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Technion – Israel Institute of Technology
Faculty of Mechanical Engineering
Internal Combustion Engines Lab

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לשכת המהנדסים האדריכלים והאקדמאים במקצועות הטכנולוגיים בישראל
AEAI

טכנולוגיות הנעת כלי טייס בלתי מאוישים

הכנס התשיעי

חוברת תקצירים

הפקולטה להנדסת מכונות, הטכניון
חיפה
ד' שבט תש"פ
30 בינואר 2020

Conference Program

9th Conference on Propulsion Technologies for Unmanned Aerial Vehicles

Thursday, January 30, 2020
Shirley and Manny Ravet Auditorium, D. Dan and Betty Kahn Building
Faculty of Mechanical Engineering, Technion, Haifa

8:30 – 9:00	**Welcome and Registration**
Opening session	**Chairman: Leonid Tartakovsky,** Technion
9:00 – 9:30	**Welcome:** ***Alon Wolf,*** Vice President for External Relations and Resource Development, Technion ***Oleg Gendelman*****,** Dean, Faculty of Mechanical Engineering, Technion ***Yigal Ben-Shabat*****,** Head, Propulsion Branch, Directorate of Defense Research & Development, MAFAT ***Emanuel Liban*****,** President, Association of Engineers, Architects and Graduates in Technological Sciences in Israel
9:30 – 10:00	**Keynote lecture:** **New Industry Expectations Drive New Technologies** ***Jeff Ratcliffe*****,** Chief Technical Officer, Northwest UAV, USA
Plenary session 1	**Chairman: Yitzhak (Itche) Hochmann,** Edmatech
10:00 – 10:30	**What's your next invention in UAV propulsion? Innovation and the challenge of uncertainty** ***Yakov Ben-Haim*****,** Technion
10:30 – 11:00	**Israel Air Force Quadrennial Defense Review Roadmap for UAS Propulsion Technologies** ***Colonel Dr. A*****,** Head of Engineering Department, Materiel Directorate, Israel Air Force, IDF, Israel
11:00 – 11:25	**Coffee break**
Plenary session 2	**Chairman: Michael Shapiro,** Technion
11:25 – 11:50	**Using Engine Metamodeling Toward Fault Detection** ***Ohad Gur*****,** IAI – Israel Aerospace Industries, Israel
11:50 – 12:15	**UAV Engines – Advanced Manufacturing Process** ***Guido Zanzottera*****,** Zanzottera Technologies Srl, Italy
12:15 – 12:40	**Managing the Effects of Impulse Torque** ***Tom B. West*****,** CEO, HFE International, USA
12:40 – 13:05	**Surface Engineering for Enhancing Performance of Propulsion Systems**

	Izhak Etsion, Technion, Israel
13:05 – 13:15	**Best Student Poster Award Ceremony**
13:15 – 14:20	**Lunch**
Session "New Concepts "	**Chairman: Nir Geva,** Elbit Systems
14:20 – 14:40	**Four-Stroke Diesel Engine with In-Cylinder Steam Reforming for High Altitude Operation** ***K. Karsenty, L. Tartakovsky and E. Sher,*** Technion, Israel
14:40 – 15:00	**Exploring the Use of Hydrogen-Enriched Fuel in an Internal Combustion Engine Powered UAV** ***Guy Ben-Haim, Michael Stanovsky***, Elbit Systems, Israel
15:00 – 15:20	**Is a Hydrogen Fuel Revolution just around the corner?** ***Michael N. Kubi***, Kubigroup Technology and Strategic Consultation, Israel
15:20 – 15:40	**Rate Limiting Constraints in Phase-Change-Materials (PCM) for Miniature Aircraft Propulsion Systems** ***Matan Feldman, Dan Michaels, Eran Sher,*** Technion, Israel
Session "Engine Performance"	**Chairman: Jacob Feldman,** Israel Aerospace Industries
14:20 – 14:40	**Long term maintenance and preservation of UAV propulsion systems** ***Ilay Lerner***, Elbit Systems, Israel
14:40 – 15:00	**Improved Ignition for Small-scale UAV Engines** ***Joseph Lefkowitz***, Technion, Israel
15:00 – 15:20	**Malfunction Detection – Parameters Relation Approach** ***Idan Biner***, Aeronautics, Israel
15:20 – 15:40	**Centering and friction reduction between parts of the cylinder-piston group** ***Y. Kligerman and I. Cohen***, Technion, Israel
15:40 – 16:00	**Coffee break**
Panel session	**Development trends in UAV Propulsion – where and when?**
16:00 – 16:30	**Moderator: Jacob Feldman, Israel Aerospace Industries** Panelists: J. Ratcliffe (Northwest UAV), E. Liban (Edmatech), L. Tartakovsky (Technion), N. Geva (Elbit), I. Biner (Aeronautics)
Closing remarks 16:30 – 16:35	**Leonid Tartakovsky**, Chairman Organizing Committee

Posters session

1. **Akash Kalghatgi**, Porpatham E and Thangaraja J, Application of UAV for automated roadway system. Vellore Institute of Technology, Vellore, India
2. A.L. Zhmudyak, L.M. Zhmudyak, Method of Gas Exchange for Four-Stroke Engine with a Port in the Cylinder Sleeve. R&D, Natural Intelligence, Ltd., Israel
3. B. Arav[1], **Y. Sizov**[2]**,** B. Gurevich[3], Opportunities and prospects of hybrid solar powered and solar assisted conventional and self-driving e-vehicles. 1- Community of scientists and experts “RHV”, Rehovot, Israel; 2 - Faculty of Mechanical Engineering, The Afeka Tel-Aviv Academic College of Engineering, Tel Aviv, Israel; 3 - Sami Shamoon College of Engineering (SCE), Ashdod, Israel
4. **Haibo Zhang**, Zhou Chen and Izhak Etsion, Model for Friction Reduction Effect of Soft Coating Materials. Department of Mechanical Engineering, Technion, Haifa, Israel
5. **Denis Buntin**, Leonid Tartakovsky, Reforming-controlled compression ignition with OME_1 synthetic e-fuel: engine simulations and heat-release rate investigation. Faculty of Mechanical Engineering, Technion, Israel
6. **Amnon Eyal**, Leonid Tartakovsky, Second-Law Analysis of the Reforming-Controlled Compression Ignition. Faculty of Mechanical Engineering, Technion, Israel
7. **Adi Zur**, Michael Shapiro, Leonid Tartakovsky, Development of a compact reformer for onboard hydrogen production in IC engine with High-Pressure Thermochemical Recuperation. Faculty of Mechanical Engineering, Technion, Israel
8. **David Diskin**, Leonid Tartakovsky, Reduction of combustion irreversibility through combining Fuel Cell and Internal Combustion Engine. Faculty of Mechanical Engineering, Technion, Israel
9. **Yahav Boim, Andy Thawko**, Leonid Tartakovsky, Study on Particle Formation from Hydrogen-rich Reformate Combustion Process in ICE. Faculty of Mechanical Engineering, Technion, Israel
10. **Asher Lichinitzer**[1], Leonid Tartakovsky[2], Development of a novel direct gaseous injector for IC engine with High-Pressure Thermochemical Recuperation. 1 - Rafael Advanced Defense Systems; 2 – Technion, Israel
11. **Karin Linshitz**[1], Joseph Lefkowitz[1], Moshe Berreby[1, 2], Flow characterization of arc plasma wind tunnel by laser absorption spectroscopy of nitric oxide and water molecules. 1 – Technion, Israel; 2 - Rafael Advanced Defense Systems
12. **Galia Faingold**, Joseph K. Lefkowitz, A Numerical Investigation of NH¬3/O2/He Ignition Limits in a Non-Thermal Plasma. Faculty of Aerospace Engineering, Technion, Israel
13. **I. Laso**, **N. Rozin**, J. Van der Lee and J.K. Lefkowitz, A New Ignition Tunnel Design. Faculty of Aerospace Engineering, Technion, Israel
14. **M. Palman**[1], B. Leizeronok[1], R. Miezner[1], B. Cukurel[1], V. Andreoli[2], U. Vyas[2], G. Paniagua[2], T. Gurbuz[3], M. Ilhan[3] and S. Acarer[3], Development of Adaptive Cycle Micro-Turbofan Engine for UAS Applications. Faculty of Aerospace Engineering, Technion, Israel
15. **L. Badum**, B. Cukurel, Potential of Additive Manufactured for the Design of a 300 W Micro Gas Turbine Towards UAV Applications. Faculty of Aerospace Engineering, Technion, Israel

Organizing Committee

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- *Benny Brinder*, Israel Defense Forces
- *Daniel Budianu,* Israel Aerospace Industries
- *Ariel Dvorjetski,* MAFAT, Ministry of Defense
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- *Nir Geva*, Elbit Systems
- *Yitzhak (Itche) Hochmann*, Edmatech Advanced Engineering Consultants Ltd.
- *Emanuel Liban*, President, Association of Engineers, Architects and Graduates in Technological Sciences in Israel
- *Michael Shapiro*, Faculty of Mechanical Engineering, Technion – Israel Institute of Technology
- *Eran Sher*, Faculty of Aerospace Engineering, Technion – Israel Institute of Technology

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- *Emanuel Liban*, Israel Society of Mechanical Engineers – *Chairman*
- *Idan Biner*, Aeronautics
- *Daniel Budianu*, Israel Aerospace Industries
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- *Yitzhak (Itche) Hochmann*, Edmatech
- *Nir Geva*, Elbit Systems
- *Michael Shapiro*, Technion
- *Eran Sher*, Technion

Oral presentations

Keynote lecture

New Industry Expectations Drive New Technologies

Jeff Ratcliffe

[1]Chief Technical Officer, Northwest UAV, McMinnville, OR, USA
* Presenting author email: jeff.ratcliffe@nwuav.com
Keywords: Unmanned, Aviation, Propulsion; Technology; Telemetry; Data; Reliability

The inception of the unmanned industry was defined by a singular market force: immediate and urgent need for surveillance. This singular driving force lead to the use of already available components and propulsion systems, and acceptance of throw-away modular systems. Fast-forward to today, and that singular market force shaping the unmanned systems industry has evolved into two primary market forces: The drive for reliable operations and the need for consistent performance. This paper explores how these market forces are influencing the development of Small UAS propulsion technologies.

These are not easy problems. Payloads are have become more expensive than the UAS platforms they are typically flying on and they are often critical for strategic mission success. This increases the pressure for them to return safely, which in turn drives the need for reliable propulsion. One of the most direct paths to reliability is creating technologies and systems designed specifically for unmanned vehicles and the situations and environments where they operate. Small UAS encounter broad weather envelopes and must be compatible with a variety of payloads which often have specific technical requirements (low noise, low vibration, low electro-magnetic signature, etc.). Propulsion also has to be compatible with the mission for those payloads which adds additional technical requirements (rain, temperatures extremes, heavy fuel, altitude etc.) Because small UAS are flying in such a wide range of environments, their propulsion systems must be designed to accommodate those temperatures, *not* as an exception but as a matter of course, without effecting their long-term performance. Purpose-built propulsion systems can achieve this with key technologies such as cooling efficiency, carbon fouling and wear coatings, and tight production systems and combustion controls.

This drive for reliable operations requires control of every aspect of propulsion. It requires thorough and thoughtful design and development from the very beginnings of the concept all the way through sustaining engineering to meet each of these rigorous requirements. It requires strict control of the operation of the engine and its immediate environment, it requires control of maintenance performed. It requires continuous improvement in design, strict configuration management and production controls and methodical training and communications for operations and maintenance in the field. It requires new technologies to be developed such as advanced bearings and coatings to help prevent unexpected changes in performance and catastrophic failures. In short it requires an aviation mindset.

The need for consistency beyond the obvious effects on reliability are driven by the different types of operations that unmanned systems perform as contrasted with manned operations. With unmanned operations you can have a single operator flying four or more different aircraft of the same type in a single day. These operations are common in “hub and spoke” type of operations where multiple aircraft are launched from a maintenance and operations “hub” and then handed off to various “spokes” where they perform their assigned missions. At the end of the mission each “spoke” will then return the aircraft handing it back to the “hub” for recovery and maintenance. Because of these and other scenarios, operators of unmanned systems are more aware of differences between differences between airframes and have high expectations for consistent performance from one aircraft to the next. To ensure successful flight operations, SUAS and their propulsion systems need to be consistent and predictable. Though it is not the quickest route, the clearest route to consistent SUAS products is quality controlled processes, with regulated facilities that maintain the highest standards.

The key to consistently maintaining the highest levels of performance, reliability. and consistency is telemetry collection, mining, and aggressive exploitation. SUAS utilization rates are far higher than general aviation aircraft and because of this, a higher pace is required for addressing problems in operations as they arise allowing all of these technologies to meet the markets need for increased reliability and consistency.

Acknowledgement
This work was supported by Northwest UAV.

Plenary lecture

What's your next invention in UAV propulsion? Innovation and the challenge of uncertainty

Yakov Ben-Haim
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Keywords: Innovation; uncertainty; info-gap; robustness; search and evasion

Innovation is the name of the game, whether that game is war, or the market, or competition within an organization. Innovation is the process of discovering or developing what was previously unknown or even believed to be impossible. Surprise is an essential element of innovation. The innovator may be surprised (Wow! I didn't think that was possible.) and certainty the adversary will be surprised. The challenge of innovation is that both sides are engaged in the process, and neither side knows what will be the next innovation, either their own or their adversary's. This uncertainty about the future presents a major challenge in choosing a strategy for designing, developing, and managing new technologies.

Edward Luttwak stressed "the virtue of suboptimal but more rapid solutions that give less warning of the intent … and of suboptimal but inherently more resilient solutions …. This is why the scientist's natural pursuit of elegant solutions and the engineer's quest for optimality can often yield failure in the paradoxical realm of strategy."

"Do your best" is the motto of professionals in many fields, including of course engineering. But in the paradoxical realm of technological innovation, in conflict with an intelligent adversary, what does it mean to do your best?

This talk presents a response to that challenge, based on info-gap decision theory (Ben-Haim, 2006, 2010, 2018).

The search for ever better systems should guide the engineering designer. However, uncertainty, ignorance, and surprise diminish the importance of optimal designs.

The concept of an innovation dilemma assists in understanding and resolving the designer's challenge. An innovative and highly promising new design is less familiar than a more standard approach whose implications are more familiar. The innovation, while purportedly better than the standard approach, may be much worse due to uncertainty about the innovation. The resolution (never unambiguous) of the dilemma results from analysis of robustness to surprise (related to resilience, redundancy, flexibility, etc.) and is based on info-gap decision theory.

Info-gap theory provides decision-support tools for managing the challenges of design and decision under deep uncertainty. We discuss the method of robustly satisfying critical requirements as a tool for protecting against pernicious uncertainty.

These ideas will be illustrated with a simple example of designing propulsion for an autonomous aircraft for catching an evasive target. Deep uncertainty surrounds the evasive strategy and capability of the target. This presents substantial challenges to the designer of a UAV that must establish and maintain an effective distance from the target. The emphasis of the example is not on design details, but rather on the methodology by which alternative designs can be prioritized, in light of the uncertainty.

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Yakov Ben-Haim, 2018, *Dilemmas of* Wonderland: *Decisions in the Age of Innovation***,** Oxford University Press.

Many more sources at: info-gap.com

Plenary lecture

Using Engine Metamodeling Toward Fault Detection

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Keywords: engine, metamodel machine-learning, neural-network

Engine test stand is a reach source for various engine parameters which are accumulated during engine tests and runs. This data was used to create metamodel for engine parameters. The current effort will show the usage of several engines datasets to train a machine learning neuron-network based surrogate.

First, the raw data was manipulated to create a usable dataset for model training. These data manipulations are characterized as:

1. Omitting the engine stop periods, i.e. using only 1000 rpm and above data
2. Smoothing the stepped data due to high tolerance parameters
3. Adding rate to parameter sampling
4. Scaling of the parameters according to their own average and standard deviation

To enable these manipulations, Pandas, python based tool, was used.

It was decided to concentrate with engine temperature as the label to be modelled. The model configuration was then found using criterion based on the error moving average mean and standard deviation. Several sensitivity studies were conducted, among such: feature selection, number of epochs, suitable number of hidden layers, and optimized number of neuron.

The final model configuration exhibits mean error of less than 10 Centigrade with standard deviation of about 20 Centigrade. This compared to engine temperature of about 800 Centigrade, i.e. the accuracy is sufficient.

Then, the model used to predict engine run as a validation process. This validation process examines engine run which were not used as training sets, thus proving the model accuracy.

Finally fault engine run is used to demonstrate the capability of such a model as a "fault detection" tool in a future HUMS (Health Usage and Monitoring System).

Figure 1 shows the comparison of model prediction, compared with actual engine run. The upper chart contains results from a normal operating engine while the lower is for fault engine run. The differences are obvious – while the normal operating engine is replicate with good accuracy – about 20÷30 Centigrade errors, the fault engine model error is much higher - about 100 Centigrade. This implies on possible use of such models as fault detection systems' core.

