Volume 46, 2021

PRINT ISSN 0379 0479
ONLINE ISSN 2349-2120

INDIAN JOURNAL OF CRYOGENICS

A yearly journal devoted to
Cryogenics, Superconductivity and Low Temperature Physics

Published by
Indian Cryogenics Council

Supported by
Science and Engineering
Research Board

Proceeding of
National Conference on Cryogenics for Space

Hosted by
Liquid Propulsion Systems Centre, (ISRO), Thiruvananthapuram
December (12-14), 2019

November, 2021

Volume 46, 2021
INDIAN JOURNAL OF CRYOGENICS
November, 2021

VOLUME 46, 2021

PRINT ISSN 03790479
ONLINE ISSN 2349-2120

INDIAN JOURNAL OF CRYOGENICS

**A yearly journal devoted to Cryogenics,
Superconductivity and Low Temperature Physics**

**Published by
Indian Cryogenics Council**

Supported by

**Proceeding of
National Conference on Cryogenics for Space**

Hosted by

**Liquid Propulsion Systems Centre (ISRO)
Thiruvananthapuram**

December (12-14), 2019

November, 2021

Indian Journal of Cryogenics

(A yearly journal devoted to Cryogenics, Superconductivity and Low Temperature Physics)

All the papers received for publications in “Indian Journal of Cryogenics” are reviewed by a large number of Professors, Scientists and Engineers from Universities, Government Institutions and Corporate Sectors across the country in an honorary capacity. Papers are also sent to experts abroad for reviewing.

Communication regarding submission of papers should be addressed to:

Prof. T.S. Datta
Chief Editor,
Indian Journal of Cryogenics
Cryogenic Engineering Centre,
IIT, Kharagpur
tsdatta59@gmail.com
icc.iuac@gmail.com
Phone: +91 9818947190

OR

Prof. M.D. Atrey
President
Indian Cryogenics Council
Dean (R&D) and Professor
IIT, Bombay
matrey@iitb.ac.in
icc.iuac@gmail.com
Phone: +91 9833617522

For detailed information please visit our website: **http://www.indian-cryogenics.com/**

Indian Journal of Cryogenics

(A yearly journal devoted to Cryogenics, Superconductivity and Low Temperature Physics)

General information:

A) Papers received for publication are reviewed independently by two or more referees and based on their reports the editorial board takes a decision whether to accept the paper as-it-is or reject it or to publish it with minor corrections as per the recommendations of the referees. Papers may as well be returned to the authors with the recommendations from referees for carrying out additional studies or analysis. Such papers are considered for publication in the next issue of the journal.

B) IJCS is the only Indian journal which publishes research work in low temperature physics, superconducting materials, superconducting magnets and the cryogenics. IJC gives utmost importance to the publication of articles on cryogenic engineering. The Editorial Board encourages work on indigenous development of cryogenic and superconducting magnet systems as import substitutions and publishes in IJC.

C) As per the decision of the Editorial Board we started publishing one review article (by invitation) in each volume of the IJCS beginning with Vol. 41. These articles are invited from peers with long experience in the field of superconductivity, low temperature physics, cryogenic engineering or covering the status of major cryogenic related projects in India.

D) All the manuscripts should be prepared strictly as per the Journal Template available in the ICC website: **http://www.indian-cryogenics.com**

E) In general, the title should be short and crisp, abstract should not exceed 150 words and should reflect the main results, new findings being reported in the paper. Please do not write introduction in the abstract. Abstract submitted for the abstract book of the symposium need not be repeated in the manuscript. All the figures and illustrations should be very clear and readable.

F) Any illustration, figure or a table if taken from a published work should be credited and acknowledged so. The responsibility for getting copyright permission for using such illustrations lies solely with the author(s). The journal or the editors, chief editor or the editorial board members will not be responsible for any copyright violation.

G) Indian Cryogenic Council has an agreement with **Indianjournals.com** for publishing IJC online. Vol. 37 onward are now available online. Fellows and members can access all the papers in these issues, free of charge, through a log-in procedure. Following are the current rates for subscribing print version as well as the online version..

1.	Printed copy and online version	:	Rs. 5000/-
2.	Online version only	:	Rs. 4000/-
3.	ICC members	:	Free online access
4.	Foreign : Online version only	:	$225/-
	Print & online versions	:	$250/-

For subscriptions & payment, please contact: **www.indianjournals.com**

For enquiries and other information related to Indian Journal of Cryogenics please contact:

Prof. M.D. Atrey
President
Indian Cryogenics Council
IIT, Bombay
matrey@iitb.ac.in
icc.iuac@gmail.com

Dr. Soumen Kar
Secretary (Technical), ICC
Inter- University Accelerator Centre
New Delhi-110067
kar.soumen@gmail.com
icc.iuac@gmail.com

PREFACE

The National Conference on Cryogenics for Space (NCCS-2019) was conducted in association with the Indian Cryogenics Council (ICC) from 12 to 14 December 2019. The venue for the conference was the Liquid Propulsion Systems Centre (LPSC), Thiruvananthapuram, Kerala, which is one of the lead centres of ISRO. The theme of the conference was “Cryogenics for Space”and its focus was on the application of cryogenics to space and space related areas. The topics of the conference were chosen to reflect this. They were grouped into four broad areas viz. design and development, facilities and testing, materials and propellants as well as applications and spinoffs. Under these categories, a broad range of subjects such as propulsion, combustion, heat transfer, structures, testing and instrumentation, propellants, cryocoolers, superconductors, etc. were covered. A large number of high quality technical papers were received for the conference. These were subjected to thorough peer review. Several VIPs and 400 delegates, including fifty students, from across the country attended the conference. They included delegates from ISRO, BARC, IUAC, VECC, IPR, IITs, NITs, TATA, INOX, Shell-n-Tube, etc. In addition to the oral and poster presentations, there were two plenary talks and eight invited lectures as well as exhibitions. The plenary talks were delivered by the very eminent scientists Dr. V. Narayanan and Prof. Milind Atrey.

