Rem Soloukhin's Gold Hands in Shock and Detonation Phenomena Studies

Nikita A. Fomin

Physical and Chemical Hydrodynamics Laboratory
Heat and Mass Transfer Institute of Belarus National Academy of Sciences
ul. P. Brovki 15, Minsk, 220072, Belarus

1 Introduction

Professor Rem Ivanovich Soloukhin (1930-1988) was a pioneer of shock waves, explosions, detonation, and flow lasers research in the USSR and in Belarus and he played an important role in international science. An innovator of some of the most powerful devices for studying fluid dynamic processes – particularly explosions, Rem Soloukhin was taken in the prime of life. Academician of the Belarus Academy of Sciences, corresponding Member of the USSR Academy of Sciences, recipient of the Lenin Prize, author of several books and many articles, and valued member of the Editorial Board of many leading International Combustion, Explosions and Shock Wave Journals, like Combustion and Flame, Combustion, Explosions and Shock Waves, Experiments in Fluids and many others, he was a much-loved international figure.

Born in the village of Gus' Khrustalny (Crystal Goose) near the city of Vladimir in central Russia, he experienced the hardness of the war in his boyhood and was among the first student in the reconstructed Lomonosov University in Moscow. Among his teachers were Stupochenko, Predvoditelev, Kapitsa, Landau and Lavrentiev. His diploma (BS/MS) (calibration of a gage for recording detonation pressure in a tube) was prepared under guidance of Dr. Tatiana Bazhenova at the G.M. Krzhizhanovsky Power Research Institute of the Academy of Sciences of USSR (PRI AN USSR), where he worked then as a laboratory assistant and as an engineer since 1953.

2 Pioneering experiments with shock tubes at the Krzhizhanovsky Power Research Institute, Moscow (1953-1958).

In 1953, Rem Soloukhin proposed the construction of a smooth shock tube of rectangular cross-section - the copper wave-guide 7 meters long**,** which was reinforsed with thick metal plates outside. The first papers of Rem Soloukhin were published in 1957 [1,2] in the Proceedings of the IVth Conference of young scientists at the Power Research Institute AN USSR. One of these papers described the development of two variants of the structure of barium-titanate-based piezoelectric transducers, analysis of their resolution, and application to record the values and profiles of pressures

Correspondence to: fomin@hmti.ac.by

arising due to bubble oscillations in the case of an underwater explosion. An unusual technique was used to record long-time signals: photographing of the oscillograph screen on a moving film.

Rem Soloukhin also used the schlieren method to observe shock waves initiated by an electric spark in water. He with T.V. Bazhenova and S.G. Zaitsev studied detonation wave development in gas mixtures employing pressure gages, framing cameras and streak cameras. These two papers served as a basis for the Soloukhin's candidate's thesis (corresponding to Ph.D. thesis) that was approved in December 1957. His first international paper was delivered in 1958 at the 7th International Combustion Symposium in London [3].

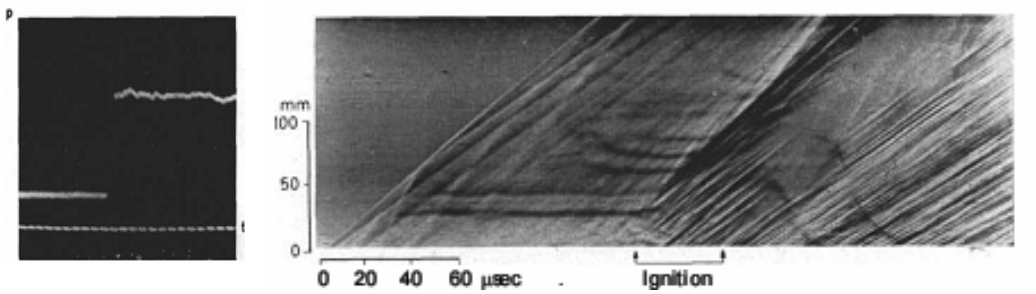


Figure 1. Soloukhin's pressure record in shock wave and Schlieren streak image of ignition initiation behind the shock wave in a mixture of natural gas and oxygen (1957).