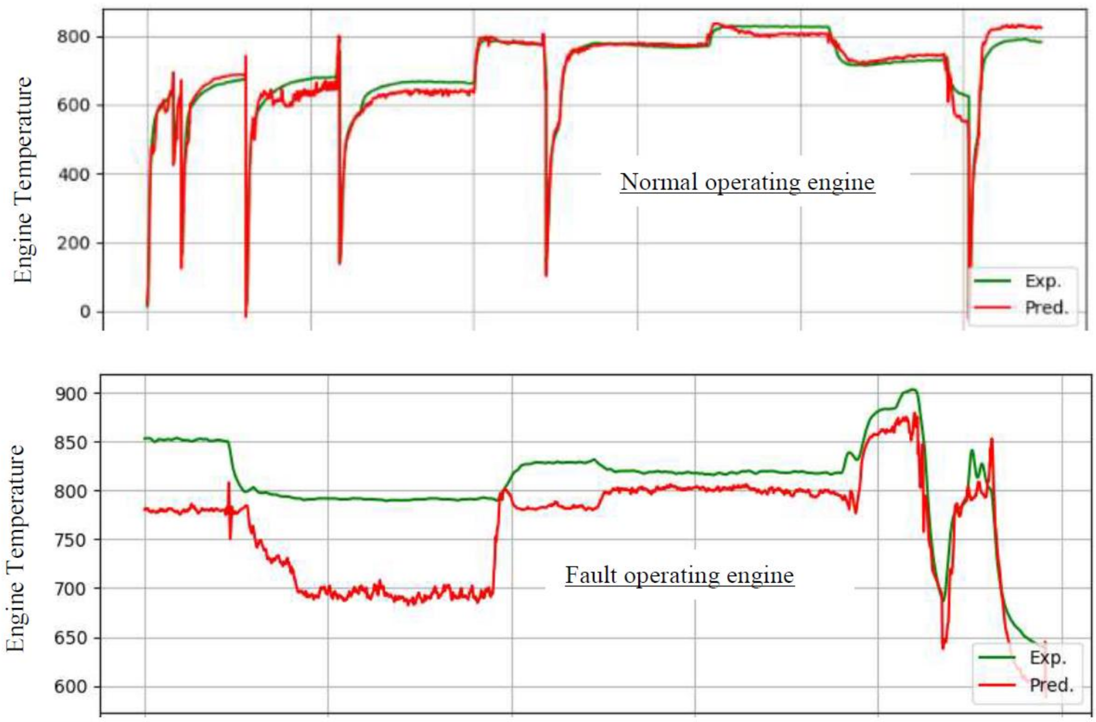

Figure 1. comparison between model prediction and experiment

Plenary lecture
Improved Ignition for Small-scale UAV Engines

J.K. Lefkowitz[1]*

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* Presenting author email: joseph.lef@technion.ac.il
Keywords: Ignition; plasma-assisted combustion; internal combustion engine;

Ignition for small scale UAV engines is a topic with challenges unique from larger internal combustion engines (ICEs) or gas turbine engines. The main limitation of small engines is their reduced geometric size, which increases the surface to volume ratio leading to quenching of ignition kernels as well as reduction of the average flame speed early in kernel development. As a result, the minimum ignition energy (MIE) needed for ignition is greater for UAV engines then larger ICEs, forcing operating conditions to richer mixtures in order to ensure successful ignition with low coefficients of variation (COV). In addition, incomplete combustion of the charge results in low combustion efficiency, which can be mitigated by a strong ignition event.

Strategies to improve ignition can allow engines to run mixtures at stoichiometric or lean conditions in which the combustion efficiency is greater, and thus have lower specific fuel consumption (SFC). For this study, two strategies will be discussed: spark-assisted microwave discharges and nanosecond repetitively pulsed (NRP) discharges. Spark-assisted microwave ignition combines a capacitor discharge with a sub-critical microwave field, which sustains the plasma created by the initial spark (Wolk *et al.*, 2013). NRP discharges utilize short duration (≈ 10 ns) pulses repeated at frequencies up to 100s of kHz, which results in the creation of a quasi-continuous plasma with low overall energy deposition compared to DC discharges (Nagulapally *et al.*, 2000). Both systems operate by increasing the energy and/or duration of the spark beyond those with conventional capacitive or inductive discharges, without necessarily creating unacceptable damage to the electrodes of the spark plug.

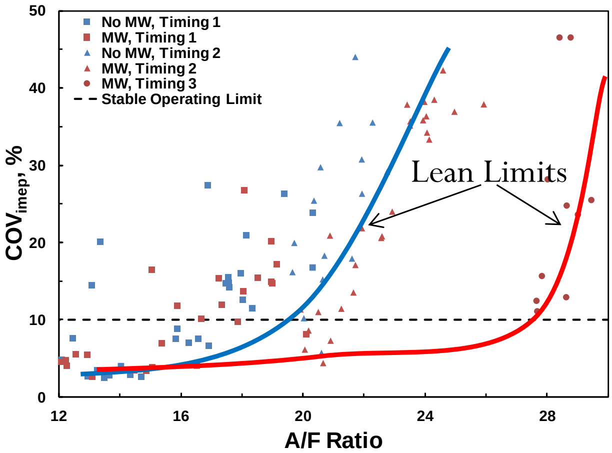

Figure 1. Coefficient of variation of the indicated mean effective pressure for standard and microwave-enhanced engine operation, showing the limit of stable operating conditions at 2000 rpm with full open throttle (FOT). Copied with permission from (Lefkowitz *et al.*, 2012).

In Figure 1, results of a small internal combustion engine experiment are presented, using both conventional and microwave assisted discharges, showing the extension of the lean limit using the microwave system. For these tests, a small scale engine, Fuji Imvac Model BF-34EI, is coupled to a Fuji Electric dynamometer, and equipped with a 360 pulse per revolution encoder, an NTK air/fuel ratio sensor, a TSI air flow sensor, and a Kistler in cylinder pressure transducer for quantitative measurement and control of important engine parameters. The Fuji Imvac BF34-EI is a carbureted single cylinder, four-stroke engine with 34 cc of displacement (39 mm bore and 28 mm stroke length), weight of 2.6 kg, peak power output of 1.49 kW (2.0 hp) at 7,500 rpm, and peak torque of 1.96 Nm (46.5 lbft) at 5,000 rpm. The results indicate an increase in the lean limit from A/F = 20 to A/F = 28 using the microwave-assisted spark, using an acceptable COV in the indicated mean effective pressure (IMEP) of $\mathrm{COV_{IMEP}} = 10\%$. This resulted in stable operation at conditions minimizing SFC.

The other type of discharge, NRP, has been tested extensively in ICEs, i.e. (Sevik *et al.*, 2016) and has also been shown to increase lean operating limits. Studies conducted in flowing environments more typical of gas turbine engines have revealed that the long duration and efficient energy coupling of the NRP discharge can lead to very large ignition events using the same energy as a standard igniter. In Figure 2, examples of ignition events in a 10 m/s flow using various numbers of pulses at a frequency of 10 kHz is presented. The fuel in this case is methane, with an equivalence ratio of φ = 0.6. The energy for each pulse is ≈ 3 mJ, meaning the 50 pulse case uses only 150 mJ, which is comparable to a capacitor spark discharge. As can be clearly seen in the images of Fig. 2, by pulsing multiple times at high frequency, a continuous kernel can be generated which extends as long as the discharge is applied. Due to the short duration of each pulse, the overall energy deposition is much lower per pulse than a capacitor discharge (which is typically > 100 mJ). The low losses to gas and electrode heating allow NRP discharges to use less energy, and the high frequency allows the total energy to be spread over a large volume without creating individual ignition kernels (as would be the case at lower frequencies).

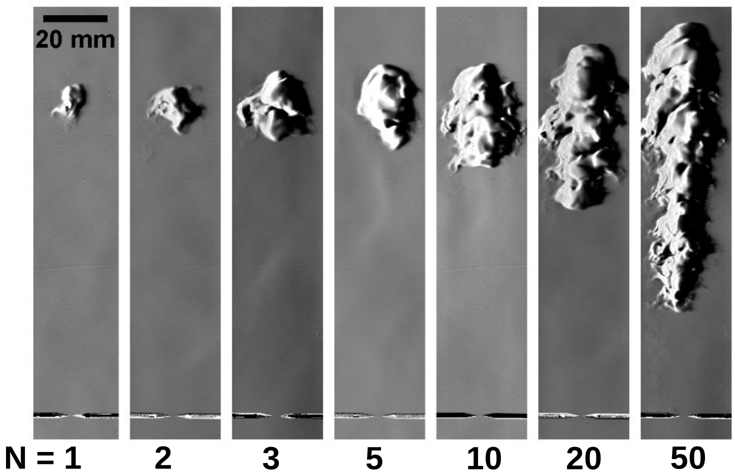

Figure 1. Schlieren images of ignition kernels 8 ms after the initial discharge for φ = 0.6, spark gap distance = 2 mm, velocity = 10 m/s, number of pulses = 1 – 50, and $\tau = 3\ 1 \times 10^{-4}$ s. Copied with permission from (Lefkowitz and Ombrello, 2018).

To conclude, ignition for small engines can be greatly enhanced by alternative ignition technologies, two of which are discussed here. The key operating characteristics for an improved ignition device are extending the ignition limits and increasing the flame propagation rate, both of which are necessary for small-scale engines in which wall quenching plays a dominant role. The viability of such approaches is of course still linked to the scale, weight, and cost of such systems.

References

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Plenary lecture

Managing the Effects of Impulse Torque

T.B. West P.E.[1*]

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Keywords: Torque; Impulse; UAV; engine; IC

Torque impulse in small single cylinder and boxer IC two stroke engines can be as high as 15 x nominal torque. This creates many challenges for the aircraft manufacturer and the power plant manufacturer. This abstract presents some of those challenges and how HFE International has addressed them.

Effects on Power Measurement

High power to weight ratio, single cylinder engines are difficult to measure on a dyno due to their drastic change in torque output over a single revolution. Most manufacturers including HFE International must devise mechanical, electrical and software filters to average these torque impulses in order to measure the power output of the engine. It is in this averaging and mechanical damping where some of the variation in reported output power can occur for the same engine between manufacturer and customer tests. There are little to no standards between manufacturers on how to average these values and why one algorithm is better than another. HFE International has measured both single and boxer style two stroke engines and have found the raw torque impulse (after mechanical damping) to be as shown in figure 1. These torque impulses occur only once per revolution during the power stroke but are damped by a flywheel on the dyno to reduce the effect of the impulse.

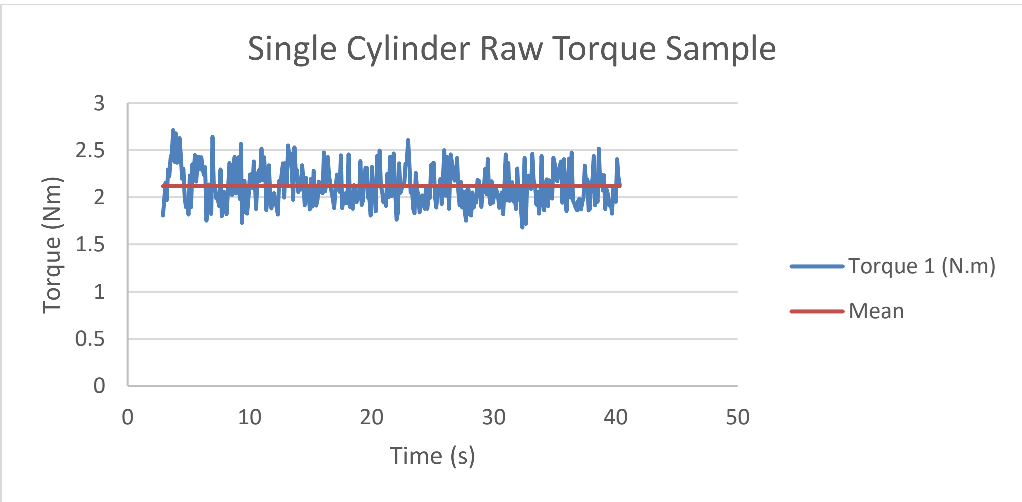

Figure 1. Raw torque measurement of a single cylinder engine at HFE International before software filtering.

Effects of Vibration Isolation

While testing on hard mount benches, vibration isolated mounts and on airframes it has been shown that the amount of power and efficiency can change between setups causing the system to require more or less fuel in an EFI controlled engine at a similar load and speed. HFE

International has theorized that this variation is proportional to the amount of impulse torque applied to the flywheel (propeller). In the case of a hard-mounted engine, a larger percentage of the impulse can be applied to the flywheel where a soft mounted engine applies some of that energy to moving the engine mass on the isolation mounts. This "loss" of torque impulse applied to the flywheel directly reduces the energy that the flywheel can apply to the intake/compression stroke. Reduced momentum thus reduces overall efficiency. HFE International has modelled many types of mounts and their effect on transmitted vibration and resulting efficiency and will present some examples.

Effects on Engine Parts and Ancillary Hardware

Torque impulse on a single cylinder engine can produce up to a 10 gee acceleration per revolution. In the past 15 years and more than 100,000 hours of testing there has been a change from heavy rugged connectors, harnesses and ancillary hardware to light weight hardware and connectors. It was found that lighter weight components reduced failures. The lighter weight components reduce stress at tie points and mounts due to the lower force applied at the same acceleration. This correlates with Newtons second law. These smaller light-weight components must be very durable and as such are made from the latest advanced polymers. Some of these advancements will be shared in the presentation.

Plenary lecture

Surface Engineering for Enhancing Performance of Propulsion Systems

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Keywords: Surface engineering; texturing and coatings; friction and wear; fuel consumption; reliability.

Surface engineering technologies can enhance and optimize performance of propulsion systems by reducing friction and wear of crucial components and thereby reducing fuel consumption, improving reliability, reducing maintenance cost and increasing life cycle of these components. In this presentation we will review pioneering studies performed by the Technion tribology research group on optimization of surface texturing and coatings to obtain best performance of various mechanical components used in unmanned aerial vehicles propulsion systems.

The original idea of surface texturing is based on producing a very large number of micro-dimples on one of the surfaces of triboelements that are in relative sliding. These micro-dimples, see Fig. 1, act as micro hydrodynamic bearings in cases of lubricated contacts to produce a certain load carrying capacity which relieves the solid/solid contact pressure thereby reducing substantially friction and wear (Etsion, 2005).

Figure 1. Regular Micro-Surface Structure in the Form of Micro-dimples

Coating is one of the most effective surface engineering techniques that is widely used to enhance the surface tribological performance Holmberg et al (1998). However, trial and error is still the only way in many industries to select some important parameters such as the coating thickness and coating material properties for an optimized coating design Holmberg et al (2007). A scientific guideline is thus in need so that these parameters can be determined more efficiently. To this end, it is important to theoretically study the coated surface contact.

The contact between two rough surfaces occurs at the summits of their highest asperities. The summits of these asperities can be assumed spherical and the contact of two rough surfaces can be replaced by a single equivalent rough surface contacting a rigid flat. Fig. 2 presents schematically such a contact between a coated rough surface and a rigid flat where the coating follows the roughness of the substrate. A statistical approach can be used for studying the contact of rough surfaces. For this, a contact model of a single coated asperity in contact with a rigid flat has to be developed. Indeed, several such models were developed in our research group to optimize tribological performance of both soft and hard coatings. These models include. For example, onset of plastic yielding Goltsberg *et al* (2011), weakening effect of very thin hard coatings Goltsberg and Etsion (2013), strengthening effect of soft coatings Goltsberg *et al* (2018), static friction coefficient of hard coatings Chen and Etsion (2018) and many more. Some of the models were already verified experimentally Bar-Hen and Etsion (2017), showing that an optimum coating thickness exists depending on substrate surface roughness and on coating and substrate material properties.

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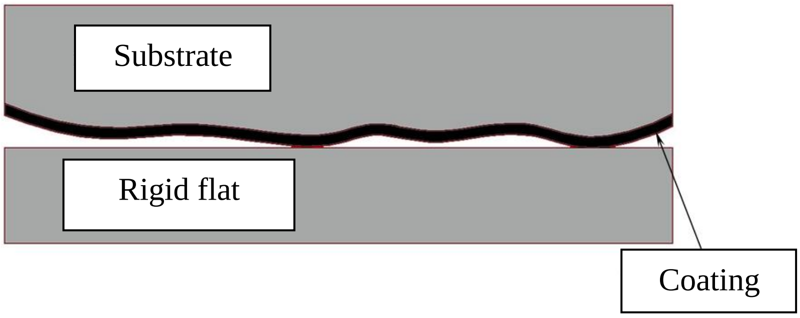

Figure 2. A coated rough surface in contact with a rigid flat

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Four-Stroke Diesel Engine with In-Cylinder Steam Reforming for High Altitude Operation

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Keywords: Steam reforming of methanol; small aircraft; Diesel engines; high altitude conditions

Due to the low ambient pressure, the operation of a natural-aspirated four-stroke engine at high altitude is very limited. Supercharging is an effective mean to extend the upper-limit altitude, but this arrangement calls for additional significant weight, thus shorten the aircraft cruising range. Here we propose a different unique method to extend the upper-limit altitude. We propose a special in-cylinder steam reforming arrangement to significantly increase the engine efficiency at high altitudes, thus allowing engine operation at higher altitudes with a negligible weight penalty. The gain in the engine performance at high altitude is attributed to the present unique method of heat recovery, the charge increase, the wider flammability and the higher burning velocity of the hydrogen-enriched mixture as obtained by the in-cylinder steam reforming process.

