1945-2020
MECHANICAL ENGINEERING
INDIAN INSTITUTE OF SCIENCE

Indian Institute of Science
भारतीय विज्ञान संस्थान

75 years of the Department of
Mechanical Engineering

Foreword

Mechanical Engineering activities at the Indian Institute of Science commenced formally in 1945 with the establishment of the Department of Internal Combustion Engineering that later merged with the subsequently created Mechanical Engineering department.

On this important milestone of 75 years of Mechanical Engineering at IISc, we look back through this booklet that encapsulates the history of the department, some of its important activities over the years, and its more recent research directions. Needless to say, it is impossible to have a complete description of the activities of a department over such a large time period condensed in an objective manner into a small booklet. The goal of this booklet is therefore not to be exhaustive, but to act as a reference and marker to capture some of the salient points in the history of the department and its present, and has been done through a series of articles put together by the Office of Communications with input from many past and present faculty members and alumni of the department. To all these contributors of the articles and the Heritage Committee of the department that has worked hard for the past year, I would like to express my deepest and sincere thanks. Without their efforts and that of the former chair of the department, Prof. Ananthasuresh, over a very difficult year through the COVID-19 pandemic, this booklet would not have been possible.

I hope this booklet, in a small way, conveys the sense of excitement and pride that many faculty and students of the department have felt over the past 75 years.

Raghuraman N Govardhan
Professor and Chair
1 January 2022

Members of the ME Department in 1985

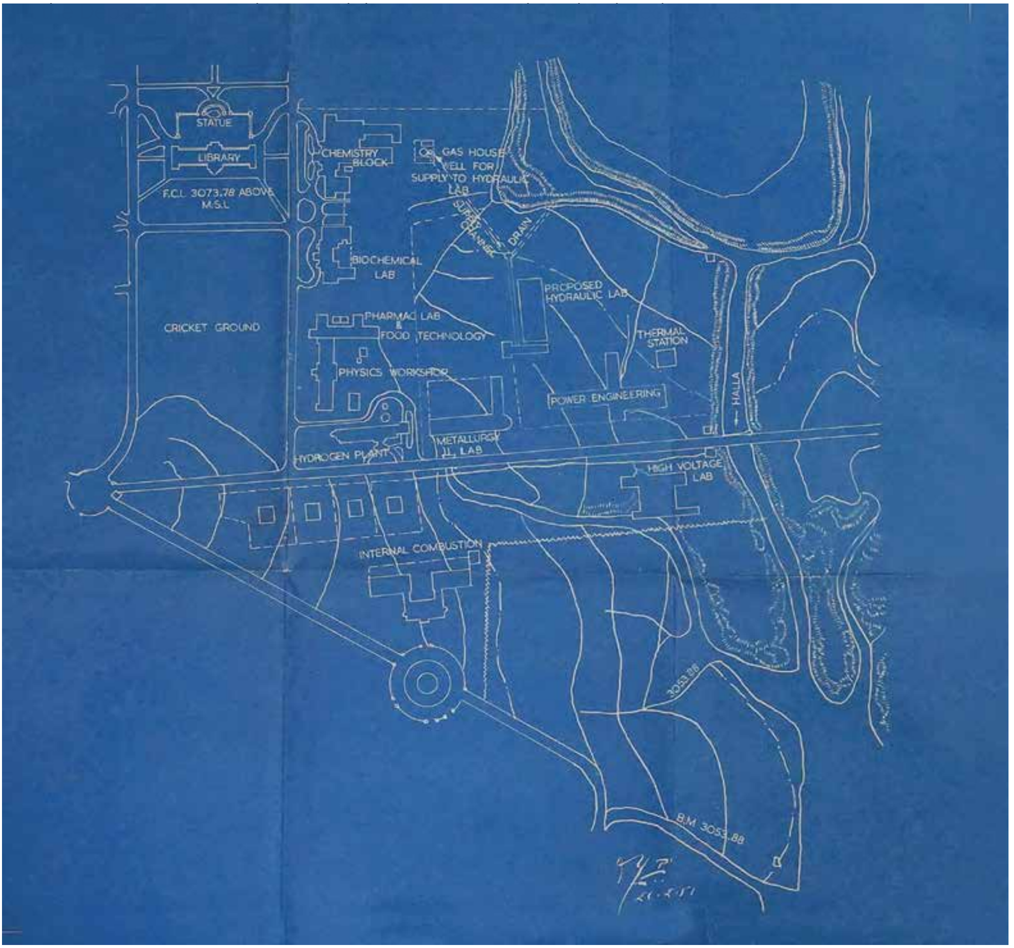
Making Things Work:

75 Years of Mechanical Engineering

By Ranjini Raghunath

Times were tough for IISc in the 1930s. It faced a serious cash crunch – income from both the Mysore Government and JN Tata's Bombay properties had dwindled. World War II was looming on the horizon. Criticism was growing that the Institute was focusing too much on "pure sciences" like physics and biochemistry, and doing too little of the applied research that Tata had originally wanted. Courses in engineering other than electrical engineering were "completely ignored in the early life of the Institute," according to Sir M Visvesvaraya, former president of IISc's Court.

To rectify this neglect, a Joint Committee of the Council and Court members was set up in 1940. This committee recommended, among other things, the establishment of a central workshop that would deal with "problems of design and construction of industrial plants for various manufacturing processes." It also suggested that "as soon as funds become available, a Department of Mechanical Engineering be established at the Institute."



Plan for a proposed hydraulics laboratory in 1951, showing the location of different wings including Power Engineering and Internal Combustion Engineering that would eventually merge to form the ME Department

But the Department wasn't set up right away – even though related courses like applied mechanics and hydraulics, and heat engines were taught to students as early as in the 1930s. Its forerunners were the departments of

Internal Combustion Engineering (ICE) and Power Engineering (PE) – the latter had a separate Mechanical Engineering section – established around 1945-46. These two merged into what is now the Department of Mechanical Engineering (ME) during the 1970s.

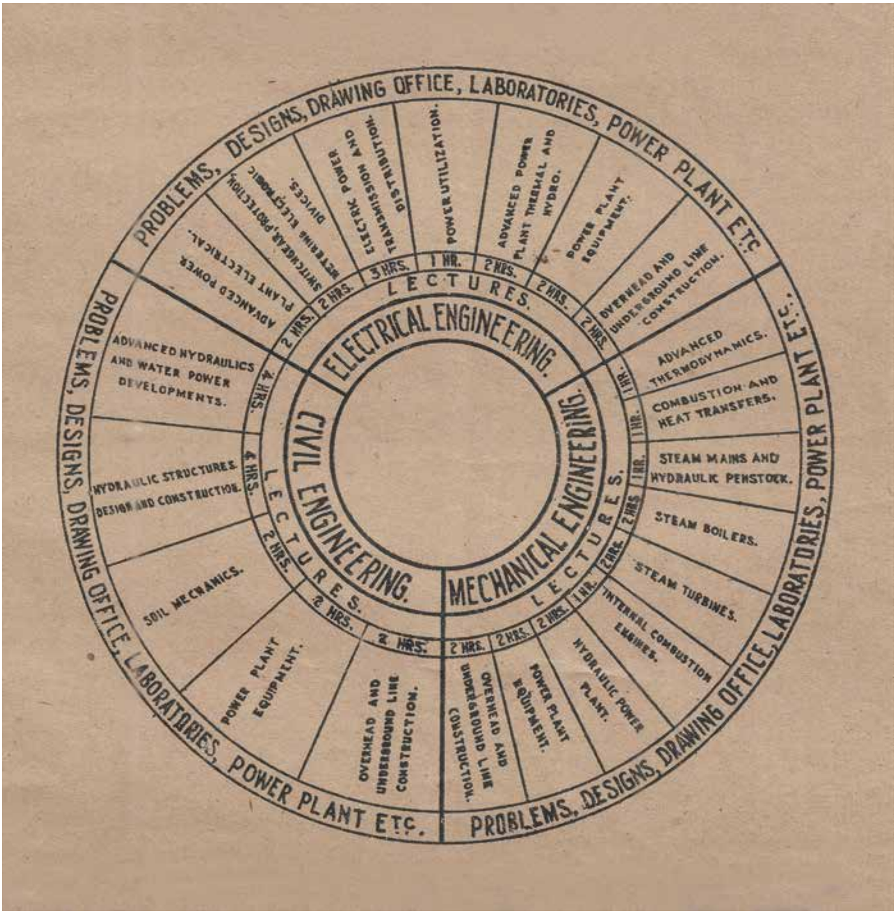
Over the past 75 years, research at ME has spanned a wide range of areas, from engines, foundry and heat transfer to more recent interdisciplinary explorations such as robotics and biomechanics. Its faculty members have led and participated in national and international initiatives related to energy, acoustics and design. At home, they have also helped establish many of IISc's departments and centres, including Sustainable Technologies, Product Design and Manufacturing, Nano Science and Engineering, Energy Research, BioSystems Science and Engineering, Continuing Education, Industrial and Scientific Consultancy, even the JN Tata auditorium, points out GK Ananthasuresh, faculty member and until recently the Chair of the Department.

"Our department has been a quiet force, but I would also call it quite a force," he says. "It has had a tremendous impact on the campus."

Engines and energy

The impact of World War II on the Institute was enormous. "The War that is going on," Visvesvaraya once announced to the IISc Court, "is a mechanical engineer's war." Industry-relevant research got a shot in the arm, and new courses on aerospace engineering and metallurgy were added. A new Department of Internal Combustion Engineering (ICE) was also set up in 1945, and Major BC Carter was appointed to head both ICE and the central workshop.

During the early years, ICE researchers extensively tested and designed various types of engines and their components, working together with industry partners on collaborative projects nurtured by the newly formed Council of Scientific and Industrial Research (CSIR). Around the same time that ICE was set up, a new Department of Power Engineering (PE) was also established, to support the electrical power projects that mushroomed across the country after the war. Its foundation stone was laid in 1947 by former Cabinet Minister Syama Prasad Mukherjee, and the building was inaugurated by Rajendra Prasad, the then President of India, in 1951. MS Thacker, who would go on to become IISc's Director, was appointed its first head. A few years later, it was bifurcated into an Electrical Engineering and a Mechanical Engineering section.



From a 1945 memorandum on a proposal to establish Power Engineering. Proposed curriculum for first year students

From the early days, the emphasis on hands-on learning was heavy. Students built equipment and machines that they needed for their projects on their own in the workshop. A full-fledged thermal power station was also set up on campus to train students in operating and maintaining it round the clock.

In 1950, Arcot Ramachandran joined IISc as an assistant professor, and later became the head of the Mechanical Engineering section. By all accounts, he was a trailblazer. He kick-started research on heat transfer and thermal sciences, which helped spawn major programmes on energy research across the country. He was also an exceptional administrator who is said to have introduced many new programmes and courses like nuclear engineering and machine design. "The Department owes a lot to Arcot Ramachandran," says J Gururaja, a former student who also worked with Ramachandran in later years. "He was always looking beyond the current state of affairs at that time: What new branches can there be? What new areas can we start? Who were the competent people available?" Ramachandran was even tipped to become IISc's Director – Satish Dhawan was eventually appointed – before moving on to head IIT Madras, and later the Government of India's newly established Department of Science and Technology (DST).

To this day, heat transfer and energy research – which Ramachandran pioneered – continue to be an important part of the Department's focus. More recent research has focused on thermo-chemical storage, combustion and spray research, refrigeration technologies and heat management in spacecraft systems. Many ME faculty members also helped establish and continue to be associated with the Interdisciplinary Centre for Energy Research at IISc, which is pursuing innovative research on solar power, supercritical carbon dioxide-based power generation, and clean coal technologies.

Changing directions

A few years after Ramachandran left IISc, the Department's focus shifted. In the early 1970s, Dhawan brought LS Srinath, the head of the Mechanical Engineering Department at IIT Kanpur, to IISc and tasked him with merging ICE and the ME section into a single Department of Mechanical Engineering. "He [Srinath] was interested in creating an integrated approach to mechanical science. That is how the division [of mechanical sciences] was founded and he became the first Chairman," says Gururaja.

Soon after the merger, the Department became involved in a crucial social experiment. In the early 1970s, science and technology institutes in the country were severely criticised for not doing enough to address rural problems, and for focusing solely on urban challenges. Faculty members at IISc, including many from ME, lobbied the Institute administration, and as a result of their efforts, the Cell for the Application of Science and Technology to Rural Areas (ASTRA) was set up in 1974. It mobilised the development of many rural technologies – biogas plants, low-carbon housing, and small-scale fertiliser industries, to name a few. Several extension centres were also set up in villages near Bangalore to train local people to become self-reliant. Many of ASTRA's early initiatives were assigned as ME student projects. ASTRA later evolved into the Centre for Sustainable Technologies, which continues to work on rural development.

Similar to ASTRA, another initiative called SuTRA (Sustainable Transformation of Rural Areas) was led by former faculty member Udipi Shrinivasa in the 1990s. It was created as an independent programme unit under IISc's Society for Innovation and Development. The aim was to implement developmental projects in a set of villages surrounding ASTRA's extension centre in Ungra village, Tumkur district. An important outcome from SuTRA was the development of biodiesel from non-edible seeds including *Pongamia*. Other projects involved building rainwater harvesting structures, using satellite maps to spot locations for drilling borewells and preserving perishable agro products by dehydration.

Yet another socially relevant initiative that ME researchers were involved in was the development of microhydel power generators which use turbines to generate electricity. An ultra-low head propeller turbine ideal for flat terrains was developed and installed near Mandya, Karnataka. Several cross flow turbines were also installed in various parts of the country, including Kedarnath and Arunachal Pradesh.

ME also made critical contributions to industry in two key areas. One was the development of cast-iron crankshafts to replace forged crankshafts in automobiles in order to reduce production cost by 30-40%. Another was work on industrial acoustics, particularly on mufflers and silencers to reduce noise in vehicle exhaust, an area pioneered by faculty member Manohar Munjal. He and others in the Department worked on several industry projects related to noise control and vibration, even stealth technologies for Indian Navy submarines and silencers for limiting cockpit noise in a fighter aircraft. Manohar has also advised the government on defining noise control norms and policies, and was instrumental in setting up a research hub called the Facility for Research in Technical Acoustics (FRITA) at ME in 1998. "He defined technical acoustics for the country," says Ananthasuresh.

