Nanjundappa Rudraiah (1932–2019)

Professor N. Rudraiah (NR), former Vice-Chancellor of Gulbarga University, Kalaburgi, INSA senior scientist and honorary Professor (for life), Department of Mathematics, Bangalore University, Bengaluru passed away on 19 September 2019 in Mysore leaving behind a large circle of admirers and lovable students. He lost his wife (Manonmani) in 2011 and is now survived by his son and two grandchildren. He was an exemplar and highly committed to his teaching and research profession throughout his life and an institution builder. His demise has brought an end to the era of a dedicated applied mathematician of international repute.

Rudraiah, fondly known to his students and admirers as NR was born on 18 August 1932 in Bellave village of Tumkur district, Karnataka. He graduated with an M Sc, degree in Mathematics from Central College in Bengaluru, University of Mysore (then) having completed the B Sc (Hons.) from the same college. He then did M A in Applied Mathematics from the University of Toronto, Canada and obtained his Ph D in 1964 from the University of Western Ontario, London, Canada. NR joined the Department of Mathematics of Central College, Bangalore University as Lecturer in 1964 and became Reader in Mathematics in the University of Mysore in 1965. Next year he was appointed as Professor in the Department of Mathematics of Bangalore University and by his hard and dedicated work he established a strong research group in fluid mechanics by attracting a number of talented students. He had several funded projects from UGC, DST, CSIR, INSA, DAE, DRDO, ISRO and other funding agencies and pursued quality research in different areas in fluid mechanics. He did collaborative research on interdisciplinary areas with several leading researchers all over the world and enabled his students to follow suit. Being a visionary, he established a centre for advanced study in fluid mechanics funded by the UGC in 1980. Due to the sustained research activities of the centre, UGC continued its support for three decades. Under this programme, he attracted students from all over the country to pursue their research and also visitors from India and abroad. He also conducted innumerable training programmes for young researchers in the country and initiated them to basic research. National and international conferences and workshops organized by him attracted researchers from all leading research institutes of the country and abroad.

He made immense contributions to various areas of fluid mechanics. Linear and nonlinear convection in single and multicomponent fluid systems in both fluid and porous layers is one of the major areas in which he worked extensively and contributed significantly. Emphasis was laid in estimating the amount of heat and mass transfer in fluid flow which are found to be important in the extraction of geothermal energy. In the study of multicomponent fluid systems, the importance of various observable evidences was also accentuated in detail such as cross-diffusion, radiation, thermal modulation, volumetric heating, chemical reaction, Coriolis force due to rotation, electric force due to applied electric field and the Lorentz force due to applied magnetic field. Some innovative results were uncovered in connection with multicomponent convection involving rotation and/or magnetic field. He successfully used regular and singular perturbation techniques in the study of magnetoconvection problems and studied forced and free convection in a vertical layer of porous medium. By realizing the importance of non-Newtonian behaviour of fluids in various circumstances, he concentrated on the studies of convective instability by considering various types of non-Newtonian fluids namely, viscoelastic fluids, couple stress fluid, micropolar fluid, power law fluid and so on. He initiated work on convection in magnetic fluids and nanofluids because of their applications in industrial problems particularly in understanding the control of heat transfer. In addition, he used different types of basic temperature gradients to know their impact on the onset of convection along with other mechanisms. The work on turbulent convection in porous media was also commenced and more importantly chaotic convection in porous media was studied numerically by developing algorithms, numerical codes and packages. Another field of investigation was Marangoni and combined Bénard–Marangoni convection in fluid/porous layer under the influence of various additional effects.

Another frontier area of research in which he worked on is the stability of fluid flows in fluid and porous layers. His work on the stability of heterogeneous flows in the presence of geomagnetic field paved the way to establish a new semi-circle theorem explaining the growth of frequency of disturbances in the atmosphere. An analog of the Richardson number in magnetohydrodynamics was also established by NR. The universal stability of stratified rotating superposed conducting fluids was analysed along with hydromagnetic stability of compressible fluids and the nonlinear stability of helical flows. Investigation was carried out to comprehend the interaction among the Tollmien–Schlichting–Stuart mechanism of instability due to shear and aligned magnetic field and Rayleigh–Bénard–Thompson mechanism of instability due to thermally unstable stratification and aligned magnetic field in a horizontal conducting fluid layer. He also developed a deep interest and fascination for flows under the influence of electric and magnetic fields in spite of branching out to several areas of fluid mechanics. As late as 2009, he carried out research on surface instabilities of electro- and magneto-rheological fluids. He showed that it is possible to delay and even prevent the onset of Rayleigh–Taylor instability if the fluids can be polarized by an electric field and if the applied field is sufficiently strong.