Sixty technical papers were presented in 12 technical sessions at the conference. An ISRO-academia panel discussion was held with scientists and professors. The discussion gave an opportunity to young researchers to acquaint themselves with the various ongoing cryogenic activities in the country. As many as 14 industry booths were put-up at the venue and kept open throughout the conference. The event also included visits to various ISRO facilities at LPSC, the VSSC space museum and the rocket engine test facilities at ISRO Propulsion Complex (IPRC), Mahendragiri, Tamil Nadu. The organizing committee extends heartfelt gratitude to all the speakers, participants, exhibitors, and volunteers, for making the conference a grand success.

It was planned to release this special edition of the Indian Journal of Cryogenics on NCCS-2019 shortly after the conference. However, due to the COVID-19 pandemic, it has been possible to release it only now. It comprises of 30 papers presented at NCCS-2019. These papers were selected based on their relevance to the theme of the conference and their technical merit. The selected papers were subjected to an extensive review process. The technical and literary content of each selected paper was evaluated before incorporating them in the Journal. The Chief Editor, Prof. T.S. Datta has provided invaluable guidance for the release of this issue of journal. The editorial staff of the journal are also to be appreciated for their efforts in bringing out the journal. It is hoped that this Special Edition of the Indian Journal of Cryogenics will provide a basis for expanding frontiers for the application of cryogenics in space.

Dr. V. Narayanan
Distinguished Scientist & Director
LPSC/ ISRO, Thiruvananthapuram

Dr. T. John Tharakan
Group Director, PRG
LPSC/ ISRO, Thiruvananthapuram

EDITORIAL

It is a matter of great satisfaction that we were able to bring out the Volume 46 of the "Indian Journal of Cryogenics" (IJC) within the year 2021. This was despite the fact that the second wave of the devastating Covid-19 had overtaken the country. This issue contains 30 papers selected out of a total of 60 papers presented at the "National Conference on Cryogenics for Space (NCCS 2019)" during December 2019 at the Liquid Propulsion System Centre (LPSC),Thiruvananthapuram, Kerala.

This symposium was very timely as the ISRO, over the years, has established a vast cryogenic infrastructure at LPSC and IPRC in the wake of developing complex Cryogenic Engine indigenously. The Indian Cryogenics community feels proud of the achievements of ISRO in putting the country among the select group of countries having developed capability to land on other planets. It was a proud moment for Indians to watch India's second mission to the Moon, **Chandrayaan-2** which was launched on 22nd July 2019 from Satish Dhawan Space Centre, Sriharikota. Indeed it was a significant technological leap over all the previous missions. In addition, ISRO has other significant activities on the development of cryo-vacuum simulation chamber, cryocooler and such other cryo-systems. For several years good number of LPSC scientists have been participating in "National Symposia on Cryogenics and Superconductivity" and contributing research papers for the IJC. The ISRO responded graciously and accepted the request from the Indian Cryogenics council (ICC) for organising a conference dedicated to Space Cryogenics. Dr. V Narayanan, Director LPSC kindly agreed to hold this conference. It was heartening to see young scientists of ISRO presenting variety of quality papers on basic studies as well as on the system developments.

As Chief Editor, I had requested the conference organisers to publish some selected reviewed papers in the Volume 46 of the Indian Journal of Cryogenics to which they readily agreed. The organisers also took the responsibility of reviewing these papers. The guest editors Dr. T John Tharakan and Dr. V Narayanan along with their team members did an excellent job in selecting and reviewing these papers. I take this opportunity and thank the Guest Editors and all the reviewers for providing their services which resulted in the timely publication of the issue 46.

I would like to extend my sincere thanks to my colleagues in the IJC Editorial Board. My special thanks to Prof. Milind Atrey, President (ICC), Dr. Soumen Kar, Secretary (Technical), ICC and Ms. Tania, Secretarial Assistant (ICC) for their whole hearted support and contribution in publishing this volume. I also thank Dr. R G Sharma for his guidance and advice on critical decisions. Finally, I thank the entire readership of the journal to whom we owe our existence.

We also place on record our gratitude to SERB (DST) for its support to the publication of IJC.

T S Datta
Chief Editor
IIT, Kharagpur

November, 2021

CONTENTS

Indian Journal of Cryogenics doi: 10.5958/2349-2120.2021.00001.7 *Vol. 46, 2021*

Influence of low temperature and flow properties in dynamic behaviour of cryogenic pipelines

Perumal Pillai R.[1] and Murugha Dhas K.[1]

[1]Cryo Test Facilities Entity, ISRO Propulsion Complex, ISRO, Mahendragiri
E-mail ID: r.perumalpillai@iprc.gov.in

The dynamic behaviour of cryogenic fluid pipelines under varying conditions and environments plays a vital role in the design of cryogenic systems. The natural frequency of the cryogenic fluid pipeline varies due to the changes in physical properties of materials with respect to change in the operating temperatures. The dynamical characteristics of the system are determined from its natural frequencies and damping ratios. Induced thermal stress in stainless steel pipelines is caused by pipeline contraction during low temperature service. It is controlled by expansion loops in the pipeline excite at regular intervals along the length. This however significantly alters the natural frequency of the system. This paper describes the influence of a low temperature environment on the dynamic behaviour of a cryogenic fluid pipe line. Thermo-structural FEM analysis has been carried out to find the effect of low temperature in the cryogenic fluid line and the results are compared with experimental data.

Key words: Cryogenic, pipeline, vibration, fluid-structure interaction

Indian Journal of Cryogenics doi: 10.5958/2349-2120.2021.00002.9 *Vol. 46, 2021*

Thermal simulations and experimental validation for the induction of indigenously developed copper alloy in regeneratively cooled Cryogenic vernier engines

Adarsh A.N.*, Siju K. Mathew, Baiju A.P., Bijukumar K.S., Jayan N. and Nageswaran G.

Cryogenic Propulsion Engine and Stages Entity, Liquid Propulsion Systems Centre, ISRO, Thiruvananthapuram
E-mail ID: anadarshnjr@gmail.com

Thermal simulations are carried out using a 1-D heat transfer code developed specifically for the vernier engine. Fin conduction through ribs is modelled as two dimensional. By means of simulations, engine required to obtain the maximum possible safe thermal operating conditions of engine are arrived at. The temperature distribution is evolved for this condition. Experimental validation is done by subjecting the engine to a 1060s endurance hot test. Coolant channel exit temperature estimated from the test closely matches with thermal simulations. With the theoretical simulation and experimental validation, thermal and structural integrity of copper alloy is validated and is successfully inducted into vernier engines for flight operation.

