INAE Monthly E-News Letter Vol. VIII, Issue 12, December 1, 2017

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From the Editor's Desk

Engineers are applied hopefuls

Another new year is about to begin. As in all previous years, we want happiness for ourselves, as well as for those around us. We want to be happy, and as happiness works best in an illusionary mind, we wish to Read more...

Purnendu Ghosh
Chief Editor of Publications

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Another new year is about to begin. As in all previous years, we want happiness for ourselves, as well as for those around us. We want to be happy, and as happiness works best in an illusionary mind, we wish to have an illusionary mind, in the hope that illusions become realities, though we know that illusions are an erroneous perception of reality. But, as Eckhart Tolle writes, "If you can recognise illusion as illusion, it dissolves. The recognition of illusion is also its ending. Its survival depends on your mistaking it for reality."

We want to live in a world where "integrative engineering and biomimicry create abundance by design." In the conceptual utopian world farms will emulate natural ecosystems, rivers will run clean, fish and wildlife and oceans will be stabilising. Is it possible to have such a world? It depends upon what we think about our future world. Do we see in the future world a state of balance and peace? Can we think that man will have no enmity or competition with nature? Can we see in the future world abolition of cultural, racial and gender-based prejudices? Can we see in the future world sensibly developed and rightly used technologies? Only utopian visionaries believe that such future projections are possible. Dystopian visionaries, on the other hand, see only disaster. In their disastrous world life and nature will be recklessly exploited and eventually destroyed. In this world artificial intelligence, rather than native intelligence, will govern all our activities. We will be the slaves of technology, and as a result, we will completely lose the freedom of our mind. Both these extreme visionaries are well meaning, but as we know, idealist visionaries are as unreal as excessive optimists are. Engineers are applied hopefuls.

Applied hope is an imagination that has good chance of becoming a reality. Applied hopefuls, a term coined by Armory Lovins, don't lose hope in the future world. They believe, "If things are not working right, it isn't the end yet." They don't leave the job in-between. They continue working on it until a satisfactory solution is found. In the world of applied hopefuls mere optimism is not enough and the practitioners of applied hope are not mere theorists. They understand the subtle difference between hope and hype. They promise only what they can deliver. Applied hope "requires you to combine sizzle in your brain, fire in your belly, perseverance rooted like a redwood, and soul as light as a butterfly." Applied hopefuls are 'practitioners' and not mere 'theorists'. Applied hopefuls are not afraid to create or face the astonishing world of 'collective intelligence'. Applied hopefuls are optimum optimists, and also the best adaptationists. An adaptationist can extend or contract oneself as per the demands of the situation. An adaptationist knows how to manage situations when extrapolations fail.

ACADEMY ACTIVITIES

NIAS –MNRE-TERI–INAE Workshop on "Enabling 100 GW Solar Power Capacity By 2022" The NIAS –MNRE-TERI–INAE Workshop on "Enabling 100 GW Solar Power Capacity By 2022" was on November 9, 2017 at India International Centre Annexe, New Delhi. The objective of the workshop was to deliberate on all pertinent issues relating to enabling 100 GW Solar Power Capacity in India by 2022 with a view to arrive at actionable recommendations to be forwarded to the concerned stakeholders and policy makers for consideration. The event was attended by about 45 delegates.During the Inaugural Session, Prof Baldev Raj, Chair of the workshop delivered the Welcome Address and gave a brief overview of the purpose of the workshop. The Keynote Address was delivered by Dr Ajay Mathur, Director General, TERI, New Delhi. The Programme comprised of four Technical sessions on Infrastructure and Human Resource for +100 GW Solar Power and to Add 20-25 GW Each Year; Technology Choices and Manufacturing Status; Business Models for 100 GW and Overall Ecosystem and Policy Issues related to Mission. The workshop concluded with the session on summarizing and way Forward and Final Remarks by the Chair.

Abdul Kalam Technology Innovation National Fellowship

INAE and DST have taken an initiative to institute "Abdul Kalam Technology Innovation National Fellowships" to outstanding engineers to recognize, encourage and support translational research by individuals to achieve excellence in engineering, innovation and technology development. All areas of engineering, innovation and technology are covered by this fellowship. A Maximum of 10 Fellowships will be awarded per year. A meeting of the search -cum-Selection Expert Committee was held on Sept 25, 2017 at INAE Office, Gurgaon to select the first cut of nominations received for the subject Fellowship. The names of the awardees of the subject fellowship will be announced shortly during a function being organized by Department of Science and Technology (DST), Government of India.

The launch of the Fellowship was covered by Rajya Sabha TV in the Science Monitor and Gyan Vigyan programmes during which Dr BN Suresh, President, INAE and Prof Indranil Manna, Vice-President, INAE were interviewed. The Science Monitor and Gyan Vigyan programmes may be viewed at the links given below.

https://www.youtube.com/watch?v=O1pAjyDPiGg

https://www.youtube.com/watch?v=A71IdDBB6c0

INAE Annual Convention 2017

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INAE Annual Convention 2017
The Annual Convention of the Academy will be held on **December 15-16, 2017 at TCS, SIPCOT IT Park, Siruseri, Chennai, followed by a local excursion** to Mahabalipuram **on December 17, 2017** for all interested INAE Fellows. In addition, a Cultural Programme followed by the Annual Fellows Dinner will be organized on December 15, 2017.

TCS SIPCOT Building

The highlights of the Annual Convention are as under.

(i) Inauguration by Mr. N Chandrasekaran, FNAE, Chairman, Tata Sons.

(ii) Two Plenary Talks by eminent personalities.

(iii) Industry Session in which the winners of the INAE Innovator Entrepreneur Award 2017 will make a presentation on the innovations for which they have been awarded.

(iv) Technical Sessions in which newly elected Fellows (whose Fellowship is effective from Nov 1, 2017) and INAE Young Engineer Awardees 2017 will be making presentations relating to their own significant engineering contributions.

(v) The Grand Awards Function in the afternoon of December 15, 2017 wherein Innovative Student Projects Awards, Innovator Entrepreneur Award, Young Engineer Awards, Prof. Jai Krishna and Prof. SN Mitra Memorial Awards, Outstanding Teachers Awards and the Life Time Contribution Awards in Engineering will be presented by the President, INAE.

(vi) The Annual General Meeting of Fellows of the Academy in the morning of Dec 16, 2017 including Induction Ceremony.

(vii) Meetings of INAE Forums on the sidelines of the Annual Convention.

All INAE Fellows and Young Associates have been invited to participate in the Annual Convention. An invite has also been sent by TCS to the Fellows for attending the event. The participation of maximum INAE Fellows and Young Associates in the Annual Convention is looked forward to.

Annals of INAE

The soft copy of the Annals of the INAE Volume XIV, April 2017 containing the text of the lectures delivered by Life Time Contribution Awardees; newly elected Fellows of the Academy and

INAE Young Engineer Awardees 2016 has been uploaded on INAE website under the Publications sub-head. The same can be downloaded from the link given below

http://inae.in/ebook/inae-annals-2017/

INAE on Facebook and Twitter
INAE has created a Facebook and twitter Account to post the news of recent INAE activities in the Social Media. The same can be viewed at the link below.

(a) Facebook -link https://www.facebook.com/pages/Indian-National-Academy-of-Engineering/714509531987607?ref=hl

(b) Twitter handle link https://twitter.com/inaehq1

All INAE Fellows are requested to visit and follow the above to increase the visibility of INAE in Social media.

