

## Roddam Narasimha

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Professor Roddam Narasimha, known as ‘Roddam’ to his close colleagues and ‘RN’ to his students, has been an outstanding teacher<sup>1</sup>, a world-class researcher<sup>2</sup>, a dynamic leader<sup>3</sup>, and a builder of institutions<sup>4</sup>; while his professional interests are primarily in fluid dynamics, they extend significantly to other areas such as formal aspects of education<sup>5</sup>, philosophy<sup>6</sup>, history and history of Indian science<sup>7</sup>, India’s nuclear policy and national security<sup>8</sup>, and others; and he has dispensed advice and wisdom to the highest circles in the country and his opinion counted in the USA and Europe too<sup>9</sup>. The depth of his contributions to fluid dynamics, a subject that has occupied his intellectual life from the start of his career, is a matter of public record. So is the fact that a topnotch research effort has surrounded him for more than four decades without interruption<sup>10</sup>, no matter how many diversions were pressed upon him. The rigour and class that he brings to his own research is much admired, as is his larger influence even on those who cross his path briefly. Altogether, his intellectual impact has been remarkable and extensive.

Yet, RN’s unpretentious style makes it hard to appreciate the full extent of his accomplishments without some personal knowledge. His tenacity and tendency to

hone mastery over a subject by returning to it several times over, and the unspoken moral authority he exerts on his colleagues, are not easy to discern. The public record of his service to the country is somewhat sporadic<sup>11</sup>. A few autobiographical notes<sup>12</sup> that exist shed only modest light on his formative life and his involvement with Indian scientific enterprise. One hopes that a comprehensive account of all facets of his life and endeavours will appear in the future. This short article cannot do full justice to them and is only a partial account focussed on RN’s professional work with some account of his formative years, in so far as the latter aids in understanding the former. No attempt has been made to list all the positions that he held or the awards he received (those interested may visit the webpage <http://www.jncasr.ac.in/roddam/>). As RN’s students, we are both conscious of the importance of avoiding superlatives in this writing, and beg the reader’s indulgence for those that have crept in. The account is more or less chronological, but some important and somewhat personalized qualifiers are provided in the end notes where we felt free to express subjective views; they should be read as part of the text. Two brief overview sections, which are entirely personal, are provided at the end.

### Formative years in Bangalore

RN was born (20 July 1933) and grew up in Bangalore<sup>13</sup>, and sometimes spent summer vacations in his grandfather’s home, not far from the Indian Institute of Science (IISc), with which he has been associated for six decades. Home and school environments influenced him profoundly<sup>12</sup>. His father, R. L. Narasimhaiya, was among the early graduates in science in the small town whence he came; he obtained a postgraduate degree from the University of Allahabad where the great Indian physicist Meghnad Saha taught. Returning to Bangalore after a Master’s degree (*ca.* 1930), his father taught in neighbourhood high schools before joining the Central College as Physics Professor. He wrote extensively on science in Kannada, some of which

are reprinted even today. While RN did not learn much science directly from his father, the latter’s example and attitude – scientifically modern, socially liberal and culturally conservative – seem to have played a great role in shaping the young RN<sup>12</sup>. His mother, R. N. Leela Devi, did not attend school beyond age ten, but she was well read and sophisticated: the prayers she taught her children to recite before bed time were for intelligence and knowledge<sup>12</sup>.

RN studied at Acharya Pathashala, a reputed private school in Bangalore<sup>13</sup>. C. N. R. Rao also belonged to the same class but studied in a different section. The school had excellent and dedicated teachers, as was the norm those days, despite their paltry salaries. Two books



Young Roddam Narasimha.



Parents: Smt. Leela Devi and Shri R. L. Narasimhaiya.



K. Venkata Ramaiah, teacher at Acharya Pathashala who taught RN the importance of writing – briefly and honestly.

he received from one of his teachers (B. L. Ashwathanarayana Rao) influenced him greatly: *Lives of Great Scientists* opened his eyes to the intellectual world of Western science and the Kannada trans-creation of Lewis Carroll's *Alice in Wonderland* ignited his imagination. An event of huge impact was the visit by the late C. V. Raman, Nobel Laureate and the biggest name of that day in Indian science. Raman's speech had an electrifying effect on RN who, for a time, considered studying physics at college; but socio-political circumstances of the recently independent India eventually led him to pursue a Mechanical Engineering degree from the University of Mysore. During those undergraduate days, he happened to visit IISc on an Open Day, when the institute labs were open to the public (this tradition continues to this day). He saw Spitfire aircraft of World War II vintage (loaned for the occasion by the Indian Air Force), standing in the quadrangle of the Department of Aeronautical Engineering. It was love at first sight: he was so fascinated by the overall design of the aircraft and the complex technology that made it fly that he decided to study aeronautics after his undergraduate degree. Despite the discouraging advice he got from a senior person in the field, his father's encouragement enabled him to pursue his dream<sup>12</sup>.

