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# MYSTERIES OF ACADEMICIAN GODUNOV

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*Dedicated to the memory of Sergey Godunov*

**Abstract:** Academician Sergey Konstantinovich Godunov is an outstanding Russian scientist, a classic in the world of mathematical science, and a recognized leader in modern applied mathematics. He is known worldwide for his research in ordinary differential equations, partial differential equations, computational mathematics, continuum mechanics, and linear algebra. His contributions include methods for calculating critical parameters of nuclear devices, the general theory of difference schemes for solving differential equations, and the theory of elasticity. The difference scheme created by S.K. Godunov for calculating discontinuous solutions of gas dynamics equations using the "through-counting"method with adequate "smoothing"of shock waves gained worldwide fame as the Godunov scheme. These memoirs are dedicated to the last years of Sergey Konstantinovich's life, our joint work on the linearized Godunov scheme, and impressions from personal communication with Academician S.K. Godunov.

**Keywords:** biography.

## 1 Acquaintance

I first became acquainted with the name of Sergey Konstantinovich Godunov when I was 7 or 8 years old. At that time, I often sat in my father's office, watching him work and browsing through books. One book

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particularly attracted me—a yellow one titled "Introduction to the Theory of Difference Schemes." It contained many formulas and graphs, and I often took it from the shelf, not knowing its title or reading it—just because of its beauty. My father, Academician Vladimir Evgenievich Fortov, was then working in Chernogolovka on shock-wave experiments. He once saw me looking at this book and said, "Do you know whose book you are holding?" I replied, "No." "It belongs to the greatest mathematician of our time, Sergey Konstantinovich Godunov. The whole world calculates using his numerical scheme", said my father. That was the first time I heard about Sergey Konstantinovich.

PHOTO 1. Academician Sergei Konstantinovich Godunov, 1980s.

Later, while studying at Moscow University in the Faculty of Computational Mathematics and Cybernetics, the name of S.K. Godunov was mentioned in almost every lecture hall. The Godunov scheme was actively used in scientific organizations studying computational gas dynamics. However, I did not work with this scheme personally; different numerical methods were used for the turbulent flows I studied. In 2016, with Academician Eduard Evgenievich Son, we went to the Novosibirsk Akademgorodok to participate in an international mechanics colloquium organized by the Kutateladze Institute of Thermophysics. This was my first time speaking at such an important and responsible event, and I was very nervous. After my presentation, I immediately left the hall to take a break. In the corridor, I noticed a sturdy

elderly man sitting at a table, engrossed in writing formulas. Eduard Evgenievich was standing next to him and called me over, saying, "Look how unclear his writing is!" I approached and saw that the conservation law formulas were written in a divergent form, very convenient for computational work. I responded, "On the contrary, everything is extremely clear and precisely written; you could write a program right away." "Let me introduce you—this is Sergey Konstantinovich Godunov," said Eduard Evgenievich. I was stunned. Before me was the living legend, the world classic of computational mathematics, the great Godunov! I thought, too bad I hadn't worked with his scheme! There would have been something to discuss. Sergey Konstantinovich looked up and said, "And you are Svetlana Vladimirovna Fortova. I've been expecting you." Knowing that I headed a small but enthusiastic computational department at the Institute of Automation and Design of the Russian Academy of Sciences, created by Academician O.M. Belotserkovsky, he began telling me about his idea of linearizing the famous Godunov scheme. He was very eager to involve us in this research. My colleagues and I decided to support Sergey Konstantinovich and began working on the scheme, testing it on standard problems. We worked intensively on developing the linearized version of the scheme for five years. An excellent conference was organized in Novosibirsk for Sergey Konstantinovich's 90th birthday, where he gave the first presentation on the linearized scheme developed for accurate calculations.

