

points highlighted in the earlier report¹ about the heart warming performance of Indian American children. As earlier, a number of girls took top positions. The Prime Minister of India, Narendra Modi, made a reference to the superb performance of the Indian American children in

these very competitive contests, in his address to the US Congress on 6 June 2016.

2. Shapira, Ian, *The Washington Post*, 26 May 2016.

1. Subbarao, E. C., *Curr. Sci.*, 2014, **107**(3), 338–340.

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MEETING REPORT

The third P. J. Paul memorial combustion researchers meet*

The third combustion researchers meet was held in Vikram Sarabhai Space Centre (VSSC) at Thiruvananthapuram during 27 and 28 February 2016, following the second successful meeting that took place at a beach resort in Chennai¹. The tradition of getting faculty and scientists in R&D institutions *on an invited basis*, to discuss in-progress parts of combustion science practiced in the academic environment and problems of development in defense and aerospace industry was continued this year as well with much wider and deeper interest by the participants. The aim of creating a conducive environment for learning from each other and allowing the students to relate the research practiced in their environment with developments seemed a well worth the idea because many students participated in this workshop. The current meet had 29 presentations from faculty and scientists with 6 student presentations. Selected highlights are set out below.

The first talk was presented by Sujith (IITM) on using theory of complex networks in thermo-acoustics; the basic idea being that acoustic signals from flowing fluids contain the nature of the local flow field and such signals when subject to select analysis may reveal the flow behaviour. Much discussion followed. Establishing the value of such analysis on the basis of conservation equations was suggested as being important. Sundarara-

jan (IITM) spoke of the use of genetic algorithms in optimizing the performance parameters of liquid rocket engines. He described how the best operating conditions within the constraints given could be arrived at using this algorithm. Varun Shivakumar (IITM) spoke of a model of heterogeneous quasi-1D model for composite solid propellants that was shown to predict the burn rate behaviour of a large number of propellants. The principal features of the new quasi-1D model were elucidated and the features that give confidence in making good predictions were brought out. Joseph Mathew (IISc) presented the progress on LES by explicit filtering for problems of flows with shocks that are relevant to propulsion. The simulations of free supersonic jets, and jets impinging on wedge deflectors relevant to space launch vehicles were shown to be consistent with experimental results. Swethaprovo Choudhuri (IISc) presented the work on mitigating instability by subjecting the swirler in a combustor to a rotary motion such that the higher intensity turbulence and higher swirl number generated in the flame stabilization region might alter the flame position, structure and thereby mitigate thermo-acoustic instabilities. Several techniques, such as particle image velocimetry, high speed, intensified, chemi-luminescence imaging were utilized to observe the impact of swirler rotation rate on the dynamics of the unstable flame. The disruption of the flame-corner vortex interaction in outer recirculation zone due to an enhanced turbulent flame speed and increased swirl number are found to be responsible for the observed mitigation by the proposed strategy.

A. Mukhopadhyay (Jadavpur University) described the fundamental experi-

mental and analytical studies on jet break-up phenomena pursued in his laboratory. The conclusion that these studies corroborate with linear stability is consistent with the literature. Srikrishna Sahu (IITM) spoke on the laser-based measurements related to droplet clustering in sprays with regard to their cause and consequence using a twin-fluid air-assist atomizer. The present work has obtained a comprehensive data set for droplet clustering statistics for different liquid mass loading (by varying the air and the liquid volume flow rates) on water spray. Kriethika Narayanaswamy (IITM) spoke about chemical kinetic modelling of jet fuel surrogates using computational tools. The use of surrogates is to more accurately assess the role of specific components in jet fuels.

Bhaskar Dixit (Jain University) discussed the work he was doing on some puzzling situations encountered in diesel-on-water pool fire combustion along with his colleagues. Experiments with the combustion of a diesel layer over water for a long burn time of 30 to 45 minutes showed that after the main fire there was a long pause and an unexpected substantive flare-up. Studies on small pool fires showed that the relatively small density difference between diesel and water allowed some diesel to sink and this would surface later when the density of water came down due to heating and caused the flare up. A. T. Sriram (M.S. Ramaiah School of Advanced Studies, Bengaluru) presented the computational results on a model can-type combustor's flow field that consists of combinations of interesting elementary configurations like jet-in-cross-flow, opposed jets and swirl. He described the results of computations based on $k-\omega$ model for turbulence and eddy dissipation model for combustion.

*A report on the third P. J. Paul memorial combustion researchers meet held on 27–28 February 2016 at Vikram Sarabhai Space Centre, Thiruvananthapuram, India. The event was supported by VSSC, Liquid Propulsion System Centre (Thiruvananthapuram) and projects from Indian Institute of Technology (IIT), Chennai.