The principle is demonstrated by considering a conventional Diesel engine. We show that with a suitable in-cylinder catalyst and well controlled injection of the fuel/steam mixture during a certain period in the compression stage, a significant increase in the ideal cycle efficiency is achievable (from 67% to 78% at SPT atmospheric conditions for an initial compression ratio of 25). In such an arrangement, the fuel injection session comprises a two-stage process. In the first stage, fuel and water are injected over the catalyst into the hot cylinder charge during late-stage compression. Residual heat is absorbed due to a steam reforming process to produce hydrogen. The heat absorption cools the compressing mixture and enables higher amount of cylinder charge, and a higher compression ratio up to the maximum allowed pressure, while the temperature of the cylinder charge remains constant. In the second stage, only fuel is injected to initiate combustion while the absorbed heat (of the first stage) is released through the hydrogen oxidation. Essentially, the absorbed heat is exploited to produce extra hydrogen fuel, which increases the cycle efficiency. Preliminary comparative tests with a real diesel engine have shown promising results. In these tests, we measured the pressure diagram in the commercial engine and in the modified one, and analyzed the diagrams to yield the instantaneous rate of heat absorption and release during the cycle. The engine power and its fuel consumption were also measured, and showed a power increase of around 10% and a corresponding decrease in the specific fuel consumption of about 8%.

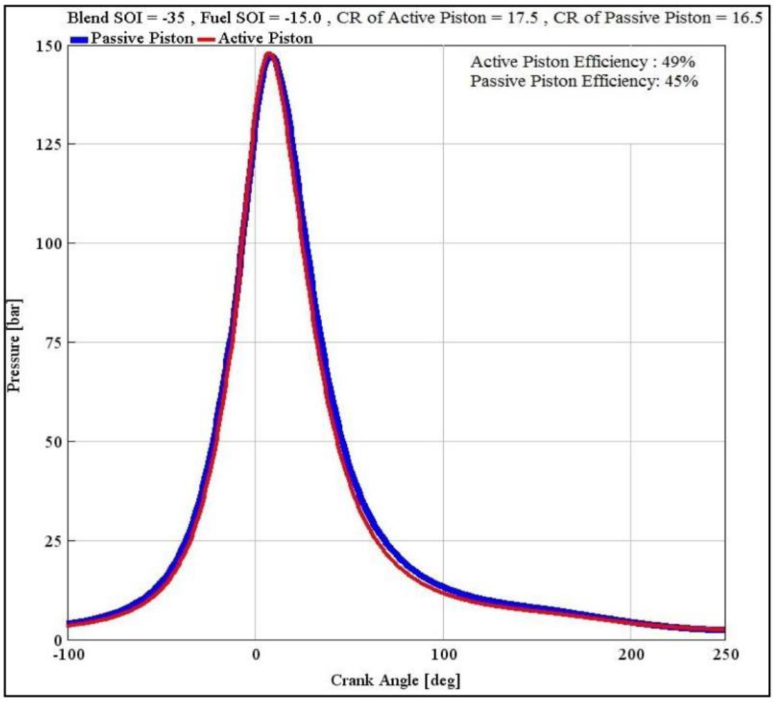

Figure 1 – The pressure trace diagram of the modified Diesel cycle for active and passive catalysts

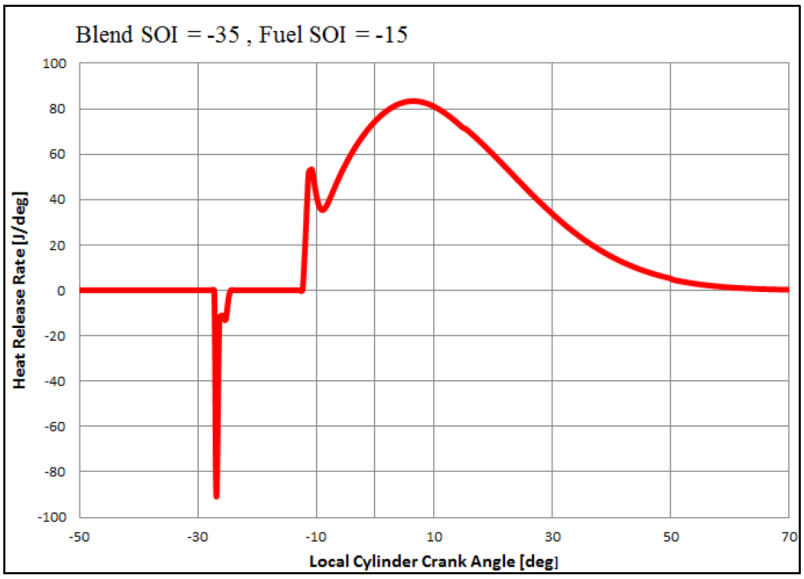

Figure 2 - Apparent Gross Heat Release Rate (Energy per Degree)

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Exploring the Use of Hydrogen Enriched Fuel in an Internal Combustion Engine Powered UAV

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Keywords: UAV; Hydrogen Enrichment; Internal Combustion

In recent years, much research effort and interest has gone into hydrogen fuel-cells, with several prototypes being built by both the automotive and aeronautical industries. As a result, much advancement has been made regarding safe on-board hydrogen storage, and on-board hydrogen production. This new generation of light-weight hydrogen storage tanks, hydrogen on-board generators and hydrogen supply components may assist in expanding the range of current internal combustion engine (ICE) UAV's by means of fuel enrichment.

The advantages of hydrogen combustion in ICE are well established. For spark ignition (SI) engines, hydrogen's higher flame speed and lower combustion temperatures contribute to a reduction in heat-loss, while its wide flammability limit allows stable ICE operation with very lean hydrogen-air mixtures. However, the low density of hydrogen gas, requiring large heavy storage tanks for any sort of reasonable range, deemed attempts at building a hydrogen fuelled ICE automobile as unviable (let alone airborne platforms where weight restrictions are even higher).

It has also been established that the same advantages of combusting pure hydrogen (if to a lesser extent) can be achieved with combustion of hydrogen enriched gasoline. A review of the literature on the subject matter found BSFC improvement of up to 20% demonstrated at part load [1].

With a typical UAV mission profile consisting mainly of cruise and loiter, inherently part-load engine operating regimes, a hydrogen enrichment system operational only during cruise and loiter can offer BSFC savings that will go towards expanding the UAV's range and mission time.

The viability of a hydrogen enrichment system as such will be examined for a typical ICE powered MALE UAV. The weight constrictions of such a system will be discussed and compared with available data on current hydrogen storage and production methods.

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Is a Hydrogen Fuel Revolution just around the corner?

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Keywords: Hydrogen Fuel; Fuel Cell; FCEV; Hydrogen Economy; Energy Transition

According to the US Energy Information Administration - Annual Energy (IAE) Outlook 2019 - in the year of 2050 gasoline vehicles are expected to keep the Lion Share of US light-duty vehicles sales or 70% of the annual light vehicles market, where BEV's share to be 14% , FFV's share to be 6%, PHEV's, Diesel and others share to be 10%. These figures are consistent with IAE reports from the Obama term.

The IAE Outlook of a gradual increase in the presence of EV's during the next 30 years, is in agreement with historic data from several countries that went through natural as well as enforced transportation technology transitions, and on the other hand it challenges highly-optimistic predictions and forecasts of national and organizational entities that perceive Hydrogen FCEV's as the ultimate future clean transportation technology.

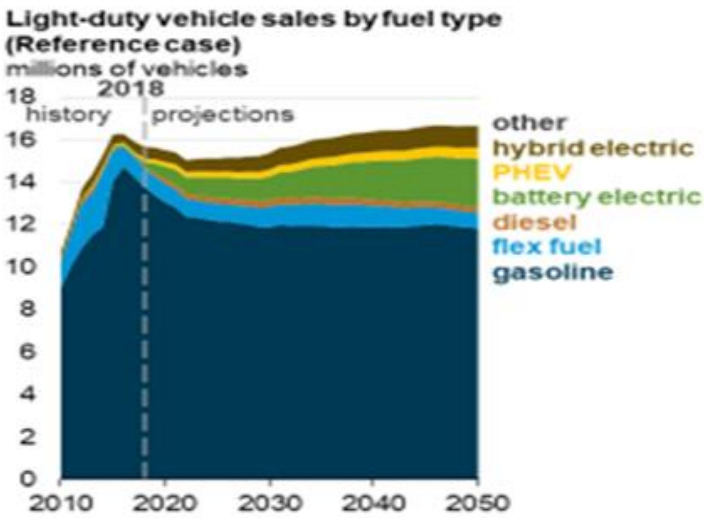

Figure 1 US EIA Vehicles market share forecast 2020-2050

Understanding the challenges related to the Hydrogen Economy and to the Hydrogen Fuel visions as part of the Electric Vehicles vision is therefore a key issue when planning ones national energy portfolio, as well as national infrastructure in light of transportation technology transition forecasts.

In our review, we will challenge the "Hydrogen Revolution" vision, through the historical data of the 50 years long diesel transition in France, as well as the short-time, constrained and partial transition to ethanol fuel in Brazil during the military regime. We will argue that optimistic predictions of FCV's and EV's market-share tend to disregard the significance of incentives and mandates, although financial and non-financial incentives strongly influence sales. We will show that almost all of US FCV's are in California, and almost half of US EV sales are in California, where state and local incentives are added to the federal tax. We will show the effect of incentives in Holland, illustrated by a characteristic pattern of a spike in sales before the incentives expire and a sharp drop afterwards.

We will go through the Hydrogen Fuel concept, and how it is being promoted in several countries and by several international organizations as the ultimate clean and green future energy. We will review the 3 major vehicle manufacturers in Japan and Korea have developed and commercialized Fuel Cell Cars, and their plans to commercialize Fuel Cell Busses and Trucks.

We will discuss through the hydrogen technology key parameters: Production, Logistics, Pollutants, Safety, Barriers, Costs, and will claim that Hydrogen is a far more challenging fuel comparing to other fuels involved in transportation transitions. We will indicate that transportation transitions are proven to be slow, and also hydrogen is expected to remain such, as it is strongly dependent in local factors, and in substantial budgets and incentives. We will conclude that the viability of hydrogen as a broad range future transportation fuel in near future is questionable, though it may take a market share in specific niches and countries.

We will present DMFC technology as an emerging potential competitor to hydrogen FC technology and will talk about methanol as a valid clean fuel for marine applications and heavy duty trucks, and HALE drones. We will discuss the use of hydrogen in high altitude, and will talk about a methanol drone with TCR and HP hydrogen injection as a viable alternative to a classic drone with typically two turbochargers.

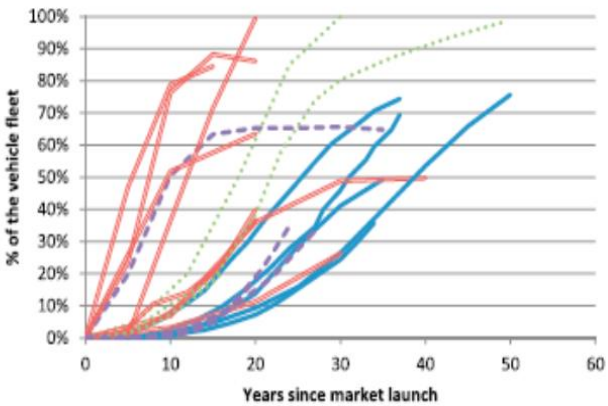

Figure 2 FCEV's Forecasts since Years of market launch

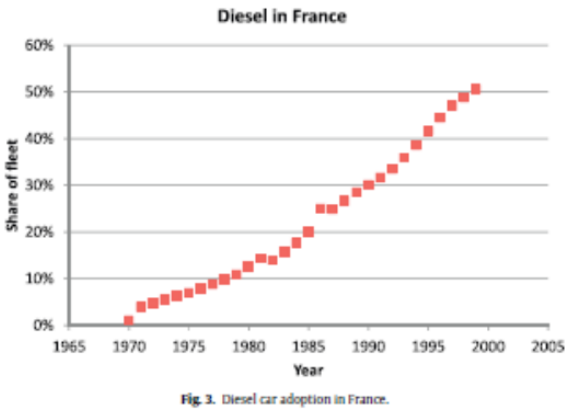

Figure 3 Diesel Cars Market Share in France

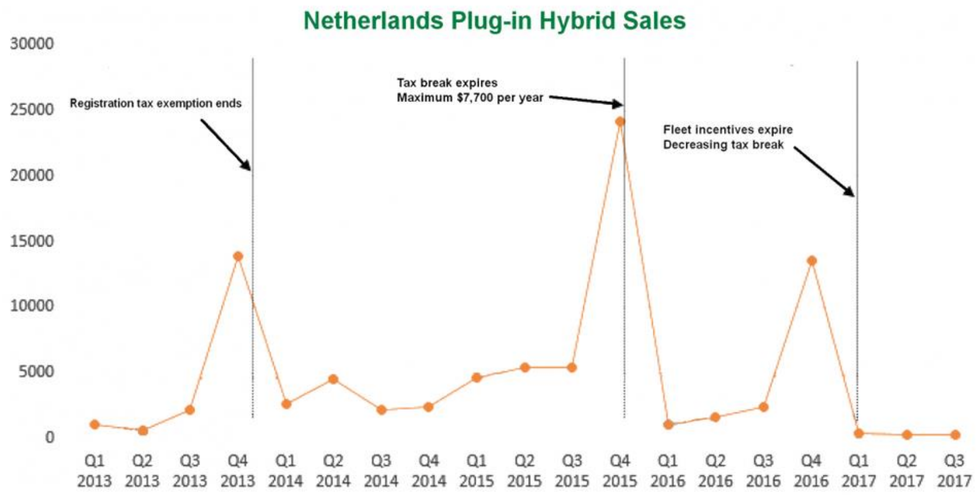

Figure 4 Incentives Dependence of PHEV Cars in the NL

Rate Limiting Constraints in Phase-Change-Materials (PCM) for Miniature Aircraft Propulsion Systems

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Keywords: Micro Aerial Vehicles; Phase Change Materials; Nucleation; Thermodynamic stability

With the immeasurably growth of use in Unmanned Aerial Vehicles (UAV), so does the need for Micro Aerial Vehicles (MAV), which require extremely lightweight propulsion systems. Whereas common MAV currently use electric batteries as their power source, this work examines the possibility of using Phase-Change Materials (PCM) in such propulsion system; where PCM are substances characterized by high latent heat, e.g. cryogenic fluids.

The proposed system involves a rapid depressurization of such substances (see O-B line in Figure 1) from a stable liquid state to create vapor nuclei (bubbles), followed by nuclei growth till they coalesce, forming a continuous vapor phase which is heated and later drive a micro-turbine. Therefore, the transformation rate from liquid to vapor plays a prominent role in the system, and the limiting transition rates of several materials are investigated in terms of their initial temperature and pressure (with respect to the critical values), as well as of the dimensions of the orifice through which they exit.

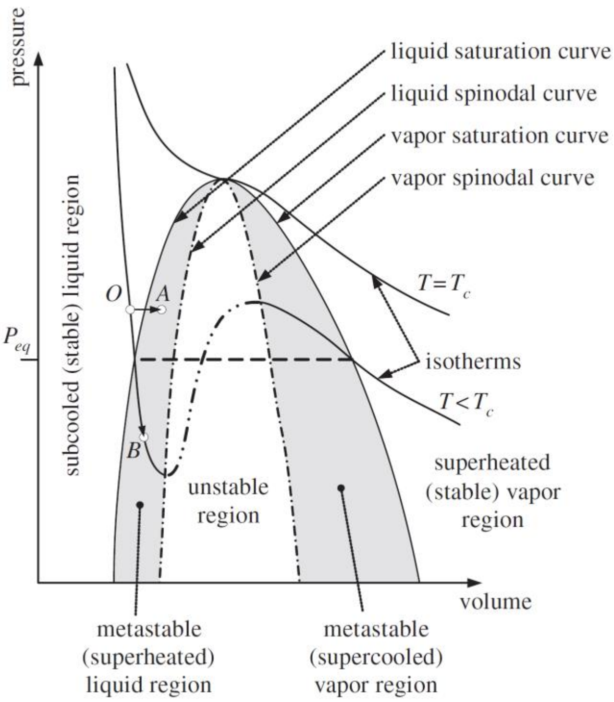

Figure 1. Isotherms of a pure liquid depicted on a P-V diagram (Sher, et al., 2008)

While the applicable initial temperature range is quite narrow and restricted to the vicinity of the critical temperature due to nucleation considerations (both homogeneous and heterogeneous), the initial pressure is rather wide and was only limited to avoid heavy pressure vessels. However, changes in both parameters significantly affect the nucleation rates obtained and the products of propulsion systems, thus a parametric analysis of these impacts is reviewed using the Classical Nucleation Theory, Carey's estimation (2007) and two common heterogeneous nucleation theories - by Alamgir and Lienhard (1981) and Elias and Chambr`e (1993).

