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

DEPARTMENT OF
AEROSPACE ENGINEERING

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 החמישה עשר
במנועי סילון וטורבינות גז

15th Israeli Symposium on Jet Engines and Gas Turbines

November 17 2016,
Department of Aerospace Engineering,
Technion, Haifa, Israel

BOOK OF ABSTRACTS

יום ה', ט"ז חשון ה'תשע"ז, 17/12/2016
אודיטוריום, בניין הפקולטה להנדסת אוירונוטיקה וחלל, טכניון, חיפה.

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יום ה', ט"ז חשון ה'תשע"ז, 17/11/2016

אודיטוריום, בניין הפקולטה להנדסת אוירונוטיקה וחלל, טכניון, חיפה.

Propulsion Branch
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15th ISRAELI SYMPOSIUM ON JET ENGINES & GAS TURBINES,
Auditorium (room 235), Faculty of Aerospace Engineering, Technion, Haifa, Israel,
November 17 2016

TECHNICAL PROGRAM

	15th ISRAELI SYMPOSIUM ON JET ENGINES & GAS TURBINES, NOVEMBER 17 2016, Auditorium , Faculty of Aerospace Engineering (room 235)
07:45 - 09:00	**(Registration) הרשמה**
09:00	Opening: **Professor Yeshayahou Levy**, Chairman, Head, Turbo and Jet Engine Laboratory, Faculty of Aerospace Engineering, Technion.
	Professor Yaakov Cohen, Dean, Faculty of Aerospace Engineering, Technion.
	Major Uri Zvikel, Head, Propulsion Systems Branch, Aeronautical Division, MOD/MFAT
	Major Avi Yosfan, Head of Engineering, Propulsion Branch, IAF
09:20 - 13:10	**(First Session, In English) מושב ראשון**
	RECENT ADVANCEMENTS IN ENGINE DESIGN
35 min. lectures	**Session Chairman: Beni Cukurel, Technion**
A1	**Alan Epstein,** Pratt & Whitney, *"Is the Future Electric: Hope, Hype, or Reality?"*
A2	**Ryan M. Chapin,** GE Aviation, *"Digital Solutions for the 21st Century"*
A3	**Bruno Aguilar** ,Honeywell, *"Conjugate Heat Transfer Analysis for Gas Turbine Film-Cooled Blade"*
11:05 - 11:25	**(and refreshments Break) הפסקה וכיבוד קל**
A4	**Joachim Kurzke,** GasTurb, *“Engine Families”*
A5	**Boris Glezer,** Optimized Turbine Solutions, *"Getting The Outmost Benefits From Turbine Cooling"*
A6	**Bayindir Saracoglu,** VKI, *"Challenges of Detonation Engines for Future Jet Propulsion"*
13:10 -14:30	**ארוחת צהריים וסיור במעבדה למנועי סילון (Lunch and laboratory visit)**

TECHNICAL PROGRAM (Cont.)

Lectures in Hebrew, 20 min. lectures. 14:30 - 17:00 כל ההרצאות 20 ד' ובעברית.					
	Second Session מושב שני **14:30 -15:30 room 165**		**Third Session מושב שלישי** **14:30 -15:30 room 241**		**Forth Session מושב רביעי** **14:30 -15:30 room 235**
	Material & Stress		**Turbomachinery**		**Simulations & Modelling**
	Session Chairman: **Alex Roizman, Technion**		**Session Chairman:** **Shalev Aizik, IAI**		**Session Chairman:** **Dan Fishman, Rafael**
B1	**Alex Katz,** Technion, *"Turbine Blades made of Ceramic Matrix Composites CMC , SiC/SiC "*	**C1**	**David Lior**, R-Jet "Closed Cycle Micro turbines for CHP market"	**D1**	**Ella Berlowitz Paska,** Rafael *"Compressor Test Bench Development Process"*
B2	**Inna Kprovsky**, IAF, *"Thermomechanical Fatigue, Sulfidation & H.C.F. of P&W JT3D Turbine Blades"*	**C2**	**Alon Grinberg ,** IAI, *"Turbo shaft Aero Engine Modeling Using NPSS Software"*	**D2**	**Eli Yakirevich,** BSE, Technion, *"Transonic Linear Turbine Cascade Development in Technion"*
B3	**Koresh Ido,** Rafael, *"Ceramic matrix composites as a structural material for high temperature applications"*	**C3**	**Michael Lichtsinder,** Bet Shemesh Engines, *"Influence of Turbine Outlet Flow Swirl Angle and Reynolds Number on Small Jet Engine Performance"*	**D3**	**Konstantin Rosenberg,** Rafael, *"Compressor Development Process – Verification of Simulations"*
15:50-15:30 הפסקה וכיבוד קל Break and refreshments					
	Fifth Session מושב חמישי **15:50 -16:50 room 165**		**Six Session מושב שישי** **15:50 -16:50 room 241**		**Seventh Session מושב שביעי** **15:50 -16:50 room 235**
	Fuel & Combustion		**Noise & Instrumentation**		**Dynamics & Vibration**
E1	**Alex Roizman**, Technion, *"Suppression of Combustion Instability"*	**F1**	**Oksana Stalnov**, Technion, *"Fan Noise"*	**G1**	**Alex Ferdinskoif**, Technion, *"Comparing experimental and simulated dynamics of a tunable micro turbo-jet engine laboratory simulator"*
E2	**Moshe Rabaev**, IAF, *"Jet Fuels, Characteristics and Properties"*	**F2**	**Shalev Aizik**, IAI, *"Commercial High Bypass Engine Instrumentation"*	**G2**	**Eyal Setter**, Rafael, *"Analysis and Experimental Study of Jet Engine Rotor Dynamics"*
E3	**Yuval Dagan**, Rafael, *"A Preliminary Computational Study of a Micro Jet Engine Combustion Chamber Using Compressible Large Eddy Simulations"*	**F3**	**Mordechai Peled,** *"Utilization of Turbo-Fan Engine's Residual Energy as a Source of Electricity for Consumers in a Plane Using Thermo-Electric Cell"*	**G3**	**Ronen Payevsky**, Bet Shemesh Engine, *"Modeling of Rotating Assembly Dynamics for small jet engine"*

תודתנו נתונה לגופים ומוסדות אשר תמכו ביום העיון:

AKNOWLEDGMENTS

חיל האוויר	
מפא"ת	
טכניון - מכון טכנולוגי לישראל	
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THE 15th ISRAELI SYMPOSIUM ON JET ENGINES AND GAS TURBINES

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

Thursday, November 17 2016, Technion, Haifa

This year, as in the previous years, we gathered to hold the 15th Israeli Symposium on Jet Engines and Gas Turbines. During the last few years there is an ongoing expansion of activities in Israel in turbo jet propulsion and power generation using gas turbines. This is in addition to the serial production of small engines, production of various engines' components 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 six 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 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 Jet Engine Laboratory website (see below).

Looking forward for a fruitful and enjoyable symposium!

Professor Yeshayahou Levy
Chairman of the symposium
Technion, Faculty of Aerospace Engineering,
e-mail: levyy@technion.ac.il
http://jet-engine-lab.technion.ac.il

A1

Is the Future Electric: Hope, Hype, or Reality?

Alan Epstein

Vice President – Technology and Environment

Pratt & Whitney

Much has been seen recently in the press and technical literature about advanced aircraft concepts that are electrically powered – some battery powered, some hybrid, and some turboelectric. One major motivation for most of these concepts is to combat climate change by reducing aviation's CO_2 production. Over 90 percent of aviation's CO_2 is produced by single and twin aisle airliners (Figure 1), so technical approaches to electrifying aircraft must be relevant at that size. This implies prodigious amounts of energy and power are required (Figure 2).

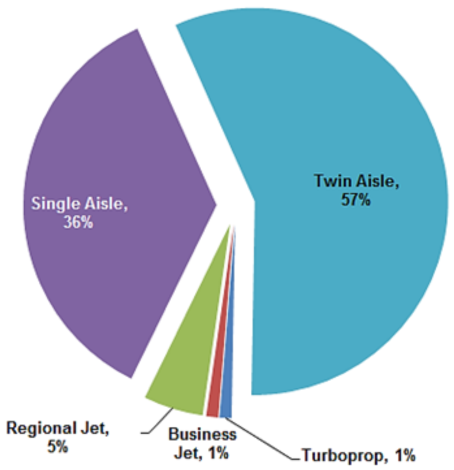

Fig 1: Annual global jet fuel consumption

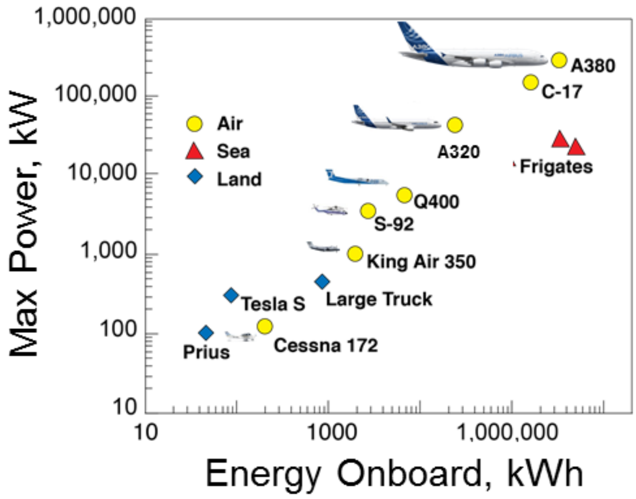

Fig 2: Vehicle maximum energy and power

This talk explores the performance needed for electrically powered commercial aircraft. It considers the impacts of efficiency, weight, and cost. It contrasts the current state-of-the-art with the implied requirements of an electric future. It compares the net CO_2 from a notional grid-powered aircraft to one using gas turbines, both at today's technology levels and at those projected over the next 25 years. It discusses the sensitivity of such analyses to policy assumptions. The implications of electric propulsion and improved aircraft jet engines and gas turbines are then discussed. Although mainly focused on commerical aviation, general and military aviation applications are breifly explored.

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Digital Solutions for the 21st Century

Ryan M. Chapin

Chief Project and Portfolio Manager, Digital Services and Solutions

GE Aviation

GE Aviation is investing big in the concept of a "digital twin"—a digital model of a physical asset—to eliminate unplanned disruptions and reduce life cycle costs. This is all part of GE's drive to become a digital industrial company, leveraging its Predix operating system for the Industrial Internet.

Digital twin models (Figure 1) are built to represent everything from a critical piece part to a complex system like an engine or aircraft. By combining big data, data science and physical domain expertise, GE has transformed from reactive on-condition maintenance to predictive analytics-based maintenance for an individual asset based on how and where the asset has flown. As a result, GE has greatly reduced unscheduled engine removals, increased asset availability and time on wing, and saved customers millions in annual fuel costs. Digital twin models have also successfully demonstrated the capability to predict the onset of asset disruptions, giving customers time to plan for appropriate maintenance.

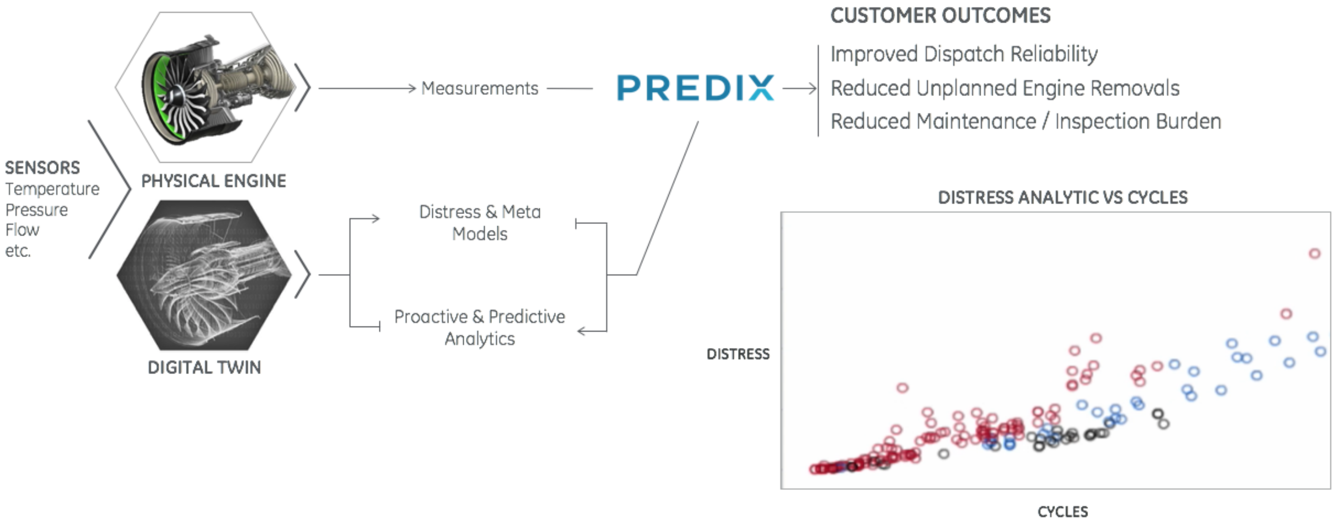

Fig 1: Digital twin model overview

This presentation will provide a summary of how GE utilizes big data, data science and domain expertise to drive improved life cycle cost for our customers.