RN joined the Department of Aeronautical Engineering at IISc for a Diploma in 1953 and followed it with Associates degree. The Chairman of the department, O. G. Tietjens, was a student of Ludwig Prandtl<sup>14</sup>. Tietjens was inaccessible to students directly but taught a fluid mechanics course regularly, always stressing basics and depth of understanding, rather than overwhelming students by the breadth of topics that could be covered. The atmosphere on the campus was very formal then – professors drove to the department and were rarely seen without

a tie. This tradition was broken by Satish Dhawan who joined the Department of Aeronautical Engineering in 1951 after obtaining his Ph D from the California Institute of Technology (Caltech). Dhawan was informal and freely interacted with students and machinists alike (though he became more distant as responsibilities grew), but was extremely serious about his work. He built three wind tunnels including a small supersonic tunnel for research and demonstration to students. RN liked the depth of ideas in fluid mechanics in spite of the commonness of its occurrences and chose to work with Dhawan for the Associates thesis. As stated in his autobiographical essay<sup>12</sup>, he learnt from Dhawan how to do research without being stymied by lack of equipment. For example, RN found a way to photograph the oscilloscope display time series using an

ordinary camera: Experiments were conducted at night, a film roll was manually pulled at constant speed in front of a camera with an open shutter and developed later in a dark room. Hot wires<sup>15</sup> were not available in India, and letters from Anatol Roshko, who worked at Caltech, came with a few almost invisible wires pasted on their back for use in Bangalore. His two papers on laminar-turbulent transition<sup>16,17</sup>, the latter of which was co-authored with Dhawan, are still among the most influential fluid dynamics papers to have come from Bangalore. He has returned to this topic multiple times; for example, see endnotes and ref. 18.

### Maturing at Caltech

Foreign professors and department Chairmen at IISc left the country in mid-1950s. Tietjens returned to Germany in 1954. Before leaving, he advised RN to pursue Ph D either at Gottingen or at Caltech, but Dhawan preferred Caltech and RN went there in 1957. California was very modern even by US standards in those days and it was a different world for a vegetarian young man from Bangalore. Thanks to a few Indians who were already at Caltech (including Rao Valluri and Krish Karamchetty), he settled down soon enough. For his doctoral thesis, RN started working on aeroacoustics under the guidance of Hans Liepmann<sup>19</sup> (who was also Dhawan's advisor). RN set up a facility (almost single-handedly) for measuring jet noise in an anechoic chamber, and the findings were published with Mollo-Christensen<sup>20</sup>.



RN with D. Balasubramanian and C. N. R. Rao.



RN with Satish Dhawan.



RN with his Caltech colleagues. From left to right: Anatol Roshko, Gary Brown and Hans Liepmann.

The Advisor felt that thesis would be done soon but the Student was not satisfied: Liepmann had designed a nozzle for measuring flow rates from the continuum to molecular limit, and RN began to develop a theory using the Boltzmann equation with the Bhatnagar–Gross–Krook (BGK) approximation developed a few years earlier<sup>21</sup>. This work<sup>22</sup> drew immediate attention: Russia had just launched the first space vehicle *Sputnik* and launching a satellite became a national objective in the US; rarefied gas dynamics being an essential approximation of flow around space vehicles, RN's expertise assumed sufficient importance for him to be hired as a consultant, while still a student, by one of several companies that were set up to support NASA on its space programme. RN completed his Ph D in 1961 (thesis title: 'Some flow problems in rarefied gas dynamics').

The stay at Caltech was extremely satisfying and the association with Hans Liepmann, in particular, was very rewarding: this influence was felt more by virtue of wide-ranging topics that were discussed informally between them over the years – less through the specific technical discussions related to the thesis topic<sup>23</sup>. RN's performance and skill sets generated several opportunities for him in the US but he was keen on returning to Bangalore – which he did in 1962.

### Creative and full-fledged scientist in Bangalore

RN joined the Department of Aeronautical Engineering at IISc as Assistant Professor in 1962 where his success has since become legendary. Here he attempted a balance between 'building' and 'doing'. His research style was shaped by the quest for the most interesting

research that could be done in Bangalore with the facilities available or could be built locally. In a few years' time there was a group of outstanding students and assistants who quickly became experts in their subjects. Much of the research those days concerned shock structure and the Boltzmann equation<sup>24</sup>, turbulent bursting<sup>25</sup>, supersonic flows<sup>26</sup>, flow control<sup>27</sup>, wake structure and turbulence modelling<sup>28</sup>, reverse transition or relaminarization<sup>29</sup> (where a turbulent flow goes back to an orderly laminar state) and drag reduction<sup>30</sup>. An ingenious example of how the boundary layer theory could be applied outside of fluid mechanics is his work on the vibration of elastic strings<sup>31</sup>. This was also the period during which he was actively engaged in rural technologies, two examples of which are given in endnotes and ref. 32. No doubt the influence he felt from his Associateship days at IISc and his graduate school days at Caltech had a lingering effect on the choice of topics. Many of them were initially connected to the research that was going on elsewhere, especially in the US, but as time went by, doing self-generated things, even if unfashionable, became addictive – as he himself has stated (see endnotes and ref. 12).

