acq. #2107R/a
u

SECURITY INFORMATION

UNCLASSIFIED
~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

5-1/25

COMPUTER CONTROL OF TACTICAL AIRCRAFT

Report No. 5

24 March 1952

REGRADED: UNCLASSIFIED
AUTHORITY: ltr fr. Ft. Monmouth SIGSU-EM 1b1a
DATE: 7 April 59

Notice:-This document contains information affecting the national defense of the United States within the meaning of the Espionage Act, (U.S.C. 50:31, 32). The transmission of this document or the revelation of its contents in any manner to any unauthorized person is prohibited by law.

Control Systems Group:

M. Cohn
M. Davis
R. Hulsizer
L. Kypta
L. Lavatelli
D. Lazarus
R. Norberg
A. Taub
R. Trogdon
N. Wax

Prepared by:

R. Hulsizer
R. Hulsizer

L. Lavatelli
L. Lavatelli

D Lazarus
D. Lazarus

CONTROL SYSTEMS LABORATORY
UNIVERSITY OF ILLINOIS
URBANA, ILLINOIS

Contract DA-11-022-ORD-174
TB3-0538

COPY 65 OF 80 COPIES

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

FOREWORD

In the fall of 1950, Louis N. Ridenour, Dean of the Graduate College of the University of Illinois on leave of absence to consult for the Defense Department, and J. von Neumann of the Institute of Advanced Studies pointed out that contemporary control devices and systems for military application were seriously lacking in reliability and versatility and that greater use of redundance would make them less subject to the deficiencies of individual components. After a group of the faculty examined this problem informally for several months, the Control Systems Laboratory was formed in February of 1951 for a more thorough study. One conclusion of the study was that the utilization of redundant devices would have to be coordinated by a device capable of making decisions. The Ordvac computer built at the University of Illinois is such a device and it was decided to test the feasibility of including a decision-making computer in a control system by applying the computer to the control of tactical aircraft. The first program for this work and early results are described in this report.

The first months of the Laboratory's existence were made possible by the financial support of the Office of Naval Research through contract Nonr-534(00). Subsequently financial support was provided by a tri-service contract administered by the Ordnance Department of the Army under Contract DA-11-022-ORD-174.

ABSTRACT

This report discusses the application of a modern high-spped digital computer as an aid to a particular complex military operation: the automatic and simultaneous control of a large number of tactical aircraft. It discusses the problems connected with automatic computer control and serves as a general introduction to a series of subsequent reports. These reports are concerned with the details of the various components used in the control system and with some preliminary tests of the system. At present it seems feasible that the use of such a computer system would be a very real aid to tactical air operations.

TABLE OF CONTENTS

1. INTRODUCTION

Some ten months ago, a group in this laboratory became interested in the possibilities of using modern high speed digital computers for military purposes. If properly coded a modern computer such as the University of Illinois' Ordvac can perform reliably and rapidly much of the bookkeeping, arithmetic, and control at present performed by human beings in military control systems. The maximum complexity of a military control system in which men perform these operations depends first upon the rate at which each individual can perform his task and then upon the number of such individuals whose actions can be coordinated. Because of the difficulty of coordinating large numbers of men performing interdependent tasks, the size of a control operation can not be enlarged indefinitely by the use of increased numbers of personnel. In this event, the digital computer may allow considerable expansion of the operations by aiding the coordination and by relieving the men of their routine tasks. Our Laboratory has decided to explore this possibility. We believe that the traffic handling capacity and the degree of centralization of a tactical control system which includes Ordvac should be determined. To insure the military value of our work an operation was chosen that saturates and breaks down because the human links become overloaded and uncoordinated. The desired function of this operation is the control and guidance of a large number of tactical aircraft engaged in flights from their bases to their targets under all flying conditions. The source of data for guidance is primarily radar, but it is hoped that the versatility of the computer will allow other guidance facilities to be included. Some of the facilities, for example, control from a forward air controller post, may be very difficult to include in the computer control link. We have therefore started on the problem by limiting the data source to a single radar for the whole area, and accepting temporarily the consequent lack of precision and coverage in the control. By experimenting with a one-radar system whose usefulness extends only to traffic control and navigation, we hope to learn something about what kind of computer would be best suited for the tactical aircraft control system. These experiments should also provide information about the general problem of using high speed computers simultaneously to control many different objects.

