ONLINE INTERACTIVE SESSION WITH PROFESSOR H. S. MUKUNDA

8th September, 2020

On the 8th of September, 2020, the regular batch of Class 11 students at Mushtifund Aryaan higher Secondary School had the marvellous opportunity of interacting with Professor H. S. Mukunda, M.E, Ph.D.

Professor Mukunda acquired his Bachelor's Degree in Mechanical Engineering from NIE, Mysore and his M.E in Aerospace Engineering from the Indian Institute of Science, Bangalore, where he was the topper of his batch (1965). He obtained his Ph.D. within 5 years from IISc itself, which, at the time, was no mean feat. He worked at a high-profile Aerospace Engineering department at IISc for 34 years and spent an additional 10 years as an advisor to advance bio-residue energy technology at IISc. He is currently a research advisor at the fire and combustion research centre at the Jain Deemed-to-be University. His teaching and research are in the area of combustion sciences for aerospace medicals, missiles and other industrial combustion devices. He has supervised over 25 Ph.D theses and published a significant number of papers in top-rated international journals. He has written 4 books related to propulsion and energy. He has participated in the development of major launch vehicles of ISRO and missiles of DRDO through review committees, and in the troubleshooting of several technical glitches, over the past 30 years.

His current research interests are in fire safety, modelling in solid propellant combustion and combustion of slurry fuels in aircraft engines. He is the chairman of a joint working group at the Gas Turbine Research Establishment on select problems of aircraft engines, and with ISRO on solid and liquid propellant combustion. He is active in the development of clean combustion solutions for a range of solid fuels including urban solid waste. He has extensively travelled abroad and participated in the International Symposium on Combustion and delivered talks on combustion in aerospace and biomass-based renewable energy. He is a Fellow of the Indian Academy of Sciences, Indian National Academy of Engineering and Aeronautical Society of India. He has received several awards, which include the Om Prakash Bhasin Award for energy, lifetime achievement award of the Solar Energy Society of India for Excellence in Research and Engineering, Distinguished Alumnus Award from IISc Bangalore in 2006, Rajyotsava Award from the Government of Karnataka in 2005, and the prestigious Visvesvaraya Award for Science and Technology in 2005.

Sir Vyankatesh Prabhudesai, Director of Mushtifund Aryaan Higher Secondary School, was a student of Professor Mukunda during his M.E at IISc Bangalore. He was taught two courses by Prof. Mukunda, namely, Mechanics and Thermodynamics of Propulsion, and Mathematical Methods in Reacting Flow. Sir Vyankatesh Prabhudesai noted that the time slot for Professor Mukunda's lecture was 2 to 3 p.m., after a rather heavy lunch break, yet the students did not experience any drowsiness during Prof. Mukunda's Lecture. With this, he concluded the introduction of Prof. Mukunda.

Professor Mukunda predicted that while we are still young, we will target certain degrees in higher studies, then possibly pursue Ph.Ds. After that we may either take up jobs in research or go to academic institutions in India or overseas. We might also finish our Bachelor degrees in Engineering or Technology and take up jobs in industries. Another possibility is that we might become entrepreneurs and develop hardware or software. Prof. Mukunda told us that it is noteworthy that as we climb higher up the ladder, science, technology and engineering become increasingly integrated. For instance, many medical devices require science(including Medicine) as well as technology for their development and execution.

Prof. Mukunda believes that in a few years, the areas of work that will attract the majority of people are neuroscience (a field related to medicine) and robotics (a field related to computer science, hardware and software). Besides, mechatronics and artificial intelligence will work hand-in-hand with the aforementioned fields and provide great benefits to society. Prof. Mukunda advised those interested in Biology and Technology to note that in a few years, there will be significant growth in these fields, as well as distinguished research activities in institutions like Cambridge, Oxford and Stanford as well as a handful of Indian universities.

Prof. Mukunda pointed out that the chief problem in India is the divide between engineering and medicine. In the last 50 years, research in engineering has been far better promoted than research in medicine. The current idea behind medicine in India is to train students to become doctors, whereas institutes elsewhere, like Johns Hopkins University have excellent medical courses integrated with engineering. This idea is not welcomed in India as yet, and hence the advanced research and development in the common areas between engineering and medicine is still very limited. Sir Vyankatesh Prabhudesai pointed out that the Indian Institute of Technology, Kharagpur, has plans to start a medical school integrated with engineering soon. Professor Mukunda, however, brought to light the fact that it will take a while for people to recognise this concept as worthwhile, whereas institutes overseas have already erased the line between the two fields. Students overseas start with engineering and slowly lean towards medicine, a rare occurrence in India. Besides, there are other factors like social pressure which stops people from switching streams.

