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Discussion of Project Whirlwind

Aspects of RDB Computer Panel

Report [redacted]

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DISCUSSION OF THE COMMENTS ON PROJECT WHIRLWIND MADE BY THE AD HOC PANEL ON ELECTRONIC DIGITAL COMPUTERS OF THE BASIC PHYSICAL SCIENCE COMMITTEE OF THE RESEARCH AND DEVELOPMENT BOARD

by

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DISCUSSION OF THE COMMENTS ON PROJECT WHIRLWIND MADE BY THE AD HOC PANEL ON ELECTRONIC DIGITAL COMPUTERS OF THE BASIC PHYSICAL SCIENCE COMMITTEE OF THE RESEARCH AND DEVELOPMENT BOARD

I. INTRODUCTION

1. This memorandum analyzes the comments of the above Panel as they specifically relate to Project Whirlwind. Comments on the report as a whole are contained in a separate memorandum.

2. In the report, the work of Project Whirlwind, the Office of Naval Research supervision of the project, relations between the two groups, and the characteristics of the Whirlwind I computer receive extremely unfavorable consideration. The history of any large and active enterprise will always disclose faults which might have been improved by better planning, and in this project like others there is a basis of fact from which the Panel conclusions are drawn. The unfavorable interpretation of the overall project is probably traceable to a combination of the following:

(a) The Panel stresses the necessity for digital computer application to real time problems without recognizing this as the primary objective of Project Whirlwind.

(b) The Panel did not include all important digital computer projects in their consideration. As a result, they have criticized Whirlwind simply on comparative size of budget, without recognizing in the report the existence of the United States Naval Computing Laboratory, which is the largest Government financed electronic digital computer enterprise in the United States.

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(c) The Panel concentrates on electronic digital computing machines as end products as if they were a standard manufactured item rather than treating them as an unknown field of research and development.

(d) It appears that the Panel did not begin its investigations by establishing an opinion of the necessity and importance of digital computers in the Military Establishment. As a result, the report contains numerous contradictions concerning the adequacy of present projects to meet these needs.

(e) The Panel gives no comprehensive and critical analysis of the technical competence of the groups studied. Comparison is made principally on the basis of information offered to the Panel, without analysis of its soundness, and the report stresses primarily the relations between the Military Establishment and the contractors.

(f) The Committee has not attempted to pick out the good points of various computing programs to give a balanced picture along with the faults.

(g) In many examples the Committee conclusions are based on incorrect information.

II. <u>PANEL CRITICISMS OF PROJECT WHIRLWIND</u>

Criticisms of Project Whirlwind, in apparent order of importance, are listed here and will be discussed in detail in Section IV. The Panel

(1) can find no end use, objective, or purpose for the existence of Project Whirlwind.

(2) criticizes severely the status of Whirlwind I terminal equipment.

(3) believes that technical progress of the Project has suffered seriously by changes in the Naval groups supervising the work.

(4) appears to feel that Project Whirlwind is too large. This is implied though not explicitly stated.

(5) disagrees with the technical specifications of Whirlwind I, although it is not clear how disagreement with specifications is possible when the Panel had not discovered Project or Whirlwind I computer objectives.

(6) raises several objections to the Whirlwind I storage tube.

Section IV gives reasons why some of the above criticisms do not show the project accurately and the others are not stated in the proper perspective.

III. GENERAL COMMENTS ON THE PANEL REVIEW OF PROJECT WHIRLWIND

1. Whirlwind was the first project visited by the Panel. One day was spent in discussing the project, an appreciable part of which was devoted to Panel orientation in their new undertaking.

The members expressed the desirability of returning for more complete information but did not have time to do so.

2. The Panel requested and received complete frankness in discussion of computer and project problems, both technical and administrative. This was done in the atmosphere that the Panel could be most helpful in remedying such problems as did exist if they could be frankly discussed. The report does not reciprocate by balancing accomplishments and good points against the problems which certainly exist in any established undertaking. The report shows that a comparable freedom of discussion was not obtained by the Panel in several other projects. The report discusses the difficulties that do exist in such a way that they may, as a result, be accentuated rather than remedied. The report may shake confidence in the good points

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of many projects rather than helping to correct the poor points.

3. In comparing Whirlwind with other projects, the Panel is comparing such problems as it could find in an organization several years in existence with the promises and hopes of newly established undertakings.

4. The Panel has not recognized that Whirlwind predates many of the other projects considered, is two years farther along than most, and consequently the Whirlwind I computer itself is two years more obsolete.

5. There is a striking discrepancy between the general recommendations of the Panel, which are very good, and their comments about Whirlwind. Whirlwind appears to be following closely along the more important general recommendations of the Panel. Whirlwind ideas have fared well in the hands of the Panel but not the actual project or the Whirlwind I computer. The report forcibly states the need for the work Whirlwind is doing but does not recognize this as being in progress.

6. In particular, the Panel stresses need for digital computation on "real time" problems but in no place recognizes Whirlwind as the major present contributor in this field or as the source of most of the ideas leading to the Panel recommendations about the importance of real time computation.

7. There is in the report no recognition of the high speed of the Whirlwind I computer, although this is the particular unique feature of Project Whirlwind work. On the other hand, the necessity for maximum speed must have been recognized because (page 47, paragraph 2) the slowness of one of the next range of machine speeds is deprecated as contributing little to real time computation.

8. Throughout the report, Whirlwind is considered as a machine divorced from a research project. This leads to many doubtful conclusions. New suggested applications for digital machines are arising rapidly, and a machine and laboratory where they can be tested, without waiting for the construction of a digital computer to order, is important.

9. The report does not recognize the assistance, both direct and indirect, which Whirlwind has given to other projects. This is especially true of the United States Naval Computing Laboratory, which is not mentioned in the report, and, to a lesser extent, is true of the Raytheon and other work.

10. The report overlooks the field of simulation as a valid use of digital computers, and therefore omits from its consideration a second primary objective of Project Whirlwind. The use of computers in simulation is of sufficient military importance that much machine development is aimed specifically at that application, and a Research and Development Board committee has been formed especially to consider the simulation field.

11. The report is at variance with several important facts. The Harvard Mark III is referred to as the first and only postwar electronic machine supported by the Military Establishment, although the Eckert-Mauchly BINAC is an electronic computer and was shipped from the manufacturer first. The latter is not included in any of the tabulations and is recognized only on one page of the report (page 47). Omitting the BINAC leaves out an important scale of reference in evaluating the computer program. It illustrates several of the difficulties which result from close adherence to certain of the Panel recommendations.

IV. DISCUSSION OF SPECIFIC CRITICISMS OF PROJECT WHIRLWIND

This section will discuss the statements given in the report with pertinent information bearing on the subject of criticism.

A. Objective of Project Whirlwind and End Use of Whirlwind I Computer

The following comments are taken from the report:

(Page 11, Section 2.3.5)

". . . recommended that the Office of Naval Research take immediate steps to find a suitable end use for the completed Whirlwind I machine. If such a use can not be found, (the Panel has been unable to find one) further expenditure for the completion of the machine should be stopped.

"If a suitable end use for Whirlwind I is found, the Office of Naval Research, in cooperation with the proposed user and contractor, should establish definite specifications to be met by the completed machine, including terminal equipment required for the intended use."

(Page 39, Section 4.4.7)

"No definite end use has been selected for this equipment."

(Page 54, Section 5.8)

"Neither the sponsor, Office of Naval Research, nor the contractor, Massachusetts Institute of Technology, has expressly named any specific computing project to be assigned to this machine."

