Łukasiewicz
Institute of Aviation

XIII International Scientific Conference on:
DEVELOPMENT TRENDS IN SPACE PROPULSION SYSTEMS

Abstracts

Presenting author	Abstract title	Company
	Keynote's	
Michael Gozin	Janus-type Hypergolic Fuels for Hybrid Systems Using H2O2 and HAN-based Oxidizer	Tel Aviv University
Maurizio Natali	State of the art of high temperature materials for rocket motors: a review	University of Perugia
	Session 1: Propulsion testing and modeling	
Justin Hardi	Overview of Cryogenic Propulsion Components Tests at the DLR M3 Infrastructure	German Aerospace Center (DLR)
Michał Zieliński	The commissioning of the high-altitude test facility for space rocket propulsion	Łukasiewicz- Institute of Aviation
Michał Kret	Challenges in developing students' remote test stand for rocket propulsion system	Warsaw University of Technology
Jiri Kozak	Dynamics of E-pumps Developed for the RELIANCE Rocket Engine	Inpraise Systems s.r.o.
Hernan Amaya	The influence of flash-boiling conditions on droplets from impinging-jet spray	Warsaw University of Technology
Rohit Thokala	Effect of flash-boiling on spray-wall interaction under low-pressure injection	Warsaw University of Technology
Tobiasz Mayer	Overview of Rocket Propulsion Test Activities at Łukasiewicz – Institute of Aviation	Łukasiewicz - Institute of Aviation
Krzysztof Matysek	Throttleable Liquid Propulsion Demonstrator Simulation	Łukasiewicz - Institute of Aviation
	Session 2: Solid and Hybrid Propulsion	
Michał Tomporowski	3D printing as a viable method of inhibiting solid propellant grains	Warsaw University of Technology

Adam Matusiewicz	Green Flip Control System – a hybrid propulsion solution for rotating a launcher's first stage	SpaceForest
Bartosz Hyży	Hybrid rocket motors' development in Students' Space Association	Warsaw University of Technology
Session 3: Green Propulsion		
Christoph Kirchberger	Green Propellant Research at DLR Lampoldshausen	German Aerospace Center (DLR)
Paweł Surmacz	GRACE Development Programme: A Green Engine for Future Spacecraft and Space Transportation	Łukasiewicz - Institute of Aviation
Konrad Wojciechowski	Engine Control Unit for a Green Microsatellite Propulsion System	Łukasiewicz - Institute of Aviation
Dawid Cieśliński	Demonstration of deep throttling with green storable propellants – a step towards future flexible space propulsion	Łukasiewicz - Institute of Aviation
Session 4: Future propulsion systems		
Michał Kawalec	Detonative Propulsion Research	Łukasiewicz- Institute of Aviation
Puneeth Bheesetty	Water Electrolysis Propulsion for Spacecraft: A Comprehensive Review and Status	Warsaw University of Technology
Maciej Jakubczak	Electric propulsion activities in IFPiLM	Instytut Fizyki Plazmy i Laserowej Mikrosyntezy

Łukasiewicz
Institute of Aviation

XIII International Scientific Conference on:
DEVELOPMENT TRENDS IN SPACE PROPULSION SYSTEMS

JANUS-TYPE HYPERGOLIC FUELS FOR HYBRID SYSTEMS USING H_2O_2 AND HAN-BASED OXIDIZERS

Keynote 1, day 1

Natan Petrutik [ab], Ilia Kaminker [a], Eli Flaxer [c], Daniel Shem-Tov [a], Tsabar Giladi [b], Yossi Bar-Bechor [b], Jagadish Das [a], and Michael Gozin [ade]

[a] School of Chemistry, Faculty of Exact Sciences, Tel Aviv University, Tel Aviv 69978, Israel.

[b] Department of Chemistry, Soreq Nuclear Research Center, Yavne 81800, Israel.

[c] Afeka, Tel-Aviv Academic College of Engineering, 218 Bney Efrayim Rd., Tel-Aviv 69107, Israel.

[d] Center for Nanoscience and Nanotechnology, Tel Aviv University, Tel Aviv 69978, Israel.

[e] Center for Advanced Combustion Science, Tel Aviv University, Tel Aviv 69978, Israel.

cogozin@gmail.com

Abstract

Development of fully green hybrid propulsion systems, in which both the oxidizer and the fuel are environmentally benign, while having a desirable performance under in-space conditions, is a formidable challenge. New air-stable solid propellants capable of exhibiting hypergolic ignitions with H2O2 and its low -freezing formulation containing hydroxylammonium nitrate (HAN) will be presented. A top performing Janus -type fuel 15 showed remarkable ignition delay time of 4 ms with HAN-H2O2 formulation, even at −40°C. The Janus-type design approach allowed modulation of the ignition delay times by varying the carbon chain-length, the type of the used transition metals and the molecular structure of the resulted solid fuels. Studies of HAN and related salts formulations with H2O2 allowed us to get an insight into the reasons for the stability of HAN-H2O2 formulations. UV-vis and EPR monitoring of selected fuels reactions with oxidizers, as well as surface wettability measurements, provided a valuable information related to the better understanding of the hypergolic reaction mechanisms, which should contribute to the design of the next generation of green hypergolic propulsion systems. Fuel 15 was successfully tested in a custom-made small-scale static hybrid motor system.

