75 YEARS
DEPARTMENT OF AEROSPACE ENGINEERING

Indian Institute of Science

Satish Dhawan

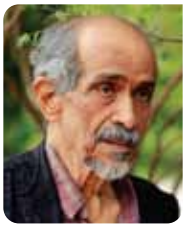
Snippets from the IISc Archives

FOREWORD

This booklet on Satish Dhawan comes at a most appropriate time, when the Department of Aerospace Engineering (AE) at IISc is celebrating its Platinum Jubilee. Dhawan was surely the most distinguished head it has had in these 75 years. In his first few years at AE he established a Fluid Mechanics Group that quickly began to make its presence felt by the research it carried out – mostly basic research, identified by Dhawan as important for tackling the specific problems faced by Indian industry. This resonated with the needs of a country that had just become independent and was pursuing, under the inspiring leadership of Jawaharlal Nehru, a path that recognized the great role that the development of science and technology needed to and could play in the future of the country. Dhawan implemented this Nehruvian philosophy through the way in which the Group's research programmes were formulated and carried out.

Dhawan's unusual abilities, and his own commitment to science and technology in general, quickly made a great impression on the campus and elsewhere. At the end of four years since he joined IISc as a Senior Scientific Officer he had become the Head of AE, and after the following seven years he was Director of IISc (when he was only 42 years) – a "meteoric" rise, as a British friend of mine told me at the time. He went on to transform the Institute, made it "a great centre of learning and research" (in the late Prof Yash Pal's words), and went on (after the next nine years) to head the national space programme and build the Indian Space Research Organisation into what surely must be the nation's most reputed S&T agency.

Dhawan was a rare combination of engineer, scientist, teacher, leader and institution builder. He was also a socially conscious, publicity-shy visionary, a wonderful friend, a great human being, a man of unquestioned integrity and a true patriot. He carried these virtues lightly, and a smile and a joke were always ready to lighten the atmosphere whenever that seemed needed – whether in personal discussion or in the Senate. The articles in this booklet bring out, in brief, all the different sides of the character of a most remarkable person. I consider myself very fortunate in having had the opportunity to have known him over most of his career, and to have worked with (or for) him on various occasions and on a variety of problems – from my Associateship thesis 60 years ago to the causes of the failure of the Augmented Satellite Launch Vehicle nearly 30 years ago. His adviser at Caltech (and mine too), Hans Liepmann, once told me at a time when India was going through some difficult times, "You know, it only takes ten Dhawans to transform your country! With your huge population, surely that must not be difficult!" I hope he was right, and that transformation will happen.



RODDAM NARASIMHA

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IISc'S REMARKABLE EXPANSION UNDER DHAWAN

Dhawan invited CNR Rao to set up the Solid State and Structural Chemistry Unit (SSCU) in 1976

Satish Dhawan was the longest-serving Director, who transformed the Institute in many ways – from reorganising academic departments to establishing new centres and encouraging the Institute community to embrace an interdisciplinary research approach.

In 1951, Satish Dhawan joined the IISc as a Senior Scientific Officer, and within a few years, he was appointed the Institute's Director. When he took charge of the Institute in December 1962, he was only 42, the youngest Director ever in the history of IISc.

At that time, the Institute was relatively small. There were only 11 departments and 5 sections. By the time Dhawan left there were some 40 departments and units in the Institute. He also created four Divisions, each with a faculty member as the Chair.

In a sense, in his tenure of more than seventeen years, the longest in the Institute's history for any Director, Dhawan could exert a long-lasting influence on the Institute's intellectual character, its programmes in both research and education, and its administrative structure. This period was also marked by an extraordinary expansion in the diversity of the research programmes at the Institute, as many new faculty joined at various times and a variety of new centres were set up.