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Conjugate Heat Transfer Analysis for Gas Turbine Film-Cooled Blade

Mr. Bruno Aguilar
Honeywell Aerospace

The presentation will cover the heat transfer analysis of a film-cooled blade used in the Honeywell F124-GA-200 turbofan engine that powers the M-346 advanced jet trainer built by Alenia-Aermacchi and currently being used by the Israeli Air Force's (IAF).

A conjugate heat transfer (CHT) model was built, Figure 1, to calculate steady state blade metal temperatures. ANSYS CFX14.0 code was selected as the computational fluid dynamic (CFD) tool to perform the CHT simulation. The two-equation SST turbulence model with automatic wall treatment was employed. The main flow inlet and exit boundary conditions were calculated from a multi-blade-row CFD code, Fine Turbo by NUMECA. A Honeywell F124-GA-200 core engine test operating at maximum power condition to simulate field operation was ran. Thermocouples were used to validate the blade metal temperature calculations.

The blade temperature comparison between test data and CHT predictions was in good agreement except at the suction side near the leading edge region. In order to evaluate the influence of the turbulence model, the thermal results of four additional turbulence models (SA, RNG, K-ε, and SST with transition control) were compared to the test data. The SST model is suggested to be the appropriate turbulence model for the film-cooled blade temperature calculation in this study.

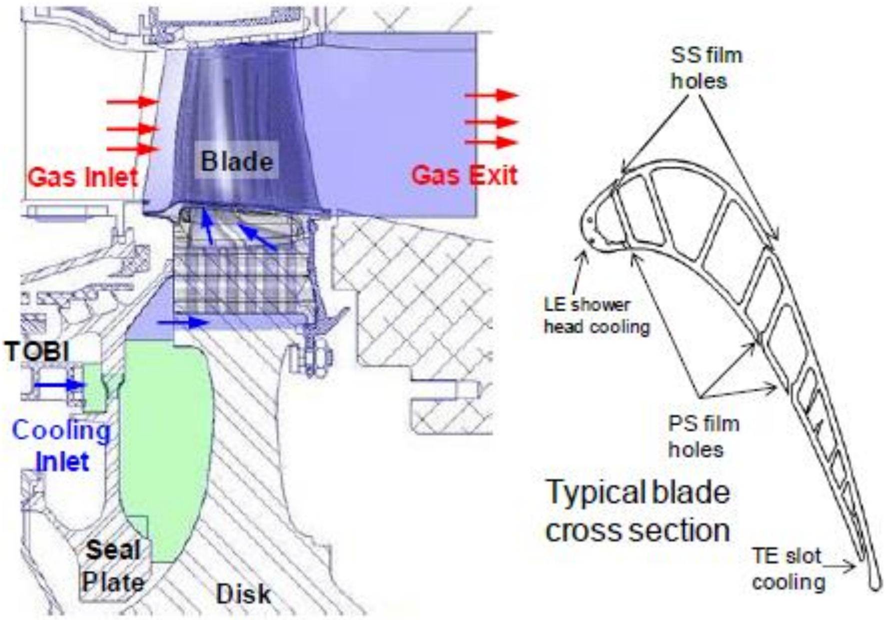


Figure 1: CFD CHT configuration

Engine Families

Mr. Joachim Kurzke,
GASTURB

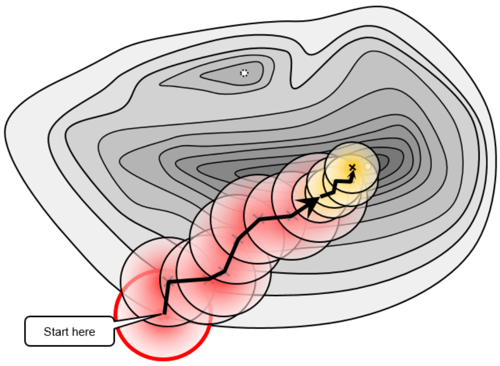
What is an engine family? Usually this is defined by a series of units all based on a common core or gas generator. The siblings of an engine family are called derivatives and they come about by designing alternative IP and LP systems around the common core, which is retained as far as possible. The derivative engines will generate higher or lower levels of thrust than the baseline but the baseline must be configured with precisely that objective in mind. This usually means compromising the baseline somewhat to allow for either growth or reduction, accepting reduced sales of the original in hopes of the benefits of greater sales of the derivatives.

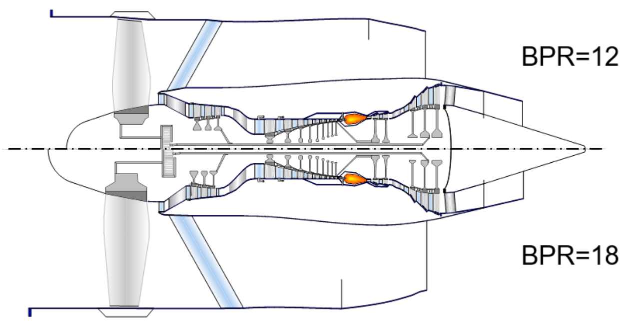
In an ideal world the gas generator of an engine family would consist of identical parts. In reality the cores of the engines are similar, but not identical. While the maximum permissible spool speed is very much limited by a common value of tolerable disk stress, the aerodynamics and the tolerable burner exit temperature differ. The flow capacity of compressors and turbines can vary within the same annulus due to re-staggered or re-designed blades and vanes. New materials and more sophisticated cooling schemes can increase the temperature capability of the turbine. Thus in an engine family the cores are very similar, but not necessarily identical.

Adapting an existing engine to a new application creates a new member or derivative of the engine family. This is a very common design task, actually much more frequent than the design of a completely new engine, which may happen only once in a decade or so. The many constraints and boundary conditions imposed by the given gas generator make the cycle selection for a derivative engine a challenge.

Traditionally the advanced projects engineer explores the design space of a new engine with extensive parametric studies. He presents the results as x-y plots which might include contour lines for important quantities. Showing the boundaries of the design space in a single figure is easy if there are only two design parameters. However, if there are more than two design parameters, then more than one figure is required for fully describing the design space. Searching for the best engine cycle becomes time consuming and difficult if the number of design variables exceeds three or four.

Instead of screening a wide range for the design variables with systematic parameter variations it is also possible to do an automatic search for the optimum engine design with the help of numerical optimization routines. This is the approach described in this presentation: the task is to optimize the 25% thrust growth derivative of a turbofan engine.





Getting the Outmost Benefits from Turbine Cooling

Dr. Boris Glezer,

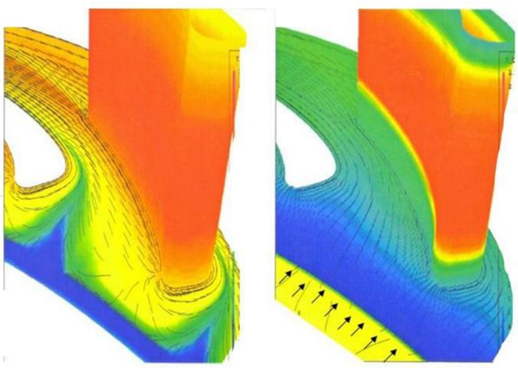
Optimized Turbine Solutions, USA

Cooling gas turbine hot section components by compressed air remains the main tool in achieving superior performance of GT engines usually outweighing the increased complexity and related cost, certain durability concerns due to application of small cooling passages, and negative effects from cooling air discharge along the gas path.
It is shown that the benefits from cooling enable much higher operating temperatures providing significant increase in engine specific output power or thrust. Selection of higher compressor pressure ratios that match the increased turbine inlet temperatures lead to an improved thermal efficiency/SFC and reduced specific weight of an engine.
Presentation is focused on cross-disciplinary hot section cooling design features that assist in maximizing benefits from turbine cooling application.

Various cooling techniques for main gas path components and cooling air delivery systems are discussed and compared. Application of film cooling for combustor liner, turbine vanes and blades that operate at high gas temperatures remains the key element of cooling techniques. Importance of cooling of the combustor-to nozzle transition is emphasized illustrating the effect of properly designed cooling flows on the nozzle metal temperatures as well as the stage losses. Improvement of cooling effectiveness with shaping of the holes in the airfoils is illustrated..

Critical role of the interior secondary cooling circuits is discussed with a special emphasis on the air delivery system for turbine rotating components. Established design practice for introduction of cooling flows into the mainstream and sealing of turbine interior from the hot gas ingress are discussed in detail providing recommendations for reduced aero-thermodynamic penalties resulting from the air injection.

A dramatic effect of blade tip clearances on turbine stage efficiency is discussed with practical design recommendations for minimizing the tip losses. A methodology of modulating cooling air flow for active blade tip clearance control during transient and steady state operation is also presented.



Challenges of Detonation Engines for Future Jet Propulsion

Bayindir H. Saracoglu,

Aeronautics and Aerospace Department, von Karman Institute for Fluid Dynamics, Rhode-Saint-Genese, Belgium

Most of the modern aero engines are powered by constant pressure combustion process based on deflagration. Thermal efficiencies attainable in such engines saturate to the attainable limits as the combustion temperatures approach to the adiabatic flame temperature. Hence a fundamental change in the engine architecture is required to realize a step change towards highly efficient propulsion systems. In this regard, detonation engines based on pressure gain combustion opens a new paradigm for the future propulsion systems.

Pressure gain combustion is defined as an unsteady process whereby gas expansion by heat release is constrained, causing a rise in stagnation pressure and allowing work extraction by expansion to the initial pressure. Such a process allows reaching higher outlet pressures for the same exit temperatures thanks to near-constant volume combustion which would allow an elevation in theoretical cycle efficiency compared to the Joule-Brayton cycle. Consequently, an ideal detonation engine could offer 30% superior efficiency (Fig. 1-right).

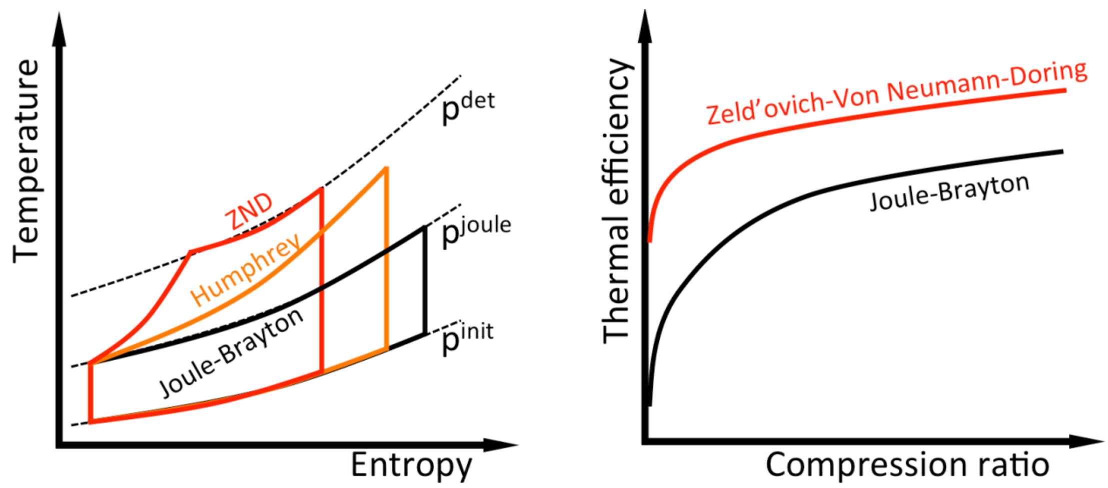


Figure 1. T-s diagram of Zeld'ovich-Von Neumann-Doring (ZND) and Humphrey cycles compared to Joule-Brayton cycle (left), comparison of Joule-Brayton and ZND cycles' thermal efficiencies (right).

