ענף הנעה
המחלקה לאוירונוטיקה
היחידה למו"פ-היחידה לתשתיות
מנהלת פיתוח אמל"ח ותשתיות
משרד הביטחון

המעבדה למנועי סילון וטורבינות גז
הפקולטה להנדסת אוירונוטיקה וחלל
הטכניון, חיפה
http://jet-engine-lab.technion.ac.il

ענף הנעה
מחלקת מטוסים
להק ציוד
חיל האויר

יום העיון הארבע עשר
במנועי סילון וטורבינות גז

14th Israeli Symposium on Jet Engines and Gas Turbines

November 5 2015,
Department of Aerospace Engineering,
Technion, Haifa, Israel

BOOK OF ABSTRACTS

יום ה', כג חשון תשע"ו, 5/11/2015 (9:00 – 17:00)
אודיטוריום, בניין הפקולטה להנדסת אוירונוטיקה וחלל, טכניון, חיפה

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DEPARTMENT OF AEROSPACE ENGINEERING

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Propulsion Branch
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14th ISRAELI SYMPOSIUM ON JET ENGINES & GAS TURBINES,
Faculty of Aerospace Engineering, Technion, Haifa, Israel
November 5 2015,

TECHNICAL PROGRAM

Start	End	
8:00	**9:00**	**(Registration) הרשמה**
		Opening (Auditorium, room 235)
		Professor Yeshayahou Levy, Chairman, Head, Turbo and Jet Engine Laboratory, Faculty of Aerospace Engineering, Technion.
		Technion's Executive Vice President for Research Professor Wayne D. Kaplan. Professor of Materials Science and Engineering
9:15	**13:00**	(Session First) מושב ראשון
		Session Chairman: Dr. Amiram leitner, Rafael
A1		**Thurmond Senter, GE Aviation, USA,** "Additive Manufacturing and the Products of Tomorrow".
A2		**Mr. Mark auBuchon, F135 CTOL/CV Program Chief Engineer , Pratt & Whitney**, "F135 Innovations in Single Engine Propulsion Control and Health Management".
A3		**Dr. Samir Rida, Honeywell Propulsion, USA,** "Combustion and Emissions Design System".
11:00	**11:20**	**(and refreshments Break) הפסקה וכיבוד קל**
A4		**Prof. Tom Verstraete, Queen Mary University of London,** "Towards multidisciplinary design optimization of composite propulsion".
A5		**Dr. Michael Klassen, Combustion Science & Engineering, Inc.,** " Use of Hydrocarbon-based Alternative Fuels in Gas Turbine Applications".
A6		**Prof. Yeshayahou Levy, Faculty of Aerospace Engineering, Technion,** "Flameless Oxidation Combustor Development For A Sequential Combustion Hybrid Turbofan Engine".
13:00	**14:30**	**(Lunch) ארוחת צהריים**

14:30	**15:50**	**(SYSTEMS 1) מושב שני** (Auditorium, room 235)
		Session Chairman: Aviad Brandstein, IAI.
B1		**Dr. David Lior, Beker Eng.,** “A feasibility study of a 100 h.p. turbo shaft engine”.
B2		**Dr. Pinchas Doron, AORA Solar Ltd.,** “The Tulip® - A Modular Hybrid Thermo-Solar Power System".
B3		**Dr. Beni Cukurel, Technion,** “A Conceptual Performance Study on Integration of a Continuously Variable Speed Fan into a Micro Turbojet”.
B4		**Lieut. Col. Mark Markovitski, Cap. Ma’ayan Kooshmarin and Ohad Miler, MOD,** “Recent Development Of Pyrotechnic Ignitors for Small Jet Engines”.
15:50	**16:05**	**(Break and refreshments) הפסקה וכיבוד קל**
16:05	**17:05**	**(SYSTEMS 2) מושב רביעי** (Auditorium, room 235)
		Session Chairman: **Dr. Beni Cukurel, Technion**
D1		**Major Efraim Muzikanski, IAF,** "Evaluation of a Catalytic Convertor for F16 I aircraft".
D2		**Alon Grinberg, IAI, Bedek Aviation Group, Engines Division, New Products Development,** "Feasibility Study for a Turboshaft Engine Application In a Solar Hybrid Gas Turbine System".
D3		**Ilan Berlowitz, IAI,** “Type Certification of Military Commercial Derivative Aircraft & Turbine Engine”.

14:30	**15:50**	**(CONTROL & STRUCTURE) מושב שלישי** (room 165)
		Session Chairman: Dr. Albert Levi, Bet Shemesh Engines
C1		**Isaac Greenberg and Simon Saraf, Rafael,** “On the Development of Ram Jet Engine”.
C2		**Michael Harel, Bet Shemesh Engines,** “The effect of acceleration In Starting Condition on Turbine Disc Design On Turbine Disc Design”.
C3		**Renata Klein, R.K. Diagnostics**, “Issues in mechanical diagnostics of jet engines”.
C4		**Dr. Michael Lictsinder, Bet Shemesh Engines,** “Behavior of Small Jet Engine Taking Into Account Heat Loss to the Engine Body during Acceleration”.
15:50	**16:05**	**(Break and refreshments) הפסקה וכיבוד קל**
16:05	**17:05**	**(combustion) מושב חמישי** (room 165)
		Session Chairman: **Dr. Valery Sherbaum, Technion**
E1		**Dr. Yuval Dagan, Rafael,** “Computational Fluid Dynamics (CFD) Analysis, Using LES, of the Lehavit combustion System”.
E2		**Dr. Valery Sherbaum, Technion,** “Advanced Vaporization System for Small Jet Engines”.
E3		**Alex Dolnik , Rafael,** “On the Development of the “Jet Fire” Combustion System”.

ACKNOWLEDGEMENTS

	חיל האוויר
	מפא"ת
	טכניון - מכון טכנולוגי לישראל
	רפא"ל
	מנועי בית שמש
	תעשייה אווירית
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	תודתנו לפרסום הכנס: לאגודה למדעי התעופה והחלל בישראל ולאגודות מהנדסים, לשכת המהנדסים והאדריכלים

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Venue: Auditorium (room 235), Faculty of Aerospace Engineering, Technion

Thursday, November 5 2015 (9:00-17:00), Technion, Haifa

This year, as in the previous years, we gathered to hold the 14th Israeli Symposium on Jet Engines and Gas Turbines. During the last few years there has seen a considerable expansion of activities in Israel in turbo jet propulsion. This is in addition to the serial production of small engines, increased electricity generation using gas turbines and combined cycles, production of various engines' spare parts and maintenance work. In Israel, many bodies are active in jet engines and gas turbine area, including: MAFAT (MoD), IAF, Israel Navy, EL-AL, IAI, Beit Shemesh Engines, RAFAEL, TAAS, ORMAT, Israel Electric Corporation, R-Jet & Becker Engineering, the Technion and more.

Improved engineering & technological innovations and new projects in Israel require continued professional meetings for the exchange of information, for cross-pollination and for creating a fertile seedbed for cooperation. During the previous twelve symposia, in every one, more than hundred scientists and propulsion engineers met and presented their work from the various industries, the MoD and Academia. These symposia were a success, wetting the appetite for more such meetings.

The Israeli Symposium on Jet Engines and Gas Turbines symposium is already mature and established symposium. It includes invited introductory lectures on selected subjects (from large engine manufacturers and Academia). In addition there are also presentations that concern activities in different Israeli industrial firms, institutes and universities as well as an open discussion and, upon request, a tour to the faculty's renovated Turbo and jet Engine laboratory. This is also a good opportunity for professional meetings, exchange of ideas and presentation of jet engine models and products from various companies.

The symposium presents an opportunities to discuss all topics relevant to jet engines and gas turbines, including aerodynamics of turbo-machines, combustion, heat transfer, structures and dynamics, simulations, control, production processes and maintenance, combined cycles and more. Preference will be given to subjects of interest in Israel. The first half of the symposia (till lunch time) will be held in English.

All presentations will be published in full, or as a "censored" version, after the conference on the conference website.

Looking forward for a fruitful and enjoyable symposium!

Professor Yeshayahou Levy
Chairman of the symposium
levyy@technion.ac.il
http://jet-engine-lab.technion.ac.il

A1

Additive Manufacturing and the Products of Tomorrow

Mr. Thurmond Senter
Manager, Military Operations & Systems Technology,
GE Aviation

Over the past several years, GE Aviation has been heavily investing in new products. Today we stand on the verge of an unprecedented level of new product introduction. The commercial engine and engine services business is a $16.7 billion dollar enterprise, and is well positioned for continued growth.

GE Aviation's military business is competing on several key next generation propulsion programs. The Adaptive Engine Transition Program (AETP) and the Improved Turbine Engine Program (ITEP) are two key opportunities for GE to deliver game changing technologies to future combat systems.

Additive manufacturing is an exciting emerging technology, and GE has a strong history of investment in additive. In February 2015, GE celebrated the first certified additive part in an aircraft engine application, and is investing in supply chain infrastructure to deliver the first full scale production additive part in the LEAP fuel nozzle.

A2

F135 Innovations in Single Engine Propulsion Control and Health Management

Mr. Mark auBuchon,

F135 CTOL/CV Program Chief Engineer, Pratt & Whitney

F135 Innovations in Single Engine Propulsion Control and Health Management. Innovations in both on and off board diagnostics and control system architecture enables improved single engine aircraft safety and reliability relative to legacy systems. The advanced control system provides improved "get home" capability with tolerance to usage and environment variation and robust fault accommodations. Advanced health management and usage based lifing algorithms are used to prognosticate the health of the engine. The combination of robust controls and the health management drives conditioned-based engine maintenance and improved engine system safety.

A3

Combustion and Emissions Design System

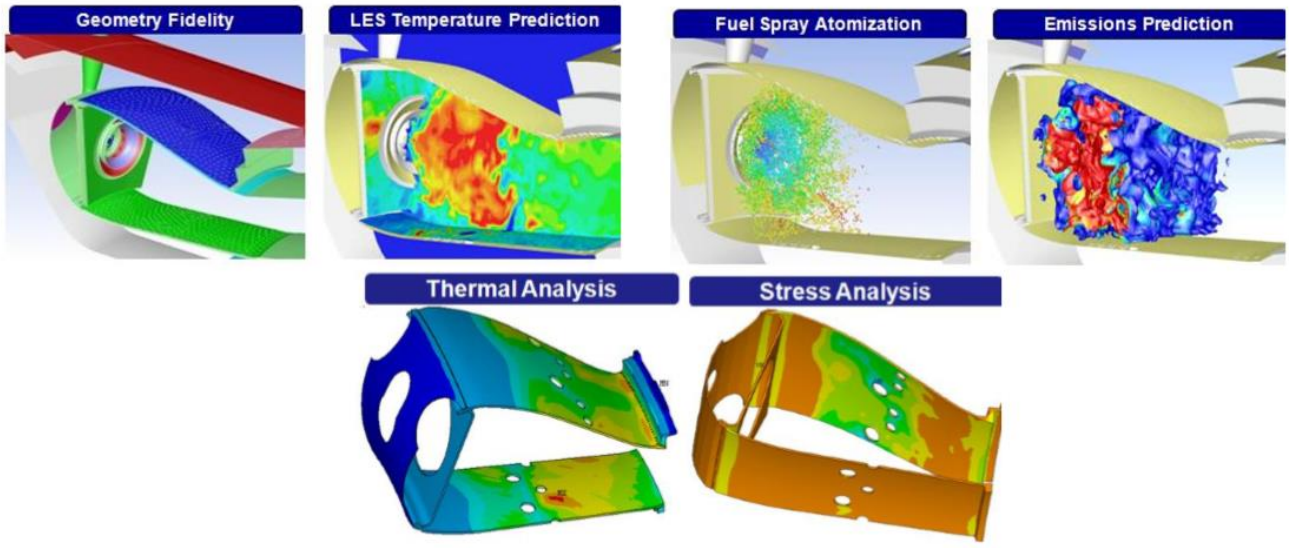
Dr. Samir Rida

Honeywell Propulsion, USA

Combustor technology is heavily influenced by the ability to rapidly manufacture, comprehensively analyze, and fully test configurations of combustion systems. These technology enablers are key to the success of combustor technologies. The Combustion and Emissions Design System (CEDS) program was launched in 2009 to improve the capabilities of combustor design system and enhance analysis tools fidelity for robust design-by-analysis. The main goal is to reduce combustor development time and cost so that a successful design is attained with significantly fewer hardware iterations. CEDS also strives to push combustion modeling technologies to maintain the competitive edge and meet challenging requirements such as 50% NOx reduction and longer service life.

