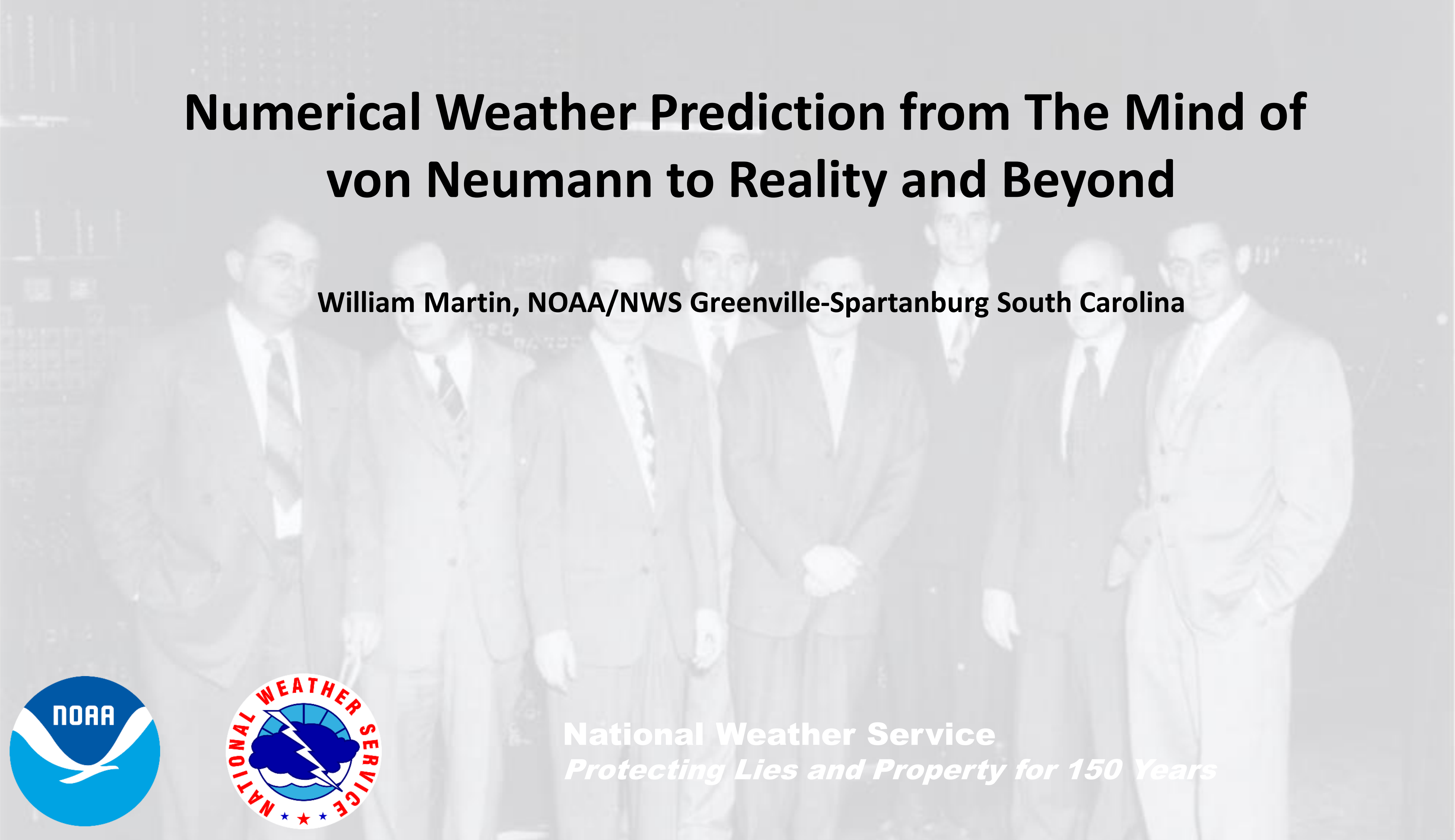


Numerical Weather Prediction from The Mind of von Neumann to Reality and Beyond

William Martin, NOAA/NWS Greenville-Spartanburg South Carolina

National Weather Service
Protecting Lies and Property for 150 Years

In November 1950, a paper was published in Tellus reporting on the first successful example of Numerical Weather Prediction (NWP), thus fulfilling the speculations of many people over the decades that it might be possible, most notably L.F. Richardson who published a book on the topic in 1922.

This paper is one of the most influential papers in the history of meteorology and the work described in it was directly followed by worldwide efforts to pursue NWP, leading to operational models by the mid 1950s.

The authors were Charney, Fjörtoft, and von Neumann. Of these, only von Neumann had a reputation of any strength at the time, widely known in scientific circles for his impressive intelligence, and large number of seminal accomplishments.

Also of significance is that the first NWP was accomplished using the ENIAC, which itself was the most important electronic computer ever, being the first of its kind.

S V E N S K A   G E O F Y S I S K A   F Ö R E N I N G E N

VOLUME 2, NUMBER 4 **Tellus** NOVEMBER 1950

A QUARTERLY JOURNAL OF GEOPHYSICS

Numerical Integration of the Barotropic Vorticity Equation

By J. G. CHARNEY, R. FJÖRTOFT[1], J. von NEUMANN

The Institute for Advanced Study, Princeton, New Jersey[2]

(Manuscript received 1 November 1950)

Abstract

A method is given for the numerical solution of the barotropic vorticity equation over a limited area of the earth's surface. The lack of a natural boundary calls for an investigation of the appropriate boundary conditions. These are determined by a heuristic argument and are shown to be sufficient in a special case. Approximate conditions necessary to insure the mathematical stability of the difference equation are derived. The results of a series of four 24-hour forecasts computed from actual data at the 500 mb level are presented, together with an interpretation and analysis. An attempt is made to determine the causes of the forecast errors. These are ascribed partly to the use of too large a space increment and partly to the effects of baroclinicity. The rôle of the latter is investigated in some detail by means of a simple baroclinic model.

I. Introduction

Two years ago the Meteorological Research Group at the Institute for Advanced Study adopted the general plan of attacking the problem of numerical weather prediction by a step by step investigation of a series of models

tions have now been performed and will be described in the present article.

These integrations would not have been possible without the use of a high-speed large-capacity computing instrument. We should

The acknowledgments section of the Tellus paper interestingly cites Mrs. K. von Neumann for her help in coding on the ENIAC. Mrs. K. von Neumann was, in fact, John von Neumann's wife, Klara. It is an interesting footnote of history that almost all of the early programmers of electronic computers were women. Why this was so, while much speculated on by modern historians, as not been adequately explained.

Also note the presence of Smagorinsky

corresponded reasonably well with the observed tendencies on the sea-level map. The pressure falls to the northeast of a well developed surface cyclone were, if anything, somewhat too great. An effort is now being made to see whether the effect of vertical motions is to reduce the falls. Some preliminary calculations indicate that this is the case.

Acknowledgments

The writers wish to thank Mrs K. von Neumann for instruction in the technique of coding for the Eniac and for checking the final code, Professor G. Platzman of the University of Chicago for his considerable help and advice in coding the computations for the Eniac, Mr J. Freeman of the Meteorological Research Group at the Institute for Advanced Study and Mr J. Smagorinsky of the U. S. Weather Bureau for their assistance in the preliminary work of data preparation and in the actual running of the computations on the Eniac at Aberdeen. Professor Platzman also participated in the work at Aberdeen, where again his advice proved most valuable. We are also greatly obliged to the staff of the Computing Laboratory of the Ballistic Research Laboratories for help in coding the problem for the Eniac and for running the computations.

How NWP became an application on the world's first electronic computer within 4 years of its invention, is an interesting story involving, the vision of John von Neumann, along with a host of now famous meteorologists.

The story also runs through Los Alamos, and the World War II atomic bomb project.

John von Neumann was born in Hungary in 1903, the son of a successful banker.

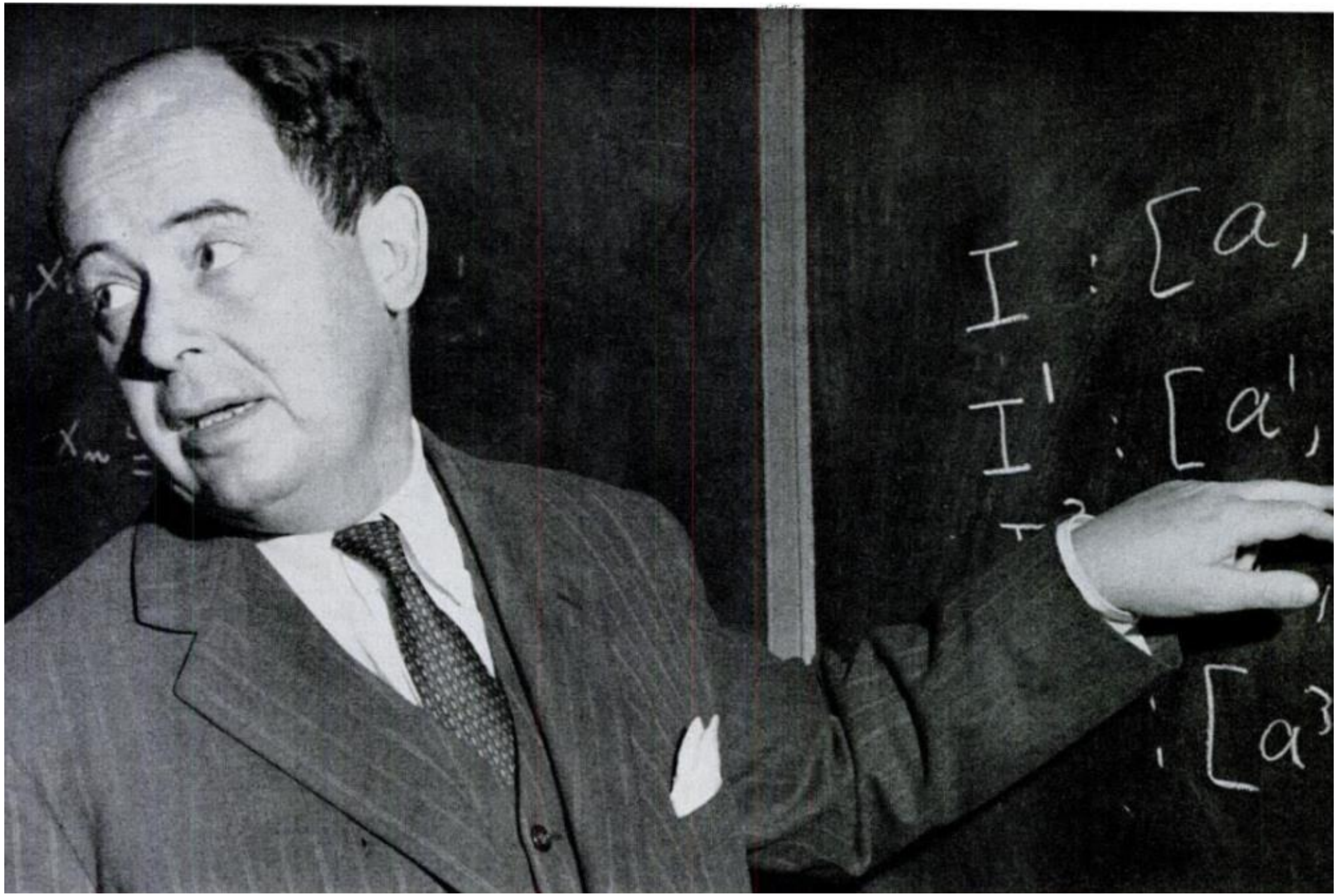
He was a child prodigy for his memory, mental arithmetic, and mathematical ability.

He published his first mathematical paper while still in the Hungarian equivalent of high school.

He simultaneously completed a PhD in mathematics, and a degree in Chemical Engineering (a fall-back option his father insisted upon).

He took his Phd in 1926.

By 1930 he had published 28 technical articles and had a reputation as one of the top mathematicians in the world.



He emigrated to the United States in 1930, and became a naturalized citizen in 1937.

Among other things ,von Neumann:

- Made seminal contributions to the foundations of mathematics.

- Made seminal contributions to quantum mechanics.

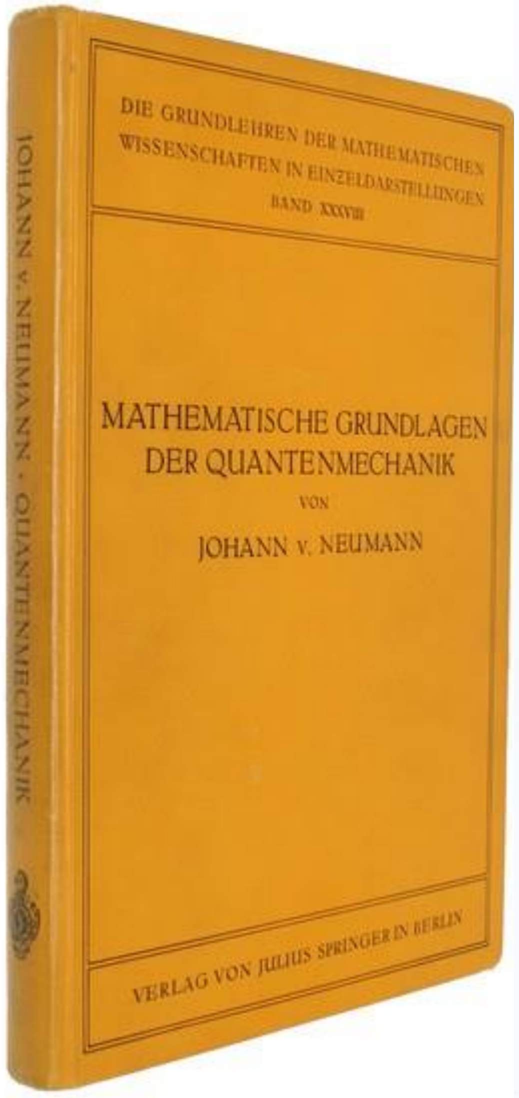
- Invented game theory.

