CONFIDENTIAL

SECRET

Statement on Status of Project WW
Prepared for the
Research and Development Board
May 10, 1950

UNCLASSIFIED

SECRET

#9

CONFIDENTIAL SECRET

Copy # one copy only

L-24

SECRET

UNCLASSIFIED

CLASSIFICATION CHANGED TO:
Auth: DD 254
By: R R Everett
Date: 3-15-60

STATEMENT ON STATUS OF PROJECT WHIRLWIND PREPARED FOR THE RESEARCH AND DEVELOPMENT BOARD

by

Jay W. Forrester

Copies to Valley, Stratton, Sage

UNCLASSIFIED

Servomechanisms Laboratory
Massachusetts Institute of Technology
Cambridge 39, Massachusetts
May 10, 1950

SECRET
CONFIDENTIAL SECRET

TABLE OF CONTENTS

ABSTRACT

On August 29, 1949 the Ad Hoc Panel on Electronic Digital Computers of the Research and Development Board Committee on Basic Physical Sciences visited Project Whirlwind. Since that time the Whirlwind computer has been brought much nearer completion, equipment is now being connected for using Whirlwind in real-time air defense research for the Air Force, and plans for the first year of machine use have been crystallized. The arithmetic element, the central control and 32 registers of test storage have been operating as a system since September 1949. All circuits and storage tubes for the first of two banks of electrostatic storage are installed and undergoing test. They should be connected to the computer in July.

In the fall of 1950, the first applications of the Whirlwind computer are to begin. Half of the time will be devoted to real-time air defense work and half for exploring other applications of high-speed digital computers with emphasis on science and engineering.

Additional terminal equipment to enhance the overall usefulness of Whirlwind is to be installed during the fiscal year 1950-51. From the start of operation in the fall of 1950, usefulness and availability of Whirlwind will increase about linearly to full time availability of the machine and all proposed terminal equipment in the fall of 1951.

I. INTRODUCTION

When the Ad Hoc Panel on Electronic Computers visited Whirlwind, the arithmetic element and central control had been installed but not yet operated. By September of 1949 these had been combined with 32 registers of test storage to give a working computer for circuit testing purposes, for checking reliability, and for developing maintenance procedures. These parts of the computer seem already to have reached a level of reliability and trouble-free performance adequate for the planned machine applications.

In the summer of 1949, the first storage tube satisfactory for Whirlwind use had been constructed. Since then the tube has been improved and a steady production schedule maintained. An unusually high yield of some 75% of the tubes meet specification for use in the computer. During the winter of 1949-50, the first bank of storage tubes was installed as quickly as available man power permitted and are now being connected to the computer. Completion of Whirlwind has proceeded fairly closely to schedule and has led to plans for machine utilization beginning in fiscal 1950-51.

The Whirlwind program in the next fiscal year will be jointly sponsored by the Office of Naval Research and the Air Force. One-half of the machine time is to be used in research and field tests in the real-time control of air defense operations. The other half will be devoted to work of interest to the Office of Naval Research.

II. AIR FORCE PHASE OF PROJECT WHIRLWIND

The Air Force has set up a working committee under Dr. George E. Valley and including Mr. John Marchetti, director of the Air Force Cambridge Research Laboratories, and others, to initiate improvements in the nation's air defense system. One duty of the committee is to improve the existing air defense system. The other part of their work, which involves Whirlwind, is to develop completely new air defense methods which can achieve a many-fold improvement of the present system.

The part of the program devoted to the development of new systems is in turn divided two ways, each relying on high-speed digital computation. In one system ordinary long-range pulsed radar data is to be correlated, future positions of aircraft predicted, and interceptions calculated. The system would be expected to handle higher aircraft density than is now possible. In the second system, new types of radar can be used, especially continuous wave doppler, to give improved moving target detection and a greatly simplified radar permitting more sets and therefore improved low angle coverage. In the doppler radar system the high-speed digital computer permits derivation of useful positions and courses from range rate and angular data that otherwise could not be interpreted with sufficient speed.