The Panel does not distinguish between "no possible objective" and "no contractually specified application." The Office of Naval Research, the Navy as a whole, and the Military Establishment have a wide range of digital computing interests.

The report (page 9(4)) criticizes machines with no obvious means of support and, by implication elsewhere, directs this toward the Whirlwind I computer. In view of the objectives discussed later, this is similar to criticizing a commercial concern for plant construction unless it had actual purchase contracts for the entire future output of the plant. The equivalent commercial procedure of making a market research study has been done continuously by the Office of Naval Research and M.I.T. to establish the importance of a digital computing center, machine, and laboratory directed primarily at real time problems.

Where definite end-use objectives for digital computers have initially existed, as the Panel prefers, these have often been revised and changed by ensuing circumstances. For example: The ENIAC was designed as a special purpose machine specifically for ballistic problems; it has been used in many other ways and perhaps its greatest contribution has been in showing the possibility of running other large electronic machines. The BINAC computer was purchased for a mobile real-time problem which was too ambitious a specification and the machine has been diverted to other use. The Panel recommends changing, probably correctly so, the immediate end objective of the Harvard Mark III computer and suggests that it remain at Harvard rather than being shipped to Dahlgren. The Whirlwind computer started with very rigid, definite specifications including equations and data to be used in aircraft stability analysis, but these have been broadened greatly as the universal utility of digital computers is better understood and the needs of the Military Establishment change. Out of all the machines studied by the Panel, average chances at present seem very much against any particular machine's being completed and used for the purpose originally intended.

The implication in the first quotation referring to "<u>the</u> proposed user" and "<u>the</u> intended use" does not fit the objectives of the project for providing a laboratory and a machine for studying digital computer applications having the greatest current priority. This misunderstanding may arise from too great a concentration on computers as specific machines rather than a concentration on digital computation as a problem in research, development, and application.

The following statement of Project Whirlwind objectives are listed roughly in the order of importance but not necessarily in the order of execution.

1. Real Time Applications of Digital Computers

The report recognizes the importance of digital computation in "real time" problems. The Panel apparently does not realize that this field comprises the primary objective of project Whirlwind. Application of digital computers to "real time" problems can be divided into two important areas.

a. Tactical Military Problems. This field is recognized in the report (page 8, section 2.2.2):

> "It is recommended that additional studies be set up, directed toward the real time computation essential to the solution of tactical military problems. Such studies should consist principally of system analyses in the guided missile or special projectile field, but should include also specialized component development such as quantizing machines and digital servos needed to give automatic access to instantaneous data by the computing elements."

Project Whirlwind has been doing most of the preceding.

The Panel further recognizes the importance of the real time tactical applications. On pages 14 and 15 it recognizes the newness of this field and that no digital equipment is yet operating in it. The need for starting a sound and integrated research and development program therefore results. The report stresses this field again on page 17, Section 3.2 (3).

Work in this field is being actively pursued by the Office of Naval Research. Plans for applying the Whirlwind I computer to studies of digital fire control are well along in the discussion stage by the Office of Naval Research and M.I.T. These plans are being made with the knowledge and encouragement of the Naval Research Laboratory, the Bureau of Ordnance and the Bell Laboratories Mark 65 project.

The Servomechanisms Laboratory, in work directly related to Project Whirlwind, is studying the application of digital computers to air traffic control for the Air Force. The extensive use of computers is specifically called for in the report of Special Committee 31 of the Radio Technical Committee for Aeronautics, and the M.I.T. air traffic control program grows out of that report. Technically, at this stage of digital computer research, air traffic control studies are synonomous with aircraft interception and military aircraft control.

Applications of the digital computer background available at Project Whirlwind and application of the Whirlwind I machine itself to the problems of land-based, anti-aircraft fire control are being jointly considered by M.I.T. and the Signal Corps.

An Annapolis postgraduate Naval officer is now doing research at Project Whirlwind on the application of digital computers to the problems of data analysis, weapon control, and ship navigation in anti-submarine attack.

The Office of Naval Research has exhibited a longer sustained interest in the application of digital computers to real time problems than any other military department. Whirlwind work has been in progress for four years, during which it has had firm support and encouragement and is now materializing into an operating laboratory and a machine suitable for research in real time problems.

b. Simulation. The Panel does not mention the many applications of simulation techniques as a proper field for digital computation. There are, nevertheless, many military groups who can derive great benefits from such work. Simulation falls roughly into two categories: one where equipment is being tested; the other where human reactions or teamwork are being studied or developed. Combinations of the two are possible. Simulation, for equipment study only, might arise in the testing of guided missile components. Simulation involving both equipment and persons accounted for the initiation of Project Whirlwind. The initial intention was to build a machine for simulating the behavior of large aircraft, based on data derived from wind tunnel tests, and to provide an associated cockpit in which a test pilot could evaluate aircraft behavior. The Whirlwind I computer is still as useful for that problem as if no other applications had arisen in the meantime. Large aircraft have now been transferred to the cognizance of the Air Forces, and the Air Materiel Command at Wright Field has recently expressed interest in reviving this particular application of digital computers.

An application of a digital computer to personnel training and group coordination is typified by mechanized game boards for a military war college.

Much of the basic information and technical work which has led to the enthusiastic recommendation of the Panel for application of digital computers to real time problems has come directly or indirectly from project Whirlwind. The first reports on this subject were issued in the fall of 1947 and unfortunately, in spite of their briefness and generality, still stand as almost the only detailed analyses of digital computer capacities required for certain tactical control problems.

2. <u>Establishment of a Laboratory for Real Time Digital Computer Research</u>

For proper pursuit of work in the important field of digital computer applications both a research laboratory and suitable computing equipment are necessary.

a. <u>Establishment of a Laboratory</u>. The importance of a laboratory for this work is recognized in the report on page 17, Section 3.2 (3):

> "Such a program should provide for: ....(3) the necessity for obtaining systems research and development by qualified individuals and institutions, in order that suitable improved systems may become available for both general purposes and real time computations."

On Page 34, Section 4.2 of the report,

> "The present program does not include sufficient emphasis on real time computation."

Digital computers are not yet ready for mass production. No electronic digital computer has yet operated well enough so that copies have been wanted. A laboratory equipped to explore the various types of applications is important in determining and demonstrating which ones justify the development or purchase of

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machines for a single specified application. Such a laboratory will make it unnecessary to procure a computer merely to determine feasibility of some newly proposed application. Once trials have been made, people will then have an informed, experienced basis on which to set specifications for a particular machine purchase.

b. Construction of a Machine for Real Time Computing Research. Effective work in this field must be based on actual demonstration of possibilities, demonstration of promising reliability in digital computing equipment, and on laboratory work with an operating machine for the evaluation of systems proposals. Whirlwind I is being constructed for these purposes. On page 15 the report cites that no such equipment is available or operating at the present time. It is certainly essential that any development as new as this be accomplished first in the laboratory before one attempts to make mobile field equipment. On page 15, paragraph 3, the report states:

> "It seems reasonable to suppose that any well balanced national defense program for the development of computers ought to include machines suitable for each of the above described purposes."

Speaking of the need for more information on actual machine performance the report states on page 22, paragraph 3:

> "With the completion of tests on a few of the more advanced projects, a great deal more information should be available for use in theoretical research into possible systems of computation to be applied to specific problems of the Military Establishment."

In the last sentence of page 4, the report recognizes that:

> "the existing contracts should also provide machines for experiments leading to the evaluation of the usefulness of high speed digital computers in fields of computation which are as yet untried and where the exact formulation of the problem is still to be accomplished."

