
Elbit Systems

Israel Aerospace Industries

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

MAFAT
Directorate of Defense Research & Development (DDR&D)
Aeronautical Division

לשכת המהנדסים האדריכלים והאקדמאים במקצועות הטכנולוגיים בישראל

drones
an open access journal by MDPI

טכנולוגיות הנעת כלי טייס בלתי מאוישים

הכנס הארצי השביעי

חוברת תקצירים

הפקולטה להנדסת מכונות, הטכניון
חיפה
ה' ט' שבט תשע"ח
25 בינואר 2018

Conference Program

7th Conference on Propulsion Technologies for Unmanned Aerial Vehicles

Thursday, January 25, 2018
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:** ***Wayne D. Kaplan,*** Executive Vice President for Research, Technion ***Yoram Halevi***, Dean, Faculty of Mechanical Engineering, Technion ***Yigal Ben-Shabat*****,** Head, Propulsion Branch, Directorate of Defense Research & Development, MAFAT ***Emanuel Liban*****,** Chairman, Israel Society of Mechanical & Aerospace Engineers
9:30 – 10:00	**Keynote lecture:** **Prospects of Advanced Compression Ignition Concepts: Thermal Barrier Coatings for Improved Engine Efficiency and Range of Applicability** ***Zoran Filipi***, Chairman, Department of Automotive Engineering, Clemson University, USA
Plenary session	**Chairman: Yitzhak (Itche) Hochmann,** Edmatech (the session will be held in English)
10:00 – 10:30	**Electric A/C Propulsion - Opportunities and Challenges** ***Emanuel Liban*****,** CEO, Edmatech, Israel
10:30 – 11:00	**Propulsion systems for UAV: One size fits it all?** ***Thomas Uhr*****,** General Manager BRP-Rotax, Vice President Powertrain BRP and R&D/Operations Lynx, Austria
11:00 – 11:30	**Coffee break**
Noon session	**Chairman: Nir Geva,** Elbit Systems (the session will be held in English)
11:30 – 11:55	**Fuel cell - Key steps for affordable and reliable technology for UAVs** ***Xiao Li*****,** Troowin Power System Technology, China
11:55 – 12:20	**Introduction of the 3W International Wankel-engine hybrid** ***Karsten Schudt*****,** Managing partner, 3W International GmbH, Germany
12:20 – 12:45	**UAS in the Israeli Defense Forces – Operational Challenges and Coping methods** ***E. Gil*****,** IDF, Israel

12:45 – 12:55	**Best Student Poster Award Ceremony**
12:55 – 14:00	**Lunch**
Session "New Concepts "	**Chairman: Michael Shapiro,** Technion (the session will be held in English)
14:00 – 14:20	**Measurement of in-cylinder pressure and temperature based on VA parameters of a spark plug** ***Nir Druker, Gidi Goldwine, <u>Eran Sher</u>,*** Technion, Israel
14:20 – 14:40	**Reforming-controlled compression ignition** ***<u>Amnon Eyal</u>, L. Tartakovsky*,** Technion, Israel
14:40 – 15:00	**Using new injection and ignition systems to enhance the efficiency of 2- and 4-stroke internal combustion engines** ***<u>Karsten Schudt</u>*, W. Seidl,** 3W International GmbH, Germany
Session "Engine Design & Performance – 1"	**Chairman: Jacob Feldman,** Israel Aerospace Industries (the session will be held in English)
14:00 – 14:20	**Investigation of oil temperature deviations in Rotax 914 engines** ***<u>Rom Kafri</u>*, *Ofer Levi, Dudu Halfon, Dan Bukhman*,** IDF, Israel
14:20 – 14:40	**The Potential of Using Organic Coolants in Diesel Engines** ***Alon Davidy*,** Israel Military Industries, Israel
14:40 – 15:00	**Demonstration of propeller-wing interaction analysis** ***Avi Ayele, Shaul Segal, <u>Ohad Gur</u>*,** IAI - Israel Aerospace Industries
15:00 – 15:20	**Coffee break**
Session "Alternative Propulsion Technologies"	**Chairman: Ariel Dvorjetski,** IDF (the session will be held in English)
15:20 – 15:40	**Challenges in Electrical Propulsion** ***I. Gerlovin*,** IAI - Israel Aerospace Industries, Israel
15:40 – 16:00	**Li/CF$_x$-MnO$_2$ Hybrid Technology for UAV Applications** ***<u>M. Destephen</u>, D. Zhang, D. Darch, E. Ndzebet*,** Eaglepicher Technologies LLC, USA
16:00 – 16:20	**Power-Lines Charging Mechanism for Drones** **Kobi Gozlan, Kfir Cohen, Nir Shvalb, <u>Boaz Ben-Moshe</u>, Moshe Sitbon, Alon Kuperman,** Ariel University, Ben-Gurion University of the Negev, Israel
Session "Engine Design & Performance – 2"	**Chairman: Benjamin Brinder,** IDF (the session will be held in English)

15:20 – 15:40	**Power Performance Enhancement for a Rotary UAV Engine** ***Jonathan Shachar Luzzatto***, Elbit Systems, Israel
15:40 – 16:00	**Split-cycle engine – main challenges and ways of their overcoming** ***H.B.Tour***, ***O. Tour,*** Tour Engine Inc., Israel - USA
16:00 – 16:20	**Limitations of Two-Stage Turbocharging of Unmanned Aerial Vehicles at High Flight Altitudes** ***Yehuda Fass, L. Tartakovsky*****,** Technion, Israel
Closing remarks 16:20 – 16:30	**Leonid Tartakovsky**, Chairman Organizing Committee

Posters session

1. **CFD Modeling of a Direct Injection Hydrogen/DME Fueled Internal Combustion Engine**
   G. Faingold, L. Tartakovsky, S. H. Frankel, Technion – IIT, Israel

2. **Numerical Simulation of Bluff-Body Stabilized Flame Combustors.**
   Yann Delorme, S. H. Frankel, Technion – IIT, Israel

3. **Development of Propulsion system (PS) concept for different Unmanned Vehicles (UV)**
   Boris Arav[1], *Daniel Feldman*[2], 1- TurboGEN Technology; 2 – Ariel University, Israel

4. **Trends in the development of electric unmanned cargo vehicles in the Russian Federation**
   K. Karpukhin, A. Terenchenko, NAMI Russian State Scientific Research Centre, Moscow, Russian Federation

5. **Features of the vision systems application for unmanned vehicles in climatic conditions of Russia**
   A. Saykin, S. Buznikov, A. Barashkov, NAMI Russian State Scientific Research Centre, Moscow, Russian Federation

6. **Four-Stroke Engine with a Port in the Cylinder Sleeve**
   A.L. Zhmudyak, L.M. Zhmudyak, Panaya, Ltd, Israel

7. **Simulation of a multicomponent underexpanded gaseous jets**
   A. Thawko, L. Tartakovsky, Technion – IIT, Israel

8. **Drive train for a Formula-student racecar**
   R. Levy, R. Baltzan, Technion – IIT, Israel

9. **Intake system for a Formula-student racecar 2017**
   M. Avraham, Technion – IIT, Israel

10. **Powertrain system for a Formula-student racecar 2018 – novel features and challenges**
    T. Lipshitz, N. Rosenblum, Y. Gil, T. Katzenstein, G. Rubinstein, K. Aridy, Y. Boim, Technion – IIT, Israel

11. **Advanced muffler for a Formula-student racecar**
    D. Buntin, Technion – IIT, Israel

12. **Theoretical Study of the 3-branches Explosion Limits of a Flammable System**
    A. Lidor, D. Weihs and E. Sher, Technion – IIT, Israel

13. **The Effect of the Initial Conditions on the IC Engines Injection Spray Generated by Homogeneous Flash Boiling**
    Y. Moshkovich, Y. Levy, E. Sher, Technion – IIT, Israel

Organizing Committee

- *Leonid Tartakovsky*, Faculty of Mechanical Engineering, Technion – Israel Institute of Technology, **Conference Chairman.** Email: tartak@technion.ac.il
- *Yigal Ben-Shabat,* MAFAT, Ministry of Defense
- *Benny Brinder*, Israel Defense Forces
- *Daniel Budianu,* Israel Aerospace Industries
- *Ariel Dvorjetski,* MAFAT, Ministry of Defense
- *Jacob Feldman*, Israeli Aerospace Industries
- *Nir Geva*, Elbit Systems
- *Yitzhak (Itche) Hochmann*, Edmatech Advanced Engineering Consultants Ltd.
- *Emanuel Liban*, Chairman of Israeli Association of Mechanical & Aerospace Engineers
- *Michael Shapiro*, Faculty of Mechanical Engineering, Technion – Israel Institute of Technology

Conference Secretary:

Ms. Shimrit Wagner-Lior, shimrit.w@me.technion.ac.il
Phone: +972-77-8871668, Fax: +972-4-8295710

Best Student Poster Selection Committee:

- *Emanuel Liban,* Israel Society of Mechanical Engineers – **Chairman**
- *Daniel Budianu,* Israel Aerospace Industries
- *Ariel Dvorjetski,* MAFAT
- *Jacob Feldman,* Israel Aerospace Industries
- *Nir Geva,* Elbit Systems
- *Yitzhak (Itche) Hochmann,* Edmatech
- *Michael Shapiro,* Technion

Oral presentations

Keynote address

Prospects of Advanced Compression Ignition Concepts: Thermal Barrier Coatings for Improved Engine Efficiency and Range of Applicability

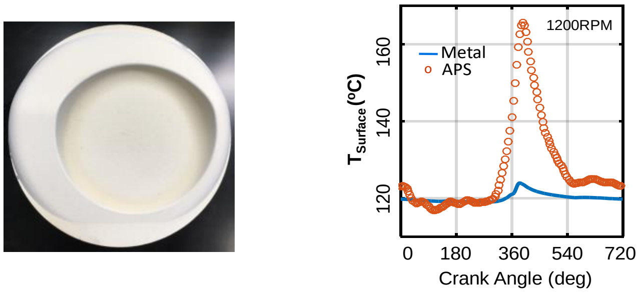
Zoran S. Filipi

Department of Automotive Engineering
Clemson University, Greenville, SC, 29607, USA
* Presenting author email: zfilipi@clemson.edu

Keywords: IC engine; heat transfer; thermal barrier coatings; homogeneous charge compression ignition

Small IC engines offer a compelling option for UAV propulsion. Most of the engines used in the early years were conversions of products originally designed for other markets, but the growth of the UAV sector creates impetus for original designs. The need for high thermal efficiency from a small package brings to the forefront two key factors, namely, compression ratio and heat losses during combustion. Reduced heat loss during the high-pressure part of the cycle is a well-recognized method for increasing thermal efficiency of any IC engine, while advanced combustion modes offer a prospect of high compression ratio and lean operation. This presentation will cover both.

Thermal barrier coatings enable manipulation of the instantaneous temperature of combustion chamber walls, thus offering a chance for strategic impact on in-cylinder heat transfer. A so called "temperature swing" effect is of a particular interest. Small size exacerbates the impact of heat losses on the near-wall zone, and further increases the relevance of thermal barrier coatings in the context of UAV applications. In case of Homogeneous Charge Compression Ignition (HCCI) engines, there is a chance for beneficial effects on combustion efficiency too. Autoignition, combustion, and low-end operating stability in an HCCI engine critically depend on the interplay between the in-cylinder thermal environment and chemical kinetics; therefore, in-depth characterization of this complex interdependence is required to maximize the benefits. Highlights of the multi-year research will include characterization of the heat transfer in the HCCI engine using experiments with heat flux probes mounted on both the cylinder head and the piston, and on-going efforts to engineer thermal barrier coatings capable of producing most desirable effects on thermal efficiency, combustion efficiency and reduced emissions.



a) b)

Figure 1. Illustrations of the: a) piston coated with a novel low-conductivity coating, and b) temperature swing on the surface of the ceramic coating, estimated from the instantaneous temperature measurement on the metal surface, using a Sequential Function Specification Method[1].

Acknowledgement

This work was supported by the NSF-DoE Partnership on Advanced Combustion Engines and General Motors.

References

1. O'Donnell, R. N., Powell, T. R., Filipi, Z. S., & Hoffman, M. A. (2017) "Estimation of Thermal Barrier Coating Surface Temperature and Heat Flux Profiles in a Low Temperature Combustion Engine Using a Modified Sequential Function Specification Approach," *Journal of Heat Transfer*, 139(4), 41201. https://doi.org/10.1115/1.4035101

Plenary lecture
Electric A/C Propulsion - Opportunities and Challenges

Emnuel Liban[1]

[1] Chairman, the Israeli Society of Mechanical and Aerospace Engineers

Keywords: UAV, Future Trends, Propulsion, UAV quadrotors, weight penalty

Electrical powered Airborne vehicles open a new horizons for designers, start-ups and existing A/C companies.

Many initiatives pop out across the globe with innovative ideas never thought before.

The possibility to separate between the power source or its generation and the propulsion of the A/C allows to design configurations with a promise of flexibility, versatility and fuel saving.

The driving factors behind this trend are ecology, development of new chemistry for high power density and a reliable batteries, advanced sensors with fusion technology and low price derived from automotive industries.

The automotive industries demonstrated the feasibility of high power control systems and powerful light electrical motors.

The electrical propulsion has the promise to lower the operational cost compared to A/C that are powered by fossil fuels.

Small vehicles like UAV quadrotors are already approaching operational state including regulations.

Many designs in different development stage are on the way to produce electrical A/C for 4 passengers and later on serious studies are being done to design hybrid commuters (regional propeller A/C), and even bigger commercial A/C.

Urban air transportation is also attracting serious interest due to congestion in the cities and lower operating costs that is associated with helicopters usage .

The lecture will cover the outstanding current developments and the challenges they face in order to succeed.

The winner will be the design that will prove that it is able to produce, distribute and use of the electrical power for propulsion in the most efficient way with the smallest weight penalty.

Plenary lecture

Propulsion systems for UAVs: One size fits it all?

Thomas Uhr
General Manager BRP-Rotax, Vice President Powertrain BRP

BRP-Rotax GmbH & Co KG, Rotaxstraße1, Gunskirchen, 4623, Austria
Presenting author email: thomas.uhr@brp.com

Keywords: Reliability; serviceability; endurance; operating cost; power to weight

What is special about UAV propulsion systems? Independent from mission or purpose of any UAV the selecting criteria for its proper propulsion system are **reliability** as a must have, **serviceability** also in rough environment in order to keep down time limited, **energy efficiency** for long endurance, **total cost of operation** and finally **power to weight** aiming for maximum payload. Local availability of fuel/energy, spare parts and maintenance expertise may also influence the decision.

Pilots on ground need to have awareness about all relevant parameters concerning health of the propulsion system in real time via proper communication concepts and feedback systems. Systems providing such data via a bus system in the format of e.g. the CAN Aerospace Protocol from the Engine Control Unit offer a clear benefit. Pilots should as well operate their UAVs as convenient as possible e.g. by using single lever operation (combined throttle and propeller pitch control lever). In general the reliability of all propulsion systems will increase and benefit from using components and systems out of serial production manufactured strictly according standardized quality processes.

What is the best solution for which purpose? Each propulsion system no matter if combustion engine, turbine engine or electric propulsion has its advantages in order to fit best for the dedicated purpose. **Electric propulsion** is gaining importance having clear advantages in power scalability, power distribution, high efficiency, minimal Noise Vibration Harshness (NVH) and limited thermal signature. But due to still limited energy density of currently available battery technology such applications will stay in the low endurance and low payload area. Photovoltaic systems could extend their endurance, hydrogen fuel cells even more significantly but also increase complexity.

Combustion engines despite their history of more than 100 years since the first aviation engine from the Wright brothers in 1903 are widely used up to Medium-Altitude / Long-Endurance missions. They are limited by the boundaries of the Carnot process and the air density in high altitude but offer less complexity, high serviceability, high fuel efficiency and low total cost of operation. **Turbine engines** in operation since the first flight of a Messerschmitt Me262 in 1942 [1] provide their advantages in Medium-Altitude and High-Altitude missions carrying high payloads at higher airspeeds of up to 644km/h [2]. Worldwide availability of Jet A-1 / JP-5 / JP-8 fuel is also a major advantage as well as low fuel price (79USD/barrel, ~0,40€/l) [3].

How will the future look like? Without doubt UAV applications will grow further rapidly in in all segments. As soon as the non-segregated airspace will be opened up certified propulsion systems and full compliance with airworthiness regulations will play a central role. **Electric propulsion** will improve power to weight by increasing the energy density of their batteries as well as of the core engine itself. Modern turbocharged **combustion engines** using electronic fuel injection and state of the art engine technology and communication will be able to offer full take-off power up to higher altitudes (15000ft [4]) reaching also higher ceiling levels while at the same time increasing power to weight ratio (1,24kW/kg [4]) and fuel efficiency (~265g/kWh [4]), as well as interfacing seamlessly into the control and communication infrastructure in today´s UAV layouts. **Turbine engine** manufacturers like Rolls-Royce advertise increasing efficiency and thrust while at the same time reducing the noise emissions of their products [5]. Thrust to weight ratios of 5,616:1 seemed to be achievable [6].

Long term seen liquefied carbon based fuels will be the superior energy storage in terms „ease of handling“ and their energy storage capabilities and can be even produced with other base material then crude oil.

References

[1] Klassiker der Luftfahrt (01/2014), *Strahljäger (Teil 2)***,** https://www.klassiker-der-luftfahrt.de/gschichte/flugzeuge/testflugberichte-der-messerschmitt-me-262-zwiefelhafter-testbericht/653132?seite=2

[2] Claudio Müller: Flugzeuge der Welt 2008. Motorbuch Verlag, Stuttgart 2008, *Northrop Grumman RQ-4A Global Hawk*, ISBN 978-3-613-02847-0

[3] IATA (November 2017), http://www.iata.org/publications/economics/fuel-monitor/Pages/price-development.aspx

[4] Rotax 915 iS Operators Manual, Appendix (2017) *Best fuel efficiency at 55% power setting*, www.flyrotax.com

[5] Rolls-Royce product page (November 2017), *AE 3007 turbine engine series*, https://www.rolls-royce.com/products-and-services/civil-aerospace/business-aviation/ae-3007.aspx#overview

[6] EASA Type-Certificate Data Sheet (2015), *AE 3007 Series Engines*, §5 Dry Weight & §6 Ratings of AE 3007A2

Fuel cell - Key steps for affordable and reliable technology for UAVs

Xiao Li[1]*

[1]Troowin Power System Technology, Wuhan, Hubei, 430056, China
* Presenting author email: x.li@troowin.com

Keywords: hydrogen; fuel cell; UAV

Conventional power source for UAVs usually includes aviation ICE (internal combustion engine) and lithium ion battery. One can achieve relatively long endurance with small aviation ICE, but has to tolerate its complexity of operation, poor reliability and not to mention the annoying vibration and noise. In the past decade, lithium ion battery has rapidly become the favourites in the market due to its simplicity and convenience compared to ICE, however, the energy density of state of the art Li-ion battery is still relatively low, resulting in poor endurance. This has long been the biggest obstacle for its wider application. Fuel cell combines the advantages of ICE and batteries, and enables UAVs to be truly more useful and practical. Thanks to significantly improved endurance, multi-rotor drones are now able to perform missions in hours rather than minutes. This work summarized our most recent progress in using hydrogen fuel cells to solve this issue. In the past several years, a common design called open cathode air-cooled fuel cell have been applied by many companies as the power source for UAVs due to its simple design, however, this kind of design has to expose the cathode of the fuel cell to open atmosphere, therefore the fuel cell stack is susceptible to air contamination and membrane dehydration, that results in unreliability in practice. The users often find that their fuel cell system cannot deliver promised power. Furthermore, open cathode fuel cell stack is unable to work at high ambient temperature such as over 40ºC, considering the stack is often installed in the fuselage, where local temperature can be much higher, this further limits the application of fuel cells. We completely solved the above issues and greatly improved the reliability and robustness by closing the cathode of our fuel cell. Our closed cathode air-cooled fuel cell is rated to operate at very high current density ($>1 A/cm^2$) and can run from -30 to 50 ºC ambient temperature. This enabled us to use fewer cells in the stack and thus cut the cost and volume significantly.

Introduction of the 3W-International 3W-180 SRE Wankel-engine Hybrid

K. Schudt
[1]3W-International GmbH, Bad Homburg, 61350, Germany
* Presenting author's email: k.schudt@3w-international.com

Keywords: Wankel engine, hybrid drive, Power boost, gasoline engines, Heavy Fuel (HF) engines

Potential end users often view the Wankel engine critically due to its history: the engine is too unreliable, its cooling is also inadequate and unreliable, and the engine is generally loud, just to name a few of the points of criticism.

To be sure, the Wankel also has many demonstrated advantages. Its construction is compact, with few moving parts. A favourable degree of mechanical effectiveness results from this since there are few friction losses. The compact construction enables greater power density with light weight and modest space requirement. The engine has a lot of power and torque with minimal displacement with very low-vibration engine operation. It can be installed independently of position. At high rotational speeds, the Wankel engine consumes smaller amounts of fuel than comparable Otto engines. These technical possibilities and the power performance ideally suit this engine for applications in which high rotational speeds are required over a long time period, for instance in unmanned helicopters.