Many details of can combustion process were described. K. R. Anilkumar (Fluidyn, Bengaluru) discussed the issues around the formation and explosion of a non-uniform hydrogen-air mixture arising out of high pressure cryo-storage of hydrogen. Accidental leak of hydrogen from such storage systems, its mixing with the ambient air resulting in the formation of a non-uniform hydrogen-air mixture, and ignition of this mixture was the subject of computational study. It was thought desirable to have a method which is relatively inexpensive and at the same time reasonably accurate, to evaluate the consequences of this potential risk, mainly in terms of the explosion overpressures. The method consisted of a combination of a 1D pseudo-source model for the expansion of the high speed hydrogen jet from the leak, 3D finite volume model for the dispersion of hydrogen in the ambient air and a modified flame-let turbulent combustion model for the burning of the resultant non-uniform hydrogen-air mixture. The modelling approach for this problem was the subject of much discussion, because it was not clear how a diffusive combustion process was being modelled like a turbulent premixed flame.

C. Prathap (Indian Institute of Space Science and Technology (IIST), Thiruvananthapuram), described experiments on combustion of natural gas to limit the emissions of nitric oxides that he had performed in a laboratory overseas. Rajesh Sadanandan (IIST) provided a broad brush overview of role of optical and laser diagnostic techniques in cryogenic propulsion research. The presentation was more in the form of a tutorial on the subject. Kowsik Bodi (IIT Bombay) described the studies he was performing on the computation of high enthalpy flows – magneto hydrodynamic flows at extreme conditions of temperature and pressure including fusion reactors with issues of arc stability. While foundations for computations are being laid, he indicated that more work needs to be done on this subject. Saurabh Sharma (IIT Bombay) spoke of the work with Sudarshankumar on flameless combustor for liquid fuels using direct injection. Characterization of droplet size distribution and exploration of the flameless combustion process were described.

On the second day, H. S. Mukunda (IISc) spoke about possible aspects of interest to future based on things remaining

undone in the past as well as those other 'good' ideas from overseas. Specifically, he brought out that new hybrids with the promise of high performance should be coupled to single-stage-to-orbit vehicles for ensuring reliable safe option for cheap access to space (CATS). He further emphasized that the science missions of ISRO could be a part of technology mission for greater impact on the nation. Subhashchandran (DRDL) spoke on hypersonic propulsion for defense applications. He described their current efforts on a vehicle under development and some variants for meeting future demands. Sundar Krishnaswami (GE Aviation, Bengaluru) described development of the low emissions technology for propulsion combustors in GE Aviation. A brief history of the development of the twin annular premixing swirler (TAPS) approach to combustor design was provided, and comparison with the prevailing technology was highlighted along with the approach to the product certification. Lastly, forward-looking technology focus areas were described.

V. Narayanan (Liquid Propulsion System Centre, Thiruvananthapuram) described the issues and problems in the development of liquid rocket engines and the role played by P. J. Paul at several stages. Amongst others, he spoke of issues with ignition in the gas generator section at low mixture ratio, and combustion instability problems of the new design of semi-cryo engine under development now. He emphasized that more theoretical studies were needed in respect of vacuum ignition of steering engine, ignition of gas generator at low mixture ratio, saw tooth pattern observed in the main thrust chamber after hot test and combustion instability modelling of semi-cryogenic engines for providing strength in making critical decisions in short duration high risk development of these engines. Jayaprakash and Kiran Pinumall (VSSC) presented an analysis of pressure spikes in large segmented solid rocket booster motors used in PSLV vehicle. In the pressure history of these motors, small pressure spikes less than 1.5 atm with a sharp rise in pressure with rise duration less than 100 ms are observed occasionally between 50 and 100 sec of the motor burning time, these being consistent with momentary increase in vehicle acceleration. After consideration of various possibilities,

these were traced largely to partial blockage of nozzle throat due to the passage of partially burned debris from the polyurethane slabs between segments of propellants. P. A. Ramakrishna (IITM) and Manu (VSSC) spoke of the idea of a new generation hybrid propellant combination not explored anywhere else – concentrated hydrogen peroxide and aluminum (70) – wax (30) combination as a high performance green propellant option for ISRO. While Ramakrishna brought out the results of performance improvements on the launch vehicle of PSLV class indicating a substantive improvement in payload capability varying from 15% and far more depending on the choices of elements, Manu described encouraging results of the very recently (previous day) conducted experiments on the system at VSSC.

S. M. Pande (High Energy Materials Research Laboratory (HEMRL), Pune) spoke extensively on the development of high energy propellants based on nitrate esters and RDX/HMX combinations needed in defense applications. He indicated that many aspects of development have been mastered at this time and these propellants will enter into propulsion systems soon. Aspects of safety of this class of propellants are being pursued presently. Akansha spoke of her preliminary studies with HEMRL on development testing of pulse induced instability in solid rockets of 40 kg class; these tests are being continued.

