transponder tested, these units both met the requirements of the National Standard and the RTCA Minimum Operational Characteristics for Airborne ATC Transponder Systems in most areas. In view of this fact, it might have been expected that a close agreement would be obtained between actual performance in a simulated DABS environment and predictions based on the ATCRBS specifications. The experimental work shows this is not the case.

Figure 2 illustrates the wide divergence of results obtained from the three transponders tested in a simulated DABS environment. For the purpose of this test, the hypothetical DABS interrogation consisted of a random string of 0.8-μsec pulses spaced on 2.0-μsec centers. Such a formulation of a DABS interrogation is a natural extension of the present ATCRBS system. The plot shows the average number of false replies produced by the transponders for each interrogation as a function of interrogation length.

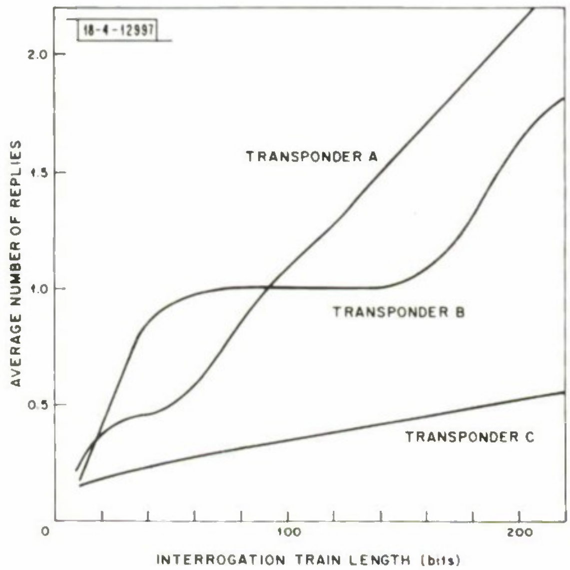

Fig. 2. ATCRBS response to random interrogations using trains of 0.8-μsec pulses with 2.0-μsec spacing and variable train length.

These data illustrate two important points: (1) a simple extension of the present ATCRBS-type modulations to a DABS implementation will result in the generation of many false replies, with the resultant garbling of both the ATCRBS and DABS systems; (2) the reactions of present transponders are not predictable by a simple model.

B. Tracking Studies

In an earlier quarterly technical summary,* we reported the results of a tracking study which showed that significant improvements in track quality could be obtained if the tracker had prior knowledge of the true state of the aircraft dynamics. In this quarter, we studied the problem of detecting an aircraft turn using surveillance data. As a baseline model, we assumed that the aircraft attempts to follow a straight-line constant-velocity trajectory but, due to atmospheric disturbances and pilot corrective maneuvers, there are random correlated accelerations which make the actual flight path meander about the straight-line course. Imprecise position

* Air Traffic Control Quarterly Technical Summary, Lincoln Laboratory, M.I.T. (15 November 1970), p. 9, DDC AD-716816.

measurements are available from the sensor system that must be used to discriminate between a meandering deviation from the flight path and a constant cross-track acceleration turn.

The first step toward a solution depends upon the fact that the residual process (the difference between the measured position and the tracker's estimate of position) of a Kalman Filter tracker is a zero mean, white-noise process when the model dynamics correctly describe the true state of nature. When the true state of nature involves a constant cross-track acceleration, the residual sequence of the baseline model remains a white-noise process, but now has nonzero mean. Finally, we need only realize that testing for the nonzero bias is equivalent to testing for the presence of a deterministic signal in a white-noise background. It is important to realize that when the signal is present, it continues to evolve with the arrival of more data samples; hence, the usual finite-duration matched-filter receiver implementation that arises in the classical radar detection problem is no longer valid. Rather, a bank of matched filters must be used. The m^{th} such filter maximizes the probability of detecting a turn that started at time $T - t_m$, where T is the interval over which the data have been collected, and t_m is the memory of the m^{th} filter.

We then noted that when a turn is in progress, the signal-to-noise ratio (SNR) at the output of each of the filters is monotonically increasing with T; it is a maximum at the output of the m^{th} filter if the turn started at $T - t_m$. This property suggests a slightly suboptimal but more practical implementation of the detector, since we need only use one filter with memory t_1 chosen to yield a good detection probability P_D in reasonable detection time. For turns starting prior to $T - t_1$, the detection probability will not be optimal but will be greater than P_D, due to the monotonicity of the SNR. On the other hand, turns starting after $T - t_1$ will be detected with probability less than P_D, but there is no significant premium to be gained in detecting the turn in time less than t_1 seconds, so long as t_1 is relatively short.

A further benefit that results from this detection scheme is the fact that it generates estimates of the time the turn was initiated and the magnitude of the rate-of-turn parameter. These estimates can be used to initiate a more general tracking algorithm that is designed to track the accelerated turn. Therefore, we have been able to develop an adaptive algorithm that adjusts the tracking model to better fit the true state of nature, hence better overall tracking performance should be possible. In the next quarter, we hope to perform simulation tests to evaluate the feasibility of this adaptive tracker and the degree to which improvements are possible.

III. AIRBORNE TRAFFIC SITUATION DISPLAY

The traffic situation display system being studied will provide pilots with a display of adjacent aircraft as well as symbols and lines to represent fixes, airways, localizers, etc. It is viewed as a natural outgrowth of and an adjunct to the NAS/ARTS equipment currently being installed.