Important Meetings held during November 2017

- **CAETS 2017 Annual Meeting and Conference on "Engineering a Better World: Challenges of the Bioeconomy" held on Nov 13-17, 2017 at Madrid, Spain in which INAE Delegation participated**

Academia Industry Interaction

AICTE-INAE Distinguished Visiting Professorship Scheme
Industry-academia interactions over technological changes have become essential in recent times so that relevant knowledge that would be sustainable in the changing conditions can be imparted to the students in the engineering institutions. While industries could gain by using the academia's knowledge base to improve the industry's cost, quality and global competitive dimensions; thereby reducing dependence on foreign know-how and expenditure on internal R&D, academics benefit by seeing their knowledge and expertise being fruitfully utilized practically and also by strengthening of curricula of educational programs being offered at engineering colleges/institutions. INAE together with All India Council for Technical Education (AICTE) launched "AICTE-INAE Distinguished Visiting Professorship Scheme" in 1999. Under this scheme, Industry experts are encouraged to give a few lectures in engineering institutions. This scheme has become popular among industry experts as well as engineering colleges.

Brief details pertaining to recent visits of industry experts under this scheme are given below.

Mr. Nawal Kishore Gupta Former Deputy Director LPSC/ISRO	Madhav Institute of Technology & Science, Gwalior Oct 5, 9-14, 2017	Delivered lectures on "Aircraft Propulsion"; "Fundamental of Rocket", "ISRO work overview" and " Gas Dynamics". He has also helped in modification of the existing syllabus. According to the feedback from the engineering college the scheme is great and students found it interesting to gain knowledge on practical aspects of Air Propulsion Technology.

Mr. Kezar Ali Shah General Manager(Environment) Wonder Cement Ltd. Udaipur, Rajasthan	College of Technology & Engineering, Maharana Pratap University of Agriculture & Technology, Udaipur Oct 5-6, 2017	Delivered lectures on "Design and Construction of Municipal & Industrial waste landfill" and "Interlinking of rivers in India". According to the feedback from the engineering institute the lectures were very informative. The students learnt technical aspects of latest developments in field of Civil Engineering through the knowledge imparted by the Industry Expert.
Dr Manish Roy Scientist 'F', Defence Metallurgical Research Laboratory, Kanchanbagh	Indian Institute of Engineering Science and Technology, Shibpur Oct 25-26,2017	Research Opportunity in European Country and "Indentation Response and Microtribology of Nanocrystalline Diamond Film". According to the feedback from engineering college the Industry Expert helped in guiding project. It is also mentioned that the scheme provides an excellent opportunity for mutual exchange of knowledge between the industry expert and academicians.

International Conferences/Seminars being organized by IITs/other Institutions

To view a list of International Conferences/Seminars being held in the month of December 2017 click here

Honours and Awards

1.	Dr BN Suresh, FNAE, President, INAE and Honorary Distinguished Professor, ISRO Headquarters, Bangalore was awarded the "Life Time Contribution Award" from Indian Space Research Organization for the year 2016-17.
2.	Prof. Sankar K. Pal, FNAE, Distinguished Scientist and former Director, Indian Statistical Institute, Kolkata was conferred the Jawaharlal Nehru Birth Centenary Lecture Award from Indian National Science Academy (INSA) for the year 2017. He was elected as Fellow of International Rough Set Society (FIRSS), Poland and also selected as an IEEE Rhino-Bird International Expert.

News of Fellows

1	Dr BN Suresh, FNAE, President, INAE and Honorary Distinguished Professor, ISRO Headquarters, Bangalore has been appointed as Chancellor, Indian Institute of Space Science and Technology (IIST). He has earlier served as the founder Director of IIST and he assumed charge as Chancellor, IIST on 6th November 2017. Dr BN Suresh has also been elected as a Fellow of Indian National Science Academy (INSA).
2.	Prof. Sankar K. Pal, FNAE, Distinguished Scientist and former Director, Indian Statistical Institute, Kolkata delivered the following talks/address: Keynote speech at 2017 IEEE International Conference on Imaging, Vision and Pattern Recognition, February 13-14, 2017, University of Dhaka, Bangladesh; Keynote speech at the Int. Conference on Electrical,

	Computer and Communication Engineering February 16-18, 2017, Cox's Bazar, Bangladesh; Plenary address at the Int. Conference on Big Data Analysis, La Trobe University, Melbourne, March 13-15, 2017; Distinguished Lecture in the Department of Computer Science, Hong Kong Baptist University, Hong Kong, May 15, 2017 and Keynote talk at the 2017 Int. Joint Conf. on Rough Sets, Olsztyn, Poland, July 3-7, 2017.
3.	Prof B Bandyopadhyay, FNAE, IDP in Systems and Control Engineering, Indian Institute of Technology Bombay, Mumbai has been elected as IEEE Fellow effective from Jan 1, 2018 for his contributions to discrete-time, multi-rate, output feedback sliding -mode control.

International Conference on Computational Intelligence on Dec 6-8, 2017 at Kanpur https://conferencealerts.com/show-event?id=187281

4th International Conference On "Computational Intelligence and Big Data Analytics" (CIBDA) on Dec 15- 16, 2017 at Visakhapatnam
https://conferencealerts.com/show-event?id=190046

IEEE International Conference on Electrical, Electronics, Communication, Computer Technology and Optimization Techniques on Dec 15-16, 2017 at Mysuru
https://conferencealerts.com/show-event?id=188634

International Conference on Intelligent Information Technologies on Dec 20-22, 2017 at Chennai
https://conferencealerts.com/show-event?id=190701

AN ENGINEER - ACADEMIC LOOKS BACK

Prem Krishna

This article attempts to connect and correlate the various aspects which influence the life and career of a person, in this case, more specifically, an engineer. These include the factors that dictate the formation of one's attitudes and character, namely, the opportunities offered, and, the environment – social, political and professional. Although the traits in the character of a person may be dictated largely by nature – genetics and inheritance, the exposure and contacts of the early years, with parents, family and teachers go a long way in forming attitudes towards life. In this article, the writer has used himself as the example to construct one possible model of an engineer's life. While going through this journey it is imperative to understand the factors that made it what it has been, it is not out of place to recount any contributions one may have made to the profession or the National development. This enables an understanding of the total package.

Since my birth in March 1938, the narrative relates to three specific time windows. The first till the completion of formal education in 1964, the next, the period of regular employment as an academic at the University of Roorkee, from 1965 to 1998, and lastly, the period post retirement from 1998 onwards. As I look back before writing this narrative, I am convinced that providence has so far been most kind to me.

My father, Professor Jai Krishna, whom the fellows of the INAE will also identify as their Founder President, joined the Thomason College of Engineering at Roorkee as a Lecturer in 1939, and then the family joined him in 1940, with me a toddler. The College set up in 1847 by the British for formal engineering education, being one of the first globally, was spread over a sprawling *(for those days – today with almost ten thousand students that aura has diminished considerably)* campus. It was a serene environment with tall green trees. There was quietness and life was organised. Transportation was restricted to walking or a few bicycles, and, the air was clean. The snowclad Himalayan peaks could be seen from the campus. Growing up a little further, I began to notice the unmistakable traits of a highly disciplined civic life – there was punctuality, tidiness, regular participation in sports, utmost regard for seniors, and, so on. There is a reference to this aspect later too. At this point it will suffice to say that a growing up youngster was bound to be affected by this environment.

Although this was too early in years for me to carry any impression of the highly significant political developments going on in those years, the sense of turbulence was noticeable, and the coming of Indian independence in 1947 was obviously too important an event to escape any Indian. There was a mixed feeling - joy for getting independence but sorrow created by the turmoil due to partition of the country. The status of engineering education and development was not much to write home about. The change in status of the country opened the gates for growth. The Thomason College was converted into the University of Roorkee in 1949. The Indian Institutes of Technology were set up – 5 to start with – at Kharagpur, Bombay, Madras, Kanpur and Delhi. Projects such as the Bhakra Dam (Mr. Nehru's temples of modern India), setting up of India's space and Atomic Energy program, and, the establishment of the Council of Scientific & Industrial Research (CSIR), are only some examples of the initiatives taken.