Pooling talent from across the world

Dhawan launched a major campaign in the late 1960s and '70s to recruit new faculty, especially from abroad. In his autobiography, *Climbing the Limitless Ladder: A Life in Chemistry* (co-published by IIScPress and World Scientific Publishing Company in 2010), CNR Rao talks about Dhawan's role in getting him back to IISc. Before moving to IIT Kanpur, Rao spent time at IISc between 1959-63, and it was during this time that the two became friends. In 1976, when Rao was keen on leaving IIT Kanpur and was contemplating accepting an offer from a US university, it was Dhawan who asked him if he would like to come to IISc and head the Inorganic and Physical Chemistry department or the Chemistry Division. Rao arrived at IISc and, the same year, he founded the Solid State and Structural Chemistry Unit, followed by the Materials Research Laboratory in 1978.

Dhawan also brought IG Sarma, again from IIT Kanpur, to set up the School of Automation in 1969 (later it became the Department of Computer Science and Automation), with a view to strengthening research and academic activities relating to control electronics and computers under the Indo-USSR agreement on Scientific Cooperation. This is why the School of Automation was an unusual academic unit in the country. A year later, a computer centre was set up (with an IBM 360).

In somewhat similar ways, Dhawan invited GN Ramachandran, then working at the University of Madras, to set up the Molecular Biophysics Unit (MBU) in 1971, and Ennackal Chandy George Sudarshan, who was then Director of the Centre for Particle Theory at the University of Texas, Austin, Texas, USA, to set up the Centre for Theoretical Studies (CTS). The Centre started functioning in July 1972. The Centre's mandate then was to take up interdisciplinary research activities and multidisciplinary programmes, involving various branches of physical sciences, mathematics, biology, engineering and social sciences. Thus, the Institute saw a major influx of talent in the early '70s.

Speedy expansion

The building which housed the Centre for Theoretical Physics is now home to Centre for Contemporary Studies

In all, seven such centres or units of interdisciplinary, interdivisional, and interdepartmental nature were set up to build strong linkages and bridge the education-research-application chain. These centres were the Centre for Theoretical Studies, Centre for Information Processing, Centre for Electronics and Design Technology, School of Automation, Centre for Continuing Education, Centre for Scientific and Industrial Consultancy and the Cell for Application of Science and Technology to Rural Areas (ASTRA). These centres acted as focal points bringing together several people with different expertise to work on specific problems.

Dhawan, who thought deeply about the societal impacts of science, played a key role in setting up ASTRA, now known as the Centre for Sustainable Technologies (CST). ASTRA was founded by Amulya KN Reddy (then a professor of electrochemistry) whom Dhawan had invited to make presentations to the Senate Committee on Research and Academic Policy and design a multi-disciplinary centre which would draw expertise from the various discipline-oriented departments at the Institute.

Dhawan was a man of very broad interests, including an interest in nature and conservation issues. Due to his interest in ecology, IISc saw the setting up of the Centre for Ecological Sciences (CES) in 1983, whose mandate right from the beginning included both theoretical work and field ecology. Madhav Gadgil, an eminent ecologist, was also handpicked by Dhawan. "He encouraged me to develop a full-fledged ecology programme here at IISc and that was how CES was born," recalls Madhav Gadgil.

Gadgil, now retired, recalls it as an interesting experiment. "We had a very interesting group at CTS: N Mukunda, who was a theoretical physicist; Sharat Chandra, who was a geneticist; and Vidyanand Nanjundiah, who did a PhD thesis in physics, but then researched developmental biology in slime moulds," he recollects.

In appreciation of

Dhawan's vision

Satish Dhawan

According to Roddam Narasimha, in the 1950s the Institute was by and large a laid-back campus, with the vigorous research group being the exception rather than the rule. But by the late 1970s research took firm root and was pursued with unprecedented vigour across the campus, the number of research students as well as academic staff having roughly tripled during Dhawan's time.

Narasimha, in his Prof. Satish Dhawan Commemoration Lecture (22 September 2011), retraced how Dhawan reorganised some of the units already on campus, soon after he took over as the Director. For example, in 1963, the Power Engineering Department was split into the present Mechanical, Electrical and High Voltage Engineering Departments. (In 2006 the High Voltage Engineering department once again became a part of the Electrical Engineering department.)

