LLWp.186
One copy only

6345
Limited Distribution Memorandum 6-11

CONFIDENTIAL

Project Whirlwind
Servomechanisms Laboratory
Massachusetts Institute of Technology
Cambridge, Massachusetts

SUBJECT: INFORMATION ON WHIRLWIND I AS REQUESTED BY LT. CMDR. RUBEL, RESEARCH AND DEVELOPMENT BOARD, IN LETTER DATED 7 FEBRUARY 1949.

To: Lt. Cmdr. D. M. Rubel
Navy Secretary
Committee on Basic Physical Sciences
Research and Development Board
Washington 25, D. C.

From: Jay W. Forrester

Date: February 15, 1949

The following answers are in reply to questions from Lt. Commander D. M. Rubel in his letter of 7 February 1949. They provide information on the digital computer work of Project Whirlwind under the Office of Naval Research Contract N5ori-60.

1. Name of Computing Machine:

Whirlwind I.

2. Contracting Agency:

Office of Naval Research (formerly Special Devices Center, now Mathematics Branch).

3. Contributing Agency:

None

4. Contractor:

Massachusetts Institute of Technology.

UNCLASSIFIED

5. Subcontractor:

Sylvania Electric Products, Inc. (Boston).

Power Equipment Company (Detroit).

Carrier Air Conditioning.

(Reader-recorders as Government Furnished Equipment from Eastman Kodak Company on prime contract with the Special Devices Center of ONR.)

6. Total Cost to Complete and
7. Cost to date:

These questions must be answered with some explanation and cost breakdown to convey the history and scope of the project. Figures are available as follows:

A. Total money that will be spent by Project Whirlwind to June 30, 1949.

B. Estimated additional amount to carry all project work to June 30, 1950. At that time the Whirlwind I computer will be assembled, tested, and in preliminary operation; and applications research using the equipment will be ready to start.

The costs under A. are divided into the several phases of Project activity. The expenditure for storage tube development is separately estimated. This basic research and tube development has been necessary because no other storage system has been available for the high speeds required in the control and simulation applications of digital computers which have been assigned to Project Whirlwind. A breakdown is given for other special research, for supporting engineering, for design and construction, for education and training as required in the work, and for establishment and operation of the laboratory facilities. The total project expenditure includes about one year of work on an analog-type aircraft stability and control analyzer before digital computation was chosen by M.I.T. and the Special Devices Center as technically more promising and as less complex and costly than analog equipment for aircraft simulation.

UNCLASSIFIED

(Questions 6 and 7 continued)

A. TOTAL COST TO JUNE 30, 1949.

1.	Total expected expenditures through June 30, 1949:		
	Appropriation under Letter of Intent NOa(s)-5216	$ 75,000	
	Appropriation under Contract N5ori-60	2,714,000	
	Additional funds requested December 1948	378,000	
	Total		$3,167,000
2.	Analog Computing methods and aircraft cockpit simulation.	$ 191,000	
3.	Serial type digital computer studies.	122,000	
4.	Preliminary studies to determine parallel computer feasibility.	106,000	
	Total expenditures before adoption of parallel-type computer program.		$ 419,000
	Total expenditure to June 30, 1949 since starting present parallel-type computer program.		$2,748,000

This total since beginning parallel-type computer design can be allocated according to the following estimates:

5.	Storage tubes (basic studies of life and storage behavior, laboratory and processing equipment, development of construction techniques, tube design, construction, testing, electron guns, beam deflection and signal output circuits, reliability tests of tubes)	$ 472,000
6.	Special supporting research (pulse transformers, vacuum tube life in pulse circuits, high-speed flip-flops, crystal studies and testing methods, magnetic recording, video amplifier and probe, mathematics and applications research, sampling servo theory, and analog-digital data conversion)	348,000

(Questions 6 and 7 continued)

7.	Supporting Engineering (voltage regulation, a-c coupled circuits, pulse delay studies, life and reliability, laboratory-designed test equipment, basic circuit development)	$ 180,000
8.	Whirlwind I design and construction (including Sylvania, Power Equipment Company, and Carrier Air Conditioning subcontracts)	1,197,000
9.	Education and training (training new staff, report editing and reproducing, visitors, thesis supervision, seminars for staff instruction, etc.)	321,000
10.	Laboratory operation (lab equipment and facilities, commercial test equipment, military security, lab power supplies, etc.)	230,000
	Total for parallel-type computer through June 30, 1949.	$2,748,000

B. ESTIMATED BUDGET FOR JULY 1, 1949 TO JUNE 30, 1950.

The following budget shows an estimate for carrying on the present research, and computer design, construction and installation leading to a computer application research program beginning July 1, 1950.