On the personal front, I obtained admission to a Public School at Nainital, a touristic destination in the hills in UP, in 1948. This had been an English medium institution till 1947 and was taken over by the Birlas and converted into the first Hindi medium Public School in India. More relevant to the tenor of this article is the fact that during the four years of my schooling at that institution, there was exposure to the same spirit of discipline, punctuality, regularity, tidiness, and, civility, as I had observed while growing up at the Roorkee campus. Added to that was another experience that left an indelible impression on my mind. This was the total commitment of the teachers towards the welfare and education of the students. The hostels were a home away from home! Next at a College at Mussoorie, another town in the Uttar Pradesh, a public school run by Irish missionaries, the experience of Nainital continued.

The exposure of these early years, must have played an important role in forming me as a person. Besides this, growing up on the Thomason College campus, with its reputation as an outstanding place for education in this subject area, must in all likelihood have created an attraction to become a Civil Engineer. Admission to the University of Roorkee even in those early years was difficult, though not as tough as today. Therefore, my admission to the Civil Engineering degree programme in the year 1956 was not only a matter of great satisfaction for me, it was a great privilege, since this programme at the University of Roorkee was highly rated amongst the young students aspiring to become engineers. At that time I could not have asked providence for more.

The three years spent at the University of Roorkee as an undergraduate student, were very significant in providing a direction to my professional as well as personal life. Besides directly experiencing the special features of life at this institution, mentioned earlier too in the article, there were a few other things that need to be mentioned. The faculty were not only of sterling quality technically, their commitment to producing outstanding graduates, and their welfare generally, is remembered even today by the alumni of that era. Another point that characterised our education was the obvious mandate to make the students as self - reliant as possible, as well as to prepare them for serving the cause of National development. An anecdote narrated by one of our teachers, Professor O.P. Jain, who also was a student at Roorkee in the early 1940s, is most illustrative in this respect. His class was assigned to design a railway bridge over the Ganges canal. The task was to be completed in two weeks, and, no other information or data were given by the teacher. When approached by the class for this additional information, the teacher told the class – you are going to become engineers, please go and find the answers!!

Furthermore, the Roorkee graduate was exposed to the 'grass roots' of Engineering practice, while being imparted with fundamental knowledge required to remain a self - learner throughout life. Those were the years when students could have a brush with real life engineering through 'shramdan' besides the structured summer training, which was part of the curriculum. For better or for worse, our engineering education seems to have veered away substantially from this philosophy, which was central to the programme in those early years at the University of Roorkee, and, from what one can see, it served the cause of National development very well. The training packaged into the 3-year programme provided a good start to our engineering careers.

Another aspect worthy of mention, for the decade pertaining to the schooling at Nainital upto graduation from the University at Roorkee, was the compulsory participation in sports and games. It is my belief that sports help to teach a person about team spirit and also give him a capacity to take defeat. The young generation today is faced with harsh competition, and sports can help them to get de-stressed to a good extent.

After a stint as a graduate trainee at the Bridge & Roof Co. at Howrah for a year, there was another year at the University of Roorkee pursuing a Masters course in Structural Engineering. The B&R specialised in design and fabrication of industrial steel structures. These two years added to my preparedness for a professional career. The next very significant turning point that followed was my admission to the postgraduate programme at the Imperial College of Science & Technology, London (affiliated to the University of London), with the objective of getting a doctoral degree. This again one would consider a fortunate opening, since the "Imperial' as it was called, had a great reputation for its quality of research in the area of Structural Engineering. Their higher education programme required a student to enter through the *Diploma of Imperial College (DIC)* course, before registration for research for a degree. Then, a research scholar was first registered for the M.Sc. degree before being moved on to the doctoral programme, if found fit. A very prudent arrangement! Having had the benefit of obtaining a master's degree from a reputed college, I was exempted from the requirement of going through the DIC course after attending it only for a few weeks, and, could utilise the time that thus became available to me, for a few months of excellent experience in a Structural Engineering consulting firm. Subsequently, admission to the research programme came through in July 1962, leading to a doctoral degree in November 1964.

Although my technical education in India was from a top-rated institution, the research and training experience in the UK was comparatively more intense. The ethos was different, but there was similarity in the emphasis on self-learning and achieving excellence, besides many other attributes. A blessing was in having a supervisor in Professor S. R. Sparks, a brilliant experimentalist, and a great human being. Our discussion on my research was held on barely 7 occasions, though I had the pleasure of meeting him socially very many more times. There was often a feeling of having been pushed into a pool at the deep end to learn how to swim.

When leaving India for studies in the UK, research in the subject of *Suspension Bridges* was contemplated. Infrastructure development was beginning to grow in the Country, and, it was anticipated that as the hilly regions will open up, there will be a need to build many suspension bridges. However, when work was started at the Imperial College, it was suggested to me that within the general area of *cable suspended structural systems,* it could be even more exciting to work on *cable suspended roof systems.* It was a fascinating experience to explore this entirely new area of research. Barely any back up literature was available which dealt with such roof structures. This allowed plenty of scope for original thinking, and explore new vistas. This was a training of mind which stood with me in the subsequent years of my professional life.

There was also a new exposure to the use of digital computers, which were in the early stages of their development – something that has changed the pattern of life on this planet beyond imagination in the decades that have followed. In 1962, solving 5-6 simultaneous equations seemed to be quite a task. By the time my PhD work was completed, two years later, a number running into hundreds was a clear possibility. Thus, as the technology for computer hardware continued to improve, solving thousands of equations (that too in quick time) did not remain a challenge. This revolutionised the very manner of looking at numerical work and engineering analysis. On the other hand, and in parallels, the electronic revolution completely changed the entire field of communications. In the 50 years that have since elapsed, the world has become smaller!

Reverting back to my journey, the Doctoral degree from the University of London, completed my formal degree requirements, upon which I returned to India. India had been independent politically for more than 17 years, and for most of these it was under the visionary leadership of Jawahar Lal Nehru. There had been effort all around to lay the foundations of a modern Nation, embracing a scientific temper in its multifarious development. However, for a person like me returning to India, the difference between the western world and India (in fact most of Asia) was stark and huge, even somewhat depressing. However, what helped greatly was the determination to anchor my heels fully in India to make the best of whatever training had been received in the foregoing years to build up a career, and indeed to give back to the country to my utmost capacity. Providence was kind to me in upholding the decision.

There were opportunities to make a career in *Academia, Research, or, the Industry.* However, there was little to debate, as the privilege of accepting the offer from the Civil Engineering Department of the University of Roorkee provided an obvious choice. There were several plusses perceived. The University flaunted some of the best known peers in Civil Engineering in the country, and Structural Engineering was without doubt the strongest nationally and comparable internationally. As an Academic at the University of Roorkee, with its reputation, one could hope to get a good exposure to sponsored field work and carry out applied research, besides teaching. It turned out to be a very good decision, and permitted a balanced combination of all three. The period of 33 years (1965-1998) was mostly utilised at Roorkee.

Soon after joining the University of Roorkee, there was a welcome opportunity to go abroad to accept offers of visiting assignments for two years (1968-1970) – first at the University of Illinois, Urbana in USA, and, in the next year at Imperial College, London. Although both these stints provided invaluable experience in their own different ways, the US assignment gave a completely new dimension, in that this gave me an opportunity to understand the US system for the first time. The department of Civil Engineering, rated the best in that country, had a faculty of 105 which included some of the best known names in the discipline, led by the redoubtable Professor N. M. Newmark. I felt humbled, and made my best efforts to learn as much as possible during the limited time I had there. In a significant development, it was possible for me to initiate the project for writing the first book on *Cable-Suspended Roofs*, under the banner of the McGraw-Hill Book Co., New York - add to the text substantially in the following year at London, and, complete it later upon my return to Roorkee.