Our scientific communication was so informal that Sergey Konstantinovich could call in the middle of the night (as many scientists of that time did): "Svetlana Vladimirovna, write this down." I would jot down his ideas, sometimes not fully understanding them, leaving them for later. "Otherwise, I'll forget; I'm already old. I'm not feeling well," he would say, regretful that age was taking its toll. We had quite active correspondence by mail, and I carefully keep his letters. I want to publish them because the scientific culture inherent in Sergey Konstantinovich is vividly expressed in these letters. Every phrase he wrote was supported by a specific reference to a book, its year of publication, and the page number. I have preserved all the letters from Sergey Konstantinovich, which are written in beautiful, literary language, even though we discussed scientific topics. This is undoubtedly due to his mother, Ekaterina Viktorovna, who studied in France and taught her son to speak perfect French, appreciate the beauty of language, literature, and history. His father, Konstantin Dmitrievich Godunov, was a well-known aeronaut and designer of balloons. Thanks to him, many cities were protected from air raids by balloons during the war. Sergey Konstantinovich was very proud of his father and, I think, in some way took him as an example, first becoming a winner of mathematical olympiads, then a student at Moscow State University, and later an academician and a world-renowned developer of difference schemes.

I often went to Novosibirsk to visit Sergey Konstantinovich for scientific discussions and to review results. Once, I flew in the evening, stayed at the university hotel, and in the morning was supposed to go to see Sergey

Konstantinovich. I planned to go at 10 a.m. (after all, Sergey Konstantinovich and his wife, Tatyana Alexandrovna, were elderly). I got up, did some exercises. There was a knock on the door. I opened it, and there stood Sergey Konstantinovich with his wife. It was 9 a.m. They said, "Svetlana Vladimirovna, we were afraid you wouldn't find the house where we live." There they were, two elderly people, standing so touchingly at my door... I thought, "My God, how could I have thought to come at 10 and not at 9 or 8 to such wonderful people?"

When I was writing my doctoral dissertation, one of its chapters was dedicated to the linearized scheme developed under Academician Godunov's guidance. Sergey Konstantinovich wrote a review of the dissertation: not about the excellent work done, but about what needed to be done further, further, and further. Further because... – and a reference to a problem was given, because and why... – and another reference. And so, the work was good. This is undoubtedly an important quality of a computational mathematician that we should all adopt. Sergey Konstantinovich always looked ahead. Another characteristic of Sergey Konstantinovich that surprised me was his reaction to failure. Usually, when we test a computational method and fail to pass standard computational tests, we get upset. After all, we have to find the error. Sergey Konstantinovich, on the contrary, was always delighted by such failures. "Oh, oh, let's tweak something here, adjust something there, increase the coefficient here and see what happens. So, what did you calculate? So, what did you calculate?" As he always said, "It's very interesting to solve puzzles. After all, science is about bringing order to the chaos of paradoxes, a considerable number of fragmented observations, remarks, and considerations that often contradict each other".

## 2 The Famous Scheme

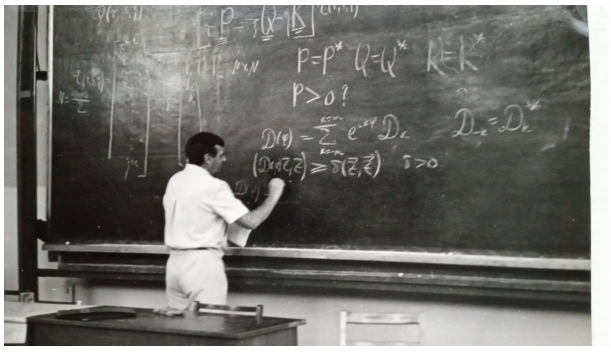


PHOTO 2. Academician S.K. Godunov giving a lecture, 1960s.

The Godunov computational scheme is a kind of world bestseller that has been in use for over 70 years. It has become a classic and is used by the entire global computational community. Sergey Konstantinovich's books

have become reference materials for scientists dealing with shock waves and, in general, with continuum mechanics. I would say that his contribution to science is astonishing. It is a true monument, not made by hands.