In appreciation of Dhawan's vision for IISc, the late Yash Pal, former Chairman of the University Grants Commission (UGC) wrote, "[Dhawan's] role in making the Indian Institute of Science a great centre of learning and research has been seminal. It is during his time that the Institute developed its unique personality and its breadth. Without his lateral vision the Institute would have been no more than an excellent institute of technology. He made it into a place that attracted talent of a wide range, where people might have been recognised in terms of the departments to which they belonged, but the boundaries were kept porous. Even deep social concerns soaked in..."


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MY FATHER, SATISH DHAWAN

Satish Dhawan with Jyotsna, one of his daughters, in Bangalore in 1962. He set up the swing for his children on the premises of the Director's Bungalow at IISc, where the family lived at the time

Jyotsna Dhawan is a cell biologist working at the Centre for Cellular and Molecular Biology, Hyderabad, and the Institute for Stem Cell Biology and Regenerative Medicine in Bangalore. In this interview, she talks about her father, Satish Dhawan, one of India's most well-known scientists and institution builders, particularly about his life away from the public glare. Here is an edited extract from that interview.

Your mother Nalini was a cytogeneticist. How did she meet your father? Was it through your grandfather BS Nirody, who was working at IISc as a horticulturist?

No, it was a completely different connection. My mother had finished her PhD in cytogenetics from Washington University in St Louis [United States] and had returned to India. Her sister, Hira, who had also been in the United States for many years had [also] returned, and had been asked by SPAN magazine to interview my father – he was at the Aeronautics Department from 1951. After she interviewed him, my mother and her sister were walking in the Institute, perhaps to meet my grandfather. And right outside the Aeronautics Department, they bumped into my father and [my parents] were introduced. Very shortly thereafter, they decided to get married. Who says love can't bloom in the Aeronautics Department! [Laughs]

You mentioned earlier that your mother's family was from a place near Kundapur, and spoke Konkani. Where did your father come from, and what language did you speak at home?

Yeah, so my father came from the North-West Frontier Province [in British India]. His father came from Dera Ismail Khan, which is near Rawalpindi. And he grew up in Lahore and Kashmir. We heard tales of his growing up in his maternal grandfather's house in Kashmir, where each of the grandchildren was given a fruit tree. And to us living in sleepy south India, the notion of a child being given a pear tree or an apple tree or an apricot tree was just glamorous and distant beyond belief. So when we were growing up, my mother tried to recreate that for us by planting three cherry trees [outside the Director's Bungalow] which I hope are still there.

The conversations were actually in English, even though my mother made heroic attempts to speak in Hindi – her Hindi was passable, not great – till we were three. But the moment we went to school, which was an English medium school, we dropped Hindi and went straight for English. So most conversations were in Indian English, with bits of Kannada, Tamil, Hindi and Konkani thrown in. I miss hearing Konkani, because it's a wonderfully expressive language. But we didn't hear much Punjabi, except for the occasional [laughs] unprintable word which my father would use while he was driving the car!

Satish Dhawan wore many hats: he served as the head of both ISRO and IISc at the same time. He was also associated with NAL, besides serving on multiple committees. And of course, he continued to do his own research. Did he also make time for his family?

Yes, he did. He was a very involved parent actually, especially in the early years. It's true that after 1972 things got very hectic because he had all of these different roles to play, but in the early years, we had many, many occasions together. Sundays were sacred. He made sure that he spent time with us. He was very good at organising activities for us to do. And not in a way that forced us to participate, but in a way that actually made us want to participate. For example, he organised these painting sessions. He was very good at painting and drawing. He would make a great ceremony of setting up paper and places for everybody to sit, including my mother. So there were three kids, and he and my mom. Everybody had their own little papers and pens and paints and water to do watercolours with. And [this continued] even at the busiest times, after he became Director [of IISc] and Chair of ISRO. It's only in retrospect that I realise how crazy it must have been for him – we didn't feel it. We felt he was always there for us. And he was always interested in what we were up to. He was never prescriptive. He never expected specific things from us. It was great.