Late, temptations came for going to the West as well as the middle eastern countries, but better sense prevailed. There was indeed no lack of opportunity within the Country. The model followed was to keep in touch with the developments abroad through visits for conferences and exchange programmes (*besides the two years for teaching assignments mentioned above),* but keep the anchor at Roorkee. Assigned to teach *Structural Mechanics,* and, *Design of Steel Structures,* I built up specialisation for these, besides the non- conventional area of *Cable Supported Structures*, a legacy from my doctoral research. *Cable Supported Structures* led to a logical interest in the subject of *Wind Engineering.* In the mid - seventies, my father, Professor Jai Krishna, who had championed the cause of establishing *Earthquake Engineering* Research, Development and Extension in India, nudged me to plunge more seriously into developmental work on *Wind Engineering.* He envisioned that as the country grows into a modern nation, it will build many tall as well as wide span structures, besides power systems of different types. These will often consist of slender and wind-sensitive structures. Thus capacity building in wind engineering was required. It is gratifying to record that Roorkee became a destination for sponsored work related to both the last named specialisations of cable structures and wind engineering.

In fact, for the developments in *Wind Engineering*, Roorkee attained a leadership position in India. Pioneering steps were taken to set up the first large boundary layer wind tunnel in India, in the early 1980s, at the University. Incessant effort was made to strengthen this field of engineering. The first Symposium on Wind Engineering to cover the Asia Pacific region was held at the University of Roorkee in 1985, and has since established itself as a 4-yearly event, I was privileged and honoured, to have been elected President of the International Association of Wind Engineering for the period 1991-95 (the only Indian so far), and India organised the 4-yearly International Conference on Wind Engineering for the first time (and only time so far) at Delhi, in 1995. An Indian Association of Wind Engineering was set up in 1993. Significant contributions were made towards wind disaster mitigation efforts of the country.

During the period being addressed at the University of Roorkee, there was ample interaction with the industry which was personally very satisfying, since it enabled exposure to problems related to complex structures often requiring a novelty of approach for their solution. Some of these worthy of special mention are, the work on several cable stayed bridges, the TIFR Giant Metre Wave Telescope system, numerous power and communication structures tested in the wind tunnel, and, so on. The year 1996-97 provided a unique excitement as the Institution celebrated its 150th year. *Soon after, in 2001, the University was converted to an IIT.* It is needless to mention that the most enjoyable and rewarding task of all was to teach the undergraduates, and, to notice the sparkle in their eyes when they grasped a point well made.

It may surprise the reader, but the (nearly) 20 years post retirement from Roorkee have brought for me as much challenge and excitement, as perhaps the 20 years in the pre-retirement period. Part of the reason for this ongoing opportunity is the globalisation mentioned below. The experience gained in earlier years has enabled me to contribute to some iconic engineering projects – to name a few - membrane roofs; cable bridges; a 115m high Shiva murty (under construction); a 486m span railway arch bridge over the river Chenab (under construction), which will be one of the highest in the world; a state-of-the-art wind tunnel being constructed at Guna (MP) by JAYPEE Associates; a major Rail-Road bridge under construction over the river Ganga at Ghazipur (UP). Of equal satisfaction has been the association in the INAE work, in earnest after 2008, the first 6 years having been as its Vice-President. An opportunity to mentor the research activities of the Central Building Research Institute at Roorkee as the Chairman of its Research Council for the last 7 years has provided me with an entirely new dimension. There were awards and recognitions but the one most cherished was the Distinguished Alumnus award 2012 of the IIT Roorkee.

Opening up of the Indian economy and globalisation from mid 1990s onwards brought about a sea change in all round growth, including that related to Engineering and Technology. We as engineers have been playing a commendable role in contributing to this growth*. I feel proud to have been part of this fraternity, and feel that this has given me a life well lived. Some industries such as the one dealing with Information Technology, gave a great fillip to the economy of the country. Similarly, there has been enormous progress in departments such as aerospace making the country proud. The Civil Engineering profession has served the goals of development well and steadily, but perhaps there is not enough glamour so as to get better recognition.

The problems of our country have varied and have enormous proportions, whether these be political, societal, or, developmental. The world order, economic or political, is not making things any easier. There is often much turbulence experienced. It is nevertheless a good augury that the dynamics has given rise to a positive direction to the growth of the Nation.

In the final count, for me as an individual, life so far has proved Swami Vivekanand's words, whose essence is that, God does not give what you want but gives all you need.

- *See "Glimpses of Indian Engineering Achievements", A Coffee Table Book, INAE, 2012.*

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Structural Integrity: A Technological Term Synonymous with Safety

B. Dattaguru

1. Preamble

Way back in 1972, on a nice sunny Wednesday (considered auspicious day in Karnataka), I submitted my Ph.D. thesis at the Indian Institute of Science and stared into the sky thinking what future has in store for me. The mind of a young engineer who completes his Ph.D. program at a reputed University finds the research world to be of wider scope, vast, but hazy. Gone are the nice days when one was a student working with and guided by a distinguished Professor. The guide would define the problem, periodically keep track of the progress, change direction of work when the need arose and help when the student is stuck. Having received the degree, the student would have to look for a career in industry or academic career in an academic institution /research laboratory. In industry or research laboratory the work is many a time governed by the organisation depending upon where funding is available and only a few could successfully take up research lines of their own choice. In an academic institution where there is no hierarchy the young researcher need to relate his/her program of work to possible funding sources for acquiring minimum scientific infrastructure. The present faculty are lucky that they get a substantial start-up grant, but this was completely absent in our days in 1960's.

Now the struggle starts for the young faculty. I remember always the words from my brother who is a distinguished Professor of Bio-Physics in USA and a Fellow of US Academy of Physics. He said that "when your supervisor is correcting your thesis do not concentrate on somehow to finish your thesis, but learn how to guide and bring your student's thesis to an acceptable level in future". The wisdom and advice from my mercurial Professor & Supervisor, Prof. A.K. Rao, that "in particular in a developing country like ours, at least some of us should concentrate on research lines which directly should benefit the Indian industry". These two have been my total guidelines when I started my research career. I later passed on these sentiments to my students.

I looked up to two areas among many needing considerable research inputs for the scientific and technological developments in the country. One is structural integrity covering "Fracture Mechanics as the Science and Damage Tolerance as the Technology". The second is Wave Mechanics with several applications to NDT, rock mechanics, earth quake engineering…etc. At that time I moved towards fracture mechanics which seemed to be of direct relevance to the then aerospace programs. In later years I found many of my colleagues have made tremendous in roads in to the wave mechanics using Mini-, Micro- and Nano sensors to identify defects and monitor their growth in primary structural components in both off-line and on-line (during the flight) situations. Structural Health Monitoring (SHM) and Integrated Vehicle Health Monitoring (IVHM) have become buzz words and research to successfully implement them is considered to be necessary to ensure Aviation safety.

2. Integrity of Structural Joints

Joints are one of the critical parts of an aircraft in ensuring safety in design and operational phases. The configurations which threaten the structural integrity of large scale structural systems are structural joints causing concern to engineers conducting design. These structures are often made in parts and assembled using joints such as fastener, riveted, adhesively bonded or welded. The last one is preferred in steel structures whereas the aerospace adopts other types. Fastener and riveted joints are preferred in metallic structures. Bonded joints are used in a limited sense in metallic structures. With the advent of composite structures as primary material for aerospace vehicles bonded joints have become extremely popular. All these joints are discontinuities and are potential sources for crack (or de-bond) initiation and their growth leading to structural failure. Many of these problems are non-linear of different variety, but can be handled by the well-developed Finite Element (FE) software.