Łukasiewicz
Institute of Aviation

XIII International Scientific Conference on:
DEVELOPMENT TRENDS IN SPACE PROPULSION SYSTEMS

STATE-OF-THE-ART OF HIGH TEMPERATURE MATERIALS FOR ROCKET MOTORS: A REVIEW

Keynote 2, day 2

Maurizio Natali*, Luigi Torre*, Michele Buconi*, and Marco Rallini*

*Civil and Environmental Engineering Department, University of Perugia, Strada di Pentima 4, 05100 Terni, Italy

maurizio.natali@unipg.it, luigi.torre@unipg.it, michele.buconi@dottorandi.unipg.it, marco.rallini@unipg.it

Abstract

During last decades, high temperature materials have been introduced and optimized for different applications in rocketry and space flight. These materials are used to manufacture liquid-propellant rocket engines, Solid Rocket Motors (SRMs) and, more recently, Hybrid Rocket Motors (HRMs). They are also used to manufacture the heat shields which protect probes and space vehicles during the hypersonic flight (also known as re-entry) through a planetary atmosphere. Among TPS materials, Polymeric Ablative Materials (PAMs) possess the widest flexibility in terms of properties tunability. Carbon/Phenolic Composites (CPCs) have shown the ability to resist heat fluxes up to 30,000 W/cm^2 (when used to produce heat shields of re-entry vehicles) and have been used to produce many parts of SRM nozzle assemblies. Carbon/Carbon Composites (CCCs) - which directly derive from CPCs - are preferred in the portion of the motor where the erosive phenomena are more severe, such as in the throat region. The aim of this contribution is to provide a modern survey of the state-of-the-art of high temperature materials for rocket motors, also covering the criticalities related to the supply chain of the raw materials.

Keywords: Thermal Protection System (TPS); solid rocket motors (SRMs); carbon/phenolic composites (CPCs); CCCs.

Łukasiewicz
Institute of Aviation

XIII International Scientific Conference on:
DEVELOPMENT TRENDS IN SPACE PROPULSION SYSTEMS

OVERWIEW OF CRYOGECIC PROPULSION COMPONENTS TESTS AT THE DLR M3 INFRASTRUCTURE

Session 1: Propulsion testing and modeling, presentation number 1

Michael BOERNER[1], Wolfgang ARMBRUSTER[1], Alexander BEE[1], Tobias TRAUDT[1], Sebastian KLEIN[1], Justin HARDI[1]

[1]*Institute of Space Propulsion, German Aerospace Center (DLR), Hardthausen, Germany*

michael.boerner@dlr.de,

Abstract

For over three decades, the M3 testing facility, located at the DLR Institute of Space Propulsion in Lampoldshausen, Germany, has been dedicated to research and technological advancements in cryogenic rocket propulsion. It focuses on exploring fundamental processes within rocket combustion chambers and supply systems, with special emphasis on propellant conditioning, transient flow, injection, ignition, and combustion. The test field is capable of replicating operating conditions for orbital engines, and to some extent, in launcher engines.

Current research topics investigated at M3 include:

- Analysis of dynamic processes in feedlines like water-hammer effects
- Investigation of the spray during the injection of liquid fuels
- Investigation of ignition and flame stabilization in combustion chambers
- Rotating detonation combustion for space propulsion applications

Technology tests include:

- Component tests for turbopumps
- Injector element characterization
- Ignition transients
- Nozzle plume interaction with structural components like landing gear

The M3 test field currently houses three active test positions (M3.1, M3.3, M3.5) for tests with liquid oxygen and liquid nitrogen, and gaseous hydrogen or hydrocarbon fuels on a laboratory scale and feed-line pressures of up to 40 bar.

The talk will detail the test capabilities and show selected test activities from recent projects.

Keywords: cryogenic propellants, space propulsion test infrastructure, injection, ignition, water-hammer.

THE COMMISSIONING OF THE HIGH-ALTITUDE TEST FACILITY FOR SPACE ROCKET PROPULSION TESTING

Session 1: Propulsion testing and modeling, presentation number 2

Michał Zieliński*, Alicja Kwitek*, Marta Żak**, Kamil Kuś*, Michał Pilich*, Michał Bielak***, Mateusz Bartela**, Mateusz Pakosz**, Kamil Pazur**, Paweł Popkowicz***, Krzysztof Rondke**, Witold Rosa***, Rafał Sikorski**, Maciej Szybowski***.