1.	Completion of Whirlwind I design, construction, installation and preliminary operation	$ 489,000
2.	Storage Tube development and construction, including control circuit and output circuit research	314,000
3.	Supporting Engineering	64,000
4.	Special Research (mathematics, computer applications, vacuum tube life, crystal research)	108,000
5.	Reports, Information, Education and Training (report editing and reproducing, discussions with visitors, seminars for staff instruction)	96,000

(Questions 6 and 7 continued)

6. Laboratory Operation:

a. Military Security	$ 27,000
b. Test equipment, laboratory facilities, equipment repair, standards for materials and components	18,000
Estimate for July 1, 1949 to June 30, 1950	$1,116,000

8. Cost to produce each additional machine:

Reproduction cost will vary greatly depending on conditions. The estimates below are for a single additional machine, not a quantity lot which would reduce unit cost, and assume duplication of the present computer without the redesigning which it is presently known would reduce the number of components and the cost. The figures are rough estimates and assume:

a. No provision for housing.

b. Construction by a commercial company skilled in electronics work.

c. Computer built from Whirlwind I drawings with essentially no changes.

d. No production equipment or personnel training for storage tube construction included. Thirty-two tubes charged at $750 each.

e. Reasonable spare assemblies included.

f. No test or laboratory equipment (might be additional $25,000).

g. No systems testing or preliminary operation (might be additional $60,000).

Reproduction cost itemization:

1. Construction and installation of power supplies	$ 75,000
2. Construction and installation of air conditioning	30,000

(Question 8 continued)

3.	Construction and installation of racks and cabinets	$ 50,000
4.	Installation and cost of wiring	100,000
5.	Construction of console and control room equipment	25,000
6.	Cost of tube complement	35,000
7.	Cost of materials	150,000
8.	Cost of construction (includes component and panel testing)	250,000
9.	Five input-output units	150,000
10.	Engineering supervision	125,000
11.	Modifications in drafting	30,000
12.	Engineering liaison from Whirlwind I computer research group.	50,000
		$1,070,000

9. a. Status, and
   b. Completion date:

The entire arithmetic element and arithmetic control are now installed and operating; racks, wireways, power supplies and airconditioning are installed and operating.

Central control is designed and under construction. It will be installed during the next few months.

Storage tubes are now working satisfactorily. Circuits are to be designed January to June 1949 and constructed July to December 1949.

Reader-recorders are to be delivered from Eastman Kodak Company May to August 1949.

The entire system is to be installed by January 31, 1950, plus or minus one month.

Time until June 30, 1950 will be required for preliminary operation, completion of drawings, parts lists, bills of material, preliminary work on instruction books.

10. Type of problems (applications):

The short register length, high speed, and reliability features make the computer especially suited to control (interception, fire control, air traffic) and simulation (equipment such as aircraft and missiles, tactics such as war college training). It is a general purpose computer.

11. Internal High-Speed Memory Type:

Electrostatic storage tube.

12. Capacity of Memory (in words):

2048 words.

13. Word length:

16 binary digits.

14. Word Time Microseconds:

Not applicable.

15. Auxiliary (External) - Memory Type:

Photographic film units being supplied by Eastman Kodak Company will be incorporated first. The computer will be able to use any type of external memory which is required and available.

16. Type of Arithmetic Unit (Series or parallel):

Parallel.

17. Addition Time[a] - Microseconds:

The addition time is 3 microseconds not including transfers.

18. Multiplication Time [b] - Microseconds:

The multiplication time is 14 to 22 microseconds, not including transfers. For longer register lengths, multiplication time will average the length of the register in binary digits times 0.75 microseconds, plus 6 microseconds for carry and sign correction.

19. Average Add. Time [c] - Microseconds, and
20. Average Mult. Time [d] - Microseconds:

In Whirlwind I, assuming a 6 microsecond storage access time, addition with two inputs from storage and one transfer to storage will require 48 microseconds. Similarly, a multiplication will require 60 microseconds. For each of the operations, three orders must be extracted from storage. A register length enough longer to hold two orders would lead to faster rather than slower speeds because the number of references to storage for control orders would be halved.