3W-International conducted many customer meetings and recognized early on that unmanned helicopter technology would be a key technology for the industrial and civilian usage of UASs. 3W-International thus decided to consider a propulsion technology that ideally covered the needs and technical parameters of this application. The choice fell to the Wankel engine. In early summer of 2017, 3W-International introduced the engine at Xponential in Dallas.

The 3W-180 SRE hybrid features 180 ccm and weighs 6.8 kg as a short engine. Its high-power version achieves 38.5 hp at 7500 rpm (rated power is 28 hp at 6000 rpm). A 5.66 hp/kg power-to-mass ratio with a consumption of 340 g/kW at full load results from this. A hybrid Wankel engine that can feed 15 kW into the system for a short time (e.g. 30 s to 60 s) independently of the batteries' capacity is involved here. This additional power can be used, for instance, when starting a helicopter in order to support the starting procedure thanks to the additional power. A built-in generator generates the electrical power that charges the super capacitors.

The 3W-180 SRE hybrid is equipped with two independent cooling systems. A water-cooling circuit takes care of cooling the engine’s housing and the generator. A second, oil-cooled, circuit takes over interior cooling of the pistons. The resulting heat can thereby be ideally transported out of all engine parts. Internal long-term tests have shown that this cooling system renders the engine long-lived and reliable.

Pursuant to 3W-International's engine philosophy, the 3W-180 SRE hybrid can be used as a gasoline or as a Heavy Fuel (HF) engine. As an HF engine, JET A-I, JP-5, JP-8 fuels can be used.

In-house development possibilities at 3W-International enable things such as silencers to be developed entirely according to customers' specifications. Noise emissions can thus be severely reduced. The mufflers' individual adaptation here is only one reason why the 3W-180 SRE hybrid is offered only as a complete drive unit. Each engine adapted in a project with the customer to his application area as well as to his flight system so that the engine delivers the best possible performance.

UAS in the IDF – Operational Challenges and Coping methods

E. Gil [1]

[1]Heron-TP UAS Operator and Advanced Payloads integration project manager, DDR&D

Keywords: IDF, UAS, Future Trends, Propulsion, Operational, Qualification

In the last 45 years, the IDF has been operating UAS (unmanned Aerial Systems) for various operational needs and scenarios.

The beginning was at the early 1970's with jet-propulsion primitive drones performing offline stills photography beyond enemy lines while today the IDF is operating large numbers and types of UAS's for different missions. Today, the UAS's are performing around 70 percent of the entire operational fight hours (the rest is done with manned aircrafts) and the numbers keep rising every year.

The main UAS categories being used by the IDF are:

1. Strategic – Large platform (up to 5.4Ton), High altitude (42Kft), Heavy payloads (up to 1.5 ton) and Turboprop Engine (PT-6)

This category is used to perform several missions simultaneously (carry several different payloads) while being airborne for long time and at a long distance.

2. Tactic/Strategic - Medium platform (up to 1.2 Ton), Medium altitude (up to 30Kft), Medium payloads (up to 500Kg) and 4 stroke Engine (Rotax)

This category is used to perform one mission for a long time at a various ranges (LOS and SAT) also able to give CAS (Close Air Support) to the Brigade level.

3. Tactic - small platform (up to 450Kg), low altitude (up to 18Kft), light payloads (up to 100Kg) and Light Engines (Wankel) or Electrical Engine.

This category is used to perform one mission for a medium/short time at a close range to give CAS and "over the corner" intelligence to the Brigade and Regiment levels. This category is also being characterized with small operation team that function as both technical and operational.

All those categories are operational in the battlefield and allow us to give the tailor made solution to each of our operational challenges.

The evolution of UAS's has been upgraded corresponding with the operational challenges of the local theatre. For example, the war against suicide terrorists at the end of the 1990's has brought up the eminence need for quick response air surveillance after a "Ticking Bomb" terrorists, so we developed fast and cheap UAS's that can stay airborne all the time (CAP – Combat Air Patrol) and reach every point fast and efficient. The 2nd Lebanon war has brought up the need of a technology to detect a rocket launcher before (or right after) the launch and etc.

To fulfil this evolution, we have established a symbiotic connection with the Development branch in the UAS Department in the IAF Materiel command. Their duty is keeping up safety of flight of the platforms, while preserving availability 24/7 for the operational arena. Moreover, as operational demands keep growing, the department is taking responsibility in managing the UAS's force build-up programs from the technical side, hand in hand with the IMOD (Israeli Ministry of Defence).

In the past, the CONOPS (Concept of Operation) for the UAS's was with up to five(!) crew members in the GCS (Ground Control Station). It had to be done in that way, due to the lack of automatic procedures in the UAS's, so they had to rely on human performance.

Ever since the end of the 1990's, there was a major shift in the development of UAS's towards automaticity (not autonomy, which would come later…) and it has placed the Israeli Defence

Force as a **worldwide leader** in the field of UAS's CRM (Crew Resource Management) and the usage of adequate crew members for operation.

How this automatic approach could reduce the number of crew members in the GCS? While in the past, a minimal UAS ground crew included:

1. A Pilot in order to steer the aircraft and perform all the sensors and engine monitoring.
2. A Payload operator to analyse the image.
3. A Mission commander to coordinate between them and to be responsible for the mission completion.

Today we are steering the aircraft using "Camera Guide" mode and Monitor the engine and sensors using "Evolving Malfunctions Detection" algorithm.

The Camera Guide mode allows the UAS Operator to "Fly the Camera" it means that wherever he watches, the aircraft performs the adequate flight path without any platform disturbance and in the maximum efficiency (in matters of velocity, fuel consumption and etc.). The Evolving Malfunctions Detection algorithm watches the sensors and the engine parameters in real time. When a slight change is monitored, the operator gets an alert, so he knows to start monitoring that specific parameter and not just general all time monitoring like in the past.

This concept is also known as "**Focus on the Mission**". It means that we eliminate all of none essential attention occupiers (Engine & Sensor monitoring, Steering, Sense & Avoid etc.) and by doing so, we are enabling the operator to stay focus on the mission which usually involves image analysis whom known as a significant attention occupier. With that done, we can perform complicated and intense operational activity with just two(!) crew members.

The qualification and training of our Operators is done in that way, so on one hand I qualify them to handle and comprehend with the most complicated operational situations, while on the other hand I qualify them to know and understand all the "under the hood" details so they will know how to handle malfunctions till the safe return home of the aircraft.

Looking into the future, the IDF is promoting new concepts in operating the current and future UAS's. We are going to the area of autonomous procedures using state of the art payloads that can scan a large area and focus the operator only on the relevant data. In the area of Engine monitoring, we are promoting autonomous easy-medium malfunctions handling, so the aircraft will detects, analyse and operate the malfunction autonomously, updating the operator post factum.

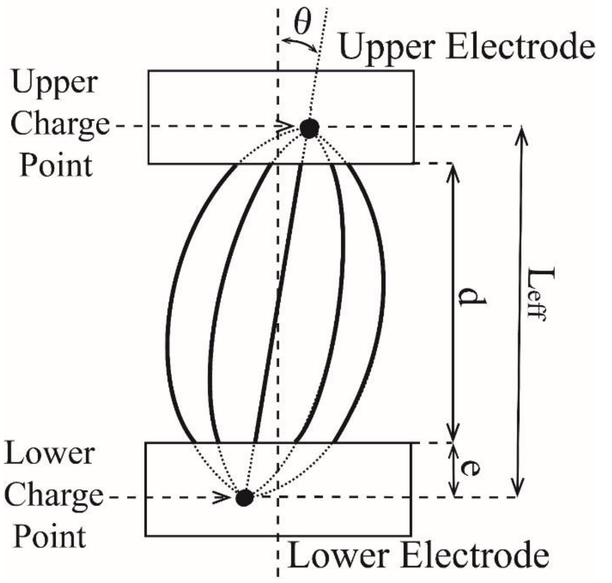
In-Cylinder Charge Density Evaluation w/o Sensors

Nir Druker, Gideon Goldwine, Eran Sher*
Faculty of Aerospace Engineering, Technion, Haifa, 32000, Israel
* Presenting author email: sher@technion.ac.il

Keywords: MAV Propulsion; Charge density measurement; Spark characteristics

We propose here a new method to evaluate the mixture charge density inside the combustion chamber of a SI engine. This is an important parameter that is needed to optimize the spark timing and the amount of fuel that is introduced to the cylinder each cycle, thus optimizing the engine operation for higher power, lower BSFC, or lower pollutants' emission.

The evaluation of the charge density is performed each cycle (on a cycle-to-cycle basis) by using the voltage-current characteristics of the spark plug gap. This real-time evaluation method, may replace two of the present in-use temperature and pressure gages, thus considerably increasing the reliability of the propulsion unit. Owing to the expected higher system reliability and system simplicity, small UAV's may significantly benefit this proposed method. The method principles and some preliminary results are presented.

The classical Townsend's model for dark discharge: $\frac{I}{I_0} = \frac{exp(\alpha d)}{1 - \gamma_c[exp(\alpha d) - 1]}$ A real spark plug showing the extent of the non-uniformity of the electrical field and the structure of the electrodes.	

Reforming-controlled compression ignition

A. Eyal[1]* and L. Tartakovsky[1]

[1]Faculty of Mechanical Engineering, Technion – Israel Institute of Technology, Technion City, Haifa 3200003, Israel
* Presenting author email: amnone@campus.technion.ac.il

Keywords: HCCI engines; Reactivity-controlled; Pollutant emissions;

In the last decades, there has been wide interest in reducing emissions and fuel consumption from vehicles. Tough regulation due to environmental, economic, and political circumstances leads to the development of cleaner and more efficient propulsion technologies. The modern ICEs should utilize low-carbon and renewable fuels for diminishing greenhouse gas emissions and oil dependence, and be more efficient.

Homogenous Charge Compression Ignition Engines received considerable attention for their high efficiency and low emissions (Yao et al, 2009). High compression ratio combined with very high heat release rate enable approximating the ideal Otto cycle, thus making HCCI engine highly efficient. The HCCI combustion is characterized by a relatively low temperature since the excess air (due to working with a lean mixture) absorbs the heat released during the combustion. This leads to extremely low particulate matter (PM) and nitrogen oxide (NOx) emissions and decreases the heat transferred to the walls. However, combustion controllability problem, limited operation range (Saxena et al, 2013), too high-pressure rise rate at high loads (Eng, 2002), and some other challenges hamper market penetration of HCCI engines. Several methods have been proposed and are investigated to resolve the mentioned above problems. These methods can be classified into two main groups, the first is based on temperature control and the second - on reactivity control. Changing the intake temperature or pressure, varying Lambda, and exhaust gas recirculation (EGR) are some first group methods. These methods show a potential for ignition timing control but mostly are limited and do not enable engine operation in the HCCI combustion mode in the whole range of operating modes (Yao et al., 2009).

Reactivity controlled compression ignition (RCCI) shows a potential both for ignition timing control and operation range extension. Basically, two types of fuel, high-reactive and low-reactive, are supplied into the cylinder in variable proportions. The ratio between them determines the mixture reactivity and by adapting the fuel reactivity to the engine regime it is possible to control the combustion timing. A pioneer research group from the University of Wisconsin – Madison used gasoline and diesel as low- and high-reactive fuels, respectively (Reitz and Ganesh, 2015). They reported on soot contraction by a factor of six, three order of magnitude NO_x reduction, and about 16 % gross indicated efficiency growth. The simulation they performed showed an improvement in fuel conversion efficiency due to reduction of heat transfer to walls and better combustion timing control.

Another method to vary the fuel reactivity according to the engine regime need without using two fuels is by streaming a primary fuel through a chemical reformer in which the fuel decomposes to a gas mixture. The reforming process utilized heat of exhaust gas, thus providing simultaneously waste heat recovery with a concomitant additional efficiency improvement. The reforming products consist of species with different reactivity. By changing the reforming conditions it is possible to control the reforming products composition and therefore, the mixture reactivity. Another option is to obtain a uniform none-reactive reformate in case the primary fuel is reactive and thus two kinds of fuel would be available to realize the RCCI concept. We call this method Reforming-Controlled Compression Ignition (RefCCI).

Some primary fuels are considered by researchers for RefCCI method. Methanol, dimethyl ether (DME), and a few other fuels are seemed to be promising. Shudo et al. (2009)

used methanol as a primary fuel. They streamed methanol in parallel through two reformers, one for dehydration of methanol to DME (reactive) and water and the second for decomposition of methanol to hydrogen (none reactive) and carbon monoxide. The ratio between the flow rate through each reformer determines the total mixture reactivity. However, this method had a main drawback of reformer deactivation and system complexity due to the need in two reformers.

In (Eyal and Tartakovsky, 2016) we examined the possibility to use methanol in a single two-stage reformer, while each reformer section is filled with a different catalyst type: acid and metal. Compressed liquid methanol and liquid water stream into a vaporizer and then into the reformer. The methanol-water gas mixture enters first to the acid section in which part of the methanol dehydrates to dimethyl ether (DME) and water; the rest methanol and the water enter then into the metal-catalyst section in which hydrogen, carbon dioxide, and some more minor species are produced. The reforming process products comprise a mixture that includes hydrogen and DME. We demonstrated that by varying the water-to-methanol ratio or the reforming temperature variation of methanol fraction that dehydrates to DME can be achieved and thus the reformate of variable reactivity can be produced. A problem of the reformer deactivation is avoided because of water production during the methanol dehydration.

DME as a primary fuel for RefCCI method is another direction studied in our laboratory and its products are mainly hydrogen and carbon dioxide. Since the DME is available anyway and the hydrogen is a reforming product, it is pretty simple to control the in-cylinder mixture reactivity while the DME is injected separately through the port or direct injection and the reformate through a direct high-pressure gas injector.

The H_2/DME ratio influence on the engine performance is shown in Fig. 1.

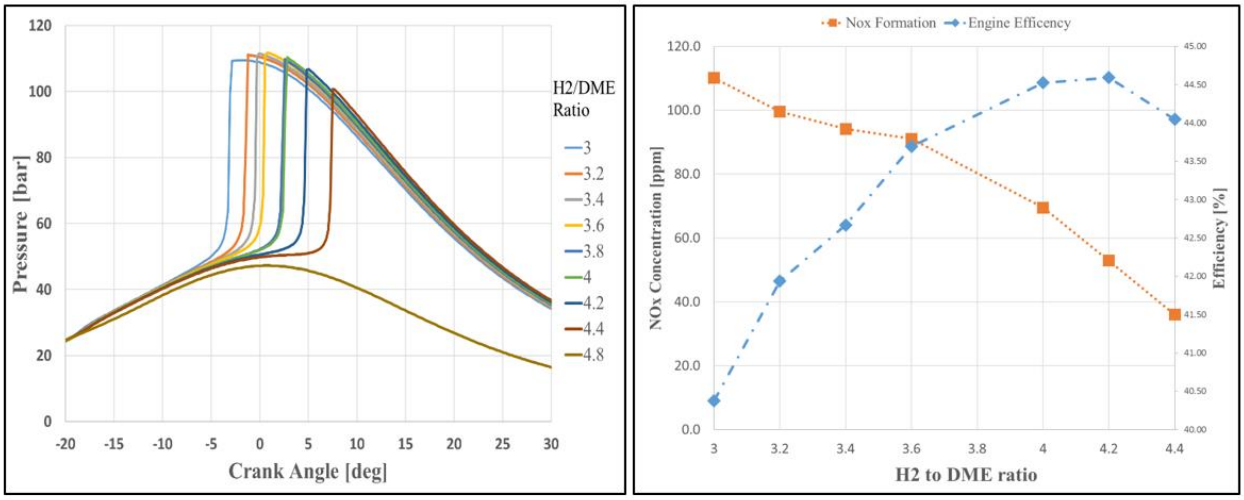


Figure 1. Effect of the H_2/DME ratio on the engine performance (Eyal and Tartakovsky, 2016)

Higher H_2/DME ratio, the lower fuel reactivity. Hence while the ratio raises the ignition timing is postponed. However, the too high ratio might cause misfiring. Maximum efficiency can be achieved through H_2/DME ratio optimization and subsequent control at various ICE operating modes.

Acknowledgement

The financial support of the Uzi and Michal Halevy Fund for Innovative Applied Engineering Research is greatly appreciated.

References

Yao, Mingfa, Zhaolei Zheng, and Haifeng Liu. "Progress and recent trends in homogeneous charge compression ignition (HCCI) engines." Progress in Energy and Combustion Science 35, no. 5 (2009): 398-437.

Saxena, Samveg, and Iván D. Bedoya. "Fundamental phenomena affecting low temperature combustion and HCCI engines, high load limits and strategies for extending these limits." Progress in Energy and Combustion Science 39, no. 5 (2013): 457-488.

Eng, J. A. Characterization of pressure waves in HCCI combustion. SAE Technical Paper 2002-01-2859., 2002.

Reitz, Rolf D., and Ganesh Duraisamy. "Review of high efficiency and clean reactivity controlled compression ignition (RCCI) combustion in internal combustion engines." Progress in Energy and Combustion Science 46 (2015): 12-71.

Shudo, Toshio, Yosuke Shima, and Tatsuya Fujii. "Production of dimethyl ether and hydrogen by methanol reforming for an HCCI engine system with waste heat recovery–continuous control of fuel ignitability and utilization of exhaust gas heat." International Journal of Hydrogen Energy 34, no. 18 (2009): 7638-7647.

Eyal, Amnon, and Leonid Tartakovsky. Reforming Controlled Homogenous Charge Compression Ignition-Simulation Results. SAE Technical Paper 2016-32-0014, 2016.

Using new injection and ignition systems to enhance the efficiency of 2- and 4-stroke internal combustion engines

K. Schudt, W. Seidl
[1]3W-International GmbH, Bad Homburg, 61350, Germany
* Presenting author's email: k.schudt@3w-international.com

Keywords: 2-stroke engines, injection, ignition, gasoline engines, Heavy Fuel (HF) engines, fuel reduction, performance enhancement, range increase

The efficient use of UASs continues to move center stage for users when it comes to such systems' technical performance. It's precisely the ranges, flight durations, and payload magnitudes that are playing an important role in this connection. These parameters are decisive for commercial applications because they are crucial for commercial success. However even military users are interested in their aircrafts' efficient deployment.

That's why the deployed engines are playing an increasingly important role. Their power is partly responsible for the range, flight duration, or transportable load. Enhancing the efficiency of existing propulsion technologies is therefore necessary. It's precisely the fuel-consumption reduction or the power enhancement with constant consumption figures that takes on a significant role in this connection. This is because reduced fuel consumption with constant power can reduce the amount of fuel taken along. A constant amount of fuel translates into a heavier payload, a greater range, or a longer flight duration. Fuel-consumption optimization is thus an important step when enhancing the efficiency of 2- and 4-stroke engines.

That's why 3W-International developed a new injector as well as a new ignition in order to target a power improvement for both future engines and for those drive units already in use. Existing drive units can be retrofitted with the new systems.

The new injection system for 2- and 4-stroke engines is called ECU030. The universally applicable electronic injection system is usable for both gasoline mixture and HF applications. Up to four ignition channels with up to two isolated, settable injection nozzles ignite the fuel mixture. Pump pressure is regulated electronically here. An automatic choke function is also built in. An automatic controller adjusts the fuel mixture to the respective air pressure and outside temperature.

The new HKZ215 ignition system is likewise usable for 2- and 4-stroke engines. The high-power ignition system was developed for significantly greater ignition power. The engine's overall power is thereby enhanced and the exhaust values improved. The HKZ is built into light, robust, nickel-plated aluminum housing.

Investigation of oil temperature deviations in Rotax 914 engines

Cpt. Rom Kafri[1*]; LtC. Dr. Ofer Levi[2]; Cpt. Dudu Halfon[2]; Cpt. Dan Bukhman[2]

[1]UAV Engines Department, UAV Division, IAF

[2]Failure Analysis Department, Depot 22, IAF

[*]Presenting author email: romkafri@gmail.com

Keywords: UAV; ROTAX; Engine; Thermostat; Investigation.

On 11.04.16, during flight of a UAV using a ROTAX 914 engine, high oil temperature was indicated (above the approved limit) while the oil pressure decrease to the approved minimal limit. The UAV landed safely. This event is added to a series of deviations in oil temperature in several engines.

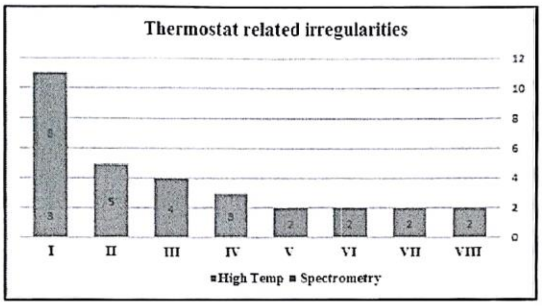


Figure 1. High oil temperature and irregular spectrometric results per engines.