New designs

Back in the 1930s, as the Institute was struggling to strengthen its financial situation, one of the cost-cutting measures proposed was the setting up of a central workshop "to avoid unnecessary duplication of staff and equipment." Over time, this facility became especially indispensable for ME students.

Many of them would spend hours each day toiling away at the workshop, designing and assembling parts and equipment that they needed for their projects. Manufacturing and design continued to remain an important part of ME, and in 1996-97, the Department started a two-year Master's in Design programme. This led to the transformation of the central workshop into the Centre for Product Design and Manufacturing (CPDM) with former faculty member TS Mruthyunjaya as its first Chair. CPDM is now deeply involved in developing futuristic manufacturing technologies, including India's first smart factory platform.

Around the same time that CPDM was launched, IISc also joined hands with Tata Consultancy Services (TCS) to start a first-of-its-kind for-profit venture called Advanced Product Design and Prototyping (APDAP) to provide design services for a slew of industry clients, including BHEL, TVS, GM India and DRDO. Its goal was to take a product from the drawing board all the way up to prototyping, and tying up with industry partners for large-scale manufacture. The initiative was largely driven by faculty members from ME.

Towards the close of the century, research on robotics and autonomous systems also picked up steam. Snake-like robots useful in search and rescue, and surgery; crawling robots to inspect pipes in hazardous conditions, and more recently, touch-based tools to cut tissue and carry out surgical procedures have all been developed. A start-up called Mimyk with roots in ME has also developed an ingenious endoscopy simulator to train medical students and doctors without using human subjects.

In 2004, with funding from DST, DRDO and the Ministry of Mines, the Department set up a National Facility for Semisolid Forming (NFSSF). A few years later, researchers working in this facility made a breakthrough: they developed an indigenous version of a process called thixocasting. In thixocasting, a metal is heated until it becomes partially liquid and injected under pressure; this makes it less viscous and improves the quality of the parts made from it. The technology has proved tremendously useful for manufacturing light-weight vehicle components, including parts for two-wheelers manufactured by TVS Motors.

In the past few decades, research at ME has become more interdisciplinary. One person who exemplified this spirit was former faculty member

Sanjay Biswas. Although originally known for his contributions to tribology, he also pursued research in areas as diverse as chemistry, nanoscience and bioengineering.

"Biswas was also an able administrator who knew how to excite people around him to take new initiatives, and then step aside when things were on the right track, only to move on to another initiative," his colleagues recounted after his passing in 2013.

An endoscopy simulator developed by Mimyk

In later years, he developed a keen interest in healthcare and began studying the mechanics of cell wall movement and cancer cell adhesion. He wanted to bring about a "radical change" in bioengineering and biodesign in the country. Biswas was among the first to start a bioengineering group at the Institute, bringing together IISc faculty members and medical doctors. His efforts played a pivotal role in the establishment of the Centre for BioSystems Science and Engineering (BSSE) at IISc.

Looking ahead

What does the future hold for ME? "We have a fairly long list," says Ananthasuresh.

In 2019, as part of an international peer review, ME was asked to assess its strengths and weaknesses, and identify areas where it needed to work on. It became clear that large-scale collaborative efforts anchored by the Department were lacking, more faculty members had to be recruited in core areas, Master's programmes needed to become more attractive, and industry networks had to be strengthened.

Ananthasuresh also points out several new research areas where the Department wants to break new ground: simulation technologies, food storage and transportation, automated agriculture, mobility engineering, space robotics and underwater exploration. New and exciting technologies are also on the horizon, he says. "Now we have cell and tissue mechanics, and biomedical devices, but we would like to go beyond that – artificial limbs, for example, that gel well with the nervous and muscular systems, and can integrate with the body."

Encouraging more women students and faculty members to join what has traditionally been a male-dominated field will also be important. "Right now, I am happy that we have three women faculty members in the Department," says Ananthasuresh. He points out that the field is "getting redefined in many ways," and moving beyond the misconception that mechanical engineers only "lift heavy weights and work with heavy machinery." "Traditional areas like refrigeration and air conditioning, power and heavy machinery have now become more R&D than fundamental research. Newer areas are emerging and more emphasis is being laid on computational modelling. So, we hope to see more women coming into the Department as students as well as faculty members."

Ranjini Raghunath is Communications Officer at the Office of Communications, IISc

Engines at IISc

By Narmada Khare

There once was a particularly popular department at IISc called the Department of Internal Combustion Engineering (ICE), and for close to a quarter of a century, the engineers there designed, constructed and tested a plethora of engines and engine accessories.

The Department of Internal Combustion Engineering as seen in a 1953 brochure

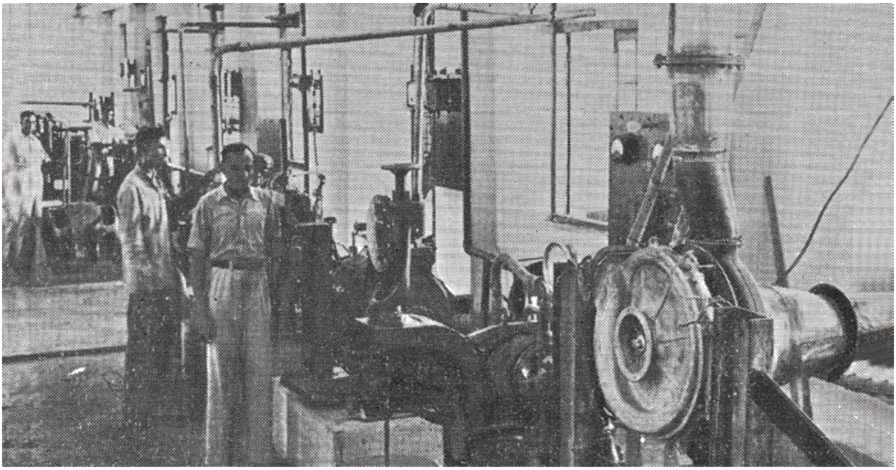
In its most basic form, an IC engine constitutes a chamber in which a mixture of air and fuel is injected. A piston plunges inward into the chamber to create very high pressure, causing the mixture to explode. This sudden explosion drives the piston back, initiating a chain of events: a crankshaft attached to the other end of the piston rotates, leading to the movement of gears, pulleys or hammers; essentially using the energy from the heat to move things. The shapes and sizes of each of these parts, the materials they are made of, the fuel used, the force with which it is injected into the chamber, the pressure imparted by the piston, the number of chambers, the number of explosions – all these factors (and more) contribute to the efficiency with which an engine generates power and moves a machine. There can be hundreds of moving parts in a machine. And when you turn an engine on, you start a chain reaction that eventually ends up turning the wheels of a car, or lifting the mechanical arm of a crane, or drawing oil out from deep seas.

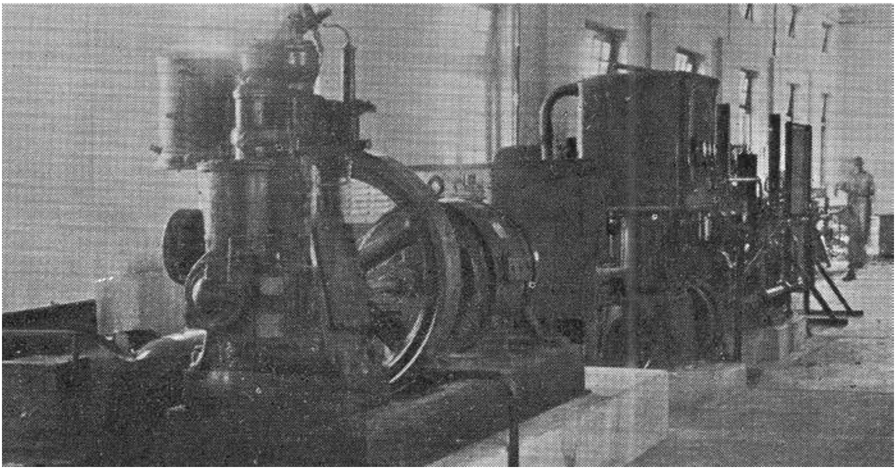
ICE at IISc

IISc did not enter the field of engine research until almost the end of World War II. In 1945, a new Department of Internal Combustion Engineering (ICE) was set up. It soon occupied the grey stone building at the southern entrance to the campus, which is now the Society for Innovation and Development.

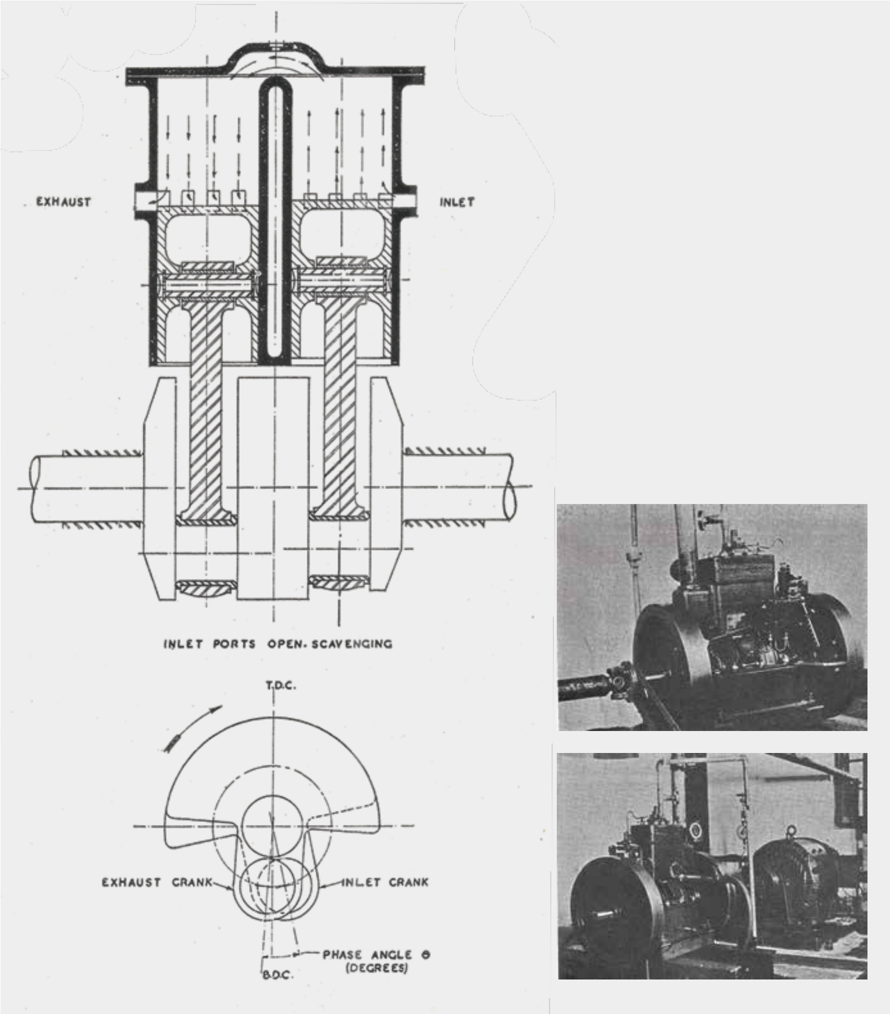
The 1944-45 Annual Reports record two developments that played a significant role in the establishment of the ICE Department. The first was the journey of Sir JC Ghosh (Director of IISc at that time) to England as a member of the Indian Scientific Mission. There, he discussed with experts from around the world about the need for new areas of research at the Institute. Upon their recommendations, he appointed Major BC Carter to teach the students at the Department of Aeronautical Engineering "the working of Internal Combustion Engines," thus sowing the seeds of a new department. The second was the decision of the Institute to start post-graduate programmes in Heavy Engineering, Power Engineering, Designing of Machinery, and Chemical Engineering, "in view of the post-war plans for the proper development of the resources of the country." From the get-go, researchers at ICE worked actively with their industry counterparts, testing and designing various types of engines and their components, housing them in a large hangar in the west wing, according to former faculty member V Kuppu Rao.

Many collaborative projects were carried out by ICE under the aegis of the fledgling Council of Scientific and Industrial Research (CSIR). One of these – led by HA Havemann, who succeeded Carter as the Department head, and VM Ghatage, Chief Engineer of Hindustan Aeronautics Limited (HAL) – focused on developing a fully indigenous six-cylinder engine for the HT2, India's first aircraft used to train air force pilots. Another of Havemann's projects centered on an engine using hot air as the working medium, which could prove useful in rural areas where organic fuels like firewood or charcoal were more abundant than gasoline or diesel.





The ICE laboratory in 1953



Design and development of a U-type two-stroke diesel engine

For the next 20-25 years, engineers at ICE invested efforts to indigenise foreign engines, to develop new engines using local material and indigenous fuels, and attempted to reduce the pollution that was always associated with the use of engines.

Examples of activities reported in the 1952-53 Annual Report give an idea of the diversity of the work carried out in the ICE laboratory: Testing of two Kirloskar engines for the effect of chromium plating on the piston ring, tests conducted on 'horizontal single cylinder engines' from Messrs Cooper Engineering Ltd to improve the geometry of the combustion chamber, development of 'twin fuel Diesel engines' to accept indigenous fuel and the installation and testing of a Derwent Mark V turbo-jet engine.

Indian industry at that time was rudimentary at best. Most engines and fuel were imported and expensive. The Department often received engines from outside sources for testing and analysis of parts. The Annual Reports describe how the stands on which engines were hoisted for testing often required significant realignment to accommodate foreign-made engines.

The engineers at ICE strove to create engines suited to Indian conditions. Indigenous fuels, vegetable oils and alcohol were tried out as cheaper replacements to imported mineral oil. Innovative techniques for manufacturing crankshafts were tried. Several observers have reported that in innovation and discovery, ICE researchers were at par with their counterparts in countries like Japan and Germany.

Less noise, more efficiency

Work in one area that considerably advanced the field was efforts to reduce the air and noise pollution caused by engines. N Raman, who joined the Department in the late 1960s and retired as a Principal Research Scientist in 2003, remembers how loud many of these engines were. "There are so many IC engines," he says. "A gas turbine is also an IC engine. We had a gas turbine section. It made a tremendous noise. It could be heard everywhere, even outside the campus. Finally, it had to be discontinued." Raman calls faculty member Manohar Munjal "one of the best in the world" in the field of acoustics; his research played a major role in reducing noise pollution. Raman himself studied tribology, the science of friction and lubricants. He worked with MV Narasimhan, a professor at ICE, on two-stroke engines that were "powerful, but very dirty." Their project to reduce air pollution and to increase fuel efficiency of the two-stroke engines was sponsored by the Department of Science and Technology, Government of India, and later the concept was handed over to TVS India.

