M. A. LAVRENT'EV (ON THE OCCASION OF HIS 70th BIRTHDAY)

November 19, 1970 marks the 70th birthday of an outstanding scientist and leading public figure: Academician Mikhail Alekseevich Lavrent'ev.

M. A. Lavrent'ev's contributions in the field of mathematics and mechanics have laid down new roads for investigating difficult problems and have provided a solid foundation and impetus to a whole series of new trends in research. Up-to-dateness and breadth of applications are found combined with rigorous mathematical research techniques, in harmonious fashion, in the scientific creativity of Mikhail Alekseevich.

M. A. Lavrent'ev

M. A. Lavrent'ev has been an active participant in the shaping of new pathways of scientific and technical progress. He is credited with completing a major transformation in the organization of scientific research in our country, viz., the founding of the Siberian division of the Academy of Sciences of the USSR. In his post as chairman of the Siberian division, Mikhail Alekseevich has successfully brought to fruition ideas of unity of fundamental scientific research, implementation of the achievements of science in the national economy, and the training of scientific cadres.

The initiative persistently shown by M. A. Lavrent'ev in searching out new forms of scientific development has borne, as one of its fruits, the appearance of the periodical Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, on whose editorial staff he has remained as a member up to the present.

The editorial staff of the periodical warmly greets Mikhail Alekseevich Lavrent'ev on his birthday and wishes him excellent health, happiness, and new creative successes.

M. A. Lavrent'ev's Contributions to the Literature on Mechanics and Applied Physics

This brief survey must be regarded as a resume of the scientific trends in the field of mechanics and applied physics reflecting the scientific creativity of Academician Mikhail Alekseevich Lavrent'ev.*

Wing Theory, Airfoil Theory. M. A. Lavrent'ev's first contributions on hydroaerodynamics hark back to the years 1929-1934. This was a time marking the beginning of the vigorous development of aeronautics and aircraft design in our country. A brilliant pleiad of young theoretical scientists was assembled at TsAGI [Zhukovskii (Joukowsky) Central Aero-Hydromechanics Institute] under the supervision of S. A.

*More detailed information on M. A. Lavrent'ev's contributions as well as a bibliography listing his papers can be found in the periodicals PMM [Prikladnaya Mekhanika i Matematika], 24, No. 6 (1960) and PMTF [Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki], No. 3 (1960) as well as in materials published on the occasion of his 70th birthday (Nekotorye Problemy Matematiki i Mekhaniki [Some Topics in Mathematics and Mechanics], Sibir. Otdel. Akad. Nauk SSSR (1970)).

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Chaplygin, numbering such major representatives of subsequent Soviet science as M. A. Lavrent'ev, M. V. Keldysh, and L. I. Sedov. It is to this period that M. A. Lavrent'ev's papers on the theory of the airfoil date back.

M. A. Lavrent'ev's paper entitled "On the structure of a stream flowing around an arc of specified shape" (Trudy TsAGI, No. 118, p. 53(1932)) investigates the problem of flow around an airfoil with an arbitrary specified contour. The general problem is reduced to a singular integral equation of the first kind, which is analyzed in detail in the paper. M. A. Lavrent'ev was successful in demonstrating the process which leads to the solution and in proving that this process converges. Next in line was the problem of the airfoil exhibiting the best aerodynamic properties. This problem in classical wing theory was also solved by M. A. Lavrent'ev [Trudy TsAGI, No. 115, p. 40 (1934)]. He proved that, of all arcs whose length and curvature do not exceed specified numbers, the arc of a circle possesses the greatest lifting force. In that paper M. A. Lavrent'ev relies on the variational properties of conformal mappings.

Impact of a Body on Water. Brilliant results in solving the problem of impact of a body on water, which are of practical importance for descent of seaplanes, date back to that same period [Trudy TsAGI, No. 152, 5-12 (1935)]. M. A. Lavrent'ev (in collaboration with M. V. Keldysh) succeeded in developing a general method for solving the problem of rigid impact in the planar two-dimensional case, reducing this problem to the Hilbert problem and then to a problem in conformal mapping. These results gave rise to an entire new scientific trend, which has not yet been investigated exhaustively.

