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Bengal School of Fluid Mechanics: Nineteenth and Twentieth Century

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Abstract

Fluid Mechanics is an important area of research in Applied Mathematics. Fluids are broadly classified as Newtonian and non- Newtonian fluids. Starting with the trend-setter Sir Asutosh Mookerjee, Bengal under the leadership of Calcutta University has a long tradition of mathematical research in the area of fluid mechanics. Amongst the prominent researchers in this field, Sir Asutosh Mookerjee published two papers in Newtonian Fluid Mechanics and initiated research in this area. Dr. B B Datta worked on stability of vortices of compressible fluids and on motion of spheroids in infinite fluid. Professor S K Banerji studied discontinuous fluid motion under different thermal conditions. He also inspired many students to work in various topics like tidal oscillations in canals, motion of viscous fluids etc. Professor N R Sen did pioneering research in the field of turbulence. Professor N N Sen made important contributions in the field of tidal oscillations in canals and stability of vortex rings. Dr. R N Bhattacharyay did notable work in the field of ship waves. Professor A S Gupta has made very significant contributions in the field of stability of flows of Newtonian and non- Newtonian fluids and Magnetohydrodynamics. He as well as Professor S K Banerji, Professor N R Sen and Professor B B Sen have been instrumental in building strong schools of research in fluid mechanics in Bengal.

Key words: Rectilinear Vortices, Tidal Waves, Turbulence, Vortex Rings, Viscous Fluids and Magnetohydrodynamics

1. Introduction

The fluid is a substance which is defined to be an aggregation of molecules. It is a substance which is capable of flowing. So the mechanics of fluid is a very important area of research in the field of Applied Mathematics. Fluids are broadly classified as Newtonian fluids and Non-Newtonian fluids. The fluids in which stress components are linear functions of rate of strain components are termed Newtonian fluids. If the stress components are non-linear functions of the rate of strain components, the fluids are called Non-Newtonian.

A brief discussion on the state of research in fluid mechanics in the western world in the late nineteenth and early twentieth century would be of interest. In fluid mechanics, it was Sir Isaac Newton 1642-1727) who was the first mathematician to consider the resistance to an object moving through air or liquid in his famous treatise *Principia* (1687). In the same treatise, he also considered the motion of water waves. Daniel Bernoulli (1700-1782) in his book *Hydrostatics* (1738) gave a lucid and consistent account of the subject. The book also contained the famous "Bernoulli's law" which relates pressure and velocity in an incompressible fluid and also takes into account a number of its consequences. In 1755, Leonhard Euler (1707-1783) deduced the equations of continuity and momentum for a frictionless fluid. He was the inventor of the fixed "Eulerian" coordinate system in fluids. He derived

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the above mentioned equations in this system as well as in a "Lagrangian" coordinate system that moves with the fluid. Later on J L Lagrange (1736-1813) took up the subject. He, P S Laplace (1749-1827) and A L Cauchy (1789-1857) developed the theory of velocity of fields generated by a potential. In 1821, L M H Navier first deduced the stress tensors for a viscous fluid and laid the foundations for the famous Navier - Stokes equations. In 1829, S D Poisson (1781- 1840) did the same. Up to this time basic flow equations and their properties were deduced. This led to the development of the theory of partial differential equations.

The period from 1840 to 1920 is remarkable in the history of the development of fluid mechanics. In 1845 G G Stokes (1819-1903) with the help of basic mechanical principles re-derived Navier's results. Stokes also made fundamental contributions for an incompressible, inviscid fluid. The theory of water waves and tidal waves were also successfully developed during this period. Vortex motion was another topic which was developed during this period. The study of vortex motion was initiated by H V Helmholtz in 1858. In a research paper in 1869, it was simplified and further developed by Lord W T Kelvin (1824-1907). H Lamb, the author of the famous treatise on hydrodynamics also made notable research contributions in wave motion and vibrations. His paper on oscillatory modes of an elastic sphere and on propagation of surface waves on a sphere were very fundamental contributions in theoretical seismology.

Both Newtonian and Non-Newtonian fluid mechanics made a tremendous impact on the Begnal School of Mathematics in Fluid Mechanics.