Out of 11 inspected substances, Hydrogen was found to be the most promising substance in terms of both specific energy and power, thanks to its remarkably low molar mass. With specific power values surpassing 1000 [W/kg] and specific energies of over 500 [W-h/kg] (under the dimensions constraints defined), it can overpower electric batteries and enables long-term missions of few hours, offering a real alternative to the current technologies powering MAV. Though being relatively inferior to Hydrogen, Methane also seems be capable of propelling MAV; with specific power possibly surpassing 200 [W/kg] and specific energies of up to 80 [W-h/kg]. Comparison of the attained results was performed using a Ragone chart (1968), as depicted in Figure 2.

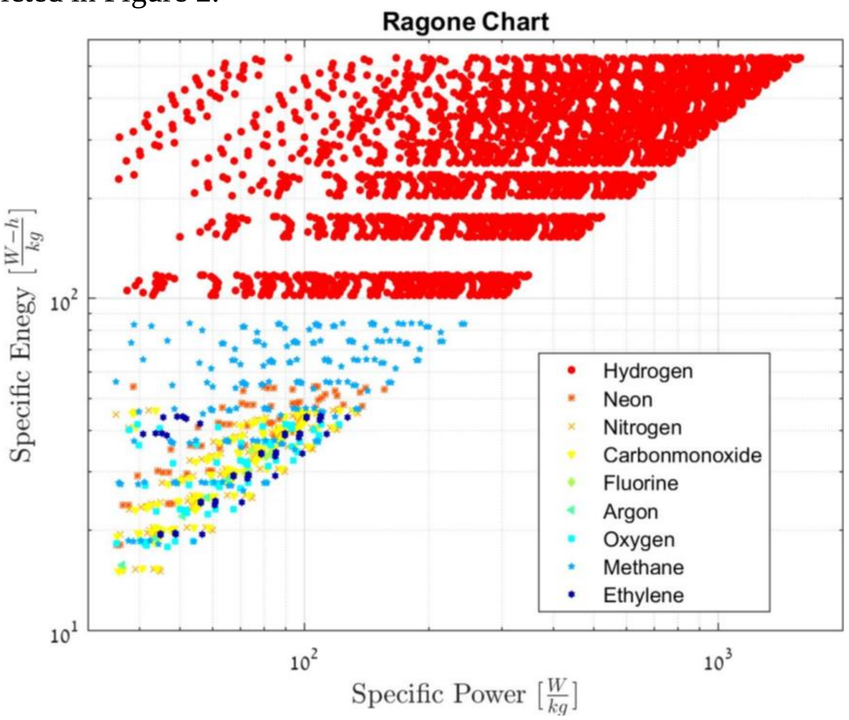

Figure 2. Ragone chart summarizing all possible outputs of the suggested propulsion system, using the inspected fluids

If the volume of the pressure vessel becomes rather significant than the fluid mass, restricting the system dimensions; Neon offers rather elevated volumetric outputs, with power density of up to 10^5 [W/m^3] and maximal energy density of $4.3 \cdot 10^4$ [W-h/m^3].

According to the abovementioned results, decompressing PCM can be clearly used as an alternative to the current MAV (and larger vehicles) propulsion systems.

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Long term maintenance and preservation of UAV propulsion systems

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Keywords: UAV engines, Preservation

Keeping a UAV fleet operational for long periods of time is a major challenge encountered by all UAV manufacturers and operators. Strict maintenance policies are implemented to ensure reliable operation of the UAV and particularly its propulsion system at all times. These procedures are based on continuous maintenance of the UAV, where the engine is either in continues operation or inoperable for long periods of time. Some UAV operators rarely use their equipment and often store the vehicle inoperable for long periods of time ranging from months to years. Making sure these engines stay airworthy after long periods of inoperability is a tedious task initialling countless man hours renewing preservation and replacing materials which are very costly.

During normal engine operation, contaminants such as humidity may be found in the fuel, oil and coolant. When the engine is active and run on a regular basis (minimum of one engine run every thirty days in order to be considered an active engine), this is generally not an issue, since the contaminants will flow down into the combustion chamber and be consumed there. It's a different story if the engine is in storage for an extended period of time. Contaminants will settle in areas that could lead to corrosion or deterioration of the engine parts, for example direct sunlight can deteriorate oil lines, humidity and sea side conditions can accelerate corrosion on metallic components, all these adversely affect engine performance.

Multiple methods of engine preservation are known in the open market today but are mostly for short term seasonal storage, long term engine storage requires periodical preservation renewal in order to insure the preservation status.

Due to continuous customer demands for the reduction in maintenance efforts and costs a thorough investigation and examination of engine components was conducted and a methodology for long term storage with extended periodical preservation renewal was developed.

Incorporating a user friendly process for long term preservation reduces the reliance of a customer skill set for preserving an engine, whilst insuring sufficient protection to the engine during this period, decreasing the need for management control for each periodical renewal and in the end a reduction in overall maintenance cost.

Centering and friction reduction between parts of the cylinder-piston group

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Keywords: Reciprocating motion; Hydrodynamic lubrication; Surface texturing; Friction reduction.

The current study is devoted to the development of the relative motion (axial, radial and tilt) model of the piston and cylinder liner. The piston and the cylinder liner may be parts of the internal combustion engine; plunger pump; piston compressor etc. The nominal radial clearance between the piston and the cylinder liner is very small, and is filled with viscous liquid or gas. The piston and cylinder performs a relative axial reciprocating motion in accordance with the predetermined law in time. Generally, the piston separates the "high" and "low" pressure areas. So, the gap viscous liquid or gas are located between the eccentrically moving walls in the presence of an axial pressure drop.

The possible frictional contact between the piston and the cylinder liner is a potential cause of the energy losses and increased wear of the contacting parts. To reduce the damage from the contact between the mating surfaces, it is desirable to achieve centering of the piston during its relative motion inside the cylinder liner. One way to achieve the centering of the piston is its profiling, which provides a supporting radial effect of the viscous liquid or gas in the gap with the cylinder liner.

One of the effective manners of the piston profiling is utilization of the axial step bearing effect. The main goal of the present study is to find the best parameters of the step bearing providing the minimum energy losses due to possible contact between the relatively reciprocating moving piston and the cylinder liner by means of the piston centering.

The governing equations of the analytical model include the Reynold’s equation of the classical lubrication theory of the incompressible liquid flow or compressible gas flow with the corresponding boundary conditions; and the dynamic equations of the piston motion inside the cylinder liner with corresponding initial conditions. The piston and cylinder liner are considered as rigid bodies. The relative piston-cylinder motion has three degrees of freedom (axial, radial and tilt); however, the axial motion is predetermined. Therefore, only two dynamic equations (corresponding to two other degrees of freedom) are considered beside of the Reynold’s equation. The relative radial displacement of the piston center of mass and the piston tilt angle around the center of mass are used in the model as two these degrees of freedom. The model implies a simultaneous solution of the hydrodynamic lubrication theory equation (Reynold's equation) and the dynamics equations.

The unknown time functions in the equations of dynamics are the radial displacement of the piston mass center and the piston tilt angle, and the unknown time function in the Reynold’s equation is the local pressure in the gap between the piston and the cylinder liner.

Because of the cumbersome nature of the analytical model, the problem of simultaneous solution of equations was solved numerically. The solver of the Reynold’s equation (algorithm and computer code) was developed based on the finite difference method that leads to a set of algebraic equations for the nodal values of the pressure, which should be solved with the corresponding boundary conditions. Dynamics equations are also solved numerically using the Euler or fourth order Runge-Kutta methods with given initial conditions.

After simulation of many time steps, a picture of the longitudinal, transverse and rotational motion of the piston inside the cylinder liner appears. Based on the obtained results, it is possible to estimate how close the piston approaches the cylinder wall during the reciprocating motion.

The estimation of the optimal piston geometry included the consideration of the various aspect ratios (length vs depth) of the step.

The analysis shows that the step profile from the high-pressure area side provides the movement of the piston along the cylinder liner axis and prevents contact between them.

Poster presentations

Development of Adaptive Cycle Micro-Turbofan Engine for UAS Applications

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Keywords: Variable cycle engine; turbojet-turbofan conversion; mission analysis; continuously variable transmission; variable bypass nozzle area

As operational envelope of unmanned air vehicles expands into high sub-sonic and transonic speed range, the engine design process requires compromises in thrust, weight, fuel consumption, size, reliability, and manufacturing cost. Moreover, engine requirements for multiple operating points (loitering and high-speed cruise) are conflicting design criteria for an efficient propulsion system. Nowadays the vast majority of modern UAV platforms are intended towards low speed applications. Therefore, the thrust is typically generated by an internal combustion engine, which drives a propeller. The typical thermodynamic cycle efficiency of these small-scale Gasoline Direct Injection or Diesel engines are ~ 35%. However, this propulsion scheme that utilizes a reciprocating engine is unsuitable for high speed flight.

Durable, highly efficient and lightweight turbofan engine is proposed to replace the current internal combustion engines. The proposed solution involves a single shaft micro turbojet to micro turbofan conversion via introduction of a fan coupled with a continuously variable transmission and a variable bypass nozzle. Later such engine can be upgraded with exhaust gas recuperation, which will significantly boost engines efficiency.

As micro gas turbine market suffers from restrained design costs, in order to shorten the design process to a minimum and to increase engine maintainability, the aspiration is to entail as few changes as possible to the existing turbojet engine core. The solution should significantly improve maximum thrust, reduce fuel consumption by maintaining the core independently running at its optimum, and enable wider operational range, while preserving simple single-spool configuration. Moreover, the variable fan coupling would allow real-time optimization for several operational modes. In addition to controllability benefits, the acquired thrust increase directly translates into greater take-off weight, while independently varying bypass area and fan speed enable transonic flight and general reduction in fuel consumption. The combination of these effects (Figure 3) yields an increase in range and loiter time. The aircraft architecture equipped with this adaptive engine can realize unique missions that were prior unattainable or required different UAV propulsion systems. One of such representative missions on which was decided to demonstrate engine performance, could be a surveillance mission.

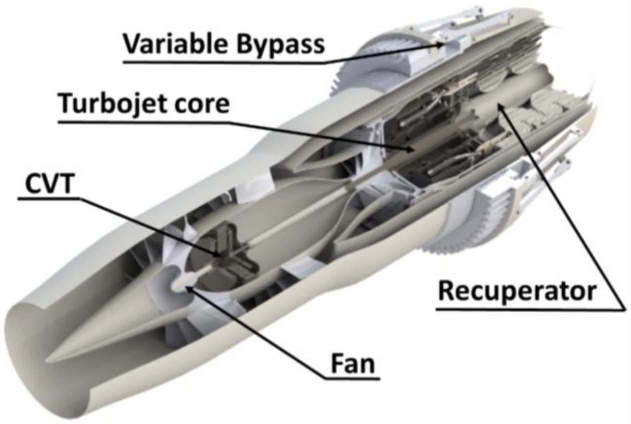

Figure 3: Illustration of CVT Coupled Turbofan with Variable Bypass Nozzle and Recuperator

For the analysis of the surveillance mission, a remote location is considered to suffer from a natural disaster. There is an urgent need to provide surveillance assistants to rescue teams on the ground. To answer their call, UAV powered by two adaptive engines will be sent to support. The UAV will ascend to 9 km altitude and cruise towards disaster region at Mach 0.9. Then it will loiter above a target maximum time possible at 5 km altitude. During this hypothetical simulation we compared performance of different engines architectures. The UAV powered by variable-gear/variable-bypass turbofan showed superior performance and was able to stay 60 minutes more above the target location, resulting in 20% additional loiter time in comparison to other propulsion systems. Comparison of various propulsion systems for three major segments of the mission can be seen in Figure 4.

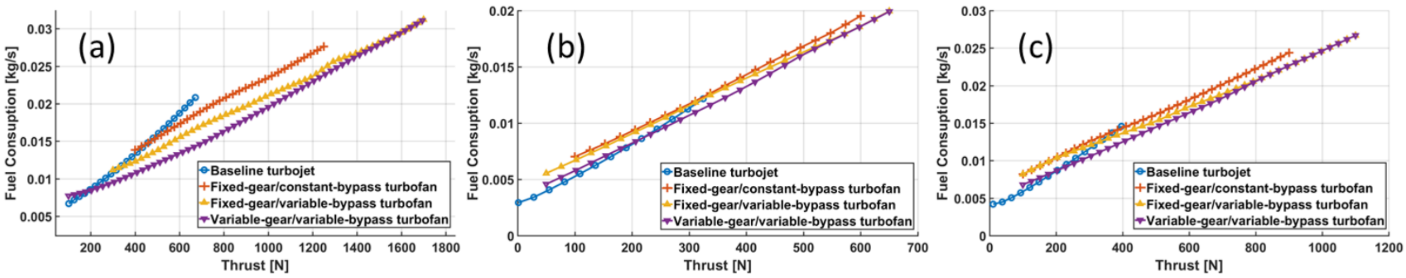

Figure 4: Comparison of various engine architectures through thermodynamic analysis: (a) Take-off, (b) Loiter, (c) Cruise

Acknowledgement

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POTENTIAL OF ADDITIVE MANUFACTURED FOR THE DESIGN OF A 300 W MICRO GAS TURBINE TOWARDS UAV APPLICATIONS

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Keywords: Ultra Micro Gas Turbine, New Gas Turbine Architectures, Additive Manufacturing, Ceramic Materials, Conjugate Heat Transfer Analysis, Reduced Order Modelling

Owing to the high energy density of hydrocarbon fuels, Micro Gas Turbines with power outputs below 1 kW have a clear potential as battery replacement in drones. However, previous work on gas turbines of this scale revealed severe challenges due to air bearing failures, heat transfer from turbine to compressor, rotordynamic instability and manufacturing limitations. To overcome these obstacles, a novel gas turbine architecture is proposed based on conventional roller bearing technology operating at 500,000 rpm and an additively manufactured monolithic rotor in cantilevered configuration with internal cooling blades. The optimum turbomachinery design was elaborated using a diabatic cycle calculation coupled with turbomachinery meanline design software. This approach gave new insights on the interdependencies of heat transfer, component efficiency and system electric efficiency. In contrast to previous research, a reduced design pressure ratio of 2.5 at 1200 K turbine inlet temperature was identified for a 300 W electric power output. A review of available additive manufacturing technology yielded material properties, surface roughness and design constraints for the monolithic rotor. Rotordynamic simulations were conducted for four available materials using a simplified rotor model. Valid permanent magnet dimensions were identified to avoid operation close to bending modes. Furthermore, a novel radial inflow combustor concept is proposed based on porous inert media combustion completing the baseline engine architecture. CFD simulations were conducted to quantify compressor efficiency for different additive manufacturing technologies, comparing four commonly available materials. Moreover, conjugate heat transfer simulations of the monolithic rotor were performed to assess the benefit of the internal cooling cavity and internal vanes for four different rotor materials. It was demonstrated that the cavity flow absorbs a large amount of heat flux from turbine to compressor, thus cooling the rotor structure and improving diabatic cycle efficiency. With this novel rotor geometry, the shaft temperature can be reduced to temperatures below 100 °C thus enabling conventional roller bearing technology. The results of this conceptual study show that UMGT electric efficiency of up to 5 % can be reached, while energy density is increased by factor 3.6 compared to lithium ion batteries. Figure 1 shows the baseline engine design.

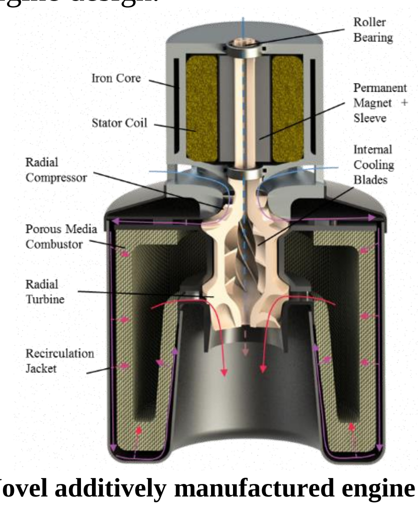

Figure 5: Novel additively manufactured engine architecture

Development of a novel direct gaseous injector for IC engine with High-Pressure Thermochemical Recuperation

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Keywords: Gaseous; DI, Injector; Hydrogen, Methanol, Solenoid, MSR

Hydrogen engines are an economical alternative to fuel cells through the implementation of combustion cycles based on Liquid Organic Hydrogen Carriers (LOHC) instead of fossil fuels. An example of such a cycle is a methanol-fueled engine with high-pressure thermochemical recuperation and combustion of a hydrogen-rich reforming mixture as first developed in the Technion IC Engine Laboratory [1-3].

One of the challenges in the above cycle is the injection of the hydrogen-rich mixture which has a major impact on combustion quality and emissions pollutant. In order to utilize the potential inherent in thermochemical recuperation and in the DI of the reformer, high flow rate through the injector is required, while the area at the engine head is limited by the valves and spark plug [2,6].

The study purpose is a development of a DI gas injector for the purpose of gathering information and creating new knowledge about the injection and mixing processes of high-pressure gaseous reformers and the development of direct gas injectors (including hydrogen-rich reformers) that will allow efficient and optimal timing injection of the gas. So far, such commercial injectors do not exist, although attempts have been made to build gas DI injectors by converting existing injectors of gasoline DI [4,5]. The prototype developed in the study is optimized for DI of hydrogen-rich gaseous mixture into a Petter's laboratory-research engine which has been converted into DI operation.