NR worked extensively on flow through and past a porous medium as the porous material can be used as an effective insulation which finds application in many industrial problems like gas cooled reactors as they involve high temperature and pressure. The main crux in dealing with these problems lies in finding a proper boundary condition at the porous surface. He modified the Beavers–Joseph (BJ) slip boundary condition and proposed a condition that takes into account of the thickness of the porous material which later came to be popularly known as the Beavers–Joseph–Rudraiah (BJR) slip boundary condition. This condition was found to be of use in biomechanical problems. Both experimentally and theoretically he demonstrated that the mass flow through a channel could be increased by placing a porous lining on its side walls and established a limit for the thickness of the porous lining.

He also worked on convection in finite enclosure with differentially heated side walls and insulated horizontal walls, a standard model problem aptly describing many important heat transfer applications. As a result, convective flow and associated heat transport processes in a rectangular enclosure under different thermal boundary conditions have been analysed including the influence of magnetic field through streamlines and isotherms. In addition, he also worked on the combined surface tension and buoyancy-driven convection in a rectangular enclosure in the presence of magnetic field using various numerical techniques. The results of this work undertaken in collaboration with the New Government Electric Factory (NGEF) were used in the manufacturing process of dry type electric transformers.

One of the fields in which NR carried out pioneering research is internal Alfven-gravity waves in stratified electrically conducting shear flows in the presence of rotation and/or magnetic field. The presence of magnetic field was found to give rise to more critical levels in an infinite fluid system and he established that as the Alfven-gravity waves cross these levels they deposit certain amount of their energy in the vicinity of these levels and an estimate of these depositions was obtained. This phenomenon was extended to various physical configurations such as rotating, dissipative and compressible systems. He established that the presence of magnetic field increases the deposition of energy by the internal Alfven-gravity waves in the vicinity of critical level. When the fluid is finitely conducting singularities disappeared from the wave equation but continued as Stokes points for the solution and still the critical level phenomena continues.

For the first time in the literature, he demonstrated the existence of valve-like critical levels for internal gravity waves in symmetric systems which hitherto were known to exist only in systems that possess an inherent asymmetry in the system. Further, he continued to establish that all critical levels are valve-like critical levels only irrespective of the systems. In other words, he showed that the ordinary critical level coalesces with the reflection level whereas in the case of valve-like critical levels they exist separately. These findings were published in a series of articles in the *Journal of Fluid Mechanics*.

He also concentrated working on atmospheric pollution problems. He developed many atmospheric diffusion models for point source, area source and line source and solved many time-dependent mathematical models of primary and secondary pollutants emitted from the point source with removal mechanisms like gravitational settling, wet deposition, chemical reaction, leakage, etc. He also developed numerical models of primary and secondary pollutants emitted from the area source for the urban region. He demonstrated the effect of mesoscale wind, called local wind, generated in the urban region. He also developed interest on problems of bio-fluid dynamics. The study of dispersion of red blood cells, white blood cells and platelets in blood plasma with couple stress brought out the rheological anomalies associated with blood flows. The work on the realistic rheological problems, incorporating the non-Newtonian characteristic of the blood and the resistance offered by the cells to the flow was also carried out and the results obtained by him were of immense use to the society at large as he was.

NR guided 54 students towards their Ph D and all are well placed in various leading institutions all over the world. He has published over 300 research papers in journals of high repute and wrote text books, monographs and 15 review articles. He was an elected fellow of all the three science academies of the country (FNA, FASc, FNASc), Fellow of the Institute of Mathematics and its Applications (FIMA) of the United Kingdom and Fellow of United Writers Association (FUWA). He was also a recipient of the FICCI gold medal and cash award, Kyushu Institute of Technology (Japan) international award for foreign researchers, William Mong Research award of the University of Hong Kong (Hong Kong), Karnataka State Rajyotsava award in the field of education and many more such awards. He was elected Vice-President and President of Indian Society of Theoretical and Applied Mechanics (ISTAM) and President of Mathematics Section of 76th session of the Indian Science Congress Association as well as Vice-President of Indian Society of Biomechanics. NR was an able and strict administrator as well. The Gulbarga University reached new heights in all its dimensions during his six-year tenure as the Vice-Chancellor. He has left an indelible mark on the university for years to come. His administrative responsibilities never deterred him from the academic research. Discipline was his buzzword and punctuality was his habit and he inculcated them into everyone of Gulbarga University. He was member of several UGC and DST committees that include the Shanti Swarup Bhatnagar prize committee and UGC commission.

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