The first two research papers in Newtonian fluid mechanics in India, were published by the great pioneer mathematician *Sir* **Asutosh Mookerjee (1864-1924)** towards the end of the nineteenth century. At a time when very little was known about original research in India, Asutosh, practically trained himself up singlehandedly by studying books, treatises and memoirs of great mathematicians and confidently embarked upto the path of scientific investigations. His keen interest in physical phenomena led him to the serious study of the works of the German mathematician R F A Clebsch (1833 - 1872). Clebsch made important contributions in the general theory of curves and surfaces, their uses in geometry, in the theory of invariants and in elliptic functions. The theories that he developed, were applied by him to various physical problems. Asutosh was immensely attracted by such exercises and was drawn to Hydrokinetics.

In his student days Sir Asutosh had extensively studied the classical treatise on fluid dynamics by H Lamb namely "*A treatise on the Mathematical Theory of Motion of Fluids*".

In his first paper in fluid mechanics, entitled "On Clebsch Transformation of the Hydrokinetic Equations" *JASB*, 59 (1890):56-59, Sir Asutosh considered hydrokinetic equations in three cases. They are irrotational motion, steady rotational motion and general rotational motion. He showed in his own research paper, how Clebsch's transformation to the third case may be simplified.

The second of his two research publications was entitled "Note on Stoke's Theorem and Hydrokinetic Circulation" *JASB*, 59(1890):59-61. In this paper Sir Asutosh gave a new proof of Stoke's formula of Hydrokinetic Circulation using Clebsch's transformation. Both the papers are analytical in nature and Sir Mookerjee's contributions in this regard are as important as those of Clebsch. With the publication of these two papers, Sir Asutosh Mookerjee became a trend-setter in the field of fluid mechanics.

Many talented mathematicians who served the newly set up department of Applied Mathematics of the University of Calcutta or who

were students of that Department have made remarkable contributions in the field of Fluid Mechanics. Notable among them are Dr. B B Datta, Professor S K Banerji, Professor B M Sen, Dr. S Ghosh, Dr. N N Sen. These great stalwarts did pioneering work in various branches of fluid mechanics. Some of them also inspired, encouraged and successfully guided students who in later years made very important contributions in the same field. The names of Professor A S Gupta, Professor H P Majumdar, Professor B N Mandal etc. bear testimony to this fact. The contribution of individual mathematicians who have made a mark in the Bengal School of Fluid Mechanics is discussed in detail.

In 1917, Sir Asutosh brought a very talented young mathematician named **Bibhuti Bhusan Datta (1888-1958)** as a lecturer in the newly set up Department of Mixed Mathematics. Soon after joining the Department, B B Datta, undertook serious research work in various branches of Applied Mathematics. In 1921, he was awarded the D.Sc. degree by the University of Calcutta for his outstanding research contributions in the field of hydrodynamics, a branch of fluid mechanics.

Some of his notable research publications in fluid mechanics are

- "On the stability of the rectilinear vortices of compressible fluids in an incompressible fluid", *PM* 40(1920):138-148.
- "Notes on vortices of a compressible fluid" *PBMS* 2(1920):1-9
- "On the stability of two co-axial rectilinear vortices of a compressible fluid" *BCMS* 10.4(1920):219-220
- "On the periods of vibrations of straight vortex pair" *PBMS* 3(1921):13-24
- "On the motion of two spheroids in an infinite liquid along their common axis of revolution" *AJM* 43(1921):134-142

Dr. B B Datta did some more work related to the motion of spheroids in infinite fluid. But unfortunately, these works were not published. However Dr. Datta's contribution in this field is quite rich.

Dr. S K Banerji (1893-966), another stalwart of the Department of Applied Mathematics, Calcutta University who served as the Rashbehary Ghosh Professor of Applied Mathematics from 1917–1921 also made notable contributions in the field of Fluid Mechanics. He has studied discontinuous fluid motion under different thermal conditions. He has investigated vortices of the monsoon front, aerial waves generated by impact and also the effect of mountain ranges on air motion. He has investigated spherical waves of finite amplitude, and also vibrations of elastic shells partly filled with liquid. (*IJP*, *Nature* 122, *PM* 32, 35, *PR* 13, *BCMS* 11).