The presentation describes how the CEDS program has a strong focus on technology improvement. The technical approach consists of evaluating CFD-based fuel spray, fuel-air turbulent mixing, and chemistry sub-models to improve performance, emission predictions, and lifing. It also aims at developing tools and processes to support thermo-mechanical and aero analysis of combustion systems in both preliminary and detailed design phases. This paper also discusses how CEDS increases CFD prediction fidelity of steady state aerodynamic performance parameters and transient operation parameters while moving from trend wise to absolute predictions. CEDS also focuses on improving advanced material characterization, lifing models, and thermo-structural analyses methods. In conclusion, it will be shown that CEDS has significantly improved Honeywell's design and analysis tools fidelity and reduced dependence on combustor rig/engine tests.

CEDS Key Focus Areas



A4

Towards multidisciplinary design optimization of composite propulsion systems

T. Verstraete

Queen Mary University of London, London, UK

Economical and more recently environmental interests have led to roughly a 70% reduction of fuel consumption of passenger jet aircrafts over the more than 65 years of service [1]. The largest contribution to this reduction is attributed to an improved propulsive efficiency which increased from 50% in the early days to 75% today for turbofans [2]. Further improvements are still expected, albeit limited and only achievable with an increased effort.

Two main concepts are explored in this work in order to reach higher propulsive efficiencies. First, we make use of advanced automatic design optimization techniques that explore autonomously different designs while striving for improved efficiencies. Second, we introduce composite materials to unlock blade designs that would be ruled out by conventional materials due to their too large structural loads. Indeed, composite materials with their superior strength to weight ratio and their ability to locally reinforce the structure have the potential to allow for more complicated shapes that feature improved aerodynamic performance.

The optimization system used in the present work uses an evolutionary algorithm which mimics Darwin's survival of the fittest applied to a population of blades. To reduce the computational cost, we use a surrogate model which substitutes the computational expensive simulations. The required level of accuracy is guaranteed through validating intermediate results during the optimization process, feeding the surrogate model with accurate simulation results leading to a self-learning process.

In current industrial design practice the different disciplines involved in the design process are mostly handled separately from each other and the design progresses iteratively from one discipline to another until a satisfactory solution is found. The result is a time consuming and costly design process with the further disadvantage that interactions between disciplines are difficult to reveal. The presented optimization tool in contrast enables the concurrent evaluation of aerodynamic and structural performance criteria, therefore facilitating the identification of the interaction of disciplines and allowing the design to progress towards global optimal solutions in a reduced design time.

We investigate two main applications. First, a transonic fan blade of a modern large bypass turbojet engine is designed using the presented optimization system. The blade is parametrized with 24 optimization parameters, while multiple aerodynamic operating conditions are simultaneously targeted. To guarantee structural integrity a static and dynamic structural analysis is performed and included into the design targets. In Fig. 1 a view on the fluid and structural mesh used for both computations is shown.

In a second application a propeller blade is investigated. Single-rotation propellers have a propulsive efficiency of the order of 90% [3] and can be designed to operate at higher speed. The objective of the design study is threefold: an increased aerodynamic performance is required whilst reducing the noise and maintaining structural integrity. This involves three different disciplines:

Aerodynamics, Aeroacoustics and Structural mechanics which are concurrently consulted in the design optimization process involving 30 optimization parameters controlling both the blade shape and airfoil. In Fig. 2 aerodynamic, aeroelastic and aeroacoustic results are shown for two different optimized configurations.

The performed studies show the potential of multidisciplinary design optimization methods to further improve component efficiencies, while reducing development time and cost by enabling the concurrent consideration of all involved disciplines.

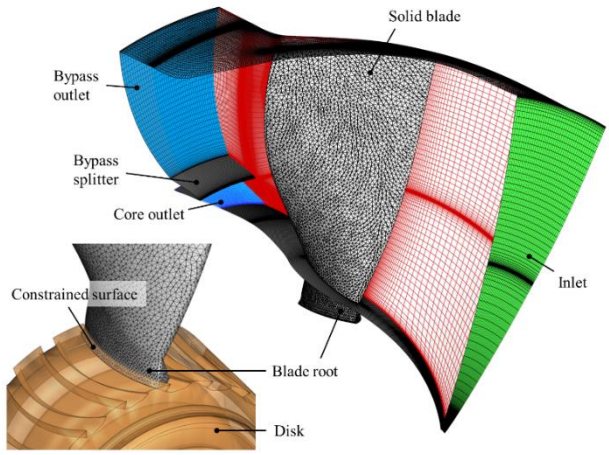


Fig 1. Computational domain of the transonic large bypass fan blade

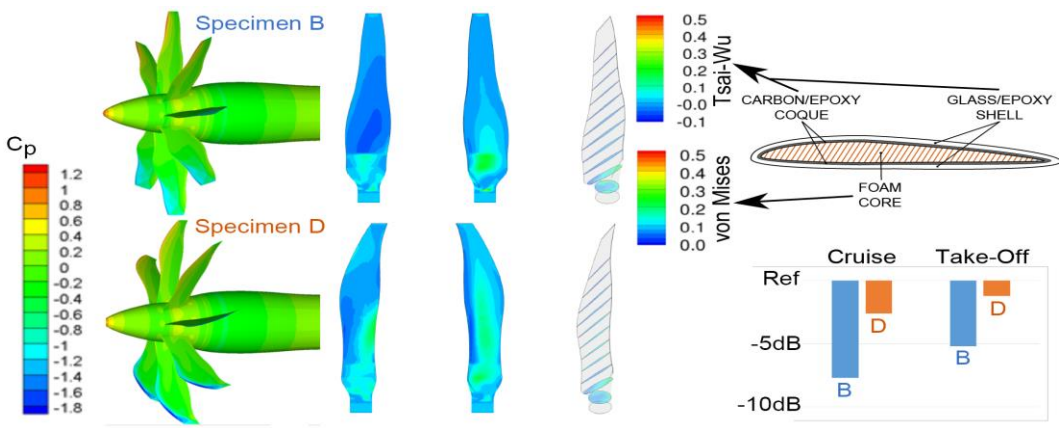


Fig 2. Pressure coefficient, Tsai-Wu and von Mises stress criteria values, and aeroacoustic gain in the propeller plane at the blade passing frequency for two different optimal propeller configurations

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A5

Use of Hydrocarbon-based Alternative Fuels in Gas Turbine Applications

Ponnuthurai Gokulakrishnan, Casey Fuller and Michael Klassen,

Combustion Science & Engineering, Inc., Columbia, MD 21045

Introduction

In recent years, the desire to diversify sources for hydrocarbons has attracted the use of alternative jet fuels. Two of the primary production methods for alternative jet fuels are from natural gas via the Fischer-Tropsch process (hereafter referred to as F-T fuels) and from plant and animal oils via hydrotreatment processes (hereafter referred to as HRJ fuels). Variations in the chemical and physical properties of the alternative fuels, however, have caused operational issues including combustion instability, which is greatly influenced by the combustion properties such as ignition, heat release rate, flame propagation and extinction. Therefore, the objective of the current work is to investigate ignition behavior of F-T and HRJ fuels relative to JP-8 at typical vitiated conditions relevant to gas turbine operating conditions.

The chemical kinetic modeling of the oxidation of jet fuels in the presence of vitiated air is important in the development and validation of kinetics models that are used in the design and analysis of efficient combustion systems. Common forms of vitiated combustion include air craft engines with fuel injection in the exhaust to increase thrust, exhaust gas recirculation (EGR) systems applied to automobile engines and furnaces for emission reduction. Generally, vitiated air consists of an air stream mixed with combustion products that consist of CO2, CO, H2O and NOX along with unburned hydrocarbons. A flow reactor experimental work to measure ignition delay time with vitiated air showed that the presence of NOx plays a major role in promoting the oxidation of jet fuel [1].

Experiments

In the current work, detailed experiments were performed in atmospheric flow reactor [1] to measure the ignition delay time of n-dodecane, JP-8 and alternative fuels such as F-T and HRJ fuels at various vitiated conditions. Table 1 lists the fuel properties investigated in the current study. Experiments were carried out with and without NO addition in the vitiated air to investigate the effect of NO on fuel oxidation over a range of conditions. Table 2 shows the experimental conditions used for the ignition delay time measurements. Figure 1 presents the atmospheric pressure ignition delay time data obtained in CSE flow reactor for stoichiometric JP-8/air as a function of temperature. Figure 2 shows the ignition delay times for JP-8, HRJ and FT (i.e, Sasol-IPK and Shell-SPK) fuels obtained at 1 atm and 875 K as a function of NO addition. It can be noted that ignition delay time was reduced by more than 50% for 500 ppm NO addition.

The primary purpose of this experimental effort is to examine the differences between petroleum based JP-8 and alternative fuels such as F-T and HRJ fuels with respect to vitiated conditions at low pressures. Comparison of the averaged change in ignition delay time values relative to JP-8 for each of the alternative fuels for a given test point is shown in Figure 3. The positive values in

Figure 3 indicate the ignition delay times that are longer than JP-8, while the negative values show shorter ignition delay time.

The results in Figure 3 show that HRJ fuels consistently have longer ignition delay times compared to JP8 across the entire range of test points in this study. The overall averaged measured ignition delay times for HRJ Camelina and HRJ Tallow are 13% and 19%, , respectively, higher than JP-8. Shell SPK fuel has a very similar ignition behavior to JP-8 with the average change in ignition delay time relative to JP-8 always within ±7% across all 23 test points. However, Sasol IPK shows much larger variation in ignition delay time, between -30% and +20% at 917 K and 823 K respectively, as shown in Figure 3.

Chemical Kinetic Modeling

In the current work, a detailed surrogate kinetic model that was developed by the authors [2,3] for the oxidation of jet fuel is extended to include the vitiated kinetics with a detailed nitrogen sub-mechanism to predict the ignition behavior of jet fuels in the presence of vitiated air. The current surrogate model consists of n-decane, n-dodecane, iso-octane and n-propyl benzene to represent the major chemical class composition (i.e., n-alkanes, iso-alkanes, and aromatics) present in traditional jet fuels such as Jet-A and JP-8 and alternative jet fuels such as Fischer–Tropsch Synthetic Paraffinic Kerosene and Hydrotreated Renewable Jet fuels. This model has been extensively validated against kinetic experimental data obtained over a wide range of conditions for ignition, flame propagation and emissions. Figure 1 shows the ignition delay time predictions of the current model for Jet-A and JP-8 compared with the experimental data obtained at 1 atm [3] and 20 atm [4] pressures.