Detonation cycle finds its realization in two main type of architectures: pulsed detonation engine (PDE) and rotation detonation engines (RDE). The former is usually composed of a long tube periodically filled with the fuel and oxidizer which ignited by spark assistance. The deflagrating flame accelerates throughout the tube, converts to a detonation wave and eventually expands to generate thrust at the outlet. In spite of the simple construction, PDE requires cyclic ignition and provides detonation pulses at relatively low frequencies which, therefore, limits the thrust generation. RDE, on the other hand, offers continuous burning of fuel owing to circumferentially moving detonation wave(s) consuming the reactants. Thus, the re-ignition requirement is nearly eliminated while much higher frequencies are attained in the rotating detonation engines.

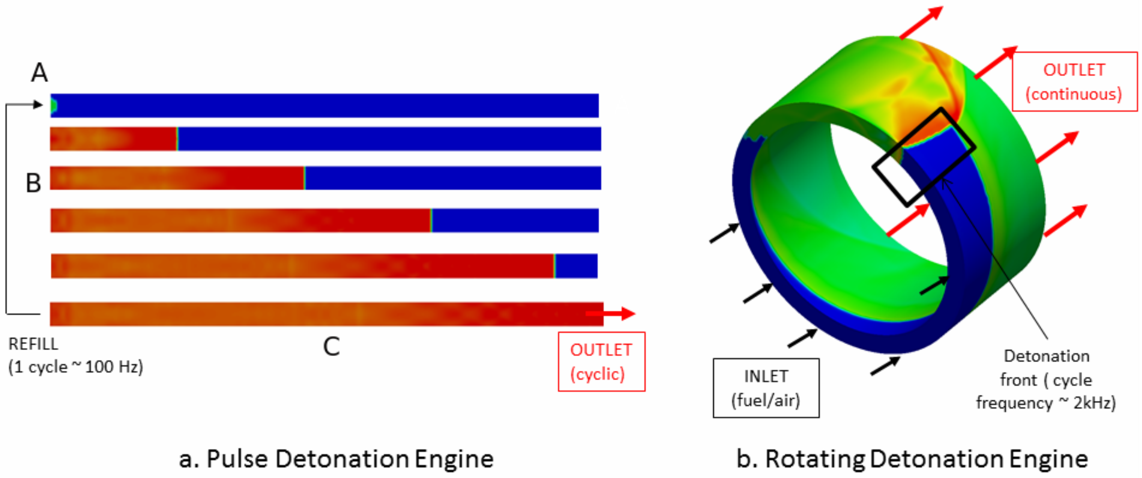


Figure 2. (a) Working principle of pulse detonation engine (PDE) and (b) rotating detonation engine (RDE)

Although detonation based engines stands for a promising alternative for jet propulsion, they entitle several engineering challenges yet to be solved for real-world implementation. The pulses created within the detonation waves result in strong Mach number variations in the flow field. Subsequently, designing and efficient downstream machinery handling abrupt changes in the flow regime stands as an issue on the expansion side. Conventional high-pressure turbine bladings suffers unstarting problem during majority of the operation. Therefore, a completely new design approach is required to harness the potential power from the detonation waves without causing severe interruptions in the operation of the cycle. On the gas generator side, the outlet of the upstream compressor experiences strong pressure pulses, much larger than the compressor exit pressure, inducing blockage which can result in stall and eventually surge. Hence, proper isolation between the combustor and compressor is still constitutes a design problem as the pressure gradients can reach up to 30 folds during the operation.

In conclusion, pressure gain attained by the detonation combustion accommodates a valuable engineering opportunity for future jet engines. Nevertheless, the realization of a feasible detonation engine requires construction addressing various major challenges on different parts of the cycle. In other words, a step change in the jet engine architecture entitles moving to a novel design paradigm.

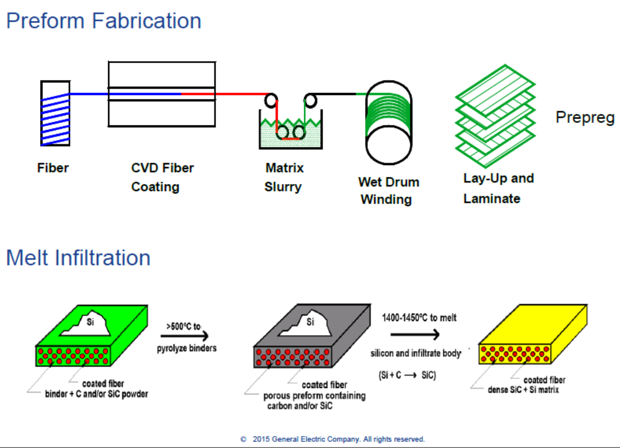
Turbine Blades made of Ceramic Matrix Composites CMC (SiC/SiC)

Alex Katz,

Israel Institute of Metals, Technion Research & Foundation Development (TRDF)

Currently, the most common materials for jet engine blades are nickel-based superalloys, such as the Mar M247 or single crystal (SC) based nickel superalloys. These materials have exceptional high-temperature strength, corrosion and oxidation resistance. Although they have been proved as highly efficient, they are hard to produce just due to their high strength. In order to achieve improved creep and fatigue resistance, usage of rhenium and hafnium is required, which makes the production process of these alloys not only hard, but also extremely highly expensive.

Modern developments in mentioned field include the family of BCC high entropy (HE) alloys, which should provide a cost efficient solution to replace the SC blades. These materials are widely studied these days, but their way into industry is yet long.



An alternative progress seems to be at a higher industrialization state, the silicon carbide/silicon carbide (SiC/SiC) ceramic matrix composites (CMC). SiC/SiC CMC is not only significantly lighter than the Ni-based superalloys, but also possesses a much higher temperature resistance making it a big technological opportunity for materials resistance in high-temperature applications.

e for their superior thermal stability, the lack of ductility have prevented the use of these in airborne applications or any other applications where safety aspects demand ductility prior to failure of a component. In order to provide some elongation the SiC/SiC CMCs are produced by embedding SiC fibers inside a SiC matrix.

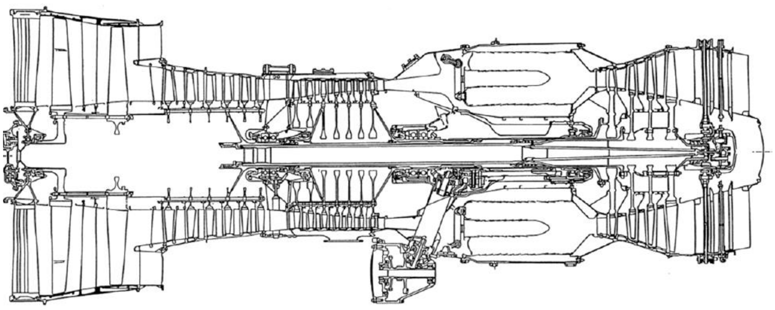
Nowadays, CMC's use in aerospace become an intensively discussed technological issue. Recently, GE announced the successful testing of the first rotating CMC for next generation combat engine F414 low-pressure turbine blades. Simultaneously, a similar development is undergoing in Rolls-Royce for their own SiC/SiC blades and even NASA is developing SiC/SiC production.

The IIM with collaboration to Israeli companies is interested to make use of industrial available melt infiltration capabilities to produce and optimize such CMC structures. This issue has a great technical-economical value and it might prove of key importance to Israeli jet propulsion capabilities.

Inna Kprovsky, IAF,

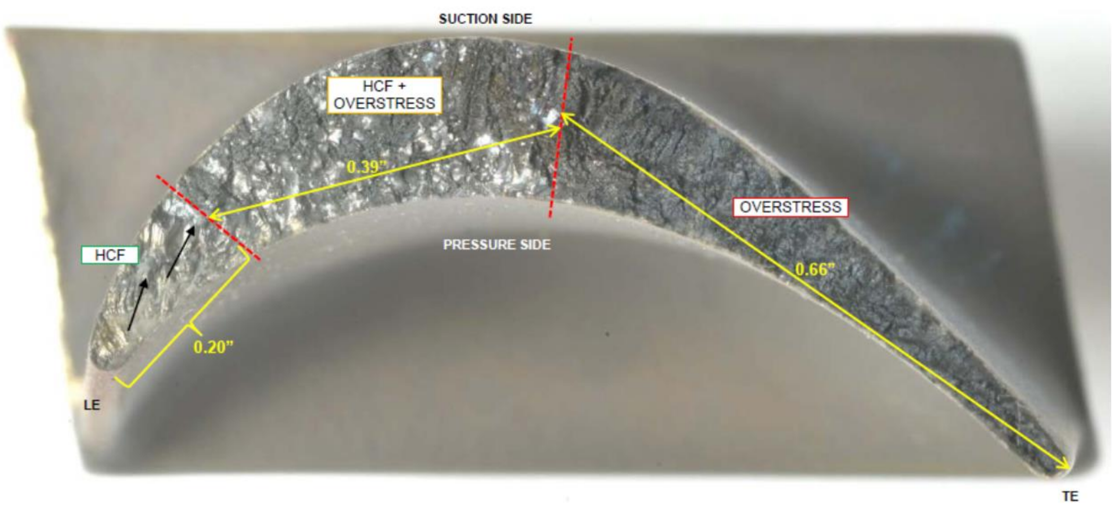
Thermomechanical Fatigue, Sulfidation & H.C.F. of P&W JT3D Turbine Blades

Israeli Air Force B707 Tanker aircraft experienced elevated EGT and vibration on one of the engines and was commanded in-flight shut down (IFSD) by the crew.
The affected engine, Pratt& Whitney JT3D-3B, was last overhauled 383 flight hours prior to the IFSD.

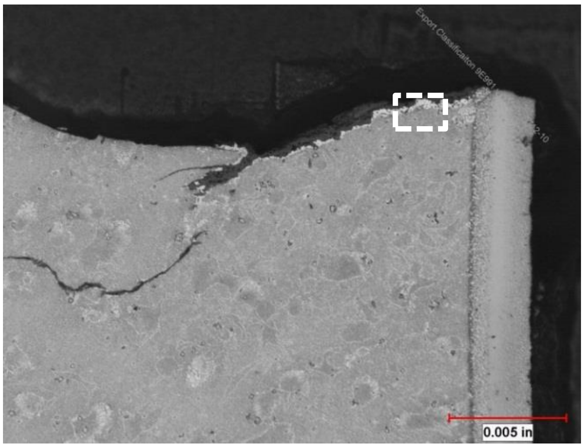


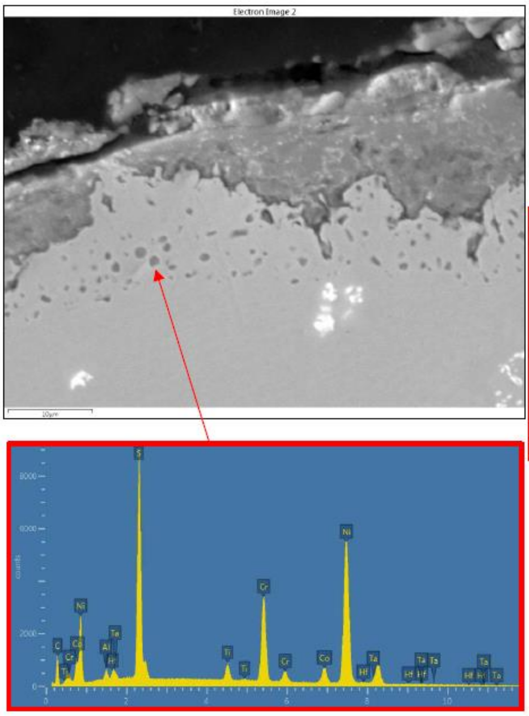
The disassembly of the engine revealed a single fractured High Pressure Turbine Stage 1 Blade, Low Pressure Turbine airfoil damage and Turbine Exhaust Case damage. No damage prior to the High Pressure Turbine Stage 1 blade was revealed.
Several similar failures are known to Pratt& Whitney.
The failure analysis of the 1st stage High Pressure Turbine fractured blade reveled:

- The fracture was initiated by a small was intergranular and highly oxidized crack in the leading edge radius approximately 1" above the root platform (~1/3 blade height). This initial crack exhibited features consistent with Thermal Mechanical Fatigue.
- High Cycle Fatigue progressed from the periphery of this crack followed by a mixture of HCF progression and overload mode for an additional (up to roughly half of the chord length) before ultimately failing in overload.



- The crack exhibited alloy depletion consistent with oxidation and sulfidation.
- There were no indications of blade coating material within the crack to suggest the crack was present during the previous overhaul.