Another important contribution of the Department was developing cast-iron crankshafts – the rotating parts that form the backbone of an IC engine – to replace forged crankshafts in automobiles, which were expected to cut down production cost by 30-40%. S Seshan, Professor Emeritus and former Chair of the Department of Mechanical Engineering (ME), who has worked at IISc for 36 years, explains, "The crankshaft is a critical component of any automobile, and mandates premium properties. It is a fairly intricate steel component, and is complicated and expensive to manufacture. Ever since the advent of automobiles (such as the Ford models), crankshafts were invariably produced, all over the world, through the hot forging process. Our department ventured into developing 'cast crankshafts', with the aim of reducing the weight as well as the cost, without compromising on the property standards. The availability of ductile iron and Austempered ductile iron served as yet another incentive for such an endeavour."

A model of the 2-stroke engine that was handed over to TVS India

Despite the promise offered by cast-iron crankshafts, for reasons that are lost to time, they did not end up in commercial use.

Winding down

Although ICE and the Department of Mechanical Engineering merged only in the 1970s, ICE seems to have struggled to acquire funding for several years before. As a 1953 brochure states, "[O]ther countries are spending a far greater amount on similar work, and unless sufficient help is forthcoming, both from the Government and private enterprises, it may not be possible to solve the numerous problems connected with and arising from, the quest for an indigenous IC Engines Industry in India."

The Annual Reports in the 1960s mention several collaborative projects between ICE and the ME section, until the merger. LS Srinath from IIT Kanpur's Mechanical Engineering Department was put in charge of this merger by Satish Dhawan. J Srinivasan, a former faculty member at the ME Department, says that the merger was recommended by an international review committee that didn't completely appreciate how rudimentary the Indian automobile industry was at that time. According to him, India still needed an academic department to study ICE. Seshan indicates that ICE was comparatively smaller in size and hence the growth potential (in terms of the number of students and faculty, and lab facilities) became somewhat constrained. Plus, many aspects were common in the curricula and courses of the departments of ME and ICE. Added to this was the slow development of the Indian automobile industry and inadequate career challenges for IC engineers. All the above lead to the merger of the two departments, for more effective common academic activities.

The ICE Department's legacy lives on in the labs of current faculty members RV Ravikrishna, who studies combustion and flow dynamics and develops technology for using biofuels, and T Naik, who focuses on renewable energy, biofuels and emission control in IC engines. Himabandu M, a senior scientific officer, is also involved in developing alternative biofuels and thermoelectric generators for hybrid vehicles.

With input from Connect Staff and ME students
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Exploring fluid mechanics and heat transfer

By Samira Agnihotri

Bifurcation of laminar buoyant jet

Fluid mechanics involves the study of fluids, gases and plasmas, and the forces that act on them. The field of heat transfer specifically focusses on the processes involved in the production, storage and transfer of heat energy. Both these fields of research have had significant applications to industry and to other disciplines of science such as biomedical engineering, agriculture, meteorology and biology, to name a few. A range of fluid mechanics phenomena like turbulent convection, drag reduction and boundary layer interactions are being studied within the Department using both experimental and computational techniques. Research on heat transfer and energy systems was initiated by Arcot Ramachandran, the first Head of the Department, in the 1960s. His pioneering initiative led to the establishment of major programmes in energy research across the country.

J Srinivasan, former faculty at the ME Department joined IISc in 1982, and his initial research was on radiation and convection. He also worked on solar energy, specifically the 'solar pond'. The water in a pond absorbs the sun's rays. The heat from this then evaporates from the top of the water surface through convection. Adding large amounts of salt to the water creates a salinity gradient that reduces convective losses. This creates a stable stratification to capture the solar radiation, the heat from which can then be used to provide energy for various purposes.

During this research, the team discovered an interesting phenomenon – the bifurcation of a jet in stratified medium. This was in collaboration with Jaywant Arakeri, Professor and former Chair of the Department, and former PhD student Anupam Dewan (now at IIT Delhi). This was a purely accidental discovery – that a freshwater jet when introduced into brine forms not a single entity but keeps bifurcating.

Later, Srinivasan's research slowly shifted to the atmospheric sciences. From 1995 onwards, he focussed on heat transfer in monsoon systems. "What makes it attractive is that fluid dynamics, heat transfer and thermodynamics interact in very complicated ways in the atmosphere. For example, the monsoon is driven by the sun's radiation, which creates a temperature gradient near the ground. This leads to convection which modifies the atmosphere, which in turn affects the way the sun's radiation reaches the ground. And when the clouds form, they too radiate heat. So, the monsoon is a complex interaction between radiation, convection, thermodynamics and a stratified medium which is the atmosphere," explains Srinivasan. "The single-process phenomena that we studied earlier in the lab were not as exciting for me anymore, and I have been studying the monsoon ever since. It is also of great practical importance to everyone," he adds.

He believes that in these times of global warming and climate change, renewable forms of energy like solar energy should be the primary focus for nations. Solar energy is now cheaper than other forms of fossil fuel-based energy. But in India, it has to be combined with hydro-energy. "We should become less and less reliant on coal and oil, and on imports of these. India should be energy self-sufficient," he states. "And we should also teach engineers about the consequences of their actions, their research, such as the discovery of oil and coal that has led to severe air pollution and damaged the health of millions of people in the long run," he concludes.

One of the largest groups in the ME Department, the thermal sciences and energy systems group has contributed significantly in basic and applied research. The newly founded Interdisciplinary Centre for Energy Research (ICER) at IISc emerged from this group's efforts. This centre handles some of the biggest projects in the Institute, namely the Indo-US solar consortium (SERIIUS), the National Centre for Combustion Research and Development (NCCRD) and the National Centre for Clean Coal Research and Development (NCCCR&D).

Faculty members Pradip Dutta and Pramod Kumar's research on supercritical carbon dioxide-based solar thermal plants gives India an opportunity to become a world leader in this next-generation technology, and to fulfil a major objective of the National Solar Mission which emphasises indigenous manufacturing.

Jaywant Arakeri and his group have studied turbulent natural convection since the 1980s. However, his involvement in the field of heat transfer began when he was asked to teach a course on the subject for Integrated ME students, earlier taught by Srinivasan. He was also influenced by the book by JS Turner on 'Buoyancy Effects of Fluids', now a classic text in the field.

Jaywant credits this interest to the encouragement of Srinivasan, and to the interactions with students. They advised many students together, one of whom was KR Sreenivas. Together they studied several interesting phenomena such as double diffusive convection, which was the underlying principle for research on the 'solar pond'. In this manner, Jaywant's field of research changed from regular fluid mechanics to heat transfer. Along with SA Theerthan, a former PhD student, he used liquid crystal sheets to study Rayleigh–Bénard convection. Their work established that line plumes near the surface are the dominant mechanism by which heat is convected away.

Jaywant and his students have also studied convection within a tall tube. "This was an accidental discovery by a summer student. If you suddenly upturn a tube with a gradient of salt in it, intricate patterns develop," he says. Through experiments to study this, they discovered a new type of turbulent flow. He has also worked on radial film flows to investigate what happens in an adverse pressure gradient. This research revealed the presence of nonlinear surface waves before the circular hydraulic jump. The team also discovered a new phenomenon of drop levitation near the hydraulic jump.

"I've worked on very diverse fields ... in some sense I've covered all non-dimensional numbers. It so happened that every few years I was getting into newer and newer fields, but the common thread has been transition and turbulence [in flows]. Most of my work has been experimental, and I try to keep the experiments as simple as possible. You get to see a lot of things which you wouldn't expect," states Jaywant. More recently, he has collaborated with Raghuraman N Govardhan on fish propulsion related problems and with Namrata Gundiah on arterial flows.

Since the 2000s, faculty members Raghuraman N Govardhan, Ratnesh Shukla, Gaurav Tomar and their labs have conducted research in experimental and computational fluid dynamics. Both the experimental and computational teams are now collaborating on a number of difficult and interesting fluid dynamics problems such as optimal surface actuation for drag reduction, thrust from rigid/flexible flapping foils for 'robotic fish', and biofluid mechanics involving flexible surfaces and unsteady boundary layers.

With input from ME students
Samira Agnihotri is Senior Editorial Assistant at the Office of Communications, IISc

A Quiet(er) Place

By Samira Agnihotri

In 1968, Manohar Munjal, an ME student in his fourth semester at the Department of Internal Combustion Engineering (which eventually became the Department of Mechanical Engineering) at IISc, was assigned his thesis topic: Analysis and design of exhaust mufflers for automobiles. This was a peculiar situation for him, as the subject had never been part of his syllabus. His friends, worried that this would harm his career, and risk his position as the class topper, urged him to go to the Department Chair and request that he be given a different topic.

Manohar Munjal with different types of silencers and ducts in his lab at IISc

But Manohar prided himself on taking up challenges and was not deterred. “After dinner, I went to the library, and in the catalogue, there was a journal called *Engineering*. In the index, I looked for the keywords ‘muffler’ and ‘silencer’. That’s how I started. During this process, I also came to know that practically nothing had been done on muffler acoustics,” he recalls.

When Manohar looked through the references cited in the papers, he found that the name of one book kept turning up: *Fundamentals of Acoustics* by Lawrence Kinsler and Austin Frey. Fortunately for him, he found two copies of it in the Department of Electrical Communication Engineering (ECE). “In 15 days, I studied the entire book, solved all the exercises in it, and that is how I taught myself acoustics. But it still didn’t tell me what happens with sound waves travelling in a silencer,” he says.

Manohar therefore came up with general design criteria for silencers, which did not exist back then. He developed an algebraic algorithm for describing the acoustics of tubular mufflers using problem solving techniques such as transfer matrix multiplication and mathematical induction, in an age that predated not just computers but also calculators. This was considered a breakthrough in the field of automobile acoustics.

Manohar soon developed a niche for himself in the field. After he graduated, he continued as a lecturer at IISc, and became an Assistant Professor in 1973. Currently an Emeritus Professor, AICTE Distinguished Chair and INSA Honorary Scientist, his work kickstarted research on the acoustics of silencers and ducts in India.

Mufflers

Manohar explains why automobiles and commercial generators need mufflers. “In an engine, the piston is sucking in air and pushing it out very rapidly; this sends out very strong pressure waves into the system, and this produces a lot of noise.” There are two types of mufflers – absorptive and reflective. In the first type, the acoustic waves pass through an absorptive material and lose energy. This energy is converted to heat, resulting in a silencing effect.

The reflective muffler is also known as an impedance mismatch muffler. Impedance refers to the interference in the passage of sound waves due to obstructions or differences in the medium. Most of the sound gets reflected in such situations. “If someone is drowning and I shout, they won’t be able to hear me, as the characteristic impedances of water and air are very different. Sound travels at different speeds in the two media, and there is a strong mismatch,” Manohar adds. Reflective mufflers use this phenomenon by including a series of structures within them that result in multiple impedance mismatches. In such mufflers, some of the sound is reflected back at every step, resulting in a loss of energy and the required dampening of sound.

A joint quest for quietness

One of Manohar's colleagues at IISc, BS Ramakrishna, a professor at ECE, was renowned for his work on electrical and architectural acoustics. Ramakrishna was like a guardian figure for DN Raju, who in the 1970s and 80s was exploring the uses of vermiculite, a mineral that expands at high temperatures, and could therefore be used as an insulator. One of the goals of his company, Vermiculite India Private Limited, was to investigate the mineral's applications in industrial noise and heat control. Ramakrishna put Manohar in touch with Raju. "That was how our association began – to see if vermiculite could be used in silencers," says Raju, whose work impressed Manohar. "Raju was very creative and gave shape to our ideas. I was a theoretician, and once I told him what I needed, he would come back in some time with beautiful sketches for fabrication," Manohar says.

From left: Manohar Munjal, Jasjit Ahluvalia of IAC Acoustics and DN Raju during the US leg of the study tour for setting up FRITA, 1996

During the 1990s, when Manohar was a member of the Science and Engineering Research Council (SERC) at the Government of India's Department of Science and Technology (DST), he gave a talk about quieter technologies and the importance of acoustics in engineering and machine design. This was an eye-opener for DST, and they sanctioned Rs 1.25 crore to set up a Centre for Excellence in Technical Acoustics at IISc. They had one condition though – a minimum of 15% of the total cost should come from industry. And so, the Facility for Research in Technical Acoustics (FRITA) was born, in collaboration with Raju as the industry partner. One of the landmark projects that they worked on together was with Tata Motors. "It was the first of its kind for the country to make a large anechoic chamber where even a truck could enter. The chamber was fully designed by FRITA, and the acoustic wedges required for it were also designed and tested at the FRITA facility. It was made fire-proof using vermiculite based coating, and is in use even to this day at Tata Motors," says Raju. Another memorable project was with the Central Pollution Control Board (CPCB). In the 1980s and 90s, diesel generators were commonly used in commercial establishments as there were frequent power cuts. But these generators were very noisy and produced a lot of fumes, and the onus to find a solution to these issues was on the user. In 2001, CPCB contacted IISc to find a permanent solution to this problem. After many iterations, Manohar and Raju made a novel prototype of a generic acoustic enclosure for generators that did not affect the wattage, had ventilation for the combustion, and also reduced the noise. It took them almost one-and-a-half years to convince genset manufacturers – including big names such as Birla Yamaha, Honda and Ashok Leyland – to adopt the technology.

