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GRIGORII ALEKSANDROVICH TIRSKIY
(On the occasion of his eightieth birthday)☆

Grigorii Aleksandrovich Tirskiy, an outstanding scholar in the field of fluid and plasma mechanics, was eighty years old on the 1st September 2009. He is a full member of the Russian Academy of Natural Sciences (Physics Section), Honoured Scientist of the Russian Federation, Honoured Professor of the Moscow Institute of Physics and Technology (MIPT), a member of the European Society of Mechanics (EUROMECH), Doctor of Science in Physics and Mathematics, professorial holder of the Chair of Computational Mathematics at MIPT, scientific supervisor of post-graduate students and head of the physicochemical gas dynamics laboratory of the Scientific Research Institute of Mechanics at the M.V. Lomonosov Moscow State University[1].

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[1] A short biography of Professor Tirskii was published in J. Appl. Math. Mech Vol. 63, No. 6, pp.829-832, 1999.

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Professor Tirskiy is active in the field of physicochemical gas dynamics, hypersonic aerodynamics and heat transfer, radiation gas dynamics, the kinetic theory of gases, the thermodynamics of irreversible processes, the physical theory of meteors, and analytical and computational hydrodynamics. He is the author and co-author of 350 pure and applied papers, published in leading Russian and foreign journals, including two monographs and three patents, and the author of a discovery and has a high citation index.

A pupil of L. I. Sedov, Professor Tirskiy is the founder of a large scientific school which is actively working in Russia and abroad. Among his pupils are 60 Candidates of Science, of whom 21 are Doctors of Science. His pupils are successfully working in the Moscow Physics and Technology, Insitute of the M.V. Lomonosov Moscow State University, the A. Yu. Ishlinskii Insitute of Problems in Mechanics of the Russian Academy of Sciences, the M. V. Keldysh Institute of Applied Mathematics of the Russian Academy of Sciences and in other higher education institutes and scientific centres of Russia. Eight of his pupils are working in science abroad and four of them are Doctors of Science in Physics and Mathematics.

We list below his most outstanding scientific results, which have contributed to the development of physicochemical gas dynamics.

1. A new exact and simple form of the relations for the mass transfer of components and the energy of the translational and internal degrees of freedom of multicomponent (with dissimilar binary diffusion coefficients of the components), multitemperature and thermally non-equilibrium mixtures of gases and a plasma, which is useful for solving physicochemical problems of gas dynamics (aerothermodynamics), was obtained using methods of the kinetic theory of gases and the thermodynamics of irreversible processes. These relations were presented as dependencies of the concentration gradients of the components and the temperature gradients of all the degrees of freedom on fluxes with exact transfer relations which are considerably simpler in compared with the classical expressions “fluxes via gradients” with the unwieldy transfer coefficients. This new form of the transfer relations enabled, both for the complete as well as for the different forms of the asymptotically simplified Navier - Stokes equations, highly accurate numerical methods to be developed for solving the boundary layer and viscous shock layer equations and the Navier - Stokes equations with a computation time that is proportional to the number of components rather than to the cube of this number, as is required when the classical form of the transfer equations (“fluxes via forces”) is used. When these new relations are employed, the computation time satisfies the “golden rule” of computational mathematics, that is, in the given case it is proportional to the number of components.
2. Using the new form of the transfer relations, the exact equations of thermochemically equilibrium flows of viscous heat-conducting multicomponent rarefied and dense mixtures of gases and a plasma with dissimilar diffusion properties of the components with a full set of all the effective transfer coefficients in an explicit form were obtained for the first time. These results won world recognition.
3. The effect of the separation of chemical elements in the case of quenched equilibrium and non-equilibrium homogeneous and heterogenous chemical reactions was discovered using the new exact form of the transfer relations “thermodynamic forces via fluxes”. This result formed the subject of a discovery.
4. In his laboratory and under his supervision, the semiphenomenological theory of the catalytic reactions of dissociated air in Earth’s atmosphere and of carbon dioxide in Mars, atmosphere on low-catalytic heat resistant coatings using the basic elementary stages was developed for the first time with his pupils (O. N. Suslov and V. L. Kovalev). The results of this theory were subsequently confirmed by American experiments in 1987. The theory was confirmed by flight and laboratory experiments and the corresponding methods were introduced into the design and calculation of the heat fluxes of re-usable gliding transport spacecraft during their re-entry into the atmosphere. These investigations at a molecular level were continued and developed by his pupils using the methods of molecular dynamics in conjunction with supercomputers.
5. In the middle of the 1980’s, he turned his attention for the first time to the fact that, in the case of the motion of spacecraft in the upper atmosphere (higher than 65 km) along a gliding re-entry trajectory (“Buran”, and the “Space Shuttle”), it is necessary to take account of the non-equilibrium (multitemperature) kinetics, that is, to take account of the self-consistent vibrational-dissociation interaction in reactions in the shock layer. Taking account of this effect within the limits of the mode approximation considerably refines (increases) the heat flux values (by up to 25%) and the equilibrium radiation temperature of the surface (by up to 100 K).
6. His discovery, together with his pupil I. G. Brykina, of new continuum models which qualitatively and quantitatively correctly describe the drag and heat transfer in the transitional (from free molecule to continuum) flow regime is a fundamental and important practical result.