Fastener joints exhibit loss of contact along bolt-hole interface and material non-linearity in some cases of interference joints. Bonded joints get in to large deformations due to eccentricity of load path and material non-linearity due to low yield stress for the adhesives. These nonlinearities can be handled with finite element software even when more than one type of non-linearity occurs together. Ultimately combining non-linear analysis with fracture mechanics poses challenge in both conceptually and in keeping the computational time to be reasonable. These problems are handled using iterative and/or inverse formulations and there is considerable ingenuity required to save computer time. We were aware a well knit group was required for success. Self and my colleagues Prof. T.S. Ramamurthy and Prof. C.R.L. Murthy became the nucleus around which we built the activity in fracture, fatigue, finite element methods and NDT.

"The strength of a chain is the strength of its weakest link" is a well-known statement. Similarly in structures with large number of joints, the strength of individual components is the strength of the weakest joint. The safety regulations during design and during operational phase are stringent and need be followed strictly by the operators. If the health monitoring becomes mandatory in all flight vehicles, the joints will be the sites needing continuous monitoring. A wide parametric study conducted by our research students showed the effect of joints on the stress distribution and maximum stresses which cause crack initiation and growth. Misfit parameter values (negative corresponds to clearance fit, positive to interference and zero to push fit), elastic modular ratio of pin to the plate, Poisson's ratios, Interfacial friction (zero corresponding to smooth, infinity corresponding to rough/bonded or interfaces with finite friction) are the parameters of considerable interest to designers. Among these the interference joint is known to increase fatigue life.

When I was in Air India as a summer visiting faculty in 1970, Boeing replaced many major joints with interference joints. The concept used is a taper lok. This certainly impressed us and later it has been a pleasure to see the influence of geometric and material parameters from our work is being picked in the real design exercises in some of the industries. The greatest happiness for an engineer is when he sees his research contributions find a place in design procedures and/or data sheets published for use in design. Technological innovation sometime went ahead of the computational/analytical developments. The innovative minds of engineers have intuitively predicted higher fatigue life due to introduction of initial stresses using interference bolt in fastener joints much before such a benefit was analytically estimated. Besides interference and interfacial friction play an important role in predicting fretting fatigue failures in fastener joints.

Adhesively Bonded Joints

Adhesively bonded joints were used in a limited sense in metallic structures in several non-aerospace industries. Classical work by L.J. Hartsmith of Mcdonnel Douglas corporation, USA brought out several advantages of bonded over conventional fastener and riveted joints. The clear ones are less sources of stress concentration since cracks starting from riveted holes have been a major worry for designers and operators. However only in 1980's with the advent of composite structures adhesive bonding method of joining became more popular. USA conducted in 1980's a US National program PABST (Primary Adhesively Bonded Structures) program to resolve certain crucial issues such as Damage Tolerance of large area bonding in aero-wing type of structures. I had the benefit of working at NASA, Langley those years and contributed to computational methods to estimate de-bond growth. A team of Scientists including me developed software known as GAMNAS (Geometric and Material

Non-linear Analysis of Structures). This software is available on COSMIC where all the US Government funded software is stored. The type of defects and their growth in bonded joints are distinctly different from fastener joints and require special attention for detection (diagnosis) and growth (Prognosis).

Growth of Fracture Research at IISc along with National programs

This is the background which created the enthusiasm in some of us to pursue research & development activity in the field of fracture & fatigue. Dr. K.N. Raju of NAL developed facility for full scale testing of aircraft. We learnt a lot related to fatigue and fracture from him. National Aerospace Laboratories (NAL) and Defence Metallurgical Research Laboratory (DMRL) have become centres of this activity under the exceptional guidance of the then Directors Dr. S.R. Valluri and Prof. P. Rama Rao. ICF 4 (International Congress on Fracture) was brought to India and was conducted in 1984. NAL Organised the International workshop on Fatigue, Fracture and Failure Analysis. It was soon evident that given reasonable funding and facilities, India will be soon be self-reliant in handling the Fracture Control in Design of Pressure vessels/ Rocket casings, Launch vehicles and the other Indian aero-vehicle programs covering fighter aircraft, helicopter and missiles without depending on the West. Aeronautics Research and Development Board (ARDB) sanctioned large number of projects to academic institutions and research laboratories from 1973 in all areas of significance to aeronautics. Their contribution to generation of large competent scientific man power was outstanding. This helped immensely the National programs which were launched in later years. Dr. A.P.J. Abdul Kalam who moved from ISRO to DRDO started Joint Advanced Technology Program (JATP) in 1983 at IISc and funded projects of relevance to DRDL programs in all branches of Aerospace. Around the same time ISRO started Space Technology Cells (STC) at several Institutions including IISc. This was the beginning of a "Golden era" for Indian Aerospace and the young engineers were bubbling with great enthusiasm to conduct research in certain novel areas and as well contribute to the national programs. Fracture Mechanics is one of these areas which designers were keen to get inputs into their vehicle programs. We could see the initiation of DRDO Aircraft programs like LCA and Missile programs through IGMDP, Space programs including SLV, ASLV, PSLV and GSLV, HAL Helicopter program ALH and it is clear that aerospace received the most important boost.

VSSC organised a task force in 1985 to bring together fracture Scientists with a mandate to bring out the procedure for the fracture analysis of Pressurized components. The procedures set by this committee were subsequently used in defence and aerospace programs. Generally, everyone is satisfied with the progress till then for their projects. However, both Aeronautics R&D Board (AR&DB) and Joint Advanced Technology Program (JATP) supported research in this area including emerging technology of Acoustic Emission for online monitoring of aircraft in flight. The use of Acoustic Emission for incipient detection of failures during ground fatigue testing of structural components seems to be well understood by then.

Early Research Lines

As young faculty members at IISc, we were not satisfied by participating only in projects though they are of National importance. IISc mandate certainly includes conducting research of national and International importance and place the institution at a high pedestal.

To help these national projects we developed certain novel research lines in finite element techniques to accurately determine the fracture parameters SIF and SERR in all the three modes of fracture. Modified Crack Closure (MCCI)) technique is known in literature, but limited to simple constant strain triangular, and linear quadrilateral elements. We developed the technique to exploit MVCCI to be applicable for several singular and non-singular elements in both 2-D and 3-D cracked fields. Later for higher order elements a numerically integrated crack closure technique has been successfully implemented. This removed any issues in applicability of the technique to certain elements and made it more versatile to handle all situations. The MVCCI equations developed by us for the singular elements have been adopted in the famous FRANC2D software of Prof. Anthony Ingraffea of Cornell University.

Experimental programs were carried out with collaboration from National Aerospace Laboratory. Dr. K. N. Raju and Dr. R. Sunder of NAL wholeheartedly helped IISc students to work on the excellent facilities in their laboratory. Crack closure measurement with striations developed with special closure fatigue cycles, fatigue failure in structural joints and explanation of crack growth retardation and the effect of temperature exposure on the retardation were some of the topics where collaborative work was carried out. IISc Aerospace department soon became an integral part of the teams on fracture and damage tolerance on most of the National programs. IISc acquired a Fatigue testing machine and primary work done on this machine was combined with NDT techniques. Prof. C.R.L. Murthy pioneered research on Acoustic Emission (AE) when major attempts were being done all round the world to adopt this technique for online monitoring and for incipient damage detection. As a technique AE at that time got accepted as an online monitoring technique during the ground test of components or full scale testing of aircraft. Many more years later with the advent of micro and nano-sensors, I do find this technique is being developed further.