The oil cooling system consists of a thermostat that can divert the oil flow to heat exchanger if a temperature limit is reached. Replacing the thermostat with its housing proved to return the engine to proper operation, which led the investigation to focus on the thermostat assembly.

The investigation consisted visual and macroscopic examinations of the thermostat assembly, X-Ray scanning, geometric review, chemical analysis of the thermostat and the oil, comparing the operations between different thermostats.

The Investigation concluded that the transfer to a different manufacturer for the thermostat, which had a higher rate of elongation. The difference led to the graduate failure of the thermostat due to wear against the housing.

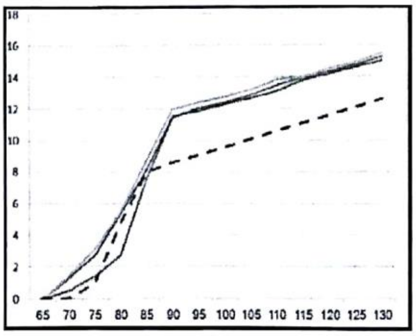


Figure 2. Elongation of new thermostat per oil temperature. Experimental results and theoretical behavior.

The Potential of Using Organic Fluids as Diesel Engines Coolant

A. Davidy[1]*
[1]Computational Engineering Department, IMI, P.O.B. 1044/66, Ramat-Hasharon, 47100, ISRAEL
* Presenting author email: alon.davidy@gmail.com

Keywords: Diesel Engine; Heat Transfer; Piston; Organic Coolants; Dowthrerm A;

Introduction

High-temperature environments and device self-heating are pushing the thermal limits of automotive applications. In general, two-phase cooling has emerged as an attractive solution to meeting the high-temperature. However, it is important to understand the benefits and limitations of various fluids when designing a two-phase cooling system [1]. The common problem with conventional water based coolants. As the conventional coolant flows over a hot spot, it “boils off”. In this “boiling off” area the heat is not being carried away as it is essentially being surrounded by air bubbles. The hot spot remains hot possibly leading to detonation or pre-ignition [2]. The coolant bubbles don’t re-condense until they reach the Radiator, further limiting the effectiveness of the system (see figure 1) [3].

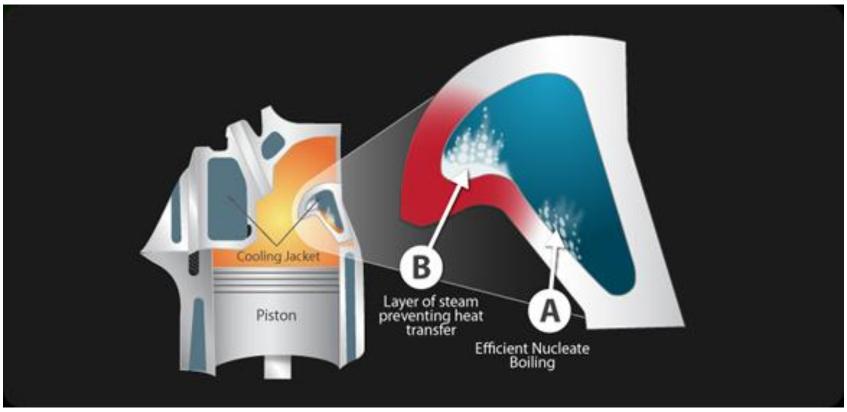


Figure 1: Engine coolant boiling [3].

The typical failures in aircraft engine are caused by overheating due to insufficient cooling. Figure 2 shows failure in the engine piston [4].

Figure 2: Severe overheat failure of engine piston [4].

Some of the key advantages of the organic coolant include [5]:
1) Low vapor pressure of the organic coolant, enabling high temperature operation near atmospheric pressure.
2) Coolant compatibility with low-cost materials and virtually no corrosion potential enabling use of plain carbon steel and aluminum.

Critical Heat Flux

There are inherent benefits of two-phase cooling. A poorly designed two-phase cooling system, however, can fail catastrophically due to critical heat flux. Figure 3 shows the transition from natural convection to nucleate boiling (A), column and slug boiling (P), and critical heat flux (C) for water at 1 atm [1]. Critical heat flux (C) is marked by an excessive rise in device temperature that can result in overheating or physical melting of system components (E). When designing a two-phase cooling system, CHF should generally be as large as possible to allow dissipation of high power density electronics; if the electronic power density if larger than the fluid CHF, overheating and potential failure are likely. Typically, critical heat flux can occur at wall superheats (temperature rise over the saturation temperature of the fluid) between 15 and 25 °C, placing a lower limit on the fluid boiling temperature for a given electronic device temperature before failure occurs [1].

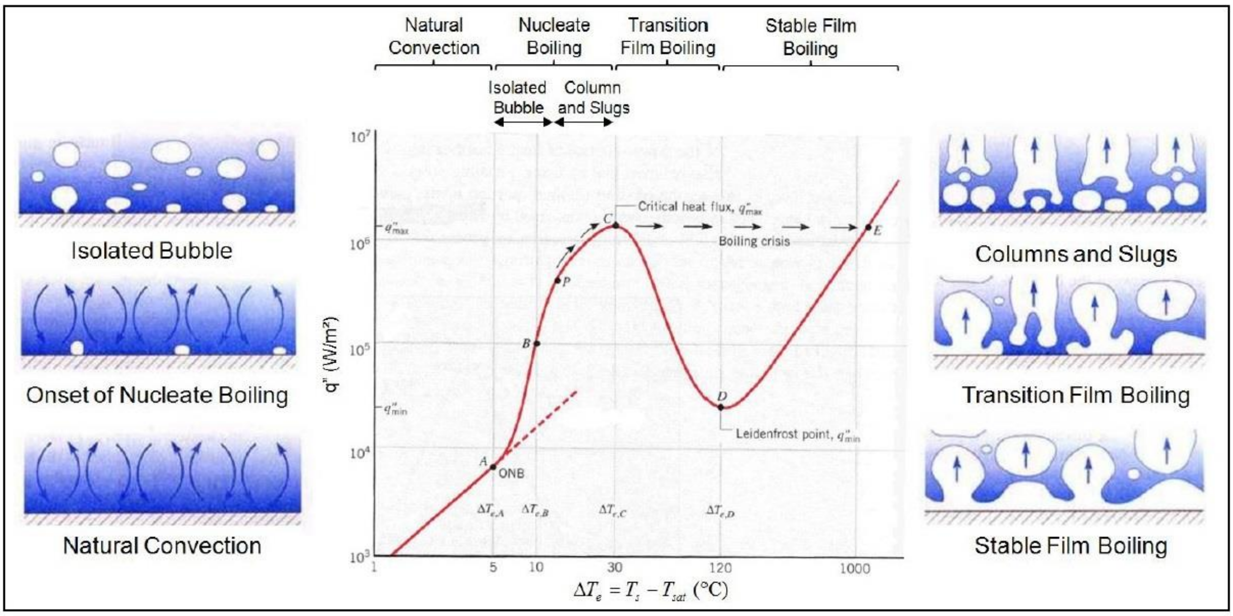
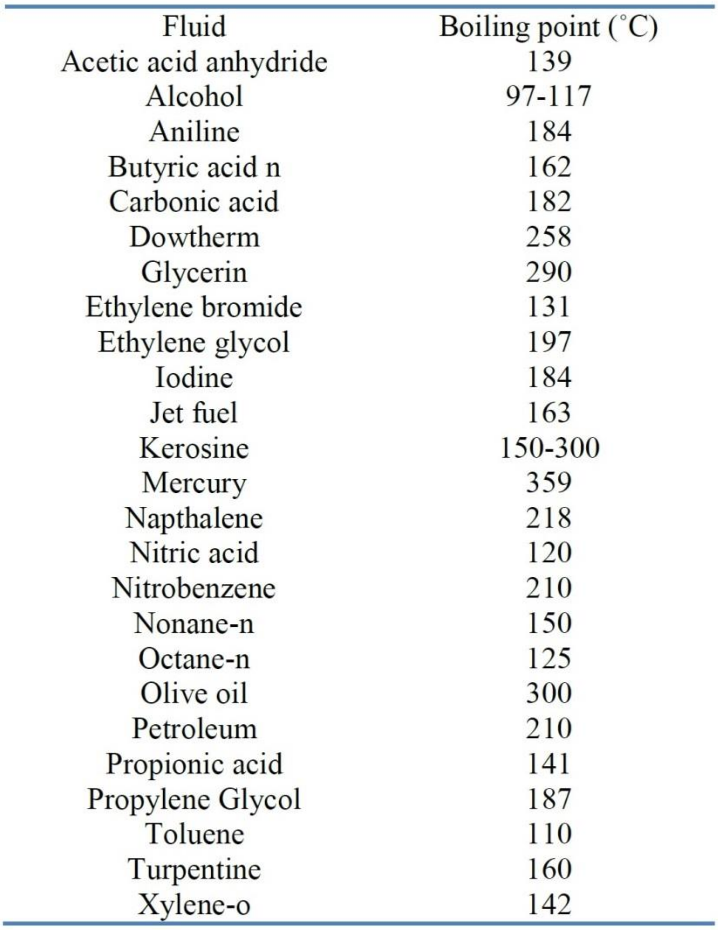


Figure 3: Two Phase failure mechanism – CHF at 1 atm [5].

High Temperature Fluids

Table 1 shows a list of notable fluids that boil at temperatures exceeding 100 °C. While most of these fluids are flammable, extremely corrosive, explosive, or harmful (or all four), three of these fluids may be suitable as a high-temperature coolant—Dowtherm (boiling point 258 °C), ethylene glycol (boiling point 197 °C), and propylene glycol (boiling point 187 °C). Dowtherm is a heat transfer fluid developed by Dow Chemical Company. It is a eutectic mixture of two stable compounds, biphenyl and diphenyl. These compounds have practically the same vapor pressure, so the mixture can be handled as a single compound rather than a binary mixture. Propylene Glycol and Ethylene Glycol are organic compounds that are widely used as automotive antifreezes [1].

Table 1: Boiling points of various fluids at 1 atm [5].



Fluid	Boiling point (°C)
Acetic acid anhydride	139
Alcohol	97-117
Aniline	184
Butyric acid n	162
Carbonic acid	182
Dowtherm	258
Glycerin	290
Ethylene bromide	131
Ethylene glycol	197
Iodine	184
Jet fuel	163
Kerosine	150-300
Mercury	359
Napthalene	218
Nitric acid	120
Nitrobenzene	210
Nonane-n	150
Octane-n	125
Olive oil	300
Petroleum	210
Propionic acid	141
Propylene Glycol	187
Toluene	110
Turpentine	160
Xylene-o	142

Thermo-physical properties of Dowtherm

DOWTHERM A is a heat transfer fluid is a eutectic mixture of two very stable organic compounds, biphenyl ($C_{12}H_{10}$) and diphenyl oxide ($C_{12}H_{10}O$). These compounds have practically the same vapor pressures, so the mixture can be handled as if it were a single compound. DOWTHERM A fluid may be used in systems employing either liquid phase or vapor phase heating. Its normal application range is 60°F to 750°F (15°C to 400°C), and its pressure range is from atmospheric to 152.5 psig (10.6 bar) [7]. DOWTHERM A fluid possesses unsurpassed thermal stability at temperatures of 750°F (400°C). The maximum recommended film temperature is 800°F (425°C). DOWTHERM A heat transfer fluid, in both the liquid and vapor form, is noncorrosive toward common metals and alloys. Even at the high temperatures involved, the equipment usually exhibits excellent service life. Original equipment in many systems is still being used after 30 years of continuous service. Steel is used predominantly, although low alloy steels, stainless steels, Monel alloy, etc. are also used in miscellaneous pieces of equipment and instruments. DOWTHERM A fluid has a freezing point of 53.6ºF (12ºC) and can be used without steam tracing in installations protected from the weather. Figure 4 shows the thermo-physical properties of Dowtherm A [6].

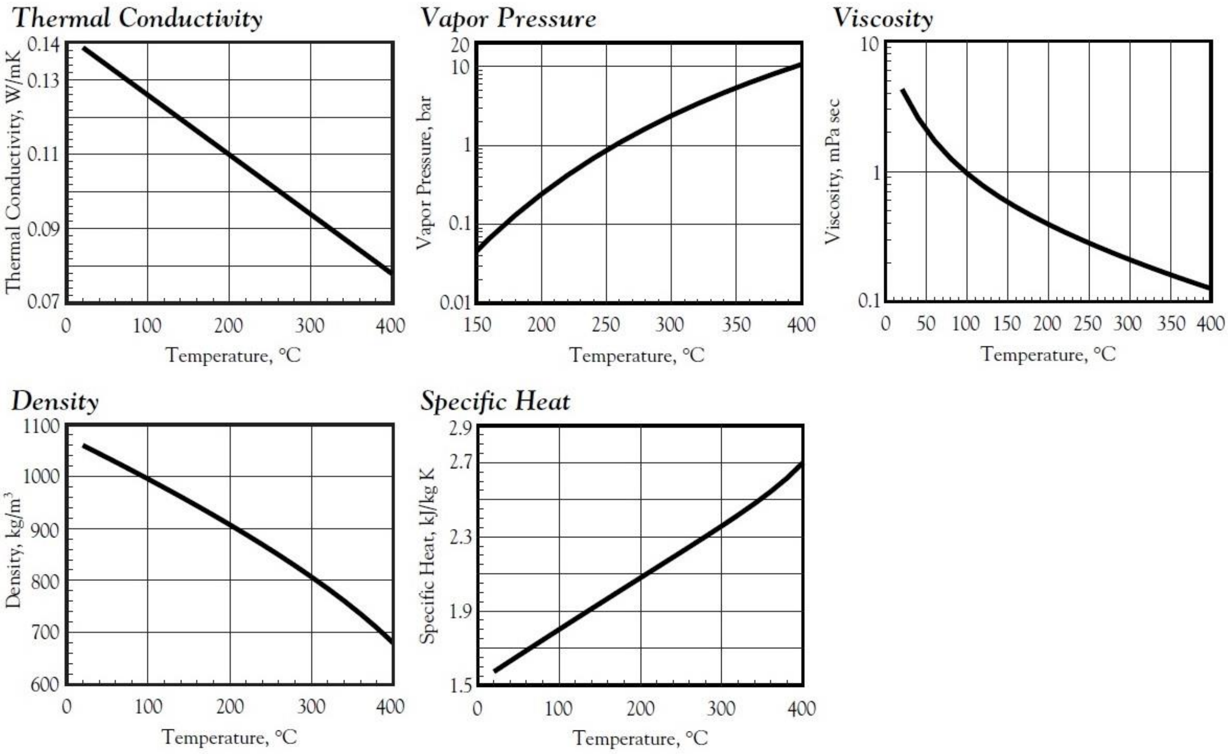


Figure 4: Liquid properties of DOWTHERM A liquid [7].

Coupled Finite element analysis model

In this work, the diesel engine piston is studied at steady-state conditions, i.e. at a continuous engine speed and load. The combustion process at steady state produces cyclic pressure loads and a high constant temperature. These load conditions could yield a piston failure due to fatigue cracking, so-called high cycle fatigue cracks [7]. The convective coefficient of the cooling fluid was taken from Sieder & Tate equation [8, 9]:

$$Nu = 0.027\, Re^{0.8}\, Pr^{1/3} \left(\mu/\mu_w\right)^{0.14} \qquad (1)$$

Where Nu is the Nusselt number, Re is the Reynolds number, Pr is the Prandtl number and μ is the viscosity of the coolant. It was assumed that the piston is made of Steel AISI 4340.The thermo-physical and thermomechanical properties of the steel are listed in Table 2.

Table 2: Thermo-physical and thermomechanical properties of steel AISI 4340

Material Property	**value**
E	205E9 [Pa]
nu	0.28
rho	7,850 [kg/m³]
alpha	12.3e-6 [1/K]
Cp	475 [J/(kg*K)]
k	44.5 [w/(m*K)]

Mechanical loads

The applied mechanical loads consist of the following two parts:

1) The peak combustion pressure which is applied on the combustion bowl, crown and top area is 13 MPa
2) The maximal inertia load at top dead center, TDC, that is, at the top of the stroke. The acceleration at TDC is calculated from:

$$a = r\omega^2\left(1+\frac{r}{\ell}\right) \qquad (2)$$

Where r is the crank shaft radius (half of the engine stroke), ω is the angular frequency, r is the crankshaft radius and ℓ is the connecting rod length.

Table 3: Operating conditions of the Diesel engine [7].

name	Expression	Description
n	2,000 [1/min]	Revolutions per minute
omega	n*2*pi	Angular velocity
stroke	0.144 [m]	Engine stroke
r	stroke/2	Crankshaft radius
conrod_length	0.26 [m]	Connecting rod length
lda	r/conrod_length	Radius-length ratio
pistonacc	omega^2*r*(1+lda)	Piston acceleration
P	130e5 [Pa]	Face load
tn	5e5 [Pa]	Input estimate of contact force
en	1.0e14 [N/m^3]	Penalty stiffness

Thermal Boundary conditions

The effects of the cyclic swing in surface temperature during the combustion cycle are small compared to the time-averaged temperatures. The major effect of the heat transfer on thermal stresses is therefore taken into account by time-averaged boundary conditions [10], that is, through constant convective boundary conditions.

The heat transfer coefficients on all boundaries are some typical values for a high speed diesel engine, as well as the bulk combustion gas temperature, engine oil temperature, and cooling water temperatures (see reference [10]). The following thermal boundary conditions are applied:

1) The combustion gas temperature (900 °C) is applied to the combustion bowl and piston crown areas as an external temperature. The heat transfer coefficient is set to 500 W/ ($m^2\cdot$°C) in these areas.

2) The outside of the piston is cooled by Dowtherm coolant, whereas the inside is cooled by the engine oil, both at a temperature of 80 °C. Different heat transfer coefficients are applied on different boundaries and thereby reflecting the different cooling rates at each boundary. For example, a high heat transfer coefficient is applied to the bottom of the piston inside as this is the area where the piston oil cooling jet is directed.

Results and Discussions

This section divided into two parts. In the beginning the thermal results are shown. Then the structural analysis results are presented.

Thermal Results

Figure 5 shows the temperature field of the engine piston.

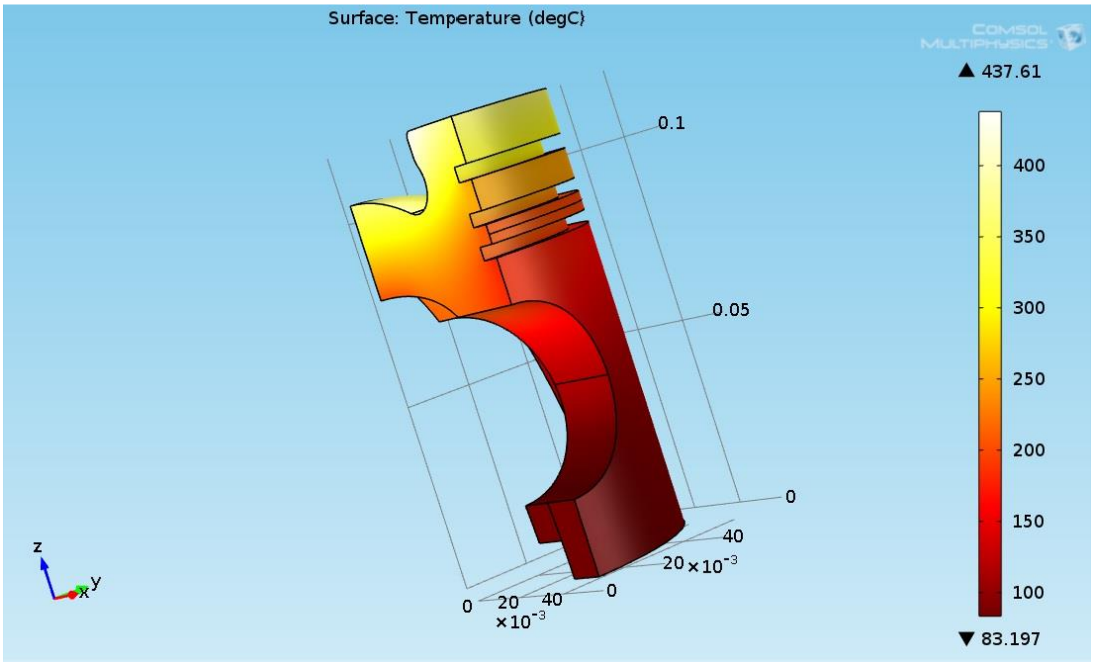


Figure 5: Temperature field of the piston.

From figure 5, it can be seen that the maximal temperarture of the piston reaches to 438°C.

Thermomechanical results

Figure 6 shows the Von Mises stress distribution in the engine piston.