NDI of the 129 incident 1st stage High Pressure Turbine blade set revealed several additional blades with lead edge cracks in the 1/3 – 1/2 span wise location with similar characteristics.

Conclusion

The airfoil fracture was due to High Cycle Fatigue progressing from a Thermal Mechanical Fatigue crack originating at the lead edge at approximately 30% span.

There were no material, manufacturing or geometry factors that were identified as probable contributors to the blade fracture. The most probable cause for the TMF crack and ultimate fracture due to HCF and overload is the airfoil material having exceeded its useful life from a thermal-mechanical fatigue standpoint.

Ceramic Matrix Composites (CMC) as a Structural Material for High Temperature Applications

Ido Koresh, Omri Yannay, Anat Shenar, Itamar Gutman

Advanced Materials Department, MANOR, RAFAEL.

Ceramic matrix composites (CMCs) are a wide variety of materials that consist of embedded ceramic/carbon fibers in a ceramic matrix. The specific CMCs' composition depends on the final product/component design specifications. CMCs offer high specific strength, low density and high thermal stability. The combination of these properties makes CMCs promising candidates for replacing conventional structural materials for high temperature and harsh environment applications (superalloys, refractory metals etc.). The CMC high temperature capabilities and high specific strength allow designing components for jet-engine and solid-propulsion systems with reduction of cooling needs and weight. This can lead to an increase in systems' efficiency and performance.

An overview on the physical properties and microstructure of CMCs is given with a special attention to their superior high temperature mechanical properties. The second part is focused on the world status in industry in terms of development and production of CMCs for highly demanding applications. Finally, the fabrication method, Metal Infiltration (MI) of CMC in RAFAEL is introduced and the main microstructure features of the final dense bodies are presented (Figure 1).

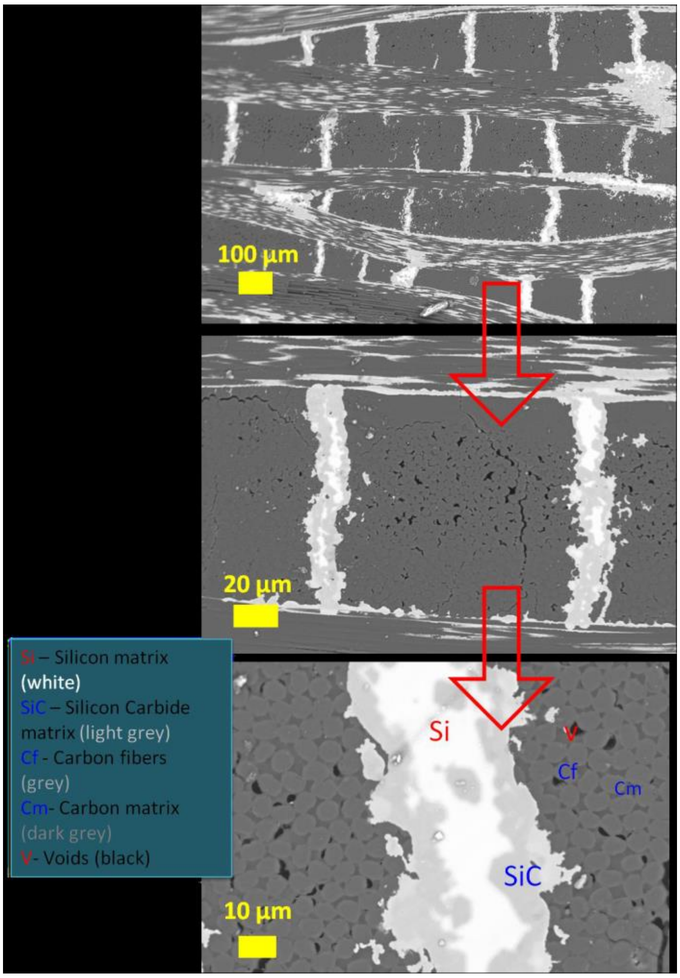


Figure 1 - CMC scanning electron microscope (SEM) micrographs taken from a cross-section surface of the samples.

מערכות לחימה מתקדמות בע"מ
חטיבת מנור וטכנולוגיות
מו"פ והנדסה-טכנולוגיות
מחלקת חומרים מתקדמים

בלמ"ס
ללא סיווג עסקי

C1

Closed Cycle Microturbines for CHP market

Prof. David Lior
R Jet Engineering

1. Introduction

Recently, there is a growing requirement for distributed/decentralized energy installations for C.H.P (Combined Heat and Power) applications, in which micro turbines are competing against natural gas piston engines .There are many advantages to micro turbines against the piston engines, such as low pollution, compactness and total efficiency but their major disadvantage is a high price currently twice compared with them., mostly in the low power range (up to 5000 kw). Micro Turbines advantages so far has been recognized mostly in the western world and won recently considerable support from governments such as Germany, Great Britain and recently U.S.A . by activating high incentive programs. There are a few micro turbines manufacturers for the C.H.P market in the world i.e Capston, Turbec, which generate less than 250kw of electric power. A cluster of several micro turbines is delivered whenever a higher power is required. The main technical features common to the above micro turbines are:

- Recuperated thermodynamic cycle,
- Open (to atmosphere) cycle,
- High speed alternator (permanent magnet) driven directly by gas turbine shaft,
- Power electronic system (invertor AC/DC,
- Convertor DC/AC) including its own control system
- Inverse electronic starting system.

At present the above design features are limited to 200kw mainly due to the alternator rotor stresses occurring at typical high speeds. Another disadvantage is the power electronics size and cost. Their size is similar to a 200kw synchronous alternator turning at 1500 rpm and the cost is twice as much. Large industrial gas turbines continue therefore, to be designed with 1500 rpm of alternator speed and install a reduction transmission between gas turbine output shaft and alternator.

2. Closed cycle CHP micro turbine design-fig.1

The closed cycle design has the following advantages-_Avoiding fouling of fluid from fuel pollution products thus attaining multi-fuel combustion thus avoiding contamination of combustor, ducts and turbines .Control of internal fluid pressure determines total power, thus bleeding or pressurizing of internal closed fluid allows constant speed operation and variable power. Increasing the mass flow and the inlet pressure simultaneously the corrected flow is kept constant and the same micro turbine is thus adaptable to increase its power which will be limited only by its structural strength. The recuperator heat transfer capacity increases when it’s cold and hot mass flows increase due to higher heat transfer factors. Using Helium or CO_2 as circulating fluid result in higher performance - power and thermal efficiency. The disadvantages of the micro turbine closed cycle are-

- Increased cost and size due to 2 heat exchangers at external flow exit and at compressor inlet.
- Pressure and heat loss in the external combustor.
- A fan is used to circulate the air through the combustor and its heat exchanger

3. Competitive Cost closed cycle design.-

Thermal efficiency-37.7% Thermal Power-522kw, Design Speed-50K rpm

a. Application of the following large gas turbine architecture –Synchronic alternator generating 50/60 HZ turning at 1500/1800 Planetary transmission 33:1 for 1500, 37:1 for1800 rpm, Electric starter driving transmission exit shaft.

The closed cycle differs from the open cycle in the combustor design which is external to the pressurized air flow. The heat energy is transmitted by conduction. The external ambient air is first heated by the combustor exhaust gas and then fuel is added to attain the desired air temperature .The external combustor is insulated to avoid heat losses through its external envelope. A fan is provided to provide fresh air and to overcome the external combustor pressure loss (calculated as 20kpa for an external air flow of 3.5 kg/hr). Heat output is generated in water in both heat exchangers one at compressor inlet and the second at combustor outlet.

4. Summary

A closed cycle design of micro turbines is presented as a cost effective solution which is competitive to gas piston engines cost and performance for the CHP markets. This design allows using efficiently the same core engine for a variable power requirement This design will result in a total energy (Power and Heat) efficiency of 85-92%.

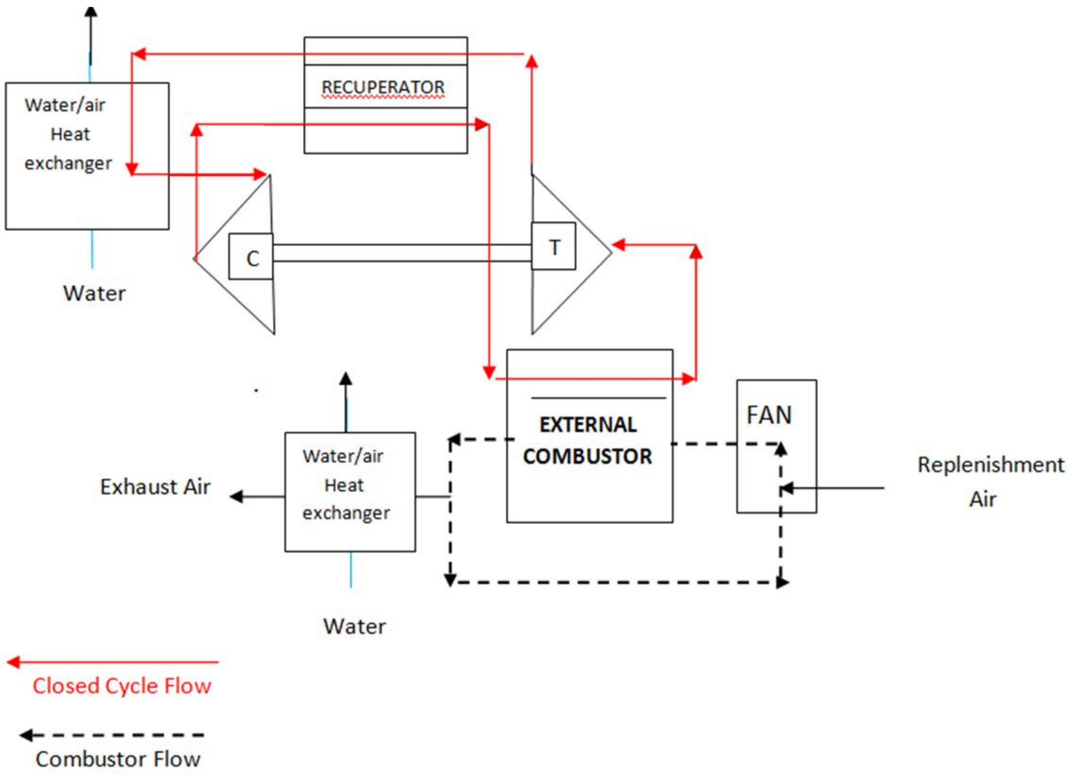


FIG.1- Closed cycle micro turbine cycle

R-Jet Engineering

C2

Turbo shaft Aero Engine Modeling Using NPSS Software

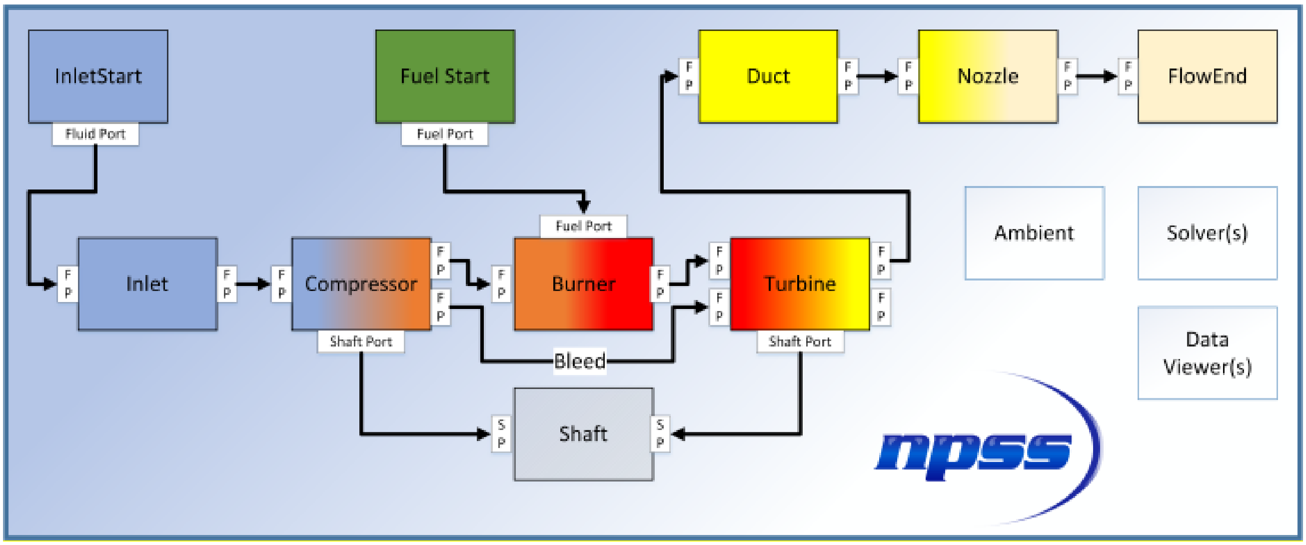
Alon Grinberg
IAI, Bedek Aviation Group,
Enignes Division, New Products Development

Gas turbine engine manufacturers usually apply full thermodynamic models to the prediction of engine performance. The performance calculation tools are modularly structured and synthesize the performance of the engine based on the characteristics of its individual components. Using these tools, a full thermodynamic model of nearly any engine configuration can be set up, allowing the calculation of engine performance with sufficient accuracy.