Professor Mukunda told us that while we may pick streams based on others' influence, sometimes, fields that seem fantastic at first, later seem average at best. Hence, while it is important to have aspirations, the perceptions of one's external environment keep varying with time. Professor Mukunda gave the example of his own son, who initially wanted to pursue Engineering at an IIT and did so (aerospace engineering) at IIT Madras, went overseas and studied at Stanford where he joined a mechanical engineering department. However, his work in fluid mechanics was related to helio-acoustics and he acquired a degree in Astrophysics, which is fairly different from engineering. He is now a scientist at the Tata Institute of Fundamental Research, Mumbai and is no longer involved in Engineering. This goes to show that one's interests keep changing as one studies further and meets new people.

Thus, it is important to account for the possibility that one may think differently in a few years due to societal influence and the Internet, et cetera. This also impacts one's aspirations drastically and it is important to keep room to account for these factors. What is important is that one picks a field that brings him/her joy. The situation may be different now because of pressure due to tests, which is considered a part of everyone's life. After graduating from an institute, it becomes evident that one's own opinions come to light and one shifts to different areas of interest. It is at this stage that it becomes important to identify one's strengths and weaknesses and choose an appropriate field of work. When Professor Mukunda was in high school, he was in a place where he had a low chance of interaction with people whom he thought were better than him, from whom he could learn things he didn't know. He had nobody to share his understanding (or lack of understanding) with. However, he was very clear about the class of work he wanted to do, and was positive he didn't want to enter an industry, but wanted to join an academic institution where he had the freedom to perform any appropriate research within the bounds of the institution, unlike a shop-floor with specific tasks. Hence, Professor Mukunda concluded that money must not be a priority when selecting a field of work, because money with no joy is stressful. Giving the example of Steve Jobs, he stated that the primary (but not sole) criterion for a career must be the fulfilment of joy, with all other criteria following after. In Prof. Mukunda's case, his research at IISc gave him joy, because, there being extremely competent people of all disciplines, there was abundant exchange of ideas among fields. Thus, it is important to surround oneself with people who one enjoys working with. This is not restricted only to academics.

At this point, Sir Vyankatesh Prabhudesai asked Professor Mukunda whether IISc should have had an undergraduate program much earlier so that the brand value of the institute would be greater and the best people in India, who often leave the country after graduating from IIT, would join IISc for research and gain better knowledge than they gained at IIT during the undergraduate program there. Prof. Mukunda pointed out that when IISc came into existence, its primary goal was to encourage frontier research in subjects like Chemistry and Electrical Engineering, those required to help the economy of the country. He noted that IISc had a B.Sc program at some point of time, in Electrical Engineering and Metallurgy. However, when IITs began to flourish, it was discovered that what was being done at IISc was not necessarily great. Also, the primary reason for a B.E program was the reservation policy of the Indian Government which, at the time, was unfavourable to a large number of bright students. Students would switch to B.Sc because of the lack of engineering institutes at the time. Hence, a large number of students who were looking forward to a decent degree in Engineering, would acquire a B.E degree and subsequently acquire a Masters or Ph.D in engineering. The primary aim of IISc was to get people to advanced levels. An M.E. was the primary goal, along with Ph.Ds. Ph.Ds in engineering were limited at the time, while science was a fairly big deal. Slowly, it was decided that it was redundant to have a B.E program at IISc due to flourishing IITs. During JRD Tata's interaction with the faculty of IISc, he specifically requested that the IISc have courses related to social sciences like History. After intra-faculty decision over a span of one year, it was finally concluded that IISc was not prepared to deal with social sciences in the midst of basic sciences like Physics, Chemistry and Math. Currently there has been a B.Sc program for 10 years. There have been changes involving younger people at the level of PUC, a little ahead of B.Sc, who can do an M.Sc or a Ph.D. This route has been chosen in order to provide something interesting to Science degree students, which were few in number.