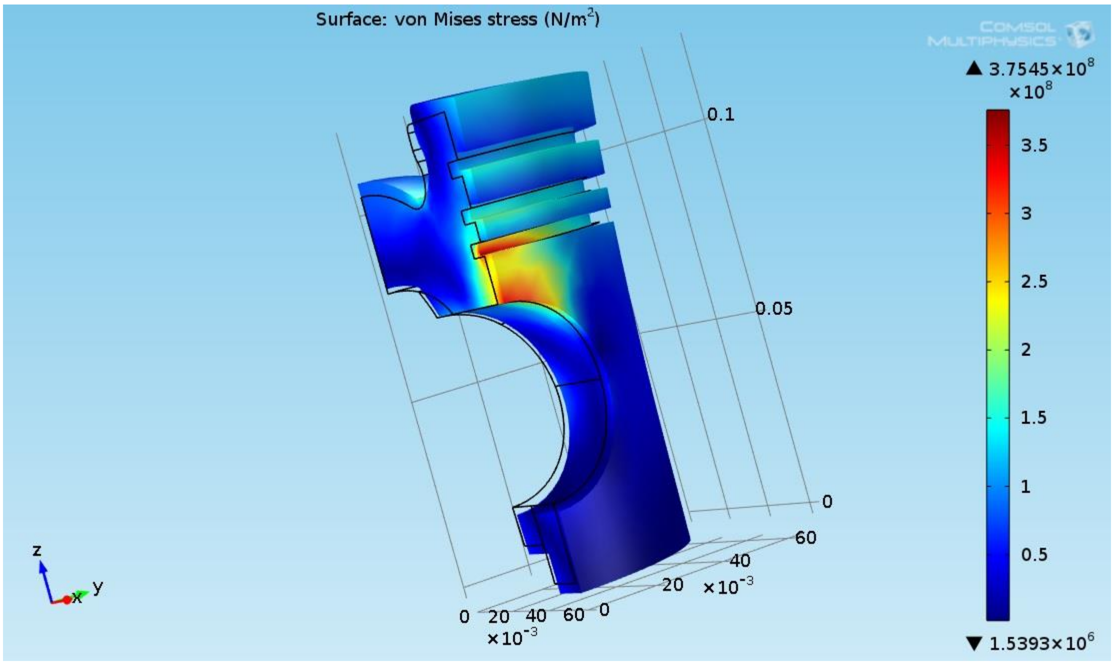


Figure 6: Von Mises stress field of the piston.

As can be seen from figure 6, The maximal stress reaches to 375 MPa. At this location the tempearture of the steel is less than 200°C (392 °F). Figure 7 Shows the effect of temperature on the tensile ultimate stregth (F_{tu}) and tensile yield strength (F_{ty}) of AISI low alloy steels [11].

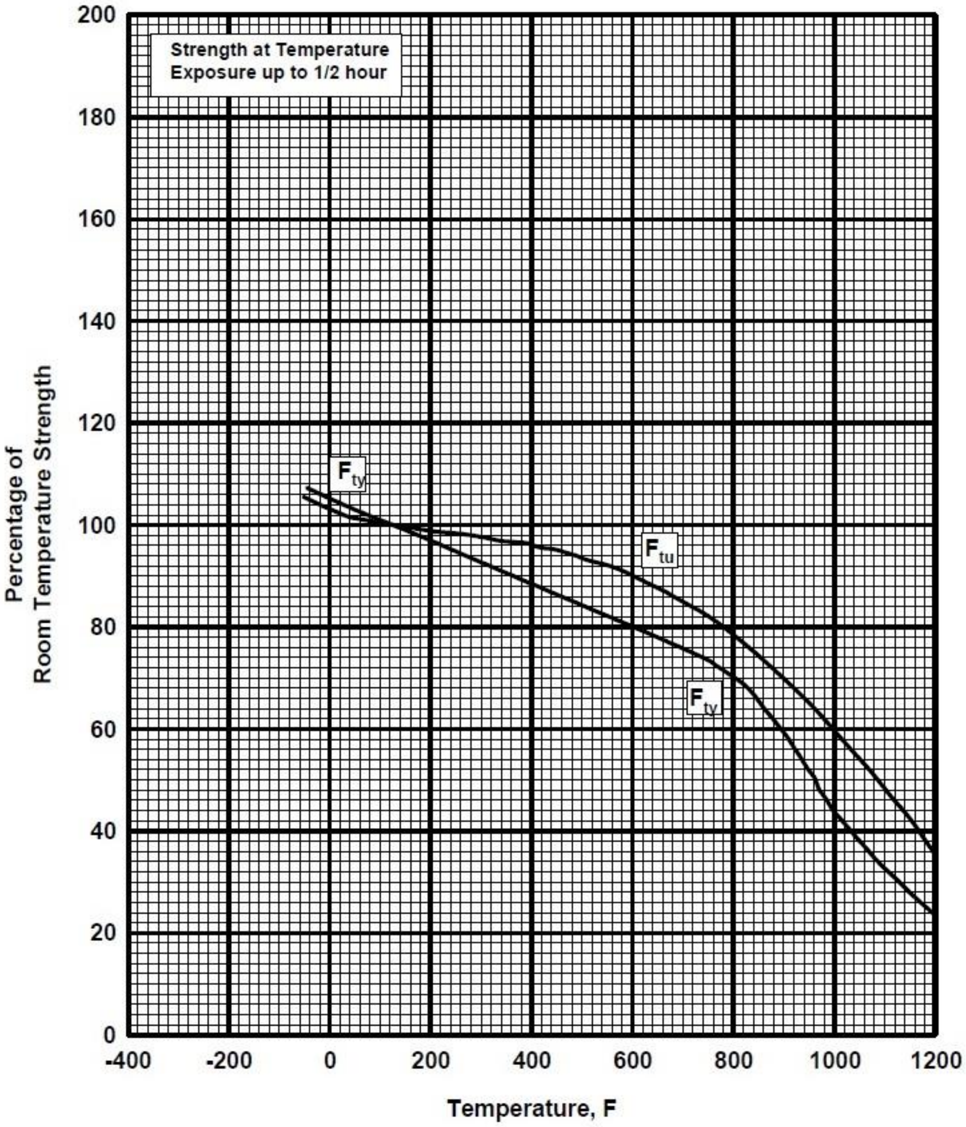


Figure 7: The effect of temperature on the tensile ultimate stregth (F_{tu}) and tensile yield strength (F_{ty}) of AISI low alloy steels (all products) [11].

From figure 7, it can be seen that the decrease in the tensile yield strength is negligible at the position, where the maximal tempearture has been found.

Conclusion

High-temperature environments and device self-heating are pushing the thermal limits of automotive applications. In general, two-phase cooling has emerged as an attractive solution to meeting the high-temperature. However, it is important to understand the benefits and limitations of various fluids when designing a two-phase cooling system. In this work, the diesel engine piston is studied at steady-state conditions, i.e. at a continuous engine speed and load. The combustion process at steady state produces cyclic pressure loads and a high constant temperature. These load conditions could yield a piston failure due to fatigue cracking, so-called high cycle fatigue cracks. The convective coefficient of the cooling fluid was calculated by Sieder & Tate equation empirical equation. It has been found that the maximal temperature of the piston reaches to 438ºC. The maximal stress reaches to 375 MPa. At this location the tempearture of the steel is less than 200ºC (392 ºF). The decrease in the tensile yield strength is negligible at the position.

References

[1] Sharar D., Jankowski, N. & Bar Cohen, A., (2012), *Two Phase Fluid Selection for High Temperature Automotive Platforms*, ARL-TR-6171,

[2] Rotax Owner Assistance Network (ROAN), Rotax 912/914 Cooling System.

[3] https://forum.miata.net/vb/showthread.php?t=496912.

[4] Piancastelli, L., (2014), *The Different Failure Modes of Automotive and Aircraft Engine*, 3rd Conference on Propulsion Technologies for Unmanned Aerial Vehicles, *Samuel Neaman Institute Technion*, *Haifa*, January 30.

[5] Makens R.F., (1964), *Organic Coolant Summary Report*, IDO-11401, Idaho Operations Office, *US Atomic Energy Commission*, *October*.

[6] Dowtherm A, *Heat Transfer Fluid, Product Technical Tool*, http://www.dow.com/heattrans.

[7] COMSOL 3.5a (2009) *Structural Mechanics Module – Model Library*.

[8] Sieder E.N., & Tate, G.E. (1936), *Ind. Eng. Chem*., 28, 1429-1436.

[9] Kern, D.Q., (1950) *Process Heat Transfer*, McGraw Hill Book Company.

[10] Borman G., (1987) *Internal-Combustion Engine Heat Transfer*, Mechanical Engineering Department, University of Wisconsin-Madison.

[11] Department of Defence (1998) *Metallic Materials and Elements for Aerospace Vehicle Structures*, MIL-HDBK-5H.

Demonstration of Propeller/Wing Interaction Analysis

Avi Ayele, Shaul Segal, and Ohad Gur [1]

[1] Aerodynamic Department, IAI - Israel Aerospace Industries

Keywords: Propeller, CFD, Wing, Interaction

The influence of a wing mounted tractor propeller was investigated using up-to-date CFD capabilities. The case involves an off-the-shelf commercial propeller with a new designed wing and nacelle. Since the propeller properties were not available except for its basic performance maps, as given by the manufacturer, a synthetic propeller was designed using indigenous IAI capabilities. Then, it was implemented into CFD analysis using EZAir – a structured solver suite with multi-zone, multi-block Navier-Stokes, CFD flow solver. EZAir can handle complex geometries using patched grids or chimera overset grid topology and incorporates a simple but accurate actuator disk model. The CFD analysis captured the influence of the propeller on the vehicle aerodynamic characteristics including details in the flow field. Thus, high fidelity analyses were available at rather preliminary stages of the design and much earlier to configuration freezing. Moreover, this capability may emphasize undesired phenomena which may be found later, during complex and expensive wind tunnel tests.

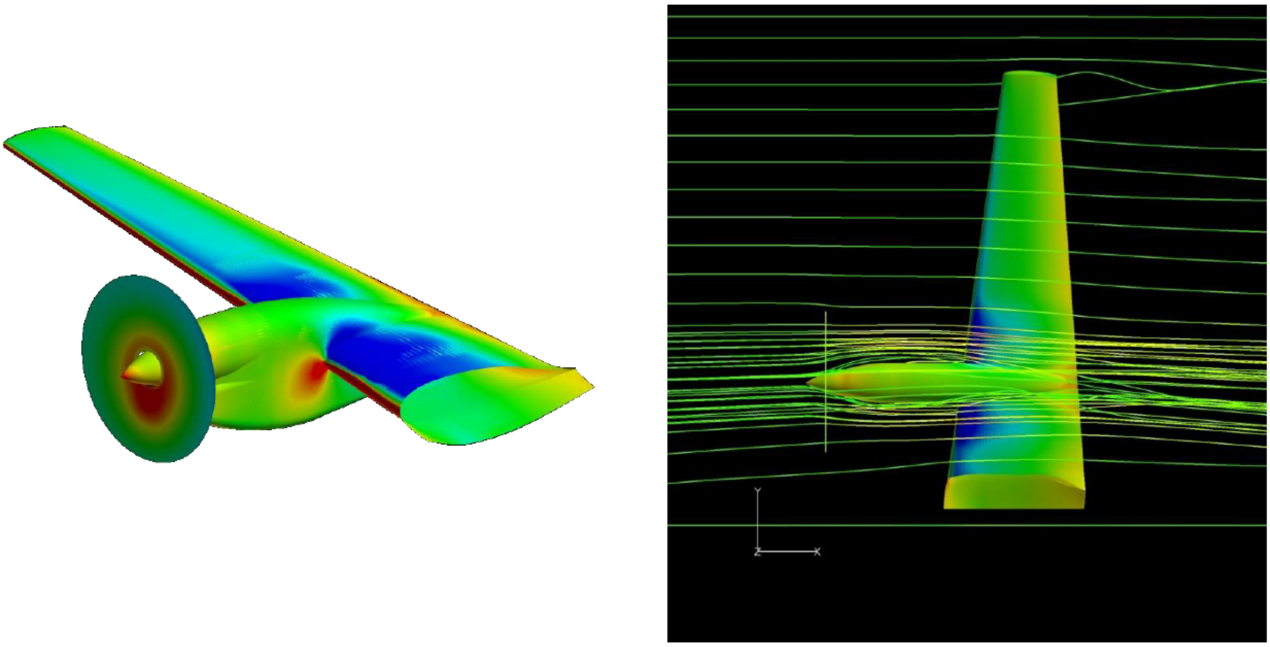


Figure 1. Propeller/Wing CFD analysis

Challenges in Electrical Propulsion

I. Gerlovin[1]*

[1]Energy Sources, Engineering Division, Israel Aerospace Industries
* Presenting author email: igerlovin@iai.co.il

Keywords: Electrical Propulsion; Battery; Energy, Propulsors

With the significant advancement in the electrical energy sources we see in the recent years, there is a notable trend towards exploitation of electrical propulsion both in manned and unmanned airplanes. Electrical propulsion, typically used in small UAVs, penetrates to more heavy airplanes and requires electrical systems to be sized to tens or hundreds of kilowatts.

Electrical propulsion provides major advantages to the UAV and many times improves its performances. For example it allows optimal installation of the propulsors across the body, allows quick power response, quiet flight, reduces operational cost and increases reliability.

Along with the aforementioned advantages, electrical propulsion introduces significant challenges to electrical and installation engineers. These challenges include:

- Battery weight, low endurance
- High voltage
- Propulsion package optimization
- Installation requirements
- Efficiency losses
- Heat dissipation
- Smart flight control
- Lack of industry experience

The electrical propulsion is not trivial and engineering challenges are severe. As such, every airplane should be considered independently for a propulsion source.

In order to increase penetration of electrical propulsion to UAVs several technological challenges must be overcome: higher energy density batteries, new energy sources for example fuel cells, lighter motors, more efficient motor controllers, new power switching devices. All those will enable the transition from conventional propulsion sources to electrical alternative.

For now new, lithium based battery chemistries are already emerging. Low cycle life and high introduction price prevents wide use in aviation. A lot of investment is made by automotive industry in this direction and eventually the aerospace industry will benefit from this progress.

The aerospace motors industry is currently led by pioneers like Siemens, with its 260KW electrical motor.

Li/CF_x-MnO_2 Hybrid Technology for UAV Applications

M. Destephen[1]*, D. Zhang[1], D. Darch[1] and E. Ndzebet[1]

[1]Eaglepicher Technologies LLC, Joplin, MO, United States
* Presenting author email: Mario.destephen@eaglepicher.com

Keywords: Carbon fluoride; manganese dioxide; hybrid; lithium; primary

Lithium carbon fluoride (Li/CF_x) is an attractive primary power source because of its high specific energy, low self-discharge (less than 1% per year), excellent thermal stability, wide operating temperature range (-40 to 85°C), and improved abuse tolerance over other lithium primary battery chemistries. However, the roadblocks that have prevented a wider market penetration of the Li/CF_x chemistry are its initial voltage delay at low temperature, thermal management issues at high discharge rates, and CF_x's material cost. Several approaches have been used to address these issues, including a partial substitution of CF_x by manganese dioxide to form hybrid cathode.[1,2] Using a web-coating process similar to that used in lithium-ion battery manufacturing, EPT has successfully developed a CF_x-MnO_2 hybrid cathode, which not only maintains all the favorable advantages of Li/CF_x, but also provides the highest specific energy and excellent performance over a wide temperature range, as compared to other lithium primary chemistries[3,4].

A pouch cell with the hybrid chemistry was developed to maximize energy density[5,6]. The pouch cell format offers opportunities for better performance with reduced weight and improved packaging efficiency for prismatic battery envelops. The main challenge for hybrid pouch cells is cell swelling, due to the well-known swelling behavior of CF_x during discharge. The swelling will not only affect the battery integrity, but will also negatively impact the battery discharge performance in the pouch cell format. Eaglepicher Technologies has addressed the swelling issue through the selection of the proper cathode active materials, cathode composition and cell design. Also, for the active materials, the ratio of CF_x to MnO_2 was optimized in terms of its effect on swelling, heat generation, and energy density requirement. Performance of the hybrid pouch cell was validated at up to 2C continuous discharge rate for a wide range of temperatures. The pouch cells deliver a nominal specific energy of >400 Wh/Kg at room temperature which is >50% above current Li-ion cells. Figure 1 shows the performance of a single pouch cell (LCF-136) under a simulated UAV profile. The discharge profile includes a 1.5C discharge rate during take-off and a C/2 discharge rate during cruise discharge. It can be seen in the Figure that the cell demonstrated the power capability required for this type of applications. Several battery packs have recently been developed for different application including UAVs.

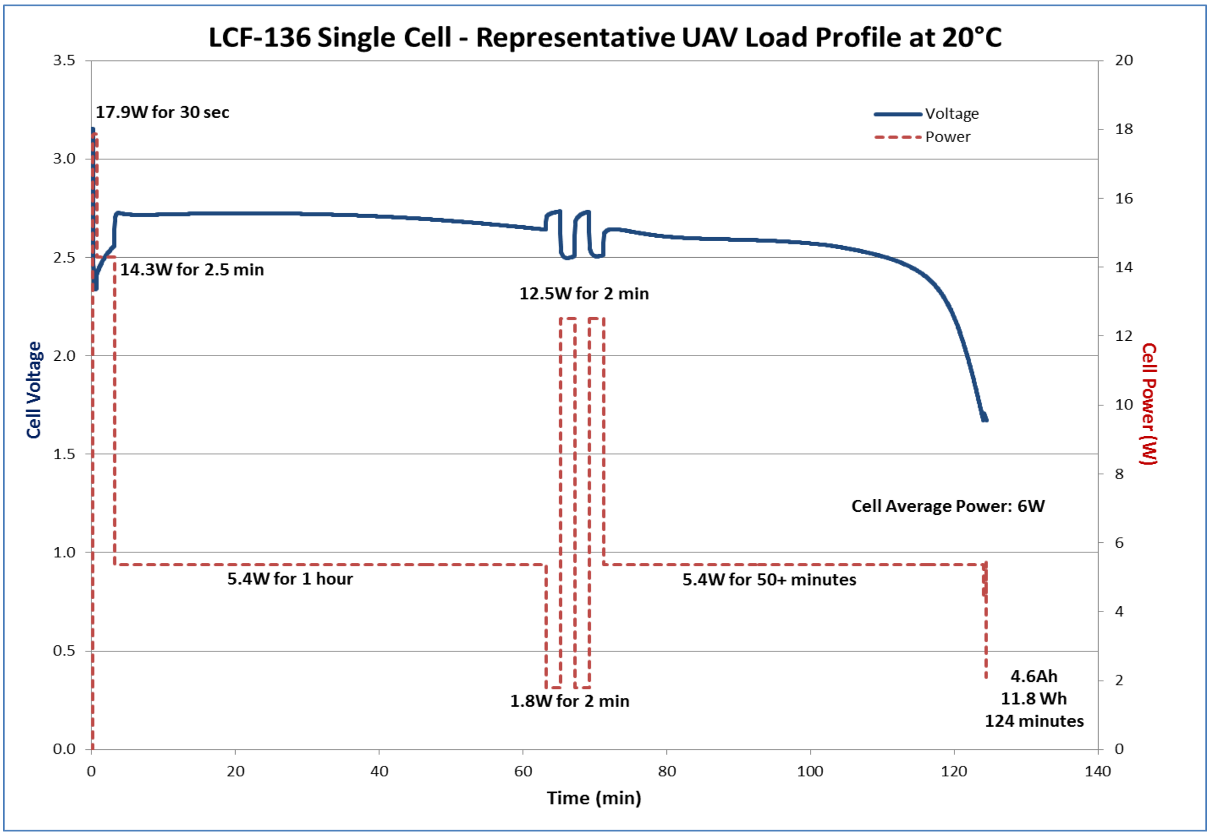


Figure 1. Performance of a LCF-136 pouch cell under a simulated UAV discharge profile

This presentation will provide a general overview of the hybrid technology development at Eaglepicher Technologies. The results from single pouch cells and battery packs will be discussed. In addition to advantages in specific energy over Li-ion batteries, the CF_x-MnO_2 hybrid technology offers advantages in shelf-life and maintenance costs (no need for re-charge prior to use). The cells and corresponding battery packs are ideal for small expendable (single-use) UAV applications. They will provide superior pack performance that will enable longer flight times.

References

[1] Marple, J. W., (1987) *Journal of Powers Sources*, Vol. 19, pp.325-335.

[2] Leger, V. Z., (1982) *US patent 4327166*.

