Acta Astronautica 145 (2018) 438–445

Contents lists available at ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/actaastro

Boris Novozhilov: Life and contribution to the physics of combustion

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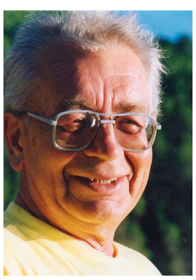
ARTICLE INFO

Keywords:
Propellants
ZN theory
Thermal explosion
Spin combustion

ABSTRACT

Professor Boris Novozhilov (1930–2017) passed away on February 19th, 2017 in Moscow. The present paper provides brief account of his life and contributions to the physics of combustion. From extensive scientific legacy left by Boris, several major achievements are discussed here: Zeldovich-Novozhilov (ZN) theory of unsteady solid propellant combustion, contributions to thermal explosion theory, the theory of spin combustion, discovery of propellant combustion transition to chaotic regimes through Feigenbaum period bifurcation scenario.



Professor Boris Novozhilov (1930–2017) passed away on February 19th, 2017 in Moscow. He is mostly known for his outstanding fundamental contribution to the theory of solid propellant combustion.

He is survived by his wife Ludmila, his daughter Natalia and son Vasily.

Born on the 8th of July 1930 in Alma-Ata, Kazakhstan (that time part of the Soviet Union, and now independent Republic of Kazakhstan), Boris soon had to move with his family to Tomsk, and then to Novosibirsk, where Boris lived during the outbreak of WWII.

His interest in physics led him to enter the course at the Leningrad Polytechnic Institute (currently Peter the Great St. Petersburg Polytechnic University), which was at the time (1948) very highly ranked in physics education in the Soviet Union. Boris graduated with honors in Applied Physics in 1953.

From 1954 Boris started his scientific career in Moscow at the Institute of Chemical Physics (currently The Semenov Institute of Chemical Physics), USSR and later Russian Academy of Sciences (Fig. 1). He worked there full time until his death. He joined the theoretical group of famous theoretician A.S. Kompaneyets and was assigned first to work on some projects related to nuclear energy. Boris' PhD thesis on the subject written nearly 60 years ago (1959) is still classified.

Communication with academician Nikolai Semenov, founding director of the Institute and Nobel Prize Laureate in Chemistry, was extremely important for Boris. Apart from Semenov, Boris benefited much from his interaction with Kirill Shchelkin, a famous Russian scientist who made outstanding contributions to the studies of detonation.

Following his PhD, Boris obtained the highest scientific degree in the Soviet Union, Doctor of Sciences (in physical and mathematical sciences) in 1968 (Fig. 2).

From 1976 to 1992 he occupied the post of the Head of the Laboratory of Mathematical Methods in Chemical Physics at the Institute. Many, if not most of his staff came from a formal mathematical background, and with some Boris used to have occasional heated arguments when he felt that excessive mathematical formalism overshadowed clear physical reasoning.

Soviet school of theoretical physics influenced greatly Boris' style of approaching problems (for example, he used to attend for some time the famous L.D. Landau theoretical seminar) and this fact helps to understand why he was so successful in developing fundamental theoretical concepts.

Physical insight into the problem has always remained a defining drive for Boris. He loved entire physics as a science, and despite working in a relatively narrow field, his understanding of and intuition in many areas of physics were amazing.

Although working initially on some projects related to the Soviet military nuclear program, Boris got quickly interested in the combustion of solid propellants. His major achievement was the development of what is now known as Zeldovich-Novozhilov (ZN) theory of unsteady propellant combustion. ZN theory was essentially developed by Boris in the 60s, although he has been refining it up to the end of his life.

Like most Soviet scientists, Boris was severely restricted in his ability to communicate with his colleagues in the West. In the late 60s he

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https://doi.org/10.1016/j.actaastro.2018.01.065
Received 4 December 2017; Accepted 31 January 2018
Available online 8 February 2018

Fig. 1. Boris Novozhilov in the 60s.