H. S. N. Murthy (IITM) and R. Perumal (Shri Harikota range) spoke on the experimental studies on ageing-related issues in composite solid propellants. Studies on the role of the additive-copper chromite on the burn rate of propellant were made by determining the role of the additive on ammonium perchlorate burn rate itself. Apparently, accelerated ageing showed decrease in burn rate. This was related to the decomposition of copper chromite due to thermal cycling over long periods of time. Jeenu (VSSC) spoke about the work he has done with his colleagues on the alumina particle size distribution in the combustion products of composite propellants with 18% aluminum loading, details that would be of value in modelling the combustion process and performance estimation. Using a large quench bomb the burnt particulate was collected in a solvent and the particle size distribution was measured

using laser diffraction particle size analyser and the surface structure is examined by scanning electron microscope. The study showed that the particles are spherical and their sizes vary from 0.1 to 300 microns. The particles have tri-modal distribution with modes at 1, 4 and 70 microns.

Thomas (VSSC) described the safety issues in large scale solid propellant processing for PSLV and GSLV class vehicles. One aspect that came up was safety in the use of fluid energy mill for fine ammonium perchlorate grinding on which practices in ISRO and HEMRL seemed different. It was suggested that this aspect needs to be discussed further. B. Chellathurai (ISRO Propulsion System Complex, Mahendragiri) described the production, storage and handling of storable and cryo-liquid propellants,

namely, UH-25, di-nitrogen tetroxide, mono methyl hydrazine, MON-3 and hydrazine, liquid oxygen and liquid hydrogen. The major hazards associated with earth storable propellants were identified as toxicity, corrosivity, fire, explosion, air and water pollution. The major hazards with cryogenic propellants and the various safety precautions taken during storage and handling of these hazardous propellants were discussed in detail. Safety lessons learnt from incidents during testing of liquid propulsion systems at IPRC were also discussed for understanding the extreme hazardous nature of liquid propellants.

Holding the workshop at the VSSC, Thiruvananthapuram brought a large number of practitioners of rocket science and technology and allowed intensive discussions on current problems and

ways of overcoming them. It is possible that a few collaborations and joint projects of relevance to aerospace combustion science will emerge from this workshop.

1. Shivakumar, V., Ramakrishna, P. A. and Mukunda, H. S., *Curr. Sci.*, 2015, **108**(8), 1412–1413.

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MEETING REPORT

Quaternary climate: recent findings and future challenges*

The ongoing Quaternary period is marked by several glacial and interglacial cycles. These long and short-term variations are well preserved in the proxy record. Long-term proxy climate records provide a perfect setup to understand the response of earth towards these long and short-term variations in climate. To address recent findings and future challenges within the Quaternary period, a national conference was held in Goa. The main objectives of the conference include understanding of Quaternary climate changes and anthropogenic influence on earth's climate using both marine and terrestrial archives and thereafter quantification of key climate factors during the past with development of sta-

ble isotopes and elemental ratios as proxies. The principle themes of conference include recent developments in the field of Quaternary climate studies, climatic proxies, glacial–interglacial climate fluctuations, Holocene climate change and archaeological studies especially in Indian context. The event also included a dedicated session for the discussion on future directions in Quaternary climate studies especially in context of the Indian subcontinent and adjoining seas.

The event included ten oral and two poster sessions followed by field trip to nearby historic sites. The inaugural function was chaired by S. N. Bhalla (Aligarh Muslim University, Aligarh). The inaugural lecture by Rajiv Nigam (NIO, Goa) focused on the environmental implications of the foraminifera and otoliths from the Indian Ocean waters. He discussed the consequences of global warming, accelerated rise in sea level, change in monsoon pattern as well as the increase in intensity and frequency of storms. He also gave an overview of the unique aspects of town planning from Dholvira, a Harappan time archaeological site in Gujarat. The massive outer protective walls were built to protect the

city from sea storms/tsunami. He also emphasized on the need to develop reliable proxies to fill the gaps in chronology for better understanding of climate change and management of future strategies and to avoid the devastations caused by natural hazards. He also threw light on the unexplored otolith (fish ear bone) proxy and its applications in the palaeoceanography. He concluded his talk by explaining the usefulness of foraminifer proxy in the indication of marine pollution and emphasized that the future research in this field lies in foraminifera culturing experiments.

The first three sessions were dedicated to palaeoclimate proxies. Talat Ahmad (Jamia Millia Islamia University, New Delhi) delivered the keynote talk. In his talk entitled 'Rising Himalaya, monsoon and climate', he emphasized on the major issues of earth system sciences including the high seismicity of Himalaya which makes North India one of the most earthquake-prone zones. He also added a note on the big event happened on earth around 55 Ma and the history of earthquakes that occurred around the Indian sub-continent in the past. He also gave a brief account on rainfall documentation

*A report on the National Conference on 'Quaternary climate: recent findings and future challenges', held at CSIR-National Institute of Oceanography, Dona Paula, Goa during 28–30 April 2016. The conference was convened and co-convened by Rajeev Saraswat, National Institute of Oceanography (NIO), Goa and Niloy Khare, Ministry of Earth Sciences (MoES), New Delhi respectively. The event was organized in association with MoES and Past Global Changes (PAGES).