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These statements come close to describing many of the applications for Whirlwind I.

In the construction of Whirlwind I much attention is being given to achieving high reliability and long periods of trouble free operation. Most other computer projects, if they treat reliability at all, are satisfied with detecting errors after they occur. In tactical control applications, where human life and valuable property are at stake, errors must be prevented, not merely discovered.

A machine like Whirlwind I can perhaps be compared to a wind tunnel or a nuclear particle accelerator. It is a research facility. Precise specification of end use is not possible ahead of time. Only the general field of application can be predicted several years in advance. Actual circumstances and priorities for applications research change rapidly.

3. <u>Training Personnel</u>

An important part of the Whirlwind program is the training of personnel. Thus far training has been limited largely to Project staff members, since the information had to be generated as well as absorbed, and adequate staff comes first. With this already done, the regular M.I.T. academic program is being extended to include additional work in digital computation. Next year sufficient courses relating to this field will be given to make up a complete master's degree program. This is being done without the persuasion by the Military Establishment suggested on page 29 of the report. Setting up a more complete training program has been delayed by unavailability of a computer for laboratory work. As Whirlwind I nears completion, and its existence can be anticipated next year, new academic courses become possible.

Page 18 (8) of the report states the necessity for orientation courses for key command and administrative personnel to keep them informed of progress and the potential use of high speed digital computers. Project Whirlwind has made some contribution to this work at the Industrial War College. It is a source of information for such training with respect to real time tactical applications.

4. <u>Development of Associated Equipment for Real Time Applications</u>

In addition to a digital computer, extensive terminal equipment may be required in most real time problems. Data must be taken in from analog devices. Results are sent to visual displays or to servo systems. The Panel criticizes Project Whirlwind for not already having such equipment. Yet this is a major undertaking in itself which will continue for many decades. To illustrate that terminal equipment is an important and continuing problem, one has only to look at the much older field of analog computation where the development of terminal equipment is still very active.

On page 8, Section 2.2.2, the report directs attention toward terminal equipment which must be associated with digital computers in real time computation. The need for servo systems to be controlled from digital input is stressed in paragraph 4 of page 35. A major contribution to this problem has been made by Project Whirlwind as the doctor's thesis research of Professor William Linvill in treating the theory of sampling servomechanisms. This will stand as a guide post in the future development of digitally controlled servos.

The proper presentation of visual displays are an important part of real time applications and an example of this type of terminal equipment has been used in connection with Whirlwind I for several months and is under continuing development.

5. <u>Construction and Operation of a Computer to Encourage Theoretical Research</u>

This is an important objective of the Whirlwind work. It overlaps the objectives given above. Nearly all M.I.T. departments have possible applications of digital computation and would be willing to undertake applications research and thesis studies. Active work is to a considerable extent awaiting a complete and operating machine. The necessity for an actual machine to stimulate such research is nicely presented by the report on page 21, Section 3.2.2:

> "It is only reasonable to suppose that workers in the field of applied mathematics usually have not concerned themselves with this phase of numerical computation, because of the sterility of any such efforts in the face of the nonexistence of machines suitable for high speed calculations. Now, however, when there are several high speed digital computers far enough along in construction so that final computation details can be predicted, it seems wise to undertake a program to foster researches in the field of pure and applied mathematics."

While it will be necessary, of course, for the Military Establishment to encourage specific research on its own problems, there will nevertheless be much of this done at M.I.T. without support of the Military Establishment. Capable persons will be attracted from all scientific fields and also the social sciences, and existence of Whirlwind I will encourage research by graduate students and staff.

6. Availability of a Machine as a Stimulus to Future Component Research

The comments made by the Panel in Section 3.2.2 about the necessity of a machine for theoretical research applies even more forcibly to the stimulus such a machine gives to component research and development. Shortcomings of an operating machine are apparent. The most rewarding areas for future development are clear. New components can be substituted into the existing machine (if it is of sufficiently flexible and accessible construction) for actual operating and reliability tests. Development of components to the point of actually operating in a machine assures complete development and prevents premature release to groups who might otherwise have to retrace much of the original development. Actual experience with the machine makes desirable specifications of new components apparent.

7. Integrated Digital Computer Research Program

It has been an objective of Project Whirlwind to maintain a balanced program in digital computer theory, component development, machine construction and applications research. These have been especially directed toward the real time problems, but one unavoidably receives an important by-product in the form of techniques and facilities for the solution of scientific and engineering problems.

8. Computing Laboratory for Engineering Problems

Facilities for the solution of scientific and engineering problems are naturally obtained as a by-product of the work discussed above. One would indeed be wasteful and negligent not to take advantage of this opportunity. To capitalize on availability of the basic computer requires, at the most, the addition of pieces of terminal equipment which might be required for scientific work but not for real time research. Machine time is almost certain to be available for this work, since it is unlikely that the research into real time problems can be organized to fully utilize machine time. If necessary, an extra operating shift at night could be devoted to routine general purpose computation.

In all probability use of the machine as a scientific computer will be achieved earlier than significant work in the real time field. Scientific applications are better understood, more trained persons are available, and perhaps more are interested in this area. Much more modest beginnings are possible. In fact, initial testing of the computer would be made on fictitious scientific problems, even if they were of no practical importance.

9. <u>Contributions to Other Projects</u>

An important part of Project Whirlwind work is to operate as a research center for dissemination of digital computer information. The Panel has reported favorably on Project Whirlwind reports which were established for this purpose. It is hard to evaluate the actual usefulness of such activity. Extensive use has been made of Whirlwind work in the United States Naval Computing Laboratory operated by Engineering Research Associates. Lesser contributions have been made to the work at Raytheon, National Bureau of Standards at Washington, the computer at the University of California at Berkeley, and the ORDVAC at the University of Illinois.

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10. <u>Other Objectives of Project Whirlwind</u>

A few other miscellaneous objectives fulfilled by Project Whirlwind are cited in the Panel report. Page 4, paragraph 2 mentions machines built for the education of the builders and the users. This is an objective of no small importance, especially when it relates to the totally unknown field of real time computation. At the time Project Whirlwind was started there was no certainty whatever that a computer could be built to operate in the range of 10,000 to 20,000 arithmetic operations per second. Furthermore, there was no available estimate of machine reliability or development difficulty in realizing a computer for military applications. Already answers to these points are emerging from preliminary testing of Whirlwind I and the preceding prototype circuits.

The Panel recognizes on page 8, Section 2.2.6 that a new and unique fundamental approach to machine design may be a justifiable reason for construction. At the time Whirlwind I was started it was most certainly new and unique and still stands as the only ultra-high-speed parallel type computer near completion. Applications of the machine to real time tactical work and to simulation are unique applications of a digital computer, and there is no doubt but what Whirlwind I is the first, and in fact the only, machine the Panel studied which can work on many of these applications.

B. Terminal Equipment in Whirlwind I

1. Terminal Equipment for Real Time Problems. The Panel makes a major point of criticizing Whirlwind I terminal equipment. The Panel may be confusing terminal equipment, as it has been specified by other projects for research purposes or restricted end uses, with the broader possibilities that Project Whirlwind makes possible. The lack of terminal equipment which the Panel criticizes is the same terminal equipment which it recommends undertaking as a major Military Establishment program in the field of digital servos, analog information quantizing units, digital-to-analog converters, and visual display devices. With respect to terminal equipment, the project has followed the step-by-step procedure recommended by the Panel. The first step is to obtain a working computer with minimum terminal facilities (fully equivalent, however, to those planned by many other computers) and to evaluate performance and achievement at that stage before attacking new, unknown frontiers.