Silencers under the sea

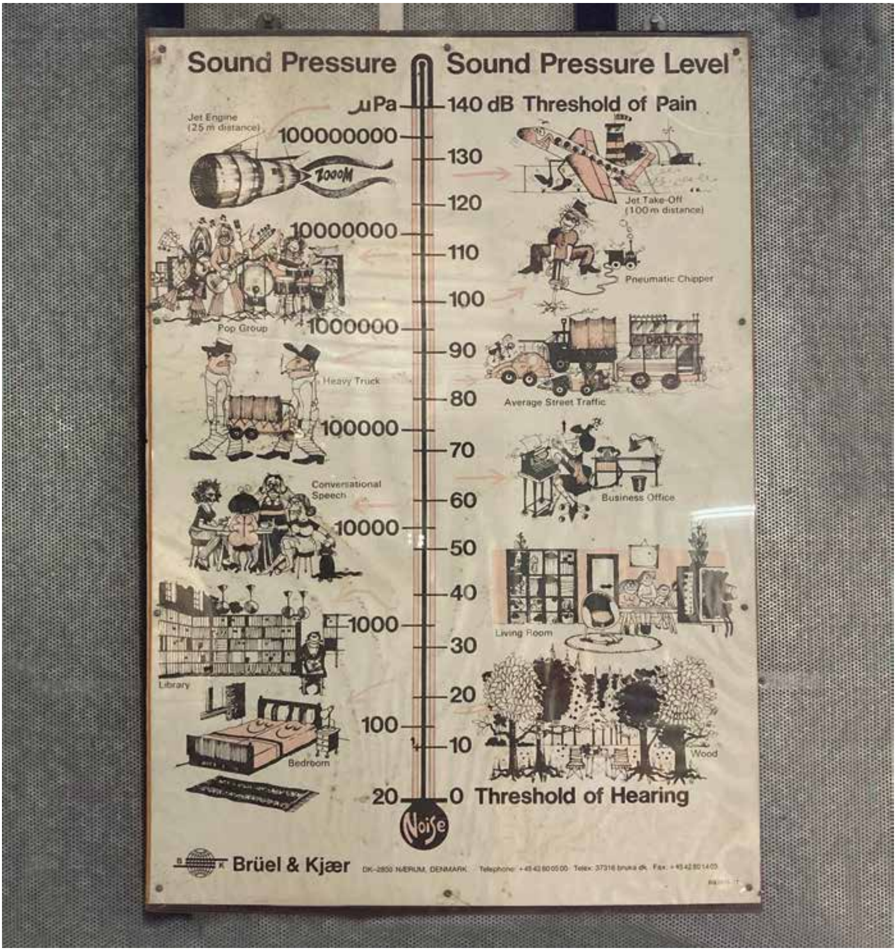
Manohar's algorithms for the design of mufflers have had other applications too. One of these was in reducing breakout noise through ducts, such as those in air conditioning and ventilation systems. Over the years, he has been teaching architects about breakout noise through these ducts, and how it can be used for industrial snooping.

When the Indian Navy was looking for ways to reduce the sound of underwater propellers, so that it couldn't be picked up by enemy sonar, they contacted Manohar through Ramakrishna. In collaboration with former ME faculty member Vijay Arakeri, Manohar worked on the noise characteristics of marine propellers and self-noise of underwater bodies. Later, Manohar was asked to work on acoustic propagation across lined hulls. "I did not know anything about submarines or underwater acoustics," he recounts. But he took up this challenge too, and developed indigenous and cost-effective stealth linings for submarines that could absorb the sonar pings of enemy ships. "Visible light and electromagnetic waves cannot move far underwater. Detection and stealth under the sea is all through the use of acoustic waves. In association with my research student Satya Narayana Panigrahi, I was able to do some pioneering work in this field for the country."

Manohar Munjal and DN Raju after signing the contract for FRITA, 2000

Noise control

Noise is measured as the sound pressure level in decibels (dB). The relative loudness of sounds in the air as perceived by the human ear is expressed as A-weighted decibels or dBA. Normal human speech is typically around 55 to 60 dBA – a shout is 75 to 80 dBA – while the sound from an automobile without a silencer is 120 dBA. "At 130 to 135 dBA, you will feel as if someone is piercing a needle through your ear, and 155 dBA can render you permanently deaf," says Manohar. He describes their very first project in noise control, in response to an enquiry by the Fertiliser Corporation of India's branch in Sindri, in Bihar. The plant used air at very high pressures for the chemical reactions to make fertilisers. The noise when this air was released through the exhaust vent was unbearable, enough to damage the ear drums. Even though these vents were placed at a height of 20 metres, the din was still too much. "When we went there, we found that there was not a single bird in the entire area. They had either died or flown away. That day, I realised how our human actions can be so cruel, knowingly or unknowingly, to the creatures around us." Manohar's silencer designs, which brought about a reduction of 50-55 dB in the noise generated, are being used by those factories even today.



A guide to sound pressure and its levels displayed in Manohar Munjal's lab

As the long-term Chair of the National Committee for Noise Pollution Control, Manohar was also instrumental in setting up guidelines for the noise limits that vehicles can produce. Any new vehicle that produces a pass-by noise of more than 74 dB cannot get a road-worthiness certificate. After several complaints were made to the National Green Tribunal about these deliberately tampered silencers, and other sources of noise like loud pneumatic horns, the Karnataka State Pollution Control Board was called upon to respond, and Manohar was once again roped in as the expert. Also in attendance were the Bangalore Development Authority, the Bruhat Bengaluru Mahanagara Palike and other public agencies. A report based on these discussions was released in July 2021.

"Reduction in noise means longer-lasting and better machines. Other benefits [of quieter technologies] on the quality of life and on aural health are perhaps not as tangible, but equally important. Prof Munjal took it upon himself to go to every industry and talk to their engineers," says Raju. "We must have reduced thousands and thousands of dB together, for the country."

Samira Agnihotri is Senior Editorial Assistant at the Office of Communications, IISc

The wake behind a foil having a flexible tail, "swimming" rightward in still water. The flow is visualised using a fluorescein dye and a sheet of green laser light

Mechanics of Life

By Karthik Ramaswamy

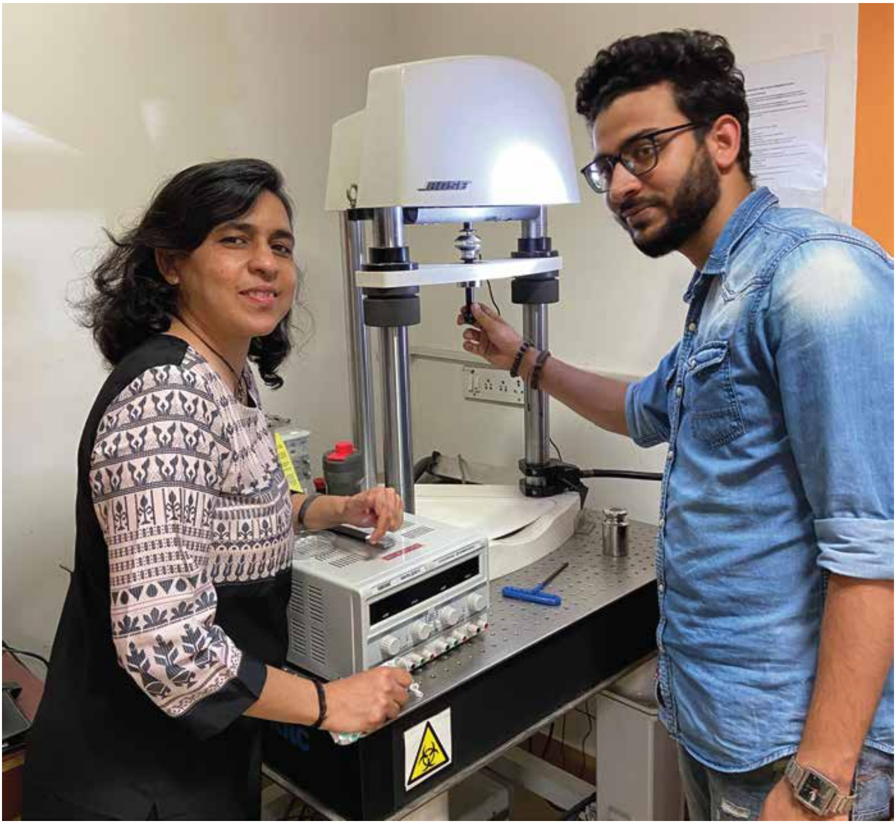
Most mechanical engineers do what we think they do – design and fabricate aircraft, machines, and other such human-made objects. But it turns out that some members of their tribe are also curious about how living things work.

One of them is Namrata Gundiah, Professor in the Department of Mechanical Engineering, who has taken on the challenge of addressing problems in biology using her training in mechanics.

Elastin and collagen

When Namrata began her PhD at the University of California, Berkeley, she was drawn to a class of rubber-like proteins secreted by cells in certain tissues that allow them to undergo large and cyclic deformations. Elastin is one such protein responsible for the "stretchiness" of tissues.

This led Namrata to investigate what happens to elastic tissues in the human cardiovascular system – specifically arteries and the heart – when they are damaged during disease. "When I, in collaboration with a cardiac surgeon, saw how damaged tissues adapt following injury, I was fascinated with how the cellular processes could contribute to changes in the tissue properties. Exploring changes to tissue properties after disease then became the subject for my postdoc for a two-year period."



Namrata Gundiah and her doctoral student Anshul Shrivastava studying hydrogels

Namrata decided that if she were to study how tissue properties change during disease (and how to design engineering solutions to handle disease), then she would have to use a "mechanobiology approach." This emerging field of science, which brings together physics, engineering and biology, attempts to understand how mechanical properties affect the fates of cells and development of tissues. Today, mechanobiology has become an integral part of her research. The questions Namrata's lab is addressing in the realm of cell-based mechanics are how cells adhere to the substrate, how they respond to mechanical cues, and how they migrate.

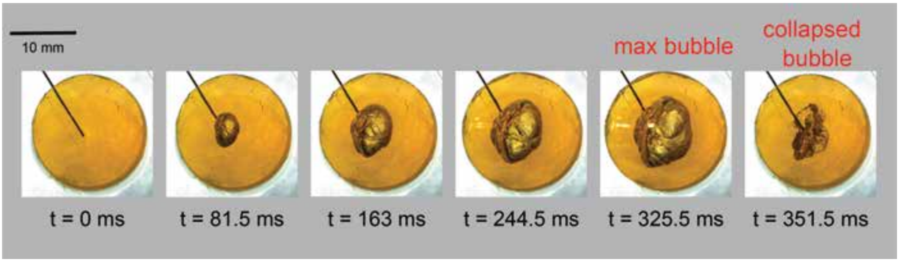
Another important focus of research for Namrata is aortic aneurysm, in which the walls of the aorta, the largest blood vessel in the body, become weak and bulge when blood flows under high pressure. This may cause the aorta to rupture. One of the primary drivers of this disease is the disruption in the balance between collagen, the main structural protein found in human beings and other mammals, and elastin, the rubber-like protein that she had studied earlier. "There's an imbalance between the two proteins – not having enough elastin and the deposition of collagen of poor quality," she says. She and her team created a disease model by changing the relative composition of the two proteins, and quantified the mechanical properties of the tissues. The ideas were tested using human aortic samples obtained from Narayana Hrudayalaya (now Narayana Health City) in Bangalore.

Hydrogels

Namrata also uses tissue engineering, a discipline that aims to restore or replace damaged tissues in the human body. Here, scaffolds of a specific material are engineered, and tissues are grown on them in a laboratory. Among the more popular tissue engineering scaffolds are hydrogels. Hydrogels are made up of large molecules or polymers that have a unique combination of properties: they do not dissolve in water, are absorbent, and are structurally sound.

In the future, hydrogels could have significant applications as biomaterials. For instance, the cornea, which is the clear, protective outer layer of the eye, is similar to a hydrogel. Like many other parts of the human body, the cornea contains the protein collagen. When collagen degrades, it damages the cornea. Namrata's lab is interested in synthesising hydrogels that are tougher so that they can be used to help corneal wounds heal. "If we are looking to the next generation of biomaterials, we need materials that are tough, can support cell growth and can serve as replacements for tissues," she explains.

Another important reason why bioengineers are interested in hydrogels is the way they rupture. "They can undergo large deformations and when they fail, they are brittle and rupture not unlike jelly, the dessert made from gelatin. Jelly has a lot of water, and can undergo large deformations, but when you break it, it has a very clean rupture surface. It breaks like glass," Namrata explains. She says that understanding the mechanics behind hydrogel failure may provide insights into tissue engineering applications.



High-speed videography of bubble inflation in gelatin gels are useful to characterise failure processes in soft hydrogels

Insect biology

When Namrata decided to set up her lab at IISc, she remembered what one of her mentors from her graduate school had told her: "When you set up your lab, you should have your bread-butter projects which will give you the moolah for your research. But always have a hobby project which you do purely for the joy of science." She took his advice seriously and decided that her hobby project was going to be insect biomechanics. She began with resilin, one of the best-known rubber-like proteins, found in the appendages of insects and other arthropods.

Namrata's insect biology research has thrown up many surprises. For instance, her lab has shown that the female parasitic fig wasp inserts her ovipositor (the appendage used for egg-laying) inside the fruit with the help of a microscopic drill enriched with zinc. Her team has also shown that mandibles of the larvae of the coffee white stem borer beetles are strengthened by zinc too. They use their mandibles to tunnel their way through wood until they find a safe place to pupate. "My student wanted to call it "cutting-edge" research, while I call it "boring" research," she says in jest.

Swimming fish

Jaywant H Arakeri, Professor, and Namrata's colleague at the Department of Mechanical Engineering, is also an engineer who has a passion for the biological world. One of the problems that this fluid mechanist studies, along with Raghuraman N Govardhan, the Department's Chair, is how fish and other aquatic animals glide through water.

When an object moves forward underwater at high speeds, the forward forces, or thrust, need to balance the forces that push it back. These forces, called drag, are the result of friction and pressure exerted by water on the moving body.

"If you look at a submarine, it has a propeller whose rotation helps it overcome the drag on it. The blades of propellers are rigid. But if you look at a fish, it's body and tail are flexible," says Jaywant. The other difference between a human-made propeller and the tail of a swimming fish is the unsteady nature of movement in the latter. "Unlike a propeller which moves at a constant speed, the fish tail constantly moves back and forth, with its speed periodically varying from zero to a maximum value." Jaywant's lab is studying how these factors – the flexibility of the body and tail of the fish and the flapping of its tail – contribute to both thrust and drag.

Jaywant's team is also addressing another related question: how efficiently do fish swim when compared to human-made objects? "There is no clear definition of efficiency. But one way of thinking about it is how much energy is expended," he says. The energy expended shows up as disturbance in the wake, the region of disturbed flow of water around a body, which can be measured. "Many people believe that the wake of a fish is quieter than that of human-made objects."

Jaywant's experiments are done in a water tunnel or in a glass tank containing water. An airfoil having a flexible flap is connected to a motor that produces oscillatory motion. "This makes it behave like a fish and we are able to measure the forces it experiences. It tells us about the thrust being generated. We can also measure the torque [rotational force]," he explains. The torque reveals how efficiently the thrust is generated.