* Space Technologies Center, Łukasiewicz Research Network – Institute of Aviation, Aleja Krakowska 110/114, 02-256 Warszawa

** Faculty of Electrical Engineering, Łukasiewicz Research Network – Institute of Aviation

*** Engineering Service Center, Łukasiewicz Research Network – Institute of Aviation

michal.zielinski@ilot.lukasiewicz.gov.pl, alicja.kwitek@ilot.lukasiewicz.gov.pl, marta.zak@ilot.lukasiewicz.gov.pl, kamil.kus@ilot.lukasiewicz.gov.pl, michal.pilich@ilot.lukasiewicz.gov.pl, michal.bielak@ilot.lukasiewicz.gov.pl, mateusz.bartela@ilot.lukasiewicz.gov.pl, mateusz.pakosz@ilot.lukasiewicz.gov.pl, kamil.pazur@ilot.lukasiewicz.gov.pl, pawel.popkowicz@ilot.lukasiewicz.gov.pl, Krzysztof.rondke@ilot.lukasiewicz.gov.pl, witold.rosa@ilot.lukasiewicz.gov.pl, rafal.sikorski@ilot.lukasiewicz.gov.pl, maciej.szybowski@ilot.lukasiewicz.gov.pl

Abstract

A high-altitude (vacuum) test facility for space rocket propulsion testing is a very intricate infrastructure. It consist of many independent, complex subsystems that work together to create development infrastructure. Paper describes process of commissioning of the test facility, verification of components and complete systems before the first commercial test. Due to the usage of high energy, storable propellants special attention must be paid to verification and adjusting safety systems. It must be tested in every aspect and across a wide range of parameters in order to function properly during actual testing. The commissioning includes a significant number of tests, from the simplest ones (providing signals to sensors) to the most complex ones, during which rocket engines will be ignited to verify the assumed vacuum test facility parameters.

Keywords: test facility, vacuum, commissioning, space rocket.

Łukasiewicz
Institute of Aviation

XIII International Scientific Conference on:
DEVELOPMENT TRENDS IN SPACE PROPULSION SYSTEMS

CHALLENGES IN DEVELOPING STUDENTS' REMOTE TEST STAND FOR ROCKET PROPULSION SYSTEMS

Session 1: Propulsion testing and modeling, presentation number 3

Michał Kret *, Korneliusz Szalkowski * Mateusz Sochacki**

* Students' Space Association, Faculty of Aerospace and Power Engineering, Warsaw University of Technology, ul. Nowowiejska 21/25, 00-665 Warsaw

** Division of Automation and Aeronautical Systems, Faculty of Aerospace and Power Engineering, Warsaw University of Technology, ul. Nowowiejska 24, 00-665 Warsaw

michal.kret.stud@pw.edu.pl , korneliusz.szalkowski.stud@pw.edu.pl , mateusz.sochacki@pw.edu.pl

Abstract:

The Rocketry Division of Students' Space Association has been developing sounding rockets for more than ten years. During that time, a number of propulsion systems, including both hybrid and solid propellant rocket engines have been successfully static tested under various test setup conditions. Increasing number of projects and tests connected to them required establishing Division's own test stand, located inside sea shipping container placed within the area of WUT Aerospace Research Centre. In this presentation test stand project history will be presented, with focus on its mechanical design, data acquisition and safety measures. Highlighted will be the greatest challenges faced by project members, solutions found to conquer them and conclusions drawn during four years of project duration.

Keywords:

Test stands, rocket engines, hybrid propulsion system, solid propellants, students' association.

Łukasiewicz
Institute of Aviation

XIII International Scientific Conference on:
DEVELOPMENT TRENDS IN SPACE PROPULSION SYSTEMS

DYNAMICS OF E-PUMPS DEVELOPED FOR THE RELIANCE ROCKET ENGINE

Session 1: Propulsion testing and modeling, presentation number 4

Jiří Kozák*, Petr Váňa*, Jan Snášel*, David Štefan**, Jan Horký*, Matěj Machoň**

* Inpraise systems s.r.o., Brno, Czech Republic

** Victor Kaplan Dpt. of Fluid Engineering, Faculty of Mechanical Engineering, Brno University of Technology, Czech Republic

jiri.kozak@inpraisesystems.cz, petr.vana@inpraisesystems.cz

Abstract

This presentation focuses on the vibrations and pressure pulsations observed during the water testing phase of electrically driven fuel (MMH) and oxidizer (MON-3) pumps designed for the RELIANCE rocket engine. It builds directly on the findings shared at Space Propulsion 2024. [1]

The study examines and correlates the operational dynamics and induced instabilities of both e-pumps across a broad spectrum of operating conditions. These insights are valuable for potential users and integrators of similar systems.

Keywords: e-pump, pump, rocket engine, RELIANCE, vibrations.

Łukasiewicz
Institute of Aviation

XIII International Scientific Conference on:
DEVELOPMENT TRENDS IN SPACE PROPULSION SYSTEMS

EFFECT OF FLASH-BOILING ON SPRAY-WALL INTERACTION UNDER LOW-PRESSURE INJECTION

Session 1: Propulsion testing and modeling, presentation number 6

Rohit Thokala*, Łukasz Boruc*, Andrzej Teodorczyk*, Łukasz Jan Kapusta*
*Faculty of Power and Aeronautical Engineering, Warsaw University of Technology, Warsaw, Poland
rohit.thokala.dokt@pw.edu.pl, lukasz.boruc@pw.edu.pl, andrzej.teodorczyk@pw.edu.pl,
lukasz.kapusta@pw.edu.pl.