You mentioned in a talk at IISc that when you were cleaning out his desk after he passed away, you found a hammer and a few nails. He was someone who is remembered for building things from scratch at the Aerospace Department. Was he a handyman at home as well?

Yes, very much so. He very much valued the idea of working with your hands. He felt that working with your hands is not separate from the intellect. It's part and parcel of it. And he had a great deal of respect for people who had the agility and capability to work with their hands. He worked with carpenters and trained people to build specific things for his own research programme. He built lots of our furniture at home. He also loved going to auctions in town to buy second-hand furniture which he would modify.

Jyotsna Dhawan

Roddam Narasimha told us that your father loved to read. What were his favourite books?

Oh, he just read voraciously. He also had a Master's in literature. He read everything – biographies, fiction, history, political theory, literature. He loved poking around in second-hand bookstores and in those days there were several in Bangalore. Although he himself was not a religious man, he had a deep respect for Indian philosophy, and so he read a lot. One of his absolute favourite books was a book of short stories by a little-read author now called HH Munro, whose pen-name was Saki. I still have my father's copy of Saki's short stories.

What do you think was your father's biggest legacy, and how would you like him to be remembered?

His professional legacy of course is there for anyone to see. At a personal level he had so much charm and grace and a sense of fairness. After my father passed away, my brother told me that some of his colleagues, who had joined ISRO as young engineers, said to him, "We joined when we were just boys. He made us human beings." I think that was his greatest legacy, and that's how I'd like him to be remembered.

RODDAM NARASIMHA: ‘DHAWAN INTRODUCED A NEW TYPE OF PERSONALITY TO IISc’

Satish Dhawan (left) with Roddam Narasimha (centre) and KR Narayanan

Roddam Narasimha is the DST Year-of-Science Professor at the Engineering Mechanics Unit, Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore. Narasimha, a former professor in the Department of Aerospace Engineering at IISc and a former director of NAL, was one of Satish Dhawan’s earliest students. In this excerpt from a wide-ranging interview, he shares his memories of Dhawan.

What was Satish Dhawan like as a teacher?

When he came for his first class, what struck me was that here was the only faculty member who came to the lecture hall smiling. Good morning, he would say, with a big smile on his face. The others were not that way at all. He saw everything as fun. He took pleasure in making things simple. I think people absorbed a great deal more from his teaching than from that of the others.

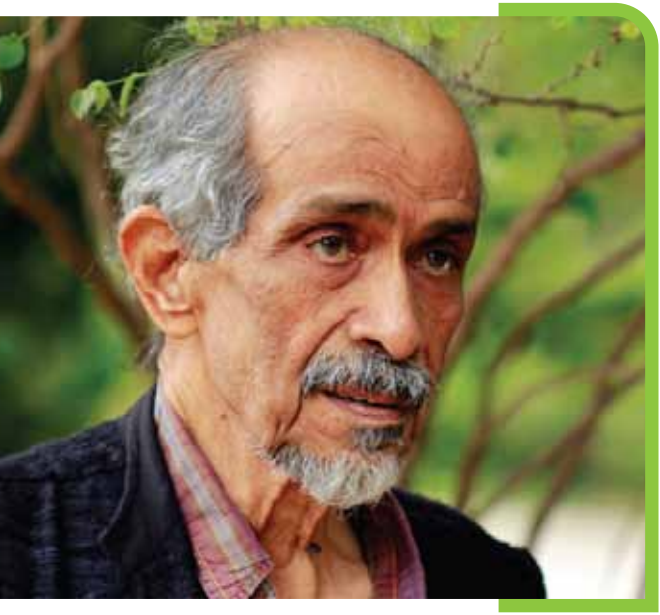
The other thing he did is that he didn't spend the lectures on details about the numbers and so on. He would derive the results and then pass on a large number of data sheets. He would work late at night getting his data sheets ready for the next day's lectures – he took it very seriously. The only man I'd compare with him on teaching was OG Tietjens, who was the head of the Department at the time, but they were otherwise very different in terms of personality.