In mid-1970s, an interdisciplinary group interested in the monsoons started nucleating at IISc and eventually led to the setting up of the Centre for Atmospheric (and now also Oceanic) Sciences (CAS) in 1982 with RN as its Convenor. His interest in the atmosphere was evident for some time already<sup>33</sup>, in part because of the Avro work (to be discussed below) and in part because of his interest in turbulent transport processes. But his interest took on a qualitatively new direction when he became convinced that an important fluid-dynamical problem to tackle was the monsoons, and central to

this effort were convective clouds. While there was a plethora of past studies on cloud microphysics (dealing with how cloud droplets form and grow), cloud dynamics remained poorly understood, particularly the consequences of the release of latent heat on entrainment and mixing processes. So, laboratory simulation of clouds was attempted at CAS and RN's group finally found a novel way to set up cloud-like plumes in the laboratory<sup>34</sup>. The results were counterintuitive, and the local addition of volumetric heating modified the flow structure and entrainment substantially. He conceived the idea of a monsoon field programme to measure the atmospheric boundary layer properties and develop flux relations relevant to monsoon conditions, and MONTBLEX (Monsoon Trough Boundary Layer Experiment) was carried out<sup>35</sup> in the Indo-Gangetic Plains in the year 1990. The data analysis led to new formulation for surface flux at low winds<sup>36</sup>.

### Involvement in aerospace programmes

India's space programme was just starting when RN returned to IISc from Caltech and his expertise in rarefied gas dynamics was immediately in demand. Vikram Sarabhai invited RN to the rocket launching centre in Thumba to witness a rocket launch. A result of this visit was that RN offered to make Monte Carlo (MC) simulations of the Boltzmann equation to meet ISRO's requirements. Graeme Bird<sup>37</sup> had started using MC techniques for solving Boltzmann equation but new tricks invented at Bangalore to solve the integrals involved<sup>24</sup> became useful later in country's space and aeronautical applications, and more broadly elsewhere.



RN with Mrs Indira Gandhi.



Explaining the LCA concept to the Defence Minister P. V. Narasimha Rao in 1985.

RN's involvement in the aeronautical programmes in the country became deeper in 1970s. Indian Airlines had procured Avro aircraft but, at some point, the pilots refused to fly them claiming that its climb rate was too low and the aircraft was unsafe to fly. A one-man 'Dhawan Committee' aided by a team of advisors from IISc, National Aeronautical Laboratory (NAL) and Hindustan Aeronautics Limited (HAL) was formed by the government to examine Avro's airworthiness. The IISc team led by RN carried out the analysis of available data and made new flight tests at Kanpur, in particular on climb rates, but the initial data showed unacceptably high scatter, in large part because the requisite experience was not yet available in the country (drag and engine thrust estimations were nontrivial). After two years of efforts, it was established that the climb rates were indeed low and was constrained by the engine power. Avro's accident records, on the other hand, were not worse than any other aircraft. It turned out that, with Rolls Royce engines which had become very reliable, a lower climb rate was not unsafe, and the aircraft designer had exploited this feature without explicitly stating so. Analysis techniques developed by the Bangalore group for assessing airworthiness were quite sophisticated<sup>38</sup> and found to be useful by others: Aircraft companies, in particular, commercially exploited the new information for specifying the engine power differently.

S. R. Valluri (who was NAL Director during 1965–84) made RN a consultant to NAL in 1969, and his regular appearance there led to useful interactions with people from NAL, HAL, Air Force and DRDO. Among the hotly debated issues was the performance of the fighter aircraft HF24. Its body was designed in India and the engine supplied by the British. It was intended to be a supersonic aircraft but the engine thrust, without reheat capability, was inadequate to achieve the stipulated speeds. The British were supposed to develop the reheat version of the engine but didn't<sup>39</sup>. The price of Rs 3.5 crores demanded for it was deemed very high by the Air Force and an Air Force officer started developing such an engine. The aircraft carrying this crashed on a test flight killing a very reputed pilot Suranjan Das (a road near the HAL Airport in Bengaluru is named after him). The changes in the body of the aircraft to accommodate the indigenous en-

gine made HF24 aerodynamically poor and the drag became too high. A suggestion of Raj Mahindra, then the head of design section at HAL, to get a reheat engine from the Russians and redesign the airframe and fuselage within the country, was accepted by the government. The proposed aircraft was named HF25, and required to have long range capability. RN was made the Chief Project Coordinator for the design of HF25 (1977–79), and spent half his time at HAL (a good example of academia–industry interaction). After three years of efforts, a new design for a supersonic aircraft that could fly at a Mach number of 1.6 was arrived at. The Air Force felt the speed was not sufficiently high and so HF25 aircraft did not enter production line. Considering the primary needs of India, RN argued that India mainly requires an aircraft with short range but maximum performance that can be met by a lighter aircraft. He worked on this idea and made an informal presentation to the Air Force for a Light Combat Aircraft (LCA) in 1979. Eventually the idea found support in Defence circles and led to the LCA programme several years later.

