

Jan Burgers and the University of Maryland

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1. Introduction

Johannes (Jan) Martinus Burgers was born in Arnhem in The Netherlands on January 13, 1895. He received his primary and secondary education in Arnhem from 1901 to 1912. To qualify for a university education he took supplementary courses in Latin and Greek from 1912 to 1914 and started studying advanced mathematics and subjects related to theoretical physics. From 1914 to 1918 Jan Burgers studied at the University of Leiden. An account of his environment at home and about his education can be found in a set of autobiographical notes [51]. Additional information about the interactions of Jan Burgers with his PhD advisor, Paul Ehrenfest, at the University of Leiden can be found in [52,53].

The potential of Jan Burgers as an outstanding scholar was recognized early and he started to work as a Professor of Aerodynamics and Hydrodynamics at the Technical University in Delft in 1918, two months before he received his PhD in the Physical and Mathematical Sciences from the University of Leiden under the supervision of Paul Ehrenfest. After an impressive career in fluid mechanics in The Netherlands, Jan Burgers became a Research Professor at the Institute for Fluid Dynamics and Applied Mathematics (IFDAM) of the University of Maryland in College Park, MD in 1955.

A considerable amount of information about Jan Burgers and his work can be found in a volume edited by F.T.M. Nieuwstadt and J.A. Steketee [54]. In addition to biographical information, this volume provides an assessment of his scholarly work and a large number of selected papers of Jan Burgers, all from the period when he was a Professor at the Technical University in Delft. The purpose of the present paper is to focus on the activities of Jan Burgers in the US in general and at the University of Maryland in particular.

2. Contacts with the US

Jan Burgers had an international outlook dating back already from his time at the University of Leiden under Ehrenfest. The early work of Burgers in fluid dynamics after his appointment in Delft received the attention of Theodore von Kármán, who had become a professor of mechanics and aerodynamics at the Technical University in Aachen, and who invited Burgers to visit him in Aachen in 1921. This meeting started a strong professional and personal friendship of Burgers with von Kármán, which continued after von Kármán went to the California Institute of Technology in Pasadena, CA in 1930 [55]. Within one or two decades the reputation of Burgers had already been recognized internationally. W.F. Durand, who had met Burgers in Aachen in 1929 at the opening of a new laboratory of von Kármán, considered von Kármán, Prandtl, Taylor and Burgers as the “big four” in aerodynamics at the time [54]. In a chapter on Taylor’s foreign peers in mechanics, G.K. Batchelor [56] wrote “It is generally accepted that there were three giants in mechanics during the first half of the century: Theodore von Kármán, Ludwig Prandtl, and G.I. Taylor. Another prominent contributor to research in various aspects of mechanics in the thirties was Johannes Burgers, a younger man.” John von Neumann in a 1949 review of recent theories in turbulence listed the work of J.M. Burgers and that of G.I Taylor, G.K. Batchelor, Th. von Kármán and L. Howarth as the most important statistically oriented modern theories of turbulence prior to World War II, with a later footnote about the importance of subsequent work of Burgers in 1950 [57].

The first visit of Burgers to the US occurred in early 1931. Durand had asked von Kármán and Burgers to contribute a volume in a series on Aerodynamic Theory [58] and had invited Burgers to visit Stanford University in Palo Alto for this purpose. Together with his wife, Jeannette (Nettie) Roosenschoon, Burgers spent four months in California including three weeks with von Kármán at Caltech. In 1938, Burgers, with his colleague, C.B. Biezeno, planned to attend the Vth International Congress of Applied Mechanics in Cambridge, MA. However, upon his arrival in Baltimore, Burgers received a telegram that his wife, Nettie Roosenschoon, was seriously ill and he had to return home immediately. Mrs. Burgers died of cancer on August 5 1939.

Contacts between Burgers and the US were interrupted during the Nazi occupation of The Netherlands from 1940 till 1945. After World War II, Burgers was invited in 1949 to participate in a dedication ceremony for the new supersonic wind tunnels at the Naval Ordnance Laboratory (NOL) in White Oak, MD and he also started to work as a consultant for NOL. It may be noted that at about the same time NOL was developing a close interaction with science in The Netherlands leading to the establishment of the

Institute for Molecular Physics at the University of Maryland under A. Michels from the University of Amsterdam in 1952 [59]. During a short visit to Caltech, Burgers accepted an invitation to spend six months at Caltech during the 1950-1951 academic year. For this purpose Burgers travelled to the US in 1950 with his second wife, Anna M. Verhoeven, who he had married in 1941. Prior to their arrival in Pasadena, Burgers first lectured at Cornell University, attended the International Congress of Mathematics in Cambridge, MA, participated in a Symposium on Plasticity at Brown University, attended a Symposium on the motion of the crust of the earth in Washington, DC, revisited NOL in White Oak, MD as a consultant, lectured at Brooklyn Polytechnic Institute and the Johns Hopkins University, went to Dayton OH for some business at the Central Air Documents Office concerning printing of the proceedings of a symposium on Cosmic Aerodynamics [13], lectured at Indiana State University, Iowa State University, and at the University of Utah, which illustrates how well known Burgers had become in the US. During his stay in Pasadena, Burgers not only worked at the Hydrodynamics Laboratory at Caltech, but also lectured at the Naval Ordnance Test Station in Inyokem, CA, at Stanford University, and at the University of California in Berkeley, CA.

After concluding his stay in Pasadena at the end of the 1951 spring semester, Burgers participated in the first US National Congress for Applied Mechanics in Chicago. It was at this congress that Burgers was approached about the possibility of coming to the University of Maryland. After the meeting in Chicago, Burgers gave some lectures at the University of Maryland. He concluded his 1950-1951 stay in the US with professional visits to Cornell University, the Johns Hopkins University, NASA at Langley Field, VA, and the National Bureau of Standards in Washington DC. Shortly after his return to The Netherlands, he received a formal offer for an appointment at the University of Maryland as a Visiting Research Professor in the Institute for Fluid Dynamics and Applied Mathematics (IFDAM) from its Acting Director, Raymond J. Seeger. IFDAM had been established in 1949 and, prior to his appointment as Acting Director, Seeger had been Chief of the Mechanics Division at NOL in White Oak, MD, while Zaka I. Slawski of NOL had served as the host of Burgers' visit to Maryland. This illustrates, as in the case of the appointment of A. Michels at the University of Maryland [59], that NOL had played a role in trying to get Burgers to join the University of Maryland. Burgers had become enthralled with the stimulating research atmosphere in the US and he gladly accepted. In view of the positive reaction of Burgers, he subsequently received an offer in May 1952 for a permanent position effective September 1, 1952 from Monroe H. Martin, the first Director of IFDAM, who also was a consultant at NOL.