Abstract

Flash boiling enhances fuel atomization and promotes mixing the injected liquid with the surrounding gas. However, spray-wall interaction under flash-boiling conditions, particularly with a low-injection-pressure strategy, is not understood yet. Therefore, this research aims to examine the characteristics of spray impingement into the wall under subcooled and flash-boiling conditions using a low-injection-pressure strategy (0.5MPa). Spray-wall dynamics were observed using a high-speed camera with global illumination, and the sprays were characterized qualitatively and quantitively before and after impingement based on the high-speed camera images.

The interaction between the spray and the wall was entirely changed due to flash-boiling, even though some quantitative interaction parameters could suggest something different. This interaction change was associated with the flash-boiling effect on the sprays prior to the impingement. For highly flashing sprays (e.g., 140°C), the spray tip propagation velocity strongly decreased, and the spray area increased, which had an impact on the spray cloud developed on the wall. This phenomenon can potentially enhance the mixing process without increasing the wall-wetting compared to sub-cooled spray injection. However, under flash-boiling conditions, a recondensation of flash-evaporated liquid can also be expected due to the low initial temperature of the wall, which should also be taken into account.

Keywords: Spray, Atomization, Injection, Spray-wall interaction, Flash-boiling, Low-pressure injection.

Łukasiewicz
Institute of Aviation

XIII International Scientific Conference on:
DEVELOPMENT TRENDS IN SPACE PROPULSION SYSTEMS

OVERVIEW OF ROCKET PROPULSION TEST ACTIVITIES AT ŁUKASIEWICZ – INSTITUTE OF AVIATION IN 2023-2024

Session 1: Propulsion testing and modeling, presentation number 7

Tobiasz Mayer *, Anna Piorun*, Bartosz Kościanek*, Grzegorz Ogórek*, Michał Kawalec**

* Space Technologies Center, Łukasiewicz Research Network – Institute of Aviation, Aleja Krakowska 110/114, 02-256 Warszawa

** Unmanned Technologies Center, Łukasiewicz Research Network – Institute of Aviation

tobiasz.mayer@ilot.lukasiewicz.gov.pl, anna.piorun@ilot.lukasiewicz.gov.pl, bartosz.koscianek@ilot.lukasiewicz.gov.pl, grzegorz.ogorek@ilot.lukasiewicz.gov.pl, michal.kawalec@ilot.lukasiewicz.gov.pl

Abstract

Łukasiewicz Research Network – Institute of Aviation (Łukasiewicz - ILOT) is a leading Polish institution specializing in green Liquid Rocket Engines (LREs) and Rotating Detonation Engines (RDEs). Especially in the domain of LREs, Łukasiewicz - ILOT is specializing in the domain of highly concentrated Hydrogen Peroxide (up to 98%+) based propulsion. Along with developing its own propulsion systems, ILOT provides testing services for global companies. Łukasiewicz - ILOT houses two operational test facilities with LRE test benches from 1 N up to 5 kN thrust (at sea level) and one for RDEs. There are two more in development for thrusts of up to 60 kN (at sea level) and up to 500 N (high altitude). This paper presents an overview of testing activities from 2023 onwards, focusing on engines for suborbital rockets, lunar landers and orbital manoeuvring purposes. Additional test campaigns have explored technologies such as aerospike nozzles, hydrogen peroxide catalysts, hypergolic propellants, deep throttling, water hammer effects, cooled combustion chambers and injection systems.

Keywords: Green Propellants, Propulsion Testing, RDE, Hypergolics.

Łukasiewicz
Institute of Aviation

XIII International Scientific Conference on:
DEVELOPMENT TRENDS IN SPACE PROPULSION SYSTEMS

THROTTLEABLE LIQUID PROPULSION DEMONSTRATOR SIMULATION

Session 1: Propulsion testing and modeling, presentation number 8

Krzysztof Matysek

Space Technologies Centre, Łukasiewicz Research Network – Institute of Aviation, al. Krakowska 110/114, 02-256 Warsaw, Poland

Krzysztof.Matysek@ilot.lukasiewicz.gov.pl

Abstract

A simulation software was developed for the Throttleable Liquid Propulsion Demonstrator (TLPD) project. The project develops technologies for deeply throttleable liquid rocket engine (from nominal 5000N to 500N at sea level), fed by high-test peroxide (HTP) of 98% concentration and ethanol. The simulator is meant as a tool to predict performance of the engine in various operating points, as well as dynamic behavior in transients between those. The modelling scope includes control system algorithm and models for control actuators dynamics, feeding system piping, throttling valves, and combustion. The bulk of the hydraulic system was created in the Simulink® Simscape™ environment, which may have shortened development time, but posed challenges during implementation, validation, and operation of the model. During the presentation, the importance

of proper auxiliary equipment modelling (like valve and injector position control actuators) will be discussed. Challenges posed by verification and validation (V&V) of the model using experimental data will be presented.