In the tactical control system shown in simplified form in Figure 1, four advantages are to be expected from the use of the computer. First, since all of the routine control is to be done by the computer at the Tactical Air Control Center (TACC), a continual fresh display of any part, or all, of the operation can be provided at the TACC. With this facility and with means for changing instructions to the computer, the TACC has control of the operation at all stages except those where guidance must be done by the forward air controller.

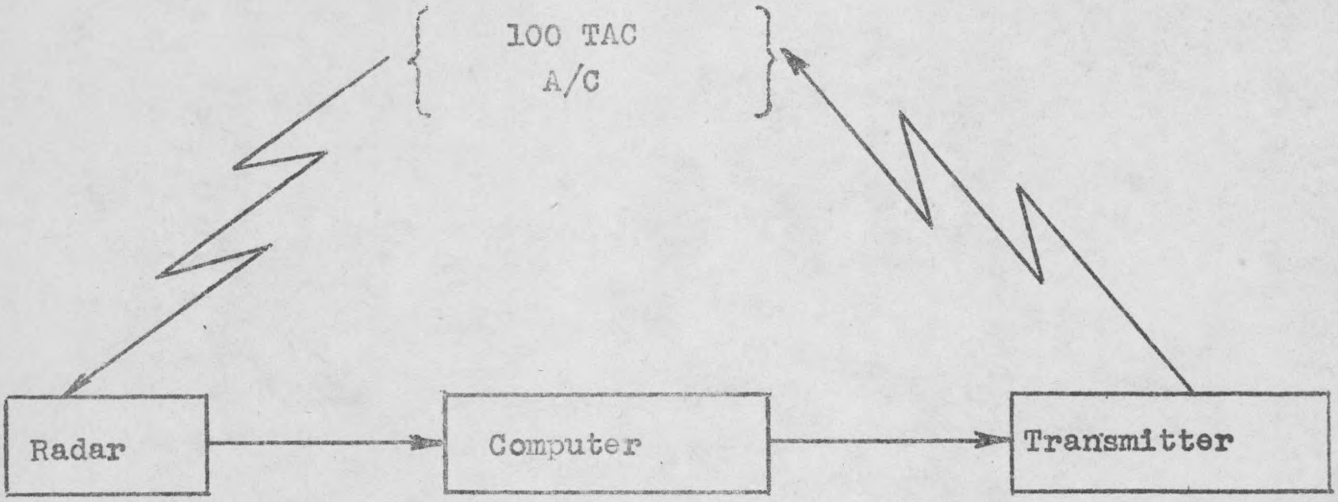

FIGURE I

Block Diagram of the Basic Computer-Control System

Second, no complex equipment is required in the plane other than a radio receiver and either a pilots-direction-indicator or an input to the auto-pilot. Since an auto-pilot can act upon the control signals as well as a human pilot, experience with this system will be valuable in planning for the use of unmanned aircraft. Some form of beacon or IFF in the aircraft would undoubtedly be valuable but not indispensable in providing good radar signals and in distinguishing the aircraft of the operation from other aircraft.

Third, the air controllers at the TACC are freed of routine controlling tasks once the mission has properly been started, and can thereby keep a larger operation under control.

Fourth, for normal, routine parts of the flight, the computer output will be the sole source of vectoring instructions for all of the planes so that it becomes quite feasible to consider placing instructions to all planes on a single audio communication channel if the number of planes per control system is less than 200 or 300. Close-control with continuous guidance of this number of planes by human controllers would require at least 75 channels.

II. DESCRIPTION OF THE ELEMENTS OF A GENERAL CONTROL SYSTEM

Figure 1 shows a diagram of the basic control system. The radar set is the sensing organ. The computer calculates the control signals, and the transmitter relays them to the aircraft. The response of the pilot or auto-pilot to these control signals is supposed to keep the aircraft on their prescribed courses. The following paragraphs will delineate these functions in greater detail.

A. Tasks of the Computer

The computer must ingest and decode data relayed from the radars and any other sensing devices used in the system. It must next sort the data, that is, identify the tactical plane to which each decoded datum belongs. If any data are received that do not fit with tracks of the aircraft of the operation, they must be regarded as bogies and brought to the attention of the TACC. If, on the other hand, data fail to appear on any plane of the operation, the computer must initiate the following two-stage lost-plane routine. At first it extrapolates the track on the basis of past history and continues to search through the incoming data for a report on this plane. Secondly, if data continue to be absent, the attention of the TACC should be summoned.