Key words: Vernier engine, indigenous copper alloy, theoretical simulation, hot test

Indian Journal of Cryogenics doi: 10.5958/2349-2120.2021.00003.0 *Vol. 46, 2021*

Development of polyurethane-based heat shielding coating for cryo-insulation

K. Monisha[1], Vibhu Unnikrishnan[1], Remya Balakrishnan[1], A. Suresh Kumar[1] and A.M. Nallaperumal[5]

Propellants Polymers Chemicals and Materials Entity,
Vikram Sarabhai Space Centre, Thiruvananthapuram-695022.
E-mail ID: k_monisha@vssc.gov.in

Thermal insulation of cryo stages is provided by polyurethane modified Isocyanurate foam (PUIR). To protect PUIR layer from aerodynamic heating, a thermally stable polyurethane based heat shield coating (PUHSC) with better bond integrity to PUIR foam layer was developed. This work briefly describes the preparation of a polyester polyol based polyurethane heat shield coating for cryo insulation. In addition to polyester polyol, PUHSC system contains hydrophobic silica aerogel which improves its thermal stability. The physical, mechanical and thermal properties of the prepared PUHSC were evaluated. PUHSC possess superior properties such as good thermal stability, low thermal conductivity, high specific heat and good bond strength compared to PUIR foam. For evaluating the thermal response of the new system conditions simulating flight, functional level tests such as aerothermal test, wind tunnel test, high altitude thermal simulation (HATS) test and wind tunnel tests were done. The system was successfully implemented in ongoing launch vehicle programmes.

Key words: Polyurethane, PUIR, heat shield coating, cryo insulation

Cycle selection and performance evaluation of tripropellant engines with $LOX/CH_4/LH_2$ and $LOX/RP1/LH_2$ combinations

Rohit G.[1], Deepak Agarwal[2], K.S. Bijukumar[1] and N. Jayan[1]

[1]Cryogenic and Semicryogenic Propulsion Engines Group, Liquid Propulsion Systems Centre, ISRO, Thiruvananthapuram
[2]Propulsion Research Group, Liquid Propulsion Systems Centre, ISRO, Thiruvananthapuram
E-mail ID: gudlarohit@gmail.com

Tri-propellant engines are concepts which are suitable to take advantage of both high density impulse in low altitude and high specific impulse in high altitude application. A tripropellant engine in a SSTO mission operates in two modes. In Mode-1, all the three propellants i.e., LOX/LH_2 and RP1 or CH_4 are used by the engine and LOX/LH_2 in Mode -2 which provide high specific impulse. A study was conducted to evaluate future engine concepts using tripropellants. In this study, performances of engines with tripropellant combinations like LOX/CH4/LH_2 and $LOX/RP1/LH_2$ are evaluated. Different engine cycles were evaluated by adhering to consistent design practices and technologies and most suitable engine configurations are derived based on merits of performance in both the modes of operation.

Key words: Tripropellant engine, Engine cycle analysis, Cryogenic engine, Methane, RP1

Indian Journal of Cryogenics doi: 10.5958/2349-2120.2021.00005.4 *Vol. 46, 2021*

Challenges in designing a POGO suppression device for cryo environment

Sunny Mitra*, Mathew Saxon, Aneesh Rajan and Sajeev P.

[1]Liquid Propulsion Systems Centre, ISRO, Valiamala, Trivandrum 695547
E-mail ID: sunnymitra111@gmail.com

The pogo phenomenon occurs, when the interaction between the longitudinal modes of vibration of the vehicle structure and the liquid propulsion system exhibits instability. To avoid this harmful effect, a pogo suppression device is required, which helps to decouple these two modes. Generally, an accumulator type of pogo corrector is used in launch vehicles. But for cryogenic feedlines, providing pressurization with a gas is difficult, and has inherent disadvantages connected with specific orientation requirements. This paper illustrates the challenges in designing a pogo corrector for cryo environment. The iterative procedure of finding the optimized design considering minimum size and weight of the system is discussed in detail. Another option with a spring material suitable for cryogenic environment and with better properties than stainless steel has also been looked into. For higher pressure applications further modifications are also considered such as nesting of springs.

Key words: POGO corrector, POGO suppression device, compliance, propulsion frequency

Indian Journal of Cryogenics doi: 10.5958/2349-2120.2021.00006.6 *Vol. 46, 2021*

Composite cryo tank development- ISRO initiatives

Sandeep Kumar, Basil Eldhose and Prasanna G.*

Composites Entity, Vikram Sarabhai Space Centre, ISRO, Thiruvananthapuram
E-mail ID: prasang@gmail.com

Composite tanks are light weight and cost effective. Attempts have been made elsewhere, to extend composites for cryogenic tank realization, without employing any additional liner. A technological paradigm shift is required to achieve linerless composite cryo tanks, which includes use of high elongation toughened epoxy system, Out-of-Autoclave curing prepreg system, skirt technology for leak venting, automated fiber placement process for laminated shell surface construction, thin-ply technology for leak tightness, in-situ and embedded health monitoring for continuous health tracking, in-situ NDE technique for inter-layer verification during processing etc. As an initial step, the team has attempted to understand and prove the need for a high elongation resin system, its efficacy at cryo temperatures and its processability to realize filament wound systems. The feasibility of progress in this route has been validated by means of studies conducted in specimen- level trials followed by sub-scale studies.