And in order to visualise flow, a fluorescein dye is used. By shining a sheet of laser light perpendicular to the foil, researchers can see the wakes and vortices (a vortex is a whirling mass of water produced by the movement of the swimming object) that are formed. His team also makes quantitative measurements of the velocity around a "swimming" foil. "For this, we use a technique called particle image velocimetry where you put really minute tracer particles of the order of 10-20 microns in water and shine a laser. And with a high-speed camera, we can measure the displacement of these particles," he elaborates.

Agriculture

Jaywant comes from a family of agriculturists. "My father was an agricultural scientist, and many of my family members are into farming. So it was natural that we started looking at fluid mechanics issues related to agriculture," he says.

Uday Kumar, Jaywant H Arakeri and other scientists inside a polyhouse at the University of Agricultural Sciences, Bangalore

The first agricultural problem that Jaywant tackled was how temperature could be regulated in a polyhouse, a kind of a greenhouse protected by a polythene mesh. Polyhouses, commonly used for growing vegetables and flowers, are of two kinds: one with a fan pad system which reduces temperature by evaporation of water constantly dripping from a wet pad. The other is a naturally-ventilated polyhouse, in which temperatures can go up substantially, especially in a tropical country like India.

To make polyhouses more energy-efficient, Jaywant has collaborated with MS Bobji (Professor, Department of Mechanical Engineering), M Uday Kumar (Professor, University of Agricultural Sciences, Bangalore), and KR Sreenivas (Professor, Jawaharlal Nehru Centre for Advanced Scientific Research) on projects funded by the Robert Bosch Centre for Cyber Physical Systems at IISc and the Indian Council of Agricultural Research. As part of one of the projects, they developed a design for a naturally-ventilated polyhouse that incorporates a solar chimney. The chimney uses the convection of air heated by solar energy. "We wanted to see if evaporation could be built into the system, while also being energy-efficient."

Yet another agricultural project was to create optimal conditions in aeroponics chambers used to grow potato tubers for seed production. Aeroponics is a method of cultivation where the roots, hanging in the air, absorb moisture and nutrients from tiny droplets that are continually sprayed on to them. "We came up with cost effective and energy efficient techniques to keep temperatures low, at both the root and shoot levels, by using fluid mechanics and heat transfer principles in the design," says Jaywant. His team has also investigated how supplemental LED lighting can be used to increase tuber production.

Jaywant's research interests in agriculture do not end there. "My students and I have come up with a small device to rapidly measure evaporation rates at the leaf level." This, he says, will tell us how much water is required by plants – and when – as we move towards precision agriculture.

Jaywant has also collaborated with Namrata to study arterial flows to understand flow-induced stresses that are believed to be responsible for several cardiovascular diseases, including atherosclerosis.

Jaywant's and Namrata's curiosities about living organisms have inspired them to make intellectually exciting journeys from the world humans have built to the biological world. And in the process, the mechanical engineers have provided us with a unique perspective of nature.

Designing a Legacy

By Sidrat Tasawoor Kanth

In a cotton field in Gujarat, the pickers have a delicate and labour-intensive task before them. That task is now less tiresome than earlier because they are trying out a light-weight, battery-powered device which makes their job faster and easier. These are prototypes of a cotton picking machine designed by Sickle Innovations, a farming solutions company co-founded by IISc alumni. It is projects like these that bring out the entrepreneur in a student, as they step into a realm full of innovation and enterprise – product design.

Cotton harvesting machine being tested in a field in Gujarat

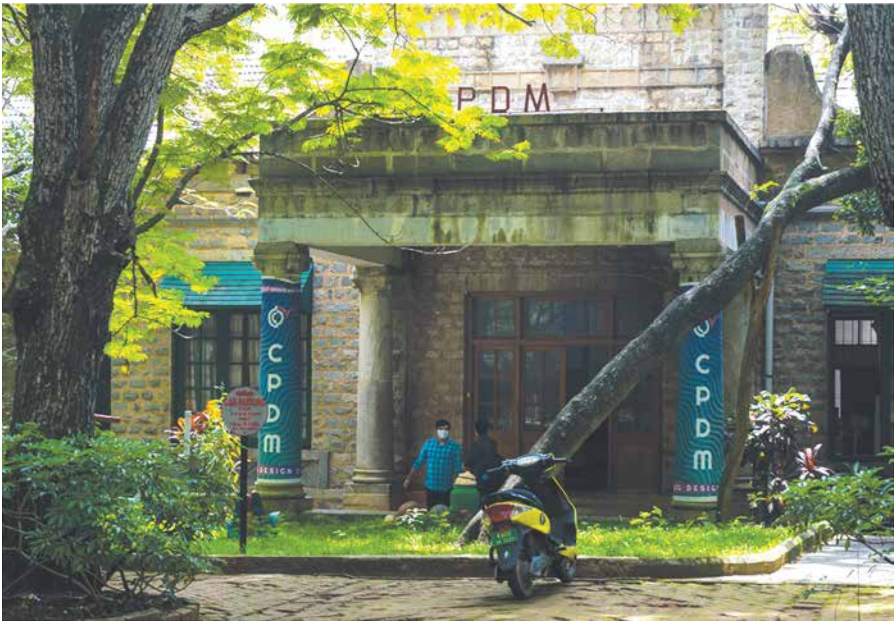
A key requirement for creating such impactful innovations is an environment that incubates and encourages out-of-the-box thinking. Which is exactly what the Department of Mechanical Engineering (ME) at IISc has been providing for the last 75 years – long before terms like 'innovation incubator' were in vogue. The Department has pioneered teaching and research in design way ahead of its time, and also contributed to developing other related interdisciplinary centres at IISc.

Sowing the seeds

The ME Department offers one of the longest running courses in design, called Design of Engineering Systems, which was initiated back in 1963 by MR Raghavan (who retired from IISc in 1988). The course has continued in one form or the other over the years. Today, it is being offered as Creative Engineering Design by Amaresh Chakrabarti (Professor and Chair of the Centre for Product Design and Manufacturing or CPDM), himself an alumnus of ME. One of Raghavan's students was TS Mruthyunjaya, who joined the Master's programme at ME when only two faculty members were working on design research – MR Raghavan and P Srinivasan. Within a few years, he became part of a growing pool of faculty researchers in ME, dabbling in the field of Mechanisms, which is the study of the construction of devices that rely on mechanical movements to perform their functions. Mruthyunjaya, who first taught the subject at ME, says, "[The] ME Department in IISc became a centre of research activity in India in the field of Mechanisms." This tradition is now being continued by his own student, Dibakar Sen, who is now a professor at CPDM and ME, and teaches a course on Mechanism Design.

Over the years, the ME design community kept assimilating expertise across subjects and backgrounds. In the early 1970s, LS Srinath came from IIT Kanpur and strengthened the Department's research in Solid Mechanics. With the merger of the Department of Internal Combustion Engineering (ICE) with ME in 1971, areas like noise control and acoustics, nurtured by faculty member Manohar Lal Munjal, began to influence design research in ME.

At the turn of the century, newer research areas were developed by B Gurumoorthy, R Narasimhan, Ashitava Ghosal and others. They established groups specialising in Computer Aided Design (CAD), Finite Element Analysis (FEA), and nanotechnology and robotics, which are the core strengths of design research anywhere in the world. Their labs continue to attract student talent to IISc. As Gurumoorthy says, "The best products of the department are the students themselves."



IISc's Central Workshop (top) was converted to the Centre for Product Design and Manufacturing in 1996

Setting up of CPDM

ME has been a nursery for several interdisciplinary centers in IISc, one of them being CPDM. Mruthyunjaya was instrumental in its establishment. He recounts how he became deeply interested in creative engineering design through the lectures of Bernard Roth, a visiting professor from Stanford University, in 1984. A couple of years later, during his sabbatical as Visiting Professor at Ohio State University, he utilised the opportunity to study design methodology in depth and eventually took over the ME Department's engineering design course in 1988. A final push towards the creation of CPDM came during the ME Department's golden jubilee year in 1995 when it was hosting the International Conference on Advances in Mechanical Engineering (ICAME). In a panel discussion, Mruthyunjaya realised the potential of a programme exclusively tailored for studying product design. With inputs from colleagues at the Centre for Electronics Design and Technology (CEDT, now known as the Department of Electronic Systems Engineering), a Master's programme in product design was launched in 1997. A year later, this led to the formation of CPDM, which is one of IISc's most sought-after departments today.

Students at CPDM

Real world applications

Taking their expertise to the field has been a long-standing practice at the ME Department. In this regard, former faculty member S Soundranayagam's contributions to turbomachinery are hailed by many, including Abdul Kareem A, a technical assistant who joined the Department 38 years ago. Abdul remembers their efforts to set up a mini hydroelectric power plant in a village in Mandya district, working with the Karnataka Power Corporation Limited (KPCL), and also their visit to Vishakhapatnam where they worked on torpedo propeller designs for the Naval Science and Technology Laboratory (NSTL).

In recent years, students of ME and CPDM have put their creative minds to focus on issues of agriculture, mobility and healthcare. These choices are a "testament to the students themselves," as Gurumoorthy puts it. "Students were not so keen on designing lifestyle products; they were more keen on solving problems of the people around us."

One of the labs working on design optimisation with a focus on biomedical devices is that of GK Ananthasuresh, who was the Chair of ME until recently. His students have developed compliant mechanisms that enable the study of the mechanical properties of cells. Compliant mechanisms are joint-less, flexible structures that can transmit forces. This technology is being commercialised by a Bangalore-based startup, BendFlex, founded by the lab's alumni. Virtual reality-based products from the lab have led to the establishment of another startup – Mimyk. His students are also collaborating with geriatric specialists to design comfortable and adaptable seating solutions for the elderly.

Biomedical devices are also the focus of the Applied Geometry and Mechanisms lab led by Dibakar Sen, where students work on prosthetic limbs, among other areas. One of their projects led to the founding of a company called Grasp Bionics, which is pushing boundaries in rehabilitating amputees. Another product designed here is a chair to make the dialysis process more comfortable for patients.

At the lab run by Ashitava Ghosal, another faculty member at ME, robotics technology is being applied to design tools that help surgeons perform minimally invasive surgeries. Manish Arora, a faculty member at CPDM heads the Universal Technology Solutions for Accessible and Affordable Healthcare (UTSAAH) laboratory, where the focus is primarily on providing efficient design solutions to make healthcare universal and accessible. Their projects range from developing better insulin pumps to rehabilitation solutions for children who are hearing impaired.

To bring these ideas to life, the ME department has continuously fostered collaboration between academia and industry. When computers became essential for designers but were still prohibitively expensive, ME started a one-of-a-kind design service for the industry where the expertise and computing resources of the ME research groups would be available to solve practical issues faced by the industry. Udipi Shrinivasa, who retired from ME as a professor in 2012, recounts how novel this scheme was back then. "People laughed at us," he says. But they went ahead and collaborated with Tata Consultancy Services (TCS) to develop the Advanced Product Design and Prototyping (APDAP) initiative. In 1995, rapid prototyping was introduced to produce quick and efficient prototypes for companies that would usually have to wait for several months for their designs to be manufactured abroad. The success of APDAP triggered engagement with Micro and Small Medium Enterprises (MSMEs), which eventually led to the birth of the Society for Innovation and Development (SID), currently headed by Gurumoorthy. "What SID has brought to the table is the comfort with which faculty can engage with the industry," he says. SID not only acts as a bridge between industry and researchers, but also incubates startups, a few of which are founded by alumni from ME and CPDM.

Future directions

With its diverse expertise in biomedical systems, ME is uniquely poised to contribute to this field. Future directions also include generative design – through which optimised design solutions can be generated on a computer and then fine-tuned by the user. Foundational work in this field is already being done by Gurumoorthy, Ananthasuresh and others. Another exciting area is the design of next-generation materials, such as those for building structures in space, which is being investigated by Aloke Kumar, a faculty member at ME. Taking inspiration from nature, his lab is experimenting with a special class of materials called 'soft matter'. Another group adapting design principles from nature is the Biomechanics Lab run by Namrata Gundiah, also a faculty member at ME.

Balancing these technological advances is the emerging spotlight on sustainability. This has already begun to take shape, as is visible within the ME Department building itself. In 2013, a new auditorium was inaugurated. It does not have a gleaming exterior or a swanky interior, not even air conditioning. It doesn't need to, since the design makes the most of its surroundings and the mild Bangalore weather. Strategically placed windows and ventilation keep it comfortable, while specially selected and locally crafted wall tiles give it the best acoustic experience. It is engineered to maximise functionality and usability while minimising maintenance.

The new ME auditorium, dedicated to Arcot Ramachandran

The design of the auditorium is a reflection of the inward-outward balance that the Department has achieved over the years. While their products are at the cutting edge of technology, they are grounded in context, application and relevance – whether it is the turbine designs of the eighties, or the biomedical devices of today.

With input from Connect staff
Sidrat Tasawoor Kanth is a PhD student at the IISc Mathematics Initiative (IMI) and a former science writing intern at the Office of Communications, IISc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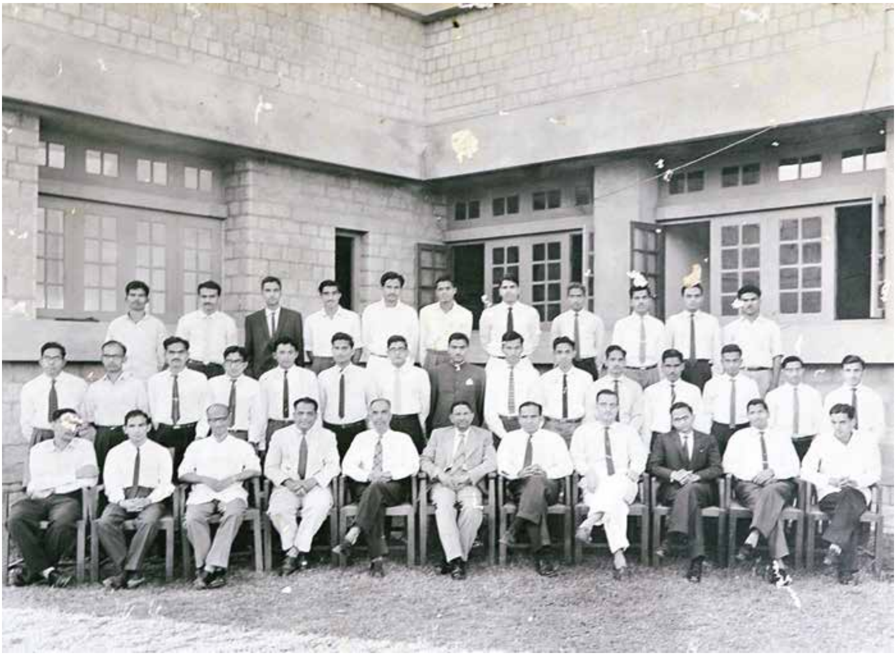
A Tour Through 75 Years of Solid Mechanics

By KRY Simha

Solid mechanics plays a fundamental role in the design and analysis (D&A) of aircraft, chemical plants, civil structures, machines and ships. This role was presented differently in aeronautical, chemical, civil, mechanical and naval engineering curricula in the early history of technical education until the middle of the 20th century. The explosive growth of industrial activity spurred the demand for engineers globally with India launching IITs and NITs, besides encouraging polytechnics and private institutes.