3. Immigration problems

On October 25, 1951 Jan Burgers and his wife Anna applied for immigration visas at the American Consulate at Rotterdam but their applications were returned with a stamped message "Visa refused under authority of Immigration Act of 1924".

To understand the origin of the problem we need to go back to the time that Burgers was a young graduate student with Paul Ehrenfest in Leiden [52,53]. Ehrenfest, born in

Vienna, had married the Ukrainian and Russian educated Tatiana Afanasyeva. After working for some time in St. Petersburg, where the couple became friends with the physicist Abram Joffe, Ehrenfest had been appointed as professor of theoretical physics in Leiden in 1921. However, Ehrenfest continued to keep close contacts with Russia. After the Bolshevik revolution, Ehrenfest shared with some intellectuals at the time the hope that through socialism a new culture could be realized with a close harmony between science and society. This inspired some of the students in Leiden, like Dirk Struik, who later would become professor of mathematics at MIT, Jan Tinbergen, who later would win a Nobel Prize in economics, and Jan Burgers [60]. In 1918, the Communist Party of Holland (CPH) was formed and Burgers joined the group of intellectuals involved in this party. Around 1930, Burgers became disenchanted with the CPH because of the undemocratic Soviet influences, which had penetrated the CPH and he formally resigned as a member of the CPH in 1930 [55]. Prior to 1951, Burgers did not have any problems visiting the US earlier, simply because this issue had not arisen. In the words of Burgers in a statement dated August 4, 1952: "Since the circumstances, prevailing in the Communist Party in Holland in the period I was a member of it, were so different from what is now the case in the communist movement, I thought it to be most near the truth not to speak about opinions and interests which I have left behind me already for more than twenty years, long before the second world war broke out. I have never been a member of a communist party organized on modern lines and I have never been a member of any sympathizing organization." However, in the early 1950's, the US had entered the infamous McCarthy period and an explanation of the early affiliation of Burgers with the CPH could no longer be avoided.

The first sign of a potential problem had already occurred in July 1951. Burgers had received an invitation from the Aberdeen Proving Grounds in Maryland to visit the Ballistic Research Research Laboratories for the purpose of delivering a series of lectures on "Non-Uniform One-Dimensional Compressible Fluid Flow" on or about July 27 1951. However, when Burgers was about to go to Aberdeen, he received first a telephone message on July 24 and subsequently a written statement, dated 27 July 1951, with the information that he was not allowed to visit the Ballistic Research Laboratories due to circumstances which could not be revealed. Upon an inquiry of Burgers, the Embassy of the Netherlands in Washington DC subsequently informed Burgers in August 1951 that he had indeed originally received clearance to visit the Aberdeen Proving Grounds but that permission had suddenly been withdrawn. Actually, prior to his trip to the US in 1950, when he needed to get clearance to visit NOL, Burgers had to submit a form concerning his personal history, which was more specific than he had to fill out in earlier years. He responded by sending Raymond J. Seeger, who at that time was still Chief of the Mechanics Division at NOL, a confidential statement about his affiliation with the CPH during 1919-1930 and his early visits to the USSR to be given to the Security Officer of NOL if needed or otherwise to be disregarded.

As Secretary of the Committee on Science and its Social Relations of the International Council of Scientific Unions, Burgers had been interacting with John Desmond Bernal as President of this committee, who was a Marxist and pro-Soviet sympathizer [61]. Bernal had even visited Burgers in his home in Delft in 1938. However, there is no evidence that

his interactions with Bernal played a role in the denial of his visa application. On the other hand, a serious problem appeared to be that his fellow student and friend, Dirk Struik, had been suspended from teaching at MIT in 1950 because he had been accused of being a Soviet spy (a suspension which would last till 1956). Burgers and his wife had visited Struik during the International Congress of Mathematics in Cambridge, MA in 1950. It is rumored that the FBI had a picture of Burgers with Struik from this visit [62]. Another potential problem was that Burgers had written in 1950 a sympathetic letter to Edward M. Corson, who had criticized in *Physics Today* the arrest of Klaus Fuchs of the Harwell Atomic Energy Research Establishment in the UK [63]. After having published that letter, Corson had lost his professorship, his position as Atomic Energy Consultant, and was no longer allowed to work or teach anywhere in the US.

In a letter, dated 15 December 1951, Burgers notified Raymond Seeger in his capacity of Acting Director of IFDAM that his request for an immigration visa had been denied. In response Monroe H. Martin, who had become Director of IFDAM and Nathan L. Drake, Head of the Department of Chemistry and who had also become Director of the newly established Institute for Molecular Physics [59], embarked on a campaign to resolve the visa problem. Monroe Martin also invoked the help of Th. von Kármán, as well as of some other scientists. In addition, George W. Fogg, Director of Personnel at the University of Maryland sent a formal request to the American Consulate in Rotterdam to issue Burgers a visa under the Exchange Program No. P-793 in June 1952. The Consulate responded that the invitation under this Exchange Program was not materially different from the invitation offered to Burgers in September 1951. On July 23 1952, Monroe Martin wrote to Burgers: “It is my considered judgment that if you can establish and document your resignation from the Communist party years ago and that since that time your convictions and actions demonstrate your sincere belief in the democratic ideals as exemplified by the United Nations, your visit will be granted. A straightforward statement of your political beliefs as a young student, the reasons for your change in conviction, and a convincing demonstration of your belief in the ideals of this country since that time will go a long way, in my estimation, towards convincing our authorities that your request for a visa should be granted.” Following this advice, Burgers prepared a “Statement concerning my political opinions”. In this statement he described his early intellectual interest in the CPH, how he became disenchanted with the CPH leading to his formal resignation as a member 1933. In addition he gave an account of his visits to the USSR in 1926, 1929, 1930, and 1936 and his visits to the US starting in 1931 and his subsequent visits to the US after World War II. He expressed how he and his wife had been impressed with the great friendship, hospitality, and courtesy experienced in the US resulting in their desire to come to the US. He presented this statement in person at the American Consulate in Rotterdam on August 5 1952. In addition, he supplied written testimonies concerning his democratic attitude from A.J. Kluyver, President of the Royal Netherlands Academy of Sciences and a Foreign Associate of the US National Academy of Sciences, from O. Bottema, Rector Magnificus of the Technical University Delft, and from H.R. Kruyt, President of the Netherlands Organization of Applied Scientific Research. The verbal response he received was not encouraging, although a promise was given that the documents would be sent to the State Department in Washington. Subsequently, in a letter, dated October 17 1952, Monroe Martin informed Burgers that

all attempts of the University of Maryland to secure a visa for him had failed. Burgers responded with a lengthy letter, dated October 24 1952, in which he expressed his great disappointment of not being able to join the University of Maryland. In a follow-up letter of January 30 1953, Monroe Martin wrote: "I have now had an opportunity to consult with a number of people in a position to advise us of the chance for success of any plan to bring you into this country as Research Professor in the Institute. From all sides I gain the understanding that, under the new Immigration Act, this will be even more difficult than before [65]. Certainly under present conditions it is not possible to set a date when we might initiate proceedings with some hope of eventual success."