- "The effect of the Indian mountain ranges on air motion" [*IJP* 5(1930):385].
- "Discontinuous fluid motion under different thermal conditions" with V N Ghatage [*IJP* 7(1932):165-228].

Some of his important research papers in this area are:

- "On surface waves and tidal waver near a promontory" *BCMS* 10.1-4(1918 – 1919):1-10
- "On the wave equation in ellipsoidal coordinates" *BCMS* 10.4(1918)179-186.

In the first paper Professor Banerji has used the theory of multiform solution as developed by Sommerfeld to solve the problem of diffraction of Surface Waves by a long promontory which for simplicity has been assumed to be either a semi-infinite plane bounded by a straight edge or a wedge forming a definite angle. The nature of the tidal waves on the flat rotating sheet of water near a promontory has also been determined by

him. His paper was "Spherical waves of finite amplitude produced by the sudden explosion of a detonating gas contained within a spherical envelope" *BCMS* 12.1-4(1920–1921):1-4. Encouraged and guided by Dr. S K Banerji, his scholar Sasadhar Dasgupta wrote and published the following important research paper dealing with tidal oscillations. The paper is titled "Some cases of tidal oscillations in canals of variable section" *BCMS* 10(1918):105-115.

Bholanath Pal has studied motion of an elongated spheroid and also of an ellipsoid of revolution in viscous fluid in the paper "On the motion of an ellipsoid of revolution in a viscous fluid in the light of Professor Oseen's objection to Stoke's treatment of the case of the sphere" *BCMS* 10(1918):81-93.

Under Professor S K Banerji's suggestions and guidance Bijon Datta published the interesting research paper entitled "On the steady motion of a viscous fluid due to the rotation of two rigid bodies about arbitrary axes" *BCMS*, 10.1-4 (1918-1919):43-61. Professor B M Sen published the important paper dealing with tidal oscillations entitled "Tidal oscillations on a spheroid" B*CMS* 15.1-4) (1924-1925):69-78.

Professor N R Sen was a brilliant student of the Department of Applied Mathematics. He served the Department as the Rashbehary Ghosh Professor of Applied Mathematics from 1924 to 1959. He made important contributions in the field of Fluid Mechanics. In the early stages of his career N R Sen worked on wave-propagation. He published "The equation of long waves in canals of varying section" *PM* 48(1924):65 and "Note on the propagation of waves in an Elastic Medium" *BCMS* 16(1926):9-14. Later on Professor Sen considered a number of problems of gas dynamics, boundary layer theory and turbulence. He pioneered research in the field of turbulence. While studying Heisenberg's spectrum of isotropic turbulence, he investigated the consequences, using Heisenberg's form of the transfer term of assuming different kinds of similarity, which necessarily cannot embrace values of the wave number k in the dissipation range except in the case energy spectrum function during decay. The resulting research papers are:-

- "Note on pressure relations within fluid spheres in equilibrium" *BCMS* 36 (1944):147 -152.
- "On Heisenberg's spectrum of turbulence" *BCMS* 43 (1951).
- "On the decay of energy spectrum of isotropic turbulence" *PNISI* (A) 23 (1957): 530
- "Isotropic Turbulence preserving similarity" *JIMS* (N.S.) 24 (1961):515.

Many students were influenced by Professor N R Sen and took up research in the field of Fluid Mechanics. One of his students **H K Ganguly** published two papers in 1939 entitled "On a steady configuration of Rotating Heterogeneous fluids" *BCMS*, 31 (1939): 68-76 and "On the equilibrium configuration of a rotating fluid envelope surrounding a rotating core" *BCMS* 31 (1939):127-136.

Another student of Professor N R Sen, Dr. N L Ghosh published the following research papers in Fluid Mechanics:

- "A note on the equilibrium of fluid matter in a steady differential rotation" *BCMS* 39 (1947):131-138.
- "A note on Hamy's theorem" *BCMS* 40 (1948):229-230.
- "On the equilibrium of a thin atmosphere round a heavy central core: spheroidal and anchor – ring configurations" *BCMS* 44 (1952): 22-26.