Dhawan always answered students' questions, and even when he conducted oral exams he was pleasant. This did not necessarily mean you got very good grades [laughs], but if he thought you had understood what had been taught, he was generous with grades.

What was Dhawan like in your interactions with him outside the classroom?

He was, first of all, a very pleasant person. When he came on this campus, he was a very unusual faculty member. The Institute in general was a relatively serious place at that time. Most of the faculty members wore a coat and tie, for example. Dhawan wore colourful Californian shirts, had a red convertible MG (a sports car) and drove from his home to the lab.

Some of the faculty members did mix with students but never at the level at which Dhawan did. Once I became his research student I would, now and then, be at his house, and we would chat about various things. He had a great sense of humour, almost always had a smile on his face, and he made you feel at ease. But if you thought that he was only that, you'd be very mistaken. He was very serious about his work. He was also serious about the country, a real patriot. For him, patriotism was never a badge he wore, but was evident by the way he was committed to doing things here. He was a man who thought India should be doing a great deal more. He introduced a new personality to this campus – professionally as well as personally.



What influence did he have on your choosing to do research in fluid dynamics?

Roddam Narasimha

Dhawan had joined the Institute in 1951, as a senior scientific officer. He had his PhD degree from what was one of the two great centres of aeronautical research in the world, Caltech (Göttingen in Germany was the other). With his research record, he quickly became an assistant professor. And that was when I joined here as a student in 1953. He had already started setting up the high-speed aerodynamics lab and a boundary-layer lab in the Department, and I assisted him there, designing supersonic nozzles and helping him to calibrate the facilities.

After I did my Diploma [equivalent to today's ME degree], I was wondering what I should do. Prof Tietjens, who was a German and Ludwig Prandtl's student, was head of the Department at that time. He asked to see me and told me that I should go abroad and do research, either at Göttingen or at Caltech. "If you decide to go to Göttingen, write to me and I'll make sure they'll admit you," he said.

Then Dhawan asked me the same question – what are you going to do? I had already helped him in the design of the new wind tunnels. He said why don't you stay here and do some research. It sounded like a good idea to me. I wasn't yet quite familiar with what research implied. So I stayed here for two years, doing the Associateship of the Institute, with Dhawan as my supervisor. The work that I did here committed me to a research career. I realised that sitting here in Bangalore you could do something which interested people elsewhere. That was a big thing for me. It was done in the lab where everything was put together by hand. Dhawan used to call them "gizmos", most of which he built – and I built some. They were all made by mechanics in the workshop. But it all worked out, and the results we got have stood the test of time.

What would you say was Dhawan's role in shaping IISc as we know it today?

I would say that he transformed the Institute. When I came here as a student, there were some departments which were very active in research; some not so active. But the war and independence had changed the needs of the country. Dhawan saw the need for doing things which the Institute was not engaged in – for example, theoretical physics, ecology, atmospheric science. In all of these Dhawan took a big initiative. He took another remarkable step. He invited the finest scientists of the country to IISc and they went on to set up new programmes here: CNR Rao in solid state chemistry, GN Ramachandran in molecular biology, and George Sudarshan in theoretical studies. He encouraged many other areas as well – all the way from science and technology for rural areas to high-energy physics. And he changed the grading system governing students' performance, moving away from the old marks system.

The net result was that academic levels in different departments were much less non-uniform than before. Partly because of his broad background – he had a degree in physics just as in engineering, and his PhD minor was mathematics. So he had a very broad vision for the Institute. He could see that everything has its place.