The first version of the scheme was created in 1953-54. At that time, Sergey Konstantinovich was defending his PhD dissertation, where he described this scheme. Many modifications of this scheme have been created. The essence of the Godunov method lies in the numerical solution of a system of equations using the Riemann problem of the decay of an arbitrary discontinuity. The Godunov method for solving systems of non-stationary equations in continuum mechanics is based on the solution (exact or approximate) of the Riemann problem of the decay of a discontinuity. The solution is sought in the form of a set of elementary waves obtained as a result of solving a system of equations. In particular, for gas dynamics, these are: shock wave, rarefaction wave, and contact discontinuity. Today, much is said about technologies that most accurately reflect physical phenomena. And about the fact that the architecture of computers should correspond to the type of problem being solved to achieve maximum performance. The Godunov method is essentially the use of such a "physical"technology back in the 1950s. Deeply understanding mechanics, he implemented it in his numerical scheme. That is, he approached the solution from the perspective of mechanics, physics, and not just computational mathematics. Hence the well-known story that his main work, which now has thousands of citations, was not published for several years in either mathematical or physical journals. He was ahead of his time with this approach to numerical modeling.

The scheme was developed over 15 years. Why so long? Firstly, the 1950s were marked by the development of our computational industry; the first computers appeared. It was already possible to move away from calculations on machines like the “Mercedes.” The “Strela” computing machine, installed in 1954 at the Institute of Applied Mathematics, was the first machine on which the Godunov scheme was tested. In fact, Mstislav Vsevolodovich Keldysh initiated its development. The atomic project required calculations because they reduced the cost of experiments, especially complex ones like nuclear explosions. The development of an effective numerical method was entrusted to the computational bureau where Sergey Konstantinovich worked immediately after defending his PhD. Later, the Godunov scheme was developed at the Institute of Applied Mathematics (IPM), which at that time had just separated from the Steklov Mathematical Institute of the USSR Academy of Sciences into a standalone institute. It should be noted that one of the IPM employees was already working on a scheme with a similar ideology. But Sergey Konstantinovich saw serious inconsistencies in it. He began to correct them, and during this time, the idea of a global physical approach to numerical modeling emerged. He applied this physical perception to his numerical scheme. The Godunov scheme was immediately applied to solving the “uranium problem”. It became an example of an amazingly convenient and reliable mechanism for calculating many physical phenomena

involving shock waves. Numerous discussions of numerical and experimental results were held together with such great scientists as Academicians A.D. Sakharov, Ya.B. Zeldovich, I.E. Tamm, Yu.B. Khariton, and many other outstanding scientists of that time.

PHOTO 3. Academician Sergey Konstantinovich Godunov participating in the seminar.

For the development of the scheme for calculating the spherical shell compression of uranium, Sergey Konstantinovich was awarded the Order of the Badge of Honor in 1954, the Order of the Red Banner of Labor in 1956, and the Lenin Prize in 1959. These state awards testify to the highest recognition of his contribution to science. It is also interesting to note that the American Automobile Association once awarded Sergey Konstantinovich a prize for his contribution to calculating hydrodynamic parameters in the design of car shapes and engine processes. As Nobel laureate Zhores Alferov said, "There is nothing more practical than fundamental science". After all, progress is determined by the availability of new scientific discoveries, which can only arise from fundamental research. The Godunov numerical scheme is a prime example of fundamental research that is applied in various spheres of human life.

During his work at the Department of Applied Mathematics, and since 1966 at the Institute of Applied Mathematics of the USSR Academy of Sciences, S.K. Godunov created many methods for the approximate solution of various problems in continuum mechanics and laid the foundations for new directions in applied mathematics. Here are just a few examples. For calculating solutions to two-dimensional problems in continuum mechanics,

special requirements arise for computational grids, and under the leadership of S.K. Godunov, work began on automating the construction of various classes of curvilinear difference grids. Currently, this area is actively developing both in our country and abroad. S.K. Godunov created a method for analyzing the flow of bodies by a gas stream. This method became a universal technique for obtaining stationary solutions using a non-stationary problem. S.K. Godunov created and justified the method of orthogonal sweeping for solving boundary value problems for systems of ordinary differential equations. Today, this method and its modifications are used to solve many problems in various fields of science.