An original continuum-continuum hybrid numerical method was developed using the proposed models (for low Reynolds numbers), the equations of a complete viscous shock layer and the Navier - Stokes equations (for high Reynolds numbers). This hybrid method enables one to solve problems in aerothermodynamics over the whole range of Reynolds numbers using the parameter for switching from a continuum regime to the transitional and the free molecule rigime established by Tirskiy and Brykina within the limits of just continuum (not kinetic) equations.

Together with this approach, computational programs were created in the group he supervised for constructing solutions of problems in hypersonic aerodynamics and heat transfer in a transitional flow regime both within the limits of the continuous equations as well as within the limits of the solution of Crook’s kinetic equations, the *S*-model of the incomplete third approximation and Boltzmann’s equation as well as by the Direct Simulation Monte-Carlo method, which are the basis of hybrid continuum-kinetic methods for solving internal and external problems in transitional and free molecule flow regimes.

7. Together with his pupils, he developed an original and efficient iterative-marching method for solving the two-dimensional equations of a viscous shock layer and the parabolized and complete Navier - Stokes equations. It was developed over the course of many years for solving both internal problems (a Laval nozzle) and external problems of supersonic and hypersonic flows past blunt bodies; this method is an order of magnitude faster than methods based on the time relaxation principle.
8. Already at the end of the 1960’s, Professor Tirskiy was laying the foundations of a new scientific trend, that is, the theory of the thermochemical breakdown of the heat resistant coatings of spacecraft. Together with his pupils, models of the thermochemical oblation of real heat-resistant coatings during orbital and extra-orbital entry of spacecraft into the atmosphere of Earth and other planets were developed. Before flight, the overall loss of mass from the heat shields of the space vehicles Zond-5 and Zond-6 (“Lunnik”),

prior to their entry into the Earth's atmosphere after flying around the Moon in 1968, was quantitatively correctly predicted on the basis of this theory.

9. Using the methods of the kinetic theory of gases, the detailed slip boundary conditions, and the temperature and concentrations jumps for multicomponent gas mixtures, taking account of heterogeneous reactions in the case of dissimilar catalytic activity of the vibrational degrees of freedom and with different vibrational temperatures of the molecules, were derived by him and his post-graduate student V. A. Kiryutin for the first time.
10. The universal "law of areas" as well as "Newton's law for radiative fluxes at velocities of motion exceeding 16 km/s in Earth's atmosphere and 40 km/s in Jupiter's atmosphere were discovered by him and his pupils.
11. A coupled problem in aerothermoballistics, in which, along the entry trajectory of spacecraft into the atmosphere, it is necessary to solve the equations of radiative aerothermodynamics taking account of heat and mass transfer for the case of a flow past bodies of variable shape and the ballistic equations of a body with a variable (unknown) along the trajectory mass and shape, was formulated and solved for the first time in the 1970's. This approach was used to calculate the entry of a space probe into the atmosphere of Jupiter and, in the 1990's, it was used for the gas dynamic verification of the basic equations of the physical theory of meteors.
12. Finally, as was noted by the Chief Designer and Vice-President of the corporation "NPO Mashinostroyeniye", Professor G. A. Yefremov, a new scientific trend was created in the group supervised by Professor Tirskiy and scientific groups working with him and the results obtained were incorporated into space rocket, aeronautical and other branches of machine construction as new technologies with a huge economic effect.

These works formed the basis of a cycle of investigations by a group of authors under his guidance, for which the prize of the Government of the Russian Federation in the field of Science and Technology was awarded in 2007.