Professor **Suddodhon Ghosh** was a luminary of the Department of Applied Mathematics of Calcutta University. He was a

brilliant product of the said department and also served the Department as a faculty member for many years. His main area of research was solid mechanics, but he made some notable contributions in the field of fluid mechanics too. His important research publications are "On liquid motion inside certain rotating circular arcs" *BCMS* 15.1-4(1924-1925):27-46 and "The steady rotational motion of a liquid within fixed boundaries" *BCMS* 19(1928):59-66.

Another brilliant student of the Department of Applied Mathematics of Calcutta University was **Nripendranath Sen**. He was much inspired by Sir Asutosh Mookerjee and took up research in fluid mechanics. He obtained his D.Sc. degree in Applied Mathematics in 1923. He published a number of papers in hydrodynamics dealing with tidal oscillations in canals with varying depths and breaths. He also worked extensively on vortex rings and their stability in compressible and non- compressible liquids. He also investigated liquid motion inside certain curvilinear rectangles. He has also studied the motion of a viscous fluid due to the rotation of two spheroids about the common axis of revolution, the motion of two spheroids in an infinite liquid and certain higher order tides in canals of variable section. Some of his noteworthy publications are:

- "Vortex rings of finite section on liquid motion inside certain curvilinear rectangles and certain analytical theorems connected with that problem" *BCMS* 11.1-4 (1919-1920):7-20.
- "On some problems of tidal oscillations" *BCMS* 12.2: 71-290.
- "On the steady motion of a viscous fluid due to the rotation of two spheroids about their common axis of revolution" *BCMS* 13(1922-1923):17-1936.
- "On the motion of two spheroids in an infinite liquid" *BCMS* 13(1922-1923):53-70.
- "On circular vortex rings of finite section in incompressible fluids" *BCMS* 13(1922-1923):117-140.
- "Higher order tides in canals of variable section" *BCMS* 14(1923-1924)19-24.
- "On vortex rings of finite circular section in incompressible fluids" *BCMS* 14(1924):247-254.
- "On the stability of vortex rings of finite circular section in incompressible fluids" *BCMS* 15.1-4(1924-1925):159-172.
- "On vortex rings in compressible fluids" *BCMS* 17.1(1926):29-50.

Inspired by Professor S Ghosh and Professor N R Sen of the Department of Applied Mathematics, Calcutta University, **K K De** has investigated vortex motion near semi-circular boundaries and infinite straight boundaries with semi-circular projection. His important publications are listed as follows:

- "On a case of vortex motion near semi-circular boundaries and infinite straight boundaries with semi-circular projection" *BCMS* 21(1929):197-202.
- "On an extension of Blasius's Theorem" *BCMS* 45.1-4(1953):121-124.
- "Resistance of an infinite cylinder due to two-dimensional motion past the cylinder, of a fluid having uniform velocity", *BCMS* 46(1954):81-85.

Another student of N R Sen, inspired by his famous guide made substantial contributions in the field of fluid mechanics. **M Ray** has considered problems on a wide variety of situations and some of his publications are as follows:

- "On the problem of the stability of a circular vortex" *BCMS* 27(1935):45-54.

- "Velocity and temperature distribution in a liquid flowing over an infinite plate: boundary layer theory" *BCMS* 44(1952):137-141.
- "Variation of temperature due to small steady disturbances in a compressible flow" *BCMS* 44(1953):45-49.
- "Turbulent flow in a plane wave of a compressible fluid" *BCMS* 46(1954): 129-134.
- "Boundary layer in a perfect gas over a flat plate under pressure gradient" *BCMS* 49.1-4 (1957):130-138.

In this context, it would be apt to discuss the contributions of another great mathematician, Professor **Bibhuti Bhusan Sen**. B B Sen, a brilliant student of the famed department of Applied Mathematics of the University of Calcutta like Professor S Ghosh made enormous contributions in the area of solid mechanics. But his contributions in the field of fluid mechanics are also noteworthy. He made two notable publications in the field of fluid mechanics and guided several students, who did excellent work in this area. Professor B B Sen published two papers entitled "Note on the application of trilinear coordinates in some problems of elasticity and hydrodynamics" *BCMS* 27(1935):73-85 and "Note on the flow of viscous liquid through a channel of equilateral triangular section under exponential pressure gradient" *RRSTSMA* 9(1964):301-307] in the field of fluid mechanics.

