MEETING REPORT

Combustion science*

The Second Combustion Science Workshop was held recently following the first successful meeting that took place at Jain University (JU) Campus, Bengaluru on 24 and 25 February 2014. The principal aim of these workshops was to get the faculty (and their students) and scientists of R&D laboratories to come together and discuss combustion science practiced in the academic environment and problems of development in defence and aerospace industry. The significant difference between this workshop and regular conferences is the in-depth discussion that occurs after each presentation. It is aimed at learning from each other and allowing the students to relate the research practiced in their environment with developments. It was (and is) held in a retreat mode to enable long walks and discussions to resolve differences in viewpoints beyond the conference room and learn some successes and failures in a direct conversational mode. The current meet had 25 presentations, including 6 student presentations. Selected highlights are listed below.

The first talk was presented by H. S Mukunda (IISc, Bengaluru) on what is termed 'quantitative minimalism' in combustion science in the current context, but with wider applicability. Specifically, he addressed the role of diffusion limitedness versus kinetic role in combustion science. He brought out from his own work, factors that were included in earlier work but later excluded after re-examination of ideas and accounting for more experimental data. He stated that taking large chemistry as important in complex problems must be weighed against its true role, since such an effort could be time-consuming and not so-relevant subsequently. He also mentioned that in problems of combustion with complex chemistry and condensed phase physics as in solid propellants (reactive c-phase) or biomass, it is prudent to take simple chemistry where needed and seek with care if the phenomenon is dominated by diffusion limitedness. Modelling phenomena without complex chemistry, if not relevant, would be far more straightforward and a reality check will anyway be the final word. Taking what is most essential rather than all factors into account was the prime emphasis.

V. Raghavan (IIT Madras) spoke on the flame spread process in a long pan fire with methanol as the fuel. The full conservation equations were solved both in the gas and condensed phase and the results were displayed; the broad features of the propagation process were captured. Bhaskar Dixit (JU) spoke on the role of free board in small pan fires. Both experimental and modelling studies were discussed. The heat flux along the wall was traced to the conductive heat transfer through the quench zone above the lip. The model was shown to capture the effects of free board and other aspects.

In the session on solid rocket motors, Kalyan Chakravarty (DRDL, Hyderabad) focused on analytical and computational tools for solid motor instability. He described the development of a quasi-1D code that can predict damping coefficients accurately as that of CFD in most cases, and almost the exact frequencies; it could be a good substitute for CFD, which is far more time-consuming. He spoke about an important possibility of a segment with much larger burning area as a middle segment of a long motor to ensure meeting the total burn area need, but ensuring stability as the unstable burn related contribution to mass flow rate is correspondingly reduced due to large fraction of mass addition close to the pressure node. Varun Shivakumar (IIT Madras) described the steady-state modelling of composite propellants, arguing that this is essential to make realistic predictions of unsteady behaviour of motor operation using composite solid propellants. He argued for the minimum model elements with the burning of the largest particle surrounded by a uniformly coated binder with fine particles. He and his student M. Zaved presented the results for a large number of propellants of Miller for which the burn rate data were available. Excellent comparisons were shown for a large number of propellants and for some propellants, the need for computation of propellant burn process was indicated to quantify one factor in the propellant model. Arvind Kumar (HEMRL, Pune) agreed to collect data on propellants produced at HEMRL and examine the model presented for further improvement in predictive capability. He indicated that aluminum combustion would be superior when it is coated with nickel.

P. A. Ramakrishna and Nikunj Rathi (IIT Madras) explained systematically the approach for ramjets for flight Mach numbers in the range 6–8, usually reserved for scramjets. The argument for the suggestion on ramjets arose from the consideration that a new propellant combination had the promise of much higher flame temperatures, thus enabling energy addition even at higher stagnation temperatures experienced at Mach numbers of 6–8. R. Abhishek (DRDL, Hyderabad) explained the principles for the choice of a propellant for a solid fuel ramjet based on the tactical mission scenarios. He indicated that meeting mission objectives needed boron-based fuel-rich propellants that are easy to ignite; the central issue of boron combustion in the secondary combustion chamber was also brought out. He indicated that the availability of boron of the right specification was also in question. A. N. Gupta (Premier Explosives Ltd, Hyderabad) described the role of the source of ammonium perchlorate in controlling the burn rate behaviour of composite propellants being produced for defence applications.

There were two presentations on thermoelectric generators (TEG) for power generation by Sudarshan Kumar (IIT, Mumbai) and Ganesh Pavan (JU) who described the attempts to establish the operating efficiency of a TEG system. The JU system was designed for 10 W output at an efficiency of 2.5%. Sudarshan Kumar presented his work on TEG with emphasis on micro combustion process in fine tubes with similar performance.