2. Emphasis on Terminal Equipment. On page 11, Section 2.3.5, the report recommends:

> "...the Office of Naval Research, in cooperation with the user and the contractor, should establish definite specifications to be met by the completed machine, including terminal equipment required for the intended use."

The Office of Naval Research and M.I.T. have carefully considered the matter of Whirlwind terminal equipment. The project is operated as a continuing research program. The amount of terminal equipment which could be designed or purchased in the work thus far has been established by the available budget and avaliable scientific personnel. It has been considered wiser to concentrate on completion of Whirlwind I with basic or minimum terminal equipment rather than to spread resources over a broader program resulting in the earlier completion of no single part of the work. Although the advisability of a particular step-by-step development procedure as recommended by the Panel on page 24, paragraph 2, is questioned elsewhere, it has, nevertheless, been followed in this part of the project Whirlwind program. The Panel recommends completing component development before continuing with systems procurement. In real-time applications a digital computer is a component of the final system. It is also a component and not the entirety of an operating computer research laboratory.

The idea of "the" end use and "the" required terminal equipment is a misconception. In real time research this equipment grows gradually as required out of concurrent system studies. System studies can not be done first or alone, because they must be developed as the possibilities of the equipment are determined. This is well stated by the Panel on page 22, Section 3.2.3:

> "It has been brought out repeatedly that future plans for the use of high-speed digital computing devices depend on whether or not equipment can be built with certain characteristic performances."

In so far as has been determined, a basic high speed digital computer can be applied interchangeably to most applications in the real-time field so long as speed is sufficient and the ultimate mobility requirements or final packaging have not yet been introduced. However, this universal nature of computers does not apply to terminal equipment. Different data converters are required for shaft position, for analog voltages, and for radar echo transit time. Output servos differ depending on the job to be done and the performance required. Visual displays may be similar to one another but are unlike terminal equipment thus far developed by other projects. The present active Whirlwind program includes enough visual display equipment to demonstrate some of the possibilities of real-time digital computation. This meets the requirements of page 22, Section 3.2.3, paragraph 2 of the report:

> "With the completion of tests on a few of the more advanced projects, a great deal more information should be available for use in theoretical research into possible systems of computation to be applied to specific problems of the Military Establishment."

3. Indefinite Terminal Equipment Plans. The report refers to Whirlwind I terminal equipment on page 53 (last paragraph):

> "Whirlwind I machine, ..., and with as yet indefinite plans for input and output equipment."

Indefinite plans exist for Whirlwind I terminal equipment only to the extent that budgets are indefinite. This is an important point and there is real danger that the Panel report will contribute to lack of confidence in the program, and, therefore, make these plans more indefinite.

Whirlwind I is so designed that there is no question about its ability to accept any terminal equipment now known or suggested. Varying amounts of matching equipment may be required, but in most cases no more than that required for matching to computers for which the equipment was specifically designed. Terminal facilities with which Whirlwind I can operate include magnetic tape units, direct teletype tie lines, local teletype equipment, radio or micro wave relay equipment, and the knobs, controls, switches, shafts and voltages of analog equipment. Much of this terminal equipment is not designed because necessity for it is far in the future. General ideas exist for the nature of the equipment to give assurance that Whirlwind I is compatible with it.

Plans for terminal equipment design or procurement are coordinated with Whirlwind I computer completion. Equipment can be accepted only at a rate set by the available personnel and by the ability to get the computer into productive operation. These will both take time.

A digital computer is not yet like a truck which can be purchased to haul a load of gravel. There is no such thing as a single specific date on which a computer is complete, a full staff ready to use it, and a full work load available. The transition from construction to use is gradual. For Whirlwind I it began in September 1949 when computation was first done with test storage. The transition will continue for at least a year and probably longer.

4. Minimum Input Equipment. The last sentence on page 53 states:

> "In this connection, some teletype equipment and Eastman Kodak Photographic equipment are being provided but no specific plans have been made for their use."

The meaning of this sentence is not clear. If it means use of the final machine, it is a repetition of previous points about objective and end use. If it means that integration of teletype and Eastman equipment into Whirlwind I is not planned, the information is incorrect.

The combination of teletype and Eastman photographic equipment is satisfactory for the real-time problems previously discussed. In addition to this equipment, most real time work will require visual scope displays for presenting pictures equivalent to radar P.P.I. plots. A suitable scope display for initial work is well along in the design stage and should be ready as soon as it can be used with Whirlwind I. In engineering work similar scope equipment can be used for the plotting of engineering curves. So far as is known, this important facility is not being planned in connection with computers limited to scientific work.

5. Initial Terminal Equipment. Page 54 of the report states:

> "As a result, the computing elements of this machine are estimated to be 85 percent complete with little progress on any adequate system for handling input and output data."

This is hardly correct. The terminal equipment being initially provided with Whirlwind I is fully equivalent to the terminal equipment being provided with other computers, especially keeping in mind the objectives of the project. The Panel may derive its view of the terminal equipment situation from some of the opinions of Project Whirlwind personnel, where it is considered that the initial project terminal equipment, as well as the terminal equipment for most other computers, is quite inadequate to exploit the full long-range

The combination of teletype and Eastman photographic equipment is satisfactory for the real-time problems previously discussed. In addition to this equipment, most real time work will require visual scope displays for presenting pictures equivalent to radar P.P.I. plots. A suitable scope display for initial work is well along in the design stage and should be ready as soon as it can be used with Whirlwind I. In engineering work similar scope equipment can be used for the plotting of engineering curves. So far as is known, this important facility is not being planned in connection with computers limited to scientific work.

5. Initial Terminal Equipment. Page 54 of the report states:

> "As a result, the computing elements of this machine are estimated to be 85 percent complete with little progress on any adequate system for handling input and output data."

This is hardly correct. The terminal equipment being initially provided with Whirlwind I is fully equivalent to the terminal equipment being provided with other computers, especially keeping in mind the objectives of the project. The Panel may derive its view of the terminal equipment situation from some of the opinions of Project Whirlwind personnel, where it is considered that the initial project terminal equipment, as well as the terminal equipment for most other computers, is quite inadequate to exploit the full long-range possibilities of highspeed electronic digital commutation. The Panel has been satisfied with modest input-output equipment where there is no plan or possibility of doing better, but dissatisfied with equivalent terminal equipment where better results are ultimately anticipated.

6. Magnitude of Terminal Equipment Problem. The proper development of terminal equipment will be a major part of the Military Establishment program in real time digital computer work.

Visual presentation equipment for monitoring purposes must be provided. The only one we know to be in operation from a digital computer is connected to Whirlwind I. This was demonstrated to 30 or 40 guests during the Harvard Computing Symposium in September, with very favorable response.

Work thus far has only dented the problem of digital servos. These will undoubtedly be as much of an undertaking as the field of analog servos in the control of instruments, radar sets, and gun mounts.

The transmittal of digital computer data by radio link lies in the near future. Both land-based and naval systems are now under development which lead in this direction.

7. <u>Digital Servos</u>. The importance of this is pointed out in the report, page 8, Section 2.2.2 and the work of Project Whirlwind in this area has been discussed under objectives.

8. <u>Discussion of Eastman Kodak Units</u>. Much discussion has revolved around Eastman Kodak photographic film input-output units. Probably no final answer is possible, but a few comments may be useful.