Vibrating Wing Theory. In December 1933, at the 3rd All-Union Conference on Aerodynamics, M. A. Lavrent'ev and M. V. Keldysh delivered a joint report entitled "Contribution to the theory of a vibrating wing." The authors solved the problem, urgent for that time, of nonsteady-state motion of an incompressible fluid around a vibrating plate of infinite extent. Some highly interesting physical inferences are drawn in this paper. In addition to refining the Glauert formula for the forces acting on the wing, the authors prove that the Zhukovskii formula for the lift of the wing remains valid for the average angle of attack when the angle of attack varies periodically. The paper pointed out the possibility of wing vibration modes in which an additional thrust appears.

Hydrofoil. The paper by M. V. Keldysh and M. A. Lavrent'ev entitled "On the motion of a wing under the surface of a heavy liquid" [Proceedings of the Conference on the Theory of Wave Drag, TsAGI, Moscow (1937), pp. 31-64] is of fundamental significance. This problem is still an urgent topic today, with the steadily increasing and widening use of hydrofoil vessels. The authors construct the solution on the basis of classical problems of flow around singularities beneath the surface of water, which they solved. This method makes it possible to find the forces acting on the wing, including the wave drag. A basically new fact was uncovered in the study: circulation flow is accompanied by wave drag even when the wing is submerged to an unbounded depth. This paper, astonishing in its elegance, gave the impetus to an entire new trend in research and applications.

Seepage. On the basis of extensive applications of variational techniques, M. A. Lavrent'ev obtained some profound results in 1938 in the theory of jet flows of an ideal liquid [Matemat. Sbornik, 4, No. 3, 391-458 (1938)]. M. A. Lavrent'ev extended the familiar Lindelöf variational principle for conformal mapping of similar regions and presented approximate formulas for such mappings. He obtained estimates of extension in conformal mapping on the boundary of a region. This led to the existence, uniqueness, and stability theorems for a broad class of jet flow patterns. Results of the application of variational principles in the theory of the flow of ground water under hydraulic structures such as dams with sheet-pile walls are particularly straightforward and lucid. The variational principles make it possible not only to analyze the phenomenon qualitatively but also to validate and refine some of the approximate approaches to solving problems involving seepage and other hydrodynamic problems.

Later on, these results were carried over by Mikhail Alekseevich to cover subsonic flow of gas [Dokl. Akad. Nauk SSSR, 20, No. 5, 343-345 (1938)].

Theory of Long Waves. Another paper of fundamental importance was the "Contribution to the theory of long waves" [Dokl. Akad. Nauk SSSR, 41, No. 7, 289-291 (1943); Zbir. Prats' Univ. Matemat. Akad. Nauk URSR, No. 8, 13-69 (1947)]. The investigation is based on the formulas of approximate conformal mapping found by M. A. Lavrent'ev. As a consequence the problem is reduced to an infinite system of ordinary differential equations for which the convergence of the sequence of the solutions to the exact solution of the problem is proved. This paper includes: "1) a new method of approximate construction of the solution of the general problem with an estimate of the error and the process converging when the solution exists; 2) the possibility of providing a rigorous foundation for Rayleigh theory and estimate of the error in the Rayleigh method; 3) some general properties of the solutions in the case of a periodically varying bottom."

The basic idea treated in the paper involves replacing the velocity of the fluid on a free boundary by its approximate expression through the inclination and curvature of the free boundary, as derived by Mikhail Alekseevich for long waves. This concept, expressed for the first time by M. A. Lavrent'ev, was of enormous applied importance in that it reduced the initial problem to an incomparably simpler one and served as point of departure for a whole series of new research efforts. In particular, M. A. Lavrent'ev and B. V. Shabat discussed the case of a solitary wave. Subsequently, the theory of long waves was generalized to the case of quasiconformal mappings and was also refined by taking the limiting derivatives of higher orders into account.

Dynamical Stability. In the joint paper by M. A. Lavrent'ev and A. Yu. Ishlinskii entitled "Dynamical forms of buckling of elastic systems" [Dokl. Akad. Nauk SSSR, 64, No. 6, 779-782 (1949)], the fundamental difference between the behavior of statically loaded and dynamically loaded elastic systems was clarified. While it is only the curved equilibrium configuration that is unstable in the first case, as obtained when the first (least) critical buckling force is exceeded, this cannot be the case in the second case. It was found experimentally that the number of forms of dynamic buckling increase with the magnitude of the suddenly applied load and that the new configurations appear after the load surpasses the regular critical value in the static problem.