Key words: CFRP, LH_2 tank, LOX tank, Permeability, Cryo tank, Toughened epoxy system

Indian Journal of Cryogenics doi: 10.5958/2349-2120.2021.00007.8 *Vol. 46, 2021*

Experimental investigation of cavitation inside a plain orifice injector

Vikash Kumar[1]*, Vaisakh S. Nair[2], T. John Tharakan[1] and Abhilash Suryan[2]

[1]Propulsion Research Group, Liquid Propulsion Systems Centre, Trivandrum, India
[2]Department of Mechanical Engineering, College of Engineering, Trivandrum, India
E-mail ID: vikashkumar@lpsc.gov.in

Injector elements having narrow flow passages are more susceptible to cavitation. It is important to understand cavitation phenomena occurring inside the injector flow passage as it can lead to fluctuation in propellant flow rate in the combustion chamber. The focus of the present work is to investigate the cavitation phenomena occurring inside the nozzle, their interaction with the internal flow and the characteristics of the external flow. Different injector elements of varying length to diameter (L/D) ratios were designed and realized. Experiments were conducted at different flow regimes to capture the various modes of cavitation occurring inside the injector element. A high speed camera was used to investigate the internal and external flow behavior. As the length and diameter increases, the injection pressure required to initiate cavitation increases. The cavitation regime extends throughout the injector length as pressure varies. The optimum cavitation number observed was found to be optimum in the range of 1.5 to 2.0.

Key words: cavitation, injector, L/D ratio, cavitation number, spray angle

Indian Journal of Cryogenics doi: 10.5958/2349-2120.2021.00008.X *Vol. 46, 2021*

Evaluation of temperature profile of a cryogenic engine igniter body during engine operation and coasting phase prior to engine restart

Siju K. Mathew, Dr. K. S. Bijukumar, A. P. Baiju, N. Jayan and G. Nageswaran

Liquid Propulsion Systems Center, Indian Space Research Organization,
Valiamala, Thiruvananthapuram
E-mail ID: sijukmathew@lpsc.gov.in

Combustion of propellants (liquid oxygen and liquid hydrogen) in the combustion chamber is initiated by an igniter cartridge using a pyrogenic ignition source in cryogenic engines of ISRO. In order to launch multiple satellites in different orbits in a single mission, it is required to re-start the engine. The evaluation of the thermal profile of the igniter is necessary to simulate the thermal environment of the igniter at the time of re-start. The evaluation of the thermal profile of two options of ignition device configured for engine re-start is studied. Transient heat transfer models were generated for two options considered. The model was validated using measured data of ground test for a typical cryogenic engine. The transient heat transfer environment of the igniter during engine operation and coasting phase was simulated. The thermal environment for qualification of the igniter for both the options was evaluated from the simulation results.

Key words: Cryogenic Engine, Igniter, Restart, Transient thermal simulation

Indian Journal of Cryogenics doi: 10.5958/2349-2120.2021.00009.1 *Vol. 46, 2021*

Design and realization of thrust measurement system for high altitude testing of cryogenic rocket engine

Cross Sapna A., D. Gayathri Devi, S. Rajapandian and L. Louis Sam Titus

Automation and Instrumentation Systems Entity, ISRO Propulsion Complex, Mahendragiri-627133
E-mail ID: cross.sapna@iprc.gov.in

In order to launch a heavier payload and to place a satellite into the planned orbit correctly, it is necessary to get the exact evaluation of the engine performance. It is important in the developmental testing of rockets to determine the effect of nozzle design, fuel/propellant mixtures, additives and changing other parameters of the engine system on performance. In order to better simulate the rocket engine operating environment, high altitude testing of cryogenic engine is necessary before flying. The most important parameters required to evaluate a rocket engine performance are thrust and rate of propellant consumption. In this work, a thrust measurement system was designed to measure the propulsion performance of a cryogenic rocket engine. The design, selection, realization, in-place calibration, usage and test results are presented.

Key words: Load cell, Thrust measurement, Measurement chain, In-situ calibration

Indian Journal of Cryogenics doi: 10.5958/2349-2120.2021.00010.8 *Vol. 46, 2021*

CFD analysis of stratification during draining of a sub-scaled liquid hydrogen tank

Rajat Kumar Bhuyan[1]*, Deepak Kumar Agarwal[2] and Sunil Kumar Sarangi[3]

[1]Indian Space Research Organisation, VSSC; Trivandrum, Kerala - 695522
[2]Indian Space Research Organisation, LPSC Trivandrum, Kerala - 695547
[3]C. V. Raman College of Engineering Bhubaneswar, Odisha - 752054
E-mail ID: rajatbhuyan@gmail.com

Thermal stratification occurring inside a cryogenic flight tank leads to failure in meeting the NPSH requirement of the pumps and thus affects smooth operation of onboard turbo machinery, particularly towards the end of a mission, resulting in a large residual quantity of propellants. Therefore, understanding the phenomenon of stratification is an important aspect of launch vehicle design. Towards this, analysis has been done on a sub-scaled liquid hydrogen tank simulating stratification in a low heat in-leak environment. Computational Fluid Dynamics (CFD) has been applied for understanding the liquid dynamics of the process over a sufficiently long duration. The model utilizes a two-dimensional axisymmetric approach along with the volume of fluid (VOF) scheme to simulate the liquid vapour interface. The effect of stratification on propellant draining has been analysed for two different intake systems, with and without a propellant intake device (PID), and the corresponding residual quantities verified. The analysis confirmed that with a PID, the residual propellant quantity can be minimized.

Key words: Stratification, Buoyancy, Heat transfer, Liquid hydrogen, Fuel acquisition system

Indian Journal of Cryogenics doi: 10.5958/2349-2120.2021.00011.X *Vol. 46, 2021*

Studies on premoulded pad for cryo insulation

Nikhil P. S., Monisha K, V. Unnikrishnan, Remya Balakrishnan, A. Suresh Kumar, A. M. Nallaperumal

Propellants, Polymers, Chemicals and Materials Entity,
Vikram Sarabhai Space Centre, Thiruvananthapuram-695022
E-mail ID: nikhil@vssc.gov.in

A premoulded pad of PUIR foam of required thickness can be moulded and bonded on a cryo tank with suitable adhesive. When compared to spray foaming, defect control and density control is possible in this technique as any defective or high density pads can be rejected at the source itself. Initially pads were moulded in metallic moulds. Thermo mechanical testing was carried out on the premoulded foam and cryo requirement is met. However, there was a variation in the density in the skin and core of the pad, leading to the peeling off of the first layers during the aerothermal test. Later moulding of a foam block and slicing it into foam pads was envisaged as an effective method for obtaining uniform density pads. The thermo mechanical properties meet the specifications. The pad also passed an aerothermal test simulating the launch condition.