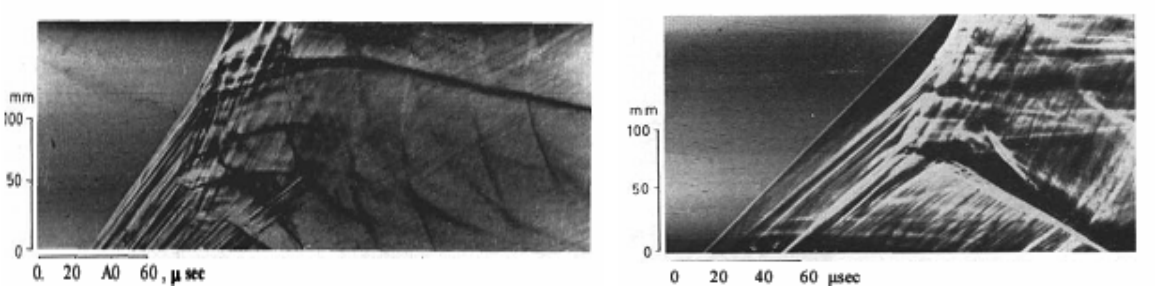


Figure 2. Soloukhin's Schlieren streak images of detonation formation in mixture of natural gas and oxygen (left) and in hydrogen-air mixture (1958).

In December 1958, Dr. Rem Soloukhin was appointed Head of laboratory at the Moscow Physico-Technical Institute (Moscow Institute of Physics and Technology) where under guidance of Academician M.A. Lavrentiev the first research team was created for future Academgorodok near Novosobirsk. In June 1959 this team moved to Siberia and the first Institute of the new scientific center -- the Institute of Hydrodynamics (presently Lavrentiev Institute of Hydrodynamics) of Siberian Branch of USSR Academy of Sciences was founded.

3 First steps in Siberia (1959-1967).

Since June 1959 till October 1967 Dr. Rem Soloukhin was Head of physical gasdynamics laboratory at the Institute of Hydrodynamics. This period of Dr. Rem Soloukhin's activity is associated with a number of important results obtained by him in the field of gas dynamics of reactive flows, mechanics of liquids with gas bubbles, application of optical methods, measurement of pulsed pressures and temperatures of the gas in fast processes, *etc.* [4,5]. Under direct or indirect influence of Dr. Rem Soloukhin, these techniques were improved and found wide use in experimental research. In his first monograph "Some methods of studying the fast processes" published in 1960 in co-authorship with Moscow's colleagues, T.V.Bazhenova, S.G.Zaitsev, I.M.Naboko, *et al.*, Dr. R.I. Sololukhin

continued promoting and improving experimental techniques [6]. He described a modified structure of a piezoelectric transducer (a cylinder 13 mm in diameter and 11 mm high) with an acoustic wave-guide filled by beeswax suppressing acoustic waves in the wave-guide. In measuring the wave reflected from the wall, he suggested that the pressure profile during the time of passage of a compression-wave passage over the transducer body should be reconstructed by means of signal differentiation.

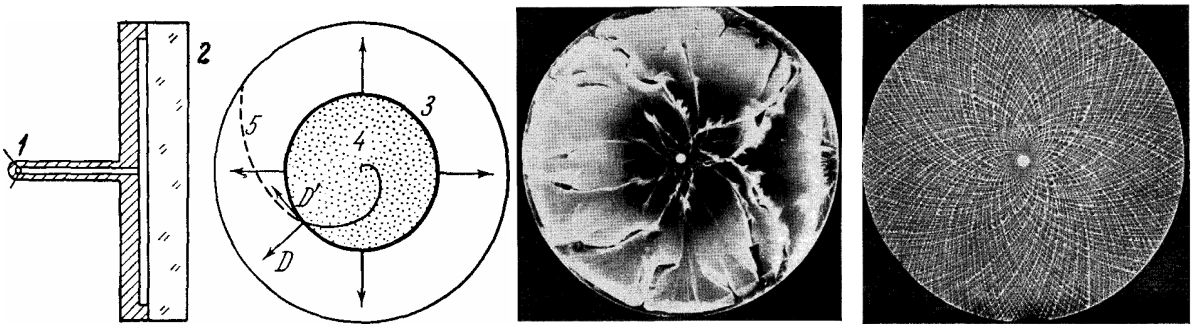


Figure 3. Diagram of the experiment for the study of the structure of a cylindrically expanding detonation front (left): (1) Detonation tube with contacts for ignition; (2) transparent surface of the explosion duct; (3) detonation front; (4) combustion products; (5) trajectory of the transverse wave. The arrows indicate the normal and tangential velocity components of the transverse wave. In the center and on the right are Soloukhin's photographs of a detonation for a decaying and non-decaying detonation in a C_2H_2+O_2 mixture [4] (1959).