Having sorted the data and taken care of the bogies and the lost planes, the computer must form up-to-date tracks on all aircraft for display to the TACC, and then calculate for each plane, if needed, the change of heading which will keep it on its assigned course.

B. Tasks of the Transmitter

The control signals produced by the computer must be translated into a suitable form to be distributed by the transmitter to the separate aircraft. Since a new control signal should be reported to each of a large number of aircraft every radar scan, the use of human operators at this point would be expensive in terms of communication channels. A code giving the identity number of the aircraft and the heading change can easily be transmitted over a single audio channel while the computer is computing another control signal. Something like fifty such coded control signals can be transmitted over a single voice channel per second; if a control interval of 15 seconds were adopted, control signals with error checking codes could be transmitted to more than 100 planes on this one channel. A coder is therefore proposed as part of the transmitter.

C. Equipment Required in the Airplanes

The least equipment required in the airplanes consists of a radio receiver and a message decoder to convert the control signals into a form suitable for the pilot or auto-pilot. Radar or IFF beacons of various degrees of complexity are not essential, but naturally would simplify the work of the radar in detecting the aircraft and of the computer in sorting the data.

D. Surveillance Equipment

Up to this point no major restrictions have been placed on the versatility of this control system by the capabilities of the various components. It is in the detection of aircraft that the most severe limitations arise. An ideal sensing device would provide the coordinates and the identity of every aircraft in the area of the operation. In practice no single radar has had at once adequate range, low-altitude coverage and angular precision for a close-control operation. The deficiency is remedied in part by compounding a radar control and warning network out of long-range search sets, height-finders, low-altitude fill-in radars, and high precision tracking radars. Each set specializes in providing a particular class of information; none of them provide **identity**, nor do any of them provide low-altitude coverage very far into enemy territory. One of the most serious difficulties in any Air Control and Warning system lies in achieving proper coordination of data from these various sources into combat operations centers like the TACC or the Tactical Air Direction Centers (TADC). It is for this reason that two principal efforts of our Laboratory are concerned with relaying radar data to a central point from diverse and dispersed data sources, and aiding the operation center to identify the reports.

To attack in some logical sequence the very difficult problem of the rapid coordination of data let us assume:

i) that radar coverage of some sort will be provided in every area where ground control of aircraft is essential, if such coverage is physically realizable; ii) that the data relay links connecting the various radar sets with the central control center must be audio channels; iii) that the computer can successfully correlate the filtered data relayed from the various sets into a coherent picture. The next paragraph will deal with the data-filtering which is required by the second assumption.

Implicit in the data-filtering operation are three separate functions: separating real target echoes from noise, separating airplane target echoes from ground clutter, and identifying the airplanes from which echoes are received. One group of our Laboratory and several groups elsewhere are working on the discrimination of radar signals from noise and on providing adequate moving target indication. The degree of success of these efforts cannot be determined at present; while the signal-to-noise and MTI (moving target indicator) developments are being brought to a feasible level, the investigation of the usefulness of computers in tactical control systems can proceed by by-passing these problems through the use of beacons in the friendly planes. Coded beacons are not essential, because the identification of the aircraft can be aided in great measure by the ability of the computer to sort the beacon responses on the basis of the tracks formed from the past observations of these aircraft. Therefore a simple non-coded beacon similar to the light-weight rendezvous beacon will suffice. If this proposal is accepted as reasonable there remains the task of relaying to the computer the coordinates of all beacon responses seen by the radar. This has been done by several different groups in the past three years over single audio-frequency channels.

The third assumption that the computer can perform the many-radar correlation can be justified by the following arguments. If no attempt is made to use redundant reports from several radars on a single plane, then the correlation problem consists merely of converting all reports to a common set of coordinates. Each radar can be assigned an area of responsibility and the computer can carry a track over the boundary between two areas. This much certainly can be done with existing computers. If the redundance provided by overlapping coverage of several radar sets is to be utilized to advantage, a description of the routine for making a "best" judgment from a set of redundant data will have to be prepared for the computer. This problem has not yet been solved by our group.