Key words: Cryo insulation, PUIR foam, Premoulded pad

Passive recirculation system for eliminating geysering in liquid oxygen feed system of cryogenic propulsion stage

Saurabh K. Joy, Rijin K. V., M. Xavier

Cryo Propulsion Engine and Stages entity, Liquid Propulsion Systems Centre, ISRO, Thiruvananthapuram
E-mail ID: saurabhkjoy@gmail.com

In cryogenic and semi-cryogenic propulsion stages, liquid oxygen (LOX) is often used as the oxidizer. LOX is supplied to the engine for combustion through stage feedlines. A stagnant column of LOX is likely to be present in some portion of the feedline before engine start. Heat in leak from ambient will cause boiling and bubble formation near the feedline walls. Excessive boiling and bubble formation can lead to geysering in the feedline, resulting in high pressure surges inside feedline components. Geysering in cryogenic feedlines can be avoided by maintaining a continuous downward flow of LOX through the feedline. This paper discusses prevention of geysering in cryogenic feedlines using passive external recirculation based on the thermo-syphon effect.

Key words: Geysering, Pressure surge, Thermo-syphon

Indian Journal of Cryogenics doi: 10.5958/2349-2120.2021.00013.3 *Vol. 46, 2021*

Numerical prediction of nozzle behavior of the CE-20 engine for developing a nozzle protection system (NPS) for testing at sea level

S. Behal[1], P.S. Virdi[1], M. Kumar[1], A. S. Ramasubramanian[2], T. K. Nandi[1]

[1]Cryogenic Engineering Centre, IIT Kharagpur, [2]ISRO Propulsion Complex, IPRC
E-mail ID: sidbehal24@gmail.com

Overexpansion in a high area ratio rocket nozzle causes fluid pressure in the divergent part of the nozzle to drop below the ambient pressure. This leads to flow separation with formation of oblique shock waves. In this paper we present numerical investigations on the sea level performance of the cryogenic engine nozzle having an area ratio of 100. The modelling is done on a 2D axisymmetric plane using Ansys FluentTM (version 19.2). Meshing is done in ICEM CFD with closely spaced meshes near the throat and the nozzle wall for capturing the flow phenomena more closely and accurately in these areas. A density based K-ω SST model is used. Both free shock separation (FSS) and restricted shock separation (RSS) are detected for varying pressure ratios. Wall pressure is observed to reach higher peaks for RSS in comparison with FSS. Also, the nozzle is subjected to maximum thermal loading for RSS.

Key words: Overexpansion, Shock separation, Pressure distribution, Nozzle protection system

Indian Journal of Cryogenics doi:10.5958/2349-2120.2021.00014.5 *Vol. 46, 2021*

Development and validation of a numerical model to investigate sloshing phenomena with baffles

Atharv Kotwal, Ankita Pai B.H., Aditya Raman and M.D. Atrey

Refrigeration & Cryogenics Laboratory,Department of Mechanical Engineering,
Indian Institute of Technology – Bombay, Mumbai
E-mail ID: matrey@iitb.ac.in

In this paper a Computational Fluid Dynamics (CFD) model is developed to study the dynamics associated with liquid sloshing inside storage vessels. The forces and moments acting on the container walls are analyzed, and the effect of force mitigation of baffles is studied. The numerical model developed is validated against the results published in literature. The model is also useful for the analysis of forces and moments acting on the wall of cryogenics vessels used in propulsion systems.

Key words: CFD, Sloshing, Baffle Design, OpenFoam

Indian Journal of Cryogenics doi: 10.5958/2349-2120.2021.00015.7 *Vol. 46, 2021*

Real-time communication for ground testing of cryogenic engines and stages of Indian space missions

Poofa Gopalan, D. Gayatri Devi and S. Rajapandian

ISRO Propulsion Complex, Mahendragiri
E-mail ID: poofa.gopalan@iprc.gov.in

The method of implementation of EtherCAT Automation Protocol (EAP) for real-time communication between the control system and the data acquisition system in cryogenic test facilities is discussed here. The different data transfer modes, the frame structure etc. are highlighted. The performance of EtherCAT communication is evaluated and the results are presented. Publisher-Subscriber communication mode is configured for the communication between the control system and data acquisition system. It is found that the transfer of 1024 byte data from data acquisition system to the control system can be realized every 10ms by defining an EAP stack in both the controllers.

Key words: EtherCAT Automation Protocol, real-time, communication, data transfer

Indian Journal of Cryogenics doi: 10.5958/2349-2120.2021.00016.9 *Vol. 46, 2021*

Thermal design and analysis of 70 K octagonal passive radiant cooler

Subrahmanya*, Jaikumar V, Tanneru Sai Goutam and D. W. Tijare

Thermal Systems Group, U R Rao Satellite Centre, Bengaluru, India
E-mail ID: sbhat@ursc.gov.in

Over the years, advancement in meteorological payloads has led to the increase in detector spectral range from short wave infrared to long wave infrared bands. As the detector spectral range coverage increases, they require lower detector temperatures, which makes heat rejection increasingly difficult. Enhancing the cooler performance requires reducing the cooler internal parasitic as well as the external environmental heat loads while constraining the passive cooler field of view to space. Efforts have been made to achieve lower temperature with improved design and considerable reduction in mass of the cooler. This paper presents the thermal design and analysis of a three stage octagonal passive radiant cooler used to attain a temperature less than 70 K with 18 mW detector dissipation which is the typical heat load for line detectors in geo-imaging missions.

Key words: Radiant cooler, Cryogenics, Heat transfer, Thermal analysis, Meteorological payload

Indian Journal of Cryogenics doi: 10.5958/2349-2120.2021.00017.0 *Vol. 46, 2021*

Investigation of transfer line cool-down transients using equilibrium two-phase models

Keerthi Raj Kunniyoor [1]*, Rahul Govind[2], K. S. Venkateswaran[2] and Parthasarathi Ghosh[1]

[1]Cryogenic Engineering Centre, Indian Institute of Technology Kharagpur - 721302, India
[2]ISRO Propulsion Complex (IPRC), Mahendragiri, Tamil Nadu- 627133, India
E-mail ID: keerthirajkunniyoor@iitkgp.ac.in

Optimization of the transfer line cool-down process is essential for propellant loading as well as thermal management in space flights. Hence, selection of an appropriate numerical model for the investigation of the same has significant industrial application. So, in this work, the predictability of cool-down transients by homogeneous and slip flow models are studied by simulating experimental work reported in the literature. By investigating the thermal and pressure transients in the wall material and fluid flow path respectively, the predictive capability of the above models is discussed in detail.