Besides the basic direction of pure and applied investigations encompassing a wide range of issue concerning the entry of spacecraft into the atmospheres of planets, Professsor Tirskiy, together with his pupils and colleagues, constantly showed an interest in the physical theory of meteors. Five candidate dissertations on this theme were defended by his pupils. In recent years, he formulated the problem of constructing a complete multievent scenario for the fall of the Tunguska meteor. This problem results from the fact that no impact crater and no meteorites have been found in the near vicinity of the epicentre of the Tunguska catastrophe. The construction of a complete scenario, in which each act follows from a preceding act, is a complex, multidisciplinary problem of physical mechanics. In his words, it is desirable to reduce the explanation of the Tunguska phenomenon to a minimum involvement of the necessary concepts and, especially, of low-probability concepts which are remote from explicit mechanical and physicochemical processes taking place along the ballistic trajectory of the folide.

Recently, he, together with physical chemists, turned his attention to the development of a new scientific specialization, nano-micro-hydro-gas dynamics. This is an original molecular kinetic theory which is the microscopic analogue of classical hydrodynamics and refers to the flow domain immediate adjacent to the surface in the flow field. It provides a microscopic description of the dynamics of molecule mass, momentum and energy transfer processes the in spatial scales of 1 to 10^3 nm and in time intervals of 10^{-2} to 10^4 nanoseconds, that is, there, where models of the continuum mechanics of a medium become inapplicable and the domain of applicability of Boltzmann's kinetic equation finishes. The approach which is developed is suitable for describing flows both in narrow and wide pores up to bulk (continuous) phases. The study of the fluid flow in microscopic systems is important for the development of many branches of science, technology and medicine such as nanotechnology, biophysics, microsurgery, the physical chemistry of a surface, etc.

The characteristic feature of Professor Tirskiy's scientific creativity is its high level, novelty, rational formulation of problems and effectiveness of the methods for solving them. His scientific school has become renowned not only in Russia but also abroad. He is an outstanding specialist in his field, striving for the most rigorous formulations and effective solutions of problems which, with respect to their profundity, lie at the level of theories developed in world science.

His outstanding scientific achievements have been acknowledged in Russia and abroad. In 2002, he was awarded the medal of the order "For Services to the Fatherland" of the second degree, he was the prize winner of the Prize of the Government of the Russian Federation in the field of Science and Technology, the M. V. Lomonosov Prize of Moscow State University, the First Prize of the Ministry of Higher Education of the USSR, winner of the S. A. Chaplygin gold medal of the Russian Academy of Sciences, winner of the Academician L. I. Sedov medal and prize, the prize of the international academic publishing company "Nauka" for the best publication in its journals, the P. L. Kapitsa medal of the Russian Academy of Natural Sciences "To the Author of Scientific Discovery" (1996), and the Academician V. N. Chelomei and S. P. Korolev medals of the Federation of Cosmonauts of Russia "For Services to National Cosmonautics".

It is interesting to note that, in recent years, he has regularly participated in the "Russian Ski-Track" competitions. While undergoing post-graduate training, he was the skiing champion of Moscow State University, during five years of study he was skiing champion of Tomsk State University and the town of Tomsk, champion of the "Nauka" Sports Club (1951) and, in the higher forms at school, he was champion of Yakutiya among the pupils.

Professor Tirskiy greets his anniversary celebrations among a friendly group of pupils and colleagues, full of energy and creative ideas.

The Editorial Board of Prikladnaya Matematika i Mekhanika, of which he was a member for 21 years, and the editorial staff of the journal, colleagues and pupils of the celebrant wish him good health and further creative successes.

A List of Professor Tirskiy's Scientific Papers for the last 11 years[2]

1999

The general gas dynamic model for the problems of hypersonic flow past blunt-nosed bodies over the whole range of Reynolds numbers. In: Proc 3rd Europ Symp on Aerothermodynamics for Space Vehicles: ESTEC. Noordwijk, The Netherlands. Paris: Europ Space Agency; 1999, 127 - 35.

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The hydrodynamic equations for chemically equilibrium flows of a multielement plasma with exact transport coefficients. J Appl Math Mech 1999 **63** (6): 841 - 61.

Aerothermoballistics of shattering and exploding meteoroids, In: Synopses of Papers Presented at the Conference Associated with the 40-th Anniversary of the Insitute of Mechanics of Moscow State University, “Contemporary Problems of Mechanics”. Moscow: Izd. MGU; 1999, 182 (coauthor with D. Yu. Khanukayeva)

Aerothermoballistics of large meteoritic bodies. In: Book of Abstracts 22nd Intern Symp on Shock Waves. London, UK, Imperial College; 1999, 232 (coauthor with D. Ju. Khanukaeva).