Engine maintenance shops can use them for investigating incoming engines, planning the extent of the repair and assessing the post repair performance.

This presentation describes typical applications of the Numerical Propulsion System Simulation (NPSS) software modeling and analysis procedure for turbo shaft aero engine. Along with introducing the NPSS tool, an example of a turbo shaft aero engine model will be described. The model was created at the New Products Development from the IAI Engines Division.

NPSS software contains NIST-compliant gas property packages for a variety of applications. The tool is based on object-oriented programming to facilitate user-definable elements and functions. NPSS also includes a sophisticated solver with auto-setup, constraints and discontinuity handling. Typical solution modes include preliminary design, off-design performance, transient performance and flight data correlation.



Influence of Turbine Outlet Flow Swirl Angle and Reynolds Number on Small Jet Engine Performance

Dr. Michael Lichtsinder

Bet Shemesh Engines Ltd.

Generally, jet engine DECK is built using the two following assumptions:

a) A turbulent flow is created in all parts of the engine
b) The turbine outlet flow swirl angle is negligible.

Assumption "a" is valid at low altitude. At a high altitude and low flight velocity, the flow is close to laminar one as a result of viscosity force increase. The friction and pressure loss increase and affect the engine performance. This effect is characterized by Reynolds Number. The engine model correction is executed if the Reynolds number is less than the critical Reynolds number.

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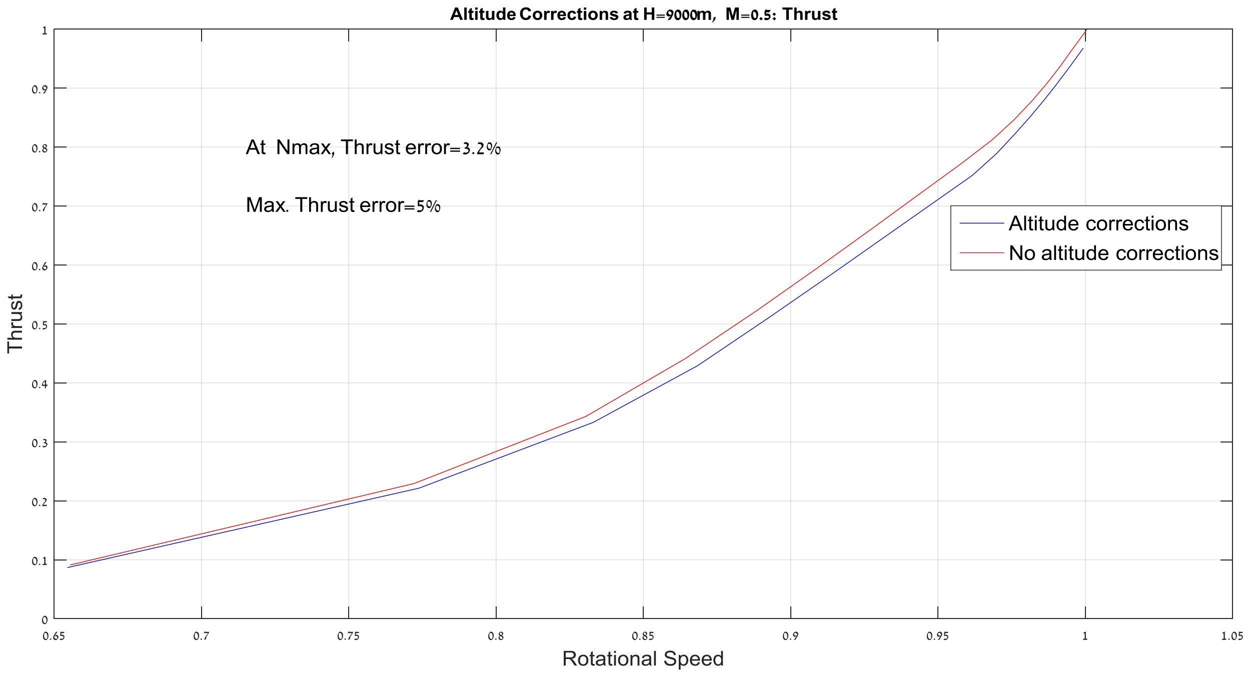
Assumption "b" leads to nozzle loss decrease, and, as a result, an error of the engine performance calculation is created.

A small engine DECK (Matlab cod) has been performed to check these two assumptions. The engine model includes corrections according to Reynolds Number of flows in the flight intake, compressor, turbine and nozzle, and according to the turbine outlet flow swirl angle.



At a high altitude, the negative influence of small Reynolds Number is 2-3% at maximum rotational speed, and the error is 2-5% at small speeds (the thrust graphs are presented in the figure). Reynolds Numbers lower than the critical value are not created in the turbine flow in flight conditions, so there is not necessity to use the turbine model correction due to Reynolds Number.

Negative influence of turbine outlet flow swirl angle on the engine performance in steady-state is 1% approximately.

Compressor test bench – Development Process

Ella Berlowitz Paska,

Jet Propulsion Department, Rafael Advanced Defense Systems, Haifa, Israel

A Compressor Test Bench (CTB) is an essential tool in the development phase of any turbomachinery system comprising a compressor. Therefore a large amount of effort has been invested in Rafael to develop a CTB that will enable a full mapping of small centrifugal and mixed flow compressors. The CTB that was built in Rafael facilities include over 100 sampling channels. The instrumentation includes: static & total pressure measurements, temperature sensors, rotational speed, vibrations sensors and axial force measurement. Several experiments have been conducted with compressors in the development phase from which we have received a comprehensive understanding of the tested compressors performances.

The presentation will focus on the motivation to build the CTB, its main capabilities, the operational concept and the main milestones in the CTB development process.

D2

Transonic Linear Turbine Cascade Development in Technion

Eli Yakirevich, Beit Shemesh Engines and Department of Aerospace, Technion – IIT, Haifa, Israel
Ron Miezner, Department of Aerospace, Technion - IIT, Haifa, Israel
Boris Leizeronok, Department of Aerospace, Technion - IIT, Haifa, Israel
Beni Cukurel, Department of Aerospace, Technion - IIT, Haifa, Israel

For a small gas turbine, in comparison to their larger counterparts, a reduced amount of fluid is supplied to an almost unchanged thermodynamic cycle; hence, the aero-thermal and chemo dynamics remain mostly the same. Nevertheless, a large decrease in Reynolds number is unavoidable. Thus, this not only alters the aero-thermal distribution on the blades and vanes, but also results in higher viscous losses. Therefore, the components', and hence the cycle's, efficiencies are reduced. Therefore, above the inherent design complexity associated with all gas turbine engines, the physics associated with mini and micro gas turbines are further complicated by dimension-specific challenges, and the key technological barrier towards broad-spectrum implementation of micro gas turbines is lack of knowledge in aerodynamically coupled heat transfer and thermal management issues.

The present research is concerned with the aero-thermal assessment of micro gas turbine stator performance, for both compressors and turbines. The most common type of transonic wind tunnels is a blow-down type. Although those facilities are able to achieve engine relevant Mach numbers, many of them are unable to produce low Reynolds number flow. Typical blow-down facilities are also only able to achieve high velocities for durations lasting merely seconds, making statistically resolved aerodynamic measurements difficult to acquire. Addressing this void, there are few continuously running Mach-Reynolds independent transonic turbine blade cascades. However, their existing test section designs do not allow changing of the stagger or incidence angle without a complete rebuild.

Facility

This effort is structured around a versatile closed-loop pressurized high-speed test facility, which provides unique research capabilities to the global research environment. To this end, an adaptive test section wind tunnel is designed to provide hot (~650K) transonic conditions for variable stagger and incidence angle profiles, enabling test-aided design capability for manufacturers.

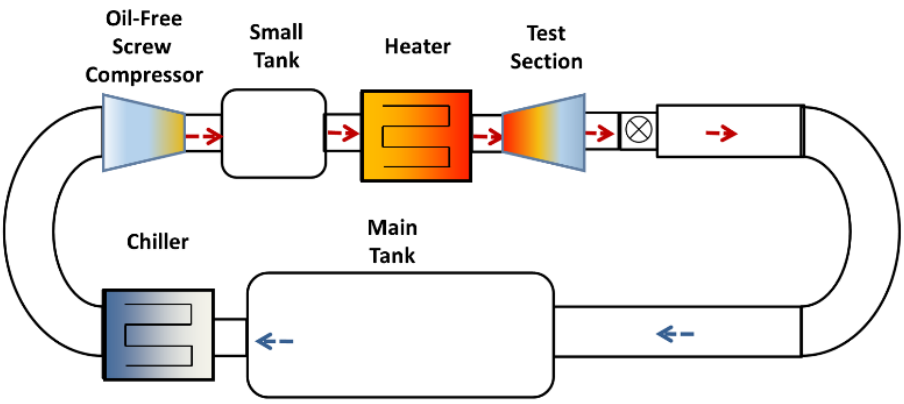


Figure 1 - Facility Layout

The unique facility is being developed in a manner which allows component testing of small scale high pressure turbines and advanced compressors stators. The main components comprising the closed test facility include a compressor, small pressure equalization tank to damp out transients, pressure drop valves, electric heater, test section, large dump tank and cooler, which reduces the inlet temperature to the compressor. The facility operates through the drive of a 500hp (370 kW) compressor which creates pressure ratios up to 8:1, with a maximum flow rate of 0.9 kg/sec. Considering the aerodynamic similarity parameters of the test turbine stage, the pressure ratio is set by combination of compressor

operating point and the valve pressure loss mechanisms and the mass flow rate is predominantly defined by the compressor rotational speed. The initial mass introduced into the isolated system defines the Reynolds number, which is coarsely adjusted prior to the startup, and fine-tuned during operation. The closed loop nature of the facility allows independent aerodynamic testing of the profile in engine representative conditions. The upstream and downstream traverse systems introduce 5-hole probes and temperature rakes, which allow measurement of static and total pressures, total temperature, as well as flow direction. Moreover, the test facility is designed for optical measurements such as Schlieren and Particle Image Velocimentry for aerodynamic performance and loss quantification, in addition to Infrared Thermography and Pressure Sensitive Paint for thermal characterization. The engine design process requires compromises in fields including thrust, weight, fuel consumption, design budget, and manufacturing cost.