- Designed the spherical-implosion method for detonating the fatman plutonium bomb

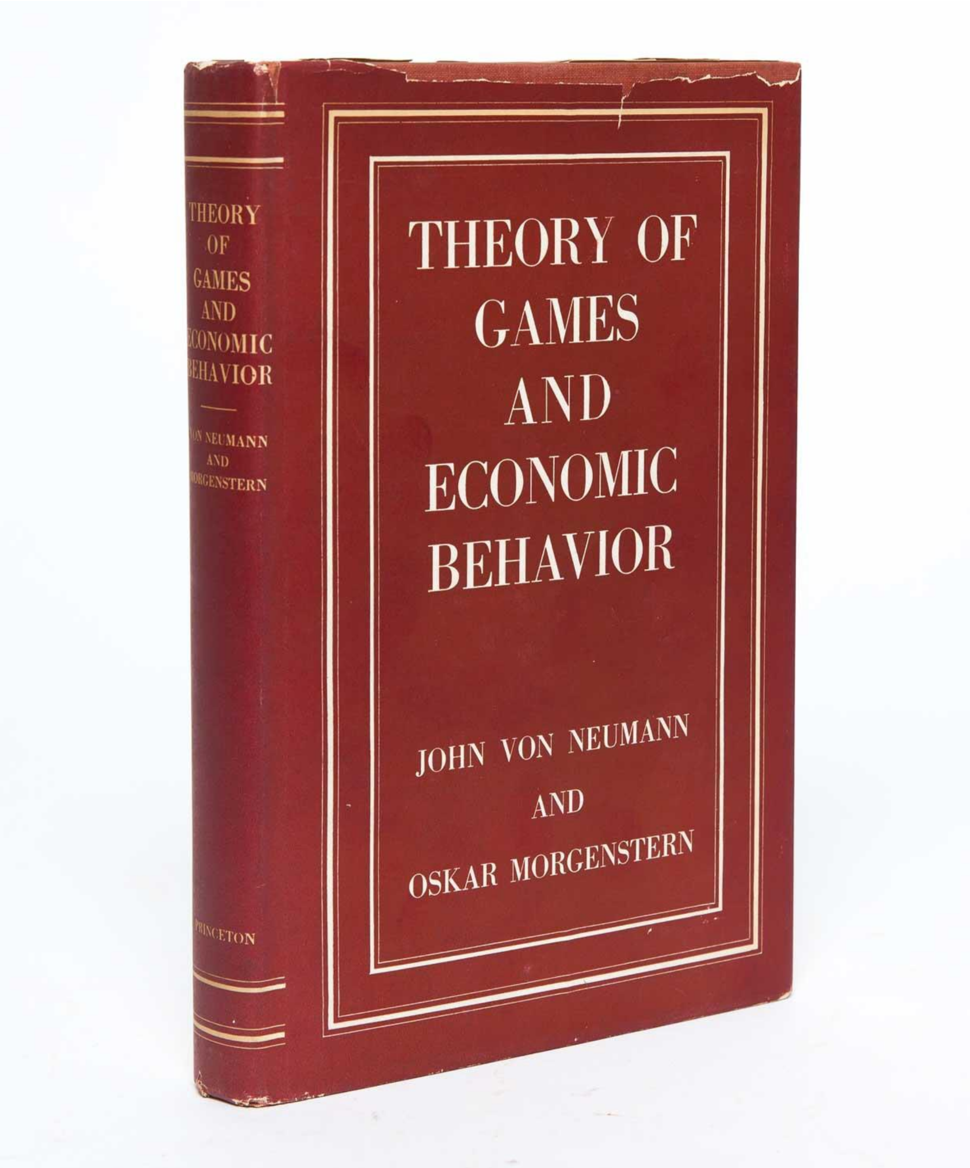
- Designed the basic computer architecture used by nearly every computer ever built

- Led numerous advisory committees that defined the United States policy with regard to nuclear weapons and missiles systems during the cold war.

- And he led the project that produced the first successful NWP.



1932



1944

1950 letter describing effort to recruit von Neumann for the AFSA/NSA to consult on cryptology. It is not known if this effort was successful.

4. If it is decided to approach von Neumann, his clearance should be completely settled before any overture is made. We must then secure his interest in our problems and convince him that, if he works with us, he will have sufficient scope to justify the use of his time; otherwise, he might very well decline to assist us in view of his many other commitments. To do this we must be prepared to introduce him to the heart of our most difficult problems and explain the exact status of our work at the first consultation.

REF ID:A65849

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

12 October 1950

From: AFSA-34
To : AFSA-OOT
Via : AFSA-03 — Concur [handwritten initials]

1. It is suggested that AFSA attempt to secure the services of John von Neumann as a consultant on cryptology.

2. John von Neumann is a professor at the Institute for Advanced Study and is recognized as one of the world's greatest minds by all mathematicians and physicists. Not only is he a brilliant researcher in mathe-
s and theoretical physics but also a great "idea man". He has done
tant research in the subjects of statistics, linear operator theory
ices) and logic and founded the mathematical theory of strategy (game
y). He is easily the world's foremost authority on the logical de-
and program theory of computing machines. All of these subjects have
ect application to the operations of AFSA.

We anticipate no difficulty in clearing von Neumann. Because of his
ordinary talents his services are continually used by numerous defence
cts, some of them highly confidential. During the war and since he
een one of the top theoreticians on the A-bomb project; he is, of
e, Q-cleared. He also consults for the National Advisory Committee
eronautics and the Aberdeen proving grounds. He is the head of a
ting machine project at Princeton which is supported by the Army.

If it is decided to approach von Neumann, his clearance should be
etely settled before any overture is made. We must then secure his
est in our problems and convince him that, if he works with us, he
have sufficient scope to justify the use of his time; otherwise, he
might very well decline to assist us in view of his many other commitments. To do this we must be prepared to introduce him to the heart of our most difficult problems and explain the exact status of our work at the first consultation.

5. It is the opinion of all the mathematicians in AFSA-34 that von Neumann can make substantial contributions to the work of AFSA.

H Campaigne

H. Campaigne

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After WWII, von Neumann worked 20 hours per day on numerous advisory committees, hydrogen bomb research, computer design, and meteorology.

Von Neumann at his home in Princeton with his second wife Klara, and his Irish Setter, Inverse.

Von Neumann, always an admirer of the military, became involved an a variety of U.S. military projects in World War II (WWII).

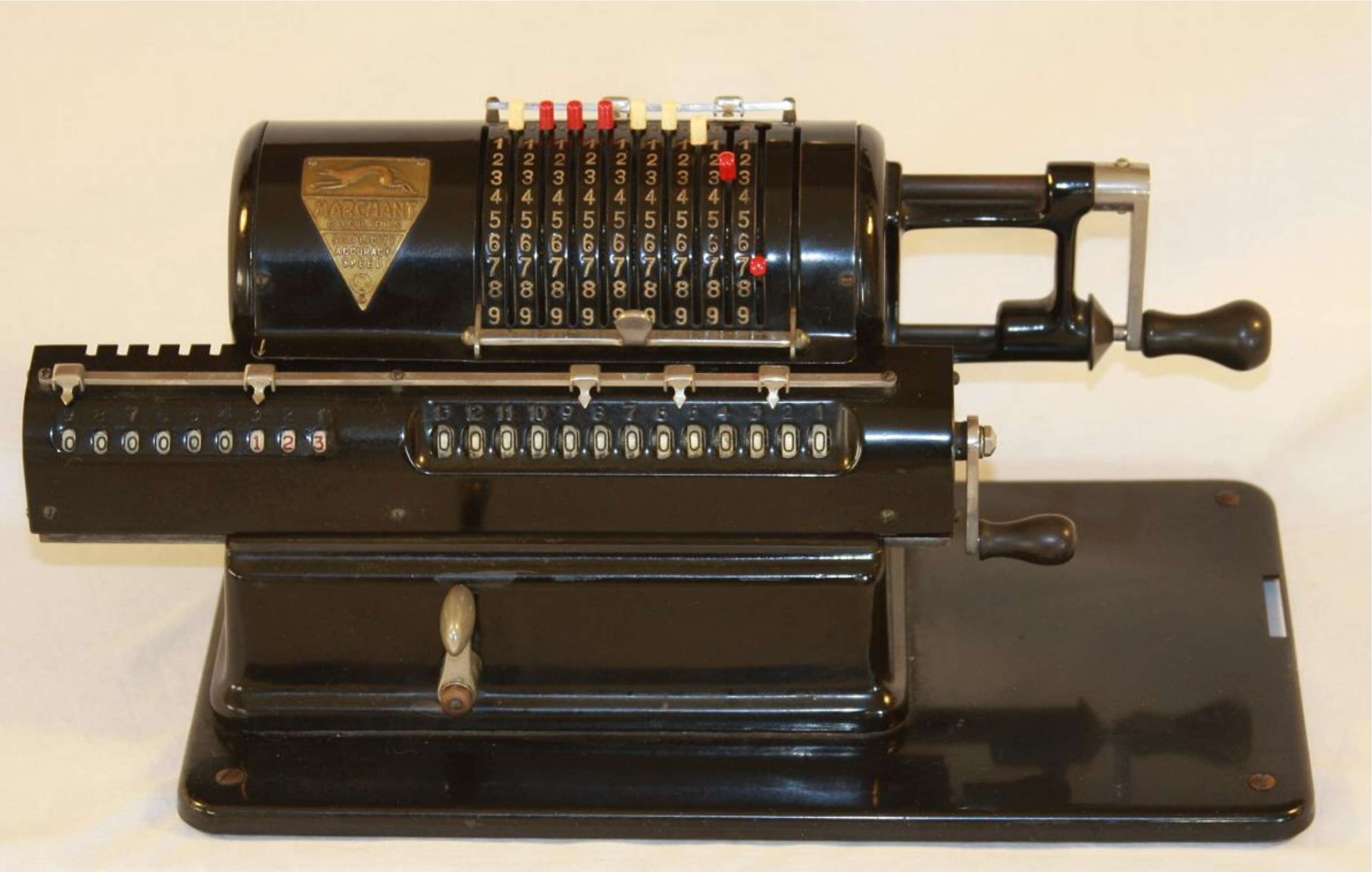
In the mid 1930s von Neumann had become deeply involved in problems of supersonic flow and turbulence. He became a consultant to BRL and the Army Ordinance Department in 1937. He worked on problems for developing shaped charges to be used in antitank weapons, including developing methods for numerical solution of the Navier-Stokes equations.

During WWII BRL developed one of the world's deepest computing capabilities which were used primarily for calculating ballistic firing tables. Demand for computation far exceeded supply, and BRL initiated the ENIAC project in 1943 (unknown to von Neumann until 1944, though he was on the scientific advisory board of BRL).

In 1943 von Neumann was asked to join the Manhattan project at Los Alamos. He is told that the project has not solved how to use plutonium. This is problematic as they only had enough uranium, which they had a design for, to build one bomb. Military strategist had predicted it would take 2 bombs to convince Germany/Japan to surrender. Based on his experience with shaped charges, von Neumann convinces Los Alamos to pursue spherical implosion with shaped charges. The method von Neumann designed is eventually used for ALL fission bombs ever produced, except the Little Man bomb.