The theoretical explanation of that phenomenon, provided in the paper referred to, is that the amplitude of the m-th buckling harmonic increases with time as $\exp(\sqrt{-\lambda_m t})$, where λ_m is the eigenvalue of the operator in the static problem. It is found that λ_m is minimized in the case of some average form m_* of buckling. This paper made a vital contribution to the theory of dynamic stability of elastic systems.

Movement of Grass Snakes and Fish. In a paper entitled "On one principle underlying the generation of thrust impelling motion," [PMTF, No. 4, 3-9 (1962)], M. L. Lavrent'ev, in coauthorship with M. M. Lavrent'ev, considered the motion of a flexible elastic rod in a rigid channel of variable curvature in an attempt to account for the movement of some live organisms, such as grass snakes and some fish, as a suitable model for the problem. Despite the absence of tangential forces this rod is capable of executing motions along the channel. By tensing its muscles, the grass snake generates a potential energy similar to the potential energy of an elastic rod. The muscular exertions of the grass snake must be such that the potential energy of the muscles decreases in response to motion in a specific direction. If the channel is assumed to be absolutely nonrigid but massive, we end up with a model describing the motion of fish in water. The authors found the optimum distribution of bending forces. The paper cites examples of how the flexural stresses and relaxations of the organism must be sequenced in order for the organism to be able to advance through the fluid.

Models of Discontinuous Flow Patterns. M. A. Lavrent'ev completed an extensive program of research on the theory of jet flows. He proposed two new schemata for the flow of a stern circulation wave around obstacles ["Variational Method in Boundary Problems for Systems of Equations of Elliptic Type" [in Russian], Izd-vo AN SSSR, Moscow (1962)]. Experience has shown that a zone bounded by the surface of the flow within which the average motion takes place on closed trajectories takes shape in a recess on the bottom or in the wake of a bluff body at high Reynolds numbers. In one of these schemata the circulation zone is simulated by a cavity on the boundary of which the flow velocity remains constant, and in the other schema it is simulated by a vortex cavity of constant vorticity. Outside that zone the flow is assumed to be a potential flow with the velocity field everywhere continuous. The assumption of constant vorticity within the separated-flow region is reasonably well justified since this mode of flow on the part of an ideal fluid constitutes the motion of a viscous fluid in the limit as the viscosity tends to zero. It must be pointed out that M. A. Lavrent'ev's schema not only makes it possible to calculate flow patterns with separation, which were previously recalcitrant to computation, but is also a far-reaching generalization of the application of the theory of flow of an ideal inviscid fluid to describe real flow patterns.

Streams of Finite Breadth. Of the recent papers by M. A. Lavrent'ev, we should single out the article entitled "On some problems in the motion of a fluid in the presence of free surfaces," [PMM, 30, No. 1, 177-182 (1966)]. Here two patterns of flow by streams of finite breadth around obstacles are considered.

Flow by streams of finite breadth around obstacles has been given only very slight study to date. But here we observe some highly intriguing phenomena, often unexpected and even paradoxal. For example, flow around a cylinder or sphere on the part of a tenuous stream takes place without separation of flow at high Reynolds numbers; the tenuous streamlet is deflected, in asymmetrical flow around a cylinder, to the side opposite the thicker portion of the divided stream, and if the cylinder is free to rotate about its axis, this flow returns to the side opposite to what was expected – in the sense opposed to a mill wheel. A sphere immersed into the thin stream forcing its way upwards is supported stably by the stream, while the sphere is ejected from the thick stream. M. A. Lavrent'ev gives a mathematical formulation of the problem of flow around this obstacle, indicating the pathway to its solution, and offers an explanation of some of the relevant effects.

Shaped Demolition Charges. One of the major scientific accomplishments to the credit of M. A. Lavrent'ev has been the founding of the Soviet school of research on cumulation processes in explosions [Usp. Matem. Nauk, 12, No. 4, 41-56 (1957)]. The development of this major scientific trend was inaugurated in M. A. Lavrent'ev's papers on the operating principles of the shaped charge, published for the first time back in the forties. The phenomenon of the intensification of the local action of the explosive charge blasting an obstacle when recesses are cut on the side facing the obstacle has long been known, since the close of the past century. Some technical applications of the effect have also been general knowledge (including the case where the recess is faced with metal).

Mikhail Alekseevich suggested an entirely novel hydrodynamic treatment of the cumulation phenomenon. The basic idea put forth by M. A. Lavrent'ev dealt with the fact that, at such high pressures as are encountered in explosions, the metal can be treated with sufficient confidence as an ideal incompressible fluid. It was shown that, under that assumption, the formation of a cumulative jet can be treated on the basis of problems of interaction between jets of liquid. In the case of a planar steady-state flow the exact solution of the problem is found, and for the case of axial symmetry some basic equations governing the process are arrived at.