Fig. 2. Photo presumably taken while defending Dr. Sci. Thesis in 1968.

developed strong collaboration with Numa Manson's group at ENSMA (École Nationale Supérieure De Mécanique et D'Aérotechnique) and the University of Poitiers. However his invitation to work at Poitiers for three years was blocked by the Soviet authorities. Another tragic episode occurred in 1978, when his permission to leave the Soviet Union for International Symposium on Combustion in Leeds was revoked just days before the event. Boris was unable to travel abroad, apart from one minor conference in Warsaw in the seventies, until 1989.

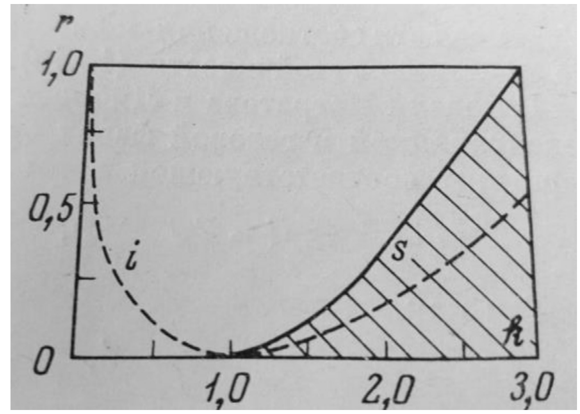

Fig. 3. Stability diagram for combustion under constant pressure.

Luckily, the situation changed later in his life, and he was able to work intensively with his colleagues in Italy (being invited there many times from 1989 to 2004). He gave a number of lectures at Politecnico di Milano and National Council of Research, actively participated in workshops and conferences, and co-authored several papers. Boris also have had very close relationships with the researchers at the Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, over a period of about 10 years (from 1994 to 2004). Boris also visited and lectured in the USA and Australia for short periods in the mid-90s.

Over the years Boris theory acquired world-wide recognition (largely due to interaction with several key scientists in the West, such as Martin Summerfield, Edward Price, Forman Williams, Fred Culick, and others, who visited Soviet Union occasionally while Boris was unable to travel abroad). Eventually that recognition led The Combustion Institute to award Boris the Zeldovich Gold Medal for outstanding contribution to the theory of combustion in 1996.

Apart from ZN theory, Boris made versatile contributions to various areas of combustion science, some of which are discussed in more detail below. He also made a number of practical inventions and contributed to development of a number of defence-related technologies. For one of such important contributions he was awarded the Russian Federation Government Prize in Science and Technology in 2012.

Boris is the author of 5 books published in the Soviet Union. For many years he taught part-time as a Professor at the Moscow Institute of Physics and Technology, a leading Soviet and Russian University in physics education.

Due to limitations of space, we provide very little exact mathematical details as it would be impossible to fit into the manuscript proper discussion of mathematical formulations and solutions of many technical problems. We have tried to provide general description of the ideas involved, as well as some illustrations of major results.

Boris theory of unsteady solid propellant combustion was built on the initial ideas presented by Y. Zeldovich in the two papers published in 1942 and 1964 [1,2], although personal interaction between the two was always rather limited. Zeldovich assumed the surface temperature of the burning propellant to remain constant, and provided, under such an assumption, his results on calculating the nonsteady burning rate of the propellant, as well as on the stability of combustion. It was rather obvious from the beginning that the Zeldovich assumption of constant surface temperature is too restrictive. It was found that predictions of such theory contradicted with the experiments as no real systems really fulfill the constant temperature condition.

Extension of the theory to the case of variable surface temperature proved to be difficult, despite efforts of many scientists working in the field. Boris succeeded in extending theory of nonsteady combustion to the real case of variable surface temperature by demonstrating that in this case both the surface temperature and burning rate are determined by the instantaneous values of the pressure and the temperature gradient