On the basis of the above assumptions the sensing equipment has been restricted to a single long-range search radar equipped with a beacon receiver, and a coder that feeds a binary representation of the range and azimuth of each beacon response into an audio communication channel to the computer. More sophisticated data-processing techniques are certainly in order and will be proposed and incorporated as work progresses.

E. Display

There is a secondary feed-back loop that is not shown in the simplified diagram of Figure I. This loop concerns human intervention and is certainly an important element from the point of view of the operations commander. The first block in this secondary loop is the display. The display presents to the Chief Duty Controller the tracks being followed by the computer with as much information about them as the computer has stored. For example, the chief controller might wish to know the present location and the precribed course of a particular plane of the operation. By setting the selector of the display to the call number of that plane this information could be read out of the memory and into the display. Or, he might wish to know the disposition of all of the planes; he would then set the display selector to read out the positions of all planes, but not their courses. Ideally, any information in the memory of the computer should be available to be displayed. A proposal for a display device is discussed in Report R-13.

F. Intervention

On the basis of what is displayed, the chief controller may wish to change some aspect of the operation's plans. In this case he would go into the second block of the secondary loop and insert the instructions for the change. It is likely that he would also wish to relay his intentions to the pilots verbally. Since the pilots do not receive their course instructions aurally, they are free to hear and answer verbal contacts. In terms of computer language, the most general provision for human intervention would be to enable the controller to change any part, or the entire content, of the memory, word-by-word. With this facility the controller is in a position of having the computer present him with a versatile and fresh display and with the ability to introduce changes in the operation.

Thus we see that the simple picture of Figure I is really much more complex and perhaps can be represented completely by the block diagram shown in Figure II.