The current model includes a detailed kinetic mechanism for nitrogen chemistry. This reaction subset also includes of a scheme for nitrogen species (i.e., NO and NO2) interaction with large fuel molecules, which are important for the vitiated kinetics at low and intermediate temperatures. For vitiated kinetics, two reaction channels were considered for the H-atom abstraction by NO2 from fuel molecules (i.e., RH) [5]: RH + NO2 = R + HNO2 RH + NO2 = R + HONO The reaction rate parameters were estimated for these reactions by group additivity theory [6] based on the rates recommended by Chan et al. [7]. In the temperature range studied in the current work, it is postulated that the presence of NO promotes the oxidation of hydrocarbon fuels by converting relatively unreactive HO2 and CH3 radicals into the reactive radical pool via the following catalytic cycle: NO + HO2 = NO2 + OH NO2 + H = NO + OH NO2 + CH3 = CH3O + NO

In the current surrogate modeling approach, the individual surrogate components were validated against the experimental data and then the model is used for the predictions of actual jet fuel oxidation. The surrogate fuel mixtures are formulated based on the derived cetane number (DCN), H/C ratio and threshold sooting index (TSI) as recommended by Dooley et al. [8]. Figure 2 shows the current model predictions for the effect of NO on JP-8, HRJ and FT fuel ignition as a function of NO at 875 K. Overall, the model predicts the trends fairly well, but further improvements are needed for FT-IPK fuels.

Table 1: Properties of the Fuels used in the experiments

Fuel	AF POSF #	ρ [kg/m3]	MW [g/mol]	N_C	N_H
JP-8	6169	796	153.9	10.96	22.1
Sasol IPK	7629	760	149.2	10.49	23.05
Shell SPK	5729	736	136.7	9.58	21.43
HRJ Tallow	6308	758	161	11.34	24.66
HRJ Camelina	7720	764	165	11.6	25.53

Table 2: Experimental Test Matrix for a Given Fuel

Test Case	T [K]	X_{O2} [vol%]	X_{NO} [ppmv]	Φ
1	917	20	0	1
2	875	20	0	1
3	875	20	90	1
4	875	20	160	1
5	875	17	0	1
6	875	17	90	1
7	875	17	160	1
8	875	14	0	1
9	875	14	90	1
10	875	14	160	1
11	875	20	0	0.5
12	875	20	90	0.5
13	875	20	160	0.5
14	875	20	0	1.5
15	875	20	90	1.5
16	875	20	160	1.5
17	832	20	0	1
18	832	20	0	0.5
19	832	20	0	1.5
20	832	17	0	1
21	832	17	90	1
22	832	17	160	1
23	832	14	0	1

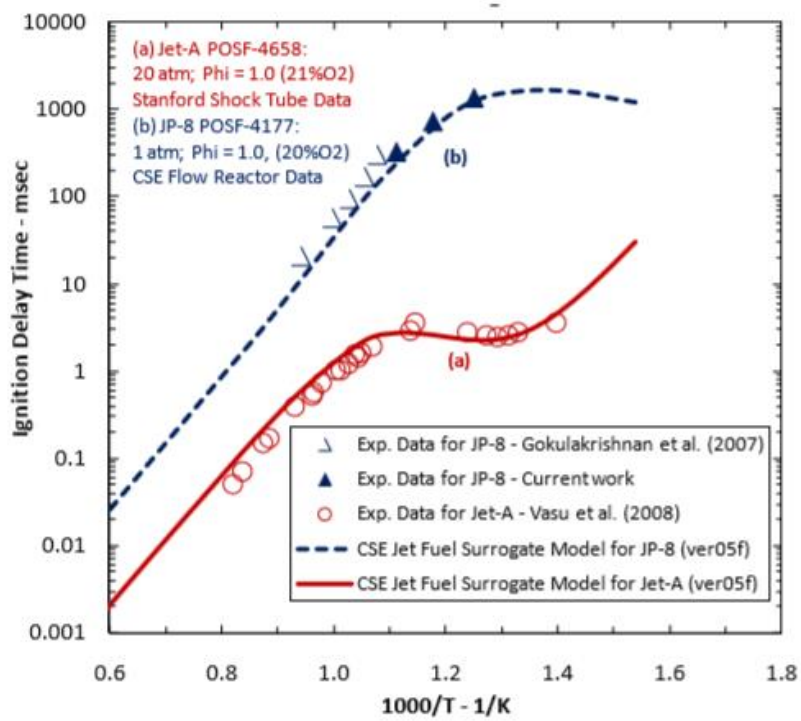

Figure 1: Comparison of data of jet fuels and surrogate model predictions using current Jet Fuel Surrogate Model

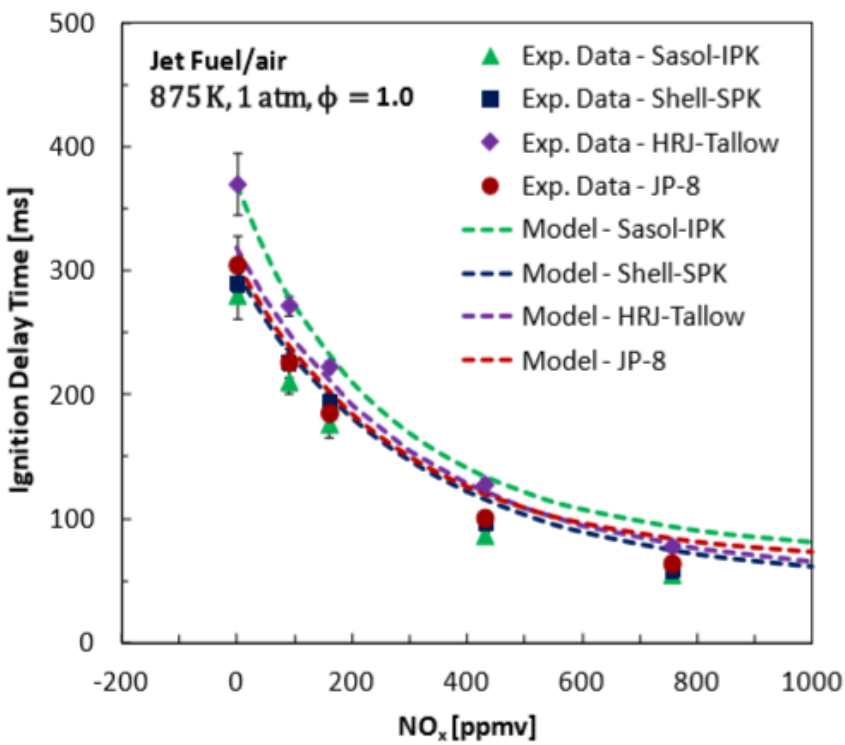

Figure 2: Current experimental data are compared with CSE model predictions for the effect of NO on the ignition of jet fuels listed in **Table 1**.

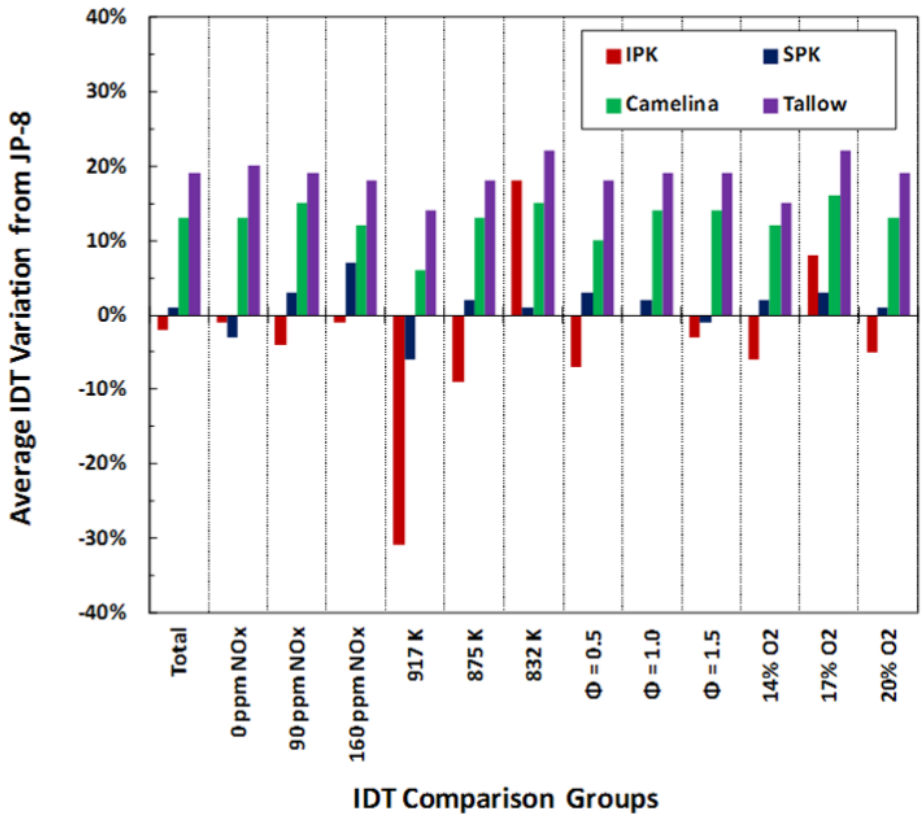

Figure 3: Average change in ignition delay time relative to JP-8 for each test point shown in **Table 2**

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A6

Flameless Oxidation Combustor Development for a Sequential Combustion Hybrid Turbofan Engine.

Yeshayahou Levy, Vladimir Erenburg, Valery Sherbaum, Vitaly Ovcharenko, Igor Gaissinski, Dan Nahoom, Alex Roizman
Faculty of Aerospace Engineering
Technion – Israel Institute of Technology, Haifa – Israel

Mario Costa, Bruno Bernardes, David Nascimento
Mechanical Engineering department
Instituto Superior Technico, Lisbon Portugal

A promising method to reduce NOx in combustion systems is the Flameless oxidation (FO) which is based on significant dilution of the incoming reactance by internally circulated combustion products. FO is currently being used mainly in industrial applications where the combustion systems are nearly stoichiometric and non-adiabatic. In such systems, significant heat is extracted from the flame region toward different processes (steam generation, glass and metal melting and more). Gas turbines are adiabatic combustion systems, have global lean stoichiometry and therefore achieving FO conditions is more difficult.

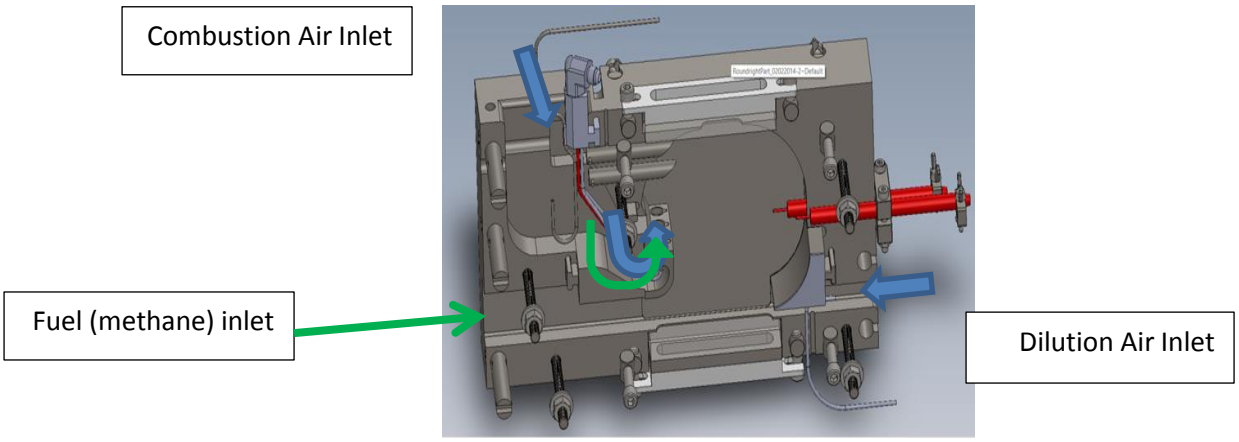
The present work is aimed to develop a FO based combustor for a sequential combustion turbofan engine where the primary combustor is fueled with H2 and the secondary combustor with hydrocarbon (jet or biojet) fuel. The work was performed within the framework of the European project AHEAD (www.ahead-euproject.eu). Being situated between the high pressure and the low pressure turbines, the inlet conditions to the combustor are non-conventional (4.9 bars and 1200K). In addition, the composition of the incoming air were also different than regular due to partial vitiation by the primary H2 combustor (mass composition of 76.4% N2, 20.8 O2 and 2.8% H2O). The required global temperature rise through the combustor was about 115 degrees C.