Thus started a difficult period in the life of Burgers. He had already told his colleagues in Delft that he was about to leave for the University of Maryland and had already paid 2/3 of the price for his passage to the US on a ship of the Holland-America line. Burgers tried to address his situation in correspondence with several well known scientists, including Th. von Kármán, S.A. Goudsmit at Brookhaven National Laboratory, B.J. Bok at the Harvard College Observatory, Michael Polyani at the University of Manchester, S. Goldstein at the Institute of Technology in Haifa, Edward A. Shills, Editor of the Bulletin of Atomic Scientists. Actually, Burgers was one among many other foreign scientists who were not being able to visit the US at the time. The situation had become so bad, that the Bulletin of the Atomic Scientists published a special issue on the visa problems for scientists with testimony of eminent American scientists on American visa policy, including Albert Einstein, Hans A. Bethe, Harold C. Urey, James Frank, Samuel Goudsmit, Cyril S. Smith, Arthur H. Compton, William P. Murphy, Victor Weisskopf [64]. In addition, Allan T. Waterman, Director of the National Science Foundation, and Howard A. Meyerhoff, Administrative Secretary of the American Association for the Advancement of Science, submitted statements at a hearing of the Commission on Immigration and Naturalization of Congress under the titles "Some thoughts on International Scientific Communication" and "Scientists and the Visa Problem", respectively [65,66]. Monroe Martin had informed Meyerhoff about the visa problem of Burgers and an appeal to give adequate consideration to foreign scientists who had their membership renounced "when full comprehension of the implications of Communism was acquired" was included in the testimony of Meyerhoff.

In 1953 Burgers tried to get help from A. Michels, a colleague at the University of Amsterdam. Michels had founded the Institute of Molecular Physics at the University of Maryland and commuted between Amsterdam and the University of Maryland on a regular basis without any visa problems [59]. On a somewhat encouraging note, Michels informed Burgers confidentially, after his return from the University of Maryland in October 1953, that the visa problem was being reconsidered. Actually, Zaka Slawski of NOL had continued to try to get the visa problem resolved. And indeed, on January 30 1954, Burgers received an invitation from the American Consulate in Rotterdam for a discussion of his visa application with the vice consul Frank M. Wyle. In the interview on February 1 1954, Mr. Wyle informed Burgers that the only possibility for solving the visa problem would be for Burgers to submit a detailed statement what he had done after his resignation from the CPH in opposition to communist principles. In response Burgers prepared a "Statement concerning the development of my political opinions" in March

1954 that was submitted to the American Consulate. This comprehensive statement, prepared by Burgers in support of his visa application, is a fascinating document elucidating the evolution of his ideas about science and society and his personal struggle to reconcile these two aspects in his personal life. A copy of this statement is contained in a previous report [55]. Nevertheless, no positive decision seemed to be imminent. It appears that the statement of March 1954 had not sufficiently resolved to what extent Burgers had opposed communism after his resignation as a member of the CPH. Hence, Burgers submitted to the American Consulate in February 1955 an addition to his 1954 statement concerning the development of his political opinion. When one reads these statements one is impressed with the openness, honesty, and personal integrity of Burgers. This latter statement appeared to resolve any remaining issues and in June 1955 Burgers received word from both Zaka Slawski of NOL and from the American Consulate in Rotterdam that a visa would be granted. Thus a long tortuous path had come to a happy ending. Burgers was relieved from his position as Professor at the Technical University in Delft effective November 1, 1955 and gave his farewell address on November 2, 1955, reflecting on his research in hydrodynamics in Delft since 1918. Two days later Burgers and his wife left for the US, where Burgers joined the Institute for Fluid Dynamics and Applied Mathematics at the University of Maryland as a Research Professor.

One may wonder why Burgers desired to go to the US sufficiently strongly so as to put up with many roadblocks. First, as mentioned in Section 2, from his travels to the US Burgers had been impressed with the dynamic research culture in the US, Second, it seems that Burgers had found the small-town atmosphere in the city of Delft intellectually a bit confining. Third, after many years of administrative duties in Delft, he probably was longing to return to full-time research. Finally, he may have experienced this opportunity to embark on a new life with his second wife Anne Verhoeven. And indeed, as described in the remembrances of his son Herman Burgers presented in Appendix IV, the move to the US has turned out to be beneficial for the personal well-being of Jan Burgers.

4. Burgers at the University of Maryland (1955-1981)

Burgers found a vibrant research climate with people like Shih-I Pai, Elliott W. Montroll, and many other prominent scientists in fluid mechanics, applied mathematics, and statistical physics during his years at the University of Maryland, where he felt at home immediately. For instance, in his speech, given at a Symposium held in 1965 in his honor [67], Burgers remarked: “The way in which we were received at the University of Maryland surpassed anything which we could have imagined when we came to America with the hope of settling here. We felt at home immediately and a deep love for this country has grown in us. The friendship one can find in United States and in particular in its scientific circles is a source of everlasting joy, which pervades all phases of one’s life and one’s work.” And “You will know how great an honor it has been for me to be a part of the University of Maryland ever since I came here, and although I have seen several other universities in this country, I have never felt the desire to move away from Maryland”.

Early after his arrival in College Park, Jan Burgers was visited by his brother Willy (1897-1988) with whom he had been collaborating on dislocations in crystal lattices leading to the concept of Burgers vector [4] (Figure 1).