### **New responsibilities as NAL Director**

RN was the Director of NAL during the period<sup>40</sup> 1984–93. NAL was among the better performing CSIR labs then, with expertise in various aspects of aircraft technology. RN honed these skills further and integrated them giving focus to the design of aircraft. His tenure saw many new initiatives, including the lead role in the development of LCA, parallel computers, civilian aircraft and numerical modelling of the monsoon. His focus was on developing advanced technologies and building products. While India had a long history of research and expertise in the field, it had not come out with its own aircraft. LCA, meant for the Indian Air Force and to be built by HAL, involved the participation of entire aerospace community in the country. Air Force wanted the LCA body to be made of carbon fibre composites (CFC) to keep the weight low. RN headed a committee to identify the hardest problems and key areas where the country's knowledge was absent or inadequate. Two areas stood out: (1) CFC and (2) flight control system. Very few countries

had the technical knowhow of CFC, and the cost of importing the material was too high (in fact, almost the proposed total cost of LCA). A list of people in the country who worked on any aspect of composite materials was prepared by NAL, irrespective of where they worked, and a meeting was convened to discuss the strategy for developing CFC. Many people came forward to work towards the goal, and the government gave the go-ahead. Indigenous CFC technology looked impossible, especially to the sceptics. NAL, in partnership with HAL for its production, began to develop the CFC technology. It took much effort from people from academic institutes (K. P. Rao from IISc, for example, got heavily involved in it) as well as the government labs. Interactions with experts from abroad did help, and finally the CFC technology was mastered. For the first LCA that was built, everything of the structure except the skin was made in India (using imported carbon fibre). NAL team led by Srinath Kumar developed a flight simulator and the flight control system. LCA was built, underwent various airworthiness tests successfully. Pilots who flew LCA were pleased with it and felt that it was as good an advanced aircraft as others they had flown. (Few minor issues remain to be ironed out, e.g., the rate of turn is marginally lower than the design specification.) The final decision to mass produce LCA is yet to be taken<sup>41</sup>. A 14-seater aircraft, *Saras*, made from composites technology was also designed during RN's tenure at NAL. It was fabricated after he left NAL, but again, not pursued seriously enough to lead to mass production.

Even during these extraordinarily busy years, RN's personal research in fluid mechanics continued unabated<sup>42</sup>; RN managed to guide seven Ph D students almost simultaneously during 1986–92. He also found time to develop new interests among which is the temperature inversion very close to the ground<sup>43</sup>, which he named the 'Ramdas effect', after the first scientist who observed it by careful measurements.

### **NIAS Director and India's nuclear policy**

The National Institute of Advanced Studies was created by Raja Ramanna (with J.R.D. Tata's strong support) for

purposes of conducting interdisciplinary work, including the task of enriching the leadership in industry, government and public affairs<sup>44</sup>. When RN was called upon to take charge of NIAS as its second director (1997–2004), it was clear to those who knew him that he had finally found a position that suited him best, especially at that stage of his life. No topic was outside the purview of NIAS: everything from consciousness to building human capital to national security fell within its realm. It was here that RN honed his dormant interests in history of science and philosophy. This period gave him a mental freedom that he did not feel before, or, it seems, has felt since<sup>6,7</sup>.

One of the lesser known activities of RN during his NIAS period is his dialogue with the outside world on India's nuclear policy. Western countries, USA in particular, were unhappy after the Pokharan nuclear blast (1998), and in a way India stood isolated for some time. RN started analysing India's security concerns, and was completely comfortable with the nuclear blast. He felt that the need of the hour was more to present India's position in a way that would convince the outside world<sup>8</sup>. He was invited to a meeting with a Committee on Nuclear Policy from the US National Academy of Sciences, whose position started out quite antagonistic – especially by the perceived designs on Pakistan. RN patiently went through the security issues related to India<sup>45</sup> in several meetings (a US delegation visited NIAS), and the result was a gradual appreciation for India's point of view.

### Back to academics: JNCASR

After his retirement from NIAS, RN has made Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR) his home – where he currently holds DST's Year-of-Science Professorship. Since it is still a continuing chapter in his life, we will not comment further on it. It suffices to say that he still works on his research projects on stability, transition, turbulence, clouds and the like, and guides students, while continuing his immersion in philosophy and science policies.

### A world citizen with local roots

In this article, we have discussed a few key tasks that RN undertook for himself

or was called upon to do, in the domains of science and science policy, but this does not represent the whole man. In this section we attempt to do it in some perfunctory way. Nor does the writing so far bring to life adequately his excellent taste, superb technical mastery and rigour, the discipline he exercises in the face of adversity, his internal compass that is not satisfied easily, great skill to explain his thoughts well, in written and in spoken words, his good judgement not to bang his head against a problem that does not yield to decent efforts. Most important of all, RN is unique in his ability to synthesize pieces of knowledge into a unified whole. He is one of the best 'systems engineers' we know. If we might put the same thing in philosophic terms, even though RN has had no real use for dry philosophy, he has transcended knowledge and acquired wisdom.