Among Professor Sen's student **Professor S K Datta** was also an alumni of the Department of Applied Mathematics of the University of Calcutta. He worked mainly on non – Newtonian fluid flow. His two notable publications are "Flow of Non-Newtonian fluid through an annulus with porous walls" *BCMS* 52(1960):155-162 and "Laminar flow of Non-Newtonian fluid in channels with porous walls" *BCMS* 53(1961):111-116. Later on Dr. S K Datta left for U.S.A. and still works there.

Another student of Professor B B Sen was Ashim Ranjan Sen. Dr. A R Sen obtained his Ph.D. in fluid mechanics under the guidance of Professor B B Sen. He worked on problems related to deep water waves. His noteworthy publication in this area is "Problems of deep – water waves – Part I, The exact and asymptotic solutions" *BCMS* 52(1960):127-146.

Rabindra Nath Bhattacharya another famous student from the department of Applied Mathematics, University of Calcutta did very good work in fluid mechanics. He studied problems related to waves produced by a pressure system moving with an acceleration over the surface of deep water due to the accelerated motion of a pressure system. He also studied problems on wave resistance of various kinds. His notable publications are:

- "Waves produced by a pressure system moving with an acceleration over the surface of deep water" *PNISI* 22 A (3) (1956).
- "Generation of fluid motion by a source moving parallel to and slightly below the free surface of a fluid" *ISBP* 5.48(1958).
- "Wave resistance of a ship moving in a circular path" *PNISI* Pt. (A) 24(1958).
- "Shallow water effect on wave resistance of a ship moving in a circular path" *PNISI* 28(A) 5 (1962).
- "Further analysis of ship waves" *ISBP* 13.139 (March 1966).
- "Wave resistance from the rate of dissipation of energy: some cases of uniformly moving point disturbances" *JSER*, 7.1 (1968).
- "Wave resistance and their forces and moments of a hovercraft and a flat ship" *TMS*, 42.2 (1974)].
- "Irregular dispersion of waves and group acceleration" *JMPS* I2.6 (1977).

- Chakraborty, R, Bhattacharya, RN – "Curvature effect on the wave resistance of a thin ship". – [Schiffstechnik, 1978, 25].
- Basu, Iva, Bhattacharya, R N. "Note on the principle of stationary phase" *CPC*, 16 (1979):167-173.
- Goswami, Bandana and Bhattacharya, R N. "Waves in deep water due to the arbitrary motion of a pressure area along any curved path on the undisturbed free surface" *ISBP*16.177 (May 1969).

Sudhir Ranjan Khamrui, a student from the famed department of Applied Mathematics was inspired by Professor Suddodhan Ghosh, the legendary teacher and mathematician of the same department and took up research in fluid mechanics. Later, when Dr. Khamrui started working in the Department of Mathematics of the Jadavpur University, he was inspired by another legendary mathematician namely Professor B B Sen. Professor Khamrui's important publications are given below:

- "On the flow of a viscous liquid through a tube of elliptic section under the influence of a periodic pressure gradient" *BCMS* 49.1-4(1957):57-60.
- "On the slow steady motion of an infinite viscous liquid due to the rotation of a cylinder" *BCMS*, 49.1-4(1957):61-66.
- "On the oscillation of a circular cylinder in a viscous liquid contained in a coaxial circular cylinder" *BCMS* 52(1960):45-50.
- "On the slow steady rotation of a spheroid of small ellipticity in a viscous liquid"*BCMS* 52(1960):63-67.

Now the contributions of some very talented students of the Department of Applied Mathematics, is discussed who made very important contributions in the field of fluid mechanics working in the later part of the twentieth century.