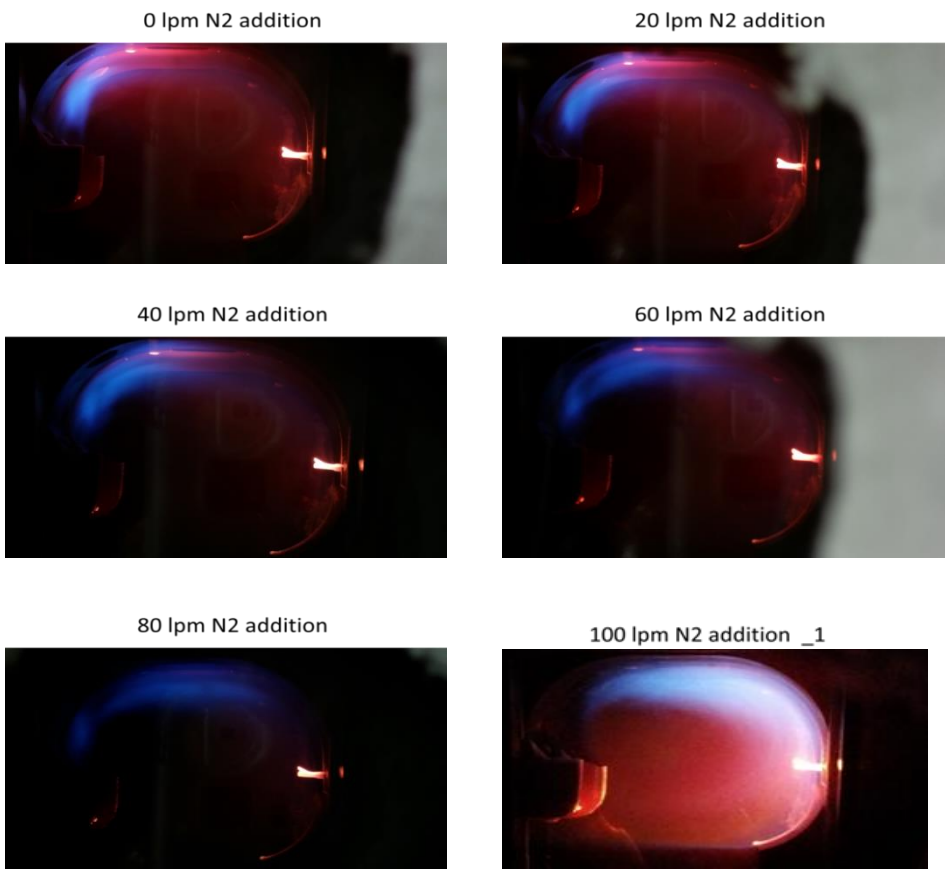
The principal design criteria were based on the requirement to keep the internal temperature as high as possible (for flame stability) but at level that is just below the NOx production threshold level (1800K). The design therefore incorporated a non-reactive by-pass stream that mixes with the combustion products in order to reduce the exhaust temperature to the required turbine Inlet Temperature (TIT) level.

Chemkin simulations reviled the theoretical feasibility of a combustion system to operate in the specific take-off and Cruise operating conditions and several design iterations were conducted to find an appropriate geometrical configuration that would allow for such a system to operate in a stable manner. The design iterations were followed by intensive CFD simulations (FLUENT) and a final design was a achieved where the predictions indicated nearly uniform internal temperature distribution with low CO (4.2ppm) and NOx (1.4ppm) emission values at the exhaust.

Experimental verification was performed using a reduced scaled laboratory model that operated at atmospheric pressure conditions while using Natural Gas (NG). The experimental model had a similar geometrical configuration and flow structure as of the full scale combustor and its characteristics were analyzed at first using the FLUENT code with similar turbulence and

combustion CFD models. The experimental model was tested at different operational conditions and its results were in accordance with the simulated values. Hence, the experimental campaign confirmed the ability of the CFD model to predict the behavior of such combustion configuration and operational regime. Therefore the campaign also confirmed its ability to predict the performance of the full scale FO combustor of the engine.





Effect of vitiation (amount of nitrogen addition) on the level of flame oxidation

B1

A feasibility study of a 100 h.p. Turbo shaft engine

Dr. David Lior

Beker Eng

In response to the AFRL competition per appendix A, a feasibility study is presented of the competition requirements which includes 2 solutions-

A conventional 2 spool none recuperated design in which the load is driven by a free turbine spool .

A recuperated 2 spool design in which the load is driven by the a free turbine spool.

The study included the 2 main requirements:

1. Fuel consumption of 0.55 lb/hp.hr which is translated to a thermal efficiency of 25% for JP10 fuel.

2. A power to weight ratio of 2 h.p/lb. (NOT including propeller transmission)

For comparison the Rotax 914F piston engine used for UAV has a SLS thermal efficiency of 30% and a power to weight ratio of 0.7 hp/lb.

Power-110 h.p , weight-156 lb.

The study indicates that the recuperated cycle is 11% more chance to achieve the design goals than the none recuperated cycle provided that its weight is less than 18 lbs for an effectiveness of 60%.

A detailed design solution for such recuperator is presented.

Another advantage of using the recuperated design is its altitude fuel consumption decreases significantly with altitude which is not the case for the conventional cycle.

The conventional 2 spool none recuperated cycle is presented in Table A and fig.1

Aerodynamic design:

- The first spool includes 2 centrifugal compressors and 2 axial turbines with abradable seals for high efficiencies. c.p.r=9.84. Higher pressure ratios is restricted due to the low air flow mass.
- Uncooled turbine rotor blades. T4=1275k. Higher temperatures are restricted due to cooling difficulty of small blades size.
- The free turbine is axial.
- The components aerodynamic efficiencies have been optimized considering restrictions in size due to a small air mass flow of 0.4 kg/sec.
- The thermal efficiency is barely 25% which makes the desired value very marginal.
- Structural design has used the following technologies to meet weight constraints-
  Using aluminum alloys for low pressure compressor and TiAl for high pressure compressor. Ceramics for turbine stators., sheet metal for combustor and casings instead of castings. Ceramic balls for bearings.
- Compact oil system-compact efficient radiator.

The weight requirement of 50 lbs thus may be achieved.

First spool-22.5 lbs

Second spool-4.5 lbs

Combustor-5 lbs
Ducts-4 lbs
Oil and fuel system-6 lbs

Inter cooling of the 2 spool cycle results in decrease of H.P.C isentropic efficiency -never the less the cycle thermal efficiency increases to 0.52 lb/hp/hr but the intercooler extra weight makes this solution prohibitive-but may be applied to civil applications.

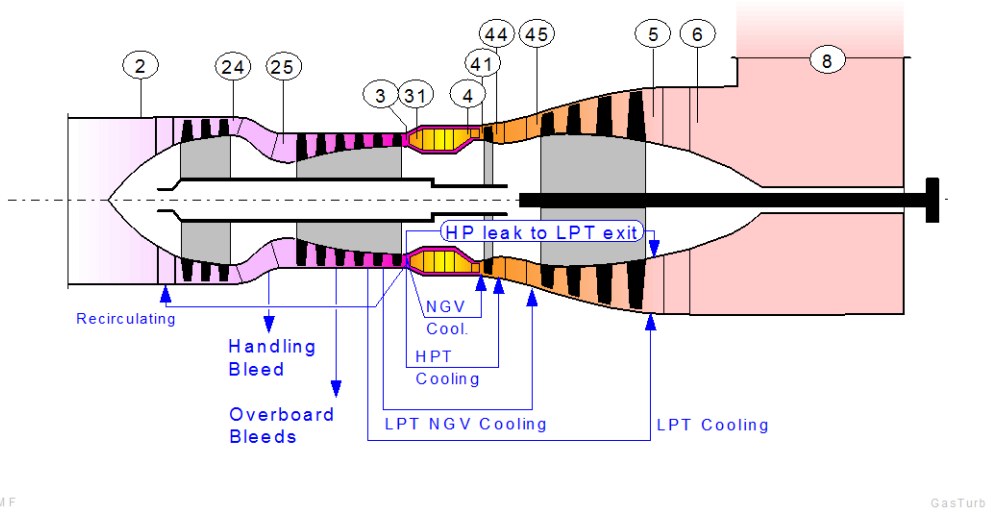


Fig 1: a none recuperated 2 spool load on free turbine cycle

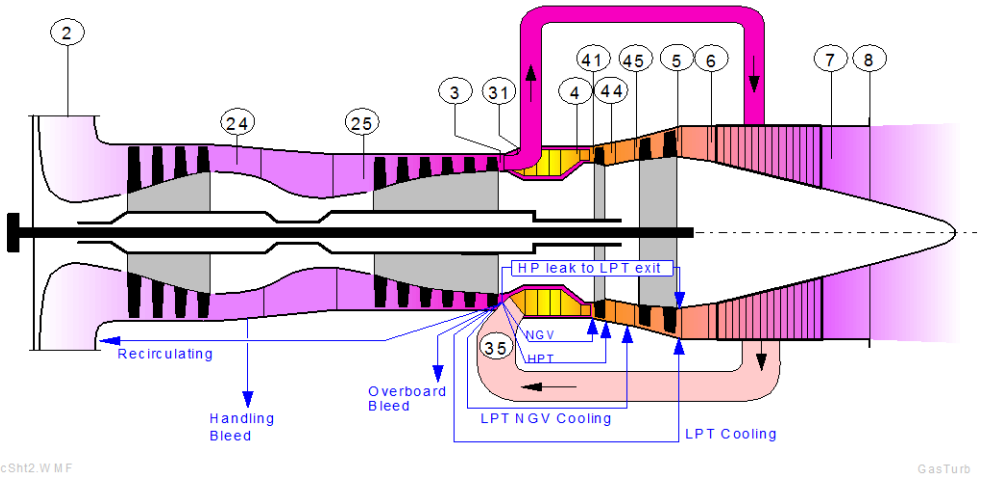


Fig.2-A recuperated 2 spool load on free turbine cycle.

The recuperated 2 spool design is presented in Table B and Fig.2.
This cycle has 1 spool with 1 centrifugal compressor driven by an axial turbine and a second spool with a second axial turbine driving the load .
The first spool is thus lighter than the first cycle-about 10 lbs less.
A ceramic regenerator [rotating matrix] is placed between the compressor exit and the combustor heated by the exhaust gases.
The regenerator weight depends on its heat transfer area and is calculated to be about 18 lbs for getting an effectiveness of 60% .
Doubling its weight to 36 lbs results an effectiveness of 75%.

Since the total weight is limited to 50 lbs the smaller 18 lbs regenerator is chosen resulting in the following weight distribution-

First spool-12.5 lbs
Second spool-4.5 lbs.
Combustor-5 lbs
Regenerator-18 lbs
Ducts----------5 lbs
Oil and fuel systems-5 lbs
Total weight—50 lbs.

The thermal cycle is depicted in TABLE B-
The free turbine delivers 79.7 kw and the fuel consumption is 6.61gr/sec resulting in specific fuel consumption of .49 lb/hp.hr.
Which is better by 11% than the design requirement.