In his work as Chairman of ISRO, did he bring something new to ISRO which made it the success that it is today?

Very definitely, yes. I think that the space programme as it is organised today is very largely the work of Dhawan. Vikram Sarabhai was the visionary who, ahead of his time in India, said we should start a space programme. So I would say the seeds were sown by Sarabhai, but the tree that you see is very largely the work of Dhawan. I think the architecture which you see – the different centres with well-defined projects – is really the work of Dhawan, if only because Sarabhai didn't have time to do it. The centres, the people who were picked to run those centres, the way the responsibilities were divided, the project system and the critical reviews they made of the projects with a lot of outside help – academics were involved in all of this. So that whole system was really Dhawan's creation. If today most people in the country look upon ISRO as the one organisation in the government which delivers, it's really because of the spirit and leadership structure that Dhawan set up.

And he had great confidence in Indian talent. I still remember the first big review they had of the SLV-3 project, of which APJ Abdul Kalam was the director. The number of people involved in that review was something like 250. It was held in an auditorium. And I wondered why instead of a small committee room he had this whole auditorium for the review. Dhawan wanted everybody to know the mission of space and the projects had to be understood not just by the scientists in each project team, not just by the leaders and the centre directors, but by *every* engineer who had any part to play in the project. And they all knew that if it came to a technical discussion, everybody was equal. It did not depend on rank or hierarchy. All these principles have constituted what people now refer to as the ISRO culture. And in some ways, I think it's one of the greatest contributions that Dhawan made.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SATISH DHAWAN: THE PIONEER OF EXPERIMENTAL FLUID DYNAMICS IN INDIA

Satish Dhawan

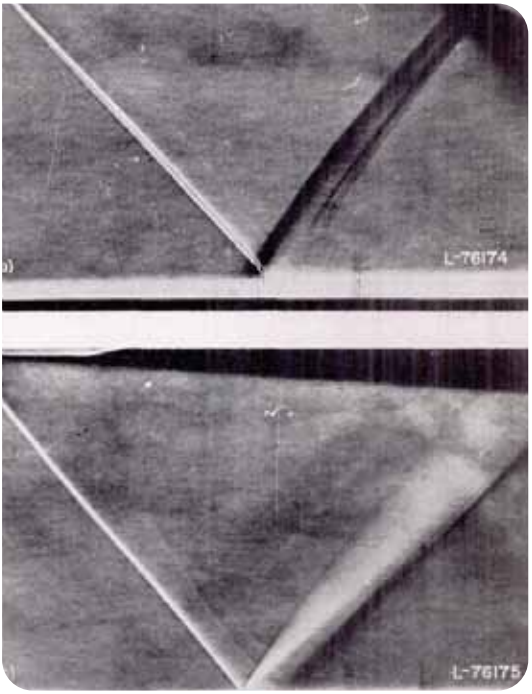
It was in 1946 that Dhawan arrived at the Guggenheim Aeronautical Laboratory of the California Institute of Technology (GALCIT, now Graduate Aerospace Laboratories), wanting to work with Hans Liepmann. But the Indian students Liepmann had worked with until then had given him the impression that "perhaps the select group that came to Caltech from India had prejudices against manual labor and essential, but not highly intellectual and glamorous, routines."

"I have often mused about the bifurcation points in one's life," wrote Liepmann, recalling this episode in his obituary of Dhawan, "the times when a small and sometimes even unwelcome choice of alternatives results in major changes in one's future. One of these bifurcations (in, I believe, 1946) resulted in my meeting Satish Dhawan."

He did take Dhawan as his student, who impressed him immediately. Dhawan joined Liepmann and another of his students, Anatol Roshko, in studying how shockwaves bounce off from a solid surface such as a wing. (Roshko later became the Theodore von Kármán Professor of Aeronautics at GALCIT, a position Liepmann once occupied. Roshko passed away in January 2017.) This was at a time when "supersonic flows and shock waves were still rather exotic phenomena", as Roddam Narasimha, one of Dhawan's earliest students, put it. They were trying to observe the interaction of shock waves with a boundary layer when the boundary layer itself hadn't been studied thoroughly in supersonic flows.