Gaganbehari Bandyopadhyay, a bright student from the Department of Applied Mathematics, University of Calcutta took up faculty position in the I.I.T, Kharagpur. He worked on a variety of problems in various branches of mathematics. He did some significant work in the field of non-Newtonian fluids. Given below are some of his notable publications in this area:

- "Couette flow formation in an elasto-viscous fluid" *PTCTAM*, Dec, 1957.
- "Some transformation of compressible flow with heat transfer" *PSMRF*, I.I.T, Kharagpur, April, 1958.
- "Adiabasy and Periodicity in heat conducting gas" *PFMS*, Bangalore, Aug., 1959.
- "Unsteady rectilinear flow of non-Newtonian fluids" *PUSNPP*, Roorkee, 1959].

One of Professor G Bandyopadhyay's famous student is **Anadi Shankar Gupta**. A brilliant student of the Department of Applied Mathematics, University of Calcutta, after completing his M.Sc. degree, A S Gupta joined IIT Kharagpur. He got his Ph.D. degree in Fluid Mechanics working under the guidance of Professor G Bandyopadhyay. For his outstanding contributions in Fluid Mechanics, Professor A S Gupta is a living legend in his own life time. Professor A S Gupta has made significant contributions in the field of Magnetohydrodynamics and the stability of flows of Newtonian and non-Newtonian fluids. His analysis of steady and transient free convection in an electrically conducting fluid [ASR, A 9(1960) 319] past a hot surface in the presence of a transverse magnetic field reveals that the field causes a reduction in the surface heat flux. This result is in agreement with the experimental findings of A F Emery [*JHT*, Trans A.S.M.E., Ser C (1963) 119]. Dr. A S Gupta and P S Gupta also showed that homogeneous and heterogeneous chemical reaction result in a reduction of longitudinal (Taylor) diffusion coefficient of a

solute dispersed in laminar channel flow [*PRSL*, A, 330(1972):59]. His corresponding analysis in the Magnetohydrodynamic case [A S Gupta and N Annapurna : *PRSL*, A, 367(1979):281] reveals that a uniform transverse magnetic field results in a reduction of Taylor diffusion coefficient of a solute dispersed in laminar flow of a conducting fluid in a channel.

Dr. Gupta [A S Gupta and L N Howard : [*JFM* 14(1962):463] derived general stability criteria for non-dissipative swirling flows of incompressible non-conducting as well as electrically conducting fluid permeated by magnetic fields. It is shown that for a swirling flow of a perfectly conducting fluid between two concentric circular cylinders in the presence of an axial current, a sufficient condition for stability with respect to axisymmetrical perturbations is that a suitable Richardson number modified to take account of the axial current is nowhere less than one fourth.

Dr. Gupta's of investigations on the flow of Newtonian and visco-elastic fluids with particular reference to their flows over a stretching surface have important applications in the polymer processing and metal working process. Stability of the flow of a viscous fluid over a stretching surface was also analysed by Dr. Gupta [A S Gupta and S N Bhattacharya, *QAM*. U.S.A., 42(1985):359]. They showed that the flow was stable. The linear stability of two viscous electrically conducting fluids separated by a plane interface and permeated by a sheared magnetic field parallel to the interface was studied by S N Bhattacharya and A S Gupta [*JFM*, 509(2004):125]. In this paper it has been shown that if the magnetic field vanishes at the unperturbed interface, the configuration is always unstable for zero surface tension provided the magnetic diffusivities of the two fields are different. Apart from his own contributions, Professor A S Gupta has guided a number of students who have done very good research in Fluid Mechanics. Here we shall briefly describe the contributions of his different students, to give an idea about the kind of research that they have done.

Dr. L Rai studied the stability of a visco-elastic fluid [L Rai and A S Gupta, *PCPS*, 63(1967):527] down an inclined plane. In this paper, it has been shown that viscoelasticity exerts a destabilizing influence on the flow.

Dr. B S Dandapath studied the nonlinear evolution of the surface wave instability of a viscoelastic fluid flowing down an inclined plane. (B S Dandapath and A S Gupta, RA (U.S.A.) 36(1997):135). In this investigation, it has been found that the evolution ultimately leads to a train of solitary waves whose number decreases with increase in the viscoelasticity of the fluid.