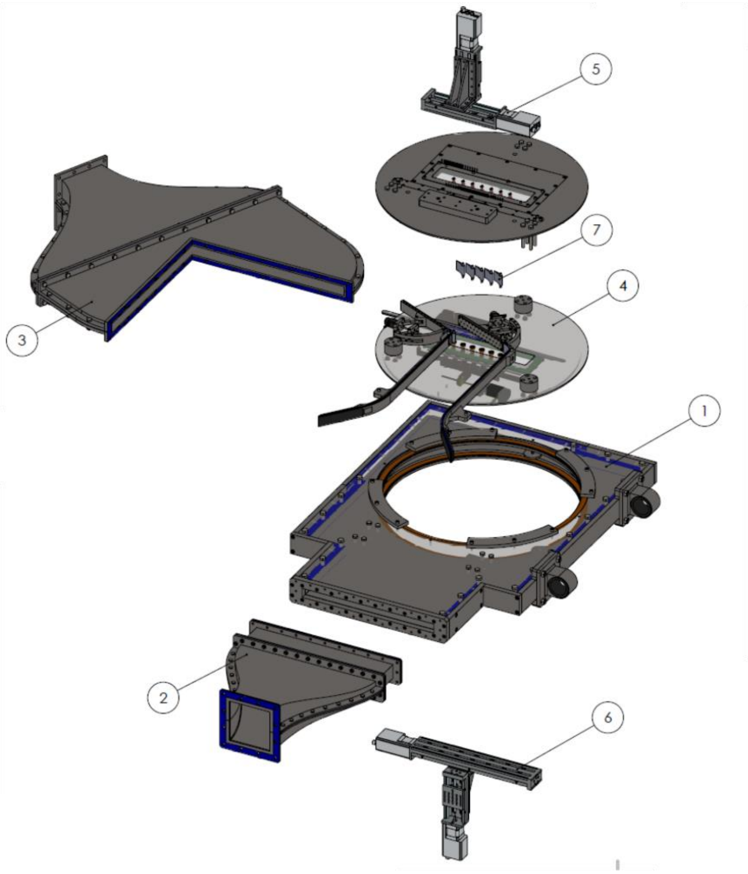
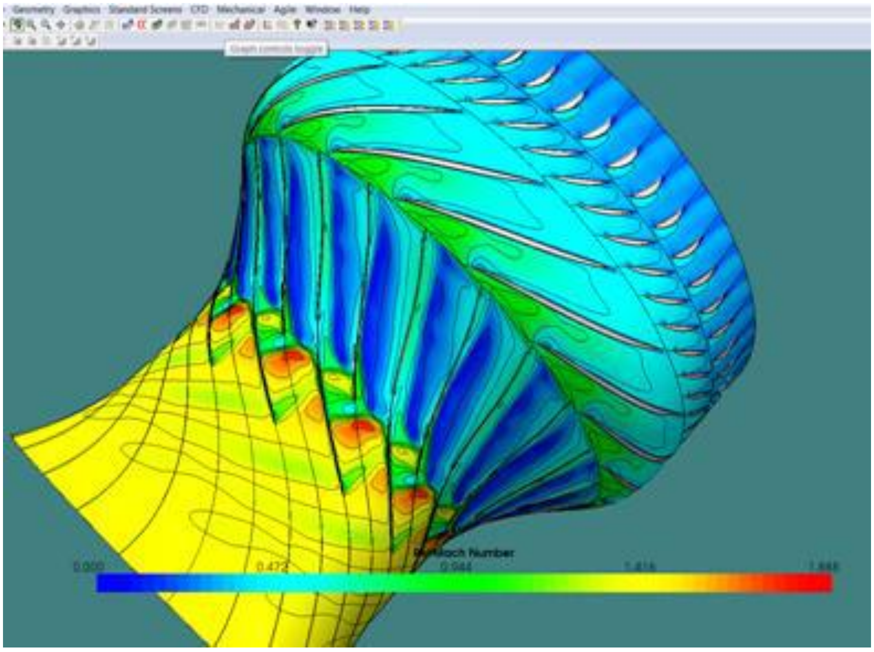


Figure 2 - Main Test Section Components: 1 - Cascade Frame, 2 - Cascade Inlet, 3 - Cascade Outlet, 4 - Rotating Disk, 5 - Upstream Measurement Traverse, 6 - Downstream Measurement Traverse, 7 - Turbine Test Section

Compressor Development Process – Verification of Simulations

Konstantin Rosenberg,
Jet Propulsion Department, Rafael Advanced Defense Systems, Haifa, Israel

Verification and validation of simulations is a necessary step in compressor development process. Verification purpose is to improve performance prediction ability by comparison of simulation results to the test results. Typical codes simulate aerodynamics and structure deformation. CFD techniques are very valuable for the aerodynamics computation. They are very useful in understanding the detailed physical phenomena in the compressor. Without this understanding it would be impossible to improve the compressor's performance or fix design mistakes.
This presentation will focus on the process of CFD simulation verification for a mixed flow compressor, and will discuss the techniques and assumptions used in the computation process.
Using advanced computation software, do we still need to run costly tests on compressors in order to map their performance?



Suppression of Combustion Instability in Gas Turbine Combustion Chamber by Injection of Free Radicals

Alex Roizman and Prof. Yeshayahou Levy

Turbo and jet Engine Laboratory,

Faculty of Aerospace Engineering, Technion

Due to the negative impact on the health of human beings and the environment caused by the pollutions from the combustion systems, internal combustion engines and gas turbines, the amounts of pollutions from these engines were restricted. Special attention is devoted to the emissions of NOx that might lead to serious health implications. Chemical reaction between oxygen and nitrogen that is responsible for the formation of NOx molecules requires relatively high activation energy. Hence, the reaction starts under relatively high temperatures (above 1600K) [1]. Therefore, gas turbine manufacturers are constantly looking for ways to reduce the combustion temperature. One of the established methods is Lean Premixed Combustion. In this method, fuel is supplied in gaseous phase and is mixed with clean air upstream of the combustion chamber, creating a well-mixed flammable mixture. In this case, the combustion temperature is a strong function of equivalence ratio. Combustion temperature drops with equivalence ratio for lean mixtures, and thus the premixed mixture is supplied with fuel/air ratio that is close to the low flammability limit. Gas turbine engines that applying have this method of NOx reduction, suffer from combustion instabilities that develop in combustion chamber and cause undesired pressure oscillations; see figure 1 where apparent extended flame length (due to long exposure) is seen. These oscillations result in engine control system disruptions, enhanced heat transfer on the combustor liner walls, increases the rate of mechanical wear, triggers flame extinction and even engine failure.


Figure 1: Combustor chamber during operation

Combustion instability in gas turbine combustion chamber causes spontaneous pressure oscillations due to oscillations in local heat fluxes. Heat flux oscillations are caused by the oscillations in equivalence ratio of the mixture, due to the changes in the flow rates. However, the changes in the flow rates themselves happen due to the pressure oscillations, creating a closed loop between the thermal oscillations of combustion process and mechanical pressure oscillations. Pressure oscillations inside the combustion chamber develop when the energy required for their formation overcomes the damping factors (e.g. heat transfer and viscous dissipation). This process could be described by the Rayleigh Criterion [2]:

$$\iint_{V\,T} p'(x,t)q'(x,t)dtdV \geq \iint_{V\,T} \sum_i L_i(x,t)dtdV \,,$$

where p`(x,t) – pressure oscillations, q`(x,t) – heat flux oscillations, V – volume of combustion chamber, T – oscillations period and L_i – damping processes.

This research suggests a solution for suppression of combustion instabilities in the combustion chamber using lean premixed mixture technique. The method includes installation of additional parallel combustor (pilot) operated under fuel rich conditions. Its exhaust gases are injected into the main combustion chamber primary zone and as a result of the fuel rich conditions (and uncomplete combustion process), pilot exhaust gases contain unstable and very reactive species – free radicals. Due to their high reactivity, the injection of the free radicals into the combustion primary zone supports the stability of combustion process. By design, the pilot combustor uses part of the fuel that is otherwise supplied to the main combustion chamber, thus total fuel rate remains constant. Figure 2 show the time dependent pressure signal as measured inside the combustor and its analysis in the frequency domain.

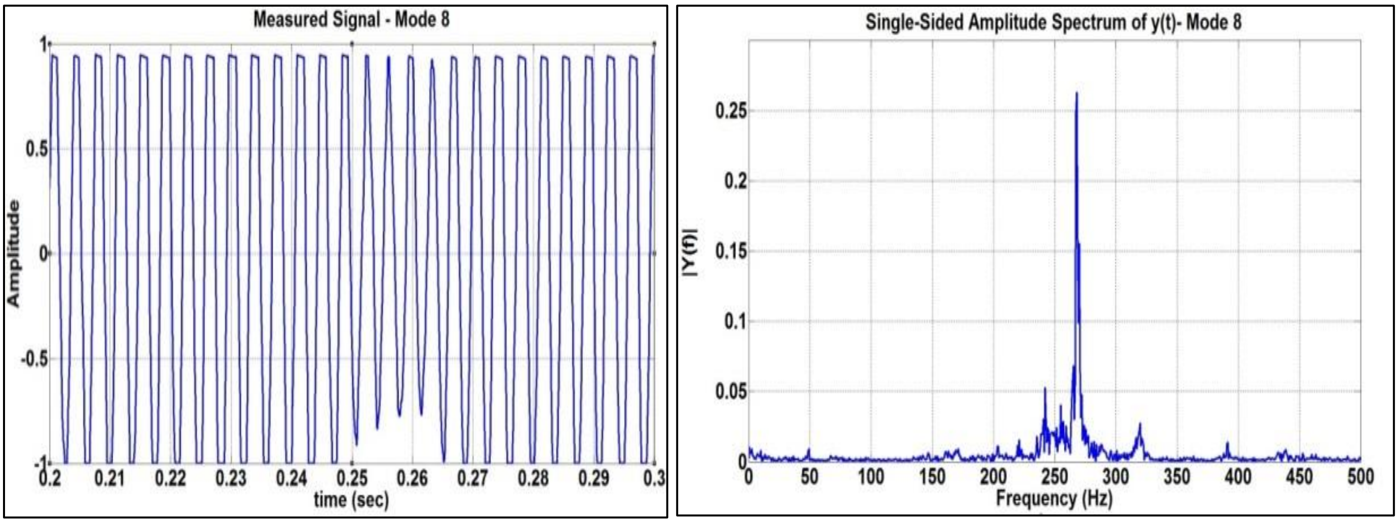


Figure 2: Representative of unstable combustor operation: a) Time variation of the combustor's internal pressure, b) the representation of the pressure oscilatipons in the frequency domain of a case of instability at high frequency

Performed experiments show that injection of free radicals into the main combustor primary zone significantly affects the combustion process. Operation of the pilot combustor allows reduction of the low flammability limit. During the experiments, the main combustor chamber was forced to operate under unstable conditions while mounting an orifice at its exhaust. Two types of combustion instabilities were received: a) Low Frequency Instability. B) Mid Frequency Instability. Experiments show that operation of the pilot combustor under fuel rich conditions significantly suppresses pressure oscillations caused by both types of combustion instabilities.

[1] Lefebvre, Arthur H., and Dilip R. Ballal, Gas turbine combustion, CRC Press, 2010.

[2] Lieuwen, Timothy C., and Vigor Yang, "Combustion instabilities in gas turbine engines (operational experience, fundamental mechanisms and modeling), Progress in astronautics and aeronautics (2005).

E2

Jet fuel - Characteristics and Properties

Moshe Rabaev

IAF / Depot 22 / Materials Division / Fuel and Chemistry Department

Ground and naval transportation employ a variety of propulsion methods, from steam engines, through internal combustion, electric and hybrid engines, to the use of nuclear energy in sea vessels. In aviation, jet propulsion remains the main method in use. The operating mechanism of aviation jet engines, as well as the composition and properties of jet fuel, have not changed much since their introduction during WWII. No real alternative to jet propulsion is expected to rise in the foreseeable future. Even the newest engines currently in development, are designed to run on jet fuel which is nearly identical, in composition and properties, to that which fueled the first jet aircraft, essentially the same kerosene composition used in heating and lightning by kerosene lamps. Despite its long history of use, this fuel maintains an extensive list of characteristics which allow the efficient and safe powering of aircraft.

Jet propulsion fuel, regardless of source, is required to contains a high energy density, high-temperature chemical stability (above 260°C), steady flow at low temperatures (below -47°C), precise distillation range and profile which allow the creation of suitable fuel-air mixtures, precise combustion properties, high purity devoid of dissolved or suspended (micrometric solids) foreign materials, and other properties.

Nearly all of the jet fuel used in civilian and military aviation comes from direct distillation of crude oil, the composition of which includes thousands of different compounds and changes significantly between sources. The jet fuel itself contains over a thousand different compounds and its composition process and facility, mixing of different batches etc. in order to maintain stable operating abilities of various jet propulsion systems, many standards and specifications are in place for the jet fuel with an extensive list of required properties - each with its own history and significance. These specifications are updated from time to time by committees with representatives, besides those of the regulator, of fuel and engine manufacturers, academic and laboratory experts, aviation companies, military representatives and others. The standards and specifications can be updated up to several times in a year, according to the accumulated information, data and experience. Many of the more recent updates concern the approval if jet fuel from alternative (coal, natural gas etc.) and renewable (biomass, cellulose, sugar, alcohol, fats etc.) sources.

In this lecture we will review briefly the history of jet fuel since its introduction, touch upon synthetic jet fuel and fuel from alternative and renewable sources and, of course, discuss the characteristics and properties of the fuel.