The Eastman Kodak input-output units fit better into real-time applications of computers than into scientific computing applications. An important and valuable feature of the film units is their ability to read at any operating speed up to their maximum limit. Lines on the film can be read with the film stationary or at any servo-controlled rate. This is not true of magnetic tape where speed must be restricted to a range which will give suitable output signal from pick-up heads. Film units are, therefore, easier to synchronize with typewriter and printing equipment.

The Eastman Kodak input-output units are today the most advanced development in high speed digital terminal equipment. They are available prior to reliably operating magnetic units and have speed, capacity and performance for certain uses ahead of magnetic units now under development. At the time the Office of Naval Research authorized the Eastman Kodak work, that form of terminal equipment appeared to show better promise than magnetic units. Whether or not this was actually true can probably never be established.

Dissatisfaction is often expressed with the specifications of the Eastman Kodak units. This is not fully founded, but wherein justified may be traceable to the policy favored by the Panel of having component development separate from computer work. The Eastman Kodak development was begun entirely independently of Project Whirlwind and later was diverted to become the Whirlwind terminal equipment for initial phases of the project work.

9. Magnetic Tape Terminal Equipment. Magnetic tape terminal equipment will be extremely important to digital computers. Most new computers are planning on this form of input and output for effective work in some fields of scientific or engineering computation. Whirlwind I should eventually be equipped with magnetic units for such applications. Project Whirlwind has done almost no work in the field of magnetic tape equipment. Need for such has not yet arisen in the original or present major objectives of the project. Also under present circumstances, duplication of magnetic tape development being done elsewhere would be unjustified. Magnetic tape

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units suitable for Whirlwind use are being designed elsewhere and can be purchased when necessity makes the required budget available.

C. Changes in Contract Direction

The Panel feels that technical direction has been adversely affected by changes in military supervision of the contract. (Page 39, Section 4.4.7):

> "The technical direction of Whirlwind seems to have suffered seriously by frequent changes in objectives and the transfer of the project from one division of the Military Establishment to another."

This is not true. Furthermore, there have not been as many changes in Naval interest as indicated on pages 52 and 53. The second sentence of Section 5.8 reads:

> "Its original intent was the completion of tactical simulation equipment for the use of this agency (Special Devices Group)",

This is not correct for the history of the project really begins with the sentence following:

> "The original simulation studies contemplated the use of analog computation. Later, the project transferred its objective to the development of the high speed computation of aeronautical problems of performance, and a decision was reached to construct a high-speed digital computer for the purpose."

This latter was the first and original objective of the project and still remains as a possible important use of the work.

There has been no change in Whirlwind I specifications or technical direction required by any changes in military supervision of the contract.

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All changes have been a broadening of possible uses arising from a realization of the flexibility and universal nature of the computing equipment under development. The aircraft analyzer was the first specific end objective and still remains in the contract. Terminal equipment for the original aircraft simulator was postponed pending tests on the digital computer. The same computing equipment as can be used for aircraft simulation is equally applicable to tactical simulation so that this as well as other real-time control possibilities were opened up. The aircraft analyzer was a real-time application placing the same requirements on a computer as the other real-time problems discussed under objectives (this, of course excepts the matter of an ultimate mobile design and final packaging). The interest of the Office of Naval Research in scientific computation is active and can be partially satisfied by the computer. Scientific computation is obtained as a by-product without having forced changes in specifications on the Whirlwind work done thus far. As noted before, it may justify the addition of further terminal facilities in the not too distant future.

The Panel has not recoginzed the universal applicability of Whirlwind I type equipment to digital research. The speed of the equipment makes it suitable for tactical and simulation studies. In scientific computing the

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high speed permits double-length operations to compensate for the short register length without serious loss in machine performance.

Whirlwind I can still fulfill its original place in the problem of aircraft stability analysis (which was to demonstrate feasibility, allow preliminary studies, and solve simplified examples). This is still an important problem in the Military Establishment and one in which the Air Forces has expressed recent interest.

The changes of interest in connection with Whirlwind I are typical of those occurring in the entire digital computing field. Actual or proposed changes in the application of the ENIAC, the BINAC and the Mark III have been discussed. The international situation has changed greatly in the last five years, military unification is taking effect, new defense weapons have been developed, and new technical information has been obtained.

D. Magnitude of Project Whirlwind

The Panel criticizes Project Whirlwind for being larger than other computer projects.

(Page 39, Section 4.4.7)

> "The scale of effort on this project is out of proportion to the effort being expended on other projects having better specified objectives."

(Page 54, last paragraph, Section 5.8)

> "The scale of effort on this project, while it has been considerably reduced in recent months, is still out of proportion to the effort being expended on other projects."

1. Scale of Reference

In these statements the Panel shows clearly that it has not established its opinion on the proper Military Establishment level for digital computer work. Here projects are compared to the average scale of all projects rather than to the importance and need for digital computer research and development. Elsewhere in the report the Military Establishment is criticized for carrying on insufficient work in the areas covered by Whirlwind. Relative size in the present situation seems hardly an adequate scale of reference.

2. U.S. Naval Computing Laboratory

The above quotation implies that Whirlwind is the largest digital computer program sponsored by the Military Establishment. In its report the Panel makes no mention of the U.S. Naval Computing Laboratory operated in St. Paul, Minnesota, by Engineering Research Associates. That organization is devoted almost exclusively to the various aspects of digital computation and operates on a budget and at a staff level of approximately three times Whirlwind's. In fact there seems to be more in common between Whirlwind and that organization than between Whirlwind and the other projects which the Panel considers. Because that laboratory must deliver working equipment to the Navy it places a similar emphasis on the importance of reliability and good design. In developing a computer for the Bureau of Ships Task 13 Project, the United States Naval Computing Laboratory is relying heavily on Whirlwind work. That computer has been based on Project Whirlwind circuits and the Whirlwind I computer block diagrams. This original information was then changed by Engineering Research Associates to incorporate improvements suggested by their own men and by Whirlwind staff and to incorporate the changes required or permitted by the particular application. In some slight sense that group is using Whirlwind I as a basis for going on to the design and construction of a "Whirlwind II." That machine is well along, and major parts of it are operating.

3. Accounting Methods

Project Whirlwind is a complete, integrated program where all charges have been totaled into one budget except for the work on input-output devices by the Eastman Kodak Company which was independently initiated. This accounting procedure is not common in the digital computer field, and most laboratories have operated on a multiplicity of contracts covering various aspects of the work. No one project then shows a budget total comparable to Whirlwind although total funds spent on digital computation might be comparable. As an example, the work at the Bureau of Standards might be cited. This program has or does include design studies and component developments at Eckert-Mauchly, design studies and component development at Raytheon, storage tube research at Raytheon, the work of the Bureau of Standards in Washington and the

Institute for Numerical Analysis in California, the associated work on the "Zephyr" computer in California, and numerous other sub-contracts. To obtain a proper comparison with Whirlwind, the total of all this work should be compiled and then a comparison made on the basis of technical accomplishment.

E. Specifications and Status of Whirlwind

1. Status

On Page 53 of the report the statement, "Whirlwind I machine, as presently envisioned ...." gives a very different impression of the machine's physical status than the more descriptive statement on the next page: "... the computing elements for this machine are estimated to be 85% complete ...."

The central control, arithmetic element, test storage, and a simple visual output display device have been operating since September, 1949. The storage row to complete the basic machine will be assembled by about the end of February, 1950, and should be integrated into the rest of the machine by May. Storage tubes for this first installation are in stock. Block diagrams for the Whirlwind I computer were prepared and made available in September, 1947. So far as is known this is the only equally complete set of block diagrams available for an electronic digital computer. They omitted some parts of the machine which are now being included in a revision of the block diagram report.