During the past quarter, our program to develop an airborne traffic situation display of NAS/ARTS data has concentrated on the construction of the display indicator and waveform generator portion of the ground monitor, and simulation studies of the airborne portion of the proposed system. Also, an examination of the present program has been undertaken to determine how best to couple it to possible future simulation studies involving pilots and controllers in an interactive environment.

A. Design Studies

With the exception of the work under way on the construction of the display indicator and waveform generator portion of the ground monitor, work on the experimental system has been concentrated on investigating the characteristic of commercially available components such as airborne computers and magnetic tape recorders.

The laboratory model of the display indicator and waveform generator is being assembled. The formats for the display control logic have been structured such that the display hardware will easily interface with most 16- to 18-bit computers via a data channel connection. This display hardware is designed so that it is expandable to allow a wide range of user options; this feature is considered desirable for the airborne display portion of the system which will be a ruggedized subset of the monitor equipment.

B. Display Simulation (Electronic Systems Laboratory, Flight Transportation Laboratory, Man-Vehicle Laboratory)

Thesis research is under way using a simulator assembled by the campus-based laboratories to assess some human factors aspects of the display in the cockpit and its usefulness as a flight instrument to aid in maneuvering in the terminal area. These studies will be completed in June 1971 and should provide useful data for the design of subsequent experiments and guidelines for the development of equipment.

C. Future Research

The capabilities of various multiple-controller simulation facilities are being assessed to determine the hardware and software needed to evaluate the impact of traffic displays on the pilot and controller performance in terminal area operations.

IV. A LASER SYSTEM FOR DETECTING SHIPPING IN THE APPROACH ZONE AT LOGAN AIRPORT

The key to increasing the utility of Runway 4R at Logan Airport is to provide a surveillance system that warns of the presence of transient hazards to aircraft caused by ships with tall masts protruding into the approach zone to the runway. A laser-gate alarm system across the channel at the approaches to the clearance zone has been proposed for alerting tower operators of the passage of these ships. A surface detection radar would complete the surveillance system.

A small study and field measurements program, sponsored by the Massachusetts Port Authority, has been completed which determined the capabilities and limitations of an experimental laser-gate detection system. Two experimental laser gates were installed across Boston Harbor at heights of 29 and 61 feet. Automatic chart recorders, time lapse cameras, and stereoscopic cameras recorded the passage of all ships and the performance of the experimental system 24 hours a day for a 2-month period. Figure 3 shows a passing Navy ship recorded by one of the two stereoscopic cameras, and indicates the location of the laser beams.

The study and field measurements program supports the conclusion that a reliable, fail-safe, laser-gate system can be designed, installed, and operated to effect a significantly increased utility of Runway 4R. Feasibility of the system has been established for visual meteorological conditions both daytime and nighttime. Masts of 1-inch diameter on ships proceeding at 15 knots can be reliably detected in clear weather. An operational system can be designed for visibility ranges down to approximately $\frac{1}{4}$ mile, with the expectation that performance would be substantially the same.

The system design is amenable to various trade-offs between safety margin, VFR runway length, and displaced threshold duty factor. The laser gates may be placed at a height of 40 to 50 feet, which will detect ships tall enough to intrude the clearance zone, while allowing small

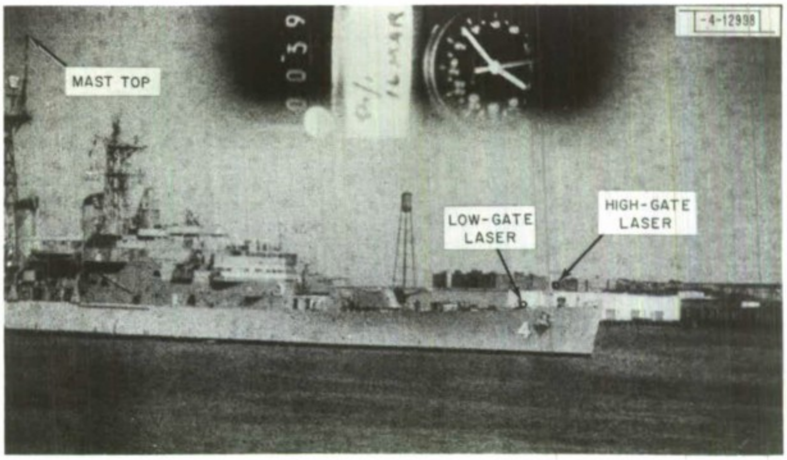

Fig. 3. Ship intercept of test laser gates installed across Boston Harbor.

craft to pass without alarm. The design would permit full use of the 10,000-foot runway with an adequate safety margin for obstructions less than 1-inch in diameter.

Analysis of ship traffic indicates that the application of a laser-gate system under nighttime visual meteorological conditions would permit the full-length use of Runway 4R except for an average of 1 hour per night when tall ships would be transiting. False alarms would be essentially eliminated in an operational system.

Recommendations have been submitted for an advanced-phase program which would lead to an operational laser-gate, ship-detection system fully integrated with airport facilities and activities. The advanced-phase program would involve the design, installation, and rigorous testing of one prototype laser gate which would be integrated with the airport surface detection radar (ASDE) to form a reliable, fail-safe, surveillance system.

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13. ABSTRACT

This report discusses the activities under way in Division 4 that are funded mainly by the Air Force. The progress on two other ATC tasks, namely, the preparation of a Technical Development Plan for the Discrete Address Beacon System for the FAA (OSEM) and studies relating to Fourth Generation ATC System Concepts for the DoT/Transportation Systems Center, is reported separately.

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14. KEY WORDS

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