These projects have resulted in several accomplishments. (i) Failure of one of the pressurised air bottle is detected much before the actual failure using AE. The project Director was very happy and he exclaimed "your project budget is 1.8 lakhs and the cost of the project is paid for since we saved one vessel which costs more than the cost of the project", (ii) Several proof tests on pressure vessels in non-aerospace industries were cleared with AE monitoring, (iii) Software is developed for estimating the Stress Intensity factors (SIF) and Strain Energy Release Rates (SERR) in different modes of fracture, (iv) Certain critical thicknesses in high technology components had to be marginally changed to accommodate both fracture and DT criteria and (v) permissible crack sizes were determined in several critical situations.

Damage Tolerance to SHM

Last couple of decades have seen a distinct change with the scientific revolution leading to the availability of micro- and nano-sensors. Fibre reinforced composites as primary structural material also changed the approach of designers in safety critical structures such as in aerospace industry. Micro sensors can be embedded in layered composites and the diagnostic methods are based on wave propagation in the structure. I could not visualise in my younger days the potential of wave mechanics, but extremely delighted that many of my competent younger colleagues have been exploiting this technique quite extensively for damage detection.

National programs NPSM and NPMASS headed by Prof. V.K. Aatre gave a tremendous fillip to the emerging micro sensors and systems, and put the safety aspect into a different perspective. It is possible to continuously monitor the structures and possible to detect cracks as they occur and grow. The information can be used in two ways: (i) If the damage or cracks detected are critical this information can be used for online Structural Damage Mitigation i.e., temporarily mitigate damage till you land and (ii) allows the cracks to be attended off line and provides prior information to MRO operations where the cracks have occurred. The later saves considerable time in diagnosing the damage locations.

Currently we are working at the International Institute for Aerospace Engineering and Management (IIAEM), Jain University on prognostic aspects of crack growth in critical components. Crack growth in standard configurations can be handled using well-known software such as NASGRO. On the other hand when one needs to investigate prognostics of crack growth in problems such structural joints where non-linearity is prevalent, special methods need be adopted and these are the aspects dealt with in the studies at IIAEM.

Structural health Monitoring (SHM) and Integrated vehicle Health Monitoring (IVHM) have become Buzz words for all operators of high technology and safety critical structures. "Can we decrease the stringent requirements of Damage Tolerance if we continuously monitor the structure" is the natural question by the LCA chief designer Dr. Kota Harinarayana. I would love to see his anticipation for the future flight vehicles come true.

Working Closely with Industry

Industry obviously needs reliable answers to their problems involved in safety critical components. They would depend on premier institutions with strong research base for this. Generally the problems faced by them do not need inputs from cutting edge research, but simple calculations done by Institutions with strong research base will be accepted with confidence. Many times we realise that there is a need to approach industrial problems with simple theories and use common sense than jump into complex methods and solutions. Engineer must carefully groom his mind to pick the right approach for the problem at hand. Design of every bracket need not be done with fracture mechanics and damage tolerance approach. I would like to highlight a few examples to bring out how problems are solved.

1. Some industry had to reproduce a bolt to be used under tension. Their reproduction was perfect including the material and dimensions. Among the dimensions they reproduced the length and shank accurately. However they did not bother about the bolt head dimension to be of any significance made it marginally bigger for operational advantage. The bolt was failing at much lower fatigue cycles than the original bolt. It was a mystery till it was discovered that the dimension considered to be unimportant viz., bolt head size is the main cause. When a given load is distributed over longer length, the root bending moment is larger. 15% larger bending stresses cause loss of 70- 80% of fatigue life. It did not require further fatigue testing and the modified bolt worked. Typical example when an engineer's mind should be alert and often complex looking problems have simple solution often based on strength of materials only.

2. A crack was discovered in a solid propellant couple of days before it was to be fired. We were rushed to the spot in view of the time constraint. The main issue is to profile the crack and later standard equations could be used to check the integrity during firing.
   We worked hard for a period of 4-6 hours to complete the job and declare the crack to be safe. The firing justified our conclusions.

3. The first time I had an opportunity to use fracture mechanics knowledge along with my distinguished colleagues was in an event happened in a major power generating station. In a rainy season a large size mud block flowed in a semi-liquid form on to a pen stock and pushed it out of its anchors. It was contemplated to replace a few hundred meters of the penstock, but there was a delay in carrying it out. In the mean a team from IISc consisting of myself and another 7 distinguished Professors visited the site. The crucial point which was identified by the team is that during the type of loading such as the one which occurred in pushing the pen stock off the anchors, only very few circumferential joints would have been damaged. Just as sugar cane breaks at one or two junctions when one tries to break it using bending load. When one or two joints break, there will be stress relief everywhere and this makes the other joints to remain intact. This logic made it possible to think of restoring the pen stock and carryout required repairs instead of replacing large section of the penstock. Then the program was to identify the damaged joint/joints using NDT, re-gouge and re-weld it and push the pen stock back to the original position and anchor it. While refilling the pen stock we used Acoustic Emission monitoring to check on the structural integrity. This operation took 3-4 months and it was a success and 30 years later we did not find any report of further damage on the restored pen stock.

4. A company used bonded joint in their road driven vehicle. They observed frequent failures at the end of lap length and this was spreading inside. When we looked at the configuration, the first comment we made was that the adherends should be tapered. The industry man said" Yeah, I should have thought about it myself" and he was about to go. We asked him to wait to allow us to estimate what taper angle to be given, using fracture calculations on Strain Energy Release Rates. In particular the peel mode causes early failure and we recommended a 60^0 which brings the peel effect to near zero value. It was implemented and no further failure has occurred. I have given this example how one should combine the use engineering sense to computational structural mechanics to arrive at the optimum answer.

Closure

I narrated four examples, but there were many. If we consider the entire IISc, the faculty would have dealt several cases of this type. My narrating these here is to make the point is to emphasise that Engineer is a bridge between science and technology. In bringing these together he needs to also use "engineering sense" (some may call it common sense and there is not much difference between these) to successfully implement. Ultimate proof is successful implementation. Development of correct theory is necessary, but not sufficient till it works and also stands the test of time. The mind of an engineer has to assimilate the theoretical part and spend considerable time to realize it.

Safety of operations is needed in every engineering field to protect their structures. Appreciation of all methods of safety could save disastrous loss of human life and money for the state. In each one of the problems there are no common solutions. This is the reason damage tolerance is called a strategy which has to evolve for each case. As such now continuous monitoring of Structures is the scientific method which could be the front end of this approach. SHM and IVHM will generate enormous data and the next few years need to concentrate on how to handle Big Data Analytics to isolate and pick the signals of warning from continuously generated huge data.

The 'making' of the mind of an engineer — Some thoughts on engineering education in India

A.K. Suresh

The academic training an engineer receives in her education sets the initial conditions for her contributions as an engineer. The successes and failures of our engineering sector are therefore traceable, in some measure, to the education system that prepares our engineers. This is not to deny the importance of life and experience in what an engineer delivers in her profession; it is rather that, if education is completely irrelevant, there is a problem right there that needs to be addressed. After seven decades of independence, it is therefore pertinent to look at how our engineering education system has evolved and how it has delivered.

In 1947 when India looked with hope towards her future as a free country, an immediate problem she had to grapple with was that of a severe shortage of skilled engineering manpower needed to address the gargantuan developmental challenges that lay ahead. Faced thus with the urgent task of developing the manpower needed, the leadership of the day opted to adopt the western model of engineering education for our country. In this article, we take a look at the way the system has evolved over the years, how it has performed and attempt to analyse what, if anything, is missing in the discourses that shape engineering education in the country. For present purposes, we use the terms 'engineering' and 'technology' interchangeably, as referring to the same general body of activity.

