A Survey of Electronic Analog Computer Installations*

L. B. WADEL† AND A. W. WORTHAM†

Summary—**A survey has been made of real-time electronic analog computer (differential analyzer) installations. This survey was conducted (1) so that a directory of the installations could be compiled and (2) so that various data regarding the installations could be made available for analysis. The survey was conducted by a mail questionnaire. Information was obtained regarding size of installation, size of staff, weekly usage of the equipment, age of installation, and availability to outside organizations from 96 installations having a total of 8,320 computer amplifiers. The results of the survey have been analyzed and are presented in this paper, together with the directory.**

Introduction

The Dallas-Fort Worth Chapter of the IRE Professional Group on Electronic Computers has conducted a survey of the United States and Canadian real-time analog computer installations. Questionnaires were mailed to 130 organizations which were thought to have such facilities; 96 questionnaires were returned and have served as a basis for the enclosed analysis. The questionnaires sought the following data:

1. Name of organization.
2. Address of organization.
3. Person in charge of computer.
4. Size of installation as measured by the number of computing amplifiers.
5. Size of technical staff associated with the computer.
6. Average number of operating hours per week.
7. Availability of the computer to outside organizations.
8. Date of the establishment of the computer installation.

Analysis of the addresses and organizations' names yielded the by-products of geographic data and the classification as to industrial, governmental, or university organization. The questionnaires were mailed during the period October, 1954–January, 1955. The resultant directory, plots, and tables have been termed the "1955 edition." It is hoped that future editions will be prepared which will be more nearly complete and even more informative.

Discussion of Terms

All of the terms used in the survey are self-explanatory with the exception of installation size. In order to define an index which describes adequately the computer size, an understanding of the electronic analog computer and its capability is necessary. The electronic analog computer (electronic differential analyzer) is a convenient tool for the design and analysis of dynamic systems, large or small, linear or nonlinear, electrical, electronic, mechanical, aerodynamic, pneumatic, chemical, economic, biological, or any combination.[1,2] This type of computer can be used simply to solve the differential equations describing a system, or it can be integrated with other components to simulate a larger system.

The key to the electronic analog computer's operation is the dc operational or computing amplifier. Such amplifiers perform the basic functions of summation, sign-changing, and integration, as well as other more specialized operations. Although utility of the computer depends also upon supporting equipment such as potentiometers, multipliers, and output recorders, the number of computing amplifiers provides the most convenient index to the capabilities of the computer. A given problem may take more or less amplifiers, depending upon to what extent passive networks are employed and how much flexibility in making parameter changes is provided for. Two simple examples are: (1) linear system described by a second-order differential equation, 3 amplifiers; (2) linearized longitudinal motion of an aircraft, perhaps 10 amplifiers. The fact that some problems require several hundred amplifiers is an indication of the complexity of today's technology, and of the electronic analog computer's abilities. It is for these reasons that the number of amplifiers was taken as the index of size for an installation.

Results and Discussion

A deadline was established so that prompt analysis of the questionnaires could be begun; it was necessary to process the data when 87 of the questionnaires (representing 7,866 amplifiers) had been received. However, all 96 installations reported are included in the directory. The numerical results are presented in tabular and graphical form below.

Geographic distribution of installations and amplifiers is shown in Table I, on the facing page.

Further analysis of the data shows that the average installation contains 90 amplifiers; is staffed by six

* Original manuscript received, February 11, 1955.
† Chance Vought Aircraft, Inc., Dallas, Tex.

[1] C. A. Meneley and C. D. Morrill, "Application of electronic differential analyzers to engineering problems," Proc. IRE, vol. 41, pp. 1487–1496; October, 1953.

[2] G. A. Korn and T. M. Korn, "Electronic Analog Computers," McGraw-Hill Book Co., Inc., New York, N. Y.; 1952.

persons; is operated 39 hours per week; and was established in 1952. A detailed breakdown of the number of installations and the number of amplifiers in governmental (G), industrial (I), and university (U) (including private research institutes) service is presented in Table II for each availability classification: not available to outside organizations (N), available for use by government contractors (AG), and available (A).