An outward-opening valve was selected, POPPET valve, instead of an inward-opening valve because the gas pressure inside the injector would be 23 [bar], while the in-cylinder pressure can reach to much higher pressure which can open the valve in an inward-opening valve configuration, the cylinder pressure is naturally seals the valve at high pressures, which promotes safety and accurate use. A higher cross area can be reached and there for a higher flow rates which is necessary in gaseous phase. See Fig 1. In this work an effective diameter of 7.8 [mm] was reached to meet the required flow rate - 30 [kg/h] of methanol steam reforming (MSR).

A solenoid actuator was chosen for the injector because it suitable for large pintle lift - calculated to 0.23 [mm], suitability for long pulse width when needed, small fuel quantity delivery when needed and minor complexity of thermal compensation because of the hot environment by pulse width and height change.

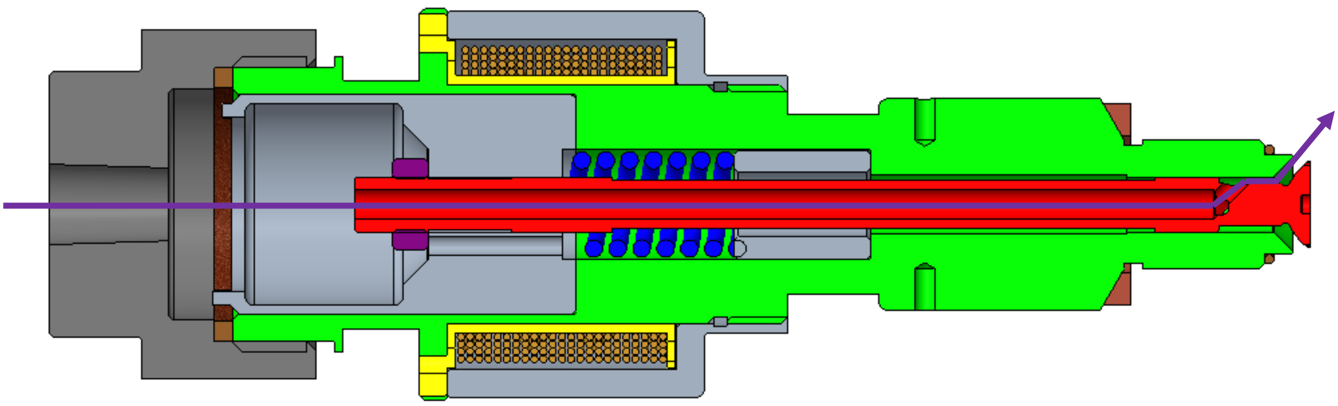

Figure 1. The injector section with gas flow marking

The mass flow calculations made acc to a chocked flow nozzle when the C_D (filling coefficient) taken for the preliminary design is 0.55 based on similar injector design [5].

For delivering the needed flow rate the solenoid designed to a short opening and closing time – about 0.002 [sec] because it needs to deliver the gas mass before the pressure inside the cylinder rise above the MSR pressure. See Fig 2.

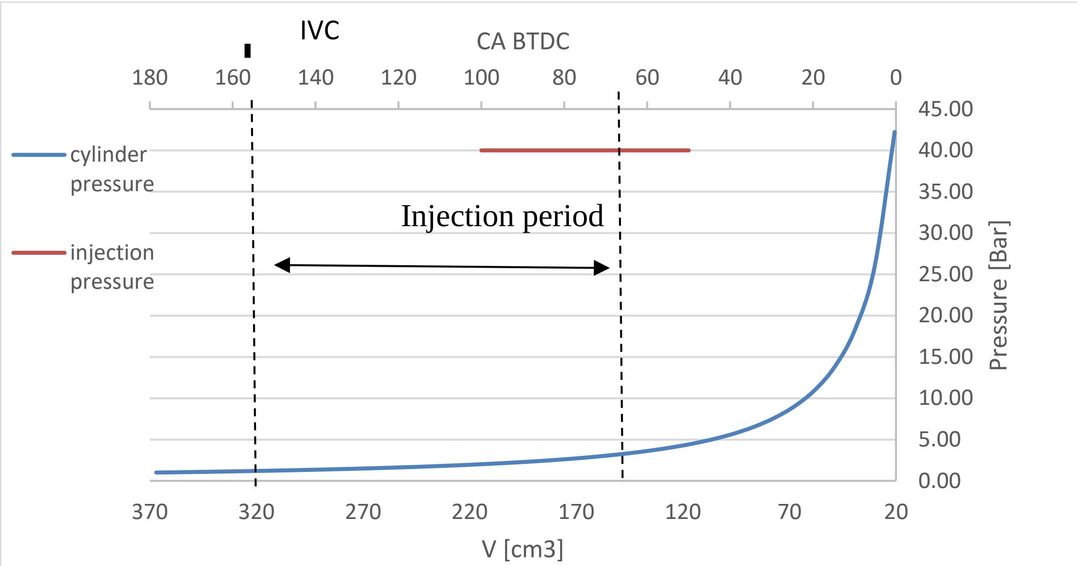

Figure 2. The fuel injection event on the isentropic compression P-v diagram of a Petter AD1. Engine geometry:
Bore x Stroke- 80x73 [mm], Compression ratio of 18.8 and Displacement of 367 [cm^3]

A 70 coils solenoid will be examined and for achieving the challenging actuation time also a parallel solenoids method will be examined because it might shorten the EMF rise-time compare to a single solenoid with the same no. of coils. The solenoids magnetic analyses predict about a 200 [N] maximal plunger starting force which gives the needed flexibility for achieving the opening time in acc to the sealing requirements. See fig 3.

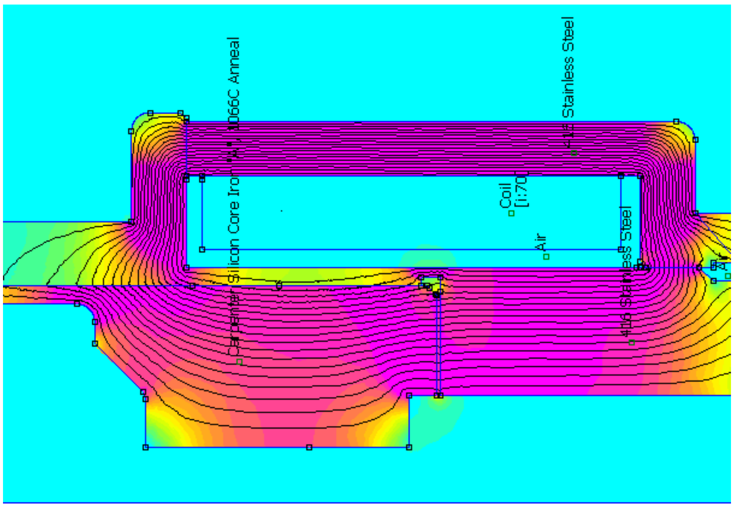

Figure 3. Axisymmetric solenoids flux density and lines analysis

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Study on Particle Formation from Hydrogen-rich Reformate Combustion Process in ICE

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Keywords: Pollutant formation; Nano-Particles; MSR; HRR; CVC

Thermochemical recuperation is a promising waste heat recovery method enabling the utilization of engine waste heat to produce onboard hydrogen-rich fuel [1]. The first ICE prototype with Methanol Steam Reforming (MSR) showed a significant efficiency improvement and gas emission reduction compared to the gasoline ICE baseline [2]. However, unexpectedly, a high particle emission level was measured despite the combustion of hydrogen-rich reformate containing 75% mol. H2 and 25% mol. CO2 [3]. Nano-Particles have a diameter of less than 0.1 μm, resulting in a significant surface area/volume ratio. Additionally, it has a high absorption characteristic making the particles to be a hazardous pollutant. Thus, due to particle toxicity, the particle formation mechanism must be investigated. The most reasonable source for the particles in ICE is the lubricant oil on cylinder walls, piston rings, and crankcase. The goal of this study is to understand the lubricant source influence on particle emissions from a hydrogen-rich reformate ICE. Thus, we have built an experimental setup of constant volume combustion (CVC) (see figure 1) representing an ICE combustion chamber. The hydrogen-rich reformate combustion inside the CVC will enable us to eliminate the lubricant source affecting particle formation. The particle measurement will be done by using an Engine Exhaust Particle Sizer (EEPS).

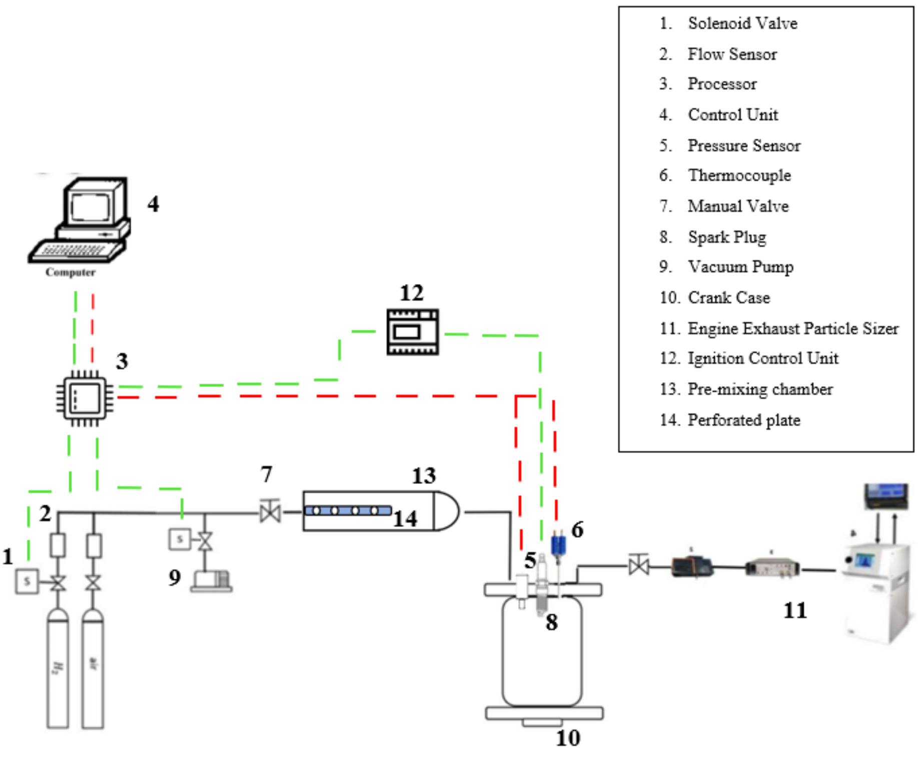

Figure 1: Experimental setup

Furthermore, we will be able to determine the heat release rate (HRR) during different combustion regimes as different CVC pressure, air/fuel ratio and etc. using a thermocouple and a pressure gauge (based on a model developed by Ceviz and Kaymaz [5]).
Reducing the particle formation will lead to further development of a hybrid propulsion system with a most efficient vehicle integrates with the lowest pollutants emission. This new technology, based on alternative fuel, for the automotive industry will lead eventually to better life quality.

Acknowledgement
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Development of a compact reformer for onboard hydrogen production in IC engine with High-Pressure Thermochemical Recuperation

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Keywords: ICE; WHR; TCR; Reformer.

Thermo-Chemical Recuperation (TCR) in ICE has been widely studied in the past decades as one of the methods to decrease pollutants from the engine and increase the efficiency of the process. This method utilizes the enthalpy of the engine's exhaust gases, known as Waste Heat Recovery (WHR) to enable the endothermic reaction of a primary fuel to produce a new fuel with better properties, usually Hydrogen. The Hydrogen is a highly rated fuel for its high Heat combustion value, wide flammability limits, high flame velocity and low carbon pollutants. However, due to its extremely low density there is a problem to store the fuel in a reasonable tank size, and compressing the hydrogen is limited due to its high flammability which introduces security issue. Onboard Hydrogen production by TCR avoids that barrier.

Supplying the hydrogen-rich reformate through the intake manifold enables less air to ingest into the cylinders due to the hydrogen low density, thus, decreases the volumetric efficiency. Direct Injection (DI) of the reformate can resolve this problem and also prevents uncontrolled combustion that might occur outside the combustion chamber due to the wide flammability limits of the hydrogen. However, raising the pressure by compression of the reformate in order to enable direct injection consumes a large amount of power, which significantly impairs the efficiency.
A former research that was carried out by Poran *et al* (2018) showed that High Pressure Thermo-Chemical Reforming (HP-TCR) can avoid this energy consumption penalty and this by pressurizing liquid primary fuel before its evaporation and reaction (Fig.1).

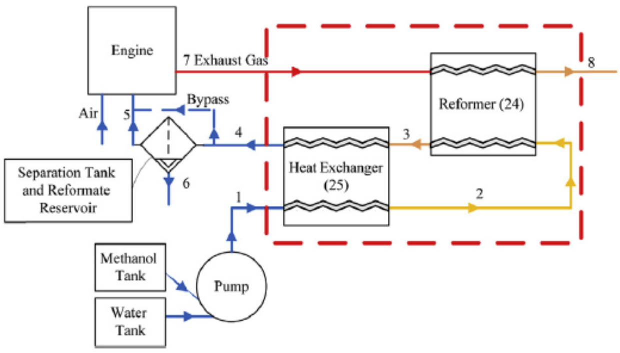

Figure 1. Schematic layout of the flow arrangement in ICE with HP-TCR, *Poran at al (2018).*

This work is focused on the development of a compact reformer for the presented above HP-TCR system where methanol and water react in order to produce onboard hydrogen and also carbon dioxide as a side product. Besides the arrangement of the catalyst in the reformer for maximum mass transfer which includes studying the coating process, the reformer needs to be designed in a way that will maximize the heat exchange between the exhaust gases and the fuel-water mixture. However, achieving high heat transfer coefficients by applying turbulent regimes will inevitably increase head losses. High head losses will increase the pressure at the exit of the combustion chamber and thus decrease the volumetric efficiency.

A method that maximizes the heat transfer area between the fluids but keeps the flow at a laminar regime for minimum head losses was developed based on the advanced capabilities of additive manufacturing (3D printing). The idea was to enable a chess pattern arrangement of the hot and cold channels for maximum heat transfer area (Fig.2).

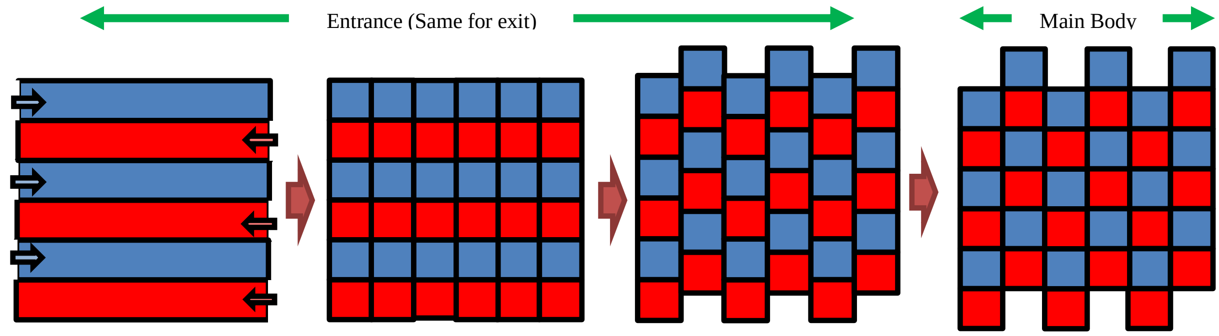

Figure 2. Schematic hot and cold tunnel arrangement cross sections along the reformer.

The reformer is designed to withstand the high pressure at the TCR reaction but still with careful attention to minimize weight and volume in order to stay attractive for automotive and aviation applications. The reformer is designed so it can work at a range of engine regimes. A study was performed for understanding the limits of the range and the effect of several parameters on both the range and the engine efficiency. The heat exchanger (numbered 25 at Fig.1), for example, is important in order to cool the reformate before its injection for achieving maximum volumetric efficiency. But on the other hand, skipping the cooling of the reformate can result in relatively high temperatures at the exhaust (T7), to reduce minimal achievable exhaust gas temperature at the reformer exit (T8) and thus, enable to widen the range of the system to withstand light load regimes (Fig.3).

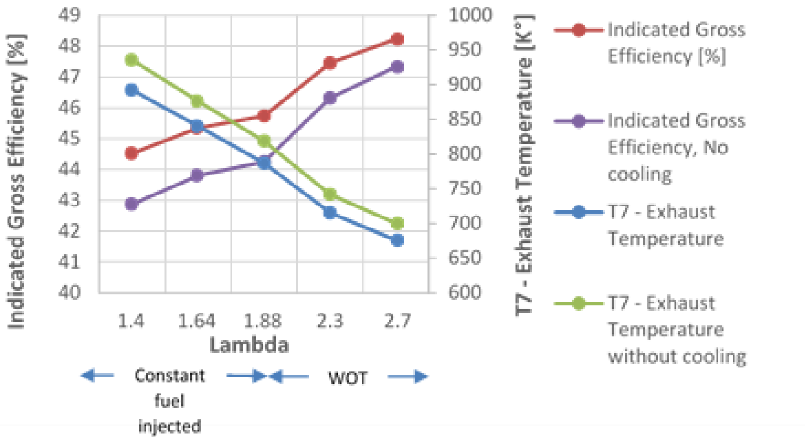

Figure 3. Engine Indicated Gross efficiency and Exhaust temperature in different regimes at Injection Pressure 30 Bar and 2.2mm diameter IRFD.