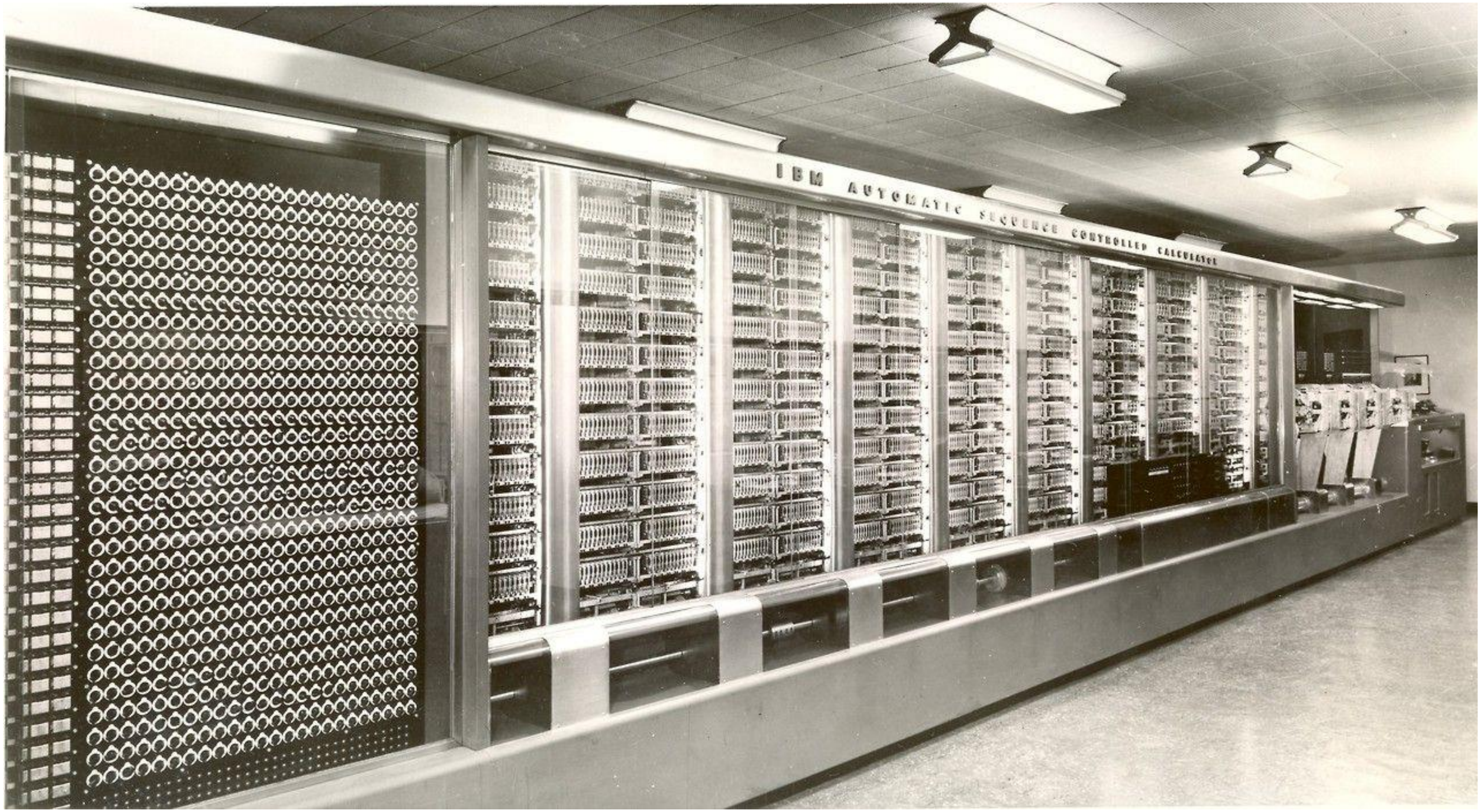
Von Neumann Los Alamos Securty Badge Photo

Von Neumann also realized extensive calculations would be needed to verify the design, and he has Los Alamos develop computing facilities second in the world only to those at BRL. He also designs numerical stability criteria needed for successful calculations following CFL (1928), a condition unknown to L.F. Richardson, who attempted the same sort of calculations by himself in 1918.



Marchant desktop calculator of the type used at Los Alamos during the Manhattan Project

IBM punch card equipment at Los Alamos during WWII. Equipment was modified to do a sequence of arithmetic operations automatically.



Harvard Mark 1. Programmable mechanical computer, also use by von Neumann/Los Alamos during WWII.
Addition: 0.3 s (versus .0002 s for ENIAC = 1500 times faster)
Multiplication: 6 s (versus .0028 s for ENIAC = 2143 times faster)

Train platform at Aberdeen, MD where late on a day sometime in late July 1944, Herman Goldstine introduced himself to von Neumann and told him he was working on a computer at the BRL that could do 333 multiplications a second.

Von Neumann immediately arranges to see the machine and is on the ENIAC advisory board within a few weeks.
Von Neumann becomes a key figure in design of the successor to the ENIAC (the EDVAC), a year before ENIAC itself is complete.

The invention of the ENIAC (Electronic Numerical Integrator And Computer) was a watershed moment in human history of the first order. It increase the ability of humans to process information by 3 orders of magnitude, and the applications and implications of computers for society are still developing.

It was designed and built by the Moore School of Engineering at the University of Pennsylvania under a contract with the Army/BRL who also participated in the project. It was designed to calculate ballistic firing tables.

During its design phase, the ENIAC designers increased the memory so that it would be capable of dealing with problems in hydrodynamics, such as the blast problems von Neumann had done. Such problems also included meteorology.

Despite the fact that ENIAC was a classified project, knowledge of its existence became widely known in academic circles prior to its declassification in 1946.

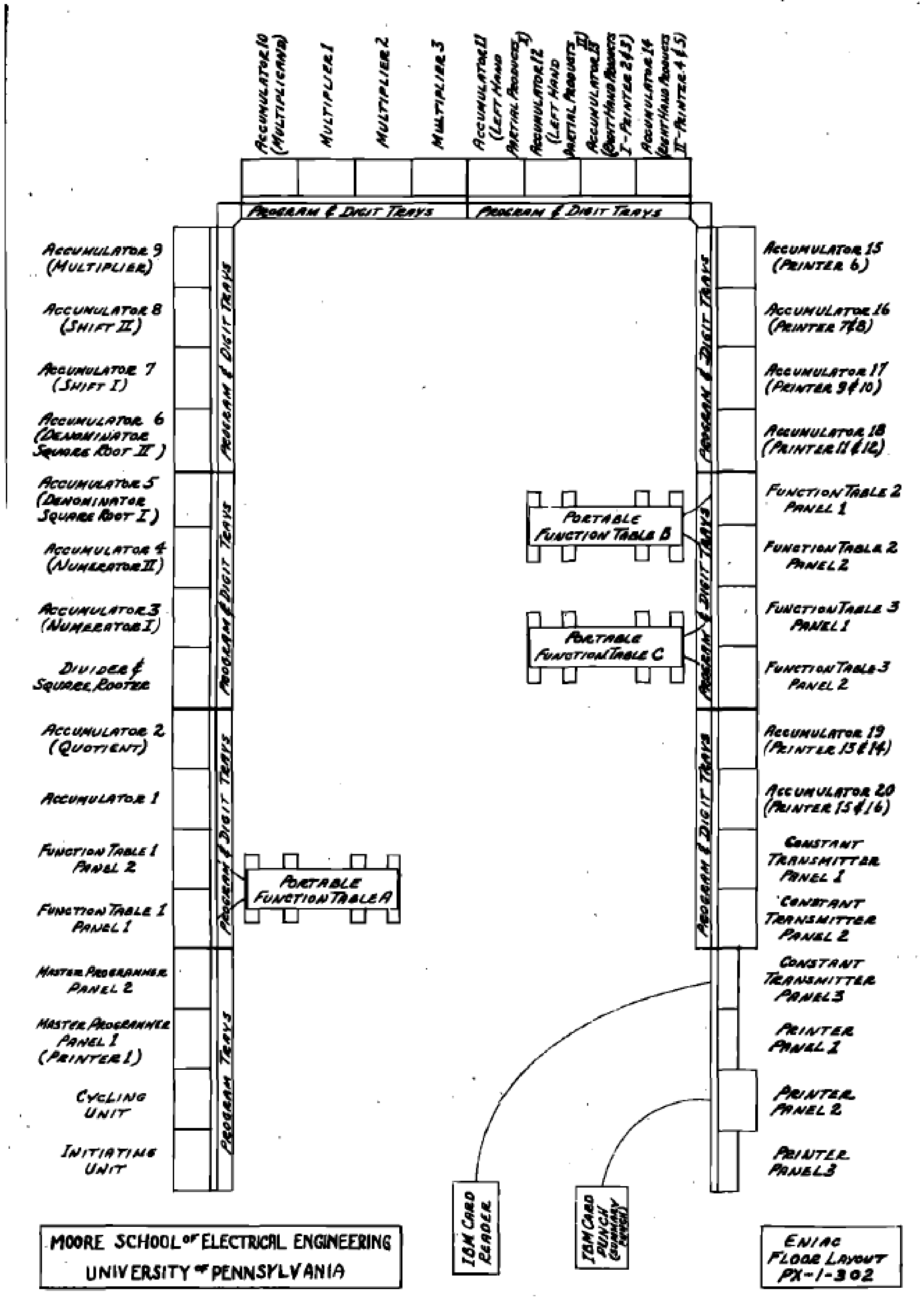
It was not known if ENIAC could be successfully built when the project was started, with the main threat being the reliability of the large number of parts.

The ENIAC wasn't so much a room full of computers, as it was a room. To the right is a diagram of the ENIAC room from its maintenance manual.

The ENIAC was physically larger than any computer built for the next 20 years, and had more vacuum tubes, by far, than any other computer ever built (18 000). The next generation of computers would have around 5000 tubes.

Not a binary machine, ENIAC could operate internally on 20 10-digit decimal numbers, giving it an equivalent memory of 100 bytes, plus unlimited storage onto punch cards.

While enormously influential, no design features of ENIAC were copied by any other subsequent computer, aside from the basic idea of doing computations with electrons.



Publicity photo of the ENIAC when it was still at the Moore School at the University of Pennsylvania.

Herman Goldstine is the officer in the upper right.

Photo of ENIAC after the move to BRL.

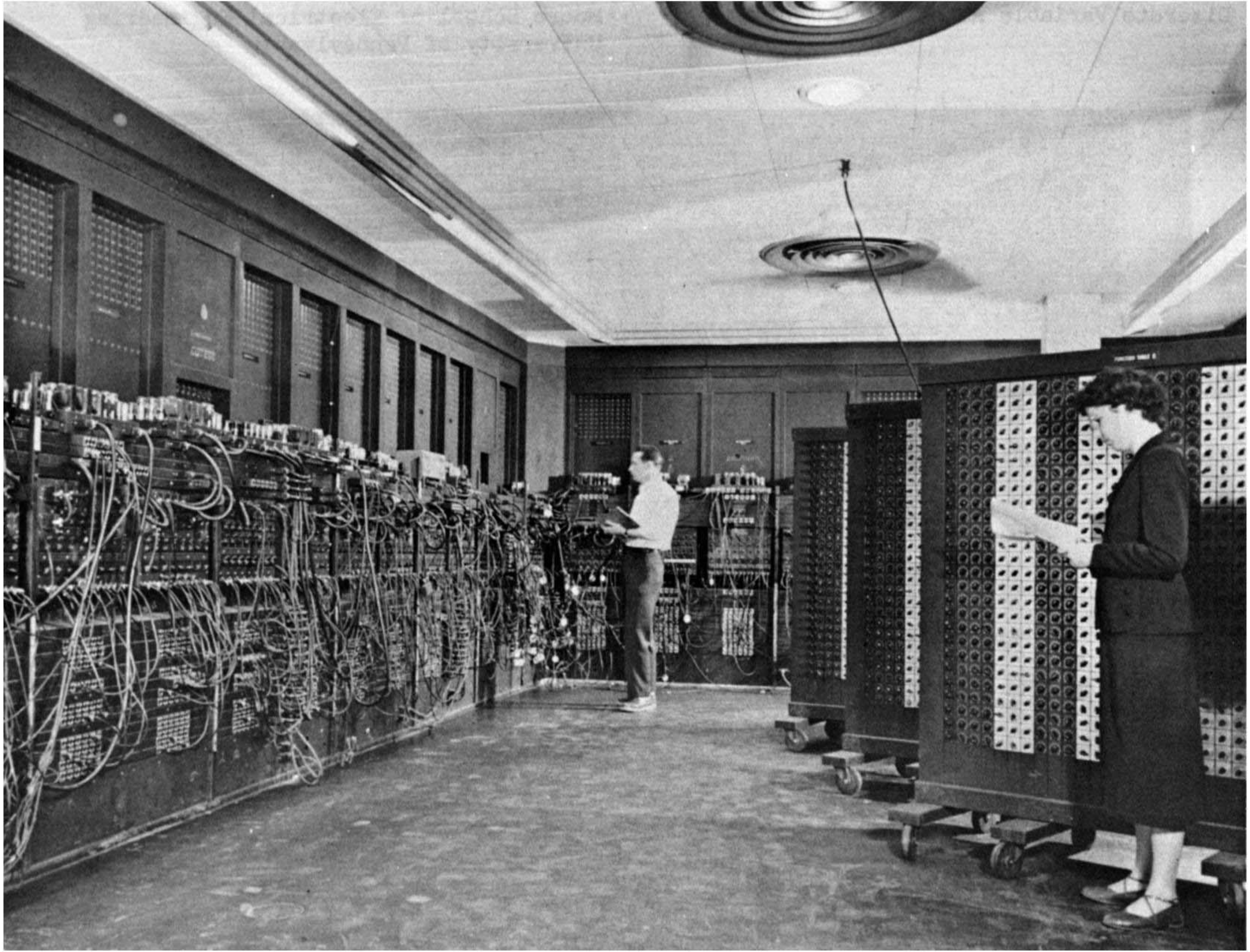
The move took 9 months.

Prior to its move, construction of ENIAC was rushed to completion in late 1945 (after the surrender of Japan); and the move to Aberdeen was delayed until a calculation for Los Alamos could be completed.

The first calculation done on ENIAC when it became operational in Dec. 1945 was a calculation done for Los Alamos testing a fusion bomb design.

This involved 1 million punch cards, and was the largest calculation in history up to that point.