Keywords: Throttling, Liquid propulsion, Simulation, Verification & Validation.

Łukasiewicz
Institute of Aviation

XIII International Scientific Conference on:
DEVELOPMENT TRENDS IN SPACE PROPULSION SYSTEMS

3D PRINTING AS A VIABLE METHOD OF INHIBITING SOLID PROPELLANT GRAINS

Session 2: "Solid and Hybrid Propulsion", presentation number 3

Michał Tomporowski *, Michał Kret *, Andrzej Ziębiński*, Jan Kindracki**, Michał Chmielarek ***

* Students' Space Association, Faculty of Aeronautical and Power Engineering Warsaw University of Technology, Nowowiejska 21/25, 00-665 Warszawa

** Institute of Heat Engineering, Faculty of Aeronautical and Power Engineering Warsaw University of Technology, Nowowiejska 21/25, 00-665 Warszawa

*** Department of High-Energetic Materials, Faculty of Chemistry, Warsaw University of Technology, Noakowskiego 3, 00-664 Warsaw, Poland

michal.kret.stud@pw.edu.pl michal.tomporowski.stud@pw.edu.pl andrzej.ziebinski.stud@pw.edu.pl jan.kindracki@pw.edu.pl michal.chmielarek@pw.edu.pl

Abstract

Solid propellant rocket motors have been under continuous development since the beginning of the last century, in space exploration and defense sectors. Their popularity comes from many advantages, such as their simplicity, storability, and comparatively low costs. A challenge in solid motor designs is providing adequate thermal insulation and propellant grain inhibition inside the combustion chamber. There are two methods for placing grain in the motor chamber. The first is binding propellant to the chamber wall through an insulative transition layer called the liner. The second method is the so-called free-standing grain, sometimes with inhibited surfaces to reduce the combustion area of the grain. In this case, the motor is characterized by a higher initial to average thrust ratio, however, the thermal insulation layer must resist higher temperatures and longer operating times.

In this presentation, a new method of inhibiting free-standing HTPB/Al/Ammonium Perchlorate propellant grains based on additive manufacturing technology, developed by the Rocketry Division of the Students' Space Association at Warsaw University of Technology, is presented. The motivations, design, and manufacturing processes will be discussed, followed by an analysis of tests, ranging from initial samples to static fire and flight tests of the FOK rocket propulsion system.

Keywords: solid propellants, internal ballistics, grain inhibition, additive manufacturing.

Łukasiewicz
Institute of Aviation

XIII International Scientific Conference on:
DEVELOPMENT TRENDS IN SPACE PROPULSION SYSTEMS

GREEN FLIP CONTROL SYSTEM – A HYBRID PROPULSION SOLUTION FOR ROTATING A LAUNCHER'S FIRST STAGE

Session 2: "Solid and Hybrid Propulsion", presentation number 4

Adam Matusiewicz*, Robert Magiera*, Rafał Ciania*, Bartosz Moczała*, Kacper Zieliński*

* SpaceForest Ldt. ul. Bolesława Krzywoustego 1B, 81-035 Gdynia

adam.matusiewicz@spaceforest.pl, robert.magiera@spaceforest.pl, rafal.ciania@spaceforest.pl, bartosz.moczala@spaceforest.pl, kacper.zielinski@spaceforest.pl

Abstract

This article describes progress made so far in Green Flip Control System development, which is a part of the SALTO (reuSable strAtegic space Launcher Technologies & Operations) project co-financed by European commission. General assumptions and requirements for the system, results of the thruster development and test campaign are presented, as well as progress made in design, manufacturing and testing of the composite main oxidiser tank prototypes.

Keywords: green, storable, hybrid, propulsion, reusable, rocket.

Łukasiewicz
Institute of Aviation

XIII International Scientific Conference on:
DEVELOPMENT TRENDS IN SPACE PROPULSION SYSTEMS

HYBRID ROCKET MOTORS' DEVELOPMENT IN STUDENTS' SPACE ASSOCIATION

Session 2: "Solid and Hybrid Propulsion", presentation number 5

Bartosz Hyży *, Marek Dzik *, Piotr Łyżwa *, Radosław Kamiński *, Jakub Tyszkiewicz*, Eliza Łapińska *, Szymon Życiński *

* Students' Space Association, Faculty of Aerospace and Power Engineering, Warsaw University of Technology, ul. Nowowiejska 21/25, 00-665 Warsaw

bartosz.hyzy.stud@pw.edu.pl, marek.dzik.stud@pw.edu.pl, piotr.lyzwa2.stud@pw.edu.pl, radoslaw.kaminski4.stud@pw.edu.pl, jakub.tyszkiewicz.stud@pw.edu.pl, eliza.lapinska.stud@pw.edu.pl, szymon.zycinski.stud@pw.edu.pl

Abstract

The Rocketry Division of Students' Space Association at Warsaw University of Technology has been developing solid rocket motors for more than a decade. The will to participate in international competitions and to explore new technologies, imposed development of hybrid rocket engines within the Association. Therefore, the work on the first series of hybrid engines began with development of Basilisk and Aurora engines.