IISc was comparatively slow to expand on this front, but under the dynamic leadership of Director Satish Dhawan in the 1970s, IISc witnessed a flurry of faculty recruitment and student enrolment in different specialisations of engineering design, which enriched solid mechanics research and teaching. This trend has continued undiminished into the new millennium with exciting new avenues of experimental, theoretical and computational solid mechanics.

Solid mechanics has universal appeal for all engineering design endeavors, but the crucial role of manufacturing and materials science in ME curricula makes solid mechanics even more potent. It is precisely in this context that design software and numerical codes empowering modern technology owe their debt to the basic principles of solid mechanics, relating external loads with internal stresses and strains for different types of engineering materials. Linking the main solid mechanics variables of stress, strain and displacement is a formidable mathematical exercise, even for simple materials under ideal conditions.



A photo of final year ME (Electrical) students and faculty, 1962-64. P Srinivasan, an ME Professor, is sitting fourth from left

In the 75 years of ME at IISc, solid mechanics can perhaps be thought of as spanning three equal epochs. In the first, Professor P Srinivasan introduced research and teaching on mechanical vibration, while Professor

MR Raghavan dealt with the dynamics of machinery and mechanical design. It is important to highlight the fact that these pioneers taught all the students of Power Engineering. In this arrangement, it is also important to appreciate the service of professors from other departments instructing ME students. The best way to illustrate this appreciation and gratitude came from an Electrical Engineering student at IISc circa 1962 who vividly recalled the lectures on vibrations delivered by Prof Srinivasan after five decades and enthusiastically shared a vintage photograph (see left).

The second and perhaps the dominating epoch of solid mechanics in ME during the seventies was spearheaded by Prof LS Srinath, whose expertise in the optical methods of stress analysis gave a big boost to experimental solid mechanics. He also promoted the legacy of Nobel Laureate in Physics Sir CV Raman and his students in engineering applications. In particular, the subtle power of scattered light stress analysis which he had developed with Max Frocht, an illustrious student of SP Timoshenko, a pioneering engineer, greatly enhanced the scope of 3D experimentation. It is also during this epoch that faculty across departments and disciplines interacted actively offering a large number of basic courses and electives covering the entire gamut of solid mechanics. Other participating ME faculty included N Srinivasa Murthy, DL Prasanna Rao, TS Mruthyunjaya, PR Arora, NS Bapat and U Shrinivasa. The surge of talent during the second epoch of ME led to rather uneven solid mechanics requirements across departments, necessitating books and course materials suitable for universities and institutes in India, and Prof Srinath blazed a new trail of writing technical books inspiring generations of students pursuing higher education. In particular, the book *Advanced Mechanics of Solids* composed in the early 1980s continues to sell in the thousands even today.

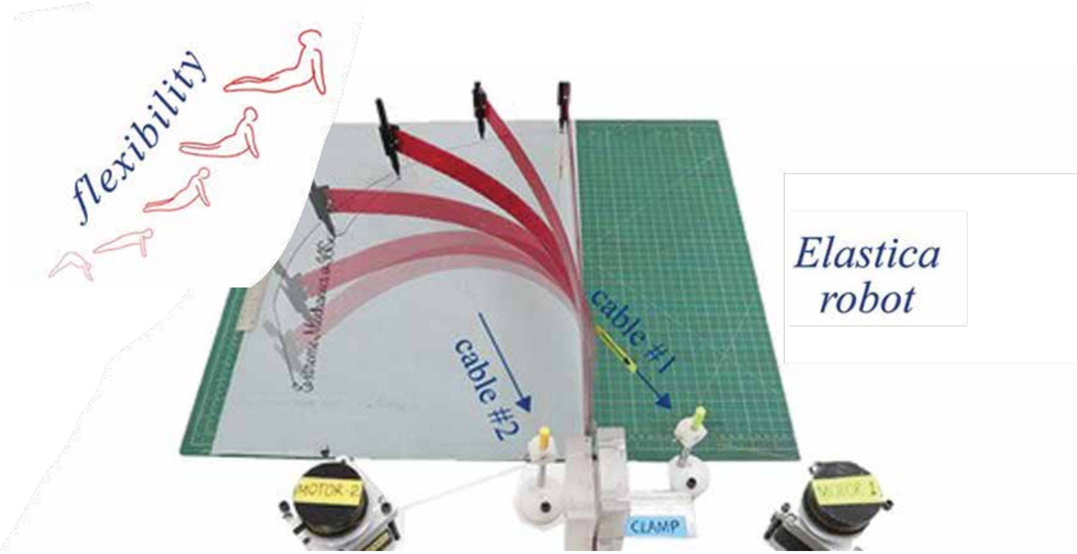
The latter half of this second epoch inducted a pair of professors (of whom I was one) applying experimental, theoretical and computational solid mechanics to studying fracture phenomena. I joined towards the end of the 1980s, and initiated the first graduate level course on fracture mechanics in India. Encouraged by the enthusiastic response from students and engineers enrolled from within and outside IISc, a book on fracture mechanics for engineering design was also published, besides a couple of books on fracture of solids and structures for impact and blast loading scenarios. Like hydrodynamic turbulence, under intense loading, fracture and fragmentation of solids obey power law cascades, which is of immense significance to powder technology and pharmaceuticals.

The joining of Prof R Narasimhan in the early 1990s propelled fracture research to greater heights, bringing recognition and several laurels to the Department, including the coveted Bhatnagar prize awarded to him in 1999. Prof Narasimhan has also been invited to be on the editorial committees of premier international journals dealing with fracture mechanics. The subject of fracture mechanics is now taught widely across universities and departments inside and outside IISc. That the course ME293: Fracture Mechanics taught jointly by this pair of professors has been offered continuously for the past 35 years is a symbol of the commitment and joy of teaching the subtle features of solid mechanics and materials science.

Left: The Scattered Light Polariscope designed by Prof LS Srinath. Right: Scattered fringes as seen in the polariscope

Towards the turn of the millennium, entering the third epoch of this narrative, Prof CS Jog delved into the deeper yet broader meaning of solid mechanics as an integral part of continuum mechanics, which also includes the fluid state. Historically, the mechanics of particles, deformable solids and fluids remained distinct and compartmentalised, fashioned after Newton, Hooke and Navier. The unification of concepts and measures initiated in the 1960s continue to be refined and reexamined in the new millennium, but the main ideas are given in the greatest ever encyclopedia of physics, compiled painstakingly by Flügge over three decades. The elegant mathematical notions of Noll and Truesdell, among others – for delineating the innately nonlinear nature of deforming continua – have been a major motivation for Prof Jog who, besides initiating and teaching a full-fledged course on continuum mechanics over the past two decades, has also authored a monumental pair of books on continuum mechanics running to well over 2,000 pages. Prof Jog has also developed 3D hybrid elements for dealing with chunky as well as slender components exhibiting both material and geometric nonlinearity. The crucial aspect of hybrid elements robustness has been demonstrated without invoking any other assumptions such as plane stress or other complicated formulae for updating rotations in the case of thin shells and plates.

Prof R Narasimhan receiving the Shanti Swarup Bhatnagar prize from the Honourable Prime Minister AB Vajpayee in 1999



The elastica robot designed by Prof Ramsharan Rangarajan

The youngest faculty member in this solid mechanics narrative is Prof Ramsharan Rangarajan, who has ushered in a brand new set of teaching skills and research techniques for interrogating the intricate geometry of deforming slender elastic structures simultaneously experiencing twisting and bending. Ubiquitous in flexible electronics in microcontrollers, sensors and actuators, slender structures can become notoriously unpredictable and unstable with ambient noise and vibration. Unveiling the visually delectable nonlinear mechanics using markers and cameras entails massive computational effort, besides devising jigs and mechanisms for manipulating the systems. It is indeed heartening to record here that this young faculty has already established great rapport with students and also with private and public R&D agencies dealing with space, marine and railway engineering.

Just as Profs P Srinivasan, MR Raghavan and LS Srinath took up the task of teaching and designing the solid mechanics curriculum of core and elective courses during the formative epoch, it is pleasing to note that solid mechanics and electives like finite elements (linear and nonlinear) offered regularly by Professors Narasimhan, Jog and Rangarajan are in great demand across IISc as also in various national and defense laboratories of India. Solid mechanics being the very core of ME activities, allied areas of research like topology optimisation, plasticity and fracture phenomena in manufacturing are also being admirably pursued by several ME faculty including Profs GK Ananthasuresh and Koushik Viswanathan, among others. This booklet, listing all of ME research activities besides this abbreviated narrative, will provide a better perspective of the universal appeal of solid mechanics.

Concluding this rather speedy bird's eye view of the ME Department's history spanning 75 years is like imaging and capturing an avalanche of momentous events in the lives of eminent teachers and students who have contributed passionately to the pursuit of excellence in technical education. Indeed, the synergistic group of faculty and students engaged in solid mechanics research and teaching has exhibited both consistency and commitment to the academic profession, publishing well over a dozen books and hundreds of seminal papers, besides mentoring about a hundred PhD theses and over two hundred Master's degree dissertations. The future is both exciting and unpredictable in as much as the growing domination of computational tools on the one hand and information technology on the other have drastically altered higher education. As long as the allure of mechanics continues uninterrupted from the time of ancient astronomy to the modern era of space odyssey, solid mechanics will always be the shining jewel in the crown of engineering design.

KRY Simha is Professor Emeritus in the Department of Mechanical Engineering

IISc's Distinctive Master's Programme in Foundry Engineering

By S Seshan

Metal casting, the sophisticated technique of making metallic components directly from liquid metal, remained more of an art for decades. The advent of the automobile and machine tool industries mandated the presence of qualified foundry engineers to manage such metal casting plants.

Melt treatment at IISc's foundry

To meet this rapidly increasing demand in India, the Master of Engineering (Foundry) programme was launched in IISc in August 1958. The Department of Mechanical Engineering at IISc was the only centre in the entire world to offer an exclusive Master's degree programme in Foundry Engineering. This is indeed a feature to be very proud of. To start with, it was a programme with two semesters of course work, followed by six months of rigorous internship in industry. The course was converted into a four-semester programme in 1970 with an approved annual intake of 15 students. Admission into this prestigious course was extremely competitive, and only the rank-holders from various universities managed to get selected. Out of this course emerged a few hundred highly qualified foundry engineers, to support the Indian metal casting industry during a crucial period of industrialisation.

S Ramamurthy, with the full support of Arcot Ramachandran, conceived and set in motion the ME (Foundry) programme. After Ramamurthy moved to Hindustan Aeronautics Limited (HAL) as General Manager (Foundry & Forge Division), MR Seshadri, a well-known teacher and researcher, took over in 1961. Seshadri was instrumental in the formation of the Bangalore Chapter of the Institute of Indian Foundrymen in 1966.

In addition to the time-bound ME programme, the Foundry group was also actively involved with doctoral research activities as well as sponsored R&D projects. Around 100 doctoral degrees were successfully completed when the going was good, and innumerable (and frequently cited) technical papers were published in reputed international and Indian journals. At one time, the Foundry Engineering group at IISc was the largest and strongest R&D group of its kind anywhere.

Some of the valuable developments that emerged as a result of this group's work include cast metal-matrix composites (based on Al, Cu and Mg), gravity die casting of cast irons, cast SG iron crankshafts for automobiles, high chromium cast irons, ultra-high-strength austempered ductile iron, soft wares for casting design and metal flow studies, and technology forecasting in the casting industry. These were all unique because they represented newer materials and/or faster, less expensive and flexible routes of mass production.

Students who graduated from this Master's course ascended to become senior executives in well-known industrial houses in India. A few started their own foundries and have done extremely well. However, by the end of the last century, due to liberalised import of castings and due to the decelerated growth, the Indian industry couldn't readily absorb all the highly qualified and well-trained engineers graduating from this valuable programme, Hence, there was a gradual shift and our postgraduates began to pursue PhD research and moved towards academic careers. Many of them have served or are still serving as senior faculty in engineering colleges (including IITs and NITs), and continue their research activities, partly in casting-related areas. Some have gone abroad and are doing very well as foundry consultants, executives and professors.

It is a pity that this prestigious programme came to a poignant end by the late 90s mainly because Master's degree-holders specialising in other, new-fangled engineering streams (such as computer science, telecommunications, IT, chemical engineering and so on) started getting placed more easily and at far higher remuneration than the Foundry Engineering graduates. Plus, these were all white-collared jobs, unlike the assignments in foundry. These cumulatively caused a rapid shift to the above greener pastures, and as a result fewer students opted for Foundry Engineering. Thus began the extinction of the once-popular Foundry Engineering course in the ME Department of IISc. It is really regrettable that such a significant, industry-oriented, full-time programme in foundry science and engineering is no longer available in India.

S Seshan is a former Professor and former Chair of the Department of Mechanical Engineering

The late Sanjay K Biswas

Sanjay Biswas' Contribution to Tribology Research

By MS Bobji

Tribology, coined from *tribos* ("I rub") and *logia* ("study of") – is the study of rubbing. It covers the areas of friction, wear and lubrication. The study of friction has a long history stretching all the way back to Leonardo da Vinci, while empirical studies on lubrication date back to the Industrial Revolution.

Tribology deals with two bodies that are brought in contact with each other and in relative motion. Tribological behaviour is affected by the surface properties of the bodies in contact. For example, geometrical properties like surface roughness and the chemical properties like presence of oxide layers will modify the friction and wear drastically. It's an area of interest for people in many fields including physicists, chemists, metallurgists and engineers.

In IISc, initial work on tribology was done in the erstwhile Department of Internal Combustion Engineering (ICE). Prof N Raman, who was associated with ICE, studied the lubrication aspects of IC engines, and used to teach a course on tribology. Prof Sanjay K Biswas expanded the scope to contact mechanics, dry friction and wear.