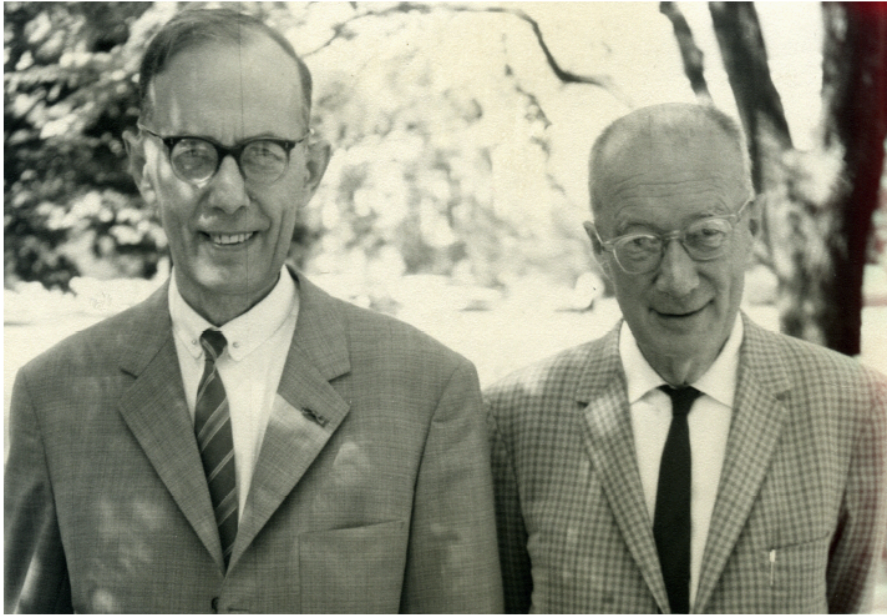


Figure 1: Willy Burgers (left) with his brother Jan (right) in College Park.

At the University of Maryland, Burgers embarked on a very productive second research career. A list of his publications from the University of Maryland is presented in Appendix II [1-50]. A characteristic feature of these publications is that they were almost all singly authored by Burgers. This does not mean that Burgers did not have graduate students and collaborators at the University of Maryland, but Burgers preferred that his students would publish their work independently.

The personal inclination of Burgers was towards research of a theoretical nature. However, Burgers also supervised PhD research in experimental fluid mechanics. First he resumed his interactions with NOL and his first student was Jacob Pomerantz, whose PhD dissertation was based on experimental work he was pursuing at NOL [68]. In addition Burgers did inherit a laboratory for experimental shock-wave research from Edward L. Resler, Jr. [69], who was leaving for Cornell University at about the time Burgers arrived at the University of Maryland. (Figure 2). Burgers organized an

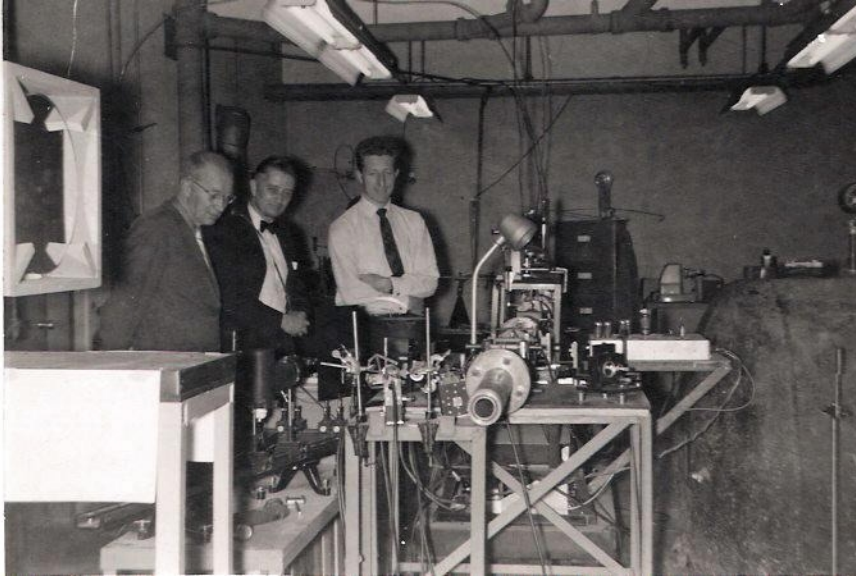


Figure 2: Laboratory of Jan Burgers in the Physics Building at the University of Maryland in 1959. From left to right: Jan Burgers, Ir. Ruys (a previous student of Burgers visiting from The Netherlands), and Tobias de Boer.

experimental research group consisting of graduate students Murray Scheibe, John P. Barach, Wim J. Witteman, P.C.T. (Tobias) de Boer, a postdoctoral research associate Jerome Daen, and a master student Andrew T. Mazzella. Murray Scheibe, a graduate student inherited from Resler [69], left after his PhD to pursue a scientific career in California. Barach had an undergraduate degree from Princeton University and became after his PhD at the University of Maryland in 1961 a professor of physics at Vanderbilt University. Witteman and de Boer were students attracted from The Netherlands. Witteman [70-72] was an exchange student with the Technical University Delft, who after leaving the University of Maryland went to the Philips Research Laboratories in The Netherlands; since 1969 he has been a professor in applied physics at the Technical University of Twente working on high-power laser systems. De Boer [23,73-75], after his PhD at the University of Maryland in 1962, became professor of mechanical and aerospace engineering at Cornell University. Mazzella was a master student who did experimental work in the research group of Burgers under the supervision of de Boer [76]. Daen [77] had been a postdoc with Peter Debye at Cornell University before becoming a postdoc with Burgers, and eventually became an administrator at the US National Science Foundation. Burgers also had a Swiss student in the laboratory, Albert Haberstick, who received his PhD in 1964 on “Experimental and Theoretical Study of an Ionizing Potential Wave in a Discharged Tube” and who became a scientist at the Los Alamos National Laboratory. Burgers must also have had some PhD students in theoretical fluid mechanics, but this information is not easily accessible from the records at the University of Maryland.

Besides supervising graduate students, Burgers was very active in pursuing research himself. At the time it was customary to publish research results as Technical Reports. The reason was that most of the research in fluid mechanics was supported by the US Air

Force Office of Scientific Research, which expected Technical Reports. In Maryland, Burgers became one of the first to specialize in new fields related to hypersonic hydrodynamics, *i.e.*, on high-speed and high-temperature flow problems [2-6,11,15].

He applied the basic equations of magneto-gasdynamics to the penetration of an originally plane shock wave through a homogeneous gas possessing a high electric conductivity, and originally at rest, in the presence of a magnetic dipole field. First he assumed that the magnetic field is affected by the motion of the gas, and that the shock wave and the motion of the gas are unaffected by the magnetic field. Thereafter the effect of the field on the motion of the gas was treated [7,8].