APPENDIX A

Articles from UAS VISION USAF Offers $2M Prize for Lightweight, Fuel-Efficient UAV Turbine

The U.S. Air Force Research Laboratory (AFRL) is kicking of a competition to demonstrate a light weight, fuel-efficient turboshaft engine for unmanned aircraft and other applications with a $2 million prize at stake. The Air Force Prize seeks a 100-bhp-class power plant that can achieve the fuel efficiency of an internal-combust ion engine with the power-to-weight ratio of a gas turbine. The winning engine will have twice the fuel efficiency of a turbine and power-to-weight ratio three times better than a piston engine. To win, an engine must produce 50-100 bhp with a specific fuel consumption of no more than 0.55 lb./hp/hr. and power-t o-weight ratio of at least 2 hp/lb.

The engine must be a turbine and must run on Jet A fuel. Results will be based on verification testing conducted by AFRL at Wright -Patterson AFB in Ohio. Although reliability is not a competition requirement, AFRL wants two back-t o-back tests to show the engine is mature enough to run more than once. The test profile will be 30 min. at maximum continuous power, followed by 5 hr. at half power, another 30 min. at maximum and 6 hr. to cool down wit out special handling before repeating the 30-min./5-hr./30-min. cycle. AFRL will provide the load dynamometer, inlet and exhaust ducting, start power and fuel. The control system will be off board and not count toward engine weight, but any actuators or pumps required to operate the Power plant will be included. The turbine prize is a first -across-t he-finish-line competition, and the first to meet the power, fuel-efficiency and power-t o-weight criteria will win the $2 million. There is no follow-on development or acquisition program, AFRL says. Teams are required to register f or the competition and, when ready, submit a request f or a verification test. This will take at least 30 days to arrange, says AFRL. So far five teams have registered, but none have yet requested a verification test . Teams registered so far include Oregon-based Volt a Volare, which is developing a hybrid-electric general aviation aircraft, the GT 4. Three individuals and a company called Turbine Innovations also have registered. AFRL is not buying the engines, it emphasizes, and “the intellectual property and engine remain the property of the contestant.” But the lab believes t here is a market , in the Air Force and the civil sector, f or an efficient , light weight ,
100-shp-class turboshaft.

B2

The Tulip® - A Modular Hybrid Thermo-Solar Power System

Dr. Pinchas Doron,

CTO, Aora-Solar

AORA Solar's "Tulip" modular, hybrid solar-thermal plant incorporates a micro-gas-turbine in a heliostat field-tower configuration. The module is rated at a nominal electric power of 100kW, with an additional 170kW of usable heat. The first demo plant was built in Samar, Israel in 2009, followed by the first European demo plant at the Plataforma Solar de Almeria, Spain which started operation in late 2011.

AORA's Tulip plant is built in a tower-heliostat field (sun-tracking mirrors that reflect the sun's irradiation onto a fixed target on the tower) configuration. The Power Conversion Unit (PCU) is located inside the "flower" at the top of the tower. The PCU includes the solarized micro-gas-turbine modified to operate using solar power, fuel (renewable or fossil), or a combination of the two – and the proprietary solar receiver. This DIAPR-type (Directly Irradiated Annular Pressurized Receiver) is based on technology originating from the Weizmann Institute of Science in Rehovot. It is designed to provide the turbine requirements and enable operation without fuel augmentation when sunlight is sufficient. Thus, it can heat compressed air to 1,000ºC and more.

The main features of the system will be presented, followed by description of the integration of a Brayton engine with solar power input, and some operational experience.

Samar (Israel)

PSA (Spain)

B3

A Conceptual Performance Study on Integration of a Continuously Variable Speed Fan into a Micro Turbojet.

Kobi Kadosh, Beni Cukurel

Department of Aerospace, Technion – IIT, Haifa, Israel

Introduction

The engine design process requires compromises in fields including thrust, weight, fuel consumption, design budget, and manufacturing cost. Turbojet engines may provide high levels of thrust at the expense of high fuel consumption; whereas turbofan engines may provide comparable thrust to turbojets and with higher efficiencies, but are heavier, and costly during design and manufacturing. Especially in the market of microjet engines (less than 1kN thrust), which suffer from inherently low component efficiencies and restrained design costs, integration of a continuously variable speed fan on the spool of a preexisting turbojet engine core could provide additional performance benefits.

Although turbofans have been around for decades, they usually consist of at least two spools and in some cases a constant ratio gearbox between the fan and low pressure turbine. To accommodate a fan, there have been pragmatic cost-effective designs incorporating a gearbox along the shaft of a single spool turbojet. However, despite the inclusion of variable area nozzle and mixer, the design process is complicated by fan to core engine matching; and therefore, such turbofan engines typically suffer from relatively poor operability and performance. If a continuously variable coupling is introduced between the engine and the fan, the ability to change gear ratios while maintaining the core running at its optimum, could enable operation in a wider gamut of conditions, and enhance performance, all-the-meanwhile maintaining a simple single spool configuration.

The current study is focused on the investigation of such an engine through a steady state simulation of various points along a specified mission profile (flight Mach, altitude, engine RPM, gear ratio and nozzle position). At each of the operating conditions, a thrust to weight ratio, TSFC, and fuel consumption comparison is conducted amongst the original micro turbojet engine, constant gear turbofan and the continuously variable coupling turbofan.

Methods

In order to fully investigate the turbojet-to-turbofan conversion process a thermodynamic cycle analysis was conducted. This analysis was carried using an extensive Matlab code with the purpose of simulating and comparing the steady-state performance of different gas turbine configurations. Initially, a basic fixed geometry turbojet was simulated to verify the code against existing leading industry simulators, and once preliminary results confirmed the algorithm's validity, following models were based upon it. Serving as a building block for more complex turbofan configurations; the simulation was expanded to include a fixed gear turbofan, a fixed geometry turbofan equipped with a CVT, and a continuously variable speed turbofan coupled with a variable bypass nozzle. The algorithm used for the steady-state performance simulation of the turbojet is shown in the flow chart below.

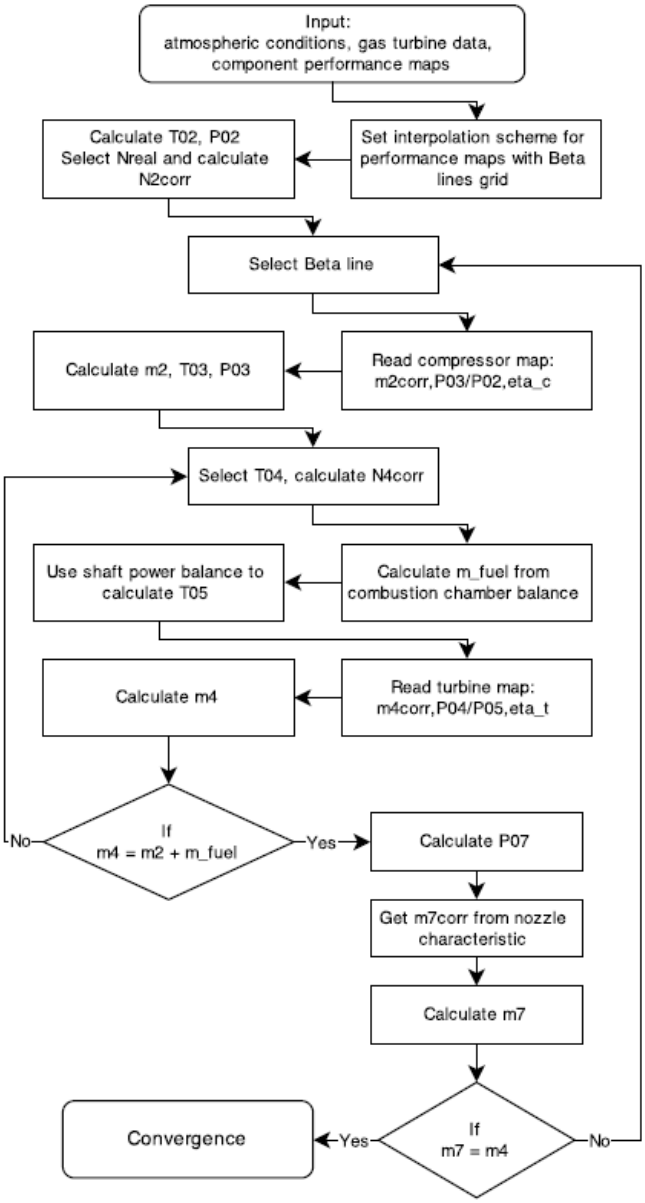


Figure 1: A flow chart depicting the steady state algorithm for turbojet simulation

In the simulation of a complete flight mission, it can be seen that changing the gear ratio according to the operating conditions enables the engine behavior to be altered to best suit the flight requirements. For the same engine thrust rating, engines that incorporated a CVT, rather than fix gear ratio turbofan, offer up to 10% better efficiency.

In the scope of future implementation of this methodology, a feasibility analysis is conducted towards a viable conversion method that improves the performance of small gas turbine, with minimal cost and R&D time. A technology survey was conducted and realistically feasible means of employing a CVT on a turbofan were analyzed considering size, weight, component efficiency, mechanical issues.

The findings of the cycle analysis and the feasibility study, concluded that, depending upon the application, there can be significant benefits to incorporating CVT into the design space as a possible turbojet-turbofan conversion tool. This is demonstrated to be best-suited for gas turbine engines with 200-300mm cores.

B4

Recent Development of Pyrotechnic Ignitors for Small Jet Engines.

Lieut. Col. Mark Markovitski, Cap. Ma'ayan Kosshmarin and Ohad Miler, MOD

מערכת הצתה למנועים קטנים

תפקיד מערכת ההצתה במנועי סילון הוא להצית את תערובת הדלק-אוויר בתוך תא השריפה של המנוע הטורבו-סילוני באמצעות יצירת נקודות של טמפרטורה גבוהה.

כיום משתמשים במנועים קטנים בשני סוגים שונים של מצתים:

- מצתים פירוטכניים.
- מצתים חשמליים.

הבחירה בסוג מערכת ההצתה תלויה במספר גורמים: גובה תנאי הטיסה לביצוע ההתנעה, הצורך בהתנעה חוזרת, משקל, ממדים, אמינות וכו'. לכן, ניתן לראות רכיבי מערכת הצתה שונים בין מנועים שבחלקן ישנו שילוב של שני סוגי המצתים ובאחרים ישנו שימוש רק בסוג אחד והשוני ביניהם מתבטא גם בבחירת מספר המצתים מכל סוג.

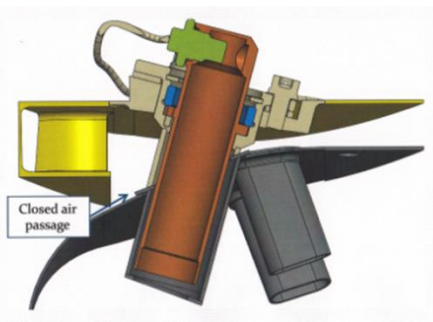
בעת תיכון מערכת ההצתה, כמו בתכן של כל מערכת אחרת, ישנן דרישות תכן העומדות בניגוד לדרישות אחרות ועל המתכנן למצוא את האיזון ביניהן כדי לקבל תכן אופטימאלי. דוגמא לדרישות תכן שכאלו הן האיזון שבין משקל ליתירות, בין בטיחות לאמינות וכו'. כמו כן, ישנן דרישות תכן ששיפור בהן יתבטא גם בשיפור דרישות אחרות. דוגמא ידועה ומקובלת לכך היא שיתירות למערכת תגרום לשיפור האמינות המערכתית, אך דבר זה התגלה שאינו תמיד נכון.

מניתוחי בטיחות שנעשו למנוע עלה צורך בניתוח תרחיש שבו אחד המצתים אינו ניזום בתהליך ההתנעה. תרחיש זה נבדק בניסוי והתגלה כמוד כשל העלול לגרום לפיצוץ המצת בעת פעולת המנוע, כתוצאה מעליית הטמפרטורה ולנזק משמעותי למנוע. כתוצאה מגילוי מוד כשל זה, משתמשים כיום במצת בודד ומשלמים ביתירות לטובת אמינות.