Friction and wear

Prof Biswas did his PhD in the UK. He told me that when was on the plane back to India, Prof Satish Dhawan [who was IISc's Director at the time] happened to sit next to the young scholar. They started up a conversation, and by the end of the journey, Dhawan encouraged him to apply to IISc. Prof Biswas' PhD had been on material plasticity, but at IISc he was looking for a new field to dive into and chose tribology.

Most tribology studies in India, even today, are heavily focused on lubrication. Very few people at the time were looking at friction and wear, which is the area Prof Biswas chose. He designed and developed an instrument – pin on disc for

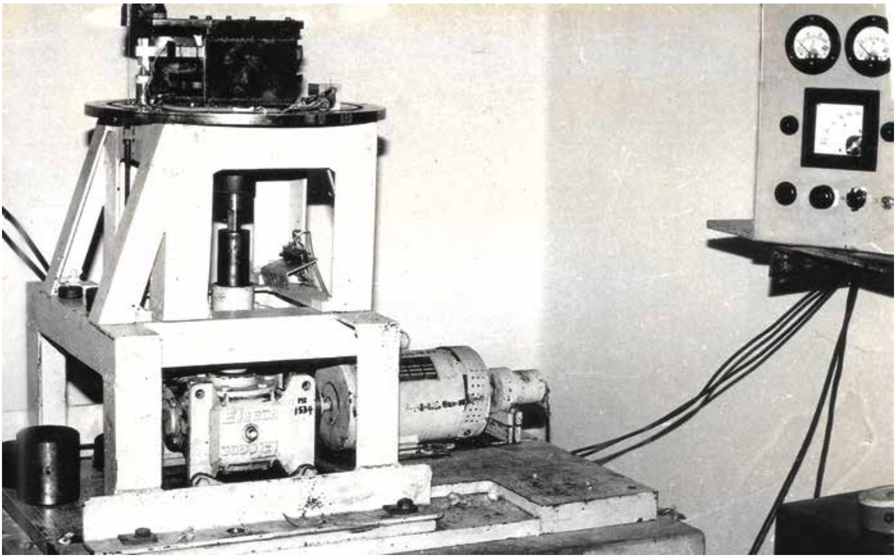


Image of the pin on disc machine from the PhD thesis of BN Pramila Bai simultaneous measurement of friction and wear. The innovation to measure wear rate in real-time became famous and a commercial success. Today there is practically no engineering college that does not have that machine – the number of PhDs produced using that instrument is enormous.

As the name indicates, the machine has a pin on a disc. The pin is stationary while the disc is rotating, and they are brought in contact (with a known force and well-defined contact pressure) in order to study how the material is wearing out. The material of the pin and the disc can be tweaked in many combinations to mimic the real-life tribological problem that you may face. For example, if you want to understand wear in a bearing, you could use steel against steel, and check if the wear varies as you change the properties of the steel.

Prof Biswas was interested in wear mechanisms – what exactly causes the material to wear out. The lifespan of mechanical components can depend on how quickly they wear out. His innovation was that he managed to measure the wear rate. Previously, scientists used to measure it by weighing the pin at the start of the experiment and comparing it with the weight at the end of the experiment. The change in weight is the amount of material that is lost. Instead, what he did was put a displacement sensor – a linear variable displacement transformer (LVDT) – on top of the pin and came up with an arrangement to measure the change in the length of the pin as it wears down, to an accuracy of 10 microns. It enabled real-time measurement of wear, which is not a constant. In the life-cycle of a component, the rate of wear is very high at the start and at the end, and less so in the middle. His experimental set-up was able to measure this very clearly.

Aluminium silicon alloys

Next, Prof Biswas moved on to working on aluminum silicon alloys, which had not really been done before, and this was picked up some time later by General Motors.

Aluminium is a lightweight material, popular because of its use in aircraft, but it was considered mainly a structural element. Its ability to resist penetration by hard objects is very low. Ideally, when we want minimum wear, we don't want the material to be soft, as hard materials resist wear better.

Prof Biswas had done a lot of work in the area of aluminium silicon alloys, and was able to apply this to internal combustion engines (which typically use steel, a much heavier metal). He was in the right place at the right time when this really took off. General Motors had been exploring the possibility of making lighter engines, to make cars lighter, which is why they were interested in aluminium silicon alloys and how they wear. IISc also had an aluminium foundry, and ME was famous for making aluminium and lightweight alloys other than steel, which helped with the research. This resulted in a long association between IISc and General Motors.

For this work, Prof Biswas collaborated with Prof BN Pramila Bai, a metallurgist who had been his student. He was a true interdisciplinary researcher even before it became a buzzword. He collaborated with people in areas like physics and biology, especially so with metallurgists. In the later part of his career, he collaborated significantly with Vikram Jayaram [a metallurgist and former Chair of the Division of Mechanical Sciences at IISc]. Tribology really needed that type of collaboration. And Prof Biswas had a knack for reinventing himself and starting out in new fields.

Nanotechnology

When I joined the ME Department in January 1993, he had heard about nanoindentation at a conference a few years before in the UK and was excited about it. Indentation is used to measure hardness – we usually take a diamond and press it on the material with a known force and measure the size of the impression. It is an important test because broadly, hard surfaces have a low wear rate. Nanoindentation was a new technique coming up at the time – it dealt with how to measure hardness when the penetration depth is very small, to the order of 100 nanometers or less. Prof Biswas wanted to build this machine, and received funding from the Department of Science and Technology (DST) for it, even though no one around him was convinced it was possible. Right at this time, I appeared for an interview for a PhD at IISc. He asked me if I wanted to work on creating an instrument for nanoindentation. I didn't know what that was, but said yes. After I joined, my seniors ragged me, "Do you know what a nanometer is? Do you know how small it is? Can you see it? If you can't see it, how can you build it?" But it didn't worry me – after all, we "see" many things without actually seeing them, like using X-rays to look at bones. We went ahead nevertheless, and I built a nanoindenter. Later, in order to "see", I had developed a small nanoindeter to work within a transmission electron microscope.

Students in the tribology laboratory in the 1990s

He started getting big projects after that, because he was already working in this field when the DST's Nano Mission started. He began to collaborate with people outside the Department, outside the engineering faculty, and we even had chemists working on it. He acquired an atomic force microscope and started getting more equipment and characterisation techniques. He was also the first to get a scanning electron microscope in ME. Prof Biswas would develop equipment that was rare or required for research right here, and used this knowledge to help develop local industries.

Prof Biswas also started the International Nanotribology Forum along with materials physicist John Pethica (who was his trekking buddy and my postdoc supervisor) and surface chemist Nicholas Spencer. The first conference was held in Sikkim in 2001. Apart from collaborations with other Indian scientists from different fields, these conferences also provided the opportunity for collaboration. Both Prof Pethica and Prof Spencer became visiting professors at IISc and collaborated across many departments.

From Prof Biswas, I learned that fundamental training in tribology can be applied in so many areas, from medical implants to agriculture, and that giving students freedom of thought makes an enormous difference to the kind of work we produce.

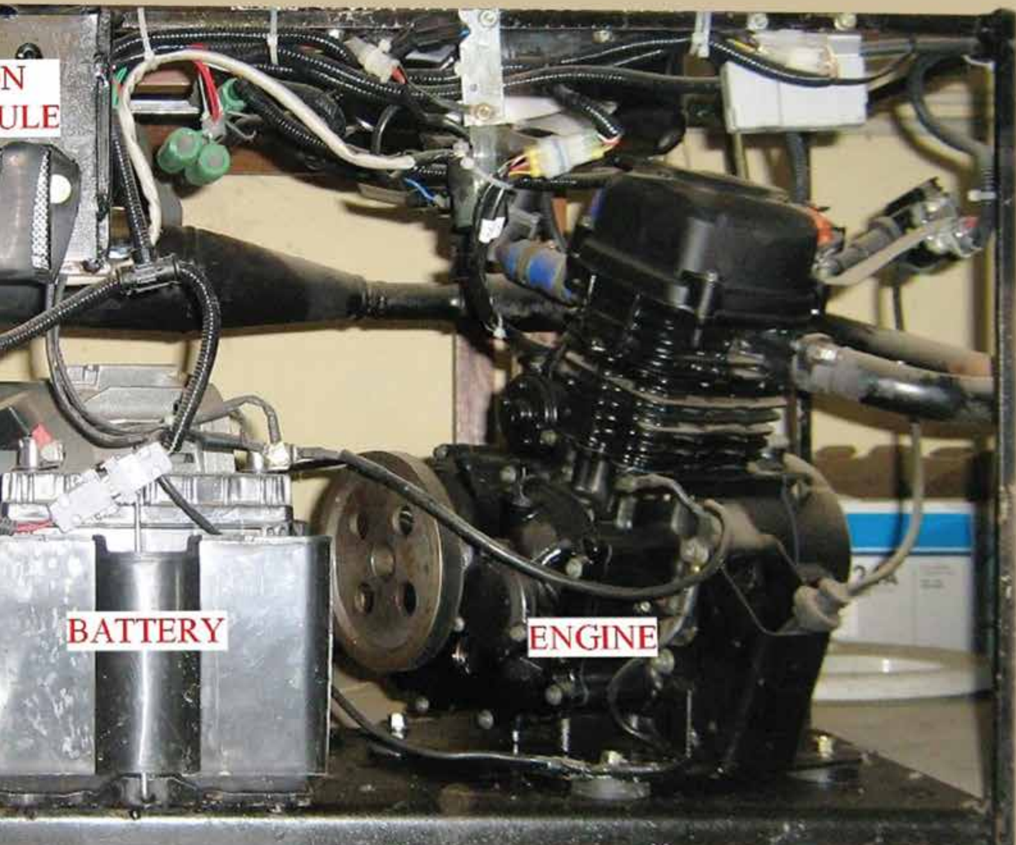
Currently, tribology related research at ME is carried out by Prof Satish Kailas and me. From tailoring surfaces at small scales, green lubrication, evaluation of lubricants, static-kinetic friction transition at high accelerations, to wear mechanisms and fretting wear, the current research encompasses fundamental, technological and product development aspects, with an emphasis on instrument development.

As told to Deepika S
MS Bobji is Professor in the Department of Mechanical Engineering

The Social Impact of ME Research

By Sukriti Kapoor

JN Tata, IISc's founder, strongly believed that scientific research played a role in social and economic transformation. The Department of Mechanical Engineering (ME) has had a history of conducting research aimed at having an impact on industry and society, a tradition that continues today.



Biogas Genset with push button start and advanced features to maximise efficiency. It generates electricity in the sub 1kW range, sufficient to power a household and can be connected to any biogas storage tank

A particular focus has been on translating technology in the area of energy. According to a souvenir published during the Department's Golden Jubilee, the turbomachines group at ME pioneered the design of microhydel power generators, which were used to power coffee estates in Coorg and small townships in Kedarnath and Arunachal Pradesh. In collaboration with the Department of Electrical Engineering, former ME faculty member S Soundranayagam and his team developed a prototype for low-cost microhydel crossflow turbines that could exploit energy from small drops in height at irrigation canals. In a DST-funded project in Nagaland, he and his team trained personnel in the use, design and installation of these turbines. Based on his design, the Science and Technology Council of Nagaland has funded the installation of two additional projects that have the potential to meet the energy demands of several villages with a cumulative population of more than 12,000.

Another important energy-related application has been the use of biofuels. In 1999, Udipi Shrinivasa, a former Professor at ME and also the Head of the Sustainable Transformation of Rural Areas Programme (SuTRA), explored the use of *Pongamia* seed oil as a cheaper and economic alternative to kerosene or diesel, as part of a project funded by the Ministry of Non-Renewable Sources. Based on his findings, the company Dandeli Ferroalloys converted their diesel engines to biofuel-based ones. Under the Karnataka Rural Development and Panchayat Raj Department, biofuel-run water pumps were established in seven villages around Kagganahalli in Kolar district, which had earlier no stored source of water apart from rainwater.

During 2006-2011, as part of two successive projects funded by the Ministry of New and Renewable Energy (MNRE), RV Ravikrishna, Professor at ME, and his team successfully developed a prototype of a small and efficient biogas-fueled 1 kW generator, suitable for powering small households. It was after this project, says Ravikrishna, that "[we] realised that there was a need to do fundamental research into other biofuels such as biodiesels, which was not available at that time." They were able to perform fundamental characterisation of biodiesels using a unique test facility built in the lab, which could help visualise the fuel spray, droplet formation and atomisation using high speed cameras and laser-based techniques.

The primary focus was on biodiesels derived from vegetable oils, such as those from *Jatropha* and *Pongamia* trees. The data generated was helpful for designing engines that could accommodate biofuels with high efficiency. Such research is vital, Ravikrishna believes, because of the impact of biofuels on the environment as well as the enormous role that energy and transportation play in our economy.

At present, Ravikrishna's lab is working on ethanol and bio-methanol as cleaner and cheaper alternatives to crude oil. Their fundamental research on biofuels and fuel injection technologies for engines goes far beyond the laboratory. The team worked with TVS Motors on small two-wheeler engines and with Ashok Leyland on large heavy-duty engines, and reported that methanol-based engines had higher efficiencies than petrol-based and CNG-based engines, respectively. Their work with Ashok Leyland is “the first indigenous effort to convert heavy-duty engines to methanol-based engines,” he says.

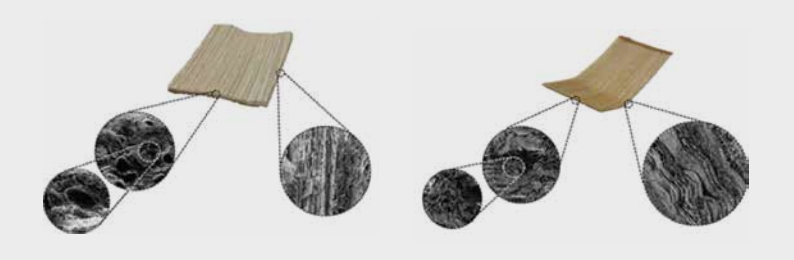
The group is set to initiate vehicle trials for methanol-based engines, as part of a recent academia-industry collaboration funded by the Department of Science and Technology, which was led by his group. The team also recently conducted a study on the life-cycle of automotive fuels from their source to vehicular emissions, on behalf of the Office of the Principal Scientific Adviser to the Government of India. This was a comprehensive study comparing various fuels including hydrogen, and powertrains such as electric and hybrid in addition to the conventional, evaluating both energy use and greenhouse gas emissions. This study is intended to aid the government's policy decisions in the energy and transportation sector.