The experiments staged by M. A. Lavrent'ev in collaboration with colleagues showed that the piercing of an obstacle is governed by the formation of a high-velocity metallic jet (cumulative jet) from the apex of the (usually tapered) lining that is compacted in the explosion and fully confirmed the basic results deriving from the hydrodynamical theory of cumulation.

Problems involving the principles of numerical computations of the deformation of the metallic cone are discussed (with a hemisphere used as illustrative example) in the same series of papers, as well as processes of energy cumulation in response to the collapse of the metallic cone (planar and spherical case) and some other problems in addition, many of which have acquired significance on their own as independent problems. In laying the foundation of shaped-charge theory, M. A. Lavrent'ev also discussed the differences between the real process and the classical hydrodynamical schema. For example, stability in the formation of the jet at small angles of collapse of the metallic cone, the presence of a velocity gradient along a real cumulative jet, the consequent elongation of the jet in flight and enhanced piercing action as the charge is removed farther away from the obstacle, the possibility of applying quasistationary methods to calculations of the interaction between such a jet and an obstacle – all these are discussed.

Directional Explosion. In 1959, M. A. Lavrent'ev posed the problem of a concentrated directional explosion, which was formulated then in a very general form: to arrange explosives in the ground such that ejection of material would take place in one single direction following the detonation. Although explosives experts were already capable of bringing off concentrated directional explosions in dam construction, the directionality achieved was still incomplete: a large amount of rock and soil flew off in directions other than the main desired direction in the wake of the detonation.

M. A. Lavrent'ev posed the problem in its simplest form: to blast the ground so that it will be moved as a rigid body. The simple solution of this problem was arrived at on the basis of two underlying hypotheses: a) the ground is an ideal incompressible fluid, and b) the momentum imparted to the ground through the explosion is proportional to the thickness of the layer of explosives. The gist of the solution is that, according to hypothesis a), the momentum must be equal to the potential of the velocities, in this case a linear function of the coordinates. And hence, according to hypothesis b), the layer of explosives must be distributed proportionately to the distance in the direction in which the blasted ground is to be thrown [Zh. Prikl. Mekhan. i Tekhn. Fiz., No. 4, 49-50 (1960)].

The method based on this solution can be utilized in the design of canals, foundation areas, or funnels. Experimental explosions that were staged provided complete confirmation of the theoretical calculations, while also making it possible to introduce certain corrections into the original schema, taking compressibility and the strength of the medium into account. Without altering the essentials of the simulation problem these corrections can be harnessed to refining the calculations of the explosive charges and also to optimum sequencing of the detonations of the charges.

Explosive Welding. Welding of metals by explosions is inherent to begin with in the cumulative effect of explosive charges shaped by metallic hollow-cone linings. When flat plates collide, a cumulative jet forms, and such high pressures are generated in the collision region that the atoms of the metals comprising the plates approach to within distances where interatomic bonds form between them, i.e., welding ensues. The first experiments on cumulation staged by Mikhail Alekseevich in Kiev in the 1944-1946 period, when he proposed investigating two-layered cumulative-effect linings made of different metals in order to enhance the breaching effect of the shaped charge, led to a result of fundamental importance. A monolithic "paste" formed after this two-layer lining had been compacted. During that same period the phenomenon of welding copper wire by high-energy forming in an explosion was exploited by Mikhail Alekseevich in order to fashion monolithic copper rods from a bundle of copper wire. It was in that way that the phenomenon of explosive welding was discovered by M. A. Lavrent'ev's research team in the 1944-1946 period.

Later on, Mikhail Alekseevich organized extensive research at the Institute of Hydrodynamics on the mechanism underlying explosive welding, and its applications in various areas of new techniques [e.g., see A. A. Deribas, V. M. Kudinov, F. I. Matveenkov, and V. A. Simonov, "Explosive welding," Fizika Goreniya i Vzryva, No. 1, 111-117 (1967)].

Hydraulic Jet Pulse Techniques. One of the major lines of applied engineering that trace their origin to M. A. Lavrent'ev's work on cumulation and shaped charges is hydraulic jet pulse work. With the object of verifying the hydrodynamical principle of penetration, Mikhail Alekseevich pointed out the possibility of simulating the process by using a water jet and clay as the medium to be pierced. This led to the design of a device which became the prototype of modern hydraulic jet guns.