The boundary layer is a thin layer of fluid in contact with any object past which the fluid flows. Take, for example, the wing of a moving aircraft. The air surrounding it can be thought of as having many layers, each of which has a different flow velocity. The boundary-layer, first proposed by Ludwig Prandtl, is a thin layer of the air in contact with the wing; across the boundary layer, the flow velocity of air decreases to zero.

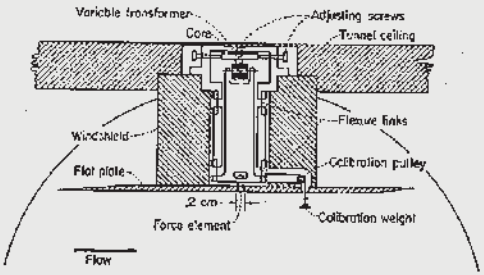
In their experiment, Liepmann, Roshko and Dhawan were interested in finding out if shock waves were reflected differently from a flat surface when the boundary layer on the surface is laminar versus when it's turbulent. In the resulting paper, which "became widely known for its revealing and defining observations", they reported a dramatic difference in the pressure distributions on the surface between laminar and turbulent flows. For laminar flow, they found that the effect of the boundary layer is felt even fifty boundary-layer thicknesses upstream of the shock, whereas for turbulent flow, it is felt over only about five boundary-layer thicknesses.



Shock-wave reflections from a flat surface with turbulent boundary layer (top), and laminar boundary layer (bottom)

Dhawan next worked on a difficult problem which became his PhD thesis – measuring skin friction. This is the resistance that an aircraft wing, for example, encounters because its surface is in contact with the boundary layer of the air. Boundary-layer theory predicted this important parameter but no one had directly measured it. This was a problem that, according to Liepmann, was of "both fundamental and direct technical importance."

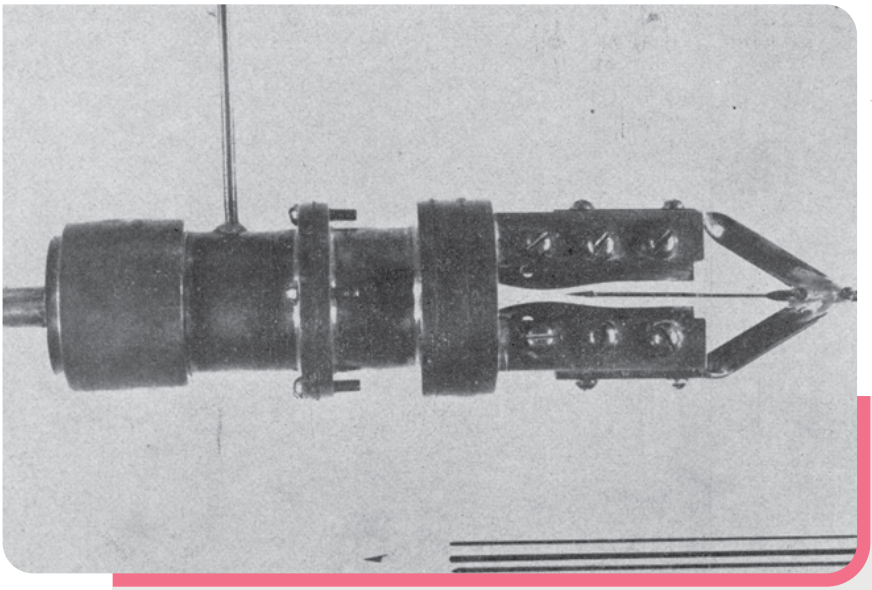
Dhawan devised an experimental apparatus to measure local skin friction on a flat plate by measuring the force exerted upon a small part of the plate's surface. This small strip was floated so that it could move freely. He then found the friction drag on it by measuring its deflection against the resistance of a spring by electronic methods. When he did this with turbulent boundary layers, he found that his observations agreed with the logarithmic expression proposed by Theodore von Kármán. However, in order to fit the data it required values of the constants that were different from the theoretical prediction. Dhawan made a few measurements at subsonic and supersonic speeds too and found that the skin friction coefficient was quite close to theoretical predictions. He then measured the skin friction coefficient in the region of transition from laminar to turbulent flow, noting that the results couldn't be explained by steady transition, and that intermittent laminar/turbulent flow fit the observations better. Dhawan, however, did not conclude that his experimental results definitely agreed with theory. He was, in Narasimha's words, "[i]ngenious in design, meticulous in execution and cautious in interpretation."