Because of more careful testing and installation checking as Whirlwind I is assembled, it may actually operate satisfactorily before other machines which are considered by the Panel to be more advanced.

2. <u>Size</u>

On Page 53 of the report Whirlwind is referred to as a "very large" machine. This is probably correct if total floor space is used as a criterion. Because the principal objective of the machine is operation as part of an integrated laboratory, its objectives have dictated a machine which is easy to service. Complete access has been provided to all machine components. The importance of this accessibility has already been demonstrated by the ease with which satisfactory performance has been obtained in the parts assembled thus far. There is very little information available on the maintenance of large electronic machines. Machines when actually constructed have always turned out larger than the original expectations based only on block diagrams prior to availability of circuit schematics and component requirements.

Considerations other than floor space are important in judging computer size. Whirlwind I will have approximately 4,500 vacuum tubes. This compares with 18,000 in the ENIAC, 12,000 tubes in the IBM Selective Sequence Electronic Calculator, and 1,500 to 5,000 in the proposals for other machines now being designed.

In considering a machine for real-time computation where speed and computing capacity are essential, the most significant measure of size is probably the equipment required per unit of computation accomplished. This might be measured in terms such as:

$$\text{Figure of Merit} = \frac{\text{Multiplications per Second}}{\text{Vacuum Tubes in Machine}}$$

Using figures from the table in the back of the report, this machine figure of merit becomes:

Computer			Figure of Merit
Whirlwind	$\frac{10,000}{4,500}$	=	2.2
N.B.S. Zephyr	$\frac{2,600}{1,900}$	=	1.4
ORDVAC	$\frac{3,100}{2,500}$	=	1.2
I.A.S.	$\frac{2,000}{2,000}$	=	1.0
Raytheon Hurricane	$\frac{1,200}{3,585}$	=	.34
N.B.S. Interim	$\frac{340}{1,200}$	=	.28
UNIVAC	$\frac{330}{4,000}$	=	.08
EDVAC	$\frac{300}{3,500}$	=	.08
Harvard Mark III	$\frac{96}{4,939}$	=	.02*
California Digital Computer CALDIC	$\frac{31}{2,000}$	=	.015*
ENIAC	$\frac{104}{19,000}$	=	.0055

* These machines are magnetic drum units, causing the slow speed.

3. Register Length

On Page 53, the report refers to Whirlwind as having "but five decimal digits capacity." This refers to the short register length of 16 binary digits. A register length this short is to mathematicians inadequate for scientific use. It is, however, quite in keeping with the objectives of Whirlwind I, which have been discussed.

With respect to real-time applications of digital computers, it is significant to note that both in England and the United States some fire control systems are beginning to be standardized with binary digit data transmission and with a register length in the range of 15 to 18 binary places.

For real-time applications the shorter register length is most efficient because few of the quantities being handled require more accuracy. In the few quantities where more accuracy is required, multiple length computation is quite satisfactory; and where the extra digits are not required, the extra storage space is not wasted. The field of real-time computation is based on very different considerations from that of scientific computation. The 16 binary digits in Whirlwind are probably shorter than will eventually be found optimum. Final systems will probably be in the range of 18 to 24 binary places. No real-time problem has arisen for either tactical or simulation uses where 16 digits does not seem adequate for the basic studies that would be made with a laboratory-based machine.

To handle scientific computation on a short register machine it may often be necessary to use either multiple-length numbers or a programmed sliding scale factor. Both of these admittedly add some inconvenience, but features have been added to Whirlwind to reduce this inconvenience. Both multiple-length and sliding-scale operations require enough extra computation so that the extra speed of Whirlwind I will be approximately equalized with the acoustic delay line type machine. In other words, multiple-length operations may cost a speed factor of 5 to 20, but the result still lies far above presently available general purpose computers for scientific computation.

In many engineering computations where the nature of the problem is well understood, the length of the computation in any one sequence is not long, and the primary job of the machine may be of a clerical nature, it is anticipated that 16 digits may be useful without the multiple length computation. This remains to be seen.

Should it ever become desirable, additional digit columns can probably be added to Whirlwind I by putting two in the space now taken by one. Such reduction results from information acquired since Whirlwind I was started.

4. Memory Capacity

Page 53 of the report refers to Whirlwind I as having "an extremely limited memory capacity." It is not clear why this statement has been made. It does not seem to arise from either the objectives of the machine or a comparison with other computers. The total storage capacity of a computer can be given in binary digits which are found as the product of the register length times the total number of registers. The proper division of total storage between the number of registers and register length depends on the application of the machine. For scientific work a longer register is undoubtedly indicated. For real-time work the capacity of the machine is determined primarily by the total number of registers available. The following table is again data taken from the back of the report and lists total registers and total binary digits in the various machines:

TABLE OF MACHINE STORAGE CAPACITIES

	Total Registers	Total Binary Digits
1. Operating Electronic Machines		
a. ENIAC	20*	660
b. IBM - N. Y. Binary Equivalent (8 registers electronic and 150 relay registers)	158*	10,400
2. Assembled Electronic Machines		
a. BINAC	512	15,360
b. Mark III**	4,350	236,000**
3. Electronic Machines Under Construction		
a. Whirlwind I	2,048	32,768
b. Hurricane	1,152	41,472
c. IAS	1,024	40,960
d. UNIVAC	1,000	40,000
e. NBS Interim	1,024	46,080
f. NBS Zephyr (not definite)	512 or 1,024	20,992 or 41,984
g. California Digital (CALDIC)**	10,000**	340,000**
h. EDVAC	1,024	45,056
i. ORDVAC	1,000	40,000
j. U. S. Naval Computing Laboratory	?	?

* ENIAC and IBM do not store instructions in the high speed internal memory so do not need as much capacity as other machines. Cable connected or paper tape instructions result in inconvenience and slowness of operation.

** Mark III and CALDIC are magnetic drum machines which are intermediate between external tape and internal electronic storage. High capacities are possible at slow access speeds. See Section IV - F on storage evaluation which follows.

Except for the magnetic drum machines, Whirlwind I is in the high range of number of registers available. Again excepting the magnetic drum machines, the capacity of Whirlwind I in total binary digits is within the range of other machines and is about 70% of the maximum proposed for other machines.

Based on the studies thus far, the design limit of 2,048 registers for Whirlwind I is sufficient to handle real-time research in multiple aircraft anti-aircraft fire control, in perhaps 50-plane air traffic studies, and is adequate for studies in tactical simulation and preliminary work in aircraft stability analysis.

F. Whirlwind Storage Tube Work

On Page 12, the Panel recommends continuation of Whirlwind storage tube research. Elsewhere it comments on the tube on the basis of information which has now become obsolete. Some corrections might therefore be indicated:

1. Special Design

Page 54 of the report describes the storage tube as being of special design. This is certainly true. It is probably to be expected of any vacuum tube for a purpose as specialized as information storage. The Selectron is likewise a tube of special design. The closest approach to a non-special tube is found in the work of Williams in England where standard cathode tubes have been used experimentally. Even in the Williams tube, however, it has been found desirable to use special storage surfaces and special tube processing to obtain better control than is found in commercial cathode ray tube processing.