[3] Zhang, D., (2010) *Proceeding of the 44th Power Sources Conference*, Las Vegas, Nevada

[4] Destephen, M., Zhang, D., Bang, H., Wang, J., Viswanathan, U., and Ndzebet, E., (2012) *The 45th Power Sources Conference*, Las Vegas, Nevada

[5] Destephen, M., Zhang, D., Bang, H., and Ndzebet, E., (2014) *The 46th Power Sources Conference*, Orlando, Florida

[6] Destephen, M., Ndzebet, E., Zhang, D., and Listerud, E., (2016) *The 47th Power Sources Conference*, Orlando, Florida

Power-Lines Charging Mechanism for Drones

Kobi Gozlan[1], Kfir Cohen[1], Nir Shvalb[1], Boaz Ben-Moshe[1*], Moshe Sitbon[1], Alon Kuperman[2]

[1]Kinematics & Computational Geometry laboratory, Ariel University, Israel
[2]Department of Electrical Engineering, Ben Gurion University, Israel
* Presenting author email: benmo@g.ariel.ac.il

Keywords: Power-Lines Charging Drone; Robotic Measure Meter; Onboard charger

In this work we present a complete proof of concept of a robotic mechanism which allows a multirotor drone to be charged form powerlines. Motivated by the demanding challenge of constructing a long duration multi rotor platform we design an "add-on" mechanism which allows a commercial drone to safely land on powerlines, perform a short-term charging loop (in 1-2 C) and finally to be able to take-off safely from the powerlines. The suggested platform should satisfy the following requirements:

- **Light weight**: overall flight time on a single charge will remain at least 85% of the original platform.
- **Fast charging**: the suggested platform should allow 2:1 charging ratio – (e.g., 30 minutes charging should allow at least 15 minutes extra flight time).
- **Rapid landing and take-off**: in order to maximize the operational time – the overall landing and take-off should take less than 1 minute.
- **Safety**: The charging tasks (landing, charging and take-off) should be safe and efficient – allowing a common operator to perform a complete charging process with success probability greater than 95%.
- **Remote operation**: the operator should be able to perform the charging manoeuvre via FPV control (no line of site) from a remote location which might be few km away.
- **Standard COTS platform**: the charging platform should be applicable for integration on standard commercial drones.

Considering all the above requirements we designed a novel robotic mechanism for connecting the powerlines (Fig. 1): the mechanism is based on a motorized measure meter with gimbal and video based control loop. The charging system contains also an onboard charger (converting 100-250V current to 24 V) and several safety mechanisms & sensors to allow a safe charging with real-time telemetry for current, heat and battery charging state.

The suggested platform was implemented on DJI's Matrice 100 drone which is powered by a 6S 4.5 Ah (~23V) battery. The overall charging mechanism weights less than 280 grams which is about 10% of the drone weights (including the on-board charger, wiring, and all the needed mechanism for performing a safe and efficient charging for powerlines). The integrated mechanism includes two wide angle FPV cameras and a long range two-way remote control with complete charging telemetry. The suggested platform was tested in several field experiments in which it was able to satisfies all the above requirements allowing the platform to charge from 25% to 75% capacity in about 15 minutes allowing the platform an additional 15 minutes flight time – to the best of our knowledge this is the first work which allows a 1:1 field charging vs flight-time for commercial drones.

Figure 1: A novel robotic power-line charging mechanism

Power Performance Enhancement for a Rotary UAV Engine

J.Shachar Luzzatto
UAV Engines Plant / Elbit Systems ISTAR, Israel

Keywords: Wankel engine, Rotory engine, turbocharger, supercharger

The need for charging an engine in the UAV industry is constantly increasing. The reasons for this is the need for higher flight altitude, improved performance, the use of UAVs as a civil aviation partner, as well as continuous improvement in the efficiency and capability of carrying sophisticated systems on the UAV.

A charged rotary engine, with its outstanding power to weight ratio, will allow better utilization of UAVs in the market, in a variety of tasks which require large payloads, long flight durations, high responsiveness – all by the improved performance of a power plant, and by its low weight and volume – allowing more capacity for fuel and loads. Missions such as environmental control, forest control, search and rescue, weather monitoring, traffic control, police enforcement, etc. – will vastly benefit from these enhanced capabilities.

In an internal combustion engine, the air pressure in the entrance decreases with the increase in flight altitude. This results in a significant decrease in engine capacity and with the performance of the vessel. All forms of charging aim to achieve a constant inlet pressure with maximum constant power, up to a value called critical height.

Today there are two methods for charging: A turbocharger that uses the exhaust gas to turn a turbine, rotating a compressor that compresses the inlet air. And a super charger, which is actually a compressor that is driven (for example) by the engine axis and compresses the inlet air. Each method has its advantages and disadvantages depending on the application and the type of engine it is charging.

As aviation is generally conservative, turbocharging is used more often. In addition, there is a considerable challenge in charging a rotary engine and using innovative technology is required to cope with this challenge.

Wankel-type rotary engines, were never modified for the implementation of a charger for high altitude use, as their unusual geometrical structure was not amenable to exploit the usual turbo/superchargers which were initially developed for piston engines.

The Work aims to achieve the unprecedented result of having high specific power *and* the capability of operating at high altitudes and improved performance throughout the existing flight envelope. This will allow expanding the capabilities of Unmanned Aerial Vehicles (UAV) for improved performance, and bettering its contribution to numerous survey tasks in our planet.

The work demonstrates a breakthrough solution, derived from reengineering of an existing high-performance Wankel engine and from the integration of a unique charger, specifically optimized for use with the said engine.

The new engine will require innovative solutions both in the modification of the structural design of the motor to be upgraded, and in the deployment of wholly-new approaches for the charger, whose operational regime, further to the Wankel peculiarities, will be different from that of a standard charger.

In the framework of an Italian bi-national research and development portfolio, the charging method, most suitable for this engine has been defined and a Supercharger were chosen. The Compressor that was developed was integrated into the engine and tested at the company's facilities. The results of the development indicate the ability of the Wankel engine to achieve the target parameters for the engine performance.

Tour Engine - High efficiency split-cycle engine

O. Tour[1, 2] H.B.Tour[1, 2, *] and E. Sivan[1]

[1]Tour Engine Israel, LTD
[2]Tour Engine Inc.
* Presenting author email: hugo@tourengine.com

Keywords: Internal combustion engine; split-cycle engine; fuel efficiency; reduced emissions;

Split-Cycle Engine splits the conventional 4-stroke cycle between two cylinders: The first cylinder (denoted the Cold-Cylinder) is used for intake and compression. The compressed air is then transferred, through a gating mechanism, from the compression cylinder into a second cylinder (denoted Hot-Cylinder) which serves as a power cylinder.

Theoretically, splitting the four-stroke cycle of the internal combustion (IC) engine between two cylinders, rather than executing the complete cycle within a single cylinder, has the following significant efficiency advantages:

- **Keeping colder temperatures at the Cold-Cylinder.** As the Cold Cylinder does not host combustion, the cylinder's temperature is kept low, which enables more efficient compression while maintaining common compression ratios.
- **Increasing the Hot-Cylinder (power cylinder) expansion ratio**. This feature increases the conversion of thermal energy to kinetic energy. A larger expansion ratio also permits less deliberate heat rejection (active cooling) as the larger expansion acts as a cooling mechanism.

Over the years, several split-cycle designs have been proposed (first attempt made by Brayton cycle engines back in the 19th century) but none has matured. Those engineering efforts could not overcome inadequate working fluid transfer between the two cylinders that led to poor combustion and thermodynamic losses. They also failed in designing a reliable, properly sealed and none-restrictive inter-cylinder gating (valve) mechanism.

Tour Engine Inc. has developed a unique inter-cylinders gas exchange mechanism that fully addresses and resolves the above-mentioned shortcomings of other split-cycle designs.

The objective of this presentation is to provide an overview of Tour Engine's novel gas exchange mechanism, which is the technology enabler of an ultra-efficient split-cycle engine. The Tour Engine's IC engine is a platform technology that revolutionizes the way IC engines are build. It can be used in transportation, stationary power generation as well as for Ariel vehicle applications.

The Tour engine has a superior power to weight ratio, it fires each revolution rather than every two crank revolutions therefore it direct develops higher torques at lowers shaft RPM.

Figure 1 show, recently built, state-of-the-art, 1 kW Tour split cycle engine. This engine is commercially aimed to power, within the US tens of millions of households.

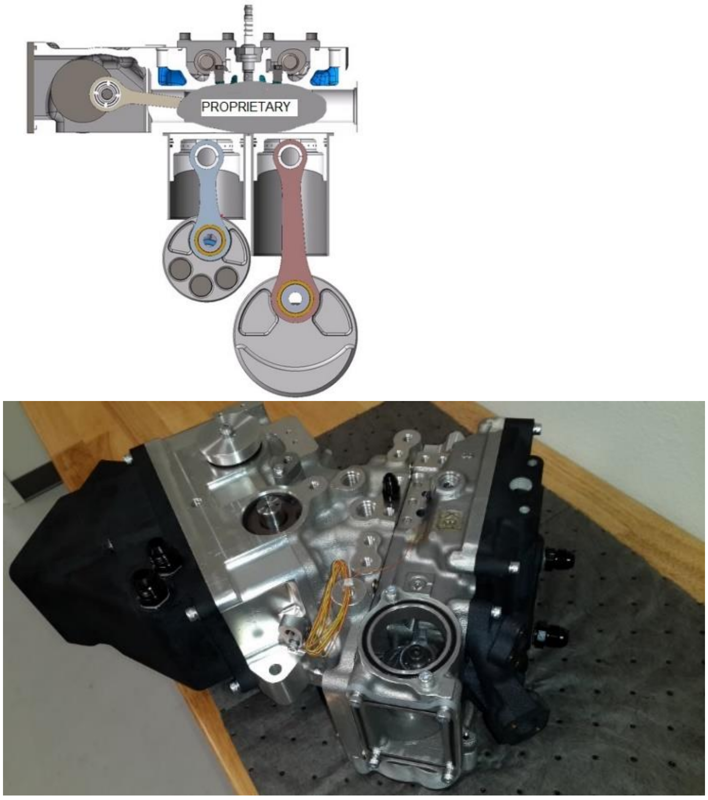


Figure 1. State-of-the-art 1 kW engine:
Left. Cross sectional view **Right.** Assembled engine.

Acknowledgement

This work is supported by the Israeli Ministry of National Infrastructures, Energy and Water Resources and the American Department of Energy.

Proceedings 7th Conference on Propulsion Technologies for Unmanned Aerial Vehicles, Haifa, Israel, January 25, 2018

Limitations of Two-Stage Turbocharging of Unmanned Aerial Vehicles at High Flight Altitudes

Y. Fass[1]*, L. Tartakovsky[1]

[1] Faculty of Mechanical Engineering, Technion – Israel Institute of Technology, Haifa 3200003, Israel
* Presenting author email: yfass@campus.technion.ac.il

Keywords: Turbocharging, High-Altitude

The UAV industry frequently uses internal combustion engines (IC) for propulsion, converting the power produced by engines to thrust using a propeller. As the UAV climbs to high altitudes the air pressure rapidly drops. To enable aircrafts flying at high altitudes without losing performance, and to take advantage of the low drag at high altitudes, a turbocharger is usually applied to overcome the problem of low pressure/density air, by compressing the ambient air back to the sea-level pressure (Hiereth & Prenninger 2007).

The turbocharger pressure ratio gradually rises as the airplane climbs to higher altitude. Therefore, higher pressure ratios at high turbocharger efficiency are needed and special control loops are designed for managing the energy balance of the turbocharger. To achieve high pressure ratio at a high-altitude flight, a bigger-size turbocharger needs to be used. A larger turbocharger with high pressure ratio has many disadvantages: Its efficiency is low at low altitudes; it is limited by the minimum air flow rate through it; has high inertia and leads to difficulties in engine-to-UAV integration due to its size. Alternatively, two or more turbochargers can be used in series, wherein the overall pressure ratio is a multiplication of the pressure ratios of the turbochargers. This approach allows overcoming some of the efficiency limitations of a single turbocharger yet maintaining the desired high pressure ratio (Chen et al. 2013; Canova et al. 2009). Hence, it is clear that applying two or more turbochargers is a promising way to achieve a high-altitude flight (Rodgers 2001), (Bents et al. 1998), (Loth et al. 1997), (Shi et al. 2014), (Li et al. 2014), (Yang, Gu, Deng, Yang & Zhang 2018).

At high altitudes, especially at altitudes that can only be achieved with two-stage turbocharging, the positive energy balance, enabling the compressor to meet the engine inlet pressure, can exist only at certain operating modes of the engine. These modes depend on the engine's and turbochargers' parameters, and usually determine the minimal engine power output, where the exhaust mass flow, pressure and temperature are high enough to provide the turbine with a gas of sufficiently high enthalpy to maintain the positive energy balance of the turbocharger. Any decrease in engine power, below this operating point, will result in a negative energy balance on the turbochargers system.

The limiting operating points can be determined by using turbine maps of the two-stage turbocharger. An example of a typical turbine map is shown in Figure 1. Point 1 on the turbine map corresponds to normal operation. The engine's exhaust mass flow rate is sufficient for operating the turbine. When the engine power output is reduced, the engine exhaust mass flow rate normally decreases as well (noted by point 2 in Figure 1). In a one-stage turbocharger, despite a decreased exhaust mass flow rate, the turbine's operating point is still inside the operating limits (Figure 1), since the turbocharger is matched for the specific engine and altitudes. Thus, opening the throttle will result in an acceptable response of the turbine, and an adequate pressure ratio for full engine power will be achieved.

However, when using two-stage turbocharging, the operating limits are different. The altitude, to which the UAV climbs, is not fitted anymore to any singular turbine map, or turbocharger, that comprises the two-stage configuration. Only the combination of both turbochargers allows producing the necessary high pressure ratio. As in the case of one-stage turbocharging, an engine power reduction at an altitude where the two turbochargers are needed will result in exhaust mass flow rate reduction. At this point, it is possible that the turbine does not produce enough power to drive the compressor. Thus, the compressor pressure ratio decreases, followed by further engine exhaust mass flow rate reduction. Eventually, the engine's exhaust mass flow rate can decrease to a level, which lies outside the operating range of the turbine, as noted by point 3 on the turbine map (Figure 1). Thus, no work will be produced by the turbine for operating the compressor and no air compression occurs in the turbocharger. In the latter case, even if the engine's throttle will be fully opened, the turbocharger will not operate. The reason is the low turbine efficiency (defined by the turbine blades geometry), which is insufficient for producing adequate power to the compressor.

In the situations described above, the UAV must descent to an altitude where the engine exhaust gas enthalpy would be adequate again for operating the turbine. This phenomenon is unique for a series two-stage turbocharger configuration, since the altitude that the UAV reaches is only achieved through joint operation of both turbochargers.

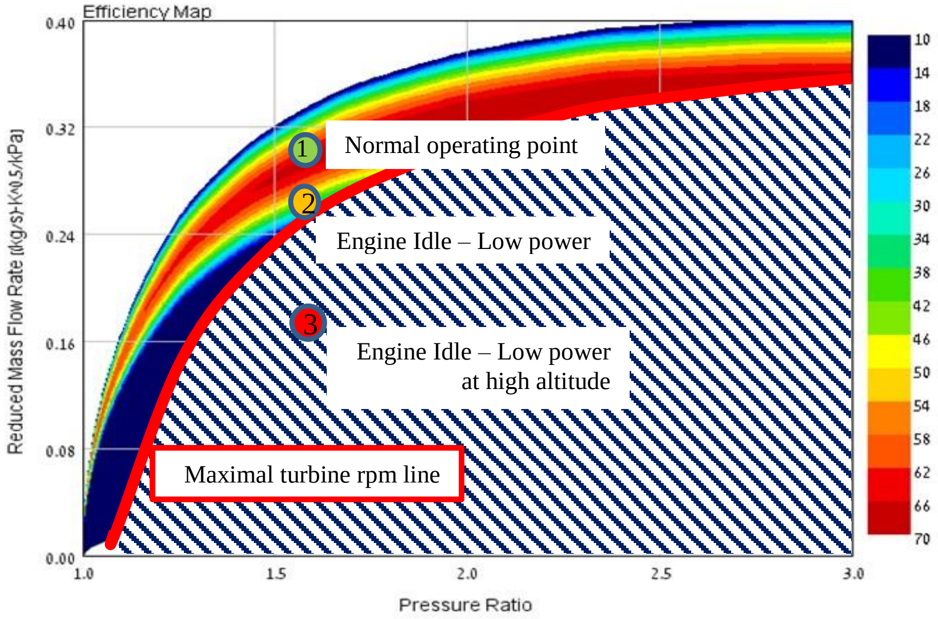


Figure 1 Typical Turbine map

Engine operation at low power demand and high altitudes is unique for UAVs. However, data on low power demands at high altitudes is fragmentary. Joint operation of a series two-stage turbocharging system and UAV engine at high altitudes has not been investigated. The problem of engine power reduction at high altitudes can be a major concern in UAV operation adversely affecting its maneuverability and limiting operation range. Thus, the ability to predict the operating limits of the UAV's engine at high altitudes is of great importance to develop appropriate problem mitigation measures and enable reliable aircraft operation.

Our Study attempts to close the mentioned above gaps. It is focused on understanding the energy balance of a two-stage turbocharging system at high altitudes, and its dependence on engine parameters and operating conditions. In particular, the research concentrates on engine low-power operation and power recovery from idle at high altitudes. For the purpose of this study a simulation model of ICE with a series two-stage turbocharging was developed, validated and deployed. The limitations of two-stage turbocharging at high flight altitudes were investigated. Finally, a basic algorithm for assessment and analysis of the operation peculiarities of engine with two-stage turbocharging at high altitudes was suggested.

Acknowledgement

This work was supported by IAI.

References

Bents, D.J. et al., 1998. Propulsion System for Very High Altitude Subsonic Unmanned Aircraft. *Aerospace Power Systems*. NASA.

Canova, M. et al., 2009. Design and Validation of a Control-Oriented Model of a Diesel Engine with Two-Stage Turbocharger. *SAE Int. J. Fuels Lubr.*, 2(2), pp.387–397. Available at: http://dx.doi.org/10.4271/2009-24-0122.

Chen, J. et al., 2013. Investigation of Influence of Two-Stage Turbocharging System on Engine Performance Using a Pre-Design Model. *ASME Turbo Expo* , (55195), p.V05AT23A014. Available at: http://dx.doi.org/10.1115/GT2013-94602.

Hiereth, H. & Prenninger, P., 2007. *Charging the internal combustion engine*, Springer Science & Business Media.

Li, H. et al., 2016. Equivalent matching model of a regulated two-stage turbocharging system for the plateau adaptability. Journal of Automobile Engineering (Sage Publications, Ltd.) Vol. 230 Issue 12. Available at: http://search.ebscohost.com/login.aspx?direct=true&site=eds-live&db=edb&AN=118145408.

Li, H., Shi, L. & Deng, K., 2014. Research on the Power Recovery of Diesel Engines with Regulated Two-Stage Turbocharging System at Different Altitudes. International Journal of Rotating Machinery. p1-10. Available at: http://search.ebscohost.com/login.aspx?direct=true&site=eds-live&db=a9h&AN=100521118 OP -

Loth, J.L., Morris, G.J. & Metlapalli, P.B., 1997. Staged Turbocharging for High Altitude 1C Engines. 33rd Joint Propulsion Conference and Exhibit. P.1-9.

Rodgers, C., 2001. Turbocharging a high altitude UAV C.I. engine. In *37th Joint Propulsion Conference and Exhibit*. Joint Propulsion Conferences. American Institute of Aeronautics and Astronautics. Available at: http://dx.doi.org/10.2514/6.2001-3970.

Shi, X., Wang, T. & Ma, C., 2014. Simulations of the diesel engine performance with a two-stage sequential turbocharging system at different altitudes. , 228 Journal of Automobile Engineering (Sage Publications, Ltd.) Vol. 228 Issue 14, p1718-1726 Available at: http://search.ebscohost.com/login.aspx?direct=true&site=eds-live&db=edb&AN=99724999.

Yang, M., Gu, Y., Deng, K., Yang, Z. & Zhang, Y., 2018. Analysis on altitude adaptability of turbocharging systems for a heavy-duty diesel engine. *Applied Thermal Engineering*, 128, pp.1196–1207. Available at: https://doi.org/10.1016/j.applthermaleng.2017.09.065.

Yang, M., Gu, Y., Deng, K., Yang, Z. & Liu, S., 2018. Influence of altitude on two-stage turbocharging system in a heavy-duty diesel engine based on analysis of available flow energy. *Applied Thermal Engineering*, 129, pp.12–21. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1359431116344684.

Poster presentations

CFD Modeling of a Direct Injection Hydrogen/DME Fueled Internal Combustion Engine

G. Faingold[1]*, L. Tartakovsky[2], S. H. Frankel[3]

[1,3]CFD Lab, Faculty of Mechanical Engineering, Technion, Haifa, Israel
[2]TICEL, Faculty of Mechanical Engineering, Technion, Haifa, Israel
* Presenting author email: gfaingold@technion.ac.il

Keywords: DME; CFD; HCCI; Flamelet comustion model; Detailed chemestr; LES

Despite media hype, the imminent death of the internal combustion (IC) engine is greatly exaggerated. Research efforts to produce more efficient, cleaner, and stable IC engines are ongoing. Alternative, low carbon intensity fuels such as biomass or hydrogen, or fuel blends are being considered for next generation IC engines. Homogeneous charge compression ignition (HCCI) engines burning hydrogen with dimethyl ether (DME) additives are being studied at the Technion. Issues related to direct injection and mixing of such fuel blends must be properly studied under motored conditions prior to engine combustion studies. Recently discovered novel turbulent-chemistry interactions associated with turbulent jet flames burning DME offer considerable modelling challenges for both RANS and LES [1].