Calculations were made by Burgers concerning the momentum that can be given to a jet of water by mixing it with a jet of high-speed steam. Apart from an application of the equations of momentum and enthalpy, this raised questions concerning the speed of condensation and the acceleration of the water [10].

Burgers presented an extended form of the Boltzmann equation for the effect of collisions upon the distribution function, in which account is taken of chemical reactions that may result from collisions and of spontaneous processes. In order to prevent the scheme from becoming too complicated, a number of assumptions had to be introduced. He elucidated the various terms that must be included on the right-hand side of the Boltzmann equation [20].

In his book 'Flow equations for composite gases' Burgers developed complete sets of flow equations for composite gases, including those giving the components of heat flow and the pressure tensor. Attention was given to both the single-and multi-fluid pictures. Topics treated included the Bhatnagar-Gross-Krook and Fokker-Planck approximations, charged particles in electric and magnetic fields, and the effects of chemical reactions and of radiation. Separate treatment of the left and right sides of the Boltzmann equation facilitated discussion of various collision problems, cross-section cutoff effect with two-particle distribution functions, the standard Maxwell-Boltzmann collision integral, and other topics [38].

Burgers paid much attention to the study of statistical plasma physics. He used, for instance, an approximate, linearized equation for the pair correlation function, containing a Debye potential instead of the Coulomb potential, to derive by direct integration a solution for the pair correlation function for the case of long wavelength plasma oscillations in a fully ionized gas without a magnetic field. The correlation was then applied to describe the effect of collisions in a linearized Boltzmann equation for the single-particle distribution function [17, 24].

Burgers also continued his work on statistical physics of turbulence [32,40,43] leading to the publication of his book "The Nonlinear Diffusion Equation," in 1972 [46]. The Burgers equation has turned out to be too simple for turbulence, but the model has been successful in other areas of science [54]. The book was reprinted on the occasion of an Inaugural Symposium of the Burgers Program for Fluid Dynamics at the University of Maryland in 2004. Inspired by the intellectual heritage of J.M. Burgers, the mission of

this Burgers Program is to enhance the quality and international visibility of the research and educational programs in fluid dynamics and related areas at the University of Maryland. The Burgers program for Fluid Dynamics at the University of Maryland has established a close collaboration with the J.M. Burgerscentrum in The Netherlands [55,78,79].

In addition to scientific work in fluid mechanics, Burgers was also interested in social subjects [34], in the foundations of quantum mechanics [27,31,37], in the philosophy of science [31,48-50], in the emergence of order and the origin of life [26,35,39,41]. Von Neumann's finding that the outcome of a measuring process is independent of the measuring apparatus effect was examined by Burgers in terms of quantum theory by using two methods for calculating the outcome of an interaction of a system of particles with the measuring process. He found the two results obtained to be equivalent [27]. Burgers discussed the problem whether an explanation of the phenomena of life can be deduced from an exclusive reliance on causal relationship as a (at that time) accepted physical description, or whether attention should be given to something more. For this more, the concept of anticipation was taken. Starting from what is observed in our own minds various notions involved in the idea of anticipation were brought forward [39]. His reflections were based on the philosophy of A. N. Whitehead, whose ideas he tried to develop in his own book "Experience and Conceptual Activity", published in 1965 [33]. However, he was rather disappointed with the general lack of interest in this book. Burgers also raised the question whether all forms of order observed in nature can be explained as results of the laws of physics. He proposed that, to explain the emergence of organization in the living world, we must introduce a principle that constitutes a relationship to an impending future [26, 35, 41].

At the University of Maryland Burgers showed himself as an impressive and eclectic scholar, highly appreciated by his colleagues. The research accomplishments of Burgers were celebrated in a Symposium on Dynamics of Fluids and Plasmas on the occasion of his retirement as Research Professor in 1965 [67]. However, he remained professionally active for another decade as Research Professor Emeritus [35-50]. Burgers died on June 7 1981, and his wife, Anna, died on November 4 1983.

A J.M. Burgers Centenary Symposium was held at the University of Maryland on May 4 1995 with a keynote lecture of F.T.N. Nieuwstadt from the J.M. Burgerscentrum in The Netherlands on *The Legacy of J.M. Burgers*.

5. A note about the children of Burgers

Jan Burgers had three children, a daughter Anneke Burgers (1920-1966), a son Herman Burgers (born in 1926) and a second daughter Marion Burgers (1932-1997). Anneke became a practicing nurse in The Netherlands and in Switzerland and eventually became a teacher in nursing in Rotterdam. Marion became one of The Netherlands' most prominent radiation oncologists and an international ambassador for excellence in care [80]. J. Herman Burgers studied law at the University of Amsterdam and political science at Stanford University (Figure 3). He had a career in the Department of Foreign Affairs of

The Netherlands. He inherited from his father a passion for human rights and was actively involved in international human rights activities [81].



Figure 3: Herman Burgers (left) in his home in The Hague with Jan Sengers in 2014.

All three children had been familiar with Anna Verhoeven before her marriage with Jan Burgers as “Aunt Annie” and she remained for the children of Burgers for them “Aunt Annie” throughout their lives. For the purpose of this article, it is interesting to note that Anneke and Marion were the first two children to visit their father in the US after he had joined the University of Maryland. They came back with the impression that their father seemed very anxious since he felt he had to demonstrate his competence as a scientist all over again.

When the death of Jan Burgers appeared to be imminent, his son Herman wrote a text about his memories of his father in the expectation that he would have an opportunity to speak at the funeral. Unfortunately, it turned out that he did not have an opportunity to read his text at the funeral, Herman has given us permission to reproduce his memories in Appendix IV, so as to preserve his tribute to his father for posterity.

Acknowledgements

The authors thank Herman Burgers for many valuable discussions and for providing us with the file of Jan Burgers related to his immigration to the US. The authors thank Tobias de Boer of Cornell University, Robert Dorfman of the University of Maryland, and Wim Witteman of the Technical University Twente for sharing their recollections of Burgers. The authors thank the staff of the Special Collections and University Archives of the University of Maryland for helping with accessing historical documents.

Appendix I: Johannes Martinus (Jan) Burgers (1895-1981)

Biographical data

Born in Arnhem (The Netherlands), January 13, 1895. Parents: Johannes M. Burgers and Johanna H. Burgers - Romyn. One brother: Dr. Wilhelm G. (Willy) Burgers.