כדי למנוע מתרחיש שכזה להתממש, הוצעו שיפורי תכן בשני מישורים:

א) הורדת טמפרטורת האוויר הזורם סביב המצת, כדי למנוע התחממות יתירה.
ב) שינוי תכן המצת עצמו, כך שיאפשר את הפעלתו ללא פגיעה בפעולת המנוע ובחלקיו השונים.

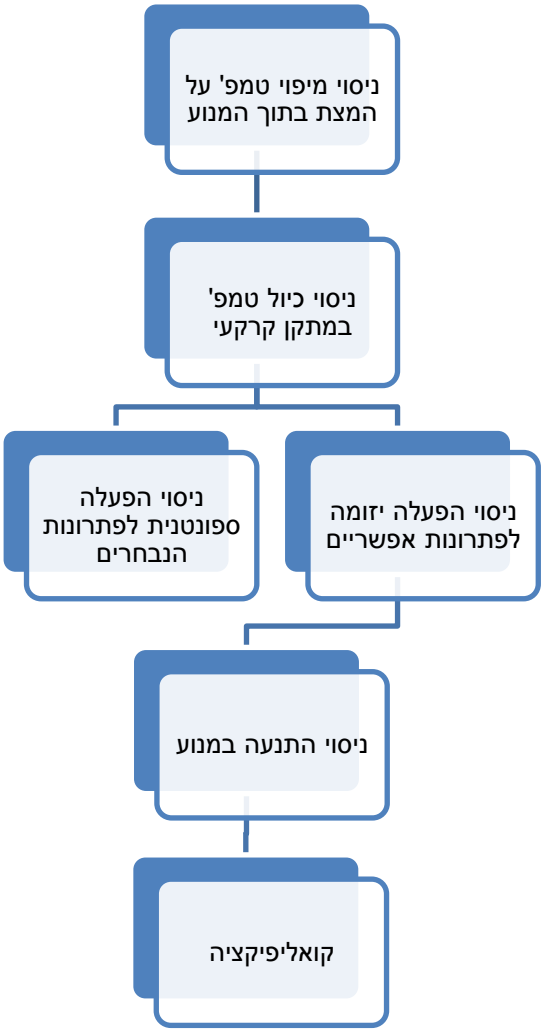
הוחלט לממש את שני שיפורי התכן הללו.



פתרון השלב הראשון כלל בתוכו פתיחת מעבר במתאם שבתוכו נמצא המצת. הדבר אפשר זרימה של אוויר "קר" יותר מהמדחס אל תוך אותו מתאם, מה שגרם להורדה משמעותית של הטמפרטורה סביב המצת.

הפתרון השני הכיל מס' קונפיגורציות שהרעיון המרכזי העומד מאחוריו הוא הדלקת המצת באמצעות מנגנון הולכת חום שהוא מהיר יותר מאשר הולכת חום בהסעה, כפי שתוכנן במצת המקורי. בכך, אנו יכולים להבטיח שהמצת יידלק מקצהו, כפי שתוכנן, ולא מאמצעו. מימוש הפתרון כלל בתוכו הכנסת חלקים שונים שהוכנסו לתוך המצת, דבר שהוביל למגע מכאני בין בית המצת למטען ההודף שלו. 2 הקונפיגורציות שעלו על הפרק היו: "אוחז להבה" ו"פיוז".

בחינת פתרונות אלו דרשה מערך ניסוי שידמה את התנאים שחווה המצת בעת התנעת המנוע ובהמשך פעולתו, כדי למנוע אירוע בטיחותי במידה והפתרון לא יענה על הדרישות ותיגרם פריצה של המצת כפי שקרה בעבר. על כן, הוצגה תוכנית הניסויים עבור בחינת הפתרונות הנבחרים:



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C1

On the Development of Ram Jet Engine.

Isaac Greenberg and Simon Saraf

Manor division, Rafael, Haifa, Israel

Ramjet is a jet engine operating at supersonic velocities. The propulsion system requires a solid fuel rocket booster to accelerate the flight vehicle to the ramjet take over velocity. The advantage of the Ramjet propulsion is in the high specific Impulse in comparison to the solid fuel rockets. Therefore, the ramjet flight envelope is for supersonic flight vehicles.

In spite of the attractive performance, the ramjet propulsion was limited in the missile development through the last 60 years. It can be explained by: a) The average specific Impulse for the propulsion, which includes the booster phase and the ramjet phase, b) The requirements for relative short ranges.

In the last 60 years, ramjet development, for long range missiles, was mainly in Russia and less in other countries that developed a few missiles but focused on R&D. Since the year 2000 we observed more ramjet missiles developments in more countries, especially in the Far East.

To develop a Ramjet engine it requires focusing on several subjects: Supersonic inlets, subsonic combustion chamber, integral rocket booster, ejectable components, fuel system (liquid or solid fuel), test facilities (connected pipe, free jet, supersonic wind tunnel), computational capabilities (design, off design, trajectories).

Ramjet development is being conducted in Rafael. Testing facilities and theoretical capabilities were established and approved in the development of all ramjet types (liquid fuel, ducted rocket and solid fuel ramjet).

In the connected pipe facility, test conditions, altitude and Mach number, are determine by mass flow rate and total temperature. By this method, combustion chamber performance can be evaluated for a wide flight envelope.

C2

The Effect of Acceleration in Starting Condition on Turbine Disk Design

Michael Harel,

Bet Shemesh Engines Ltd.

The geometric definition of a turbine disk includes generally a large (in the axial direction) hub which provides the strength to resist the centrifugal force of the blades through a relatively thin web and fir tree blades attachment or a blades platform in case of a blisk.

This design is intended to enable operation with acceptable stress level at operating temperature. In steady state condition the disk temperature is quite homogeneous but during transient conditions, temperature gradients are created which generate thermal stresses in addition to the centrifugal stresses. The worst case is a quick start from room temperature followed by a rapid acceleration to maximum RPM.

The analysis of a special case will be presented.

The starting and acceleration of maximum power were modeled first as a step function of gas and air flow temperature, speed, pressure, etc. with the disk and blade at room temperature at t=0. Later a linear variation to max power condition was assumed.

A one-dimensional analysis of the temperature distribution along the blade due to heat transfer from the gas flowing about it and along a radius of the disk, as a function of time from start will be presented. The calculation is performed on an excel sheet and also takes account of the heat flow from the disk to the surrounding cooling airflow.

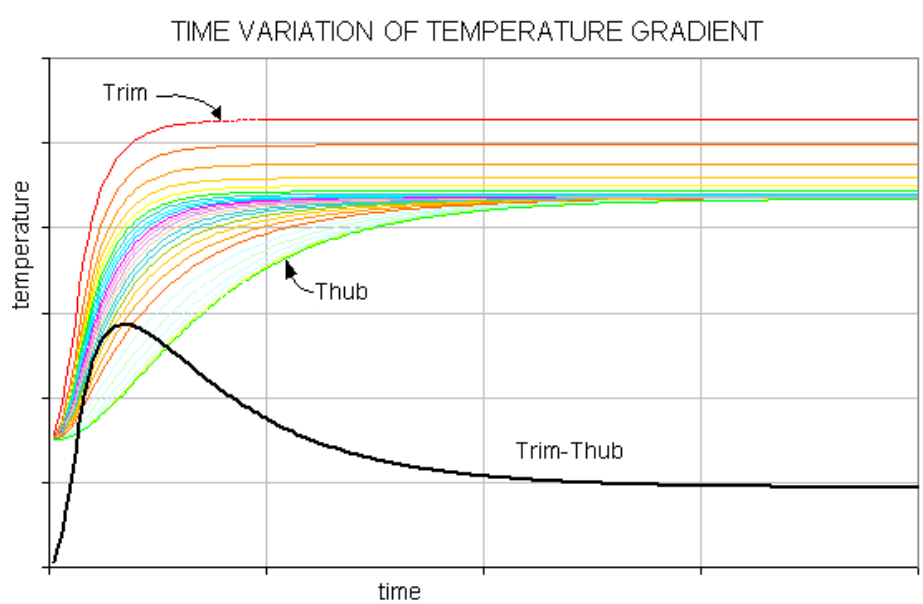
The calculation shows that only a long time after the start and acceleration to maximum RPM were completed, the temperature difference between the disc inner radius and its outer diameter (at blades roots) reached a maximum value.

The results were almost the same for both starting and accelerating models assumptions.

A one dimensional stress analysis was then performed with the relevant temperature distribution which revealed unacceptable stress-temperature combinations in the disc.

The turbine disc profile was revised and after two iterations a geometry was found for the disc with satisfactory results.

This geometry should be confirmed by an F.E.M. stress analysis**.**



C3

Issues in mechanical diagnostics of jet engines.

Renata Klein

R.K. Diagnostics, P.O. Box 101, Gilon, D.N. Misgav 20103, Israel

Health monitoring systems became common in aviation with a special emphasis on engines, aircraft structures, and helicopter drivetrains. Health monitoring of rotating machinery such as gearboxes and turbines is established and implemented in helicopters, heavy machinery, industrial plants, etc. Performance diagnostics of jet engines which is based on gas path parameters is used both in civil and military applications. However, mechanical diagnostics of jet engines, usually based on vibrations, is still under research and development, presenting special difficulties due to the non-stationarity of the signals, variability of the operating conditions and aerodynamic phenomena that affect the vibration signatures. The main topics of interest for mechanical diagnostics of jet engines are related to bearings. The classical methods for bearing monitoring are based on analysis of vibration signals which are usually captured by accelerometers located on the engine case. Two difficulties always arise when diagnosing bearings via vibrations. The first difficulty is the distortion of the signals due to the effect of the transmission path to the sensor. The second difficulty is the low signal-to-noise ratio characterizing the weak bearing signals in the presence of the accompanying strong surrounding noise originating from the vibrations of other rotating components in the engine. The task of diagnosing jet engine bearings is even more complicated as a result of several unique characteristics of jet engines. First, there are two or three asynchronous shafts that are connected aerodynamically. Second, there is a very high surrounding noise generated by the airflow. Third, the rotating speeds vary rapidly. Forth, there are large variations in thrust. Fifth, the vibration signals are essentially non-stationary. The talk will elaborate on these difficulties, present possible solutions, and illustrate with examples from real jet engine runs.

C4

Behavior of Small Jet Engine Taking Into Account Heat Loss to the Engine Body during Acceleration.

Michael Lichtsinder, Albert Levy

Bet Shemesh Engines Ltd.

Dynamic turbojet simulations make it possible to evaluate the engine behavior during transients and to design the control system in a manner to prevent dangerous situations such as compressor stall, over-temperature conditions or too lean a mixture in the combustion chamber.

The analytical treatment of the accelerating/decelerating condition of the bare engine assumes a step function change in the fuel flow to the engine, which is followed by a temperature change at turbine inlet which causes a change in the balance between turbine and compressor torques. If the turbine torque is larger than the compressor torque needed for steady state (constant RPM) operation then the engine will accelerate and vice-versa.

When the control system is modeled together with the engine in the simulation its parameters may be adjusted at design level to prevent unwanted situations during transients.

However it is well known that part of the heat produced by the additional fuel burned in the combustor during an acceleration is used to raise the temperature of the engine and thus the actual acceleration value is less than predicted by the simulation. This could impair the quality of the simulation based control parameters definition at design stage. The same applies for decelerating conditions.

A model was devised to represent the engine body temperature change due to heat transfer from the air and gas flowing in it and to evaluate the corresponding acceleration decrement. To this end the concepts of average engine body temperature, and average air/gas flow temperature had to be defined.

The heat transfer coefficients were evaluated from steady state tests, where the body temperature was measured in several RPM conditions and at various locations. Finally three bare engine accelerations which were tested and recorded for this engine are compared to simulation results which took account of the heat loss to the engine body.