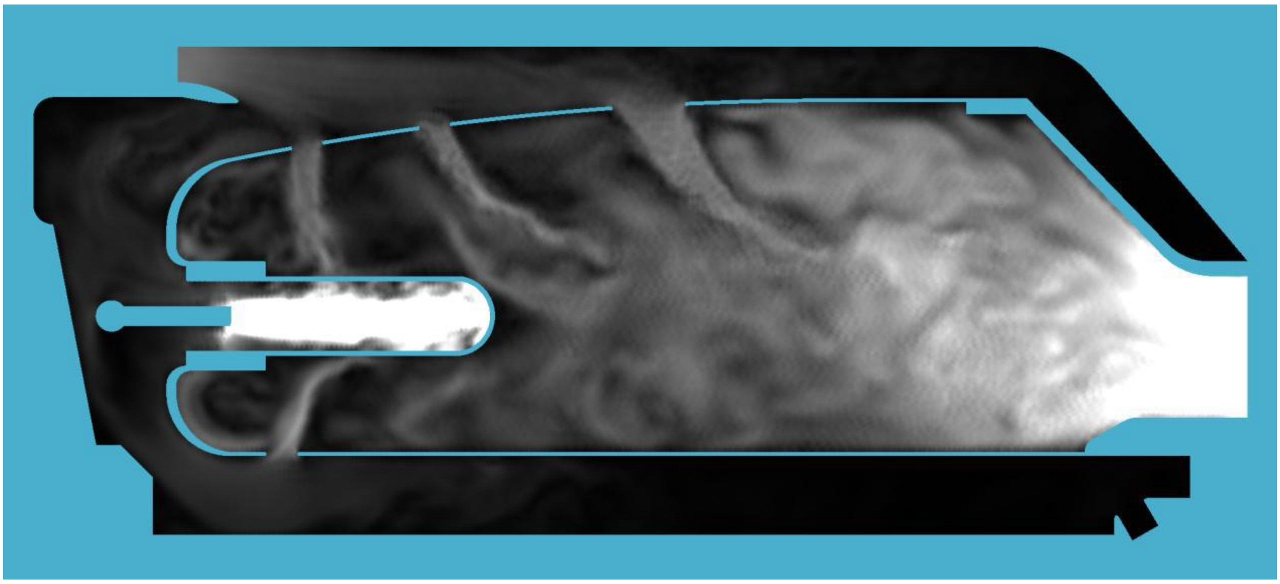
A Preliminary Computational Study of a Micro Jet Engine Combustion Chamber Using Compressible Large Eddy Simulations

Yuval Dagan
CFD Group, Aerodynamics Department, Aeronautical Systems, RAFAEL, Advanced Defense Systems

The performance, efficiency and stability of a gas turbine engine are significantly influenced by thermo-fluid dynamic interactions between engine components. The combustion chambers of micro gas-turbine based propulsion system involve complex phenomena such as atomization of liquid fuel jets, evaporation, interactions between droplets, and turbulent mixing of fuel and oxidizer. 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. Large Eddy Simulation (LES) is thus the appropriate method for the computation of such complex turbulent reacting flows.

In this study, a compressible LES is performed on a realistic micro-gas turbine combustion chamber. Using this approach, the compressible inflow conditions to the combustor are captured well, as well as the compressibility effects during ignition.

A unique method for mesh generation using Voronoi Tessellation will also be presented and preliminary results of the flow and combustion process will be discussed. An example for the instantaneous velocity magnitude distribution is presented in the figure below.



Fan Noise

Prof. Oksana Stalnov,
Faculty of Aerospace Engineering, Technion,

With the global expansion in the volume of air traffic, on the one hand, and increasingly ever strict environmental regulation, on the other, aircraft noise has become a major public concern for people living close to the busiest airports. It is therefore important to have a handle on the noise currently emitted from the aircraft because according to stringent objective by Advisory Council for Aeronautics Research in Europe this noise level must be reduced by 50% by 2020 to comply with the aim set in 2001.

The two main sources of aircraft noise are power plant (i.e. engine) and airframe. Power plant is one of the dominant contributors to the overall sound levels, particularly at take-off, while airframe noise is significant at approach/landing phase of flight. The propulsion systems of the aircraft comprise a number of high bypass ratio turbofan engines, each with many distinct noise sources, where each engine source has a particular dependence on operating conditions.

Turbofan noise spectra contain both broadband and tonal components (Peake and Parry, 2012). The tonal noise sources include fan self-noise, fan-vane interactions, and droop-fan interactions, to name a few. Historically, broadband turbofan noise has been less understood and it is much more difficult to control. The fundamental mechanism for generation of self-broadband noise is the local interaction between the trailing- and leading-edge of a blade and the turbulent eddies. The other two main broadband sources are rotor casing boundary-layer interaction and rotor-stator interaction noise.

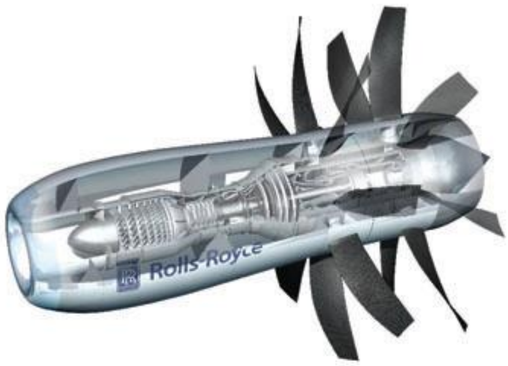


Figure 1: A modern Rolls-Royce open-rotor design concept (Peak and Parry, 2012)

As aviation will continue to grow, its unwelcome noise threatens will impact larger communities and drive ever more stringent noise regulations. Meeting the aviation noise goals of the future, envisioned by ACRE, requires design of a practically silent aircraft whose noise outside the airport perimeter is no louder than other ambient noise, such as traffic noise. Achieving cost-effective and energy-efficient reductions in aircraft noise requires evaluation of the relative contributions to total radiated noise from the many engine and airframe sources. However, there are significant difficulties inherent in addressing noise attenuation, not least due to the highly complex nature of the flow and the turbofan engine geometry. Thus, to achieve the ambitious ACRE goals, new concepts, designs and optimization methodologies, far more sophisticated than in use today, are required. The imperative of balancing the reduction of noise levels with the (sometimes conflicting) reduction in the carbon footprint therefore represents an enormous scientific and technological challenge, among which is the open-rotor concept (Figure 1).

The talk will focus on current scientific and technological challenges in the quest to understand noise generation at source and ways in which sound waves propagate away from the source. Since the turbomachinery noise is generated internally, there is a range of opportunities to attenuate and even suppress the noise. Thus, several concepts that may have the potential to reduce fan noise will be reviewed.

Peake, Nigel, and Anthony B. Parry. "Modern challenges facing turbomachinery aeroacoustics." Annual Review of Fluid Mechanics 44 (2012): 227-248.

Commercial High Bypass Engine Instrumentation

Shalev Aizik
IAI, Bedek Aviation Group,
Enignes Division, New Products Development

The performance of a jet engine is evaluated by running it in an instrumented test facility. The results are then processed and checked in accordance to the specific engine manual and overhaul guide, as instructed by the OEM (original engine manufacturer). The data is therefore limited and controlled in a way which doesn't reveal any additional information that might be useful to independent MRO (Maintenance Repair and Overhaul) facilities. It is clear that more data, mainly more accurate temperatures and pressures values in more engine stations, will provide a much better understanding of the engine performance degradation with time, and can also benefit the repair and overhaul process.

The Engine's division at IAI has undergone during the last year, for its first time ever, a process designing and instrumenting a commercial high by-pass aero engine with additional instrumentation not provided with the original engine. The instrumentation consists of total and static pressure tubes, total temperature lines, strain gages and accelerometers in various engine locations. Some even are designed to measure Gas path measurements at tough engine locations. The presentation will detail as well as describe the special instrumentation design and its unique characteristics, the installation and the routing process. Furthermore, it will provide an explanation of the egress routing method for the new lines out of various engine components. Finally, more focus will be placed on describing the design and method for measuring the forces applied upon the engine's main ball thrust bearing.

Utilization of Turbo-Fan Engine's Residual Energy as a Source of Electricity for Consumers in a Plane (Using Thermo-Electric Cells)

ניצול אנרגיה שיורית של מנועי טורבו-מניפה כמקור חשמל לצרכני מטוס (באמצעות תאים תרמו-אלקטריים)

מרדכי פלד

א. אנרגיית מנוע שיורית וצרכני חשמל

מרבית האנרגיה התרמית, המתקבלת בתהליך הבערה במנועים תעופתים ממשפחת טורבו-סילון, מנוצלת לסיבוב מכלול טורבינה-מדחס, וכתוצאה יצירת זרימה מהירה וכוח דחף. עם זאת , החוק השני של התרמודינמיקה "מכריח"' בזבוז של חלק מהאנרגיה המושקעת בתא-הבערה, בצורת פליטת גזים מנחיר המנוע, כאשר טמפרטורת הגזים הנפלטים גבוהה מהותית מטמפרטורת האוויר הנינק לתוך המדחס.

על אף מגבלות "החוק השני" המוזכר, קיים סיכוי לנצל חלק (אולי קטן) מאנרגיית הפליטה השיורית, המתבזבזת, כאשר אחד הרעיונות: התקנת תאים תרמו-אלקטריים , המוצגים בסעיף ב. צרכני החשמל במטוסים מרובים, יצוינו חלקם: תאורה, מערכות כריזה, מכשור מטבח , מנועי משאבות הידראוליות, רכיבי מיזוג-אוויר (וכו").

מקור החשמל ה"קלאסי" במטוסים מבוסס על ניצול (חלק קטן) של אנרגיית גל סובב (גל טורבינה-מדחס) להפעלת מחולל-חשמל, שיטה הכרוכה בהתאמת יחסי תמסורת \תשלובת מכניים ואיבוד אנרגיה, כפוף לנצילויות מערכות גג"ש ורכיבים אלקטרו-מגנטיים.

כפי שיובהר בסעיף ג, מנועי טורבו-מניפה הם המבטיחים ביותר לניצול רעיון הרכיבים התרמו-אלקטריים. ואילה המנועים המותקנים בדורנו במטוסים אשר היקף צריכת החשמל שלהם עצום.

ב. מאפיינים תרמו-אלקטריים

תאים תרמו-אלקטריים ידועים כמוליכים-למחצה , בהיבט החשמלי. יצירת תפוקה חשמלית משמעותית , בסיוע פערי טמפרטורה, מחייבת חומרים מאופייני מוליכות חשמלית גבוהה ומוליכות תרמית נמוכה, היחס בין מוליכויות אלה מוגדר כמקדם סיבק (seebeck). שתי דוגמאות לחומרים יעילים וניתנים לניצול :

ביסמוט-טלוריד, עופרת-טלוריד. ניתן למיין חומרים תרמו-אלקטריים לפי הטמפרטורה המרבית התואמת את יעילותם המרבית . היעילות המרבית של רשת תרמו-אלקטרית תושג, אם ישולבו מוליכים-למחצה שונים, כל סוג בהתאם לרמת הטמפרטורה המקומית (טכנולוגיית ייצור והרכבה מתקדמת). ליצירת רשת תאים יעילה המפיקה חשמל, יש למקם, בין תווך טמפרטורה גבוהה, ותווך טמפרטורה נמוכה, תאים חיוביים ותאים שליליים לסירוגין (תאים סוג P ותאים סוג N). כמו כן יש להחליט בנושא חיבורי תאים בטור, במקביל ו\או במשולב, כתלות בעוצמות זרם ו|או מתח חשמלי מבוקשות.

קיים כיום היצע של תאים במידות מגוונות של אורך ורוחב. בנוסף, ניתן להזמין, ואף לבצע חיתוך של תאים למידות עובי רצויות, משמעו: להגדיל מקדם מעבר חום ,בו-זמנית עם הפחתת משקל מערכת, או, לחלופין, להקטין מקדם מעבר חום (תפוקה משופרת !) ולהשלים עם תוספת המשקל.

ג. מאפייני זרימות במנועים

נחירי הפליטה של מנועי טורבו-מניפה מהווים, לפי התרשמות ראשונית, מתחם מבטיח להרכבה וניצול של רשת תאים תרמו-אלקטריים :

טמפרטורת זרימת הליבה - 600 מעלות צלסיוס בקירוב, כאשר טמפרטורת זרימה עוקפת מעט גבוהה מטמפרטורת הסביבה (לפי תנאי הטיסה).

מהירות זרימת הליבה (החמה) - 360 מטר\שניה , מהירות זרימה עוקפת 270 מטר\ שנייה . מהירויות אילה מאפשרות הגדרת שטפי זרימת הליבה וזרימה עוקפת כ- "מאגרים תרמיים כמעט אידיאליים ".