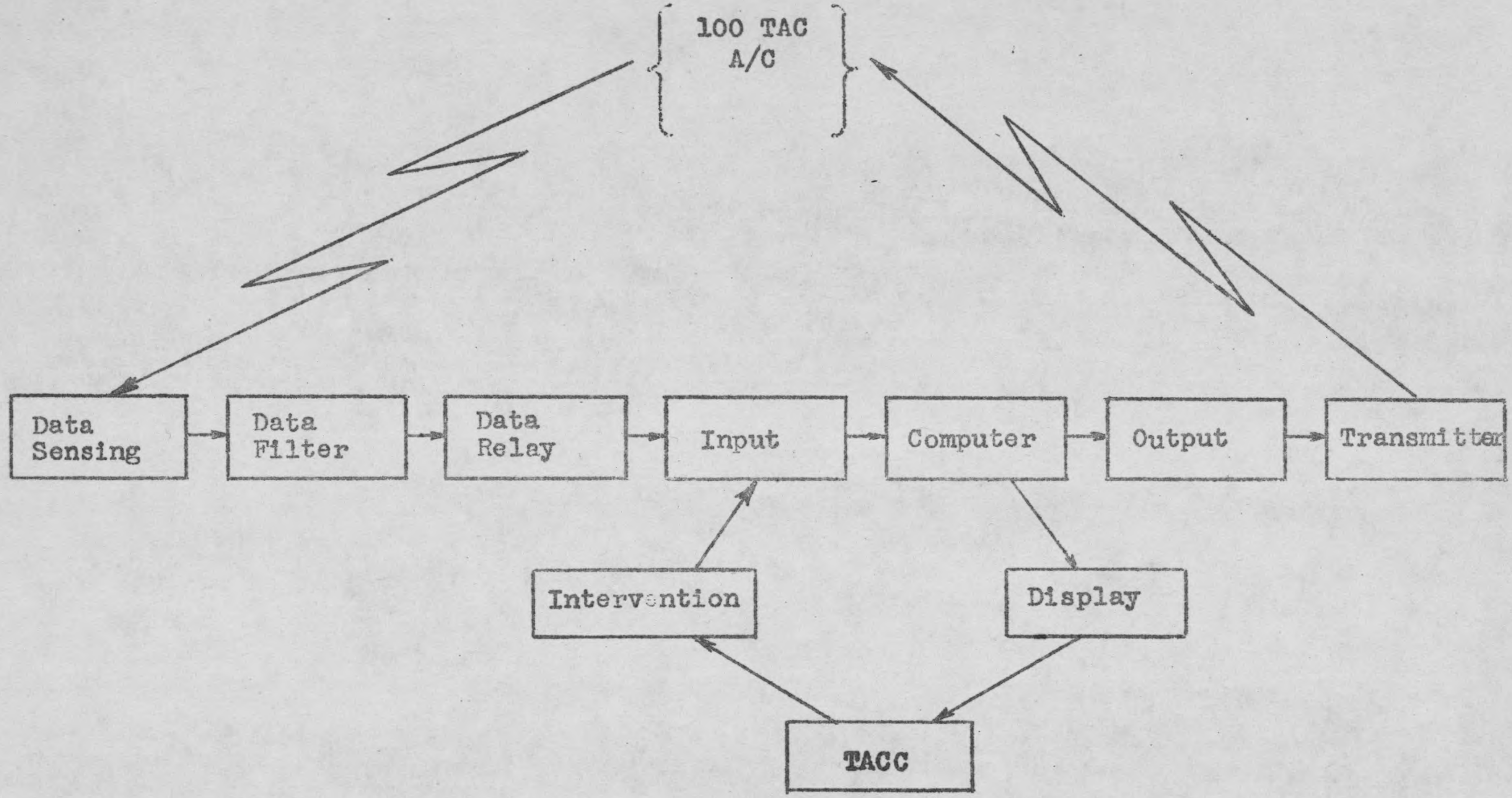

FIGURE II

Block Diagram of a Computer Control System with Human Intervention

III. THE FIRST EXPERIMENTAL SYSTEM

Turning now from this general description of the components which constitute an idealized control system let us consider the particular loop which we have used in our initial tests. It should be emphasized that the group has devised equipment that would perform the functions of the necessary components but in a most elementary manner. Figure III indicates the one-plane control loop that has been tested and also the proposed multiple plane loops that are to be tested in the immediate future. Since the nature of the computer largely determines the form of the components used we will begin our discussion of this experimental loop with the computer.

A. Ordvac

This computer was constructed by the Computation Laboratory of the University of Illinois for the Ballistics Laboratory of the Army Ordnance Proving Grounds at Aberdeen, Maryland. Its design followed in most respects the computer outlined by Goldstine and von Neumann of the Institute for Advanced Study at Princeton, New Jersey. It is a high-speed asynchronous automatic sequence control general purpose digital electronic computer. It has a Williams tube electrostatic memory for 1024 forty binary digit words corresponding to about 12 decimal digits. There are 50 separate operations that the machine is programmed to do in response to the proper order word.