Yet another important development in energy research has been the establishment of an experimental supercritical CO_2 Brayton cycle test loop facility in 2014, led by ME faculty members Pramod Kumar and Pradip Dutta, as part of an Indo-US clean energy project. This facility aims to develop power plants run on supercritical CO_2 (s-CO_2) that could replace conventional steam-run thermal power plants. Supercritical describes the state of CO_2 at a specific critical temperature and pressure which could yield more energy than steam. Coupled with a solar energy source, s-CO_2 run power plants could significantly reduce our carbon footprint.

Green manufacturing

A fitting complement to research on clean energy is research on clean and sustainable manufacturing. The Laboratory of Advanced Manufacturing and Finishing Processes (LAMFiP), led by Koushik Viswanathan, Assistant Professor at ME, works on ‘green manufacturing’ – production practices that are less polluting and that minimise waste. The manufacturing process for single-use plastics has a huge carbon footprint, in addition to the large burden that plastics place on the environment. At LAMFiP, research is being conducted on manufacturing processes for producing sustainable, biodegradable, and eco-friendly plant-based food wares and containers.

In a recent study, the research group studied deformation-microstructure relationships in areca sheath (the protective covering of areca nuts) using micro-computed tomography, scanning electron microscopy and mechanical testing, to understand its formability (the ability to be moulded into shapes such as those required for making cups and plates). Areca, a member of the palm tree family, is native to India and Southeast Asia and is a well-known alternative to plastic, but several issues prevent it from overtaking plastic, Koushik explains. At present, the team is developing solutions to make Areca sheath more stretchable – enabling the manufacture of food or beverage containers in more varied shapes – and less porous in order to delay fluid penetration and seepage, a prerequisite for making food delivery in areca containers possible.



Left: Scanning electron microscopy image of unprocessed natural areca sheath, showing microstructure along transverse and longitudinal directions. Right: Corresponding sections in the pressed plate reveal significant pore collapse and thinning

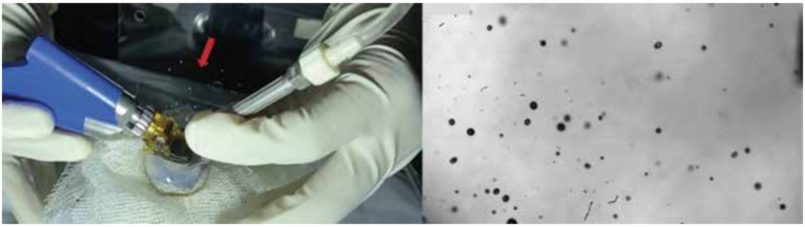
Healthcare

Research at ME has also contributed to addressing healthcare and related challenges in India.

Recently, for example, Assistant Professor Susmita Dash's lab developed a low-cost method to detect adulterants such as urea and water in milk, by analysing deposition patterns left behind after milk evaporates. Such a technique could be useful in remote and rural areas which do not have sophisticated lab equipment or resources. With this technique, they were able to detect water concentrations as high as 30% and urea concentrations as low as 0.4%. Susmita and her team plan to extend this analysis to other adulterants as well as products such as honey, and eventually develop a repository of evaporation patterns matching different adulterants at different concentrations. The method also has the potential to be automated in the future using a simple image analysis software that can scrutinise and compare photos – even those taken using a mobile phone.

Researchers at ME have also developed several biomedical devices over the years. Work at the Multidisciplinary and Multiscale Design and Device (M2D2) laboratory, led by GK Ananthasuresh – Professor at ME and Dean of Mechanical Sciences – has resulted in products designed to assist in medical procedures or improve one's quality of life. Among them is a simulator to train medical personnel in endoscopy procedures and an all-mechanical assistive chair to allow the elderly to rise from a chair with minimal effort.

While the study of aerosols and fluid mechanics falls squarely in traditional areas of mechanical engineering, Saptarshi Basu, Professor at ME, has translated his expertise in these subjects to modelling the spread of COVID-19 infection. Saptarshi's work has helped explain how the virus spreads more efficiently in humid and cold conditions compared to a dry and hot environment. "We were the first to show how the droplet vaporisation and aerodynamics contribute to the spread of the pandemic," he says. On the urgent need for developing a more integrated, holistic model from first principles, he says, "You need to have such a model in place so that you can take decisions quickly. If you can advise the government quickly, then you can save lives and the economy." In another first, a study published in *Science Advances* by his group showed that aerosols – which carry a greater risk of disease transmission – can be contained more efficiently when using triple-layered and N95 masks rather than single- or double-layered ones.



Tracking aerosols generated while using a microkeratome for LASIK surgery

Based on his lab's work on COVID-19, Dr Abhijit Sinha Roy at the Narayana Nethralaya Foundation approached Saptarshi through a colleague to conduct a COVID-19 risk assessment for doctors and hospital staff performing eye surgeries, such as glaucoma, cataract (phacoemulsification), and LASIK. Based on the outcome of these findings, the hospital staff posted informational videos on YouTube, and a standardised protocol was devised which was shared with ophthalmologists across the nation. Suggestions made for changes in surgery protocol include the use of proper personal protective equipment (PPE), flushing the air at regular intervals, sanitising the room at regular intervals, and inhibiting the use of air conditioners. Currently, nine papers published from Saptarshi's lab, including the studies on the use of masks, modelling of aerosols, and risk assessment of eye surgeries, have been included in the WHO database for COVID-19 related research.

Sukriti Kapoor is a PhD student in the Department of Microbiology and Cell Biology at IISc and a former science writing intern at the Office of Communications, IISc

Micro Hydroelectric Power:
S Soundranayagam's Legacy

By Punit Singh

Hydro power gave humanity the first motive power more than 1,000 years ago, while electric power only arrived in the last decades of the 19th century. Turbine designs for different heads (the height of stored water), flows and power capacities were optimised during the Industrial Revolution. However, building large and expansive hydro projects using dams to store and artificially raise the water's potential head came to be seen as detrimental to the environment and society in the latter half of the 20th century.

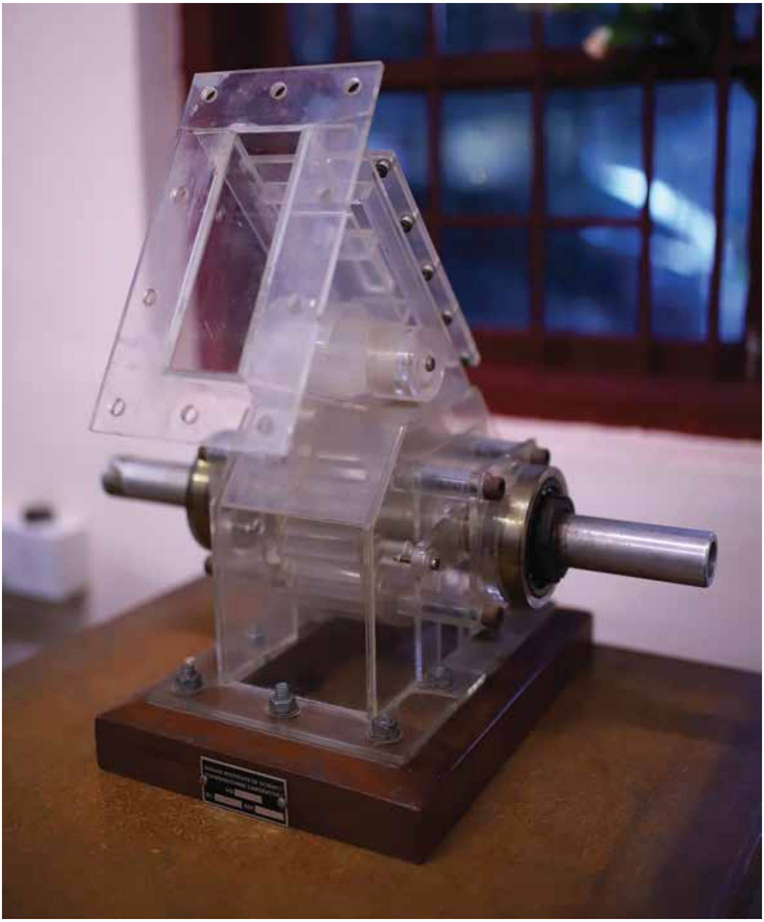
S Soundranayagam (bottom, second from left) and team working on a project

This is when micro hydroelectric pumps and turbines were evolved with the concept of zero-storage and utilising available heads in hilly regions, which are typically 15-100 m, or medium-to-low heads which can be between 1 and 15 m. The idea of a micro hydroelectric project (sometimes generating less than 1 kW to 100 kW) is relevant in this context. It does not involve damming rivers, submerging land or displacing communities, rather it reaches out to local communities who live far away from urban landscapes, to whom bringing powerlines comes at a huge cost to the state. 'Micro hydro' is a different way of life – not only accepting and appreciating technology on a small scale, but valuing the ecosystem and low consumption. Though it has not been a major focus of work at ME, one faculty member, the late S Soundranayagam, who I knew as Prof SS, made significant contributions in this field.

I met Prof SS in 1995 while I was a second-year Bachelor of Engineering student at the National Institute of Engineering (NIE), Mysore. We were very young students and were involved with a small centre – it was called the Centre for Appropriate Rural Technology or CART – run by a faculty member called UN Ravikumar. There was a programme that we had just started on micro hydro and we got to know that Prof SS had been working in this area out of his own passion, for quite some time. His colleague, Dr A Suryanarayanan, whom I happened to know as he was the father of a schoolmate of mine, was an integral part of his micro hydro team. Apart from some minuscule funding from the Karnataka State Council for Science and Technology (KSCST), he did some work on micro hydro turbines driven by his own love for rural and hilly places as well as for flowing water. His love for turbomachinery was evident, but from his conversations with me, I recall him saying that his main projects were missile and torpedo studies in his wind tunnel for DRDO and the Navy, designing auxiliary radial and axial turbines for the Gas Turbine Research Establishment (GTRE), and so on. His wind tunnel also optimised turbine aerofoils, later used for propellers used in defense applications. These were all high-end, sophisticated, and serious, sometimes confidential national projects.

He also had strong connections with the Department of Science and Technology (DST), which supported his initial micro hydro expeditions. DST at that time funded his travel to China to evaluate the micro hydro programme there. He visited Nepal, which was getting support from a British group that called themselves the Intermediate Technology Development Group (an outcome of the followers of EF Schumacher, author of the 1960s book *Small is Beautiful*). Prof SS himself was trained in Liverpool, where he got his PhD, and he was acquainted with this group as well.

I don't know when and where his love for micro hydro turbines began, but he used to trek in the Himalayas and wanted to make better turbines for the people there. Around the same time, IIT Roorkee started the Alternate Hydro Energy Centre (AHEC); they were also working on micro hydro turbines, though they did not have turbine designers at that time. They got some Norwegian funding for a few projects, but these did not take off.



A small-scale model of the micro-hydel turbine developed by S Soundranayagam

Prof SS decided to make turbines all by himself. He got the design for a cross-flow turbine from the German-Swiss firm Banki, and I think that he designed his own Pelton turbine. These two types were his favorites. The 'pump as turbine' technology (on which my own work is based), somehow did not inspire him. He once joked to me that this is kite-flying engineering, and one must make classical turbines only. But his thoughts were based on one test at IISc that failed. I showed him our success at NIE Mysore and later at Karlsruhe, where I did my PhD. He began to believe in it later, but he was quite old by then. He also designed a Kaplan turbine for a canal drop scheme (for an ultra low head, about 0.5 to 1 m) in Srirangapatna for the Karnataka Electricity Board.

From left: Jasmail Singh, Punit Singh's father, along with S Soundranayagam and his wife Rosemary, outside their home in Kodaikanal in 2014

Regarding his village projects, I know that he supplied one Pelton turbine to a place near Kochi in Kerala (which was commissioned in the year 2000 before the film *Swades* was made). He was commissioned to make a micro hydro turbine for *Swades*, for which he made a cross-flow turbine. It was more for filming than for practical purposes, as the nearest village was quite far away. He was also involved in a project at Elaneer (in Chikmagalur near Kudremukh) between 1996 and 1999, funded by KSCST-DST and implemented by a company named TIDE (they were supported or founded by former IISc faculty members). Incidentally, I built my first project 3 km from this site, for three families.

Prof SS had a small company which made these turbines. One small micro hydro system was supplied to a family in Kodaikanal. I also remember two groups in Kerala who purchased turbines from him, one based in Kannur and the other in Palakkad.

Prof SS used to visit my lab in NIE Mysore often in 1997, and advise me. When I left for IIT Delhi in 1999, he warned me not to be a campaigner and learn classic turbomachinery. But there was no one else who could teach us hardcore design. Once he knew that I had started a PhD in Germany on 'pump as turbine', he was surprised and believed in German skills and encouraged me to do thorough work. I met Prof SS again after a gap of a few years in 2009-10 in Kodaikanal, where he had moved with his wife, a German woman of Polish heritage with whom I used to speak in German. I met him several times in the years that followed, and he gave me many suggestions for my own work.

He would frequently travel to Bengaluru to help with the company of another IISc professor, Udipi Shrinivasa, who was an expert in vibrations. I remember Prof SS saying that he was advising Nagaland and other northeastern states on micro hydro projects. Prof SS passed away in 2015.

What Prof SS's legacy is depends on whom you ask. I knew him as a perfectionist who never compromised on quality. He valued good education and liked the British/European way of praxis with deep and solid connections with theory. He was also a trained carpenter and mechanic. He made so many working 'miniature' models of steam engines on his own. He was a great teacher and loved going deep into simple concepts and phenomena. He loved turbomachinery, of course, and never found anyone who matched him, especially in Indian academia. He was the best in his field. He also had a tender heart for poor people, especially in hilly regions, and that may have triggered something in him to do micro hydro work.

He could not revolutionise micro hydro – he was not a campaigner. He did have the power and connections for it, but I remember him telling me that micro hydro was his hobby, and one couldn't fill one's stomach with a hobby. Here, we disagreed. My last conversation with him was about my doing micro hydro full time in Bastar while being an academic. He was not sure that I would succeed.

I remember him most for being a great turbine designer, with no equal. Every Sunday, I run past his demolished Cox Town house on Hutchins Road to take his blessings, and I pray that I receive a fraction of his skill.

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