This presentation will demonstrate the approach used by the Association's members for execution of static fire test campaign of Basilisk engine for Twardowsky 1 rocket, along with design process of 10kN thrust, hybrid engine Aurora for Twardowsky 2 rocket in the context of knowledge gained during work on its earlier iteration. Physical models used during inner ballistics calculations of hybrid engines will also be presented with their validation by static fire test data. The design process of a few subsystems of Aurora engine, like swirl and showerhead injectors and double acting pyro valve will be summarized as a representative example of lessons learned during the exploitation and development of the first iteration hybrid rocket engine.

Keywords: hybrid rocket engines, inner ballistics, injector systems.

Łukasiewicz
Institute of Aviation

XIII International Scientific Conference on:
DEVELOPMENT TRENDS IN SPACE PROPULSION SYSTEMS

GREEN PROPELLANTS RESEARCH AT DLR LAMPOLDSHAUSEN

Session 3: Green Propulsion, presentation number 1

Christoph U. Kirchberger*+, Till Hörger*, Max Kurilov*, Felix Lauck*, Konstantin Manassis*, Florian Merz*, Julian Scholl*, Friedolin Strauss*, Philipp J. Teuffel*, Marius Wilhelm*,
Robin Scholl**, Sophie Stölzle**, and Dominic Freudenmann**
* German Aerospace Center (DLR), Institute of Space Propulsion, Satellite and Orbital Propulsion, Langer Grund, Lampoldshausen, 74239 Hardthausen, BW, Germany
** German Aerospace Center (DLR), Institute of Space Propulsion, Chemical Propellant Technology, Langer Grund, Lampoldshausen, 74239 Hardthausen, BW, Germany
+ Christoph.kirchberger@dlr.de

Abstract

The German Aerospace Center's Institute of Space Propulsion in Lampoldshausen has more than a decade of experience in green propellant research and propulsion hardware development for in-orbit applications and high-speed airbreathing propulsion. In the frame of internal research projects, ESA and third-party projects DLR researcher gained a deep and extensive knowledge on associated systems, hardware and technologies. Currently, several promising technologies are investigated and developed in parallel, namely the HyNOx mono- and bipropellant technology, based on nitrous oxide and hydrocarbon fuels, the HIP_11 technology, based on hydrogen peroxide and a hypergolic fuel, as well as nitromethane-based monopropellants. Furthermore, both improved and novel propellants, injection strategies, cooling capabilities and advanced manufacturing are looked into. The presentation provides an overview on green alternatives for chemical satellite and in-orbit propulsion and highlights recent achievements of DLR's research.

Keywords: nitrous oxide, hydrogen peroxide, ionic liquid, propulsion, HyNOx, HIP_11.

Łukasiewicz
Institute of Aviation

XIII International Scientific Conference on:
DEVELOPMENT TRENDS IN SPACE PROPULSION SYSTEMS

GRACE DEVELOPMENT PROGRAMME: A GREEN ENGINE FOR FUTURE SPACECRAFT AND SPACE TRANSPORTATION

Session 3: Green Propulsion, presentation number 2

Paweł Surmacz *, Michał Ranachowski, Zbigniew Gut, Kamil Sobczak, Adrian Parzybut

* Space Technologies Center, Łukasiewicz Research Network – Institute of Aviation, al. Krakowska 110/114, Warsaw

Abstract

GRACE is an acronym of Green Liquid Apogee Engine for Future Spacecraft – the activity founded by the European Space Agency (ESA). Initiated in 2015, this development programme is currently at its second phase, concluding with the Preliminary Design Review. The third phase, aiming at the further development up to the Critical Design Review, is being scheduled for the next 30 months, starting from the early 2025.

The paper presents major concepts, requirements, trade-offs, design evolution, and test results collected during nearly 10 years of work. The engine, developed in the frame of GRACE, is a 420 N bipropellant, designed for spacecraft. It uses 98% hydrogen peroxide of HTP-class as the oxidizer. A gas-liquid injection, being the primary concept for this design, requires a prior full catalytic decomposition of the HTP. For this reason Łukasiewicz-ILOT developed its own catalyst, already pre-qualified for the engine. In connection with the innovative fuel injector, the engine operates stably within the entire qualification pressure box. It is equipped with a low-cost high-temperature molybdenum combustion chamber, developed in the frame of another ESA activity, led by Łukasiewicz-ILOT.

Apart from the scientific part of the activity, certain development roadmap and potential application will be presented.

Keywords: chemical propulsion, liquid rocket engine, bi-propellant, hydrogen peroxide.