In this study, we consider two simulation objects using the commercial CFD code called Converge. The first is a variation of the now classic non-premixed piloted Sandia Flame D burning DME for which experimental data and previous predictions are available [3] [2]. This will serve to validate the turbulent combustion model and chemical kinetics for DME combustion. Detailed chemistry via the SAGE solver and a reaction mechanism consisting of 82 species and 351 reactions is compared to a flamelet model using the same mechanism. The second is a new data set that contains PIV and PLIF data for velocity and scalar (hydrogen) flow fields in a direct injection engine under motored conditions [4]. Recently published RANS predictions using Converge show good agreement with velocity data but mixing is poorly predicted, especially at later stages near TDC, suggesting LES might perform better [5].

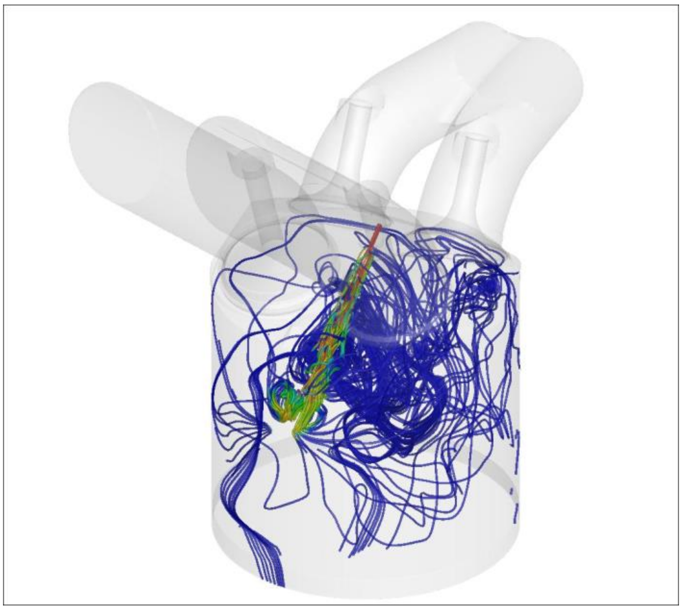


Figure 1. The Sandia hydrogen direct injection engine.

Since the software is relatively new, novel features associated with adaptive mesh refinement (AMR) and the SAGE detailed chemistry solver are also reviewed. Preliminary results and future directions related to simulating direct injection hydrogen-DME engine combustion with comparisons to measured data being obtained at the Technion are also presented.

References

[1] Arcoumanis, C., Bae, C., Crookes, R., and Kinoshita, E. The potential of di-methyl ether (dme) as an alternative fuel for compression-ignition engines: A review. Fuel 87, 7 (2008), 1014–1030.

[2] Coriton, B., Im, S.-K., Gamba, M., and Frank, J. H. Flow field and scalar measurements in a series of turbulent partially-premixed dimethyl ether/air jet flames. Combustion and Flame 180 (2017), 40–52.

[3] Fuest, F., Magnotti, G., Barlow, R., and Sutton, J. Scalar structure of turbulent partially-premixed dimethyl ether/air jet flames. Proceedings of the Combustion Institute 35, 2 (2015), 1235–1242.

[4] Salazar, V. M., and Kaiser, S. A. An optical study of mixture preparation in a hydrogen-fueled engine with direct injection using different nozzle designs. SAE International Journal of Engines 2, 2009-01-2682 (2009), 119–131.

[5] Scarcelli, R., Wallner, T., Matthias, N., Salazar, V., and Kaiser, S. Mixture formation in direct injection hydrogen engines: Cfd and optical analysis of single-and multi-hole nozzles. SAE International Journal of Engines 4, 2011-24-0096 (2011), 2361–*2375*.

Gear Shifting System for the 2017 SAE Student Car

R. Baltzan, T. Lipshitz

1Faculty of Mechanical Engineering, Technion: Israel Institute of Technology, Haifa, Israel 32000 * Presenting author email: formula@technion.ac.il

Keywords: Formula; SAE; Engine; Drivetrain; Gear Shifting

Formula Technion is an Israeli Formula Student team from the Technion: Israel Institute of Technology. This is the team's fifth year competing in Formula Student and this year featured many innovations with an entire change in the vehicle concept. The team had always used a pneumatic gear shifting system and this year decided to design an electric gear shifting system from scratch. Since the car's battery is readily available as the source of energy, an electric system seemed like a much better solution as it also allows for significant weight reduction and improvement in the vehicle's overall dynamic performance.

Unlike the few Formula Student teams that use electric gear shifting with a linear actuator, Formula Technion designed its own system, which transforms the electric motor's motion to the shift drum using a linear screw **(see Figure 3)**. Before the team received the car's engine, a series of tests was performed to determine the torque and rotational travel required to shift gears. After evaluating the results of the tests and developing a dynamic model of the system, the team set a goal of shifting gears in 80ms. An electric motor was selected based on the criteria, and thanks to a sponsorship from the German company Faulhaber, we could fit the motors in our budget. Due to the 95% mechanical efficiency of the linear ball screw, a shift time of 40ms was achieved, half of the original goal. With the battery being on-board and a lot of effort invested into weight reduction, the 3.5kg pneumatic system from the 2016 car was reduced to a 700-gram electric system this year with a 70% reduction in shift time. According to the vehicle dynamic model, the reduction in shift time cut 0.04 seconds in the acceleration event. To prevent unwanted friction and resistance, the system's design allows for many degrees of freedom, allowing the system to shift successfully despite vibrations and very high loads **(see Figure 1)**. To significantly improve lap times as well as the system's reliability, closed-loop control of the gear shifting system was used. By using an encoder, the controller always accounts for the current position of the motor relative to the shift drum. This ensures that every time an input is received, the gear shifts. Using closed-loop control, if the system gets stuck and cannot shift, the system re-centers itself and waits for the next driver input. The system uses the gear position sensor to determine how many revolutions the motor needs to rotate to shift. This also reduces shifting times because instead of using the maximum travel (from first to second gear), the system adapts itself to each gear and the necessary travel, therefore increasing the system's efficiency. To calibrate the system and compare driver feedback to the system's response, a data-logging system was used to compare shift times to current consumption, allowing for fine-tuning depending on different loads and situations (braking, accelerations, etc – **Figure 2**). The acceleration event is significantly improved by the automatic shifting capability, allowing the system to automatically shift gears at the optimal engine RPM, taking driver error out of the equation.

Figure 1

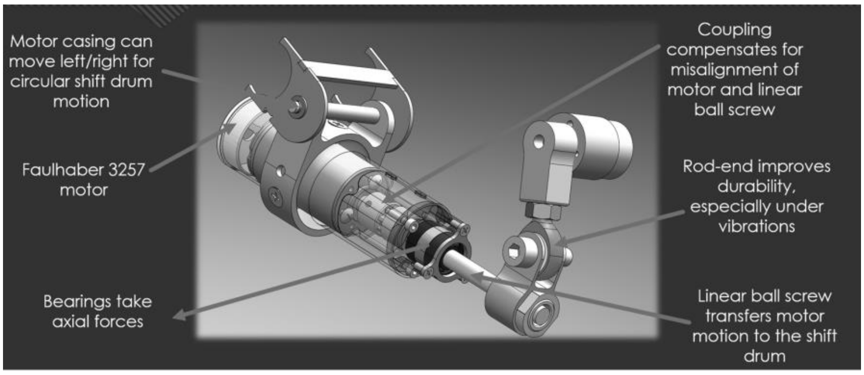


Figure 2

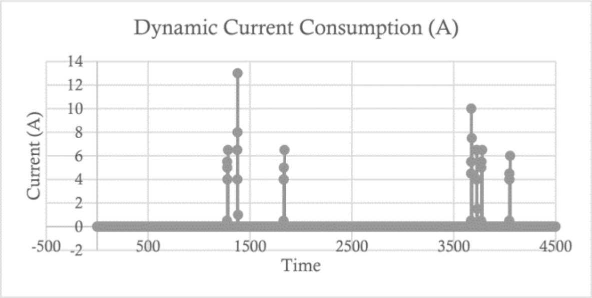
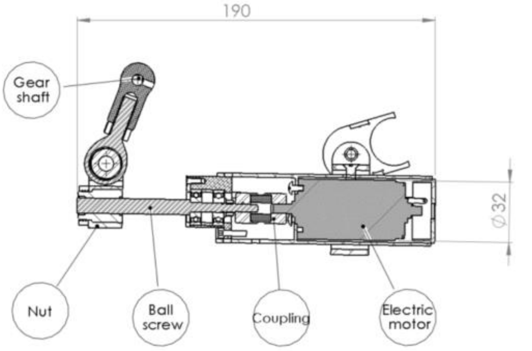


Figure 3



Acknowledgement

We would like to thank the Faculty of Mechanical Engineering at the Technion: Israel Institute of Technology for their continued support for our project as well as Dr. Leonid Tartakovsky for his knowledge and guidance which he has generously shared with us throughout the design process.
We would like to thank Grigory Kogan for his help in the development of the electric gear shifting system.

Intake System for the 2017 SAE Student Car

M.Abraham, T. Lipshitz

[1]Faculty of Mechanical Engineering, Technion: Israel Institute of Technology, Haifa, Israel 32000

* Presenting author email: formula@technion.ac.il

Keywords: Formula; SAE; Engine; Powertrain; Intake; Air; Flow

Background

The intake system was designed for the Technion's 2017 Formula Student SAE car. The application of the system is for a KTM 450 EXC-F engine and according to the Formula Student rules must include a 20mm restriction to level the playing field between teams with different types of engines.

Goals

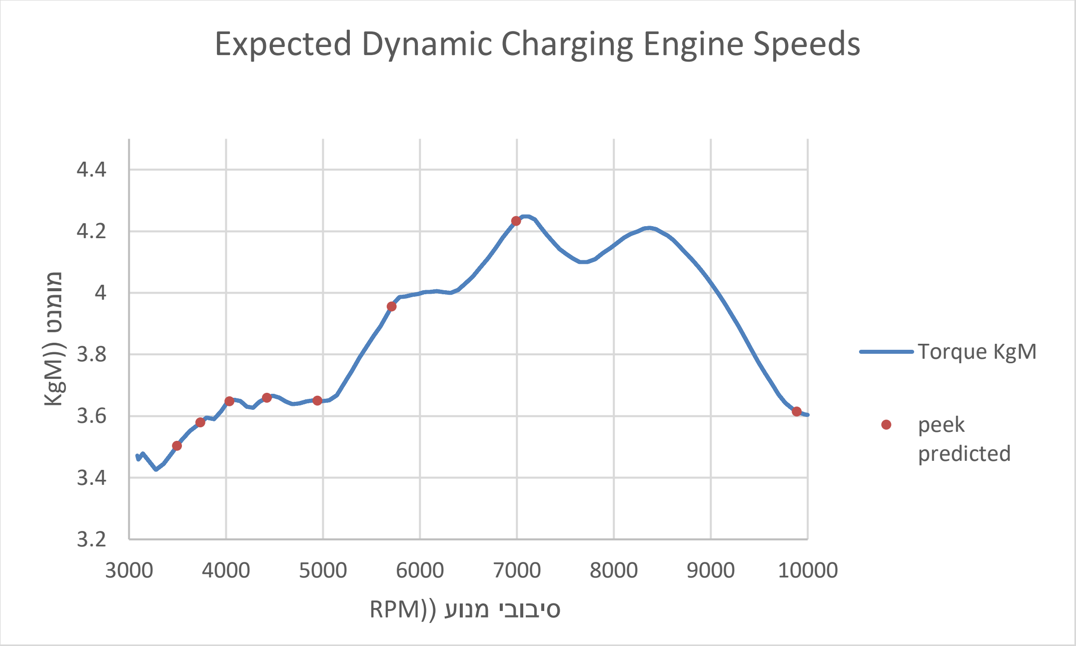
The 2017 season was the first time the team used this single-cylinder 450cc engine and with late delivery of the engines, the intake system was mainly designed based on simulations and flow analysis rather than experiments and testing. The main goals were to keep the weight as low as possible (around one kilogram for the entire intake system), incorporate the effect of dynamic charging at specific engine speeds and use composite materials (carbon fiber) for the airbox and restrictor.

Flow Analysis

Computational Fluid Dynamics (CFD) simulations were performed using ANSYS© Fluent ™ software. The software helped the team decide between two significantly different intake geometries. Due to aerodynamic considerations, the intake system was routed to the side of the car instead of the rear to increase the air flow to the rear wing. The simulations were first performed on the restrictor geometry to determine the angle at the inlet to the restrictor and out of the restrictor toward the plenum. Afterwards, simulations were performed on the entire intake system including the throttle body, airbox and runner to optimize the geometry for efficient airflow to the engine.

Results

The final intake system weighed just under one kilogram (960 grams) and there were peaks in the torque graph of the engine where the dynamic charging was planned. The final power output of the engine was 52 BHP, only 4HP less than the engine's stock power, despite the incorporation of the 20mm restriction.



Acknowledgement
We would like to thank the Faculty of Mechanical Engineering at the Technion: Israel Institute of Technology for their continued support for our project as well as Dr. Leonid Tartakovsky for his knowledge and guidance which he has generously shared with us throughout the design process.
We would like to thank ANSYS© for providing us with a student version of ANSYS© Workbench™ allowing us to use Fluent© software to design the intake system.

Powertrain for the 2018 SAE Student Car

T. Lipshitz, T. Katzenstein, N. Rosenblum, Y. Gil, G. Rubenstein, Y. Boim

[1]Faculty of Mechanical Engineering, Technion: Israel Institute of Technology, Haifa, Israel 32000 * Presenting author email: tal.lipshitz@campus.technion.ac.il

Keywords: Formula; SAE; Engine; Powertrain

Background

The Technion Formula SAE team is designing the sixth iteration of its vehicle. After switching to a single-cylinder KTM EXC-F 450 engine last year, the team is optimizing the powertrain design for optimal performance. Due to a significant weight reduction in the entire car (~40kg), the team decided to stay with a naturally aspirated engine due to the possible drivability issues that could arise from a significant increase in power.

Engine Performance

However, to increase the power and torque of the engine for optimal lap times, the team will change to a piston with different geometry to increase the compression ratio from 11.8:1 to 12.8:1. In order to optimize the engine's performance and the auxiliary engine systems, GT Suite model was built to predict engine performance and data such as air flow and volumetric efficiency. The model was built using physical properties of the engine and its geometry as well as certain boundary conditions that were determined using tests performed last year. After building the engine model, the intake and exhaust systems were optimized to find the right balance between vehicle integration and performance.

Intake System

The intake system is significantly different than the previous year's after discovering that the previous system was far from optimal. The volume of the plenum/airbox was enlarged from 3L to 5.5L which is the maximum that fit in the rules limitations. This change in volume yielded a significant increase in performance according to the GT analysis. In addition, the throttle diameter and restrictor (20mm restriction mandatory by Formula Student rules) geometry were determined through CFD analysis and our custom-made throttle was designed. Instead of using a butterfly-type throttle, the team is designing a slider throttle and a different type of throttle that swivels open, which will both be tested. The maximum mass flow rate was found with a throttle diameter of 30mm and with the addition of a bell-mouth shape at the inlet to guide the air into the throttle body.

Exhaust System

The exhaust system on a Formula Student car is mostly designed around the noise regulations that significantly affect the design of the system. However, this year the team searched for ways to gain power despite these noise regulations, in comparison to the previous year's system. The noise regulations are 110dbC at 7000rpm and 103dbC at an idle and the previous system yielded numbers much lower than this. A custom muffler was designed last year, and the team will continue to use it. As it is mostly made of titanium, it significantly reduces the overall weight of the system by around one kilogram and the noise measured with this muffler is close to that of the stock muffler that was used last year at the competitions. In order to find a good balance of low noise and reduction of backpressure, the team used the GT Suite software and decided to enlarge the inner diameter of the exhaust system in comparison to the 2017 system which yielded an increase of about 0.4 kW out of total power of 43.3kW.

Cooling System

This year's cooling system was modified for aerodynamic reasons. The previous year's radiator was placed near the rear wing and very high relative to the ground, raising the center of gravity of the car and negatively affecting the performance of the rear wing. As a result, the system was split into two radiators, one on either side of the car and in an aerodynamically strategic position to optimize the airflow to the aerodynamic elements that provide downforce which allows for higher lateral accelerations when cornering.

Fuel System

The fuel system is based on an aluminum fuel tank with a significantly smaller volume than the previous year's car since the new car is lighter and the previous tank was larger than needed due to consumption uncertainty with the new engine. The tank has a trapezoidal shape which allows for easy integration in the car and includes a baffle and anti-sloshing foam to prevent air in the fuel inlet during cornering. In order to increase the reliability of the system, a strong emphasis was put on fitting and hose selection and components such as the fuel pump, filter and regulator stayed the same due to their reliability in previous years.

Acknowledgement

We would like to thank the Faculty of Mechanical Engineering at the Technion: Israel Institute of Technology for their continued support for our project as well as Dr. Leonid Tartakovsky for his knowledge and guidance which he has generously shared with us throughout the design process.

Development of Propulsion system (PS) concept for different Unmanned Vehicles (UV)

Boris Arav[1], Daniel Feldman[2]

[1]TurboGEN Technology, Rehovot, Israel
[2]Faculty of Mechanical engineering Ariel University
* Presenting author email: borisarav@gmail.com

Keywords: Unmanned Vehicles; Propulsion system; microturbine generator (MiTG)

The effectiveness of unmanned vehicles application depends on the travel distance S or the autonomous runtime and the payload mass M_U[1,2]. It is known that the value of S under the constraints of the total mass of Vehicle M_V mainly depends on the power source (PS) mass M_{PS}(motor + fuel / battery, transmission, propeller etc.). Therefore, an important task of designing and modernizing UV is the compromise between the requirements for mass M_U and the capacity of the power source at mass M_{PS} provide the desired S at M_V = idem. The variety of power source designs (electric, on the basis of heat engines, hybrids) with the same purpose and similar parameters indicates the importance for development of a new type of power source.

The pattern between M_{PS}, S and M_U with restrictions on M_V (Figure 1) is clear [1]. With increasing $M_{PS,}$ the travel distance and M_U proportionally increases and decreases M_U. In transportation UV this compromise may correspond to the maximum transport work, proportional as: S x M_U. However, practice shows that the need to transport the desired M_U can only be achieved lowering the operating distance S or runtime.

a) b) c)

Figure 1. Correlation between the values of M_{PS}, S and M_U(a); UV Examples: Tactical Ground UV Gladiator (b) and multicopter Griff 300, M_U = 225 kg (c)

The following are the current opportunities for improving power source for Tactical Wheeled Ground UV and heavy multicopters ($M_V \leq$ 300 kg) [3] FIG. 1. In the author's' opinion, these UV have similar design PS. We used a simulation technique based typical driving cycles and generalized specific parameters UV: specific energy consumption, and power capacity and ect. [1,2,3]. We investigated the possibility of increasing S to 500 km per Example Ground UV with electrical power train. Parameters: $M_V \leq$= 3000 kg; maximum allowable mass of the power plant M_{PS} = 500 kg (+ fuel, generator / battery).

The results (Figure 2) present the following:
-Electric PS provides a maximum S of 100-120 km (M_{PS} battery mass up to 450 kg) after which charging is required (4-6 hours);
-Application of Hybrid PS with REG (Power N_E= 15 kW) increases S to 500 km at $M_{PS} \leq 500$ kg. REG base on ICEs or microturbine generators (MiTG);
- PS based on the diesel generator (power N_E= 100 kW) and an adequate supply of fuel also increases S 500 km at $MP \leq 500$ kg;
- PS based on the MiTG (power N_E= 100 kW) also provides S up to 500 km, but with M_{PS}= 250 kg. This gives the possibility of increasing the payload capacity M_U by 50%;
- In the opinion of the authors [2,4] and others [5], a hybrid PS based on a simple serial circuit MiTG with average power consumption (N_E = 45-50 kW) effectively operating at a steady state with a 100kg battery of provides S of up to 500 km, with M_{PS}= 200kg with this M_U may increase more than 60%. High efficiency, good starting properties, acceleration dynamics and low noise may also be achieved.

In whole the results obtained generalize the development, and allow us to bring the design of hybrid based power sources for Tactical Ground UV and heavy multicopter up for discussion, as it is the most appropriate use of a Series Hybrid PS based on the MiTG. The development of concept is associated with the development of rational control algorithms and the assessment of energy storage capacity of super capacitors [1,2].