The development of super computers would be intimately related to nuclear weapons research until the end of the cold war.

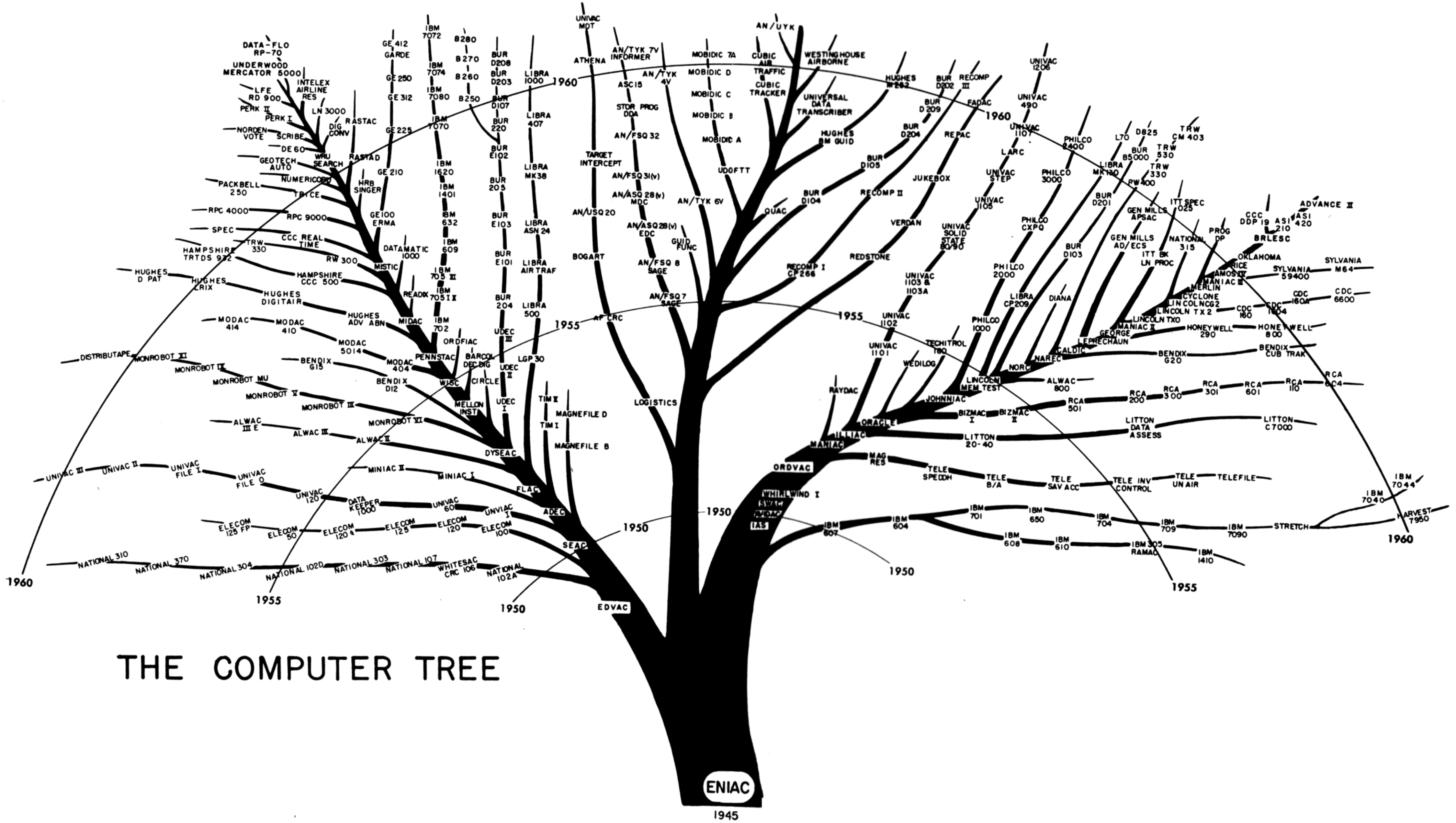


Von Neumann immediately began to dominate the design of the ENIAC successor machine, and later abandoned that project for his own Electronic Computer Project at his home institution, the IAS (Institute for Advanced Study) in Princeton.

The ECP at the IAS that was led by von Neumann, was the only time in von Neumann's life that he ran a project.

Because he needed computers for nuclear weapons calculations; because he wanted to show the world how computers should be designed so as to accelerate their development; and because he wanted to pursue his own design, von Neumann returned to the IAS to build a computer, now known as the IAS computer. The IAS computer is the second most important computer ever built, after the ENIAC, and its design, sometimes still referred to as the von Neumann architecture, is the same basic design used by almost every computer ever built.

The ECP had 3 divisions: Theory, Engineering, and Meteorology.



Computer Tree Drawn by the Army in the early 60s. Actually, all branches stemmed from the IAS computer, except for the EDVAC.

Simultaneously with completion of the ENIAC, the design of next generation computers, and the fusion bomb calculations, von Neumann initiated contacts with meteorologist about interest in numerical weather prediction. Contacts in late 1945 include Carl Gustav Rossby, the military, and members of the Weather Bureau.

Von Neumann also contacts Vladimir Zworykin of RCA (known for developing the electron microscope as well as television). Zworykin had creative ideas about weather control that preceded the invention of electronic computers, and he enthusiastically joins von Neumann in efforts aimed at weather prediction.

Zworykin, with input from von Neumann, had an 11-page draft of a proposal for NWP/weather control in Oct. 1945; prior to the completion of ENIAC in December. ENIAC is declassified in Feb. 1946.

Eventually, a formal proposal, written primarily by von Neumann with input from Carl Rossby, is made to the Navy to fund the meteorology division of the ECP at the IAS. This proposal is dated May 8, 1946; and funded in June. The proposal is handled on the Navy side by D. Rex, who later gets his PhD in meteorology under Rossby.

Partners in this proposal include the IAS, the Navy, and RCA. RCA was to design the memory tubes to be used in the new computer. Due to delays in completing these tubes, RCA and Zworykin ultimately have no impact on either the IAS machine or the NWP project.

NWP Timeline

1903 Von Neumann born in Budapest, Hungary
1906 Vacuum electronic triode tube (amplifier) invented
1918 Electronic flip-flop invented
1918 L.F. Richardson attempts NWP
1922 L.F. Richardson publishes
1928 CFL published
1936 Von Neumann first works on problems of compressible flow and turbulence
1940 Haurwitz notes NWP not practical
1944 Von Neumann works-out spherical implosion method for the plutonium bomb, involving the most advanced numerical computations ever conducted in history to that point

1943 ENIAC Project begun
1945 Late: Discussions on NWP with the Weather Bureau, Navy, RCA, von Neumann
1945 Late: ENIAC rushed to completion after the end of WWII in order to execute calculations for the fusion bomb.
1946 May: ONR proposal to establish Meteorology Group at the IAS
1946 June: ONR proposal funded
1946 August: Conference Meteorology at IAS
1948 Jule Charney arrives at the IAS
1950 March-April: First NWP runs on the ENIAC
1953 IAS conference to begin process to lead to operational NWP
1955 JNWPU produces first operational NWP
1956 Feb. : von Neumann dies

The May 1946 proposal lists H. Wexler (head of research at the U.S. Weather Bureau) as a potential head of the project. Rossby had been offered the position, but declined.

Potential advisers to the project in the proposal include: Rossby, Sverdrup, Bjerknes, Edward Teller, Chandrasekhar, Theodore von Karman, and Zworykin. Of these, Rossby is the only one that had an impact on the project.

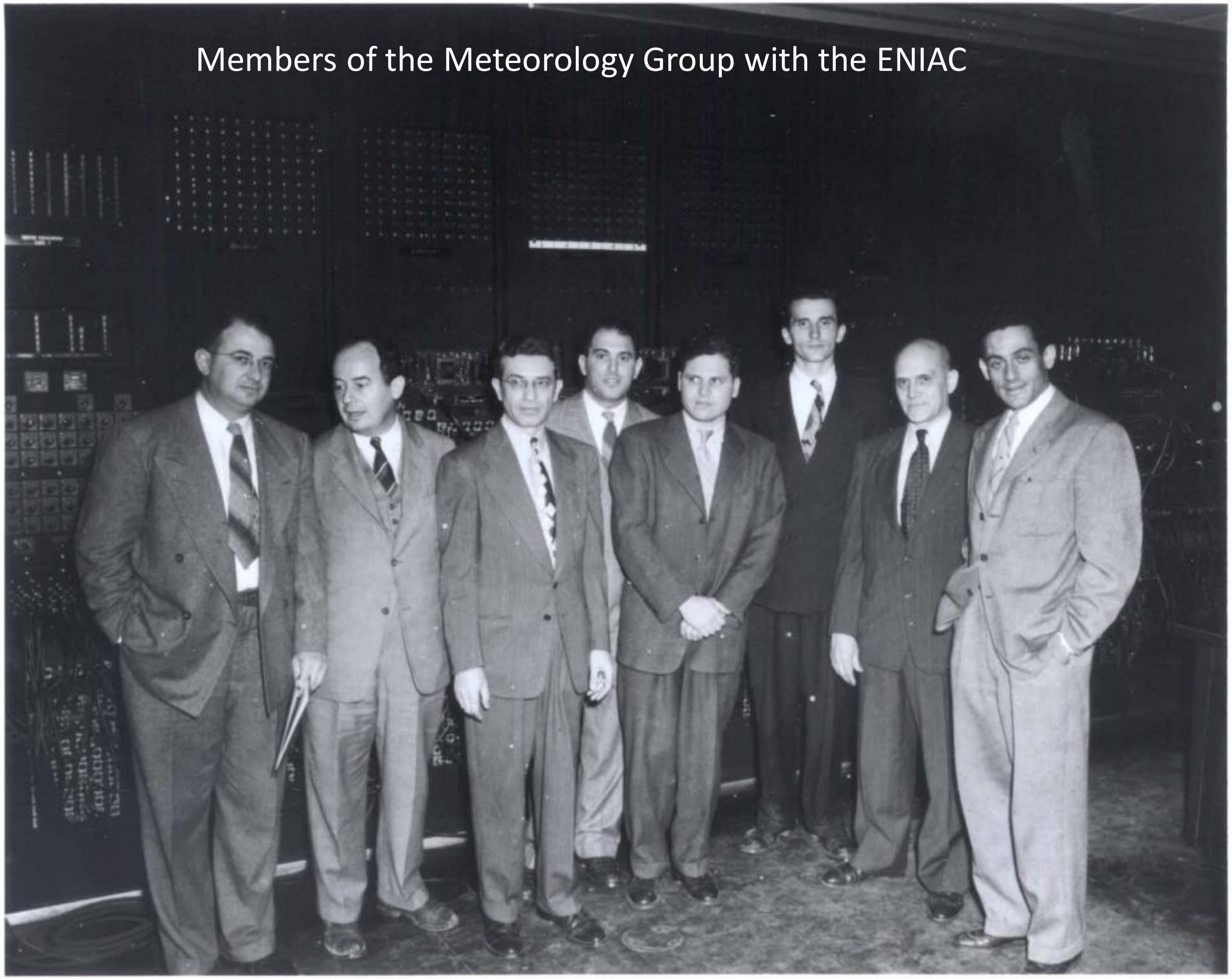
During the 9 year run of the project, many meteorologists would spend some time in residence at the IAS including: James Cooley, Jacob Blackburn, George Cressman, E. T. Eady, Arnt Eliassen, Fjortoft, Ernst Hovmoller, Adolph Nussbaum, Hans Panofsky, Irving Rabinowitz, F.G. Shuman, Norm Phillips, George Platzman, Irving Rabinowitz, Joseph Smagorinsky, P. D. Thompson, George Veronis, and Jule Charney.

Wexler was the actual head of the Meteorology Division for its first 2 years, but was not in residence.
Jule Charney joined the project in 1948, following the completion of an NRC post-doc, and quickly became the leader of the project.