Key words: Cryogenic transfer line, Cool-down, Homogeneous model, Slip flow model, SINDA/FLUINT, Two-phase flow

Qualification of onboard software for cryogenic stages

Kurian John[1]*, Jayanthy V.[2], Gopalakrishnan T.[3] and Valsa B.[4]

[1-4]Systems Reliability Entity, Vikram Sarabhai Space Centre, Thiruvananthapuram
E-mail ID: kurian_john@vssc.gov.in

The software which resides in onboard computers of ISRO's satellite launch vehicles is mission critical. Onboard software needs to perform its functional requirements under various operational conditions that may be encountered during the operation of a launch vehicle. Any error in such software may lead to catastrophic failures, which is not acceptable in a mission critical application like launch vehicle onboard software. Of the various launch vehicle onboard software elements, control software for cryogenic stages is the most complex due to stringent timing requirements and hardware interface requirements. A software is developed in adherence to process laid down in ISRO software process document.

As part of qualifying the software for cryogenic stages, the software is subjected to meticulous and a series of well-defined quality assurance (QA) and independent verification and validation (IV&V) processes. The typical IV&V activities span through the entire life cycle commencing from requirements, design, implementation and testing and includes requirements and design review, static analysis, code inspection, software tests and closed-loop simulations.

In addition to the IV&V activities, Quality Audits are carried out to ensure end-to-end traceability of requirements and compliance to established development processes and review recommendations. This paper examines the QA & IV&V techniques followed for qualification of onboard software for cryogenic stages, highlighting typical observations and improvements done thereafter.

Key words: Onboard Software, Quality Assurance, IV&V

Indian Journal of Cryogenics doi: 10.5958/2349-2120.2021.00019.4 *Vol. 46, 2021*

Analysis of rocket propulsion test data using multi-sensor data fusion technique

Mallappa*[1], S. Ramesh[2], D. G. Chandra[2], A. Rajan[3], and T. K. Nandi[1]

[1]Cryogenic Engineering Centre, IIT Kharagpur
[2]ISRO Propulsion Complex (IPRC), ISRO, Mahendragiri
[3]Liquid Propulsion System Centre (LPSC), ISRO, Valiamala, Thiruvananthapuram
E-mail ID: jabademallappabidar@gmail.com

Multi-sensor data fusion is a technique that combines data from multiple sources (sensors) to extract unique features which cannot be achieved from a single sensor. The data fusion technique is widely used in areas like sensor networks, video and image processing, robotics, intelligent system design, and many such diverse applications, to name a few. In this paper, we present a method of analyzing test data of a liquid rocket engine using the data fusion technique. A deep neural network, machine learning-based algorithm LSTM- RNN, is used for the analysis. The available sample test data from ISRO is used for the analysis. One can also predict the engine performance under operating conditions for which the test data are not available. The dynamic behavior of the engine can also be predicted through the proposed data fusion technique. The proposed method is developed in a generalized form so that it can be used for any liquid rocket engine

Key words*:* Deep neural networks, Multi-sensor data fusion, Rocket engine performance, Subsystems

Numerical analysis of fluid transient during ground testing of Cryogenic propellant feed system

Bhuvana R. G.[1], Parthasarathi Ghosh[2] and Ganesh P.[3]

[1]Cryogenic Engineering Centre, IIT Kharagpur, West Bengal 721302
[2]Cryogenic Engineering Centre, IIT Kharagpur, West Bengal 721302
[3]IPRC Mahendragiri, Tamil Nadu 627133
E-mail ID: bhuvanakabd@gmail.com

The fluid transient occurring in the cryogenic propellant feed system of the liquid propellant rocket engine during ground testing is considered. The valve characteristics and flow control strategy is observed to play a vital role in minimising the effect of the fluid transient in the pipeline and other equipment associated with the system. A one-dimensional numerical model is developed based on the finite volume method and the model is validated with the literature. The model is used to simulate the propellant feed system used during ground testing and to analyse the effect of various valve parameters on the fluid transient. Different valve parameters like closing characteristics, rangeability, and response time are modified and analysed. Valve sequencing of multiple valves present in the system is also performed. The results of different simulations performed were investigated and suggestions for selecting the suitable valve parameter for minimizing the fluid transient pressure are provided.

Key words: Valve, Cryogenic, Fluid Transient, Finite volume method, liquid rocket engine

Indian Journal of Cryogenics doi: 10.5958/2349-2120.2021.00021.2 *Vol. 46, 2021*

Cold flow testing and CFD analysis of screw pump for LOX pump of semi-cryogenic engine

Sanand T. V.[1], Deepak Dinesh, Harikumar K. and Unnikrishnan Nair P.

Liquid Propulsion Systems Centre, ISRO
E-mail ID: [1]sanandtv@gmail.com

The LOX (Liquid Oxygen) pump of a semi-cryogenic engine has an axially locked bearing cooled by LOX tapped from pump inlet. The required LOX flow rate through the bearing is ensured by a screw pump located just before the bearing. The screw pump assembly consists of helical grooves cut on the pump shaft and a bush sleeve. The baseline configuration of the screw pump has 6 helical starts and a plain bush. Test were carried out to study the effect of number of screws starts, helical grooves on the bush etc. on the pressure rise across the screw pump (4 configurations). CFD analysis was also carried out for the test setup and the results compared very well with the test data. A grid independence study for the CFD was done. CFD analysis was also carried out for 2 additional configurations with change in radial clearance between the screw and the bush.