It is astounding to realize that despite all the fame and international visibility and travel, RN never stayed away from Bangalore, his place of birth, for long periods of time (except for his graduate studies at Caltech). It is evident in his conversations that he is entirely comfortable with Western colleagues, ideas and ideals (and admires some of them) and does not wear his Indianness on his sleeve (e.g. he does not quote from its scriptures or heroes, nor invoke his access to important people in the government). But he is quintessentially Indian, very proud of his roots, Indian people and their outlook, including their foibles; he is extremely well-versed in the country's history and analyses its present with open mind, while occasionally bemoaning the lack of strategic thinking on the part of the country which has a habit of getting embroiled in day-to-day survival,

or its propensity to begin but not persevere and finish. The country seems to him always at the edge of chaos, but he recognizes that it is also a source of its incessant creativity.

In our experience, RN has not been the person to sit down formally and give advice. We ourselves rarely sought advice directly. We suspect that he expected his close colleagues to absorb it mostly from his style. He cares a lot about not being overbearing and is directly critical of no one. If you missed the subtleties of his thinking, well, it was your problem; he simply invested less time and energy on you, even if you were his student or close colleague. We believe that many people have had difficulty in coping with this trait, but some of us took to it with ease – and we are far better for it.

It has often been said privately that RN's career received a boost from the support he received, particularly from Dhawan at home and his Caltech colleagues internationally. Indeed, both Dhawan and Liepmann supported him



RN with K. R. Sreenivasan.



RN in front of his cloud tank facility at JNCASR.



RN with TRIESTE Science Prize.



RN with wife Neelima Narasimha.

appropriately. But it is clear to those of us who know him well that these two individuals, and a number of others subsequently, did so entirely because he is exceptional. His scientific judgement was impeccable even in the very first single-author paper he wrote as a young scientist.

It might be useful, if it were possible, to reduce the essentials of RN's philosophy of life, at least as it concerns a vast majority of his activities. He is a very private person and not many people know his thoughts, especially as they refer to human elements such as love and loss of life: he rarely talks about them, we think, by design. Without impinging on those private thoughts, we will reduce our experience with him to some ten maxims; there is the risk of being too simple-minded, or worse, being wrong. Though we have tried to use RN's own words as we remember them, we may have strung them together out of context. We decided to stick to facts and not to try to be humorous because RN's sense of humour is 'kind of particular' – as our Russian friends might say. We think that these maxims might especially interest younger readers.

### RN's maxims

*Maxim 1.* There are two ways of doing research. The first is to become an expert on using a set of tools and then search

for problems which fit them; the second is to learn whatever tools are needed to solve problems you find interesting. The latter is the superior way.

*Maxim 2.* Most good research work is neither pure thought nor collection of empirical facts – however causal the facts may seem. Only when you put the facts into a broad framework of pure thought can you claim to have done something worthwhile.

*Maxim 3.* Always work on more than one research problem at the same time. If you put all your energies and hopes on only one, you will regret it when it does not pan out, or when someone else scoops you. The phenomenon of scooping happens more often than you realize because all your ideas, however original you think they are, will most likely occur to others in a short time, if they have not already. Even special relativity would have occurred to someone else, had it not occurred to Einstein, within a span of a few years. So you better work on your ideas diligently – with focus and regularity of habits.

*Maxim 4.* Do not always expect grandiose results to emerge from your research, but they better be solid. Once you obtain such results and satisfy yourself that they are correct, stick your neck out and publish them. In fact, unless you have written up your results, you have not fully understood them. When you write up your results, anticipate the questions that may arise in the reader's mind and answer them at the right place and time – neither too early nor too late. Provide just the right amount of detail. Else, people will not leave you alone.

*Maxim 5.* Claiming too much will gain you the disdain of the community in the long run. Claiming too little, even for reasons of modesty, is almost as bad especially because competitive people will try to marginalize your work; so you might as well not kick yourself for not claiming as much as you ought to. And it is your task to defend your work when confronted.

*Maxim 6.* Even with all this care and consideration, beware that you may have missed the mark in your work. You should thus be prepared to admit to errors, if that is warranted.