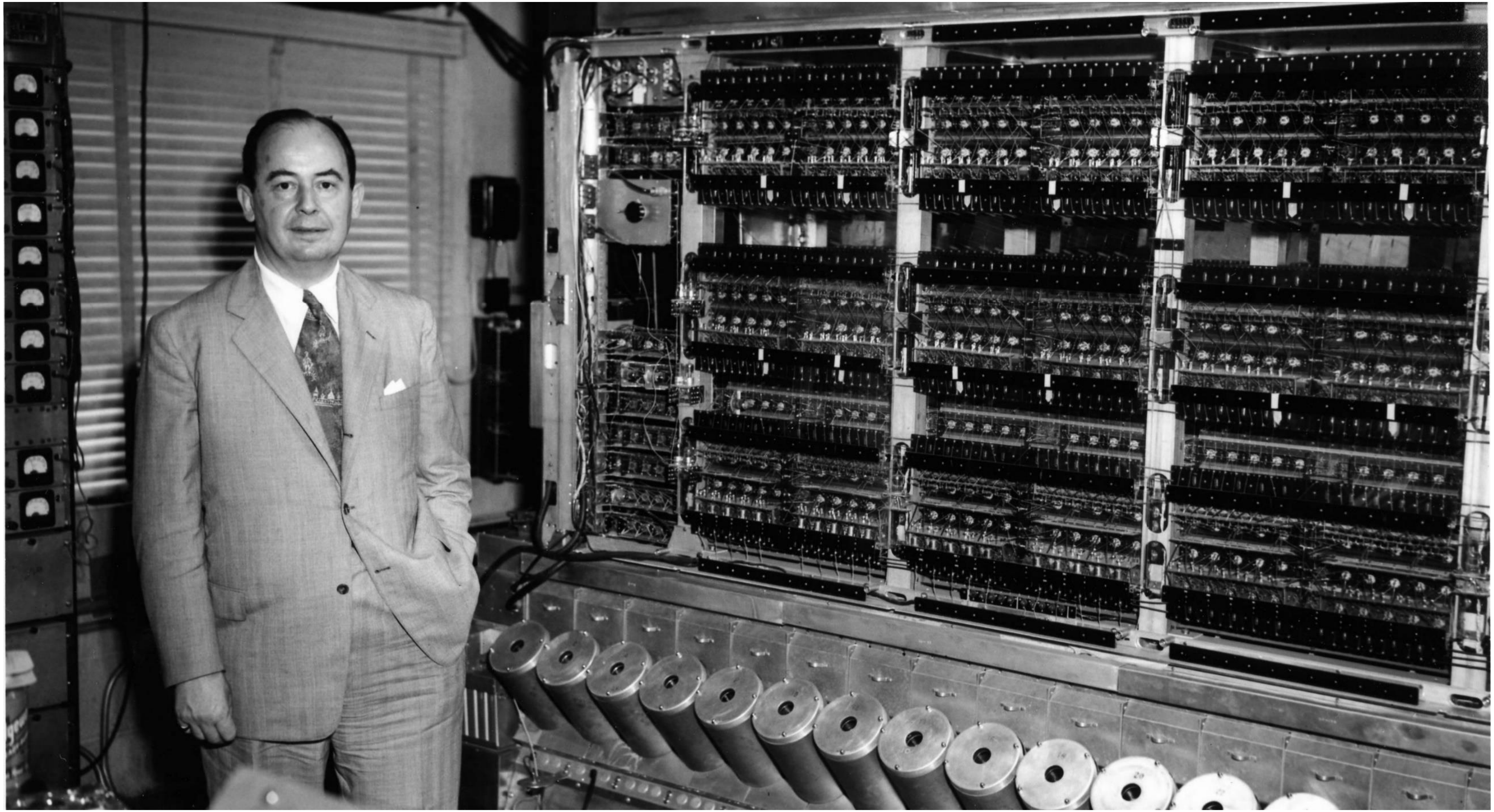
Charney had been asked to join in 1946, but declined at that time. However, during his post-doc, he did work on the theoretical underpinnings needed to reduce the equations of motion to a form suitable for numerical solution.

It was always intended to run calculations on the IAS machine, which was 2 orders of magnitude faster than ENIAC. However, delays in the RCA memory tubes led to the acquisition of time on the ENIAC. Running NWP on a machine with only 100 bytes of memory was made possible by Charney's theoretical development that led to a 2-dimensional set of equivalent barotropic equations in one variable, and by von Neumann's development of a way to solve the Poisson equation that arose from Charney's approach, with a small amount of memory.

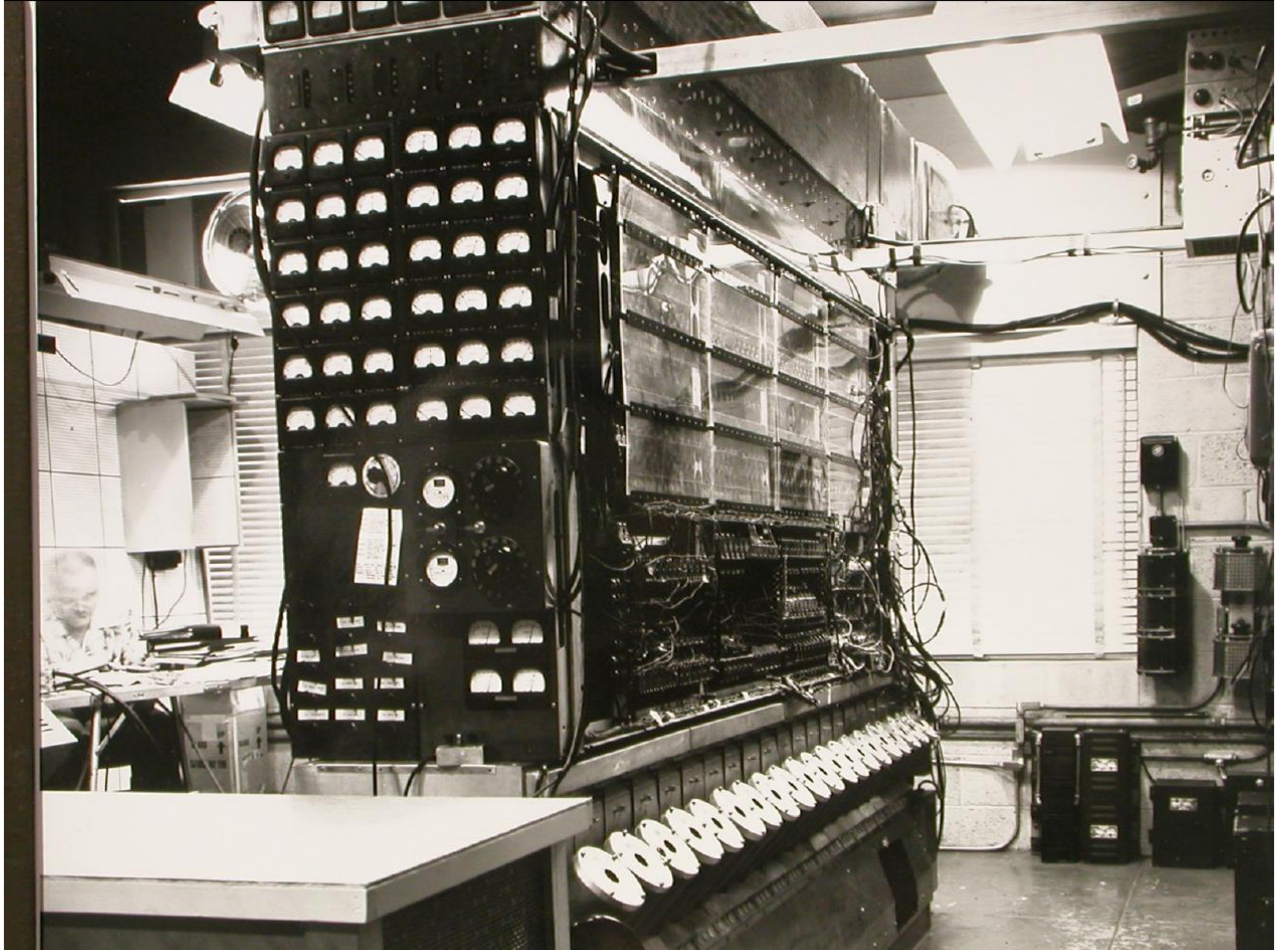
The calculation reported on in Tellus took 24 hours of wall clock time to run a 1-day forecast. They would later run the same calculation on the IAS machine in 5 minutes (=288 times faster).



From Left to right: **Harry Wexler, John von Neumann, M.H. Frankel, Jerôme Namias, John Freeman, Ragnar Fjörtoft, Francis Reichelderfer, Jule Charney.** Photo taken by J. Smagorinsky.



John von Neumann with the IAS computer. Cylinders are the CRT memory devices.



Another view of the IAS computer, with Norm Phillips nearby

NWP was pursued as one of the earliest applications of electronic computers, with efforts to gain support beginning prior to the completion of the first computer. These effort began not with meteorologists, who were skeptical, but with von Neumann.

The history of NWP raises many questions, only a few of which I will address here:

WHY did von Neumann choose NWP as one of the first major applications of computers?

Passage from the original 1946 proposal for the NWP project describing the machine von Neumann was planning to build, shows his enthusiasm for computers.

We expect that such a machine will change the conditions, methods and applications of computing fundamentally. It should compute 50,000 to 100,000 times faster than is possible at present; it should therefore change the entire inner economy of computing. It will therefore make the developing of entirely new methods of approximation mathematics highly indicated and profitable. It will accordingly cause a complete change in our estimation as to which problems can be solved by computation.

Among the fields which we intend to study in this manner, the one of dynamic meteorology is among the most important. Another field, which should have the highest priority, is that of turbulent fluid motion—and this is also essential for a more fundamental approach to dynamic meteorology.

But what were computers really good for, aside from making nuclear bombs?

Some applications run on the ENIAC 1946-1951:

MILIITARY
- Ballistic Firing Tables
- Missile tracking analysis
- Nuclear Weapons Design (implosion problems, hydrodynamics)
- Supersonic Airflow over bodies of revolution (hydrodynamics)
- Supersonic Prandtl-Meyer flow
- Wind tunnel nozzle design (hydrodynamics)

AEC (civilian nuclear, now the NRC)
- Liquid-Drop Model of Fission
- Solutions of the Fermi-Thomas-Dirac Equation
- Table of Atomic Masses

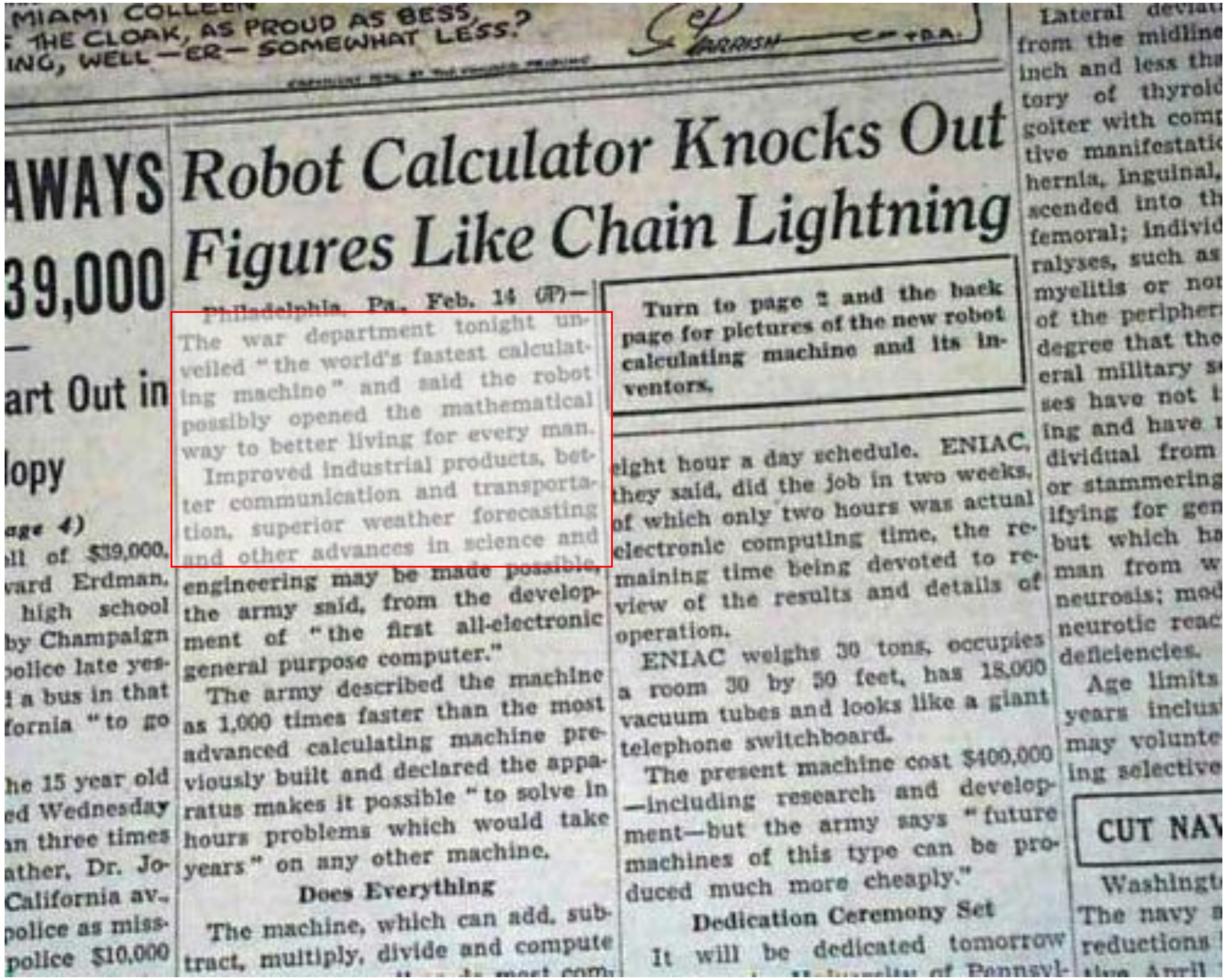
MATHEMATICAL
- Fermat's Quotient, prime numbers, pi, e and 1/e calculations
- Methods for Solving general parabolic PDEs
- Matrix inversion methods
- Error Accumulation analysis

Some applications run on the ENIAC 1946-1951 (continued):

Other Government/INDUSTRY
- Monte Carlo Calculations (JVN et al.)
- Hydrodynamic Shocks (JVN)
- Equilibrium composition of combustion gases
- Thermodynamics of Combustion Gases
- Optimum Spacing of Gas Wells (parabolic PDE)
- Well depletion computation (ODE)
- 1-D Heat Flow
- Guided Missile Trajectories

UNIVERSITIES
- Compressible Laminar Boundary Layer (1948, Cambridge, England group; hydrodynamic).
- Properties of Diatomic Gases (U. of Penn.)
- Refraction of Shock Waves (IAS)
- Wind Tunnel Design (MIT)
- Light Scattering for Spherical Particles (U. of Michigan)
- Weather Forecasting (1950, IAS)

For von Neumann, NWP was an application that really highlighted the significance of computers. If successful, it would show that computers fundamentally changed the relationship between humans and the world they inhabited. NWP was the only thing on the list above that had god-like connotations, and which would excite others.