In this particular air defense program, Project Whirlwind is only one of several cooperative groups. Raytheon is developing radar equipment, and the Air Force Cambridge Research Laboratories has already built terminal equipment to transform pulsed radar information to binary digits transmittible by telephone line. The telephone company is advising on communications, and the Federal Telecommunications Laboratory may develop still other radar sets. The Instrumentation Laboratory of M.I.T. under Professor Draper will carry on the aircraft and interceptor aspects of the work.

The Servomechanisms Laboratory has for a year studied the possibility of air traffic control by digital computers for the Air Force. The Air Traffic contract has been converted to the combined Air Intercept Program, and an MEW radar operated by the Cambridge Research Laboratory at Bedford Airport, 15 miles from M.I.T., is available. The Air Force Laboratory is now installing terminal equipment to provide radar data as binary digits on a telephone line. On the receiving end of the line, terminal equipment already built is adequate for introducing these data into the Whirlwind computer. Start of preliminary use of this equipment awaits only the completion of the radar installation by the Air Force and the completion of the first storage tube bank installation in Whirlwind by the Servomechanisms Laboratory. These two seem to be progressing abreast and should be completed by late summer.

The first task will be to successfully operate the first digital computer and radar interconnection ever undertaken in a real-time control system. The use of the computer will expand by steps through coordinate conversion, data correlation, tracking while scanning, and course prediction, to the actual flying of trial interceptions.

At the same time a parallel program using doppler radar is being developed.

III. ONR COMPUTER APPLICATIONS

Half of the Whirlwind computer time is to be available for computer applications research sponsored by ONR. During the next year, there are two divisions of this work.

First, a study contract established by ONR, with the advice and consultation of the Naval Research Laboratory, the Bureau of Ordnance, and the Bell Telephone Laboratories Mark 65 Project, is for examining the techniques of digital control as applied to naval fire control. This study is to establish the speed and capacity requirements in digital equipment for use against single and multiple targets. The study is to include:

(1) computation of ballistic data

(2) recommendations on conversion from digital to analog information

(3) automatic choice of the most suitable of several continuously available prediction equations

(4) an estimate of the types of data smoothing which can be used and the length of smoothing time

(5) proceeding as far as possible in using the Whirlwind I computer to simulate various aspects of the digital fire control system.

Second, the ONR phase of the program includes the application of the Whirlwind computer to scientific and engineering problems. Initially these will be drawn from the scientific community of M.I.T. during the time that operating procedures for the computer are being established. As more machine time becomes available, the circle from which work comes can widen. First applications of the Whirlwind computer are expected in late summer and the fall of 1950. Machine testing and the installation of additional terminal equipment will continue throughout the year and available time will increase about uniformly to full availability in the fall of 1951.

IV. THE COMMON ONR AND AIR FORCE PHASES OF THE WHIRLWIND PROGRAM

Both the ONR and the Air Force programs are based on availability of the Whirlwind I computer. Joint support has therefore been approved for completion of the basic machine and to the extension of storage and terminal equipment.

Figure 1 is a diagram showing relationship of different parts of the Whirlwind I computer and the status of each. Areas on the diagram are roughly related to the amounts of equipment involved in different components but do not show the research effort in developing the various parts of the machine. Heavily shaded equipment is now complete and operating; lightly shaded equipment is now being completed; clear equipment has not yet been undertaken.

Appendix A is the proposal sent to ONR for Project Whirlwind during 1950-51 and covers completion of the equipment of Figure 1 required for ONR and Air Force work. Many scientific applications of Whirlwind will use erasable magnetic tape storage and suitable units have been ordered from the Raytheon Manufacturing Company. Appendix A gives a detailed description of next year's program with estimated costs.

A high-speed computer calls for terminal equipment with a high information acceptance rate. High-speed data recording is to be available in the Eastman Kodak photographic film units which are completed (though requiring some modifications) and in cathode ray tube curve plotting. Figures 2 and 3 are curves, including coordinate axes, generated by Whirlwind using the limited instructions possible in 32 registers of test storage. With coordinate axes plotted by the equipment, curves will be readable to about 1%, sufficient for much engineering work. This, along with the ability of the computer to print on a typewriter the numerical values of critical quantities (for example, intercepts and the minimum value of Figure 2), should save much tabulation of data that would later require hand plotting. Figure 3 is a solution to a second order differential equation where decreasing damping is plotted along the receding z axis, and shows an interesting and compact form for presenting data output.