Married on July 30, 1919 with Jeanette D. Roosenschoon (deceased August 5, 1939); three children: Anna Charlotte, Jan Herman, Jeanette Marion Veronica. Married again on August 20, 1941 with Anna Margretha Verhoeven.

Education

Primary and secondary schools in Arnhem, 1901-1912; supplementary courses in Latin and Greek, 1912-1914, together with studies of advanced mathematics and topics in theoretical physics.

University education at the University of Leiden, 1914-1918: physics from P. Ehrenfest, J.P. Kuenen, and W. van der Woude; astronomy from E.F. van de Sande Bakhuyzen and W. de Sitter; geology from K. Martin. Candidate 22 May 1915; doctorandus 1 December 1917, PhD 12 December 1918 on a thesis “Het Atoommodel van Rutherford-Bohr” with P. Ehrenfest as thesis advisor.

Honors and awards

Elected Member of the Royal Netherlands Academy of Sciences	1931
Honorary Doctors degree, Université Libre de Bruxelles, Belgium	1948
Honorary Doctors degree, Université de Poitiers, France	1950
Ridder (Knight) in de Orde van de Nederlandse Leeuw	1955
Josiah Willard Gibbs Lecturer, American Mathematical Society	1959
Modesto Panetti Medal, Accademia delle Scienze di Torino, Italy	1961
Foreign Member, Accademia delle Scienze di Torino, Italy	1964
Bingham Medal, Society of Rheology	1964
ASME Medal, American Society of Mechanical Engineers	1965
Annual Award for Scientific Achievement, Society of Sigma Xi	1966

Positions

Assistant, Cryogenic Laboratory, University of Leiden	1916-1917
Conservator, Physical Laboratory of Teyler's Foundation, Haarlem	1918
Professor of Aerodynamics and Hydrodynamics, Department of Mechanical Engineering and Shipbuilding, Technical University Delft	1918-1955
Secretary, Department of Mechanical Engineering and Shipbuilding, Technical University Delft	1921-1924

Chairman, Department of Mechanical Engineering and Shipbuilding, Technical University Delft 1929-1931
 Research Professor, Institute for Fluid Dynamics and Applied Mathematics (IFDAM), University of Maryland, College Park, MD 1955-1965
 Research Professor Emeritus, Institute for Fluid Dynamics and Applied Mathematics (IFDAM), University of Maryland, College Park, MD 1965-1976
 Research Professor Emeritus, Institute for Physical Science and Technology (IPST), University of Maryland, College Park, MD 1976-1981

Professional activities

President Netherlands Physical Society (NNV) 1922-1923
 Secretary Committee for International Scientific Cooperation, Royal Netherlands Academy of Sciences 1934-1947
 Delegate to the meetings of the International Council of Scientific Unions in 1934 (Brussels), 1937 (London), 1946 (London), 1949 (Copenhagen), 1952 (Amsterdam), 1955 (Oslo), 1958 (Washington DC)
 Vice-President, Section of Physical Sciences, Royal Netherlands Academy of Sciences 1947-1950
 Secretary, Committee for the Study of Viscosity and Plasticity, Royal Netherlands Academy of Sciences 1934-1950
 Chairman, Committee for the Study of Viscosity and Plasticity, Royal Netherlands Academy of Sciences 1950-1954
 Organizer, 1st International Congress for Applied Mechanics, Delft 1924
 Member, International Committee for the Congresses for Applied Mechanics 1924-1946
 Founder of the International Union of Theoretical and Applied Mechanics 1946
 General Secretary, International Union of Theoretical and Applied Mechanics 1946-1952
 Secretary, Committee on Science and its Social relations, International Council of Scientific Unions 1937-1952
 Secretary, Joint Commission on Viscosity and Plasticity, International Council of Scientific Unions 1947-1952
 Co-organizer of International Congresses on Rheology in 1948 (Scheveningen) and in 1953 (Oxford)
 Victor Emanuel Distinguished Visiting Professor, Cornell University 1965

Professional societies

Koninklijk Instituut van Ingenieurs
 American Institute of Aeronautics and Astronautics (Fellow)
 American Institute of Physics (Fellow)
 American Geophysical Union
 Philosophical Society of Washington
 American Academy of Arts and Sciences
 New York Academy of Sciences (Fellow)

Appendix II: Publications of Burgers at the University of Maryland

1. The Effect of Stretching of a Vortex Core, Technical Note BN-80, IFDAM, University of Maryland, College Park, MD, 1956, 22pp.
2. Selected Topics from the Theory of Gas Flow at High Temperatures (I), Technical Note BN-83, IFDAM, University of Maryland, College Park, MD, 1956, 63pp.
3. Selected Topics from the Theory of Gas Flow at High Temperatures (II), Technical Note BN-84, IFDAM, University of Maryland, College Park, MD, 1956, 51pp.
4. Dislocations in Crystal Lattices (with W.G. Burgers), in: *Rheology I*, F.R. Eirich, ed., Academic Press, New York, 1956, Ch. 6, pp. 141-199.
5. On Steady Flow Patterns Appearing when a Sink is Combined with Boundary Layer Flow, Technical Note BN-91, Appendix I, IFDAM, University of Maryland, College Park, MD, 1957, 14pp.
6. Selected Topics from the Theory of Gas Flow at High Temperatures (III), Technical Note BN-99, IFDAM, University of Maryland, College Park, MD, 1957, 65pp.
7. The Penetration of a Shock Wave into a Magnetic Field, Technical Note BN-102, IFDAM, University of Maryland, College Park, MD, 1957, 84pp.
8. Selected Topics from the Theory of Gas Flow at High Temperatures (IV), Technical Note BN-103, IFDAM, University of Maryland, College Park, MD, 1957, 26pp.
9. Penetration of a Shock Wave into a Magnetic Field, in: *Magnetohydrodynamics*, R.K.M. Landshoff, ed., Stanford University Press, Stanford, CA, 1957, pp. 36-56.
10. On the Application of Steam Driven Water Jets for Propulsion Purposes (with A. Ghaffari), *J. Research National Bureau of Standards* **60**, 1958, pp. 137-141.
11. Selected Topics from the Theory of Gas Flow at High Temperatures (V), The Application of Transfer Equations to the Calculation of Diffusion, Heat Conduction, Viscosity and Electric Conductivity, Technical Notes BN-124a and BN-124b, IFDAM, University of Maryland, College Park, MD, 1958, 125pp.
12. On the Problem of the Postglacial Uplift of Fennoscandia I (with B.J. Collette), *Proc. Roy. Neth. Acad. Sci., Ser. B* **61**, 1958, pp. 221-241.
13. Proceedings of the Third Symposium on Cosmical Gas Dynamics, J.M. Burgers and R.N. Thomas, eds., *Rev. Mod. Phys.* **30**(3), 1958, pp. 905-1108.
14. Magnetohydrodynamics, by T.G. Cowling. New York: Interscience Publishers, Inc., 115 pp., *J. Fluid Mechanics* **3**, 1958, pp. 550-552.