Significant results were obtained by S.K. Godunov in the theory of quasilinear equations. He studied the problem of the uniqueness of generalized solutions of gas dynamics equations and considered issues related to the place of continuum mechanics equations in the theory of hyperbolic equations in conservative form, as well as the generalization of the concept of entropy, the law of its increase, and thermodynamic relations.

The global recognition of S.K. Godunov's scientific achievements is evidenced by the international conferences and symposia held in his honor both in our country and abroad. To emphasize the role of Sergey Konstantinovich's ideas and the worldwide recognition of his numerical approach, I will quote our foreign colleagues' statement at the conference dedicated to Academician Godunov's 90th anniversary: "One of the founders of the field of computational fluid dynamics, mathematician Sergey Godunov, influenced the theory and practice of scientific computing more than anyone else in this century. His work transcends time, and his contribution to applied mathematics and computational fluid dynamics has already become a classic... As the forefather of 'Godunov-type schemes,' he is known in every laboratory where compressible fluid dynamics is studied..."

## 3 Novosibirsk Akademgorodok

The idea of creating the Siberian Branch of the Academy of Sciences belonged to Academician Mikhail Alexeyevich Lavrentiev, which at that time seemed unrealistic and fantastic. Nevertheless, in 1958, in the middle of Siberia, in the taiga, the Novosibirsk Akademgorodok appeared, created for the work of 30-35 thousand scientists. In record time, all the infrastructure was erected; institutes of various directions were built within walking distance of each other. Mikhail Alexeyevich was a supporter of placing diverse institutes along one avenue precisely because "scientists should not only stew in their own environment, should not narrow their interests." It should be noted that Akademgorodok was initially planned as a single entity: scientific institutes with auxiliary premises, a university with a complex of dormitories, an experimental plant, a medical town, residential buildings, a hotel, kindergartens, and nurseries, a cultural center with a cinema, stadiums, a shopping

center, and even a large water station. It was a well-conceived and subsequently accurately realized small but convenient city for life and scientific work, designed for 30-35 thousand people. Ten years later, it became clear that the city of science should have been designed for a much larger population. A system of a local scientific state was created. A child is born and is constantly in a scientific environment. At school, he is taught by researchers who are passionate about science. Then he goes to university with excellent teachers and becomes a young scientist.

The most daring scientists went to Akademgorodok. In 1969, Sergey Konstantinovich Godunov also moved to Akademgorodok at the invitation of Academician S.L. Sobolev and Academician M.A. Lavrentiev. He was appointed head of the laboratory at the Computing Center of the Siberian Branch of the USSR Academy of Sciences. Since 1980, he moved to the Institute of Mathematics of the Siberian Branch of the USSR Academy of Sciences.

His first works in Siberia were related to studies of the behavior of metals during explosive welding, conducted jointly with experimental physicists from the Institute of Hydrodynamics of the Siberian Branch of the USSR Academy of Sciences. The calculations and their partial discrepancy with experiments led to the need to refine classical models. By studying the results of numerous experiments, S.K. Godunov managed to derive equations that, unlike the generally accepted ones, allowed for adequately describing both the elastic deformation of the medium and its flow under intense impacts. Calculations conducted under his guidance predicted a new effect—the formation of a submerged jet during the collision of metal plates. Subsequently, a nonlinear relaxation model of elastic-plastic deformations was created, which is successfully used for modeling a wide range of dynamic processes in continuum mechanics.