Łukasiewicz
Institute of Aviation

XIII International Scientific Conference on:
DEVELOPMENT TRENDS IN SPACE PROPULSION SYSTEMS

ENGINE CONTROL UNIT FOR A GREEN MICROSATELLITE PROPULSION SYSTEM

Session 3: Green Propulsion, presentation number 3

Konrad Wojciechowski*, Michał Piwowarczyk*, Hubert Graczyk*, Mateusz Rusak*, Maciej Filipowicz*

* Avionics Department, Unmanned Technologies Center, Łukasiewicz Research Network – Institute of Aviation, Al. Krakowska 110/114, 02-256 Warsaw, Poland

konrad.wojciechowski@ilot.lukasiewicz.gov.pl, michal.piwowarczyk@ilot.lukasiewicz.gov.pl, hubert.graczyk@ilot.lukasiewicz.gov.pl, mateusz.rusak@ilot.lukasiewicz.gov.pl, maciej.filipowicz@ilot.lukasiewicz.gov.pl

Abstract

Growing demand for space propulsion systems spawned a large amount of organisations that work towards developing new thrusters. To integrate them into the spacecraft platform avionics, control units are needed to handle low-level data acquisition, control and communication. Few commercial-off-the-shelf solutions are available, as most such systems are tailor-made. That is why the Łukasiewicz - Institute of Aviation developed a small engine control unit that is compatible with its green propulsion systems utilizing high-test peroxide. The result is a module capable of monitoring the propulsion system state, controlling the propellant flow and the temperature of the system's components. Focus was given to radiation hardness, reliability and limiting power consumption, while maintaining miniature form. This presentation gives an overview of the design of the system and the current state of the project.

Keywords: avionics, engine, controller, space propulsion, monopropellant, data acquisition.

Łukasiewicz
Institute of Aviation

XIII International Scientific Conference on:
DEVELOPMENT TRENDS IN SPACE PROPULSION SYSTEMS

DEMONSTRATION OF DEEP THROTTLING WITH GREEN STORABLE PROPELLANTS – A STEP TOWARDS FUTURE FLEXIBLE SPACE PROPULSION

Session 3: Green Propulsion, presentation number 4

Dawid Cieśliński *

* Space Technologies Center, Łukasiewicz – Institute of Aviation, dawid.cieslinski@ilot.lukasiewicz.gov.pl

Abstract

Throttleable Liquid Propulsion Demonstrator (TLPD) is a liquid rocket engine demonstrator enabling deep throttling, with use of green propellants: High-Test Peroxide (HTP) and ethanol with concentrations of 98% and 96% respectively. The technologies shall allow to reduce the thrust down to 10% and increase it up to 110%

of the nominal operating point (5 kN, Sea Level). The throttling is realized by two independently-actuated cavitating mass-flow regulation valves. No additional ignition device is utilized due to catalytic decomposition of the oxidizer providing the engine with heat and conditions sufficient to ignite the mixture smoothly. The combustion performance and stability is improved with use of adjustable fuel pintle injector, no actuation on the oxidizer injector is introduced in this part of development.

This paper presents the findings from the final hot fire tests campaign, where long duration tests with variable thrust were tested. Minimum and maximum stable operating points are shown, with engine dynamics assessed quantitatively. Additively-manufactured (copper-based) breadboard combustion chamber was verified

in several runs to assess the technology viability for the follow up activity. The outcomes from the TLPD are considered as potential building blocks in green storable propulsion applications, e.g., recoverable boosters, planetary or lunar landers, kick-stages. The activity named Throttleable Liquid Propulsion Demonstrator (TLPD) is a part of the Future Launchers Preparatory Programme of European Space Agency.

Keywords: throttling; high-test peroxide; green propulsion; hot fire; ESA; demonstrator.

Łukasiewicz
Institute of Aviation

XIII International Scientific Conference on:
DEVELOPMENT TRENDS IN SPACE PROPULSION SYSTEMS

RESEARCH ON DETONATION PROPULSION AT LUKASIEWICZ-INSTITUTE OF AVIATION

Session 4: Future propulsion systems, presentation number 1

Michał Kawalec *, Adam Bilar *, Maksymilian Augustyn * , Krzysztof Benkiewicz *

* Detonation Propulsion Section, Aircraft Propulsion Systems Department, Łukasiewicz- Institute of Aviation, Al. Krakowska 110/114 02-256 Warsaw

Abstract

The article presents the results of research on the process of rotating detonation conducted at the Łukasiewicz Institute of Aviation. The primary focus of the research was on testing a ramjet engine powered by aviation kerosene. Various geometric configurations were tested, including annular combustion chambers with different channel heights and various types of exhaust nozzles. The study examined the impact of combustion regime and stability on engine performance. Engine thrust and specific impulse were assessed for different operating modes, ranging from deflagration, through unstable detonation, and up to a highly stable rotating detonation process, where the velocity of the rotating detonation wave reached up to 97% of the Chapman-Jouguet velocity.