1 A little history

Let us pause to take a look at the sort of technological world that India stepped into, when she became independent. The twentieth century was characterized by an unprecedented development in science and technology, with its epistemic centre in the west. Engineering achievements in communications, transport, healthcare and other areas completely transformed the lives of people and communities. This, and the resultant growth of the big corporates, led to an ascendancy in the prestige of engineering and management education. The land grant universities had already come into being in the US in the previous century, but the focus of education changed from imparting practical skills to imparting the fundamental principles of science and mathematics. The Society for Promotion of Engineering Education (SPEE) had been formed in 1893 to oversee this change in the US [1].

The second world war saw an increasing emphasis being brought on research in the University scene. This saw, in the US, the SPEE being transformed to the American Society for Engineering Education (ASEE), a society which played an important role in shaping curricular changes. The war also brought into sharp focus the destructive potential of technology, and led to a certain amount of disillusionment with technology. Above all, it led to the recognition of a need for a 'character-building' component as an essential part of engineering education. Subsequent events through the 1960's, connected with the Vietnam war and consequent general social unrest on campuses, forced the emphasis back from research to teaching in the US to an extent [1]. Thus, in addition to the discourses on science and commerce, a democratic discourse was starting to play a role in engineering education. Another consequence of this was the initiation of several affirmative action programs in the Universities, aimed at recruiting women and minorities into engineering.

If a phenomenal growth of technology (and its use for good and bad) was one distinguishing characteristic of the previous century, another was a sharp discontinuity in the political order in the world. Post-war decolonization and the drain of the two wars saw a decline in the power of Europe and the rise of America. Many countries obtained political independence after the Second World War, resulting in a complete redistribution of political, economic and social power in these countries. While developments in science and technology and development of engineering manpower went hand in hand in the western countries, this was not so in the newly independent countries, in which a continuity in local technological traditions had often not been maintained. Not surprisingly, countries like India opted for the western model of education.

This then, was the world scene at the time of India's independence. Having set herself a target of becoming an Industrial economy and with 36 Institutions in the country offering a first degree in engineering with an annual intake of about 2500, the task to build up the educational infrastructure was urgent. Thus forced by need and propelled by aspirations, India undertook a massive expansion of engineering education in the following years. The Indian Institutes of Technology (IITs) were created by an Act of parliament. In the second plan period (1956-61) four of the original 5 IITs (IIT Kharagpur was already functioning by then) and 11 of the 17 Regional Engineering Colleges (RECs) were established [2]. Simultaneously, several new engineering colleges were also started, and the existing ones significantly expanded. In contrast to the Institutions existing at the time of independence which had a fairly static curriculum which emphasized practical aspects of engineering over principles, the IITs were envisaged to have a dynamic, science-based curriculum. The five IITs gradually took on a character inspired by the American model of Land Grant Universities where research is considered to be as important as teaching. The growth of the research culture was further fueled by the creation of Government Departments such as DRDO, DST and DOE in the 1970s. On the Industrial front, the vision was to spur the development of home-grown, science-based technologies - the CSIR had come into existence for this purpose even before independence. On the whole however, the development in this direction was slow, and opportunities for the graduates of the IITs seem to have been less than challenging.

The general emphasis of the early curricula was on basic and engineering sciences, with a significant content of Humanities and Social Sciences. The 'professional' content of the individual engineering disciplines was limited to 30-35%. However, subsequent developments saw a progressive dilution of this philosophy, with the professional content increasing at the expense of basic sciences, engineering and humanities (see [2] for an interesting account of the evolution of the curriculum at IIT Kanpur). A partial compensation was sought to be provided by increasing the flexibility in the curriculum, but the net result has still been a dilution, especially of the humanities component. There has also been a gradual erosion of those components of the curriculum which sought to bring the student close to engineering practice, such as industrial internship. Other changes have been forced by developments in computerization and the rise of new specialized disciplines.

2 Performance of the system over the past decades

We may measure the performance of the system against the yardstick of what the society generally expects out of its educational system. These expectations can be grouped under the following heads:

- **Manpower training:** Creation of trained manpower —
  —for the government and private domains to boost the productivity of the Industrial and agricultural sectors,
  —to provide directions to harness science and technology in a responsible manner for the public good,
  —to provide policy directions so that India may set and work towards its developmental goals, and also offer original thoughts on global issues.

- **Research:** Provide thought leadership and enrich the global 'knowledge pool'; also create adequately skilled research manpower for the Industrial and governmental R&D sector.

- **Development:** Provide —
  - —technological solutions to the country's problems so that the fruits of development reach all sections of the society,
  - —goods and services that enhance the quality of life of all sections of society.

Considered against these expectations, it must be admitted that significant achievements have been made. IITs have become known worldwide for the quality of their graduates, there have been important contributions to the published and patent literature in engineering disciplines, there have been important additions to national infrastructure. All these have contributed to an increase in the quality of life for a large section of the population. The INAE has recently brought out a compendium on Indian engineering achievements [3]. That said, it must also be admitted, if one takes a dispassionate view, that there seems to be a disconnect between the achievements and the goal of building a technological society that is just, fair and equitable, and at the same time forward looking and a role model to the global community of nations. While the education system has been churning out its graduates, the country's development has been uneven, with the fruits of technology largely going to the urban sector. This has led to a migration from rural to urban areas, resulting in a whole new set of challenges for the urban sector, and a progressive worsening of the rural situation in several states. Large unanswered questions remain on the manner of utilization of national resources, and the way in which developmental goals are set. In research too, it has been said that the problems being addressed in our institutions of higher learning are those made fashionable in the west; the Indian elite institutions have not, in general, been seen as a fountainhead of new ideas or new technologies. On the manpower training side, IITs were expected to act as role models for the rest of the engineering institutions in the country, but the gap between the first tier colleges and the rest has, arguably, only widened over time. The result is that, while there has been considerable expansion in the number of graduates coming out of various engineering colleges in the country, much of this number is generally seen to be of too poor a quality to attract the attention of employers. There also seems to be a disconnect in general, between the training a student goes through in the engineering college and the kind of vocation she pursues after graduation. Clearly, there are problems of considerable magnitude crying out to be addressed.

3 Reasons for the expectation-achievement gap: An analysis

The disconnect mentioned above between the broad goals of nation building and the achievements of the engineering sector points to a problem of awareness: does our training of engineering professionals make them sufficiently aware of the nature of their activity, its place in society, and the socio-cultural milieu in which that activity would be taking place? These questions are more relevant to engineering training than to scientific training - while the answers science seeks are of a universal character, engineering solutions, though technical and maybe based on universal scientific principles, have a social, political and cultural context to them. Staudenmaier [4] argues that different cultures develop different 'technological styles'. Viewed from this perspective, the problem may be traced back to the discourses that have defined and shaped engineering education in our country. Sadly, a deep analysis of this issue has been missing so far, the easier route of uncritically following the best practices evolved in the west being usually taken.

An examination of the situation reveals that the discourses which have held sway through the evolution of the engineering education in the country have traditionally been those of science and commerce. The situation is not unique to India [5], but probably has stronger implications for a young country like ours with aspirations of leapfrogging across the developmental divide. Good engineering, in the end, is more than about application of science (since the same principles can be built into a multitude of technological solutions, some relevant and others less so to the context of application), and more than about creation of wealth (since questions of equitable development, environmental concerns, societal concerns have to be factored in). This implies that the engineer should be made aware, as a part of her academic training, of the other discourses at the intersection of which her activity stands. These other discourses that may be mentioned are those of engineering itself, philosophy, history and democracy.

3.1 The engineering-philosophy discourse

We consider these together because a number of issues are common to the two threads; further, the nature of engineering is, after all, a question in philosophy. It is a thesis of this essay that philosophers in India have not become engaged adequately with this question. Indeed, philosophy of technology is a relatively new discipline even on the world scene [6].