Key words: Screw pump, LOX pump, Semi-cryogenic engine

Indian Journal of Cryogenics doi: 10.5958/2349-2120.2021.00022.4 *Vol. 46, 2021*

Development of a numerical model to predict self-pressurization and thermal stratification in a cryogenic storage vessel

Vishnu S.B.[1] and Biju T. Kuzhiveli

Centre for Advanced Studies in Cryogenics, National Institute of Technology Calicut, India- 673601
E-mail ID: [1]vishnusb90@gmail.com

Thermal stratification in cryogenic storage containers and launch vehicle propellant tanks is an important design consideration because of its direct influence on tank pressure rise and turbo pump cavitation. The rate of self-pressurization in a liquid oxygen cryogenic container is predicted using a CFD model. The Lee phase change model is used to calculate evaporation and condensation, and the volume of fluid approach is utilised to forecast the movement of the liquid-vapor interface. The results were validated by experiments conducted at the cryogenic test facility, NITC. Analyses are carried out to determine the effect of tank radius on the evolution of stratification. The aspect ratio of the tank with radius R and the liquid filling height H is established. Three alternative aspect ratios are chosen to study the influence of tank radius. It is found that cryogenic tanks with smaller aspect ratio (H/R) require more time to fully stratify and have a lower self-pressurization rate.

Key words: Thermal stratification; Self-pressurization; Liquid oxygen; CFD

Design and experimental validation of a high flow rate pyrogen igniter for cryogenic engine testing

Sreekanth K., Priyanka Shukla, Resmi R. and Vinod Kumar N.

Vikram Sarabhai Space Centre, Thiruvananthapuram-695022
E-mail ID: sreekanthk4u@gmail.com

Ignition is an important design consideration for all types of non-hypergolic propellant combinations used in rocket engines. Among the two proven ignition concepts, a generally classified under chemical or electrical categories, a conventional approach of a solid propellant-based pyrogen igniter has been successfully applied in ISRO cryogenic (LOX/ LH2) engines. Towards development of a new cryogenic engine, a "work-horse" igniter was selected from an ongoing programme for thrust chamber and gas generator ignition.

For this engine, to reduce the development cycle time, a ground test campaign of the thrust chamber was formulated using the facility pressure head in contrast to the pump-fed flight engine. This presented a difference in ignition conditions and a new igniter with a higher mass flow rate compared to the flight igniter was developed as a fall-back option. This igniter incorporated a HTPB based propellant grain triggered using electrical initiators. After detailed analysis, the system was realised and igniter hot-fire tests were carried out to confirm adequacy. This paper presents the igniter design methodology, ballistic parameters and details of the development programme.

Key words: Pyrogen igniter, LOX-LH2, Cryogenic, Flow rate

Indian Journal of Cryogenics doi: 10.5958/2349-2120.2021.00024.8 *Vol. 46, 2021*

Primary jet breakup dynamics in a coaxial air blast atomizer: Effect of nozzle geometry and air swirl on jet instabilities and atomization

Abhijeet Kumar[1] and Srikrishna Sahu[2]

[1]Institute of Fluid Mechanics and Thermodynamics,
Otto von Guericke University, Magdeburg, Germany
[2]Thermodynamics and Combustion Engineering Lab,
Department of Mechanical Engineering, I.I.T. Madras, Chennai, India
E-mail ID: [1]abhijeetkumar238@gmail.com

Understanding the influence of nozzle geometry and swirling air on the liquid jet breakup length and various instabilities during the primary breakup process of the liquid jet in a coaxial airblast atomizer is the aim of this paper. Experiments were performed in three different nozzle geometries for a wide range of air and liquid flow rates both in the presence and absence of air swirl (swirl number, S = 0 and 0.8 respectively). High-speed shadowgraphic visualization of the liquid jet core is done near the nozzle exit. The mean jet breakup length showed a weak dependence on nozzle geometry. The amplitude and frequency corresponding to Kelvin-Helmholtz instability and flapping instability were measured by tracking the temporal variation of the liquid-air interface near the nozzle exit and near the breakup point respectively. The nozzle geometry was found to strongly influence the jet instabilities. The presence of swirling air enhances the atomization process such that the mean breakup length reduces and the amplitude and frequency corresponding to different jet instabilities are increased.

Key words: coaxial atomizer, breakup length, flapping, nozzle geometry, swirl

Indian Journal of Cryogenics doi: 10.5958/2349-2120.2021.00025.X *Vol. 46, 2021*

Vibration and speed envelope analysis of cryogenic pumps induced during cavitation

R.P. Uma Dhevi[1], E. Ezhilrajan and S. Rajapandian

ISRO Propulsion Complex, ISRO, Mahendragiri
E-mail ID: umaisro@gmail.com

Cavitation is the undesirable phenomenon that has to be avoided in cryogenic pumps for any successful launch. It is very essential to study the effect of cavitation on cryogenic pumps at various process conditions a priori to ensure a successful flight. The objective of this paper is to analyze the cavitation inception, its intensification and several instabilities induced during cavitation. The ground level testing with varied conditions of flow rate and speed using actual propellants (LH_2 and LOX) were carried to investigate the vibration and speed characteristics. The speed and vibration levels has increased significantly from that of rated speed during cavitation inception. Significant broadband pump vibration frequency of 2 kHz to 10 kHz is observed during cavitation. High frequency signals are also noticed which are more sensitive at the start of cavitation. The results were used for predicting the sufficient margins (critical NPSH) required for the cryogenic tanks during flight.

Key words: Cryogenic, Accelerometers, Speed, Cavitation

Indian Journal of Cryogenics doi: 10.5958/2349-2120.2021.00026.1 *Vol. 46, 2021*

Influence of aspect ratio and fill: Level on the thermal de-stratification in an upright cylindrical tank subjected to lateral sloshing motion

Aditya Raman, Ankita Pai B H and [1]M. D. Atrey

Refrigeration & Cryogenics Laboratory, Department of Mechanical Engineering,
Indian Institute of Technology – Bombay, Mumbai
E-mail ID: matrey@iitb.ac.in

In this paper, a Computational Fluid Dynamics (CFD) model is used to analyze the thermal de-stratification process in a self-pressurized, upright cylindrical tank, half filled with liquid nitrogen. The aspect ratio (H/D) of the cylindrical tank is parametrically varied from 1 to 4 to study the effects of the geometrical dimensions on the thermal de-stratification. Different liquid fill levels (50% & 25% of container height) are also considered to assess the influence of the cryogenic liquid level on the de-stratification process. A kinetics-based Schrage mass transfer model was used to model the interfacial mass transfer due to condensation and evaporation.