Most of the final equipment of the Whirlwind computer is now operating. Reliable performance of the completed sections is already better than commonly expected of digital computers but should still be improved for use as a tool in real-time research where principal attention must go to the system as a whole and not be diverted to the computer as a single component. An average period of 3 hours is now expected in the operating equipment between isolated incorrect computational results. Component failures occur on the average of not oftener than once in 40 hours during scheduled operating periods. At the present stage of development, and if continuous additions to the computer were not being made, we estimate that the presently installed computer equipment could be kept operating about 80% of the time with the above reliability. Such satisfactory performance, even at the present stage of completion, is largely attributable to the marginal checking system.

Marginal checking in the computer is proving even more useful than expected. It not only finds most of the deteriorating components before they cause errors but locates design weaknesses and construction mistakes which are not bad enough to prevent normal operation. In the last nine months, marginal checking on a 400 tube 5-digit model arithmetic element has reduced the isolated random errors to an average of about one per week (10^{10} correct multiplications per error). One run of 45 days was achieved without an error from any cause. During this time, the 5-digit arithmetic element operated 23½ hours per day with one-half hour per day taken out for marginal checking and preventive maintenance.

The pre-testing of vacuum tubes, discovery of new accelerated life tests, and the development of better inspection methods are leading to average life expectancy in ordinary vacuum tubes of 5,000 to 10,000 hours. From the 4,000 vacuum tubes now in service, six or eight are replaced per week. Most of these are located in marginal checking, preventive maintenance periods before they cause trouble.

A regular schedule of storage tube construction was undertaken in the second half of 1949. Yields of good tubes have been high, ranging from 50% to 90% of those started. The present tubes are nominally rated at a 16 x 16 array or 256 digits although this is a minimum figure. It is confidently expected that the present tubes will actually operate at a 400 to 600 digit capacity. The tubes have operated under dynamic tests for short periods in the laboratory while storing a 32 x 32 array of 1024 digits, but not with adequate reliability. Rated capacity of the present tubes results from a compromise with reliability and can only be established after the first bank is operating. Maximum storage capacity will be set by the reliability limits which are required. Performance is but little dependent on density up to 256 or perhaps 400 binary digits. Above this figure the present tubes pass a knee in the curve where density becomes increasingly important.

Design modifications are now being made to change the size of the storage mosaic, magnitudes of holding gun current, and definition of high velocity beam. These modifications are expected to give reliable 1024 digit storage which is the Whirlwind switching limit. Unless the importance of a second tube bank to the Air Defense research dictates otherwise, the second bank will not be installed until the improved tubes are available later in the year.