TABLE I

Regions*	Number of Installations	Number of Amplifiers
Pacific	26	2981
Mountain	5	584
West North Central	5	398
West South Central	5	398
East South Central	2	50
East North Central	11	669
South Atlantic	6	404
Middle Atlantic	22	1832
New England	4	516
Canada	1	34
Total	87	7866

* U. S. Census Bureau, "Statistical Abstract of the United States: 1953," (74th ed.), Washington, D. C.

TABLE II

	Installations			
	I	G	U	Total
N	36	9	3	48
AG	3	9	3	15
A	9	1	14	24
Total	48	19	20	87

	Amplifiers			
	I	G	U	Total
N	3286	867	124	4277
AG	1256	544	554	2354
A	518	216	501	1235
Total	5060	1627	1179	7866

From these tables it is easily seen that the industrial installations have the largest average size with 105 amplifiers; the governmental installations average 86 amplifiers, and the university installations average 59 amplifiers.

The remaining data and their analysis presented in graphical form for ease of study (Fig. 1) are acumulative frequency polygon showing the per cent of installations having not more than a given number of amplifiers. For example, 88 per cent of the installations have less than 200 amplifiers while 50 per cent of the installations have less than 48 amplifiers. (This is a particularly interesting result since there is an average of 90 amplifiers per installation.) Further, the largest installation contains 564 amplifiers and the smallest contains 10.

Fig. 2 is a cumulative frequency polygon showing the per cent of the installations which were in service less than a given number of years as of January 1, 1955. It is immediately noted, for example, that 50 per cent of the installations were in operation less than $2\frac{1}{2}$ years while the oldest was established in 1946.

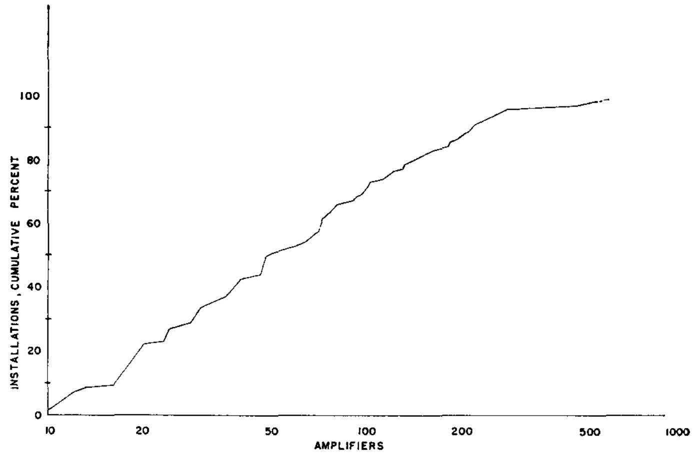

Fig. 1—Cumulative frequency polygon.

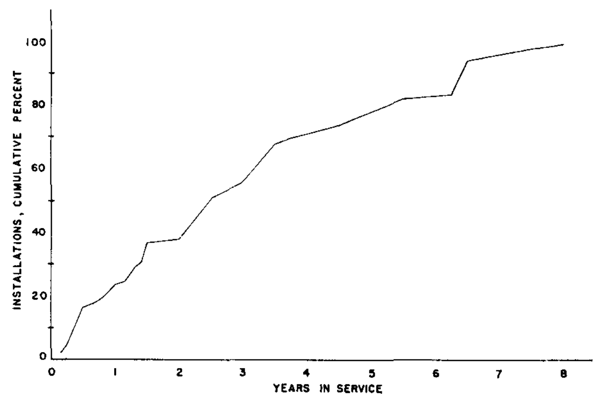

Fig. 2—Cumulative frequency polygon.

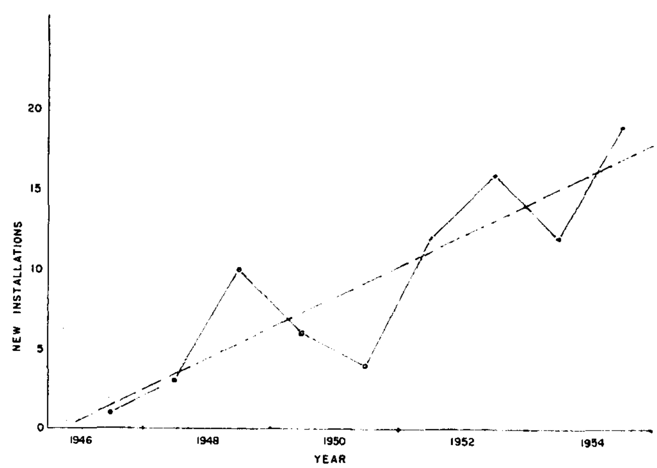

Fig. 3—New installations started each year.