Being one of the young pioneers who left Moscow with Lavrentiev to found a research city, Akademgorodok, in the western Siberia heartland of the USSR, Soloukhin continued fundamental research in gaseous and solid detonations in the exciting new surroundings. Fascinated by the phenomena of spin detonation, he with his Novosibirsk's colleagues, V.V. Mitrofanov, M.E. Topchijan, V.K. Kedrinskii, V.B. Voisekhovsky, V.V. Voevodsky, and others -- carried out fundamental experimental investigations of detonation [7-10]. For this work he won the prestigious Lenin Prize in 1965. Soloukhin's book published in Russian in 1963 [9] and in English in 1965 [10], was one of the first books describing the use of shock tube for reactive flow and detonation studies.

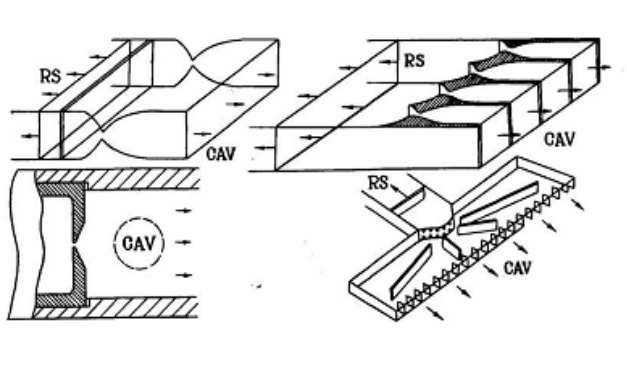
In 1962, at the age of 32, Soloukhin was the first who received the Doctor's degree in physics and mathematics awarded by Novosibirsk State University. He was one of the chief organizers of this new University in Siberia; he was the first Dean of Physics Department, and first Vice-Rector for Education and Research. He occupied Chair of General Physics from 1965 to 1973, compiling and systematizing in continuum mechanics that were comprised in a textbook for a generation of students.

4 Physical Aspects Studies in Reactive Flows.

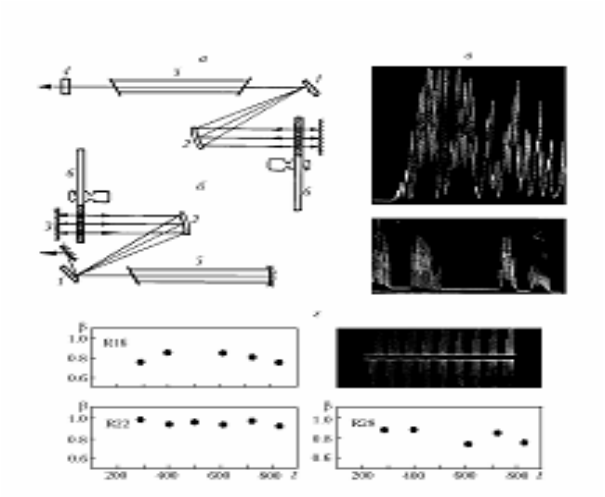
In 1967, in addition to his research and teaching, Soloukhin became Deputy Director of the Institute of Nuclear Physics in Akademgorodok. In 1970, he became Director of the Institute of Pure and Applied Mechanics in Academgorodok, and from 1976 to the time of his death he served as Director of the Heat and Mass Transfer Institute of the Belarus Academy of Sciences in Minsk. During these busy years he published monograph on new diagnostics of very fast processes [11], a number of original and review articles with world leading scientists [12-15]. Simultaneously, he held Chair of General Physics at Novosibirsk State University (up to 1973) and Chair of Thermal Physics at Belarus State University (since 1973) and gave regular lectures to large classes of admiring students. His scientific interest at that time includes more physical problems, for instance, an excitation of molecules by electric discharge, vibrational relaxation processes, and population inversion producing in high power lasers. In 1972, a new advanced concept of high power flow laser, a mixing GDL, was proposed and