Professor Mukunda then answered a common question: how is India different from the rest of the world with respect to aerospace? Professor Mukunda answered this by stating that aeronautics made its entrance into India in 1945 because of HAL, which is also how aircraft was developed. Space technology arrived much later and was built with the help of the French and the Americans. Over a period of time, it was clear that the need for the Air Force to obtain advanced airplanes was high. The government, at the time, assumed India did not have the technology to build aircraft because India was at least 25 years behind the rest of the world in some areas. Therefore, they always purchased aircraft from France, the UK, Russia and the USA. This led to people feeling betrayed and caused people to go overseas, which was an attractive proposition. Unlike the present-day situation, overseas education was assumed to be flawless at the time. Overall, the encouragement of purchase of aircraft from overseas had more negative aspects than positive ones. It was only after a lot of struggle that LCA (Light Combat Aircraft) were built in our country. Indigenously built engines like the Kaveri were replaced by others. While India has never been able to adequately build gas turbine engines, it has been able to build rocket engines based on liquid and solid fuels. Prof. Mukunda clarified that the phrase ‘rocket science’ used to indicate a difficult task is quite misleading, because rockets are not as difficult to build. The difficulty of meeting requirements of domestic applications, meeting the cost and the time-frame, is high. Therefore, Prof. Mukunda said that building a stove is more difficult than rocket science. Therefore, rocket science is not actually ‘rocket science’ (as used as a phrase). As far as rocket engines are concerned, the major requirement is mechanical engineering. A small part of it is combustion-based, but the rest of it is not as intricate. Solid rockets, on the other hand, have more complications with regard to fuel flow, the way propellant burns, et cetera.

Prof. Mukunda once told A. P. J. Abdul Kalam (who believes solid rockets are easy to build) that solid rockets were very involving to build while liquid ones were relatively simple. India had a strong programme for solid fuel rockets while liquid fuel ones were purchased from overseas. Today, India has mastered both kinds to a large extent. However, India still lags behind other developed nations because of the lack of commitment of monetary resources and an intellectual environment, both of which are required. There is also the fact that foreign airplanes and rockets are considered superior, which is a hurdle in the development of indigenous aircraft. Without developing a fully working model at first, it is impossible to develop a model better than others’. Constant reminders of inferiority slow development. Building a working model of an aircraft, however inefficient, is the primary step, without which fine-tuning and development of variants is impossible. Prof. Mukunda believes this applies even to our own lives. We must accept who we are, do what we can and slowly build on that to improve ourselves.

A student at Aryaan Study Circle then asked Prof. Mukunda whether aircraft gas turbine engines or marine gas turbine engines are more efficient. Prof. Mukunda said that is unfair to classify them separately. There are even gas turbine engines used to generate electricity on the ground. In marine gas turbine engines, a part of the power generated is used to generate electricity whereas the rest is used to provide propulsive force. The main difference is that aircraft gas turbine engines require a significantly higher thrust-to-mass (mass of the **engine**) ratio, around 60-100 Nkg^{-1}. This is not required in marine and land-based gas turbine engines. However, land and marine-based gas turbine engines need to operate for longer durations at a stretch, whereas aircraft gas turbine engines operate only for a few hours. The life expectancy of an aircraft gas turbine engine is around 4000-10000 hours whereas that of a land or marine gas turbine engine is around 20000 hours. Marine gas turbine engines also have to face adverse conditions like salt, which causes rusting. Even within aircraft gas turbine engines, those that fly in harsh conditions like deserts must be better fortified. The reason behind the complexity of aircraft gas turbine engines is the turbine inlet temperature, controlled by the turbine blades. Though the inlet temperature may go to around 2300K, it is typically limited to around 1200K-1700K. Better engines are classified by enhanced turbine inlet temperature, and the current best is around 1750K for aircraft gas turbine engines. The life of the blades in this case is not very large due to extremely hot air flow. Marine gas turbine engines, on the other hand, may be used at around 1200-1300K due to the long continuous running hours, because efficiency is not a priority. Sir Vyankatesh Prabhudesai pointed out the outstanding reliability record of aircraft gas turbine engines, especially those of formation flights. The intricate design of gas turbine engines has a drawback: thermal cycling. The engine is cold at first, then expands thermally during its running and contracts again after cooling down. This leads to a phenomenon called 'creep' due to which component gradually elongate. This must be managed well: keeping too small a clearance for it leads to friction and too large a clearance leads to leakage and loss of performance. The effort that goes into choosing, conditioning and testing construction materials is very intricate. Building a certain class of engine requires a certain quality of intellectual and infrastructural input. This did not happen adequately in India, where intellectuals leaned towards aerospace and defence because aeronautic institutions emphasised that they were yet to grow, which reduced appeal. The intellectuals gravitate towards ISRO and DRDO, which is why India has not progressed as well in gas turbine engines as in aerospace.

Another student asked Prof. Mukunda how accommodating the Indian education system is to changes such as switching from Engineering to Medicine as a stream. Prof. Mukunda clearly stated that Indian systems are not very accommodating. Though there are courses in biomedical engineering, those with deep interest will be better off at institutions overseas, like Johns Hopkins and Stanford, where medicine can be integrated with any engineering course.