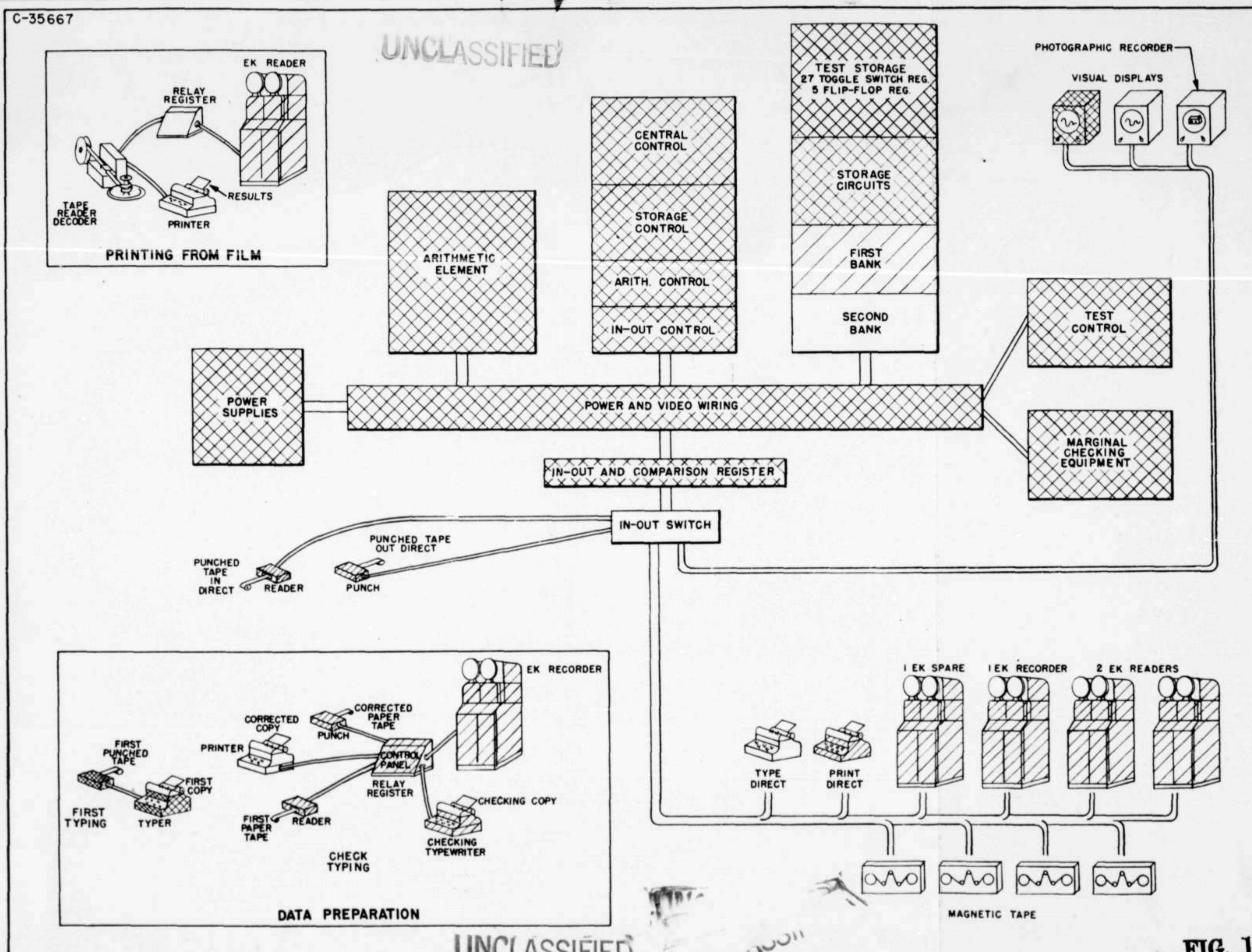
C-35667
UNCLASSIFIED
EK READER
RELAY REGISTER
TAPE READER DECODER
RESULTS
PRINTER
PRINTING FROM FILM
ARITHMETIC ELEMENT
CENTRAL CONTROL
STORAGE CONTROL
ARITH. CONTROL
IN-OUT CONTROL
TEST STORAGE
27 TOGGLE SWITCH REG.
5 FLIP-FLOP REG.
STORAGE CIRCUITS
FIRST BANK
SECOND BANK
PHOTOGRAPHIC RECORDER
VISUAL DISPLAYS
TEST CONTROL
POWER SUPPLIES
POWER AND VIDEO WIRING
MARGINAL CHECKING EQUIPMENT
IN-OUT AND COMPARISON REGISTER
IN-OUT SWITCH
PUNCHED TAPE OUT DIRECT
PUNCHED TAPE IN DIRECT
READER
PUNCH
EK RECORDER
CORRECTED COPY
CORRECTED PAPER TAPE
PUNCH
PRINTER
FIRST PUNCHED TAPE
FIRST COPY
CONTROL PANEL
RELAY REGISTER
FIRST TYPING
TYPER
FIRST PAPER TAPE
READER
CHECKING COPY
CHECKING TYPEWRITER
CHECK TYPING
DATA PREPARATION
1 EK SPARE
1 EK RECORDER
2 EK READERS
TYPE DIRECT
PRINT DIRECT
MAGNETIC TAPE
UNCLASSIFIED