*Maxim 7.* Protect your time as much as possible. Do not get drawn into too many things. If people offer you new opportunities, or flatter you into thinking that your participation in committee

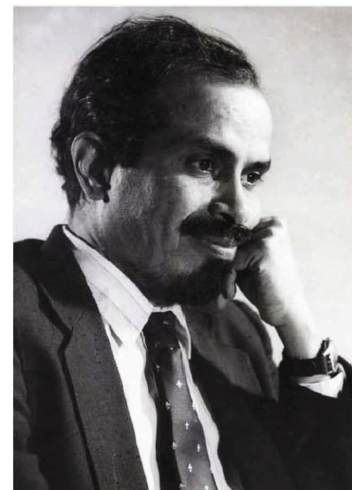
work is important, do not be impressed – and, unless you are already passionate about the issue, find as many polite ways of saying 'no' as possible. If they believe seriously that your participation is truly necessary, they will come back to you one more time. If they do, accept it by stating that you may not be able to deliver as much as they expect, but work hard to do much more, whether or not you are passionate about the issue. Personal responsibility overwhelms passion.

*Maxim 8.* Rejoice every external appreciation of your work but do not expect admiration to come flooding your way, simply because you have given your best.

*Maxim 9.* Doing your job well does not necessarily endear you to your colleagues – so do not particularly strive for it or expect it. Be polite to them, but if their style diverges from yours in fundamental ways, avoid interactions with them. Do not delude yourself into thinking that you will change them.

*Maxim 10.* As much as possible, keep your private life separate from your professional life. There will then be fewer things for people to gossip about you.

It is clear that some of these maxims contain great wisdom – though some others are confining and no doubt the result of RN's own negative experiences as a young researcher; we have in mind events such as needless delays and added scrutiny in research publication from authors with Indian address, the condescending attitude he saw in some Western colleagues, occasional usurpation of credit by others, etc. But there seems little doubt that these maxims carry a lot



of wisdom and the source of RN's impact on his colleagues.

As his students, we are completely convinced that he is a high-level researcher. The earlier generation of his students, who knew him at the time he pursued science with single-minded love and without other engagements, thought that he was destined to remain that way. In fact, they were certain that his temperament was not suited to become a great administrator. Time has proven them wrong. He has shouldered great responsibilities with poise and effectiveness that can only come from an inner strength and confidence built up during his young and formative days. But these students were perhaps right in one way: even deeper science could have emerged from him. But this speculation is neither here nor there. We often wonder how he could do so many things, and think that he is an exceptional person.

#### Endnotes and references

1. It is the considered opinion of many of his students that RN excels in both one-on-one research interactions and class room teaching. His lectures were meticulously organized and carefully delivered.
2. As a researcher, RN cares enormously about quality than quantity though the latter exceeds the norm in his field substantially: he has published steadily from the start of his career till now, often in the best journals of his field, spanning about 60 years. For him, writing is an integral part of doing research because it allows one to marshal one's thoughts rigorously and express them attractively. He takes pride in seeing his work appear in print. Most of his papers are strong (some exceedingly so) but the key point is that none of them is poorly written. Recognition of his special standing in the community has come from far and wide. Among the prestigious visiting positions he held, reflecting this standing, we list only three: Clark B. Millikan Professor and Sherman Fairchild Distinguished Scholar at Caltech, and the Jawaharlal Nehru Professor of Engineering at Cambridge University. He has been elected Member of the US National Academy of Sciences and of Engineering, Fellow of the Royal Society of London, Fellow of the American Academy of Arts and Science, Fellow of the Third World Academy of Sciences, and Fellow of all the three prestigious science academies in India. He has the rare distinction of being elected Honorary Fellow of the Indian Institute of Science in 2008.

3. At the Indian Institute of Science, he was Dean of Engineering (1980–82) and the Chairman of the Department of Aerospace Engineering (1983–84); he also served as the Convenor of the Centre for Atmospheric Sciences (1982–89). As Dean, we recall that he refused to spend his time signing routine papers but chose to use the time on academic matters instead. When RN was the Director of the National Aeronautical Laboratories (1984–1993), the lab saw many new initiatives, including the lead role in the development of the Light Combat Aircraft (LCA), parallel computers, civilian aircraft and numerical modelling of the monsoon, etc. He was President of the Indian Academy of Sciences during 1992–94 and the Director of National Institute of Advanced Studies (1997–2004). As Chairman of the Engineering Mechanics Unit at the Jawaharlal Nehru Center for Advanced Scientific Research, he oversaw initial years of its evolution.
4. Among other things, he started the Centre for Atmospheric Sciences at IISc in 1982 and the Engineering Mechanics Unit at JNCASR in 1989. He is the Founder-President of the Indian Society for Mathematical Modeling and Computer Simulation, and has been responsible for getting off the ground the Asian Congress of Fluid Mechanics (in 1980). The journal *Sadhana*, published by the Indian Academy of Sciences, is his creation; see also (5) below. RN was instrumental in establishing the Ministry of Earth Sciences in New Delhi. Most people are unaware that the institute-wide Fluid Mechanics seminar at IISc was created by him.
5. His interest in higher education was behind the inception of the journal *Resonance* of the *Indian Academy of Sciences*. His main point, expressed to a few of us on more than one occasion, has been that Academies should not merely recommend action to the government but also constructively do things themselves.
6. See, for example, his book, *Verses for the Brave*, a special publication of IAS (2000), rendering some selected verses from Yoga-Vasistha into English; also 'A metaphysics of living systems: the Yoga-Vasistha view', *J. Biosciences*, 2002, **27**, 645–650. See also *Science and Beyond: Cosmology, Consciousness and Technology in the Indic Traditions*, co-edited with his IAS colleagues and published by IAS (2004), and *Nature and Culture*, on the history of science, philosophy and culture in Indian civilization (Munshiram Manoharlal Publishers, 2011). The special meaning attached to proofs in Indic mathematics has been discussed in his paper, 'Pramanas, proofs and the yukti of classical Indic science',