2. Cost of Storage Tube

In the same section of the report the storage tube is referred to as being of very expensive construction. The meaning of this is not quite clear. Several standards for measuring cost might be used. Perhaps costs should be measured against other vacuum tubes regardless of purpose or the cost of the storage tube should be considered relative to other storage devices. These possibilities are discussed later.

a. Comparison of vacuum tubes on an absolute basis depends entirely on how badly the tube is needed. At present electrostatic tubes are the only storage devices suitable for digital computer work in real-time problems. Within any likely range, tube cost might be unimportant in comparison to military applications of the equipment.

b. With regard to possible redesigns the tube cost can probably be drastically reduced. The first sixteen Whirlwind I storage tubes have been constructed (not including research and development) for about $2,250 each. This includes all overhead, allocatable costs, organizational inefficiencies in setting up new model-shop schedules, and so forth. The tube can probably be produced now on a model-shop hand-made basis for $1,500 each including all proper allocations.

c. For a scale of reference we might compare this cost of $1,500 with factory production prices of the following tubes:

	Sale Price
Dumont 2 gun cathode ray oscilloscope tube	$ 150
Electron Tube Corporation 4 gun cathode ray tube	400
S-Band, Tunable, 900 KW Magnetron	505
Image Orthicon	1,200
RCA Selectron (Unconfirmed second hand information. May be either model-shop or factory production)	1,500

In comparison to the above production prices, the present model shop cost does not seem excessive.

d. Perhaps the most significant comparison of storage tube costs is on a scale that recognizes performance characteristics. Storage capacities, costs, and access time must be included. Cost is often improperly quoted on the basis of storage capacity alone. If access time were of no importance punched paper tape or printed books would be the least expensive storage methods. A figure of merit which we might call a performance-unit can be defined for comparing storage elements:

$$\text{Performance-unit} = \frac{\text{Digit Capacity}}{\text{Access Time}}$$

Total capacity can be measured in binary digits. Access time can be measured in micro-seconds. Either a higher storage capacity or a shorter access time increases the performance-unit rating of the storage. Actually this rating of performance is still unfair to the higher speed storage units when they are considered for heavy computing loads such as occur in real-time work. Storage access time is the primary factor limiting machine speed in present machine designs. Cutting access time by a factor of two will increase machine speed by almost the same factor. In military systems this may mean that only half as much computing equipment would be required in a given problem and that the entire cost of a second machine could be devoted to increasing the storage speed of the first. This latter interpretation will not, however, be used.

One might compare the cost per performance-unit for the three major types of machine storage: magnetic drums, acoustic delay lines, and storage tubes. Since the lives of drums and acoustic lines are probably longer than for tubes, it will be necessary to include the cost of storage tube replacement. In the comparison below, a five-year period has been assumed. The cost of providing replacement storage tubes for a five-year interval will be included, and it is assumed that the other types of storage are either worn out or obsolete by that time. The estimates which follow include the initial cost and five-year maintenance of the associated control circuits. Magnetic drum costs and acoustic line purchase costs are based on estimates obtained from manufacturers of such equipment. The electrostatic tube figures are based on estimates of a 2,000 hour tube life, an initial cost of $1,200, and the ability to re-process a tube once for an additional 2,000 hour life for $200. It is assumed that 32 such tubes are in the installation and that five years represents 10,000 hours of operating time.

Description	Magnetic Drum	Acoustic Line	Electrostatic Tube
Total Binary Digits Stored	120,000	43,000	32,000
Access Time in Micro-Seconds	16,000	150	10
Number of Tubes in Associated Control	650	700	800
Yearly Cost for Maintenance of Control	$ 3,000	$ 3,000	$ 5,000
5-Year Cost for Maintenance of Control	$15,000	$15,000	$25,000
5-Year Cost of Original and Replacement Storage Tubes			$112,000
Cost of the Acoustic Tank		$ 2,000	
Cost of Storage Control		$28,000	$115,000
Original Cost of Magnetic Drum Unit and Control	$25,000		
5-Year Cost for the Installation	$40,000	$45,000	$252,000

The following table derived from the above figures shows how the cost per stored digit differs from the cost per performance-unit which accounts for the importance of speed.

	Cost Per Digit	Cost Per Performance Unit
Magnetic Drum	$0.33	$5,300.
Mercury Line	1.05	157.
Electrostatic Storage Tube	7.90	79.

This table shows that although the cost per digit for electrostatic storage is relatively high the performance cost in high speed work is much reduced. Depending on the nature of the real-time application the importance of high speed computation might be weighted even more heavily in favor of a high speed storage system.

3. Availability of Tubes

The report states that much remains to be done before the storage tube can be considered a satisfactory element of high speed memory. Certainly a great deal of work remains to be done before an optimum tube for military use is developed. With regard to Whirlwind I requirements, 16 tubes are now on hand for initial installation. Work should be continued to get higher speeds and greater densities for future requirements. In addition, development of storage tubes should be supplemented by research into other types of high speed storage which might be more compact and durable for military use.

4. Storage Capacity

The report comments correctly that the maximum storage capacity at the time of the Panel visit was 256 digits. Since that time means have been found for using the same tubes at somewhat higher densities. A slightly different tube has been operated in the laboratory for short periods of time with a capacity of 1024 digits but it is not considered ready for computer use. A tube storing 256 digits is entirely adequate for all initial work with the Whirlwind I computer. Higher density tubes can be expected by the time they are required. Incidentally, 256 digit capacity is the same as the RCA Selectron tube.

V. SUCCESSIVE DISCUSSION OF REPORT REFERENCES TO WHIRLWIND

The following comments discuss in order those parts of the report relating specifically to Whirlwind. General aspects of the report are covered in a separate memorandum (L-17).

(Page 1, paragraph 1)

Among the various objectives of the Panel it would appear that not enough attention has been given to comparing probabilities of completion, current status, and objectives of the various projects to properly evaluate Whirlwind work.

(Page 3, Section 1.2)

The Panel has left out of its consideration at least two computer projects which are necessary for a proper correlation of Whirlwind with the national activity. These are the U. S. Naval Computing Laboratory operated by Engineering Research Associates and the BINAC computer.

(Page 4, paragraph 2)

Education of the builders and users of real-time digital equipment is an important outcome of Whirlwind work.

(Page 4, paragraph 3)

The statement that the Harvard Mark III is completed may be premature since it is not yet operating.

(Page 4, last paragraph)

Evaluating the usefulness of high-speed computers in untried fields is an important part of Whirlwind work.

(Page 8, Section 2.2.2)

This is a good and important recommendation regarding real-time work and nearly all the recommendations are being pursued to a greater or lesser extent by Project Whirlwind.

(Page 8, Section 2.2.6)

Whirlwind should qualify under the new and unique fundamental approach to machine design.

(Page 9, Section 2.2.6 (3))

Project Whirlwind seems to have a well-defined objective of value to the Military Establishment and this objective is carefully and thoroughly stressed in many of the general sections of the Panel report.

(Page 9, Section 2.2.6 (6))

The recommendations against elaborate auxiliaries may be directed against Whirlwind but have been discussed in Section IV.

(Page 11, Section 2.3.5)

It is hard to understand how the Panel missed the relationship of Whirlwind to real-time problems in which the Panel is apparently much interested. The objectives of the Project are discussed in Section IV.

(Page 11, Section 2.3.5 (2))

The Panel asks for definite specifications for Whirlwind I. Definite specifications exist and appear in reports of the project and of ONR. The Panel may reach the wrong conclusions by thinking of single end uses for computers rather than their application to certain classes of problems. The Panel has recognized two classes of machine application, one to computation and one to real-time problems. The specifications for most digital computers fit the former classification, the specifications for Whirlwind fit the latter.

(Page 12, Section 2.3.5)

The development of computer components completely divorced from an actual digital computer is discussed in a separate memorandum. It seems improbable that really effective work can be done in the general field of computer components unless there is specific incentive and motivation created by an important application. The considerations here are much the same as pointed out on page 21 under the heading "Stimulation of Theoretical Research."

