# Quarterly Technical Summary

# Air Traffic Control

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# INTRODUCTION

This is the first report in the Quarterly Technical Summary series covering the Air Traffic Control activities at Lincoln Laboratory. The previous work on ATC was included in the General Research Quarterly Technical Summary. Because the allowable effort on ATC is comparatively small, it has been focused on only one facet of the problem; namely, on the data acquisition and communications task. The new group has started to make significant progress in several study aspects of the problem and has also obtained experimental L-band multipath data from an experimental air-ground test system. When additional support is received, the program will be expanded to include over-all system design studies, and the investigation of radar improvements and multilateration systems, both ground- and satellite-based.

15 May 1970

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# AIR TRAFFIC CONTROL

## I. INTRODUCTION

As reported in the last General Research Quarterly Technical Summary,* Lincoln Laboratory has initiated a research and development program in the area of Air Traffic Control. This effort is motivated both by the obvious interest and involvement of the Air Force in the evolving Air Traffic Control system as well as by the Laboratory's desire, with encouragement of Dr. Foster of DDRE, to apply a fraction of its expertise to problems in the civilian sector. Thus, whereas the present modest program is supported as part of the Air Force sponsored General Research program, it is hoped that the effort will expand into a more comprehensive program sponsored jointly by the Air Force and the Department of Transportation.

For completeness, some aspects of the program reported in the last General Research Quarterly Technical Summary are repeated here.

## II. HISTORY

In the summer of 1969, a study group was formed at the Massachusetts Institute of Technology for the purpose of becoming familiar with the operation and problems of the present ATC system. Members of Lincoln Laboratory, Instrumentation (now Draper) Laboratory, Electronic Systems Laboratory, and the Flight Transportation Laboratory participated. Members of the study group visited a number of ATC facilities including the Nashua FAA Center, the Logan Tower and Radar room, the Kennedy Tower and Common IFR room, NAFEC (National Aviation Facility Experimental Center) in Atlantic City, the ARTS installation at Atlanta, and made several visits to the DOT/FAA in Washington. During this study period, the DOT ATCAC (Department of Transportation Air Traffic Control Advisory Committee) report† became available in draft form. Much of the group's work consisted of understanding this report and its recommendations. The study group received briefings from the Chairman and the Secretary of the DOT ATCAC. A number of other informal briefings were given, including one by Logan air traffic controllers.

In concert with the recommendations of the ATCAC report, the study group concluded that a greatly increased air traffic control sytem capacity, achieved through a high level of automation of ATC functions, was required to meet the air traffic needs of the next few decades. Improvements are required in all aspects of the system, including ground handling and airport design, landing systems, automation of ATC functions, surveillance, and communications. While the Laboratory has substantial background in several of these fields, one very specific area matched to the Laboratory's current activities and expertise is the development of a data acquisition and communication (DA/C) system adequate to support the needs of automated air traffic control. Such a system must provide continuous, accurate position data on each aircraft using the airspace, plus a two-way digital data link to relieve the necessity for the manual interchange of flight data and control instructions by controller/pilot voice communications.

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* General Research Quarterly Technical Summary, Lincoln Laboratory, M.I.T. (15 February 1970).

† Report of the Department of Transportation Air Traffic Control Advisory Committee (December 1969).

In late 1969, an ad hoc group was formed at the Laboratory, with the concurrence of the Lincoln Laboratory Joint Advisory Committee, to work toward the development of advanced DA/C systems. The immediate goal was to understand more fully the limitations of the current system and the requirements for advanced systems, and to generate an outline for a research and development program directed at meeting these requirements. The program outline was prepared in the form of a proposal which was submitted informally to the DOT/FAA in February 1970. The proposed program included the investigation of near-term improvements to the present primary and secondary radar surveillance systems, the development and experimental implementation of an improved surveillance/data link system using rho-theta interrogators and discrete-addressable transponders, and the investigation and test of alternate surveillance techniques, especially those accomplishing position determination by multilateration from a network of ground stations or satellites.

## III. INTERIM PROGRAM OUTLINE

While awaiting a response from DOT/FAA, we have initiated a modest-sized interim program which includes the following activities.

### A. Analytical and Design Studies

(1) Develop a detailed understanding of the present ATC system, especially the interaction of the DA/C subsystem with the NAS and ARTS automation program. (This effort will be useful in providing a framework for the design of an advanced system, as well as in identifying particular problem areas in the existing DA/C system which could be helped by nearer-term improvements.)

(2) Develop quantitative performance requirements on an advanced system based on the desired system functions of ground-based collision avoidance, Intermittent Positive Control (IPC), final approach surveillance, airport surface surveillance, etc.

(3) Investigate the ability of a system based on discrete address beacon transponders to meet the requirements placed on the advanced system. Areas to be considered include compatibility with the present Air Traffic Control Radar Beacon System (ATCRBS) during the transitional phase, use of multiple range measurements by independent interrogators and/or slaved receivers for accurate position determination, system overload (problem of multiple interrogation from different sensors), modulation design for adequate data link rate and ranging capability, etc.

(4) Evolve one or more system designs in sufficient detail to provide the framework for the implementation of prototypes. This effort should identify those questions whose resolution depends most heavily on the test and evaluation phase.

### B. Multipath and Interference Studies

Carry out a combined field measurement and analysis effort to determine the environment in which the advanced system will operate. The major issue with regard to multipath appears to be to define the type of antenna structures required to realize acceptable multipath levels on air-ground links. A major goal of interference investigation will be to determine whether an advanced system can hope to operate on the same frequency as the existing ATCRBS during the transitional period.