in *Asia-Europe Dialogue and the Making of Modern Science* (ed. Arun Bala), Palgrave Macmillan, 2012, 93–109. See also his article 'Culture views Nature: Bacon and Samkhya compared' in the book *Nature and Culture* by Narasimha, R. and Menon, S., PHIPSC, vol. 14, pt. 1, Centre for Studies in Civilizations, New Delhi, 2011. The same theme is continued in Narasimha, R., 'Axiomatism and computational positivism: Two mathematical cultures in pursuit of exact science', *Economic and Political Weekly*, 2003, 3650–3656 and in 'The Indian half of Needham's question: Some thoughts on axioms, models, algorithms and computational positivism', *Interdisc. Sci. Rev.*, 2003, **28**, 54–66. A common theme is that the notion of proof held sacrosanct in Western mathematics was supplanted in the Indic tradition by the focus on successful algorithms and computability, often obliterating the proof by which the algorithms were established. The reader may recall the bafflement that G. H. Hardy felt when he first saw Srinivasa Ramanujan's captivating formulas without proof (Hardy, G. H., *A Mathematician's Apology*, Cambridge University Press, 1940).

7. RN is a keen student of history and can regale a listener with fascinating stories, especially as they relate to Asia as well as its relationships within its own regions and with the outside world, but we are unaware of any significant scholarly publications of his on general history. However, his writings on the history of science and technology are numerous. See, for example, his Millennium Essay, 'Rocketing from the Galaxy Bazaar', *Nature*, 1999, **400**, 123, in which he contrasts the technology available to the British and Tippu Sultan's armies of the time, and how and why the disparity changed sign and grew over decades that followed. See also his article 'Sines in terse verse', *Nature*, 2001, **414**, 851. The book he co-edited, *Dynamics of Technology: Creation and Diffusion of Skills and Knowledge* (Sage Publications, 2003), is a must-read.
8. A few details of how he came to be engaged in this way are given later in the text. When RN was the Director of National Institute for Advanced Studies (1997–2004), he was invited to meetings with a Committee on Nuclear Policy from the US National Academy of Sciences, where he presented India's policies and goals in nuanced ways. He was actively engaged in 2004 in organizing a joint Indo-US workshop in Goa on Science and Technology on Counter Terrorism. See his articles: 'Evolution of India's Nuclear Policy' presented at the XIII International Amaldi Conference on