FIG. 1

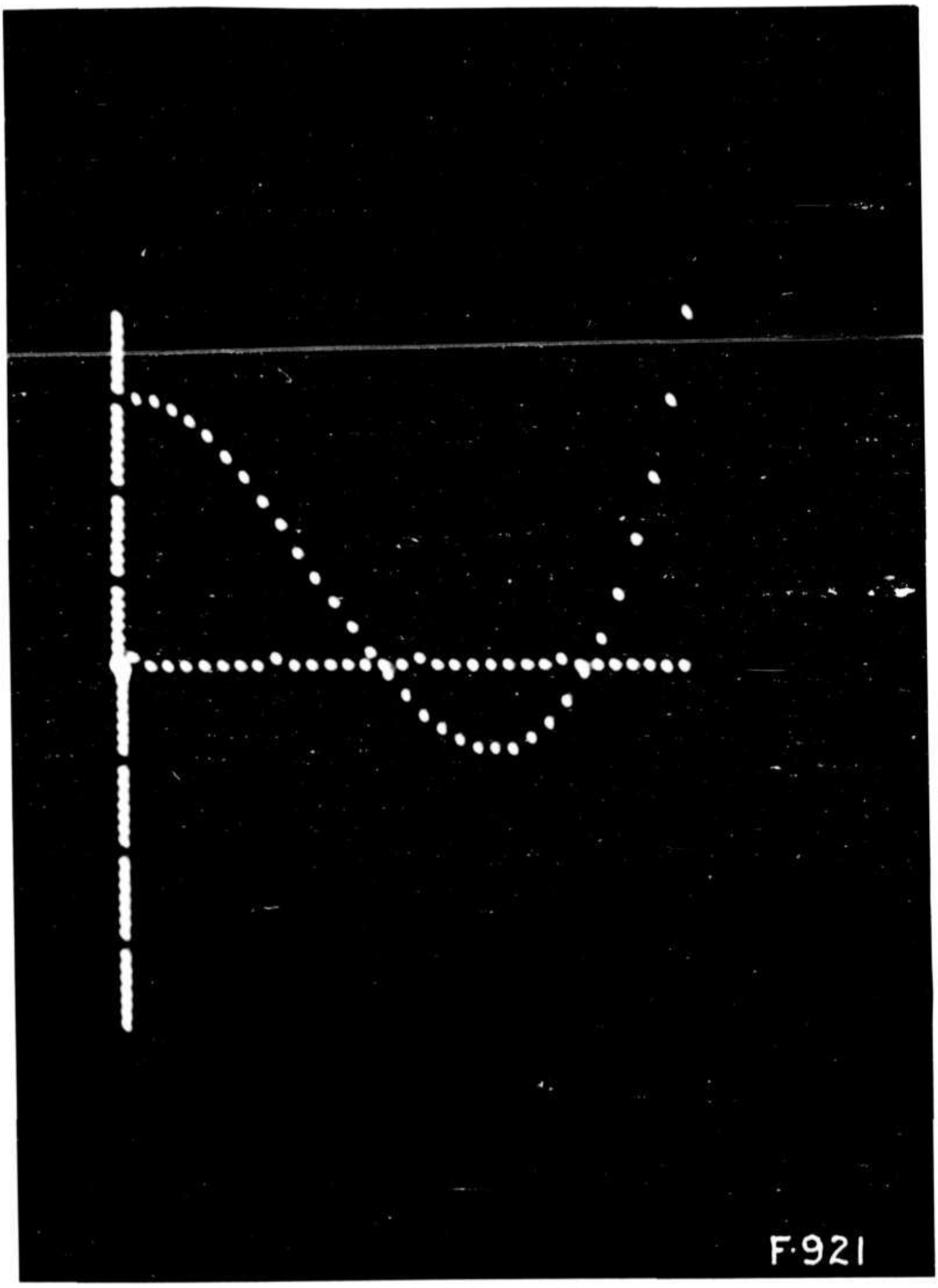