successfully realized in shock tube experiments[16]. Since 1976, these high power lasers were developed under guidance of Prof. Rem Soloukhin in Minsk [17-19]. Here many young scientists presented their PhD theses and became professors on the basis of these studies. Among them are Nikita Fomin, Siarhei Zhdanok, Oleg Penyazkov, Oleg Achasov (1954-2002), and many others. Fig. 4 summarizes some of these studies.

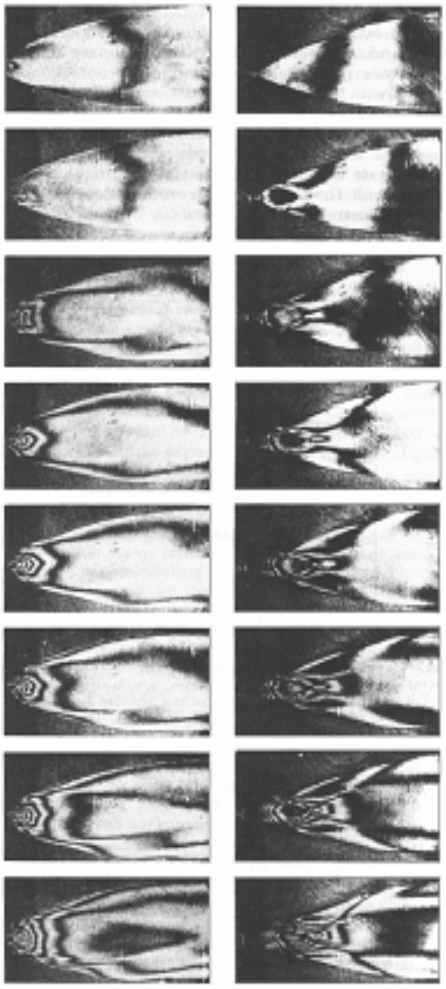
At that time joint investigations of detonation phenomena were being continued with French colleagues (Ch. Brochet, J. Brossard, R. Brun, F. Fisson, G. Dupre, C. Paillard, …) both in Minsk and in France (mainly in Poitiers and Orleans) [20, 21].



Schematic representation of the configuration of high power flow laser systems with double expansion and mixing of lasing and pumping components in supersonic flow [18].



Optical scheme of the Soloukhin-Yakoby laser spectrograph, typical records, and measurement results on vibrational levels population [19].



Michelson interferometer frame records of starting processes in mixing gasdynamic lasers [17].Time interval between frames is varied up to 1 μs.

Figure 4. Summary of Soloukhin's high power lasers research in Minsk [17-19].

Thus, using the gasdynamic approach the population inversion in a thermally pumped molecular gas system was successfully initiated in a shock tube [16]. Subsequently, gain measurements and laser power extraction simulation were also carried out by means of the shock tube technique [17-19]. The most impressive results were obtained with the use of a high pressure shock tube operating in a double expansion and mixing flow regimes, see Fig.4. Not only shock tubes but also fast combustion and detonation processes were used to provide thermal pumping for appropriate gas mixtures.

The original scheme of the laser spectrograph with a spatial distribution of different wavelengths was developed under guidance of Rem Soloukhin and Yurii Yakoby in Novosibirsk. We call such laser systems "Soloukhin-Yakobi spectrographs". A number of similar schemes were patented and a series of such spectrographs were built then in Minsk, providing the possibilities of precise measurements of molecular levels distributions in strongly non-equilibrium conditions [19].

5 Concluding Remarks.

In conclusion, it should be stressed that the above considerations and examples clearly demonstrated the high capability of the shock tubes connected with Rem Soloukhin's skilful fingers in the modeling of detonation and reactive systems, incl. high temperature fluid mechanic and optical phenomena associated with complicated non-equilibrium processes of electronic, molecular and radiative energy transfer. Since 1985, Rem Soloukhin started the development of new diagnostic technique based on digital image recordings and statistical optics. Now the approach is called the "speckle photography", that is an advanced digital laser image acquisition system with statistical image analysis. Professor Rem Soloukhin was very enthusiastic about this novel technique [22].