Dr. G C Layek investigated the flow of an incompressible viscous electrically conducting fluid in the presence of a uniform transverse magnetic field in a channel with constrictions [G C Layek, A S Gupta, T Roy Mahapatra and C Midya, *JFE* (U.S.A.) 125(2003) 952]. In this paper it has been shown that the flow separates downstream of the constriction. With increase in the magnetic field, the flow separation zone diminishes in size and for large magnetic field, the separation zone disappears completely. The results of this study have important bearing on blood flow through constricted arteries.

Stability of hydromagnetic Dean flow between two arbitrarily spaced concentric circular cylinders in the presence of a uniform axial magnetic field was investigated by **Dr. T R Mahapatra** [with A S Gupta and S Dholay, *Physics Letters* (U.S.A.) A 373(2009):4338]. It has been found that electrically non-conducting walls are more destabilizing than perfectly conducting walls. The critical radius ratio for which there is a transition from axisymmetric to asymmetric mode of existability is determined for various values of the magnetic field.

Dr. M Reza showed that when there is a uniform shear of a conducting fluid past a porous plate in the presence of a uniform transverse magnetic field, steady flow exists for suction as well as blowing at the plate [M Reza, A S Gupta and J C Mishra, *ZAMP*, 56(2005):1030]. This remarkable result has relevance to the problem of transpiration cooling.

Dr. S Sengupta studied the effect of rotation on onset of thermohaline convection in a layer of viscous fluid heated from below and subjected to a stable salinity gradient. [S Sengupta and A S Gupta, *ZAMP*, 22(1971):906]. In this investigation, it has been shown that rotation exerts a stabilizing influence on the flow and the marginal state oscillatory. Further for disturbances of finite amplitude, it is found that subcritical instability is possible.

Several brilliant students from the Department of Applied Mathematics joined the Indian Statistical Institute and did very good research in the field of fluid mechanics. Notable among them are Professor Ambarish Ghosh and Professor H P Majumder.

Professor Ambarish Ghosh, a well-known student of the Department of Applied Mathematics, joined the ISI, Kolkata in a faculty position. In 1961, while doing research work in Paris, Ambarish Ghosh published the research papers in French entitled "Contribution á l'ê tu de de la couche limite laminare instationaire",[*Publications scientifiques et Techniques du Ministêre de l' Air*, 381: 325-368].This particular work has been cited by many other researchers. The paper has been translated into English by Klaus Gersten and published in the book entitled "*Boundary layer theory*" by Hermann Schlichting; Springer Verlag, 1996.

Some of Professor Ambarish Ghosh's other important publications are:

- "Superposition of convective oscillations and viscous oscillations near a vertical wall" *BCMS* 63.1-4(1971):51-55.
- (with P Bhattacharyya) "On the boundary layer inside the conical surface of a Hydrocyclone" *BCMS* 64(1972):193-204.
- (with P Bhattacharyya) "On turbulent boundary layer inside the conical surface of a Hydrocyclone" *BCMS* 65(1973):145-157.
- (with K D Debnath) "Stationary rectilinear vortices in the corner of plane walls meeting at right angles" *BCMS* 66.2 (1974):91-99.
- (with P Bhattacharyya) "Turbulent boundary layer on the conical surface of a Hydrocyclone and its behaviuor on entering the solid body rotating liquid – Part I" *BCMS* 71(1979):221-234.
- (with P Bhattacharyya) "Turbulent boundary layer on the conical surface of a Hydrocyclone and its behaviuor on entering the solid body rotating liquid – Part II" *BCMS* 71(1979):283-294.
- "A study of flow field in a Hydrocyclone" *PSAC*, (1983):518-522.
- (with K D Debnath and A K Majumder) "On the flow in a rectangular cavity" *IJPA* 14.5 (1983):646-660.

H P Majumder, another student from the Department of Applied Mathematics, University of Calcutta joined the ISI in Kolkata and he has done a lot of good research in the field of fluid mechanics. Most of his research papers deal with turbulence and related matters. His list of seventy four publications are attached at the end of this article. But here the more important publications are identified. He has also done some work in the field of blood flow – which depicts mathematical modeling in Biomathematics, using techniques of fluid mechanics.