Robot Calculator Knocks Out Figures Like Chain Lightning

Philadelphia, Pa., Feb. 14 (AP)—The war department tonight unveiled "the world's fastest calculating machine" and said the robot possibly opened the mathematical way to better living for every man.

Improved industrial products, better communication and transportation, superior weather forecasting and other advances in science and engineering may be made possible, the army said, from the development of "the first all-electronic general purpose computer."

The army described the machine as 1,000 times faster than the most advanced calculating machine previously built and declared the apparatus makes it possible "to solve in hours problems which would take years" on any other machine.

Does Everything

The machine, which can add, subtract, multiply, divide and compute

Turn to page 2 and the back page for pictures of the new robot calculating machine and its inventors.

eight hour a day schedule. ENIAC, they said, did the job in two weeks, of which only two hours was actual electronic computing time, the remaining time being devoted to review of the results and details of operation.

ENIAC weighs 30 tons, occupies a room 30 by 50 feet, has 18,000 vacuum tubes and looks like a giant telephone switchboard.

The present machine cost $400,000—including research and development—but the army says "future machines of this type can be produced much more cheaply."

Dedication Ceremony Set

It will be dedicated tomorrow

G.I. Taylor was present at this event, a guest of von Neumann.

In February, 1946, the ENIAC was declassified, with a media event announcing its existence to the world. Weather forecasting was cited in the press-release as an application.

Did von Neumann really have that much of an impact on NWP?

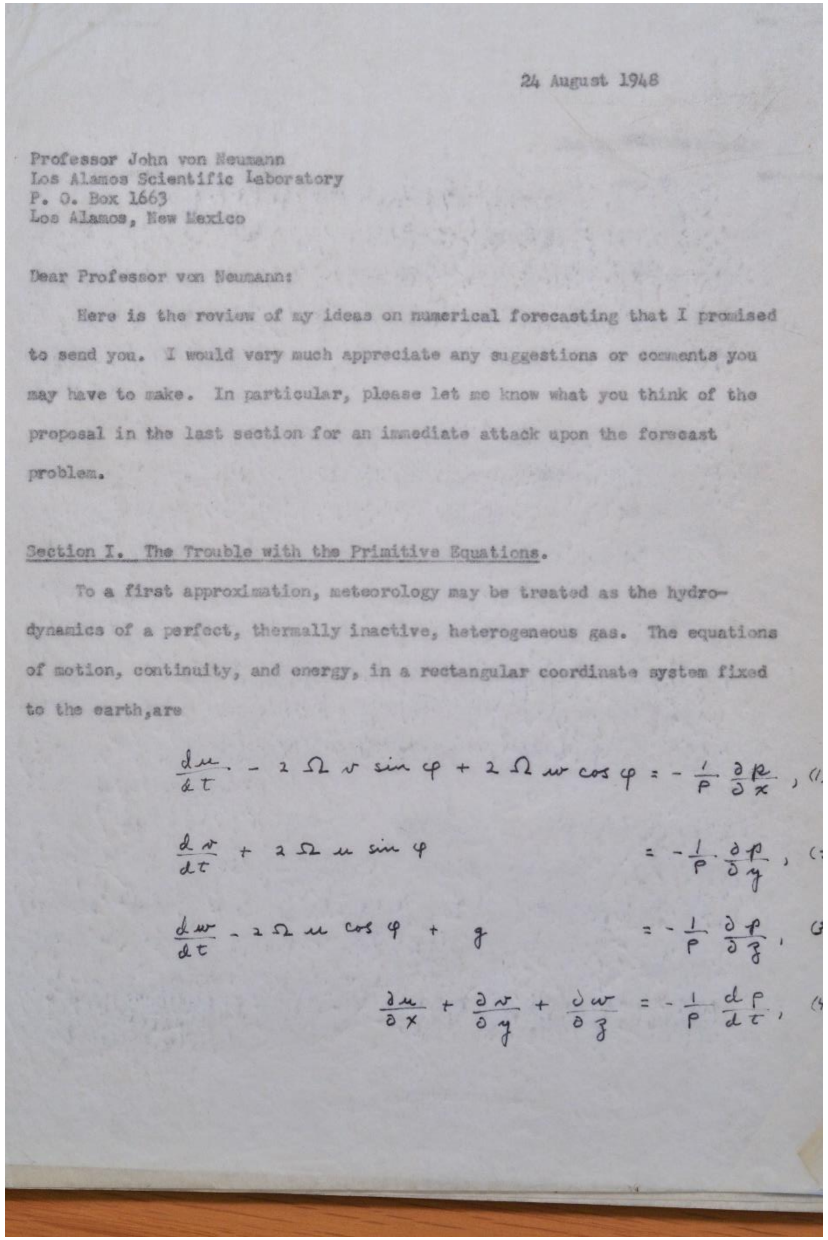
When electronic computers arrived, the meteorological community was not immediately aroused. There was no one with Richardson's vision with the motivation to attempt it, and there was no real expectation that doing something like just running Richardson's method on the ENIAC would go anywhere by itself. The mathematics behind using finite differences to integrate partial differential equations was an area that few in meteorology knew much about. The diffidence of meteorologist to NWP at the time of the invention of the ENIAC is in contrast to the confidence of von Neumann. Von Neumann already knew all the relevant math. He had been integrating PDEs numerically for nearly 10 years. He knew frontwards and backwards how to do it. He'd been thinking about such problems as turbulence and meteorology for years. He had just pioneered how to do just such calculations at Los Alamos for the fission bomb, with particular care in the design of the calculations so as to maintain computational stability. Von Neumann had read Richardson's book, and likely knew the strengths and weaknesses of Richardson's methods as he had done considerably more advanced things himself.

Clearly, the NWP project would not have occurred without von Neumann's interest and connections.

The Tellus paper is the only formal meteorology paper with von Neumann's name on it, yet he was intimately involved with every aspect of the meteorology project, from theory, programming, and the establishment of operational use.

From reports on the Meteorology group, von Neumann is given sole responsibility for handling all of the numerical issues: inventing a method that would work on the ENIAC of solving the Laplacian matrix using Fourier transforms; establishing the numerical stability criteria and boundary conditions.

He also involved himself in discussions of all aspects of the project.



24 August 1948

Professor John von Neumann
Los Alamos Scientific Laboratory
P. O. Box 1663
Los Alamos, New Mexico

Dear Professor von Neumann:

Here is the review of my ideas on numerical forecasting that I promised to send you. I would very much appreciate any suggestions or comments you may have to make. In particular, please let me know what you think of the proposal in the last section for an immediate attack upon the forecast problem.

Section I. The Trouble with the Primitive Equations.

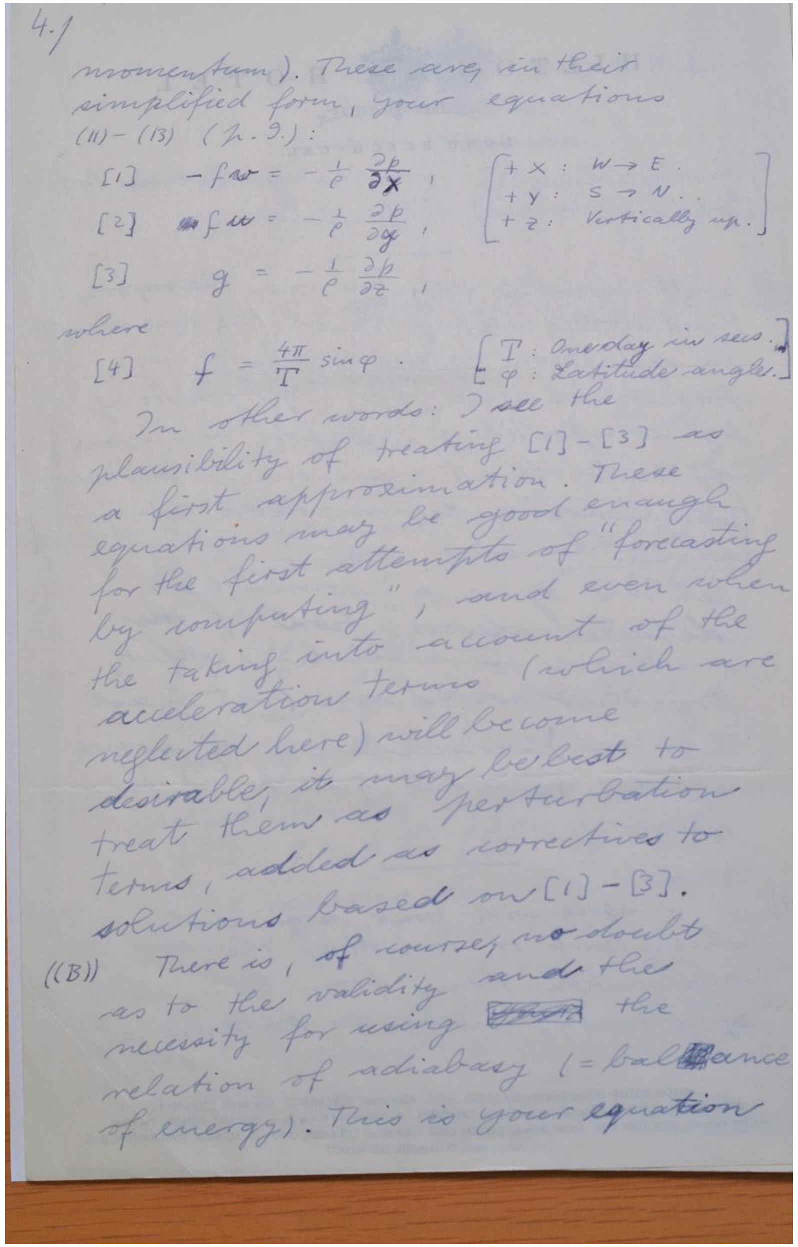
To a first approximation, meteorology may be treated as the hydrodynamics of a perfect, thermally inactive, heterogeneous gas. The equations of motion, continuity, and energy, in a rectangular coordinate system fixed to the earth, are

$$\frac{du}{dt} - 2\Omega v \sin\varphi + 2\Omega w \cos\varphi = -\frac{1}{\rho}\frac{\partial p}{\partial x},$$

$$\frac{dv}{dt} + 2\Omega u \sin\varphi = -\frac{1}{\rho}\frac{\partial p}{\partial y},$$

$$\frac{dw}{dt} - 2\Omega u \cos\varphi + g = -\frac{1}{\rho}\frac{\partial p}{\partial z},$$

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = -\frac{1}{\rho}\frac{d\rho}{dt},$$



4./

momentum). These are, in their simplified form, your equations (11)–(13) (p. 9.):

$$[1] \quad -fv = -\frac{1}{\rho}\frac{\partial p}{\partial x},$$

$$[2] \quad fu = -\frac{1}{\rho}\frac{\partial p}{\partial y},$$

$$[3] \quad g = -\frac{1}{\rho}\frac{\partial p}{\partial z},$$

[+x : W → E.
+y : S → N.
+z : Vertically up.]