### C. Prototype System Implementation

Develop and field test a prototype discrete address beacon system. Hardware items will include airborne beacon transponders, an interrogator with its associated interrogation control computer, and auxiliary ranging receivers, if required as part of the proposed sytem. It is expected that this effort will include the development of an improved rotating interrogator antenna with controlled shaping of the antenna pattern in the vertical plane and monopulse capability permitting azimuth determination on a single transponder reply. Software will include developmen and implementation of algorithms for interrogation ordering, tracking, and multiple input position determination. If compatible operation in the present ATCRBS band is envisioned, a central part of the effort will be to prove out this capability.

When additional support becomes available, this effort will be expanded to include the other areas of the proposed program, including over-all system design, investigation of radar improvements, and examination of multilateration systems, both ground- and satellite-based.

## IV. PRELIMINARY RESULTS

### A. Surveillance Data Requirements for Ground-Based Collision Avoidance

In the existing ATC system, the prevention of mid-air collisions is the primary responsibility of the controller on the ground. It is generally assumed that ATC capacity will ultimately be limited by the present manual method of control and that automation of most ATC functions will become necessary. Automated ATC will naturally include collision avoidance in positive control areas. Moreover, one of the main recommendations of the DOT ATCAC report was to extend this protection, when required, to all aircraft (Intermittent Positive Control). Because of the fundamental character of the problem, as well as its amenability to fairly accurate mathematical modeling, an analysis of the ground-based collision avoidance problem has been carried out with the main objective of determining the requirements placed on the data acquisition system in order to achieve a given level of performance.

Previous analyses have concentrated on the decision logic and on the false-alarm problem in the case of the airborne Collision Avoidance System (CAS), working with range and range-rate data only. Our approach assumes complete data, i. e., vector position and velocity of each aircraft, and concentrates on the statistical decision-theory aspects of the problem. Velocity is obtained by tracking, and two tracking algorithms are considered. An attempt is made to characterize the performance of such a system, including both the missed-detection and false-alarm aspects in terms of parameters of simple physical significance. These parameters are expressed in terms of the data accuracy, data rate, hazard-definition parameters, and parameters related to knowledge of the intent of each pilot. As expected, large uncertainties in intent may easily dominate errors in surveillance data but, with a reasonable degree of order in the traffic, quite meaningful requirements can be extracted for the data quality. A detailed report of this work is now in preparation.

## B. Position Fix Accuracy Using High-Altitude Satellites

An analysis of the position fix accuracy attainable using high-altitude satellites has been completed and a final report is ready for publication. A single unified analysis is used to treat several different two- and three-satellite systems. Range, range-difference, and altitude measurements are considered. The nonlinear position estimation problem is solved by linearization, and the range of validity of the linearization is shown to include systems resulting in three coordinate rms position fix errors of 10 km or less.

The dependence of position fix accuracy on the many system parameters is studied for all the types of position fixing schemes using two and three satellites. System performance was shown to be characterized by a set of asymptotic performance limits; these asymptotes are tabulated for a number of two- and three-satellite deployments. The tabulations provide enough information to do detailed parameter trade-offs that are useful in system design.

## C. Signal Multipath Measurements on an Air-to-Ground Link

Multipath on air-ground links will degrade the performance of an ATC data acquisition and communication system in several ways. Ground or sea reflections can cause lobing in the ground antenna pattern, resulting in deep nulls and loss of targets. Reflections from buildings, such as hangars, can cause false targets to be reported. Energy diffusely scattered from buildings, trees, or rough terrain will arrive at the antenna from various azimuths and thus degrade the angular accuracy of a monopulse or other beam-splitting system. To obtain a more quantitative understanding of these problems and of the constraints that multipath places on antenna and signal design, an experimental program has been started to measure air-ground multipath at L-band associated with various antenna characteristics and siting locations. Measurements are being made at several sites using short pulse transmissions from an aircraft, with the receiving antenna located on the roof of the receiver truck or on a tower. The received waveform, consisting of the direct path signal plus later arriving signals from paths involving reflections or scattering, is displayed on an oscilloscope and recorded photographically. Locations are chosen to permit measurements of the ground reflection from various types of terrain, both rough and smooth, from the surface of the ocean at various sea states, and from objects such as trees and buildings.

The airborne transmitter consists of digital timing logic, which generates pulses of approximately 20-nsec duration synchronized by a cesium beam timing standard, and RF circuitry to permit modulating a carrier with this pulse. The RF power amplifier is a 35-watt traveling-wave tube. The receiver consists of bandpass filters, a wideband high-gain amplifier chain, and an envelope detector. The receiver noise figure is approximately 5 dB. In the measurements to date, omnidirectional antennas have been used on both the transmitter and receiver. Both transmitter and receiver timing are controlled by cesium beam clocks to permit synchronized operation without a tracking loop in the receiver. The pulse repetition rate is 50,000 pulses per second.

With the transmitter located in an aircraft, measurements have been made with the receiving antenna on the roof of a truck on Hanscom Field, on a Coast Guard tower overlooking the ocean, and on a pole on a hilltop in rural Massachusetts. Measurements have also been made at various locations on Hanscom Field with both the transmitter antenna and the receiver antenna on trucks to measure the detailed reflection pattern from a hangar.

Future plans include further air-to-ground measurements with omnidirectional antennas, plus the use of directional receiving antennas for improving signal-to-noise ratio and obtaining direction of arrival as well as time of arrival of reflected or scattered pulses.

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14. KEY WORDS

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| air traffic control | multipath at L-band |
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