Another aspect of the research involved the analysis a small turbine engine powered by gaseous hydrogen, utilizing detonative combustion. In these experiments, various combustion chamber geometries were initially tested, with particular attention to their impact on the stability of the detonation. After analyses and a series of tests, the annular combustion chamber was selected as the most efficient, perfectly suited for integration with the turbine. As part of these experiments, tests were conducted up to 95% of the maximum turbine shaft speed. Additionally, tests were performed with secondary air circulation circuit, aimed at cooling both the combustion chamber and the turbine itself, as well as increase of the mass flow rate through the chamber-turbine system.

Another aspect of the study involved experiments on a liquid-propellant rocket engine using nitrous oxide (N2O) and propane (C3H8). In these tests, a small hemispherical combustion chamber was examined. This shape is optimal from a structural strength perspective.

The results of this research provide valuable insights into the optimization of combustion processes in future aviation and rocket engines utilizing detonation process.

Keywords: RDE, detonation, ramjet, kerosene, hydrogen, propane, nitrous oxid.

Łukasiewicz
Institute of Aviation

XIII International Scientific Conference on:
DEVELOPMENT TRENDS IN SPACE PROPULSION SYSTEMS

WATER ELECTROLYSIS PROPULSION FOR SPACECRAFT: A COMPREHENSIVE REVIEW AND STATUS ASSESSMENT

Session 4: Future propulsion systems, presentation number 2

Puneeth Bheesetty*, Marisha Jmukhadze**, Joshit Mohanty*** , Sujatha Alla****
* Aerospace Engineering, Faculty of power and aeronautical engineering, Warsaw University of Technology, plac Politechniki 1, 00-661 Warszawa, Poland
** Aerospace Engineering, Faculty of power and aeronautical engineering, Warsaw University of Technology, plac Politechniki 1, 00-661 Warszawa, Poland
*** Engineering Management and Systems Engineering, Batten College of Engineering, Old Dominion University, 2101 W45th St, Norfolk, VA 23529, United States
**** Engineering Management and Systems Engineering, Batten College of Engineering, Old Dominion University, 2101 W45th St, Norfolk, VA 23529, United States
*puneeth.bheesetty@gmail.com
**m.jmukhadze@gmail.com
***jmohanty@odu.edu
****salla001@odu.edu

Abstract
As the demand for novel and highly efficient space propulsion systems continues to grow, it is essential to strategically organize research efforts to ensure future advancements are both focused and impactful. While technologies like ion thrusters and nuclear propulsion dominate the current landscape, water electrolysis propulsion remains in its infancy, with a Technology Readiness Level (TRL) of 2 to 3. This system operates by splitting water into hydrogen (H_2) and oxygen (O_2) for propulsion. Despite early demonstrations by NASA in 1997 and more recent conceptual designs, significant progress has been limited, largely overshadowed by more mature technologies like ion thrusters. Research on water electrolysis propulsion has not been continuous from its initial demonstrations to the present day. This study aims to critically review the existing body of research on water electrolysis propulsion for space applications, tracing its development throughout the years and evaluating the pace of advancement. By offering a comprehensive meta-analysis, our work aims to provide a clear roadmap, equipping potential researchers with a “benchmark overview” as a starting point in their research.

Keywords: Water Electrolysis Propulsion, Space Propulsion Systems, Technology Readiness Level (TRL), Meta-Analysis.

Łukasiewicz
Institute of Aviation

XIII International Scientific Conference on:
DEVELOPMENT TRENDS IN SPACE PROPULSION SYSTEMS

ELECTRIC PROPULSION ACTIVITIES IN IFPiLM

Session 4: Future propulsion systems, presentation number 3

Maciej Jakubczak *, Olgierd Cichorek *,**, Agnieszka Jardin *, Arsenii Riazantsev *, Jacek Kurzyna *

* Institute of Plasma Physics and Laser Microfusion (IFPiLM), Hery 23, 01-497 Warsaw, Poland

** Space Research Center PAS, Bartycka 18a, 00-716 Warsaw, Poland

maciej.jakubczak@ifpilm.pl

Abstract

After 10 years of research and development of thrusters for small satellites, the Institute of Plasma Physics and Laser Microfusion (IFPiLM) has become specialized in two distinct technologies: Hall thrusters and ablative pulsed plasma thrusters, with a special focus on alternative propellants for these devices. The vacuum facility and available diagnostic tools, including thrust stand and different ion collectors, allow reliable assessment of the performance and of different efficiency factors like beam divergence. In the latest versions, the 500 W-class krypton-fueled Hall thruster (targeted at minisatellites) was able to deliver 25 mN of thrust with specific impulse exceeding 2500 s, whereas the 1 J PFPE-fueled pulsed plasma thruster (for nanosatellites) provided impulse bit of 19 µNs with specific impulse of 400 s. Future development plans for these thrusters aim for further increase of thrust-to-power ratio and lifetime.

Keywords: electric propulsion, micropropulsion, Hall thruster, ablative pulsed plasma thruster, plasma diagnostics.