where

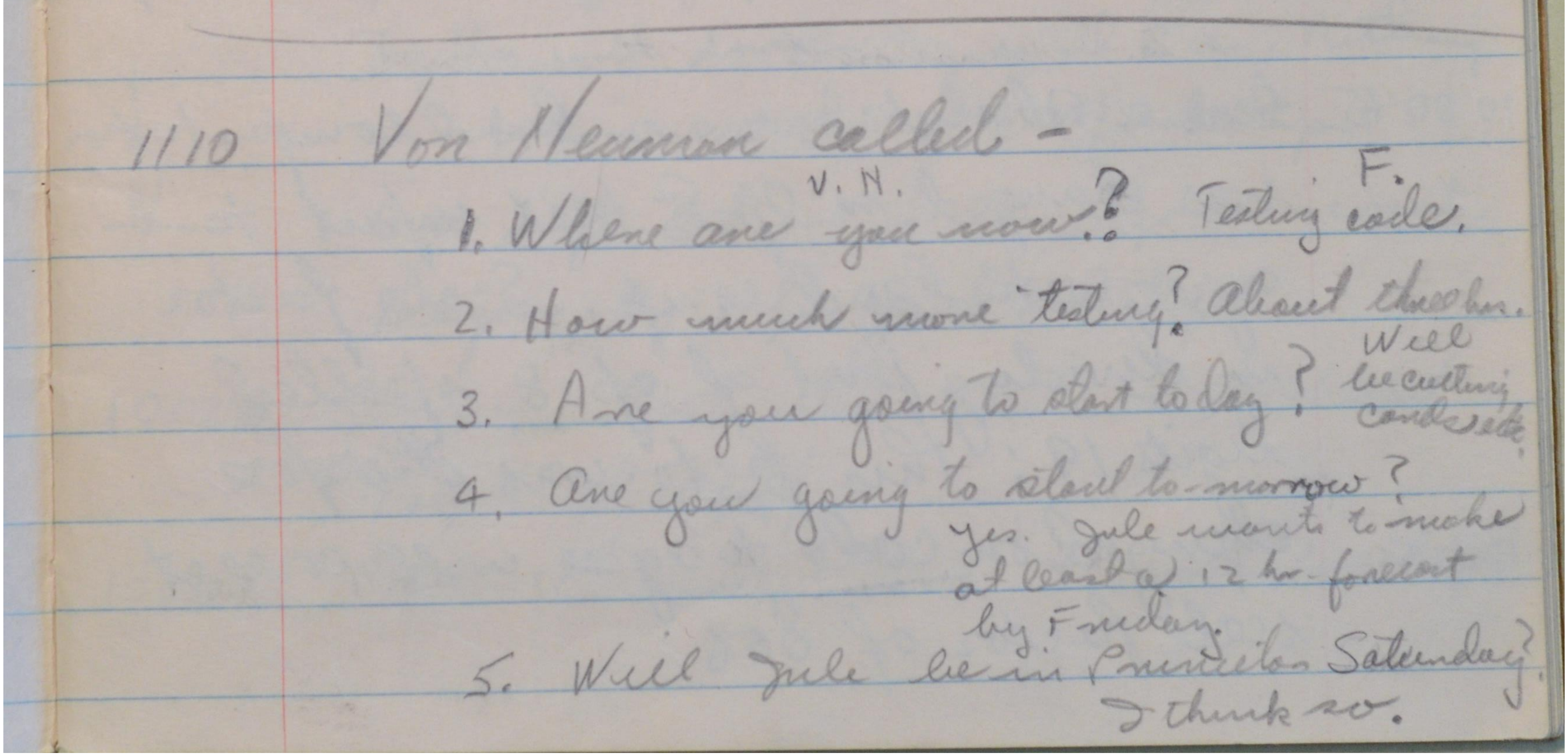
$$[4] \quad f = \frac{4\pi}{T}\sin\varphi.$$

[T : One day in secs.
φ : Latitude angle.]

In other words: I see the plausibility of treating [1]–[3] as a first approximation. These equations may be good enough for the first attempts of "forecasting by computing", and even when the taking into account of the acceleration terms (which are neglected here) will become desirable, it may be best to treat them as perturbation terms, added as correctives to solutions based on [1]–[3].

((B)) There is, of course, no doubt as to the validity and the necessity for using the relation of adiabasy (= balance of energy). This is your equation

In the Summer /Fall of 1948, Charney and von Neumann had a lengthy exchange of letters discussing the equations that might be used for NWP. Charney's initial letter from Sep. 17 1948 was 26 typed pages. Von Neumann's response was hand written Aug 24, 1948 on hotel stationary and ran 23 pp.



1110 Von Neumann called -

V. N. — F.

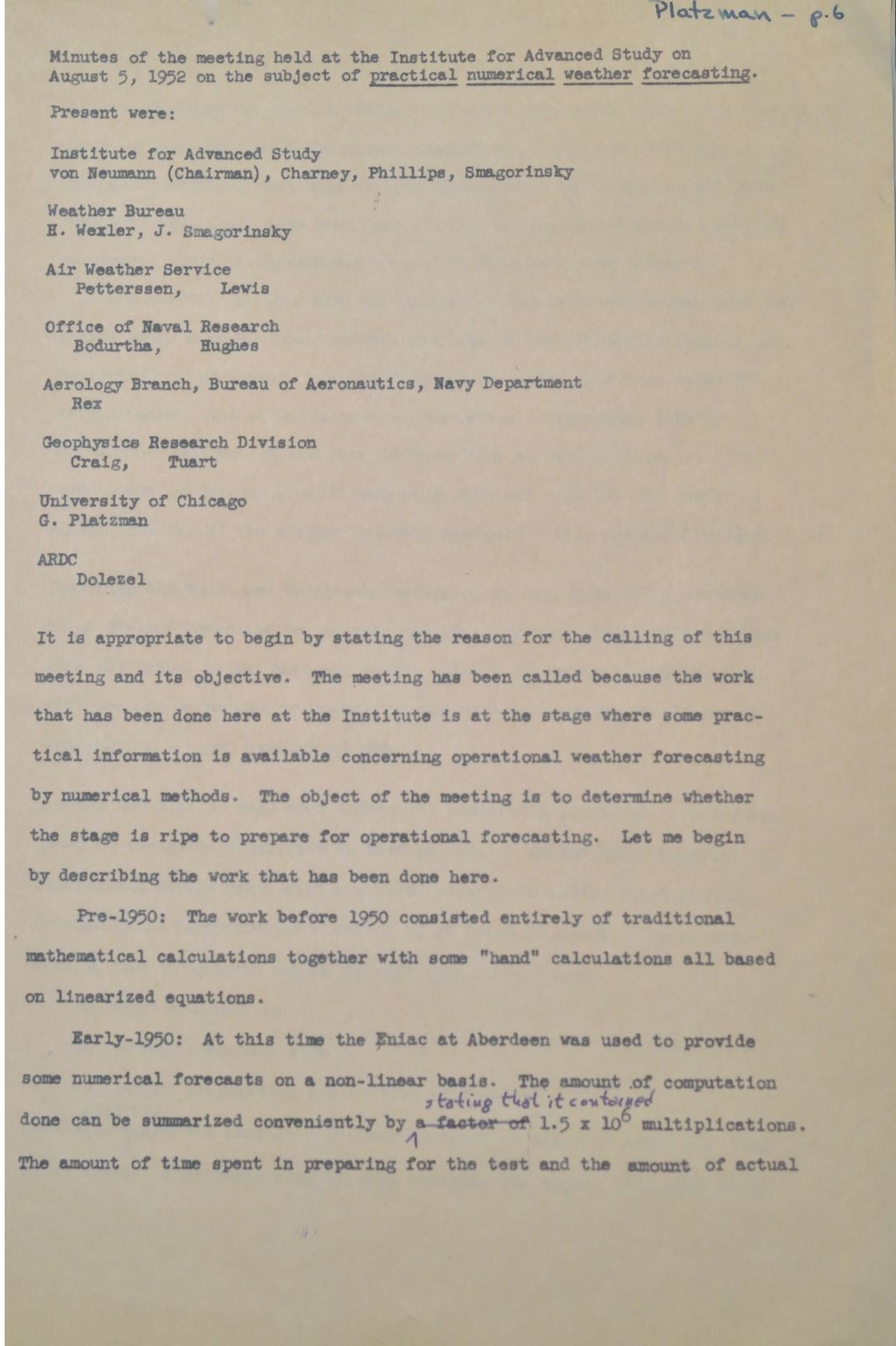
1. Where are you now? — Testing code.
2. How much more testing? — About three hrs.
3. Are you going to start today? — Will be cutting cards etc.
4. Are you going to start to-morrow? — Yes. Jule wants to make at least a 12 hr. forecast by Friday.
5. Will Jule be in Princeton Saturday? — I think so.

From the Log kept during the round-the-clock activity running the first NWP on the ENIAC. Von Neumann called several times during the runs to check on progress and give advice. Log kept from March 5 – April 6, 1950.

Report from the meeting Aug. 7 1952 at the IAS designed to begin the process that would lead to the JNWPU. This was chaired by von Neumann, who also did most of the talking.

Von Neumann was also involved with the establishment of GFDL and climate forecasting, and served on advisory committees overseeing the establishment and operation of the JNWPU.

So, yes, von Neumann had a deep and far-reaching impact on the development of NWP, leading to the its operational use in 1955, a remarkably short period following its becoming a theoretical possibility with the completion of the ENIAC.



Platzman – p.6

Minutes of the meeting held at the Institute for Advanced Study on August 5, 1952 on the subject of practical numerical weather forecasting.

Present were:

Institute for Advanced Study
von Neumann (Chairman), Charney, Phillips, Smagorinsky

Weather Bureau
H. Wexler, J. Smagorinsky

Air Weather Service
Petterssen, Lewis

Office of Naval Research
Bodurtha, Hughes

Aerology Branch, Bureau of Aeronautics, Navy Department
Rex

Geophysics Research Division
Craig, Tuart

University of Chicago
G. Platzman

ARDC
Dolezel

It is appropriate to begin by stating the reason for the calling of this meeting and its objective. The meeting has been called because the work that has been done here at the Institute is at the stage where some practical information is available concerning operational weather forecasting by numerical methods. The object of the meeting is to determine whether the stage is ripe to prepare for operational forecasting. Let me begin by describing the work that has been done here.

Pre-1950: The work before 1950 consisted entirely of traditional mathematical calculations together with some "hand" calculations all based on linearized equations.

Early-1950: At this time the Eniac at Aberdeen was used to provide some numerical forecasts on a non-linear basis. The amount of computation done can be summarized conveniently by ~~a factor of~~ stating that it contained 1.5×10^6 multiplications. The amount of time spent in preparing for the test and the amount of actual

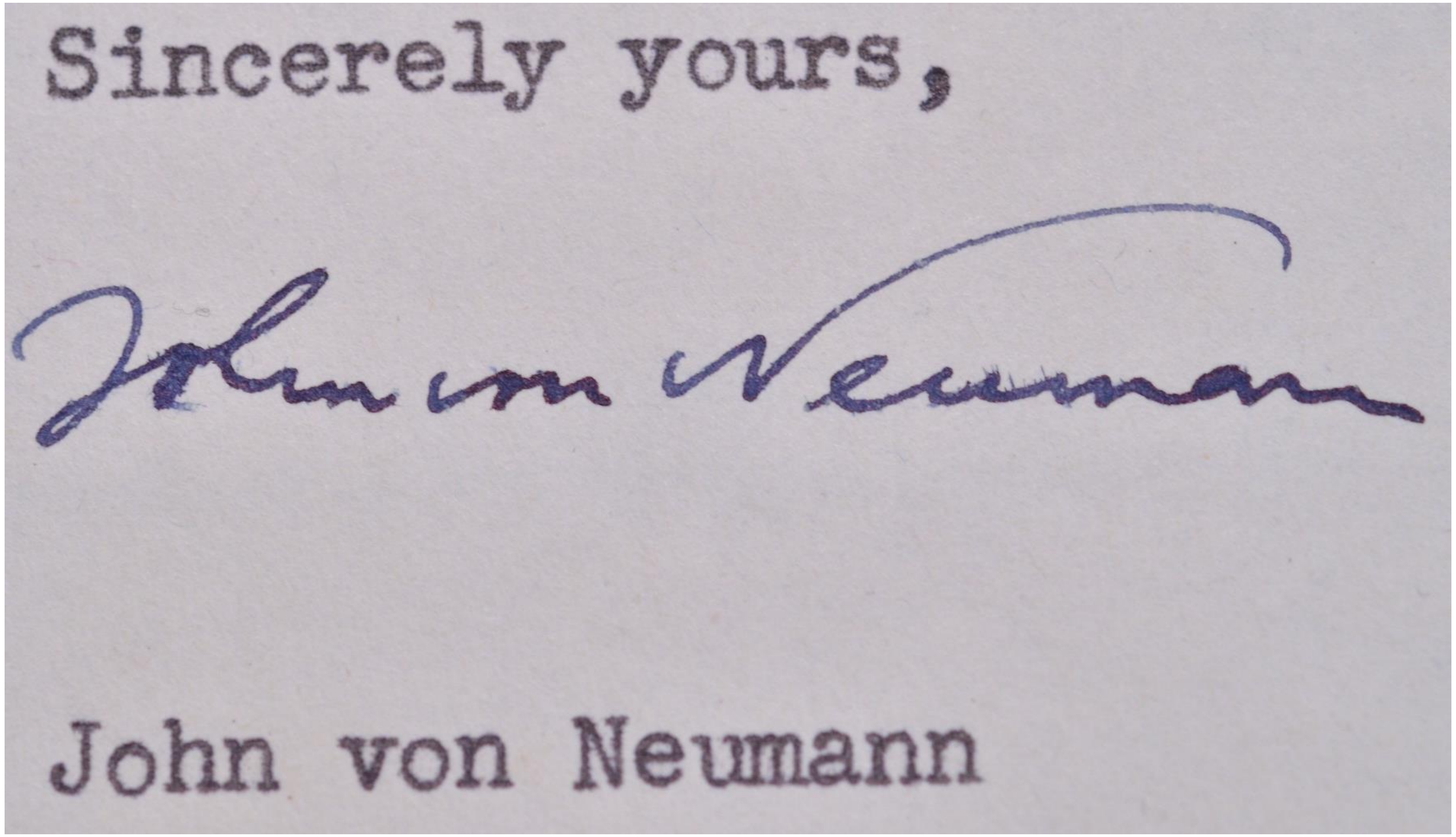
What is the broader significance of NWP, if any?