Among his over 300 research articles, monographs, and patents are numerous review articles wherein he delighted the state of knowledge of experimental methods in fluid dynamics, detonation and explosions. In this fast changing field, his articles are beautiful expositions of the state of the art of the problem.

As a member of national and international boards for publications and meetings, Professor Rem Soloukhin gave generously himself to the job. The list of all the board and commissions on which he served is long. And his favorite board was ICDERS, where during a long time he was Co-Chairman with Professors Numa P. Manson (France) and Antony K. Oppenheim (USA) of the International Colloquium on Dynamics of Explosions and Reactive Systems. At the 12th ICDERS in Ann Arbor, Michigan, USA, on July 27, 1989, the R.I. Soloukhin award "Gold Hands" was established in recognition of the experimental genius of Rem Ivanovich and his role in founding the colloquium series.

Acknowledgements

This paper is dedicated to Professor Rem Soloukhin, my Master. I have known Rem since 1972, when student, I undertook a thesis on flow mixing laser under his supervision. During my scientific formation I have a pleasure to discuss flow dynamics and shock tube experiments with his friends, Profs. R. J. Emrich (1917-2005), N. P. Manson (1913-1993), A. K. Oppenheim (1915-2008), Ya.B.Zel'dovich (1914-1987), with his first supervisor, Prof. Tatiana Bazhenova, with his student team from Moscow -- Profs. L.G. Gvozdeva, S.A. Losev. I.M. Naboko, A.I. Osipov, S.G. Zaitsev, with his first Siberian students -- Profs. M. Topchiyan, V. Mitrofanov, with his first international Post-Doc -- Prof. Piotr Wolanski, with his French colleagues and friends -- Ch. Brochet, J. Brossard, R. Brun, F. Fisson, G. Dupre, C. Paillard, and many others.

The author also wishes to thank also Belarusian colleagues and Rem Soloukhin last students -- Academician Siarhei Zhdanok, Profs. Oleg Penyazkov, and Oleg Achasov (1954-2002) for long-term friendship, joint work and many useful scientific discussions.

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Request PDF on ResearchGate | Atomistic Studies of Shock-Wave and Detonation Phenomena in Energetic Materials | The major goal of this PhD project is to investigate the fundamental properties of energetic materials, including their atomic and electronic structures, as well as mechanical properties, and relate these to the fundamental mechanisms of shock wave and detonation propagation...Â The major goal of this PhD project is to investigate the fundamental properties of energetic materials, including their atomic and electronic structures, as well as mechanical properties, and relate these to the fundamental mechanisms of shock wave and detonation propagation using state-of-the-art simulation methods. The use of schlieren photography has been essential in unravelling the complex nature of high-speed combustion phenomena, but its line-of-sight integration makes it difficult to decisively determine the nature of multi-dimensional combustion wave propagation. Conventional schlieren alone makes it impossible to determine in what plane across the channel an observed structure may exist. To overcome this, a technique of simultaneous high-speed schlieren photography and soot foils was demonstrated that can be applied to the study of detonation phenomena. Using a kerosene lamp, soot was deposited o R.I. Soloukhin â€œShock wave studies of the physical properties of gasesâ€ 2 547â€“556 (1959). B.F. Gordiets, A.I. Osipov et al â€œVibrational relaxation in gases and molecular lasersâ€ 15 759â€“785 (1973). R.I. Soloukhin â€œDetonation waves in gasesâ€ 6 523â€“541 (1964). L.V. Alâ€™tshuler â€œUse of shock waves in high-pressure physicsâ€ 8 52â€“91 (1965). G.A. Galechyan â€œAcoustic waves in plasmaâ€ 38 1309â€“1330 (1995). A.I. Osipov, A.V. Uvarov â€œKinetic and gasdynamic processes in nonequilibrium molecular physicsâ€ 35 (11) 903â€“923 (1992). M.S. Dzhidzhoev, V.T. Platonenko, R.V. Khokhlov â€œCHEMICAL LASERSâ€ 13 247â€“268 (197