Acknowledgement
This work was supported by the Israel Innovation Authority in the framework of KAMIN program.

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Reduction of combustion irreversibility through combining Fuel Cell and Internal Combustion Engine

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Keywords: Combustion, ICE, Fuel Cell, Irreversibility

The study deals with energy conversion of fuels for the purpose of work extraction. The main idea of the proposed research is increase of the energy conversion efficiency in propulsion systems beyond the currently known levels through reduction of combustion irreversibility. The latter is achieved by combining a Fuel Cell (FC) and an Internal Combustion Engine (ICE) in a hybrid propulsion configuration. The novelty of the suggested approach is in reduction of combustion irreversibility by the combined production of electrical and mechanical work out of fuel oxidation process by combining a fuel cell with an internal combustion engine, where both FC waste heat and unreacted hydrogen are utilized in the combustion cylinder of ICE.

In ICE, the internal energy of the fuel that consisted of molecular bonds is converted in a process called combustion. The conversion is to another form of energy – kinetic energy of the new molecules, which represented macroscopically as high temperature. From this stage, combustion engines operate similar to heat engines, i.e., work is extracted from heat (for example, in internal combustion engines by pressure in the cylinder acting on the piston), and a certain amount of heat is wasted to the surrounding (by exhaust gases and heat transfer losses).

In FC, a chemical reaction between fuel and oxygen takes place by splitting the reactant molecules to ions and electrons, and then recombining them to products. The advantage of this route is the ability to produce electrical work from the separated charges, and thus it is called electrochemical reaction. The separation process of the atoms and the movement of the charges cause voltage losses. This affects heat generation in a fuel cell. FC typical efficiencies are between 35% and 65% (O'hayre, Ryan, et al, 2016), i.e., heat generation is in the same order of magnitude as the work produced. In addition, typical FC working at the optimal operating mode exhausts between 10 to 60% of the supplied hydrogen fuel (Kulikovsky, A. A., 2009). Hence, utilization of this unreacted fuel and waste heat is of utmost importance and could allow significant efficiency gain.

In order to assess the boundaries of the potential efficiency and power increase, thermodynamic calculations were performed. In these calculations, first and second laws of thermodynamics were applied. Efficiency and power of ICE were calculated, based on the theoretical Otto and Diesel cycles, with modification of the cooling losses influence. The fundamental calculations were focused on the influence of the combustion driving force on power and efficiency. A potential of producing electrical work in the process of combustion was evaluated.

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Reforming-controlled compression ignition with OME_1 synthetic e-fuel: engine simulations and heat-release rate investigation

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Keywords: Homogeneous Charge Compression Ignition; Reactivity-control; Thermochemical Recuperation; Oxymethylene Ethers; Fuel Reforming.

In current ICEs, one-third of the supplied fuel energy is wasted along with exhaust gases. This wasted energy can be recovered by various waste heat recovery (WHR) methods. The WHR method that utilizes exhaust gas energy to sustain endothermic fuel reforming reactions is often referred to as thermochemical recuperation (TCR). TCR presents two major advantages over other WHR methods: (1) lower heating value (LHV) increase due to the WHR through endothermic reactions and (2) onboard hydrogen-rich reformate production leading to increased flame velocity, wider flammability limits, and reduced combustion irreversibility. Hence, TCR improves ICE efficiency, not only due to WHR but also because of lean burn benefits, approaching efficiency of ideal Otto cycle with a potential of using higher compression ratios.

Combination of TCR and homogeneous charge compression ignition (HCCI) combustion (HCCI-TCR) (Fig.1) enables further improvement of thermal efficiency and simultaneous mitigation of nitrogen oxides (NO_x) and particulate matter (PM) formation. HCCI combustion is governed by a chemical-kinetic mechanism, in which homogenously premixed air-fuel charge is compression-ignited. There is no direct control tool, as ignition or injection timing in a SI or CI engines, respectively. As a result, controllability of ignition and combustion phasing in HCCI process are the main challenges.

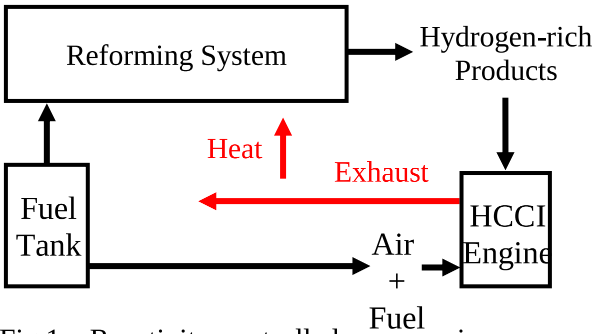

Fig.1 – Reactivity-controlled compression ignition system

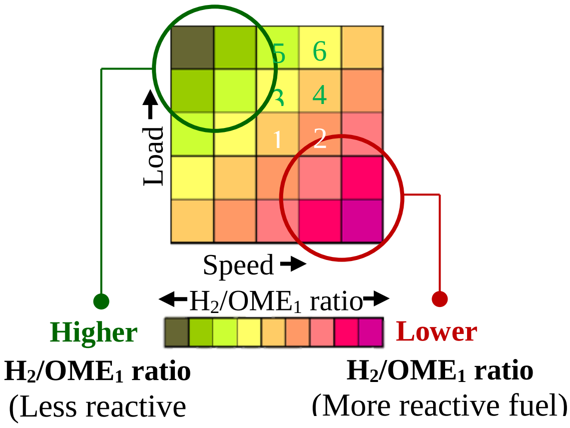

Fig. 2 – Engine fuel-reactivity demand [1]

Combustion management in HCCI engine is possible by controlling reactivity of combusted fuel, through controllable variation of fuel composition and fuel characteristics, depending on engine operation mode. At given engine regime (load and speed), the combustion timing is determined by the reactivity of the fuel injected into the cylinder (Fig.2). In case of HCCI-TCR system, primary single high-reactive fuel can be used, providing low-reactive hydrogen-rich fuel after reforming and supplying into the cylinder both the non-reformed and the reformed fuels in the controllably varying ratios. Combination of reactivity-controlled compression ignition (RCCI) with WHR through TCR is called Reforming-Controlled Compression Ignition (RefCCI) [1].

The selection of a primary fuel is very important for any engine, especially for an HCCI engine with TCR. Availability and supply infrastructure of the primary fuel, as well as the energy value, the thermal conditions of the reforming process, the reformate composition, the cost of catalysts and long term stability factors should be taken into account. Mentioned above criteria can be possibly met by oxymethylene dimethyl ethers (OMEs), a class of oxygenated synthetic fuels, which have recently attracted increasing interest due to their fascinating characteristics. The simplest compound in OME family is OME_1, also named dimethoxymethane (DMM) or methylal. OME_1 stays in liquid phase at ambient conditions, due to its relatively high boiling point (42˚C). This allows convenient fueling without any need in new fueling infrastructure. In addition, methylal can be renewably produced through CO_2 trapping (e-fuel, P2x fuel). Steam-reforming of OME_1 is possible with moderate exhaust gas temperatures (~250-300˚C) over bi-functional catalyst [2].

The reported study was mainly focused on two primary objectives: first, a comparison and validation of methylal oxidation and pyrolysis mechanisms in terms of ignition delay times and heat release rates (HRR) using a control volume combustion apparatus (CVCA) model; second, an investigation of possibility to control HCCI combustion process by controlling OME_1 reforming products composition. Both aspects were analyzed using GT-Power software, which is a common tool in the research and development of ICEs. Generally, fuels with lower octane ratings, such as n-heptane, diesel and DME (OME_0), display two-stage ignition. However, a unique phenomenon has been discovered in this research by simulating three different combustion mechanisms of OME_1 suggested in [3-5] in CVCA model.

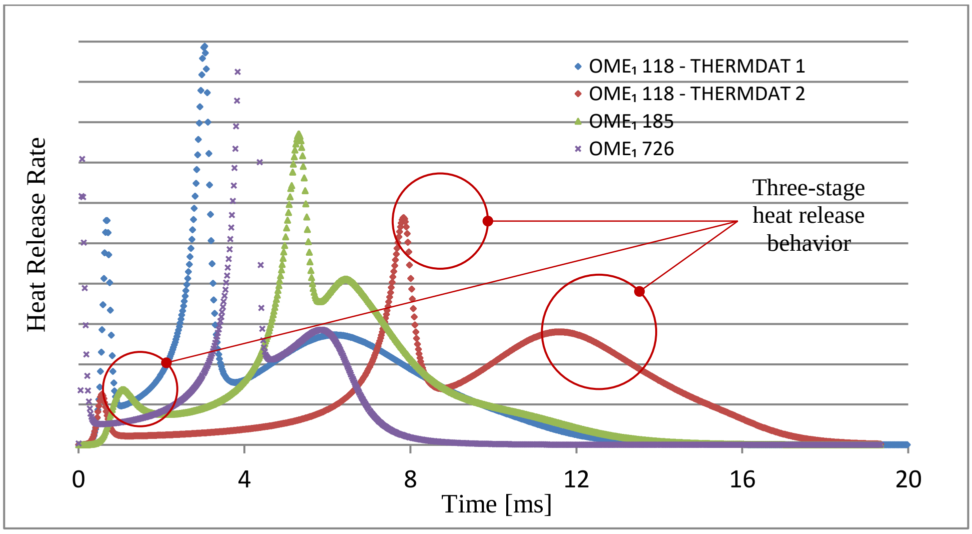

Fig.3 – Qualitative heat release rates comparison for different oxidation and pyrolysis mechanisms of OME_1 in CVCA @ equivalent ratio (φ) of 0.15. 118, 185, 726 numbers refer to amount of chemical reactions in mechanisms [3-5] accordingly. Thermdat 1, 2 refer to slightly different thermodynamic databases for kinetic modelling.

As shown in Figure 3, all three mechanisms display three clearly distinguished peaks, which define a three-stage heat release behavior. In addition, an influence of thermodynamic source on HRR behavior can be noticed for proposed mechanism by Naegeli [3]. Figure 4 illustrates the influence of H_2-to-OME_1 ratio on the ignition delay. As can be seen, higher H_2-to-OME_1 ratio causes longer delay. As much as the engine load is higher, more H_2 in the combusted fuel is required to achieve the same delay. The delay must be adapted to the engine speed. Higher ignition delays are required at lower engine speeds. Therefore, for each operating regime (load and speed) specific H_2-to-OME_1 ratio exists that allows the ignition delay to be fitted to this mode (Figure 2). Note that too long ignition delay could lead to misfire and the subsequent engine performance worsening.

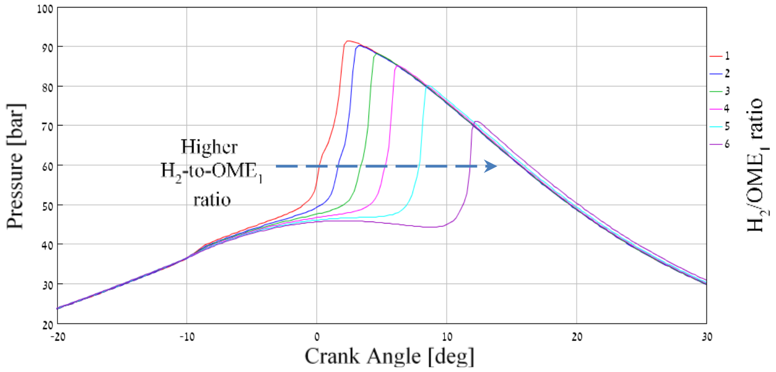

Fig.4 – In-cylinder pressure – Crank Angle diagram for different H_2/OME_1 ratios @ 2500 [RPM], BMEP=4[bar], EGR=0 (CR=16), reaction mechanism by Naegeli [3].

Simulation results obtained for typical operating modes show a potential of achieving high efficiency and ability to build a control map for different engine regimes by managing H_2-to-OME_1 ratio (Table 1).

#	Speed [rpm]	BMEP [bar]	H_2/OME_1	Engine Eff. [%]	CA at Max. Pressure [deg ATDC]	Lambda (at EVO)	NOx emissions [ppm]
1	2500	4	5	47.4	8.55	2.33	~0
2	3500	4	2	47.5	7.88	2.38	~0
3	2500	5	8	47	9.09	1.89	3
4	3500	5	4	47.8	7.29	1.95	2
5	2500	6	10	44.8	7.55	1.58	54
6	3500	6	5	46.8	5.5	1.68	44

Table 1 – Typical operating modes (observed in Fig.2) for r_c=16, EGR=0.

The presented method enables significant improvement of the HCCI engine efficiency through waste heat recovery, hydrogen combustion and high compression ratio. Moreover, combusting hydrogen and OME_1 mixture allows operation range expansion. Further research is ongoing to further expand H_2-to-OME_1 speed/load map, investigate ignition properties and HRR rate of OME_1, and prepare experimental setup for simulation results validation.

Acknowledgement

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Flow characterization of arc plasma wind tunnel by laser absorption spectroscopy of nitric oxide and water molecules

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The hypersonic flight regime includes atmospheric entry and re-entry, ground testing and flight for both powered and unpowered vehicles. High enthalpy supersonic wind tunnels are one of the most powerful ground testing facilities for aerospace science research and development. These facilities are mainly used for testing components under the harsh conditions of high temperature and heat fluxes experienced by vehicles traveling at hypersonic velocities (Mach > 5) [1]. Thermal Protection Systems (TPS) are vital components of these vehicles, which often are designed to undergo ablation in order to shed surface layers, avoiding penetration of heat flux to the interior of the vehicle. For evaluation of TPS performance, it is necessary first to characterize the high enthalpy flow generated by plasma wind tunnels, which produce conditions characteristic of the immediate surroundings of a vehicle traveling at hypersonic velocities [2].

Another important aspect of the arc plasma heated wind tunnel is its utility as an experimental platform for exploring real gas effects and high temperature gas dynamics. The field in which thermochemical properties of the gas play a significant role is called aerothermodynamics [3]. This research field investigates all aspects of heat and mass transfer in real gases as well as between gases and surfaces, especially when the flow is presumed to be in a highly non-equilibrium state [4]. There are still difficulties in properly modeling the flow field at such high temperatures to enable prediction of critical phenomena such as shock wave stand-off distance and TPS ablation rate over a blunt body. Air at various pressures is used in high enthalpy supersonic wind tunnels, as practical applications of hypersonic aerothermodynamics takes place in air at altitude. When air goes through the arc within the tunnel, it is heated up to extremely high temperature (> 10,000 K) and becomes a plasma containing a certain amount of molecular and atomic ions, free electrons, and neutral stable species and radicals. The concentrations of each of these species, in a non-equilibrium flow, is determined by their individual formation and consumption rates, which in turn is dependent on the local temperature and pressures experienced by the flow, as well as the residence time. The complexity of this situation requires multiple simultaneous measurements to fully characterize the flow and thus validate the detailed rate equations needed for simulations. Nitric oxide (NO) is produced during the arc discharge and remains frozen in the flow as it expands through the supersonic nozzle, making it an excellent indicator for flow conditions. We will use tunable diode laser absorption spectroscopy (TDLAS) to measure the rotational/translational temperature, gas velocity, and NO concentration simultaneously across and downstream of an arc-tunnel plasma plume.

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A Numerical Investigation of NH¬3/O2/He Ignition Limits in a Non-Thermal Plasma

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Keywords: ammonia oxidation; ignition; non-equilibrium plasma; plasma-assisted combustion

The de-carbonizing of our power sources is a necessary means to mitigate the harmful effects of greenhouse gases (GHG) emitted from fossil fuels over the last century. A move towards renewable energy in the upcoming years is essential, placing storage and transport technologies at the forefront of energy research. Using renewable energy, ammonia (NH_3) can be synthesized, stored and transported, making it a viable carrier of energy from intermittent sources. Furthermore, the safe storage and transportation of ammonia are relatively well-developed, due to its widespread use in agriculture and industry. The produced ammonia can be used as a fuel for various applications, including power generation and transportation [1]. However, ammonia cannot be used as a "drop-in" replacement for traditional fossil fuels due to its incompatibility with existing combustion systems [2]. For ammonia to be utilized as fuel, its poor combustion qualities, including slow laminar burning velocity, a narrow flammability range and high ignition threshold [2], must be addressed.

Recently, significant advances in the use of plasma to enhance combustion performance have been demonstrated, including reduction in ignition energy and time, increase of flame speed, and widening of flammability limits [3]. Considering the on-demand nature of plasma-assisted combustion, this technology could alter ammonia combustion properties without the cold-start limitation. For ICEs or gas turbines, a plasma discharge inside the combustion chamber can serve to match the characteristics of diesel or gasoline. Outside of the combustion chamber, plasma can be used to reform ammonia into hydrogen before injection. A deeper understanding of the reaction kinetics and species created by ammonia decomposition in a plasma discharge can provide important insight which will enable clean and efficient combustion.