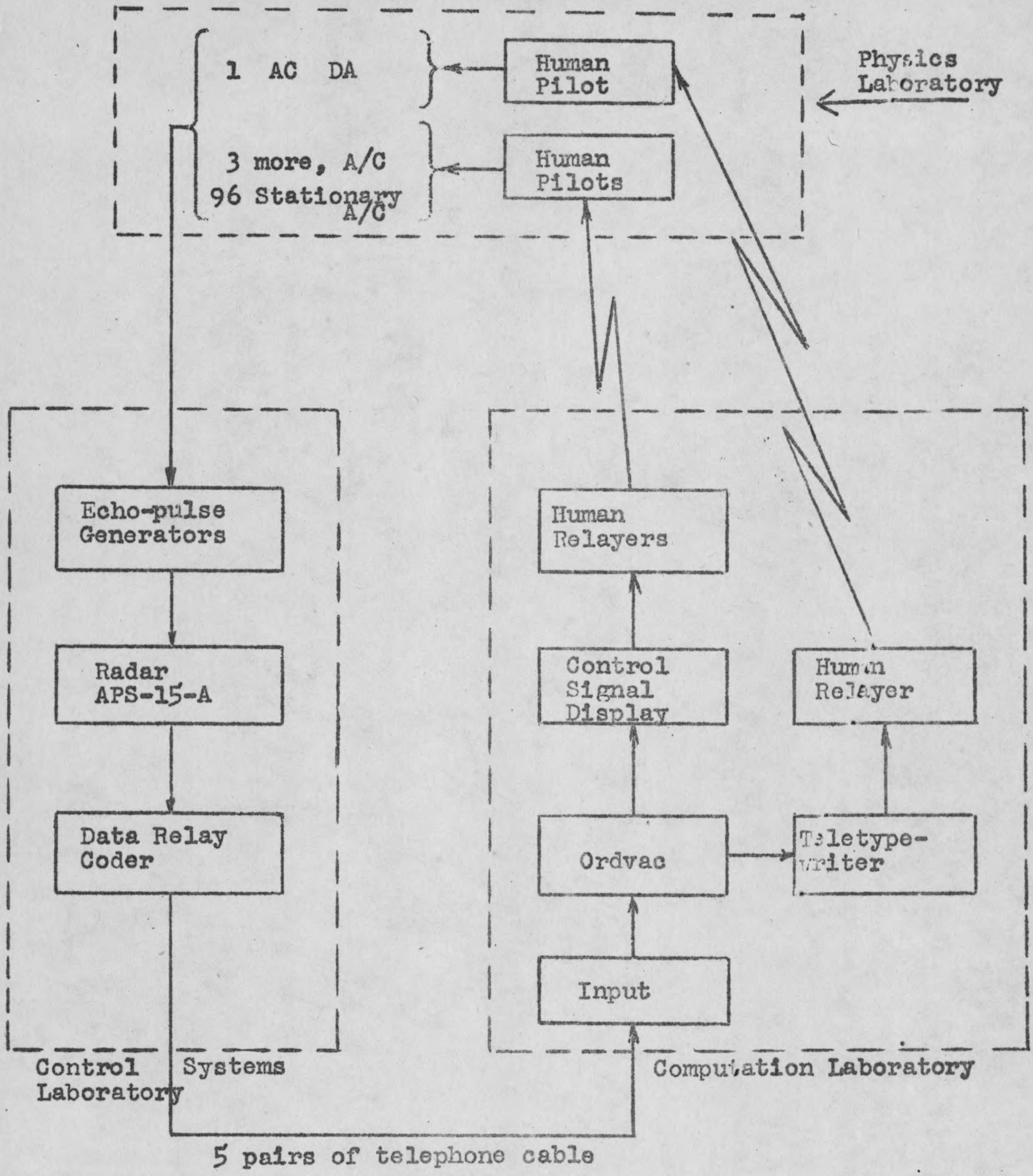

FIGURE III

Elementary Control System. This test system provides computer-control of four simulated aircraft manned by human "pilots". DA stands for the aircraft simulated by the Differential Analyzer.

The following table gives some of the time characteristics of the machine in microseconds.

Memory access	25 microseconds
Right or left shift	15
Addition	100
Multiplication	570-1000
Division	1000

The machine is designed to be loaded with all the necessary orders and numbers before a computation is started. The input and output devices that were used before the machine was delivered to Aberdeen were a standard teletype tape reader and a teletype printer and were not high speed.

A description of a high-speed input device for this application is described in Report R-8. A high-speed output device is described in Report R-12. The use of this computer to control the simulated aircraft of these tests is described in Reports R-9 and R-14. Report R-9 discusses the sorting or identification functions and the control computations performed by the computer and Report R-14 is the code for the computer. The output device described in Report R-12 is being constructed. In the meantime a temporary solution was employed as described in the next section.

B. Output

The slow speed printer is a suitable output device for controlling a single plane. As soon as the radar report on the single plane is received by the computer, a control signal is calculated and is printed on the teletypewriter and then relayed by voice to the airplane. As soon as more than one plane is involved, the output problem is no longer trivial. For now, since Ordvac can only do one operation at a time, the long time consumed in the printing operation interferes with the ingestion of radar reports on the other aircraft. For tests in the immediate future where we intend to control four aircraft, and track-while-scanning 96 stationary targets, Ordvac will be programmed to display the control signals in one of the forty memory tubes. These signals will be observed on the slave tube and relayed by voice to the aircraft in these immediate tests. Ultimately the more flexible link described in Report R-12 will be used in which there will be no human relayers.

C. Simulated Aircraft

The next element of the loop is the group of aircraft being controlled. It has been taken as axiomatic that considerable testing of the loop using simulated aircraft can be done profitably before it becomes worthwhile to procure flights of real airplanes. In addition a simple method of simulating a large number of planes is available that is sufficiently general to test the major features of the controlled flight operation.

The simulation is achieved by inserting into the radar video a pulse which appears at a time corresponding to the desired range and azimuth positions of the airplanes. Thus the simplest simulator consists of a range control and an azimuth control. A "pilot", knowing the desired speed and heading of his "aircraft", can determine by graphical means the proper positions of the range and azimuth controls. The time interval between radar scans, 15 seconds, is sufficient to allow the "pilot" to advance successively the controls to the proper position. Thus the echo which appears in the PPI scope simulates a real airplane moving continuously over the area surveyed by the radar. Furthermore, the data processing link treats this "target" just like a real one and the target coordinates generated by the data relay are just as acceptable to the computer as are those of a real aircraft. In addition the "pilot" can make his "aircraft" follow the control signals from the computer. Thus the simulation is complete.