21. Average Access Time to High-Speed Memory - Microseconds:

The storage access time design goal is 6 microseconds, which can probably be met. Present equipment gives 25 microseconds.

22. Maximum Access Time to High-Speed Memory:

Storage access time is fixed and not variable as in a serial machine.

23. Average Transfer Time between High-Speed Memory and Auxiliary Memory:

Present Eastman Kodak equipment is designed for 2000 words per second, with up to 25 binary digits per word. It provides for recording both the word and its complement for checking purposes.

24. OSC Rate, M.C.:

1 and 2 megacycles per second.

25. Code:

Single address code is used and is stored in the high-speed memory.

26. Number of Instructions per Word:

Each order consists of one word containing an operation instruction and the address of a word in storage.

27. Checking:

A complete and automatic system of marginal checking is being installed. This can detect the gradual deterioration of electronic circuit elements before they reach the point of causing trouble. Tests show this is a powerful method of insuring trouble-free operation and an efficient weapon against intermittent electronic failures, which are the most difficult to prevent and detect.

The computer performs a check of all number transfers, accomplished by means of an auxiliary transfer check bus and check register. The check register checks every transfer, essentially by duplicate operation through separate circuits. Continuous checking is not done in the arithmetic element.

Check problems are being designed to indicate trouble. Trouble-location problems to locate a failure have been designed and demonstrated, often to an accuracy of a single vacuum tube or circuit element.

The photographic input-output equipment records both the number and its complement, which are compared for checking.

28. Number of Tubes:

Tubes total 4,500, including power supplies, six reader recorders, and test storage. In test storage are some 700 tubes which will not be used after the entire machine is in operation and which would not be put into a duplicate machine.

29. Number of Crystals:

About 12,000 diode crystal rectifiers are used. About 2,800 pulse transformers are used.

30. Net Floor Space ft^2:

These figures are for the present equipment, where little effort has been made to conserve space and where complete accessibility has been maintained for servicing. Areas are for the entire rooms, and provide for desirable access to all components and room for test equipment and the personnel who at times are required to be around the equipment.

Computer room	1,800 square feet
Control room	500
Power supply room	400
Air conditioning equipment	400
	3,100 square feet

In addition, the control room should be extended to provide for conference tables, space for observers, and space for additional terminal facilities. Another 1,000 square feet would be desirable for these purposes.

31. Cost of Maintenance per Month @ 8 hours per Day, and
32. Cost of Salaries per Month.

Maintenance is estimated at $10,000 per month, which includes repair parts, salaries of required maintenance personnel for eight hours per day, the cost of operating a storage tube construction shop for the estimated number of replacement tubes, and operating power. This estimate presumes the simultaneous existence of a computer applications group, and a parallel research program to help share certain fixed costs such as guards, discussions with visitors, and some administration.

33. Total Cost to Operate per Month @ 8 Hours per Day, and
34. Personnel Requirements to Operate:

The cost and personnel to operate the computer can vary over a vast range depending on the type of computer application and the percentage of the time it is used. What is the time division between studies of control applications, of simulation, and use for scientific computation? What is the nature of the scientific problems; are they of wide variety or do they fit into families of similar problems? Does the machine staff code problems or is this done by the person or group having the problem? Is a teletype communications center included to bring in problems from a large number of machine users? Is the cost of expanding terminal facilities for special studies to be included?

Only a few persons (2 to 5) would be required for actual physical operation of the computer. Depending on the answers to the above questions, the total personnel may range from 15 to 250 for useful full-scale effective use of the equipment (this does not include continuing development of new digital computer equipment). Likewise, the budget might range from $12,000 to $150,000 per month, depending on the type and urgency of the applications.

35. Number of Persons Building Machine (Number of Professionals and Number of Non-Professionals):

The present Project Whirlwind group has 63 staff and 120 non-staff to carry on the activities listed under Question 7.

36. Power Requirements in KW:

Power to the computer:

Filaments	35 KW	
Direct current	18	
		53 KW
Losses in power supplies and isolating motor generators		28
Room lighting		6
Air conditioning (average estimate)		10
Total		97 KW

37. Percentage of Time in Operation:

The computer is not yet completed and actual data not yet obtained. The percentage of time in operation is expected to be high as confirmed by tests on the five-digit test arithmetic element which has been equipped with marginal checking circuits.

Jay W. Forrester

Jay W. Forrester

JWF:bc