Fig. 3 supplies even more growth information: the number of new installations which began each year. Although the data are extremely variable and possibly cyclic, a least-squares line has been fitted to aid in possible forecasts for the future.

Fig. 4 presents a cross-plot of the number of years in service versus the number of amplifiers. Special symbols differentiate between the various types of installations. The correlation coefficient for years in service versus the logarithm of the number of amplifiers for all types of installations is 0.59, and 0.65 for industrial installations only. The least-squares lines for all organizations and for industrial organizations alone are given for extrapolation purposes. However, the erratic variation in all the data is reason for extreme caution in extrapolating; for example, some installations may not have grown at all since their original establishment.

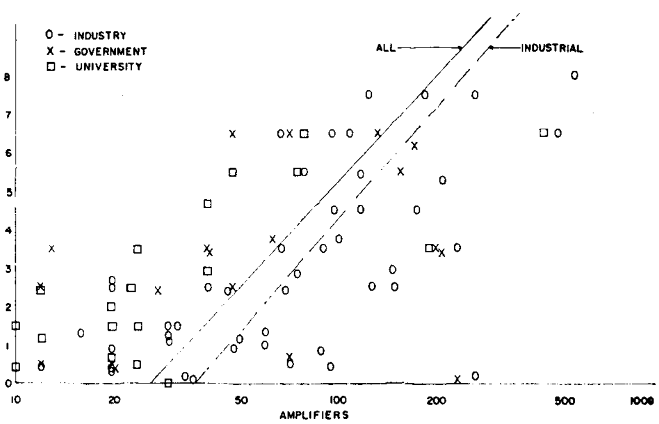

Fig. 4—Correlation of age and size of installations.

Directory

A directory of the installations returning the questionnaires is presented in Appendix I. A number of unlisted organizations are known to have electronic analog computer facilities but did not return the questionnaires, making it impossible to include them here. On the other hand, there are undoubtedly other installations in existence which were not contacted because of the incomplete mailing list available to the authors. Readers who know of installations not listed will render a distinct service by forwarding names of such installations to the authors so that they may be included in subsequent editions of the directory. Suggestions will also be welcomed for additional items of data to be requested in future surveys.

Appendix I*

Directory of Real-Time Electronic Differential Analyzer Installations 1955 Edition