Sir Vyankatesh Prabhudesai asked Prof. Mukunda whether acquiring a Masters degree and a Ph.D is better in India (IISc in particular) or overseas, as well as why Prof. Mukunda did not do so overseas. Professor Mukunda stated that there were a few limitations in his case. He finished his PUC in 1958, around the time when IITs began to rise. His father was a teacher in middle school and communication systems were nearly absent. The first time he exited Mysore was on a tour at an engineering college. Fortunately, he heard of IISc due to a classmate's relative who served as faculty there. He learnt of someone working in his office at 7 p.m. calmly, an idea that appealed to Prof. Mukunda. In fact, Prof. Mukunda did not even apply to any other institute for admission. Prof. Mukunda pointed out that in India, students work very hard to get past IIT-JEE and on clearing it, believe that they have achieved the maximum possible. The systems in India do not demand that students exercise a lot of their intellectual prowess in doing what they are. Barring a few students who have a definite aim to progress in a select direction, many students who graduate from IIT aren't exceptional. The same students, if overseas, must work much harder because the competition works very hard too. This helps one bring out the best in oneself. In India, due to the lack of external pressure, one does not grow if there is no internal pressure. The intellectual environment present at foreign institutions is not easy to come by at any institution in India. Interaction among and across faculty and students has a long way to go in India.

A student pointed out that there has been a marked shift to electricity for passenger vehicles. However, rocket propulsion still uses natural fuels. He asked Prof. Mukunda whether there was a chance of the usage of electricity for rocket propulsion in the near future. Prof. Mukunda clearly stated that this was not possible due to the vastly higher energy density of fossil fuels as compared to batteries. Rocket propulsion requires large amounts of energy to be delivered in extremely small time periods. This demand cannot be met by a battery. However, batteries find use on land vehicles, where certain factors like charge rate and range must be considered. Batteries, however, can be used to power small, light, short-haul aircraft. This is a new innovation in which India has the opportunity to make progress. It does not require a lot of investment, and would be a significant value addition to the country's economy.

Another student asked Prof. Mukunda whether it is possible to tap nuclear energy for rocket propulsion and whether there is work going on in this field. Prof. Mukunda said that research on this has been conducted much earlier. He explained that in a gas turbine engine, the fuel is around 90% of the mass of the engine while the components are around 10% of it. On the other hand, in a nuclear rocket engine, the hardware is of great mass and it produces lower thrust. Nuclear rocket propulsion finds use in higher stages when sufficient velocity has already been attained and there is requirement of lower thrust for a longer time period. Typically, in nuclear rockets, hydrogen is heated to high temperatures and exhausted to the nozzle to provide the necessary thrust. This has not been used as much as gas turbines due to nuclear safety ideas. In the event of an explosion, the debris poses significant hazard. Thus, nuclear propulsion is not greatly emphasised upon.

Sir Vyankatesh then referred to the rampant usage of the term 'indigenisation' and asked about the percentage of Light Combat Aircraft, rockets and satellites that was indigenously developed. Professor Mukunda stated that some parts and control elements of Light Combat Aircraft, which are not available in India, are obtained from a USA-based company called

Moog. These parts would be commercially unviable to produce in India due to the limited market, as compared to the aircraft industry in the USA, developed over 70 years. To build a large number of parts for a single model of aircraft in India is not feasible. Hence, such small but critical components are not built in India. This would lead to overshooting of the development budget which might lead to projects not being sanctioned at all. The freedom to buy small parts from overseas and integrate them into a single aircraft is of great help. The hardware (like the wings, for instance), however, can easily be built in India. As regards launch vehicles, 95-98% of them were built in India for both, solid and liquid-fuelled rockets. With regard to satellites, they must stay in orbit for long durations, hence many parts must be qualified to meet high standards and must be able to tolerate harsh conditions like that of a vacuum. Thus, many such parts were imported from overseas. However, today, only around 10-15% of parts are imported. As long as access to no part is denied, the origin of parts does not make much of a difference. Only sometimes when the Missile Control Regime was imposed on India, there was some difficulty in importing parts. This actually turned out to be good for India because it sparked thought about localisation of parts.