In 1959-1960, Mikhail Alekseevich returned to the concept of obtaining a high-velocity jet for breaking down especially hard rock, in particular, anthracite coal seams. Several hydropulse-jet devices were built at the Institute of Hydrodynamics of the Siberian Division of the Academy of Sciences USSR. [M. A. Lavrent'ev, B. V. Voitsekhovskii, and É. A. Antonov, Topics in the Theory and Practice of Pulsed Water Jets (Voprosy Teorii i Praktiki Impul'snykh Vodyanykh Strui), Inst. Gidrodinamiki SO AN SSSR (1960)]. Hydraulic jet guns are now being used in an experimental prototype of a mining-drifting combine. The hydraulic jet gun is the basic component of a hydropulse facility for pulsed high-energy forming of metals and for freeing castings from scale and molding sand etc.

High-Velocity Impact. Focusing attention on the phenomenon of the collision of a compact body with an obstacle at velocities on the order of tens of km/sec is a logical extension of M. A. Lavrent'ev's work on cumulation effects. In 1960, M. A. Lavrent'ev addressed the 1st All-Union Congress on Mechanics with a report entitled "Piercing at cosmic velocities," which contained a new statement of the classical momentum problem. The detonation of high explosives in a charge having an unlined charge hollow forms jets of detonation products which are expelled at velocities to 15 km/sec. M. A. Lavrent'ev posed the problem of learning how to use the cumulation phenomenon to advantage in accelerating rigid bodies. This problem was resolved with success at the Institute of Hydrodynamics in the 1961-1966 period.

Investigations of high-velocity impacts have been carried out under the supervision of M. A. Lavrent'ev at the Institute of Hydrodynamics in a whole series of instances of practical importance. These include, e.g., the study of the interaction between metallic obstacles, thin protective shields, and light porous materials. A whole series of new and peculiar effects has come to light in the investigation of the interaction between specimens of brittle materials. The appearance of secondary foci of failure in brittle specimens, traceable to the interaction of waves reflected back from free surfaces, is quite intriguing. At the maximum velocities (presently attainable) it has become possible to successfully cross the threshold at which the bulk of the mass of the body collided with escapes in the form of metallic vapor.

Spinning Detonation. In 1956, M. A. Lavrent'ev turned his attention, in his capacity as supervisor of the special courses on the physics of explosions at the Moscow Physicotechnical Institute (MFTI), to the persistence of one "obscure" topic in the theory of detonation of gases, viz. the phenomenon of spinning detonation which had not yet been successfully accounted for. All that was known was that the region of brightest emission within the range of propagation of the detonation through shock tubes executes a spiralling motion (detonation "spin"), but the mechanism underlying the phenomenon had escaped discovery.

Thanks to the support by M. A. Lavrent'ev and to the attention he gave to the problem, this problem was solved in principle within a matter of years by his pupil B. V. Voitsekhovskii [Dokl. Akad. Nauk SSSR, 114, No. 4, 717-720 (1957)].

Vortex Rings. M. A. Lavrent'ev posed some problems relating to: the mechanism underlying the formation of vortex rings; the structure of the vortex ring when the way the ring forms is specified; the pattern of motion and the maximum distance traversed by the vortex ring; transfer of impurities by a vortex ring and loss of impurity as the vortex ring executes motion, etc. [e.g., see A. A. Lugovtsov, B. A. Lugovtsov, and V. F. Tarasov, "Motion of a turbulent vortex ring," Proc. Inst. Hydrodynamics, Siberian Branch, Acad. Sci. of the USSR, Dynamics of a Continuous Medium, No. 3 [in Russian] (1969)].

Under M. A. Lavrent'ev's supervision, colleagues of the staff of the Institute of Hydrodynamics conducted numerous experiments over a broad range of Reynolds numbers (from 10^2 to 10^7) and over a broad range of vortex-ring scales (from 1 cm to 4 m) in air and in water. The results of the experiments provided answers to most of the problems posed by M. A. Lavrent'ev and led to a deeper understanding of the laws governing the motion of vortex rings in a viscous fluid. On the basis of the experimental results a mathematical model of the phenomenon was constructed to account for and describe the motion of a turbulent vortex ring and the transfer of impurities by the ring traversing a uniform incompressible viscous fluid.