Aerojet-General Corp., Azusa, Calif.	3 N
Argonne National Lab., Lamont, Ill.	3 AG
Armour Research Found., Chicago, Ill.	3 A
Battelle Memorial Inst., Columbus, Ohio	2 A
Beckman Instruments, Inc. (Berkeley Div.), Richmond, Calif.	3 A
Ballistic Research Lab. (Guidance and Control Branch, Ballistic Measurements Lab.), Aberdeen Prov. Grd., Md.	2 N
Ballistic Research Labs. (Exterior Ballistics Lab.), Aberdeen Prov. Grd., Md.	3 N
Beech Aircraft Corp., Wichita, Kan.	3 N
Bell Aircraft Corp., Buffalo, N. Y.	2 A
Bell Aircraft Corp., Buffalo, N. Y.	5 AG
Canadair Ltd., Montreal, Can.	2 N
CDC Control Services, Hatboro, Pa.	2 A
Chance Vought Aircraft, Inc., Dallas, Tex.	5 N
Collins Radio Co., Cedar Rapids, Ia.	3 N
Convair, Ft. Worth, Tex.	4 N
Convair, San Diego, Calif.	6 AG
Defense Research Lab., Austin, Tex.	2 AG
Detroit Arsenal, Center Line, Mich.	4 AG
Douglas Aircraft Co., Inc., El Segundo, Calif.	1 N
Douglas Aircraft Co., Inc., Santa Monica, Calif.	4 N
Dow Chemical Co. (Computation Lab.), Midland, Mich.	1 N
Dynalysis Dev. Labs., Inc., Los Angeles, Calif.	4 A
Electronic Associates, Inc. (Computation Center), Princeton, N. J.	4 A
Frankford Arsenal (Pitman-Dunn Lab.), Philadelphia, Pa.	3 AG
General Motors Corp. (Aeroproducts Operations, Allison Div.), Vandalia, Ohio.	3 A
Gilfillan Brothers, Inc., Los Angeles, Calif.	3 N
Glenn L. Martin Co., Baltimore, Md.	3 N
Grumman Aircraft Engrg. Corp., Bethpage, L. I.	4 N
Holloman Air Dev. Center (Computer Branch, Tech. Anal. Div., DCS/Operations), Holloman AF Base, N. Mex.	5 N
Hughes Aircraft Co. (Guided Missile Res. and Dev. Div.), Culver City, Calif.	4 N
Hughes Aircraft Co. (Radar Res. and Dev. Div.), Culver City, Calif.	5 N
Hughes Tool Co. (Aircraft Div.), Culver City, Calif.	1 N
Jack and Heintz, Inc., Cleveland, Ohio	2 N
Jet Propulsion Lab., Pasadena, Calif.	3 N
Johns Hopkins Univ. (Operations Research Office), Washington, D. C.	4 N
Leeds and Northrup Co., Philadelphia, Pa.	1 N
Lockheed Aircraft Corp., Burbank, Calif.	4 N
Louisiana State Univ. (LSU Computation Facility, Elec. Engrg. Dept.), Baton Rouge, La.	2 A
Mass. Inst. of Tech. (Dynamic Anal. and Control Lab.), Cambridge, Mass.	6 AG
W. L. Maxson Corp., New York, N. Y.	2 A
Minneapolis-Honeywell Regulator Co. (Aeronautical Div.), Minneapolis, Minn.	5 N
NACA Ames Aeronautical Lab., Moffett Field, Calif.	5 N
NACA Langley Aeronautical Lab., Langley Field, Va.	3 AG
Naval Research Lab., Washington, D. C.	3 AG
New York Univ. (College of Engrg.), New York, N. Y.	1 A
North American Aviation, Inc., Downey, Calif.	4 N
Northrop Aircraft, Inc., Hawthorne, Calif.	5 N
Northwestern Univ. (Aerial Measurements Lab.), Evanston, Ill.	3 AG
Oregon State College (Mechanical Engrg. Dept.), Corvallis, Ore.	1 A
Picatinny Arsenal (ORDBB-TRI), Dover, N. J.	1 AG
Picatinny Arsenal (ORDBB-TH1), Dover, N. J.	1 AG
Polytechnic Inst. of Brooklyn (Microwave Research Inst.), Brooklyn, N. Y.	1 A
Project Cyclone, Reeves Instrument Corp., New York, N. Y.	6 AG
Puget Sound Naval Shipyard (Planning Dept., Design Div.), Bremerton, Wash.	2 N
Purdue Univ. (Div. of Engrg. Sciences), West Lafayette, Ind.	2 N
Purdue Univ. (School of Aeronautics), West Lafayette, Ind.	2 N
Radio Corp. of America (Radar Engrg., Engrg. Products Dept., Electronic Products Div.), Moorestown, N. J.	1 N

* A: available to outsiders; AG: available to outside government contractors; N: not available to outsiders.
1: 10–20 operational amplifiers; 2: 21–40; 3: 41–80; 4: 81–160; 5: 161–320; 6: 321–640.