The comparison showed reasonable agreement to the tests results. This agreement could be improved by revision of the average air/gas and body temperature definitions.

D1

Installation of catalytic converter in IAF F16I ("Sufa").

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IAF, Propulsion Branch

Air quality problem in IAF F16I is known since the aircrafts first arrived to IAF in 2005. The source of the problem is a combination of entrance of oil and fuel products from the engine, into the environmental conditioning system and into the cockpit, mainly in the start phase of the mission and at first light of afterburner and takeoff. Air quality issues cause in convenience in the cockpit, bad smell, eye burn and sometimes nausea and weakness.

Over the years tremendous efforts were made in this issue by IAF aircraft engineering, maintenance and health departments, which focused on investigating and understanding the phenomenon which included development of tools to monitor and to measure the amount of oil and fuel products which enter into the cockpit, and also included an attempt to define acceptable products levels.

In early 2011, after creating a monitoring plan for the F16I's, Aircraft Department was asked to remove F16I's engines in order to investigate the engine based on the monitoring results. In order to avoid a serviceability crisis of F16I's caused by the request of high number of engine removals, a special activity was initiated by the Propulsion Branch, together with P&W. The aim of the activity was to find and to evaluate solutions that are possible to incorporate in a relatively short time and that would improve the quality of cockpit air. During this activity a wide number of solutions were suggested which involved engineering changes to the aircraft, and required maintenance policy changes in IAF. Among the solutions, and after doing a wide literature survey, a solution of installing a catalytic converter was suggested.

The technology of catalytic conversion enables the dismantling of oil and fuel products, which exhausted by the engine, into products that are harmless, such as oxygen and hydrogen. This technology exists in automotive industries and in civil aviation field. After initial examination, a process of performance qualification of the installation of converter on IAF's aircrafts was defined. Initial experiments, which were made on AIRBUS's catalytic converter showed a decent of 75% in oil and fuel products in engine exhaust. Successful concept evaluation started a development plan of a converter specific for the F16I's.

For the first time, a catalytic converter is being developed for a fighter jet. The development is being done with the cooperation of P&W, BASF (which specialize in development and production of catalytic converters) and F16 manufacturer LM. In the year 2012, IAF procured 5 prototypes of this product that was developed and evaluated in an accumulated 1250 flight hours. In the year 2014, IAF decided to procure converters for the entire F16I fleet.

D2

Feasibility Study for a Turboshaft Engine Application in a Solar Hybrid Gas Turbine System

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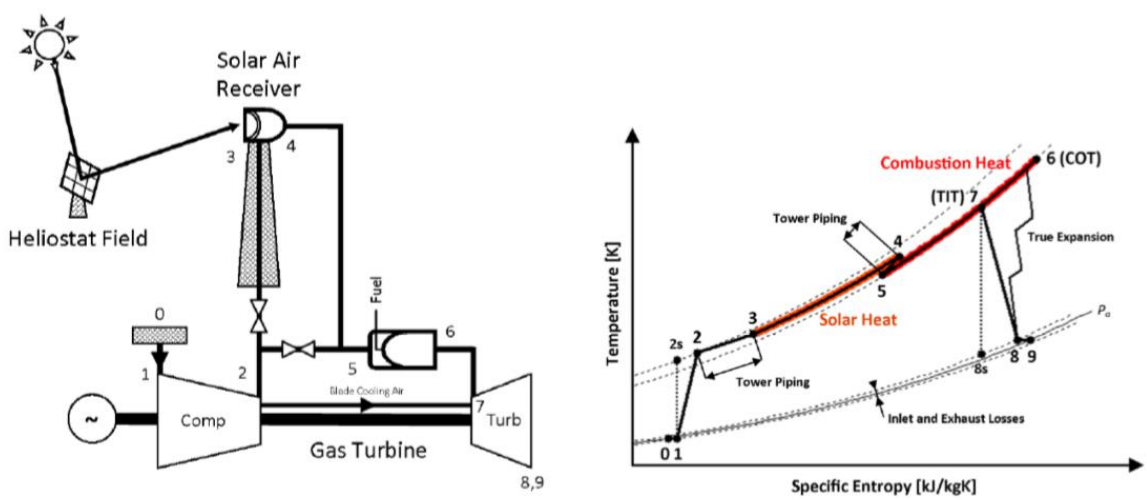
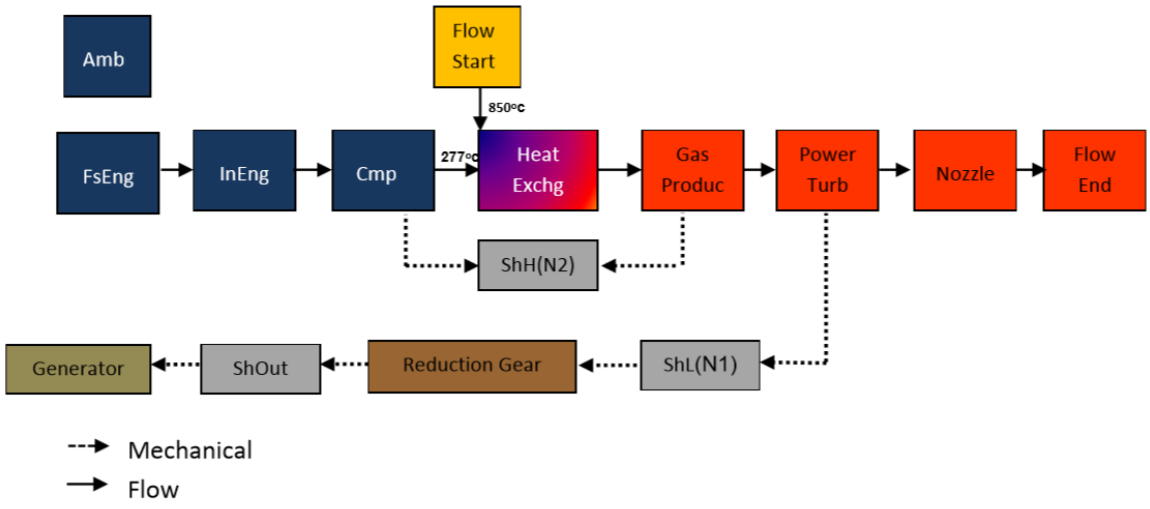
Increasing world-wide population and consequently growing electricity demand, promote the development of new sustainable energy technologies. Those become of primary importance in the effort to reduce emissions of carbon dioxide and other greenhouse gases. The relatively high cost of solar thermal power plants remains a key challenge for the world to rely on such power source as well as a barrier to faster global deployment. Solar hybrid gas turbine technology, however, has the potential for cost reduction and is also one of the most competitive with conventional electricity generation systems. Previous demonstrations of solar hybrid gas turbine power plants were conducted in several projects in the past (SOLUGAS, SOLGATE, SOLHYCO). The gas turbines applied in these projects were Turbotec T100 model (100kW), aero derivative turboshaft (250kW) and Solar Energy Mercury 50 model (1MW).



A novel solar power plant concept is presented, based on the use of solar thermal receiver generating hot gases of ~800°c coupled with an operating converted aero engine gas turbine of ~1MW with no combustion chamber. The converted aero engine gas turbine uses a heat exchanger fed by solar receiver hot gases instead of a combustor, and thereby not burning any other fuel.

In this study, a T53 turboshaft engine was modelled using NPSS software code, to first check its off-design performance and the new design point. Afterwards, a converted T53 gas turbine with an addition of a heat exchanger instead of a burner was modelled and investigated to determine a cycle feasibility and system efficiency:

- Off-design simulation for turbine inlet temperature (TIT) effect on output power study
- Off-design simulation for cycle efficiency in terms of enthalpy [Pout/(h4-h3)] study
- Design simulation for regeneration mode configuration



Following the study results, it appears that the aero engine turboshaft gas turbine may be applicable in other heat producing systems and industries as well: CO2 capture systems, gasifiers and chemical plants. The advantage of these systems is their ability to produce heat continuously throughout the day and thus rely on the gas turbine to supply its own operating power.

D3

Type Certification of Military Commercial Derivative Aircraft & Turbine Engine.

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The US Armed Services and numerous air forces around the world, are directed (when appropriate and viable) to procure derivatives of commercial aircraft and turbine engine due to cost saving. This leads to the adherence to civil airworthiness standards, when the intended use is consistent with civil operation.

A military commercial derivative aircraft & turbine engine is an aircraft with FAA Type Certificate (TC) and produced under Production Certificate (PC) - commercial off-the-shelf product. The aircraft may be modified for use as a military aircraft and the military modifications may be fully or partially FAA approved to civil statutes for the purpose of retaining airworthiness certification.

Military specifications are concerned mainly with performance, while civil standards mainly focus on flight safety. Civil processes provide an excellent basis for military programs. However, civil target levels may be different for the military application.

The key concept of this presentation is that the future of Military Transport Aviation (tanker-transport aircraft, maritime patrol aircraft, intelligence-surveillance-reconnaissance aircraft, transport helicopters, etc.), and advanced Unmanned Aerial Vehicle (UAV) will be based on procurement of military commercial derivative equipment, and integration and harmonization of the civil and military certification procedures.

There are two approaches for military commercial derivative turbine engines:

1. The military accepts a commercial off-the-shelf FAA/EASA certified engine for their basic requirements, then addresses additional desired requirements such as armament gas ingestion, EMI/EMC, enhanced corrosion resistance, etc., separately from the FAA certification. For example: Boeing KC-46A is installed with military version of P&W 4000-94 turbofan engine, which has 500 lbs. more thrust and a different generator package.
2. Both a military qualification and FAA certification are performed concurrently with many common tests conducted using pre-agreed "harmonized" requirements established to satisfy both the civil and the military engine system specifications. For example: An AgustaWestland AW159 “Lynx Wildcat” installed with a military version CTS800 of the Light Helicopter Turbine Engine Co. (LHTEC), a joint venture between Rolls-Royce and Honeywell, commercial turboshaft T800 engine.

There are three different engine specifications potentially applicable to various types of military commercial derivative turbine engines:

- The commercial engine specifications of the FAA 14 CFR Part 33 [*Airworthiness standards: Aircraft engines*] & Part 34 [*Fuel Venting and Exhaust Emission requirements for Turbine Engine Powered Airplanes*],

- The Department of Defense (DoD) Joint Service Specification Guides JSSG-2007A [*Engines, Aircraft, Turbine*] specifications for manned aircraft, and
- The US Air Force AFGS-87271A [*Engines, unmanned air vehicle, air breathing gas turbine, expendable*] specifications for UAV engines.

The requirements of the two military specifications are arranged to correspond to the subject matter of the FAA specification. This arrangement provides an indication of the similarities and differences among the specifications. Most of the military requirements are also required by the FAA, although the methods of verification may be different.

The presentation:

- Examine the legal basis of application of civil airworthiness standards to military commercial derivative aircraft (MCDA) & turbine engine.
- Provide an overview, from a global perspective, of the airworthiness approach used for military type-certificated aircraft including procedures for Conformity and Compliance, Levels of Approvals and Seams between civil and military configuration.
- Analyze the guidelines, functions and requirements applicable to type design, production and continued airworthiness certification associated with MCDA.
- Examine the Tailored Airworthiness Certification Criteria (TACC) methodology to optimize civil certification of MCDA & turbine engine
- Investigate civil and military policies and procedures, their evolution and current format for both the FAA Military Certification Office (MCO) and Military Airworthiness Authorities (MAWA) Forum of the European Defense Agency (EDA).
- Investigates perceived areas of harmonization and weaknesses, of the current certification processes and conclude by summary of findings, recommendations and future work.
- Provides Case Studies of MCDA & turbine engine.

E1

Computational fluid dynamics analysis of the Lehavit combustion system using LES.