(Page 14, last paragraph)

The Panel points out the importance of real-time work such as that being done by Project Whirlwind. An important division of real-time computing, the field of digital simulation, is not included in the Panel report.

(Page 17, Section 3.2 (3))

The importance of system research and work in real-time computation is again stressed here.

(Page 18, Section 3.2 (6))

This Panel recommendation relates to adequately staffed computing groups and apparently applies to the field of scientific computation. No specific recommendation is included in the report for maintaining laboratories for the real-time research recommended by the Panel.

(Page 18, Section 3.2 (7))

The training of personnel in the field of digital computation is an important result of the Whirlwind program.

(Page 18, Section 3.2 (8))

Information for military command and administrative orientation in digital computation can come only from groups working actively in the field. Several laboratories can provide this information for scientific computation but much of such information in the field of tactical problems and simulation by digital computers is originating at Whirlwind.

(Page 21, Section 3.2.2)

The Panel here makes a very important point about the stimulation of theoretical research and this applies to the availability of Whirlwind I at MIT. The resulting theoretical research should be of great importance to the Military Establishment.

(Page 22, Section 3.2.3)

The first paragraph points out that future plans for digital computation depend on the determination of possible performances. This is an important part of the Whirlwind computer program.

(Page 22, last paragraph)

The Panel is placing some dependence on information to be obtained from tests on the more advanced computers. This would appear to include Whirlwind.

(Page 25, 2nd paragraph)

The Panel recommends step-wise computer development depending only on well known and developed components. While this may be satisfactory with respect to scientific computation, it is hardly possible (because of required speeds) if any serious immediate work is to be done on military tactical problems. With respect to Whirlwind, the computer might be thought of as one step in a step-wise development, where the computer is a component for real-time system research.

(Page 25, Section 3.2.5)

The report stresses the need for complete engineering design in prototype systems selected for duplication. It points out that grave faults exist in systems completed to date because of lack of reliability and frequent failure. They might in fact go further and stress that good engineering design is necessary if reliability is to be achieved, even in systems not scheduled for duplication.

(Page 26, Section 3.2.6)

The importance of establishing computing groups is recognized. This is a by-product which can be obtained from the basic Whirlwind program.

(Page 29, paragraph 1)

As Whirlwind I nears completion, the MIT educational program in the digital computer field is being expanded. As the Panel recognizes, such a program could not be established in a vigorous and healthy way without the availability of an actual computing machine.

Beginning in the fall of 1950, MIT will probably have almost a full program of master's degree study in the field of digital computation.

(Page 31, Section 3.2.9)

Continuity is recognized as being of great importance. This is certainly true and must be recognized if a healthy digital computer program is to be maintained.

(Page 34, Section 4.2)

The Panel suggests that the present program does not include sufficient emphasis on real-time computation. This is probably true.

It is not however apparent from the report that the Panel realizes the extent of Project Whirlwind work in this area.

(Page 35, paragraph 1)

The concentration of component development in agencies having computer contracts is criticized. This seems to indicate a lack of "system consciousness." It is doubtful that a proper component development program can be maintained without close integration with computer work. This is discussed at greater length in another memorandum (L-17).

(Page 35, paragraph 4)

Project Whirlwind is working on interconnection of digital and analog equipment as recommended.

(Page 37, Section 4.4.2)

The recommendation for changing the location and application of the Mark III computer typifies the fleeting nature of definite computer end use plans.

(Page 39, Section 4.4.7)

There has been no necessity for technical changes in direction or specifications in Whirlwind as a result of the contract transfers from one branch of the Navy to another. These changes have required a certain amount of staff time for coordination and liaison but, otherwise, have had no effect on the Whirlwind work.

The second paragraph relating to no definite end use is discussed under Project objectives in Section IV of this memorandum. It is true that no contracts exist for the end use of the equipment and this is the point which was discussed with the Panel. It is time that such contracts be worked out to give continuity to the project work into the next fiscal year. At the time of their visit it appeared to be the intention of the Panel to encourage the establishment of a budget and plans for this computer application work.

The report states that the scale of Project Whirlwind is out of proportion to the effort being expended elsewhere. This raises the question of what is a proper reference. Should scale be referred to other projects or the needs of the Military Establishment? Elsewhere the report stresses the insufficient Military Establishment program in those things which Project Whirlwind is doing. If a relative scale for Whirlwind work is desired, it might be better to find it in the larger digital computer program of Engineering Research Associates, or the Mark 65 and other advanced fire control systems, or the work in missile defense and aircraft intercept centers, or in the applications of digital computers to air traffic. These have all been discussed in Section IV.

(Page 40, Section 5.1)

The Panel apparently likes the clear statement of Project Hurricane objectives. Whirlwind had similarly clear objectives in its inception but these have changed and broadened with time. The Panel is here comparing a machine near completion with one in a much earlier stage of development.

(Page 47, paragraph 2)

The Panel here recognizes the computers slower than Whirlwind as being too slow for real-time computation.

(Page 50, Section 5.6)

The problems surrounding the EDVAC illustrate the difficulties which are encountered when the Military Establishment approaches the present state of the digital computer field as if computers were end products for which pure machine construction contracts can be written divorced from research, development, and continuity into machine application.

(Page 52, Section 5.8)

The original intent of Project Whirlwind was the aircraft analyzer, not, as stated, the development of tactical simulation equipment.

(Page 53, paragraph 2)

The report recognizes here the extensive work required in the development of circuits and unique computer components.

(Page 53, paragraph 3)

The interest of the Special Devices Center in tactical problems was more an addition to Whirlwind possibilities than a change in specifications. It did not create any change in Whirlwind I specifications.

(Page 53, paragraph 4)

The interest in general scientific computation has likewise been an addition to Whirlwind possibilities without resulting in changes in technical specifications.

(Page 53, last paragraph)

The term "presently envisioned" hardly implies the same thing as the actual machine status referred to on the next page as "85 percent complete." The size of the machine, its register length and its memory capacity are discussed in Section IV as well as plans for input-output equipment.

In considering terminal equipment the Panel may not be giving proper weight to the different approach followed in Project Whirlwind where the basic computer was designed first, followed by detailed design of terminal equipment, whereas many other projects have built terminal equipment first, leaving the computer itself till the last.

(Page 54, paragraph 1)

The report states that the scheme for input-output depends on intended use. This should be interpreted to mean that actual purchase and construction of equipment will in many cases await definite contract commitments and budget. The general scheme for how various kinds of terminal equipment will be used is well known.

The end of the first paragraph refers to absence of a specific computing project assignment for Whirlwind I. This is discussed in Section IV under Project objectives. It is probably premature to say exactly what computing will be assigned to any of the other machines at the time they are completed.

(Page 54, paragraph 2)

At the time the Panel visited the project only a prototype storage tube was available. The required 16 tubes for initial installation are now in stock. The tube is of a special design but by any applicable vacuum tube standards, is not unduly expensive. Cost is considered in Section IV. The tube is now considered satisfactory as an element of high-speed memory. It still, however, requires final proof in an actual operating computer as do nearly all other modern computer storage systems. Much remains to be done only in the sense that the tube can be improved still further in capacity and speed and in so doing, will become still more valuable for real-time computer applications. Maximum storage capacity of the tube has been increased since the Panel visited.

(Page 54, paragraph 3)

The scale of the project is again referred to with respect to other projects rather than with respect to the importance of the results of the project work.