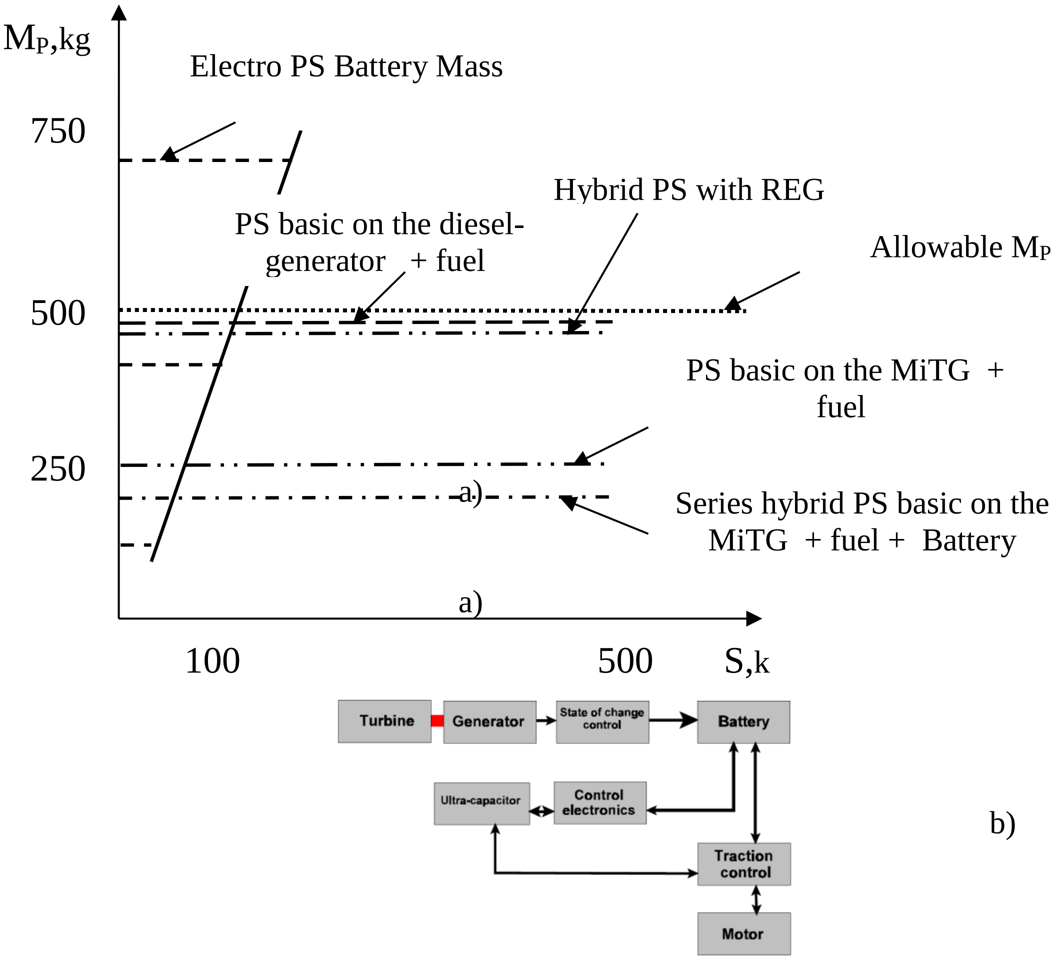


Figure 2. The relationship between S and power plant mass M_{PS} weight of different types of PS (a); Typical series hybrid PS configuration (b)

References

[1] Ehsani M., Gao Y. (2010) Modern Electric, Hybrid Electric and Fuel Cell Vehicles: Fundamentals, Theory and Design, CRC PRESS, New York.
[2] Arav BL (2011) Analysis of the concepts of hybrid transmission systems vehicles, Journal AAI, 5, 35-39.
[3] Information on https://www.pinterest.com/kochnj0662/unmanned-vehicles/; http://griffaviation.com/; https: //www.fusecrunch. com / griff-300-mega-drone.html
[4] Arav B., Shulman R. (2015) Refinement of Hybrid Motor-transmission Set Using Micro Turbine Generator, Procedia Eng., International Conference on Industrial Engineering, Vol. 129, 166-170.
[5] Information on http: /www.capstoneturbine.com/; http: / www. microturbine-01-HILTECH.pdf

Trends in the development of electric unmanned cargo vehicles in the Russian Federation

K. Karpukhin[1]*, A. Terenchenko[2]

[1]Head of department “Hybrid vehicle”, NAMI Russian State Scientific Research Centre, Moscow, 125438, Russia.
[2]Head of Centre “Power units”, NAMI Russian State Scientific Research Centre, Moscow, 125438, Russia.
* Presenting author email: K.Karpukhin@nami.ru

Keywords: Electric vehicle; unmanned vehicle; truck; energy efficiency; technical vision

Introduction

Active development of unmanned vehicles leading foreign automakers began with the 1980s for cars, trucks, agricultural machinery, aerial vehicles and vehicles for military purposes, "in-plant" transport, ensuring the maintenance of all transport operations in modern logistics centers and storage areas. Unmanned vehicles, practically all the leading automakers of the world, especially in the USA, Japan, China, Israel, Germany, Italy, Korea and etc.

Transportation by truck is one of the most popular in the world. Road transport by trucks with unmanned functions have already become a reality. At the end of 2017, the company Tesla motors produced the Tesla electric truck Semi. Tesla Semi, dispersed for 100 km/h in 5 seconds and overcomes 500 km with a load of 36 tons.

Main part

Russian state policy, in the field of transport, based on "the Transport strategy until 2030". By 2030, Russia should increase the performance of the transport system. It is expected to achieve increase of productivity in the transport sector in 1,3 – 1,5 times, while goods are in transit with intercity and international road transport should increase to 14 – 20 hours a day. The achievement of these indicators extensively requires a considerable increase in the burden on drivers of vehicles that is associated with the risk of fatigue, increasing the risk of accidents and unacceptable for reasons of safety when carrying passengers and cargo.

Currently, NAMI Russian State Scientific Research Centre with KAMAZ are developing electric unmanned cargo vehicle, on the basis, of a KAMAZ truck. Promising the vehicle would be an unmanned structure in which a movement control system, will be placed on the chassis without cab or on a special loading platform and the length of the loading platform truck by eliminating the driver's cabin will be increased to the anterior border of the chassis frame. Maximum effect on increasing the volume of the cargo platform will be achieved by use of the electric motor, because the internal combustion engine protrudes above the chassis. This new design solution will allow to increase the volume of the loading platform 20 to 50% and increase the volume of transported cargo.

Acknowledgement

This paper was supported by the Ministry of Education and Science of the Russian Federation, agreement No.14.624.21.0049, unique identifier of the project: RFMEFI62417X0049.

References

Saykin, A., Bakhmutov, S., Terenchenko, A., etc. (2014). *Tendency of Creation of "Driverless" Vehicles Abroad*, Biosciences Biotechnology Research Asia, p. 241-246.

Shadrin, S., Ivanov, A., Karpukhin, K. (2016). *Using data from multiplex networks on vehicles in road tests, in intelligent transportation systems, and in self-driving cars*. Russian engineering research, p. 811-814.

Dakroub, H., Shaout, A., Awajan A., (2016). *Connected Car Architecture and Virtualization*, SAE papers, p. 153-159.

Brooke, L. (2017). *Hands-free for 700 miles.* Automotive engineering, p. 20-23.

Theoretical Study of the 3-branches Explosion Limits of a Flammable System

A. Lidor[1]*, D. Weihs[1] and E. Sher[1]

[1]Faculty of Aerospace Engineering, Technion – Israel Institute of Technology, Haifa, 3200003, Israel
* Presenting author email: alon.lidor@gmail.com

Keywords: Explosion limits; Hydrogen ignition; Ignition delay; Ignition temperature

Explosion (or self-ignition) of fuel mixtures is a well-known phenomenon in the field of combustion science, both as a desired effect, and as a phenomenon to be avoided. The most obvious example of beneficial use of the explosion process is the Diesel engine, where unlike the spark ignition (SI) engine, no external means are required to initiate the fuel combustion. Storage and transportation of fuels, the risk of fires on oil and gas platforms and knocking (unwanted premature combustion of the fuel in the cylinder) are a few examples of instances where the explosion of the fuel is an unwanted (and often fatal) event. The study of self-ignition of hydrogen mixtures is important in the development of various energy systems, since hydrogen is considered as a potential alternative fuel in future developments. Relative to common hydrocarbon fuels, hydrogen has a high enthalpy of combustion (40kWh/kg compared to common hydrocarbon fuels with ~12kWh/kg), in addition to being a much cleaner fuel. While these properties make hydrogen a lucrative potential future fuel, it can self-ignite at relatively low temperatures, especially if stored at high pressures. That is why the study of the explosion limits of hydrogen is of utmost importance to any future development of hydrogen-based energy system, whether it is a low pressure fuel cell, or a high pressure storage tank. The explosion limits are defined as the curve on a pressure-temperature diagram which describes the threshold between the explosive and non-explosive regions of a fuel mixture. For H_2-O_2 (or H_2-Air) mixtures there exist three distinct explosion limits, each within a different pressure range. It is interesting that over a temperature range of less than 200K, there are two different pressure ranges for which self-ignition occurs, interspersed with two non-explosive regions. To date, most different approaches for the study of the explosion phenomena tackle only a single branch of the explosion limits, while requiring high computational resources for complex chemical kinetics analysis.

Our approach is based on the assumption that the three distinct mechanisms governing self-ignition are all present in every case, with each mechanism being the most dominant in its respective range. Since we know that self-ignition is macroscopically characterized by a rapid reaction, generating heat and consuming the reactants (while generating chain-carriers and products), we can use this to develop a self-ignition criterion. Below the self-ignition limit the system exhibits a very slow reaction, while at the self-ignition limit (or slightly above it) the ignition delay time is decreased dramatically. The ignition delay times of different fuels, at different conditions, have been studied experimentally for many years, by various methods (such as shock tubes and reactor vessels).

For the lower and intermediate branches, we employ a simplified reactions mechanism which includes both gas phase and surface reactions. By examining the characteristic times of the different chain-carriers, we can see that the hydrogen atoms generation rate is the limiting factor in the ignition initiation. We further develop this by applying the chain ignition theory, formulating the overall production rate of the H atoms and the ignition delay time for the mechanism. Based on a fairly large volume of experimental data, we follow Semenov suggestions that the product of the ignition delay time τ_{ig} of the mixture (for the intermediate and lower limits) and the chain branching-termination coefficient ϕ is constant. We show analytically that ϕ is a complicated function of pressure and temperature, while proposing a general form of the type:

$$\tau_{l-i} = (C_l p^{n_l} + C_i p^{n_i}) C_T \exp\left(\frac{E_T}{T}\right)$$

The time delay is a product of two independent terms; one being pressure dependent, and the other temperature dependent. The pressure term is composed of two terms characterizing the intermediate and lower limits. The different constants are rational calibration constants that are derived from comparison to experimental data. For the upper branch we use the well accepted general correlation between the ignition delay time and thermodynamic conditions of the mixture:

$$\tau_u = C_u p^{n_u} \exp\left(\frac{E_u}{RT}\right)$$

where the constants are again calibrated against available experimental data. The ignition delay time of the mixture under any initial conditions is a result of the three mechanisms occurring simultaneously. Each mechanism dominates the time delay in its region but two mechanisms may have comparable effects in particular in the vicinity of the two turnover points. The resultant time delay in any region may therefore be evaluated from the Le-Chatelier rule:

$$\frac{1}{\tau} = \frac{1}{\tau_u} + \frac{1}{\tau_{l-i}}$$

We show that the ignition curve (the complete "peninsula" curve for the three explosion limits) is represented by an arbitrary pre-specified time delay (an "iso-time delay" curve), with sensitivity for the slow to fast transition rate of the reaction rate at the explosion limits. By fitting the constants to available experimental data, we were able to show that the complete ignition limit curve can be represented by a single, unified expression, capturing the unique behavior of the phenomenon, while basing our approach on chemistry and physical fundamental concepts (Fig. 1).

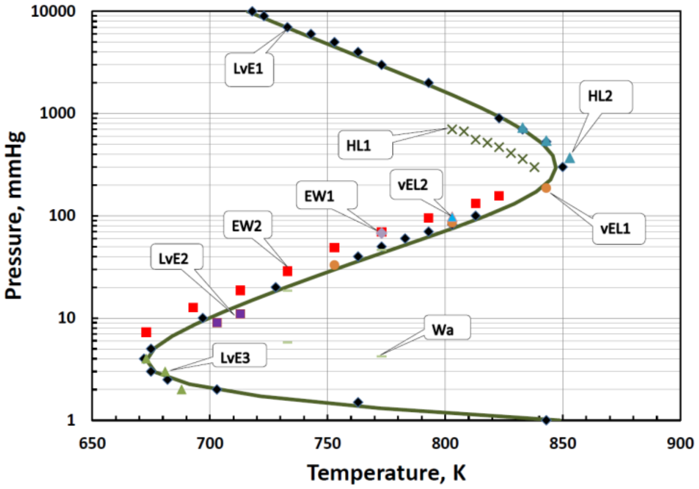


Figure 1. Explosion limits for H_2-O_2 stoichiometric mixture. Our model (solid line) compared to experimental results (shapes) (taken from Lidor et al. (2017)).

References

Lidor, A., Weihs, D., Sher, E. (2017), *International Journal of Hydrogen Energy*, **42**(16), 11976-11979.

Features of the vision systems application for unmanned vehicles in climatic conditions of Russia.

A. Saykin[1]*, S. Buznikov[2], A. Barashkov[3]

[1]Head of Department "Special Programs", NAMI Russian State Scientific Research Centre, Moscow, 125438, Russia.
[2] Chief Specialist of Intelligent Systems Department, NAMI Russian State Scientific Research Centre, Moscow, 125438, Russia.
[3]Head of Department "Vehicle Security", Testing Centre of NAMI Russian State Scientific Research Centre, Moscow Region, Dmitrov, 141830, Russia
* Presenting author email: a.saykin@nami.ru

Keywords: unmanned vehicle; technical vision system; stereo camera; radar; lidar

The creation of unmanned vehicles (UV), systems for traffic control and technical vision systems (TVSs) are priority tasks. The most active work is carried out in the USA, Japan, Germany, Israel and Sweden. The implementation of the UV will increase productivity and reduce the cost of cargo and passenger transportation, ensure road safety, fuel consumption, travel time, the emission of harmful substances.

Commercially available TVSs, provided favorable working conditions, have limited capacity to assess the surroundings (Navarro, 2017; Medina-Flintsch, 2017; Son, 2015). TVSs testing on Ford, Mazda, FIAT, VW, Volvo, Mitsubishi, Subaru vehicles, indicated that stereo cameras have proved to be the most effective. Their work ensured the collisions elimination at UV speeds up to 50 km/h, while radars were effective at speeds up to 30 km/h, lidars - up to 20 km/h, and complex systems consisting of radar and lidar - up to 35 km/h.

The tests of TVSs were also conducted in conditions typical for Russia: contaminated windshields, insufficient illumination, adverse weather conditions, absent, faded or hidden marking of lanes.

Tests confirmed the efficiency of all TVSs under ideal conditions - clear weather, dry coating, clean line markings. When snow covered 15% of lane marking, none of the TVSs was effective. A number of TVSs did not work during the tests: "snow covered lane" at night conditions; crossing a partially worn-out dash line of marking under good weather conditions; in conditions of "diffuse fog" and "continuous fog"; when the main-beam headlamps were switched on and, to a greater extent, when the dipped-beam headlamps were switched on; when dipped-beam headlamps and main-beam headlamps of counter vehicles were switched on, especially at night; crossing a continuous wet marking line; crossing a worn-out dash line of marking.

The obtained results testify the need for further, deeper research of these systems, which would necessarily take into account the Russian operating conditions.

Acknowledgments

This paper was supported, by the Ministry of Education and Science of the Russian Federation, agreement No. 14.625.21.0043, Unique project identifier is RFMEFI62517X0043.

References

Navarro, J., Deniel, J. (2017) *Influence of lane departure warnings onset and reliability on car drivers' behaviors*, Applied Ergonomics.

Medina-Flintsch, A., Hickmann, J. (2017) *Benefit-cost analysis of lane departure warning and roll stability control in commercial vehicles*, Journal of Safety Research.

Son, J., Yoo, H. (2015) *Real-time illumination invariant lane detection for lane departure warning system,* Expert Systems with Applications.

The Effect of the Initial Conditions on the IC Engines Injection Spray Generated by Homogeneous Flash Boiling

Y. Moshkovich[1]*, Y. Levy[1], E. Sher[1]

[1]Faculty of Aerospace Engineering, Technion I.I.T, Haifa, 32000, Israel
* Presenting author email: yahavmoshko@gmail.com

Keywords: Spray; Flash Boiling

Introduction

The flash boiling method is one of the most promising methods to obtain a spray with very small droplets and with a uniform distribution (Levy et al. 2014). Today, flash boiling sprays are widely used to generate fine sprays in household applications such as deodorants, insect control and some pharmaceutical applications. The potential of using flash boiling atomization in combustion chambers is widely recognized worldwide and many initiatives in this direction are under fairly advanced development stages. In this method, the spray is generated under well determined specific thermodynamic conditions, while a liquid having a high vapor pressure is discharged into a low pressure ambient.

Methodology

In this work we study the effects of pressurized liquid initial conditions on the spray characteristics as generated by the homogenous flash boiling process. We study the effect of Chlorodifluoromethane (CHClF2 or R-22) initial conditions on the droplets velocity, size distribution and radial distribution of the droplets velocity and size. We used a TSI Phase Doppler Particle Analyzer (PDPA) to characterize the spray, and a controlled 3D positioning system to measure the droplets characteristics at accurate and specific positions.

Figure 1 – Experimental flash boiling spray.

Four-Stroke Engine with a Port in the Cylinder Sleeve

A.L. Zhmudyak[1], L.M. Zhmudyak[2*]

[1]R&D, Panaya, Ltd., Hod HaSharon, 4524079, Israel
[2] Rehovot, 7645501, Israel
* Presenting author email: l_jmoudiak@hotmail.com

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

We propose a four-stroke engine, where the exhaust gas from the cylinder flows out through the valves and through the port in the cylinder sleeve.

In modern engines with turbocharging pressure after intercooler, p_{int}, is higher than pressure in exhaust manifold, p_g. Due to this pressure ratio a constantly open port in the cylinder sleeve can be used for gas exchange. Back flow of combustion products into the cylinder won't occur, since $p_{int} / p_g > 1$.

Method of Work of the Proposed Engine.

We term such engine as “A-engine”. Let us consider the working processes of the A-engine at full loads, where $p_{int} / p_g > 1$.

At the last stage of a combustion stroke (near BDC) and at the first stage of an exhaust stroke (Figure 1), the exhaust gas flows from the cylinder 4 through both exhaust valve 1 and port 2, into the exhaust manifold 6 and then to the turbine of turbocharger. Exhaust is facilitated since gases flowing out through both port 2 and valve 1.

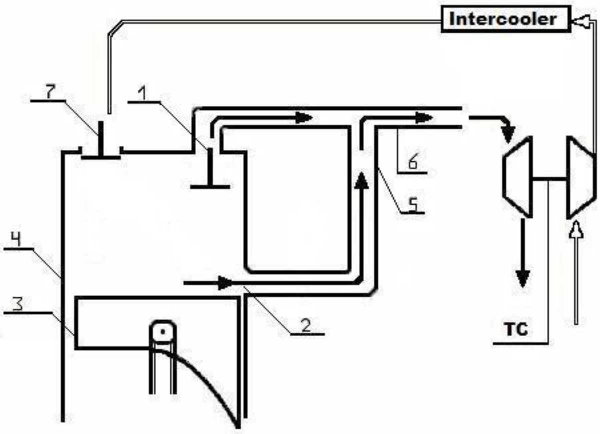


Figure 1. Exhaust.

As only half of the gases flow through valve 1, the temperature of the exhaust valve and cylinder head is lower than in the conventional engines.

The air from the compressor of the turbocharger is supplied to cylinder 4 through intake valve 7. At the last stage of the intake stroke (Figure 2) the piston again opens port 2 in the cylinder sleeve. At full load, pressure in the cylinder is higher than the pressure in exhaust manifold 6. Thus, air flows away from the cylinder through port 2. The airflow in figure 2 is indicated by the arrows.

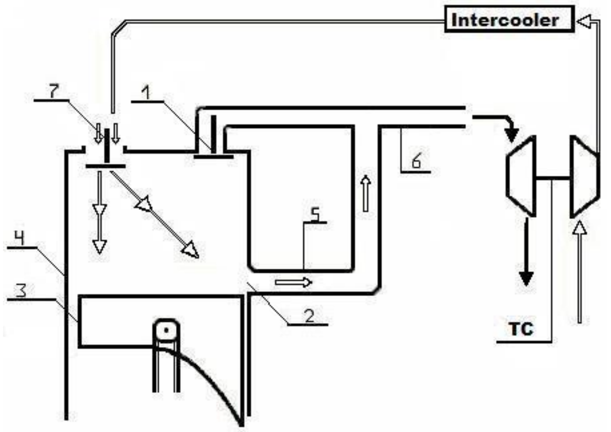


Figure 2. Intake, $p_{int} / p_g > 1$

The scavenging through the cylinder cools the internal cylinder walls, the piston, etc., therefore reduces the predisposition for detonation. Due to this intrinsic air cooling in spark ignition engines, the boost pressure and/or compression ratio may be increased.