Key words: CFD, cryogenics, sloshing, stratification, Open FOAM

Indian Journal of Cryogenics doi: 10.5958/2349-2120.2021.00027.3 *Vol. 46, 2021*

Sensitivity studies on the effect of axial clearances on the turbine efficiency

Sanand T.V.[1], Deepak Dinesh, Harikumar K. and Unnikrishnan Nair P.

Liquid Propulsion Systems Centre, ISRO
E-mail ID: sanandtv@gmail.com

Small values of clearances between the rotating and stationary elements of high speed turbomachinery involve a potential risk of rubbing. This occurs under the combined action of pressure, thermal and centrifugal loading and can lead to a system failure. It is preferable to keep the clearances on the higher side in order to avoid such risks without compromising the performance of the hardware. An experimental study was taken up to investigate the influence of the axial gaps between the stationary and rotating elements of a liquid rocket engine axial turbine on its performance. A subsonic, two row, axial flow turbine was used for the study. A turbine with provision for varying the axial gaps between the rotor and stator were realized. Tests were done with gaseous nitrogen as the medium and a dynamometer was used tor control the turbine speed as well as to absorb the power generated by the turbine. The axial gap between the stationary and rotating elements was varied from 1.4 mm to 3.5mm. For a given test, the gap was kept constant at the selected value and the test speed was varied from 70% to 130% of the nominal value. The overall efficiency of the turbine was evaluated and was used for comparison of turbine performance. At each value of the axial clearance, two tests were carried out to confirm the results. It is observed that there is no significant loss of performance due to the increase in the axial clearance within this range. The highest value of the axial clearance is preferred as it involves least risk of rubbing without any loss of performance.

Key words: Axial clearances, turbine efficiency

Indian Journal of Cryogenics doi: 10.5958/2349-2120.2021.00028.5 *Vol. 46, 2021*

Criticalities in high pressure cryogenic test facilities

A.S. Ramasubramanian[1], S. Antony Manicka Raja and V. Michael Packiaraja

Thrust Chamber Test Facility, ISRO Propulsion Complex, Mahendragiri
E-mail ID: s_rama@iprc.gov.in

An indigenously developed cryogenic engine using Liquid Oxygen (LOX) and Liquid Hydrogen (LH2) as propellants powers the upper stage of the Indian launch vehicle. The engine works on the gas generator cycle which aid in the modular development of the engine, wherein, individual subsystems were developed and tested independently. The thrust chamber had to be tested in the standalone pressure fed mode, without the turbopumps, to qualify it at nominal and off nominal conditions. In this regard, a unique facility, the Thrust Chamber Test facility, was realized at ISRO Propulsion Complex, Mahendragiri. During the realization and commissioning of the facility and testing of the thrust chamber, certain challenges were encountered. Approaches adopted to overcome the challenges posed by chill down of high-pressure cryogenic tanks, chill down of high-pressure cryogenic fluid transfer superinsulated pipelines, rapid pressurisation requirement of the test article and selection of flow components for high pressure applications are detailed in this paper.

Key words: Cryogenic tank, Superinsulation, Chill down, Annular flow Pressurisation

Indian Journal of Cryogenics doi: 10.5958/2349-2120.2021.00029.7 *Vol. 46, 2021*

Liquid nitrogen storage and distribution system for 6.5-meter large thermal vacuum chamber-LTVC

Pawan Kumar*, B. Gorai and V. Poonia

Thermal Vacuum Test Systems Division, Space Applications Center, ISRO, Ahmedabad – 380058
*E-mail ID: *pawankumar@sac.isro.gov.in*

Cryogenic systems have been playing a significant role in space simulation and thermal vacuum testing of satellite payloads and sub-systems. Usually liquid nitrogen (LN_2) is a preferred fluid for space simulation systems. This is due to its various favourable operating characteristics like- very low temperature to liquefaction, wide temperature range, inert non-reacting nature, large latent heat of evaporation, abundance, availability and low cost of usage. Space Applications Centre (SAC) has established a 6.5m diameter Large Thermal Vacuum Chamber-LTVC facility to cater to the need for integrated payload level thermal vacuum tests. One of the critical sub-systems is LN_2 storage and its distribution system. LN_2 (approx. 4,00,000 litres) is stored in storage tanks (1,34,000 litres each). The Liquid Nitrogen and GN_2 distribution system consist of vacuum jacketed SI cryogenic lines of different sizes (1/2" to 4" sized- approximately 2000m) which are spread across the facility, connecting various thermal and vacuum systems. This paper presents the system configuration, manufacturing/ fabrication, testing of LN_2 storage and distribution systems.

Key words: LN_2 tanks, Thermal vacuum, Cryogenic, GN_2, Vacuum Jacket, Super Insulation

Indian Journal of Cryogenics doi: 10.5958/2349-2120.2021.00030.3 *Vol. 46, 2021*

Instrumentation design considerations for automatic ground testing of rocket engines

A. Siva Vasanth[1], J. Stalin and A. Benzigar Rajan

[1]Automation Instrumentation System Entity,ISRO Propulsion Complex, Mahendragiri
E-mail ID: [1]asivavasanth@gmail.com

Ground testing (qualification and acceptance) testing of integrated rocket engine (thrust chamber, turbopumps, gas generators, steering engines etc.) is mandatory before actual launch. Since the rocket engine operates with hazardous cryogenic fluid, handling and disposing is also critical tasks. Above all, the safety of test stand, working personnel, Test article Under Test (TUT) and environmental safety is paramount importance. The instrumentation system for testing a rocket engine consists of a programmable automation controller(PAC) based control system, sensors, signal conditioning system, field actuators, network system, data storage as well as retrieval and archiving system. The main challenges in designing the instrumentation systems are availability of the system, real time software, fast reaction time, high bandwidth data and statuary safety requirements. This paper addresses some key issues with respect to design of the instrumentation system requirement for ground testing of rocket engine adhering to standards such as IEC61499(Distributed Industrial Automation System), IEC61131-3(Programming Language) and IEC61508(Standard for Functional Safety).

Key words: Transmitters, Transducers, Field actuators, Control System, Solenoid Valve

CONTENTS

CRYOGENIC INSTRUMENTATION

New United Process, New Delhi 110028; Mob.: 9811426024