J. Jayaprakash (VSSC) discussed the recent flight of GSLV-Mk3 (also termed LVM3-CARE mission) carrying a re-entry

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payload with several flight details not usually available otherwise. He mentioned a problem related to burn rate of the solid propellant that appeared to be lower than expected despite all standard practices for propellant production and testing established over a long time. This was an invitation for academia to put their minds to the issue. Biju Kumar (LPSC) presented the issues surrounding the cryogenic (liquid oxygen–liquid hydrogen) testing. He indicated that in a major static test conducted, the engine experienced high frequency instability of the first tangential mode (about 3.3 kHz), which was unexpected because of earlier tests. On a careful study, the issue was traced to cavitating venturies that had been placed in the high-pressure fluid supply circuit. The conditions in the cavitating venturi caused pressure fluctuations due to local flow velocity being larger than the acoustic speed of the two-phase flow. Resolution of the problem was sought in increased area of the venturi such that the local speed was brought down below the two-phase acoustic speed. This change showed that all normal test behaviour was recovered. Of course, such a situation was not expected to occur in flight mode since the system does not have cavitating venturies. T. Sundararajan (IIT Madras) spoke about computational efforts on the simulation of the high-altitude test facility being built at Mahendragiri (ISRO). Exhaustive simulations displayed known physical insights into the problem.

S. R. Chakravarty (IIT Madras) and his student provided impressive time-resolved flow pictures of combusting flow stabilized behind a step. Many interesting details of the flow dynamics were brought out; to whether these phenomena are still coupled to the incoming flow remains to be resolved. R. I. Sujith (IIT Madras) spoke about intermittency in flows as precursor to fully turbulent flow and associated chaos with particular reference to flows in gas turbine engines. The usefulness of the knowledge of a precursor to instability is yet to be explored. His student, E. Gopalakrishnan spoke engagingly about the role of noise in causing flow transitions (the bifurcations), some smooth and some abrupt with experiments on Rijke tube. Dalton Maurya and Gurusharan Singh (GTRE, Bengaluru) outlined the issues facing combustion processes in gas turbines today. Gurusharan Singh clearly brought out where they stand with regard to after-burner instability issues. Achintya Mukhopadhaya (Jadavpur University) discussed the extensive tools like colour sensing, crossed wavelet transform technique and symbolic time-series techniques to provide an early detection of lean blow-off situations in gas turbines using premixed and partially premixed flames.

A. Ramesh (IIT Madras) spoke on the use of biogas in homogenous charge compression ignition engine with diesel for auxiliary injection. This effort aimed at small engines compete with standard low-capacity direct injection diesel engines working on dual-fuel mode and small capacity gas engines working on biogas directly. Sri Vallabha (IISc) spoke on the large eddy simulation of jet flows with water spray using several strategies for sub-grid scale modelling. The computations were carefully performed and comparison with experiments showed some parts to be reasonable and some others as not so good. As to why there were differences between predictions and experiments and how to reconcile them were also discussed. Many experiments on droplet dynamics were reported by Anand and colleagues (IIT Madras). P. Mahesh (IIT Madras) described measurement of drop distributions with advanced laser technology in situations of interest to gas turbines. He indicated that while the use of drop size distribution with d^2 law was standard in gas turbine combustor design, the drop groups that he has measured might influence emissions and need to be accounted for. Swetaprovo Chaudhuri (IISc) spoke of the need for taking turbulence–combustion interaction in premixed flames to a greater level of detail than considered now and presented an approach to track the flame movements in a turbulent flow field and its consequences.

There were three independent student presentations. S. Snehesh (IISc) presented his work on Fischer–Tropsch process, particularly on catalyst development, since this was an item commercially denied for supply for development in India; very encouraging reactor performance was reported. S. Krishna (IISc) spoke of the experiments on trapped vortex combustor with methane and syngas as fuel with reasonable comparison with calculations. Anirudha Ambekar (IIT, Mumbai) spoke on the combustion behaviour of liquid monopropellant – isopropyl nitrate. The results of the elegant experiments at high pressure were explained on the basis of wall heat transfer coupled combustion process.

The meeting had several takeaways – further collaborations between various institutions which participated in the workshop in respect of understanding propellant combustion and progressing steady and unsteady solid propellant modelling efforts to continue. Highlighting the issues on gas turbine combustion will lead to greater GTRE–academia interactions aimed at resolving problems of significance in gas turbines. Other along-the-beach conversations in the evenings and mornings have created prospects for greater interactions among all concerned.

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