In the present study, we develop a detailed chemical kinetics model including all relevant electron collision reaction processes. Using this model, we investigate the effect of a nanosecond repetitively pulsed (NRP) discharge on ignition properties. Simulations of homogeneous combustion in an NRP discharge are performed with a code combining the ZDPlaskin discharge solver [5] and CHEMKIN combustion chemistry solver [6].

The model was used to perform a series of simulations under varying pulsed discharge frequencies and pulse numbers, at atmospheric pressure and moderate to high temperatures (600-1500 K). For a moderate amount of pulses, a reduction of 40-60% in ignition delay time is achieved, with higher frequencies yielding shorter ignition delay times. Analysis of OH radical time evolution reveals that high PRFs support an increasing radical pool at low temperatures, whereas at lower PRFs radicals recombine in between pulses. In the thermal runaway phase, the radicals formed in conventional chain branching events are prevalent, so that OH formed in later pulses has little effect. At low temperatures and high PRFs, higher pulse frequencies allow for lower initial temperatures which will result in ignition. At a high enough frequency, the hysteresis of ignition and extinction is altered due to a high amount of radicals supplied and sustained by the plasma, so that there is a smooth transition and reactions at all temperatures.

Acknowledgements
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A New Ignition Tunnel Design

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Keywords: ignition; NPHFD; plasma-assisted combustion; minimum ignition energy

Background

Ignition becomes a particular challenge in the field of aerospace for cases like –but not limited to– high-speed engines and high-altitude relight of gas turbines, where some attributes (e.g. ignition probability, kernel growth rate, etc.) are determined by both the ignition device and the scenario in which the ignition is intended to happen.

In the last years, nanosecond-pulsed high-frequency discharge (NPHFD) plasmas have been pointed out as an optimal ignition method in flowing mixtures [1,2]. However, experiments carried out so far have been constrained to certain scenarios in which the initial temperature and the velocity were limited to 300 K and 10 m/s, respectively [1,2]. In addition, methane is the only fuel implemented until now.

New design

Having enhanced previous designs, the Combustion & Diagnostics Laboratory at the Technion is building an innovative ignition tunnel that goes one step further, approaching real scenarios like the ones mentioned above. Being able to handle more extreme conditions, it allows exploring the effect of:

- Higher initial temperatures: up to 1000 K,
- Higher flow velocities: up to 100 m/s,
- Different turbulence regimes: up to Re = 240,000,
- Different fuels:
  - Gaseous fuels (methane, hydrogen, ethylene, propane),
  - Liquid fuels (embedding a high-temperature fuel vaporization system),
  - Heavy hydrocarbon fuels,
  - Alternative fuels (ammonia, biofuels…).

Figure 1. Setup of the ignition tunnel.

Equipped with a plasma pulse generator that provides 10 ns FWHM pulses with peaks up to 20 kV at a maximum pulse repetition frequency of 200 kHz, the setup is able to deposit the amount of energy required by these demanding conditions, reaching energies up to 10 mJ per pulse and power of up to 2 kW.

Another of the innovative points is the diagnostics setup, consisting of:

- A high-speed schlieren imaging system –able to take up to 50,000 frames per second at high image resolution– in order to measure the ignition probability and track the kernel growth rate.
- A high-speed infrared camera –capable of taking images up to 5,000 frames per second in the spectral range of 1-5.5 μm– used to measure the temperature and concentration of major species, including water, carbon dioxide, carbon monoxide, methane, ethane, ethylene, acetylene and formaldehyde.

Results obtained from experiments in this new ignition tunnel are intended to provide a better understanding of ignition phenomena and contribute to its optimization in the previously mentioned engines.

Acknowledgements

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Second-Law Analysis of the Reforming-Controlled Compression Ignition

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Keywords: Homogenous charge compression ignition; fuel reactivity control; thermochemical recuperation; exergy analysis; hydrogen; dimethyl-ether

There is agreement among experts that internal combustion engine (ICE) will stay a leading propulsion tool for transportation in the foreseen future [1-3]. However, to be competitive, ICEs have to improve significantly their energy efficiency, mitigate emissions, and use diverse low carbon-intensity renewable fuels [4]. Low-temperature combustion (LTC) engines in all their modes (HCCI, RCCI, etc.) characterized by relatively low fuel consumption and pollutant emissions are considered a promising solution to meet those targets [5,6]. To improve further the LTC engine efficiency, recycling the exhaust gas available enthalpy is an attractive option. One way to implement it is the thermochemical recuperation (TCR) method. According to this approach, the exhaust waste heat is utilized to sustain endothermic reactions of primary fuel reforming in a catalytic reactor [7]. This approach raises the fuel heating value and results in on-board hydrogen production with subsequent benefits in terms of efficiency and emissions mitigation.

In the RefCCI system (Figure 1) [8], the available energy of exhaust gas is utilized to sustain endothermic reactions of high-reactivity primary fuel reforming to low-reactivity hydrogen-rich reformate. In principle, various high-reactivity primary fuels may be suitable for the RefCCI engine. In the reported study, the considered primary fuel is DME.

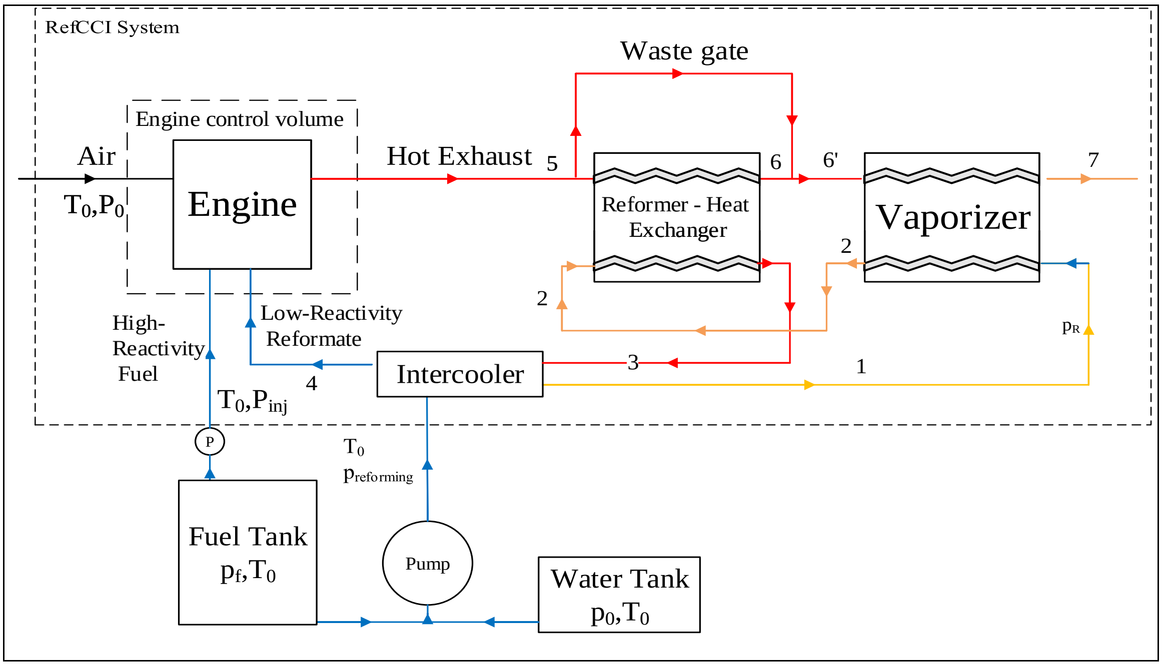

Figure 6 – RefCCI schematic layout.

The second-law analysis is a widely accepted method of identifying possible ways of efficiency improvement [9-12]. After mapping the exergy destruction sources, it is possible to redesign the system for minimizing exergy destruction and the subsequent efficiency improvement.

The main objective of the reported study is to fill this knowledge gap and provide new insights on the influence of various factors on exergy destruction in a RefCCI system and possible ways of system efficiency improvement. The study first maps the exergy distribution in the entire RefCCI system. Then, it examines how a modification of various parameters may affect the exergy destruction in each individual system component and in the entire RefCCI system. Notably, the effects of reformate intercooling and bypass a part of the exhaust flow out of the reformer are analysed for the first time. Such an analysis, together with understanding limitations and main sources of not-destructed exergy loss in the RefCCI system, is useful in a search for possible methods of available energy recycling and the subsequent efficiency improvement.

Exergy mapping results (Figure 2) showed that about a third of exergy supplied to the RefCCI system is destructed due to irreversibility processes in the cylinder itself, and approximately five percent is destructed in the reforming system (intercooler, vaporizer, and reformer). The rest of exergy is transferred by work and heat interactions of the system with its environment and flows out with the exhaust gas (approximately 8%). About 45% and 38% of the engine exergy destruction is related to chemical reaction and in-cylinder-walls heat interaction, respectively. The reformer is the main source of exergy destruction in the reforming system.

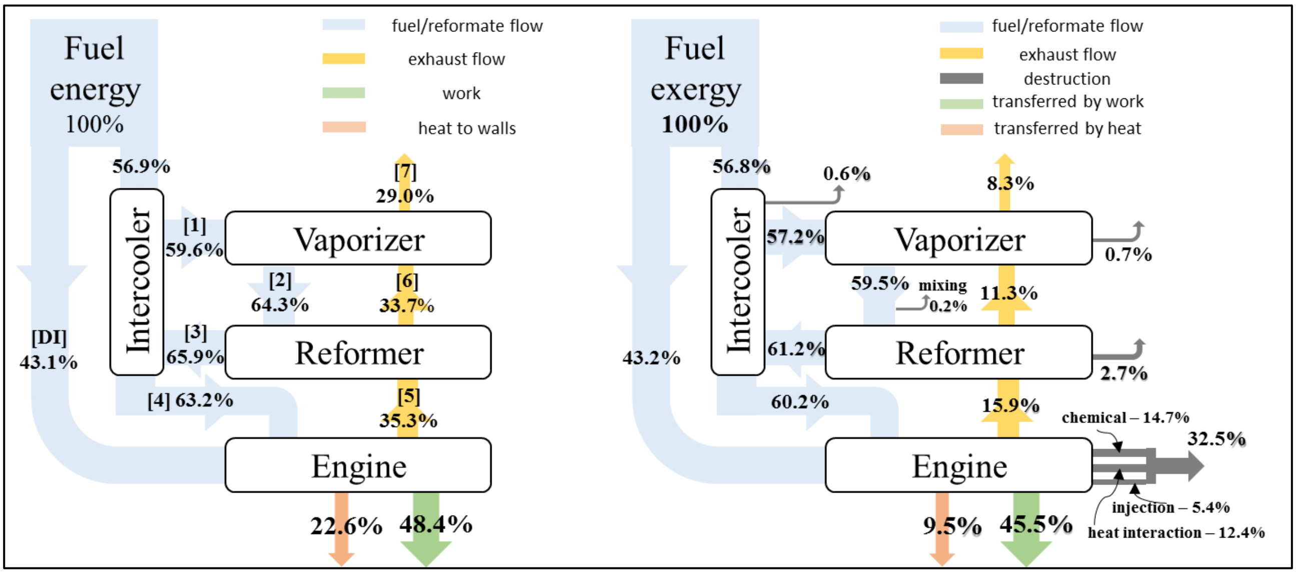

Figure 2 – Energy and exergy distribution in the RefCCI system for the reference case.

Among the investigated factors affecting exergy destruction, the following were found to have a positive impact on second-law efficiency of the considered RefCCI system: reduction of the cooled and hot EGR rate, when applicable; optimization of the reforming pressure; injection timing retarding (in the constraints of ensuring efficient charge mixing and combustion); optimization of exhaust gas bypass out of the reformer; compression ratio increase (under constraints of preventing too low exhaust gas temperature); avoiding VVA, when applicable.

Cooled EGR reduces engine exergy destruction and exergy transferred by heat but increases the exergy outflowing the system with the exhaust gas. If this exergy flow can be utilized by other tools with the resulting system efficiency improvement, then cooled EGR can be beneficial. However, this option was not investigated here.

An important advantage of the VVA is that it enables the necessary fuel reforming at low-load regimes. Hence, using it can be justified at these operation modes.

Depending on the engine operation regime, the efficiency improvement due to second-law optimization can reach up to 7.1 % and if the CR is increased to 18:1 instead of 16:1 - up to 9.2%. The higher improvement is achieved at the highest load cases and at high speed.

Acknowledgement
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Model for Friction Reduction Effect of Soft Coating Materials

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Keywords: elastic-plastic contact; spherical contact; soft coating; static friction

Introduction

Owning to this friction reduction effect, soft coatings are usually used as solid lubrication especially in some industrial applications requiring contact without any type of liquid lubrication, to control the friction and achieve higher efficiency and durability. However, trial and error procedure concerning both the choice of material and coating thickness is generally used to achieve good results due to the lack of a general theoretical model. In the present study we modelled the soft-coated spherical contact and present a comprehensive description of the static friction mechanisms in soft-coated contacts. A similar behavior was found to the pioneering experiments of Bowden and Tabor [1], who measured the friction coefficient of a steel slider on indium coated steel surfaces (soft coating). The effects of dimensionless contact thickness, normal loading, and material properties are revealed and explained by studying a wide range of these parameters.

Finite element model

Based on the finite element (FE) model for homogenous spherical contact in [2], the FE model for the full-stick contact between a homogeneous sphere and a rigid flat under normal and tangential loading is developed, as shown by Figure 1.). Initially, a load-controlled normal loading P is applied on the rigid flat. This creates a contact area at the contact interface. Then a displacement-controlled tangential loading $(u_x)_i$ increasing in a stepwise manner is applied, where i is the step number of the consecutive tangential displacement. The increasing u_x leads to an increase in tangential force Q and the decrease of tangential stiffness. Finally when the tangential stiffness vanishes, the maximum tangential force $Q_{\max}$ that the contact junction can support is obtained, and then the static friction coefficient μ is $Q_{\max}/P$.

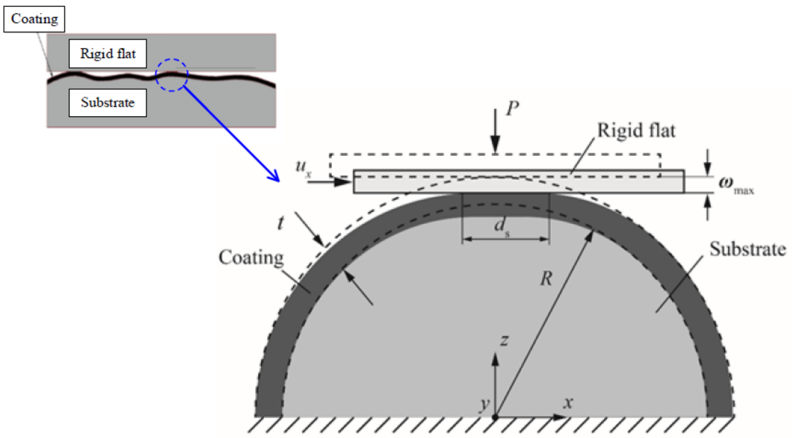

Figure 1. Schematic of a coated sphere in contact with a rigid flat, to which a normal load P (a) with a subsequent tangential displacement u_x (b) is applied..

Results and discussion

Figure. 2 presents the result of the static friction coefficient μ vs. the dimensionless coating thickness t/R. The μ shows a transitional behavior from decreasing μ to increasing μ when t/R increases. This transitional behavior was also observed experimentally in Ref. (Bowden and Tabor, 1954). A minimum static friction coefficient μ_m exists at a thickness $(t/R)_m$. In the present case, the soft coating decreased the static friction coefficient μ by 61% at $(t/R)_m$ compared to μ_{su} of the uncoated case.

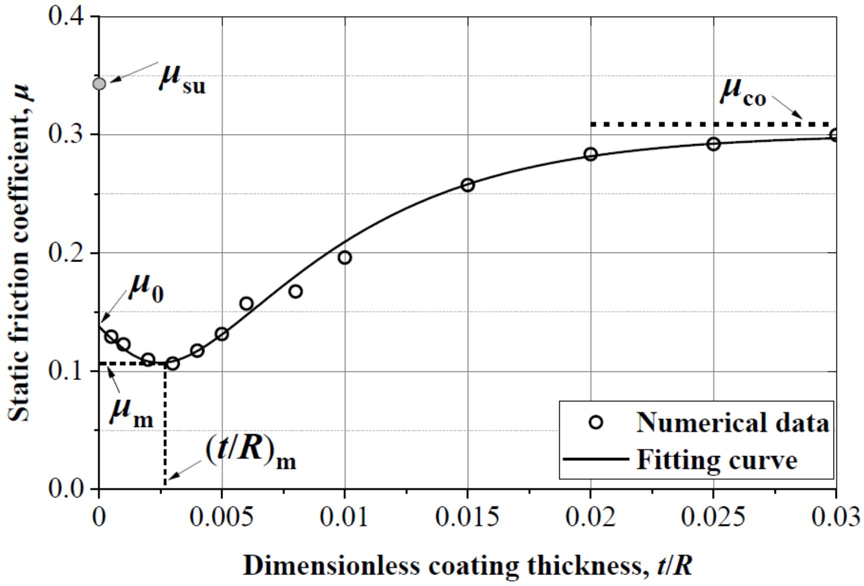

Figure 2. The effect of coating thickness t/R on static friction coefficient μ.