Sir Vyankatesh Prabhudesai then asked whether the reason for ISRO and DRDO doing better, than NAL and HAL, is the stringent certification required, as opposed to the not-so-stringent certification for aircraft and missiles. Prof. Mukunda said that while this is true for space vehicles, it is not greatly applicable for defence systems. For instance, satellites must be certified to withstand extreme conditions and must pass a far more rigorous environmental clearance than defence systems must. Aircraft are man-rated and hence undergo even more rigorous testing. However, this is not the primary reason for the low speed of development. No longer are aircraft built only by the government. Design and execution is largely controlled by respective aircraft agencies. Outsourcing activities to private companies leads to competition and large numbers of people becoming involved in these difficult skills. This demand for speed implies higher costs. In a government agency, however, due to lower funding, development slows down. NAL, for instance, unlike ISRO, has had no clear focus for a long time. It had no character till 1983 till President Kalam's rule, when he launched the Integrated Guided Missile Development Program, which was mostly successful. It was a program such that the country owned it. This has also happened with ISRO. When a program is such that the country owns it, demand is higher and work is faster. The situation with aircraft is fairly good, although there was greater potential for this in our country.

Sir Vyankatesh Prabhudesai then asked Prof. Mukunda to guide us regarding our choice of branch, which is an uncertainty for many students, and also whether he faced this dilemma while choosing a field. Prof. Mukunda warned us in advance that any data from his era is irrelevant, because his era was fuelled by peer pressure. Beside mechanical engineering, electrical engineering was considered to be a good branch. Prof. Mukunda selected mechanical engineering because of his liking for it. He advised us to exercise thinking with our own minds in this regard. There are also other governing factors like our IIT-JEE rank. He also added that the fancy for computer science and electrical engineering is not well-driven and is often based on peer pressure. However, not all students are capable of deciding what is best for them. The two factors to consider are: one's liking for a subject and one's competence in the subject. It is not a great loss to not get one's desired field, because a good branch does not guarantee much. After getting a degree, one still has the option of pursuing his/her desired field. Deeper commitment to oneself with ability and knowledge is more important.

Sir Vyankatesh Prabhudesai then asked whether knowledge in chemistry is an additional requirement in rocket propulsion, besides physics and math, which are required for other branches of engineering too. He pointed out that bright students are usually interested in physics and math. He also asked how it is possible to generate interest in chemistry, and how important it is for the future of students. Prof. Mukunda stated that the kind of chemistry required for rocket propulsion is simple enough for any engineering student to learn. To pursue chemical engineering, a minimum standard of chemistry is required, which is important for one to become a good chemical engineer. He said that excepting some select fields, knowledge in chemistry is not as critical as that in other subjects.

A student asked Prof. Mukunda about the scope for hydrogen-cell vehicles like those developed by Toyota and Honda, and whether they could be a potential replacement for electric cars. Prof. Mukunda replied by stating that terrestrial transportation systems are a haven of new technology and ideas. Electric vehicles are used to reduce emissions by using renewable energy sources for generation of electricity. Hydrogen, too helps reduce emissions. Chemical fuels are far more efficient than battery-based vehicles, and an alternative to natural gas, gasoline and diesel is hydrogen. The major issue is that hydrogen is extremely light and its production and transportation poses safety issues. Prof. Mukunda believes that development and acceptance of hydrogen vehicles will be slow and hydrogen will have low probability of becoming mainstream as compared to natural gas or electricity, however, it is definitely an approach that has significance.

Another student then asked Prof. Mukunda how combustion of solid, liquid and gaseous fuel occurs simultaneously in hybrid rockets. Prof. Mukunda clarified that this occurs only in rockets and not in aircraft, which use kerosene as a fuel. Prof. Mukunda then explained the mechanism for each type of rocket: solid, liquid and hydrogen. Liquid fuels have safety concerns and cause fires in the vent of crashes. Solid fuels are even more hazardous due to the integrated oxygen and fuel and it is near impossible to prevent and put out fires caused by solid fuel. In hybrid rockets, with a liquid oxidiser like oxygen and a solid fuel like polybutadiene or methylene, the fuel and oxidiser are separate, hence safety is better ensured. Hence, hybrid rockets are considered a safer option for the transport of humans into space. Performance is not compromised. Marushka Fernandes, a student at Aryaan Study Circle, then proposed the vote of thanks.

Overall, this interactive session with Prof. Mukunda gave us a fresh insight into a wide array of topics ranging from rocket propulsion to advice for our future. His long-standing experiences and his opinions on education, aircraft development and research in India will definitely be of immense help to all students. On behalf of the students of Aryaan Study Circle, I would like to thank Prof. Mukunda for spending his invaluable time to impart his knowledge to us, as well as Sir Vyankatesh Prabhudesai for giving us the opportunity to meet such revered personalities from time to time.

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