A more sophisticated technique of simulation is to solve the flight problem continuously with a differential analyzer. The input to the differential analyzer operated by the "pilot" is the desired heading of the aircraft and the output is connected through selsyns to the range and azimuth controls of the simulator. The advantage of such a system is that, besides being a little more realistic as far as the pilot is concerned, the differential analyzer supplies a graphical record of the trajectory of the simulated plane.

The third element of simulation tests the ability of the system to handle many targets, except that these targets are not required to move. This loads up the computer with a realistic amount of data, forces it to do sorting, and so provides a test of many of the computational procedures. Report R-11 describes the modification of the radar to provide for simulated aircraft.

D. Radar

The radar that we used was a surplus APS-15A. The antenna rate was adjusted to be 15 seconds. The pulse repetition rate was also altered, so that there were at least 32 transmitter pulses per beamwidth (3°). The radar was further modified for simulation of aircraft discussed above. It was set up in the 200-mile, beacon response, mode of operation.

Under the assumption that the aircraft are beacon equipped, the moving target indication and signal-to-noise functions of the data filtering components are omitted. The identification problem is to be solved without the use of beacons and becomes, therefore, the computational task of Ordvac. It is for these reasons that no data filtering component is shown in Figure III.

E. Data Relay

The data relay in our system performs the following operations. It divides the 128-mile circle-of-coverage of our radar into 110 azimuthal sectors, and 128 range sectors making 14,000 area elements. As the antenna goes through its scan of this area, the video is examined and a pulse transmitted to the computer whenever one of the 14,000 area elements contains a beacon pulse. In order to tell the computer the coordinates of the area element in which a pulse occurred, a synchronizing pulse is transmitted over a separate channel to the computer as each area element is examined for targets. To compute the coordinates of any area element, the computer must simply keep track of the number of synchronizing pulses received since the antenna scan started, and it must be told the order in which the 14,000 area elements are scanned. Since 14,000 synchronizing pulses must be transmitted during the 15 second scan period, the average frequency of synchronizing pulses is about 1000 a second, a rate easily transmitted over direct-wire lines available between the buildings of the University.

F. <u>Input</u>

The last element in this experimental loop is the input device. It was mentioned above that Ordvac can do only one operation at a time, and this means that incoming data must be stored, until the computer is ready to accept them. This storage facility is part of the function of the input device. The other function of the input device is to provide rapid ingestion of the data, since the teletype input is too slow for our requirements. This input device is described in Report R-8.

IV. TEST AND CONCLUSION

The system made up of the components just described was tested several times in the interval from January 1 until February 8, 1952. A single airplane, simulated by the differential analyzer, was automatically flown over several polygonal courses. These tests, summarized in Report R-10, were made primarily to evaluate the ingestion and computational parts of the codes as well as the choice of the control constants. On the whole the tests were successful but revealed a fairly low frequency hunting. The cause of this hunting is suspected to be due to periodic errors introduced by the data processing device described in Report R-11.

The single plane tests were terminated by the delivery of Ordvac to the Ballistics Laboratory at Aberdeen. Computation time on Ordvac is still available to the Control Systems Laboratory, but before the multiple plane control and sorting tests can be started, this group must provide a practical relay link for transmitting radar plots to Ordvac at Aberdeen.* This problem was bypassed in our first tests by using several direct-wire telephone pairs running between this Laboratory, the Physics Laboratory and the Computer Laboratory. Compression of our requirements to one standard line is indicated and would test in a very real sense the feasibility of this general control scheme.

---

* Such a link is described in Report R-11

In summary this group has had as its purpose the feasibility of using modern high-speed digital computers for aiding the control of complex military operations. We have felt that a typical problem is the control of large numbers of tactical aircraft in all weather, day and night missions. The necessary components and their functions have been outlined. We have then embarked on a program of testing the various aspects of this control system, using the simplest possible components in an effort to get to the heart of the problem quickly. It is hoped that within a year we will be simultaneously controlling a number of live aircraft in a way that will demonstrate the usefulness of these techniques to the armed services.