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The performance, efficiency and stability of a gas turbine engine are significantly influenced by thermo-fluid dynamic interactions between engine components. Experimental techniques have had only limited success in supplying sufficient information that is required to develop proper theoretical models for those interactions. Failure of engine components, such as flame holders or turbine blades is common result of insufficient understanding of thermo-fluid dynamic interactions in the combustor. The combustion chambers of micro gas-turbines based propulsion system involve complex phenomena such as atomization of liquid fuel jets, evaporation, interactions between droplets, and turbulent mixing of fuel and oxidizer, giving rise to spray-flames. Hydrodynamic instabilities play important role in combustion and in particular in micro gas-turbine combustors. They appear in laminar as well as in turbulent flow regimes, while changing the flame evolution downstream.

The common up-to-date technique for flow simulation in industry is Reynolds Averaged Navier-Stokes computation (RANS). However, the success of these approximations in the simulation of these complex flow fields has been limited so far. On the other hand, direct numerical simulation (DNS) is not feasible for most practical cases. Recently, LES became the preferred technique for predicting flow features in combustors since the flow field under consideration is characterized by low Reynolds number, flow is very unsteady and wall layers are not dominant. This is a case where the advantages of LES are significant. LES resolves the large scale energetic turbulent motions, which are mainly associated with large-scale mixing and cooling. LES technique is thus appropriate for computation of separated flows such as found in the combustion chambers of gas-turbines.

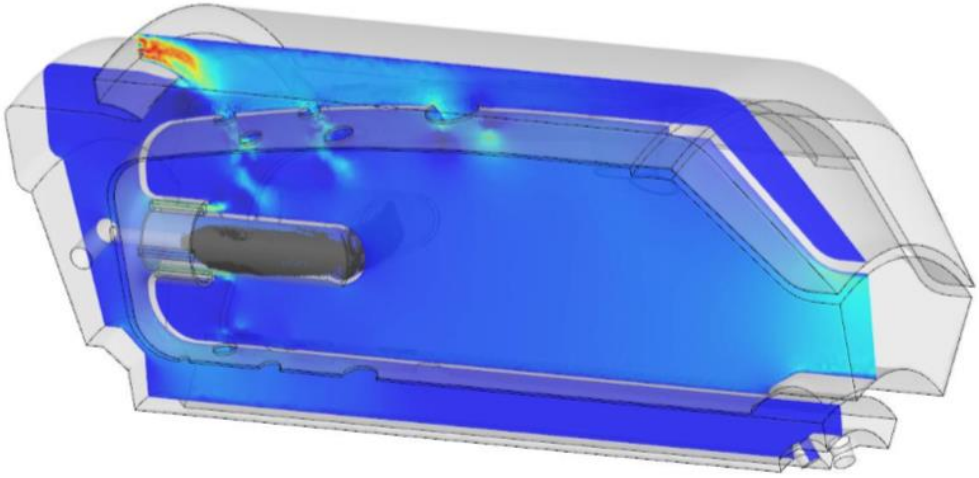

Figure: Axial velocity distribution in a cross-section of the Lehavit combustion system

In our previous study1, unsteady turbulent spray-flame evolution was computationally studied in a simple configuration. The presence of a recirculation zone, which is common in jet engine combustors, has a significant role in spray and flame dynamics, diverting the flame in cyclic motion. This presentation discusses the development of a computational infrastructure for micro gas-turbines combustion chambers, using LES. Preliminary results of the Lehavit combustion chamber computation will be presented, as well as the unsteady spray-flame dynamics that occur in similar flow condition on simpler geometries.

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Advanced Vaporizer for Small Jet Engines.

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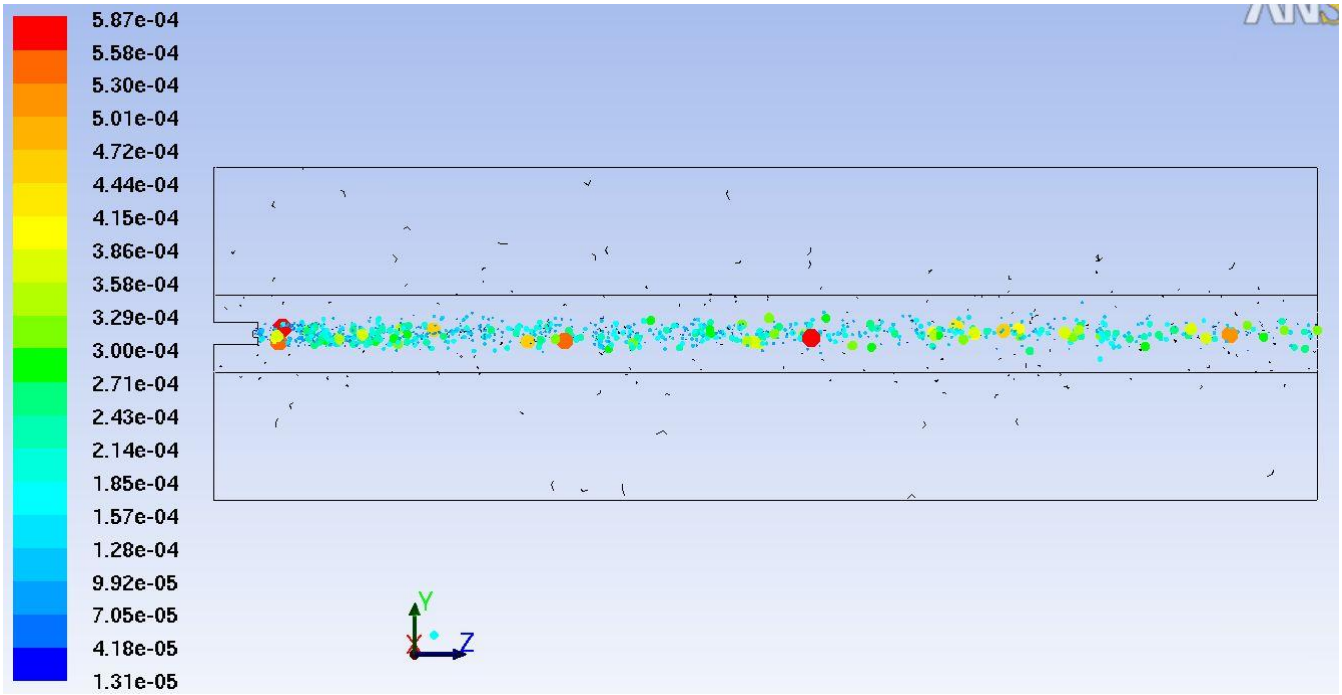
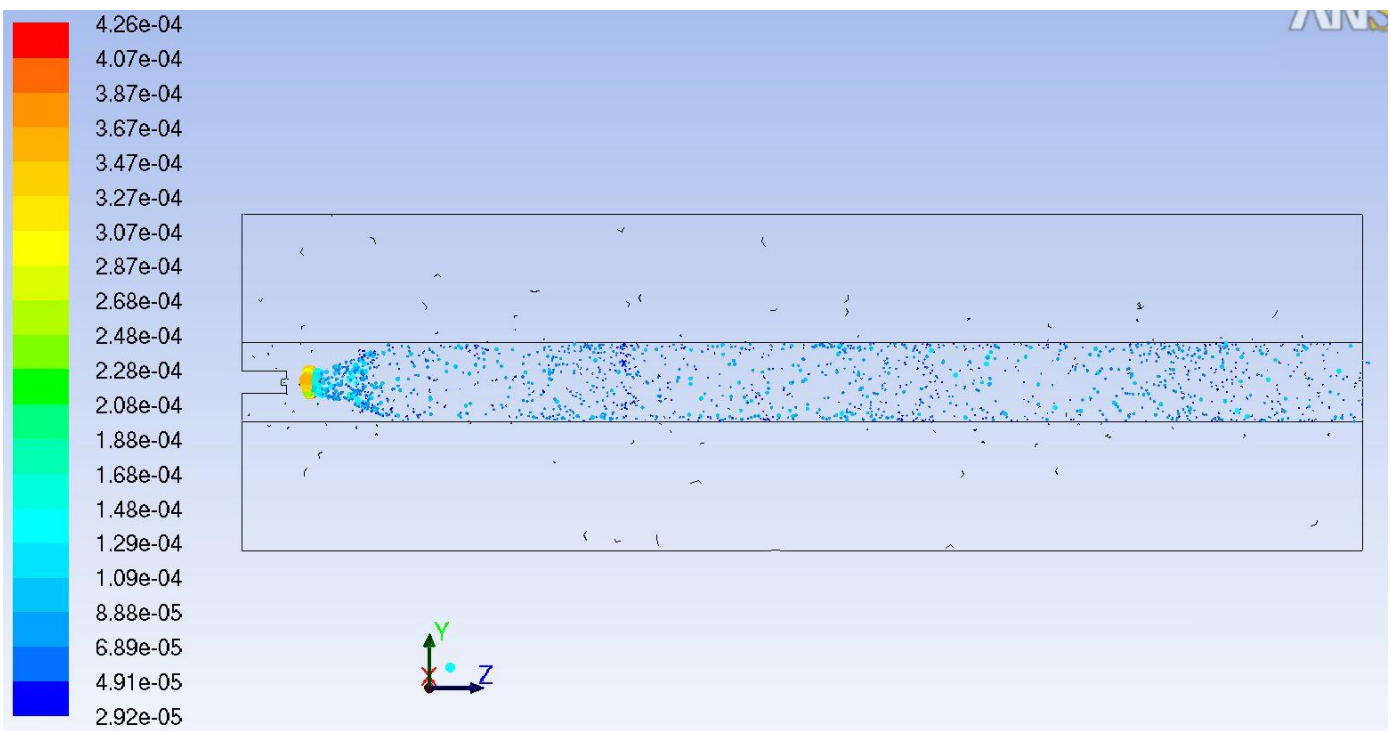
In recent time vaporizing fuel injection systems have found a wide application in small jet engines. A main drawback of the vaporizer is that they do not provide full evaporation; from the other hand, during some operation modes the vaporizer wall can be overheated and destroyed because of high temperature inside a combustor in vicinity of the vaporizer which can achieve more than 2000K [1]. In the presented work a possibility to improve the vaporizer characteristics is considered. For this goal two changes in inner configuration of the vaporizer was proposed:

1. Increasing spray angle of fuel at the vaporizer inlet;
2. Rotation of two-phase flow inside the vaporizer.

In this work the first results of the rotation effect on two-phase flow inside a vaporizer are presented including qualitative theoretical analysis of behaviour droplets at two-phase rotation flow, rotation effect on evaporation rate, and preliminary CFD simulations of a straight tube which generic vaporizer. It is shown that rotation can significantly increase the fuel atomization inside the vaporizer (Fig. 1), fuel evaporation rate, and decrease temperature of the vaporizer wall.



a)



b)

Fig. 1 Droplets distribution inside the straight tube; a) axial air flow, b) rotating air flow

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E3

On the Development of the "Jet Fire" Combustion System

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Development of a new combustion system involves several prominent steps such as empirical and mechanical design, computer aided aero-thermal calculations, testing and measurements in the combustor test rig and final testing within working turbojet engine. The sooner any possible malfunction of combustion system is obtained the less is overall impact on the timetable of the whole engine development program may be, hence it is very important to have high confidence in combustor performance before including it in first engine prototypes.

There are two key milestones in the process of a combustion system development. The first milestone is a verification of the detailed aero-thermal calculation of a combustion system against design point specification requirements. The second milestone is completing of the full range testing in the combustor test rig which includes measuring of the combustor performance in the whole engine operating envelope, obtaining combustor quenching envelope, altitude ignition performance, etc.

This presentation discusses the development of the JetFire engine combustion system. Both aero-thermal calculation results and the combustor test rig testing results will be presented and compared.