- Problems of Global Security, 2000; ‘Nuclear risk reduction centres in South Asia’, Working Group Report, Centre for Strategic and International Studies, Washington, 2004, Narasimha, R. and Rajagopal, S., ‘The future of the nonproliferation enterprise’ in *New Challenges to the Nuclear Non-Proliferation Regime* (2004, pp. 26–28) Meeting of Working Group I, CISAC (Stanford), Bangkok.
9. RN served on the Board of Directors of Hindustan Aeronautics Limited for several years; during 1977–79, he was the Chief Project Coordinator in Hindustan Aeronautics Limited, and led a joint HAL–NAL–IISc team carrying out early conceptual studies of the LCA. He remains the Co-Chairman of the Joint Scientific Working Group of the Indo-French atmospheric research satellite *Megha-Tropiques*. More importantly, he served as a member of the Scientific Advisory Council to the Prime Minister (Rajiv Gandhi and Manmohan Singh), served three terms on the National Security Advisory Board, and was a member of the Space Commission (1989–2012). RN was a Member of US National Science Foundation’s Advisory Committee for International Science and Engineering (AC-ISE) during 2012–13.
  10. The first student to obtain Ph D under RN’s guidance is S. M. Deshpande in 1969, and presently guiding four students at JNCASR. Even before his first student graduated, he was the inspiration for several Ph D theses written formally under Dhawan’s guidance when he was quite busy as the IISc Director. M. A. Badri Narayanan, S. K. Ojha and T. S. Prahlad were among them. RN had a particularly long intellectual relationship with Badri, who constantly thought up new but vague ideas. Most of them would not pass the muster of RN’s constructively critical scrutiny but some that did led to successful collaborations. Turbulent bursting was among the latter.
  11. One can find numerous accounts of RN in Indian newspapers (and a nice video on the YouTube). These accounts vary from the award of *Padma Bhushan* (coincidentally with Rajesh Khanna) and *Padma Vibhushan* (coincidentally with Sharmila Tagore) to his somewhat sensational resignation from the Space Commission, but many of them repeat standard phrases and provide little insight.
  12. A few reminiscences of Dhawan were authored by RN (see, e.g., the obituary in *Current Science*, 2002, **82**, 222–225). They are partly autobiographical in that they contain some details on the nature of fluid dynamics research in mid-fifties in IISc, of which RN was a part. The most recent article, ‘Satish Dhawan’, in *A Voyage Through Turbulence* (ed. Davidson, P. A. *et al.*), Cambridge University Press, 2011, is also the most comprehensive. The direct autobiographical note, ‘How I became a scientist’, can be found in *One Hundred Reasons to be a Scientist* (ed. Sreenivasan, K. R.), International Centre for Theoretical Physics, 2004. We have used some material from that note.
  13. For a lively description of Bangalore of those days, see the autobiography of C. N. R. Rao, *Climbing the Limitless Ladder: A Life in Chemistry*, 2010, World Scientific. The book also contains a brief discussion of Acharya Pathashala.
  14. Prandtl, considered the father of modern Fluid Mechanics, pioneered the theoretical and experimental investigations of boundary layer and established an outstanding school in Goettingen; Sir James Lighthill regarded Prandtl’s work equal in importance with the theory of relativity. For more details on the impact of Prandtl’s work, see *One hundred Years of Boundary Layer Research* (eds Meir, G. E. A. and Sreenivasan, K. R.), Springer, 2006.
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  19. For a brief biography of Liepmann, see Narasimha, R., Roshko, A. and Gharib, M., Hans W. Liepmann. *Annu. Rev. Fluid Mech.*, 2013, **45**, 1–17.
  20. Mollo-Christensen, E. and Narasimha, R., Sound emission at high subsonic velocities. *J. Fluid Mech.*, 1960, **8**, 49–60.
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  22. Narasimha, R., Nearly free molecular flow through an orifice. *Phys. Fluids*, 1960, **3**, 476–477; Orifice flow at high Kunden numbers. *J. Fluid Mech.*, 1961, **10**, 371–384; Collisionless expansion of gases into vacuum. *J. Fluid Mech.*, 1962, **12**, 294–308.
  23. They did co-author a paper. See Liepmann, H. W., Narasimha, R. and Chahine, M. T., Structure of a plane shock layer. *Phys. Fluids*, 1962, **5**, 1313–1324.
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- sure gradients in a convex surface. *J. Fluid Mech.*, 2006, **366**, 97–115.
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  39. The demand for such engines was steeply declining in the UK around that time because of huge changes occurring in the British aircraft industry and the project was not internally funded. There was an offer from the British to develop it if India were to pay for it.
  40. The decision to take on this new responsibility was not easy for RN. Roughly speaking, academic work occupied his full attention until about 1972. In the decade or so that followed, he was getting involved gradually in many ‘outside’ activities (as described in the text), but he attended to them primarily as an academic. The NAL directorship was a qualitative change. One of us was present in a conversation in which RN’s wife, Dr Neelima Narasimha, made the clinching summary: ‘You already do so many of these things anyhow, so why not do that with some status?’
  41. RN believes that India has enormous talent. Given a challenging problem, many are willing to go the extra mile provided they are convinced that their efforts will lead to a product in which funders are actually interested. The aeronautics community in India has been disappointed that LCA did not go farther despite successful design and fabrication; and that, with time, the valuable expertise that was gained during the development of LCA will be frittered away. Referring to LCA and *Saras* experiences, he feels that real development will not occur unless one learns from setbacks and failures: the aircraft should be produced and problems identified and corrected. The potential for exporting these aircraft is huge. This calls for long term vision at the highest level.
  42. We cite only few representative papers from a large number: Bhat, G. S., Narasimha, R. and Wiggins, S., A simple dynamical system that mimics open flow turbulence. *Phys. Fluids*, 1990, **2**, 1983–2001; Kailas, S. V. and Narasimha, R., Similarity in vita-detected events in a nearly neutral atmospheric boundary layer. *Proc. Roy. Soc. London*, 1994, **447A**, 211–222; Govindarajan, R. and Narasimha, R., Stability of globally developing boundary layer in pressure gradients. *J. Fluid Mech.*, 1995, **300**, 1117–1147; Govindarajan, R. and Narasimha, R., Low-order parabolic theory for 2D boundary-layer stability. *Phys. Fluids*, 1999, **11**, 1449–1458.
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  44. As one of us had heard from Raja Ramanna, there existed a lacuna in Indian administrative circles on a broad understanding of the world, its history, its large-scale politics, leadership (as opposed to mere management), long-range strategic thinking, ability to work within the system to ‘get things done’, etc. All its directors (Raja Ramanna, RN, K. Kasturirangan and V. S. Ramamurthy) have had the appropriate outlook for advancing this difficult task.
  45. India’s interest in nuclear weapons has been entirely defensive rather than offensive, and the main focus has been to protect itself against possible attacks. Educating the world about the reasons for possessing a nuclear weapon had become essential at that time.

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