Ramo-Wooldridge Corp., Los Angeles, Calif.	5 N
Rand Corp., Santa Monica, Calif.	3 N
J. B. Rea Co., Inc., Santa Monica, Calif.	4 A
Redstone Arsenal (Computation Lab.), Huntsville, Ala.	2 N
Rensselaer Polytechnic Inst. (Computer Lab.), Troy, N. Y.	2 A
Republic Aviation Corp. (Guided Missiles Div.), Hicksville, L. I.	2 N
Sandia Corp., Sandia Base, Albuquerque, N. Mex.	3 N
Schlumberger Well Surveying Corp. (Research Labs.), Ridgefield, Conn.	2 N
Southern Research Inst., Birmingham, Ala.	1 A
Sperry Corp. (Sperry Gyroscope Co. Div.), Great Neck, N. Y.	4 N
Sperry Corp. (Sperry Gyroscope Co. Div.), Great Neck, N. Y.	4 N
Sperry Corp. (Sperry Gyroscope Co. Div.), Great Neck, N. Y.	3 N
Sperry Corp. (Sperry Gyroscope Co. Div.), Great Neck, N. Y.	3 N
Taylor Model Basin (Code 535), Navy Dept., Washington, D. C.	2 N
Technical Operations, Inc., Arlington, Mass.	2 A
Temco Aircraft Corp., Dallas, Tex.	2 N
Univ. of Buffalo (Physics Dept.), Buffalo, N. Y.	1 A
Univ. of California (Electrical Engrg. Div.), Berkeley, Calif.	1 A
Univ. of Colorado (Engrg. Experiment Station), Boulder, Colo.	1 A
Univ. of Kansas (Dept. of Elec. Engrg.), Lawrence, Kan.	1 A
Univ. of Michigan (Willow Run Res. Center, Engrg. Res. Inst.), Ypsilanti, Mich.	5 A
Univ. of Minnesota (College of Engrg., Inst. of Technology), Minneapolis, Minn.	2 A
USNAMTC (Simulation Lab.), Pt. Mugu, Calif.	4 AG
U. S. Naval Gun Factory (Physics Branch, Code 724), Washington, D. C.	1 AG
U. S. Naval Ordnance Lab., Corona, Calif.	3 N
U. S. Naval Ordnance Lab., Corona, Calif.	5 A
U. S. Naval Postgraduate School (Dept. of Math. and Mechanics), Monterey, Calif.	1 AG
U. S. Naval Postgraduate School (Elec. Engrg. Dept.), Monterey, Calif.	1 N
U. S. Navy Electronics Lab., San Diego, Calif.	1 AG
U. S. Navy Electronics Lab., San Diego, Calif.	1 N
Westinghouse Electric Corp. (Control Engrg. Dept), Buffalo, N. Y.	1 N
Westinghouse Electric Corp. (Aviation Engrg. Dept.), Lima, Ohio	1 N
Westinghouse Electric Corp. (Atomic Power Div.), Pittsburgh, Pa.	3 N
Westinghouse Electric Corp. (Analytical Section 5-L-51), E. Pittsburgh, Pa.	4 N
Westinghouse Electric Corp. (Air Arm Div.), Baltimore, Md.	4 N
White Sands Prov. Grd., N. Mex.	3 N
White Sands Prov. Grd., N. Mex.	5 N
Worcester Polytechnic Inst. (Dept. of Elec. Engrg.), Worcester, Mass.	1 A
Wright Air Dev. Center (Aeronautical Res. Lab.), Wright-Patterson AF Base, Ohio.	4 AG

Acknowledgment

It is a pleasure to acknowledge the general assistance of J. P. Haynes and Mrs. F. Bentley, as well as the assistance of Mrs. M. Cohen in typing the manuscript, and Mrs. E. Bird in executing the figures.

A Digital Computer for Use in an Operational Flight Trainer*

W. H. DUNN, C. ELDERT, AND P. V. LEVONIAN†

Summary—**The requirements for a digital computer for use in an operational flight trainer are presented with emphasis being placed on the real-time aspects of the problem. The general purpose digital computer is shown to be inadequate for this purpose and a special purpose digital computer is described which meets the requirements.**

Introduction

A REAL-TIME simulator is a device which simulates a physical system, responding to external stimuli as fast as does the actual system. In the case of the operational flight trainer, the simulator is required to sense pilot's actions and actuate cockpit instruments so fast that the pilot cannot distinguish between simulator response and true airplane response.

In the digital operational flight trainer a numerical or step-by-step solution of the flight systems' equations is made with a time interval chosen which is sufficiently small to ensure accuracy and stability of the solution. The flight system as simulated by the trainer described here involves a system of ten simultaneous nonlinear differential equations with the forces and moments being under the indirect control of the pilot. In order for the digital flight trainer to simulate the flight system in real-time, it is required once each time interval to (a) sample the pilot's commands (through examination of the throttle, control surface deflections, etc.), (b) make a numerical solution of the systems equations, and (c)

* Original manuscript received July 8, 1954; revised manuscript received January 19, 1955. This work was performed as part of a project sponsored by Special Devices Center, ONR.
† Moore School of Electrical Engineering, University of Pennsylvania, Philadelphia, Pa.