2000

Aerothermoballistics of breaking up of large cosmic bodies. In: Proc 22nd Intern Symp on Shock Waves, London, UK, Imperial College, 1999. London: Acad Press; 2000, V. 1, 739-44 (coauthor with D. Ju. Khanukayeva).

Interaction of cosmic bodies with the atmospheres of the Earth and planets. Sorosovsk Obraz Zhurnal 2000; **6(**5): 78 - 82.

Hydrodynamic equations for chemically equilibrium flows of a multicomponent plasma. In: Encyclopaedia of Low temperature Plasma / Edited by V. E. Fotrov. Moscow: Nauka, MAIK Nauka/Interperiodika; 2000, V. 1, 523-36.

2001

Collision of the Shoemaker - Levi 9 comet with Jupiter. Sorosovsk Obraz Zhurnal 2001; **7(**6): 63-9.

Dimensional Analysis. Sorosovsk Obraz Zhurnal 2001; **7** (6): 82-7.

The accelerated method of global iterations for solving the external and internal problems of aerohydrodynamics. In: Abstracts IV Europ Symp on Aerothermodynamics for Space Vehicles. CIRA, Capua, Italy; 2001, 118 (coauthor with B. V. Rogov).

Similarity and physical modelling. Sorosovsk Obraz Zhurnal 2001; **7(**8): 122-7.

Model of the interaction of cosmic bodies with a non-isothermal atmosphere. In: Collection of Proceedings of the Conference 21st Century Near-Earth Astronomy. Zvenigorod, Moscow Region. Moscow: Geos; 2001, 367-78.

Interaction of cosmic bodies with the atmospheres of the Earth and planets. Comet-asteroid hazard - threat from the Cosmos. In: Annotated Proc 8th All-Russian Congress on Theoretical and Applied Mechanics. Perm; 2001, 558 (coauthor with D. Yu. Khanukayeva).

Elements separation in hypersonic flow over a body due to the multicomponent diffusion, nonequilibrium homogeneous chemical reactions and heterogeneous surface recombination. In: Book of Abstracts 23rd Intern Symp on Shock Waves, Fort Worth, Texas, USA. Arlington, Tx: The Univ of Texas at Arlington USA; 2001, 230 (coauthor with S. A. Vasil’evskiy).

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2002

The accelerated method of global iterations for solving the external and internal problems of aerodynamics. In: Proc IV Europ Symp on Aerodynamics for Space Vehicles. CIRA, Capua, Italy. ESA SP-487. 2002, 537-44 (coauthor with B. V. Rogov).

Rigorous modeling of the full and partially chemical equilibrium flows with reference to hypersonic aerodynamic and heat transfer problems. In: Book of Abstracts West East High Speed Flow Field. Aerospace Application for High Subsonic to Hypersonic Regimes. Marseille, France: Ecole Polytech Universitaire de Marseille. Universite de Provence; 2002, 47 (coauthor with S. A. Vasil’evskiy).

Model of the breakup of meteoroids in the atmosphere. In: Trudy Mat Tsentrd im N I Lobachevski. Vol. 16. Models of the Mechanics of a Continuum Medium. Materials of the XVI Session of the Intern School on Models of Continuum Mechanics; Kazan: Izd Kazansk Mat Obshchestva; 2002, 268 - 71 (coauthor with D. Yu. Khanukayeva).

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The use of the moment method to derive the gas and plasma transport equations with transport coefficients in higher-order approximations. Prikl Mat Mekh 2003; **67** (3) 406-33 (coauthor with V. M. Zhdanov).

A method of partial chemical equilibrium in hypersonic aerodynamics problems. In: Proc 24th Intern Symp on Shock Waves, Beijing, China. 2003, 231 - 9 (coauthor with V. G. Gromov, V. I. Sakharov and E. I. Fateeva).

Establishment of the basic equations of the physical theory of meteors from the position of hypersonic aerodynamics and heat and mass transfer and their solution for a non-isothermal atmosphere. In: Synopses of the Proc of the All-Russia Conference: Aerodynamics and Gas Dynamics in the XXI Century. Moscow: Izd MGU; 2003, 113-4.

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Aerodynamics and heat transfer prediction in hypersonic transitional flows by using continuum-flow models. In: Papers East West High Speed Flow Field Conf. Beijing, China; 2005, 91 -6 (coauthor with I. G. Brykina and B. V. Rogov).

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Translated by E. L. S.