In starting the cylinder pressure at the last stage of the intake stroke (when port 2 opens, Figure 3) is lower that the pressure before the turbine, in the pipes 6 and 5. Therefore, when the piston is near BDC and port 2 is open (Figure 3), exhaust gases from exhaust pipe 5 flow into the cylinder. As a result, starting is improved.

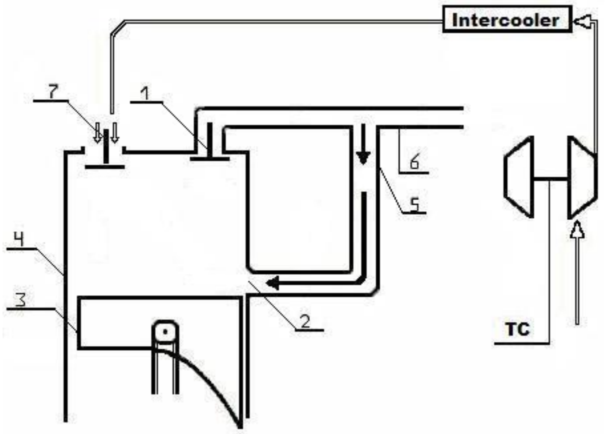


Figure 3. Intake at low loads, idle running, and starting; $p_{int} / p_g < 1$

Conclusion

In modern four-stroke engines with turbocharges the constantly open port in the cylinder sleeve may be used (together with valves) for gas exchange. 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. A-engine has unique high scavenging through the port in the sleeve. In consequence of scavenging and decreasing mass of exhaust gases flowing out through exhaust valve, temperatures of fresh charge, piston and other parts have been reduced. Low temperatures permit boost pressure and/or compression ratio increasing (without detonation) and hence power and efficiency increasing.

Multicomponent alcohol reformate mixing in a combustion chamber of ICE

A. Thawko*, L. Tartakovsky

Technion – Israel Institute of Technology, Technion city, Haifa 3200003, Israel
* Presenting author email: Andythawho@gmail.com

Keywords: Multicomponent jet; CFD; MSR; ED; TCR

Waste heat of an internal combustion engine can be partially recovered using the energy of the exhaust gases, to promote endothermic reactions of fuel reforming in a process called Thermo-Chemical Recuperation (TCR), and presented in figure 1. Alcohols such as methanol and ethanol as primary liquid fuels, can be reformed at relatively low temperature to produce multicomponent gaseous fuels with higher heating value following equation 1 and 2, respectively. The obtained experimental results [1] showed that engine energy efficiency is improved by 18%-39% (higher values at lower loads) and pollutant emissions are reduced by 73-94%, 90-96%, 85-97%, 10-25% for NOx, CO, HC and CO2 emissions, respectively, compared with gasoline in a wide power range.

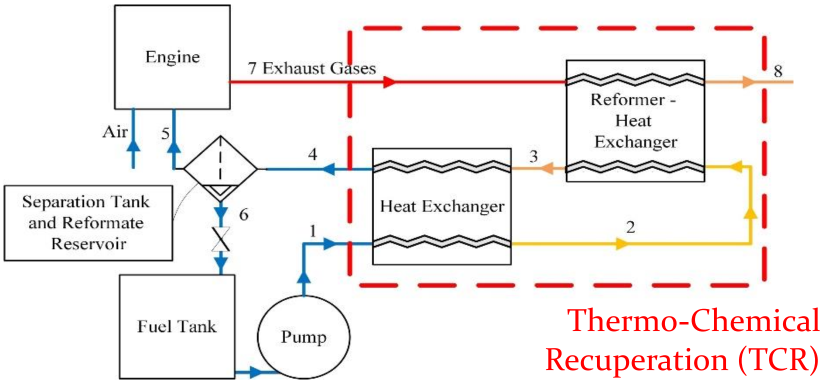


Figure 1. Schematic of the high pressure TCR system.

(1) Methanol Steam Reforming (MSR)
$CH3OH+H2O \rightarrow 3H2+CO2$ $\Delta H \approx 50$ kJ/mol

(2) Ethanol Decomposition (ED)
$C_2H_5OH \rightarrow CH_4 + H_2 + CO$ $\Delta H \approx 50$ kJ/mol

We go beyond the previous studies in this field by applying direct injection of the reformate multicomponent gas instead of the traditional pure gases like the hydrogen, methane and etc. We aim at investigation of the processes of multicomponent gaseous jet development and mixing in a high-pressure chamber with moving boundaries. Computational fluid dynamics (CFD) simulation of multicomponent gaseous fuel jet in a constant chamber was indicated that the integral parameters of a multicomponent gaseous jet are determined by the molar weight of the injected gas mixture. Also, Rising the injection pressure or increasing the nozzle diameter won’t precede the wall-guided mixture formation for typical ICE sizes. Understanding and description of these complex processes will allow future engineering development of internal combustion engine (ICE) with higher efficiency and lower emissions.

Acknowledgement

This work is supported by Nancy and Stephen Grand Technion Energy Program (GTEP).

References

[1] Poran A, Tartakovsky L. Performance and emissions of a direct injection internal combustion engine devised for joint operation with a high-pressure thermochemical recuperation system. Energy 2017;124:214–26.

Advanced Muffler Design for a Formula SAE Race Car

D.Buntin*, N.Sela, L.Tartakovsky

Faculty of Mechanical Engineering, Technion: Israel Institute of Technology, Haifa, Israel
32000

* Presenting author email: buntin.isr@gmail.com

Keywords: Formula; SAE; Exhaust; Muffler; Engine; Acoustics; Design

The Technion Formula SAE team is designing the sixth generation of its vehicle. Last year the team had significantly changed the concept, switching from the Suzuki GSX-R600 four cylinder engine to a KTM 450 EXC-F single cylinder engine. The reason for the change is a long term goal to raise the weight to power ratio of the vehicle due to the intake restrictor required by the FSAE rules. Switching to the new engine requires redesign of the race car components and some of them are even designed from scratch.

The FSAE rules also have a strict limit on noise levels allowed for the engine. The noise is limited to 103 db(C) at idle engine speed and 110 db(C) at a pre-determined high engine speed based on the bore and cylinder size of the engine. As a result, an analysis of noise and acoustics is required in order to design an exhaust system that is quiet, but also reduces the amount of backpressure in the system in order to not impact the engine power.

One of the important components of the exhaust system is a muffler, which is an acoustic element that reduces the noise produced by the engine exhaust strokes during its operation. In the past team used brand named exhaust mufflers for the exhaust system designs, however last year we designed our first own lightweight, low backpressure acoustic muffler from titanium.

Main components of the muffler had been 3D printed with titanium in Israel Institute of Metals using electron beam technology. Another set of components had been laser cut from titanium pipes and thin plates at Binot Topaz Ltd. Company. A muffler design included acoustics and performance analysis stages in assistance of GT Suite software using single cylinder engine model. The set of components used in the muffler is presented in figure 1.

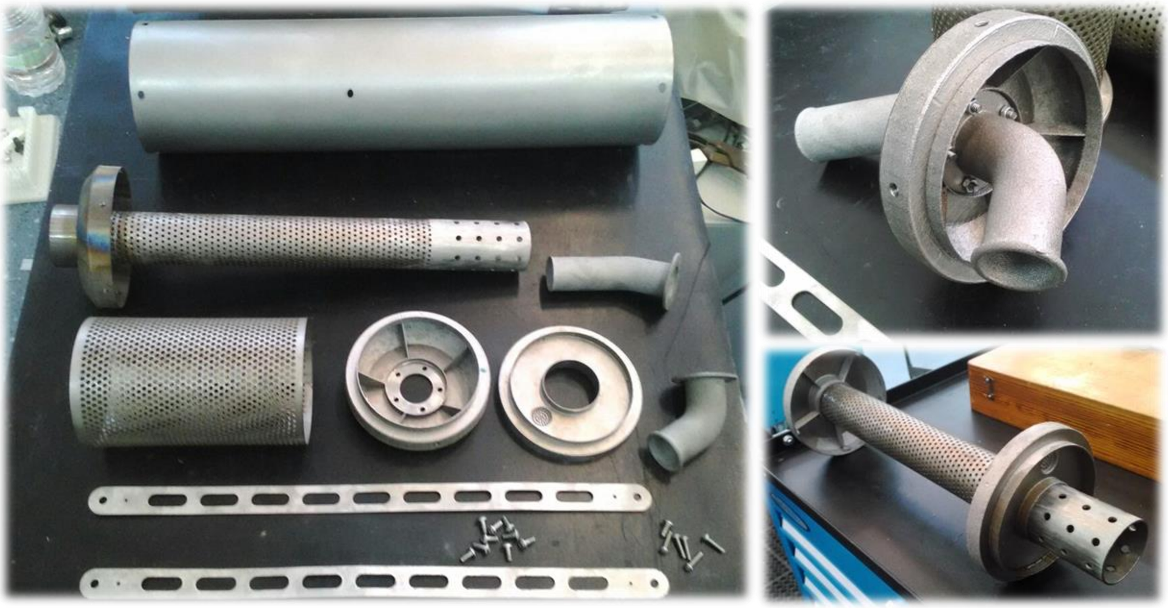


Figure 1. Components of the advanced titanium muffler.

Additional manufacturing processes before the assembling were machining, rolling, welding, thread making, drilling and filling with absorption material. A fully assembled muffler has a reduced weight of 1 kg, compared to a stock KTM muffler.

An acoustic comparison experiment was done between the designed and the stock KTM muffler with an additional spark arrestor element, figure 2. An experiment was held at the same environmental conditions for both mufflers at idle engine speed and high rpm speed as required by the FSAE rules.

Figure 2. Advanced muffler experiment on the Formula SAE car.

The results are showing the acoustic reduction ability of the designed muffler in comparison to the stock KTM muffler. One can see a strong ability of the designed muffler to reduce acoustic noise at idle speed range, almost identical to the stock muffler with additional noise reducing element, also a good ability on the high rpm level.

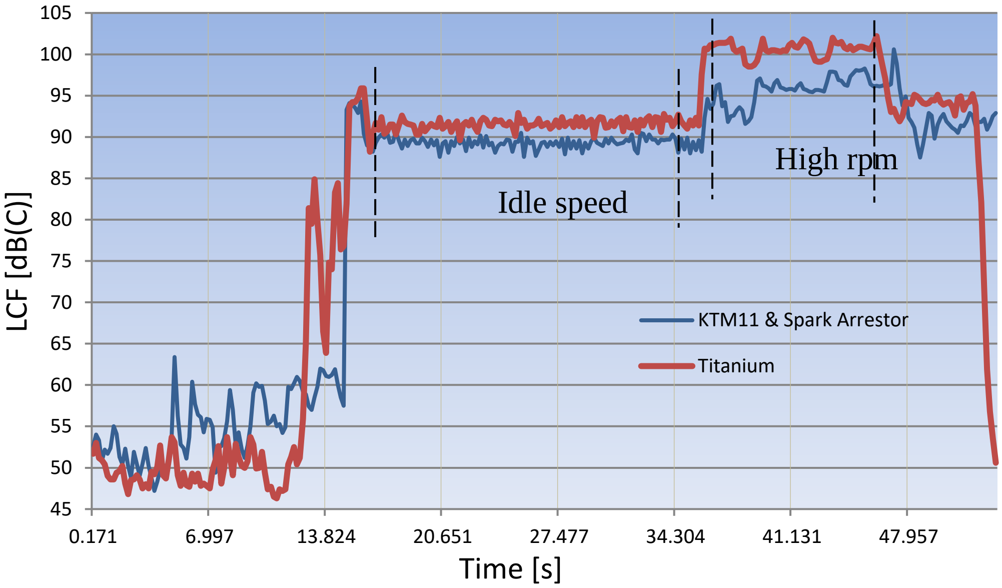


Figure 3. Results from the muffler noise level comparison test.

The designed muffler is expected to be a part of the sixth generation Formula SAE race car.

Acknowledgement

This work was supported by Technion Research & Development Israel Institute of Metals, Binot Topaz Ltd., Technion Mechanical Engineering Workshop, Formula SAE Techion Team.

References

[1] M.Hahlin (2013) *Single Cylinder ICE Exhaust Optimization*, Lulea University of Technology

[2] L.Beranek, L.Ver (2006) *Noise and Vibration Control Engineering: Principles and Applications*, *Second Edition*, John Wiley&Sons, Inc.

[3] T.D.Rossing, N.H.Fletcher (2004) *Principles of Vibration and Sound, Second Edition*, Springer Science.

Numerical Simulation of Bluff Body Stabilized Premixed Flames Using Immersed Boundary and Adaptive moving mesh methods

Yann T. Delorme[1]*, and Steven H. Frankel[1]

[1]Department of Mechanical Engineering, Technion Israel Institute of Technology, Haifa, Israel

* Presenting author email: delorme.yann@gmail.com

Keywords: Stabilized Premixed Flame; High Order Numerical Methods; Adaptive Grid Stretching; VOLVO Flygmotor, Immersed Boundary Method

Clean and efficient propulsion systems are very important today. Because of economical and environmental reasons, modern engines need to allow for high power with low full consumption as well as low pollutant emissions. The most common approach is to run the combustor with lean fuel mix, resulting in lower flame temperature, thus lower Nox emissions. The main problem is that the flame becomes unstable in these conditions, resulting in flame extinction and loss of engine performance. By adding the presence of a buffed body, it is possible to stabilize lean combustion by inducing vortex shedding and recirculation of hot gases.

This problem is difficult to simulate numerically as it involves a wide range of spatial and temporal scales. It is generally accepted that Large Eddy Simulation (LES) is needed to capture the unsteady physics resulting from the presence of the bluffed body, as well as the complex interaction between the chemistry and the turbulence. It is also accepted that LES benefits from the use of low dissipation high order numerical methods that are not easily found in most available commercial software.

In this current study, we are applying our in-house LES solver (MIRACLES) to the VOLVO Flygmotor bluffed body stabilized premixed flame. This case has been widely studied experimentally and allows for validation of combustion models by comparing the numerical predictions with experimental measurements. Previous studies tried to predict numerically the instantaneous and mean flow features of this case. Wu et al. (2017) compared two different numerical approaches (structured finite volume meshes versus unstructured Discrete Galerkin methods) and performed LES. They showed that the high order DG method predicted better the reacting flow field. Potturi et al. (2017) performed a similar study, but using a low order accurate finite volume code with a hybrid RANS / LES approach. They showed that they were capable of predicting the mean flow features, but that the solver was dissipating some of the instantaneous flow features. In both studies, the need for a good grid resolution is emphasized, especially at the edge of the flame. Our MIRACLES solver solves the compressible Navier Stokes equations using high order energy stable numerical schemes on a structured Cartesian mesh. To capture the presence of the V-gutter inside the channel, an Immersed Boundary Method (IBM) is used. To improve the grid resolution in region of interest without increasing the overall cost of the simulations, a novel Adaptive Grid Stretching approach is used. This approach allows for a saving of about 60% of the mesh points, while maintaining high mesh resolution dynamically in regions of high vorticity and thin flame front.

The solver is applied to the Volvo case in 2D. Three cases are going to be presented: a non reacting case, and two reacting cases with different inlet temperatures. The capacity of the solver to capture qualitatively the main flow features will be evaluated, as well as the computation cost saving obtained by using the dynamic mesh approach. Finally, flow physics between the three cases will be compared, in a time averaged fashion as well as different instantaneous snapshots before and after the transition from stable to unstable vortex shedding (see figures below)

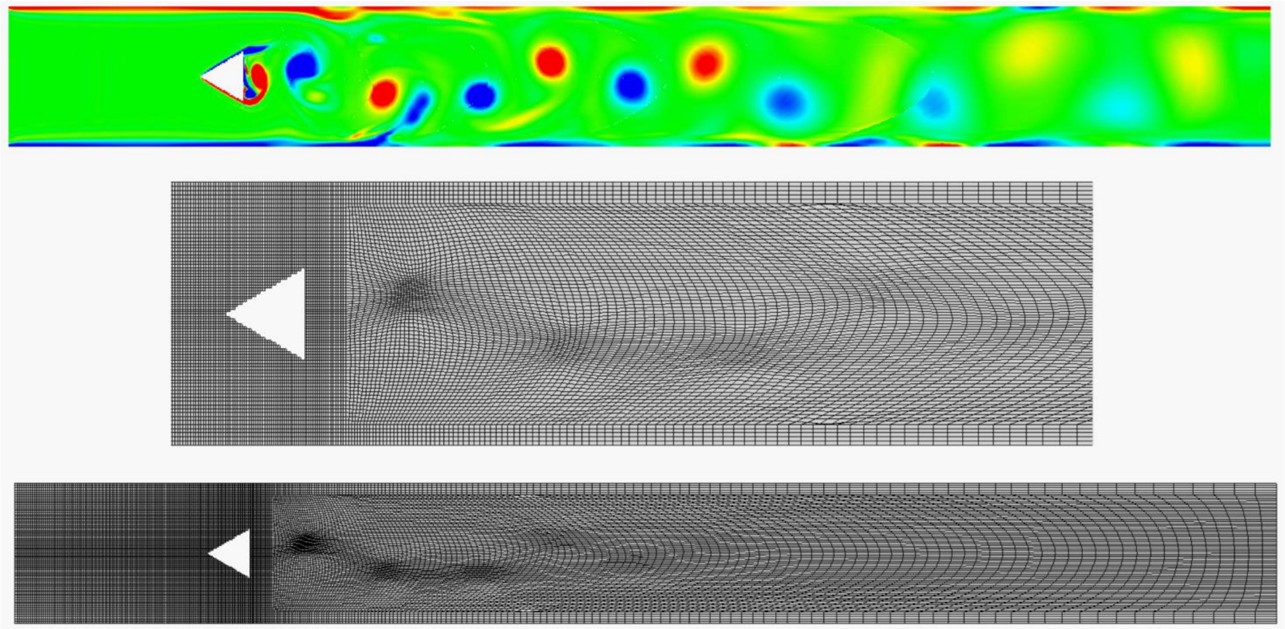


Figure 1. Instantaneous snapshot showing the instantaneous vorticity resulting from the presence of the V-gutter as well as the top and bottom walls. The instantaneous mesh is also seen and the dynamic stretching at the different vortex locations can be observed.

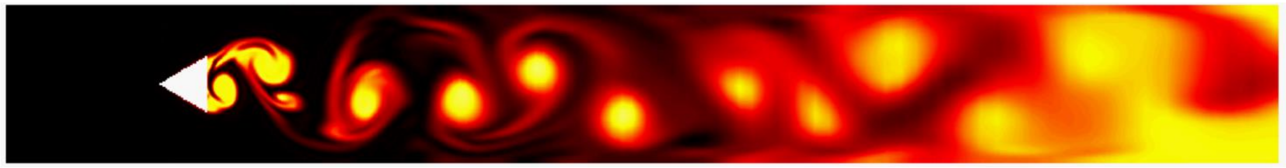


Figure 2. Instantaneous temperature field for a low inlet temperature (300K). The regions of recirculation can be clearly identified by the high values of temperature.

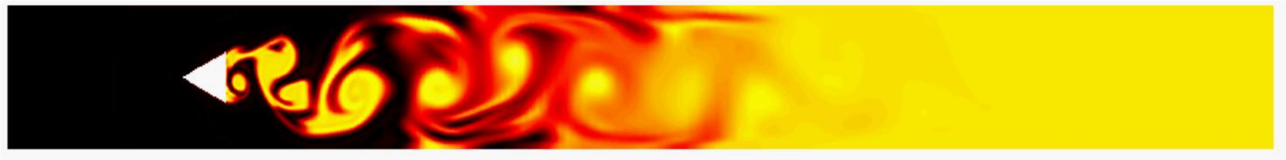


Figure 3. Instantaneous temperature field for a high inlet temperature (600K). The larger burning rate can be seen and results in complete combustion before the end of the computational domain.

References

Amarnatha Sarma Potturi, Conrad H. Patton, and Jack R. Edwards. "Application of Data-Driven SGS Turbulent Combustion Models to the Volvo Experiment", 55th AIAA Aerospace Sciences Meeting, AIAA SciTech Forum, (AIAA 2017-1792) (https://doi.org/10.2514/6.2017-1792)

Hao Wu, Peter C. Ma, Yu Lv, and Matthias Ihme. "MVP-Workshop Contribution: Modeling of Volvo bluff body flame experiment", 55th AIAA Aerospace Sciences Meeting, AIAA SciTech Forum, (AIAA 2017-1573) (https://doi.org/10.2514/6.2017-1573)