מתחמי נחיר פליטה אינם מתאפיינים ברכיבי מעטפת רבים, ניתן לאתר משטחים חשופים, המאפשרים התקנת תאים תרמו-אלקטריים רבים, אשר ייתנו סיכוי להפקת הספק חשמלי משמעותי.

הגישה (הפיזית) למתחמי מעטפת נחיר פליטה אינה בעייתית (בהשוואה למתחמים קדמיים של המנוע). עם זאת, נזכיר, שיש דגמי מנועים הכוללים מיזוג זרימת ליבה חמה וזרימה עוקפת קרה.

ד. מגבלות וקשיים ביישום

על אף כל הנתונים המבטיחים , המוצגים בסעיפים ב ו- ג , ניתן להצביע על שורת התלבטויות וקשיים, במסלול לעבר תפוקה חשמלית, אשר מצדיקה יישום הטכנולוגיה המפורטת כתחליף, ולו חלקי, ליצירת מקור הספק חשמלי (נכון לכל מיזם, המתיימר להגדיל נצילות טכנולוגית) :

תכן מבני של נחירי הפליטה מבוסס על הפחתת השפעות גרר אווירודינמי, כולל שיקולים של ערכי מספר ריינולדס ומערבלות. התכן מבני המוזכר כאן, מקשה ממש על איתור מיקום לתאים התרמו-אלקטריים בין שני מאגרי החום המפורטים בסעיף ג. וודאי ככל שמדובר במספר נחוץ של מאות ואף אלפי תאים תרמו-אלקטריים.

תאים תרמו-אלקטריים מישוריים נידרש למקם\ לעגן על משטחי נחיר מנוע קוניים, נתון המחייב חומר מתווך בין התאים ובין משטחי הנחיר הקוניים.

הספיקות הגבוהות , המוגדרות לעיל, של זרימת הליבה וזרימה עוקפת מופחתות, במצבי הפחתת ספיקת דלק, למטרת הפחתת כוח דחף מנועים. מצב זה וודאי מתקיים בשלבי המראה ונחיתה.

ככל שמבוקש להגדיל נצילות , כמוכן להגדיל הספק חשמלי מופק, יש להגדיל את עובי התאים התרמו- אלקטריים , ואת מספרם. כאן דרוש לבחון השפעה על משקל המנוע ומיקום מרכז הכובד שלו.

להתרשמות ראשונית: משקל סגולי של ביסמוט – טלוריד (Bi_2Te_3) זהה, מעשית, למשקל סגולי של פלדות.

Comparing Experimental and Simulated Dynamics of Tunable Micro Turbo Jet Engine laboratory Simulator

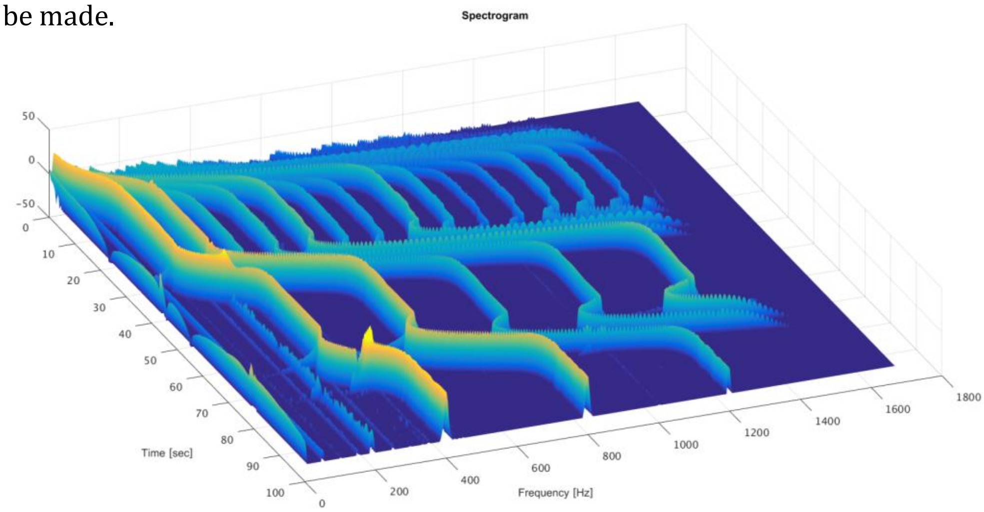
Alex Ferdinskoif and Prof. Izhak Bucher

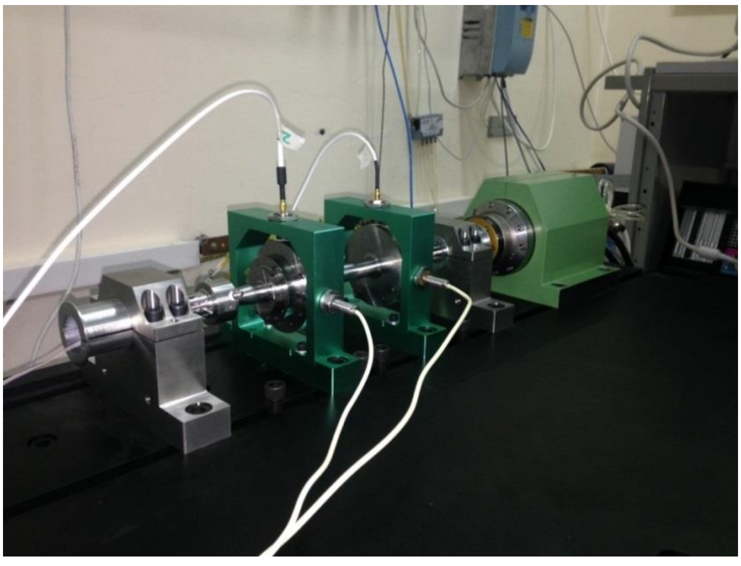
Faculty of Mechanical Engineering, Technion

In the conceptual design phase of a jet engine, the rotation speed range is determent according to the performance requirements and the dimensional requirements. One of the critical requirements in the rotor design is absence of critical speeds in the rotation speed range. To withstand this requirement, Finite Element analyses are performed at the preliminary phase of the design and design modifications are subsequently implemented.

This research seeks to explain the causes for the gap between the Finite Element model and experimental system measurements. As a part of the research, an experiment system was designed and manufactured, allowing to apply a wide range of dynamic loads while a high-speed rotation of the rotor to examine the difference between the dynamical parameters.

In order to emphasis this differences, our system allows controlling the supports stiffness and the rotating speed, so that we can isolate the system Modes of vibration and study the differences. Our two controlled stiffness range boundaries allow as altering the order of rigid and flexible vibration modes. This arrangement provides an experimental means with which comparison and mode correction can be made.

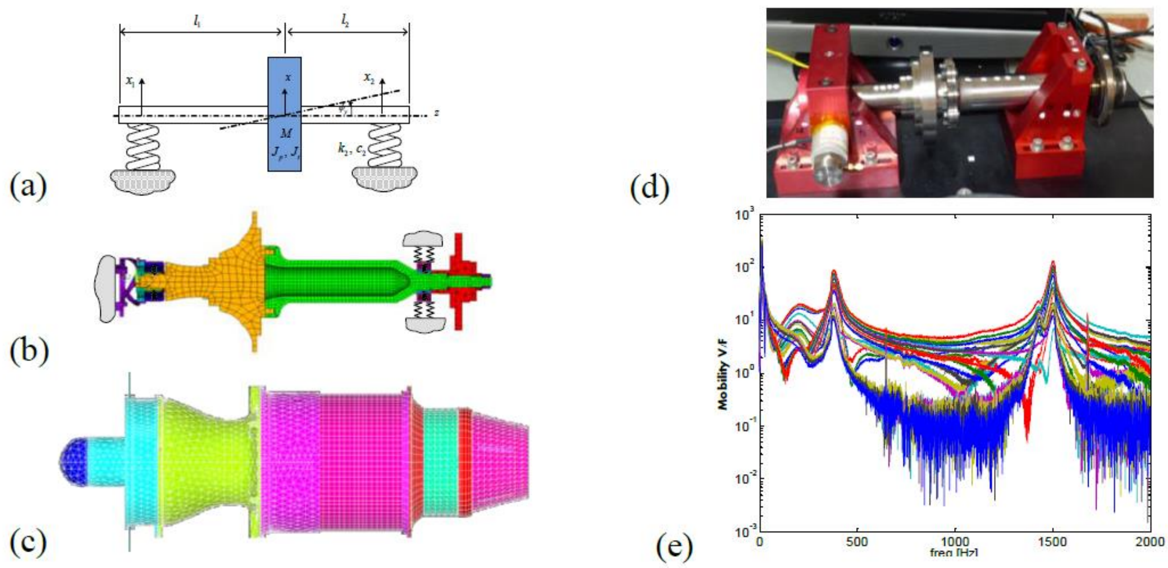




Dynamics of Jet Engine Rotor in the Design Process- A Combination of Analysis and Experiments

Eyal Setter,
RAFAEL - Advance Defense Systems LTD

Rotordynamics has a substantial effect on a jet engine structural integrity and on the design feasibility. In rotating systems, the natural frequencies of the structure tend to vary with the speed of rotation, mainly due to the gyroscopic effect and centrifugal stiffening, thus posing the risk of a critical speed in the operation range. Avoiding critical speeds and estimating the level of excitation while running through critical speeds has to be tackled at early stages of the design, where the level of uncertainty is relatively high, yet, changes in the design is relatively cheap. At this stage, no experimental prototypes are present, thus analytical and numerical models are mainly used. The question of model complexity then arises, in order to yield approximate estimates quickly enough, yet reasonably accurate. However, the analysis cannot hold by itself without experimental verification, especially where the mechanical properties of unorthodox design need to be calibrated. Finding the smart blend of analysis and experiments is thus of great importance. In the presented study, a given rotor design was analyzed by three models of increasing complexity: (a) A 4DOF (Four Degrees of Freedom) analytical model of a rigid rotor, (b) A simplified FE (Finite Element) compliant rotor model, and (c), a detailed FE model that included the engine housing . Simulations have shown that where the rotor is suspended on flexible bearing supports, the dynamics of the rotor is decoupled from the housing and the simplified models predicted the rotor critical speeds accurately enough compared to the detailed model. This allowed higher levels of simulation, as sensitivity analysis to unbalance, damping, acceleration rates, and rotor modifications, to be run on the lighter models, hence saving time and computational efforts. The numerical models were validated by a simplified rotor test rig (d) that shared the actual rotor stiffness and inertial properties, as well as the fixation method to the engine housing. The modal experimental results (e) were also used to calibrate the stiffness of the supports. It is believed, that a smart symbiosis between experiments and simulations at early stages, can allow the desired certainty level in the design process that would eventually yield a successful development.



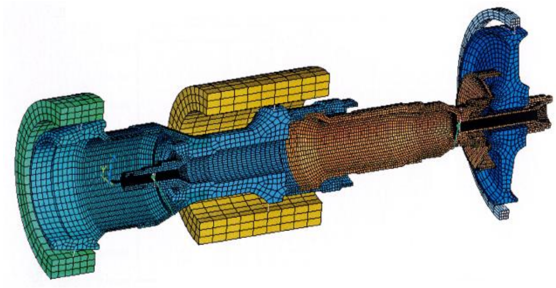
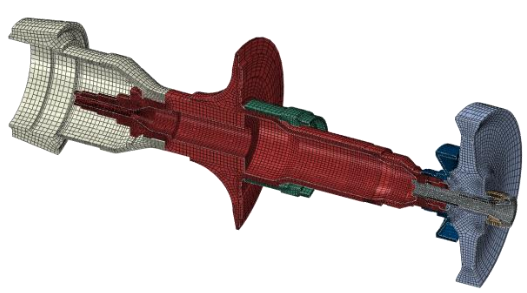
G3

Modeling of Rotating Assembly Dynamics for a Small Jet Engine

Ariel Cohen, Ronen Payevsky, Yochanan Nachmana

Bet Shemesh Engine

During the development of a small jet engine, unacceptable vibrations were observed in the engine operating window. In order to identify and resolve the problem, rotordynamic simulations were performed on a simplified 3D representation of the rotating assembly.

Correct representation of the rotating assembly geometry is necessary for accurate simulation of the dynamic behavior. Of particular importance are the compressor/turbine blades, which are generally simplified for the purposes of the simulations, and the modeling of connections in part assemblies.

A series of modal impact tests was performed in order to calibrate the model and boundary conditions, leading to a significant improvement in the accuracy of the results, relative to initial simulations.