15. Selected Topics from the Theory of Gas Flow at High Temperatures (VI), Some Aspects of Particle Interaction in Gases, Technical Note BN-176, IFDAM, University of Maryland, College Park, MD, 1959, 40pp.
16. Some Problems of Magneto-Gasdynamics, in: *Lectures on Fluid Mechanics*, S. Goldstein, ed., Interscience, New York, 1960, pp. 271-299.
17. Statistical Plasma Mechanics, in: *Plasma Dynamics*, F.H. Clauser, ed., Addison-Wesley, Reading, MA, 1960, Ch. 5, 1960, pp. 119-186.
18. Magnetogasdynamics Problems from the Point of View of Particle Dynamics, in: *Aeronautics and Astronautics*, N.J. Hoff and W.G. Vincenti, eds., Pergamon Press, Oxford, 1960, pp. 288-304.
19. Motion of a Completely Ionized Gas across a Magnetic Field in the Presence of an Electric Force, *Rev. Mod. Phys.* **32**, 1960, pp. 868-880.
20. The Boltzmann equation for flows with Chemical reactions, in: *Physical Chemistry in Aerodynamics and Space Flight*, A.L. Myerson and A.C. Harrison, eds., Pergamon Press, Oxford, 1961, pp. 4-11.
21. A Functional Equation Related to the Boltzmann Equation and to the Equations of Gas Dynamics, in: *Partial Differential Equations and Continuum Mechanics*, R.E. Langer, ed., University of Wisconsin Press, Madison, WI, 1961, pp. 289-317.
22. On the Application of Two-Particle Distribution Functions, Technical Note BN-243, IFDAM, University of Maryland, College Park, MD, 1961, 29pp.
23. Considerations on the Optics of the Integrating Schlieren Instrument (with P.C.T. de Boer), Technical Note BN-258, IFDAM, University of Maryland, College Park, MD, 1961, 72pp.
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29. Statistical Problems Connected with the Solution of a Non-linear Partial Differential Equation, in: *Proceedings Advanced Seminar on Non-linear Problems of Engineering*, W.F. Ames, ed., Academic Press, New York, 1964, pp. 123-137.
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33. *Experience and Conceptual Activity, A Philosophical Essay based upon the Writings of A.N. Whitehead* (book), MIT Press, Cambridge, MA, 1965, 277pp.
34. Curiosity and Play, *Science* **154**, 1966, pp. 1680-1681.
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36. Early Developments of Hot-Wire Anemometry in the Netherlands, in: *Advances in Hot-wire Anemometry*, W.L. Melnik and J.R. Weske, eds., University of Maryland, College Park, MD, 1968, pp. 25-28.
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38. *Flow Equations for Composite Gases* (book), Academic Press, New York, 1969, 332pp.
39. Reflections on the Concept of Life, paper P-4127, Rand Corporation, Santa Monica, CA, 1969.
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41. Causality and Anticipation and their Meaning for Biology, *Proc. Roy. Neth. Acad. Sci. Ser. B* **75**, 1972, pp. 375-384.
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44. Summation of Series of Fractions depending upon the Roots of the Airy Function, in: *For Dirk Struik: Scientific, Historical and Political Essays in Honor of Dirk J. Struik* (Boston Studies in the Philosophy and History of Science), R.S. Cohen, J.J. Stachel, and M.W. Wartofsky, eds., D. Reidel Publ., Dordrecht, 1974, pp. 15-19.
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Appendix IV: Remembering Jan Burgers by J. Herman Burgers

Jan Burgers stood out by the exceptional force of his personality, in at least three respects: by the power of his intellect, the intensity of his feelings, and the strength of his will and energy. If I should characterize him in one expression, I would call him a passionate man; He was also a man of robust physical health, until those very last years when an insidious disease step-by-step demolished his mind and body.

When I say that he was an exceptional person, I should add immediately that he was the son of exceptional parents. His father had only had elementary schooling and worked as a clerk at the railway post office, but he was a man who already in his young years had developed a fascination for the natural sciences and who had acquired a vast knowledge

of physics, astronomy, geology, and so on, by sheer self-education. In the provincial town where he lived, he gave lectures year after year on such subjects as magnetism, electricity, optics and astronomy, for audiences of like-minded admirers of the miracles of science. He also assembled in the course of his life an enormous collection of microscopes, physical instruments and many kinds of curiosities, gradually transforming his house into a museum.

Such was the home in which Jan Burgers grew up, together with his brother, Willy Burgers, and several foster-brothers. His intellectual brilliance was recognized in his high-school years, and so it was decided that he should go to college. Having finished high school he had first to learn Latin and Greek, since this was at the time still a requirement for admission to a university. In 1914, nineteen years old, he started his academic studies at the University of Leiden.

There he had the luck of becoming the pupil of a unique teacher, Paul Ehrenfest, an Austrian who had been appointed professor of physics at Leiden in 1912. Ehrenfest was a bosom friend of Albert Einstein and knew many other European scientists; he was thoroughly acquainted with all the latest developments in physics. Under his stimulating guidance, Jan Burgers completed his university studies in three and a half years. His productivity during these few years was remarkable. Besides doing research that resulted in articles that were published in leading European journals of physics, he wrote a fundamental treatise on the then brand-new theory of Ernest Rutherford and Niels Bohr concerning the structure of the atom. The University accepted this treatise as a doctor's dissertation and awarded him the doctor's degree in November 1918.

Even before that, the Technical University in Delft had taken an unusual step and appointed Jan Burgers, 23 years old, as a full professor to do teaching and research in aerodynamics and hydrodynamics. This was one of the few fields of physics to which my father had hardly given any attention during his student years so he had to acquaint himself quickly with the subject before starting his teaching. Soon afterwards, he found his principal mentor in the science of aerodynamics in Theodore von Kármán, a Hungarian, who was at that time professor in Germany and who after the Second World War became the scientific adviser of the United States Air Force. Jan Burgers and von Kármán became close friends. We can safely assume that the three people who have had the strongest influence on the development of Jan Burgers as a scientist were his own father, professor Ehrenfest, and professor von Kármán.