- (with A K Chakraborty) "On the inertial energy spectrum of turbulence in a reacting gas", *MRC*, Pergamon Press 14.5-6 (1987):317.

- (with A K Chakraborty) "Some remarks on a stably stratified turbulent shear flow" *ICHMT*, Pergamon Press, 15(1988):163.
- (with L N Persen and H Qiann) "The round thermal jet: undisturbed and in cross flow" *IJHMT* 36.6 (1993):1589.
- (with S C Ghosh) "Acceleration correlation in a homogeneous turbulent flow possessing helicity" *PSRSAS* 48(1993):458.
- (with N Islam and A Chanda "A mathematical model for turbulent bubble plume", *PSRSAS* 53(1996):575-581.
- (with U N Ganguly, S Ghorai and D P Dolai) "On the distributions of axial velocity and pressure gradient in a pulsatile flow of blood through a constricted artery" *IJPA*, 27.11(1996):1137-1150.
- (with J Lahiri and A K Chakraborty) "Effects of temperature dependent viscosity on an incompressible fluid flow over a stretching sheet" *JTAFM*, 2.1-2(1999-2000):41-49.

Sujit Kumar Bose another brilliant product of the Department of Applied Mathematics stood first class first from the University of Calcutta in 1959. He has investigated diverse problems of hydraulic flow, wave phenomena etc using the mathematical theories of Fluid Mechanics. Two of his notable research papers published in the end of the twentieth century are worth mentioning, first with S Dey and G L N Sastry entitled "Clear water scour at circular piers: a model" *JHEASCE*, 121.12(1995):860 – 875 and second with S. Dey entitled "Bed shear in equilibrium scour around a circular cylinder embedded in loose bed" *AMM*, 18.5 (1994):265-273.

A trend in research which was first started by Sir Asutosh Mookerjee more than hundred years back has taken deep roots in the mathematical arena of Bengal and a brief survey, as exposed above gives an insight into the valuable contributions of the famed mathematicians who have been nurtured by the University of Calcutta.

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Abbreviation

AJM-American Journal of Mathematics

AMM-Applied Mathematical Modelling

ASR-Applied Scientific Research (Holland)

BCMS-Bulletin of the Calcutta Mathematical Society

CPC-Computer Physics Communications

ICHMT- International Communication Heat Mass Transfer

IJHMT- International Journal of Heat Mass Transfer

IJP-Indian Journal Physics

IJPA-Indian Journal of Pure and Applied Mathematics

ISBP-Inst. Ship Building Progress

JASB –Journal Asiatic Society of Bengal

JFE- Journal of Fluids Engineering

JFM- Journal of Fluid Mechanics

JHEASCE-Journal of Hydraulic Engineering, American Society of Civil Engineers

JHT- Journal of Heat transfer

JIMS-Journal of Indian Mathematical Society

JMPS-Journal of Mathematical and Physical Sciences

JSER- Journal of Science and Engineering Research

JTAFM - Journal of Theory and Applied Fluid Mechanics

MRC-Mechanics – Research Communication

PBMS-Proceedings of the Benaras Mathematical Society

PCPS- Proceedings of Cambridge Philosophical Society

PFMS-Proceedings of Fluid Mechanics Symposium

PM-Philosophical Magazine

PNISI- Proc. National Institute of Sciences of India

PR-Physics Review

PRSL-Proceedings of Royal Society London

PSAC-Proc. of the Second Asian Congress, Beijing

PSMRF-Proceedings of the Symposium on Mechanics of Real Fluids

PSRSAS-Physica Scripta, Royal Swedish Academy of Sciences

PTCTAM-Proceedings of the third Congress on Theory and Applied Mechanics

PUSNPP- Proceedings of the UNESCO Symposium of non-linear Physics Problems.

QAM- Quarterly Applied Mathamatics

RA-RheologicaActa

RRSTSMA- Rev. Roum. Sci. Tech. Ser. MechaniqueAppl

TMS-The Mathematical Student

ZAMP-Zeit. Ang. Math. Phys. (Germany)

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