Since the 1970s, S.K. Godunov, together with his students, has been actively researching mixed problems for hyperbolic systems of equations, computational problems in stability theory, and dichotomy for ordinary differential equations, as well as in linear algebra. Based on the developed mathematical apparatus, S.K. Godunov, along with colleagues and students, actively continued the development and numerical calculations of various models in continuum mechanics.

Another factor that influenced his move to Siberia was Sergey Konstantinovich's search for passionate students. He said that he had become somewhat bored teaching at Moscow State University. "Because students started coming with tennis rackets instead of notebooks."This was fundamental for him. You must not only do well scientifically but also act morally and humanly right. He accepted such people into his life. He was a brilliant lecturer. His engaging, precise, and concise lectures attracted students. Sergey Konstantinovich taught several courses—Continuum Mechanics, Equations of Mathematical Physics, Methods of Approximate Calculations, Differential Equations, Numerical Methods of Linear Algebra, Modern Aspects of Linear Algebra, Theory of Hyperbolic Systems, Equations of Nonlinear Elasticity Theory.

When such scientists teach young people their science, they can inspire many students with their passion. Students receive knowledge as if "first-hand". Sergey Konstantinovich was a serious mountaineer. He was introduced to


PHOTO 4. International Congress of Mathematicians, Moscow, 1966.

mountaineering by the outstanding mathematician Boris Delone, his teacher. During one of the ascents in 1958, Sergey Konstantinovich was caught in a rockfall. The injury was so severe that he remained unconscious for several hours and then took a long and difficult time to recover. Doctors prescribed him a lot of walking. Therefore, in Akademgorodok, Sergey Konstantinovich walked 20-25 km daily. His wife, Tatyana Alexandrovna, his faithful and reliable companion throughout his life, supported the idea of moving to Siberia.

Tatyana Alexandrovna... I really want to talk about her. Every one of our scientists should have such a friend! They met at the Mechanics and Mathematics Department of Moscow State University during their studies. Tatyana Alexandrovna was an excellent lecturer and conducted seminar classes at Novosibirsk University. She treated each student with care, remembered everyone by their work, and kept a notebook for each. But when Sergey Konstantinovich had health problems, and doctors said that his diet and regularity needed improvement, Tatyana Alexandrovna sacrificed her scientific achievements, left her job, and started feeding Sergey Konstantinovich regularly and deliciously. She nursed him back to health.

I remember when I visited them during one of my trips, Tatyana Alexandrovna talked a lot about their travels and studies, bustling about. I couldn't

tear myself away from these bright and full-of-life old folks. But I had to go to the airport; a minute later, and I would miss my flight. I said goodbye, ran out, opened my bag, and there... were wrapped sandwiches. I thought to myself that my stomach would be just fine after such care!

There was another tender story that I cherish in my heart. Three years ago, I called on February 23 to congratulate Sergey Konstantinovich on the holiday. I called at the end of our workday; it was around 8 or 9 pm Novosibirsk time. It was dark, February. Usually, Sergey Konstantinovich would be asleep at this time. But here, he picked up the phone. I congratulated him. But he didn't hear well and didn't realize it was me. He mistook me for his daughter, who lives in Germany. I listened to his tender voice, full of meaningful memories for him... "Do you remember", he said, "the star that was always to the right of the house when you stepped onto the balcony? Now it has become much brighter and shifted to the left". I realized I couldn't tell him he was mistaken, that I wasn't his daughter. In his heart, there was not only science...

PHOTO 5. S.K. Godunov in his office at the Sobolev Institute of Mathematics, Akademgorodok, 2016.

**But I would like to end with another quote from Sergey Konstantinovich that may inspire many young scientists: "When you solve a problem, you constantly have to make different hypotheses, fantasize, go all out, and it's still unknown whether it will work out or not. As a rule, it doesn't work out, you know? But sometimes you're lucky. Without that, there's no discovery".**

PHOTO 6. Academician Sergei Konstantinovich Godunov and doctor of physics and mathematics Svetlana Vladimirovna Fortova, Akademgorodok, 2017.

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