I shall not go further into Jan Burgers' performance as a scholar of fluid dynamics and applied mathematics, since I am not a scientist myself and, therefore, absolutely incompetent to appraise his merits in that field. But I would like to mention that his scientific interest extended to much more than just his professional field. He was by nature not a specialist but a universalist, and he kept abreast of developments in many fields of modern science. He always had an absorbing interest in its most fundamental problems, such as the structure of the atom and the structure of the universe, quantum physics, relativity, causality, finality, and the origin of life. One problem that fascinated him in particular was that of the relationships and contrasts between the phenomena of

life and the phenomena of physics. He felt a need for an encompassing philosophical vision in which those two sets of phenomena would be brought together.

In his forties he became familiar of the American scientist and philosopher Alfred Whitehead, and he became convinced that those ideas came closest to solving the mystery that obsessed him. Ever since, his ambition was to develop Whitehead's ideas into a coherent and comprehensive view of the world. This resulted in several writings and eventually in his book on *Experience and Conceptual Activity*, which was published in 1965, when he was seventy years old. The lack of response met by these writings must have been one of the gravest disappointments in his life.

From his childhood Jan Burgers had a profound belief in the value of the scientific quest for knowledge. But the urge to know and to understand was only one side of his personality; there also was the emotional and artistic side. Those who have known him intimately are aware that he was a man of strong emotions. Music was one of his principal emotional outlets. In his musical tastes he was a typical romanticist, as he was in his tastes for novels and short stories. This side of his character also inspired his interest in the visual arts, as well as his intense love of nature. He was fond of walking and hiking, all by himself, in lonely landscapes; and he was a prolific maker of sketches and drawings, in particular of flowers, trees and mountains.

Jan Burgers had an astonishing energy. His scientific productivity was impressive, from his first book that appeared when he was 23, up to his last book, which he published when he was 80. There was something intense and passionate in many things he undertook. For instance, when at some time he took an interest in seaweeds, he accumulated within a few years a huge collection of seaweeds, each of them neatly dried and pressed on cardboard. All his life he was a passionate collector of stones and minerals, and he meticulously registered each piece with its name and the time and the place where he had found it. In general, keeping accurate records was one outlet for his unremitting activism. He made precise notes during all his major travels and he was for many years an enthusiastic photographer. Later on, this was superseded by an enthusiasm for drawing. It is simply incredible how many good sketches he could make during one boat trip on the Hudson or one bus ride in Mexico. Incidentally, it is typical for his activist character that he came to prefer drawing instead of photographing. Likewise, his customary way of experiencing music was not by listening but by playing the piano, although sometimes he could be deeply moved by listening to music played by others.

My father's productivity was the joint product of his energy and his will-power. This will-power gave him his self-discipline that enabled him to concentrate on the aims he had chosen. On the other hand, this dominating will sometimes put a strain on the members of his family and the assistants in his laboratory. Jan Burgers, who had been much admired already at an early age, took it for granted that those who were close to him would respond to his needs and wishes. At the same time he felt little inclination to adjust himself to the society in which he lived.

This has been a peculiar trait of my father's character during most of his life in Holland. He had grown up in a poor but very unusual household and he had an aversion to the tastes and styles of what he regarded as bourgeois society. He was highly successful and highly esteemed in his work, but socially and politically he felt himself an outsider and he preferred to stay that way. He was a non-smoker and a non-drinker, he did not engage in small talk, nor in any organized sports, and during the nineteen-twenties he was a member of the Communist Party. His capacity to devote himself intensively to various fields of interest was matched by his capacity to completely ignore other fields. His many-sided interests were always addressed to subjects of his own choosing. He eagerly studied, for instance, the geography, history and culture of China, Central Asia and the Western Hemisphere, but he had only limited attention for the history and architecture of the Netherlands.

This does not mean that he was a solitary man. He had enjoyed the family life with his brother and foster-brothers in his parental home. During his student years at Leiden he made very good friends with his fellow students in the science department, and together they formed a sophisticated but cheerful club in which he played a leading role. In this club he met his first wife, my mother, whose life later on was plagued by prolonged illnesses and who died in 1939. At the University of Leiden he also met Anna, who in 1941 would become his second wife.

In the years after the Second World War my father seemed to become more lonely. Several of his old friends had died, some others had settled abroad. At the same time he got bored of doing his work from 1918 onward in the same job and even in the same street. In these post-war years he paid several visits to the United States. In particular, he and Anna lived a full year in Pasadena, where he worked at the California Institute of Technology. In America he not only found interesting work, but he and Anna also became acquainted with interesting and congenial people. All this contributed to their decision to leave their native country and to start a new life in the United States. In 1955 Jan Burgers laid down his professorship at the Technical University in Delft and entered the University of Maryland.

Emigrating, when you are sixty years old, may seem a very hazardous enterprise! You cut yourself off almost completely from the ties you have formed over the years. How will you ever manage to build a new circle of friends at that age? Miraculously, this is precisely what happened; Jan and Anna really started a new existence and before long they had also made many new friends, not just acquaintances but really intimate friends. After some years in College Park, they were already in regular contact with more genuine friends in America than they were in Holland at the time they left.

Probably the United States is the only place where such a miracle can happen, because American society is so open and so flexible and because it is so accustomed to receiving and integrating people with entirely different backgrounds, I think, even my father's peculiarities were more readily accepted in the US than they were in the stiffer social climate of Holland. It may sound paradoxical, but I am sure my father was a better

integrated member of society during the American part of his life than during the Dutch part.

The fact that Jan Burgers succeeded so well in taking root in his new country is something he owed partly to himself and partly to his wife, Anna, who was an excellent complement to his personality by her independent character, her practicality, and her keen personal interest in people. Whereas in the beginning it was, of course, mainly Jan Burgers' professional contacts that brought them into touch with new friends, she soon brought in friends of her own. It was on her initiative that they entered the Unitarian Church. This proved to be a most valuable step, because there they found themselves members of a community of like-minded people who responded to my father's needs for intellectual and personal contact. I am deeply grateful for the friendship he experienced in that community. I am particularly thankful for the sense of solidarity displayed by those Unitarian friends who gave tireless help to my parents when their life became clouded by my father's creeping disease.