The question we want to address from a philosophical standpoint is whether engineering deserves its own place in the sun apart from that of science. Let us first note, with this purpose in mind, that it is really not necessary to distinguish between 'science' and 'engineering science'; the whole thing is really a continuum.

What is the nature of engineering? Is it technical art, is it applied science? Views have tended to swing between these two extremes. The former view emphasizes the creative aspects of technology, and hence attempts to trace a continuity with art. This view gained prominence at the time of the Renaissance in Europe, but the proponents of the view tended to be from backgrounds other than science and engineering, and therefore had little first-hand experience with the methods of either. Technology may have come about initially as an expression of man's creativity being employed towards a better lifestyle, but over the millennia, science has caught up to a stage where it is itself spawning technologies. Further, technology has become indispensable to the progress of science as demonstrated by the need for sophisticated instrumentation and computing devices, not to mention gigantic artefacts such as the Large Hadron Collider. This symbiotic existence of science and technology in the modern day, makes it difficult to draw a clear separation between the two, but more importantly for our purposes, it diverts attention from other aspects of the personality of technological activity, than the purely scientific. While the heavy scientific underpinning of technological action (see Mario bunge [6]) cannot be denied, the type of superstructure technology builds has to be sensitive to multifarious other factors, as already pointed out. The view has been put forth by Skolimowski and others [6] that science is about what is, while technology is about what should be; in other words, science concerns itself with the world as it is, while engineering tries to change it to better suit our purposes. This then brings up the question of who decides what is to be. If it is accepted that this decision is itself external to technology, it leads to the view that technology is value-neutral, a view that may not be entirely correct (besides having undesirable connotations on the responsible use of technology) considering that many technologists are self-motivated in their work.

One has to thus accept a working definition of technology in order to make progress, while the philosophical questions continue to be debated. Following Vincenti [7], we may think of engineering as being concerned with the design, production and operation of artefacts which change the world around us in some premeditated way, in order to achieve some recognized need. The centrality of design in the activity of an engineer has often been emphasized [6,7]. Vincenti[7] describes the hierarchical structure of the design activity, and shows how the upper strata of the activity (which are concerned with the conception of the problem and its formulation in engineering language) are subject to contextual influences from other fields such as sociology and environment, while the lower strata (concerned with the production of plans, prototypes, etc) depend on 'engineering knowledge' that derives from a complex interplay of experiment and theory. This latter thus employs methods similar to science, but is a body of knowledge that stands on its own.

From the viewpoint of epistemology, recognizing that the body of engineering knowledge is something that stands apart from, and converses with, the body of scientific knowledge, has important implications not brought out by the simplistic view that engineering knowledge is a part of scientific knowledge. Recognizing this and according to engineering knowledge its rightful place is essential to the growth of that knowledge, and for preparing the ground for original contributions in engineering.

The relevance of the above to the present analysis of engineering education are obvious. A view of engineering that emphasizes its individuality emerges as an essential component of engineering education. The lack of this is probably a main reason why there is a neglect of (one might even say a lack of respect for) purely engineering work in the academic sphere. Vincenti's account of airfoil research in the early decades of the last century is instructive on how important such research can be for progress. Similarly in the initial years of the biology revolution, enormous effort was spent on generating random mutations and screening the mutants for desirable traits, and much progress in industrial biotechnology resulted from such efforts. Of course, such purely empirical research does involve considerable investments, but history shows that such investment is worthwhile in creating a leadership position in technologies. It may even be argued that a similar order of importance and multiplication of effort is necessary for developing meaningful solutions to the problems that beset India's countryside.

3.2 The history-democracy discourse

As in the case of the previous discussion on engineering and philosophy, it pays to consider history and democracy together in this broad analysis. History is replete with instances of public pressure influencing the adoption or abandonment of technologies: developments in the tobacco industry, automotive fuel (lead and its replacements), Chlorofluorocarbons, are prominent examples. But there are also debates engendered by social (rather than human health) issues that have impacted technological developments - we in India are witnesses to several. Staudenmaier [4] recognizes three phases in the life of any successful technology - a design phase, a maintenance phase and a senile (or obsolescence) phase. The design phase, which we may call as the phase of 'tooling up', is characterized by flexibility - the technology is responsive to external inputs in this phase. In the maintenance phase, the technology has gained such momentum that the society tries to adopt itself to its ways - the technology itself is rigid in this phase. In the final phase, other competing technologies, themselves in the design phase, are trying to replace the old technology, but the rigidity developed in the maintenance phase tries to counter this. The point is illustrated by the history of the automotive industry in the US. Staudenmaier also categorizes the different stakeholders who play a role in the adoption (or continuance) of a technology in its various phases, among various constituencies. His illustrations are instructive of the kind of democratic pulls and pressures which are active at various stages in the life of a technology. It is particularly important to recognize the vested interests that come into being in the maintenance phase of the technology, supported advertently or inadvertently by governmental regulations and societal adaptations to the technology, which often militate against rational decision-making.

Since historical times, technology has inspired excitement and awe on the one hand, and fear on the other. Philosophical discussions on technology have tended to be of two kinds: the analytical tradition referred to in the earlier section is a late entrant in the field; the earlier tradition by far, is concerned with the effect of technology on society and is continuous with traditions in sociology and the humanities [6]. The kind of fear inspired by technology, that it has a Frankenstein-type potential to run on its own logic and take over its maker, is prevalent even today and is articulated in discussions of artificial intelligence, genetic engineering, and so on. The wealth of fiction and movies on such themes is also a testimony to the public imagination that the theme captures. Given such a scenario, views held by influential people or cliques, well informed or otherwise, have played an important role in history in advancing certain types of development over others. For example, the view, going back to Aristotle, that there is a fundamental difference between 'natural' substances and human-engineered artefacts, and that technology can never reproduce 'natural' substances, formed an important basis for the criticism of alchemy. Proceeding further, similar views also delayed the emergence of synthetic organic chemistry as a discipline. It is a consequence of the political developments of the twentieth century that public opinion is increasingly taking a position of influence in deciding on technological options.

In recognizing the role of democracy in technological decisions, one should emphasize the need for informed debates; engineers and technologists themselves have the role of spreading awareness about the pros and cons of different technological alternatives. While there is often an impatience about the time taken for decisions to emerge in a democratic set-up, if the delay is caused by informed debates, it is time well spent, since adoption of large scale technologies can completely alter the landscape of society for decades to come. A knowledge of democratic traditions and institutions, would therefore seem to be an essential component of the repertoire of an engineer.

4 Epilogue

In this essay, I have tried to take a step back and seek reasons for the gap between the performance of our educational sector and its engagement with national developmental goals, and identify the missing pieces in the thinking that informs engineering education in the country. A preoccupation with the 'disciplinary' content of engineering curricula, which has led to a total lack of an in-depth analysis of the different discourses that should inform engineering activity, is identified as the main reason for the gap, and for an uncritical adoption of western models to answer our educational needs. Clearly, such an analysis has to be an ongoing one which continuously interacts with the 'practice' of engineering education. It also calls for a continuous research effort and development of resource material in areas such as the philosophy of technology, history of technology and the nature and role of democratic institutions in the context of engineering activity. It is essential that such developments are rooted in the Indian context for them to make a significant difference to the preparedness of our graduates to address our engineering and developmental challenges. Perhaps there is an urgent need for an Institutional framework which, from a vantage point, takes a meta-level look at the contextuality of engineering activity and develops this 'confluence of discourses' to guide the development of engineering education in the country. Such an Institutional framework seems essential so that the output of the engineering education system is relevant to, and sensitive to, national needs, while at the same time being in step with international developments.

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