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Opportunities and prospects of hybrid solar powered and solar assisted conventional and self-driving e-vehicles

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Keywords: hybrid solar powered and solar assisted e-vehicles; roof solar chargers

According to forecasts in Israel, there will be more than 250.000 e-cars in 2030. To charge them, it will be necessary to create a charging infrastructure and increase the energy production. Therefore, the mission of using solar energy to charge e-cars during the day with the help of individual roof solar chargers (RSC) becomes relevant. The technical capabilities of modern film solar panels (SF) meet the requirements of application on various conventional and self-driving e-vehicles. In 2019 the production or testing of solar assisted e-cars class L6e, L7e, A, B, according to the European classification (Hyundai, Kia, Renault, etc) with built-in RSC was started in order to increase the e-car’s range. Unfortunately, the current level of efficiency of the SF does not allow to provide the required city e-car’s daily energy consumption determined according to the WLTP cycle and to develop solar powered e-Cars. However, there is a considerable potential for increasing SF efficiency and lowering their cost. In sunny countries, RSC hybrid solar powered and solar assisted e-vehicles can become competitive with traditional hybrids in terms of cost of ownership and range.

Therefore, it is important at the R&D stage to determine the capabilities and prospects of RSC e-vehicles in the function of the main factors. In the developed model for evaluating the efficiency, it is proposed to use an e_{RSC} value equal to the ratio of RSC solar power generation E_{RSC} to e-car’s daily energy consumption E_{DC}. The authors conditionally divide all e-vehicles into solar powered ($e_{RSC} \geq 0.9$) and solar assisted ($e_{RSC} < 0.9$). It is proposed to consider an efficiency criterion $e_{RSC} \approx 0.3$. This is determined by the economic feasibility of using RSC. RSC power generation E_{RSC} depends on solar activity, S_{SF} area and their η_{SF} efficiency. Daily consumption E_{DC} depends on daily range R_V and design factors. The mass of the e-vehicle M_V is a factor that links the available and required energy. On one hand, daily energy consumption E_{DC} and the specific energy consumption required per km p_{DC} depend on M_V. On the other hand, M_V is the basis of cars' classification and the surface sizes of the car on which SF can be placed. The authors' measurements show that the SF area depends on the wheelbase B and the width W: $SF \approx 0.5\ B * W$ (micro e-cars, segment L6e, L7e and e-cars, segment A); $SF \approx 0.4\ B * W$ (e-cars, segment B, C, etc).

The simulation's results for Israel’s solar activity and daily range R_V = 20-30 km (micro e-cars), R_V = 45km (e-cars), show the presence of restrictions that establish the effectiveness of the use of RSC. (Figure 1). Test data from more than 30 different e-cars was used for analysis. With an increase in mass M_V, the following occurs: a) - a slowdown of the increase in the SF area and the value of E_{RSC} for all η_{SF} values; b) - proportional increase in daily consumption E_{DC}. The ratio of E_{RSC} and E_{DC} and, accordingly, the effectiveness e_{RSC} of RSC e-vehicles depending on mass is more complex. For micro e-cars with weight less than 600-800 kg with a speed limit of 25-45 km / h, the E_{DC} value lies in the E_{RSC}'s area. An efficiency of $e_{RSC} \geq 0.9$ is ensured with the achieved efficiency SF ($\eta_{SF} \geq$0.15-0.2) of mass production. Thus, the installation of roof solar chargers allows to create a hybrid solar powered conventional and self-driving micro e-cars. *Eco-friendly* micro e-cars are convenient for short trips up to 8-10 km (60% of all trips in Israel) in congested streets and parking. They are more friendly than ebikes/scooters to people and safety and may have a great market potential. For e-cars with weight more than 1000 kg (segment A, B, C, D, etc) without speed limitation, the E_{DC} value does not lie in the E_{RSC}'s area, even with the prospective SF efficiency (η_{SF} = 0.4). Therefore, installing roof solar chargers on these e-cars is problematic. In the best case, with an increase in η_{SF} = 0.3, it is possible to create a hybrid solar assisted e-cars class A. This coincides with the opinion of other authors, however, this does not exclude the possibility of using various solar chargers during car parking.

The concept of effective application of RSC is presented. It is based on the ratio of RSC solar power generation to e-vehicles' daily consumption, takes into account the daily mileage of the car and its segment. The concept shows the opportunities and prospects of hybrid solar powered and solar assisted conventional and self-driving e-vehicles.

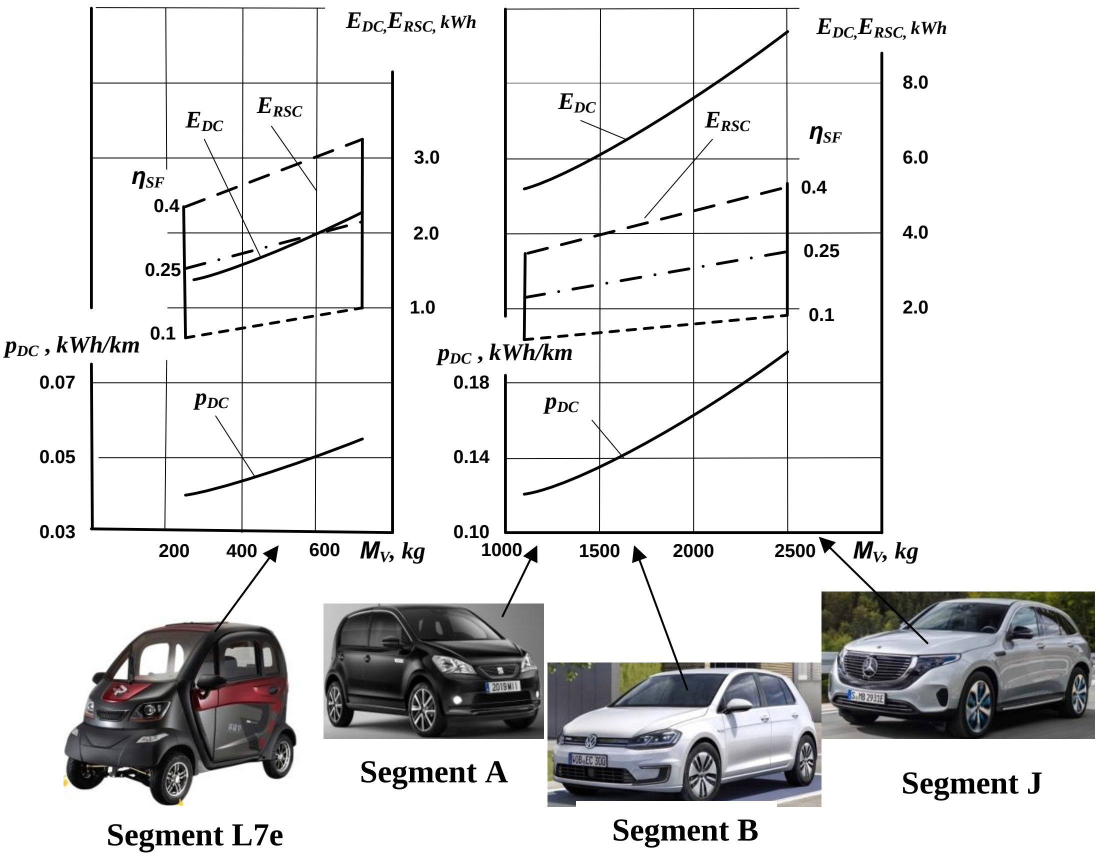

Figure1. E-car's daily energy consumption, specific energy consumption and roof solar chargers' solar power generation in the function of the different e-cars' mass

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Method of Gas Exchange for Four-Stroke Engine with a Port in the Cylinder Sleeve

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Keywords: four-stroke; engine; port; cylinder sleeve

We propose a four-stroke engine, where the exhaust gas from a cylinder flows out through the valves and through a constantly open port in the cylinder sleeve. The invention relates, first, to naturally aspirated aircraft engines.

Description of the Method.

At the end of the power stroke, when the piston is near BDC and at the first stage of an exhaust stroke (Fig. 1), the exhaust gas flows from the cylinder through both exhaust valve 1 and port 2. (Exhaust gas flows through the port to the atmosphere.)

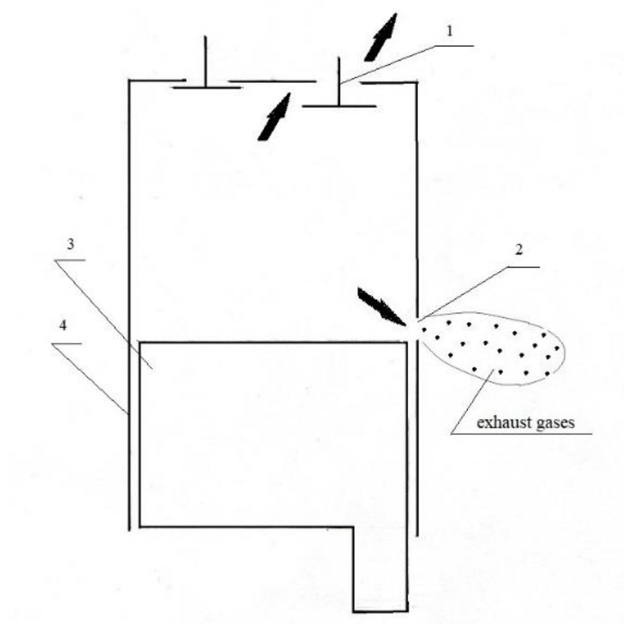

Fig. 1. *The end of the power stroke. The black arrows show the exhaust through both: the port and the exhaust valve 1. The exhaust gas that have flowed out of the cylinder through the port are shown with black dots.*

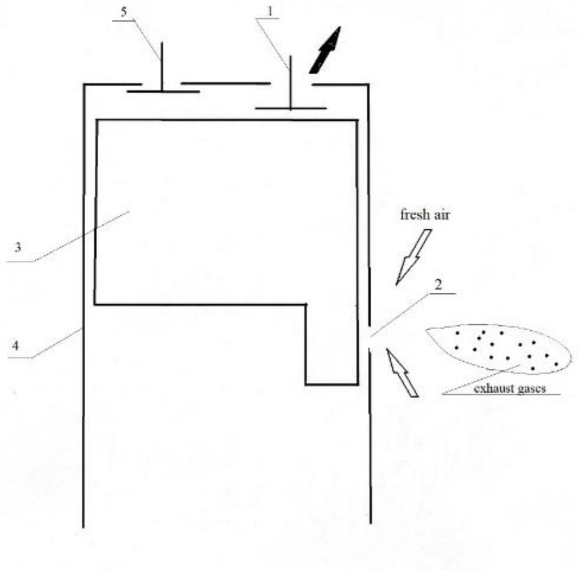

Fig. 2. *The end of the exhaust stroke, the piston is near TDC. Air is sucked to the port.*

Then, in the exhaust stroke, the piston pushes exhaust gas through the exhaust valve 1, see Fig. 2, black arrow.

The exhaust gas, which had previously flowed out of the cylinder through the port, fly away from the port by inertia, and fresh atmospheric air is sucked to the port. Air flow to the port is indicated by white arrows in Fig. 2. The exhaust gas, which previously has flown away from the cylinder, is depicted by black dots.

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At the next stroke – the intake stroke – see Fig. 3, air passes (white arrows) through the intake valve 5 into the cylinder.

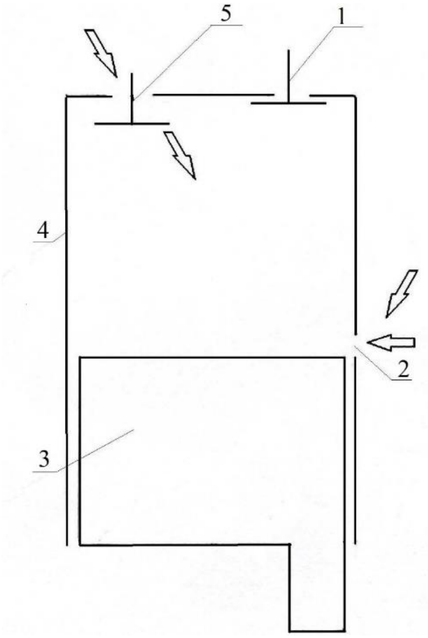

Fig. 3. *The intake stroke, the piston is at BDC. The white arrows show the air entering the cylinder through both: the intake valve 5 and the port.*

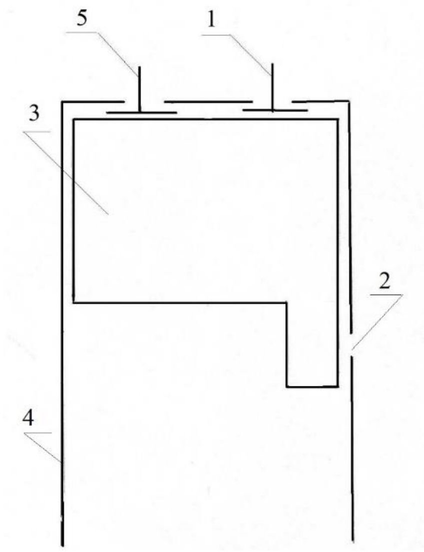

Fig. 4. *The end of the compression stroke, the piston is near TDC.*

At the end of the intake stroke (Fig. 3) port is opened. At this moment there is fresh air outside the port, the pressure inside the cylinder is lower than the pressure outside the cylinder. Therefore, air intakes into the cylinder (Fig. 3, the white arrows) through the port.

Then there are: compression (Fig. 4), combustion, the power stroke, - and the cycle repeats.

The Effectiveness.

The easy exhaust through the valves and the port in the sleeve allows an increase of rotation frequency of the crankshaft, resulting in a power increase. As only half of the gas flow through exhaust valve 1, the temperature of the exhaust valve and cylinder head is lower than in the conventional engines. Thereby in SI engines, the compression ratio may be increased.

An additional intake through the port increases the filling of the cylinder with a fresh charge. More important is another: there is no return of exhaust gas into the cylinder at the end of the intake stroke.

Application of UAV for automated roadway system

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Over the past few decades, the magnetically levitated trains have gained popularity in Europe and Asia due to the energy efficiency, low maintenance, high speed and smoothness in motion. With increasing advancements in technologies, the methods for levitating the mass have improved, namely, electro-dynamic levitation, hybrid magnet levitation and latest ones being the use of superconductors. But all such methods have limited applications viz. trains, contact-free bearings, load transfer on an industry's floor, and in many scientific and medical experiments. Considering the advantages of levitation technology in railways over the long run, many concepts have been proposed to adapt the same for roadways but is found to be impracticable. The major reason being the fact that vehicles on a road don't run over rails but can move freely and change lanes at any time, thereby requiring the entire road to be magnetized either using permanent (natural) magnets, electromagnets or superconductors. This problem can be solved by changing the methods of levitating the same mass of vehicle but using different methods that utilize the existing infrastructure of roadways, i.e. asphalt and rocks or concrete. The major advantage of levitation using air thrust is that they can glide over any surface type viz. wet and slippery, asphalt or concrete road, rocky or smooth surface, etc. whereas Mag-Lev has a strict requirement surfaces made of magnetic materials viz. diamagnetic or ferromagnetic. Another advantage is that the air thrust force remains the same along every distance over surface unlike magnetic field strength which decreases exponentially with increase in distance between two magnets either attracting or repelling. The current paper describes an approach to lift loads using air levitation and propelling it along a path between two end points. Here, we attempt to present this idea using a preliminary prototype which is constructed using a simple mechanism. We have used the primary components of a quadcopter, viz. motors and controllers, flight stabilizer and altitude sensor for creating a lift, whereas the secondary components like batteries are replaced by a continuous regulated power supply from the mains and the need for a remote controller is eliminated because the control system inside flight stabilizer is designed to keep the platform steady at a height using PID algorithm. The model of the hovering platform over which the desired load will be carried is built using ABS plastic sheets for rigid construction. Unlike a regular UAV, the high power of which is used for lifting light loads to a high altitude, our model uses the maximum power of its motors for lifting heavy loads at a height as low as 30 milli meters over ground. The platform is set in motion along a direction using a guidance rail. Similar to the guidance system of a Mag-Lev train, this guidance rail fixed to the flat ground surface is made of a 1-dimensional array of electromagnets (EM) that are energized to either of North-South polarity or switched-off on command. These electromagnets create a field of attraction and repulsion towards the alternate polarity permanent magnets that are attached at the bottom of the hovering platform, causing the platform to be attracted towards EM ahead of it and repelled by EM behind it thereby causing forward propulsion.

The vehicles therefore hovering at just 20-30 mm over the road surface, can collectively move along and change lanes with ease, similar to the existing ones, while being automatically guided by an active system (of EM array). Such active guidance system being a complex computer algorithm that calculates the speed, position, travel plan and milestone points of every vehicle at every instance, is similar to every railway's traffic control system. This may ensure that every vehicle hovering over the roadway can travel without any traffic congestion or accidental mishaps. Also, such vehicles require continuous power feed using overhead powerlines like any train, therefore eliminating the need for establishing a charging infrastructure, unlike that required for Electric Vehicle transition. This being another application of an Unmanned and Automated Aerial Vehicle with the potential of causing a major disruption in transportation sector, can provide a safer, comfortable and more efficient way of mobility for the future than Autonomous Electric Vehicles.