Sketch of the instrument Dhawan developed for direct measurement of skin friction

Dhawan came back to India after his PhD and joined IISc's Department of Aeronautical Engineering in 1951. (The department was later renamed Aerospace Engineering.) Two years later, Roddam Narasimha enrolled in the department for a two-year diploma (equivalent to a Master's) in aeronautics. He learned to love fluid dynamics in those two years, not least due to Dhawan's influence. "Dhawan's lectures were advanced, simple and elegant all at the same time," wrote Narasimha in a memoir, "and quickly gave students a sense of confidence."

In the labs, Dhawan was building the instruments necessary for research, including the first supersonic wind tunnels in India. With his students, he once rigged up a supersonic wind tunnel that, as Narasimha recalls, "ran on compressed air from two wartime surplus oxygen tanks from a Dakota [aircraft]." Dhawan's labs had other custom-made "gizmos" that "somehow managed to convey an impression of both science and engineering." In this period, Narasimha says, "I learnt how, with some ingenuity, one can overcome what seem like insuperable difficulties."



A 5 x 5 mm wind tunnel developed in Dhawan's lab that ran on compressed air stored in oxygen tanks salvaged from an aircraft

This was an approach that Liepmann approved of. A tradition of scientific research on engineering problems was what GALCIT was about, with its research programme emphasising a solid grounding in the basic sciences. Theodore von Kármán, the first director of GALCIT, had envisioned it "as a center for the fusion of science and technology."

After returning to IISc, Dhawan with his student Narasimha began studying what happens at the boundary between laminar and turbulent flow, motivated by certain problems they encountered in the design of the HF-24 aircraft. Specifically, they wanted to investigate if there was a sharp front separating turbulent flow downstream from laminar flow upstream. Howard Emmons of Harvard University had proposed that the laminar to turbulent transition happens at isolated points that give rise to turbulent spots. Rather than a "front" separating laminar from turbulent flow, this picture proposed "islands" of turbulence in a laminar sea. This implied that laminarity could exist both upstream and downstream from such turbulent spots, and that the spots, as they moved downstream and grew, eventually led to fully turbulent flow. The fraction of time that the flow was turbulent at any point on the surface was called the intermittency at that point. Emmons had a statistical theory that related this intermittency to the rate at which spots were born on the surface and their propagation characteristics.

If this picture was correct, it would imply that laminar and turbulent flow coexist everywhere, in different proportions determined by the intermittency, which goes from zero to one as the flow progresses. A subsequent experiment by other researchers, while confirming Emmons' ideas about turbulent spots, did not compare their intermittency measurements with Emmons' theory. Finding this odd, Dhawan and Narasimha made measurements of their own that suggested that Emmons' idea of spots being generated across the whole surface of the plate wasn't correct. They concluded that the simplest way to explain the data from their experiments was to assume that all spots were created at one location a certain distance from the leading edge – but randomly in time, meaning that transition does not occur everywhere on the plate.

With these and other experiments, Dhawan pioneered experimental fluid dynamics research in India. In Narasimha's words, "In a very real sense I think Dhawan established at IISc and by example elsewhere in the country a tradition of scientific research on engineering problems."

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