FIG. 2

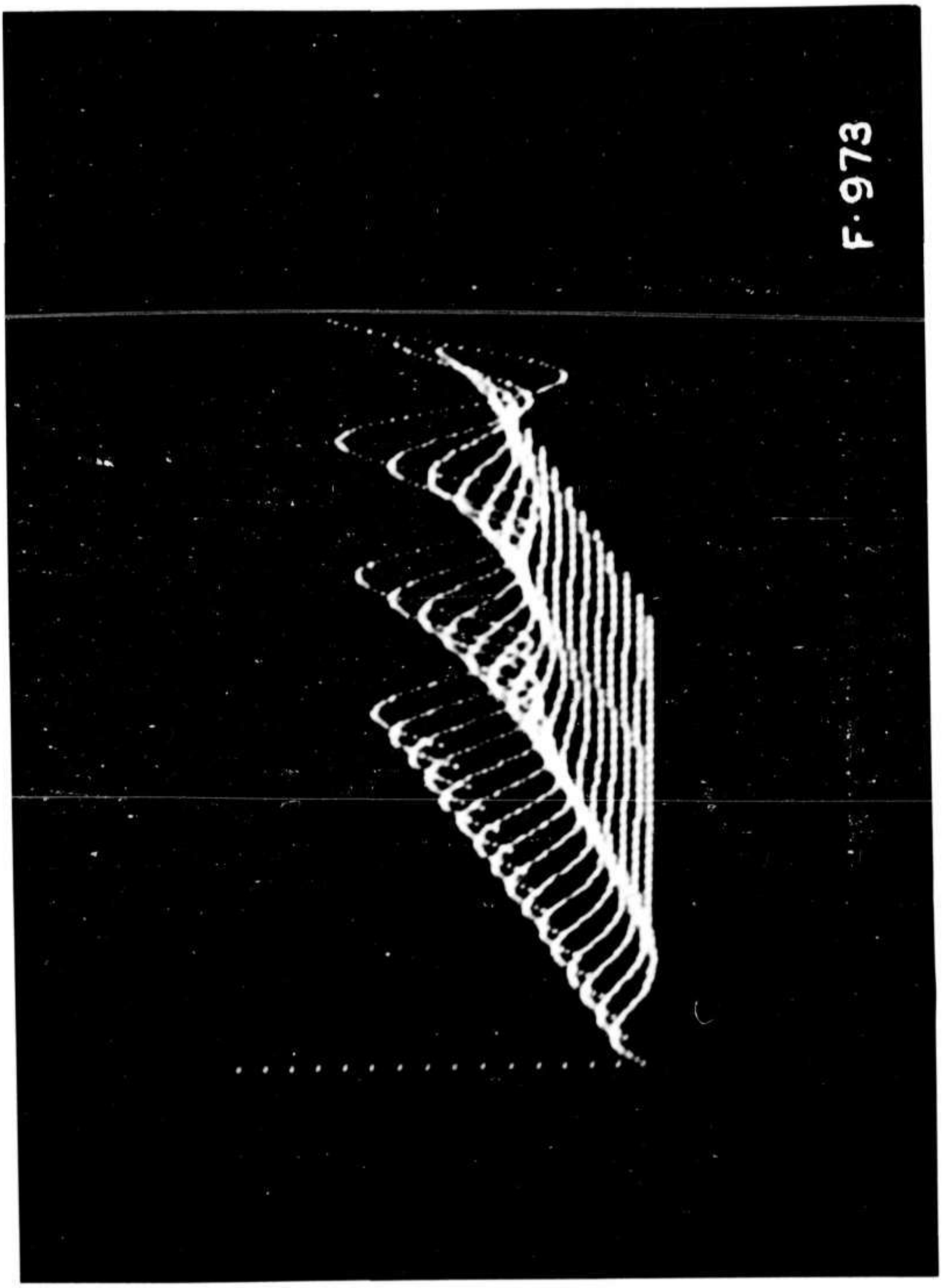

FIG. 3