The success of NWP showed that von Neumann was right. Computers meant more than just a more efficient way of processing numbers. Von Neumann felt that electronic computers would have deep and far-reaching consequences. Thermo-nuclear bombs and NWP were both expressions of these, and NWP was something people were not afraid of.

If the weather can be predicted, who knows what else might be possible.

But NWP also shows there are limits. Humans are not gods after all, as we now know, following Lorenz and Godel. For basic logical and mathematical reasons, weather forecasts beyond a couple weeks are not practical, no matter how powerful computers become.

“I am thinking about something much more important than bombs. I am thinking about computers.“--


Sincerely yours,

John von Neumann

John von Neumann

Von Neumann receiving the Presidential Medal of Freedom prior to his death.

TIMELINE

1816 first use of electronics (telegraphy).
1903 von Neumann born in Budapest, Hungary.
1906 vacuum electronic triode tube (amplifier) invented.
1918 electronic flip-flop invented, using 2 triodes.
1918 L.F. Richardson attempts NWP.
1922 L.F. Richardson publishes.
1928 CFL published.
1935 von Neumann first works on supersonic and turbulent flow calculations.
1936 Turing defines basic parameters of computation by machine.
1937 von Neumann works on shaped charge calculations for BRL.
1939 first use of flip-flops for logic circuits.
1941 Haurwitz notes NWP not practical.
1943 BRL begins ENIAC project.
1943 von Neumann designs spherical implosion method for Pu bomb.
1944 heavy computations conducted at Los Alamos for implosion design using punch card machines and desk-top mechanical calculators.
1944 July late von Neumann learns of the building of the ENIAC.
1944 Theory of Games published.
1945 July 16 Trinity test of implosion bomb.
1945 August Hiroshima and Nagasaki bombings, Japan surrenders.
1945 Late; ENIAC rushed to completion using double shifts.
1945 December first job run on ENIAC in operational mode, done for Los Alamos.
1945 December: first talks about NWP with Weather Bureau.

TIMELINE continued

1946 January: Meetings at the US Weather Bureau with von Neumann
1946 February: Public unveiling of ENIAC, with weather forecasting proposed as an application. G. I. Taylor present.
1946 May: NWP proposal submitted by IAS/von Neumann to NRL
1946 June: NWP proposal funded by NRL
1946 August: Weather conference at IAS
1947 Transistor invented
1948 Charney joins the ECP
1950 March 5-April 6:NWP computations conducted on ENIAC
1951 IAS computer completed
1953 Watson & Crick publish structure of DNA
1955 October: ENIAC turned-off
1955 May: NWP becomes operational at the JNWP
1956 von Neumann diagnosed with pancreatic cancer
1957 von Neumann named AEC commissioner
1957 von Neumann expected to be named UC professor at large
1957 Feb. 8 von Neumann dies from pancreatic cancer
1958 IAS machine turned-off
1953 L.F. Richardson dies
1969 US sends astronauts to the moon
1990 Cold war ends with American victory
1991 LLNL cancels Cray-3 order
2000 Human genome sequenced.

APPENDIX

What follows is an appendix, giving a photographic record of the report of the 1946 IAS Meteorology meeting that was written by von Neumann. This conference was invitation-only, and the report of it has not been published.

Agenda for Conference on the Meteorological Computing Project, Institute for Advanced Study, Princeton, N.J.
August 29, 30, 31, 1946.

ATTENDANCE:

J. von Neumann
H. Wexler
B. Haurwitz
R. B. Montgomery
A. Cahn, Jr.
G. A. Hunt
C. L. Pekeris
W. M. Elsasser
Lt. Cmdr. D. F. Rex
C.-G. Rossby
J. Jaw
V. P. Starr
H. C. Willett
H. Panofsky
J. E. Miller
J. Namias
J. Charney

FIRST DAY - BACKGROUND
Dr. J. von Neumann, Chairman

1. Opening remarks and talk on capabilities of electronic computers--J. von Neumann.
2. O.R.I. interest--Lt. Cmdr. Rex.
3. Some comments on meteorological research--C.-G. Rossby.
4. Meteorological research from the viewpoint of the dynamic meteorologist--B. Haurwitz.
5. Meteorological research from the viewpoint of the synoptic meteorologist--H. Willett.
6. Meteorological research from the viewpoint of the weather forecaster--J. Namias.
7. The Richardson-Elliott approach to numerical forecasting--Albert Cahn, Jr.
8. General Discussion.

SECOND DAY - FORMULATION
Dr. C.-G. Rossby, Chairman

1. Formulation of the research program.

THIRD DAY - ORGANIZATION
Dr. J. von Neuman, Chairman

(Meeting of prospective members of the research group plus Dr. Rossby)

1. Organization of the research unit and preliminary allocation of research surveys and problems to individuals.

2. Housing - Dr. Herman H. Goldstine.

CONFERENCE ON METEOROLOGY
August 29-30, 1946

August 29th:

Attendance:

John von Neumann
Harry Wexler
B. Haurwitz
R. B. Montgomery
A. Cahn, Jr.
G. A. Hunt
C. L. Pekeris
W. M. Elsasser
Lt. Commander D. F. Rex
C. G. Rossby
J. Jaw
V. P. Starr
H. C. Willett
H. Panofsky
J. E. Miller
J. Namias
J. Charney
R. Elliot

Morning Session

Talk on high-speed numerical computing, its role in general and its possible uses in meteorology, by John von Neumann.

Afternoon Session

Statements by various participants: Chairman - John von Neumann

Lt. Commander Rex, ORI interest
C. G. Rossby, some comments on meteorological research
B. Haurwitz, meteorological research from the viewpoint of the dynamic meteorologist
H. Willett, meteorological research from the viewpoint of the synoptic meteorologist
J. Namias, meteorological research from the viewpoint of the weather forecaster
A. Cahn, Jr., The Richardson-Elliott approach to numerical forecasting.

General discussion.

Friday evening

Dinner at Princeton Inn. Present: Dr. Aydelotte, Dr. Zworykin, all participants except Commander Rex who had to return to Washington in the afternoon.

August 30:

Morning Session

Forty minute talk by Dr. T. W. Schumann from Capetown, South Africa (not scheduled). Short statements by various participants. General Discussion. Chairman, C. G. Ross

Afternoon Session

(Conclusion) Short statements by various participants. General discussion. Statement by John von Neumann on the character of the Institute's meteorological project and the advisory character of this conference. Formulation of tentative program and assignments (See below). Chairman: C. G. Rossby.

COPY

Tentative list of problems and assignments:

1. TYPE PROBLEMS: Various differential equations and partial differential equations, which are included because of their prototype character rather than because of their direct applications in meteorology. They are essential in testing the use of existing or planned high-speed computing machines and of the numerical techniques that require further development and that are likely to be important. For these problems, it is desirable but not absolutely necessary, that they should be in the field of meteorology or in adjacent fields. Some rather abstract problems were suggested by Dr. Charney. Dr. Pekeris suggested stability questions connected with turbulence. The first one of these is the Heisenberg-Lin equation of stability. This is a one-variable, linear, total differential equation proper-value problem, to be surveyed for various combinations of the parameter values. Later non-linear extensions might follow. It was decided to begin with the Heisenberg-Lin problem. Pekeris will take charge of it when he joins the project about November 1, 1946.

2. METEOROLOGICAL STABILITY PROBLEMS: These are linearized stability questions, similar to the Heisenberg-Lin problem, but superimposed on the typical meteorological flow conditions (and not, like the Heisenberg-Lin problem, on the Poiseuille flows). They are sometimes simpler and sometimes more difficutl than the Heisenberg-Lin problem. Haurwitz and Panofsky had ideas on such problems and are considering them.

3. GENERAL CIRCULATION: The problem of the significance of the stationary and zonally-symetric general circulation of the atmosphere came up several times during the conference and was extensively discussed. It was decided to make an effort to determine this circulation pattern. This problem was temporarily assigned to Panofsky.

4. TROPICAL HURRICANE THEORY: Haurwitz is interested in this theory, has already given thought to the problem, and is in possession of what seems to be adequate empirical material for a first approach. He will pursue this problem further.

5. DIAGNOSTIC USE OF COMPUTATION: Hunt suggested the analysis of the velocity, pressure, etc., distributions in some large, representative volume of air. (Say, fifteen hundred miles by one thousand miles on the ground and 30 thousand feet high. Possibly a smaller sample volume will have to be used for observational reasons.) He wishes to determine, by smoothing the data and calculating the residual which they may leave in the equations on motion, what are the non-directly-accounted-for forces; that is, what the eddy-viscosity or Reynolds-stress-tensor is. It is probably necessary to utilize, not the individual data thus obtained, but rather their correlation with the velocity, pressure, etc. data in the volume in question.

It was recognized that the problem was of paramount importance and was very difficult. In particular, it is likely to require a considerable extension of present observational procedures and the full numerical capacity of the planned machine. On the other hand, it seemed worth while to begin now with a preparatory consideration of the problem. Hunt was asked to give further attention to it.

6. FORECAST BY DIRECT INTEGRATION: The renewal of Richardson's effort by R. Elliot was discussed. It was felt that the numerical attack should be repeated immediately, since even the existing mechanical computing facilities have capacities considerably in excess of those that were available to Richardson or to Elliot. It seemed dubious whether the efforts to eliminate the flow velocities from the equations should be continued. That seemed to lead into considerable analytical difficulties and resulted in some rather questionable approximations, while the recent experiences of the New York University group indicate that the velocity observations are satisfactorily feasible. No immediate assignment was made.

Evening

Conference at the Princeton Inn between the members of the working group: Present - John von Neumann, Dr. H. Wexler, Captain G. Hunt, Dr. A. Cahn, Dr. B. Haurwitz, Dr. R. Montgomery, Dr. W. Elsasser, Dr. H. Panofsky.

MONTGOMERY is likely to be a part-time consultant. ELSASSER is occupied full time by his present responsibilities at RCA, but John von Neumann expects to consult with him at frequent intervals. The discussion of problems was continued and the assignments were partly revised and made specific.

CAHN will undertake to carry out problem No. 6 from start to finish. More specifically - a) He will formulate the dynamic equations to be used in the prediction, b) set them up for a numerical approximation method, c) familiarize himself with the working of the ENIAC and possibly also of the Harvard machine, d) supervise the actual integration. Cahn will consult with Montgomery, and also with Panofsky and Haurwitz on (a), with John von Neumann on (b), with von Neumann or Goldstine on (c). When (c) is reached, von Neumann will make efforts to obtain permission to use the ENIAC or the Harvard machine. Cahn will clearly require considerable assistance on (d), the details of which will be arranged concurrently with securing the use of the machines in question.

There was a discussion about where Cahn should be stationed. It was agreed that he would work for the project at Provincetown, Massachusetts, from September 1 to September 15. Hunt, Montgomery, Haurwitz and Panofsky are in the neighborhood and available. (From September 15 to October 1, he expects to take a vacation.) After October 1, he will be stationed in Washington or Princeton (at least during October), preferably in Washington, in order to be near Wexler and the empirical material available at the Weather Bureau.

MONTGOMERY, for the time being, will also give thought to the problem considered by Cahn. He expects to be able to visit Princeton a week or more in October. In order that proper arrangements may be made, he will discuss this matter with the Director of the Woods Hole Oceanographic Institution.

HUNT is stationed in Princeton until November 1st. After November 1st, he leaves the Army and will continue in Princeton at least part-time on the project. He may then join it full time; the decision is to be made then. He will be cooperating with Cahn as the need arises. He will also continue thinking about the problem concerning the diagnostic use of computation, both in its theoretical and observational aspects. However, the magnitude and the general importance of this problem make it appear inappropriate to assign it to any one member of the group. Hunt will give his main attention to the problem of general circulation.

PANOFSKY: It is intended to assure Panofsky's services for the group as completely as possible. Panofsky shares this desire. John von Neumann will discuss with Professor Spilhaus of New York University, and with Panofsky, the possibility of obtaining part of Panofsky's time and of achieving a coordination of the work in which he is interested between New York University and the Project.

HAURWITZ: In consideration of the difficult teaching situation at MIT, Haurwitz cannot yet commit himself about the precise plans. They will be clarified about October 1st. In any case he expects to join the project part-time beginning October 1st and probably full time for the three months beginning February 1st. He will stay in contact with the other members of the group and he will give his main attention to the Theory of the Tropical Hurricanes. He may also consider some meteorological stability problems which were discussed.

WEXLER will continue at the Weather Bureau until late Fall. As soon as housing in Princeton becomes available, he will move to Princeton and join the project at least half-time, and intends to spend the major part of the week in Princeton. Beginning October 1st, he will supervise the working group, especially where its work is located in Washington, and he will visit Princeton frequently to consult with John von Neumann. Adequate office facilities are likely to become available in November; at that time it is contemplated to make these visits quite frequent.

VON NEUMANN will be available in Princeton until sometime about September 13th. He will then be away, at Los Alamos, to return on October 1st. He will be continuously available and will participate in a normal manner beginning about October 1st. From that time, every effort will be made to concentrate the project at Princeton.

General: Beginning October 1st, meetings will be repeatedly held to discuss problems and to re-assess the situation. The timing of these meetings will, of course, depend on the development of the work. At any rate, there will be a meeting before October 10th to discuss the devleopments during September and to make plans for the immediate future.